FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

Division of Environmental Assessment and Restoration, Bureau of Watershed Restoration

CENTRAL DISTRICT • WITHLACOOCHEE BASIN

FINAL REPORT

Nutrient TMDL for Rainbow Springs Group and Rainbow Springs Group Run (WBIDs 1320A and 1320B)

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Contents

Acknowledgments ii

Chapter 1: INTRODUCTION 1

1.1 Purpose of Report 1

1.2 Identification of Waterbodies 1

1.3 Background 11

Chapter 2: DESCRIPTION OF WATER QUALITY PROBLEM 13

2.1 Statutory Requirements and Rulemaking History 13

2.2. Information on Verified Impairment 13

2.3 Nutrients 14

2.3.1 Nitrate **Error! Bookmark not defined.**

2.3.2 Phosphorus 15

2.4 Ecological Issues Related to Nutrients 15

2.4.1 Water Clarity 15

2.4.2 Human Recreational Impacts 16

2.5 Rainfall and Temperature Data 21

2.6 Monitoring Sites and Sampling 22

2.7 Discharge Data 22

2.8 Nitrate in Impaired Waterbodies 24

Chapter 3. DESCRIPTION OF APPLICABLE WATER QUALITY STANDARDS AND TARGETS 27

3.1 Classification of the Waterbody and Criterion Applicable to the TMDL 27

3.2 Applicable Water Quality Standards and Numeric Water Quality Targets 27

3.2.1 Nutrients 27

3.2.2 Outstanding Florida Water Designation 28

Chapter 4: ASSESSMENT OF SOURCES 29

4.1 Types of Sources 29

4.2 Information on Potential Sources of Nitrate in the Rainbow Springs Group and Rainbow Springs Group Run Springshed 29

4.2.1 Wastewater and Stormwater Sources 30

4.2.2 Land Uses and Nonpoint Sources 33

Chapter 5: DETERMINATION OF ASSIMILATIVE CAPACITY 40

5.1 Determination of Loading Capacity 40

5.2 TMDL Development Process 41

5.2.1 Nitrate Target 41

5.2.2 Target Setting 48

5.3 Setting the Monthly Average Concentration for Nitrate 50

5.4 Critical Conditions/Seasonality 52

5.5 Calculation of TMDL Percent Reduction 53

Chapter 6: DETERMINATION OF THE TMDL 55

6.1 Expression and Allocation of the TMDL 55

6.2 Load Allocation 57

6.3 Wasteload Allocation 57

6.3.1 NPDES Wastewater Discharges 57

6.3.2 NPDES Stormwater Discharges 57

6.4 Margin of Safety 57

Chapter 7: NEXT STEPS: IMPLEMENTATION PLAN DEVELOPMENT AND BEYOND 58

7.1 Basin Management Action Plan 58

References 60

Appendix A: Background Information on Federal and State Stormwater Programs 65

Appendix B: Change-Point Analysis of the Suwannee River Algal Data 66

List of Tables

Table 2.1. ***Verified Impaired Spring-Related Segments in the Withlacoochee Basin _______ 13***

Table 2.2. ***Temperature (^{o}F) and Precipitation (Inches) at NOAA Station (Ocala - 086414), 1981–2010_______ 21***

Table 2.3. ***Nitrate Concentrations for Rainbow Springs Group, 2001–2010 ___ 25***

Table 2.4. ***Nitrate Concentrations for Rainbow Springs Group Run, 2001–10 _______ 26***

Table 4.1. ***Permitted WWTFs in the Rainbow Springs Group and Rainbow Springs Group Run Springshed _______ 31***

Table 4.2. ***Major Land Uses in the Springshed (SRWMD 2006–2008 and SWFWMD 2009 land use coverages)_______ 36***

Table 4.3. ***Potential Fertilizer Application Ranges for Selected Land Uses in the Rainbow Springs Springshed _______ 38***

Table 5.1. ***Monthly Average Nitrate Concentrations for Rainbow Springs Group and Rainbow Springs Group Run (2000–10)_______ 52***

Table 6.1. ***Daily Maximum for Target Nitrate Concentration (mg/L)_______ 55***

Table 6.2. ***TMDL Components for Rainbow Springs Group and Rainbow Spring Group Run_______ 56***

List of Figures

Figure 1.1. ***Major Geopolitical and Hydrologic Features in the Main Contributing Area for Rainbow Springs and Rainbow Springs Group Run_______ 2***

Figure 1.2. ***Location of the Two Impaired WBIDs in Marion County _______ 3***

Figure 1.3. ***Named Springs in the Rainbow Springs Area _______ 4***

Figure 1.4. ***Conceptualized Ground Water Flow Patterns to Rainbow Springs Group and Rainbow Springs Group Run (Knowles 1996)_______ 6***

Figure 1.5. ***Springsheds for Rainbow Springs and Silver Springs _______ 8***

Figure 1.6. ***Springshed for Rainbow Springs Group and Rainbow Springs Group Run_______ 9***

Figure 1.7. ***Aquifer Vulnerability in the Estimated Rainbow Springs Springshed _______ 10***

Figure 2.1. ***Phosphorus and Orthophosphate in the Impaired WBIDs, 1963–2005 _______ 16***

Figure 2.2. ***Underwater Photo of Rainbow Springs, 1955 (State Archives of Florida)_______ 17***

Figure 2.3. Underwater Photo of Rainbow Springs, 1955 (State Archives of Florida) 18
Figure 2.4. Downstream of Rainbow Spring #1, 2011 (Department) 19
Figure 2.5. Algae South of Rainbow Spring #1, March 2009 (Florida Geological Survey [FGS]) 19
Figure 2.6. Rainbow Spring #4, South of Vent, March 2009 (FGS) 20
Figure 2.7. Rainbow Spring, #4, North of Vent, Close to Shoreline, November 2009 (FGS) 20
Figure 2.8. Precipitation for Ocala, 1981–2010 (NOAA Climate Information for Management and Operational Decisions [CLIMOD] Product, October 20, 2011) 22
Figure 2.9. Surface Water Monitoring Sites Associated with Rainbow Springs Group and Rainbow Springs Group Run 23
Figure 2.10. Average Annual Discharge in the Rainbow River, USGS Station 02313100 (Source: USGS 2012) 24
Figure 2.11. Nitrate Trend for Rainbow Springs Group, 1956–2011 25
Figure 2.12. Nitrogen Trend for Rainbow Springs Group Run, 1994–2010 26
Figure 4.1. Domestic Wastewater Facilities in the Rainbow Springs Group and Rainbow Springs Group Run Springshed 32
Figure 4.2. Population Density in the Rainbow Springs Group and Rainbow Springs Group Run Springshed (based on 2010 Census data) 34
Figure 4.3. Principal Land Uses in the Rainbow Springs Springshed (based on 2006–08 GIS coverages) 35
Figure 4.4. Density of OSTDS (Septic Tanks) in the Rainbow Springs Springshed (Marion County 2008; FDOH 2010) 37
Figure 4.5. Annual Weighted Mean Wet Deposition of Inorganic Nitrogen from 1997 to 2011, Site FL05 (Source: NADP website) 39
Figure 5.1. Springs Included in Algal Growth Studies by Stevenson et al. (2007) 43
Figure 5.2. Change-Point Study Sites within the Suwannee River System 45
Figure 5.3. Relationship Between Mean NOx Concentration and Mean Periphyton Biomass from 12 Sampling Sites in the Suwannee, Santa Fe, and Withlacoochee Rivers 46
Figure 5.4. Relationship Between Mean NOx Concentration and Mean Periphyton Cell Density from 12 Sampling Sites in the Suwannee, Santa Fe, and Withlacoochee Rivers 47
Figure 5.5. Change-Point Analyses (the 95% Confidence Interval) 49
Figure 5.6. Central Tendency and Upper 95% Confidence Interval Approach 49
Figure 5.7. Upper and Lower 95% Confidence Interval Approach 50

Figure 5.8. Rainbow Residual Plot (USGS Station 02313100 and SWFWMD Water Management Information System [WMIS]) from Multiple Rainbow River Springs, 1992–2012 ____ 53

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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

Florida STORET Program

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

2012 Integrated Report

http://www.dep.state.fl.us/water/docs/2012_integrated_report.pdf

Criteria for Surface Water Quality Classifications

http://www.dep.state.fl.us/legal/Rules/shared/62-302/62-302.pdf

Water Quality Status Report: Withlacoochee

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

Water Quality Assessment Report: Withlacoochee

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

Florida Springs

http://www.floridasprings.org/

U.S. Environmental Protection Agency, National STORET Program

Region 4: TMDLs in Florida

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

National STORET Program

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

Chapter 1: INTRODUCTION

1.1 Purpose of Report

This report presents the Total Maximum Daily Load (TMDL) for nitrate (NO_3), which was determined to be a cause of the impairment of Rainbow Springs Group and Rainbow Springs Group Run within the Rainbow River Planning Unit of the Withlacoochee Basin. These waterbodies were verified by the Florida Department of Environmental Protection (Department) as impaired for nutrients (algal mats) and included on the Verified List of impaired waters for the Withlacoochee Basin that was adopted by Secretarial Order in November 2010. The TMDL establishes the allowable level of nutrient loadings to Rainbow Springs Group and Rainbow Springs Group Run that would restore these waterbodies so that they meet their applicable water quality criterion for nutrients. This report will be used as the basis for discussions during the development of the Basin Management Action Plan (BMAP).

1.2 Identification of Waterbodies

For assessment purposes, the Department has divided the Withlacoochee Basin into water assessment polygons with a unique **w**ater**b**ody **id**entification (WBID) number for each watershed or stream reach. Rainbow Springs Group and Rainbow Springs Group Run are segments of the Rainbow River designated as WBIDs 1320A and 1320B, respectively.

The impaired segments, which include the main group of springs and a downstream portion of the Rainbow River, are located in Marion County, Florida, north of Dunnellon (**Figure 1.1**). ***Rainbow Springs Group*** (WBID 1320A), the uppermost segment of the Rainbow River, contains numerous springs discharging from limestone crevices and sand boils and is located in Rainbow Springs State Park. Rainbow Springs Group is the fourth largest spring group (by magnitude) in Florida, with an average flow of 456 million gallons per day (MGD). The 2 largest springs in the group are Rainbow Spring #1, which consists of multiple, irregularly shaped, linear fractures in the limestone within a designated swimming area of Rainbow Springs State Park, and Rainbow Spring #4, which is located about 50 feet downstream beneath a limestone ledge about 10 feet below the surface. ***Rainbow Springs Group Run*** (WBID 1320B) is a segment of the Rainbow River downstream from Rainbow Springs Group that contains 2 other major springs, Rainbow #6 and Bubbling Spring. Rainbow #6 is located about 0.4 miles downstream from the head of the river and issues from a conical depression nearest the west bank of the river. Bubbling Spring, located about 200 feet downstream from Rainbow #4, issues from a small crevice in the limestone.

Spring discharge in these 2 segments provides most of the flow in the Rainbow River. Numerous smaller springs discharge from limestone crevices and sand boils in the river bed and along the banks, contributing flow and nutrients to the system for its entire southward journey of approximately 5.7 miles to the Withlacoochee River. These segments of the Rainbow River support a complex aquatic ecosystem and are also important cultural and economic resources for the state. **Figures 1.2** and **1.3** show the two impaired WBIDs and the springs within them, respectively. These springs occur along the first 1.5 miles of the Rainbow River (Champion and Starks 2001).

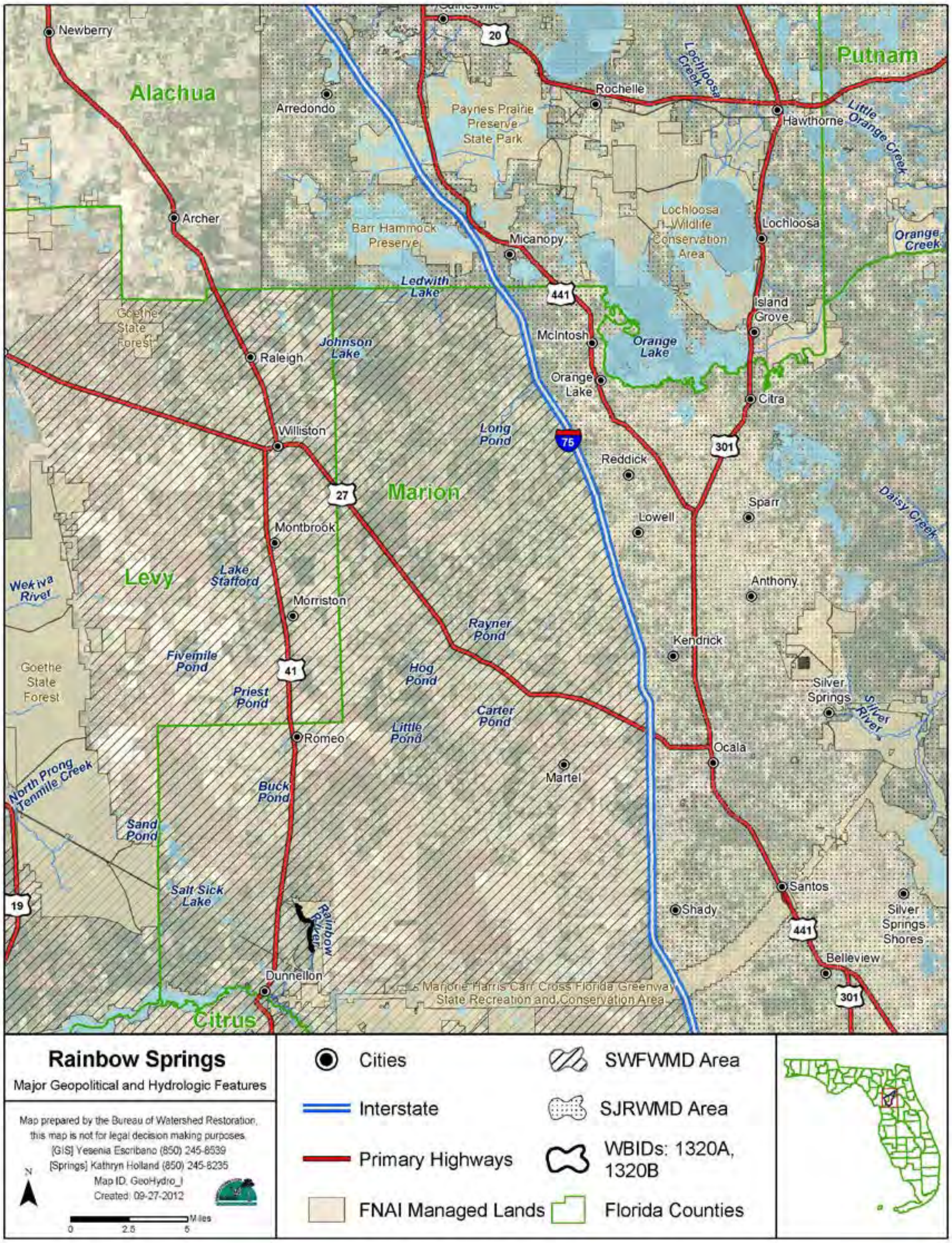

Figure 1.1. Major Geopolitical and Hydrologic Features in the Main Contributing Area for Rainbow Springs and Rainbow Springs Group Run

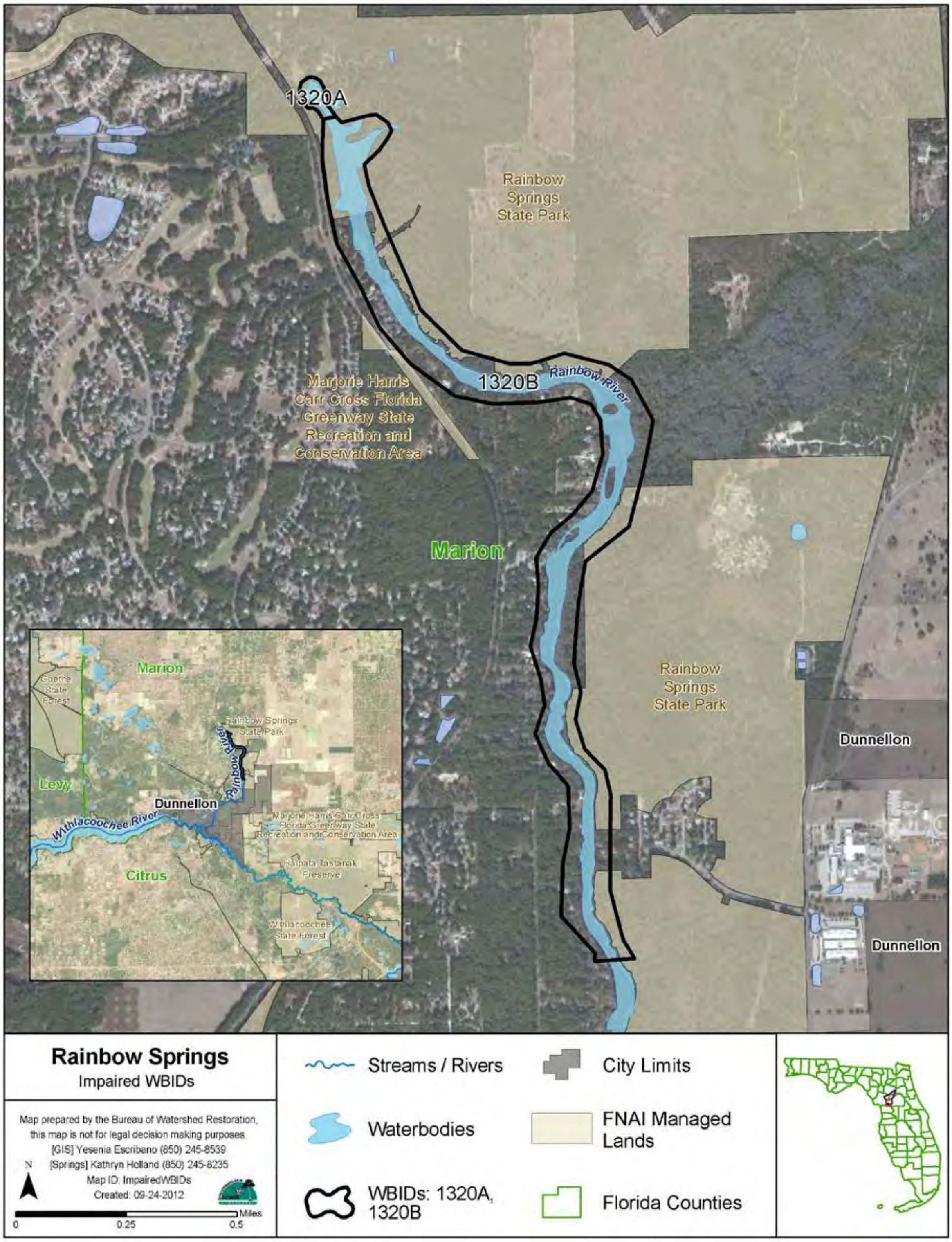

Figure 1.2. Location of the Two Impaired WBIDs in Marion County

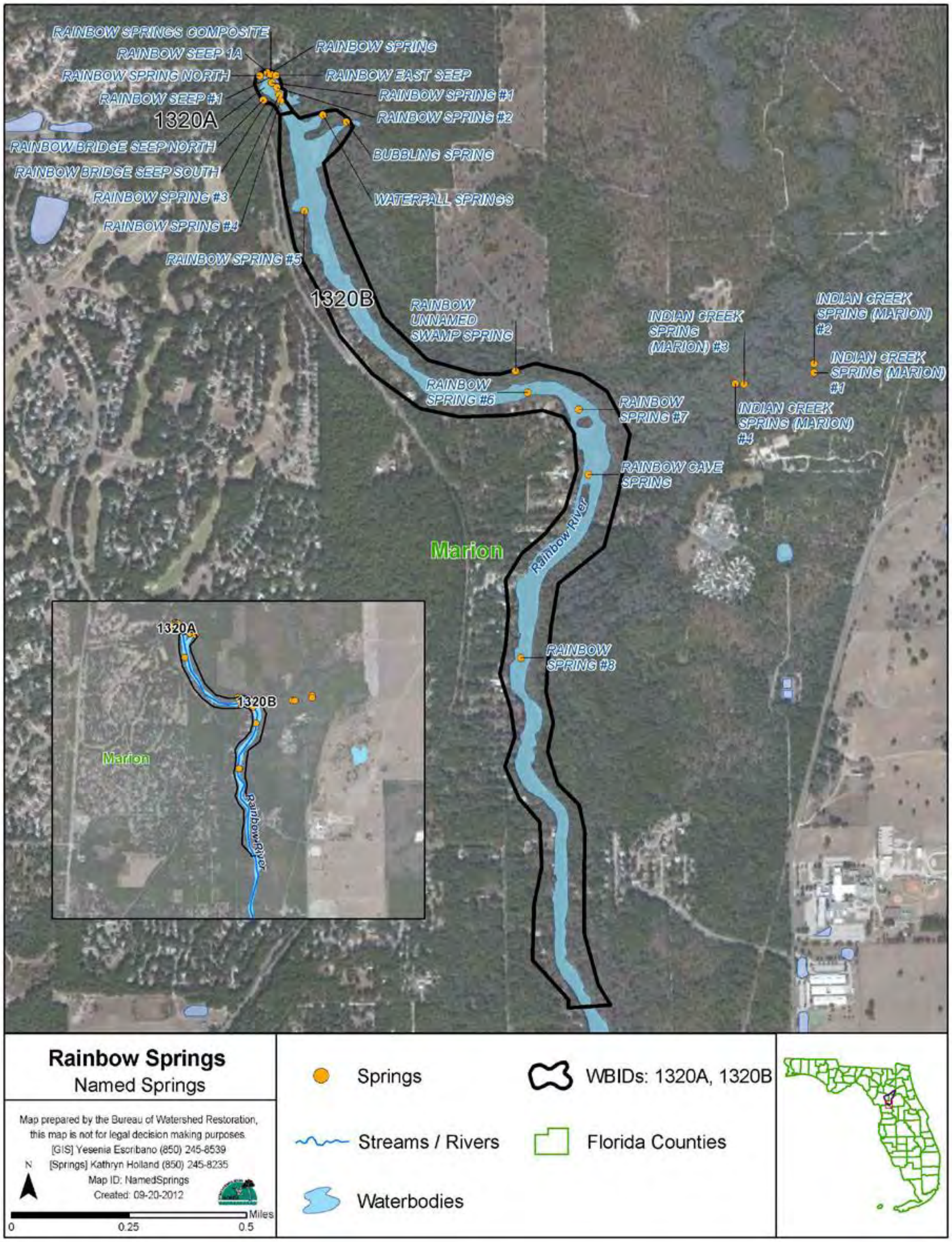

Figure 1.3. Named Springs in the Rainbow Springs Area

In the Rainbow Springs area, the hydrogeologic framework includes a surficial aquifer system, an intermediate confining unit in some places, and the underlying carbonate Floridan aquifer. In most of the area, the confining unit is thin or breached by sinkholes and solution features. The upper Floridan aquifer (UFA) is unconfined throughout most of southwestern Marion County. In this area, infiltration to the Floridan aquifer is rapid, and the depth to ground water ranges from 10 to more than 50 feet below the land surface (Basso 2009). Rainbow Springs Group and the Rainbow River occur in a karst region where the topography and drainage are caused by the underground erosion and subsidence of near-surface carbonate rocks. Within the rock, slightly acidic rainwater causes the limestone to dissolve, and further dissolution along zones of fractured rock and bedding planes causes the development of caves and interconnected openings known as conduits. Ground water migrates within these zones, and springs occur where hydraulic head differences in the aquifer coincide with openings in the earth.

