Draft Report
Santa Fe River and Springs Environmental Analysis

Phase 1 – Summary of Existing Environmental Data and Proposed Phase 2 Detailed River Health Evaluation

Prepared by

The Howard T. Odum Florida Springs Institute

Draft Report
Santa Fe River and Springs Environmental Analysis

Phase 1 – Summary of Existing Environmental Data and Proposed Phase 2 Detailed River Health Evaluation

Date

May 2017

Prepared by

The Howard T. Odum Florida Springs Institute

Table of Contents

Figures iv
Tables vi
Executive Summary 1
Section 1.0 Introduction 1
Section 2.0 Environmental Baseline 1
2.1 Physical Environment 1
2.1.1 Geography 1
2.1.2 Springshed 3
2.1.3 Land Use 5
2.2 Hydrology 10
2.2.1 Rainfall 10
2.2.2 River and Spring Discharge 10
2.2.3 Minimum Flow and Levels 12
2.3 Water Quality 12
2.3.1 Santa Fe River Focus Area FDEP Nutrient Study 38
2.4 Biology and Ecology 42
2.4 Human Use 45
2.5 Ginnie Springs System Ecosystem Assessment 46
2.5.1 Introduction 46
2.5.2 Spring Segment Area, Mean Depth, Volume, and Length 46
2.5.3 Flow Measurements 51
2.5.4 Light Attenuation Measurements 55
2.5.5 Water Quality Data 58
2.5.6 Fish Biomass 64
2.5.7 Vegetation Mapping 67
2.5.8 Ecosystem Metabolism 68
2.5.9 Ginnie Springs System Summary 71
2.6 FSI Synoptic Study 73
2.6.1 Underwater Light Transmission 79

2.6.2 Stream Discharge and Current Velocity 80
2.6.3 Secchi Disk Visibility 84
2.6.4 Water Quality 85
2.6.5 Nitrate Loads 92
2.6.6 Community Export 93
2.6.7 Summary of FSI Baseline Study 94

Section 3.0 Phase 2 and 3 Lower Santa Fe River and Springs Environmental Assessment Project Plan Scope 99

3.1 Project Objectives 99
3.2 Phase 2 Scope 100
Physical and Water Quality Data Collection 101
Physical Setting 101
Water Quality 102
Biological and Human Use Data Collection 102
Biological 102
Human Use 102
Task 3 – Monitoring Report 102
Task 4 – Interactive Map 103
3.3 Phase 3 Scope 103
3.4 Payment .... **Error! Bookmark not defined.**
Estimated Fee 103

Section 4.0 References 105

Table of Exhibits

Figures

Figure 1. Overview of the Upper and Lower Santa Fe River 1
Figure 2. Physiogeographic provinces of the Santa Fe River study area. (From White, 1970 and SDII, 2011) 2
Figure 3. Springsheds of the Santa Fe River (SDII, 2011) 4
Figure 4. 2010 Land use within the Lower Santa Fe River and Ichetucknee River surface water basins (SRWMD, 2013) 8
Figure 5. Land use within the Santa Fe River BMAP basin in 2008 (FDEP, 2012) 9
Figure 6. Annual rainfall averages in the Santa Fe River Springshed Basin (1903-2016) 11
Figure 7. Monthly average discharge of the Santa Fe River at Worthington Spring (USGS 02321500) 14
Figure 8. Monthly average discharge in the Santa Fe River near Fort White (USGS 02322500) 15
Figure 9. Monthly average discharge in the Ichetucknee River at US 27 (USGS 02322700) 16
Figure 10. Santa Fe River flow-duration curves and SRWMD critical flows near Fort White from 1927 to 2016 (USGS 02322500) 17
Figure 11. Ichetucknee River flow-duration curves at US Hwy 27 from 1917 to 2016 (USGS 02322700) 18
Figure 12. Comparison between annual rainfall and discharge from the Santa Fe River near Fort White from 1900 to 2016 (USGS 02322500 Santa Fe River near Fort White) 19
Figure 13. Period of record NOx-N data for the Santa Fe River at Worthington Springs 26
Figure 14. Period of record NOx-N data for the Santa Fe River at O'Leno State Park 27
Figure 15. Period of record NOx-N data for Hornsby Spring 28
Figure 16. Period of record NOx-N data for the Santa Fe River at U.S. Hwy 441 29
Figure 17. Period of record NOx-N data for Columbia Spring 30
Figure 18. Period of record NOx-N data for Poe Spring 31
Figure 19. Period of record NOx-N data for Gilchrist Blue Spring 32
Figure 20. Period of record NOx-N data for Ginnie Spring 33
Figure 21. Period of record NOx-N data for the Santa Fe River at U.S. Hwy 47 34
Figure 22. Period of record NOx-N data for the Ichetucknee River at U.S. Hwy 27 35
Figure 23. Period of record NOx-N data for the Santa Fe River at U.S. Hwy 129 36
Figure 24. Map of Santa Fe FDEP Nutrient Study stations 39
Figure 25. Santa Fe FDEP Nutrient Study average NOx-N (mg/L) by station (January 2013 – September 2016) 40

Figure 26. Santa Fe FDEP Nutrient Study average NOx-N (mg/L) times series (January 2013 – September 2016) ... 41

Figure 27. Groundwater travel times in the Santa Fe River Basin (AMEC, 2013). ... 43

Figure 28. Study segments of the Lower Santa Fe River conducted by Johnston et al. (2016) ... 45

Figure 29. Ginnie Springs property location ... 47

Figure 30. Ginnie Springs location map and sampling stations ... 48

Figure 31. Deer Spring and Twin Spring bathymetric maps ... 49

Figure 32. Ginnie and Dogwood Springs bathymetric maps ... 50

Figure 33. Devil Springs System bathymetric map ... 51

Figure 34. Time series of Santa Fe River stage and WSI flow sampling dates (USGS data) ... 53

Figure 35. SRWMD/USGS flow data at Ginnie Spring (Station ID 02322400) with WSI estimates ... 54

Figure 36. Flows for the Ginnie Springs Outdoors property (data provided by KES for 1988 and 1989) ... 55

Figure 37. Percent PAR transmittance (@ 1 meter) within Florida springs ... 57

Figure 38. Percent PAR transmittance (@ 1 meter) within spring runs ... 57

Figure 39. Average nitrate-nitrogen concentrations in Florida springs ... 63

Figure 40. Comparison of the diversity of fish species observed at each spring in the Ginnie Springs Group ... 66

Figure 41. Ginnie Springs Group fish density and biomass compared to other Florida springs ... 67

Figure 42. Comparison of Ginnie Springs Group ecosystem productivity and photosynthetic efficiency to other Florida springs ... 70

Figure 43. Gross primary productivity efficiency versus discharge for the Ginnie Springs Group (red symbols) and other Florida springs ... 71

Figure 44. Santa Fe River and Ichetucknee River and springs. ... 74

Figure 45. Upper Santa Fe River Segment 1 monitoring station locations ... 75

Figure 46. Lower Santa Fe River Segment 2 monitoring station locations ... 76

Figure 47. Lower Santa Fe River Segment 3 monitoring station locations ... 77

Figure 48. Lower Santa Fe River Segment 4 and the Ichetucknee River monitoring station locations ... 78

Figure 49. PAR percent transmittance (@ 1m) by Santa Fe River and Springs stations (October - December 2016) ... 81

Figure 50. PAR Diffuse Attenuation by Santa Fe River and Springs stations (October - December 2016) ... 82

Figure 51. Santa Fe River flow measurements (October – November 2016) ... 83

Figure 52. Secchi disk (m) measurements in the Santa Fe River and springs (October - December 2016) 85

Figure 53. Dissolved oxygen (mg/L) in the Santa Fe River, Ichetucknee River, and associated springs (October - December 2016) 87

Figure 54. Hydrogen ion concentration (pH) in the Santa Fe River, Ichetucknee River, and associated springs (October - December 2016) 88

Figure 55. Specific conductance in the Santa Fe River, Ichetucknee River, and associated springs (October - December 2016) 89

Figure 56. Water temperature (degC) in the Santa Fe River, Ichetucknee River, and associated springs (October - December 2016) 90

Figure 57. Nitrate+Nitrite Nitrogen (mg/L) in the Santa Fe River, Ichetucknee River, and associated springs (October - December 2016) 91

Figure 58. Total phosphorus (mg/L) in the Santa Fe River, Ichetucknee River, and associated springs (October - December 2016) 92

Figure 59. Schematic of the Santa Fe for NOx-N (tons/yr) – October – December 2016 96

Tables

Table 1. Land use within the Lower Santa Fe River and Ichetucknee River surface water basins in the 1970s, 1988, and 2010 (SRWMD, 2013) 6

Table 2. Land use classifications in the Santa Fe River Basin in 2008 (FDEP, 2012) 7

Table 3. Santa Fe River and springs discharge (cfs) period of record 13

Table 4. Santa Fe River Segment 1 (Worthington Springs at SR 121 to O'Leno State Park Santa Fe River Sink) period of record water quality summary 21

Table 5. Santa Fe River Segment 2 (Santa Fe River Rise to U.S. Hwy 27) period of record water quality summary 22

Table 6. Santa Fe River Segment 3 (U.S. Hwy 27 to U.S. Hwy 47) period of record water quality summary 23

Table 7. Santa Fe River Segment 4 (U.S. Hwy 47 to Suwannee River confluence) period of record water quality summary 24

Table 8. Ichetucknee River (Main Boil to Santa Fe River confluence) stations period of record water quality summary 25

Table 9. Springs discharge measured at the Ginnie Springs Group by WSI the 2012 and 2013 sampling events 52

Table 10. Average Light Attenuation Measurements at Sampling Stations 56

Table 11. Data sonde water quality summary for Summer 2012 deployments 59

Table 12. Data sonde summary for Winter and Spring 2013 deployments 60

Table 13. Water quality summary data for spring stations and the Santa Fe River (July – May 2013) 62

Table 14. SRWMD water quality data at Ginnie Spring (November 1997 – July 2011) 64

Table 15. Ginnie Springs Group fish biomass and counts 65

Table 16. Observed plant species present during sampling events 68

Table 17. Santa Fe River and springs monitoring stations 79

Table 18. Santa Fe River flow measurements 83

Table 19. Secchi disk (m) measurements in the Santa Fe River and Lower Ichetucknee River (October – December 2016) 84

Table 20. Estimated nitrate+nitrite nitrogen concentrations and loads for the Santa Fe River and springs (October - December 2016) 93

Table 21. Santa Fe River and Lower Ichetucknee River particulate export 93

Table 22. NOx-N (tons/yr) on the Santa Fe River by decade – 1980 - present 97

Table 23 – Estimated labor and expenses for Phase 2 and 3 104

Executive Summary

The Santa Fe River is an Outstanding Florida Water and home to over 60 named springs. The River provides essential habitat for a wide diversity and abundance of flora and fauna, and is a major contributor to the economic vitality of the surrounding areas. However, the Santa Fe River and springs are not immune to the negative impacts being witnessed in the 1,000+ artesian springs throughout North and Central Florida. The environmental health of the region's rivers and springs is declining due to a variety of stressors, including reduced discharge, increased nitrate-nitrogen levels, excessive recreation, aquatic plant management activities, and structural alterations. These changes result in a shifting ecological baseline for the rivers and springs.

The groundwater basin feeding the Santa Fe River springs has lost about 600 mi^2 or 36% over the past 70 years. Because of this reduced recharge area, average flows in the river and springs have declined by more than 30%. Reduced flows have been accompanied by elevated nitrate nitrogen, well above the numeric nutrient standard intended to prevent ecological impairment due to excessive nutrients. In response to the combined effects of these two stressors and others, yet undocumented, much of the native submerged aquatic vegetation formerly prevalent in the springs and river is now absent, and has been replaced by massive growths of nuisance filamentous algae. Ecosystem productivity and the fish and wildlife populations formerly supported in the river, have apparently declined because of these impairments.

In response to the lack of a holistic and coherent plan for restoring the Santa Fe River and feeder springs, the Florida Springs Institute and partners have prepared this Phase 1 Baseline Report. This document provides a summary of existing studies and data relevant to the Santa Fe River and springs as they are today. Based on this compilation of available information, this document also includes a scope of services for Phase 2, a comprehensive, multi-year monitoring program to fill existing data gaps, evaluate the environmental health of the entire river and springs aquatic ecosystem, and to culminate in a Phase 3 management plan and road map for recovery. Completion of the proposed Phase 2 effort will require the combined resources of the state government and local stakeholders to support an integrated monitoring effort.

Section 1.0 Introduction

The Santa Fe River is an Outstanding Florida Water and home to over 60 named springs. The River provides essential habitat for a wide diversity and abundance of flora and fauna, and is a major contributor to the economic vitality of the surrounding areas. However, the Santa Fe River and springs are not immune to the negative impacts being witnessed in the 1,000+ artesian springs throughout North and Central Florida. The environmental health of the region's rivers and springs is declining by every measure due to a variety of stressors, including reduced discharge, increased nitrate-nitrogen levels, excessive recreation, aquatic plant management activities, and structural alterations. These changes result in a shifting ecological baseline for the rivers and springs.

Santa Fe River and springs restoration is the focus of the State of Florida and several non-governmental organizations, including Our Santa Fe River, Inc., the Ichetucknee Alliance, the Suwannee/St. Johns Chapter of the Sierra Club, and the Howard T. Odum Florida Springs Institute (FSI). As these groups work towards their shared goal of comprehensive restoration of the Santa Fe River and springs, there is often little historic baseline data available to assess recovery or continuing decline. The Santa Fe River and springs have been the focus of a variety of disjointed studies in recent decades. However, there is still much to be understood concerning the environmental health of the river and springs, regarding the complex karst topography of the area, human use and land use dynamics, their ecology and biology, chemistry, and more. While the river and springs have been visibly declining in health for decades, there is little empirical data available to determine cause-and-effect relationships needed to establish a more productive management scheme. Additionally, continued in-depth monitoring of the system will increase the likelihood that any increasing negative damages occurring will be caught before it is irreparable.

This document provides a Phase 1 summary of existing studies and data relevant to the Santa Fe River and springs as they are today. Based on this compilation of available information, this document provides a Phase 2 scope for filling data gaps, evaluating the environmental health of the entire river and springs aquatic ecosystem, and providing a Phase 3 management plan and road map for recovery.

The Santa Fe River and its associated springs from Worthington Springs in Union County to the Santa Fe River's confluence with the Suwannee River is the focus of this report (Figure 1). The Howard T. Odum Florida Springs Institute (FSI) with partial funding from Our Santa Fe River, Inc., prepared this Phase 1 evaluation of the river and springs.

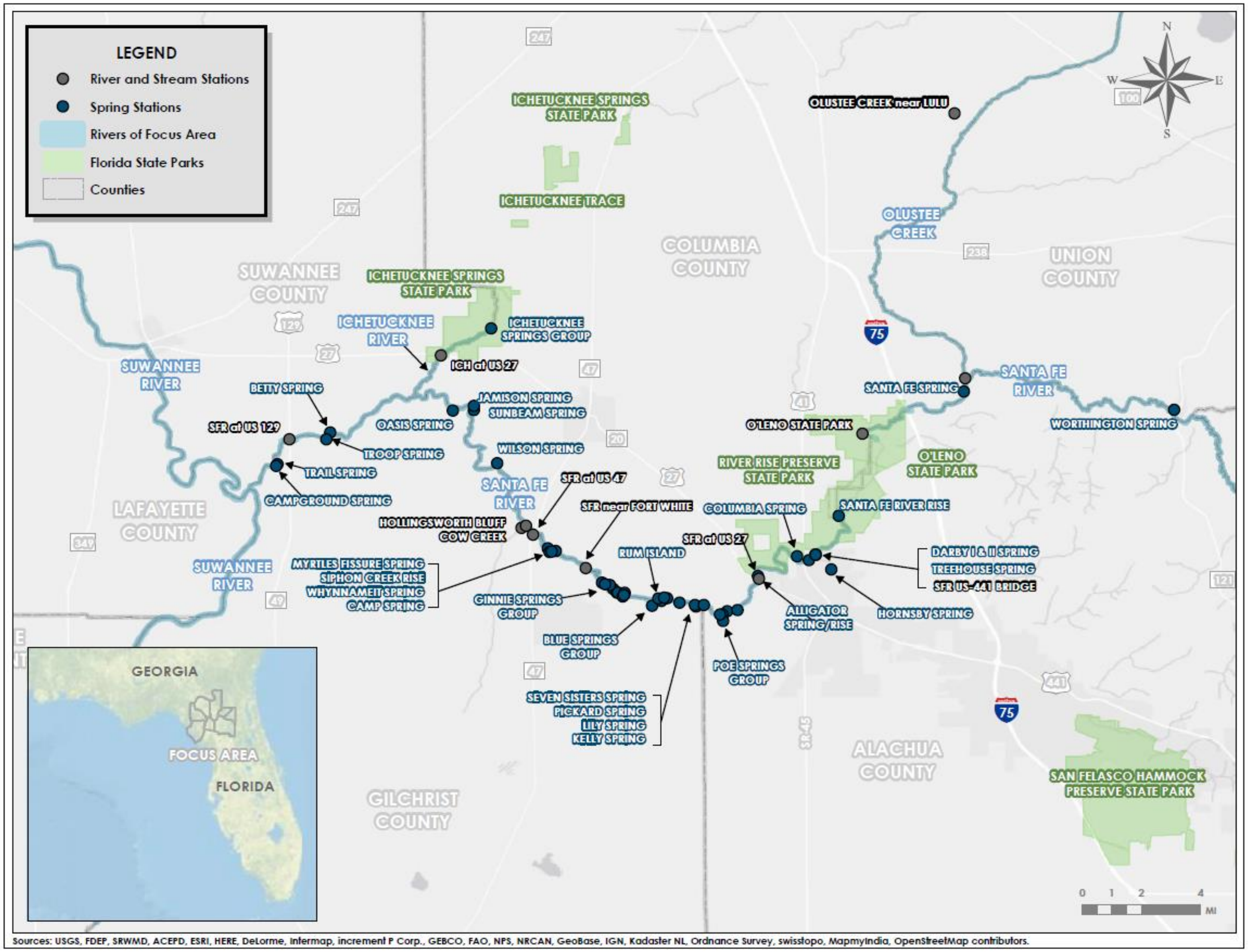


Figure 1. Overview of the Upper and Lower Santa Fe River

Section 2.0 Environmental Baseline

2.1 Physical Environment

2.1.1 Geography

The Santa Fe River is a second-order tributary that flows from east to west into the Suwannee River. The Santa Fe River is about 75 miles long and has a surface watershed of about 1,380 square miles. The river divides naturally into two sections: the Upper Santa Fe River, extending from Lake Santa Fe downstream to O'Leno State Park, and the Lower Santa Fe River, starting at River Rise Preserve State Park to its confluence with the Suwannee River.

The Santa Fe Rivers' major inflow contributions are from three tributaries – New River, Olustee Creek, and the Ichetucknee River, and from numerous springs, generally located downstream from Olustee Creek. Only two significant springs, Worthington Spring and Santa Fe Spring, historically fed the Upper Santa Fe River. The River Rise downstream of the Santa Fe River Sink located in O'Leno State Park is the largest individual spring along the Santa Fe River, delivering the entire surface water flow of the river under the natural land bridge in O'Leno State Park, as well as considerable clear, groundwater inflows from the eastern portion of the Santa Fe River Springshed.

Soil permeability and confinement of the aquifer distinguish the Upper Santa Fe River from the Lower Santa Fe River. The watershed of the Upper Santa Fe River is underlain by up to 100 feet of low permeability soils, which confine the Floridan Aquifer System below. The primary water source feeding the Upper Santa Fe River is surface runoff, much of which filters through a floodplain swamp, imparting organic color (tannins) from the peat substrate. The primary water source to the springs that provides up to 80% of the Santa Fe River's flows is the groundwater spring inflows from the Upper Floridan Aquifer.

There are five physiographic provinces in the region (Figure 2) that gives the Santa Fe River its features; Gulf Coastal Lowlands, Bell Ridge and Waccasassa Flats, High Springs Gap, Western Valley, and the Northern Highlands (White, 1970; SDII, 2011).

The Northern Highlands are a high plateau with little karst, large areas of low soil permeability, and aquifer confinement. The Upper Santa Fe River begins in the Northern Highlands at Lake Santa Fe, Little Lake Santa Fe, and the Santa Fe Swamp (Nordlie, 1990; Smock and Gilinsky, 1992; Johnston et al., 2016). The Western Valley is a low valley that is situated between the Northern Highlands and the High Springs Gap and is composed of a karst plain, sandy soils, and sinkholes. It is also known as the Newberry Plain in Alachua County.

The transitional boundary of the Upper and Lower Santa Fe River occurs between the Northern Highlands and the Western Valley/ Gulf Coastal Lowlands and is known as the Cody Scarp (Figure 2) (Puri and Vernon; 1964; White, 1970; Upchurch and Lawrence, 1984; Upchurch, 2002, 2007; SDII, 2011). This transition marks a distinctive change between the confined (in the Northern Highlands) and the unconfined aquifer typical of the Lower Santa Fe River. At this geologic transition, the entire flow of the Santa Fe River goes underground at River Sink in O'Leno State Park. The river's water flows underground for approximately three miles through subterranean caves and returns to the surface at River Rise in River Rise Preserve State Park.

During periods of low river flow the water discharging from the Santa Fe River Rise is comprised of only 4% of the River Sink water while the other 96% is estimated to come from other sources and in particular the Old Bellamy Cave system to the east of the River Rise. However, during intermediate discharge 73% of the River Rise flow originates from the water contributed at the River Sink (Martin and Screaton, 2001; SDII, 2011).

The following areas that encompass the Lower Santa Fe River are the High Springs Gap, the Bell Ridge, and the Gulf Coastal Lowlands. The Lower Santa Fe River is dominated by surficial limestone karst geology, very little confinement of the underlying Floridan Aquifer System, highly permeable soils, and generally drier plant communities. The Santa Fe Karst Plain is characterized by porous limestone formations that comprise the Floridan Aquifer System. Groundwater from at least 36 springs from the Floridan Aquifer (e.g. River Rise, Treehouse, Hornsby, Columbia, Poe, Gilchrist Blue, Ginnie, Rum Island, etc.) discharge into the Santa Fe River after the river emerges. Further downstream, the Ichetucknee River - a spring-fed river—discharges into the Lower Santa Fe River. The Bell Ridge is an outlier in this area, however, as it bisects Gilchrist county from the north to the south. This feature is a dune ridge that occurs atop the Waccasassa Flats which are characterized by sandy, clayey soils of low permeability (Col et al., 1997; SDII, 2011).

Karst features comprised of sinkholes, springs, estavelles, suckholes, and swallets, illustrate the interdependence of surface and groundwater along the Lower Santa Fe River. A study done by Karst Environmental Services, Inc. (2007), mapped many interdependent karst features along the Lower Santa Fe River which further solidify the complex nature of the Santa Fe River system.

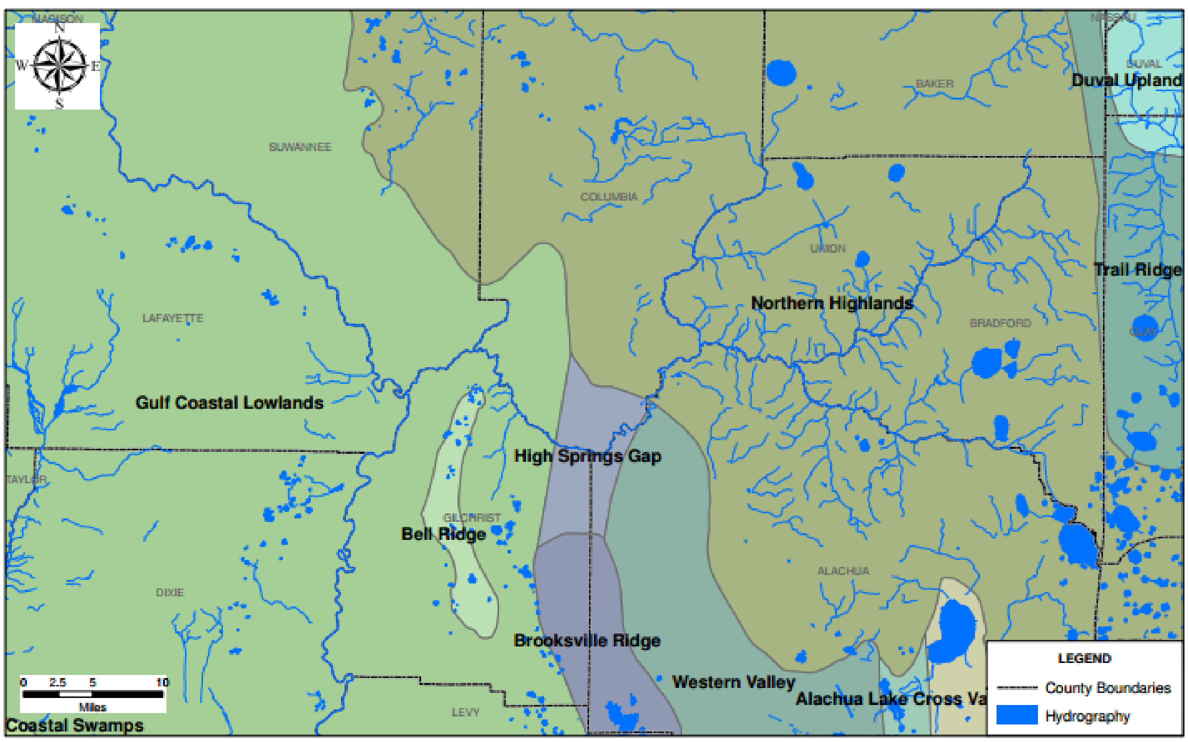


Figure 2. Physiogeographic provinces of the Santa Fe River study area. (From White, 1970 and SDII, 2011)

2.1.2 Springshed

According to historic and recent groundwater level data and maps of the potentiometric surface (Florida Springs Institute, 2012), about 70+ years ago, the Santa Fe River springshed included an estimated 1,775 square miles. By 2008, the Santa Fe River springshed had declined considerably to about 1,114 square miles. These estimates indicate that as of 2008, there had been an estimated 37% reduction in the size of the springshed that supplies water to the Santa Fe River Springs. The reduced springshed area is attributed primarily to groundwater pumping from municipal wells, agricultural wells, and private wells. Daily and seasonal rainfall, combined with anthropogenic groundwater withdrawals that remove water from the Floridan Aquifer, lower the level of the aquifer and diminish the flow of water from the Santa Fe River Springs.

In 2011, SDII Global Corporation updated the springshed delineation of the Santa Fe River for the Alachua County Environmental Protection Department. Delineated were eight individual, overlapping springsheds (Figure 3). The springsheds were developed for groups of springs rather than individual springs due to the interconnectedness of the springs and the difficulty in delineating a true divide between springsheds. The recharge area found for the springsheds does not entirely correlate with the appropriate amount of land that would commonly be needed to fully account for the discharge leaving the springs (1 cfs per mi^2) (Faulkner, 1973). The hypothesized and generally verified complex karst conduit system has been confirmed through numerous cave studies (Wilson and Skiles, 1988; Kincaid, 1998; Martin and Screaton, 2001; Butt et al., 2007, 2015), and in some way accounts for the observed discrepancies in the mapped springsheds.

The Santa Fe River Rise was found to have connections to Sweetwater Lake which is located between the Santa Fe River Sink and the River Rise. Additional groundwater inputs originate from the Old Bellamy cave system to the east and from the northwestern boundary of the springshed as far as lower Olustee Creek (Butt et al., 2007). Travel times in this cave system were estimated to average 2.7 miles per day (Hisert, 1994).

The Hornsby Spring and Treehouse Spring springshed was clustered to include Columbia Spring, Darby Spring, and a few other unnamed springs in the area. Butt et al. (2005) found a direct link from Mill Creek Sink and Lee Sink to Hornsby Spring in Alachua County. Dye-trace travel times from Mill Creek to Hornsby Spring were 12-13 days, and 28-31 days from Lee Sink. Treehouse and Columbia springs were found to be composed of mostly river water with some groundwater flow influence, while Darby and Hornsby flows were comprised predominantly of groundwater. The overall springshed extends east towards Mill and Lee sinks and towards Mill and Cellon Creeks.

The Poe Springs cluster's springshed resides to the southeast with recharge occurring in multiple swallets or sinkholes located near the Cody Scarp. Rum Island and Gilchrist Blue's springshed was shown to have sources from the northeast and the southeast.

The Ginnie Springs cluster includes the Ginnie Springs Group, July Springs, and Devils Ear and Eye. This springshed extends to the north and south of the Santa Fe River. The springshed model showed that the springshed for this group originates in the Newberry Karst Plain, and that the southern reach of the springshed terminates at the Bell Ridge (Figure 2). Previous dye tracing has not shown a connection between July Spring and Ginnie Spring, however, divers have confirmed a connection between July Spring and the Devils system (Wilson and Skiles, 1988; SDII, 2011).

Additionally, it appears that the springshed north of the Santa Fe River feeds July and the Devils group, while the southern reaches of the springshed feed the Ginnie system.

Siphon Creek, Sunbeam Spring, and Wilson Spring springsheds could not be differentiated and were grouped. This springshed capture zone is quite small and extends on both sides of the river.

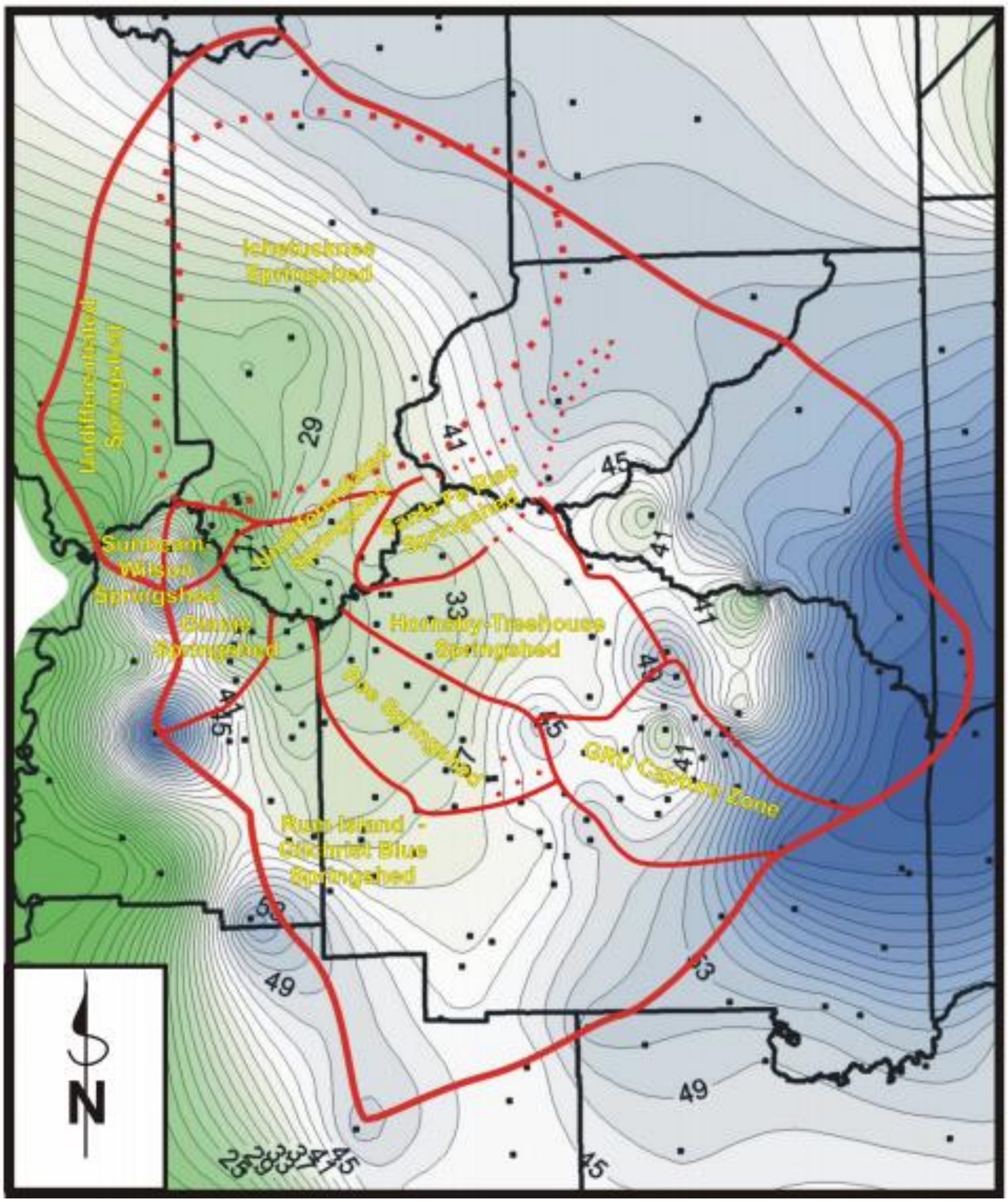


Figure 3. Springsheds of the Santa Fe River (SDII, 2011)

The Ichetucknee River and springs springshed was also surveyed. Water sources to the Ichetucknee begins in Alligator Lake as well as Cannon Creek, Clay Hole Creek, Rose Creek, and several other small streams that drain off the Northern Highlands and into sinkholes at the Cody Scarp. Dye tracing from the Clay Hole Creek sinkhole complex surfaced at the Ichetucknee Springs in 65 to 125 days (Karst Environmental Services, 1997). The Ichetucknee springshed extends to the north and encompasses Lake City, including an estimated 400 square miles.

2.1.3 Land Use

A combination of agriculture, rangeland, and silviculture is the dominant land use/land cover in the Santa Fe River surface water basin, with an estimated total coverage over 70%. Recent mapped land use changes in the Santa Fe River Basin have resulted in increased urban development and reduced agriculture (Table 1). Urban land cover has increased from 2% in 1970 to 10% in 2010. Agriculture, while still being the second largest land use, decreased from 30% to 16% between 1970 and 2010. The increase in urbanization may be increasing run-off which may be resulting in higher peak discharges; however, this change in runoff is expected to only result in minor changes in average flows in the river (Suwannee River Water Management District, 2013).

Table 2 shows the land use estimates within the Santa Fe River Basin in 2008 (FDEP, 2012). The discrepancies in land use between the two figures occurs because the Santa Fe River Basin used by the SRWMD did not include land areas that fell outside their district (Figure 4 and Figure 5) (SRWMD, 2013). On-going replacement of forested areas by intensive row-crop, irrigated land uses is visibly evident near the Santa Fe River since 2010.

Table 1. Land use within the Lower Santa Fe River and Ichetucknee River surface water basins in the 1970s, 1988, and 2010 (SRWMD, 2013)

FLUCC	Description	1970s		1988		2010	
		Area (acres)	Percent	Area (acres)	Percent	Area (acres)	Percent
1000	Urban and Transportation	16,655	1.9	26,218	3.1	87,724	10.2
2000	Agriculture	252,836	29.5	212,803	24.8	140,522	16.4
3000 and 4000	Forest and Rangeland	489,689	57.2	516,860	60.3	502,638	58.7
5000	Water	11,935	1.4	14,731	1.7	13,356	1.6
6000	Wetlands	85,139	9.9	84,808	9.9	111,050	13.0
7000	Other	312	0.0	1,138	0.1	1,316	0.2
Total		**856,567**	**100.0**	**856,558**	**100.0**	**856,605**	**100.0**

Table 2. Land use classifications in the Santa Fe River Basin in 2008 (FDEP, 2012)

Land Use	Acres	%
Urban and Built-Up	120,298	11%
Agriculture	231,827	22%
Rangeland	29,096	3%
Upland Forest	508,485	47%
Water	14,735	1%
Wetland	159,915	15%
Barren Land	5,715	1%
Transportation, Communication, and Utilities	13,100	1%
Total	**1,083,171**	**100.0%**

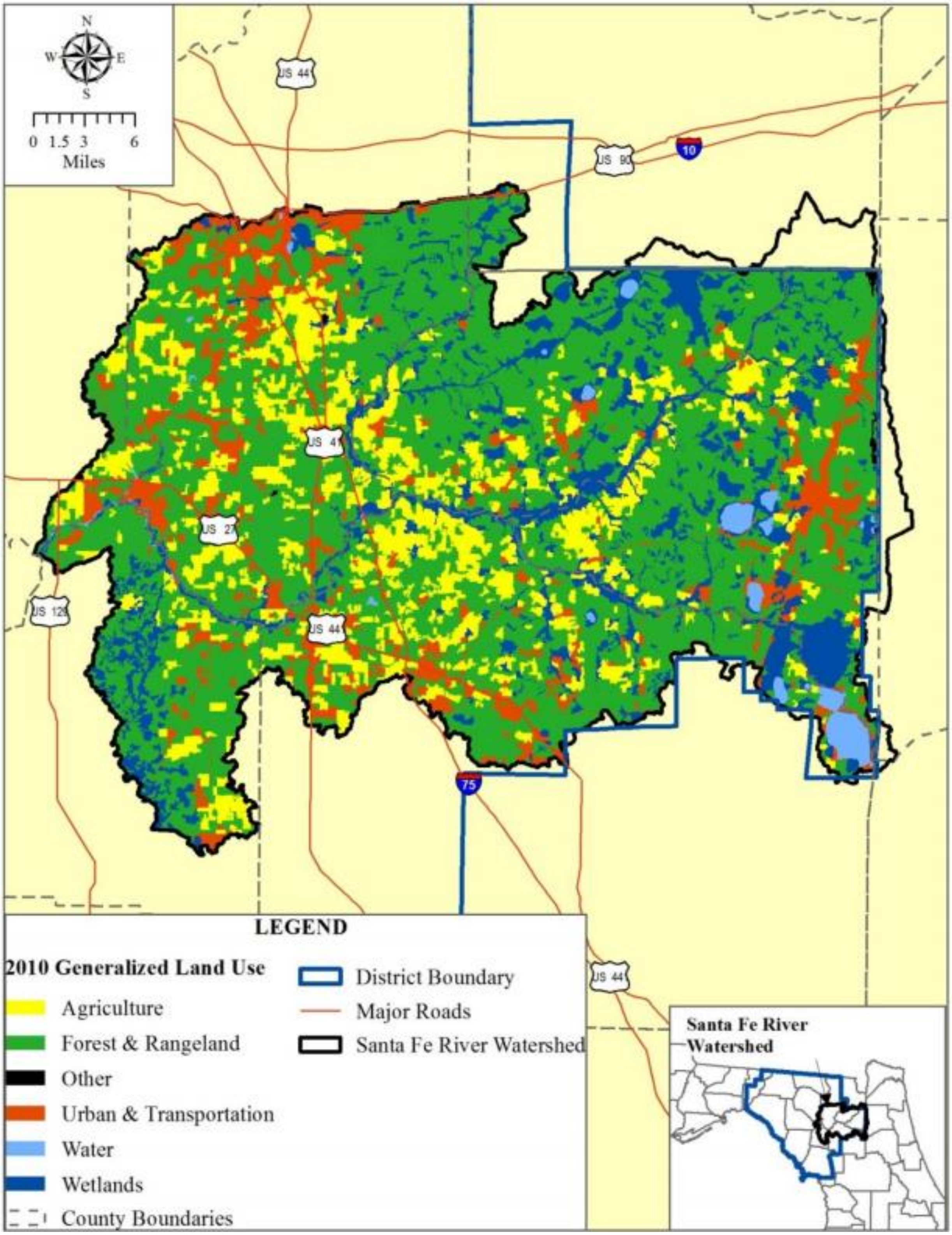


Figure 4. 2010 Land use within the Lower Santa Fe River and Ichetucknee River surface water basins (SRWMD, 2013)

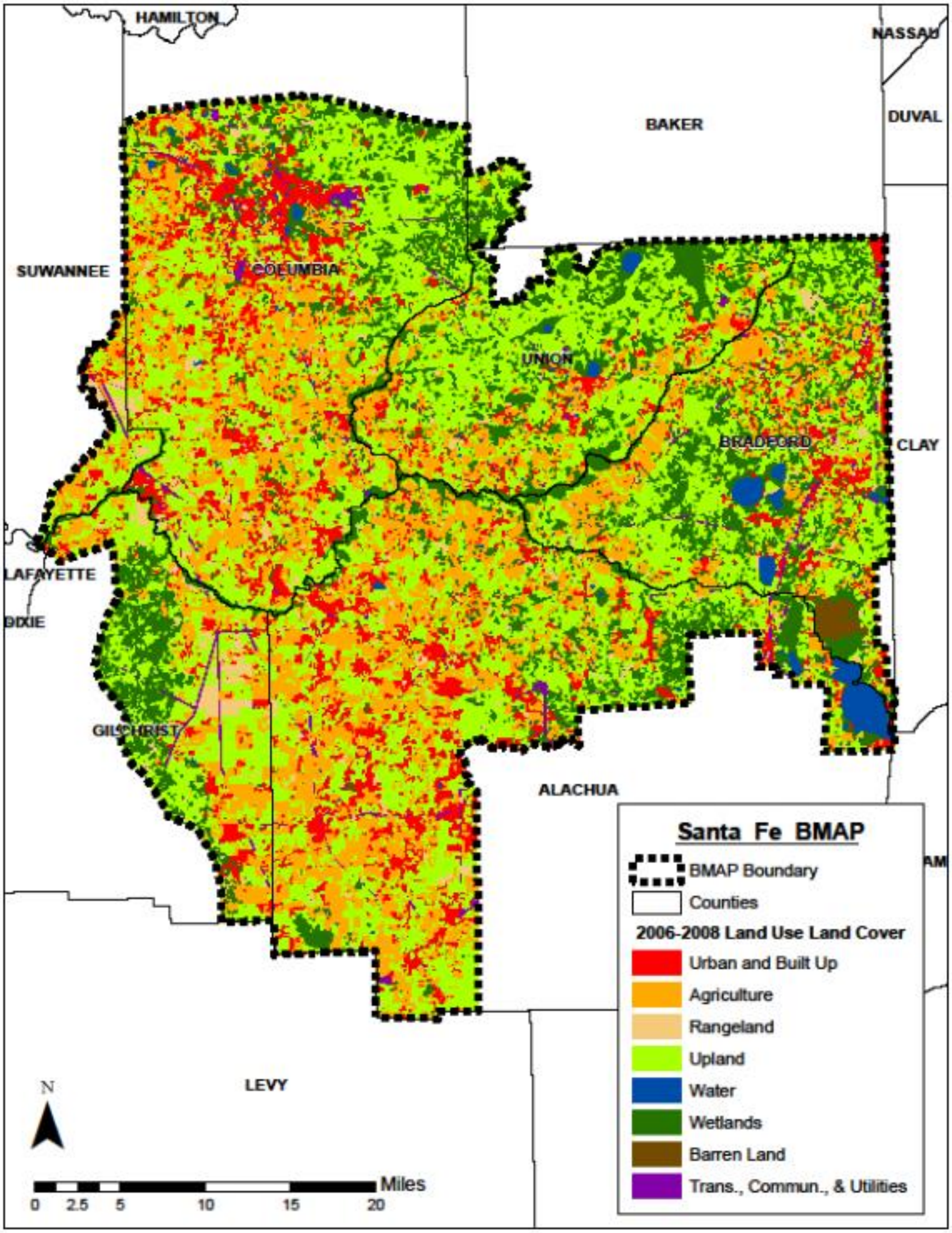


Figure 5. Land use within the Santa Fe River BMAP basin in 2008 (FDEP, 2012)

2.2 Hydrology

2.2.1 Rainfall

Rainfall and resulting groundwater recharge is the primary source of input to the groundwater aquifer that feeds the Santa Fe River and springs. The long-term median rainfall in the Santa Fe River springshed is about 51 inches per year. While there is considerable year-to-year variation in rainfall totals (34 to 70 inches per year) there has been no significant upward or downward change in the long-term rainfall in north central Florida over the last 113-year period (Figure 6). Detailed analysis of these data indicates a relatively steady increase in rainfall totals during the first half of the period-of-record (about 12 percent) and a steady decline during the last 50 years (about 13 percent).

