FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

Division of Environmental Assessment and Restoration, Bureau of Watershed Restoration

CENTRAL DISTRICT • WITHLACOOCHEE BASIN

# DRAFT

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


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**Ground Water Management Section**


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# Acknowledgments

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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

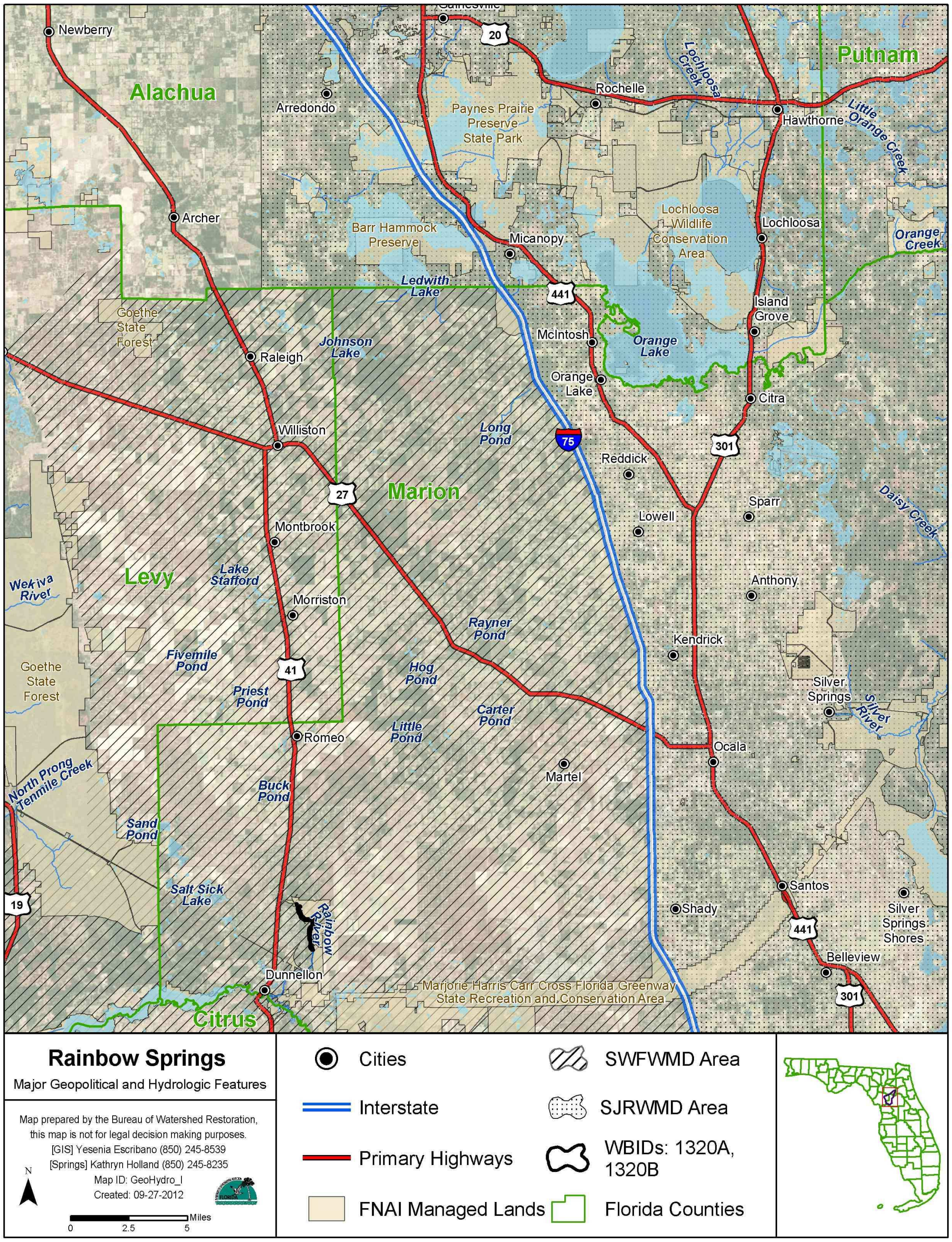
This report presents the Total Maximum Daily Load (TMDL) for nitrate ($NO_3$), which was determined to be a cause of the impairment of Rainbow Springs Group and Rainbow Springs Group Run within the Rainbow River Planning Unit of the Withlacoochee Basin. These waterbodies were verified by the Florida 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, 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 is the fourth largest spring group (by magnitude) in Florida, with an average flow of 493 million gallons per day (MGD). These springs occur along the first 1.5 miles of the Rainbow River (Champion and Starks 2001). The two largest springs in the group are Rainbow Spring #1, which consists of multiple vents within a designated swimming area of Rainbow Springs State Park, and Rainbow Spring #4. Rainbow Springs Group Run is a segment of the Rainbow River downstream from Rainbow Springs Group that contains two other major springs, Rainbow #6 and Bubbling Spring, as well as numerous smaller springs that contribute flow and nutrients to the system. Spring discharge in these two segments provides most of the flow in the Rainbow River, which receives discharge from numerous springs along the riverbed 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 waterbodies lie in a karst plain region where the landforms and surface water features depend on the underlying geology. In general, the topography and drainage in karst regions 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 with limestone at or near the land surface.




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

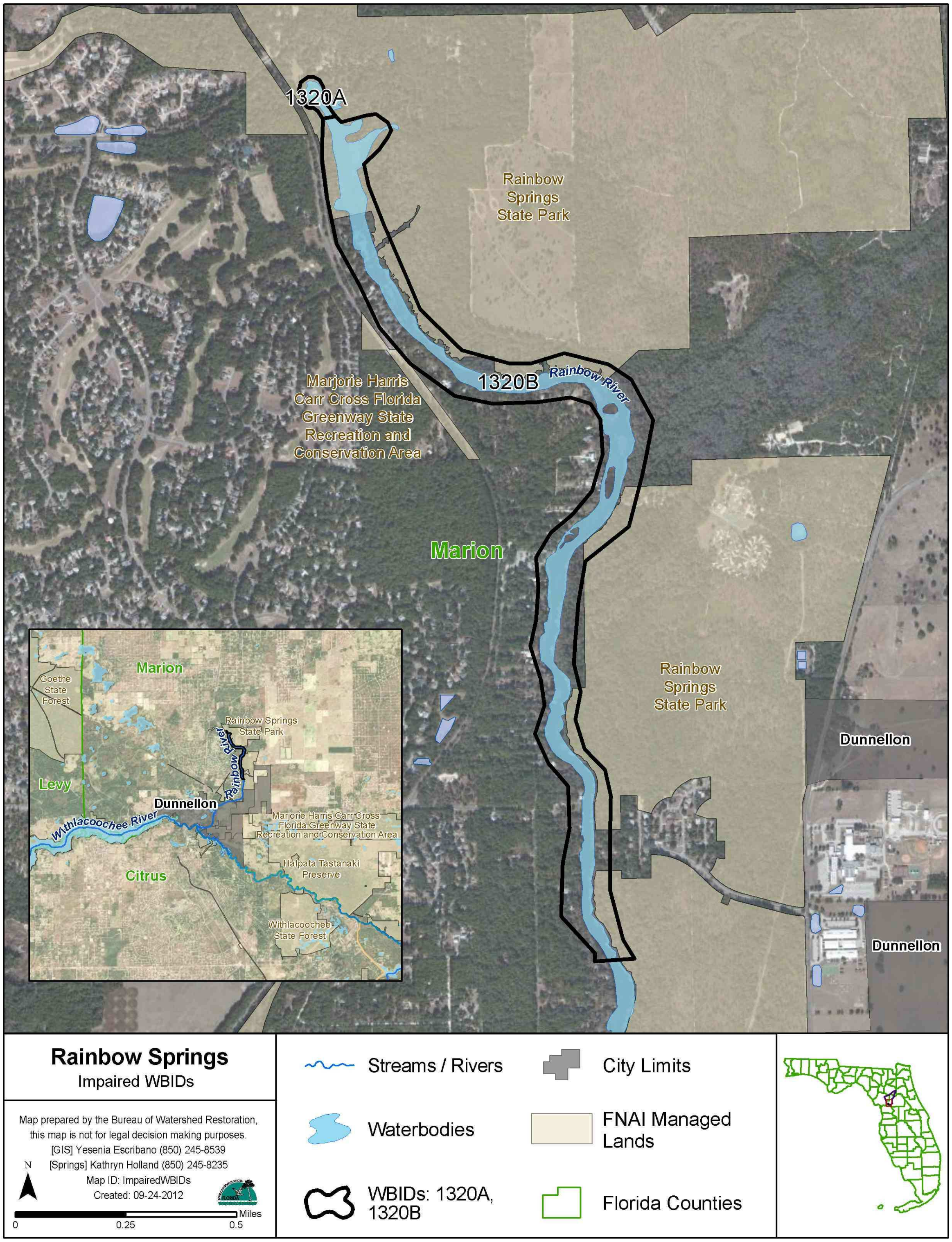



**Figure 1.2. Location of the Two Impaired WBIDs in Marion County**

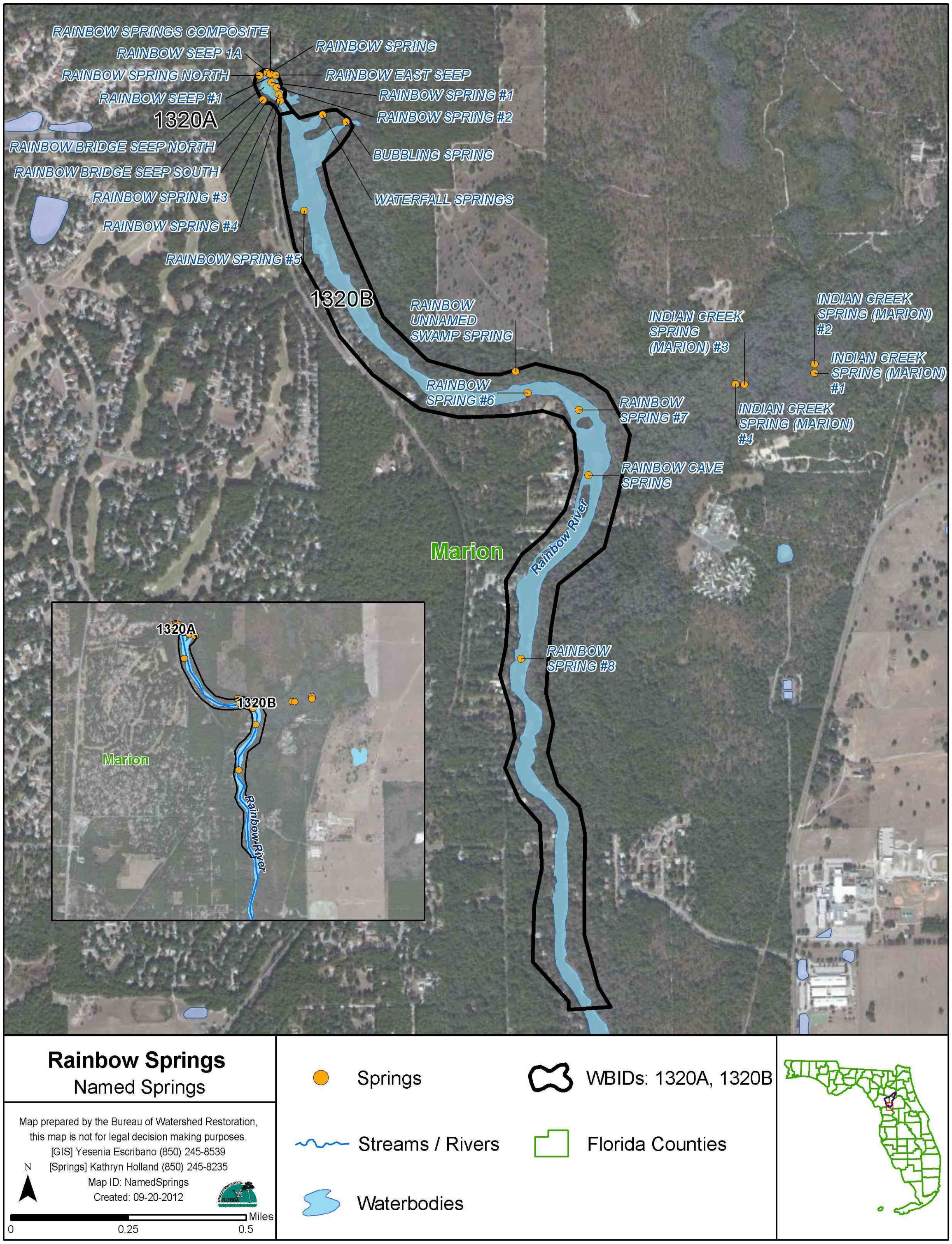



**Figure 1.3. Named Springs in the Rainbow Springs Area**

The karst topography is marked by numerous sinkholes and minimal surface drainage, the most notable being Indian Creek. Knowles (1996) provided details on the hydrogeologic units, shown in **Figure 1.4**. The karst topography of the Rainbow Springs watershed is largely unconfined at the surface, and recharge of the Floridan aquifer by local rainfall is high in most areas of the watershed (>10 inches per year) (Faulkner 1970). The Floridan aquifer is the principal source of water for Rainbow Springs (Jones *et al.* 1996). The upper Floridan aquifer (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).