Rainbow Springs Group and Rainbow Springs Group Run are located along a north-south ridge in the center of the Florida peninsula. The overlying clayey sediments of the Hawthorn Group have been eroded in this area, leaving the underlying, permeable limestone exposed at or near the land surface. The karst topography is marked by numerous sinkholes and minimal surface drainage, the most notable being Indian Creek, which may have been an important tributary to the Rainbow River in earlier times (Rosenau et al. 1977). Knowles (1996) provided details on the hydrogeologic units underlying the Rainbow Springs area, shown in **Figure 1.4**. The Floridan aquifer is the principal source of water for Rainbow Springs (Jones et al. 1996). The UFA, which is largely unconfined in the Rainbow Springs recharge area, is approximately 600 feet thick. Faulkner (1970) noted that water discharging from the springs comes predominantly from the upper 100 feet of the UFA, which is characterized by rapid flow and short residence times.

In areas where the Hawthorn Group sediments cover the limestone and where the Avon Park Formation is near the land surface, recharge is largely concentrated at sinkholes, due to lower rock permeability in these areas. This is the case northwest and southeast of Dunnellon (Knowles 1996). The Avon Park Formation has lower permeability because of sand- and clay-filled solution cavities and because of dolomitization (areas where limestone has been converted to dolomite through the replacement of calcium by magnesium) (Jones et al. 1996). Recharge of the Floridan aquifer by local rainfall is high in most areas of the watershed (>10 inches per year) (Faulkner 1970).

Jones et al. (1996) found that the chemistry of the water discharging from Rainbow Springs Group indicated that the water moved through a short, shallow flow system and that much of the water had been in the aquifer for only a few decades. Two major fractures in the limestone of the UFA occur in the contributing area for Rainbow Springs Group and likely serve as conduits for the rapid transport of large quantities of ground water to the springs. One fracture trends northwest from the springs along the Marion–Levy County line, and the other trends northeast from the springs toward Ocala. Faulkner (1970) found that a large portion of the ground water discharging from Rainbow Springs from 1966 to 1968 had not been in the aquifer for more than 16 years, and studies using tritium (a rare isotope of hydrogen, 3H) support the findings that much of the water in the Rainbow Springs watershed is relatively young (Faulkner 1970; Swancar and Hutchinson 1992).

The entire contributing area for water that goes to a spring group via ground water recharge and migration and via surface water inputs is known as its springshed. In the case of Rainbow Springs Group, its source is exclusively ground water that is recharged locally by rainfall in the

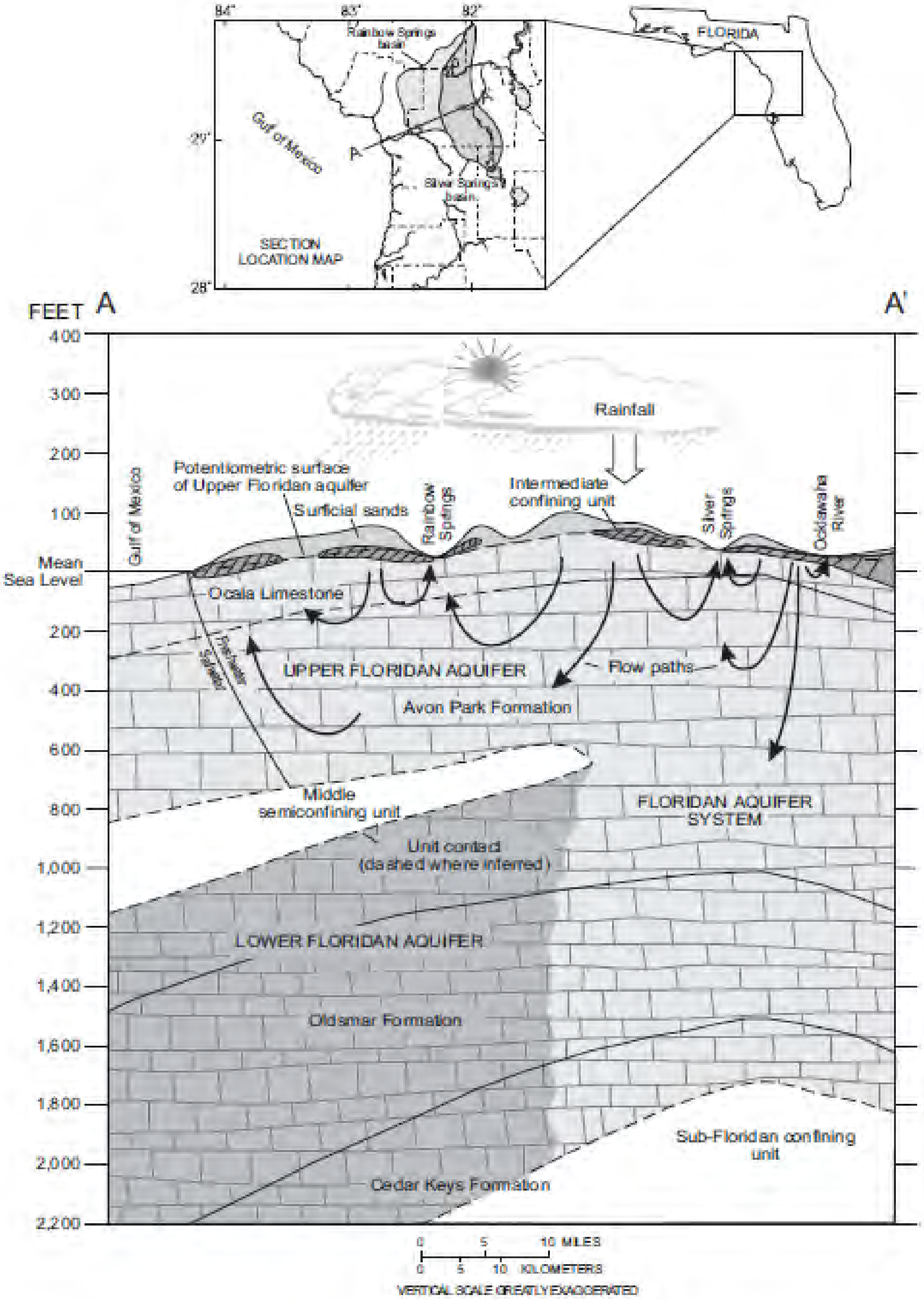

Figure 1.4. Conceptualized Ground Water Flow Patterns to Rainbow Springs Group and Rainbow Springs Group Run (Knowles 1996)

springshed. **Figure 1.5** shows the estimated springshed that was drawn based on the 1994 potentiometric surface in the Rainbow Springs ground water basin (Jones et al. 1996). The area includes parts of Marion, Levy, and Alachua Counties. While this area has often been used to depict the Rainbow Springs springshed, it should be noted that springshed areas are indefinite and dynamic, depending on precipitation and withdrawals. The immediate recharge area encompasses about 350 square miles of the southern half of the estimated springshed, where transmissivity rates are high and flow is relatively rapid. It has been speculated that portions of ground water discharging from the springs can enter the aquifer from as far away as Campville in Alachua County, about 50 miles to the northeast (Jones et al. 1996).

Adjacent to and overlapping the Rainbow Springs springshed in some areas is the predevelopment springshed of Silver Springs Group that was created by the St. Johns River Water Management District (SJRWMD) primarily from 1936 potentiometric surface data mapped by the U.S. Geological Survey (USGS) in 1980 (Johnston et al. 1980). As shown in **Figure 1.5**, the water falling in certain areas shown on the map may recharge one or both of these spring groups.

The approximate springshed area for Rainbow Springs Group is 686 square miles, while the Rainbow River surface watershed is almost 9 times smaller (77 square miles) and surface runoff has very little influence on river flow (Southwest Florida Water Management District [SWFWMD] 2008). **Figure 1.6** shows a detailed springshed map for Rainbow Springs**.**

In evaluating the potential sources of nutrients impacting the springs and spring run, the Department considered activities within the 1996 estimated springshed coverage and the surface watershed of the river, since ground water basins in the area do not coincide with the boundaries of surface water drainage divides (Faulkner 1973). Nearly all of the drainage in this area is internal, either directly into closed depressions or by seepage into the unconfined limestone of the UFA. Aquifer Vulnerability Assessments, or AVAs, are useful tools for evaluating the potential for contaminants to enter ground water. Modeled aquifer vulnerability is a function of several factors, including the nature of confining sediments above the aquifer, depth to ground water, the presence or absence of karst features, and median nitrate or dissolved oxygen (DO) concentrations measured in monitoring wells, which serve as “training points” within the modeled area.

The vulnerability of the Floridan aquifer in the Rainbow Springs springshed was assessed for the portions of the springshed within Marion, Levy, and Alachua Counties using county-specific Florida Aquifer Vulnerability Assessment (FAVA) models that had been independently developed for local governments (Baker et al., 2005; Advanced GeoSpatial, Inc. 2007; Advanced GeoSpatial, Inc. 2009). These county models are based on the specific aquifer and soil data available within the modeled areas that determine the distribution of training points and therefore the ranges of vulnerability. When the county-specific model results are aligned on a single map, the vulnerability ranges depicted in **Figure 1.7** for the three models are similar enough that they can be combined. Ideally, a model would be created for a single area that included the entire springshed. The individual models for the three areas indicate that most of the springshed is “more vulnerable” or “vulnerable” to contamination, transitioning to “vulnerable” in the northeastern part of the springshed where the confining unit exists.

Additional information about the springs’ hydrology and hydrogeologic setting is available in the Water Quality Assessment Report for the Withlacoochee Basin (Department 2006).

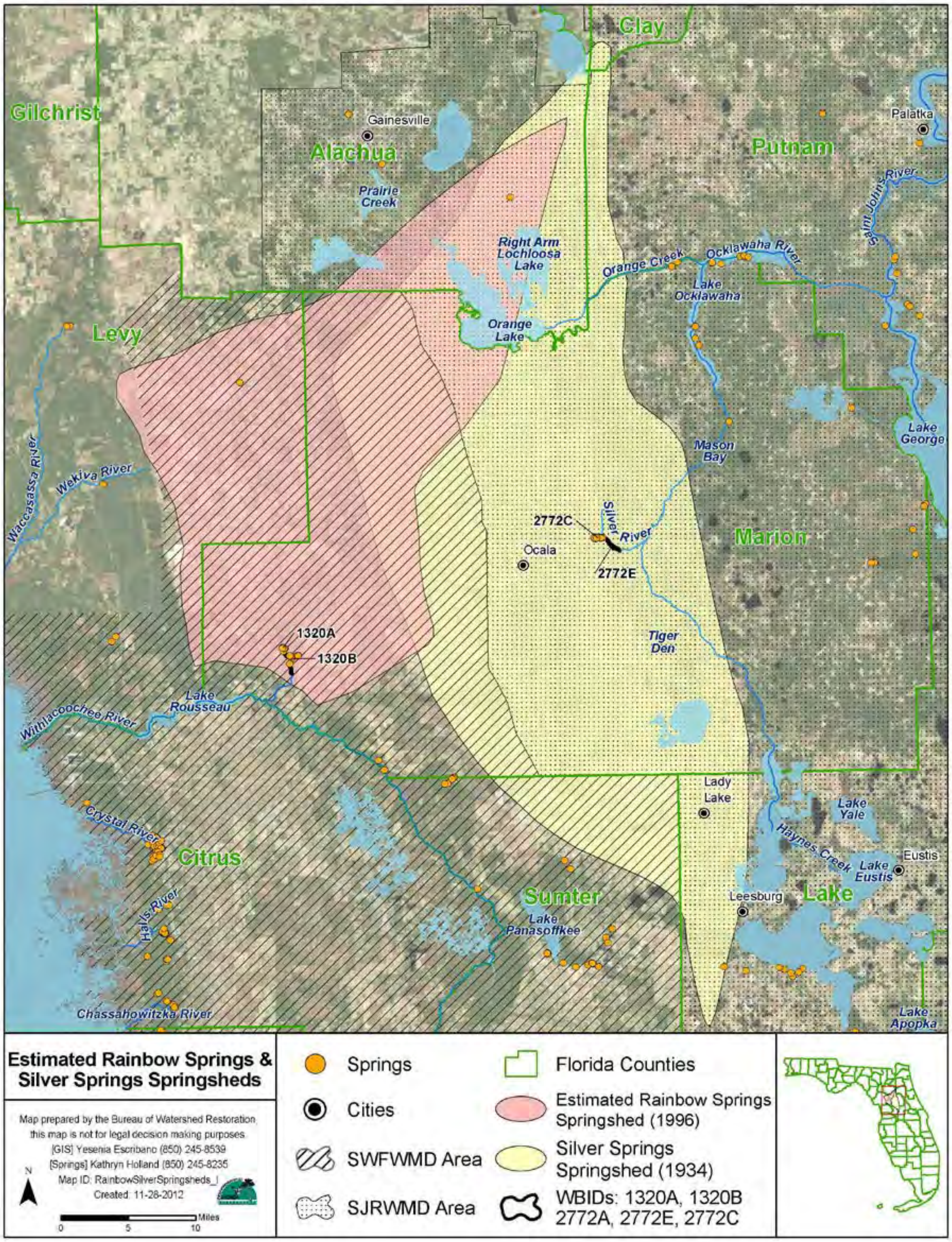

Figure 1.5. Springsheds for Rainbow Springs and Silver Springs

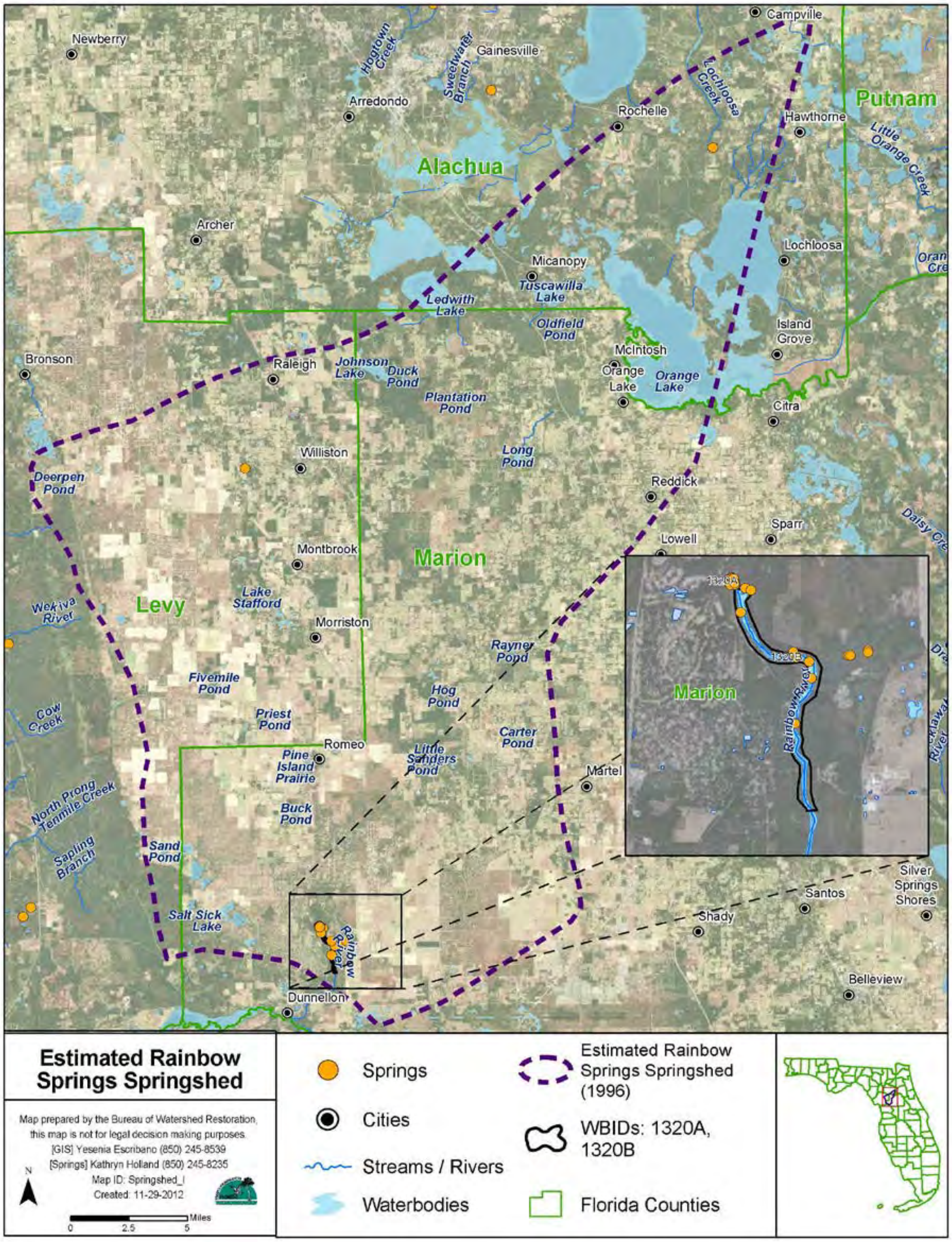

Figure 1.6. Springshed for Rainbow Springs Group and Rainbow Springs Group Run

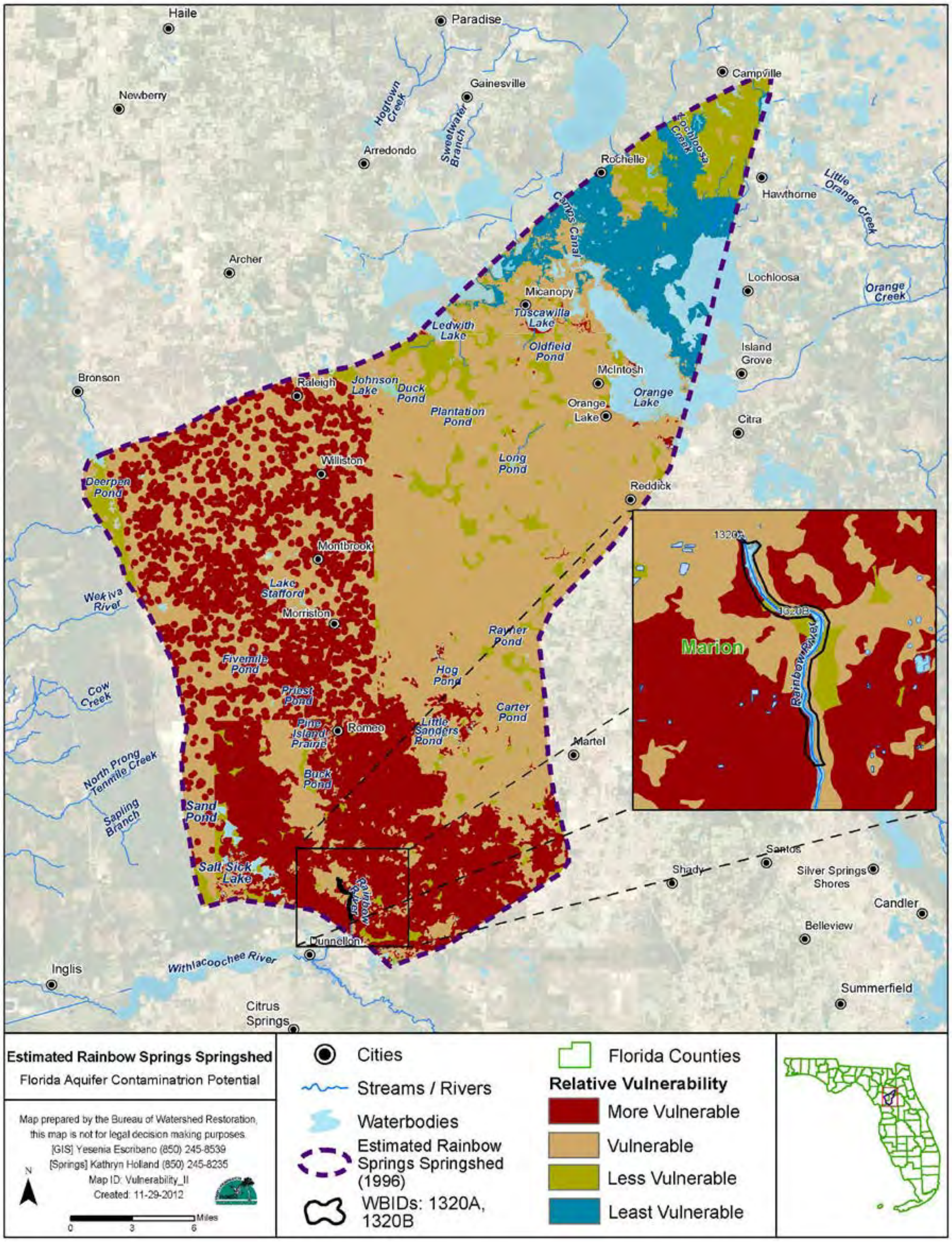

Figure 1.7. Aquifer Vulnerability in the Estimated Rainbow Springs Springshed

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 Rainbow Springs Group and Rainbow Springs Group Run. The restoration of these waterbodies will depend heavily on the active participation of stakeholders in the springshed, including landowners in the contributing area; agricultural interests; Marion, Levy, and Alachua Counties; the city of Dunnellon; the SWFWMD; the Florida Department of Agriculture and Consumer Services (FDACS); other local governments; businesses; and private citizens.

Rainbow Springs and the Rainbow River are economically valuable to southwestern Marion County and the state, and that value is directly dependent on the physical and ecological health of the system. Many of the springs and uplands are contained within Rainbow Springs State Park. At more than 1,470 acres, the park encompasses the headwaters and several miles of the river, as well as much of the land along the eastern edge of the river. Visitors come to the state park and river for sightseeing, swimming, boating, diving, snorkeling, fishing, and tubing. Also, several festivals held both in Dunnellon and in Rainbow Springs State Park attract large crowds. Considerable real estate development over the last 3 decades in the area around the springs and along the river contributes jobs and income to the area. Most new developments are part of the Villages of Rainbow Springs Property Owners Association, and developers identify proximity to the springs as a major benefit of living in these communities.