2.2.2 River and Spring Discharge

Historic water quality and discharge data were collected from the USGS, FDEP STORET, and the Suwannee River Water Management District (SRMWD) Water Data Portal. Data were summarized by river segments that are marked by major breaks at river/highway intersections:

- Segment 1 (Worthington Spring at SR 121 to the Santa Fe River Sink in O'Leno State Park)
- Segment 2 (Santa Fe River Rise to U.S. Hwy 27)
- Segment 3 (U.S. Hwy 27 to US Hwy 47)
- Segment 4 (U.S. Hwy 47 to Suwannee River confluence)
- Ichetucknee River (Main Boil to Santa Fe River confluence)

Table 3 provides a summary of average discharges reported for the Santa Fe River and associated springs for three relatively long time intervals: <= 1969, 1970-1999s, and 2000's. Of the 18 stations that had been monitored since 2000, 10 have been discontinued between 2010 and 2014.

Monthly average discharges were plotted with LOESS (locally weighted regression and smoothing scatterplot) curves for select stations on the Santa Fe and Ichetucknee Rivers with long periods of record to identify long-term trends (Figure 7 through Figure 9):

- Santa Fe River at Worthington Springs (USGS 02321500)
- Santa Fe River near Fort White (USGS 02322500)
- Ichetucknee River at US 27 (USGS 02322700)

Over the period of record, stream discharges at Santa Fe River at Worthington Spring, Santa Fe River near Fort White, and ICH at US 27 averaged 353 cfs, 1,400 cfs, and 340 cfs, respectively. All stations display a general declining discharge trend since the mid-1970's. Documented changes in average flow of these key stations from the 1970-90's to the 2000's period of record are:

- Santa Fe River at Worthington Springs: 415 cfs to 252 cfs – a 39% flow reduction
- Santa Fe River at Fort White: 1500 cfs to 1058 cfs – a 29% flow reduction
- Ichetucknee River at US 27: 383 cfs to 298 cfs – a 22% flow reduction.

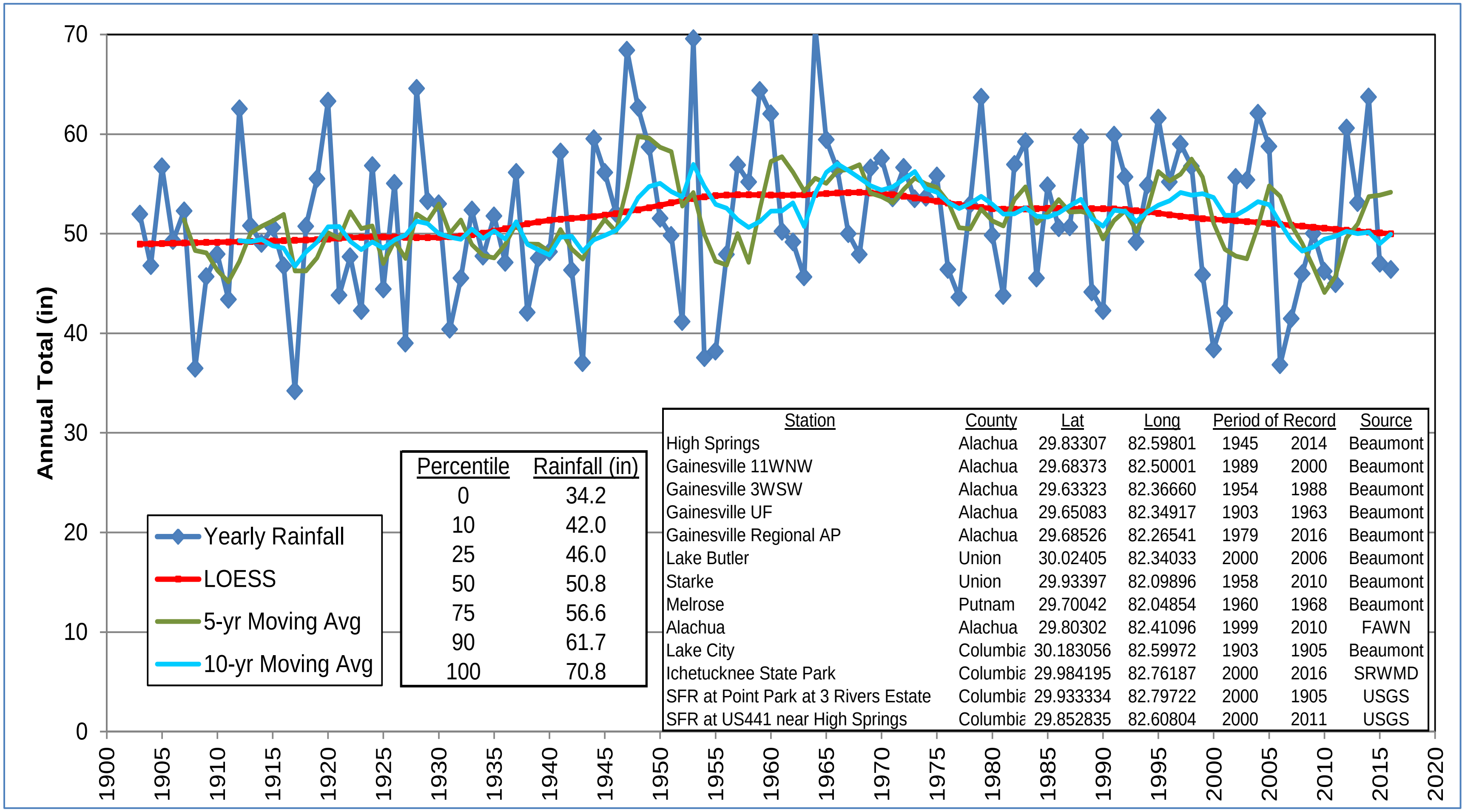


Figure 6. Annual rainfall averages in the Santa Fe River Springshed Basin (1903-2016)

2.2.3 Minimum Flow and Levels

In 2013, the SRWMD adopted minimum flows and levels (MFL's) for the Lower Santa Fe River and Ichetucknee River and Priority Springs. One of the major components of the SRWMD's MFL is the determination of the Baseline Flow, meaning the historical flow levels prior to anthropogenic impairment. The SRWMD made this determination using flow data from 1933 to 1990 to construct flow duration curves.

This Baseline Flow is represented on

Figure 10 and Figure 11 by the SRWMD as a series of flow duration curves with "controlling" Critical Flow points. These points are the estimated critical flow requirements that ensure the protection of the Santa Fe and Ichetucknee river water resource values (SRWMD, 2013). A second determination was also made by the SRWMD for the MFL's. This determination is the allowable shift in the baseline flow that can occur without significant impairments to the ecosystem. This metric is noted in the figures as the MFL metric flow. The average allowable shifts were 7 percent and 3 percent in the Santa Fe River and Ichetucknee River, respectively (SRWMD, 2013).

The figures below show the actual measured flow duration curves for the noted decades of available data for the Santa Fe and Ichetucknee rivers. It is interesting to note that the flow duration curve for the Santa Fe River near Fort White station and in the Ichetucknee River near US 27 for the most recent period of record since 2000 are clearly below all of the MFL critical flow metrics adopted by the SRWMD and FDEP.

Figure 12 provides a summary of annual rainfall and discharge from the Santa Fe River near Fort White above US 47 (USGS 02322500). The rainfall and discharge LOESS curves follow a similar trend until the 1970's when they diverge. Since that time measured flows in the Santa Fe River are on a continuing decline despite rainfall totals within normal historic levels.

2.3 Water Quality

Table 4 through Table 8 provide a summary of water quality for the Santa Fe River and associated springs for <1960's, 1970-1990's, and 2000's by study segment. Spring and river stations within each segment have been averaged and a more detailed summary can be found in FSI (2016).

Table 3. Santa Fe River and springs discharge (cfs) period of record

Station	Type	Average Discharge (cfs)			Number of Records			Source
		<=1960s	1970s-1990s	>=2000s	<=1960s	1970s-1990s	>=2000s	
Santa Fe River at Worthington Spring	Spring	420	415	252	13972	10957	6214	USGS 02321500
Olustee Creek near Lulu	River		89	80		2	53	USGS 02321600
Santa Fe Spring	Spring		53	62		5	47	SRWMD 02321897
O'Leno State Park	River			427			1927	USGS 02321898/SRWMD/USGS 02321910
Santa Fe River Rise	Spring		550	351		56	482	USGS 02321958
Treehouse Spring	Spring		211	192		10	86	SRWMD 02321971
Hornsby Spring	Spring		135	47		16	86	SRWMD 02321970
Santa Fe River US-441 Bridge	River		704	211		2648	3908	SRWMD 02321975
Columbia Spring	Spring	423	167	105	1	4	47	SRWMD/USGS 02321977
Poe Spring	Spring	69	62	39	7	18	136	SRWMD/USGS 02322140
Poe Woods Spring	Spring		56			1		ACEPD
Watermelon Spring	Spring			2			1	ACEPD
Rum Island Spring	Spring		61	17		1	15	SRWMD RUM010C1
Gilchrist Blue Spring	Spring		44	42		15	80	SRWMD/USGS 02322350
Ginnie Spring	Spring		51	38		12	48	SRWMD/USGS 02322400
Santa Fe River near Fort White	River	1647	1500	1058	14582	10826	6124	USGS 02322500
ICH at US 27	River	357	383	298	340	92	5620	SRWMD/USGS 02322700
Santa Fe River at US 129	River			1581			5181	USGS 2322800

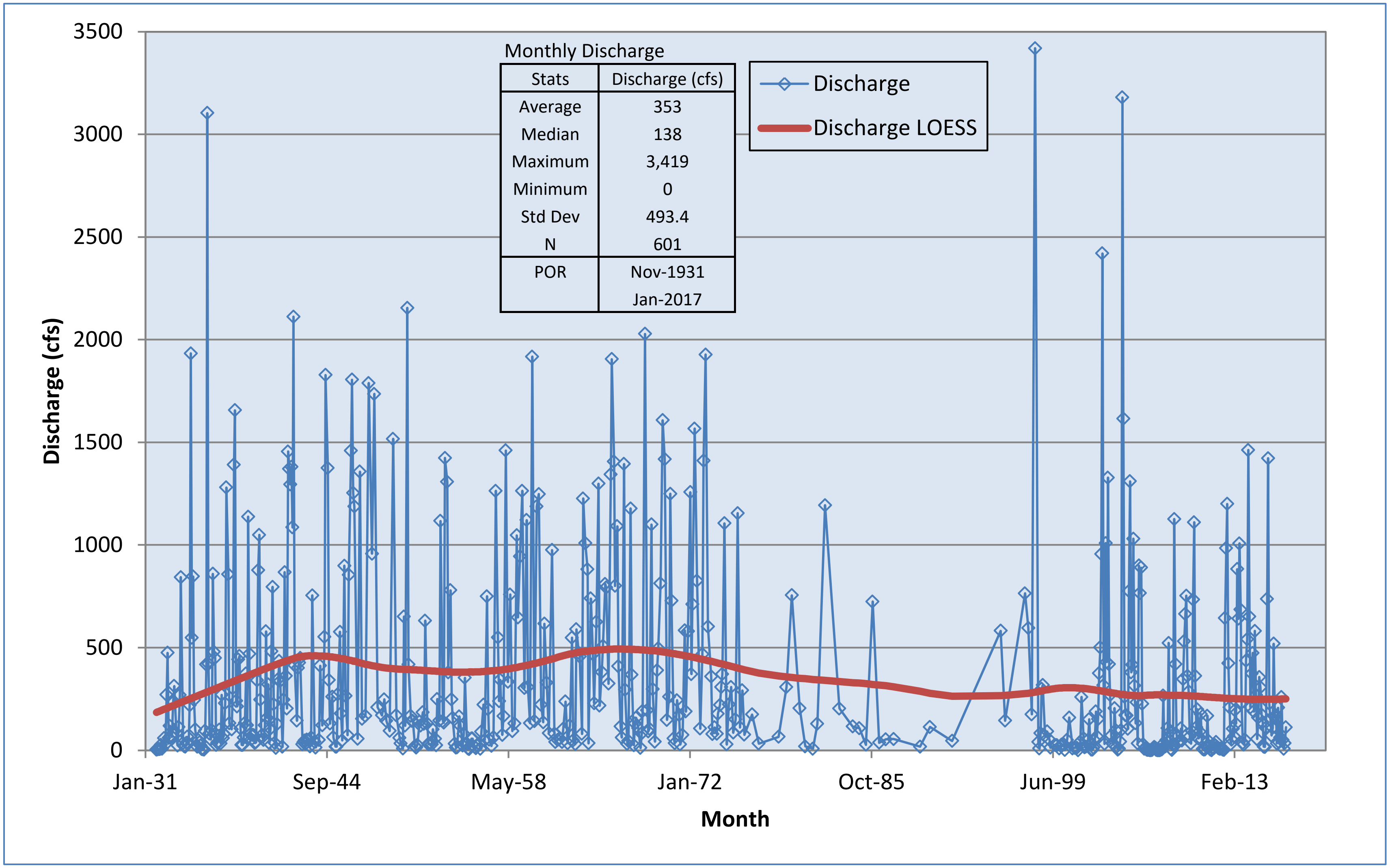


Figure 7. Monthly average discharge of the Santa Fe River at Worthington Spring (USGS 02321500)

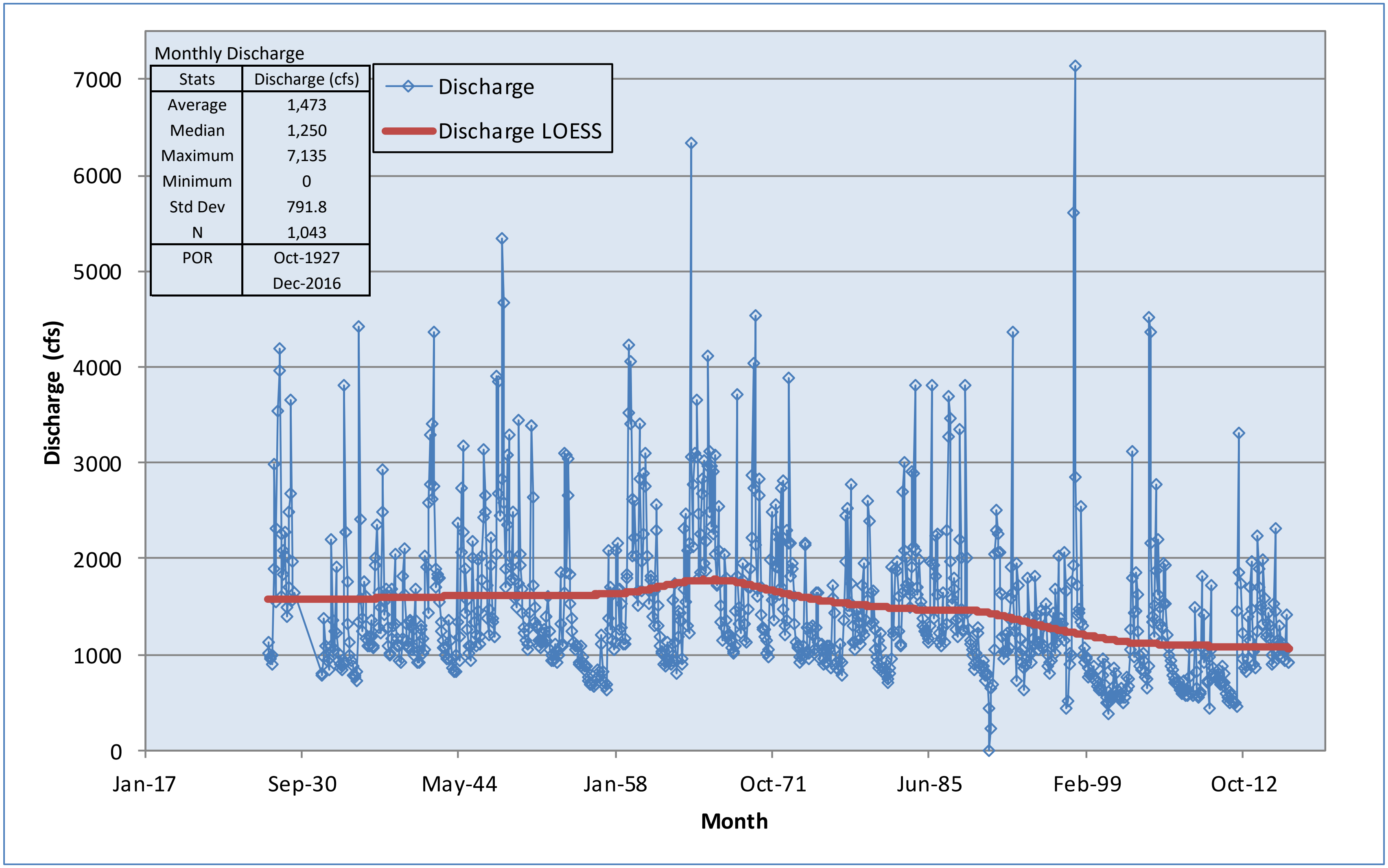


Figure 8. Monthly average discharge in the Santa Fe River near Fort White (USGS 02322500)

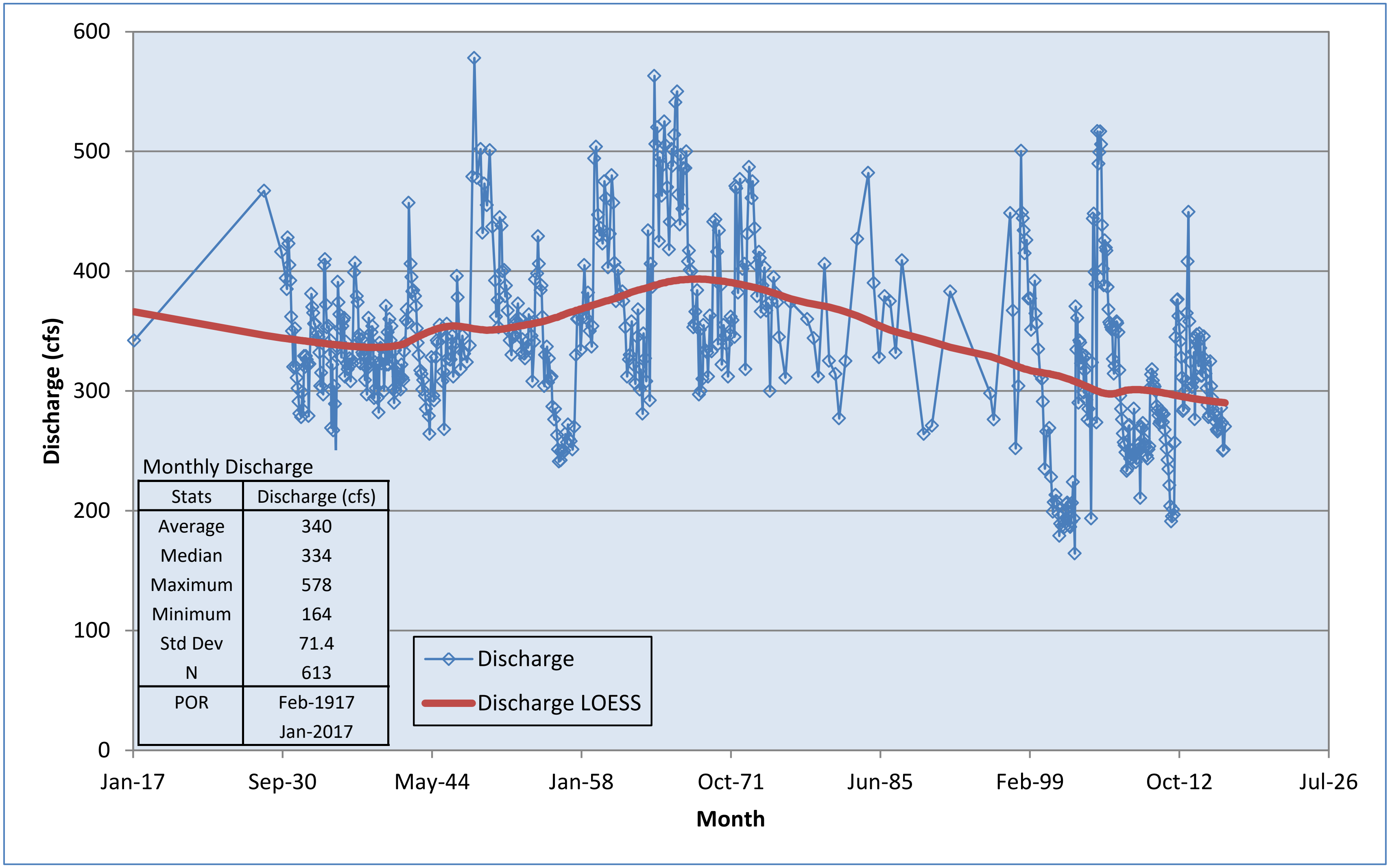


Figure 9. Monthly average discharge in the Ichetucknee River at US 27 (USGS 02322700)

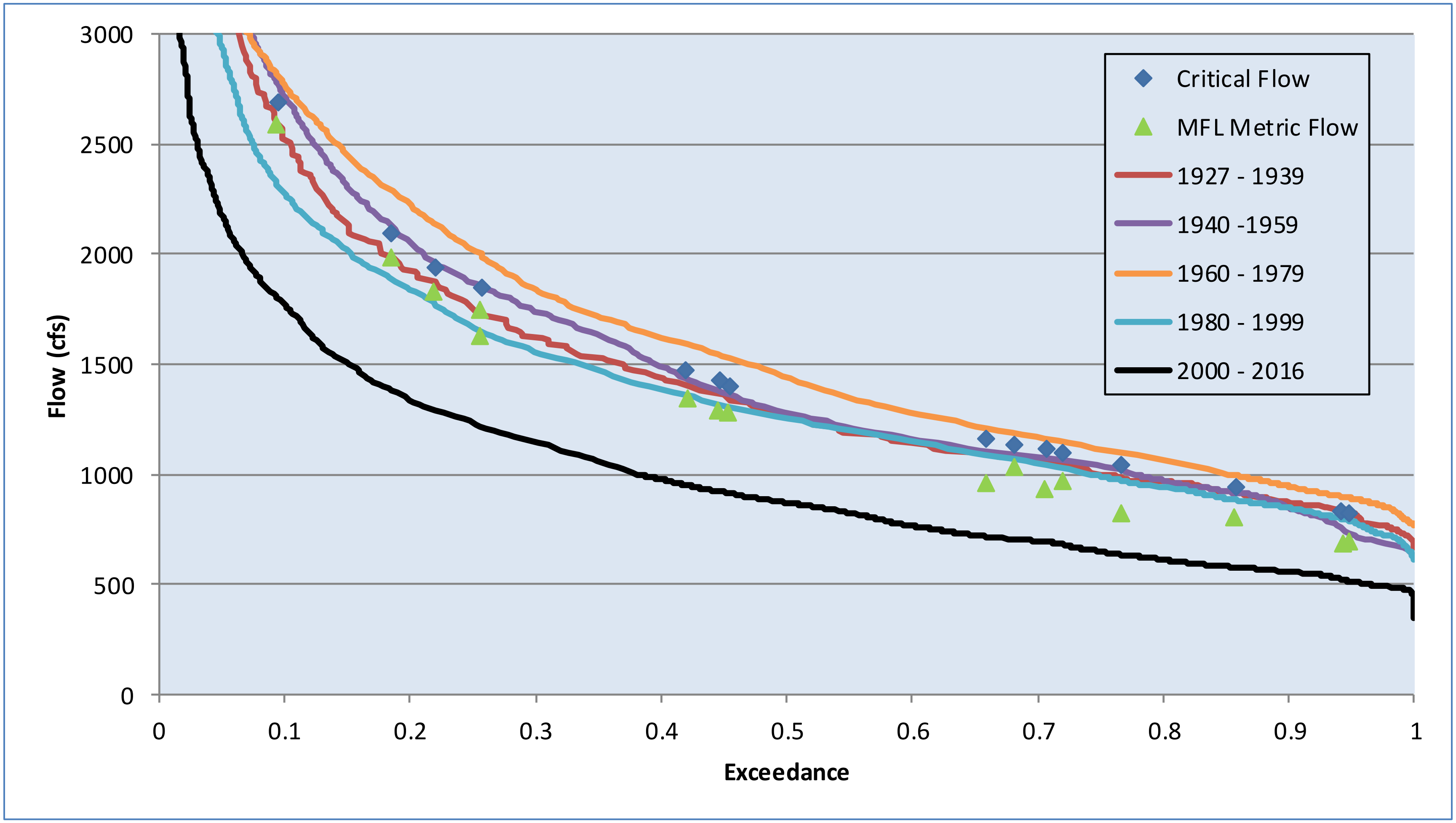


Figure 10. Santa Fe River flow-duration curves and SRWMD critical flows near Fort White from 1927 to 2016 (USGS 02322500)

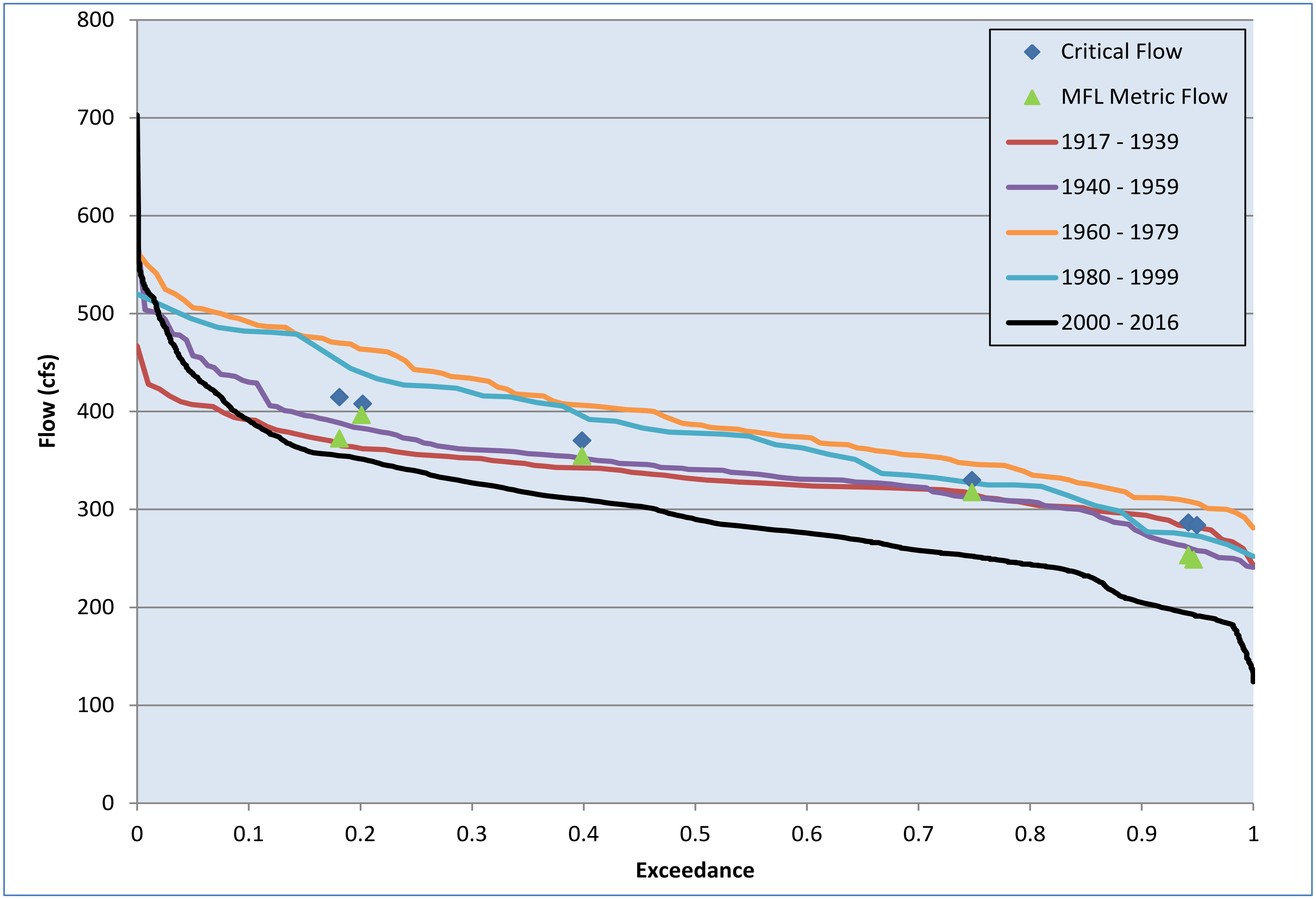


Figure 11. Ichetucknee River flow-duration curves at US Hwy 27 from 1917 to 2016 (USGS 02322700)

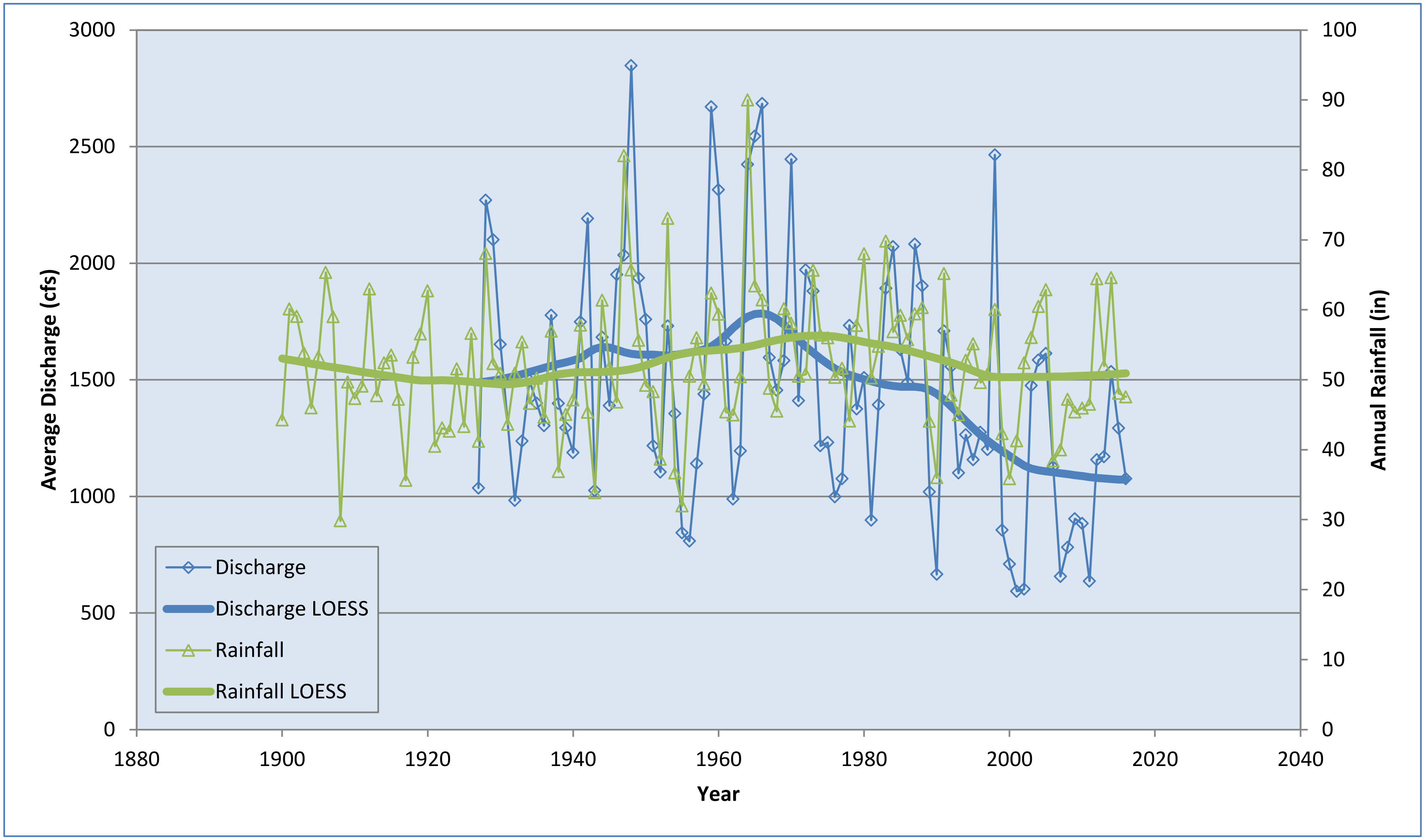


Figure 12. Comparison between annual rainfall and discharge from the Santa Fe River near Fort White from 1900 to 2016 (USGS 02322500 Santa Fe River near Fort White)

NOx-N concentration data were plotted with LOESS curves for select stations on the Santa Fe and Ichetucknee Rivers to identify long-term trends (Figure 13 through Figure 23). Recent (2000's) average NOx-N concentrations generally are lower upstream of the springs and rise with distance downstream:

- Santa Fe River at Worthington Spring (0.20 mg/L)
- O'Leno State Park (0.12 mg/L)
- Hornsby Spring (0.44 mg/L)
- Santa Fe River at U.S.-Hwy 441 (0.20 mg/L)
- Columbia Spring (0.24 mg/L)
- Santa Fe River at US HWY 27 (0.14 mg/L)
- Poe Spring (0.23 mg/L)
- Gilchrist Blue Spring (1.87 mg/L)
- Ginnie Spring (1.51 mg/L)
- Santa Fe River at U.S. Hwy 47 (0.72 mg/L)
- Ichetucknee River at U.S. Hwy 27 (0.49 mg/L)
- Santa Fe River at U.S. Hwy 129 (0.62 mg/L)

Water quality in the surface water feeding the Upper Santa Fe River and in the Floridan Aquifer and at the Santa Fe River Springs is directly affected by the land use activities that occur in the surrounding springshed. When land use activities are intensive and entail large and consistent applications of nutrients and pollutants to the soil, the quality of water in the Floridan Aquifer and the flow of water discharging at the springs are compromised.

Agriculture in the Santa Fe springshed includes a combination of tilling, mowing, fertilizing, irrigating, and disposal of animal waste. In areas of the Santa Fe springshed where soil permeability is high and the aquifer is unconfined, aquifer water quality is vulnerable to leaching of nutrients from fertilizers and animal/human waste disposal. Likewise, residential, commercial, and industrial sites affect the Floridan Aquifer through discharge of untreated stormwater, leaching of nutrients from treated wastewater discharge sites (i.e., sprayfields, rapid infiltration basins, and on-site waste disposal systems), and leaching of fertilizers and pesticides from yards and golf courses. Cumulatively, these sources diminish the quality of water in the Floridan Aquifer and ultimately, the quality of water that discharges at the springs that feed the Santa Fe River.

Some general differences observed between the river and the springs water quality in these four segments of the Santa Fe River include lower dissolved oxygen concentrations in the springs versus the rivers, higher color in the river than in the springs, and higher salts, specific conductance, salinity, and nitrate nitrogen in the springs than in the river.

A number of temporal trends are also apparent in these data. Flow is declining over time at most river and spring stations. Nitrate is increasing over time at most river and spring stations. Color is increasing in most of the sampled springs, apparently as an indirect consequence of reduced spring flows and more frequent flow reversals in some springs (e.g., Columbia, Hornsby, and Poe), coloring groundwater with tannins from the river.

Table 4. Santa Fe River Segment 1 (Worthington Springs at SR 121 to O'Leno State Park Santa Fe River Sink) period of record water quality summary

			River			Spring		
Parameter Group	Parameter	Result Units	<1970s	1970s-90s	2000s	<1970s	1970s-90s	2000s
BACTERIOLOGICAL	FC	#/100ml		89.4	136			
	TC	#/100ml		329	381			
BIOLOGICAL	Chl-a	ug/l		0.713	0.38			
	Chl-a corr	ug/l			0.250			
	Chl-a Uncorr	ug/l		1.37	4.10			
	Chl-b	ug/l			1.30			
	Chl-c	ug/l			6.3			
	Pheo-a	ug/l			5.10			
DISSOLVED OXYGEN	DO	%			59.8			11.7
		mg/l		6.04	5.98		0.967	0.780
FLOW	Flow	cfs	420	415	292		53.5	61.6
GENERAL INORGANIC	Alk	mg/l		28.9	36.9		141	137
	Cl-T	mg/l		17.4	17.5		8.13	7.85
	F-T	mg/l		0.150	0.150		0.275	0.268
	SIO2	mg/l			7.90			
	SO4	mg/l		8.23	7.20		43.0	32.1
GENERAL ORGANIC	TOC	mg/l					7.40	6.80
	DOC	mg/l		24.86	29.49		9.80	7.49
METAL	Ca-T	mg/l		16.9	21.4		46.7	49.8
	K-T	mg/l		1.07	1.35		0.700	0.832
	Mg-T	mg/l		4.98	6.95		12.6	11.8
	Mn-T	mg/l			1.89			2.45
	Na-T	mg/l		7.13	8.06			
NITROGEN	NH3-N	mg/l		0.033	0.053		0.045	0.053
	NH4-N	mg/l		0.025	0.042			
	NOx-N	mg/l		0.171	0.150		0.170	0.229
	TKN	mg/l		0.762	1.06		0.170	0.373
OXYGEN DEMAND	BOD5	mg/l		1.10				
PHOSPHORUS	OrthoP	mg/l		0.205	0.161		0.140	0.120
	TP	mg/l		0.267	0.211		0.135	0.144
PHYSICAL	Color	PCU		231	260		27.5	62.0
	pH	SU		6.68	6.82		7.40	7.23
	Salinity	ppt		0.00	0.054		0.00	0.108
	SpCond	umhos/cm		170	160		373	343
	Turb	NTU		1.82	4.69		0.325	0.700
SOLID	TDS	mg/l		132	158		170	230
	TSS	mg/l		2.30	1.71			
TEMPERATURE	Wtr Temp	C		20.3	20.9		21.9	21.8

Table 5. Santa Fe River Segment 2 (Santa Fe River Rise to U.S. Hwy 27) period of record water quality summary

			River			Spring		
Parameter Group	Parameter	Results Units	<1970s	1970s-90s	2000s	<1970s	1970s-90s	2000s
BACTERIOLOGICAL	EColi	#/100ml			49.0			34.4
	Enterococi	#/100ml			220			40.3
	FC	#/100ml		33.4	60.3		6.67	55.2
	TC	#/100ml		147	616		112	8,405
BIOLOGICAL	Chl-a	ug/l		1.16	1.69			
	Chl-a corr	ug/l		0.500	1.05			0.587
	Chl-a Uncorr	ug/l		1.12	24.4			1.23
	Chl-b	ug/l			0.685			
	Chl-c	ug/l			1.18			
	Pheo-a	ug/l		0.500	0.766			2.36
DISSOLVED OXYGEN	DO	%			41.9			25.5
		mg/l		3.72	4.36		1.19	1.98
FLOW	Flow	cfs		704	211	423	416	278
	Velocity	ft/sec			0.450			
GENERAL INORGANIC	Alk	mg/l		91.5	109		152	142
	Cl-T	mg/l		15.0	16.5		13.4	14.1
	F-T	mg/l		0.180	0.205		0.190	0.215
	SIO2	mg/l			10.9			12.5
	SO4	mg/l		39.9	60.5		43.9	67.5
GENERAL ORGANIC	DOC	mg/l			16.4		8.90	7.86
	TOC	mg/l		16.9	16.3		7.86	10.8
METAL	Al-T	ug/l			160			510
	As-T	ug/l			1.05			1.50
	Ca-T	mg/l		40.6	54.8		57.7	65.1
	Cd-T	ug/l			0.018			0.375
	Cr-T	ug/l			0.482			0.350
	Cu-T	ug/l			0.283			1.25
	Fe-T	ug/l			350			163
	K-T	mg/l		1.32	1.24		0.838	1.15
	Mg-T	mg/l		7.65	10.7		9.36	10.8
	Mn-T	mg/l			4.04			2.76
	Na-T	mg/l		7.91	9.67		7.75	9.41
	Ni-T	ug/l						0.750
	Pb-T	ug/l			0.143			2.50
	Se-T	ug/l						2.00
	Zn-T	ug/l			2.50			4.73
NITROGEN	NH3-N	mg/l		0.026	0.033		0.016	0.040
	NH4-N	mg/l		0.023	0.035		0.013	0.043
	NOx-N	mg/l		0.308	3.56		0.680	0.565
		tons/day					1.15	
	TKN	mg/l		0.472	0.605		0.186	0.437
	TN	mg/l						0.551
OXYGEN DEMAND	BOD5	mg/l		1.13	1.19			0.973
PHOSPHORUS	OrthoP	mg/l		0.124	0.115		0.098	0.095
	TP	mg/l		0.153	0.147		0.134	0.123
PHYSICAL	Color	PCU		150	145		20.7	78.1
	pH	SU		7.00	7.19		7.19	7.24
	Salinity	ppt		0.012	0.147		0.007	0.163
	SpCond	umhos/cm		310	379		415	387
	Turb	NTU		1.12	1.93		0.484	1.51
SOLID	TDS	mg/l		226	276		269	289
	TSS	mg/l		2.97	2.61		1.62	2.55
TEMPERATURE	Wtr Temp	C		21.4	21.9		22.5	21.8

Table 6. Santa Fe River Segment 3 (U.S. Hwy 27 to U.S. Hwy 47) period of record water quality summary

			River			Spring		
Parameter Group	Parameter	Result Units	<1970s	1970s-90s	2000s	<1970s	1970s-90s	2000s
BACTERIOLOGICAL	EColi	#/100ml			7.50			9.15
	Enterococi	#/100ml			132			6.18
	FC	#/100ml		49.8	82.0		1.96	11.4
	TC	#/100ml		248	446		6.32	271
BIOLOGICAL	Chl-a	ug/l		0.627	1.40			
	Chl-a corr	ug/l			0.417		0.578	0.643
	Chl-a Uncorr	ug/l		0.415	39.3			0.771
	Chl-b	ug/l			0.491			1.39
	Chl-c	ug/l			1.43			5.30
	Pheo-a	ug/l			1.87			1.67
DISSOLVED OXYGEN	DO	%			57.2			38.2
		mg/l		5.22	5.10		3.50	3.67
FLOW	Flow	cfs	1,647	1,500	1,058	69.0	53.3	38.3
GENERAL INORGANIC	Alk	mg/l		126	138		159	167
	Cl-T	mg/l		10.8	11.0		7.22	9.15
	F-T	mg/l		0.146	0.149		0.132	0.128
	SIO2	mg/l			8.42			8.08
	SO4	mg/l		23.6	28.1		11.2	17.9
GENERAL ORGANIC	DOC	mg/l			8.63		6.73	2.20
	TOC	mg/l		10.6	8.41		5.03	2.00
METAL	Al-T	ug/l						22.9
	As-T	ug/l			0.938			1.27
	Ba-T	ug/l						3.23
	Ca-T	mg/l		48.5	60.0		54.4	64.9
	Cd-T	ug/l						0.313
	Cr-T	ug/l						0.900
	Cu-T	ug/l						1.63
	Fe-T	ug/l			6.00			33.8
	K-T	mg/l		0.974	0.771		0.473	0.571
	Mg-T	mg/l		5.97	7.31		5.63	6.57
	Mn-T	mg/l			3.39			1.75
	Na-T	mg/l		5.75	6.65		3.82	5.00
	Ni-T	ug/l						1.03
	Pb-T	ug/l						2.19
	Se-T	ug/l						3.25
	Zn-T	ug/l						2.86
NITROGEN	NH3-N	mg/l		0.019	0.028		0.026	0.025
	NH4-N	mg/l		0.013	0.030		0.005	0.030
	NOx-N	mg/l		0.729	0.694		1.13	1.39
		tons/day					1.17	
	TKN	mg/l		0.316	0.411		0.112	0.164
	TN	mg/l						0.346
OXYGEN DEMAND	BOD5	mg/l		1.21	1.00			0.935
PHOSPHORUS	OrthoP	mg/l		0.084	0.071		0.050	0.050
	TP	mg/l		0.104	0.097		0.072	0.060
PHYSICAL	Color	PCU		88.2	89.7		5.04	11.1
	pH	SU		7.32	7.37		7.38	7.94
	Salinity	ppt		0.010	0.139		0.00	0.271
	SpCond	umhos/cm		322	359		349	388
	Turb	NTU		0.781	1.12		0.203	0.321
SOLID	TDS	mg/l		210	228		205	218
	TSS	mg/l		2.34	1.73		4.04	1.69
TEMPERATURE	Wtr Temp	C		21.8	22.0		22.2	22.2