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 the 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 springshed. **Figure 1.5** shows the 686-square-mile 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. Adjacent to it and overlapping in some areas is the springshed of Silver Springs Group. 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 the Rainbow Springs Group is 686 square miles, while the Rainbow River surface watershed is almost 9 times smaller (73 square miles) and 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**.**

Aquifer vulnerability is a function of several factors, including the nature of confining sediments above the aquifer, depth to ground water, and the presence or absence of karst features. The Florida Aquifer Vulnerability Assessment (FAVA) model developed by the Florida Geological Survey (FGS) (Arthur *et al.* 2007) was used to evaluate the potential for surface sources of

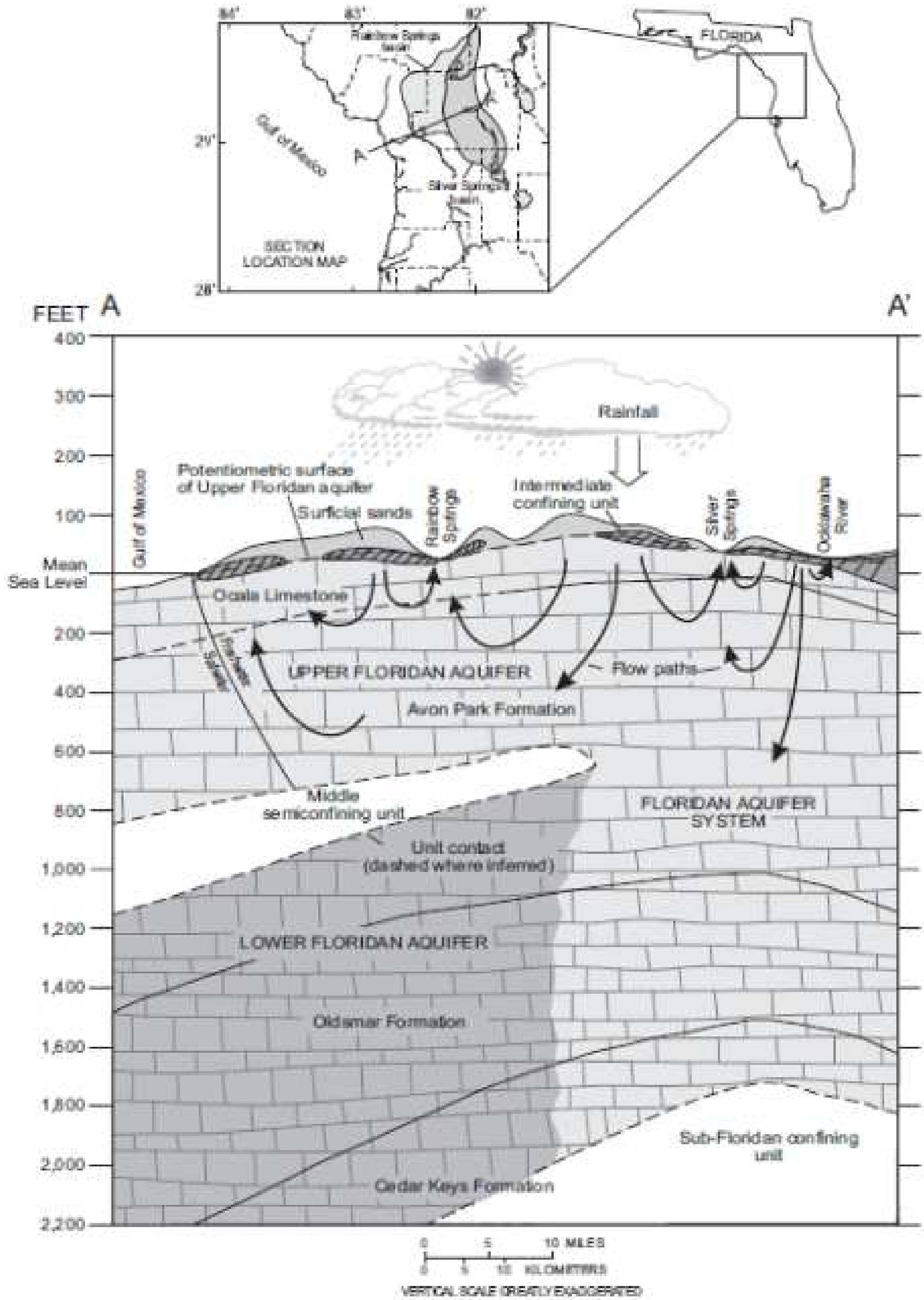



**Figure 1.4. Conceptualized Ground Water Flow Patterns to Rainbow Springs Group and Rainbow Springs Group Run (Knowles 1996)**

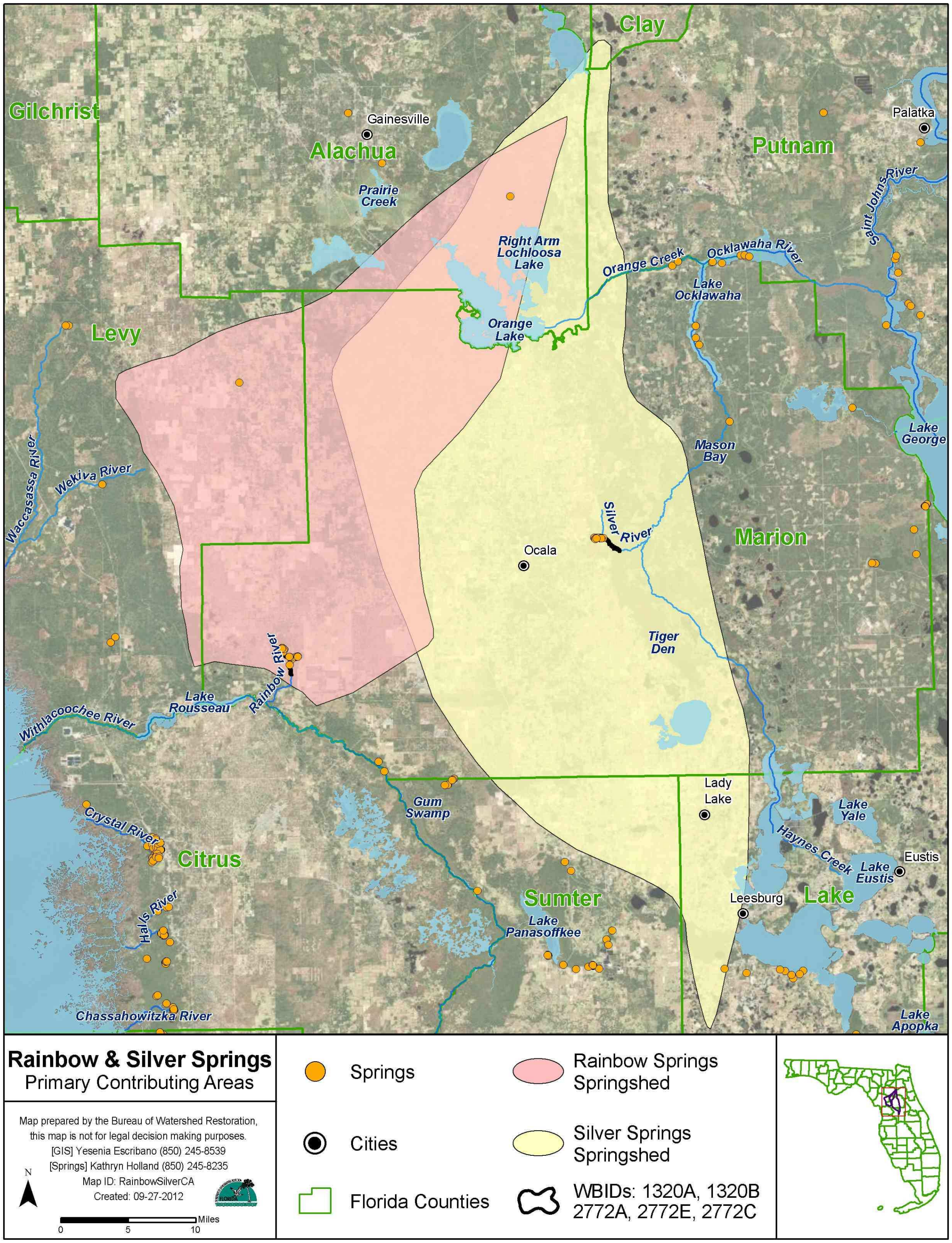



**Figure 1.5. Springsheds for Rainbow Springs and Silver Springs**

contamination to affect ground water within the springshed. The vulnerability of the Floridan aquifer was assessed for the portion of the springshed within Marion and Alachua Counties using county-specific FAVA models that had been developed (Advanced GeoSpatial, Inc. 2007; Department, 2008). The statewide FAVA for the Floridan aquifer was used to assess aquifer vulnerability within the portion of the springshed located in Levy County, because it does not have a county-specific assessment. Considerably different datasets were used for county versus statewide inputs because more detailed and comprehensive data were available for Marion and Alachua Counties. As a result, it is not possible to directly compare the vulnerability assessment for Levy County with the Marion and Alachua County models. The statewide FAVA model classifies the portion of the springshed in Levy County as “most vulnerable.” The Marion and Alachua County models, which are more closely aligned, classify the area nearest Rainbow Springs as “more vulnerable” to contamination, transitioning to “vulnerable” in the northeastern portion of the springshed where a confining unit exists (**Figure 1.7**).

In evaluating the potential sources of nutrients impacting the springs and their impaired receiving water (the Rainbow River), the Department considered the 1996 springshed coverage as well as the surface watershed of the river. Nearly all of the drainage in this area, except for a small area adjoining the Rainbow River, is internal, either directly into closed depressions or by seepage into the unconfined limestone of the UFA. Ground water basins in the area do not coincide with the boundaries of surface water drainage divides (Faulkner 1973).

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

## 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 Marion County, the cities of Dunnellon and Ocala, the SWFWMD, the Florida Department of Agriculture and Consumer Services (FDACS), other local governments, landowners, businesses, and private citizens.

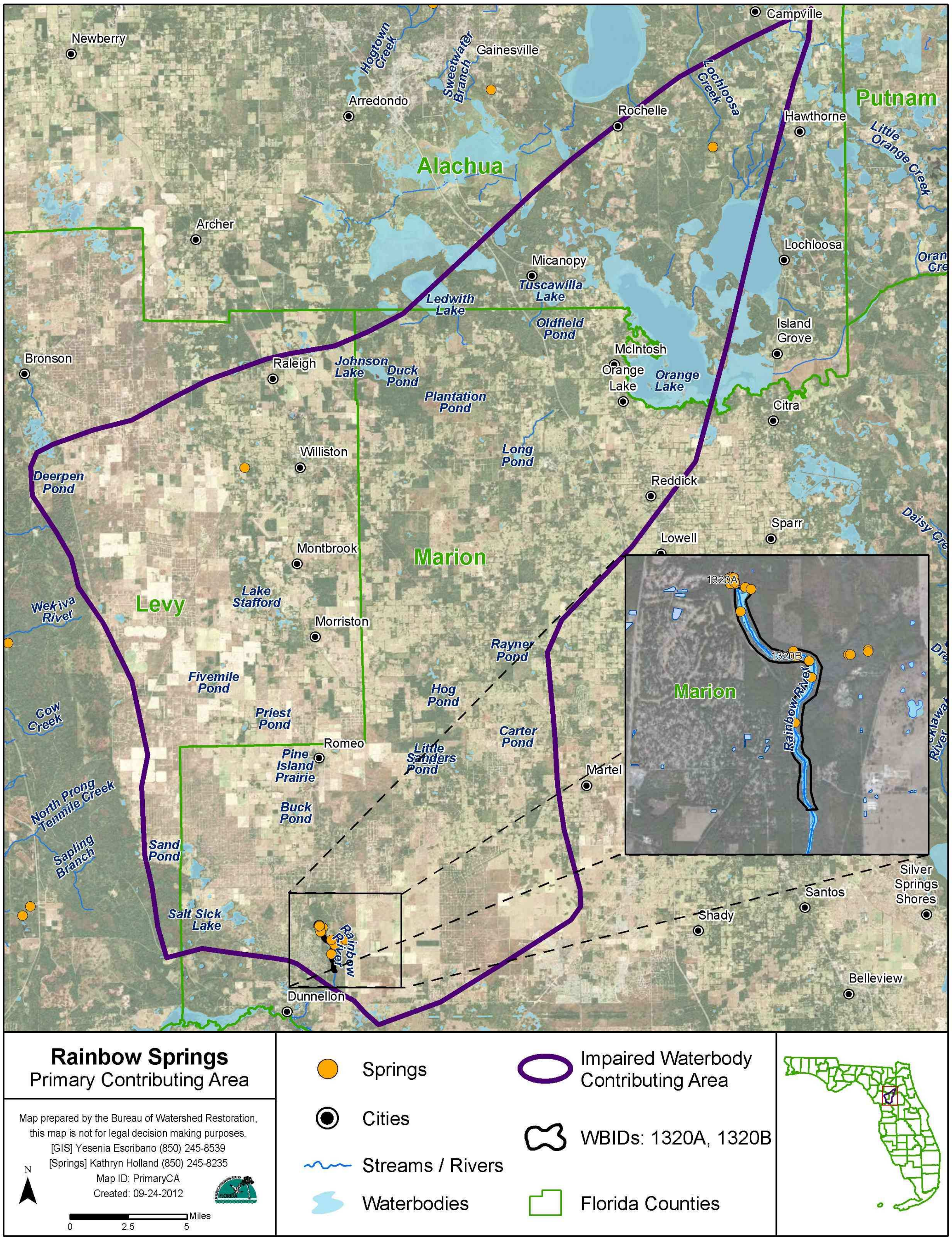



**Figure 1.6. Springshed for Rainbow Springs Group and Rainbow Springs Group Run**

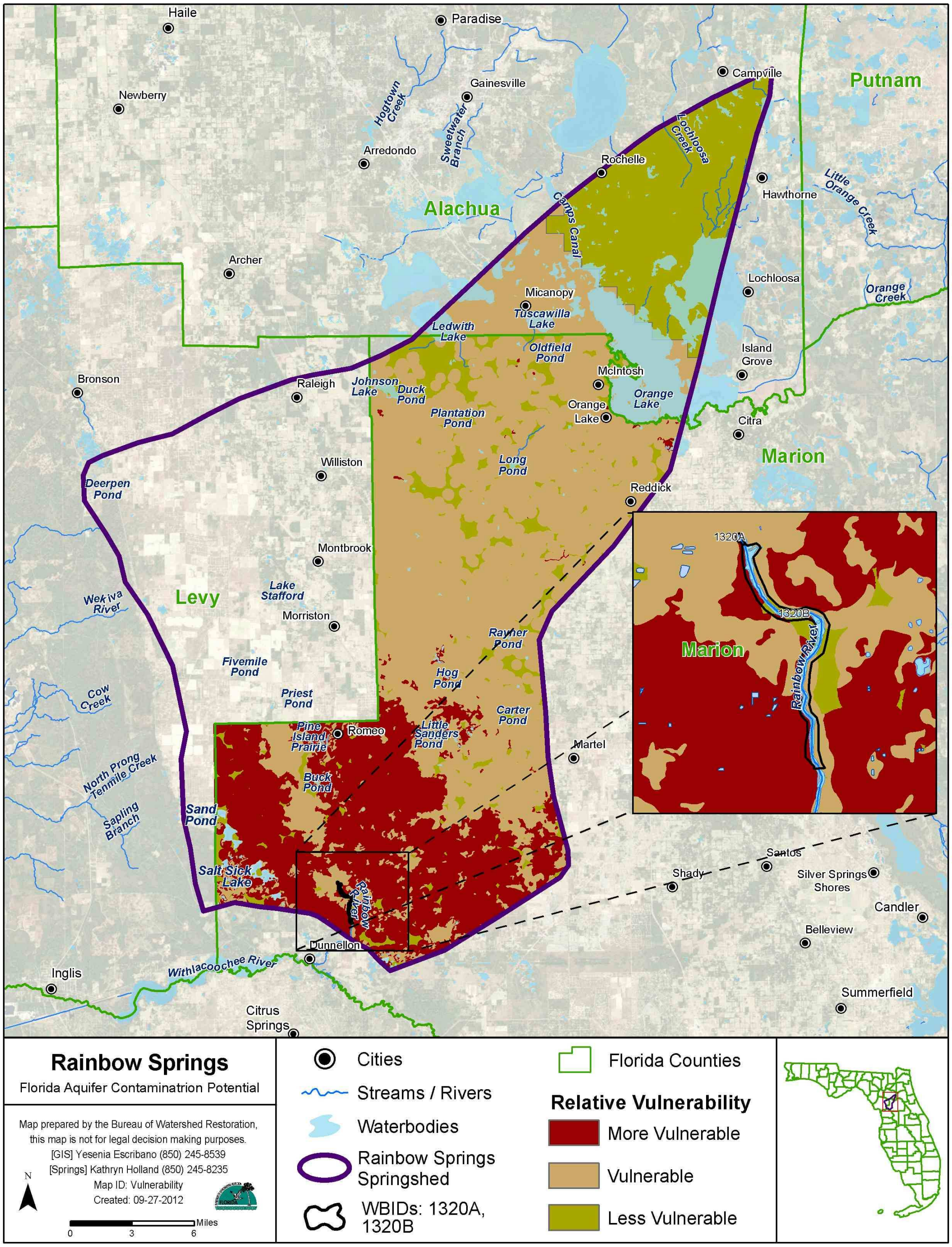



Figure 1.7. FAVA Map in Portions of the Rainbow Springs Group and Rainbow Springs Group Run Springshed

Rainbow Springs and the Rainbow River have significant economic value to southwestern Marion County, and that value is directly dependent on the physical and biological 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, 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]

Since 2002, the SWFWMD and Rainbow Springs Aquatic Preserve have been involved with efforts to understand the river's exceptional water clarity and the link between water clarity and spring discharge. Vegetation mapping is ongoing; *Lyngbya* removal 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 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, much of the agricultural land use area in the northwestern part of Levy County is classified as an Agricultural Protection Zone in the Marion County Comprehensive Plan.