The SWFWMD has supported numerous efforts to restore and protect the springs and river. It has designated the river as its Number 2 priority waterbody and funded several projects under the Surface Water Improvement and Management (SWIM) Program. SWIM Plan implementation includes working with local governments to improve and/or maintain the ecological health of the river and providing homeowners, landscape professionals, and retail outlets with educational information and incentives that will lead to behavior changes to protect water quality. In September 2008, SWFWMD staff developed a technical summary of projects that have been completed since the 2004 SWIM Plan was adopted.[1]

In 1991, SWFWMD began extensive aquatic vegetation mapping, which continues today and provides valuable information on changes in the river's natural systems. Since 2002, the SWFWMD and Rainbow Springs Aquatic Preserve have been involved with efforts to

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[1] More information on these projects can be found in the quarterly SWIM Program project status reports. The fourth quarter 2012 report is available at: http://www.swfwmd.state.fl.us/files/database/site_file_sets/34/swim_project_status.pdf.

understand the river's exceptional water clarity and the link between water clarity and spring discharge. Removal of the invasive benthic cyanobacterium *Lyngbya* and revegetation were completed in 2002. The SWFWMD has also completed numerous stormwater improvements projects, with several still under way. Details of these projects are available at the SWFWMD website listed in the footnote below.

Marion County has implemented measures including a comprehensive Watershed Management Program to identify and address water quality issue from stormwater runoff, a Springs Protection Ordinance that specifies guidelines for development in the Rainbow Springs primary protection zone, and stormwater and wastewater treatment standards that are protective of karst features and ground water. Additionally, the northwestern part of Marion County is classified as Farmland Preservation Area in the Marion County Comprehensive Plan to protect traditional agricultural land use areas.

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 U.S. Environmental Protection Agency (EPA) a list of surface waters that do not meet applicable water quality standards (impaired waters) and establish a TMDL for each pollutant causing the 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 contained 10 waterbodies in the Withlacoochee 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 Rule 62-303, Florida Administrative Code (F.A.C.) (Identification of Impaired Surface Waters Rule, or IWR), in April 2001. The IWR was modified in 2006 and 2007.

2.2. Information on Verified Impairment

Rule 62-303, F.A.C., includes a methodology for listing nutrient-impaired surface waters based on documentation that supports the determination of an imbalance of flora or fauna. In 2009, the Department used available water quality data provided by the SWFWMD and, in the IWR database, the Department's Springs Initiative monitoring network data from 2001 to 2009, Ecosummaries, and other available information to document the increasing nitrate concentrations and effects of nutrient enrichment in the spring run and river. Two WBIDs in the Rainbow River were listed as impaired for nutrients because of their consistently elevated concentrations of nitrate (above 0.6 milligrams per liter [mg/L]) and the corresponding evidence of imbalance of flora and fauna downstream. This information, documented by Hicks et al. (2009), supplemented the determination of impairment for the 2010 Verified List of impaired waters. **Table 2.1** lists the waterbodies in the Withlacoochee Basin on the Cycle 2 Verified List that are addressed in this report.

Table 2.1. Verified Impaired Spring-Related Segments in the Withlacoochee Basin

WBID	Waterbody Segment	Parameters Assessed Using the IWR	Priority for TMDL Development	Projected Year of TMDL Development
1320A	Rainbow Springs Group	Nutrients (Algal Mats)	Medium	2012
1320B	Rainbow Springs Group Run	Nutrients (Algal Mats)	Medium	2012

2.3 Nutrients

Nutrient overenrichment can cause the impairment of many surface waters, including springs. The two major nutrient groups monitored are nitrogen (N) and phosphorus (P), which are essential nutrients to plant life. For aquatic vegetation and algae to grow, both nutrients must be present. One nutrient can be present in excess, but if the other is absent, the overgrowth of vegetation or algae is unlikely to occur. Historically, many spring systems have had sufficient naturally occurring phosphorus to promote an overgrowth of vegetation or algae, but this did not occur because there was very little nitrogen in the water column.

Nitrogen is found in several forms and is ubiquitous in the environment. Nitrate (NO_3) is the form of nitrogen that occurs in the highest concentrations in ground water and springs. Nitrite-nitrogen (NO_2), an intermediate form of nitrogen, is almost entirely converted to nitrate in the nitrogen cycle. While nitrate and nitrite are frequently analyzed and reported together as one concentration (nitrate + nitrite as nitrogen), the nitrite contribution is always insignificant. Historically, nitrogen was only a minor constituent of spring water, and typical nitrate mg/L.

The source of the nitrate in the springs is ground water from the UFA, and elevated nitrate levels in the ground water of this area have also been observed. A review of private well sampling data collected by the Florida Department of Health (FDOH) from the Rainbow Springs springshed found that out of more than 222 well samples collected, 41% had nitrate concentrations in Florida were less than 0.2 mg/L until the early 1970s. Since then, elevated concentrations of nitrate have been found in many springs. With sufficient phosphorus in the water column, seemingly low nitrogen concentrations can actually cause a significant shift in the balance of spring ecological communities, leading to the degradation of biological systems due to the overgrowth of algae and sometimes invasive aquatic plants (Harrington et al. 2010).

2.3.1 Nitrate

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

Nitrate concentrations in water samples from Rainbow Springs Group now often exceed 2 mg/L. Long-term records indicate that nitrate concentrations at Rainbow Springs have increased from a concentration of $\leq$ 0.1 mg/L in 1927, to concentrations that now often exceed 2.0 mg/L, or 20 times the historical level. Additionally, Department data show that current nitrate levels in Rainbow Springs are 40 times the background level of 0.05 mg/L found in many of Florida’s springs. Average annual nitrate concentrations ranged between approximately 0.2 and 0.3 mg/L from the 1970s to the early 1980s, increasing to above 1.0 mg/L in the 1990s. Jones et al. (1996) also found nitrate concentrations averaging 1.0 mg/L for the largest springs in Rainbow Springs Group; between 2001 and 2005, the results averaged about 1.3 mg/L, and the average concentration has continued to increase to the present level of approximately 2 concentrations greater than 1 mg/L and that the higher concentrations were found at the center of the springshed (Harrington et al. 2010).

The sources of nitrate in the ground water and springs include fertilizer applications (agriculture, golf courses, lawns, etc.), animal waste, domestic wastewater, and atmospheric deposition. Nitrate emerging from Rainbow Springs is primarily from inorganic sources of nitrogen, mainly fertilizer (Jones et al. 1996). About 42% of the land in the Rainbow Springs springshed is agricultural, and thus much of the fertilizer likely originates from agricultural activities. By contrast, only about 18% of the land is residential, with less than 1% recreational (ballfields and golf courses). It should be noted, however, that the majority of these land uses lie closer to the springs than the agricultural land uses. Despite the increasing nitrate levels, the river's ecosystem is still considered to be in a relatively healthy state.

The problems caused by increased nitrate concentrations are not completely understood, although nitrate levels above background may support increased algal growth and increased growth of the invasive exotic plant *Hydrilla*. Some studies (Cowell and Botts 1994; Stevenson et al. 2004; Heffernan et al. 2010) suggest that other attributes such as DO, flow, conductivity, and salinity, which are less studied in spring systems than nitrogen, may also contribute to increased algal coverage. There is clear evidence, however, that nitrate does fuel the growth of algae in spring run river systems (Stevenson et al. 2007).

2.3.2 Phosphorus

Neither orthophosphate nor total phosphorus (TP) has shown an increasing temporal trend in the Rainbow Springs system, and concentrations remain close to those levels found in the 1950s. Therefore, phosphorus was not considered a target nutrient for the TMDL. In general, only the inorganic form of phosphorus, orthophosphate, is found in ground water in Florida. **Figure 2.1** shows the historical orthophosphate results for Rainbow Springs Group. While the overlying Hawthorn Group can contribute orthophosphate to ground water throughout much of the state, this geologic formation is of limited extent in the Rainbow Springs springshed and therefore is not a major contributor of orthophosphate. The median orthophosphate concentration from 2001 to 2006 was 0.029 mg/L at both Rainbow Spring #1 and #6, 0.034 mg/L at Rainbow #4, and 0.037 mg/L at Bubbling Spring (Harrington et al. 2010). Jones et al. (1996) measured TP in 60 wells throughout the Rainbow River watershed and found values ranging from 0.023 to 0.764 mg/L. The highest values in ground water were found west and southwest of Ocala, and horse farms were indicated as probable sources.

2.4 Ecological Issues Related to Nutrients

2.4.1 Water Clarity

Water clarity or transparency, in the headsprings (WBID 1320A) is exceptional, with a horizontal Secchi depth of about 230 feet, and ranging from >200 feet at the upstream boundary of WBID 1320B to >50 feet at the downstream boundary of the WBID (M. Szfraniec, SWFWMD, pers. comm.). Water clarity in the Rainbow River decreases with increasing distance from the headsprings area, while chlorophyll *a* increases with increasing distance (Anastasiou 2006). Approximately 83% of the variability in water clarity can be explained by chlorophyll *a* concentrations (SWFWMD 2008). The SWFWMD study showed that clarity was greatly affected by increases in chlorophyll *a*, but once chlorophyll *a* reached a concentration of 1.0 microgram per liter (µg/L), the observed changes in clarity were much smaller. In a complementary study conducted by Cowell and Dawes (2007), phytoplankton was shown to be the source of chlorophyll *a.* Experiments conducted to test nutrient effects on phytoplankton indicated that biovolume increased when nitrate + trace metals were at elevated concentrations.

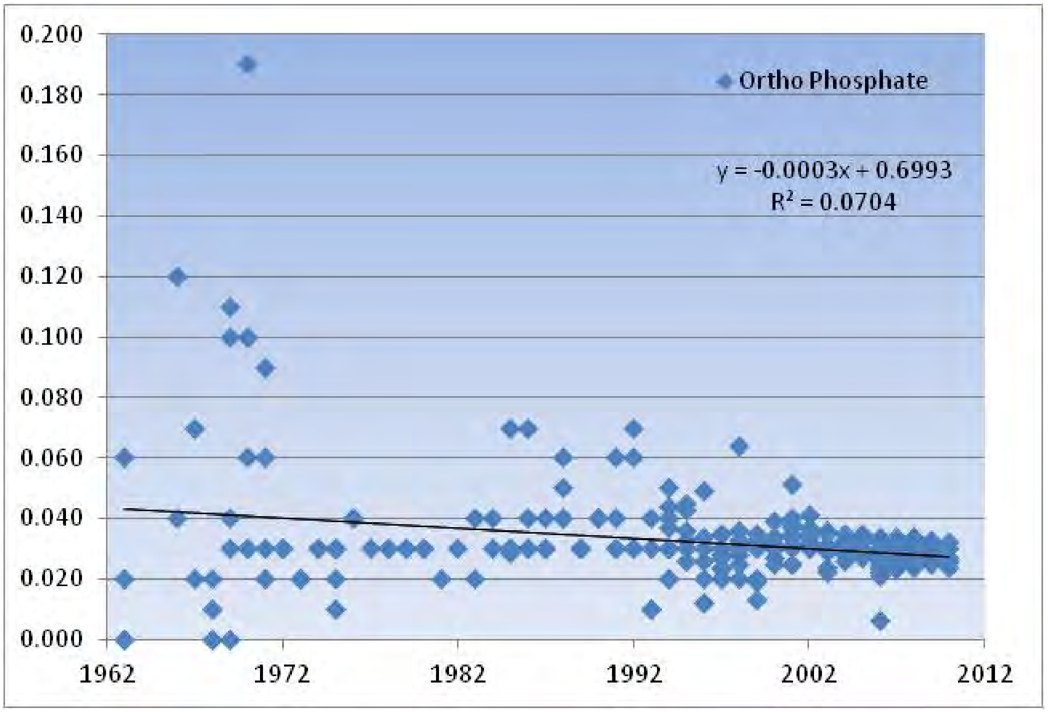

Figure 2.1. Phosphorus and Orthophosphate in the Impaired WBIDs, 1963–2010

2.4.2 Human Recreational Impacts

The Rainbow River attracted over 262,000 visitors between 2010 and 2011, with the number of visitors increasing substantially during the summer months (Department 2011a). Heavy recreational use in the springs area and along the river causes noticeable damage to vegetation. At the headsprings, the swimming area becomes denuded of vegetation due to foot traffic and trampling. Recreational users increase turbidity, introduce pollutants, and ward off fish and wildlife. Motorized boats deter wildlife, and the improper use of motorboats can cause the development of extensive propeller scars in submerged aquatic vegetation (SAV) beds (Cichra and Holland 2012). Boats moving at higher than recommended speeds create wakes that can erode the banks of the river.

Photographic evidence presented when these waters were being evaluated for listing indicated that algal smothering could lead to an imbalance of flora and fauna. Photographs taken in the 1950s document healthy SAV populations and crystalline water clarity, with little to no algal smothering. Photographs taken within the past five years document algal growth at the springs and river (**Figures 2.21** through **2.7**).

Figure 2.2. Underwater Photo of Rainbow Springs, 1955 (State Archives of Florida)

Figure 2.3. Underwater Photo of Rainbow Springs, 1955 (State Archives of Florida)

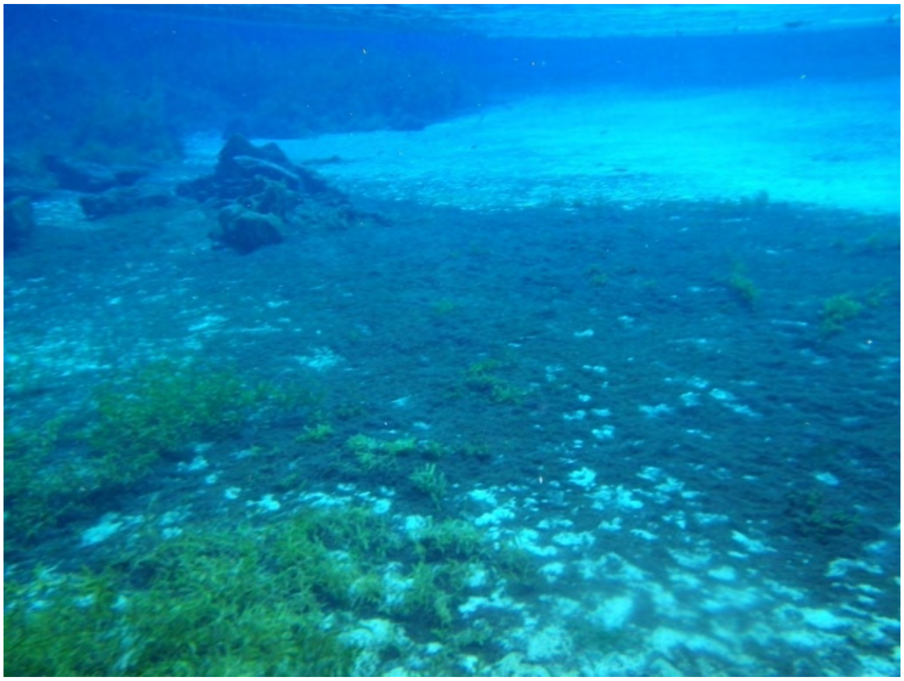

Figure 2.4. Downstream of Rainbow Spring #1, 2011 (Department)

Figure 2.5. Algae South of Rainbow Spring #1, March 2009 (Florida Geological Survey [FGS])

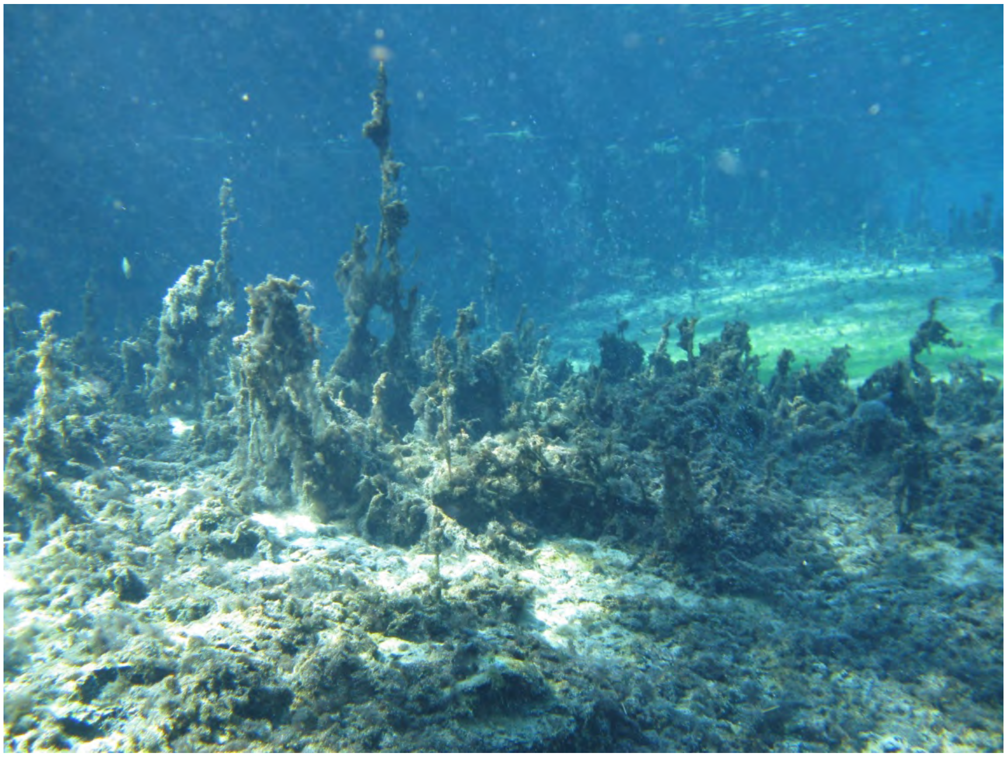

Figure 2.6. Rainbow Spring #4, South of Vent, March 2009 (FGS)

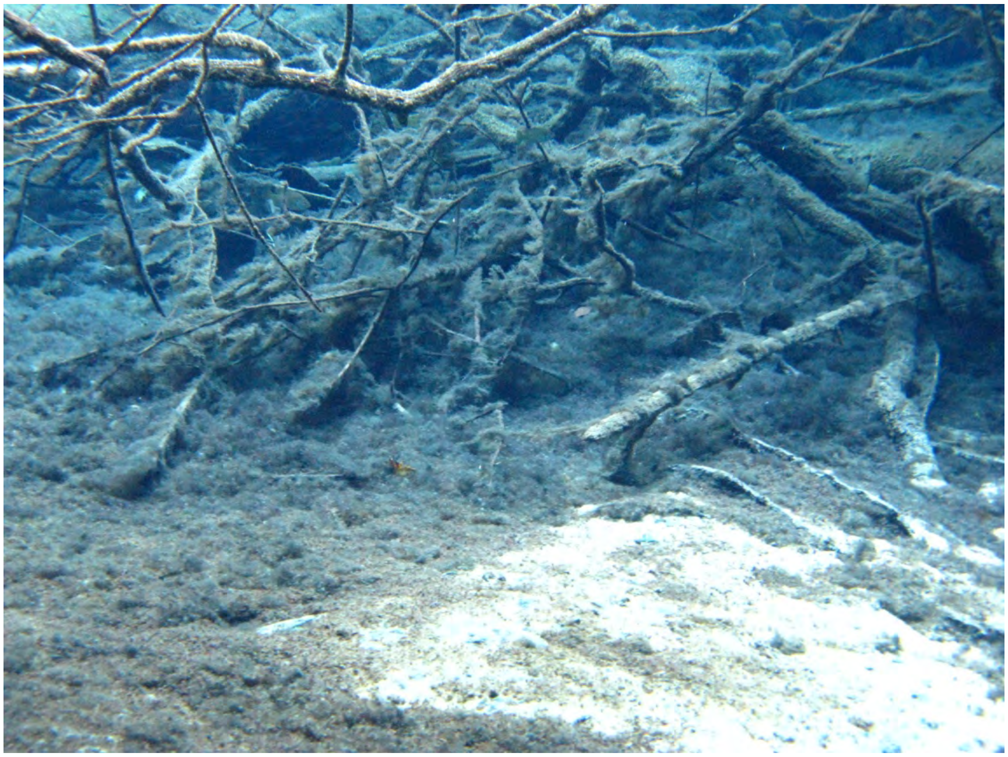

Figure 2.7. Rainbow Spring, #4, North of Vent, Close to Shoreline, November 2009 (FGS)

2.5 Rainfall and Temperature Data

The climate in the Rainbow Springs area is humid subtropical, with hot, rainy summers and cool, generally dry winters. Recharge to ground water is entirely dependent on rainfall. In a typical year, more than half of the rainfall in the area (on average about 25 inches) occurs during the 4 months from June through September as a result of seasonal thunderstorms and tropical systems. The rest of the year is comparatively dry, averaging about 3 inches per month. Rainfall and temperature data were reviewed for the 30-year period of record from 1981 to 2010 (**Table 2.2**). Annual rainfall averages about 50.6 inches per year (in/yr) with an average air temperature of about 71°F (National Oceanic and Atmospheric Administration [NOAA] 2010).

Table 2.2. Temperature (°F) and Precipitation (Inches) at NOAA Station (Ocala - 086414), 1981–2010

Source: NOAA 2010

Analysis	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
30-Year Mean–Maximum Temperature (°F)	70.1	73.2	77.8	83	88.7	91.2	92.2	91.7	89.4	84.1	77.3	71.5	**82.4**
30-Year Mean–Minimum Temperature (°F)	45.2	48.2	52	56.5	63.5	69.9	71.7	71.9	69.4	62.1	53.7	47.3	**59.3**
30-Year Mean–Average Temperature (°F)	57.7	60.8	64.9	69.7	76.1	80.5	81.9	81.8	79.4	73.1	65.5	59.4	**70.8**
30-Year Mean–Precipitation (inches)	3.17	3.27	4.56	2.4	2.98	7.42	6.71	6.32	6.07	3.03	2.1	2.57	**50.6**

Figure 2.8 shows the 30-year historical precipitation trend measured at Ocala. Over the 30-year period, the lowest annual rainfall of 28.58 inches occurred in 2000, and the highest annual rainfall of 74.71 inches occurred in 1982. The NOAA "normal" value for rainfall from 1981 to 2010 is 49.68 inches. Munch et al. (2006) reviewed rainfall data beginning in 1891 and noted that expected precipitation at this station has declined since 1980. The annual average precipitation from 1891 to 1980 was 53.30 inches.