Table 7. Santa Fe River Segment 4 (U.S. Hwy 47 to Suwannee River confluence) period of record water quality summary

Parameter Group	Parameter	Result Units	River			Spring		
			<1970s	1970s-90s	2000s	<1970s	1970s-90s	2000s
BACTERIOLOGICAL	EColi	#/100ml			439			
	Enterococi	#/100ml			77.1			
	FC	#/100ml		68.7	112		28.8	6.95
	TC	#/100ml		322	563		188	
BIOLOGICAL	Chl-a	ug/l		0.845	1.31			
	Chl-a corr	ug/l		3.83	0.900			3.26
	Chl-a Uncorr	ug/l		12.4	32.2			0.700
	Chl-b	ug/l		0.283	0.769			
	Chl-c	ug/l		1.35	1.69			
	Pheo-a	ug/l		2.55	1.39			0.385
DISSOLVED OXYGEN	DO	%			75.1			39.5
		mg/l		5.67	6.21		3.44	3.37
FLOW	Flow	cfs			1,581			
	Velocity	ft/sec			0.567			0.195
GENERAL INORGANIC	Alk	mg/l		128	146			
	Cl-T	mg/l		9.70	9.75			
	F-T	mg/l		0.146	0.149			
	SIO2	mg/l			8.88			
	SO4	mg/l		22.3	26.4			
GENERAL ORGANIC	DOC	mg/l		8.11	7.19			
	TOC	mg/l		8.73	6.60		1.73	0.712
METAL	As-T	ug/l			3.00			
	Ca-T	mg/l		49.3	61.0		55.0	103
	Cd-T	ug/l			0.500			
	K-T	mg/l		0.630	0.660		1.72	5.40
	Mg-T	mg/l		6.05	7.04		4.49	7.80
	Mn-T	mg/l			2.96			
	Na-T	mg/l		5.23	5.69		3.87	14.8
	Pb-T	ug/l			5.00			
NITROGEN	NH3-N	mg/l		0.023	0.033			0.007
	NH4-N	mg/l		0.017	0.029		0.009	0.010
	NOx-N	mg/l		0.584	0.606		3.05	7.70
		tons/day					2.33	
	TKN	mg/l		0.267	0.348		0.142	0.189
OXYGEN DEMAND	BOD5	mg/l		1.22	1.20			0.424
PHOSPHORUS	OrthoP	mg/l		0.077	0.059		0.058	0.047
	TP	mg/l		0.103	0.077		0.070	0.052
PHYSICAL	Color	PCU		77.9	53.4			2.80
	pH	SU		7.42	7.58		7.32	7.41
	Salinity	ppt		0.004	0.135		0.100	0.213
	SpCond	umhos/cm		321	354		362	448
	Turb	NTU		0.827	1.10		0.317	0.760
SOLID	TDS	mg/l		205	224			
	TSS	mg/l		2.42	2.38		2.22	1.57
TEMPERATURE	Wtr Temp	C		21.5	21.9		22.2	22.1

Table 8. Ichetucknee River (Main Boil to Santa Fe River confluence) stations period of record water quality summary

			River			Spring		
Parameter Group	Parameter	Result Units	<1970s	1970s-90s	2000s	<1970s	1970s-90s	2000s
BACTERIOLOGICAL	EColi	#/100ml						15.7
	Enterococi	#/100ml						6.45
	FC	#/100ml			101		46.6	15.2
	TC	#/100ml					122	72.7
BIOLOGICAL	Chl-a	ug/l		0.505	0.891			
	Chl-a corr	ug/l			1.18			1.34
	Chl-a Uncorr	ug/l		12.5	1.54		0.417	0.913
	Chl-b	ug/l						1.76
	Chl-c	ug/l						1.97
	Pheo-a	ug/l			0.751			0.677
DISSOLVED OXYGEN	DO	%			66.8			36.9
		mg/l		5.35	6.40		4.30	6.23
FLOW	Flow	cfs	357	383	298			
	Velocity	ft/sec			1.12			0.478
GENERAL INORGANIC	Alk	mg/l		139	146			
	Cl-T	mg/l		5.60	6.10			
	F-T	mg/l		0.146	0.152			
	SIO2	mg/l			10.5			
	SO4	mg/l		11.7	13.0			
GENERAL ORGANIC	TOC	mg/l		2.57	1.97		2.17	2.43
METAL	Al-T	ug/l						11.2
	As-T	ug/l						63.3
	Ba-T	ug/l						4.31
	Ca-T	mg/l		49.2	54.4		49.9	54.9
	Cd-T	ug/l						33.7
	Cr-T	ug/l						0.986
	Cu-T	ug/l						2.23
	Fe-T	ug/l						212
	K-T	mg/l		1.58	0.392		1.08	2.19
	Mg-T	mg/l		6.26	6.82		6.24	6.86
	Mn-T	mg/l			2.99			0.432
	Na-T	mg/l		4.53	3.93		4.10	3.76
	Ni-T	ug/l						1.02
	Pb-T	ug/l						463
	Se-T	ug/l						3.74
	Zn-T	ug/l						2.58
NITROGEN	NH3-N	mg/l		0.018	0.037			0.006
	NH4-N	mg/l					0.010	0.017
	NOx-N	mg/l		0.501	0.495		0.518	0.606
		tons/day					1.04	
	TKN	mg/l		0.112	0.173		0.091	0.092
OXYGEN DEMAND	BOD5	mg/l			0.480		1.20	0.337
PHOSPHORUS	OrthoP	mg/l		0.049	0.040		0.045	0.043
	TP	mg/l		0.074	0.064		0.066	0.059
PHYSICAL	Color	PCU		11.9	5.30			2.18
	pH	SU		7.49	7.72		7.47	7.63
	Salinity	ppt		0.001	0.106		0.100	0.152
	SpCond	umhos/cm		308	317		311	321
	Turb	NTU		0.347	0.499		0.289	0.453
SOLID	TDS	mg/l		180	191			
	TSS	mg/l			2.20		2.21	1.55
TEMPERATURE	Wtr Temp	C		21.5	21.6		21.4	21.8

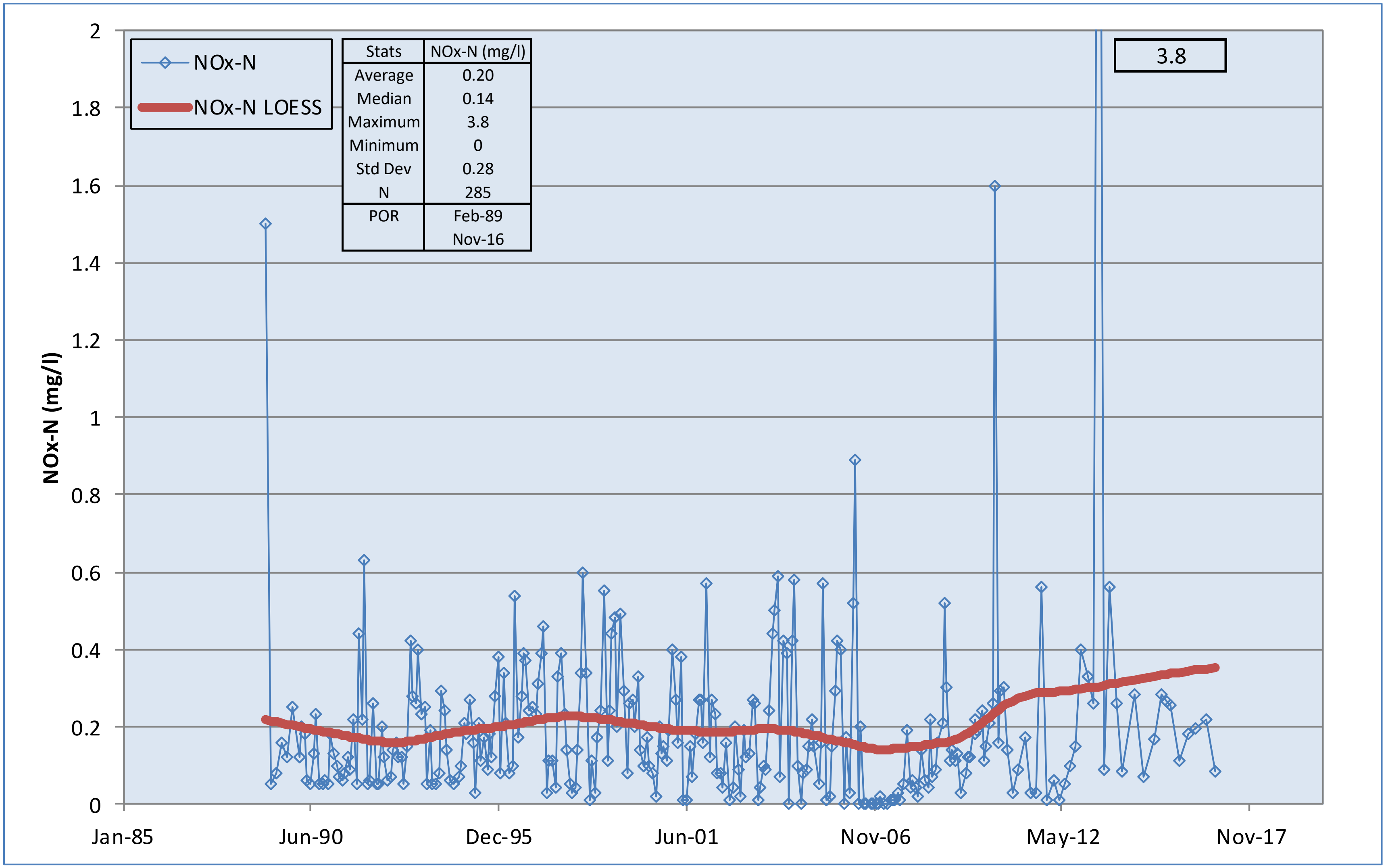


Figure 13. Period of record NOx-N data for the Santa Fe River at Worthington Springs

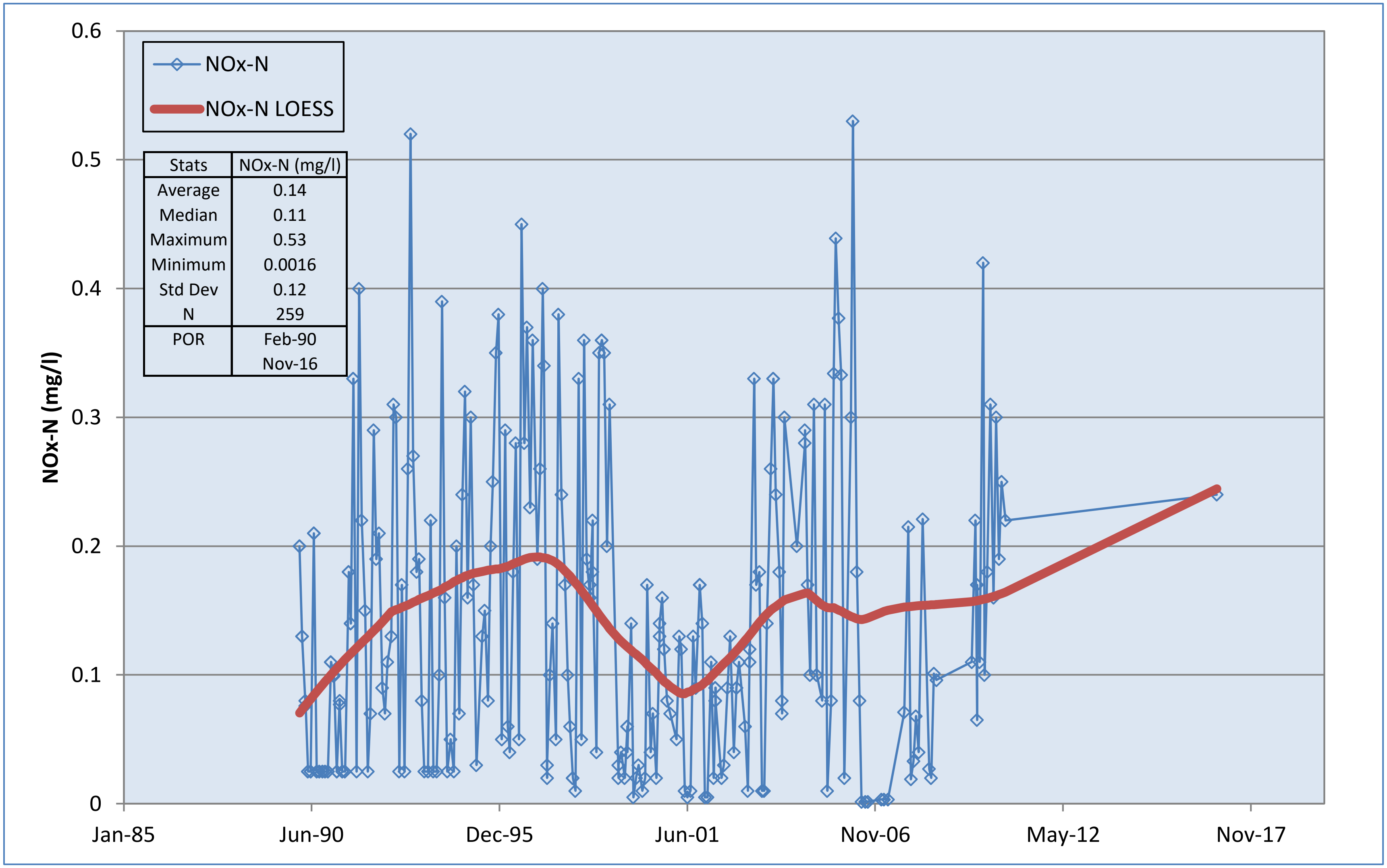


Figure 14. Period of record NOx-N data for the Santa Fe River at O'Leno State Park

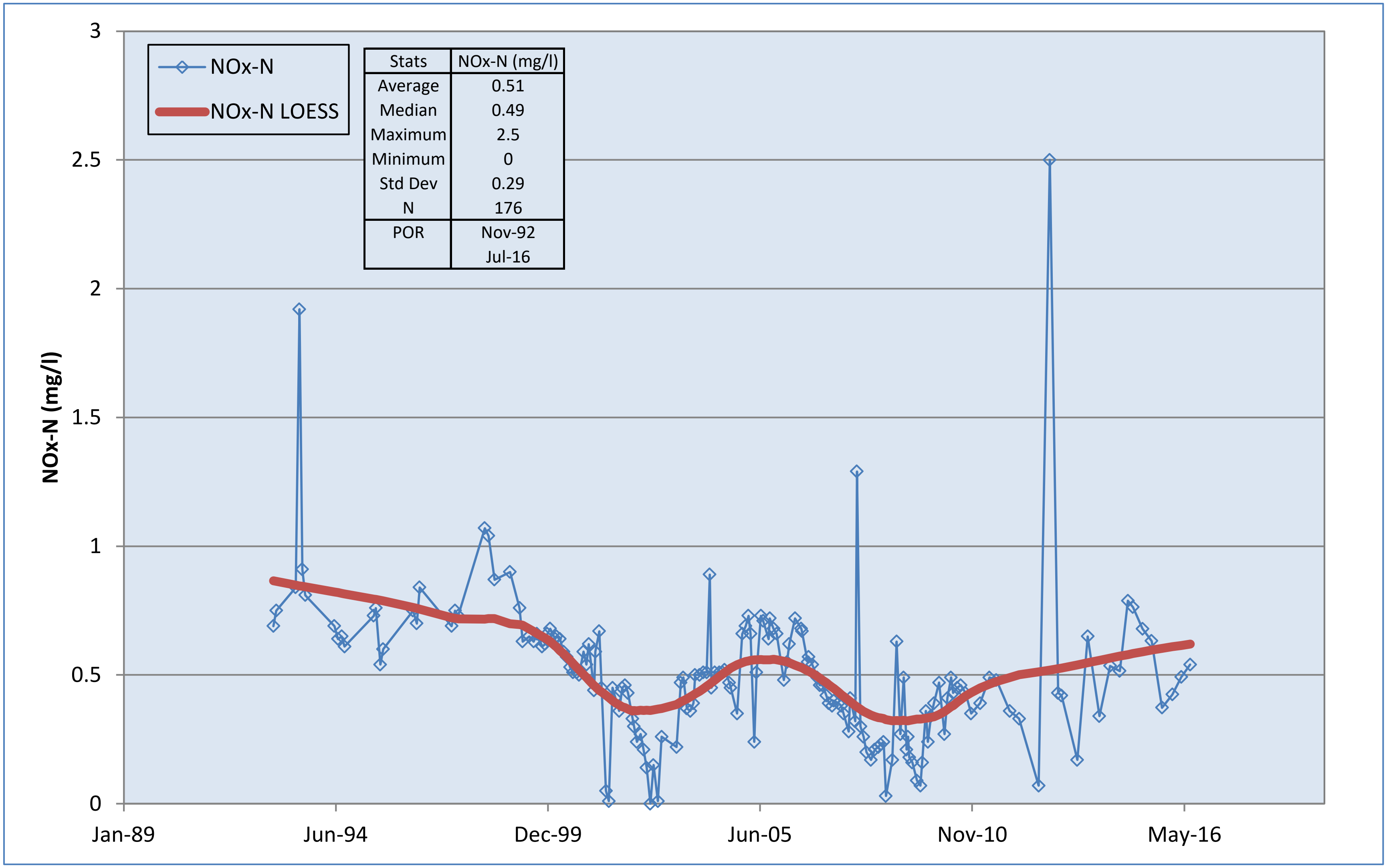
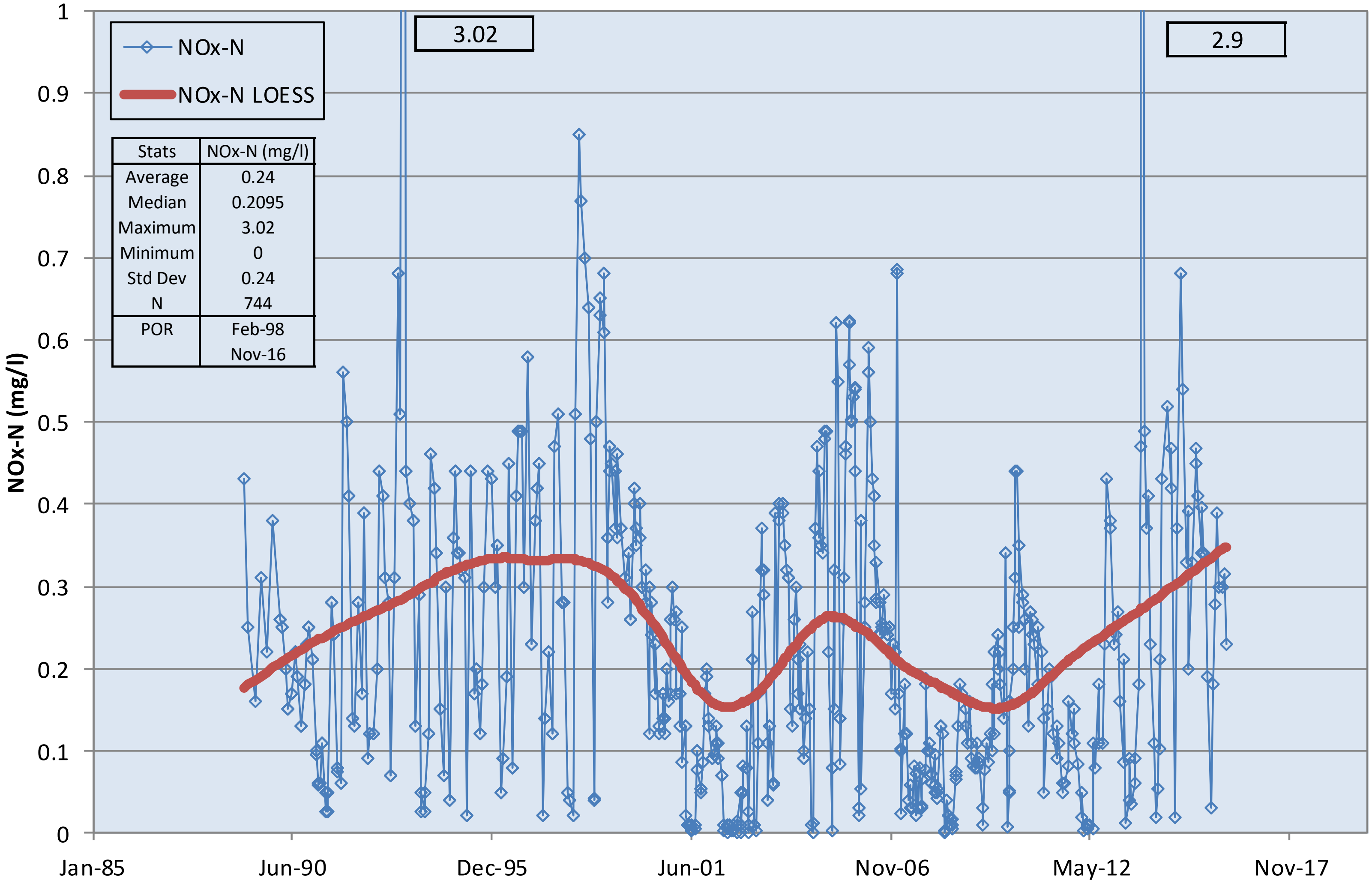
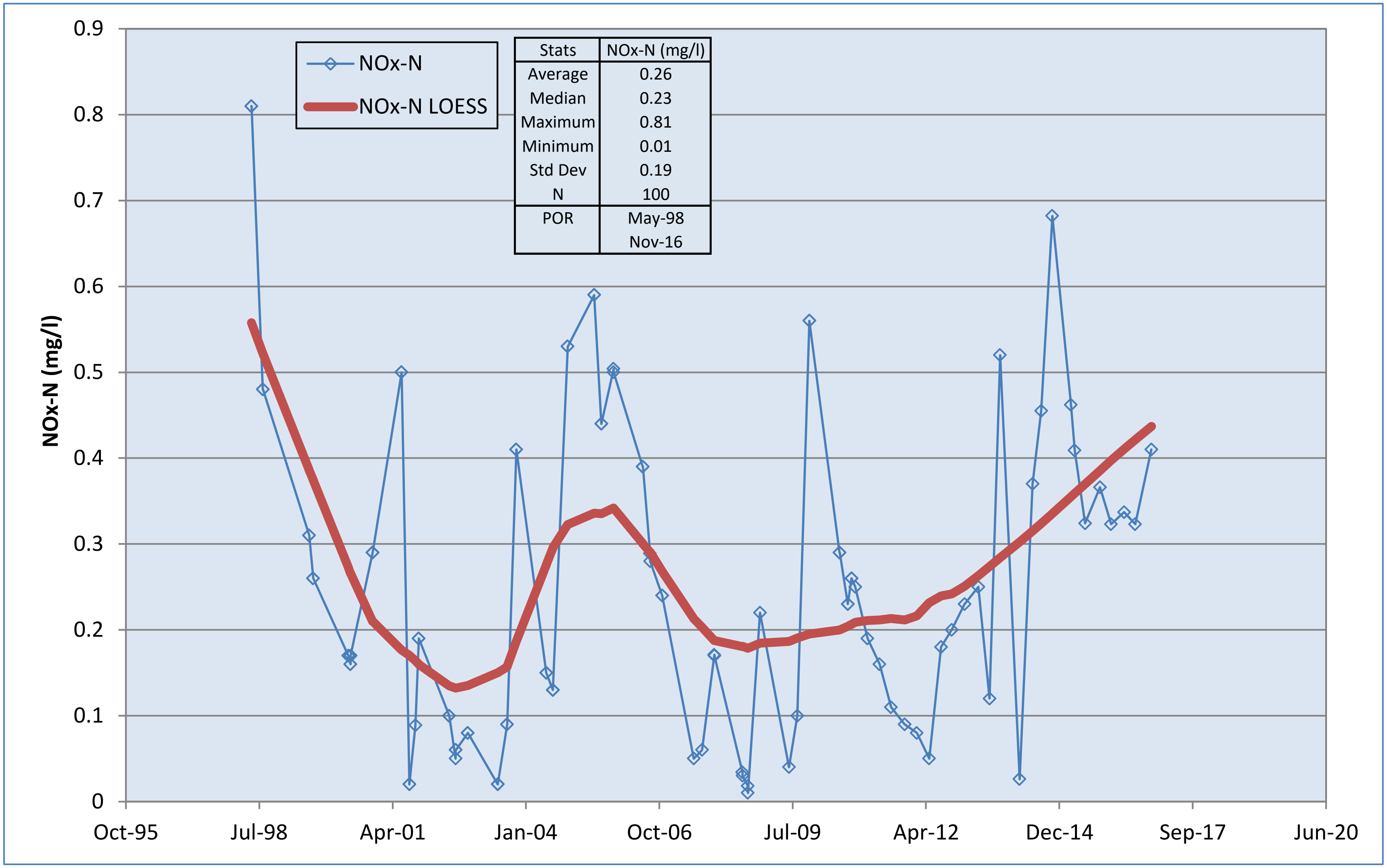


Figure 15. Period of record NOx-N data for Hornsby Spring



Stats	NOx-N (mg/l)
Average	0.24
Median	0.2095
Maximum	3.02
Minimum	0
Std Dev	0.24
N	744
POR	Feb-98 Nov-16

Figure 16. Period of record NOx-N data for the Santa Fe River at U.S. Hwy 441



Stats	NOx-N (mg/l)
Average	0.26
Median	0.23
Maximum	0.81
Minimum	0.01
Std Dev	0.19
N	100
POR	May-98 Nov-16

Figure 17. Period of record NOx-N data for Columbia Spring

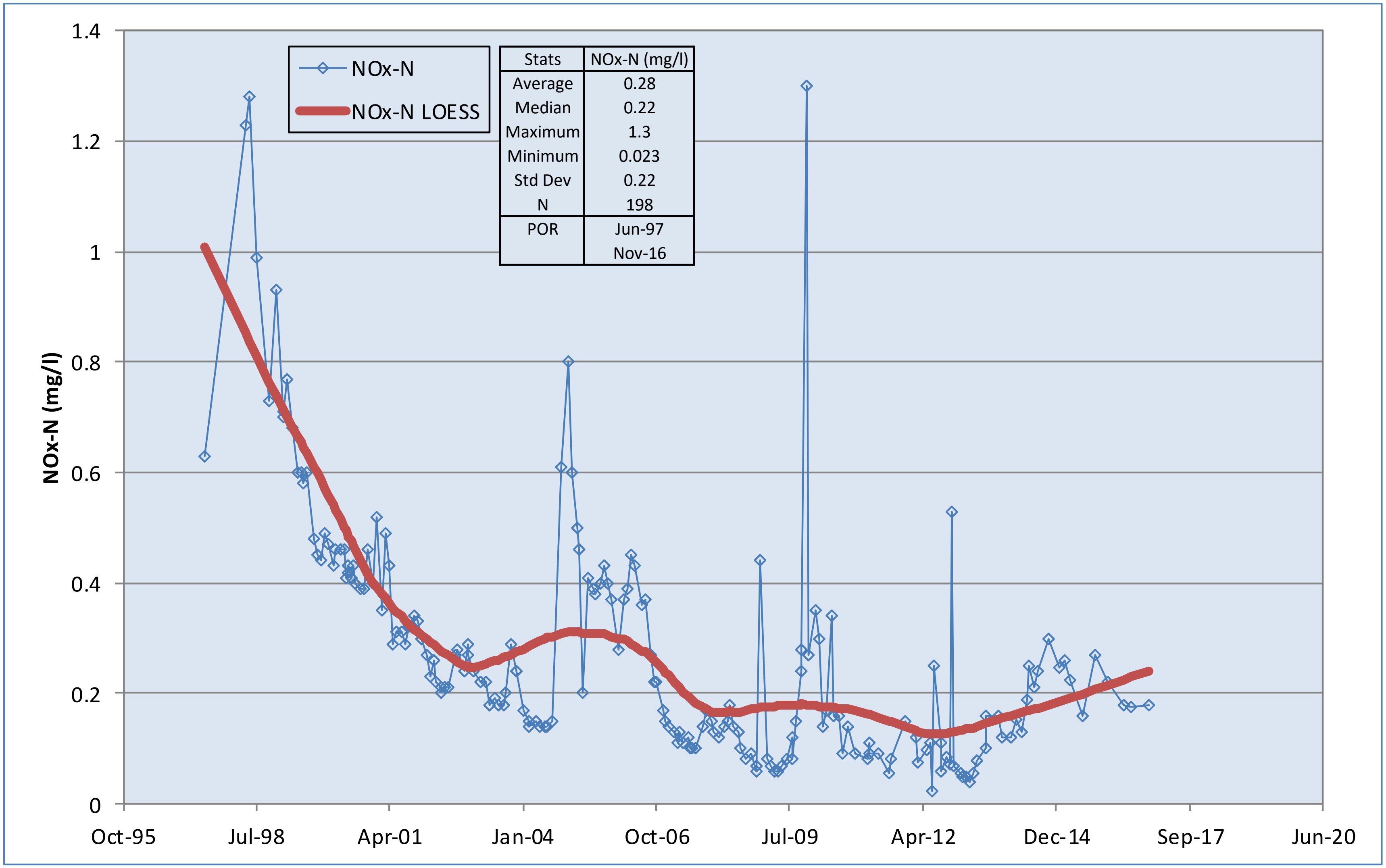
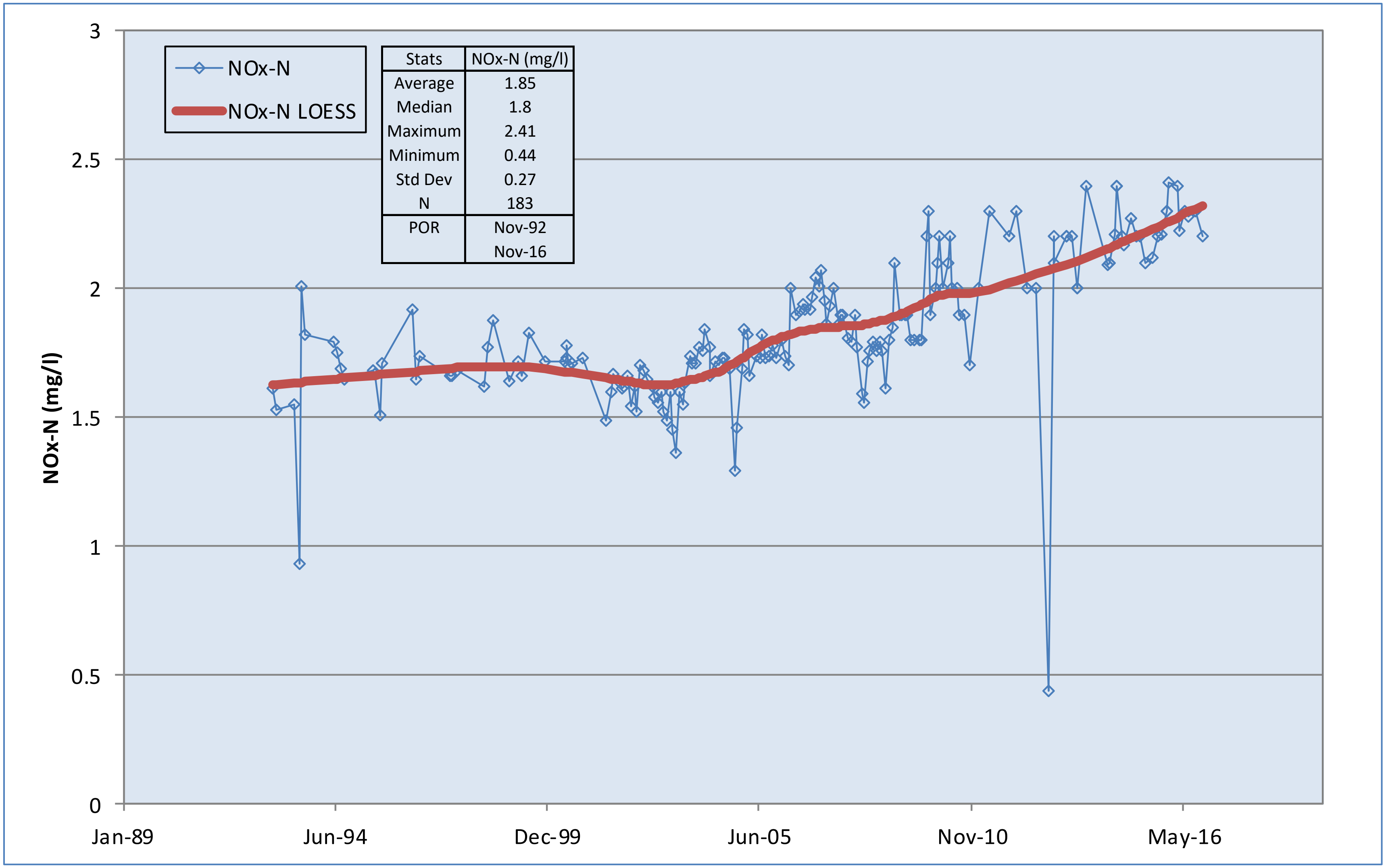


Figure 18. Period of record NOx-N data for Poe Spring



Stats	NOx-N (mg/l)
Average	1.85
Median	1.8
Maximum	2.41
Minimum	0.44
Std Dev	0.27
N	183
POR	Nov-92
	Nov-16

Figure 19. Period of record NOx-N data for Gilchrist Blue Spring

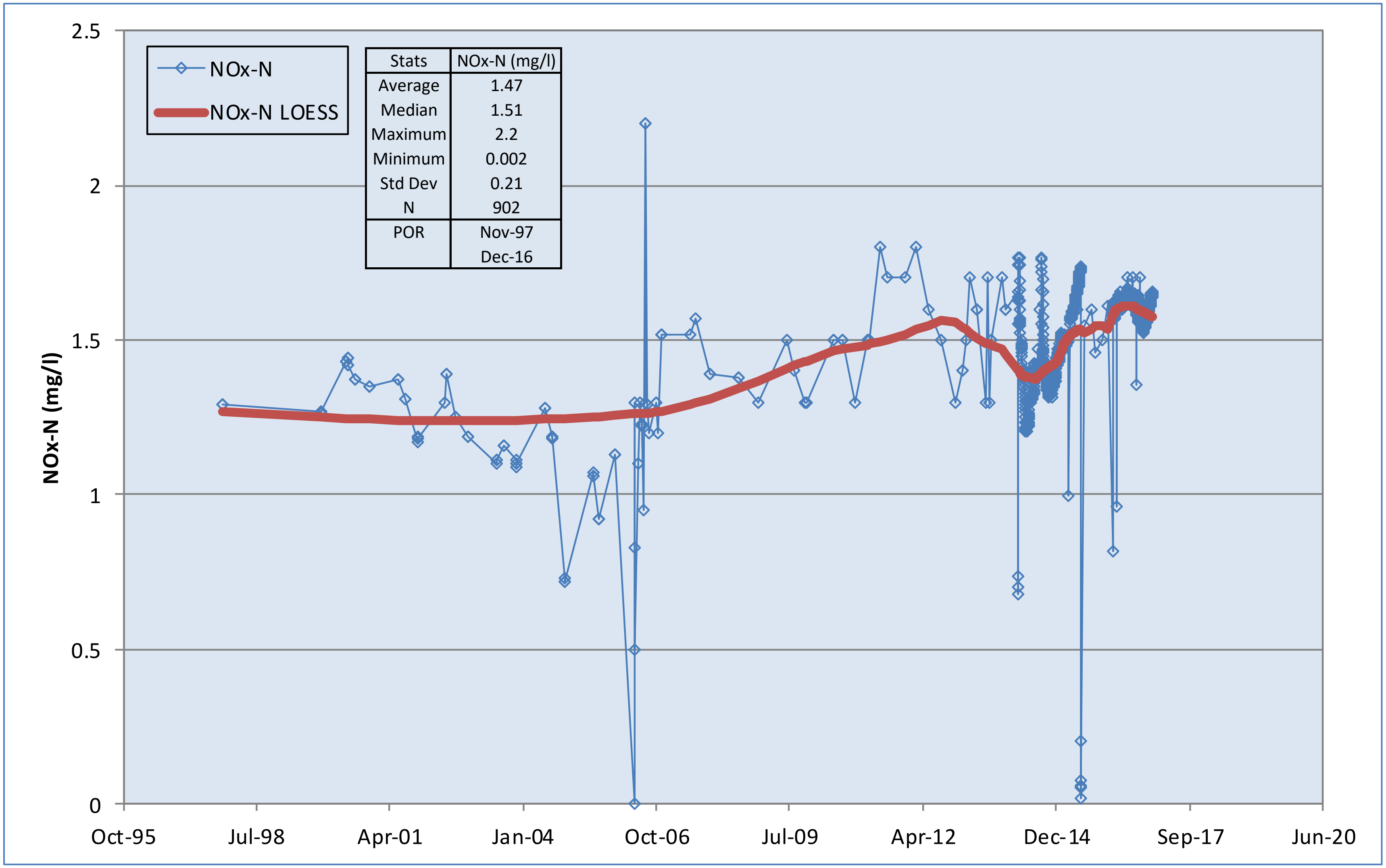


Figure 20. Period of record NOx-N data for Ginnie Spring

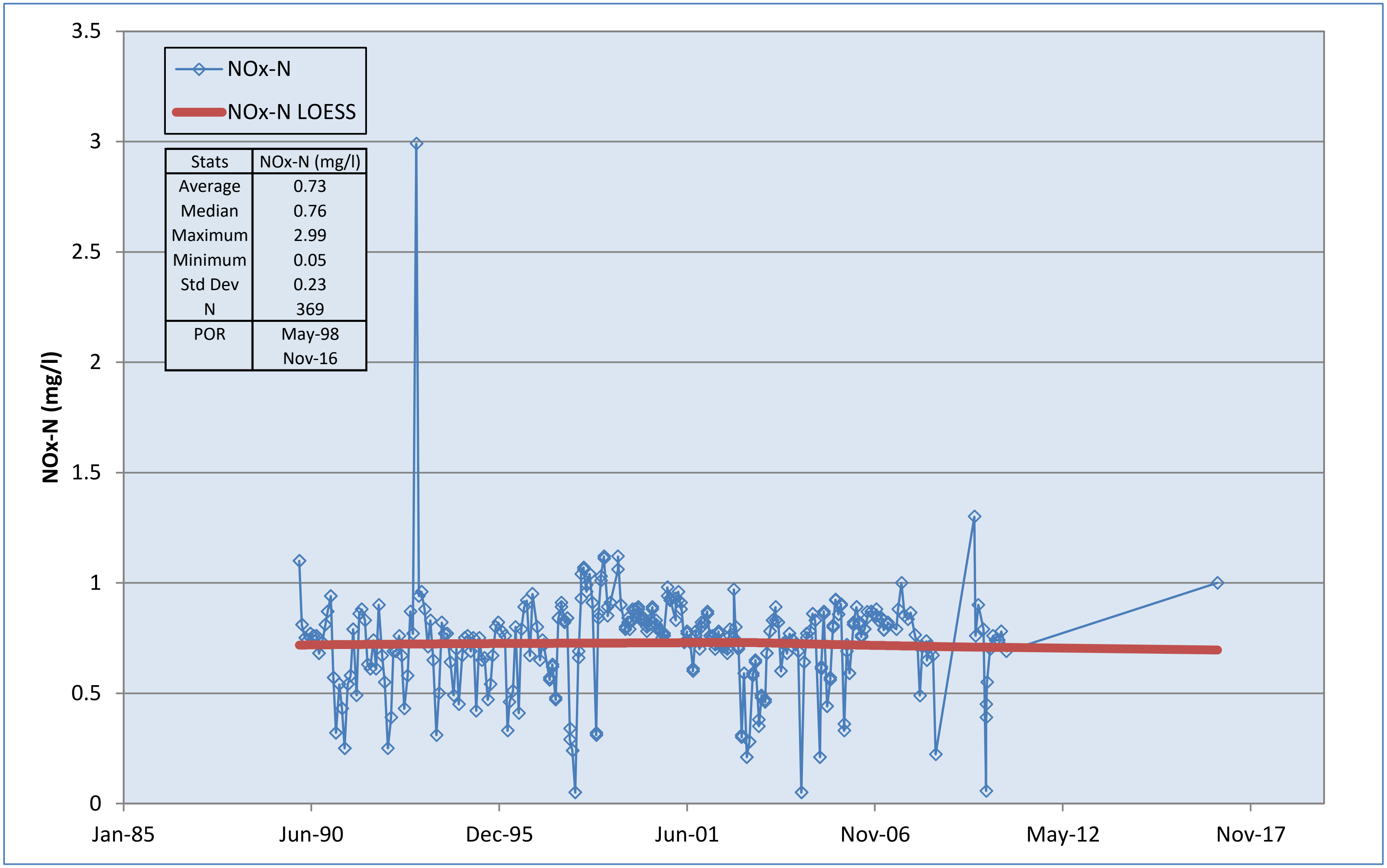


Figure 21. Period of record NOx-N data for the Santa Fe River at U.S. Hwy 47

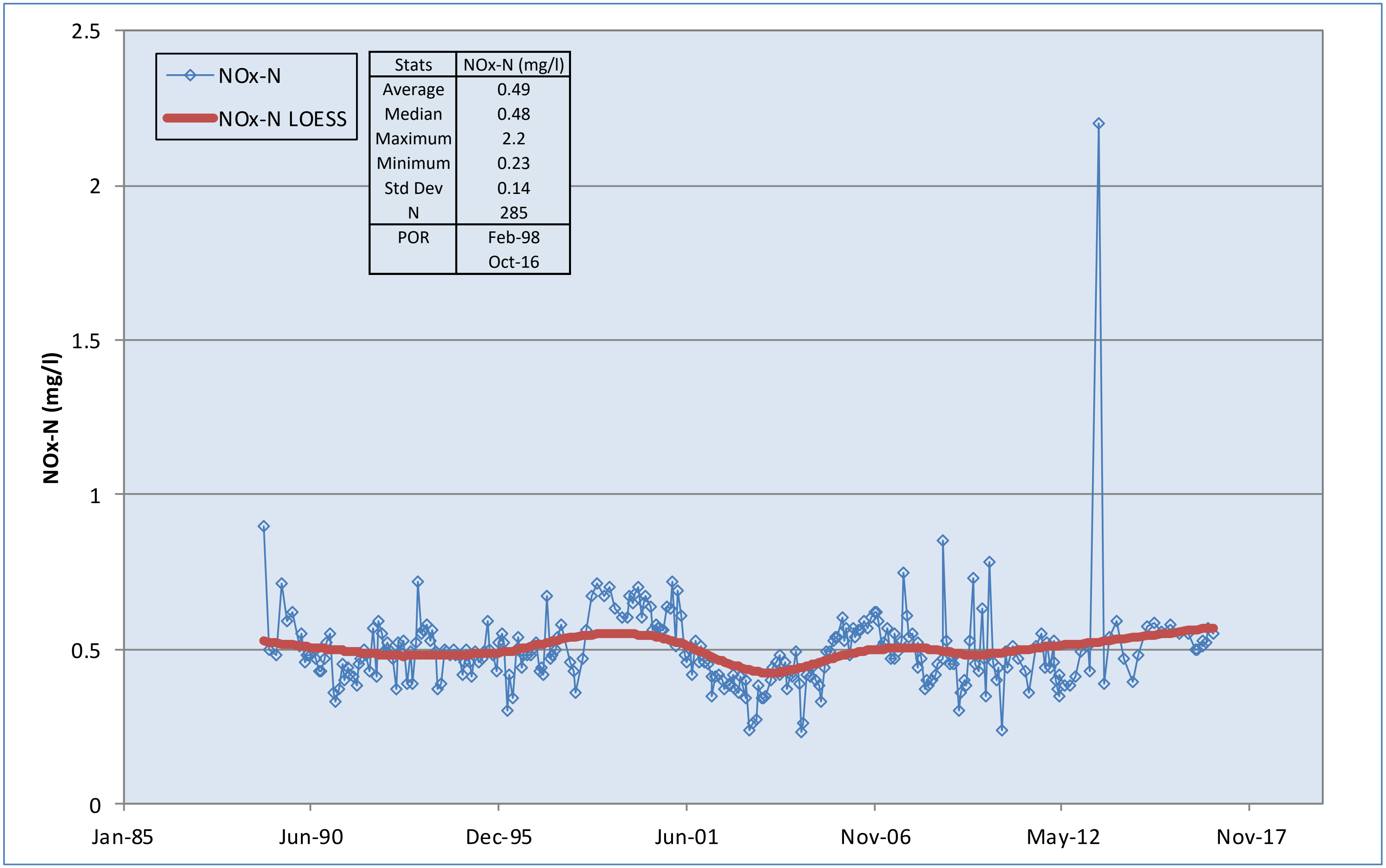


Figure 22. Period of record NOx-N data for the Ichetucknee River at U.S. Hwy 27

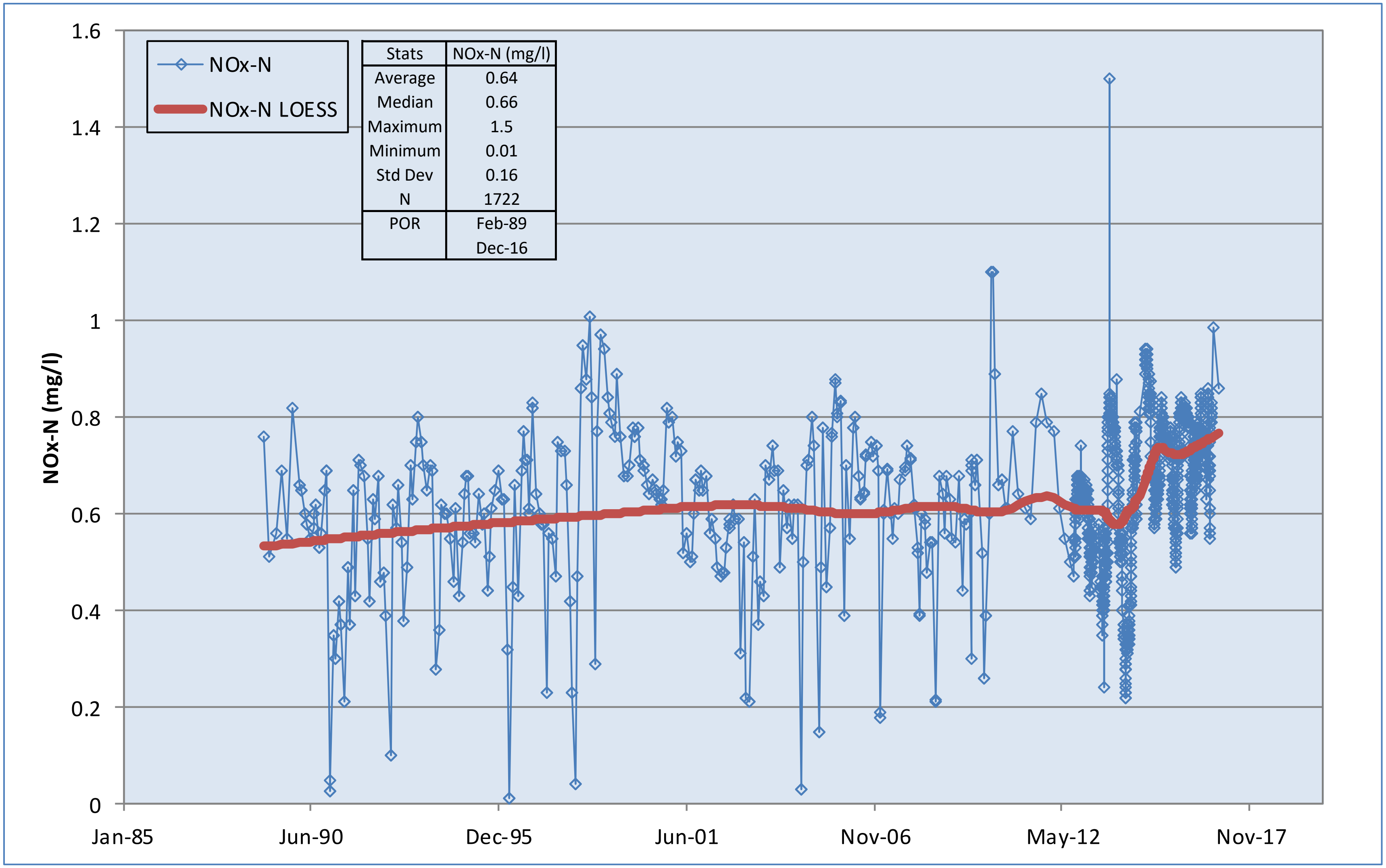


Figure 23. Period of record NOx-N data for the Santa Fe River at U.S. Hwy 129

Increased nitrate concentrations have occurred in the Santa Fe River over the last several decades. This increase resulted in the addition of the waters of the Lower Santa Fe River to the "Impaired Waters List" in 2008 for nutrients (nitrate nitrogen) and for low dissolved oxygen (FDEP, 2008). Elevated nitrate concentrations are believed to be related to an increase in the frequency of algal blooms during low-flow periods when the river water is primarily spring-fed and has the highest nitrate concentrations (FDEP, 2008).