[1] More information on these projects can be found in the SWIM Program *Project Status Report, First Quarter 2012,* available at http://www.swfwmd.state.fl.us/files/database/site_file_sets/34/swim_project_status.pdf.

# 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, including the Rainbow River. 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 in the IWR database, data from the Department's Springs Initiative monitoring network, and other available information to document the nitrate concentrations and effects of nutrient enrichment at Rainbow Springs Group and Rainbow Springs Group Run. The SWFWMD provided the bulk of the nitrate data used in the evaluation. Department Springs Initiative monitoring data from 2001 to 2009 were also used. These spring-related waters were listed as impaired for nutrients because of their consistently elevated concentrations of nitrate (above 0.6 milligrams per liter [mg/L]) and corresponding evidence of imbalance of flora and fauna caused by algal smothering. 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 causes the impairment of many surface waters, including springs. The two major nutrient groups monitored are nitrogen (N) and phosphorus (P). These are essential nutrients to plant life, including algae. For aquatic vegetation and algae to grow, both nutrients have to be present. In fact, one 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 trigger an imbalance, but it did not occur because there was very little nitrogen in the water.

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 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 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. This is approximately 40 times the background level of 0.05 mg/L. From the 1970s to the early 2000s, there was a steady increase in nitrate concentrations in the springs. Between 2001 and 2005, the readings averaged about 1.2 mg/L, and between 2005 and 2007, they increased to the present level of approximately 2 mg/L. In a review of private well sampling data collected by the Florida Department of Health (FDOH) from the Rainbow Springs springshed, it was found that out of more than 222 well samples evaluated, 41% had nitrate concentrations greater than 1 mg/L and that the higher concentrations were found at the center of the springshed (Harrington *et al.* 2010).

Nitrates are a byproduct of many human activities, including fertilization (agriculture, golf courses, lawns, etc.) and human and animal waste disposal practices. Nitrate emerging from Rainbow Springs is primarily inorganic, pointing to fertilizers as the origin (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 (ball fields 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 are not completely understood, although nitrate levels above background may support increased algal growth and increased growth of the invasive exotic plant *Hydrilla*. There is clear evidence, however, that nitrate does fuel the growth of algae on the river bottom, the growth of vegetation in the impaired segments, and the growth of planktonic algae in the water column in the lower reaches of the Rainbow River, all of which contribute to reduced water clarity.

### *2.3.2 Phosphorus*

Neither orthophosphate nor total phosphorus 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. 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 total phosphorus in 60 wells throughout the Rainbow River watershed and found values ranging from 0.023 to 0.764 mg/L. The highest values 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 Rainbow River decreases with increasing distance from the headsprings area, while chlorophyll *a* increases with increasing distance (Anastasiou 2006). Approximately 83% of the 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 micrograms 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 testing nutrient effects on phytoplankton indicated that biovolume increased when nitrate+trace metals were at elevated concentrations.

### *2.4.2 Human Recreation Impacts*

The Rainbow River attracts over 30,000 visitors per year, and the number of visitors increases substantially during the summer months (Holland and Cichra 1994). Heavy recreational use in the springs area 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 manatees and other wildlife, and boats moving at higher than recommended speeds create wakes that can erode the banks of the river.

Photographic evidence of increased algal coverage in the springs and river supports the shift from healthy stands of *Sagittaria* to smothered benthic conditions. Photographs from the 1950s document healthy populations of submerged aquatic vegetation (SAV) and crystalline water clarity, with little to no algal smothering. Recent photographs, taken within the past five years, contrast with historical photographs and document changes that have occurred in the aquatic community at the springs and river (**Figures 2.1** through **2.6**).

**Figure 2.1. Underwater Photo of Rainbow Springs, 1955**

**Figure 2.2. Underwater Photo of Rainbow Springs, 1955**

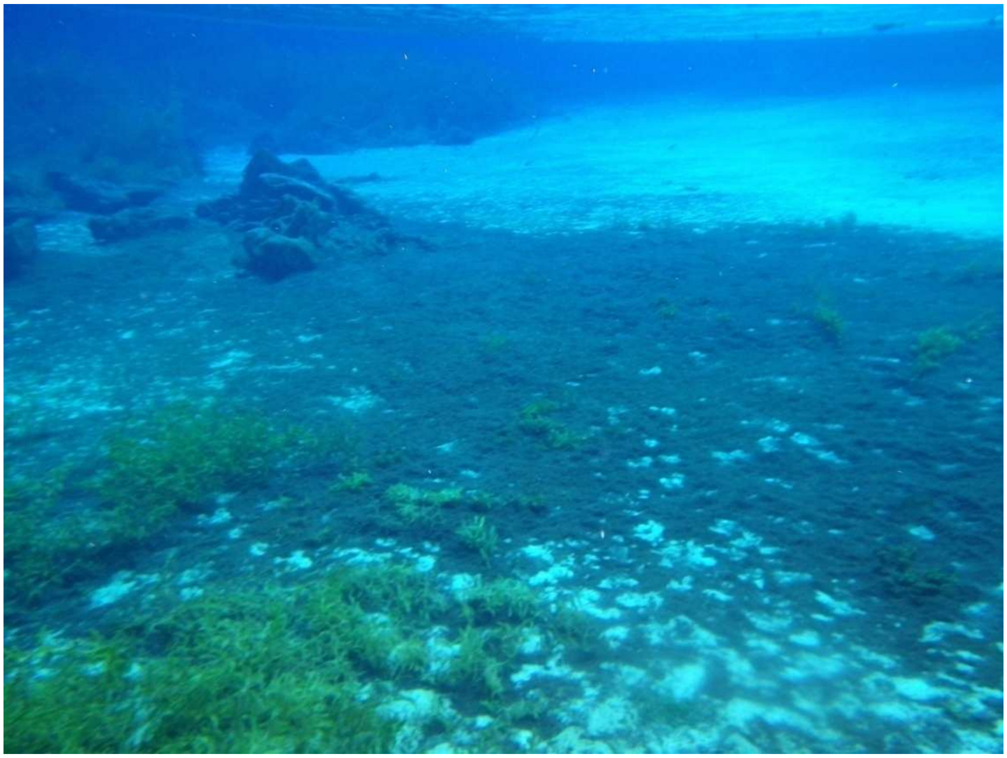


**Figure 2.3. Downstream of Rainbow Spring #1, 2011**

**Figure 2.4. *Lyngbya* sp. Algae near Rainbow Spring #1, 2011**

**Figure 2.5. *Hydrilla* at Rainbow Spring #6 , 2011**

**Figure 2.6. Rainbow Spring, 2011. Dark areas downriver of the swimming area indicate *Hydrilla* and benthic algae with few native plants (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 2.7** 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.

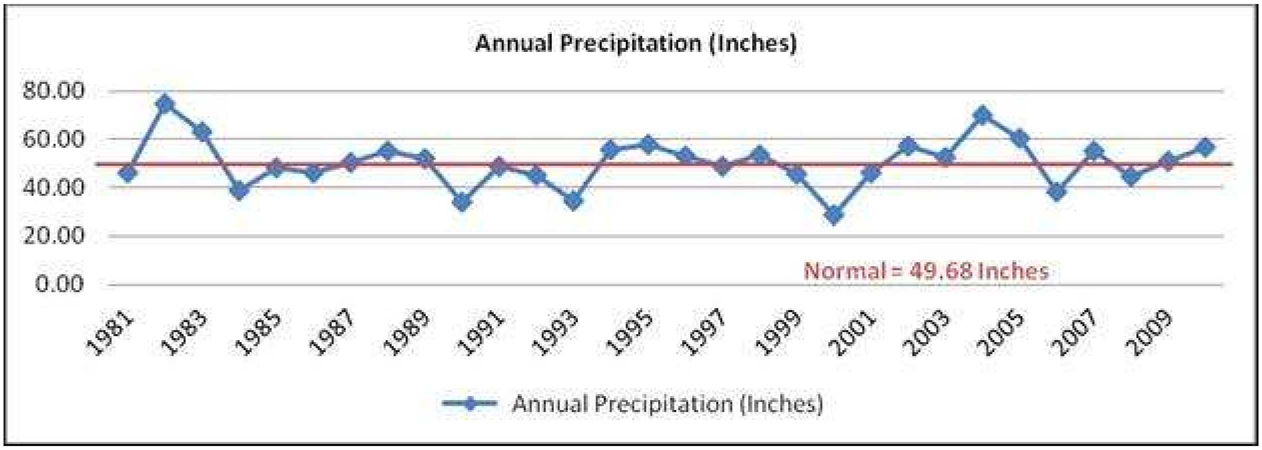



**Figure 2.7. Precipitation for Ocala, 1981–2010 (NOAA Climate Information for Management and Operational Decisions [CLIMOD] Product, October 20, 2011)**

## 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 U.S. Geological Survey (USGS) National Water Information System (NWIS) databases contain many of these data. **Figure 2.8** 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 the Rainbow Springs Group, springs along Indian Creek, and numerous vents along the 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 of 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 NWIS, 2012). Long-term discharge measurements for the Rainbow River (**Figure 2.9**) indicate that flow has 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 to 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.