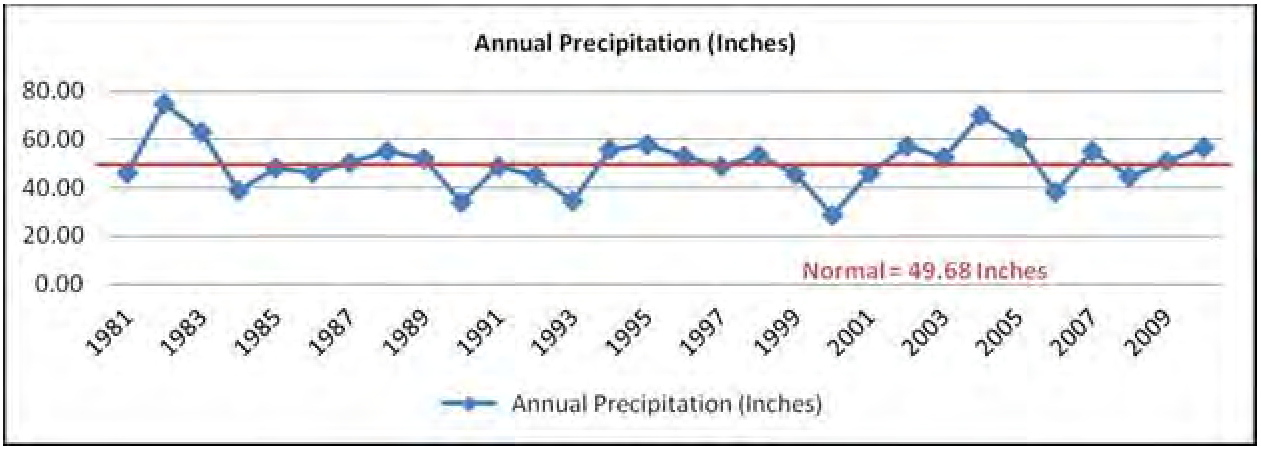

Figure 2.8. Precipitation for Ocala, 1981–2010 (NOAA Climate Information for Management and Operational Decisions [CLIMOD] Product, October 20, 2011)

2.6 Monitoring Sites and Sampling

Historical water quality data for Rainbow Springs are limited, but they do provide an indication of current versus "background" water quality. Water quality data have been collected from various locations around the springs and in the river since the 1950s, and the EPA Storage and Retrieval (STORET) and USGS National Water Information System (NWIS) databases contain many of these data. **Figure 2.9** shows the locations of the current and past routine water quality sampling stations and biological stations monitored by the Department and SWFWMD.

2.7 Discharge Data

Ground water discharge from Rainbow Springs Group, springs along Indian Creek, and numerous vents along the Rainbow River account for 97 to 99% of the Rainbow River's flow (Water and Air Research, Inc. and SWFWMD 1991). The USGS discharge measurements are made approximately 0.25 miles upstream of the bridge on State Highway 484 (5 miles downstream from the headsprings). Surface inflow between the springs and measuring site is negligible except after heavy rains. Discharge is computed from the relationship between artesian pressure at Rainbow Springs well (290514082270701) and discharge at the measuring site (USGS 2012).

Long-term discharge measurements for the Rainbow River (**Figure 2.10**) indicate that flow fluctuated between 386 and 1,060 cubic feet per second (cfs) during the period from 1965 to 2012. Rainbow River discharge varies seasonally and has been shown to correlate directly with rainfall. The mean monthly average computed between 1965 and 2011 was lowest in June (644 cfs), which corresponds to the end of the dry season, and highest in October (729 cfs), at the end of the wet season.

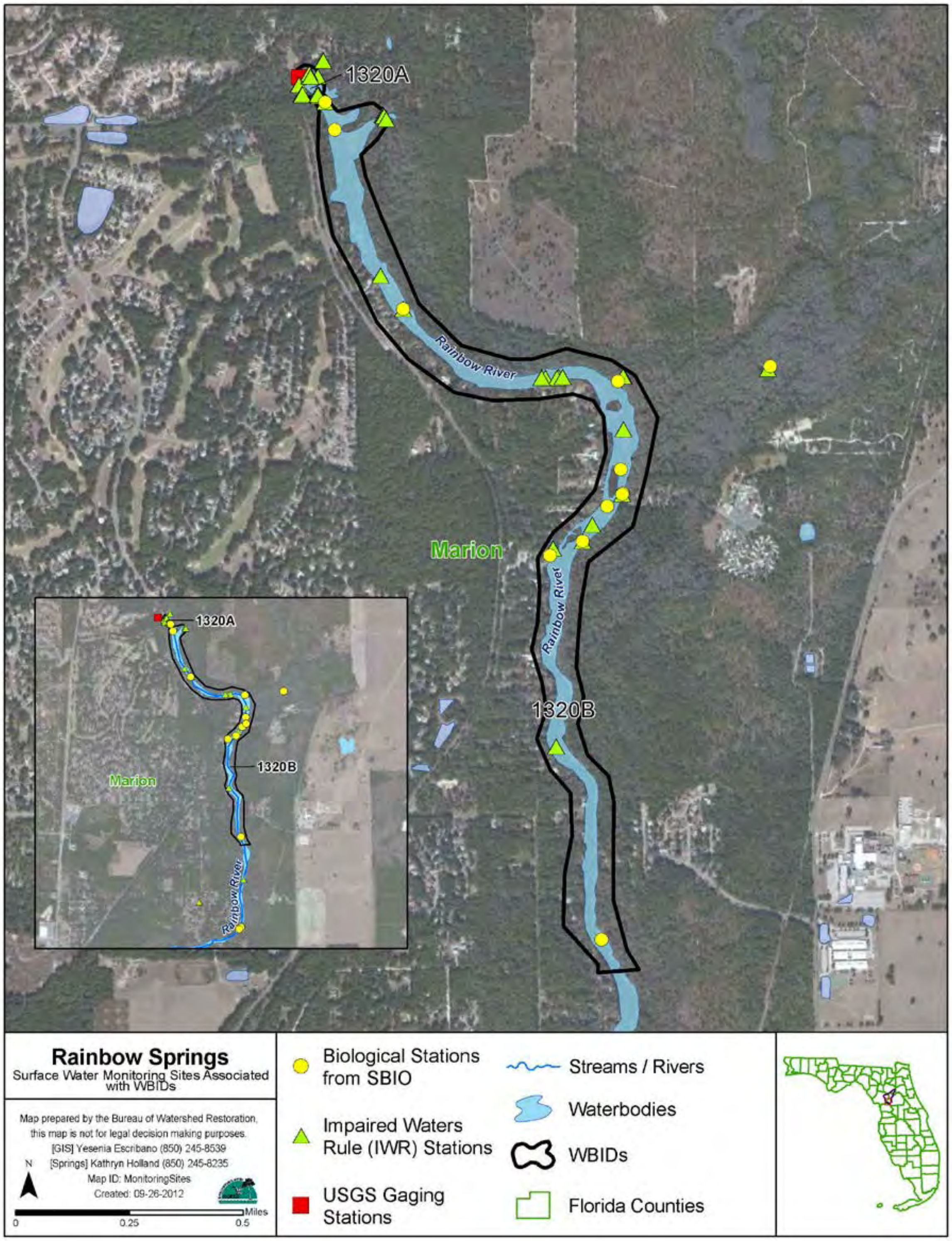

Figure 2.9. Surface Water Monitoring Sites Associated with Rainbow Springs Group and Rainbow Springs Group Run

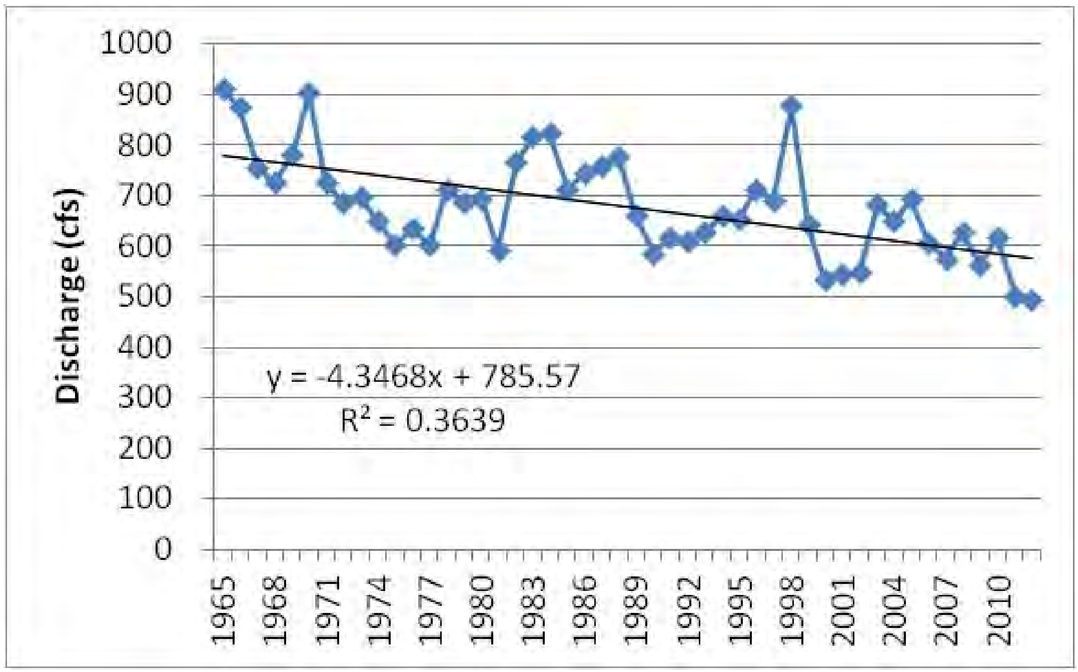

Figure 2.10. Average Annual Discharge in the Rainbow River, USGS Station 02313100 (Source: USGS 2012)

2.8 Nitrate in Impaired Waterbodies

Data show that nitrate is the predominant form of nitrogen for Rainbow Springs Group. Nitrate has been measured at Rainbow Springs since the late 1950s, documenting an increasing trend in concentrations over time (**Figure 2.11)** (Jones et al. 1996; Harrington et al. 2010). Median nitrate concentrations in Rainbow Springs Group from the 1950s through the early 1980s fluctuated between 0.1 and 0.3 mg/L. In 1988, a nitrate concentration of 0.93 mg/L was measured; concentrations have remained above 0.5 mg/L since that time and either at or above 1.0 mg/L during the verified period (January 1, 2000, through June 30, 2007) (**Table 2.3**).

In Rainbow Springs Group Run, total nitrogen (TN) was included in the trend analysis (**Figure 2.12**) due to a data gap in nitrate sampling between 1997 and 2001. TN includes nitrate-nitrogen, and while TN values in these waters may be slightly higher than nitrate values, TN is useful as a surrogate for nitrate for periods when historical nitrate data are not available. Nitrate concentrations in Rainbow Springs Group Run fluctuated during the verified period but appear to be increasing over time.

Since the water quality target for springs is nitrate, only nitrate data from 2001 through 2010 were used to calculate annual mean, median, minimum, and maximum nitrate values for both WBIDs (**Tables 2.3** and **2.4**).

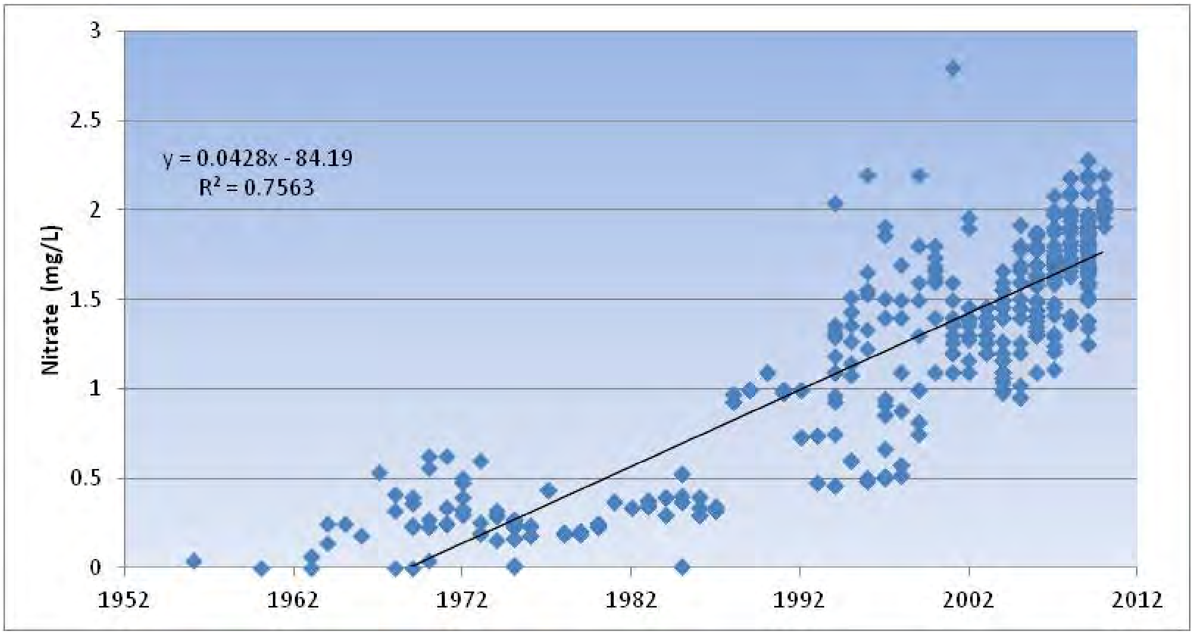

Figure 2.11. Nitrate Trend for Rainbow Springs Group, 1956–2011

Table 2.3. Nitrate Concentrations for Rainbow Springs Group, 2001–2010

[1] n = Number of samples
[2] All nitrate values are in mg/L.

Year	Nitrate *n*[1]	Nitrate Average[2]	Nitrate Median[2]	Nitrate Minimum[2]	Nitrate Maximum[2]
2001	3	1.23	1.3	1.2	1.3
2002	6	1.4	1.4	1.1	1.9
2003	8	1.33	1.1	1.2	1.4
2004	19	1.24	1.1	0.98	1.6
2005	8	1.51	1.6	0.96	1.8
2006	17	1.59	1.7	1.3	1.8
2007	14	1.73	1.68	1.46	2
2008	14	1.87	1.9	1.63	2.1
2009	27	1.81	1.8	1.5	2.2
2010	7	2.03	2.02	1.91	2.2

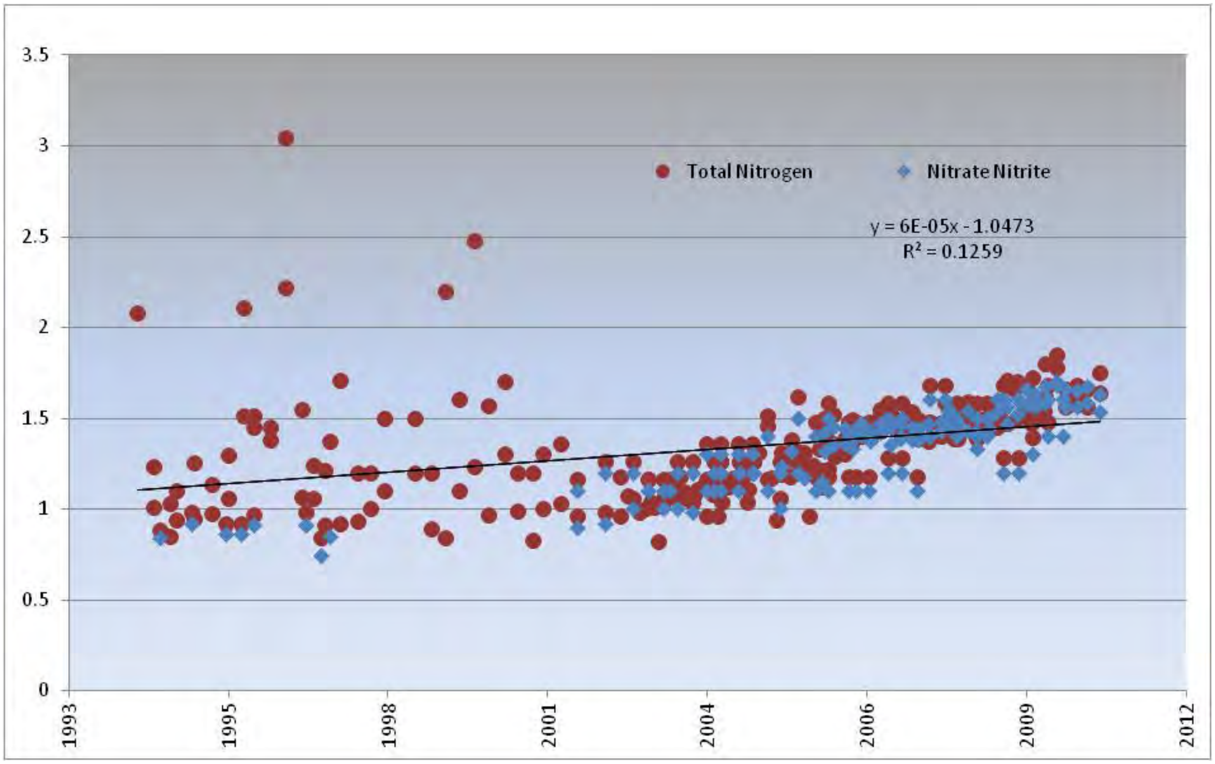

Figure 2.12. Nitrogen Trend for Rainbow Springs Group Run, 1994–2010

Table 2.4. Nitrate Concentrations for Rainbow Springs Group Run, 2001–10

[1] n = Number of samples
[2] All nitrate values are in mg/L.

Year	Nitrate *n*[1]	Nitrate Average[2]	Nitrate Median[2]	Nitrate Minimum[2]	Nitrate Maximum[2]
2001	2	1.00	1	0.90	1.10
2002	4	1.08	1.1	0.92	1.20
2003	9	1.09	1.1	0.98	1.20
2004	20	1.20	1.2	1.10	1.30
2005	11	1.24	1.2	1.00	1.50
2006	21	1.33	1.4	1.10	1.50
2007	22	1.40	1.4	1.10	1.60
2008	20	1.46	1.47	1.33	1.60
2009	20	1.52	1.58	1.20	1.67
2010	12	1.60	1.62	1.40	1.70

Chapter 3. DESCRIPTION OF APPLICABLE WATER QUALITY STANDARDS AND TARGETS

3.1 Classification of the Waterbody and Criterion Applicable to the TMDL

Florida's surface waters are protected for six designated use classifications, as follows (available: http://www.dep.state.fl.us/water/wqssp/classes.htm):

Class I	**Potable water supplies**
Class II	**Shellfish propagation or harvesting**
Class III	**Fish consumption, recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife**
Class III	**Fish consumption, recreation or limited recreation, and/or Limited propagation and maintenance of a limited 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)**

Rainbow Springs Group and Rainbow Springs Group Run are Class III fresh waterbodies (with designated uses of recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife). The Class III freshwater quality criterion applicable to the impairment addressed by this TMDL is excessive nutrients, which have been demonstrated to adversely affect flora or fauna.

3.2 Applicable Water Quality Standards and Numeric Water Quality Targets

3.2.1 Nutrients

Thresholds of nutrient impairment for streams have been interpreted in the IWR, Section 62-303.351, F.A.C. (Nutrients in Streams), to include stream segments if an imbalance of flora or fauna occurs due to nutrient enrichment. This imbalance includes algal blooms, changes in alga species richness, excessive macrophyte growth, a decrease in the areal coverage or density of seagrasses or other SAV, and excessive diel oxygen variation. In 2009, Rainbow Springs Group and Rainbow Springs Group Run were included in Florida's list of impaired waters based on these narrative criteria. At that time, elevated nitrate in the water was determined to be the cause of excessive algal growth. Excessive algal growth can cause a variety of adverse ecological impacts, including, but not limited to, reduced water clarity, habitat smothering, the provision of nutrition and habitat for pathogenic bacteria, the production of toxins that may affect biota, the reduction of oxygen levels, and an increase in diurnal swings of the DO regime in the stream. Macroalgae mats can produce human health problems, foul beaches, inhibit navigation, and reduce the aesthetic value of clear springs or stream runs.

Ongoing research on many Florida springs has resulted in significant progress in understanding 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 Rainbow Springs, TP concentrations average about 0.03 to 0.04 mg/L, which is lower than the median orthophosphate concentration found for the Floridan aquifer system of the Withlacoochee Basin (0.058 mg/L, in Harringon et al. 2010). Additionally, the average range of TP in the impaired WBIDs is below the 0.065 to 0.09 mg/L concentration range shown to contribute to biological impairments (Hallas and Magley 2008; Gao 2008). As nitrate is the dominant form of nitrogen in the Rainbow River system based on concentration, the nutrient linked to the algal growth is nitrate nitrogen.

Chapter 5 discusses the nutrient impairment and the setting of the TMDL target concentration for nitrate.

3.2.2 Outstanding Florida Water Designation

The Rainbow River, whose flow is fed primarily by Rainbow Springs, has been designated as an Outstanding Florida Water (OFW) because of its diverse ecosystem, which includes numerous species of fish, birds, and reptiles. Rainbow Springs was also designated a National Natural Landmark by the National Park Service in 1972, designated an Aquatic Preserve in 1986, and recently named as a site on the Great Florida Birding Trail.

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 magnitude 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. Wastewater treatment facilities (WWTFs) that discharge directly into surface waters 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 and those sources that do not directly discharge to the impaired surface water, including stormwater runoff, wastewater sprayfield sites, agricultural fields, silviculture, mining sites, septic systems, and atmospheric deposition.

The 1987 amendments to the Clean Water Act redefined certain nonpoint sources of surface water 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 to surface water, such as those from local government master drainage systems, construction sites over five acres, and a wide variety of industries (see **Appendix A** for background information on the federal and state stormwater programs).

To be consistent with Clean Water Act definitions, the term "point source" is used in this document to describe traditional point sources (such as domestic and industrial wastewater discharges to surface water) and stormwater system discharges to impaired surface waters that require an NPDES stormwater permit when allocating pollutant load reductions required by a TMDL (see **Section 6.1**).

4.2 Information on Potential Sources of Nitrate in the Rainbow Springs Group and Rainbow Springs Group Run Springshed

Nitrogen occurs in several forms in the environment, and much of the nitrate found in the impaired springs and spring run could have been derived from inputs of organic nitrogen and ammonium nitrogen that were converted to nitrate via the biochemical processes of ammonification and nitrification. The predominant sources of nitrate can sometimes be identified from the analysis of information on the ratio of stable isotopes of nitrogen (δ15N/ δ14N) in water samples. Values of less than 6 per mil (i.e., parts per thousand) are generally indicative of inorganic fertilizers, while values greater than 9 per mil indicate organic nitrogen from human or animal waste (Katz et al. 1999).