Land use is the primary determinant of nitrogen source and loading rates. Fertilizer use is the primary source of nitrate pollution in the Santa Fe River Springshed, and is coming from residential, commercial, institutional, recreational, croplands, orchards and nurseries, and road land uses. Pasture and concentrated feeding operations (CAFOs) contribute livestock waste as a nitrogen source. Very limited nitrates are contributed by industrial, mining, undeveloped and utility land uses in the Santa Fe River Springshed (AMEC, 2013).

AMEC (2013) estimated the amount of nitrate nitrogen (NO_3-N) contributed by various land uses in the Santa Fe River Basin in 2004. This study found that 43% of the nitrate originated from pasture lands with less than 1% from CAFOs. An estimated 38% of the nitrate was sourced from fertilizer applied to tree plantations, field and row crops, residential, commercial, institutional, recreational, and orchard/ nursery land uses. Septic systems contributed an estimated 17% of the nitrogen load to the land surface, while permitted wastewater facilities contributed an estimated 1%. These totals add up to approximately 3.2 million pounds per year of nitrogen applied to the land surface within the springshed. Additional projections made to 2030 using changing land use trends in the area showed very little difference between 2004 and 2030 loading rates (AMEC, 2013). Travel times for the nitrate pollution were also studied and showed high uncertainty due to the karst limestone features typical of the area. Certain areas (Figure 27) were shown to have travel times of less than a month while other areas could fall between 25-100 years, although those times could also be much higher since there are known limestone conduits in the area.

More site-specific nitrate contamination studies were done for Poe and Hornsby Springs (Chasar et al., 2005; ACEPD, 2014). Chasar et al. (2005) found elevated levels of $\delta^{15}N$ isotopes in both Hornsby and Poe Springs which are likely indicators of nitrogen sources from human/animal waste or from denitrification. Denitrification was thought to be the likely culprit due to the enriched delta ^{15}N-NO_3 values, excess N_2, low dissolved oxygen, and elevated dissolved organic carbon. Interestingly, ACEPD (2014) found evidence of wastewater influences in Poe, Hornsby, and Watermelon #2 springs as indicated by the presence of sucralose, and elevated chloride and sulfate concentrations. Two wells near Hornsby Spring showed similar trends which point to the small wastewater treatment plant and rapid infiltration basin at Camp Kulaqua near Hornsby Spring as a likely source (ACEPD, 2014). Three wells within the Poe springshed also showed elevated levels of chlorides potentially sourced from wastewater influences or other non-point nitrogen loads. Wells in areas with a high density of on-site, septic systems showed low nitrogen concentrations and were deemed unusable in testing for nitrogen sourcing likely due to possible river water intrusion.

Pesticides and organic wastewater compounds were also measured in Poe and Hornsby Springs by Chasar et al. (2005). Three pesticides were detected: atrazine, metolachlor, and hexazinone. Thirteen organic wastewater compounds were also detected at low concentrations, with DEET being the highest. Bacterial testing indicated that Poe and Hornsby Springs met fecal coliform drinking water standards two of the three times tested and met recreational water standards all times. Viral data showed the springs susceptible to fecal pollution; however, the test did not confirm whether the virus detected was active or inactive. Viruses detected during the study correlated with the dates where bacterial indicators were also the highest.

Stable isotope testing of nitrogen and carbon was used to indicate trophic status and as tracers for the transport and transformation of nutrients (Chasar et al., 2005). The isotopic signatures of particulate organic matter, algae, and consumers reflect the availability of inorganic carbon and nutrients (Goerike et al., 1994; Chasar et al., 2005). Additional information regarding nutrient sources from sewage and fertilizers are provided by isotopic ratios and elemental composition. These values have been significant enough to show source and scale of the anthropogenic contributions (Lake et al., 2001; Fry, 1999; Tucker et al., 1999; Cabana and Rassmussen, 1996; Mako and Ostrom, 1994; Chasar et al., 2005). Hornsby and Poe Springs $\delta^{13}C$ signature revealed that filamentous algae were not an important source of food to invertebrates and forage fish. Similar studies in other systems reaffirm this conclusion. Filamentous algae may provide habitat or exist as a substrate for other periphyton that may be grazed. Algae tested in Hornsby Spring had slightly less enriched isotopes compared to those of Poe Spring. Poe Springs' invertebrates and biota were shown to be consistently enriched in ^{15}N relative to Hornsby Spring. The higher ^{15}N indicates possible contributions from animal waste or denitrification. In both spring runs, the concentrations of the isotopes decreased with increasing distance from the spring vent. Both sites had higher enrichment in $\delta^{13}C$ and $\delta^{15}N$ in invertebrates and fish which could be because of a change in loading rate but is more likely due the increase in temperature and photosynthetically active radiation (Chasar et al., 2015).

2.3.1 Santa Fe River Focus Area FDEP Nutrient Study

The Florida Department of Environmental Protection (FDEP) has been monitoring groundwater monitoring wells (MW), spring (SP), and surface water (SW) stations for nutrients and other possible pollutants since January 2013 in the Santa Fe Springs Focus Area Nutrient Study (FDEP, 2012). Figure 24 provides a map of the Santa Fe River Focus Area FDEP study stations. The blue boundary line identifies the springshed associated with Ginnie and Gilchrist Blue springs. All of these sampling stations lie within the Santa Fe River springshed.

Figure 25 identifies average NOx-N between stations, while Figure 26 provides the NOx-N time-series by station type over the period of record. Nitrate concentrations at the SW and SP stations have generally remained constant over the first three years of quarterly sampling, while the MW station nitrate levels have been increasing. The highest MW station is MW12 with a starting value measured as 32 mg/L in January 2013, the most recent value of 77 mg/L in September 2016, and a period-of-record average of 51.4 mg/L. The highest nitrate nitrogen concentrations are measured at the two monitoring wells adjacent to active dairy farms (MW12 and MW7).

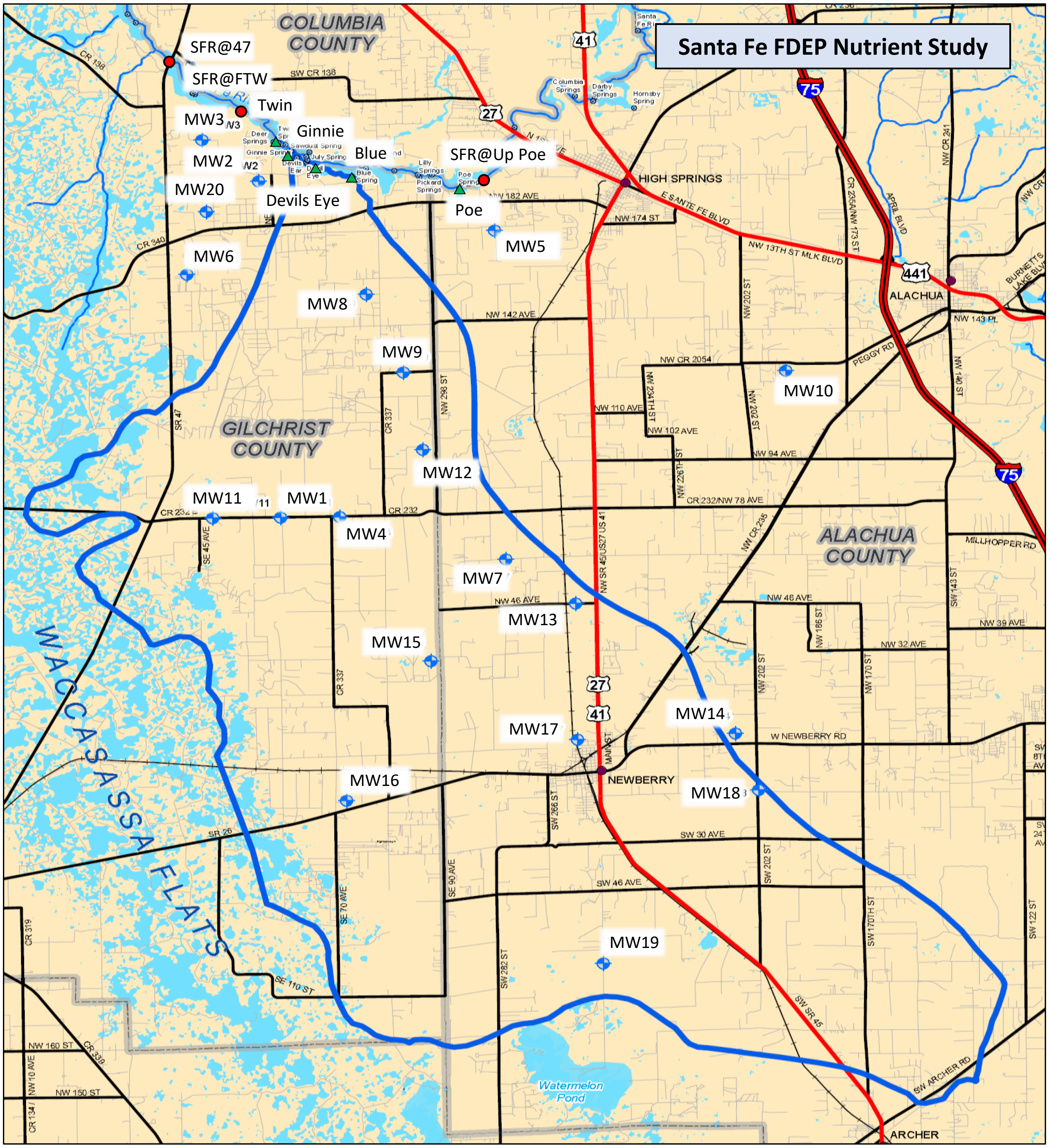


Figure 24. Map of Santa Fe FDEP Nutrient Study stations

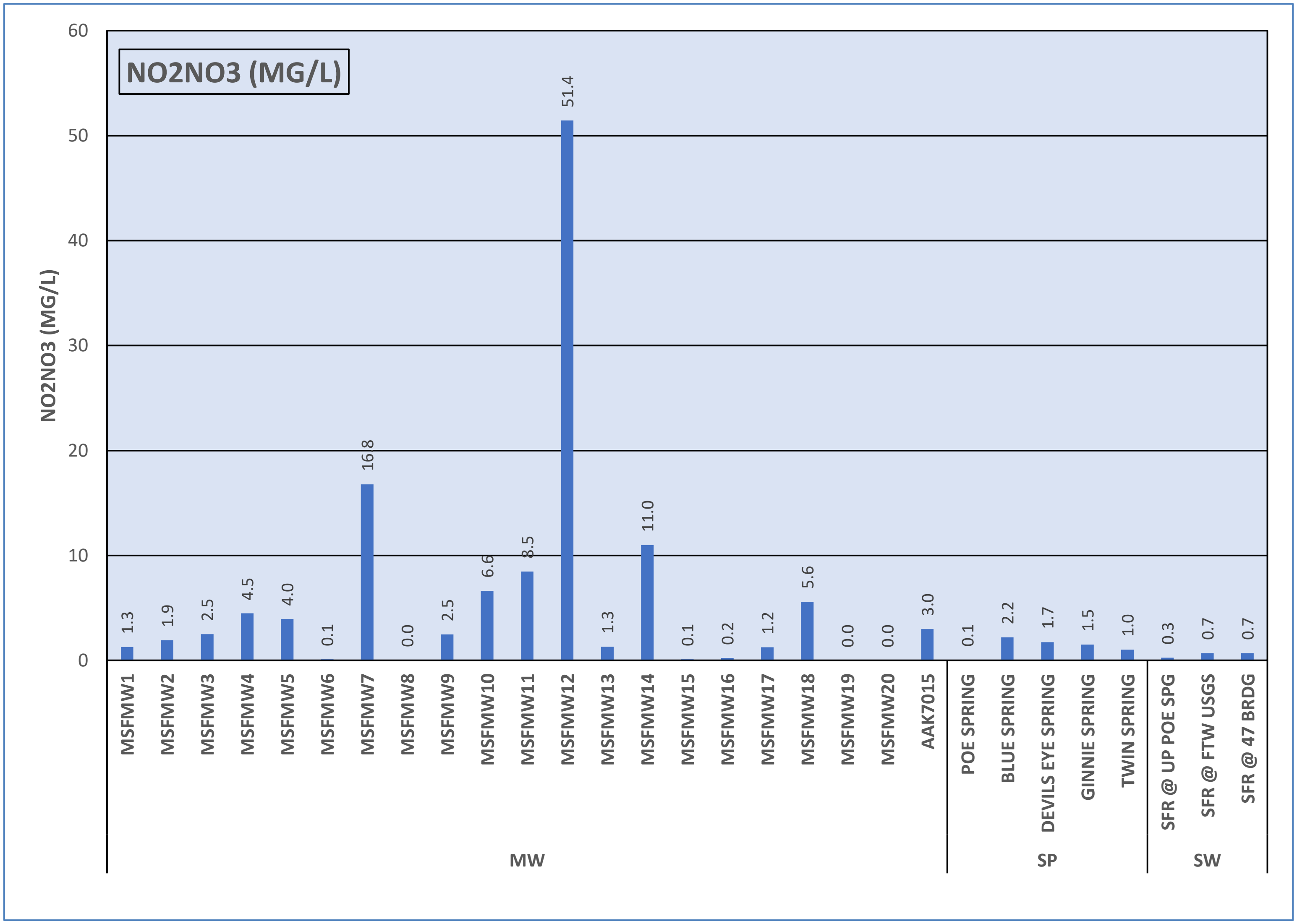


Figure 25. Santa Fe FDEP Nutrient Study average NOx-N (mg/L) by station (January 2013 – September 2016)

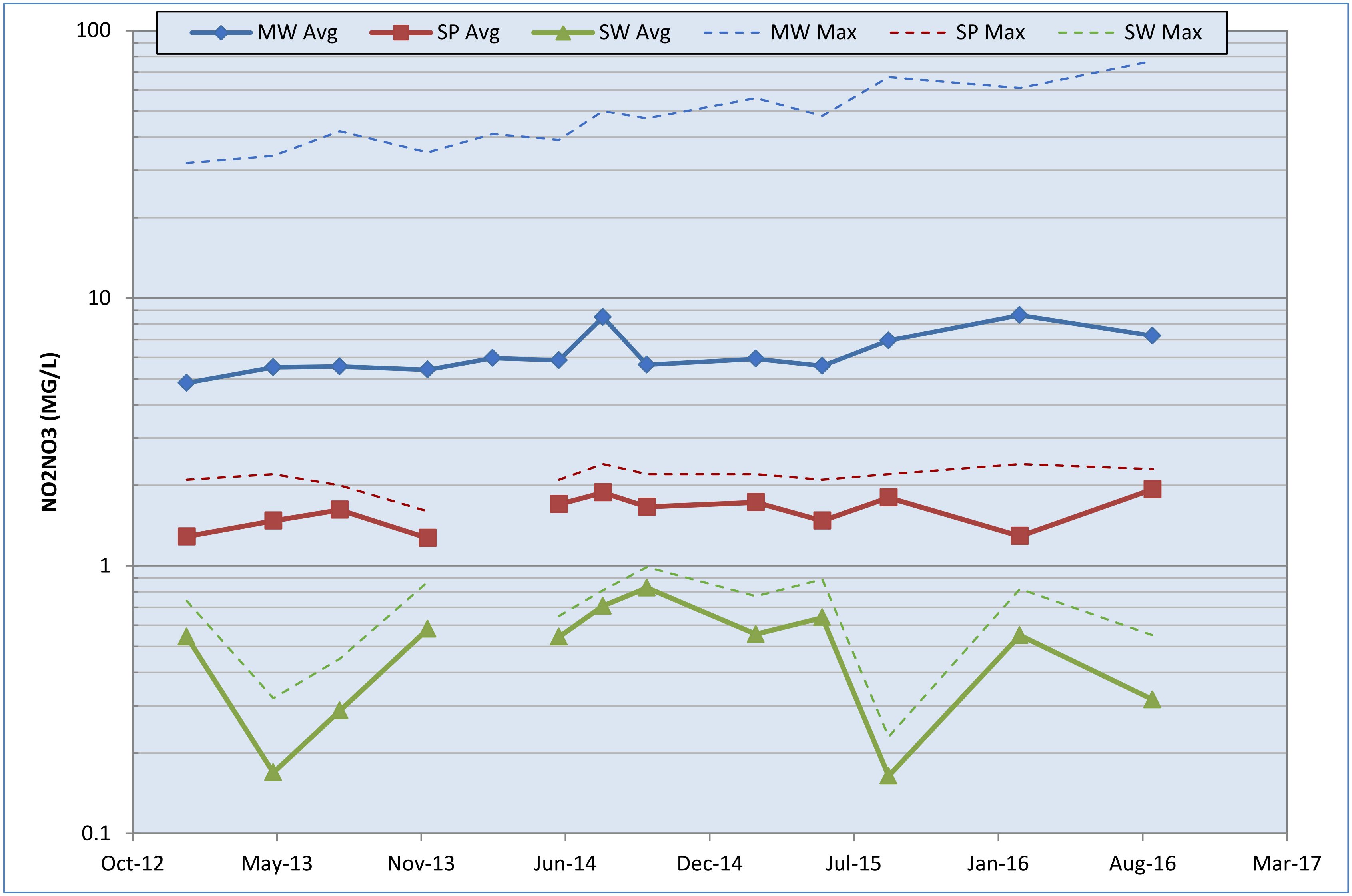


Figure 26. Santa Fe FDEP Nutrient Study average NOx-N (mg/L) times series (January 2013 – September 2016)

2.4 Biology and Ecology

A recent survey focusing on the ecology of the Lower Santa Fe River was conducted by Johnston et al. (2016) and looked at the turtle populations in the upstream river segment most influenced by blackwater (5 km stretch starting at the Santa Fe River Rise), and the downstream segment primarily spring-fed (Poe Spring to Deer Spring) (Figure 28). Ten native turtle species were found in both the blackwater and spring-fed segments. The density of all turtle species surveyed were found to be three to four times higher in the spring-fed segment of the river than in the blackwater influenced river. Given the population structure seen for three of the most abundant turtle species (*Pseudemys suwanneisis, S. minor,* and *Trachemys scirpta*) in the river stations versus the spring stations, it appears the springs are acting as turtle nursery areas. The occurrence of springs proved to be a major influence on the abundance and population structure of the turtles surveyed.

While no historical surveys of turtles in this region exist, there has been anecdotal documentation of turtle populations plummeting in the 1960s and 1970s due to harvesting. Johnston et al. (2016) suggested that turtle populations are currently growing or in recovery. Their report concluded that surveys should continue in this area, particularly because of how integral springs may be to turtle reproduction.

In addition to the turtle survey, Johnston, et al. (2016) summarized other biological data about the ecology of this section of the Santa Fe River and springs. Vegetation observed along the black water river banks included Water Hyacinth (*Eichhornia crassipes*), Duckweed (*Lemna sp.*), Water Spangles (*Salvinia minima*), Alligator Weed (*Alternanthera philoxeroides*), Smooth Water-hyssops (*Bacopa monnieri*), Marsh Pennywort (*Hydrocotyle sp.*), Water Milfoil (*Myriophyllum sp.*), and Smartweed (*Polygonum densiflorum*). The dark tannic water in this stretch of river limits the amount of submerged aquatic vegetation. During low river periods, nuisance algae (*Lyngbya wollei* and *Cladophora spp.)* has been known to thrive in this area. Limited information was found regarding the benthic macroinvertebrates of the blackwater influenced segment, however, Asiatic clams (*Corbicula fluminea*), unionid mussels (*Elliptio, Villosa*), Apple Snails (*Pomacea paludosa*), and Banded Mystery Snails (*Viviparus geogianus)* were found during the Johnston study. A study conducted in 2011 by Florida Fish and Wildlife Commission in the Upper Santa Fe River documented the occurrence of freshwater mussels. Eleven species of mussels, with one being federally listed as endangered and five listed as a Florida Species of Greatest Conservation Need (SGCN), were found in the Santa Fe River near Worthington Springs; while ten species were found with one being federally listed as endangered and five listed as SGCN (Florida Fish and Wildlife, 2011). American Alligators (*Alligator mississippiensis*), Plain-bellied water snakes (*Nerodia erythrogaster)*, and Brown water snakes (*N. taxispilota*) were also encountered.

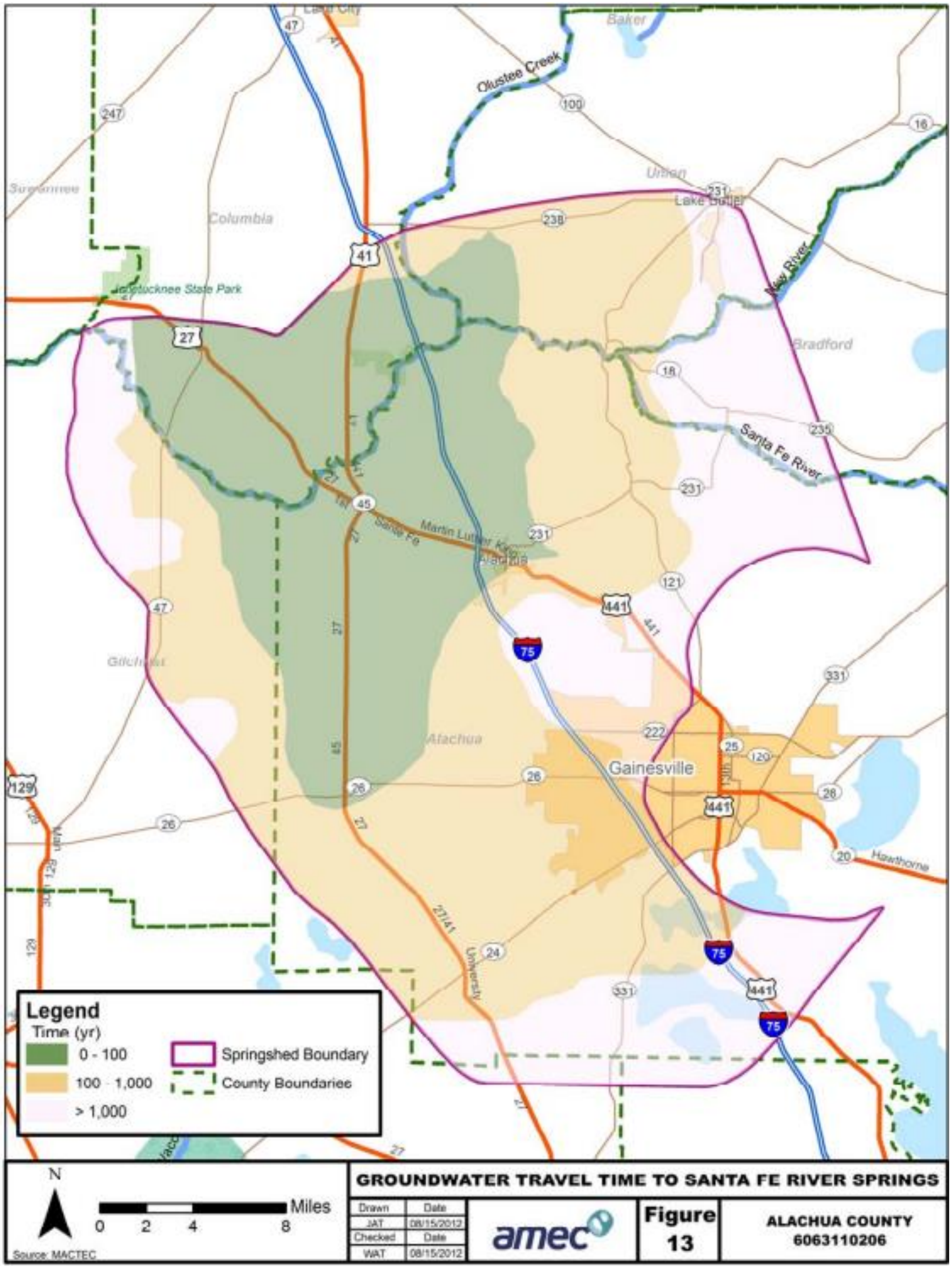


Figure 27. Groundwater travel times in the Santa Fe River Basin (AMEC, 2013).

Johnston et al. (2016) observed in the spring-fed segment submerged aquatic vegetation including: Muskgrass (*Chara* sp.), Carpet Moss (*Fontinalis* sp.), invasive hydrilla (*H. verticillata*), Indian Swampweed (*Hygrophila polysperma*), pondweed (*Myriophyllum* sp.), Springtape (*Sagittaria kurziana*), and Tapegrass (*Vallisneria americana*). The invasive species appeared to tolerate lower light conditions than the native plant species so when river levels rise and tannic water infiltrates, the invasive species may be able to outcompete the native ones (Bowes et al., 1977; Spener and Bowes, 1985; Johnston et al., 2016). Nuisance benthic and epiphytic algae (*Vaucheria spp.* and *L. wollei*) have occurred on the Santa Fe River since the 1990s and appeared most abundant during periods of drought (T. Morris, Pers. Obs.; Johnston et al., 2016). Algal communities studied on this stretch of river were found to occur the most nearest to the springs (Mattson et al., 1995; Johnston et al., 2016).

Macroinvertebrates in the spring segment of the river include various species of non-biting flies (Diptera - primarily chironomids), mayflies (Ephemeroptera), and stoneflies (Trichoptera), mollusks (Gastropoda - primarily snails, *Elimia floridensis*, Campeloma, Hydrobiidae, and Ancylidae, and bivalves [*Corbicula*, *Elliptio*, *Musculium*, *Sphaerium*, *Villosa*], crustaceans (primarily the amphipod *Hyalella azteca*), and worms (oligochaetes). Additionally, crayfish (*Procambarus* spp.) are very common in this segment of the Santa Fe River (Schramm and Martin, 1986; Johnston, 2016).

Limited fish surveys have occurred along the Santa Fe River. The Upper and Lower Santa Fe River was surveyed in 1967 and a total of 60 species were found, with 43 species of fish in the Upper Santa Fe River and 42 reported in the Lower Santa Fe River (Hellier, 1967). More recent observations have noted the presence of bowfin (*Amia calva),* which was not noted in Hellier (1967) or Bonvechio et al. (2005). The occurrence of the South American Suckermouth Catfish (*Pterygoplichthys* spp.) has also recently documented in the Santa Fe River (Nico et al., 2012), and Gulf coast sturgeon (*Acipenser oxyrinchus*) have recently been reported.

Additional vertebrate species encountered in this stretch of the river were *A. mississippiensis*, *N. erythrogaster*, *N. taxispilota*, and Eastern Diamondback Rattlesnakes (*Crotalus adamanteus*), River Otters (*Lontra canadensis*), Beavers (*Castor canadensis*), introduced Capybaras (*Hydrochoerus hydrochaeris*), and West Indian Manatees (*Trichechus manatus*) (Johnston et al., 2016; Mitchell and Johnston, 2012).

Upland vegetation communities along the Lower Santa Fe River and Ichetucknee River include bay swamp and cypress popash swamp (Ichetucknee only), cypress swamp, hardwood swamp, and hydric hardwood hammock, mesic hardwood hammock, marsh, and hardwood cypress (Lower Santa Fe only). Soil in the communities were primarily loamy/clayey except for the river banks and the bay swamp which are sandy (Atkins, 2012).

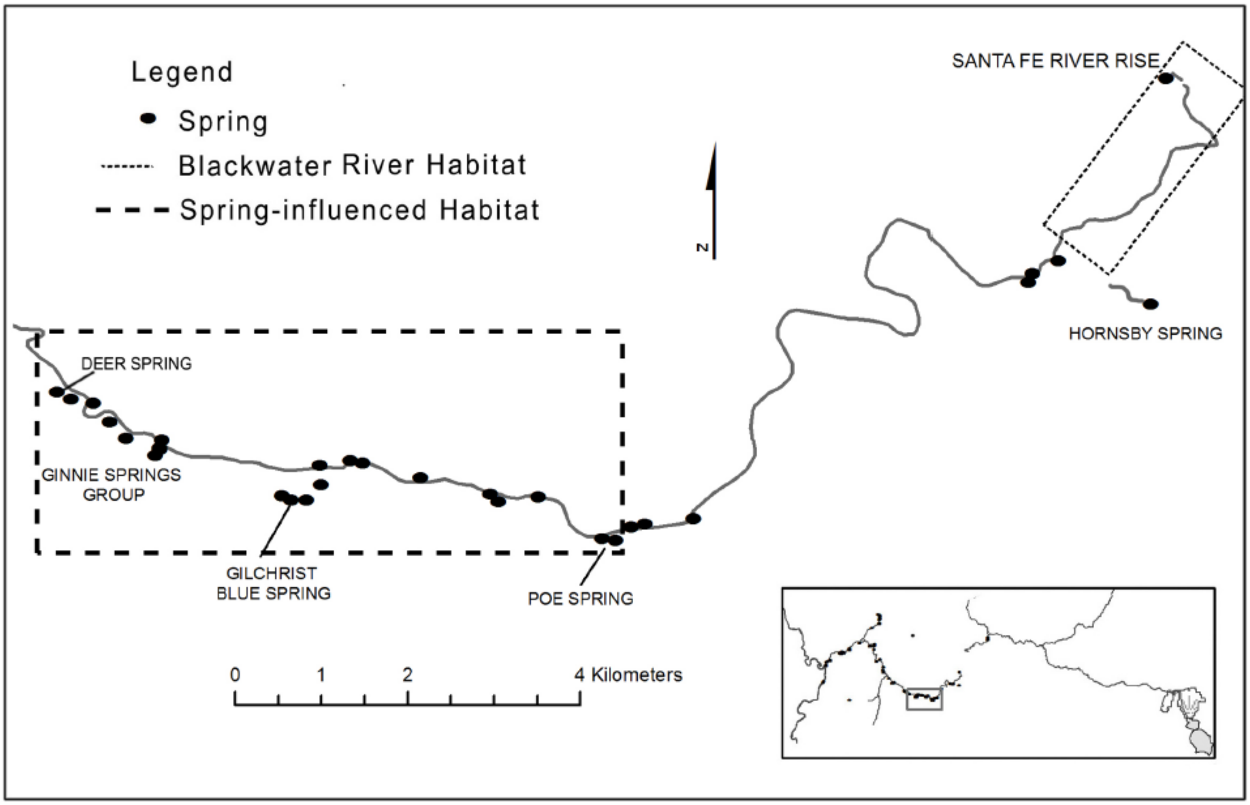


Figure 28. Study segments of the Lower Santa Fe River conducted by Johnston et al. (2016)

2.4 Human Use

The human use at several parks on the Santa Fe River was estimated during the period of 2008 to 2013 (Borisova et al., 2014). For Ichetucknee Springs State Park, Poe Spring, Rum Island Spring, Ginnie Springs, Gilchrist Blue Springs, and Hornsby Spring, there was an estimated annual average of 175,217 visitors who spent about 459,181 visitor-days, with most being spent at Ginnie Springs (205,000) and Ichetucknee Springs (177,651) (Borisova et al. 2014). These estimates vary widely from year to year and are influenced by weather, seasonality, and economic changes.

Human use on the Lower Santa Fe River changes dramatically from upstream to downstream. Boating, in both paddle-craft and motorized vessels, is common on the river. Most of the recreational use and boat traffic on the Santa Fe River is between the US 441 bridge and the HWY 47 bridge. This is due to the higher concentrations of boat ramps and river access points in this section. In the upper section of the river, recreation is also limited due to shallow depths and obstructions of flow paths by shallow gravel bars and downed logs. Kayaking, canoeing, and limited fishing still occur (Johnston et al. 2016). Canoe outfitters on the Santa Fe River estimate an average of 9,160 visitor-days annually. Swimming, snorkeling, and picnicking are popular at Poe Springs, Rum Island Springs, Blue Springs, and Ginnie Springs. Ginnie and Blue Springs both offer overnight camping. In the summer, many people enjoy tubing at both Ichetucknee Springs State Park and on the Santa Fe River adjacent to Ginnie Springs Outdoors. Scuba divers frequent Ginnie Springs for both open-water and cave diving, averaging about 15,000 visitor-days annually. For the 2012/2013 fiscal year, the estimated total economic value of the recreation centered around these parks, and services was $47.51 million (Borosova et al., 2014).

2.5 Ginnie Springs System Ecosystem Assessment

2.5.1 Introduction

The Ginnie Springs property is in the northeastern portion of Gilchrist County approximately three miles west of the Alachua County line and 350 feet south of the Columbia County line. A total of five named first and second magnitude springs including Ginnie Spring, Devil's Eye, Devil's Ear, Dogwood Spring, and Twin Spring are located on the property immediately south of the Santa Fe River. Figure 29 and Figure 30 show the location of the Ginnie Springs Outdoors, Inc. (GSO) property and the springs within the property boundary.

The GSO park is perhaps the most popular private springs recreation site in the State of Florida and is world-renowned for its cave diving opportunities. Camping is permitted on the property and facilities exist in each spring to facilitate access to the water via stairs to avoid erosion of the spring banks.

This report describes an ecological evaluation that was completed at GSO during 2012 and 2013 by Wetland Solutions, Inc. (WSI, 2013). This study evaluated discharge, springs water quality, water clarity, and biological indicators for five of those springs (Deer, Twin, Dogwood, Ginnie, and the Devil Springs System).

2.5.2 Spring Segment Area, Mean Depth, Volume, and Length

Bathymetric surveys were used to estimate the mean depth, water volume, wetted surface area, and spring run average width and total length, for each of the five spring systems studied. The bathymetric maps for Deer Spring and Twin Spring are shown in Figure 31; Dogwood Spring and Ginnie Spring are shown in Figure 32; and the Devil Springs System is shown in Figure 33.

Deer Spring has an estimated wetted surface area of approximately 863 m^2 and an estimated water volume of 527 m^3. The estimated mean depth of the Deer Spring system is 0.6 m. Deer Spring discharges from a narrow, limestone spring vent (approximately 2.5 m deep) into a circular pool about 30 m in diameter. An approximately 4 m wide spring run forms on the eastern side of the pool and flows about 50 m northeast to the Santa Fe River at a depth of approximately 0.75 m.

Twin Spring has an estimated wetted surface area of approximately 835 m^2 and an estimated water volume of 817 m^3. The estimated mean depth of the Twin Spring system is 1.0 m. Twin Spring discharges from a narrow, limestone fissure (approximately 3 m at the deepest point) into an oval-shaped pool with a length of approximately 40 m. The Twin Spring channel forms at the northeast corner of the pool and is approximately 25 m long and 9 m across with an average depth of about 1 m.

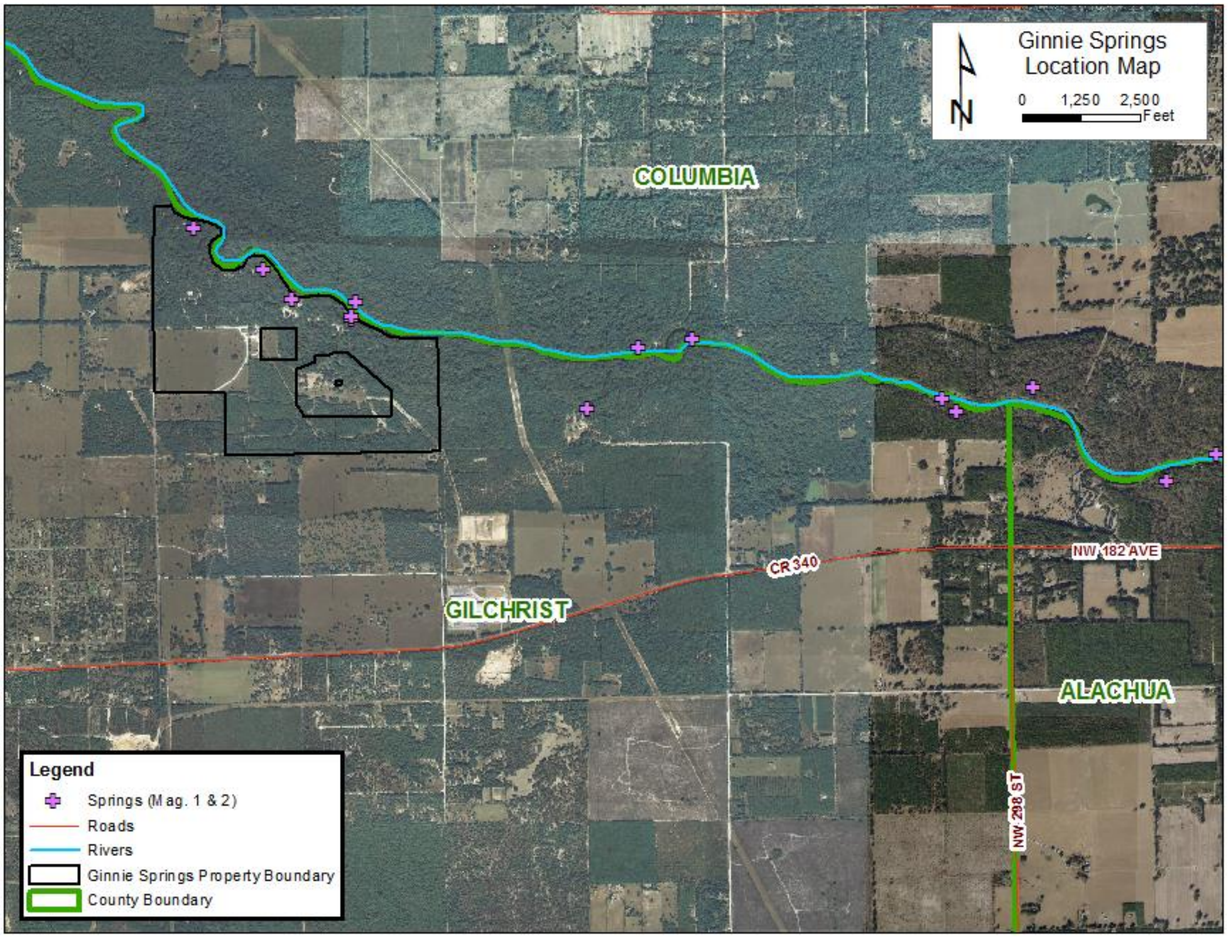


Figure 29. Ginnie Springs property location

Dogwood Spring has an estimated wetted surface area of 1,271 m^2 and an estimated water volume of 1,309 m^3. The estimated mean depth of the Dogwood Spring system is 1.0 m. The Dogwood Spring boil is approximately 23 m across. Dogwood Spring has a narrow, limestone spring vent (approximately 2 m by 10 m). The Dogwood Spring channel is about 50 m long with an average width of about 14 m.