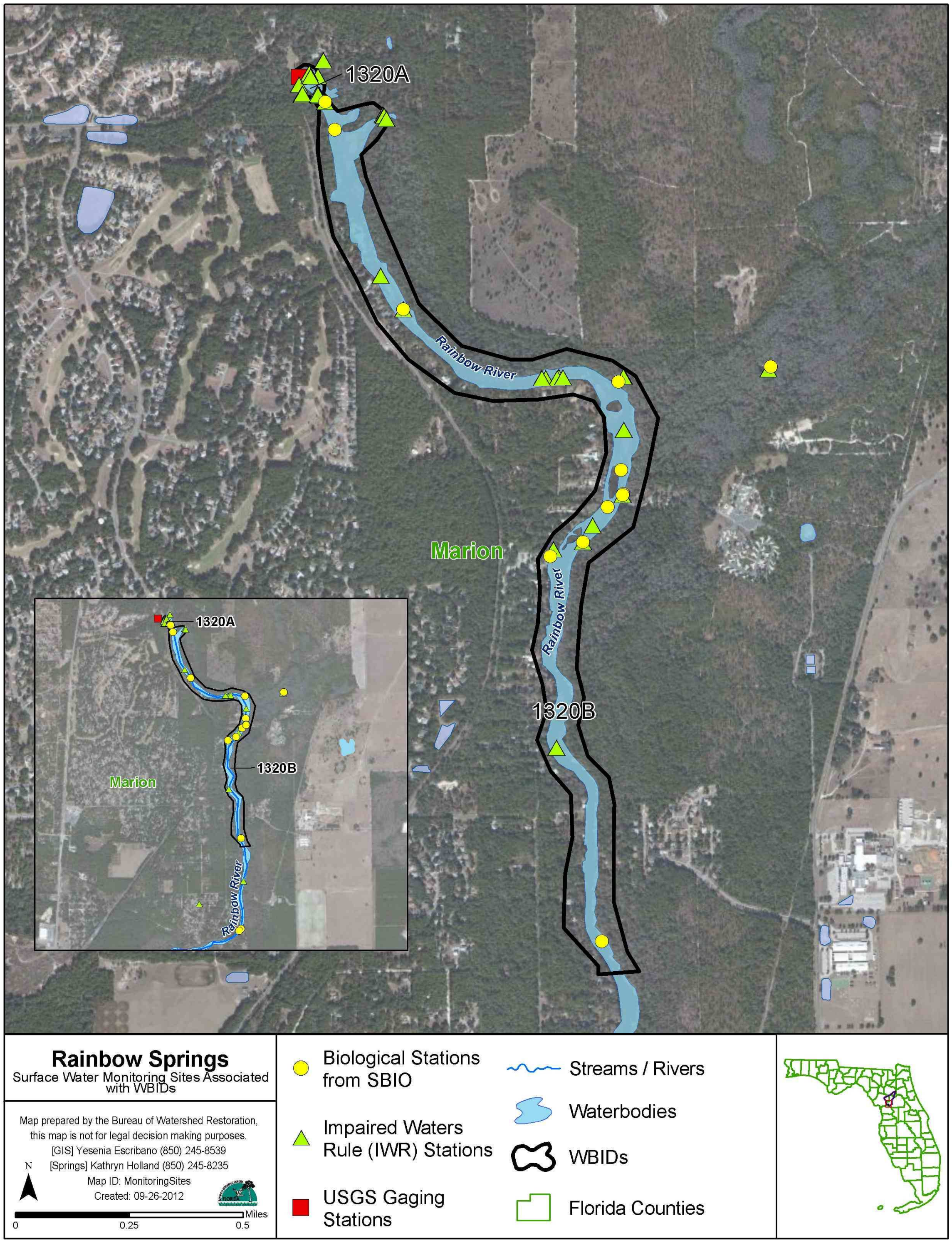



**Figure 2.8. Surface Water Monitoring Sites Associated with Rainbow Springs Group and Rainbow Springs Group Run**

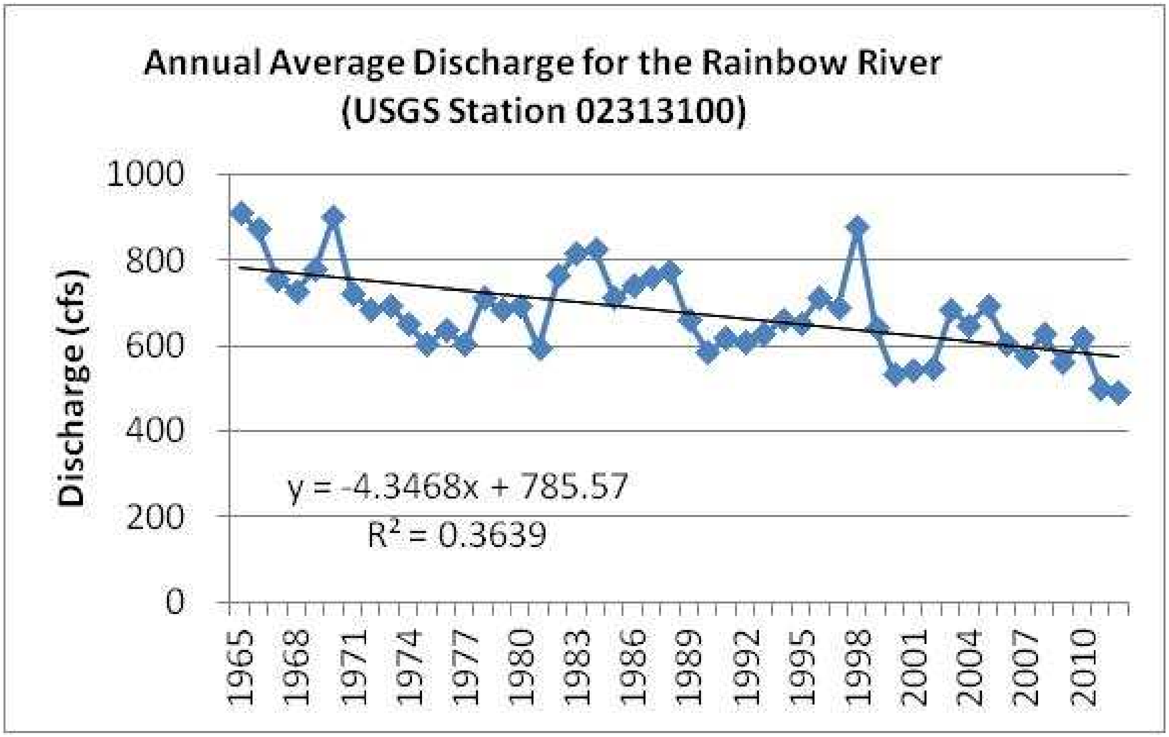


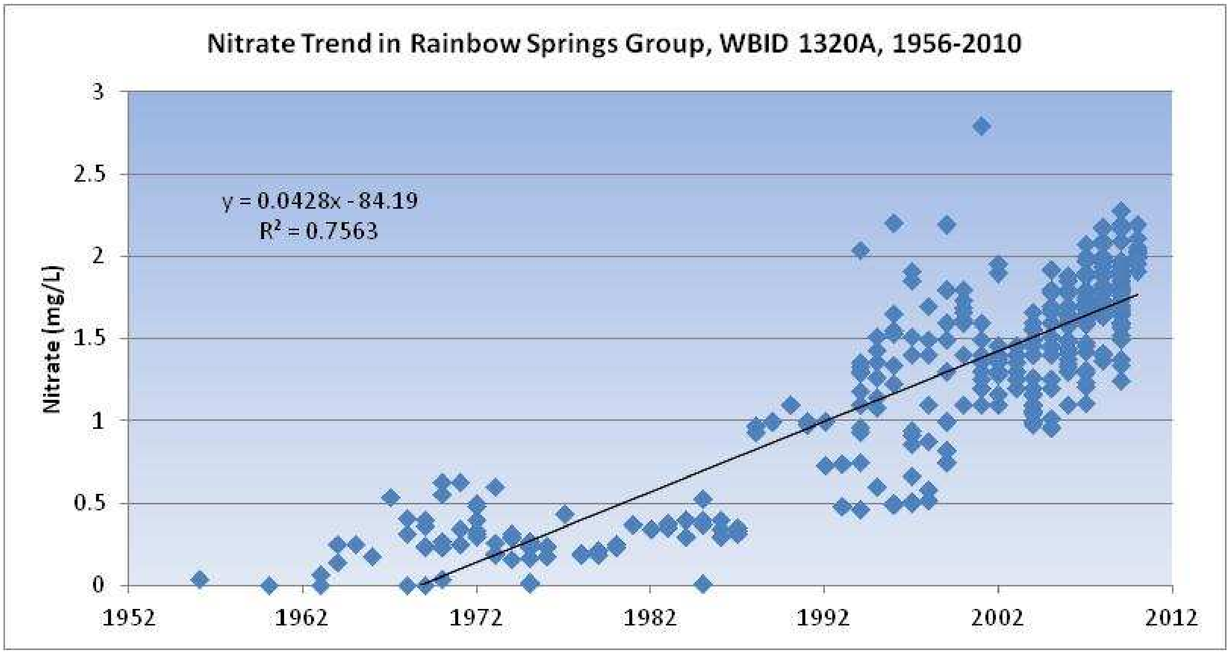

**Figure 2.9. Average Annual Discharge in Rainbow River (Source: SWFWMD)**

## 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 2.10)** (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 2.11**) 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 2.10. 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 |

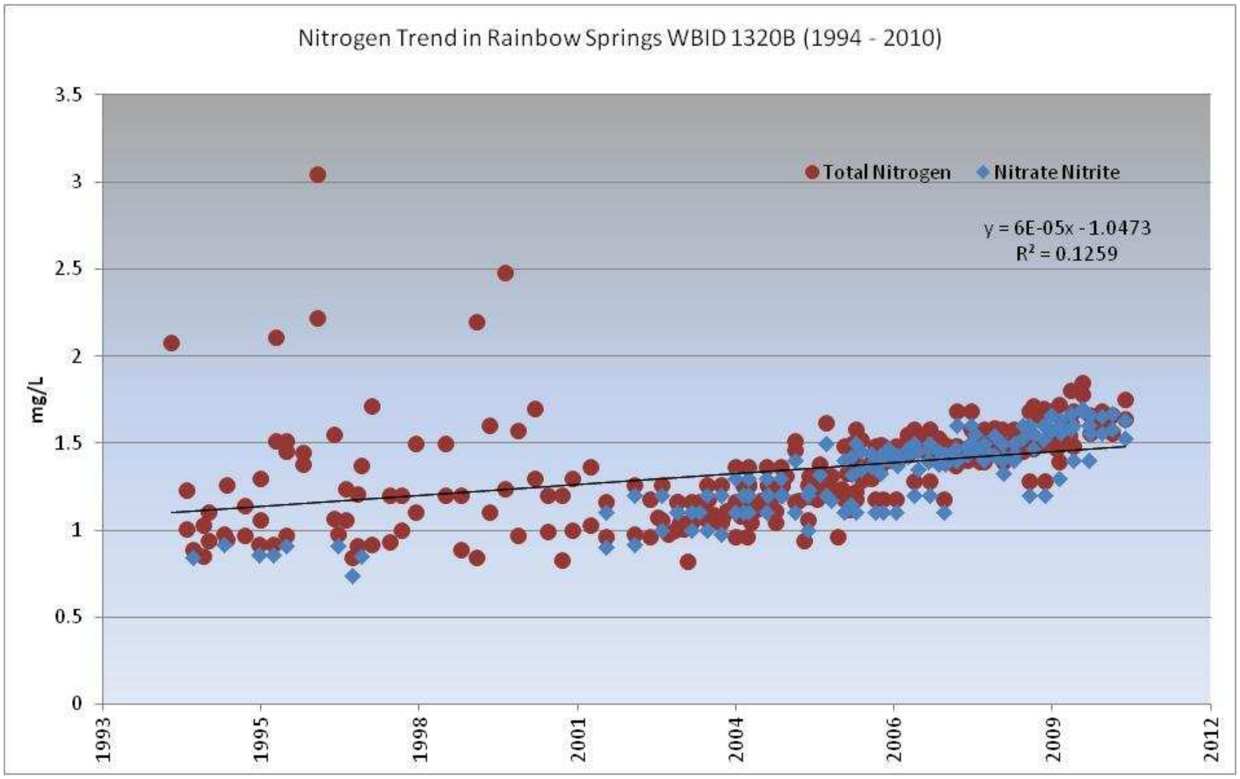



**Figure 2.11. Nitrogen Trend for Rainbow Springs Group Run, 1994–2010**

**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 five designated use classifications, as follows:

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

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.

For Rainbow Springs Group and Rainbow Springs Group Run, benthic macroalgae mats and excess *Hydrilla* growth were shown through phototographic evidence and vegetation monitoring to be a significant problem. Excessive algal growth causes a variety of ecological impairments, 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 dissolved oxygen (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, total phosphorus (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 Withalacoochee 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 2007). 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. In 1972, Rainbow Springs was also designated a National Natural Landmark by the National Park Service.

# 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 surface water that require an NPDES stormwater permit when allocating pollutant load reductions required by a TMDL (see **Section 6.1**). However, the methodologies used to estimate nonpoint source loads do not distinguish between NPDES stormwater discharges and non-NPDES stormwater discharges, and as such, this source assessment section does not make any distinction between the two types of stormwater.

## 4.2 Documentation of Sources of Nutrients in the Rainbow Springs Group and Rainbow Springs Group Run Springshed

Information on the ratio of stable isotopes of nitrogen (δ15N/ δ14N) can provide information about the sources of nitrates in springs. Values 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 results of several isotope studies indicate that the nitrate in Rainbow Springs Group and Rainbow Springs Group Run comes primarily from inorganic sources, most likely fertilizer (Jones *et al.* 1996). Isotopic signatures from 2011 monitoring conducted by the Department confirmed that the nitrate in the spring samples 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 nitrate 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 that it was unlikely that the nitrogen was from natural sources such as the decay of unfertilized soils, since nitrate concentrations in wells and springs were too high, and it is likely that there is a combination of inorganic and organic sources within the springshed.

### *4.2.1 Wastewater and Stormwater Sources*

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

#### Permitted Wastewater Discharges

There are only 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 a surface water, but none of these discharges to the impaired waters, and concrete batch plants are not significant sources of nitrate. The rest of the permitted facilities discharge to ground water via drainfields, rapid infiltration basins, or spray irrigation and 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 source of nitrate than the industrial plants (**Table 4.1** and **Figure 4.1**). Three domestic WWTFs in the Rainbow Springs area have design flows of greater than 0.1 MGD.

#### 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 MS4 permits in the Rainbow Springs springshed. The permit issued to Marion County includes the major portion of the springshed, although a small portion of the area would be covered by the permit issued to Alachua County. Both are covered by Phase II MS4 permits. In the Marion County permit, direct discharge to the Rainbow River is identified.

While the existing NPDES entities are not currently being assigned a specific allocation or reduction, some of them may still be included in the BMAP process because of their nonpoint source contributions. The potential involvement of MS4s in this area may not be limited to the typical discharges of urban stormwater to surface water. They also include discharges of stormwater to the UFA via ponds, sinkholes, and injection or "drainage" wells.

## 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)
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 CBP | 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 MHP | 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 |

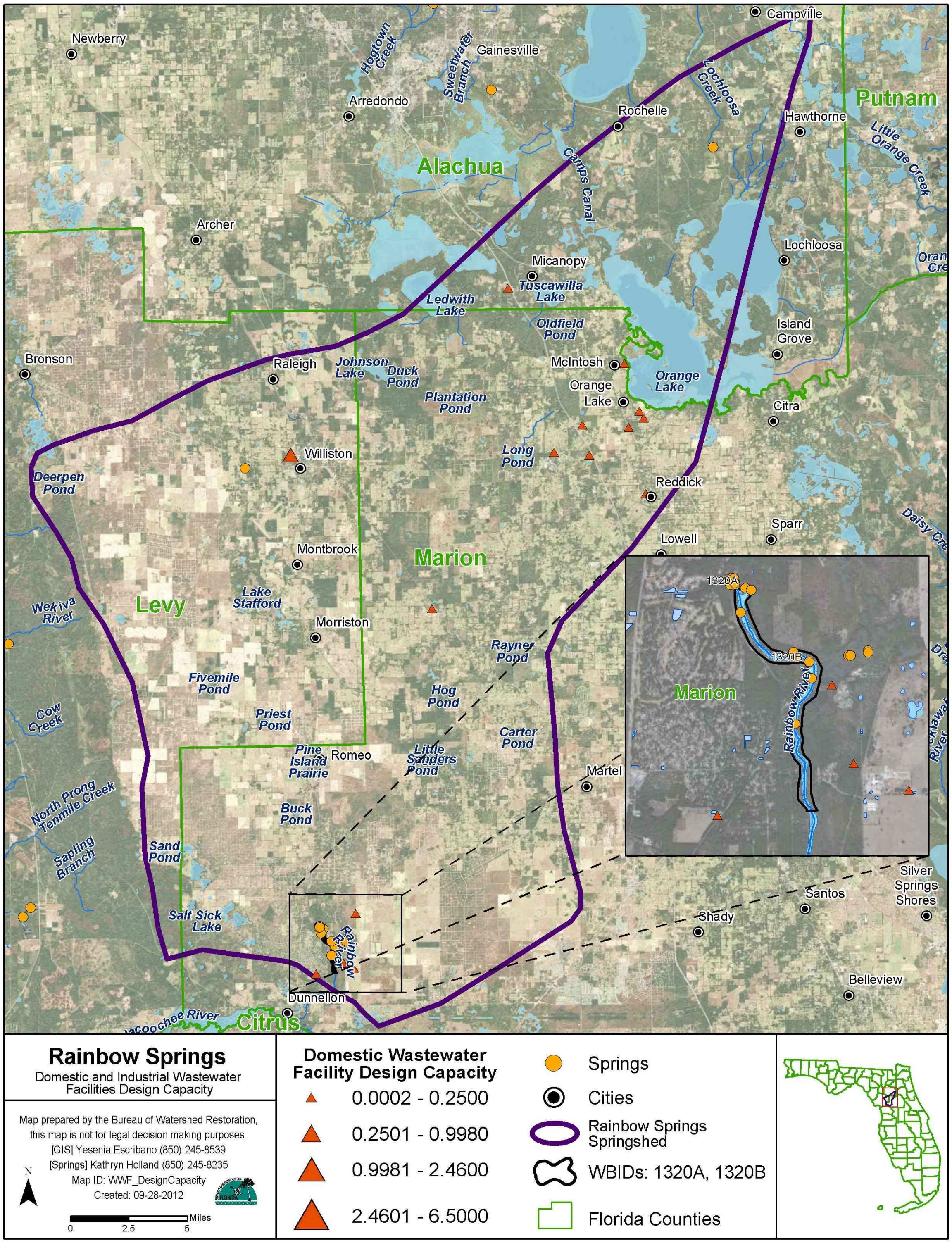



**Figure 4.1. Domestic Wastewater Facilities in the Rainbow Springs Group and Rainbow Springs Group Run Springshed**

### 4.2.2 Land Uses and Nonpoint Sources

In the springshed, most of the nitrate 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). 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 St. Johns River Water Management District (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 and their percentage. 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.