The δ15N/ δ14N values from several sampling events fall within the range typically associated with inorganic fertilizer sources of nitrogen (Jones et al. 1996; Albertin et al. 2010). Isotopic signatures from 2011 monitoring conducted by the Department confirmed that the nitrate isotope ratios in the spring samples were similar to those found more than 10 years earlier and continued to indicate that the nitrate was mainly from inorganic sources. While nitrate occurs naturally in the environment through nitrogen fixation, bacterial processes, and lightning, the elevated and increasing levels of nitrate in the environment are attributed to anthropogenic sources. Anthropogenic sources of inorganic nitrate include fertilizer applied to agricultural fields, pastures, yards, golf courses, and other sites. Anthropogenic sources of nitrogen derived from organic material include domestic wastewater and residuals, septic tank effluent, and animal waste derived from equine and cow/calf operations. Jones et al. (1996) indicated it was unlikely that the nitrogen was from natural sources such as the organic material in unfertilized soils, since nitrate concentrations in wells and springs were found to be much higher than would likely be released by the sandy soils in this area, which are naturally low in organic carbon content.

4.2.1 Wastewater and Stormwater Sources

Typical "point sources" of pollutants are permitted facilities that discharge directly to surface water. These include WWTFs and regulated stormwater discharges.

Permitted Wastewater Discharges

There are 21 permitted WWTFs in the Rainbow Springs springshed, according to the Department's Wastewater Facilities Regulation (WAFR) database. Two of these facilities (concrete batch plants) have NPDES permits to discharge to surface water, but none discharges to the impaired waters, and concrete batch plants are not significant sources of nitrogen. The rest of the permitted facilities discharge to ground water via drain fields, rapid infiltration basins, or spray irrigation and would be considered nonpoint sources as they do not have NPDES permits for surface water discharge. Three of these have industrial wastewater permits, but these facilities include car washes and other minor sources that are not likely to have appreciable impacts on Rainbow Springs. Sixteen of the facilities in the springshed treat domestic wastewater, which is a more significant potential source of nitrogen than the industrial facilities (**Table 4.1** and **Figure 4.1**). Three domestic WWTFs in the Rainbow Springs area have design flows of greater than 0.1 MGD. It is difficult to evaluate potential loading to ground water from domestic wastewater application sites as they vary in nitrogen concentration and in method of application.

Permitted Stormwater Discharges

A municipal separate storm sewer system (MS4) is a publicly owned conveyance or system of conveyances (i.e., ditches, curbs, catch basins, underground pipes, etc.) that is designed or used for collecting or conveying stormwater and that discharges to surface waters of the state. There are two Phase II MS4 permits in the Rainbow Springs springshed. The permit issued to Marion County (FLR04E021) includes the major portion of the springshed. A small portion of the area is covered by the permit issued to Alachua County (FLR04E005). The Marion County permit identifies the Rainbow River as a receiving water, but according to the Marion County stormwater maps, there is no discharge to the impaired segment of the Rainbow River (Mowry 2012)

While it may not be appropriate to assign a specific allocation or reduction to the existing NPDES entities as potential point sources, some of them may still be included in the BMAP process because of their nonpoint source contributions. These nonpoint source discharges include discharges of stormwater to the UFA via detention ponds and sinkholes.

Table 4.1. Permitted WWTFs in the Rainbow Springs Group and Rainbow Springs Group Run Springshed

[1] Permit limit for volume treated and discharged in MGD
[2] DW = Domestic waste; IW = Industrial waste; CBP = Concrete batch plant
[3] NPDES permit (Y-yes or N-No)
Note: Facilities listed in **bold** with yellow highlighting have design flows greater than 0.1 MGD.

Facility ID	Facility Name	County	Design Capacity[1]	Facility Type[2]	NPDES[3]
FLG110337	Florida Rock - Williston Concrete Batch Plant	Levy	0.00	CBP	Y
FLG110371	A Materials Group Inc. Plant #14	Levy	0.00	CBP	Y
FLA012612	**City of Williston WWTF**	**Levy**	**0.45**	**DW**	**N**
FLA012693	**Rainbow Springs Utilities**	**Marion**	**0.23**	**DW**	**N**
FLA490415	**Juliette Falls WWTF**	**Marion**	**0.10**	**DW**	**N**
FLA010770	Grand Lake RV Resort WWTF	Marion	0.065	DW	N
FLA016154	Petro PSC Truck Stop	Marion	0.05	DW	N
FLA012658	Dunnellon High School WWTF	Marion	0.036	DW	N
FLA012660	Reddick RV WWTF	Marion	0.025	DW	N
FLA012717	Rainbow Springs State Campground WWTF	Marion	0.015	DW	N
FLA010690	Sportsman Cove WWTF	Marion	0.015	DW	N
FLA011317	Knight's Inn WWTF	Alachua	0.015	DW	N
FLA012682	Sateke Village WWTF	Marion	0.01	DW	N
FLA012662	Crystal Springs Mobile Home Park	Marion	0.01	DW	N
FLA010672	Reddick Collier Elementary School WWTF	Marion	0.01	DW	N
FLA012686	Ocala Jockey Club WWTF	Marion	0.01	DW	N
FLA010737	Ocala Jai Alai – WWTF	Marion	0.01	DW	N
FLA012657	Romeo Elementary School	Marion	0.00	DW	N
FLA010753	Seyler's Car Wash Recycle System	Marion	0.01	IW	N
FLA687723	CIC Inc (328 Pit)	Marion	0.00	IW	N
FLA012711	MFM Acquisition Corp	Marion	0.00	IW	N

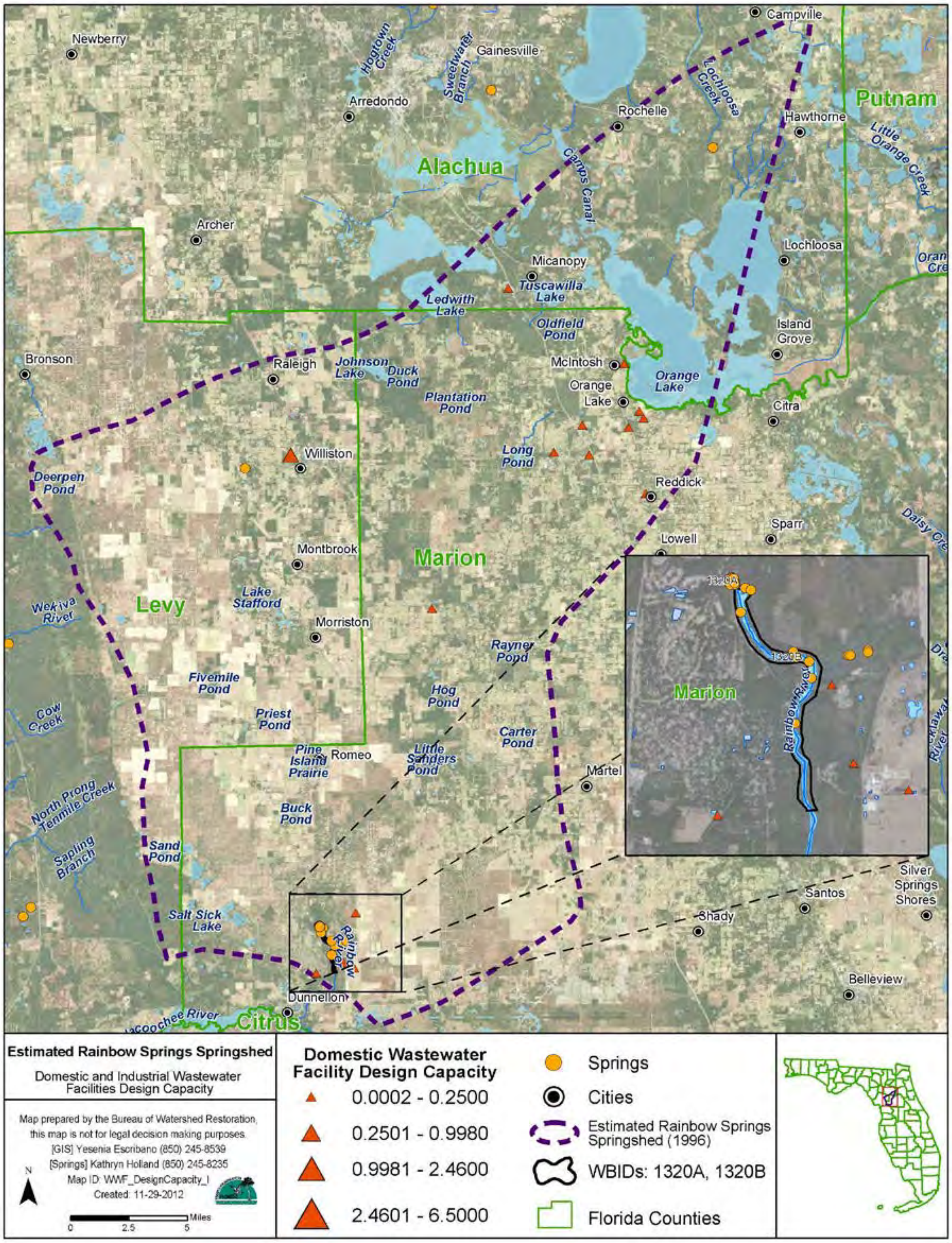

Figure 4.1. Domestic Wastewater Facilities in the Rainbow Springs Group and Rainbow Springs Group Run Springshed

4.2.2 Land Uses and Nonpoint Sources

In the springshed, most of the nitrogen loading comes from nonpoint sources that discharge to ground water. These sources include fertilizer-applied agricultural lands, fields, pastures, lawns, golf courses, and other areas; animal waste; septic tanks; domestic wastewater application sites; and atmospheric deposition.

Population

Population and household data were acquired from the U.S. Census Bureau's 2010 Census. The total population for Marion County is 331,298, with 137,726 households and 164,050 housing units (HU). The population density in Marion County is 209.1 people per square mile of land area and 103.53 HU per square mile. The total population of Levy County is 40,801 people, with 16,404 households and 20,123 HU. The population density in Levy County is 36.5 people per square mile of land area, with 18 HU per square mile. For Alachua County, the total population is 247,336, with 100,516 households and 112,766 HU. The population density in Alachua County is 282.7 people per square mile of land area, and there are 128.9 HU per square mile.

Population density in the Rainbow Springs springshed is approximately 500 or fewer people per square mile. A significant portion of that area has a much lower population density than the average (100 or fewer people per square mile, based on the 2010 Census tract information). Population centers in the springshed include Dunnellon, the western edge of Ocala, and Williston. Approximately 18% of the springshed is zoned residential, the majority of which is low-density residential. However, it is important to note that several large tracts in this area that were zoned residential in the early to mid-2000s have yet to be developed due to a downturn in the building industry. There are also numerous riverfront homes along the Rainbow River below the state park, mainly on the western bank. **Figure 4.2** shows the population density of the surrounding area Census tracts for the springshed.

Land Use and Land Cover

The distribution of different land use categories in the contributing area for Rainbow Springs was assessed using the 2009 SWFWMD, 2009 SJRWMD, and 2006–08 Suwannee River Water Management District (SRWMD) land use geographic information system (GIS) coverages. **Figure 4.3** and **Table 4.2** show the distribution of various land use categories and land covers. Agricultural areas were the predominant land uses in the proposed restoration area, covering around 38% of the area. Horse farms and cow-calf operations make up the majority of this land use classification in western Marion County and eastern Levy County, followed by row crops and some nurseries. Upland forested areas and residential areas in the springshed comprise 29 and 14% of land use, respectively. Residential land use is the dominant land use close to the springs, both along State Road (SR) 41 and also SR 40.

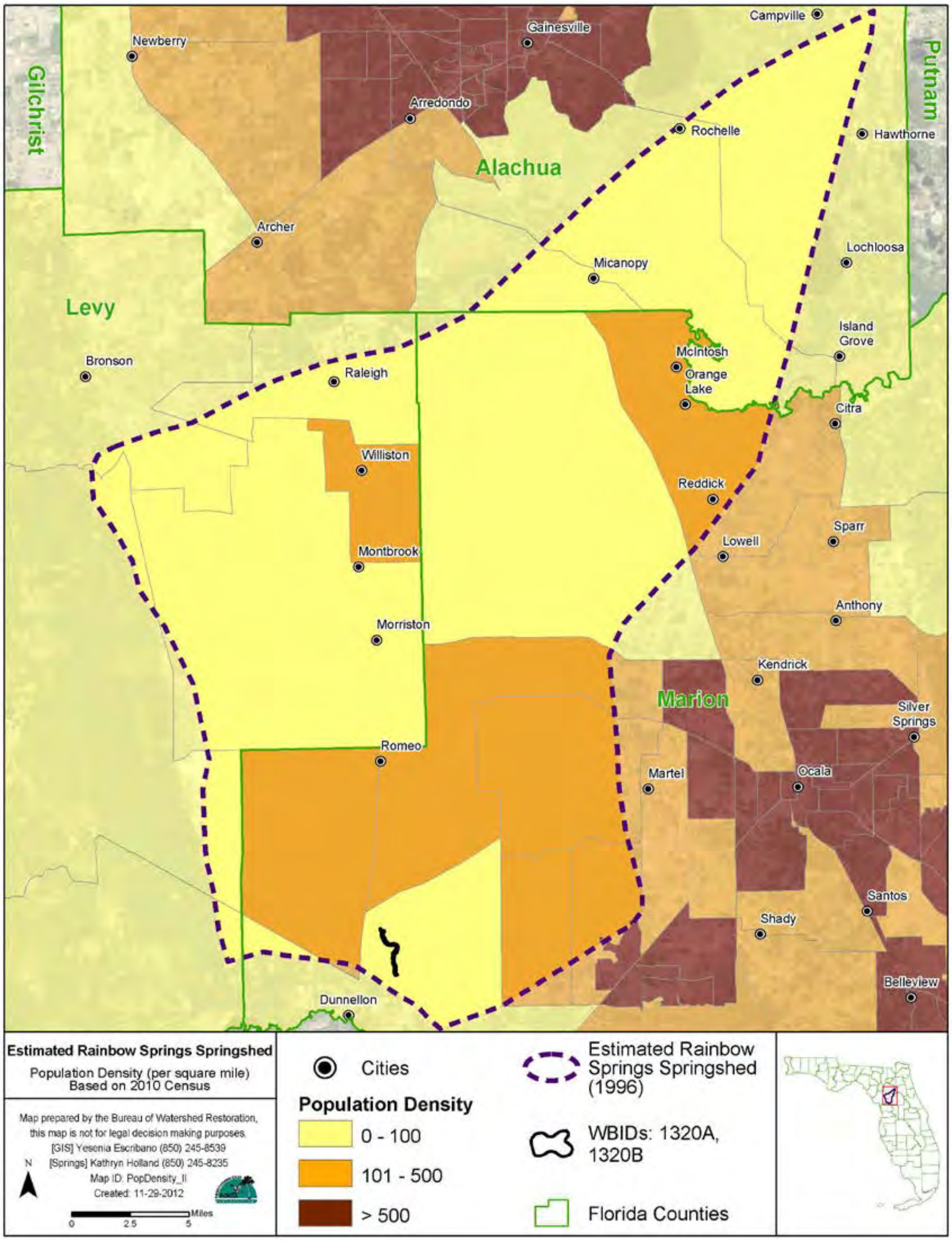

Figure 4.2. Population Density in the Rainbow Springs Group and Rainbow Springs Group Run Springshed (based on 2010 Census data)

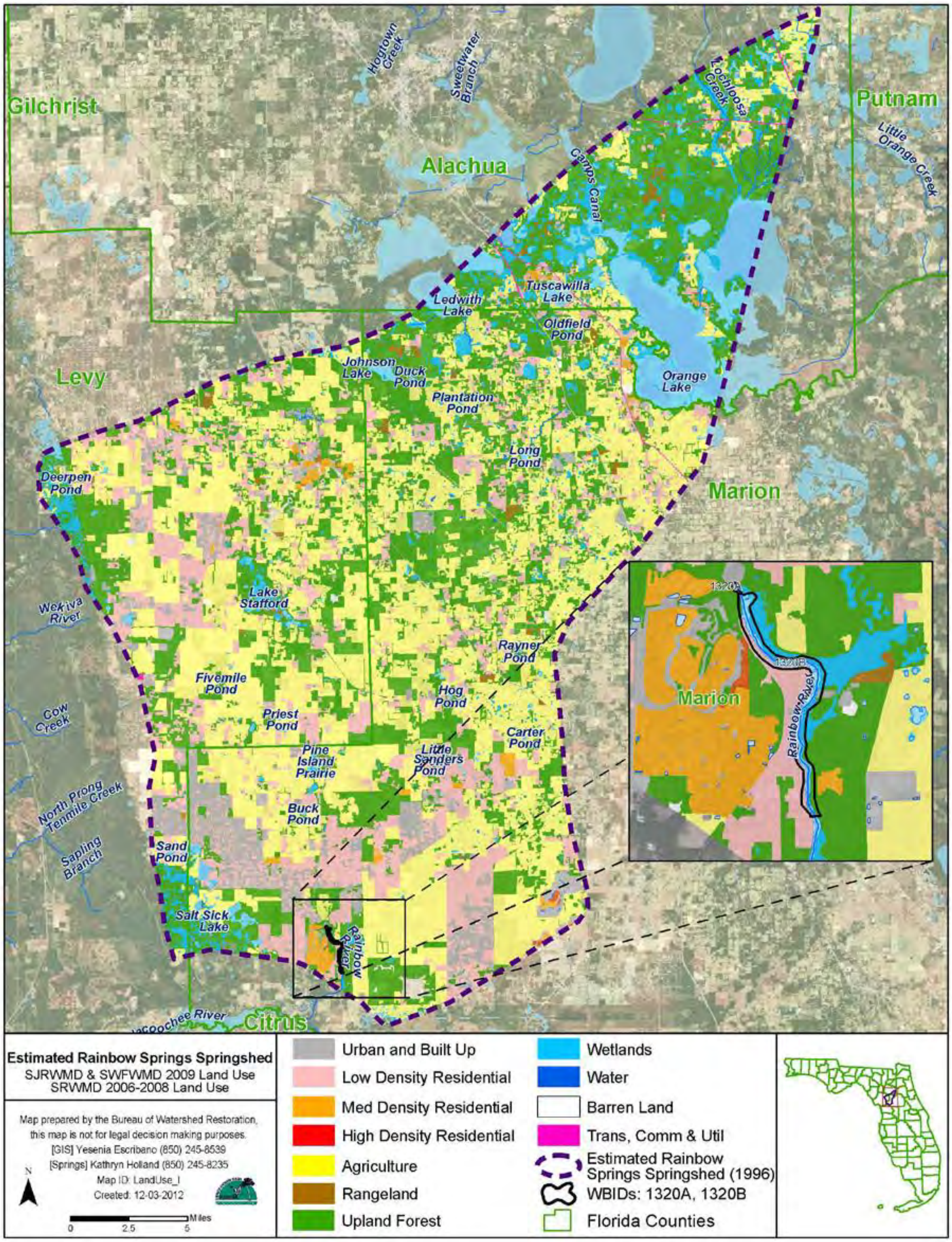

Figure 4.3. Principal Land Uses in the Rainbow Springs Springshed (based on 2006–08 GIS coverages)

Table 4.2. Major Land Uses in the Springshed (SRWMD 2006–2008 and SWFWMD 2009 land use coverages)

Land Use	Acres	Square Miles	% of Contributing Area
Low-Density Residential	58,968.40	92.14	13.43%
Medium-Density Residential	3,319.48	5.2	0.76%
High-Density Residential	254.06	0.4	0.06%
Urban and Built-Up	23,736.56	37	5.40%
Agriculture	168,029.18	262.55	38.26%
Rangeland	3,197.71	5.05	0.73%
Upland Forest	129,827.57	202.86	29.56%
Water	10,916.6	17.06	2.49%
Wetlands	37,407.82	58.45	8.52%
Barren Land	614.20	0.96	0.14%
Transportation/Commercial/ Utilities	2,924.87	4.57	0.67%
Total	**439,196.53**	**686.24**	**100%**

Onsite Sewage Treatment and Disposal Systems

Onsite sewage treatment and disposal systems (OSTDS), also known as septic systems, are used for the disposal of domestic waste at homes that are not on central sewer, often because providing central sewer is not cost-effective or practical. When properly sited, designed, constructed, maintained, and operated, OSTDS are a sanitary means of disposing of domestic waste. The effluent from a well-functioning OSTDS is generally higher in TN concentration than secondarily treated wastewater from a sewage treatment plant, although the wastewater profile can vary from home to home. On average, the TN concentration released to the environment by a typical OSTDS is 57.7 mg/L (Hazen and Sawyer 2009). However, septic tank effluent will undergo further denitrification and nitrification in the drain field, resulting in even lower TN input to ground water. Under a low-density residential setting, nitrogen inputs from OSTDS may not be significant, but under a higher density setting, one could expect a TN input of 129 pounds per acre per year (lb/acre/yr) (Harrington et al. 2010). The actual load to ground water is a portion of this amount. For the Wekiva River Basin, MACTEC (2010) estimated that the load to ground water from septic systems was approximately 56% of the input.

As of 2010, Marion County had approximately 97,371 OSTDS (Marion County 2008), Levy County approximately 48,332 OSTDS, and Alachua County approximately 99,796 OSTDS (FDOH 2011). About 8,279 of these OSTDS are situated in the Rainbow Springs springshed. Data for estimating septic tank numbers in the springshed are based on the FDOH statewide inventory of permitted OSTDS GIS layer (FDOH 2010), which is updated annually (**Figure 4.4**). There is some uncertainty about the septic tank counts in this inventory, depending on how current the records are at the local health departments and if older paper records are included in the inventory. As a result, the actual numbers of septic tanks may be undercounted.