Ginnie Spring has an estimated wetted surface area of approximately 2,097 m^2 with an estimated water volume of 2,534 m^3. The estimated mean depth of the Ginnie Spring system is 1.2 m. The Ginnie Spring boil is approximately 30 m across with an approximately 4.3 m deep spring pool with gently sloping sandy sides. The spring channel contains several submerged trees and is approximately 70 m in length and has an average width of 18 m. On the north side of the channel the banks are sloped and on the south side of the channel the bank is more nearly vertical and is covered by masses of tree roots and wooden retaining walls.

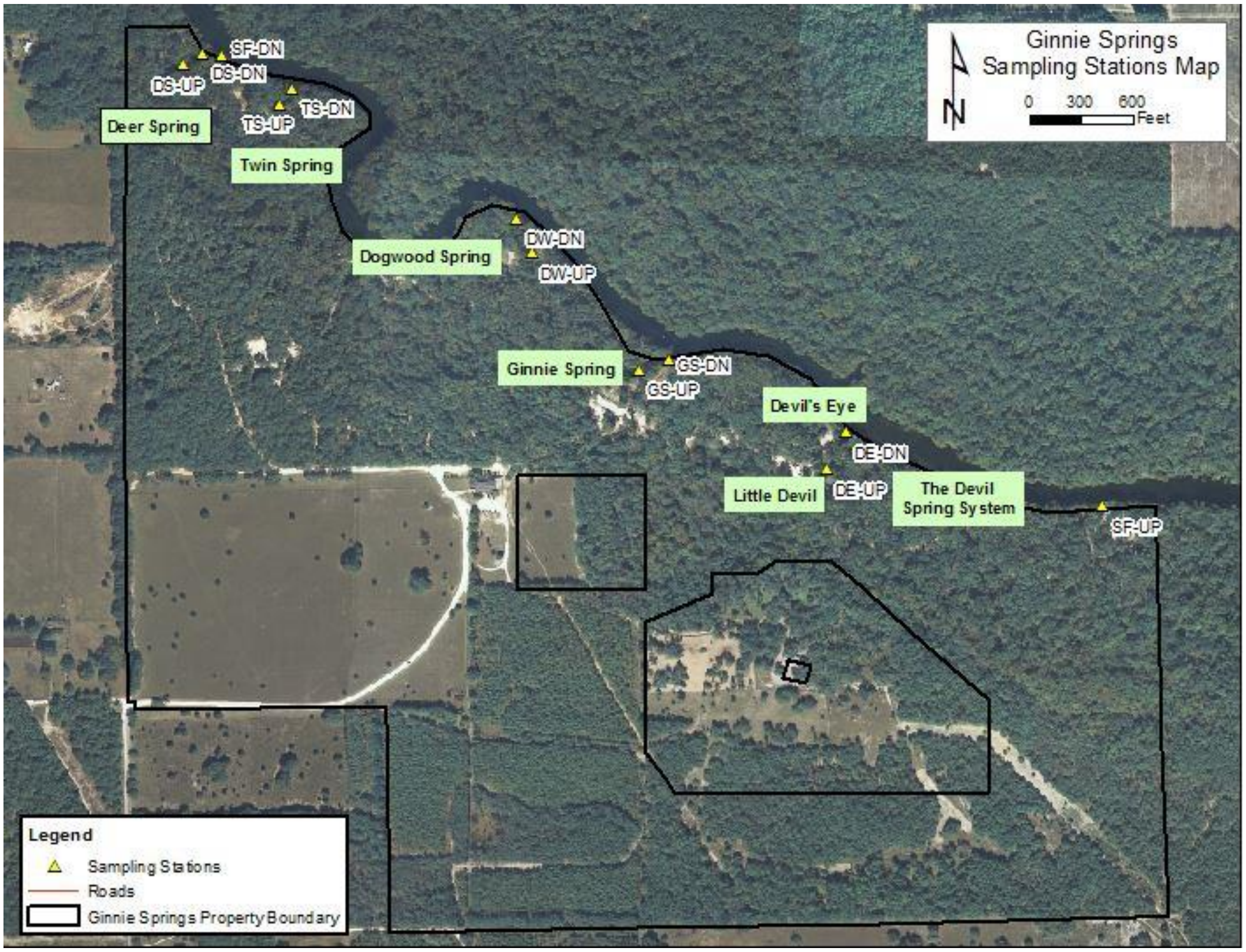


Figure 30. Ginnie Springs location map and sampling stations

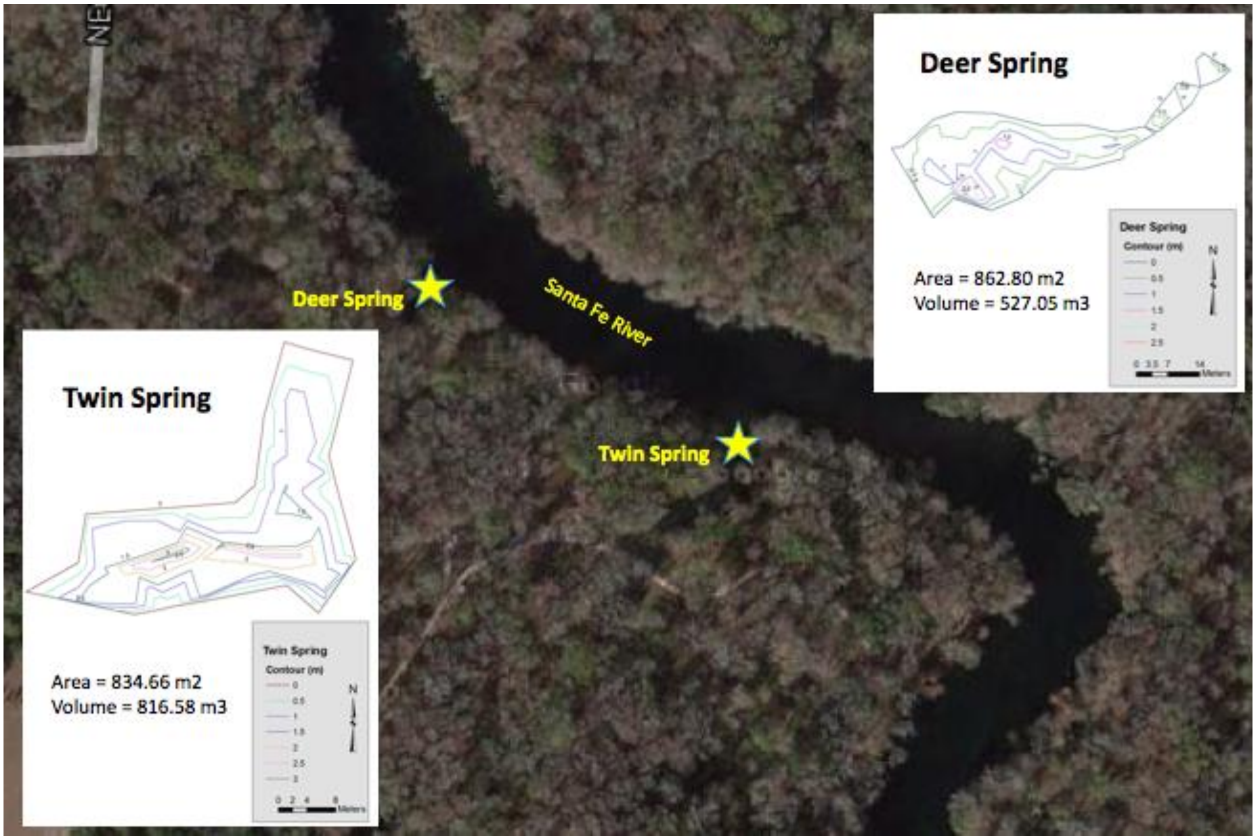


Figure 31. Deer Spring and Twin Spring bathymetric maps

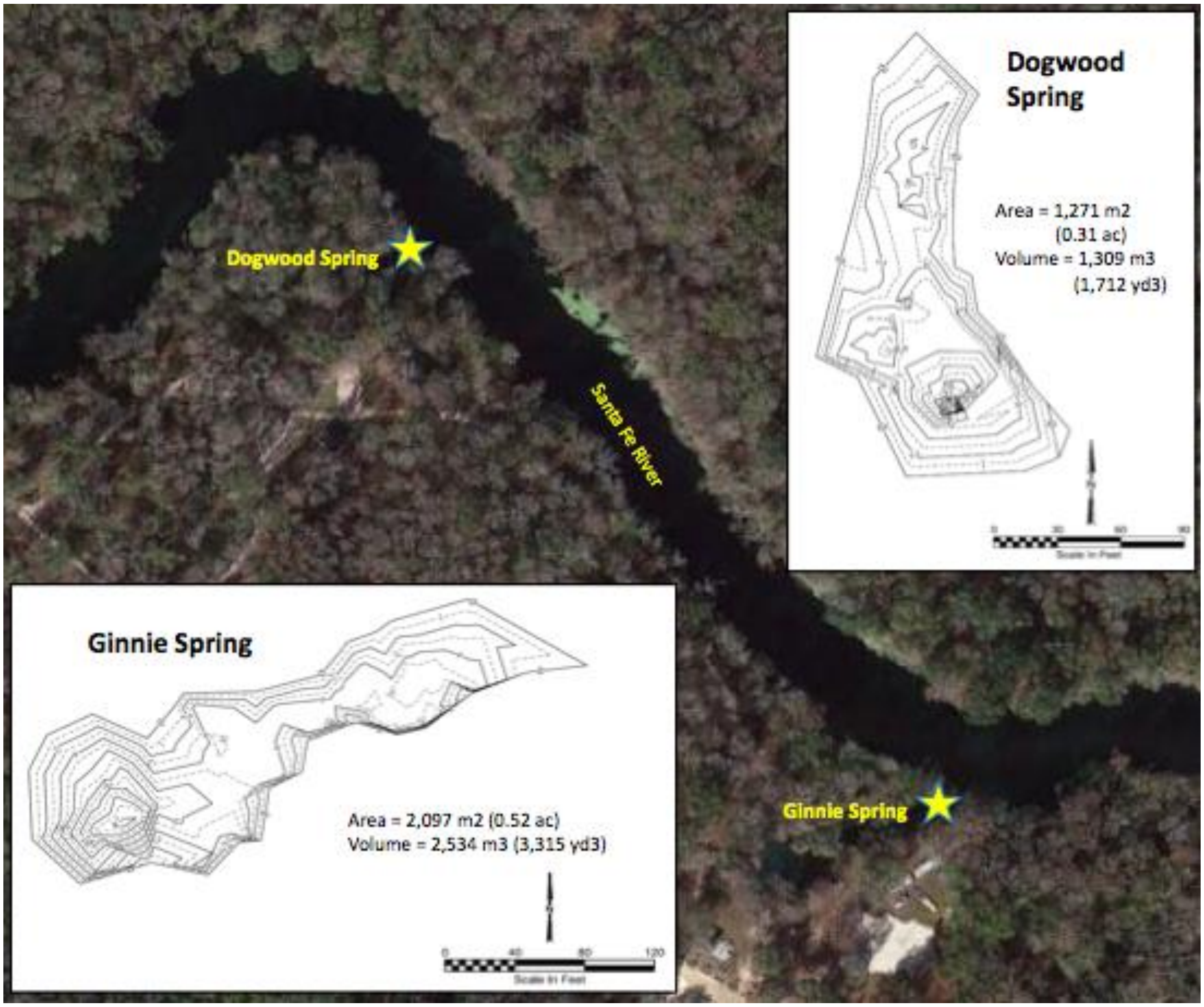


Figure 32. Ginnie and Dogwood Springs bathymetric maps

The Devil Springs System for this study included only Little Devil Spring and Devil's Eye Spring. The Devil Springs System has an estimated wetted surface area of 1,923 m^2 with an estimated water volume of 1614 m^3. The estimated mean depth of the Devil Springs System is 0.8 m. The Little Devil spring vent is approximately 7 meters across and flows into an oval-shaped pool (approximately 7 m wide and 10 m in length). The spring run flows northeast about 70 meters until it is joined by the spring flow from the Devil's Eye boil. The Devil's Eye boil is circular with a diameter of approximately 5 meters across and a total depth of about 6 meters. Devil's Eye Spring flows into a circular pool. The combined flow from Devil's Eye and Little Devil Spring enters the Santa Fe River and passes over the Devil's Ear Spring boil to the North.

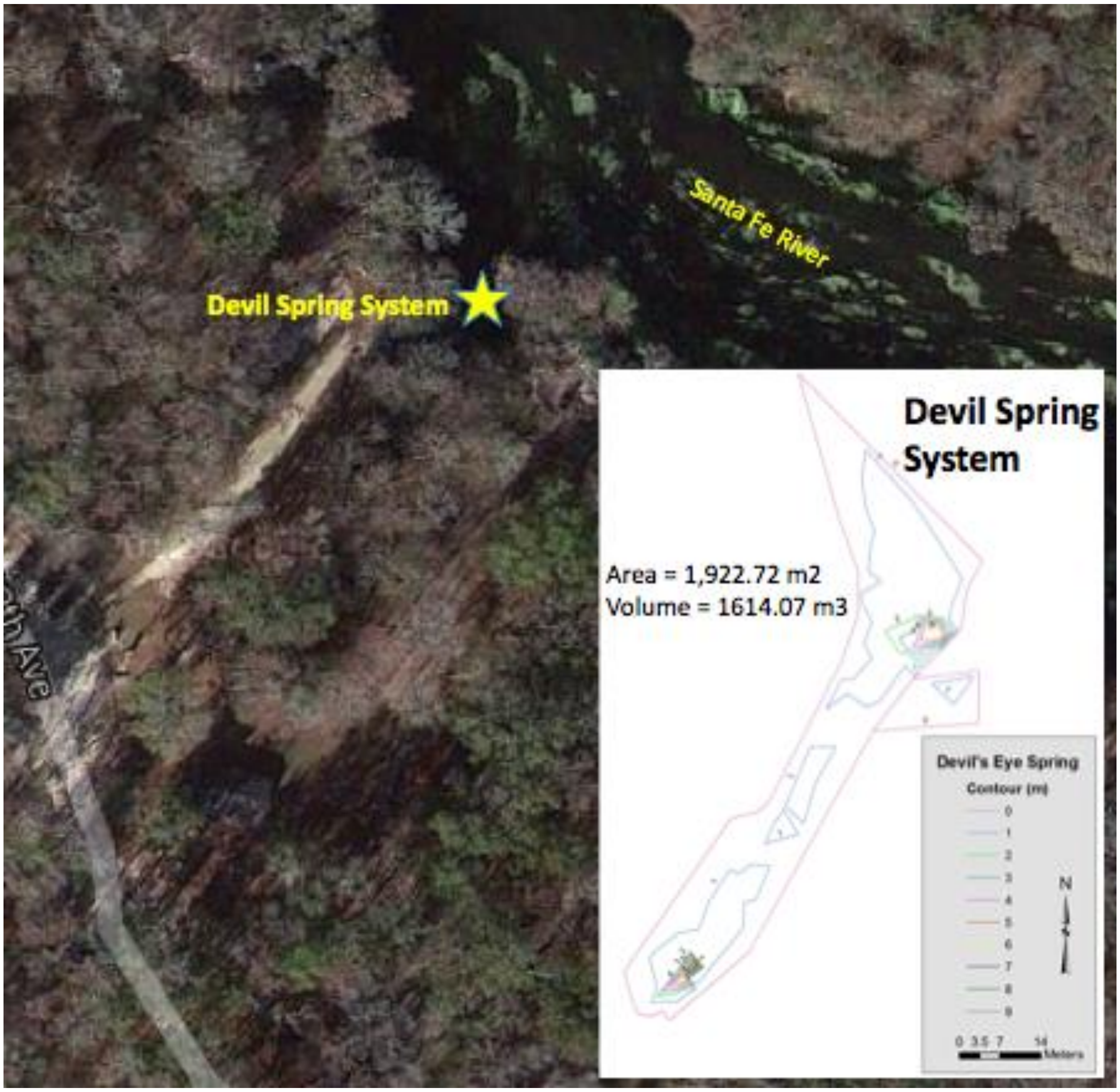


Figure 33. Devil Springs System bathymetric map

2.5.3 Flow Measurements

Table 9 summarizes flow measurements collected during each sampling event. During the period of this study, flows averaged -0.4 cfs at Deer Spring, -2.6 cfs at Twin Spring, 8.3 cfs at Dogwood Spring, 32.4 cfs at Ginnie Spring, 12.4 cfs at the Devil Springs System, and -3.9 at Little Devil Spring. Table 9 also includes the Santa Fe River flows and stages (USGS Station 2322400) during each event. The highest Santa Fe River flows were observed in Summer 2012 following Tropical Storm Debby (1,600 cfs) with the lowest in Winter 2013 (813 cfs).

In Spring 2013, negative flows were measured for both Deer and Twin Springs. During this period the Santa Fe River as measured at Fort White upstream from the US 47 bridge (USGS 02322500) was in flood stage (Figure 34) and dark water from the Santa Fe River was observed in both boils. Negative flows were also measured at Twin Spring in Winter 2013, however the spring boil was observed to be clear, not indicative of negative flow.

Table 9. Springs discharge measured at the Ginnie Springs Group by WSI the 2012 and 2013 sampling events

	Flow (cfs)						Santa Fe River (USGS 2322400)	
Date	Deer Spring	Twin Spring	Dogwood Spring	Ginnie Spring	Devil Spring	Little Devil Spring	Flow (cfs)	Stage (ft NGVD 29)
7/26/2012	---	---	12.05	35.61	---	---	1,600	22.54
8/2/2012	---	---	9.58	37.11	---	---	1,370	22.24
8/9/2012	---	---	7.82	31.91	---	---	1,310	22.16
Summer 2012	---	---	9.82	34.88	---	---	1,427	22.31
2/12/2013	0.38	-0.65	9.03	27.88	11.82	---	812	21.21
2/20/2013	0.48	-1.23	7.50	27.22	11.63	---	813	21.21
3/18/2013	0.18	-1.78	10.31	32.15	13.05	---	841	21.26
Winter 2013	0.35	-1.22	8.95	29.08	12.17	---	822	21.23
5/8/2013	-1.18	---	---	39.63	---	-6.45	---	22.58
5/15/2013	---	-3.94	6.09	---	---	---	1,430	22.07
5/31/2013	---	---	---	26.68	12.71	-1.26	927	21.44
Spring 2013	-1.18	-3.94	6.09	33.15	12.71	-3.86	1,179	22.03
Average	**-0.42**	**-2.58**	**8.28**	**32.37**	**12.44**	**-3.86**	**1,142**	**21.86**

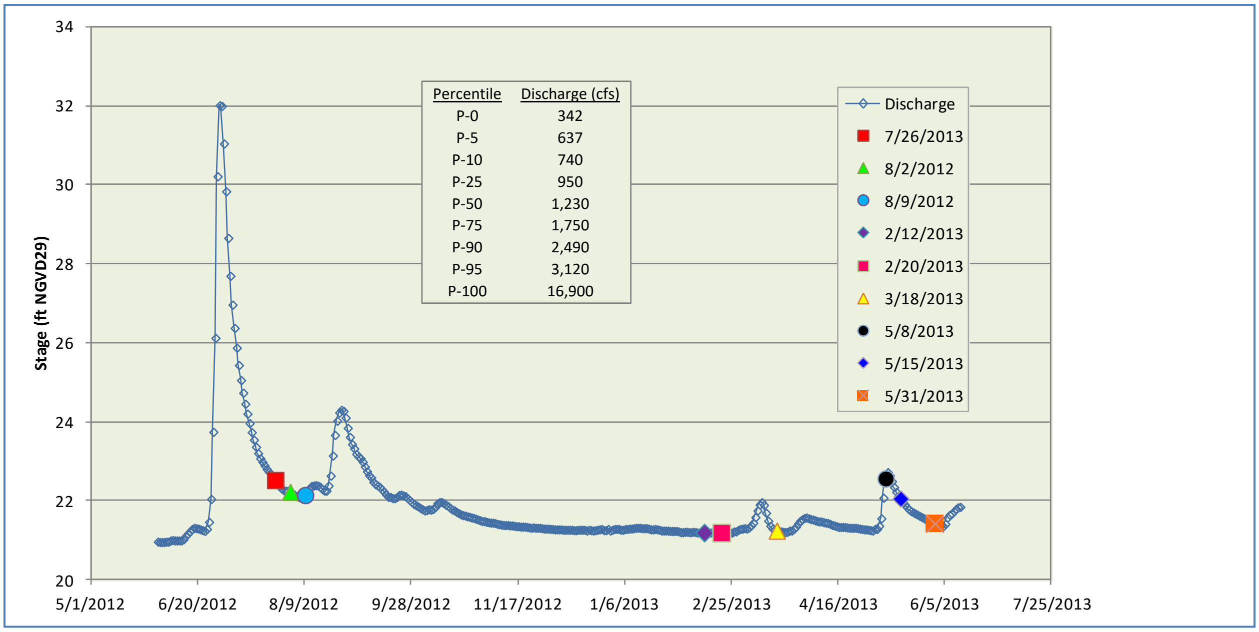
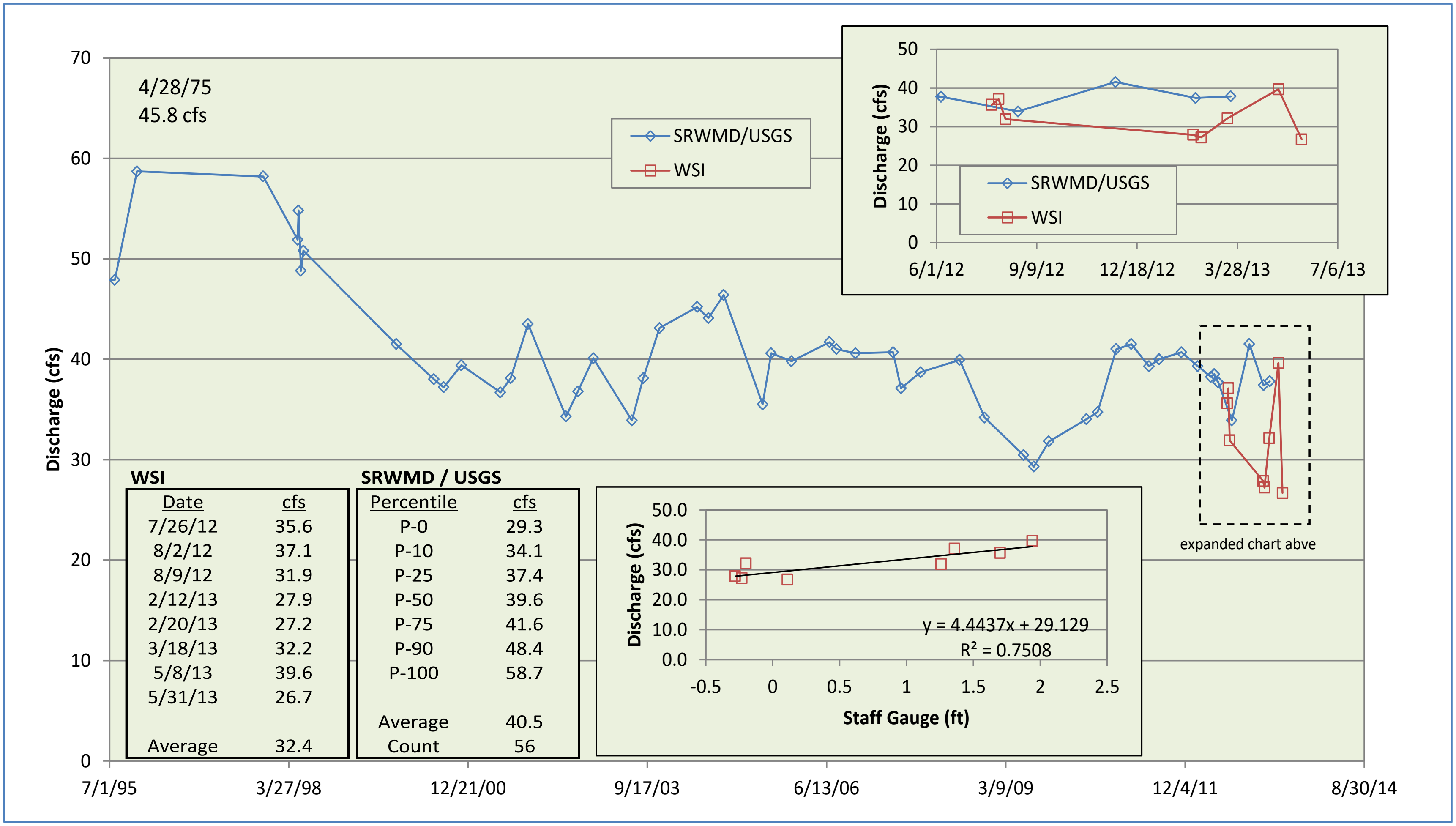


Figure 34. Time series of Santa Fe River stage and WSI flow sampling dates (USGS data)

Figure 35 presents Ginnie Springs discharge data reported by the SRWMD/USGS with estimates from WSI. These data indicate that since 1995 the average flow was 40.5 cfs, with a range from 29.3 cfs to 58.7 cfs. Ginnie Spring flows collected by WSI show three events below the lowest discharge reported by SRWMD/USGS. Discharge estimates from this study had a strong correlation with the onsite staff gauge ($R^2 = 0.75$).



WSI

Date	cfs
7/26/12	35.6
8/2/12	37.1
8/9/12	31.9
2/12/13	27.9
2/20/13	27.2
3/18/13	32.2
5/8/13	39.6
5/31/13	26.7
Average	32.4

SRWMD / USGS

Percentile	cfs
P-0	29.3
P-10	34.1
P-25	37.4
P-50	39.6
P-75	41.6
P-90	48.4
P-100	58.7
Average	40.5
Count	56

Figure 35. SRWMD/USGS flow data at Ginnie Spring (Station ID 02322400) with WSI estimates

Previously, Karst Environmental Services, Inc. (KES) provided flow data collected in 1988 and 1989 for all nine springs on the Ginnie Springs Outdoors property (Figure 36). Total average flow from the nine springs measured by KES in 1988 and 1989 was 243 cfs (approximately 24% of the flow of the Santa Fe River downstream), representing a large first magnitude springs group. For the five springs monitored in this report, the total average flow measured by KES in 1988 and 1989 was 98.1 cfs, compared to average total flow of 48.5 cfs for this study (2012 and 2013).

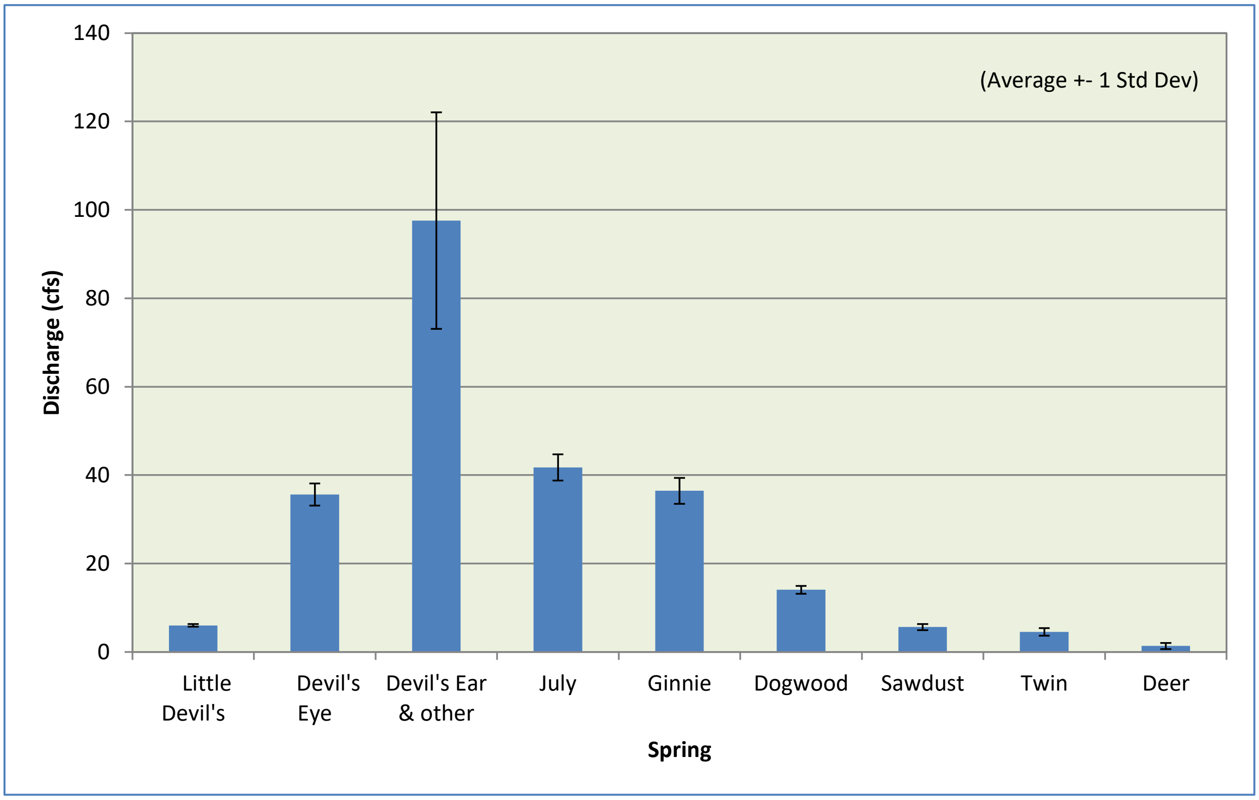


Figure 36. Flows for the Ginnie Springs Outdoors property (data provided by KES for 1988 and 1989)

2.5.4 Light Attenuation Measurements

Table 10 summarizes the average light attenuation at each of the upstream and downstream water quality stations during the field events. Detailed light attenuation measurements for each sampling event are provided in WSI (2013).

The average light attenuation, k, for each spring upstream and downstream station was 0.42 m^{-1} and ranged from 0.23 m^{-1} (downstream Ginnie Spring station) to 0.73 m^{-1} (downstream Deer Spring station). The percent light transmittance (1 m) was similar between the spring stations ranging from about 50% to 80% with absorbance ranging from about 20 to 50%.

Overall, the data indicates that the five spring systems were discharging groundwater with similar clarity and that this clarity remained essentially unchanged until it began to mix with dark water in the adjacent Santa Fe River. As discussed in the 2012 Ginnie Springs Ecological Analysis Report (WSI 2012), the tannic-colored water in the Santa Fe River upstream of the Ginnie Springs Outdoors property had much higher light attenuation (5 m^{-1}), much lower light transmittance at one meter (0.71%), and almost complete absorbance (99.3%) during the 2012 sampling events. The diluting properties of the spring inflows were evident in the Santa Fe River downstream of Ginnie Springs Outdoors with a lower k of 4.7 m^{-1}, a higher light transmittance at one meter (1.07%), and a slightly lower absorbance (98.9%) measured during the Summer of 2012.

Table 10. Average Light Attenuation Measurements at Sampling Stations

Station	k (m^-1)	% Trans.	Birg. Absorp. (%)
Deer Spring Up	0.32	73.53	26.47
Deer Spring Down	0.73	50.18	49.82
Twin Spring Up	0.32	72.90	27.10
Twin Spring Down	0.47	62.91	37.09
Dogwood Spring Up	0.31	74.78	25.22
Dogwood Spring Down	0.50	63.85	36.15
Ginnie Spring Up	0.50	63.06	36.94
Ginnie Spring Down	0.23	79.70	20.30
Little Devil Spring Up	0.37	72.63	27.37
Devil's Eye Spring Down	0.47	63.21	36.79
Santa Fe Up	5.00	0.71	99.29
Santa Fe Down	4.69	1.07	98.93

Light transmittance values from Deer, Twin, Dogwood, Ginnie, and the Devil Springs System were compared to other spring systems in Florida and showed similar ranges for average light transmittance values as shown in Figure 37. Additionally, values from the downstream stations were compared to values from spring runs of other Florida Springs. These values, shown in Figure 38, are also within the typical ranges observed in other Florida Springs although these values generally show higher variability than measurements closer to the spring vents. The very low percent transmittance (averages of 0.71% for upstream and 1.07% for downstream stations) for the Santa Fe River provides a comparison for dark water rivers.

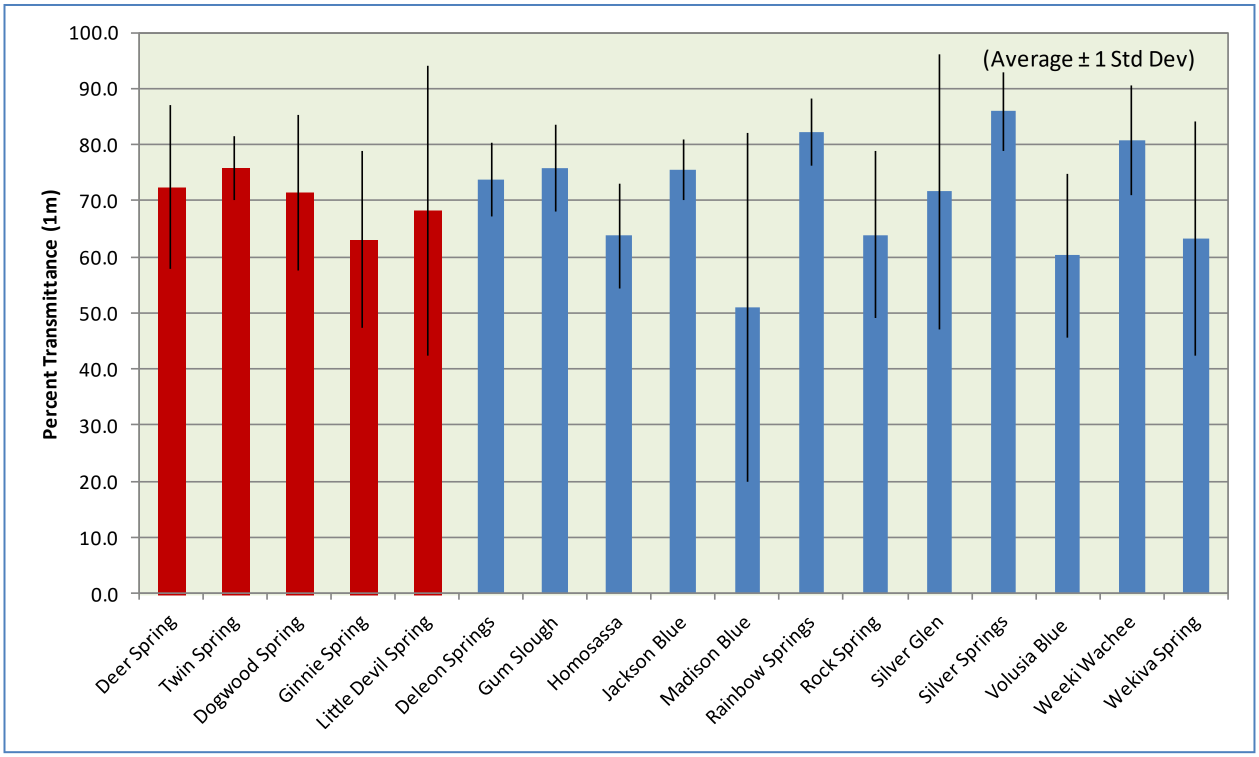


Figure 37. Percent PAR transmittance (@ 1 meter) within Florida springs

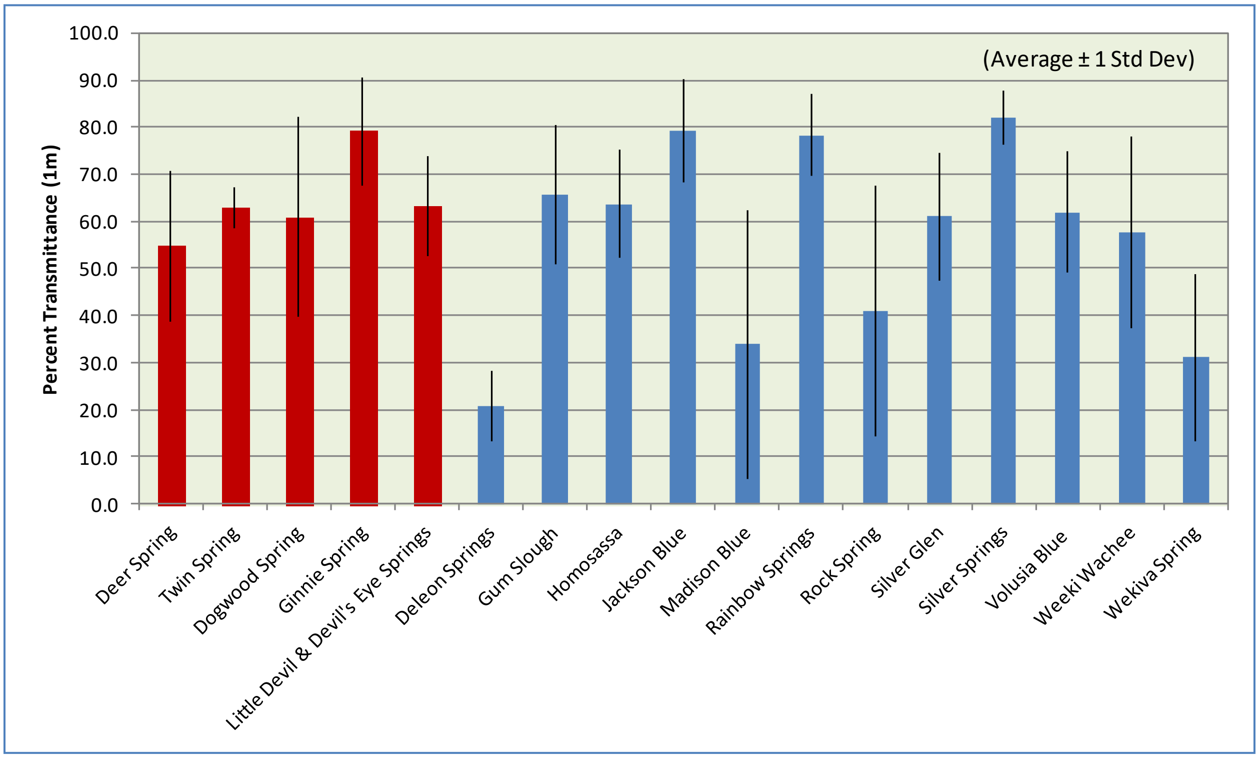


Figure 38. Percent PAR transmittance (@ 1 meter) within spring runs

2.5.5 Water Quality Data

Water quality data from sonde deployments in the Ginnie Springs Group and in the Santa Fe River, during the summer 2012, winter 2013, and spring 2013 sampling periods, are summarized in Table 11 and Table 12. It should be noted that data collection from the Santa Fe River only occurred during the Summer 2012 sampling period.

Temperatures in the spring boils for all sonde deployments were generally between 22.3 and 22.6°C, with temperatures in the Santa Fe River approximately 2° warmer during the Summer 2012 sampling period. The pH values were between 7.4 s.u. and 7.7 s.u. at all upstream spring locations during all sampling periods. The pH values for the downstream spring stations were similar and varied between 7.4 s.u. and 7.9 s.u. The pH values in the Santa Fe River were approximately 6.8 s.u. upstream and 7.3 s.u. downstream.

Average specific conductance values for Ginnie Spring ranged from 335 to 358 µS/cm. The specific conductance values measured in Dogwood Spring during the Summer 2012 sampling event were slightly lower (298-320 µS/cm) than those values measured in Ginnie Spring for all sampling events (326-366 µS/cm). Specific conductance in the Santa Fe River varied between 286 and 330 µS/cm with higher values at the downstream station. During the Summer 2012 sampling period, the spring inputs within the sampled reach of the Santa Fe River had an observable effect on water temperature (decrease), pH (increase), and specific conductance (increase) compared to the river's water chemistry below Ginnie Springs Outdoors. These effects may be somewhat exaggerated because the downstream Santa Fe River water samples were collected on the same side of the river as the springs, possibly before mixing of the spring and river water was complete. Field parameter time series data from the deployed data sondes are provided in WSI (2013).

Table 11. Data sonde water quality summary for Summer 2012 deployments

Parameter	Stats	GS-UP	GS-DN	DW-UP	DW-DN	SF-UP	SF-DN
Temp (C)	Average	22.47	22.33	22.31	22.34	25.15	24.87
	Median	22.46	22.31	22.30	22.31	25.11	24.81
	Max	22.57	22.46	22.45	22.46	26.18	25.74
	Min	22.45	22.29	22.29	22.28	24.46	24.29
	StDev	0.02	0.04	0.02	0.05	0.39	0.37
	N	676	673	676	93	665	334
pH (SU)	Average	7.53	7.65	7.62	7.86	6.81	7.34
	Median	7.46	7.49	7.62	7.86	6.81	7.35
	Max	7.63	7.85	7.64	7.87	6.87	7.39
	Min	7.41	7.44	7.60	7.84	6.78	7.23
	StDev	0.09	0.18	0.01	0.01	0.02	0.04
	N	676	669	674	91	655	329
SpC (uS/cm)	Average	335	337	318	303	303	322
	Median	336	337	318	303	305	324
	Max	337	339	320	316	314	330
	Min	326	334	316	298	286	309
	StDev	2.0	0.8	1.2	2.9	7.8	6.3
	N	676	673	676	93	665	333
DO (mg/L)	Average	3.31	3.39	2.46	2.69	2.78	2.41
	Median	3.29	3.37	2.46	2.67	2.80	2.48
	Max	3.55	3.70	2.72	2.86	3.21	2.86
	Min	3.17	3.21	2.31	2.59	2.50	1.77
	StDev	0.07	0.08	0.06	0.06	0.15	0.26
	N	676	633	548	93	665	334
DO (%)	Average	38.22	39.09	28.36	30.95	33.92	29.31
	Median	37.90	38.80	28.30	30.70	33.95	30.14
	Max	41.10	42.70	31.40	33.00	39.12	35.09
	Min	36.60	37.00	26.60	29.80	30.78	21.64
	StDev	0.85	0.98	0.65	0.72	1.85	3.19
	N	676	633	548	93	665	334
Turbidity (NTU)	Average	---	-0.8	---	-0.9	-0.1	0.8
	Median	---	-0.9	---	-1.2	-0.6	0.4
	Max	---	1.2	---	14.9	32.6	13.9
	Min	---	-1.3	---	-1.3	-1.9	-2.3
	StDev	---	0.4	---	1.8	2.3	2.3
	N	---	671	---	93	663	332

Table 12. Data sonde summary for Winter and Spring 2013 deployments

		Sonde Deployment			
		Winter 2013		Spring 2013	
Parameter	Stats	GS-UP	GS-DN	GS-UP	GS-DN
Temp (C)	Average	22.34	22.31	22.44	22.27
	Median	22.34	22.31	22.44	22.26
	Max	22.35	22.55	22.45	22.44
	Min	22.34	22.11	22.44	22.11
	StDev	0.00	0.09	0.00	0.07
	N	1441	1438	1053	1090
pH (SU)	Average	7.60	7.70	7.63	7.86
	Median	7.61	7.70	7.64	7.86
	Max	7.64	7.74	7.67	7.89
	Min	7.53	7.60	7.55	7.75
	StDev	0.03	0.02	0.03	0.02
	N	1441	1438	1053	1090
SpC (uS/cm)	Average	348	343	358	360
	Median	348	343	356	358
	Max	350	345	366	366
	Min	346	336	353	353
	StDev	0.9	0.6	3.8	3.5
	N	1441	1438	1053	1089
DO (mg/L)	Average	3.55	3.42	3.71	3.65
	Median	3.55	3.45	3.69	3.65
	Max	3.59	3.88	3.94	4.03
	Min	3.49	0.00	3.66	3.39
	StDev	0.02	0.25	0.05	0.12
	N	1441	1441	1053	1089
DO (%)	Average	40.89	39.41	42.84	41.99
	Median	40.90	39.60	42.60	41.99
	Max	41.30	44.70	45.40	46.29
	Min	40.30	0.00	42.20	38.99
	StDev	0.22	2.83	0.63	1.42
	N	1441	1441	1053	1089
Turbidity (NTU)	Average	---	---	---	-1.7
	Median	---	---	---	-1.8
	Max	---	---	---	3.1
	Min	---	---	---	-2.0
	StDev	---	---	---	0.4
	N	---	---	---	1090

Water quality results from grab samples collected during each field event over the 2012-2013 period are summarized in Table 13 with detailed analytical laboratory reports provided in WSI (2013). The average nitrate nitrogen concentration measured was 0.87 mg/L in Deer Spring, 0.80 mg/L in Twin Spring, 0.89 mg/L in Dogwood Spring, 1.39 mg/L in Ginnie Spring, and 1.90 mg/L in the Devil Springs system. The maximum nitrate concentration reported for the Ginnie Springs Group was 2.10 mg/L in the Devil Springs system, while the minimum reported nitrate concentration during this period was 0.71 mg/L in Twin Spring. Differences between upstream and downstream spring run stations were minor, indicating a relatively low level of biological activity for either assimilatory (plant and algae uptake) or dissimilatory (denitrification) nitrate utilization.