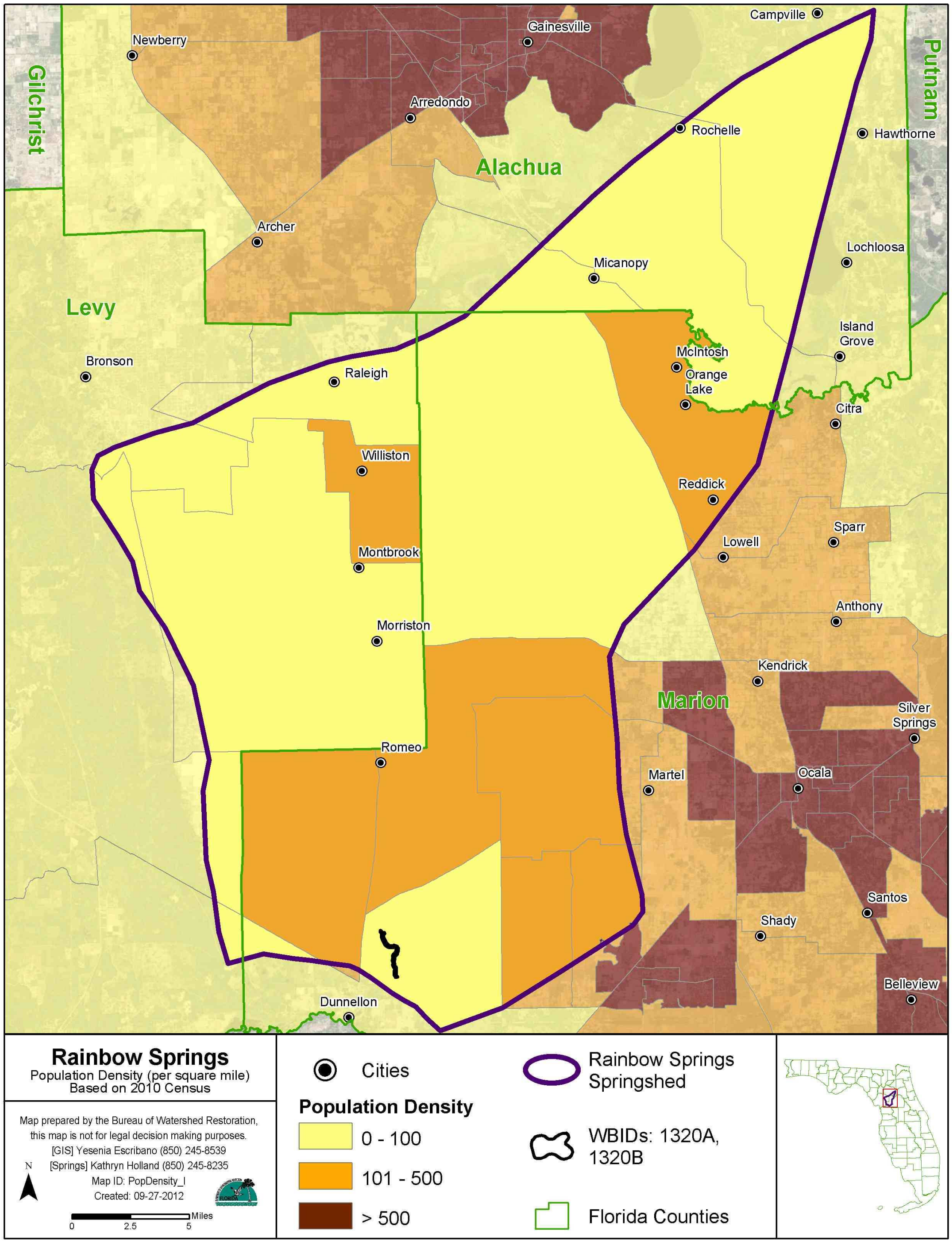



**Figure 4.2. Population Density in the Rainbow Springs Group and Rainbow Springs Group Run Springshed (based on 2010 Census)**

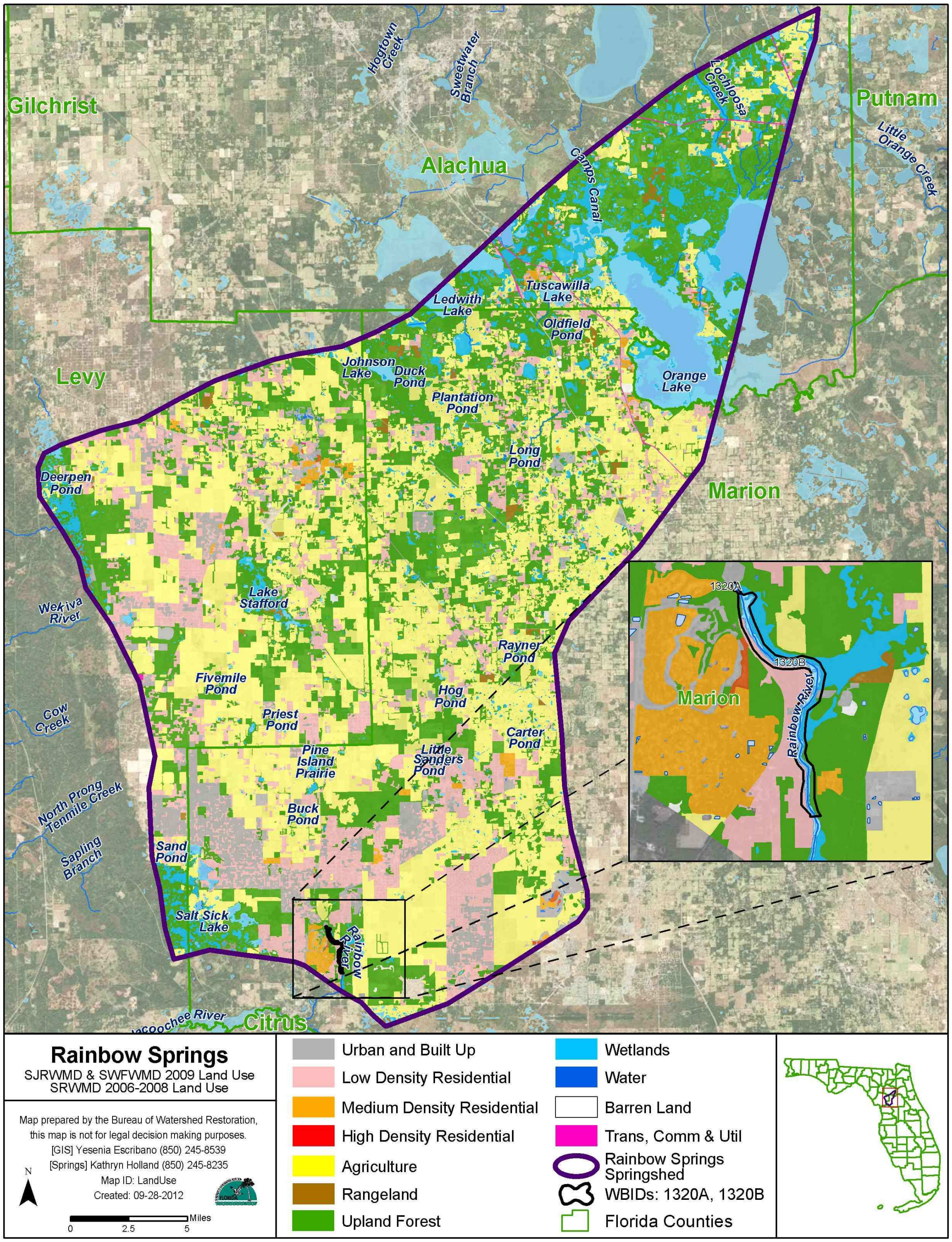



**Figure 4.3. Principal Land Uses in the Rainbow Springs Springshed Based on 2006–08 GIS Coverages**

## 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) are used for the disposal of domestic wastes 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). Under a low-density residential setting, nitrogen inputs by 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).

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). An estimated 8,279 of these OSTDS are in the Rainbow Springs springshed. Data for estimating septic tank numbers in the springshed are based on the FDOH statewide inventory of OSTDS GIS layer (FDOH 2010) (**Figure 4.4**). There is some level of uncertainty with these septic tank counts due to the methods used to derive them and the fact that all residential zoned properties have not been developed.

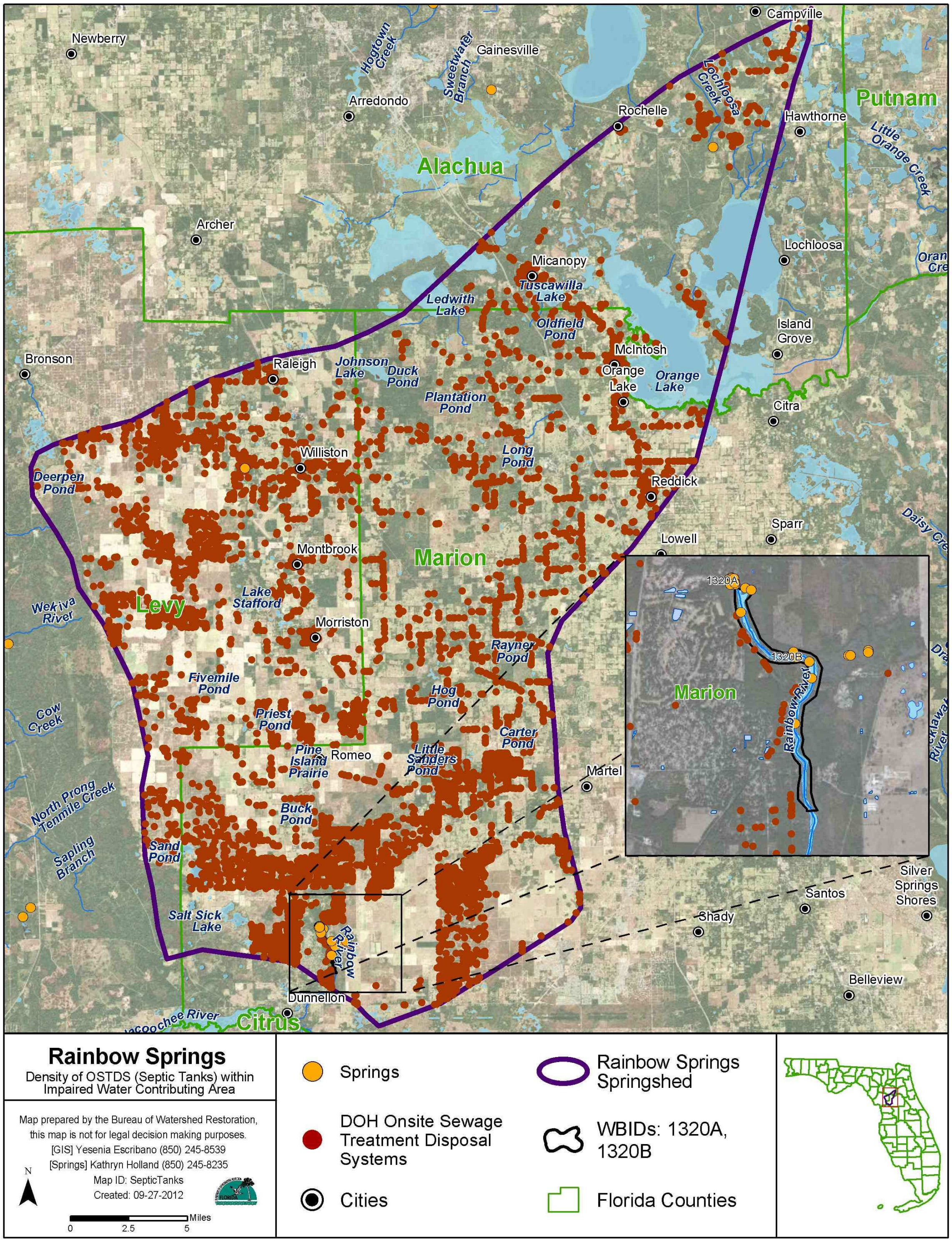



Figure 4.4. Density of OSTDS (Septic Tanks) in the Springshed (Marion County 2008; FDOH 2010)

### 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 (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 nitrate leaching from improperly stored manure can reach ground water and contribute to the loading of nitrate to ground water and receiving springs.

### Fertilizer and Atmospheric Deposition

A study of the Rainbow Springs catchment concluded that the predominant source of nitrate in the springs was fertilizer. Fertilizer, principally from improved pastures, was estimated to contribute about 46% of the total potential contribution of nitrogen to Rainbow Springs. In addition to the 200-plus horse farms, improved pastures, and hayfields, there are approximately 13 golf courses and 26 nurseries in the contributing area. **Table 4.3** summarizes the potential nitrogen inputs from fertilizer applied for these land uses as well as residential lawns. Atmospheric deposition was also identified as an important potential nitrogen source (~17%) (Jones *et al.* 1996).

### 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) |

# 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 under question 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 target nitrate concentration for Rainbow Springs Group and Rainbow Springs Group Run was established based on several lines of evidence, including (1) carrying out laboratory nutrient amendment bioassays; (2) comparing metabolic rates, specifically, the ecological efficiency of aquatic communities; (3) examining the ecological condition of algae and nutrients as described by Stevenson *et al.* (2007); and (4) examining the relationship between periphyton biomass and cell density and the nitrate concentration from studies conducted here and at other spring-dominated systems.