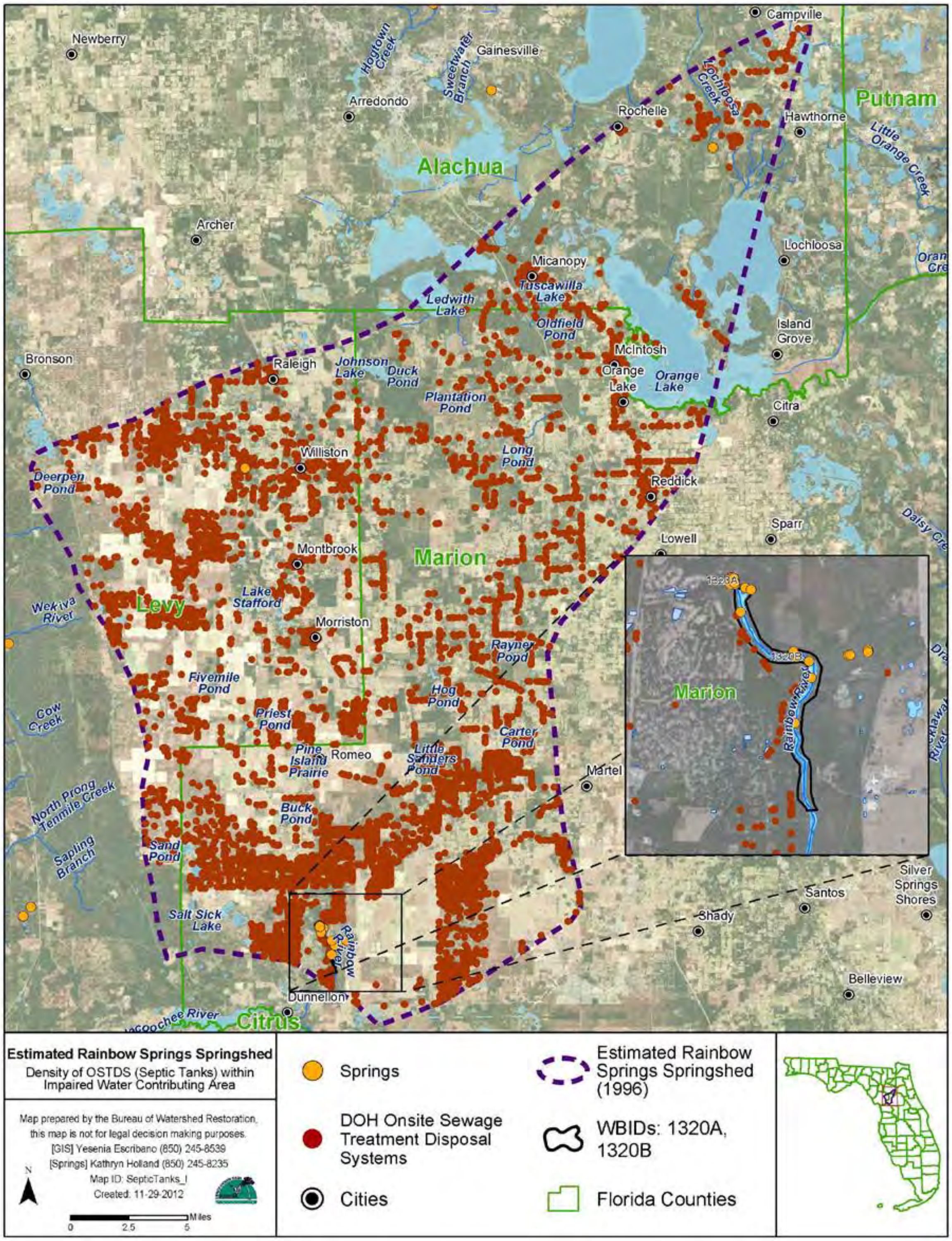

Figure 4.4. Density of OSTDS (Septic Tanks) in the Rainbow Springs Springshed (Marion County 2008; FDOH 2010)

Livestock

Equine facilities (horse farms), cow/calf operations, and associated improved pasture are significant agricultural land uses in the springshed. The combined estimated contribution from livestock waste can vary, with between 10 and 30% of the nitrogen load reaching ground water (Katz et al. 1999); Jones et al. (1996) estimated that animal wastes from horse farms and cattle operations made up 30% of the potential nitrogen contribution to Rainbow Springs.

There are numerous horse farms in the area surrounding Rainbow Springs, especially in Marion County. Because of the relatively large number of horse farms (more than 200) in the contributing area, animal waste could be a significant source of nitrate to the springs. Animal waste management is often a challenge for horse farms. An average 1,000-pound horse produces about 50 pounds of manure and about 10 pounds of urine per day (Higgins et al. 2008). A small percentage of nitrogen leaching from improperly stored manure can convert to nitrate, reach ground water, and contribute to the loading of nitrate to ground water and receiving springs.

Fertilizer

A study of the Rainbow Springs catchment concluded that the predominant source of nitrate in the springs was fertilizer. Jones et al. (1996) estimated that fertilizer, principally from improved pastures, provided about 46% of the total potential contribution of nitrogen to Rainbow Springs. In addition to the 200-plus horse farms, improved pastures, and hayfields, approximately 13 golf courses and 26 nurseries in the contributing area use fertilizer. **Table 4.3** summarizes the potential nitrogen inputs from fertilizer applied for these land uses as well as residential lawns. Some percentage of this input reaches ground water. As an example from the Wekiva River Basin, MACTEC (2010) estimated the load to ground water from fertilizer application to be between 10 and 20% of the input.

Table 4.3. Potential Fertilizer Application Ranges for Selected Land Uses in the Rainbow Springs Springshed

Note: Estimated loadings from fertilization are conservative, based on recommended agronomic rates and not actual field data.

Nitrogen Source	Estimated Nitrogen Inputs Per Year (lb/acre/year unless otherwise noted)	Comments
Hayfield	320	Bahia grass; assume 4 cuttings (Mylavarapu et al. 2009)
Fertilized pasture	50–160	Bahia grass (Mylavarapu et al. 2009)
Container nursery, controlled-release fertilizer	17–472	Based on 2 to 3 pounds of controlled-release fertilizer per cubic yard of potting mix, ranging from pot size #1 to pot size #25 spacing (Yeager 2009; Garber et al. 2002)
Golf course, turf or lawn, bermudagrass–central Florida	174–261	4 to 6 pounds/1,000 square feet (Sartain et al. 2009)
Golf course, turf or lawn, St. Augustine grass–central Florida	87–131	2 to 3 pounds/1,000 square feet (Sartain et al. 2009)

Atmospheric Deposition

Atmospheric deposition was also identified as an important potential nitrogen source (~17% of the total input) (Jones et al. 1996). Atmospheric deposition from wet fall was estimated from the closest National Atmospheric Deposition Program (NADP) monitoring station, located at the Chassahowitzka National Wildlife Refuge. This station has been in operation since August 1996 (NADP; available: http://nadp.sws.uiuc.edu/). Wet deposition is computed by multiplying the precipitation-weighted mean ion concentration (mg/L) for valid samples by the total precipitation amount in centimeters for the summary period and dividing by 10. Records indicate an annual average input of nitrogen from wet deposition to be 3.00 kilograms per hectare (kg/ha) at the station from 1997 to 2011, or about 2.68 lb/ac/yr (**Figure 4.5**). Wet deposition and dry deposition of nitrogen are not proportional, with dry deposition sometimes exceeding wet deposition in arid regions or in urban areas where air emissions are high. Dry deposition data were not available for this area.

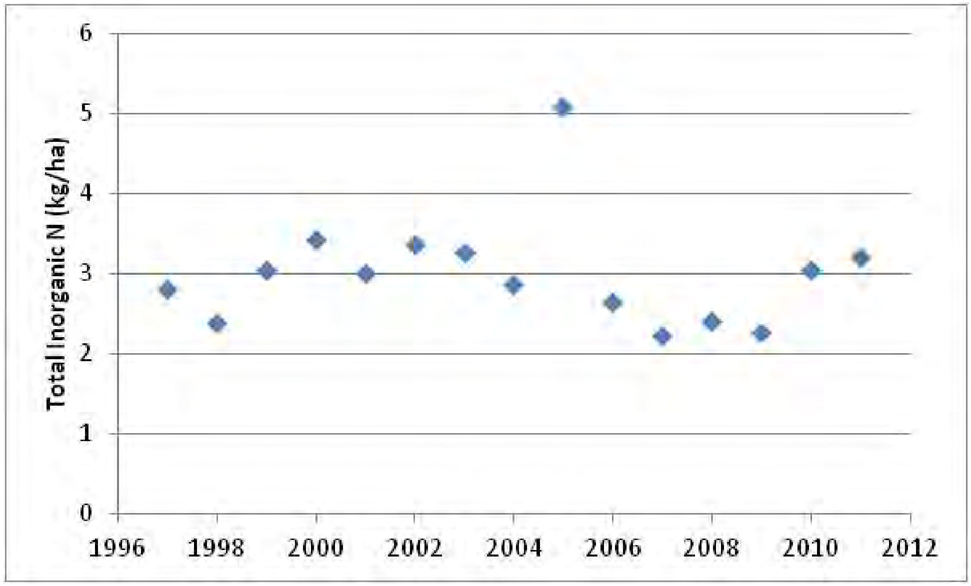

Figure 4.5. Annual Weighted Mean Wet Deposition of Inorganic Nitrogen from 1997 to 2011, Site FL05 (Source: NADP website)

Chapter 5: DETERMINATION OF ASSIMILATIVE CAPACITY

The Department often 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 Rainbow Springs Group and Rainbow Springs Group Run.

5.1 Determination of Loading Capacity

Typically, 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.

The predominant source of nitrate loading to Rainbow Springs Group and Rainbow Springs Group Run is ground water, which discharges from the major spring vents as well as smaller springs and seeps along the river. Thus, a direct relationship between surface water loadings in the watershed is not appropriate. This nontypical situation requires the use of an alternative approach for establishing the nutrient TMDL.

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 being analyzed 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 the contributing area for Rainbow Springs Group and Rainbow Springs Group Run is internally drained, most surface drainage flows toward sinkholes and closed depressions, where it infiltrates and reaches Rainbow Springs as ground water. Thus flow estimates based on surface drainage area ratio are not possible.

Estimates of current nutrient loads from the ground water of Rainbow Springs Group and Rainbow Springs Group Run could still be made based on spring flow and concentration. However, as both current and TMDL loads would be generated from the same flow data, there would be a linear or proportional relationship based on current and target concentrations. 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 Target

The Department has worked to derive response-based thresholds that link nutrient thresholds to biological and environmental risk. The target nitrate concentration for Rainbow Springs Group and Rainbow Springs Group Run was established using several lines of evidence that evaluated (1) results from laboratory dosing studies conducted at various scales, (2) *in situ* algal monitoring, (3) real-world surveys of biological communities and nutrient levels in Florida springs, and (4) the relationship between periphyton biomass and cell density and the nitrate concentration from studies conducted in spring-dominated systems.

Laboratory Studies

Nutrient amendment bioassay work was conducted by Cowell and Dawes (2004), who examined the required nitrate concentration in the Rainbow River to achieve a reduction of biomass of *Lyngbya wollei*. Using *Lyngbya* cultures incubated in a series of nitrate amendments, they found that both the biomass and growth rates were low in treatment groups with nitrate concentrations at or below 0.30 mg/L, while the biomass and growth rates were significantly higher in treatment groups with nitrate concentrations at or higher than 0.60 mg/L. The experiment also showed that the biomass and growth rates in the 0.30 and 0.070 mg/L treatment groups were similar, suggesting that a further reduction of nitrate concentration below the 0.30 mg/L level probably would not achieve a dramatic further reduction of *L. wollei*.

Similarly, Albertin et al. *(*2007) found that the growth of small *L. wollei* mats in nitrate-dosed raceways approached maximum levels at concentrations above 518 to 546 micrograms of nitrate per liter (µg N/L). In similar studies using *Vaucheria*, growth rates were low at nitrate concentrations below 69 µg N/L and increased substantially from 69 to 644 µg N/L. Further growth rate increases at nitrate concentrations above 644 µg N/L were minimal.

In smaller scale microcentrifuge tube microcosms conducted to evaluate the growth response of individual macroalgal filaments to precise levels of nitrate dosing at high phosphate levels, Stevenson et al. (2007) found that the growth rate of *L. wollei* was minimized at nitrate concentrations below 34 µg N/L. Growth rates increased substantially at nitrate concentrations from 34 to 230 µg N/L and approached maximum levels at concentrations above 230 µg N/L. For unexplained reasons, the growth rate of *Vaucheria* did not respond to nitrate additions in the microcentrifuge tube microcosm experiments. Note that the microcosm experiments were conducted for 11 days and the mescocosm studies generally lasted for 21 days.

As discussed by Stevenson et al. (2007), the difference in results between the raceway and microcentrifuge tube experiments were likely related to the differences in scale of the experiments. In the microcentrifuge tube microcosms using individual macroalgal filaments, very accurate control of nutrient levels was possible. In the larger scale raceways using small algal mats, substantial nutrient depletion was possible and could not be accounted for, which resulted in a higher estimate of regulating nitrate concentrations. Recognizing the limitations of the laboratory experiments, Stevenson et al. (2007) recommended using the ED90 (i.e., the nitrate-nitrite concentration that produces 90% of the maximum growth) determined from the highly controlled microcentrifuge tube experiments as a preliminary nitrate criterion that could be refined using additional information. The best estimate for the nitrate ED90 determined from the laboratory experiments was 230 µg N/L for *L. wollei* and 261 µg N/L for *Vaucheria* sp.

Field Surveys

Numerous surveys of macroalgae and nutrients in springs have been conducted to demonstrate the cause-effect relationships between elevated nutrient concentrations and macroalgal growth, and to evaluate the nitrogen or phosphorus concentrations associated with proliferations of macroalgae. In a survey of Florida springs (**Figure 5.1)**, macroalgae were found at 59 of the 60 sampled sites, and an average of 50% of the spring bottoms were covered by macroalgae, with the thickness of macroalgal mats commonly being 0.5 meters (m) or more and as thick as 2 m in one spring boil (Stevenson et al. 2004). *L. wollei* and *Vaucheria* sp. were the two most common taxa of macroalgae that occurred in extensive growths in the studied springs; however, 23 different macroalgal taxa were observed in the spring survey. During the surveys, the abundance of *Vaucheria* spp. within the springs was found to be positively related to nitrogen concentrations. Nonlinear models of *Vaucheria* percent cover and thickness along the TN and nitrate gradients explained substantially more variation than a linear model, with a clear threshold in *Vaucheria* response at 0.454 mg N/L as nitrate (i.e., 0.591 mg N/L as TN), Excessive growth and cover of *Vaucheria* were found at sites with nitrate concentrations at or above the 0.454 mg/L threshold, with *Vaucheria* abundance being significantly less at sites with lower nitrate levels (Stevenson et al. 2007). Note that an analogous relationship between nitrate and *L. wollei* abundance was not observed. The excessive growth of *Vaucheria* sp. is considered to constitute an imbalance of the natural biological communities. Therefore, to provide for a margin of safety, a protective target nitrate concentration would need to be below the observed 0.454 mg N/L nitrate *Vaucheria* threshold.

TMDL Development Activities

The Wekiva River and Rock Springs Run are spring-dominated systems that were placed on the state’s impaired waters list due to evidence of an imbalance in aquatic flora characterized by excessive algal growth and lower ecosystem metabolic activities. There was also evidence that the impairment of the Wekiva River and Rock Springs Run was caused by elevated nitrate. The mean nitrate concentration in the Wekiva River and Rock Springs Run ranged between 0.60 and 0.70 mg N/L, which is significantly higher than levels found at nearby minimally disturbed reference sites with similar characteristics (Juniper and Alexander Springs). Additionally, the Wekiva River and Rock Springs Run nitrate-nitrite levels were above the threshold nitrate concentration identified by Stevenson et al. (2004) to be associated with nuisance *Vaucheria* growth (Gao 2008).

During the development of the TMDL for these waterbodies, protective nutrient concentration targets were derived using periphyton and water quality data collected from spring-dominated portions of the Suwannee River and two tributaries, the Withlacoochee River and Santa Fe River (Hornsby et al. 2000). These data were considered applicable to the Wekiva River and Rock Springs Run since the Suwannee River is heavily influenced by spring inflow, and in the absence of anthropogenic inputs, the algal communities would be expected to be generally similar in composition to those in the Wekiva River and Rock Springs Run.

An evaluation of periphytometer data collected from 1990 through 1998 at 13 sites along the Suwannee River showed positive correlations for both periphyton biomass versus nitrate concentration and cell density versus nitrate concentration. For both cell density and biomass, periphyton abundance significantly increased when nitrate concentration increased above approximately 0.350 mg/L. The data were further evaluated using a change-point analysis to better define the nitrate concentration that may significantly impact periphyton biomass and

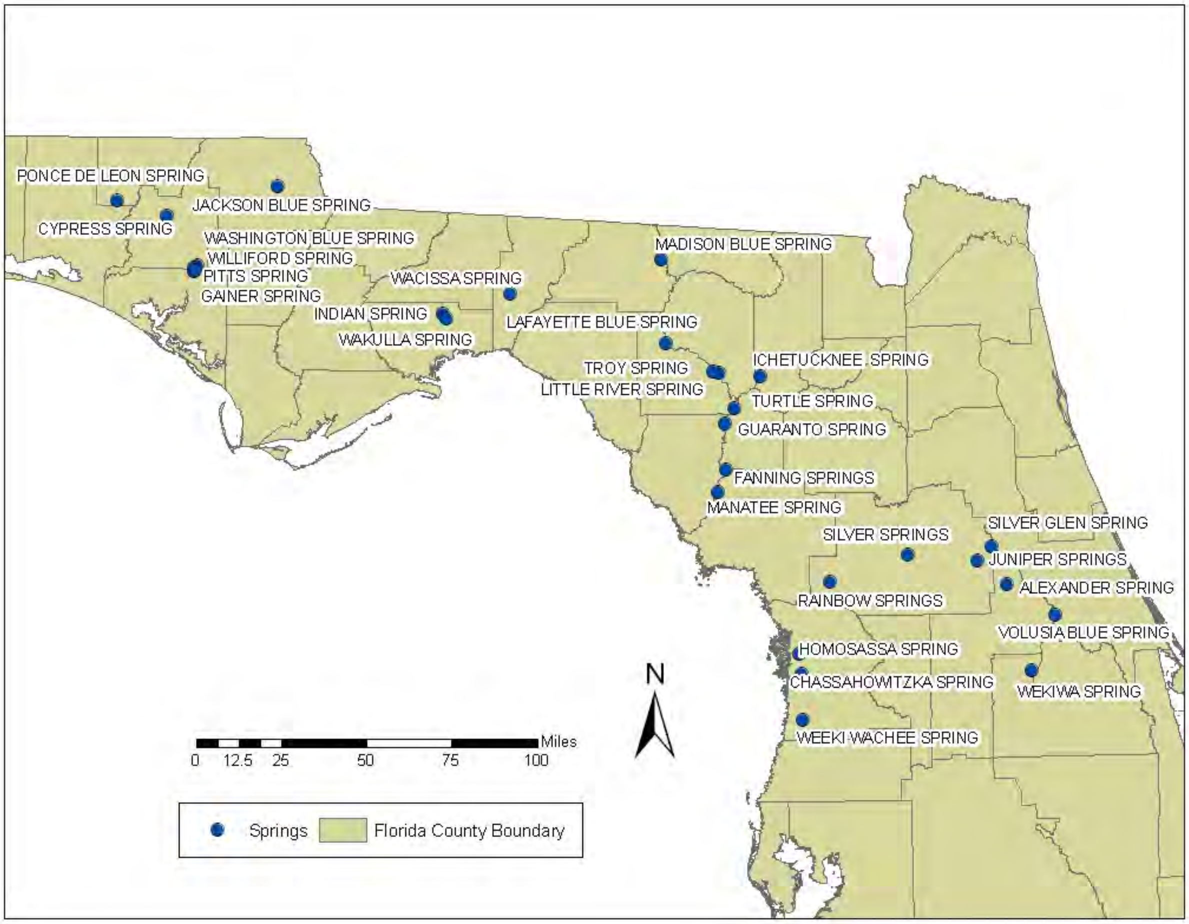

Figure 5.1. Springs Included in Algal Growth Studies by Stevenson et al. (2007)

cell density. The change-point analysis fits a step function through observed data by examining the probability of each data point as the change point. For both periphyton cell density and periphyton biomass, change-point step functions were shown to be the best model among the models tested, supporting the use of change-point analysis.

For the relationship between cell density and nitrate concentration, the change-point step function identified 2 cell density levels. The first level had 162,998 cells per square centimeter (cm^2) ($P = 0.009$), which was considered as the baseline condition under which no significant nitrate impact was detected. The second level had about 616,293 cells/cm^2 ($P = 0.0001$), which was significantly elevated above the baseline condition. The change-point analyses also indicated that the critical increase in mean algal cell density occurred when the nitrate concentration was between 0.286 and 0.401 mg/L (Niu 2008). This suggests that to prevent the periphyton cell density from increasing to the higher level, the target nitrate concentration should not exceed 0.401 mg/L.

Similarly, the change-point analysis of the relationship between periphyton biomass and nitrate concentration identified 2 biomass levels. The first level had a periphyton biomass near 1.73

g/m^2 ($p < 0.0001$), which was considered to be the baseline condition under which no significant nitrate impact was detected. The second level had an increased algal biomass near 4.15 g/m^2 ($p = 0.0001$). The nitrate concentration that significantly changed the biomass level from 1.73 to 4.15 g/m^2 was identified by the change-point step function as 0.420 mg/L, indicating that, to prevent periphyton biomass from switching to the higher level, the nitrate concentration should not exceed 0.420 mg/L.

Since periphyton cell density exhibited a slightly more sensitive response to increasing nitrate concentrations, that relationship was used as the basis for the nitrate target concentration. Although the nitrate concentration that resulted in the periphyton cell density increase could be at any level between 0.286 and 0.401 mg/L, 0.286 mg/L was chosen as the TMDL nitrate target concentration for the Wekiva River and Rock Springs Run systems to maintain both cell density and biomass at baseline conditions; it also provided a an adequate margin of safety that is reasonably protective of the biological communities within these systems (Gao 2008).

Following the adoption of the TMDL, the change-point analysis was repeated using additional data collected from 1990 through 2007 for the same sites located along the Suwannee River. To account for any long-term temporal changes at a site, the period of record was divided into four periods. The average periphyton abundance and nitrate-nitrite data for each period for each site were used to repeat the change-point analysis. A nitrate concentration change point of 0.440 mg/L was determined for both periphyton cell density and biomass. Since these change points represent the lower concentration range for the group of sites with significantly higher periphyton abundance, compared with the baseline group, a target nitrate concentration should include an appropriate margin of safety to ensure that sites do not reach this level.

Relationship between Periphyton Biomass and Cell Density and Nitrate Concentration

Hornsby et al. (2000) evaluated periphyton and water quality data collected from the Suwannee River and 2 tributaries, the Withlacoochee and Santa Fe Rivers. Much of the length of the Suwannee River was heavily influenced by spring inflow. Their evaluation 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 [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 within the Suwannee River system (including the Withlacoochee and Santa Fe Rivers) (**Figure 5.2**).

Figure 5.2. Change-Point Study Sites within the Suwannee River System

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 the Department of Statistics, Florida State University (FSU), to conduct a change-point analysis for a dataset of 13 long-term periphyton monitoring sites from 1990 to 2007 provided by the SRWMD (Niu 2008). 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 B** 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 concentration of approximately 0.441 mg/L (**Figures 5.3** and **5.4**).