Except for the May 8, 2013 sampling event at Deer Spring, color values in both springs were less than 5 CPU which is consistent with the high levels of light transmittance measured in the springs. The higher color values of 15 and 10 CPU at Deer Spring can be attributed to the tannic-colored Santa Fe River water backing up into Deer Spring during the May 8th sampling event.

Average sulfate concentrations were measured within each spring during the Winter 2013 and Spring 2013 sampling events. The average sulfate concentration for the upstream spring boils was 11 mg/L and average sulfate concentrations ranged from 10.75 mg/L in both Deer and Dogwood Springs to 11.50 mg/L in the Devil Springs System. The average sulfate concentration within the spring runs was 11.45 mg/L and varied between 10 mg/L (within Deer Spring) and 14 mg/L (within the Devil Springs System).

Average total chloride concentrations were measured within each spring during the Winter 2013 and Spring 2013 sampling events. The average total chloride concentration within the upstream spring boils was 5.54 mg/L and the range of concentrations varied between 4.93 mg/L in Twin Spring to 6.00 mg/L in the Devil Springs System. The average total chloride concentrations within the spring runs varied in a slightly wider range of 4.90 mg/L (within Deer Spring) to 7.73 mg/L (within the Devil Springs System) and averaged 5.83 mg/L. In general, chloride concentrations increased upstream from Deer Spring toward the Devil Springs System.

For the Summer 2012 sampling event, the average nitrate nitrogen concentration at the upstream Santa Fe River station was 0.32 mg/L and the nitrate nitrogen concentration at the downstream river station averaged 0.45 mg/L. Average color measured in the Santa Fe River was 187 CPU upstream and 160 CPU downstream. The decrease in color and increase in nitrate indicate mixing of spring and river sources at the downstream edge of the property.

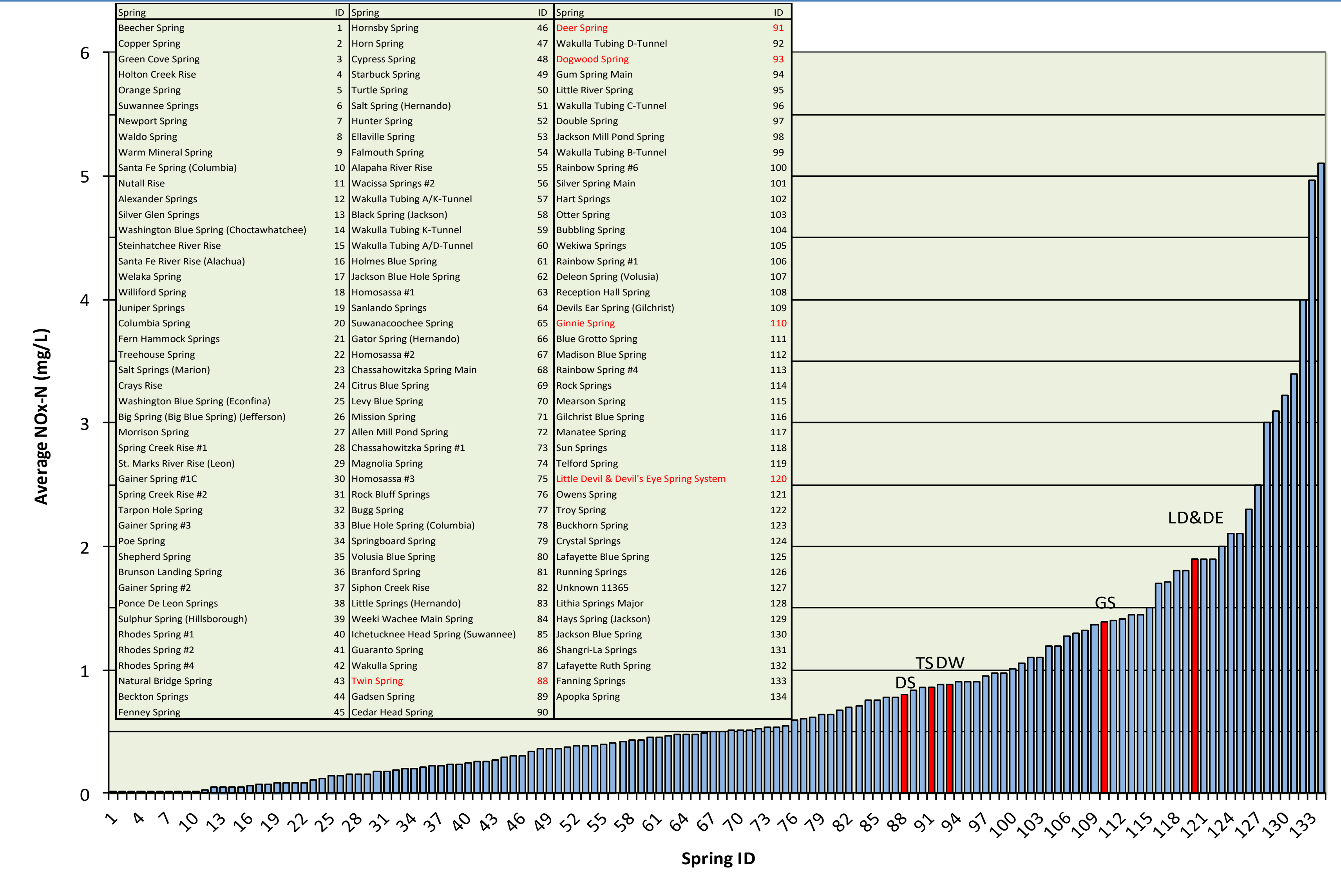
Nitrate data from Deer, Twin, Dogwood, Ginnie, and the Devil Springs System were compared to other Florida springs as shown in Figure 39. The SRWMD has reported water quality data at Ginnie Spring from November 1997 through July 2011. These data were summarized and are presented in Table 14. Over this period, the nitrate nitrogen concentration in Ginnie Spring has averaged 1.32 mg/L which is similar to the value of 1.39 mg/L found during this study. The maximum nitrate value reported at Ginnie Spring was 1.8 mg/L while the minimum reported concentration during this period was 0.72 mg/L.

Table 13. Water quality summary data for spring stations and the Santa Fe River (July – May 2013)

Parameter	Units	Date	Deer Spring		Twin Spring		Dogwood Spring		Ginnie Spring		Devil Spring System		Santa Fe River	
			Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
NOx-N	mg/L	7/26/2012	---	---	---	---	0.82	0.79	1.20	1.20	---	---	0.32	0.42
		8/2/2012	---	---	---	---	0.79	0.80	1.30	1.20	---	---	0.33	0.48
		8/9/2012	---	---	---	---	0.74	0.76	1.10	1.10	---	---	0.31	0.46
		2/20/2013	0.86	0.79	0.74	0.71	0.88	0.88	1.40	1.50	1.70	1.60	---	---
		3/13/2013	0.98	0.94	0.88	0.94	1.00	1.10	1.60	1.60	1.90	1.80	---	---
		5/8/2013	0.75	0.74	---	---	1.00	1.10	1.60	1.80	2.10	1.5*	---	---
		5/31/2013	0.87	0.83	0.78	0.79	0.97	0.98	1.50	1.50	1.90	1.40	---	---
		Average	0.87	0.83	0.80	0.81	0.89	0.92	1.39	1.41	1.90	1.60	0.32	0.45
Color	CPU	7/26/2012	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	200	200
		8/2/2012	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	160	120
		8/9/2012	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	200	160
		2/20/2013	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	---	---
		3/13/2013	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	---	---
		5/8/2013	15 U	10 U	---	---	5 U	5 U	5 U	5 U	5 U	5 U	---	---
		5/31/2013	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	---	---
		Average	6.4 U	5.7 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	187	160
Cl-T	mg/L	2/20/2013	4.90	4.90	4.80	4.90	5.10	5.20	5.60	5.70	5.70	7.80	---	---
		3/13/2013	5.00	4.80	4.80	5.10	5.10	5.10	5.40	5.60	5.70	7.10	---	---
		5/8/2013	5.60	5.50	---	---	6.80	6.60	6.60	6.30	6.50	7.70*	---	---
		5/31/2013	5.20	4.40	5.20	5.00	5.60	5.60	6.10	6.00	6.10	8.30	---	---
		Average	5.18	4.90	4.93	5.00	5.65	5.63	5.93	5.90	6.00	7.73	---	---
SO_4	mg/L	2/20/2013	10.0	10.0	11.0	11.0	10.0	10.0	11.0	11.0	11.0	14.0	---	---
		3/13/2013	10.0	10.0	11.0	12.0	10.0	10.0	10.0	11.0	11.0	13.0	---	---
		5/8/2013	12.0	11.0	---	---	12.0	12.0	12.0	12.0	12.0	14.0*	---	---
		5/31/2013	11.0	9.00	11.0	11.0	11.0	11.0	11.0	11.0	12.0	15.0	---	---
		Average	10.75	10.00	11.00	11.33	10.75	10.75	11.00	11.25	11.50	14.00	---	---

U= below parameter detection limit

*= sample taken adjacent to Devil's Eye Boil



Spring	ID	Spring	ID	Spring	ID
Beecher Spring	1	Hornsby Spring	46	Deer Spring	91
Copper Spring	2	Horn Spring	47	Wakulla Tubing D-Tunnel	92
Green Cove Spring	3	Cypress Spring	48	Dogwood Spring	93
Holton Creek Rise	4	Starbuck Spring	49	Gum Spring Main	94
Orange Spring	5	Turtle Spring	50	Little River Spring	95
Suwannee Springs	6	Salt Spring (Hernando)	51	Wakulla Tubing C-Tunnel	96
Newport Spring	7	Hunter Spring	52	Double Spring	97
Waldo Spring	8	Ellaville Spring	53	Jackson Mill Pond Spring	98
Warm Mineral Spring	9	Falmouth Spring	54	Wakulla Tubing B-Tunnel	99
Santa Fe Spring (Columbia)	10	Alapaha River Rise	55	Rainbow Spring #6	100
Nutall Rise	11	Wacissa Springs #2	56	Silver Spring Main	101
Alexander Springs	12	Wakulla Tubing A/K-Tunnel	57	Hart Springs	102
Silver Glen Springs	13	Black Spring (Jackson)	58	Otter Spring	103
Washington Blue Spring (Choctawhatchee)	14	Wakulla Tubing K-Tunnel	59	Bubbling Spring	104
Steinhatchee River Rise	15	Wakulla Tubing A/D-Tunnel	60	Wekiwa Springs	105
Santa Fe River Rise (Alachua)	16	Holmes Blue Spring	61	Rainbow Spring #1	106
Welaka Spring	17	Jackson Blue Hole Spring	62	Deleon Spring (Volusia)	107
Williford Spring	18	Homosassa #1	63	Reception Hall Spring	108
Juniper Springs	19	Sanlando Springs	64	Devils Ear Spring (Gilchrist)	109
Columbia Spring	20	Suwanacoochee Spring	65	Ginnie Spring	110
Fern Hammock Springs	21	Gator Spring (Hernando)	66	Blue Grotto Spring	111
Treehouse Spring	22	Homosassa #2	67	Madison Blue Spring	112
Salt Springs (Marion)	23	Chassahowitzka Spring Main	68	Rainbow Spring #4	113
Crays Rise	24	Citrus Blue Spring	69	Rock Springs	114
Washington Blue Spring (Econfina)	25	Levy Blue Spring	70	Mearson Spring	115
Big Spring (Big Blue Spring) (Jefferson)	26	Mission Spring	71	Gilchrist Blue Spring	116
Morrison Spring	27	Allen Mill Pond Spring	72	Manatee Spring	117
Spring Creek Rise #1	28	Chassahowitzka Spring #1	73	Sun Springs	118
St. Marks River Rise (Leon)	29	Magnolia Spring	74	Telford Spring	119
Gainer Spring #1C	30	Homosassa #3	75	Little Devil & Devil's Eye Spring System	120
Spring Creek Rise #2	31	Rock Bluff Springs	76	Owens Spring	121
Tarpon Hole Spring	32	Bugg Spring	77	Troy Spring	122
Gainer Spring #3	33	Blue Hole Spring (Columbia)	78	Buckhorn Spring	123
Poe Spring	34	Springboard Spring	79	Crystal Springs	124
Shepherd Spring	35	Volusia Blue Spring	80	Lafayette Blue Spring	125
Brunson Landing Spring	36	Branford Spring	81	Running Springs	126
Gainer Spring #2	37	Siphon Creek Rise	82	Unknown 11365	127
Ponce De Leon Springs	38	Little Springs (Hernando)	83	Lithia Springs Major	128
Sulphur Spring (Hillsborough)	39	Weeki Wachee Main Spring	84	Hays Spring (Jackson)	129
Rhodes Spring #1	40	Ichetucknee Head Spring (Suwannee)	85	Jackson Blue Spring	130
Rhodes Spring #2	41	Guaranto Spring	86	Shangri-La Springs	131
Rhodes Spring #4	42	Wakulla Spring	87	Lafayette Ruth Spring	132
Natural Bridge Spring	43	Twin Spring	88	Fanning Springs	133
Beckton Springs	44	Gadsen Spring	89	Apopka Spring	134
Fenney Spring	45	Cedar Head Spring	90		

Figure 39. Average nitrate-nitrogen concentrations in Florida springs

Table 14. SRWMD water quality data at Ginnie Spring (November 1997 – July 2011)

Parameter Group	Parameter	Units	Average	Median	Min	Max	Std Dev	N
DISSOLVED OXYGEN	DO	mg/L	4.02	3.80	3.40	7.20	0.674	38
GENERAL INORGANIC	Alk	mg/L	154	150	133	296	26.2	34
	Cl-T	mg/L	5.41	5.40	3.35	6.20	0.549	34
	F-T	mg/L	0.109	0.105	0.030	0.220	0.043	34
	SIO2	mg/L	7.30	6.75	5.60	12.9	2.32	8
	SIO2-D	mg/L	3.12	3.10	2.98	3.31	0.106	11
	SO4	mg/L	10.2	9.80	5.80	35.9	4.72	34
GENERAL ORGANIC	DOC	mg/L	1.48	0.800	0.200	8.60	2.00	34
	TOC	mg/L	1.51	0.600	0.200	10.6	2.35	34
METAL	Ca-T	mg/L	57.8	58.5	46.8	68.3	5.05	34
	K-T	mg/L	0.288	0.300	0.00	0.500	0.137	34
	Mg-T	mg/L	5.51	5.50	3.75	6.75	0.617	34
	Mn-T	mg/L	3.06	3.08	2.97	3.11	0.062	4
	NA-T	mg/L	2.94	2.85	2.15	4.00	0.430	34
NITROGEN	NH4-N	mg/L	0.039	0.020	0.010	0.100	0.030	36
	NOx-N	mg/L	1.32	1.31	0.720	1.80	0.200	39
	TKN	mg/L	0.184	0.165	0.040	0.520	0.124	36
PHOSPHORUS	OrthoP	mg/L	0.030	0.030	0.020	0.040	0.006	36
	TP	mg/L	0.040	0.040	0.030	0.070	0.011	36
PHYSICAL	Color	CPU	5.29	5.00	5.00	10.0	1.19	34
	pH	SU	7.48	7.49	6.80	7.91	0.184	38
	Salinity	ppt	0.092	0.100	0.00	0.200	0.055	36
	Secchi	m	1.77	1.25	0.700	6.40	1.25	36
	SpCond	umhos/cm	314	314	268	340	15.7	37
	Turb	NTU	0.170	0.145	0.030	0.450	0.093	34
SOLID	TDS	mg/L	187	188	126	230	18.9	34
TEMPERATURE	Wtr Temp	C	22.3	22.3	21.6	22.5	0.150	38

2.5.6 Fish Biomass

Following the two Summer 2012 fish count events in the Ginnie and Dogwood spring systems, four additional fish counts in Dogwood Spring and three additional fish counts in the Deer, Twin, Ginnie, and the Devil Springs System were conducted over the 2013 Winter and Spring sampling periods. Table 15 summarizes the total count, density, and biomass for each sampling period at each of the spring systems. A detailed summary of each fish count conducted from July 2012 to May 2013, including fish species observed, is provided in WSI (2013).

Over the period of record, the average fish live-weight biomass estimates were the highest and similar for Deer Spring, Twin Spring, and the Devil Springs System with estimated biomasses of 65.9, 65.6, and 66.2 kilograms per hectare (kg/ha) respectively. The average biomasses for the period of record were lower for Dogwood and Ginnie Springs with average biomasses of 24.6 kg/ha and 38.0 kg/ha, respectively.

The number of fish per hectare was also evaluated in each spring. The average fish densities for Deer Spring, Twin Spring, and the Devil Springs System were the lowest and similar with densities of 1,640, 2,001, and 2,244 fish/ha, respectively. The average fish densities were higher for Dogwood and Ginnie Springs with average densities of 2,960 fish/ha at Dogwood Spring and 3,368 fish/ha at Ginnie Spring. Striped mullet were the most significant fish species, from a biomass standpoint, with minnows being the most common in terms of population density. Thus, the lower biomasses and higher densities estimated for Dogwood and Ginnie Springs are attributed to the lower number of striped mullet and higher number of minnows observed in both systems as compared to Deer Spring, Twin Spring, and the Devil Springs System.

Table 15. Ginnie Springs Group fish biomass and counts

Location	Date	Number of Fish	Total Density (#/ha)	Total Biomass (kg/ha)
Deer Spring	Winter 2013	109	1,263	42.0
	Spring 2013	174	2,017	89.9
	Average	**142**	**1,640**	**65.9**
Twin Spring	Winter 2013	178	2,133	46.5
	Spring 2013	156	1,869	84.6
	Average	**167**	**2,001**	**65.6**
Dogwood Spring	Summer 2012	743	5,842	18.0
	Winter 2013	232	1,825	21.8
	Spring 2013	154	1,212	34.0
	Average	**376**	**2,960**	**24.6**
Ginnie Spring	Summer 2012	1,472	7,017	41.4
	Winter 2013	259	1,233	21.5
	Spring 2013	389	1,855	51.1
	Average	**706**	**3,368**	**38.0**
Little Devil & Devil's Eye Spring System	Winter 2013	435	2,262	67.1
	Spring 2013	428	2,226	65.4
	Average	**432**	**2,244**	**66.2**
Grand Average		**365**	**2,443**	**52.1**

Note: Deer (862.8 m^2), Twin (834.66 m^2), Dogwood (1271 m^2), Ginnie Spring (2097 m^2), & Little Devil & Devil's Eye Spring System (1922.72 m^2)

Figure 40 displays the number of species of fish found at each spring system during this study. Ginnie Spring and Dogwood Spring had the highest diversity of species with 16 and 12 distinct species recorded respectively over the 2012 and 2013 sampling events. WSI (2016) provides a detailed list of species and their count found at each spring.

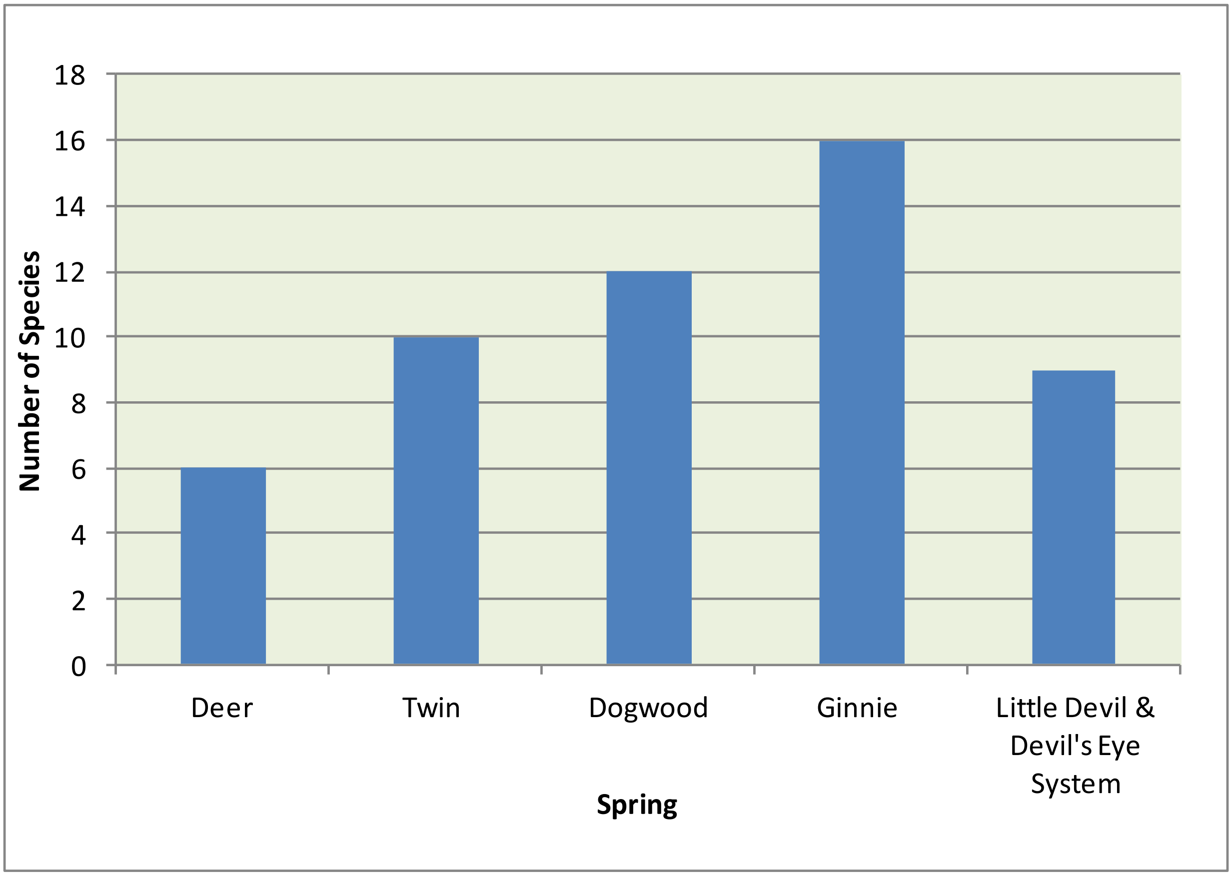


Figure 40. Comparison of the diversity of fish species observed at each spring in the Ginnie Springs Group

Estimated fish biomass and population densities were compared with other Florida springs studied using the same visual count technique (WSI 2010). Figure 41 displays this comparison of the Ginnie Springs Group to other Florida Springs. For both Ginnie and Dogwood springs (using the detailed counts) the numbers of fish per hectare were higher than all but five of the other studied springs. For fish biomass, both Ginnie and Dogwood springs were less than any of the other springs studied. In comparison to the other springs previously studied, Ginnie and Dogwood springs had large populations of minnows and juvenile fish, but low total fish live-weight biomass. The remaining three springs, Twin, Deer, and the Devil Springs System, had biomasses and densities like the other Florida springs studied.

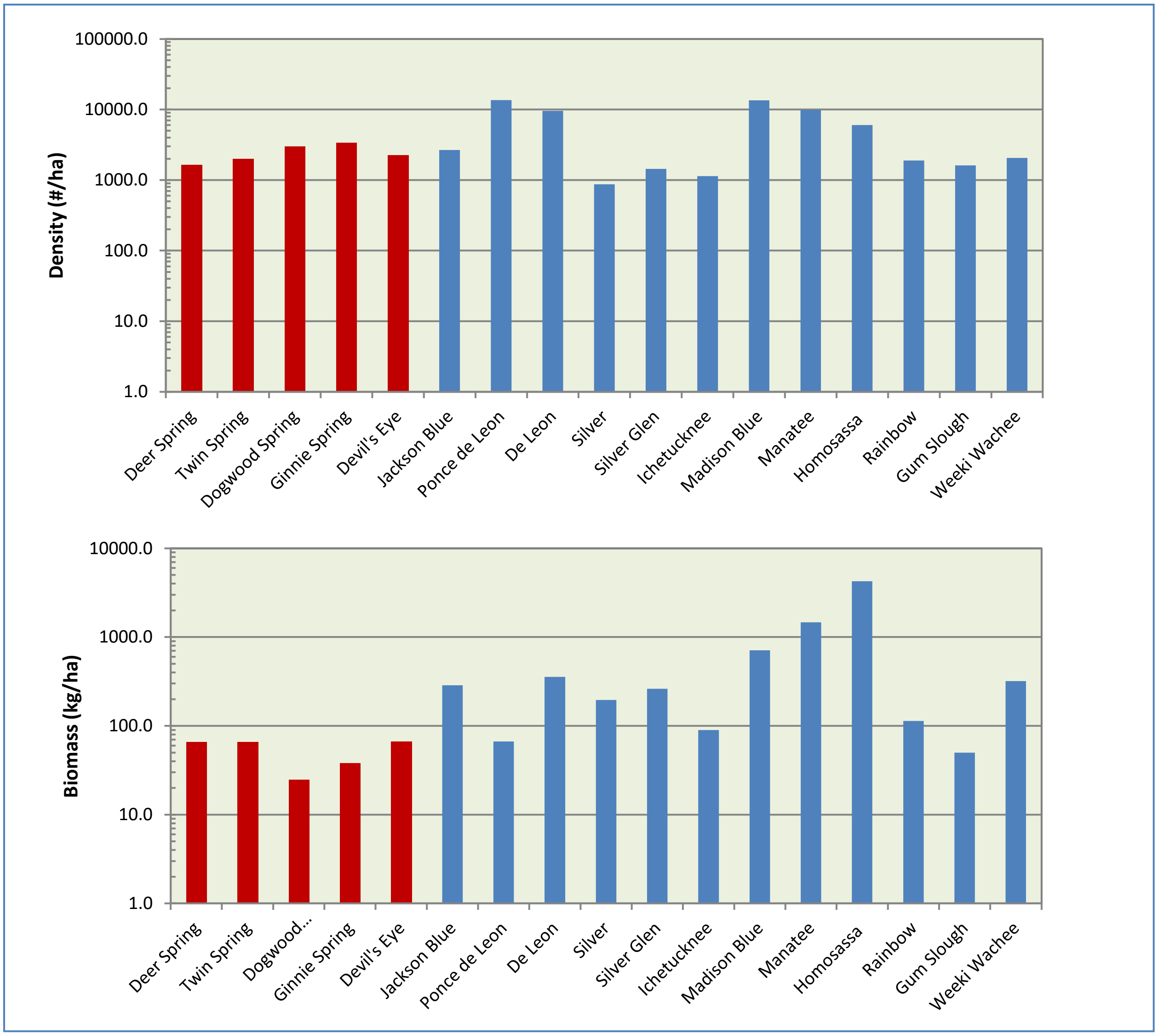


Figure 41. Ginnie Springs Group fish density and biomass compared to other Florida springs

2.5.7 Vegetation Mapping

Approximate vegetation communities and substrates were mapped in each spring run and species occurrence is summarized in

Table 16. Most the springs and their spring runs had no vegetation within the primary flow path, but had beds of vegetation in several areas along the bank.

Table 16. Observed plant species present during sampling events

Common Name	Scientific Name	Deer Spring Winter 2013	Deer Spring Spring 2013	Twin Spring Winter 2013	Twin Spring Spring 2013	Dogwood Spring Summer 2012	Dogwood Spring Winter 2013	Dogwood Spring Spring 2013	Ginnie Spring Summer 2012	Ginnie Spring Winter 2013	Ginnie Spring Spring 2013	Devil Spring System Winter 2013	Devil Spring System Spring 2013
Hydrilla	*Hydrilla verticillata*			X	X	X	X	X				X	X
Pennywort	*Hydrocotyle spp.*						X						
Red ludwigia	*Ludwigia repens*					X	X	X	X	X	X	X	X
Spider lily	*Hymenocallis liriosme*								X	X	X		
Strap-leaf sagittaria	*Sagittaria kurziana*			X	X	X		X	X	X	X	X	
Water hyacinth	*Eichhornia crassipes*			X	X		X						
Water lettuce	*Pistia stratiotes*	X	X										

Deer Spring exhibited a decrease in the amount of algae and the amount of water lettuce between the Winter and Spring 2013 sampling events. Twin Spring also showed a decrease, from Winter to Spring 2013, in all species of aquatic plants present. For Dogwood Spring, there was a reduction in algae in the channel and around the boil during Spring 2013 sampling and pennywort was only present during the Winter 2013 event. It should be noted that some strap-leaf sagittaria was observed at Dogwood Spring during the Spring 2013 and Summer 2012 sampling periods, though it was not present in the Winter 2013 sampling period. Ginnie Spring also exhibited a decrease in the amount of algae from Winter to Spring of 2013 and a decrease in the amount of eelgrass over the entire study period (July 2012- May 2013). The Devil Springs System also showed a reduction of algae in the channel and the absence of strap-leaf sagittaria present near the mouth of the run between Winter 2013 and Spring 2013 sampling events. In general, algae was the most dominant plant type in all five springs.

Between Winter and Spring sampling in 2013, all five spring runs showed a decrease in the amount of algae cover around the spring vent and in the spring run. This is presumably a result of increased recreational activity during the spring months. Algae samples were collected in each of the spring runs and analyzed under a microscope to determine composition. *Lyngbya* sp. was the most common genera of algae present in all samples. *Spirogyra* sp. was present in some samples. Diatoms were also very abundant in all the algal samples.

2.5.8 Ecosystem Metabolism

In Ginnie Spring, average Gross Primary Productivity (GPP) ranged from 2.10 g $O_2/m^2/d$ (Summer 2012) to 3.28 g $O_2/m^2/d$ (Winter 2013), over the three deployment periods. Community Respiration (CR) ranged from 4.17 g $O_2/m^2/d$ (Summer 2012) to 8.72 g $O_2/m^2/d$ (Winter 2013), resulting in an average negative Net Primary Productivity (NPP) of -5.62 g $O_2/m^2/d$ (Winter 2013) to -2.07 g $O_2/m^2/d$ (Summer 2012). For these data, the estimated Photosynthesis to Respiration (P/R) ratio ranged from 0.52 (Summer 2012) to 0.73 (Spring 2013), and the photosynthetic efficiency range was from 2.19% (or 0.27 g O_2/mol, Spring 2013) to 4.25% (or 0.53 g O_2/mol, Winter 2013).

In Dogwood Spring, GPP was lower at 0.94 g $O_2/m^2/d$ during the Summer 2012 deployment period. Average CR was 1.49 g $O_2/m^2/d$, resulting in an average negative NPP in Dogwood Springs of -0.55 g $O_2/m^2/d$. In Dogwood Spring the measured P/R ratio was 0.64, and the photosynthetic efficiency was 0.68% or 0.08 g O_2/mol.

Both springs had a negative NPP (CR exceeds GPP). A negative NPP is not uncommon in springs that are closely surrounded by upland forest due to the inputs of leaf litter and runoff that may exceed the amount of internal carbon production in the spring's aquatic plant community.

Ecosystem metabolism estimates from Ginnie and Dogwood springs were compared to similar data from other Florida springs that have previously been studied (Figure 42). This comparison indicated that Ginnie Spring and Dogwood Spring both have low GPP compared to other spring systems, but have similar values for NPP. For CR, Ginnie Spring has similar values and Dogwood Spring has low values compared to other spring systems. When normalized for incident solar radiation, Ginnie Spring was found to have a photosynthetic efficiency a little above average for Florida springs during Winter 2013 and a little below the median during Summer 2012 and in Spring 2013. The photosynthetic efficiency for Dogwood in Summer 2012 was found to be well below the 25th percentile of other measured springs. These data indicate that Dogwood Spring might be significantly impaired compared to other springs and that Ginnie Spring also has a low level of spring health comparable to other stressed springs in Florida.

Figure 43 shows the existing data relating photosynthetic efficiency and spring discharge for the studied Florida spring systems. Both Ginnie and Dogwood follow the same general relationship observed for other springs. Spring photosynthetic efficiency is typically positively correlated with increasing spring discharge.

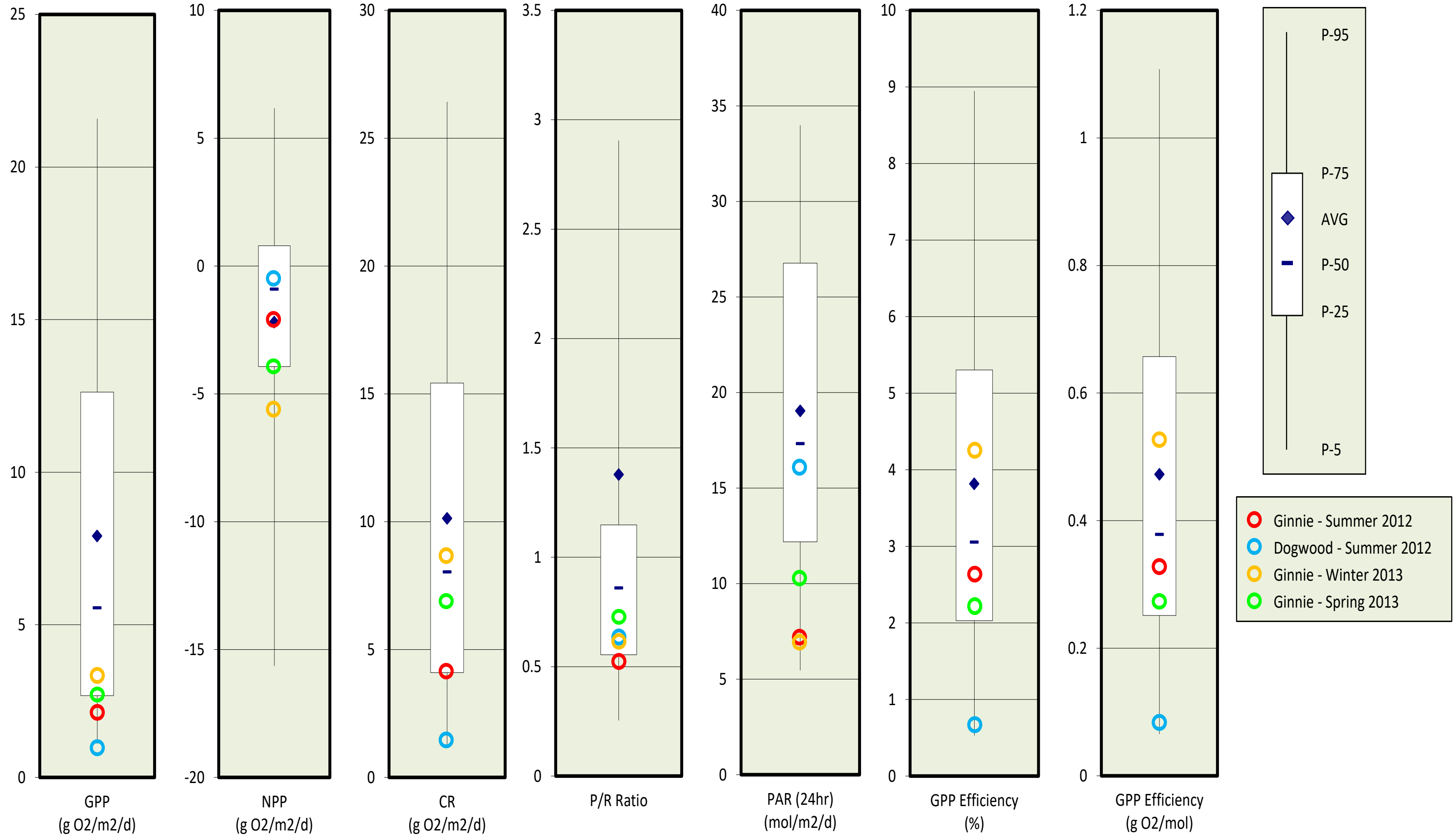


Figure 42. Comparison of Ginnie Springs Group ecosystem productivity and photosynthetic efficiency to other Florida springs

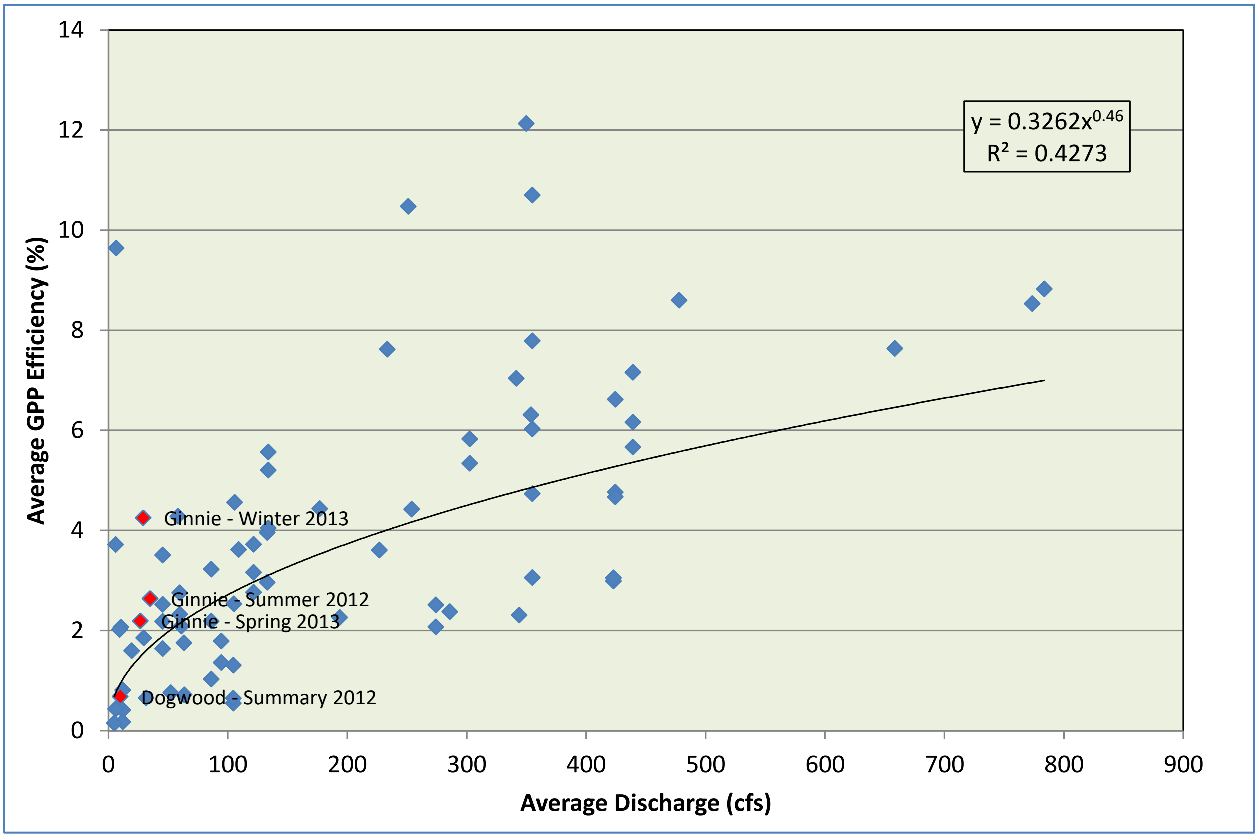


Figure 43. Gross primary productivity efficiency versus discharge for the Ginnie Springs Group (red symbols) and other Florida springs

2.5.9 Ginnie Springs System Summary

The ecological health of five representative springs located at Ginnie Springs Outdoors was evaluated between July 2012 and May 2013, including Deer Spring, Twin Spring, Ginnie Spring, Dogwood Spring, and the Devil Springs System, using standard physical, chemical, and biological indices (WSI, 2013). Ecological data from the Ginnie Springs Group collected for this study were in turn compared to other spring ecosystem data from throughout north Florida.

The Ginnie Springs Group is suffering from similar environmental conditions that are causing impairment in other springs throughout North Florida (Knight, 2015). An estimated 50% decline in spring flows is likely an important contributor to some of the water quality and biological impairments documented at the Ginnie Springs Group. Reduced flow is known to reduce gross primary productivity and photosynthetic efficiency in spring systems (WSI 2010). Reduced flow is a direct result of lower aquifer head or pressure and may result in spring reversals, as was observed at nearby, upstream Hornsby, Poe and Rum Island Springs in 2012. Flow reversals from the Santa Fe River into the springs may result in the import of large volumes of tannin-stained, low-hardness surface runoff into the aquifer, coloring well water and groundwater in submerged caves. The flushing time for this colored water is apparently increasing in length as flow reversals along the Santa Fe become more common, and groundwater levels continue to fall from excessive groundwater pumping. Colored water in the spring reduces clarity and absorbs a greater percentage of incident solar energy critical for aquatic primary productivity.

Nitrate nitrogen levels are increasing rapidly in the springs of the Ginnie Springs Group and in nearby Gilchrist Blue Spring. These concentrations are approximately 35 times higher than the estimated background concentrations in the local groundwater prior to agricultural and urban development in the springshed. These concentrations are also more than five times higher (500% increase) than what is allowed in springs under Florida's water quality standards. These concentrations of nitrate are thought to result in impairment of springs due to algal smothering of native plants and habitats (FDEP, 2008).

At the same time nitrate concentrations are rising in Ginnie Springs, they are lower and staying relatively constant in upstream Poe and Hornsby Springs. These differing responses highlight the different contributing water sources to these springs. The Ginnie Springs Group draws water from a springshed to the south away from the river, while the other springs derive water more to the east along the alignment of the Santa Fe River. Hornsby and Poe Springs nitrate levels are now essentially the same as those in the Santa Fe River, providing additional confirmation that those two springs have lost much of their artesian groundwater inflows and are now behaving as river resurgences. If aquifer levels continue to fall due to excessive pumping in the springsheds that feed the Ginnie and Blue Spring Groups, then it is likely that it is just a matter of time before these springs also become dominated by stained river water.

Based on anecdotal evidence, plant community changes appear to be accelerating in the Ginnie Springs Group. The cover of submerged aquatic vegetation, once very high in these springs, had declined to essentially zero by the winter of 2012 and the spring of 2013. The causes for these changes are not definitively known, but since there is no physical explanation such as increased recreational pressure or mechanical removal, then a chemical link to the groundwater inflow is suspected. Similar plant community changes have been observed at other springs in North Florida (Manatee, Fanning, and other springs along the Suwannee River), and the submerged aquatic plant community in the Santa Fe River has crashed several times in the last decade as well. It has been hypothesized that elevated nitrate concentrations can contribute to the loss of macrophytic plants and the preponderance of filamentous algae in springs (Knight 2012), but the presence of elevated concentrations of other unknown anthropogenic agents in the groundwater such as herbicides is conceivable and deserves additional study.