#### Laboratory Nutrient Amendment Bioassays

The nutrient amendment bioassay work was conducted by Cowell and Dawes (2004), who examined the required nitrate concentration in the Rainbow River to achieve a reduction of biomass of *Lyngbya wollei*. *L. wollei* is a nuisance blue-green benthic algal species that dominates the Rainbow River due to elevated nitrate concentrations. Using *Lyngbya* cultures incubated in a series of nitrate amendments, Cowell and Dawes (2004) found that at the end of the nutrient amendment experiments, both the 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. In addition, the experiment 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*.

#### Relationship between Ecological Efficiency and Nitrate Concentration

Wetland Solutions, Inc. (2007) studied the effects of nutrient concentrations on community metabolic rates in the Wekiva River, Rock Springs Run, Alexander Springs Creek, and Juniper Creek. The gross community primary production, community respiration, net primary production, and ecological efficiency were measured and examined. The community metabolic parameter shown to have a significant functional relationship with nutrient concentrations was ecological efficiency, which is defined as the quotient between the rate of gross primary productivity (GPP) and the incident photosynthetically active radiation (PAR) during a specified interval. It is an ecosystem-level property that estimates the overall efficiency of an aquatic ecosystem in using incident solar radiation.

**Figure 5.1** shows the correlation between ecological efficiency and nitrogen oxide (NOx, an equivalent term for nitrate) concentration. The target ecological efficiency defined using this method is 0.25 grams of oxygen per mole (g $O_2$/mol). Using the ecological efficiency nitrate concentration equation defined in **Figure 5.1**, the target nitrate concentration is 0.293 mg/L.

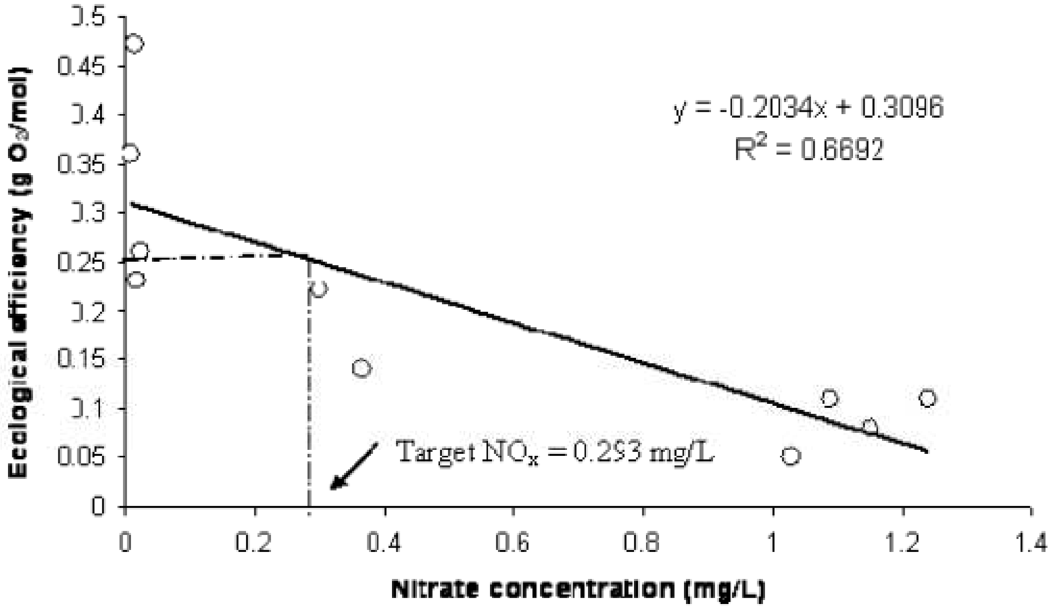



**Figure 5.1. Correlation between Ecological Efficiency and Nitrate Concentration in the Wekiva River, Rock Springs Run, Alexander Springs Creek, and Juniper Creek**

### Examining the Ecological Condition of Algae and Nutrients in Stevenson et al. (2007)

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

The study involved both field and laboratory components. In the field experiments, excessive growth and cover of *Vaucheria w*ere found at sites with nitrate concentrations at or above 0.454 mg/L. In the laboratory experiments, the taxa *L. wollei* and *Vaucheria* spp. were found to have saturating nitrate concentrations of 0.230 and 0.261 mg/L, respectively (Stevenson *et al.* 2007). The study covered 28 springs throughout Florida, including Rainbow Springs (**Figure 5.2**).

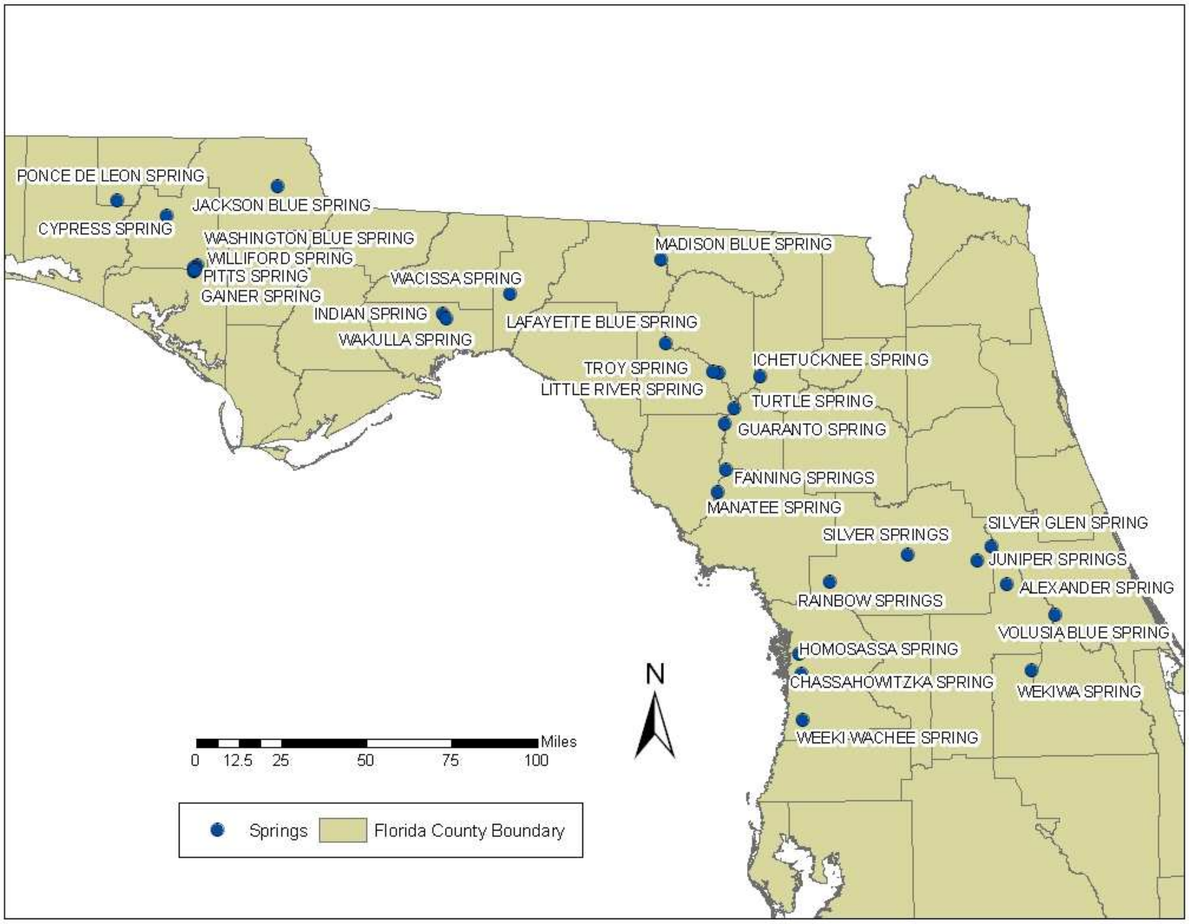



**Figure 5.2. Springs Included in Algal Growth Studies Conducted by Stevenson *et al.* (2007)**

### Relationship between Periphyton Biomass and Cell Density and Nitrate Concentration

The nitrate target suggested by the Rainbow River study was corroborated by the findings of Hornsby *et al.* (2000), who evaluated periphyton and water quality data collected from the Suwannee River and 2 tributaries, the Withlacoochee and Santa Fe Rivers. Much of the length of the Suwannee River was heavily influenced by spring inflow. Hornsby *et al.* 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 5.3**).

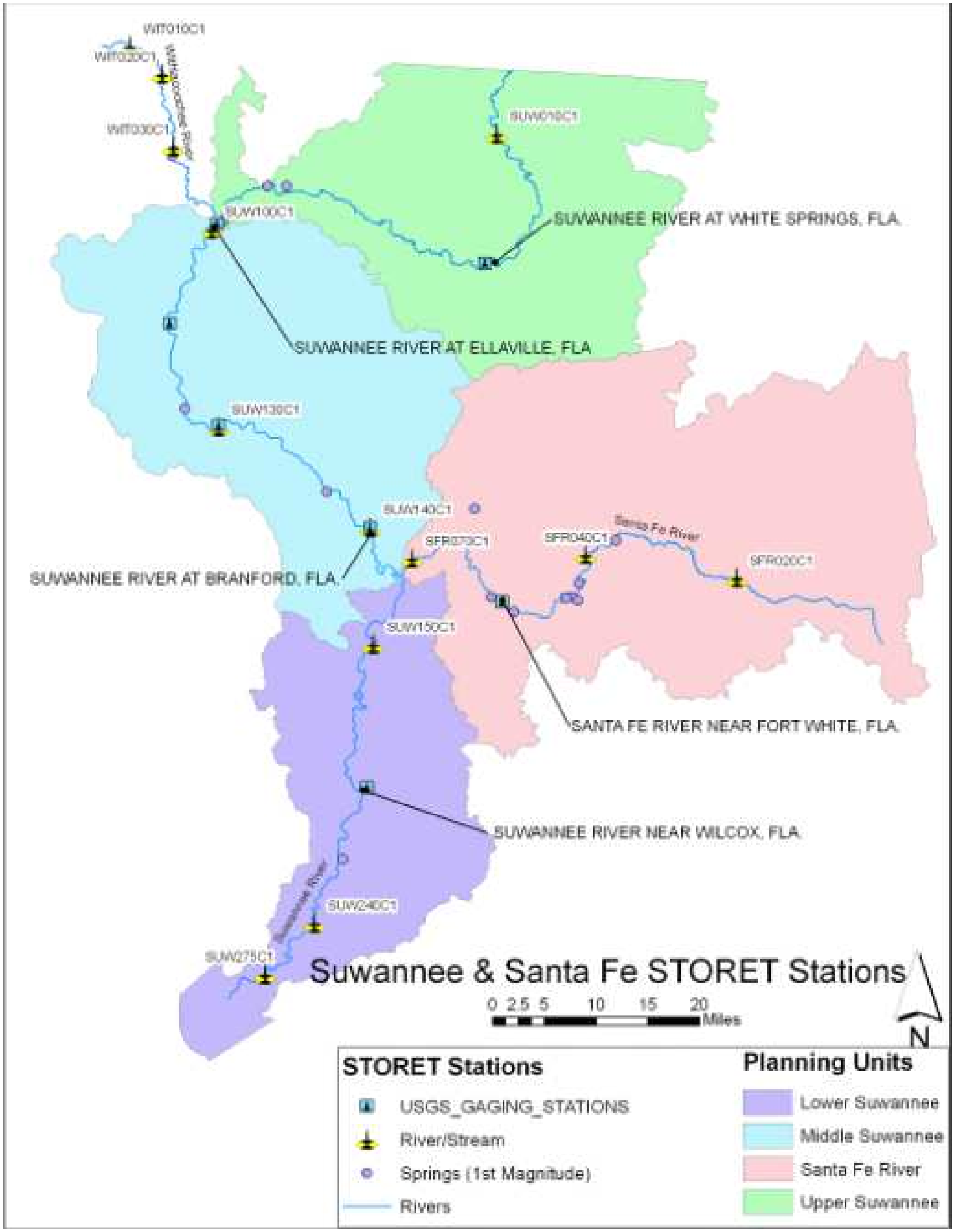



**Figure 5.3. Change-Point Study Sites within the Suwannee River System**

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 5.4** and **5.5**).

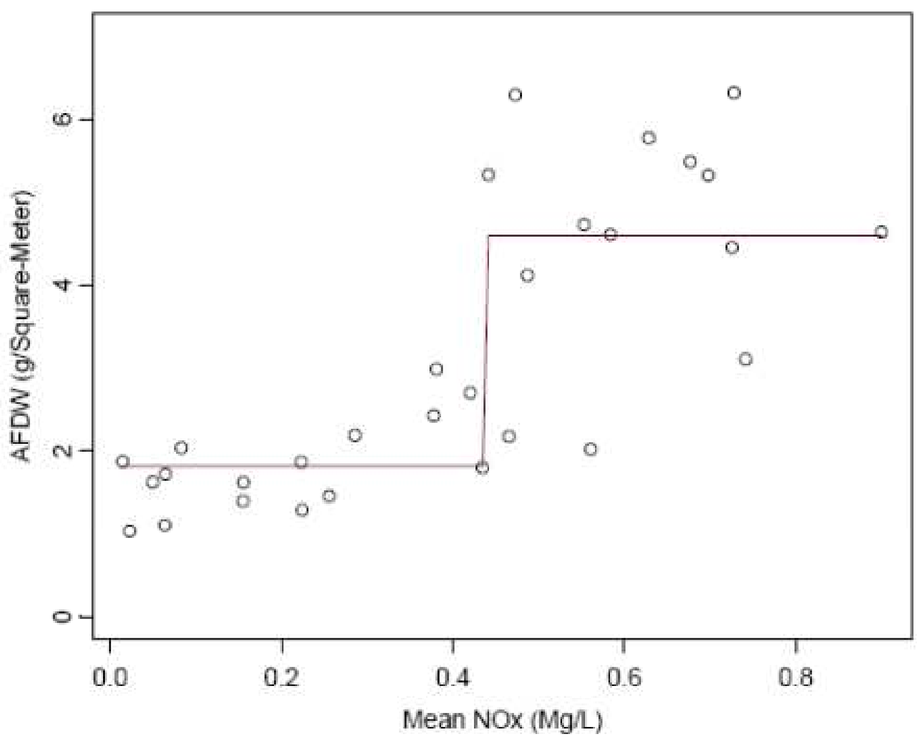



**Figure 5.4. Relationship Between Mean NOx Concentration and Mean Periphyton Biomass from 12 Sampling Sites in the Suwannee, Santa Fe, and Withlacoochee Rivers**