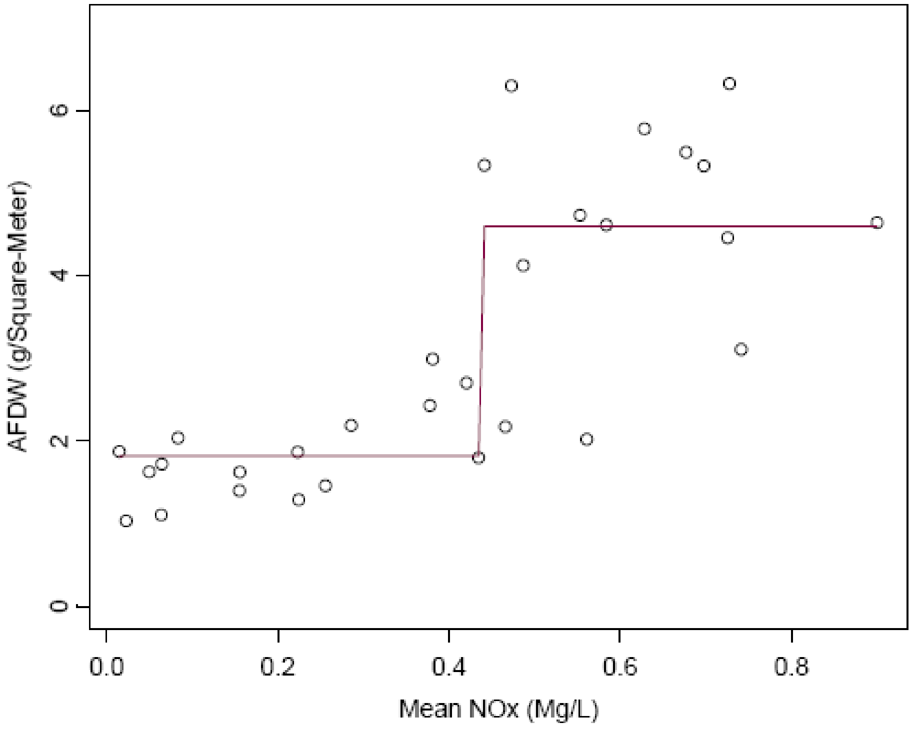

Figure 5.3. Relationship Between Mean NOx Concentration and Mean Periphyton Biomass from 12 Sampling Sites in the Suwannee, Santa Fe, and Withlacoochee Rivers

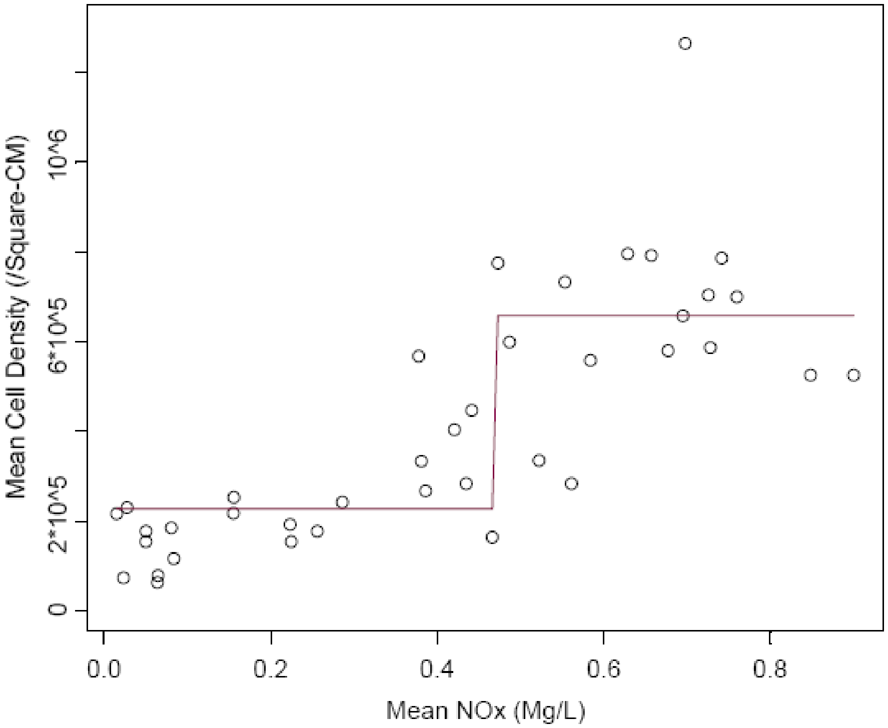

Figure 5.4. Relationship Between Mean NOx Concentration and Mean Periphyton Cell Density from 12 Sampling Sites in the Suwannee, Santa Fe, and Withlacoochee Rivers

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 B**). One level is about 218,732 cells/cm^2 (P = 0.0000), 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 the 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 2 biomass levels (**Table 4** in **Appendix B**). One level is about 1.82 grams per square meter (g/m^2) (P = 0.0000), and the other is about 1.82 + 2.97 = 4.79 g/m^2 (P = 0.0000). In this study, 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 B**).

5.2.2 Target Setting

Based on the 4 lines of evidence discussed in the previous sections, nitrate was the primary factor causing the elevated growth of algae at concentrations 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. 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 NO_3 (**Figure 5.5**), the lower boundary being 0.378 mg/L NO_3.

It is important to note that the change-point analysis provides a concentration of nitrate at which change (excessive algal growth) 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 of NO_3, the TMDL threshold must be established below that interval to be protective of the resource.

While the change-point analysis showed that the change in periphyton was related to nitrate, the next step was to determine the relationship of nitrate concentration to periphyton. The best relationship between nitrate and periphyton cell density is an exponential relationship, as shown in **Figure 5.6**. 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.

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. By taking the lower cell density at the change point of 0.441 mg/L, the Department has targeted a more conservative condition in the waterbody. Once identified, that cell density was again used to identify a nitrate number prior to the change points by finding the equivalent lower 95% confidence interval (**Figure 5.7**), 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.

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 Rainbow Springs Group and Rainbow Springs Group Run. 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.

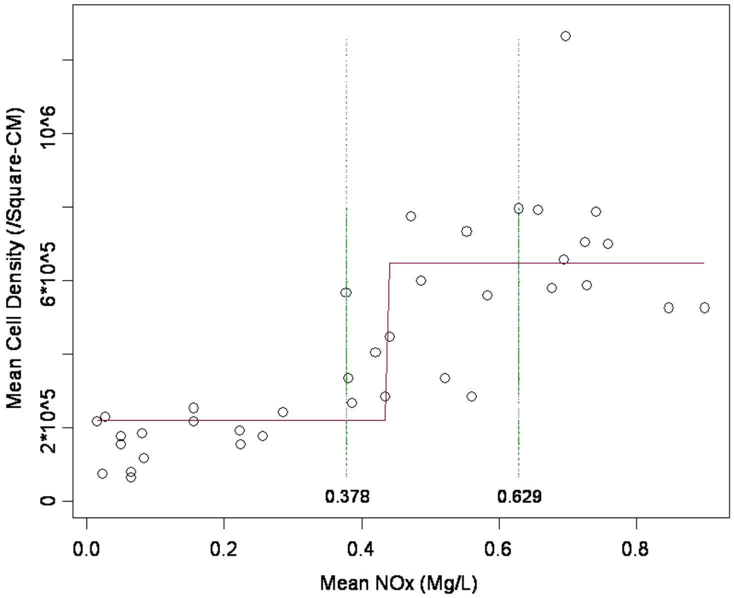

Figure 5.5. Change-Point Analyses (the 95% Confidence Interval)

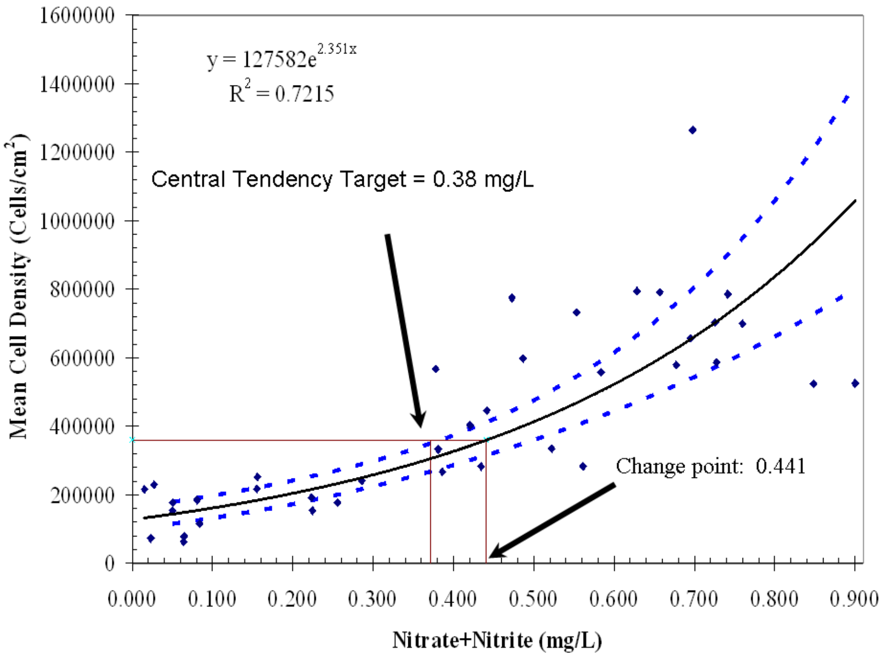

Figure 5.6. Central Tendency and Upper 95% Confidence Interval Approach

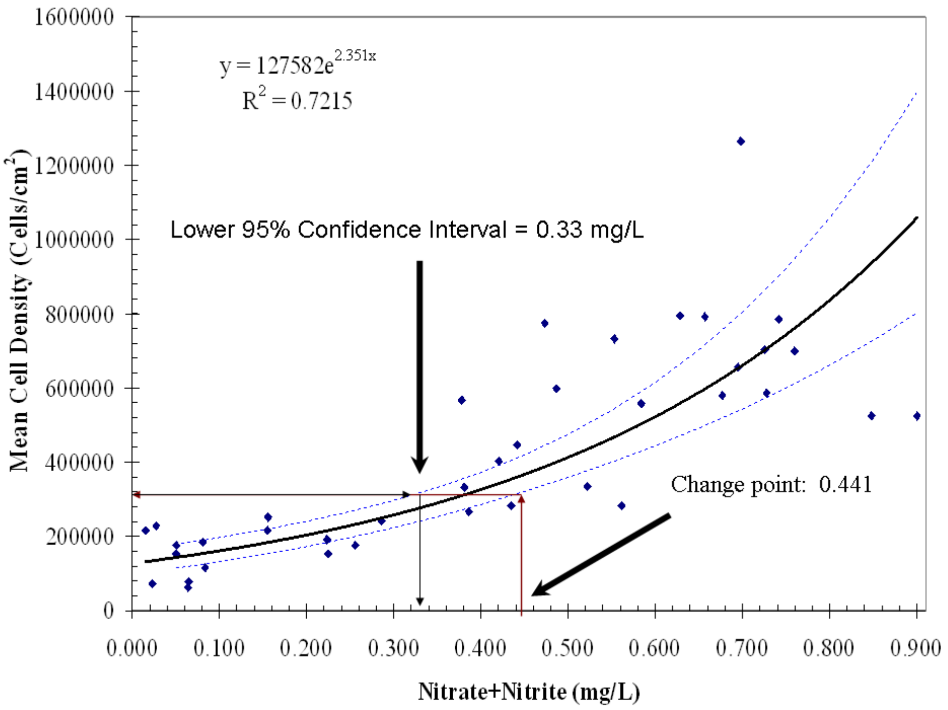

Figure 5.7. Upper and Lower 95% Confidence Interval Approach

Based on the information provided above, 0.35 mg/L nitrate is the target concentration that the Department determined will not cause an imbalance in the aquatic flora or fauna in Rainbow Springs Group and Rainbow Springs Group Run. Excessive growth of algae 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. It is likely that implementation of the TMDL for nutrients may result in improvements to the DO regime in the river by reducing algae levels.

5.3 Setting the Monthly Average Concentration for Nitrate

After carefully reviewing all the above studies, the Department established a monthly average of 0.35 mg/L nitrate (nutrients) as the TMDL for Rainbow Springs Group and Rainbow Springs Group Run, mainly because 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 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 (Cowell and Dawes 2004) was from a nutrient amendment experiment. Significant differences in growth rate and biomass between the above-0.600 mg/L and below-0.300 mg/L treatment groups were not observed until 8 to 12 days after the nutrient amendment study started. This suggests a time lag between the change of the nitrate concentration and the response from *Lyngbya*.

In addition, the *Lyngbya* nutrient amendment study conducted by Cowell and Dawes (2004) was carried out 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 stream flow, and no light attenuation from changing water color. These natural processes are very common in natural stream systems such as Rainbow Springs and could significantly influence the response of algae to changes in water column nitrate concentrations. Therefore, treating the nitrate concentration obtained from the *Lyngbya* study as an exact instantaneous value is also not necessary. It is more appropriate to treat the target value as an average concentration 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. Expressing the target as a monthly average provides a margin of safety because restoration activities designed to address the highest monthly average nitrate concentrations should help to ensure that average nitrate concentrations over the rest of the year are even lower.

Since the nitrate target will be established as a monthly average in this TMDL, long-term monthly average concentrations were calculated for each month based on measured concentrations over a reasonable period that is representative. To ensure 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.

For Rainbow Springs Group and Rainbow Springs Group Run, the percent reductions required for this TMDL were calculated using the monthly values for nitrate averaged over the period from January 2000 through October 2010. The longer period including more recent data was used instead of the Cycle 2 verified period (January 1, 2000, through June 30, 2007) because nitrate concentrations have increased in these WBIDs since 2007. The maximum monthly average for each WBID was then considered in the calculation of a target for percent reduction (**Table 5.1**). There was only one data point for December for Rainbow Springs Group and only three data points for December in Rainbow Springs Group Run available to calculate the monthly average. **Table 5.1** summarizes the monthly averages with monthly average rainfall for both WBIDs. These data show that elevated nitrate concentrations occur in both wet and dry months.

Table 5.1. Monthly Average Nitrate Concentrations for Rainbow Springs Group and Rainbow Springs Group Run (2000–10)

* Very limited dataset; not statistically valid
ND = No data for this month
\- = Empty cell/no data

Month	Rainbow Springs Group (WBID 1320A) Average (mg/L)	Rainbow Springs Group Run (WBID 1320B) Average (mg/L)	30-Year Rainfall 1981–2010) (inches)
January	1.55	1.38	3.55
February	1.92	1.39	3.11
March	1.57	1.37	4.02
April	1.44	1.23	2.78
May	1.71	1.42	3.55
June	1.47*	1.26	7.20
July	1.55	1.39	6.20
August	1.72	1.37	5.84
September	1.56*	1.32	5.60
October	1.45	1.24	2.71
November	1.76	1.42	2.47
December	ND	1.15*	2.65
Maximum Monthly Average	**1.92**	**1.42**	**-**

5.4 Critical Conditions/Seasonality

Establishing the critical conditions for algae growth in a given watershed depends on many factors. For typical surface waters, the critical conditions exist when there 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. Similar correlations have also been noted for some spring systems, but they may not be as dramatically influenced by rain events. The water discharged from the springs that comprise Rainbow Springs Group is from infiltrating precipitation somewhere in the recharge area that migrated within the UFA system to the spring vents. Water discharged from the vents is from a mixture of sources and may range from days to decades in age. At Rainbow Springs, fluctuations in spring water quality have been observed, and these could be a response to flushing from seasonal rainfall events or to seasonal nonpoint impacts such as fertilization. However, throughout the year, nitrate concentrations remain above the 0.35 mg/L threshold for algal growth.

One potential seasonal influence on the growth of some forms of algae may be stream velocity, which is based on spring discharge, which is in turn influenced by precipitation. Stevenson et al. (2007) noted a positive correlation between current and the growth of *Vaucheria.* In addition, sediments that have accumulated for months may provide a flux of nutrients to the water column under certain weather or DO conditions. For the TMDL established for Rainbow Springs Group and Rainbow Springs Group Run, there does not appear to be any correlation between monthly average nitrate concentrations and rainfall.

A correlation has been proposed between discharge reductions and increasing nitrate concentration. To evaluate this relationship, the SWFWMD analyzed nitrogen data and USGS flow data from 1992 to 2012; these indicate that an increase in nitrogen is not significantly related to flow, although nitrogen concentration is increasing with time (**Figure 5.8)**. The findings were consistent with evaluations of six other springs by the district using similar analyses (SWFWMD 2012).

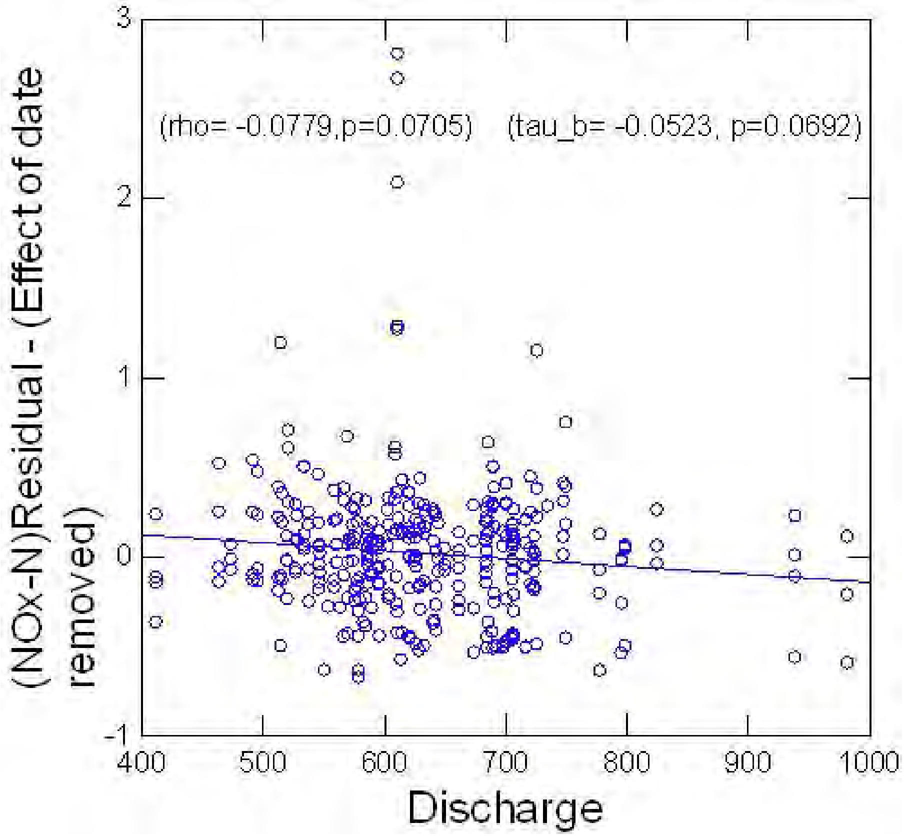

Figure 5.8. Rainbow Residual Plot (USGS Station 02313100 and SWFWMD Water Management Information System [WMIS]) from Multiple Rainbow River Springs, 1992–2012

5.5 Calculation of TMDL Percent Reduction

Based on an examination of the data depicted in **Table 5.1**, the percent reductions were based on the data from Rainbow Springs Group, which has the highest monthly average nitrate concentration in February. This approach will be protective for all seasons and add to the implicit margin of safety.

The maximum monthly average nitrate concentration for Rainbow Springs Group was 1.92 mg/L in February; in Rainbow Springs Group Run, May and November were the months with the highest monthly average of 1.42 mg/L. These averages were calculated from data available between January 2000 and October 2010, although in some months data were very limited. To obtain a percent reduction that is reasonably representative of both WBIDs and is adequately protective, the Department used the maximum monthly average nitrate concentration for Rainbow Springs Group, which is upstream of Rainbow Springs Group Run. Addressing the upstream WBID will be protective of downstream waters, since there is limited inflow from surface waters. 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

For Rainbow Springs Group:

[(1.92 mg/L – 0.35 mg/L) / 1.92 mg/L] * 100

Equals an 82% reduction in nitrate.

An 82% percent reduction in nitrate concentrations in both WBIDs is proposed because it is a protective value that, when achieved, will satisfy the nutrient reduction requirement for the system. The nitrate in these segments comes from ground water discharging from Rainbow Springs Group and the springs along Rainbow Springs Group Run.

Chapter 6: DETERMINATION OF THE TMDL

6.1 Expression and Allocation of the TMDL

The percent load reductions 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. Maximum daily limit (MDL) targets for nitrate were determined using the equation below, established by the EPA (2006). In the following equation, it is assumed that the nitrate data distributions are lognormal:

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

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

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; and
CV = coefficient of variance.

For the maximum daily nitrate limit, 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 a 5% exceedance (EPA 2007, pp. 19 and 20), the daily maximum nitrate limit for Rainbow Springs Group and Rainbow Springs Group Run is 0.47 mg/L.

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

Statistics	Rainbow Springs Group (WBID 1320A), Rainbow Springs Group Run (WBID 1320B)
Mean (mg/L)	1.62
CV	0.19
Daily maximum to achieve monthly average nitrate of 0.35 mg/L	0.47

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.

This TMDL has been developed for nitrate, which is a product of the chemical and biochemical conversion of organic and ammonium nitrogen, and the amount of nitrate released from sources can depend on the factors that influence these conversion processes. Thus, there is no straightforward relationship between loading of nitrogen and nitrate released. In this chapter, the discharges are for nitrate.

The objective of a TMDL is to provide a basis for allocating acceptable loads of the target pollutant 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:

TMDL = $\sum \square \mathrm{WLAs} + \sum \square \mathrm{LAs} + \mathrm{MOS}$

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

TMDL $\cong \sum \square \mathrm{WLAs}_{\textbf{wastewater}} + \sum \square \mathrm{WLAs}_{\textbf{NPDES Stormwater}} + \sum \square \mathrm{LAs} + \mathrm{MOS}$

WLAs for stormwater discharges (if applicable) are typically expressed as “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 Rainbow Springs Group and Rainbow Springs Group Run is expressed in terms of concentration of nitrate and represents the loading of nitrate that the river can assimilate and maintain ecological balance (**Table 6.2**).

Table 6.2. TMDL Components for Rainbow Springs Group and Rainbow Spring Group Run

[1] N/A = Not applicable

WBID	Parameter	TMDL (mg/L)	TMDL % reduction	Wasteload Allocation for Wastewater[1]	Wasteload Allocation for NPDES Stormwater % Reduction	LA % reduction	MOS
Rainbow Springs Group (WBID 1320A), Rainbow Springs Group Run (WBID 1320B)	Nitrate as monthly average	0.35	82%	N/A	82%	82%	Implicit

6.2 Load Allocation

Because no target loads were explicitly calculated in this TMDL report, the TMDL is represented as the percent reduction of nitrogen loadings required to achieve the nitrate target. The percent reduction assigned to all the nonpoint source areas (LA) is the same as that defined for the TMDL percent reduction. To achieve the monthly average nitrate target of 0.35 mg/L in Rainbow Springs Group and Rainbow Springs Group Run, the nitrate contribution to the impaired waters that comes from sources in the contributing area needs to be reduced by 82%. 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.

The nonpoint sources included in the LA include fertilizer, domestic wastewater from OSTDS and wastewater application sites, animal waste, atmospheric deposition, and stormwater discharges to ground water. The LA also includes loading within the springshed from stormwater discharges regulated by the Department and the water management district that are part of the NPDES Stormwater Program but do not discharge to the impaired waters (see **Appendix A**).