2.6 FSI Synoptic Study

The Florida Springs Institute (FSI) conducted an ecological baseline assessment of the Santa Fe River and springs from October through December 2016 (FSI, 2017). For this baseline assessment, the Santa Fe River was divided into four study segments, with one segment within the Upper Santa Fe River, and three within the Lower Santa Fe River. FSI also conducted related monitoring within the Ichetucknee River during this 2016 study period.

- Upper Santa Fe River
    - Segment 1 (Worthington Spring at SR 121 to the Santa Fe River Sink in O'Leno State Park)
- Lower Santa Fe River
    - Segment 2 (Santa Fe River Rise to U.S. Hwy 27)
    - Segment 3 (U.S. Hwy 27 to US Hwy 47)
    - Segment 4 (U.S. Hwy 47 to Suwannee River confluence)
- Ichetucknee River (Main Boil to Santa Fe River confluence)

Study segment locations are illustrated in Figure 44 with detailed maps identifying monitoring station locations in Figure 45 through Figure 48. Monitoring stations were selected to best characterize water quality and quantity conditions within each study segment. Table 17 presents a summary of stations monitored during this study within each segment, and includes stations described above that are monitored by the USGS, SRWMD, and FDEP.

The following ecological metrics were measured during the Santa Fe River and Springs Baseline Study:

Physical Environment

- Insolation and photosynthetically active radiation (PAR) and underwater light transmission of PAR
- Stream discharge (water level and flow) and stream velocity
- Secchi disk visibility

Water Chemistry

- Water quality field parameters (temperature, pH, dissolved oxygen, specific conductance)

- Nitrate+nitrite nitrogen [NOx-N], and total phosphorus [TP]

Ecosystem Level

- Community export (fine particulate export)
- Flora and fauna

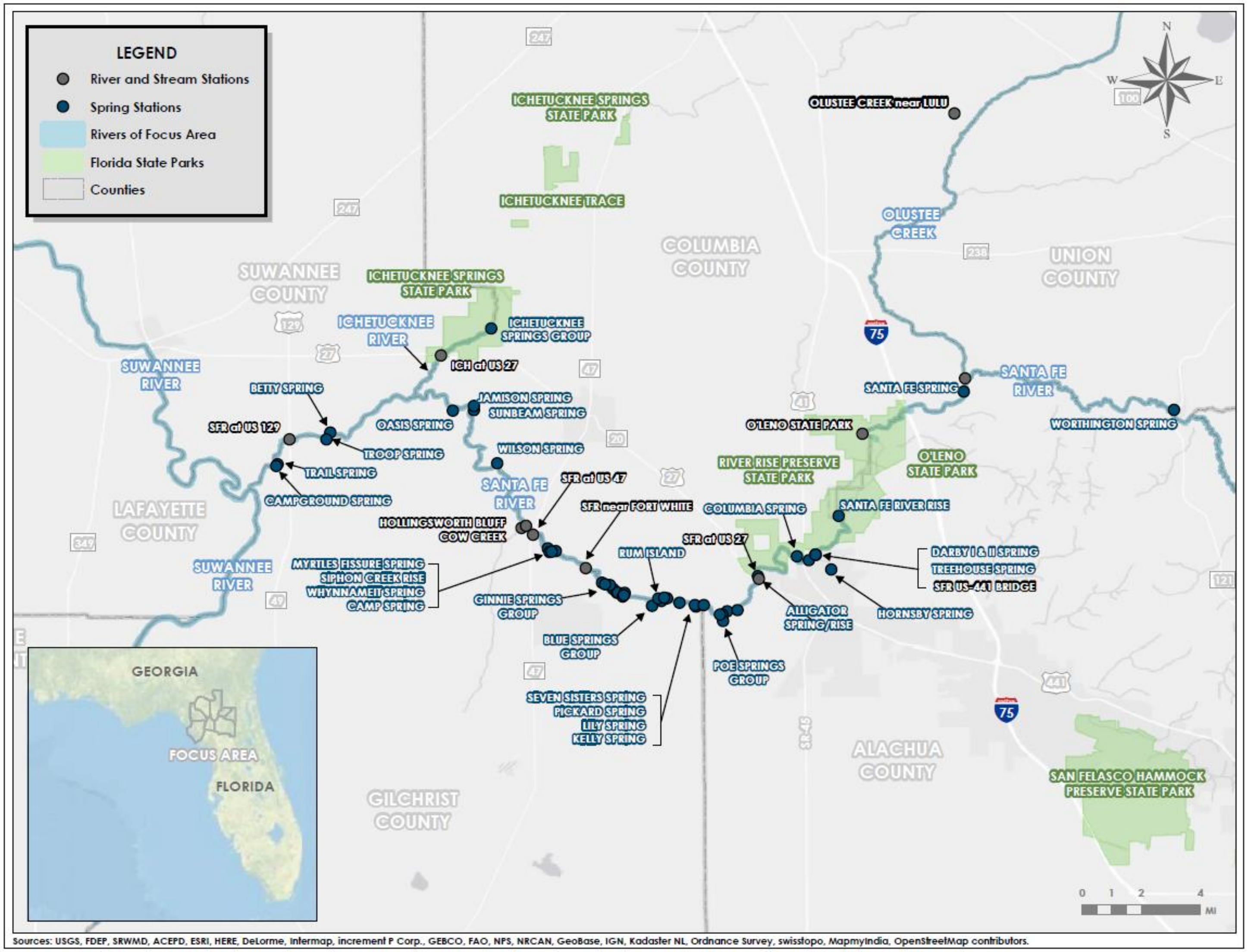


Figure 44. Santa Fe River and Ichetucknee River and springs.

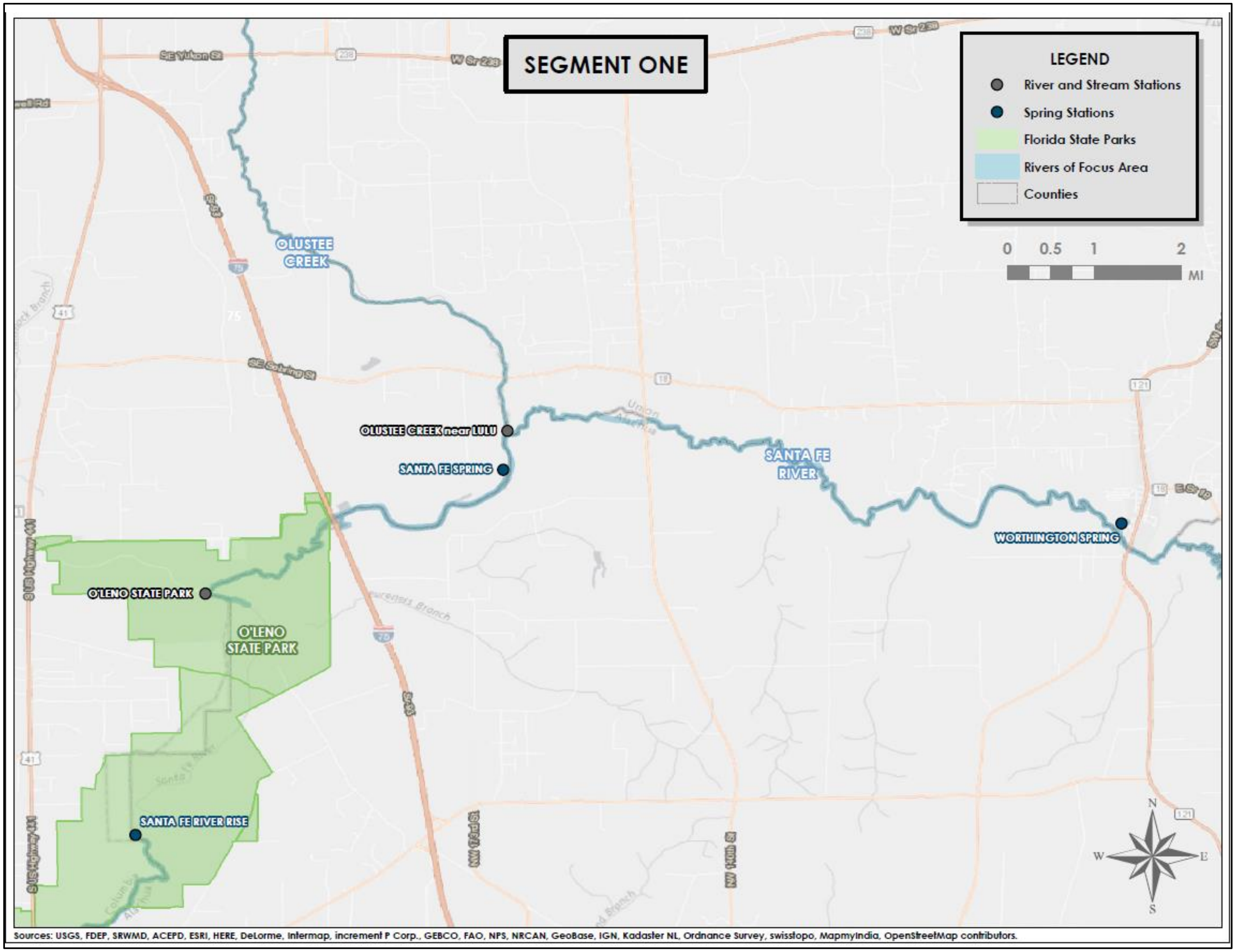


Figure 45. Upper Santa Fe River Segment 1 monitoring station locations

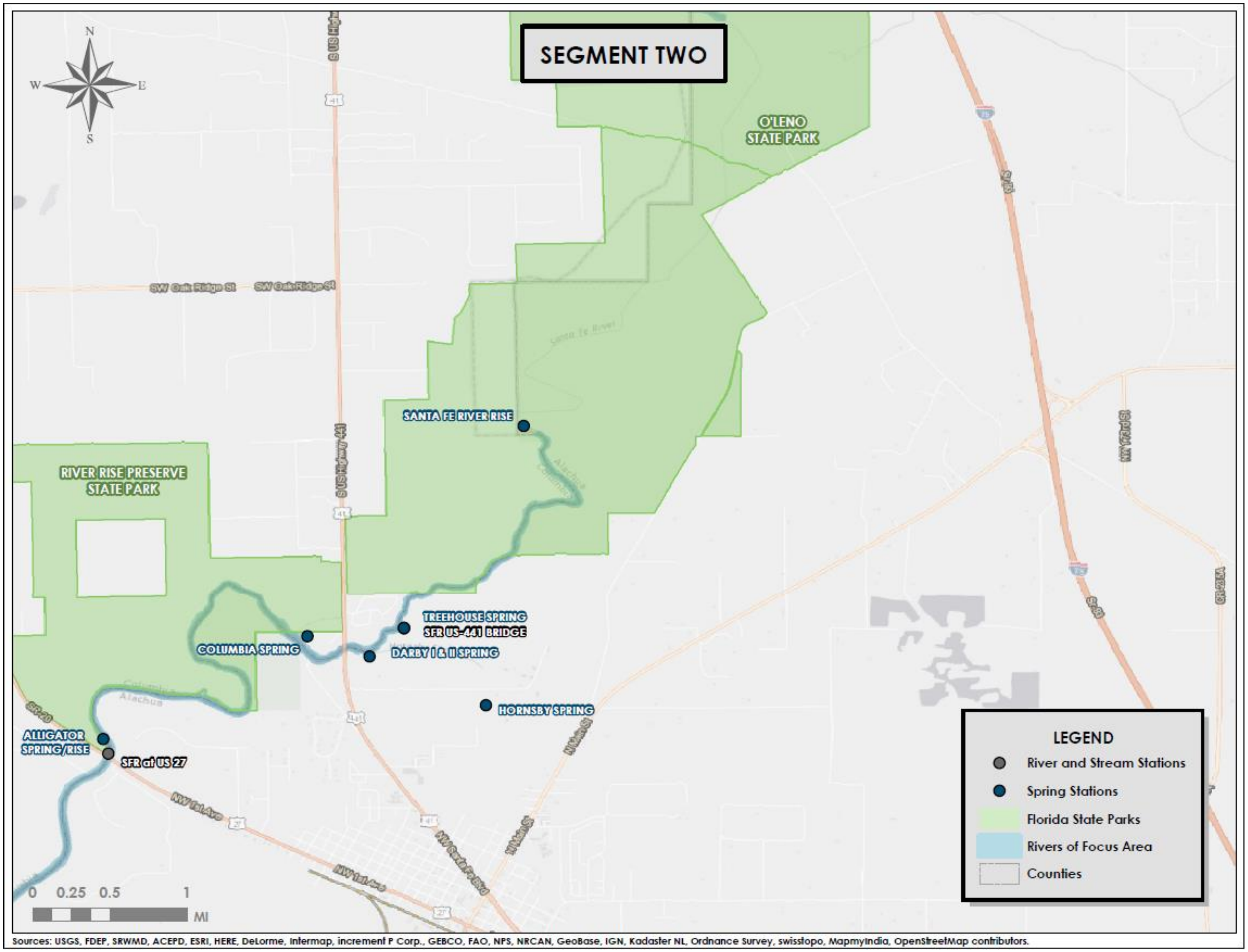


Figure 46. Lower Santa Fe River Segment 2 monitoring station locations

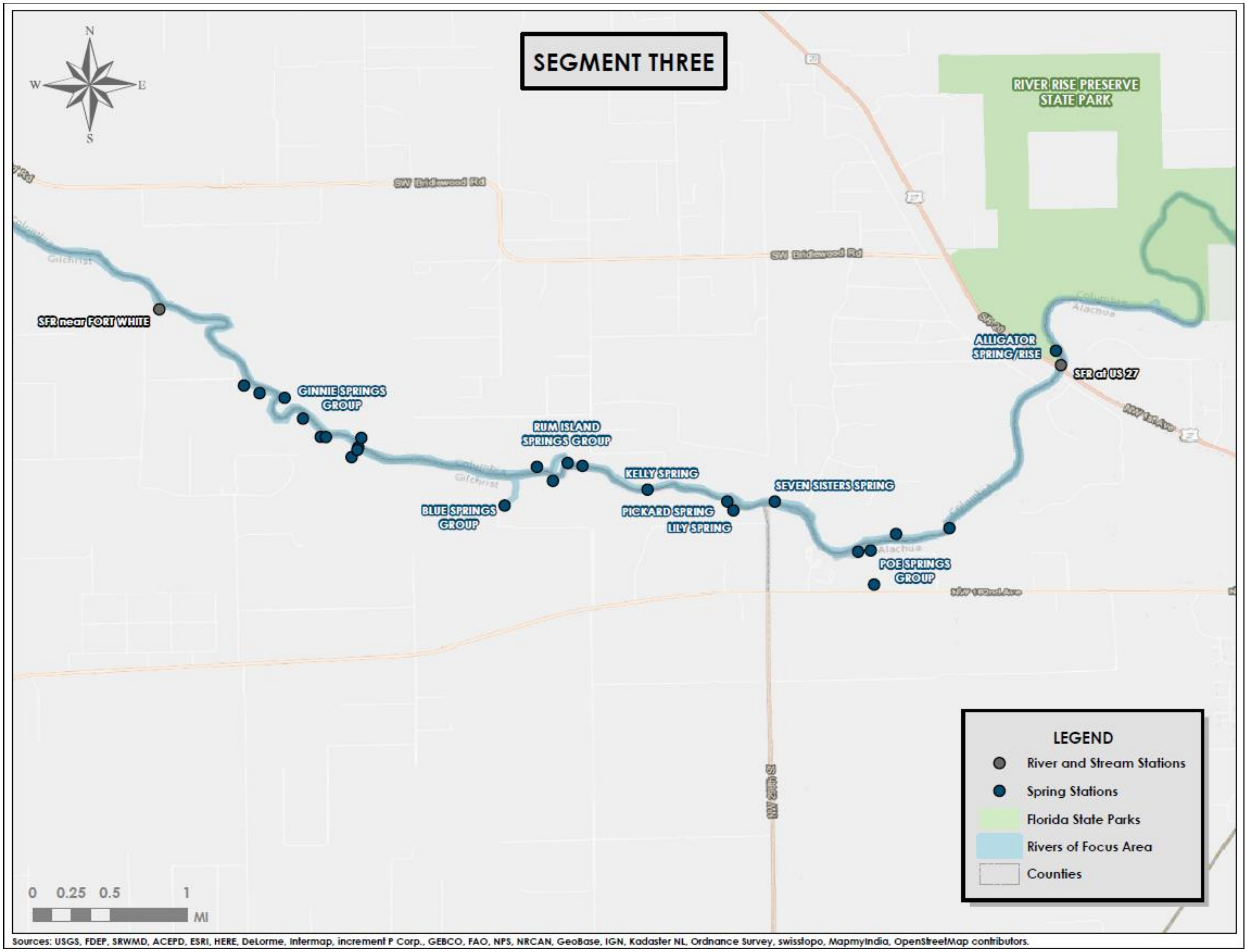


Figure 47. Lower Santa Fe River Segment 3 monitoring station locations

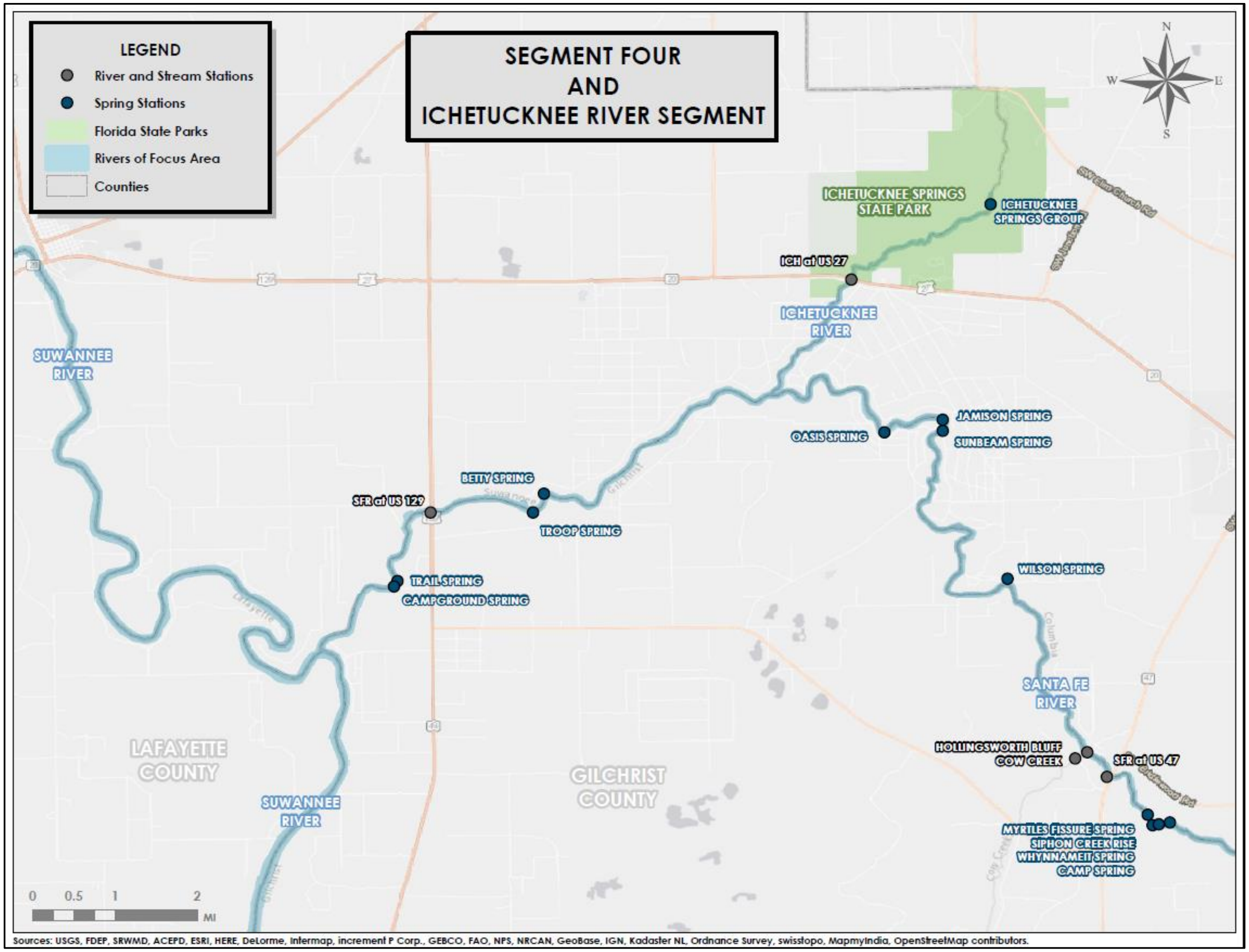


Figure 48. Lower Santa Fe River Segment 4 and the Ichetucknee River monitoring station locations

Table 17. Santa Fe River and springs monitoring stations

Station	Type	Latitude	Longitude	USGS/FDEP/SRWMD
Segment 1 - Worthington Spring at SR 121 to O'Leno State Park				
SFR at Worthington Spring	River	29.921667	-82.426389	2321500
Worthington Spring	Spring	29.925878	-82.427525	
SFR above Olustee	River	29.94068	-82.52959	
Olustee Creek	River	29.94130	-82.52971	2321600
SFR below Olustee Creek	River	29.94043	-82.53019	
Upstream Santa Fe Spring	River	29.93497	-82.52914	
Santa Fe Spring	Spring	29.93461	-82.53008	2321897
SFR I-75	River	29.92771	-82.55683	
O'leno State Park	River	29.914167	-82.580000	2321898
Segment 2 - Santa Fe River Rise to U.S. HWY 27				
Santa Fe River Rise	Spring	29.87350	-82.59133	2321958/ 2321910
Treehouse Spring	Spring	29.85515	-82.60281	2321971
Hornsby Spring	Spring	29.85252	-82.60671	2321970
SFR US-441 Bridge	River	29.85297	-82.60864	2321975
Columbia Spring	Spring	29.853889	-82.611806	2321977
Columbia Spring Main Channel	Spring	29.85426	-82.61264	
Columbia Spring Side Channel	Spring	29.85391	-82.61272	
Alligator Spring/Rise	Spring	29.844445	-82.631111	
SFR at US 27	River	29.84387	-82.63069	
Segment 3 - U.S. HWY 27 to the U.S. HWY 47				
Poe Spring	Spring	29.82626	-82.64957	2322140
Rum Island	Spring	29.83352	-82.679831	
Gilchrist Blue Spring	Spring	29.83026	-82.68245	2322350
Devil's Eye Spring	Spring	29.83500	-82.69684	
Ginnie Spring	Spring	29.83514	-82.69689	
Dogwood Spring	Spring	29.83820	-82.70174	
Twin Spring	Spring	29.84049	-82.70583	
Deer Spring	Spring	29.84120	-82.70737	
SFR near Fort White	River	29.848611	-82.715278	2322500
SFR at US 47	River	29.86480	-82.74038	SFR060C1
Segment 4 - U.S. HWY 47 to Suwannee River confluence				
SFR above ICH	River	29.93557	-82.7912	
SFR below ICH	River	29.93276	-82.80956	
Betty Spring	Spring	29.91486	-82.83997	
Troop Spring Run	Spring	29.91144	-82.84206	
SFR at US 129	River	29.91169	-82.86016	2322800
Campground Spring	Spring	29.89864	-82.86638	
Trail Spring	Spring	29.89839	-82.86668	
SFR UNS 27	Spring	29.89686	-82.87252	
SFR UNS 28	Spring	29.89120	-82.87402	
SFR-54	River	29.88906	-82.87858	
Ichetucknee River (Main Boil to Santa Fe River confluence)				
Canoe Launch	River	29.982309	-82.760283	
Midpoint	River	29.964167	-82.763647	
Tube Takeout	River	29.954761	-82.784472	
ICH at US 27	River	29.952860	-82.785896	2322700
LIR-15	River	29.93331	-82.79942	
SFR UNS 21	Spring	29.93242	-82.80082	

2.6.1 Underwater Light Transmission

The input of solar energy is the one major environmental factors that is seasonally variable in springs. The influx of light is also the most important determinant of overall ecosystem primary productivity in clear-water springs. Light attenuation by dissolved and particulate matter in spring water limits solar energy available to submersed aquatic plants and other primary producers. Figure 49 and Figure 50 provide a summary of the measured percent transmittance and diffuse attenuation coefficients at the Santa Fe and Ichetucknee River stations. Detailed light measurement data are provided in FSI (2017).

The percent transmittance between the stations averaged 47.4 percent at 1 meter, ranging from 1.91 percent (Olustee Creek) to 81.6 percent (Poe Spring Run), while the diffuse attenuation coefficient averaged 1.08 m^{-1} (range 0.20 to 3.96 m^{-1}). The average percent transmittance of the river stations was 34.4 percent, while the spring stations averaged 61.3 percent. The average diffuse attenuation coefficient at the river stations was 1.56 m^{-1} and the spring stations was 0.56 m^{-1}. Light attenuation generally decreased from the Upper to the Lower Santa Fe River as the dark tannic water of the Santa Fe River was diluted by relatively clear groundwater spring inputs, particularly for Segment 3. The Ichetucknee River is a spring fed system; therefore, light attenuation was generally low for all monitored stations.

2.6.2 Stream Discharge and Current Velocity

Spring discharge is second only to solar input as one of the most important forcing functions that regulates overall spring habitat support of plant, fish, and wildlife communities (Odum 1957; Knight 2015). Stream discharge and velocity were measured in the Upper (Segment 1) and Lower Santa Fe River (Segments 2 and 3) using a portable flow meter.

Table 18 and Figure 51 provide summaries of discharges measured during the assessment, while FSI (2017) provides detailed discharge measurements. Stream discharge during Fall/Winter 2016 increased in the Santa Fe River from 20.4 cfs at the town of Worthington Springs (SR 121 bridge gauge); to 155 cfs at the beginning of Segment 2 at the Santa Fe River Rise; to 1,080 cfs at the end of Segment 3 at U.S. Hwy 47; to 1,478 cfs near the confluence with the Suwannee River; for an overall increase of 1,458 cfs (7,147%).

Stream discharge changes within each segment are summarized below, with Segments 1 and 3 showing the greatest increases. The highest density of spring inputs on the Santa Fe River occurs within Segment 3 between U.S. Hwy 27 and U.S. Hwy 47. The Ichetucknee River and springs were adding an estimated 259 cfs of spring water to the Santa Fe River below U.S. 47 during this study.

- Segment 1 – Santa Fe River at Worthington Springs (20.4 cfs) to River Rise (155 cfs) = 135 cfs (662 %);
- Segment 2 - Santa Fe River Rise (155 cfs) to U.S. Hwy 441 (204 cfs) = 49 cfs (32 %) and U.S. Hwy 441 (204 cfs) to U.S. Hwy 27 (210 cfs) = 6 cfs (3 %), for a total of 55 cfs (35%);
- Segment 3 - U.S. Hwy 27 (210 cfs) to U.S. Hwy 47 (1,080 cfs) = 870 cfs (414 %);
- Segment 4 – U.S. Hwy 47 (1,080 cfs) to Santa Fe River above Suwannee River confluence (1,478 cfs) = 398 cfs (37 %), including 259 cfs from the Ichetucknee Segment (measured at U.S. 27)

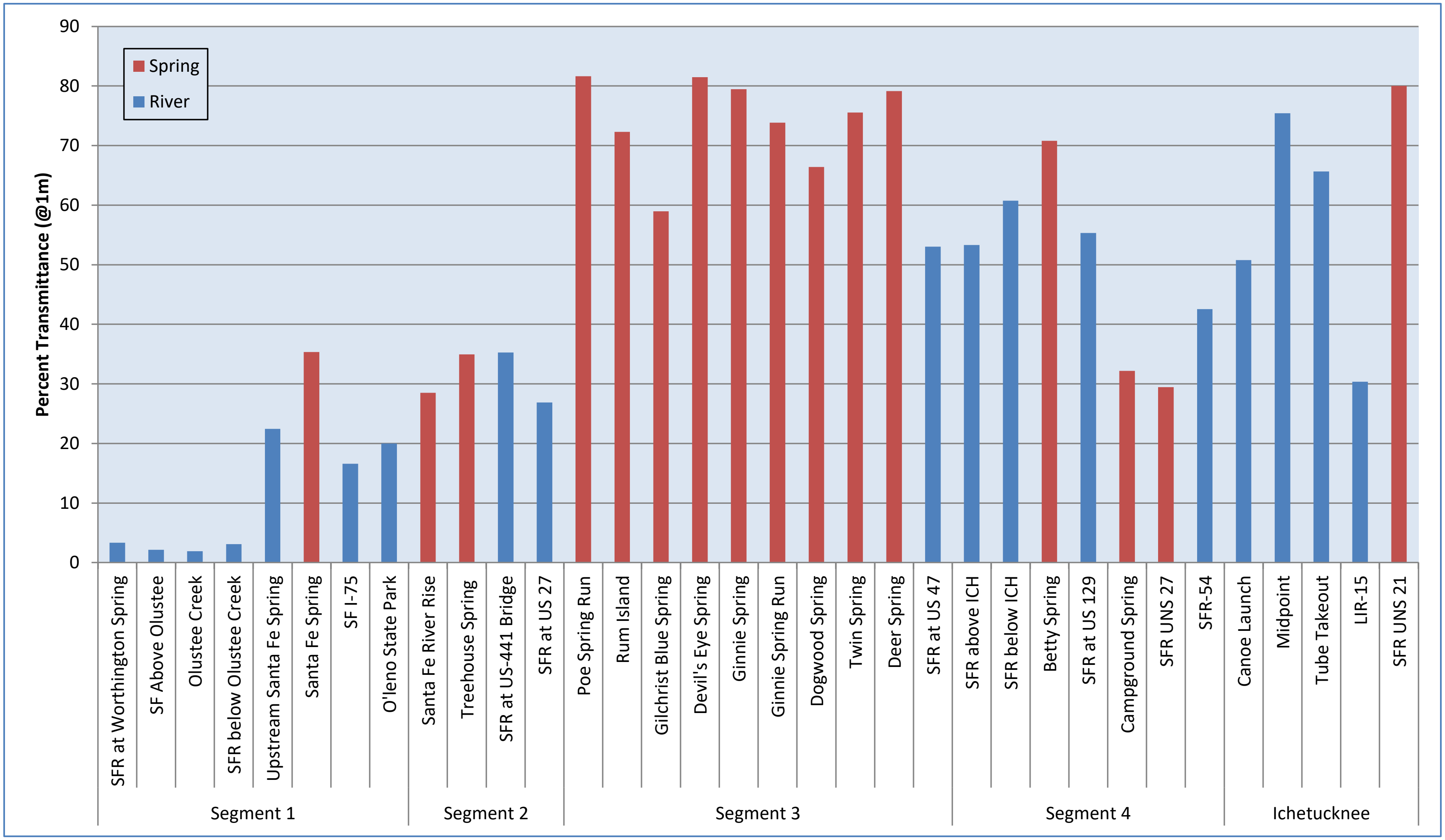


Figure 49. PAR percent transmittance (@ 1m) by Santa Fe River and Springs stations (October - December 2016)

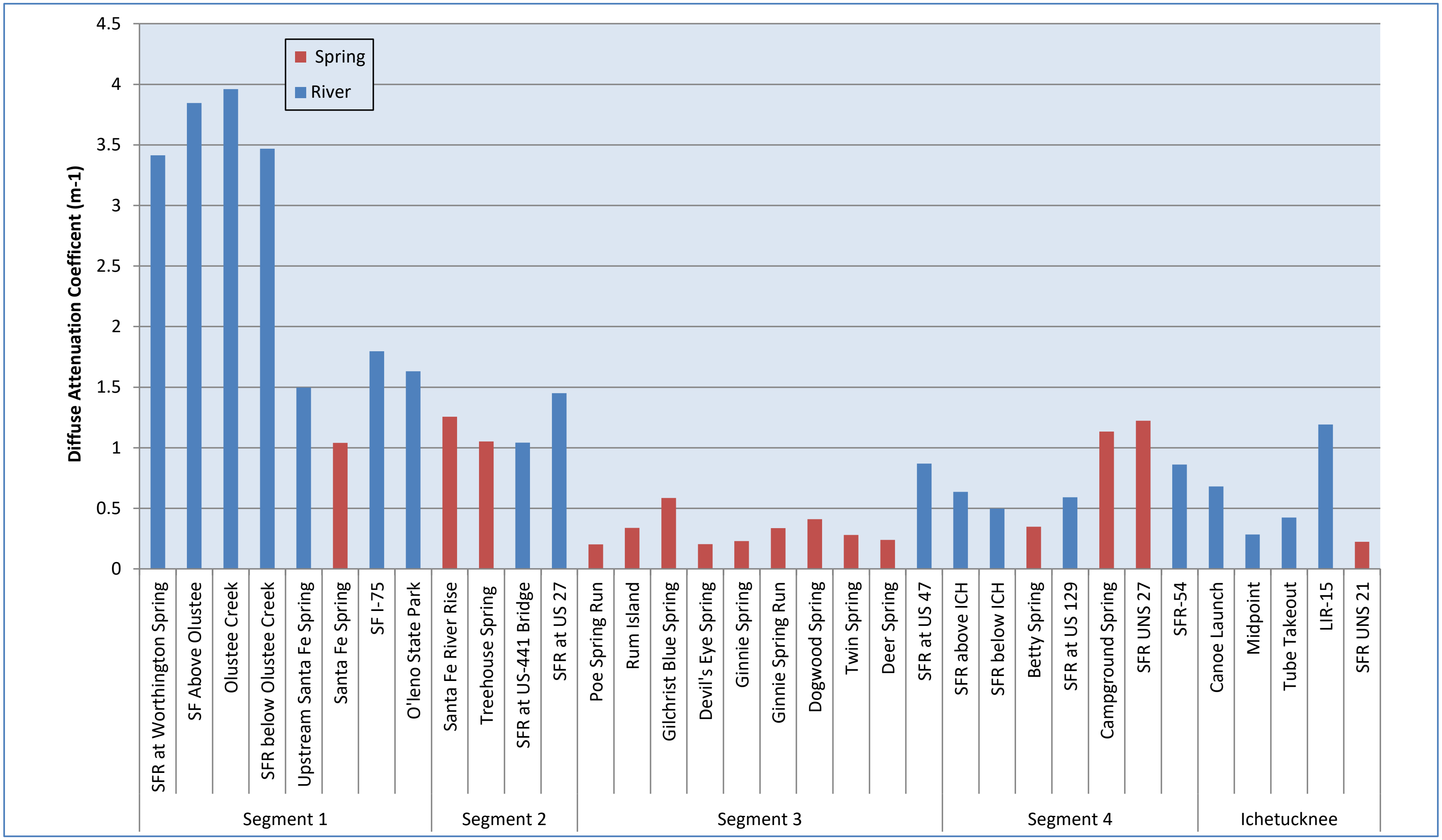


Figure 50. PAR Diffuse Attenuation by Santa Fe River and Springs stations (October - December 2016)

Table 18. Santa Fe River flow measurements

Segment	Station	Date	Width (ft)	Average Depth (ft)	Discharge (cfs)	USGS Station	Discharge (cfs)
1	Worthington Spring	11/11/2016			0		
	Olustee Creek	11/11/2016			0		
	Santa Fe Spring	11/11/2016	28	1.6	56.5		
2	Santa Fe River Rise	11/17/2016	162	1.9	155	232195	170
	SFR US-441 Bridge	11/17/2016	126	2.9	204		
	Treehouse Spring	11/17/2016	117	2.6	166		
	Columbia Spring	11/17/2016	66	0.7	82.7		
	SFR at US 27	11/17/2016	133	3.5	200		
	SFR at US 27	11/21/2016	134	3.7	220		
3	Gilchrist Blue Spring	10/14/2016	37	2.3	40.2		
	Poe Spring Run	11/21/2016	51	0.8	45.1		
	Ginnie Spring Run	10/14/2016	41	3.1	36.7		
	Ginnie Spring Run	11/21/2016	45	2.6	34.9		
	SFR at US 47	11/21/2016	133	3.2	1,080	2322500	896

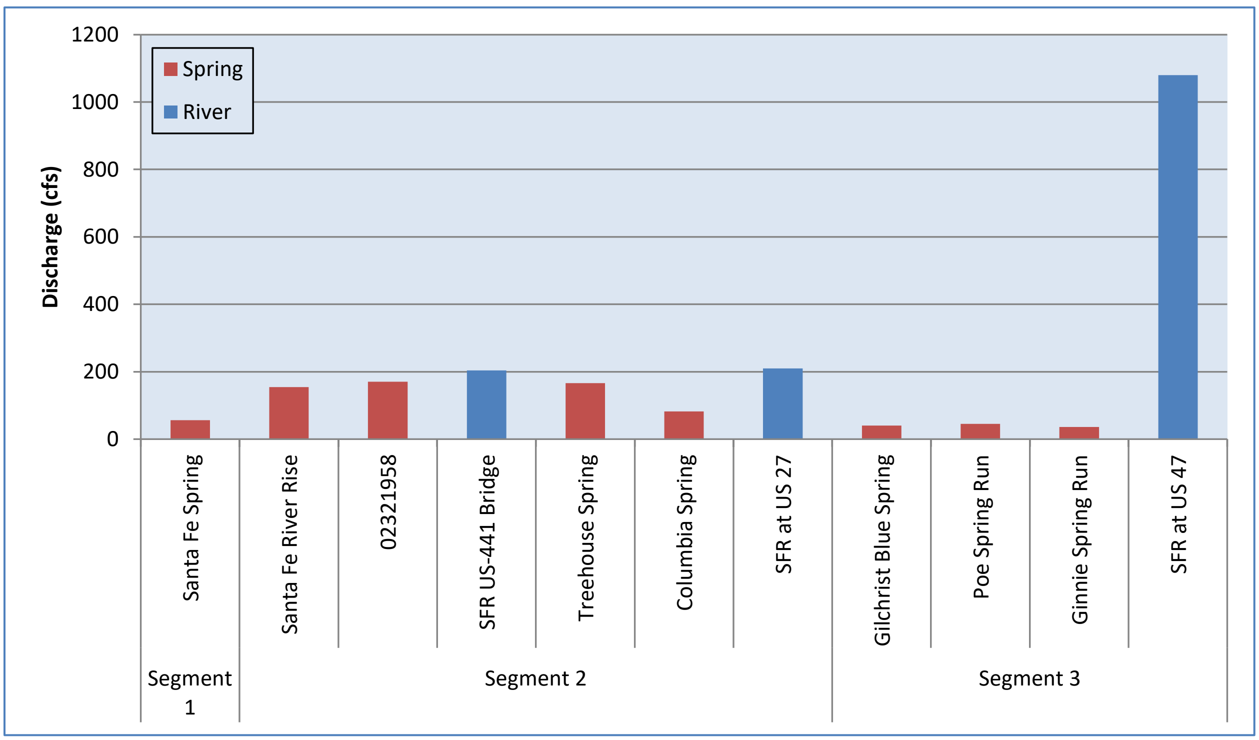


Figure 51. Santa Fe River flow measurements (October – November 2016)

2.6.3 Secchi Disk Visibility

Horizontal and vertical Secchi disk visibility measurements were collected on multiple dates at multiple stations along the Santa Fe River (Table 19). These measurements provide additional information concerning water clarity and the light attenuation properties of the water in the Santa Fe River. Secchi disk visibility generally increased from the Upper to the Lower Santa Fe River as the dark tannic water of the Santa Fe River was diluted by relatively clear groundwater spring inputs. The Secchi disk visibility between the stations averaged 6.95 meters, ranging from 0.65 m (Santa Fe River above Olustee) to > 30 m (Gilchrist Blue Spring).

Table 19. Secchi disk (m) measurements in the Santa Fe River and Lower Ichetucknee River (October – December 2016)

Segment	Station	Secchi (m)
1	SFR at Worthington Spring	0.75
	SFR above Olustee	0.65
	Olustee Creek	0.95
	SFR below Olustee Creek	0.86
	Upstream Santa Fe Spring	2.05
	Santa Fe Spring	4.75
	SFR I-75	> 1.2
	O'Leno State Park	2.7
2	Santa Fe River Rise	3.4
	Treehouse Spring	3.8
	Alligator Spring/Rise	3.4
	SFR at US 27	> 2.5
3	Rum Island Spring	> 24
	Gilchrist Blue Spring	> 30
	Ginnie Spring	24.8
4	Campground Spring	> 6.5
	SFR-54	> 3.3
ICH	LIR-4	9.47
Average		**6.95**

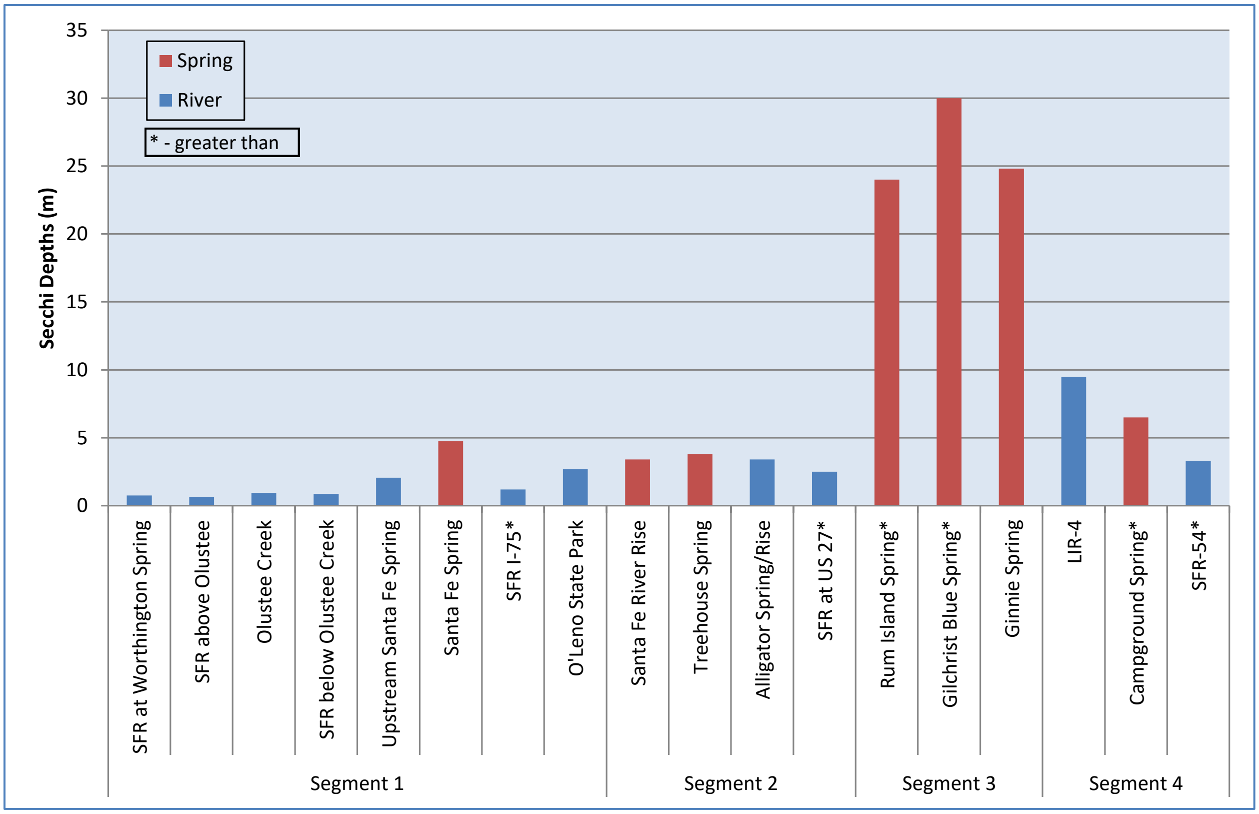


Figure 52. Secchi disk (m) measurements in the Santa Fe River and springs (October - December 2016)

2.6.4 Water Quality

Figure 53 through Figure 58 provide a summary of average water quality grab sample results at each station during the monitoring events. Detailed water quality data are presented in FSI (2017).