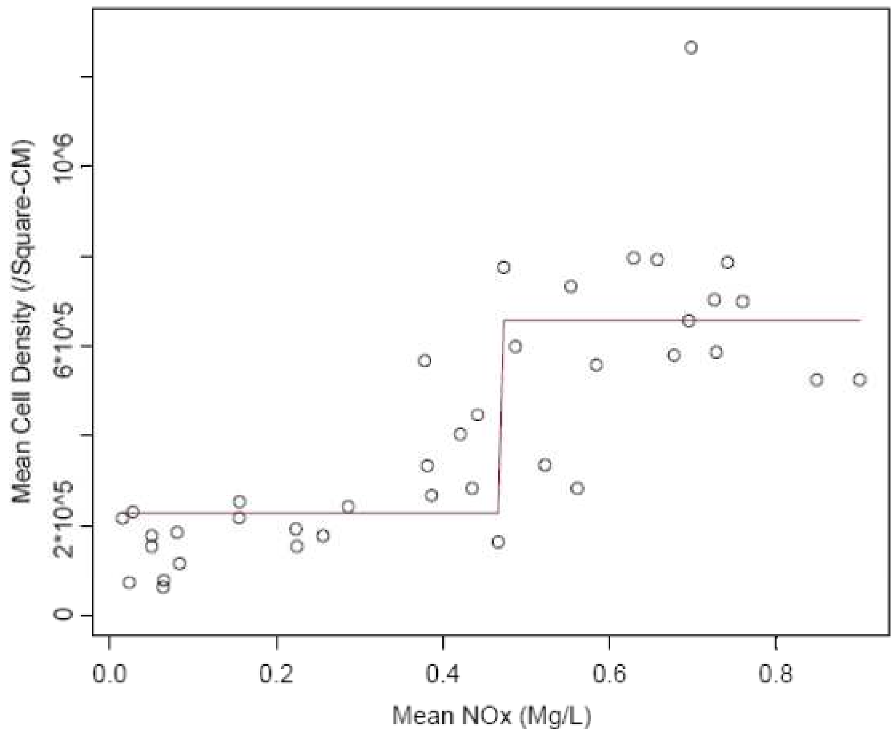



**Figure 5.5. Relationship Between Mean NOx Concentration and Mean Periphyton Cell Density from 12 Sampling Sites in the Suwannee, Santa Fe, and Withlacoochee Rivers**

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 per square centimeter (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 5.6**), 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 (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 provided a definitive conclusion that the change in periphyton was related to nitrate, the second part is finding the relationship of nitrate concentration to periphyton. The best relationship between nitrate and periphyton cell density is an exponential relationship, as shown in **Figure 5.7**. This relationship can be used to define a nitrate target that prevents change. The first approach to finding a target was using the change point of 0.441 mg/L to identify an equivalent cell density concentration relative to the central tendency (an exponential curve $R^2$=0.72) of the relationship. Once identified, the nitrate concentration prior to the change point can be identified by finding the equivalent upper 95% confidence interval, i.e., an $NO_3$ value of 0.38 mg/L.

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 5.8**), i.e., an $NO_3$ value of 0.33 mg/L.

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

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. An elevated pollutant concentration in the system alone does not necessarily constitute impairment as long as there is no negative response from the local aquatic flora or fauna.

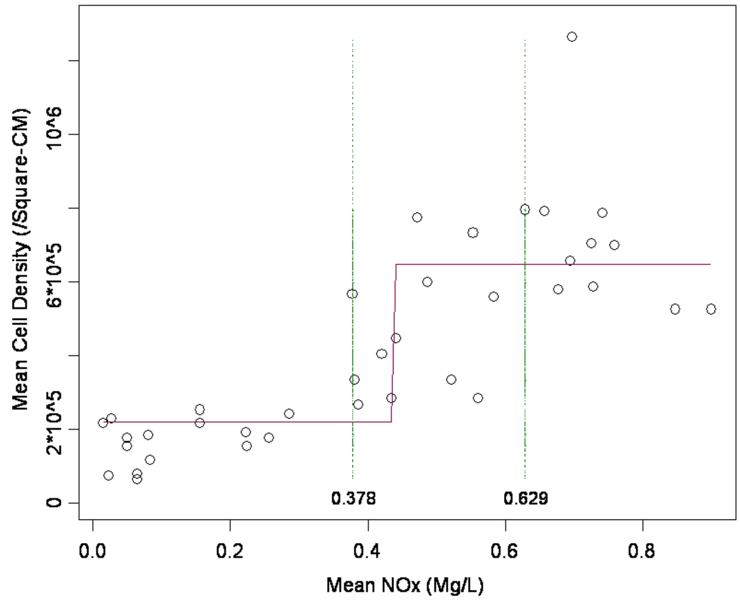



**Figure 5.6. Change-Point Analyses (the 95% Confidence Interval)**

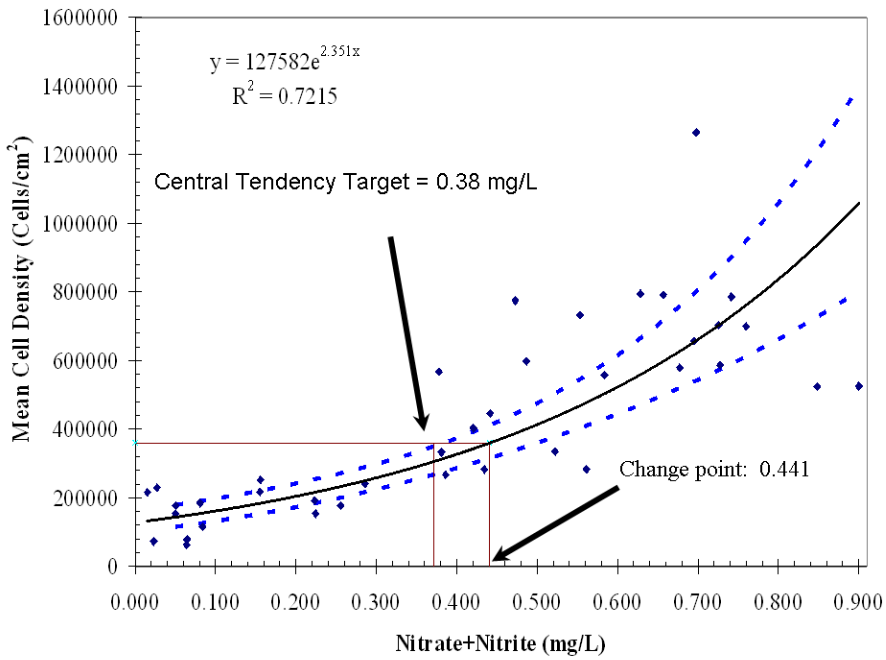



**Figure 5.7. Central Tendency and Upper 95% Confidence Interval Approach**

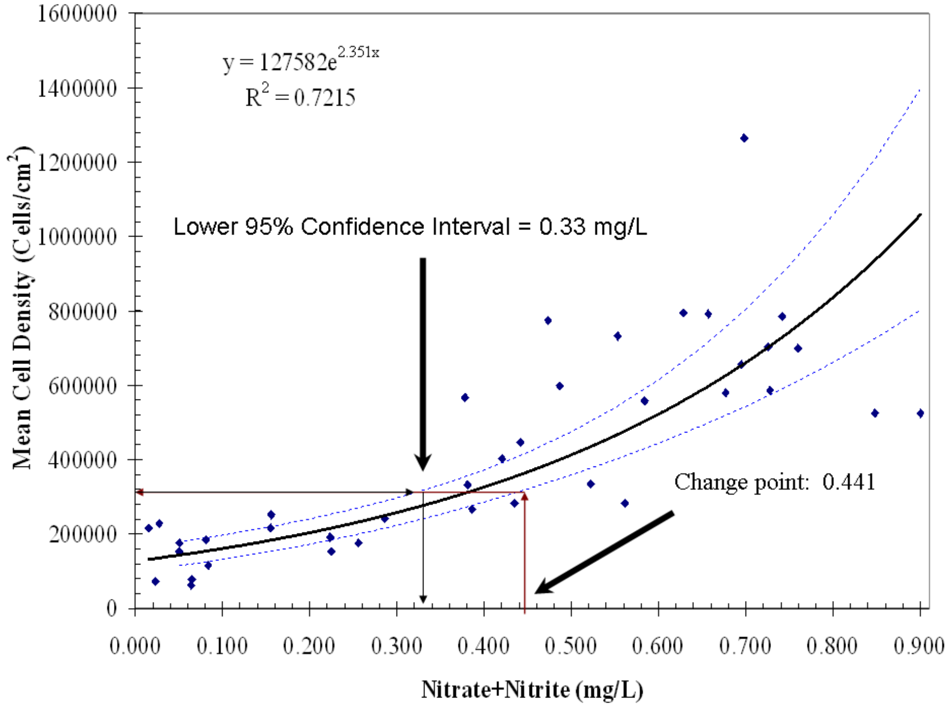



**Figure 5.8. Upper and Lower 95% Confidence Interval Approach**

Based on the information provided above, 0.35 mg/L nitrate is the target concentration that will not cause an imbalance in the aquatic flora or fauna in Rainbow Springs Group and Rainbow Springs Group Run. The reductions in $NO_3$ will reduce any pollutant impacts associated with the excessive growth of algae. The 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. In addition, the implementation of the TMDL for nutrients may result in improvements to the DO regime in the river by reducing the excessive growth of algae.

## 5.3 Setting the Monthly Average Concentration for Nitrate

After carefully reviewing all the above studies, the Department believes that establishing 0.35 mg/L nitrate (nutrients) as the TMDL for Rainbow Springs Group and Rainbow Springs Group Run as a monthly average is appropriate. This is mainly because the changes in aquatic vegetation biomass do not respond to the change of nutrient concentration instantaneously. Therefore, a short-term exceedance of the target concentration may not produce negative biological or ecological effects. The nitrate TMDL target obtained from the Suwannee River study was based on the correlation between 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 apparently suggested 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 *Lyngbya* 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.

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

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

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 1 data point for December for Rainbow Springs Group and only 3 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.

It has been proposed that there may be a correlation between long-term discharge reductions and increasing nitrate concentration. To evaluate this relationship, nitrate in the impaired waterbodies and discharge in the Rainbow River (USGS Station #02313100) were plotted for two periods: the entire period of record (1965–2010) and the period used for TMDL development (2000–10). **Figures 5.9a** and **5.9b**, respectively, show the results for each period. These plots indicate that there is no significant correlation between discharge and nitrate concentration for either period.

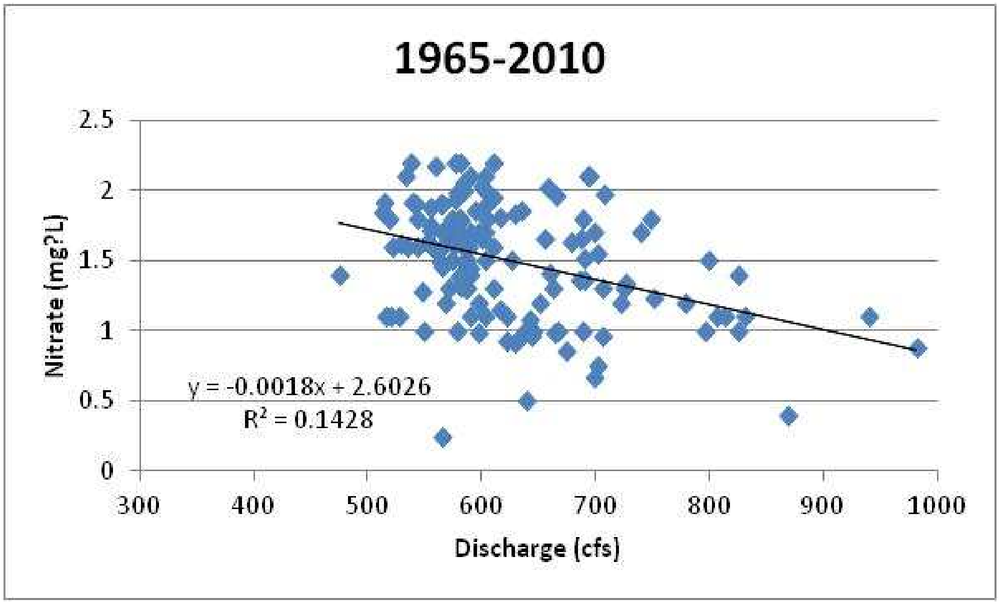



**Figure 5.9a. Relationship Between Discharge (USGS Station 02313100) and Nitrate Concentrations in the Impaired WBIDs, 1965–2010**

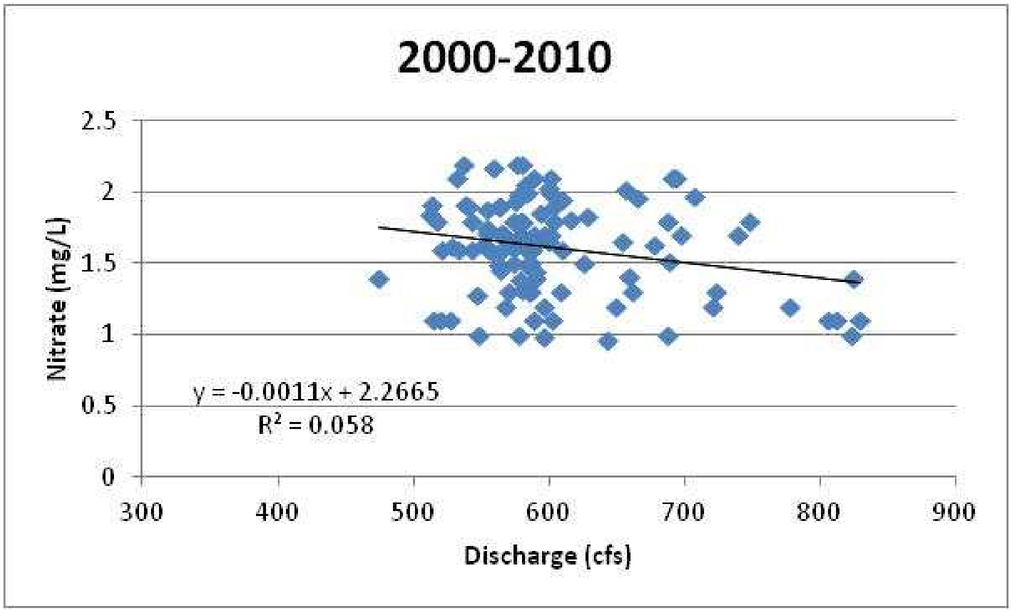



**Figure 5.9b. Relationship Between Discharge (USGS Station 02313100) and Nitrate Concentrations in the Impaired WBIDs, 2000–10**

## 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 targets for nitrate were established 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.