6.3 Wasteload Allocation

6.3.1 NPDES Wastewater Discharges

Currently, there are no NPDES wastewater facilities that discharge directly into Rainbow Springs Group and Rainbow Springs Group Run. Any new potential discharger is expected to comply with the Class III criterion for nutrients and with nitrate limits consistent with this TMDL.

6.3.2 NPDES Stormwater Discharges

There are currently no direct stormwater outfalls from NPDES MS4 stormwater facilities to the impaired segment of the Rainbow River. However, the roadways within a subdivision adjacent to Rainbow Springs Group Run are included in the Marion County MS4, and any discharges from this system would be subject to the MS4 wasteload allocation (WLA) in **Table 6.2**. The Rainbow River is included in Marion County's Phase II MS4 permit as a waterbody that receives discharge from the stormwater system.

6.4 Margin of Safety

Consistent with the recommendations of the Allocation Technical Advisory Committee (Department 2001), an implicit MOS was used in the development of this TMDL, and was provided 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 a conservative concentration from the 4 lines of evidence (Chapter 5). Requiring the 0.35 mg/L target to be met every month should result in a nitrate concentration even lower than the target concentration during the summer algal growth season based on a seasonal analysis of 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 adds 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.

A BMAP will be needed to support the implementation of this TMDL. The BMAP will be developed through a transparent, stakeholder-driven process intended to result in a plan that is cost-effective, is technically feasible, and meets the restoration needs of the applicable waterbodies. The restoration plan will take into account the sources of nitrogen within the contributing area, including legacy loads from past land use activities, as well as the complexity of the aquifer system that conveys pollutants to the impaired waters.

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 to the management of 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.

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Appendix A: 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 (ERP) 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 Florida Department of Transportation (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/ERP 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 B: 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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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 limited 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) provided 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.

Appendix B—Page 2

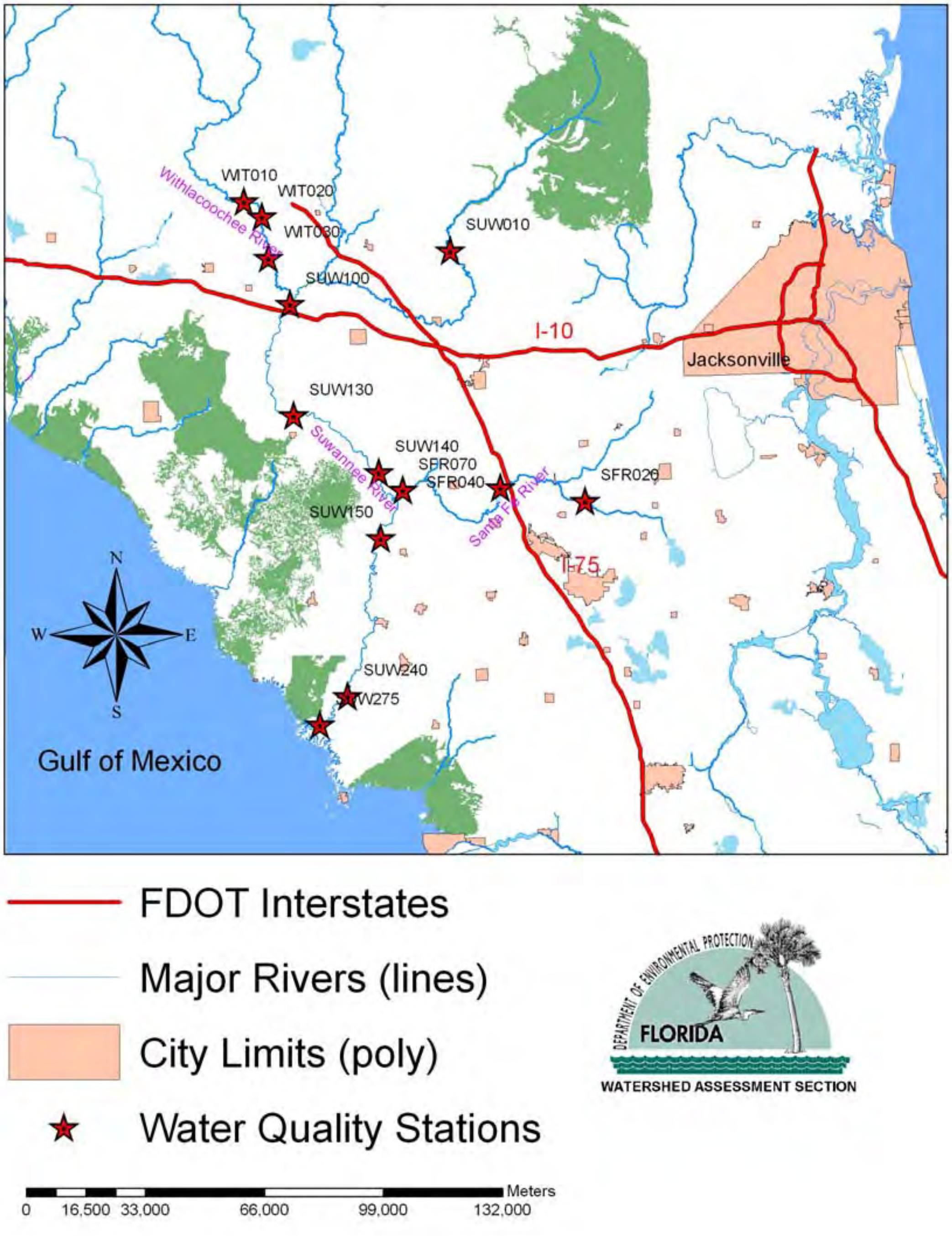


Figure 1. Locations of Water Quality Stations from Which Measured Nitrate and Periphyton Abundance Were Used for This Analysis

For each of the 13 stations, sample averages of NOx, total abundance, and biomass for the periods 1990-1994, 1995-1998, 1999-2002, and 2003-2007 were calculated based on the original measurements. Sample averages are used in the analysis instead of individual samples for the purpose of reducing randomness variation and better representing the environmental conditions during the given time periods. Sample sizes for each of the 13 stations in the four time periods range from 5 to 20. Annual averages were not used due to small sample sizes (There were no, or only one or two observations for some years at some stations).

It was noticed that data at station SUW275 were collected only in 1990-1992 and stations WIT010, WIT020, and WIT030 had measurements only during the period of 1990-1991. At other 9 stations, data were collected up to 2007 or 2006. Niu and Gao (2007) noticed that station SUW275 reported much lower mean abundance (163243.90). The authors consulted with Mr. Robert Mattson of SRWMD and learned that "the site SUW275 is 'Suwannee River at Gopher River' that is located way, way down on the river." Mr. Mattson considers that SUW275 is the upper, tidal freshwater region of the Suwannee estuary. Current velocities there can be quite strong, and it also may be that the area got a short "shock" of salinity during the drought of 1990-91, even though it is usually a totally freshwater site. Mr. Mattson commented that "the site is a bit different and may not be entirely comparable to upstream, riverine sites such as SUW100 (Suwannee River at Ellaville - at the confluence with the Withlacoochee) and SUW130 (Suwannee River near Luraville, between Ellaville and Branford)."

Based on discussion between the authors of Niu and Gao (2007) and Mr Mattson, we think that the data at station SUW275 is not comparable with those at other stations. Thus the data at SUW275 was removed from the change point analysis in the report prepared by Niu and Gao (2007). For the change point analysis of this updated data set, Station SUW275 will also be removed from the analysis, i.e., data from other 12 stations will be used.

Appendix B—Page 4

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

If there exists an integer r $(1 < r < n)$ that split the observations into two groups, $\{Y_1, \ldots, Y_r)$ and $\{Y_{r+1}, \ldots, Y_n)$, 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 called 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 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:

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

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 $\{L(l=\widehat{\beta_1}\,(l) / se(\widehat{\beta_1}\,(l)), l = 2, 3, \ldots, (n - l)\}$ where $se\,(\widehat{\beta_1}\,(l))$ is the estimated standard error of $\widehat{\beta_1}(l)$.

Step 3. Let $L(l_1) = max\{L(2), L(3), \ldots, L(n - 1)\}$ 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 $\widehat{\beta_1}\,(l)$.

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 $\{X_1, X_2, \ldots, X_k\}$. Fit the model

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

Then the estimated coefficients $\{\widehat{\beta_1}, \widehat{\beta_2}, \ldots, \widehat{\beta_k}\}$ will be the k estimated level-shift values.

III. Model Comparison

Model (2) fits a step function $\beta_0 + \beta_1\,S_i\,(l_1) + \beta_2\,S_i\,(l_2) + \ldots + \beta_k\,S_i\,(l_k)$ 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 $\{(X_i, Y_i), i = 1, 2, \ldots, n\}$ 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:

$$Y_i = \beta_0 + \beta_1 + x_i + \varepsilon_i, \qquad i = 1, 2, \ldots, n \tag{3}$$

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:

Appendix B—Page 6

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

When different models are fitted to the observations $\{(X_i, Y_i), i = 1, 2, \ldots, n\}$, 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

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

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:

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

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 of 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).

Table 1. Mean NOx and Mean Abundance Data at the 12 Suwannee River Stations (Sorted by Mean NOx)

- = Empty cell/no data

(1) One change point was detected at Mean NOx=0.441 with the test statistic of 7.68 and confidence level over 95%. 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.

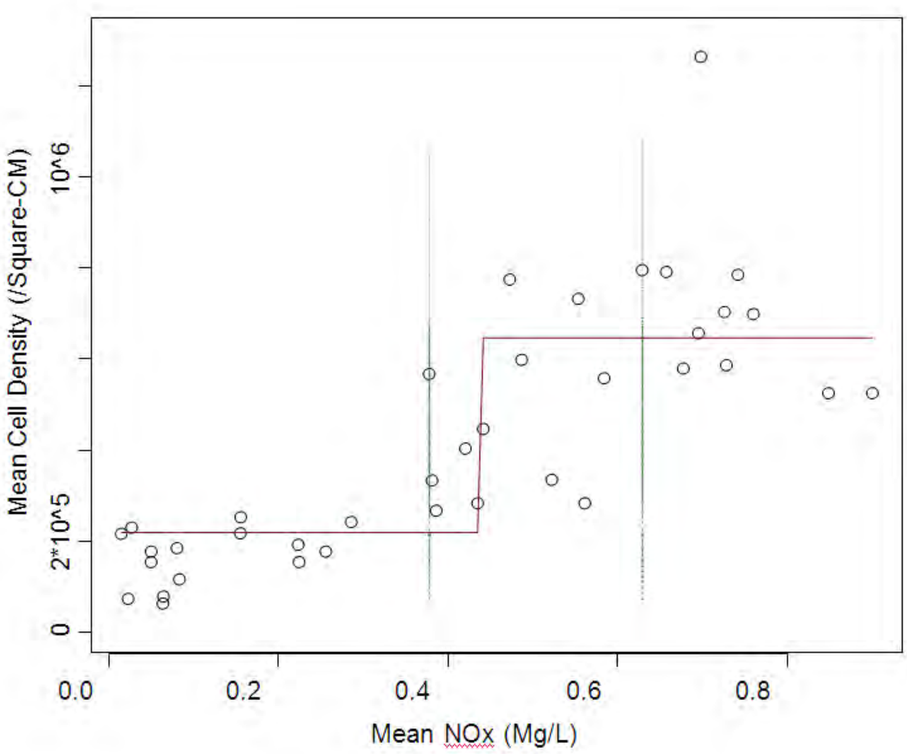
Station	Mean NOx	Mean Abundance	Station	Mean NOx	Mean Abundance
SUW010*(03-07)	0.015	215863	SUW130(03-07)(1)	0.441	446534
SUW010(95-98)	0.023	72775	SUW130(95-98)	0.473	774970
SUW010(99-02)	0.027	229545	SUW150(90-94)	0.487	598208
SUW010(90-94)	0.050	153580	SUW130(99-02)	0.522	334294
SFR020(99-02)	0.050	177079	SFR070(90-94)	0.553	732480
SFR020(90-94)	0.064	62343	SUW240(90-94)	0.561	282885
SFR020(95-98)	0.065	78021	SFR070(95-98)	0.584	557997
SFR040(99-02)	0.081	184470	SFR070(03-07)	0.629	795424
SFR020(03-07)	0.084	115671	SFR070(99-02)	0.657	791649
SFR040(90-94)	0.155	216861	SUW150(03-07)	0.677	579348
SFR040(03-07)	0.156	252165	SUW240(99-02)	0.695	656715
WIT020(90-91)	0.223	191813	SUW150(95-98)	0.698	1264802
SFR040(95-98)	0.225	153825	SUW240(03-07)	0.726	703205
WIT010(90-91)	0.256	176644	SUW140(03-07)	0.728	586243
WIT030(90-91)	0.286	241469	SUW240(95-98)	0.741	785583
SUW100(95-98)	0.378	567218	SUW150(99-02)	0.760	699194
SUW130(90-94)	0.381	332953	SUW140(99-02)	0.848	524728
SUW100(99-02)	0.386	266619	SUW140(95-98)	0.900	525039
SUW100(90-94)	0.421	402964	-	-	-
SUW100(03-07)	0.435	282783	-	-	-

<u>**Appendix B—Page 8**</u>

Figure 2. Change Point Analysis for Data from the 12 Stations at the Suwannee River System (Mean Abundance vs Mean NOx)

Change Points: Mean NOx=0.441 with the test statistic of 7.68 and confidence level over 95%.

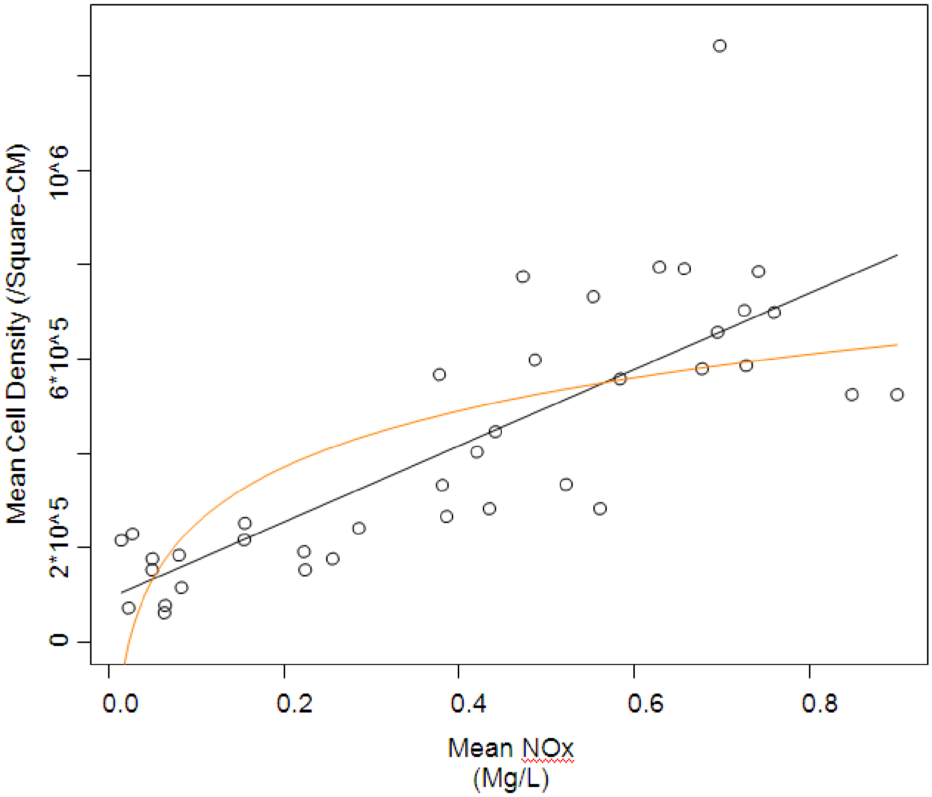
The 95% confidence interval for the change point based on 1000 Bootstrapping samples is [0.378, 0.629] with Bootstrapping average estimate for the change point at NOx=0.480.



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



Appendix B—Page 10

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

2. *Mean Biomass vs Mean NOx*

a). Change Point Analysis

Table 3 presents the mean NOx and mean biomass data (ash free dry mass – AFDM/cm^2) at stations along the Suwannee river and its two major tributaries (Withlacoochee and Santa Fe). Biomass data are not available for the period of 1999-2002 at the 12 stations.

Change point analysis was performed for mean biomass vs mean NOx. When data from the 12 stations are used, one change point 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).

Table 3. Mean NOx and Mean Biomass Data at the Suwannee River Stations (Sorted by Mean NOx)

- = Empty cell/no data

(1) One change point was detected at 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.

2) Both Bootstrapping 95% confidence intervals are skewed towards higher values than NOx=0.441. The Bootstrapping method removes some samples and repeats some other samples in the original data. Therefore bootstrapping samples may change the structure of the original data. For small sample size below 30, bootstrapping interval estimates are not recommended.

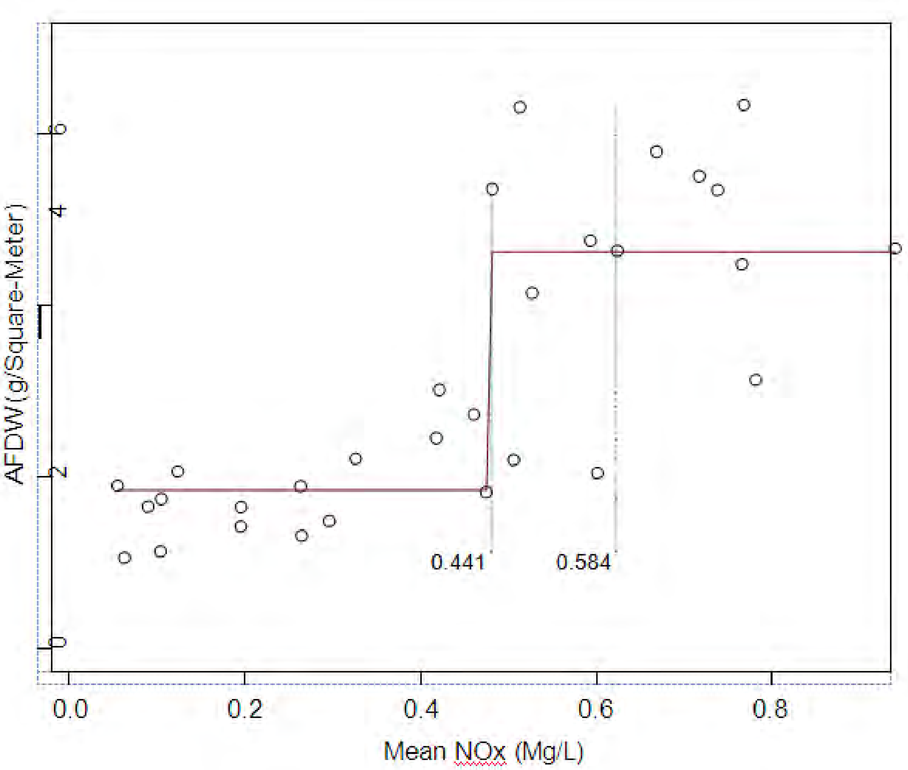
Station	Mean NOx	Mean Biomass	Station	Mean NOx	Mean Biomass
SUW010(03-07)	0.015	1.871	SUW100(03-07)	0.435	1.795
SUW010(95-98)	0.023	1.030	SUW130(03-07) (1)	0.441	5.340
SUW010(90-94)	0.050	1.624	SUW130(95-98)	0.473	6.301
SFR020(90-94)	0.064	1.103	SUW150(90-94)	0.487	4.124
SFR020(95-98)	0.065	1.717	SFR070(90-94)	0.553	4.735
SFR020(03-07)	0.084	2.037	SUW240(90-94)	0.561	2.019
SFR040(90-94)	0.155	1.396	SFR070(95-98)	0.584	4.616
SFR040(03-07)	0.156	1.619	SFR070(03-07)	0.629	5.781
WIT020(90-91)	0.223	1.867	SUW150(03-07)	0.677	5.495
SFR040(95-98)	0.225	1.287	SUW150(95-98)	0.698	5.333
WIT010(90-91)	0.256	1.456	SUW240(03-07)	0.726	4.460
WIT030(90-91)	0.286	2.187	SUW140(03-07)	0.728	6.328
SUW100(95-98)	0.378	2.428	SUW240(95-98)	0.741	3.106
SUW130(90-94)	0.381	2.991	SUW140(95-98)	0.900	4.644
SUW100(90-94)	0.421	2.702	-	-	-

Appendix B—Page 12

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.

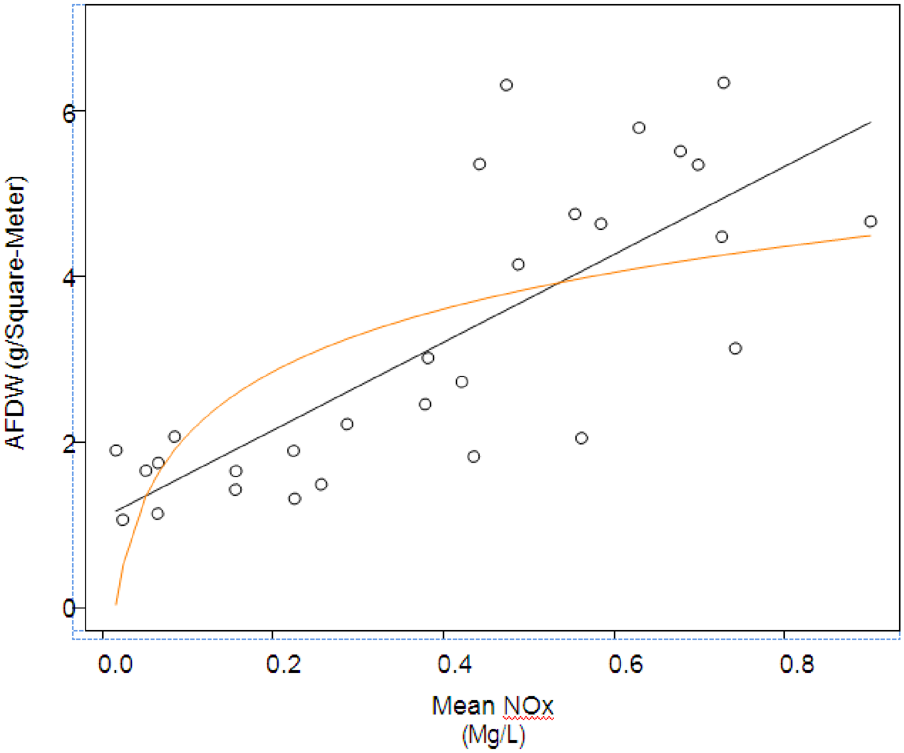


b). Model Comparison

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.

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.

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



Appendix B—Page 14

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 point 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.

Appendix B—Page 16

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