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

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

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

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

It should be noted that the various components of the revised TMDL equation may not sum up to the value of the TMDL because (1) the WLA for NPDES stormwater (if applicable) is typically based on the percent reduction needed for nonpoint sources and is also accounted for within the LA, and (2) TMDL components can be expressed in different terms (for example, the WLA for stormwater is typically expressed as a percent reduction, and the WLA for wastewater is typically expressed as mass per day).

WLAs for stormwater discharges are typically expressed as “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 nutrients and represents the loading the river can assimilate and maintain the biological criterion (**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[1] | 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 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 loads from the nonpoint source areas contributing to these impaired WBIDs need 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.

It should be noted that the LA also includes stormwater discharges to ground water. 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 are also included in the LA (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 receiving water.

## 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.

If the Department determines that a BMAP is needed to support the implementation of this TMDL, it 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.

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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**June-August, 2008**

# I. Background

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

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

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

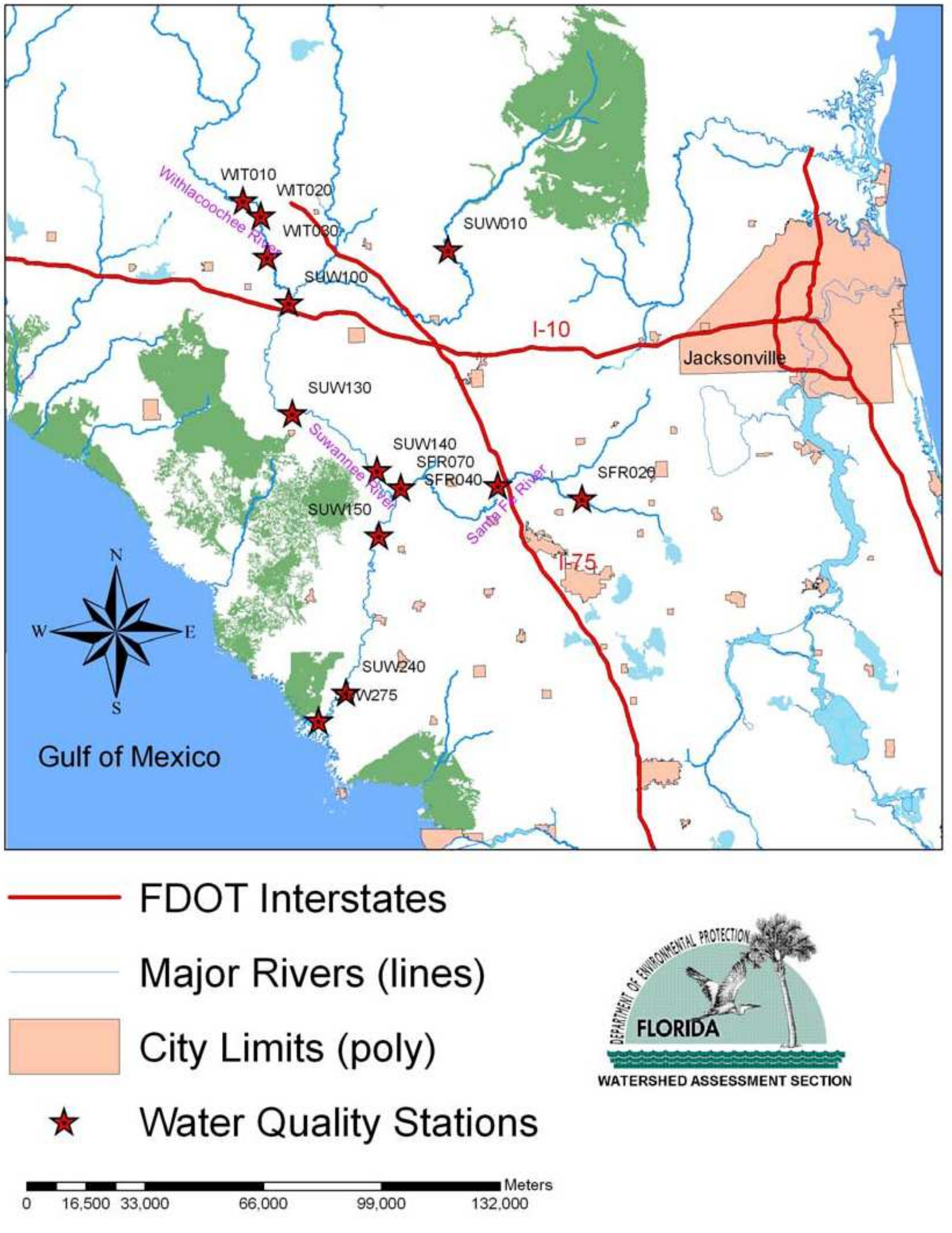


Figure 1. Locations of water quality stations from which measured nitrate and periphyton abundance were used for this analysis.

## II. The Detection Procedure

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

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

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

If there exits an integer *r* $(1 < r < n)$ that split the observations into two groups, $\{Y_1, \cdots, Y_r)$ and $\{Y_{r+1}, \cdots, Y_n)$, such that mean value $\mu_1$ of the first group is different from mean value $\mu_2$ of the second group, we define *r* as a change-point in the response variable. The procedure introduced in this report will detect whether such a change point exists or not. In other words, this procedure only detects a possible **level shift** of the response variable but not variance changes. If a level shift of the response variable is detected at *r* $(1 < r < n)$, the corresponding value $X_{r+1}$ is call a change point, i.e., the response variable $Y_{r+1}$ changes into a new level at $X_{r+1}$.

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

**Step 1**. Fit the linear regression model:

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

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

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

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

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

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

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

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

## III. Model Comparison

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

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

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i, \qquad i = 1, 2, \cdots, n. \qquad (3)$$

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:

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

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

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

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

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

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

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

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

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

# IV. Change Point Analysis of Suwannee River Algal Data

## 1. Mean Abundance (Cell Density) vs Mean NOx

### a). Change Point Analysis

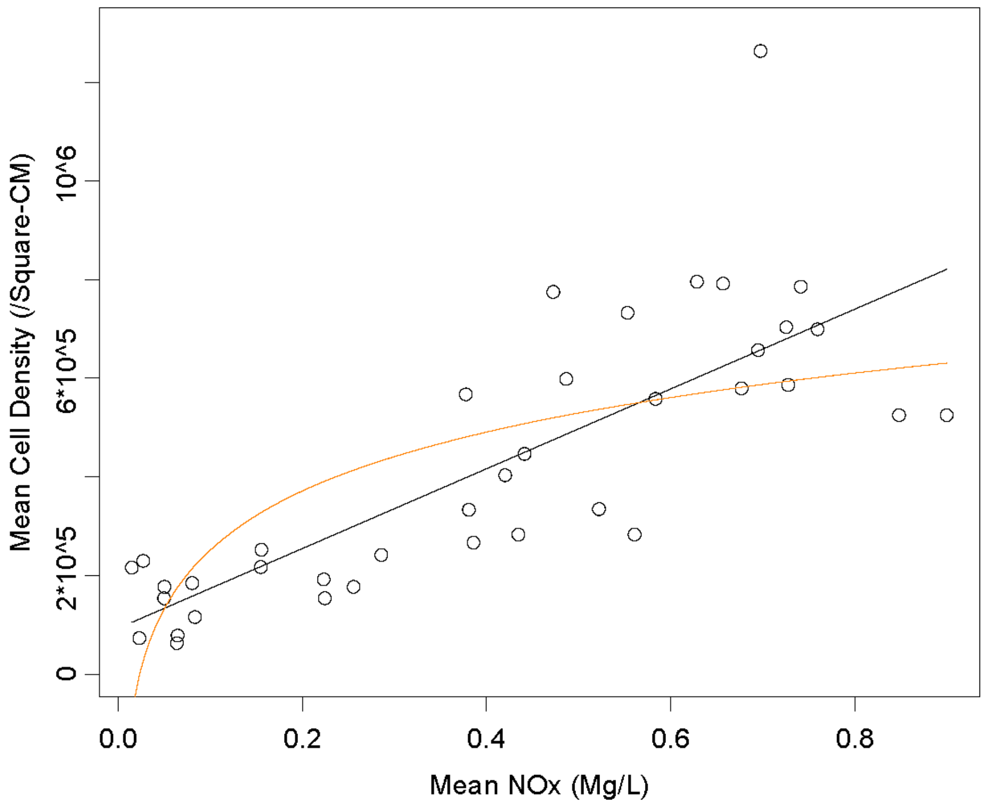
Table 1 presents the mean NOx and mean abundance data at stations along the Suwannee river and its two major tributaries (Withlacoochee and Santa Fe). The data were collected by the Suwannee River Water Management District (SRWMD).

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

## b). Model Comparison

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

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



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

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

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

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

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

**SBC Value: 923.3**

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

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

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

**SBC Value: 921.7**

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

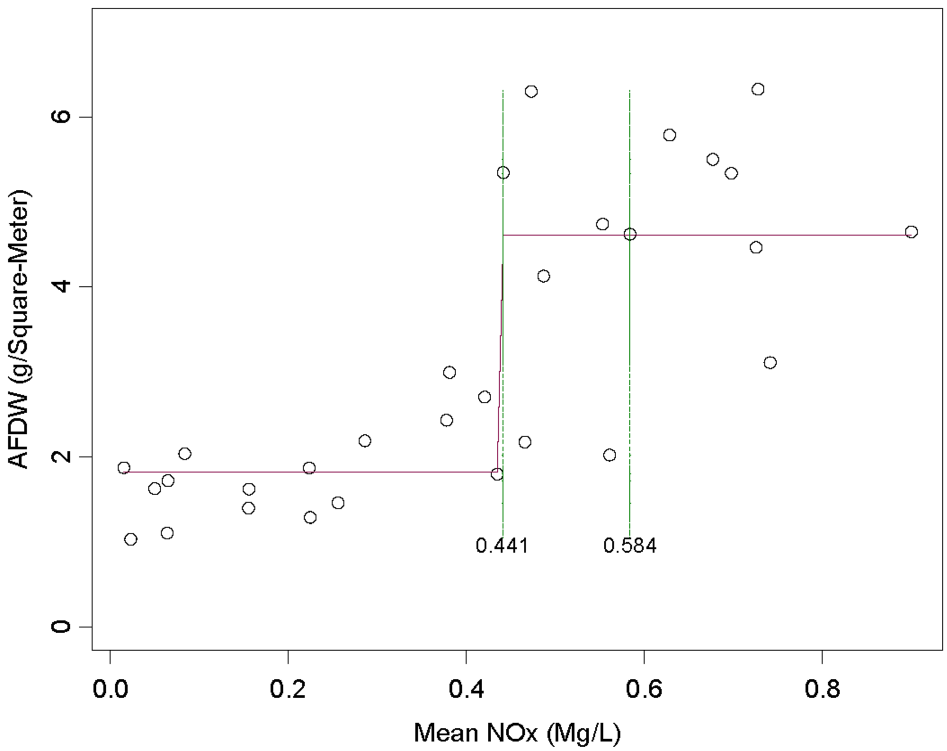
```
Coefficients:
                  Value  Std. Error    t value    Pr(>|t|)
(Intercept) 649141.0952  48888.2774    13.2781      0.0000
        MN1 172786.9495  28267.9784     6.1125      0.0000

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

**SBC Value: 933.1**

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

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

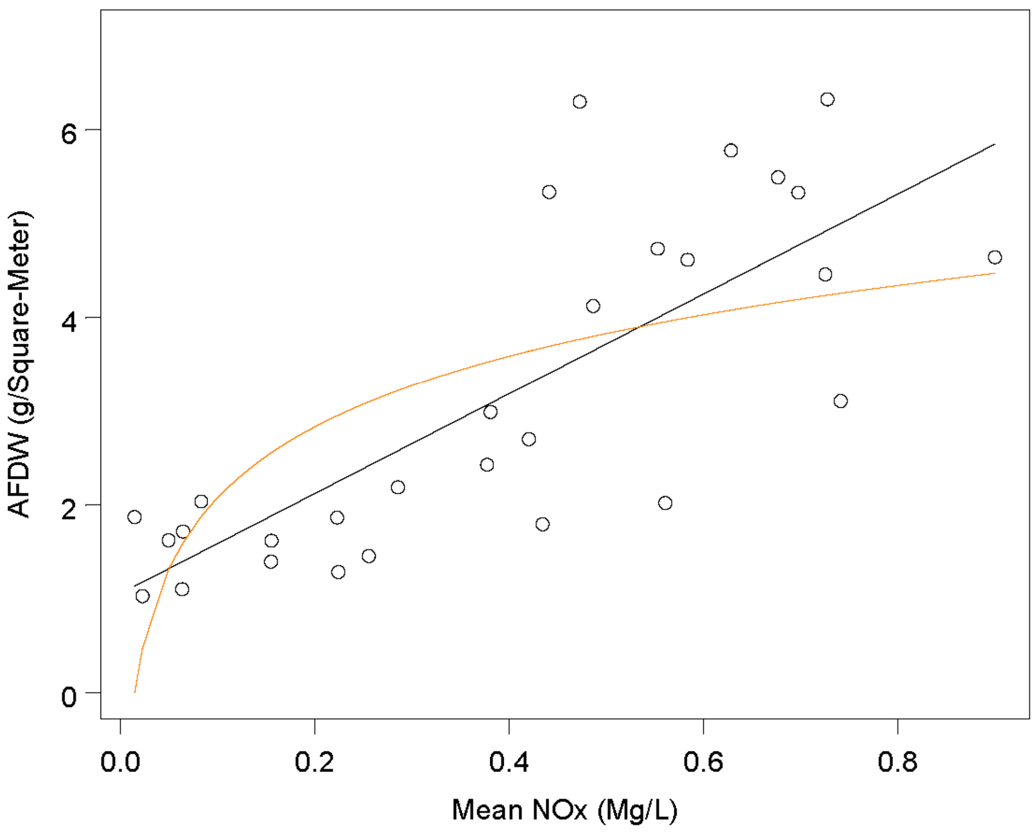
**The 95% confidence interval for the change point based on 1000 Bootstrapping samples is [0.441, 0.584] with Bootstrapping average estimate for the change point at NOx=0.464. There were no potential change points at the significance level of $\alpha = 0.05$ detected below NOx=0.441.**



## b). Model Comparison

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

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



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

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

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

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

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

**SBC Value: 1.29**

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

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

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

**SBC Value: 12.74**

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

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

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

**SBC Value: 22.04**

## 3. Summary and Conclusions

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

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

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

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

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

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