Dissolved oxygen (DO) concentrations were generally lower in the spring stations (average 3.56 mg/L, range 0.87 to 8.49 mg/L) compared to the Santa Fe River stations (average 5.91 mg/L, range 1.8 to 8.96 mg/L). Groundwater discharge from many springs tend to have low, stable DO concentrations, while DO concentrations in spring run/river stations fluctuate in response to plant photosynthesis and oxygen diffusion from the atmosphere.

Spring and Santa Fe River pH measurements were similar with an average of 7.45 SU and 7.52 SU, respectively. Spring pH measurements ranged from 7.21 to 7.77 SU, while the river station pH values ranged from 6.75 to 8.08 SU.

Specific conductance in the Santa Fe River changed in response to spring discharges. The lowest specific conductance measurements were observed in Section 1 of our study area at stations Santa Fe River at Worthington Spring (173 µmhos/cm) and Santa Fe River above Olustee Creek (155 µmhos/cm). The highest specific conductance was measured in Segment 4 at Troop Spring Run (949 µmhos/cm) with the next highest measurement at Santa Fe River Rise (510 µmhos/cm).

Water temperatures from spring discharges are typically stable, while river stations fluctuate in response to daily and seasonal air temperature changes. The lowest water temperature measurement was observed in the Segment 1 Worthington Spring (15.34 ^{o}C) while the highest was measured in Segment 2 Santa Fe River Rise (22.53 ^{o}C). Worthington Spring was not flowing during this study period and the low water temperature is likely due to low air temperatures at the time of sampling.

Average Santa Fe River nitrate+nitrite nitrogen (NOx-N) concentrations increased from 0.21 mg/L in Segment 1 (SFR at Worthington Spring) to 0.89 mg/L in Segment 4 (SFR-54), with the highest concentration of 1.0 mg/L observed in Segment 3 (SFR at US47). For springs sampled during this study, average NOx-N concentrations increased from 0.30 mg/L, 0.40 mg/L, 1.34 mg/L, and 12.27 mg/L in Segments 1, 2, 3, and 4, respectively. The spring with the highest NOx-N concentration (49 mg/L) was Troop Spring in Segment 4.

Only select stations were analyzed for total phosphorus. Average Santa Fe River TP concentrations decreased from 0.183 mg/L in Segment 1 (SFR at Worthington Spring) to 0.062 mg/L Segment 4 (SFR-54). Average spring TP concentrations also decreased from 0.118 mg/L, 0.168 mg/L, and 0.076 mg/L in Segments 1, 2, and 3, respectively.

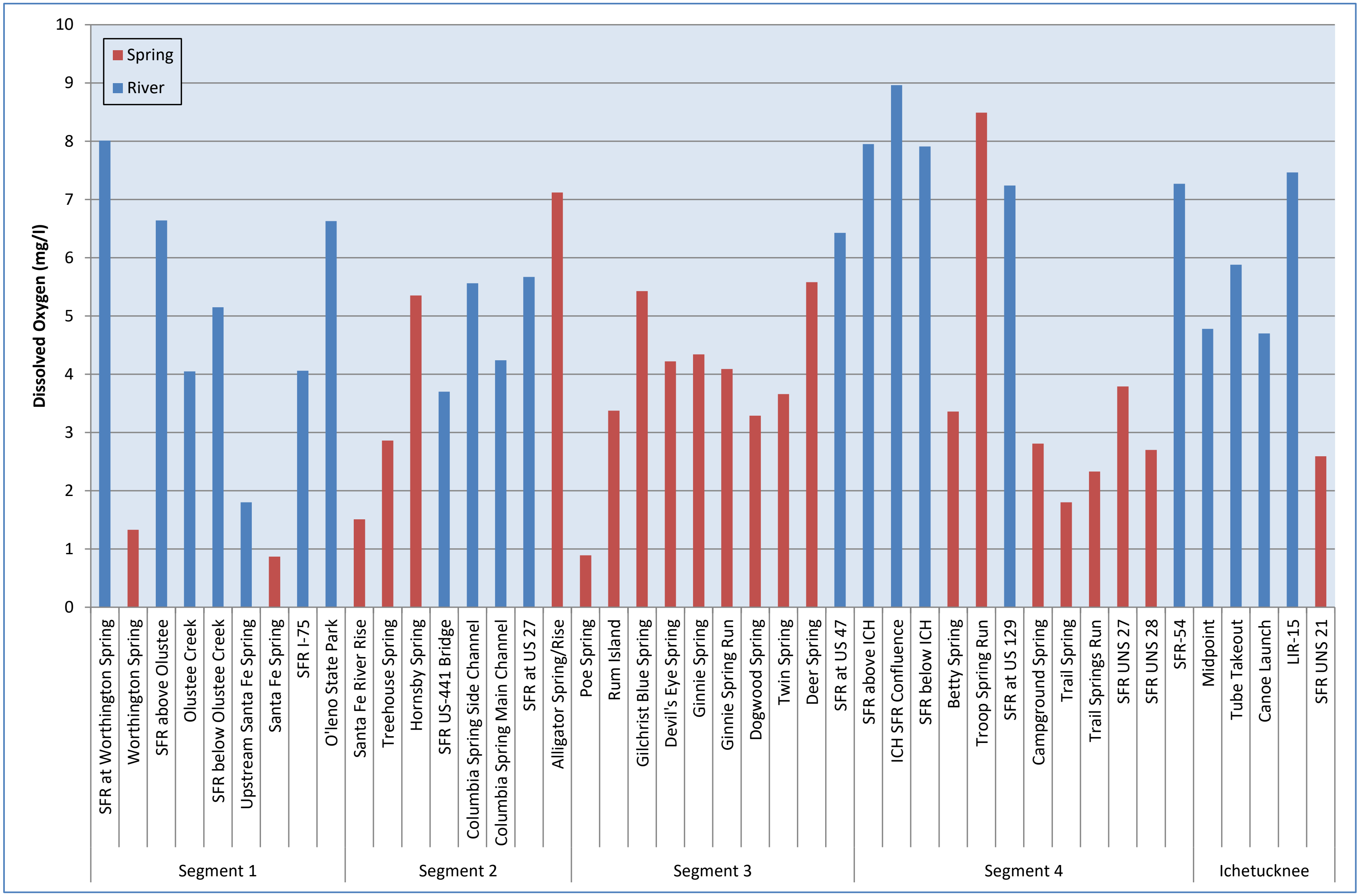


Figure 53. Dissolved oxygen (mg/L) in the Santa Fe River, Ichetucknee River, and associated springs (October - December 2016)

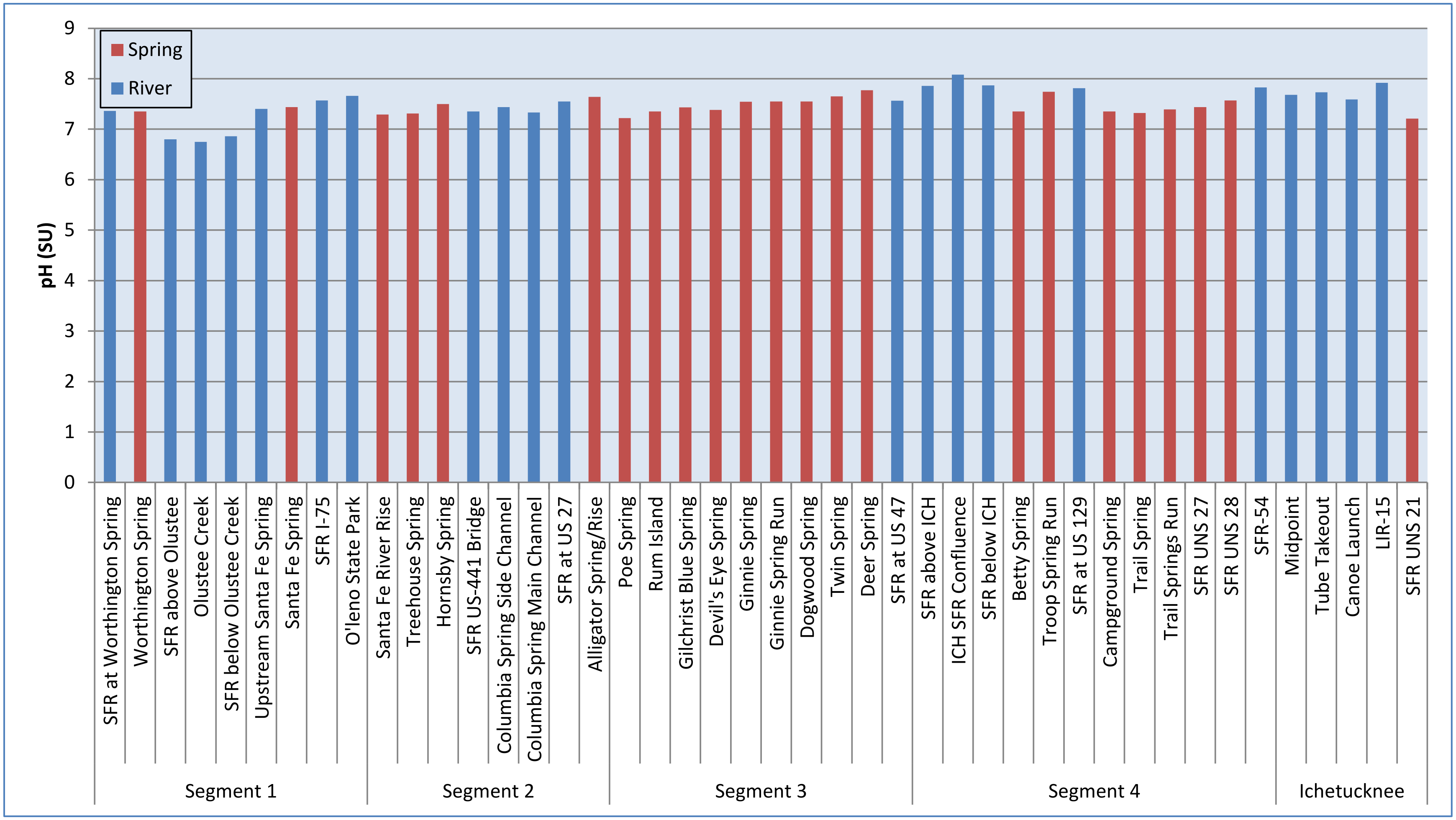


Figure 54. Hydrogen ion concentration (pH) in the Santa Fe River, Ichetucknee River, and associated springs (October - December 2016)

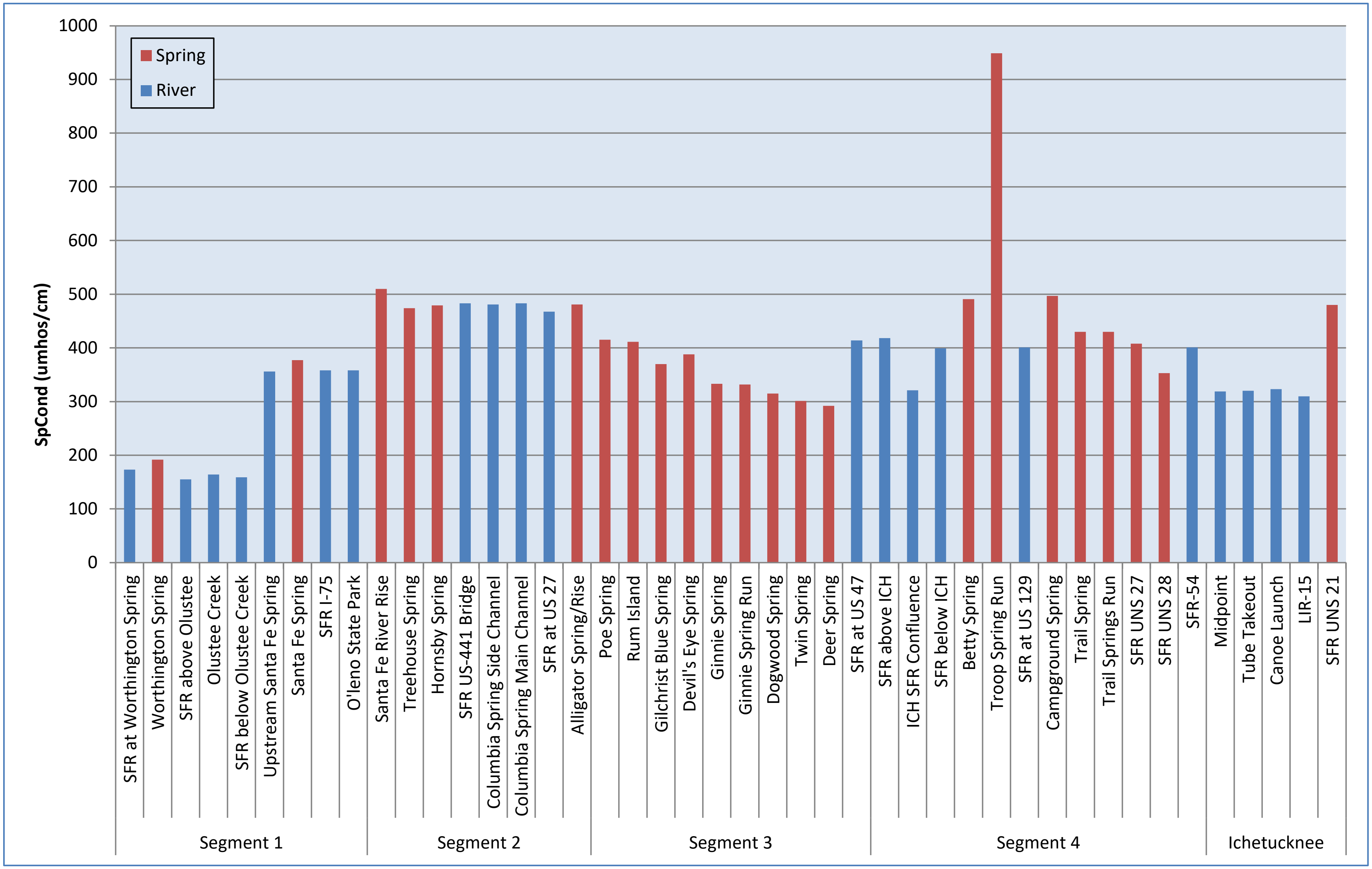


Figure 55. Specific conductance in the Santa Fe River, Ichetucknee River, and associated springs (October - December 2016)

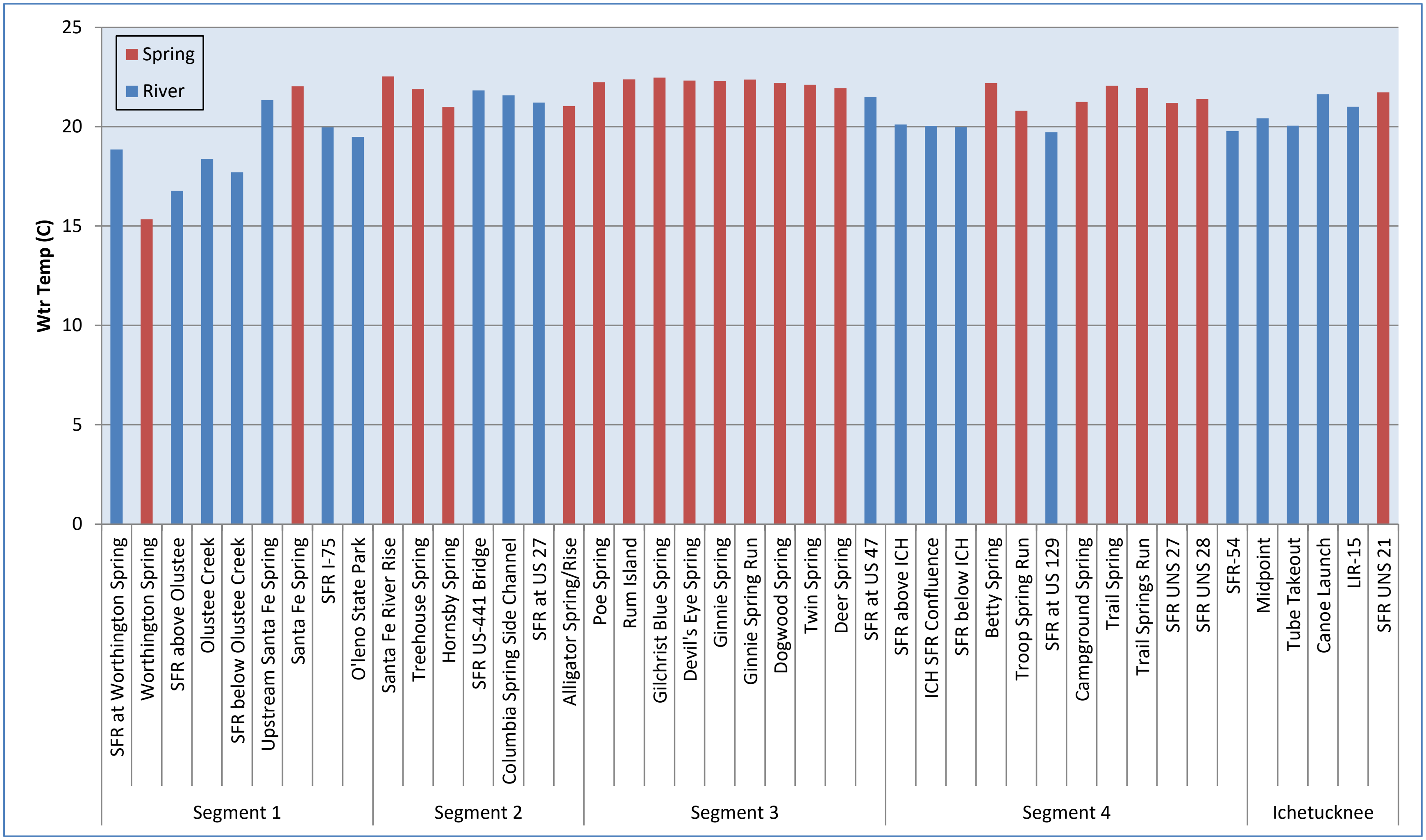


Figure 56. Water temperature (degC) in the Santa Fe River, Ichetucknee River, and associated springs (October - December 2016)

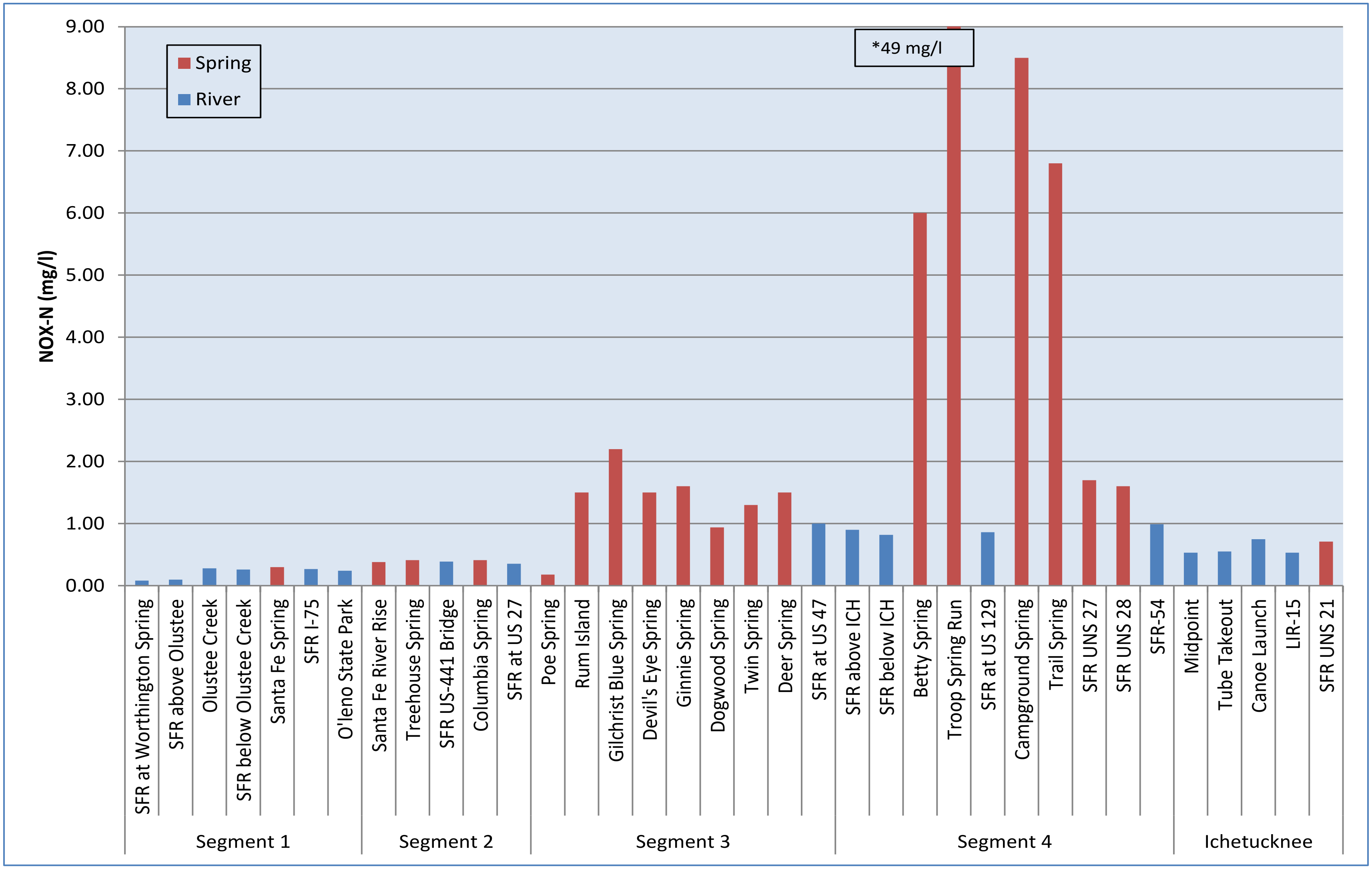


Figure 57. Nitrate+Nitrite Nitrogen (mg/L) in the Santa Fe River, Ichetucknee River, and associated springs (October - December 2016)

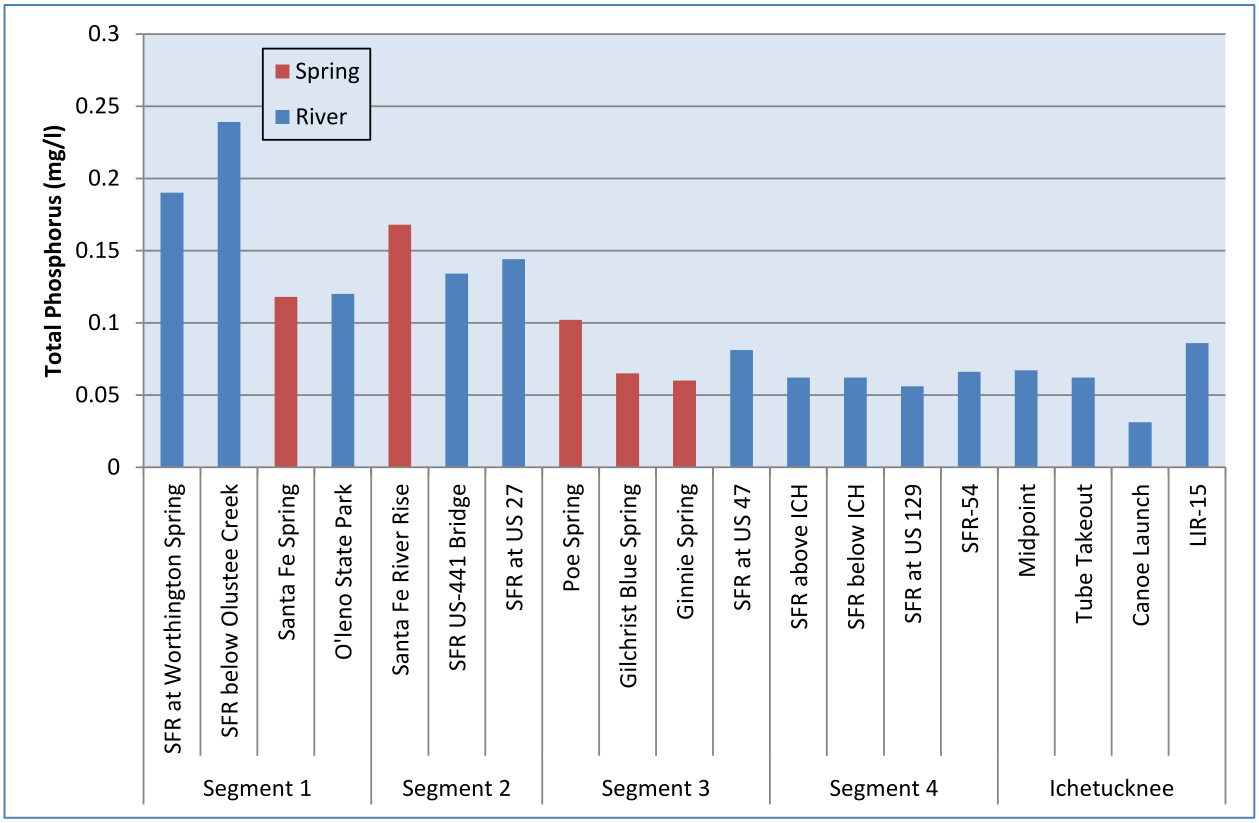


Figure 58. Total phosphorus (mg/L) in the Santa Fe River, Ichetucknee River, and associated springs (October - December 2016)

2.6.5 Nitrate Loads

Table 21 summarizes nitrate load estimates within each Santa Fe River segment during this study period. Nitrate loads increased in the Santa Fe River from 71.7 tons/yr in Segment 2 at the Santa Fe River Rise to 1,342 tons/yr in Segment 4 at U.S. Hwy 129, for an increase of 1,270 tons/yr (1,771 %). Nitrate load changes within each segment are summarized below, with Segment 3 showing the greatest increase. The highest density of spring inputs on the Santa Fe River occurs within Segment 3 between U.S. Hwy 27 and U.S. Hwy 47.

- Segment 1 – Santa Fe River at Worthington Springs (1.69 tons/yr) to O'Leno State Park (18.3 tons/yr) = 16.6 tons/yr)
- Segment 2 - Santa Fe River Rise (71.7 tons/yr) to U.S. Hwy 441 (82.2 tons/yr) = 10.5 tons/yr (15 %) and U.S. Hwy 441 (82.2 tons/yr) to U.S. Hwy 27 (69.9 tons/yr) = -12.3 tons/yr (-15 %), overall change -1.8 tons/yr (-0.025%)
- Segment 3 - U.S. Hwy 27 (69.9 tons/yr) to U.S. Hwy 47 (1,063 tons/yr) = 993 tons/yr (1,421 %)
- Segment 4 - U.S. Hwy 47 (1,063 tons/yr) to U.S. Hwy 129 (1,342 tons/yr) = 279 tons/yr (26 %)

Table 20. Estimated nitrate+nitrite nitrogen concentrations and loads for the Santa Fe River and springs (October - December 2016)

Segment	Station	Discharge (cfs)	NOX-N (mg/l)	Tons/year
1	SFR at Worthington Spring*	20.4	0.084	1.69
	Santa Fe Spring	56.5	0.300	16.7
2	O'leno State Park*	77.5	0.240	18.3
	Santa Fe River Rise*	192	0.380	71.7
	Treehouse Spring	166	0.410	67.0
	SFR US-441 Bridge	204	0.410	82.2
	Columbia Spring	82.7	0.410	33.4
	SFR at US 27	200	0.355	69.9
3	Poe Spring Run	45.1	0.191	8.48
	Gilchrist Blue Spring	40.2	2.20	87.1
	Ginnie Spring Run	35.8	1.58	55.7
	SFR at US 47	1,080	1.00	1,063
4	SFR at US 129*	1,478	0.923	1,342
ICH	ICH at US 27*	259	0.548	139

* - USGS/SRWMD Station data

2.6.6 Community Export

Community export data for the study segment are summarized in Table 21 with detailed data provided in FSI (2017). Particulate organic matter export rates varied widely. Positive values indicate a net production of detrital material (material leaving the study segment), while negative values indicate a net accrual of detrital material (material being deposited in the study segment). During the study period, organic matter export rates were positive for all events.

Table 21. Santa Fe River and Lower Ichetucknee River particulate export

Date	Station	Dry Matter (g/d)	Organic Matter (g/d)	Dry Matter (g/m2/d)	Organic Matter (g/m2/d)
10/14/2016	Ginnie Spring	2,893	981	3.236	1.097
10/14/2016	Gilchrist Blue Springs	2,495	1,450	1.497	0.870
12/2/2016	ISSP North Canoe Launch	3,877	1,699	3.218	1.410
12/3/2016	ISSP Midpoint	7,509	4,519	0.081	0.049
12/4/2016	ISSP Tube Take Out	9,635	6,377	0.077	0.051
12/5/2016	LIR-15	4,917	2,854	0.021	0.012

2.6.7 Summary of FSI Baseline Study

The Santa Fe River 2016 baseline study area consisted of the entire Lower Santa Fe River (River Rise to the Suwannee River) and portions of the Upper Santa Fe (Worthington Spring to O'Leno State Park), in addition to the Ichetucknee River, a major spring-fed tributary to the Lower Santa Fe River.

The 2016 discharge and water quality monitoring data from the Upper and Lower Santa Fe River indicate that this river and spring system is impaired in several respects compared to historical data. Average flows in the study area have been declining since the 1970s. Nitrate+nitrite nitrogen concentrations and loads have generally been increasing.

Dissolved oxygen concentration generally increased in the Santa Fe River from 5.19 mg/L in Segment 1 to 7.87 in Segment 4. pH, also, increased from 7.20 SU to 7.89 SU going downstream. Specific conductance increased from 243 µmhos/cm to 388 µmhos/cm; however, Segment 2 had the highest measured specific conductance value at 478 µmhos/cm. Temperatures were relatively consistent along the study area.

Nitrate+nitrite nitrogen concentrations in Segment 3, which is the most densely spring populated study area, averaged 1 mg/L for the river and 1.34 mg/L for the springs. This is about 20 and 26.8 times higher than background levels of this nutrient (about 0.05 mg/L) and 2.9 and 3.8 times higher than the Florida numeric springs standard of 0.35 mg/L for the river and spring averages, respectively. Segment 1 was the only section of the river that complied with Florida's nitrate nitrogen numeric standard (0.21 mg/L). Segment 4 had the highest nitrate average for springs at 12.27 mg/L, while the river average was 0.89 mg/L. Two of the springs sampled in this river segment (Troop and Campground) had very high measured nitrate concentrations that raised the spring average.

Figure 59 is a schematic that summarizes spring and river flows and nitrate concentrations, with the yearly estimates of the tons of NOx-N, at key measurement stations along the Santa Fe River. These numbers were based on the discharge measurements and reported NOx-N concentrations observed during the 2016 study period. The estimated nitrate nitrogen load increased dramatically with distance down river, from 1.7 tons/year in the Santa Fe River at the S.R. 121 Worthington Springs station, to 1,342 tons/year in the Santa Fe River at U.S. 129, upstream of the confluence with the Suwannee River. This is an observed net increase of more than 1,340 tons of nitrogen per year entering the river, primarily from groundwater sources.

One notable section of the river that illustrates the complex relationship between groundwater and surface water in the region, is the river segment between US 441 and US 27. At US 441, flow was measured at 204 cfs and then shortly downstream Columbia Spring discharged 82 cfs into the Santa Fe River. A simple mass balance would assume the US 27 discharge would be upwards of 286 cfs however, the actual reading was 200 cfs. The Columbia Springs system includes an upstream swallet that accounts for most this spring's input. Another interesting feature of this river stretch is the Alligator Sink/Spring system. Approximately 5,600 ft above the US 27 bridge and gauging station is the Alligator Sink that diverts a significant amount of the Santa Fe River flow through an underground cave system. (Butt, Morris, & Skiles, 2007). However, the rise of the Alligator Spring/Sink system occurs 750 ft before the US 27 gauging station, returning all original river water. Santa Fe River flow is reduced in the segment between Alligator Sink and Alligator Rise by the amount of flow that travels underground. During droughts, this portion of the river completely stagnates, eliminating the opportunity for any recreational boat traffic.

Table 22 was created to summarize spatial and temporal data for the mass of NOx-N and flow of the upper and lower sections of the Santa Fe River. The comparative data began in 1980 due to a lack of both flow and NOx-N data available prior to this date. Four stations (SFR at Worthington Spring, SFR near Fort White, SFR at US 129, and ICH at US 27) have had data collected regularly and consistently since the 1980's and continue to afford reliable data to be used for long term trends. SFR at US 441 had flow data until September 2010. Since then stage and water quality samples have only been collected. Since some stations were monitored less than five times in an entire decade those decadal averages are less reliable as a true indicator of long-term flows and masses. Nonetheless, Table 22 is useful in viewing long term trends in flow and nutrient loading while moving down the Santa Fe River.

Flow from 2000 to 2010 appears to be increasing in the four stations noted above but very minimally (3.3 to 9% increases) as does the concentration of NOx-N. Over a longer period, however, flow rates are still shown to be declining.

- SFR at Worthington Spring: 1980 to 2016 - 38% reduction in discharge
- SFR at US 441: 1980 to 2010 - 63% reduction in discharge
- SFR near Fort White: 1980 to 2016 - 30% reduction in discharge

Average NOx-N concentrations in mg/L and in tons/yr during the most recent decade have gone down at SFR at Worthington Spring, SFR near Fort White, and SFR at US 441 compared to the 1980s and 1990s averages. The average for the 2010s NOx-N has gone up since the 1980s at SFR at US 129. Interestingly, there are stations (Olustee Creek near Lulu, Treehouse Spring, Hornsby Spring, Rum Island Spring, and Gilchrist Blue Spring) where the NOx-N concentrations have risen, yet the nitrogen mass has declined due to declining flows.

Using the SFR near Fort White station because of the extended period of record as an indicator of the overall conditions for the upstream of the Santa Fe River, it appears as though NOx-N concentrations began to decline after the 1980s but have increased in the 2010s by 3% (mg/L) and 12.6% (tons/yr). During the same period, flow continued to decrease and has only begun increasing in the 2010s by approximately 9%. Additional research into changes in land use or policies between 2000 and 2010 could potentially uncover the deviation in the reduction of NOx-N. Additionally, further investigation into the conductivity and color in the Santa Fe River and springs could show whether the sources of NOx-N are coming from groundwater or surface water.

Based on the results of other Florida spring studies, declining flow and elevated nitrogen are often associated with ecological changes. Given the historic trends and the current conditions observed in this study, the Santa Fe River continues to be impaired with very little indication of improvement.

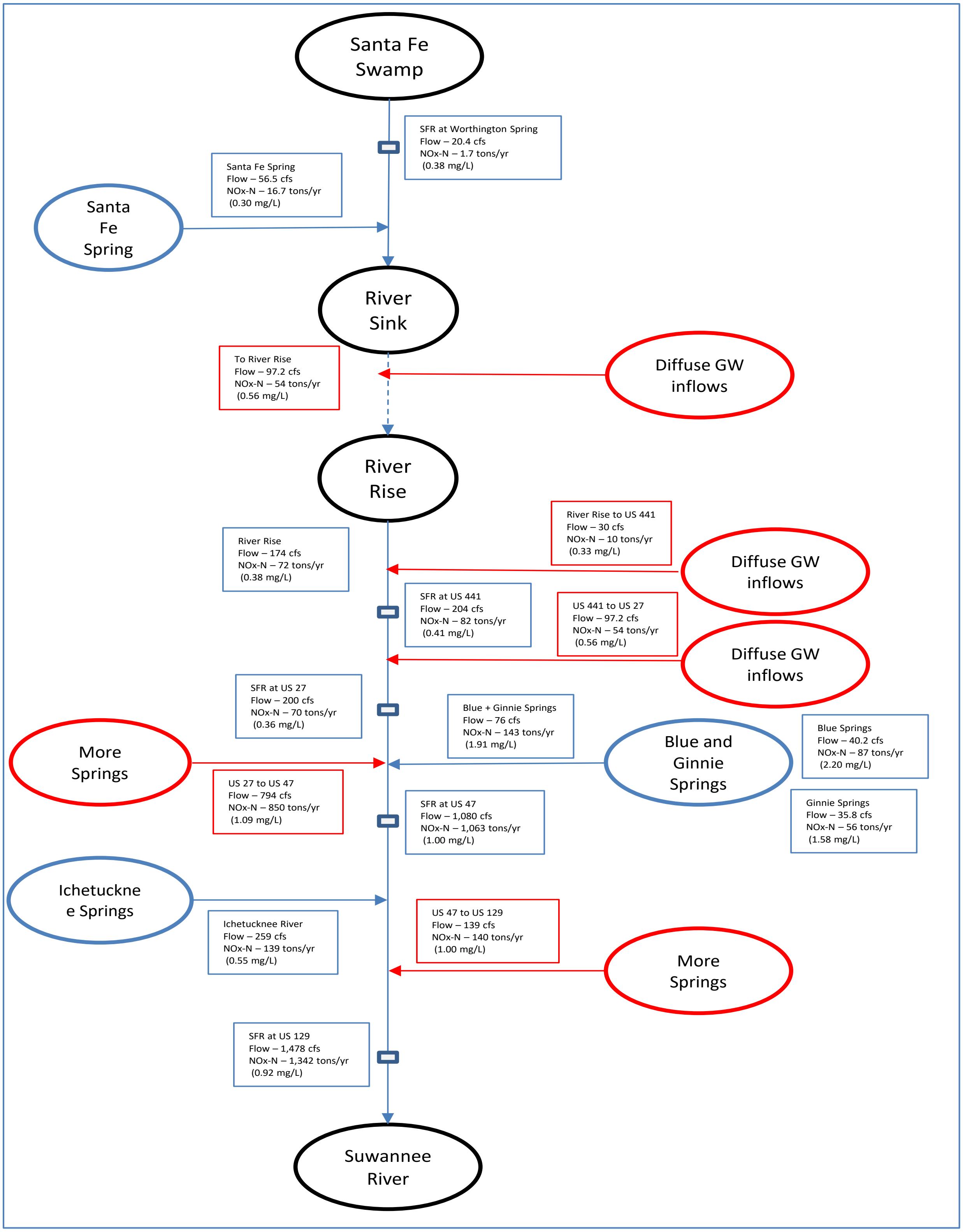


Figure 59. Schematic of the Santa Fe for NOx-N (tons/yr) – October – December 2016

Table 22. NOx-N (tons/yr) on the Santa Fe River by decade – 1980 - present

Segment	Station Name	Parameter Group	Parameter	Units	1980	1990	2000	2010
1	SFR at Worthington Spring	FLOW	Flow	cfs	418	373	248	257
		NITROGEN	NOx-N	tons/yr	148	69.6	39.2	78.0
				mg/l	0.360	0.189	0.160	0.309
	Olustee Creek near Lulu	FLOW	Flow	cfs		89.3*	110	17.9
		NITROGEN	NOx-N	tons/yr			4.05	0.757
				mg/l			0.038	0.043
	Santa Fe Spring	FLOW	Flow	cfs		53.5*	56.1	67.5
		NITROGEN	NOx-N	tons/yr		8.95	10.0	18.0
				mg/l		0.17*	0.182	0.272
	O'Leno State Park	FLOW	Flow	cfs				427
		NITROGEN	NOx-N	tons/yr				99.6
				mg/l		0.148	0.108	0.237
2	Santa Fe River Rise	FLOW	Flow	cfs	562	301*	68*	352
		NITROGEN	NOx-N	tons/yr		231	255	43.2
				mg/l		0.78*	3.80	0.125*
	Treehouse Spring	FLOW	Flow	cfs		211	205	173
		NITROGEN	NOx-N	tons/yr		113	60.1	52.0
				mg/l		0.546	0.298	0.305
	Hornsby Spring	FLOW	Flow	cfs		131	58.7	31.1
		NITROGEN	NOx-N	tons/yr		98.6	24.6	14.5
				mg/l		0.764	0.426	0.473
	SFR US-441 Bridge	FLOW	Flow	cfs		704	207	259
		NITROGEN	NOx-N	tons/yr		214	38.1	63.3
				mg/l	0.292	0.309	0.187	0.248
	Columbia Spring	FLOW	Flow	cfs		167*	97.7	119
		NITROGEN	NOx-N	tons/yr		76.5	21.0	32.1
				mg/l		0.465	0.219	0.273
	SFR at US 27	FLOW	Flow	cfs	177*	297*		743
		NITROGEN	NOx-N	tons/yr				260
				mg/l			0.05*	0.355*
3	Poe Spring	FLOW	Flow	cfs		60.1	48.0	30.9
		NITROGEN	NOx-N	tons/yr		42.4	12.9	4.56
				mg/l		0.716	0.272	0.150
	Rum Island	FLOW	Flow	cfs		60.8*	23.7*	15.8
		NITROGEN	NOx-N	tons/yr		88.6	27.0	21.3
				mg/l		1.48*	1.16*	1.37
	Gilchrist Blue Spring	FLOW	Flow	cfs		44.2	45.7	31.9
		NITROGEN	NOx-N	tons/yr		73.2	79.0	66.8
				mg/l		1.68	1.76	2.13

Segment	Station Name	Parameter Group	Parameter	Units	1980	1990	2000	2010
	Ginnie Spring	FLOW	Flow	cfs		51.6	37.7	38.0
		NITROGEN	NOx-N	tons/yr		64.7	60.2	56.1
				mg/l		1.28	1.63	1.50
	SFR near Fort White	FLOW	Flow	cfs	1,588	1,374	1,020	1,113
		NITROGEN	NOx-N	tons/yr	1,225	980	729	821
				mg/l	0.783	0.725	0.727	0.749
4	SFR at US 129	FLOW	Flow	cfs			1,556	1,608
		NITROGEN	NOx-N	tons/yr			925	1,083
				mg/l	0.648	0.582	0.604	0.684
ICH	ICH at US 27	FLOW	Flow	cfs	357	393	301	295
		NITROGEN	NOx-N	tons/yr	223	191	142	149
				mg/l	0.633	0.494	0.480	0.514

*Indicates average is based on less than 5 data points.

Section 3.0 Phase 2 and 3 Lower Santa Fe River and Springs Environmental Assessment Project Plan Scope

3.1 Project Objectives

The Santa Fe River located in north-central Florida, drains surface water runoff from the Santa Fe Swamp in northeast Alachua County, to the west under I-75, disappears underground at O'Leno State Park, and re-emerges at River Rise north of High Springs on the Karst Plain and flows with significant groundwater inflows west to its confluence with the Suwannee River south of Branford. The estimated total length of the Santa Fe River is 75 miles.

The entire Santa Fe River and its many feeder springs are Class III waters of the State of Florida and receive additional protection by their designation as an Outstanding Florida Water in 1987. Despite these designations, the Santa Fe River has been determined to be impaired by excessive nitrate-nitrogen concentrations and by excessive groundwater pumping. These impairments have been recognized through establishment of a nitrogen Total Maximum Daily Load by the Florida Department of Environmental Protection and a Minimum Flow and Level determination by the Suwannee River Water Management District.

Ongoing water quality and flow monitoring by these agencies has determined that the water quantity and quality in the Santa Fe River are continuing to decline. The ecological effects of this decline are evident in the loss of much of the native submerged aquatic vegetation and the subsequent proliferation of excessive growths of filamentous algae. These observed changes are evident in the main river channel and in the feeder springs.

In response to these observed changes, the Howard T. Odum Florida Springs Institute, with support from Our Santa Fe River, Inc., a local non-profit, citizen's advocacy group focused on the current and future health of the river, have teamed to compile a preliminary environmental assessment of the Santa Fe River and springs. The project approach includes multiple phases, including:

- Phase 1 - summary of existing environmental data for the Lower Santa Fe River (this report)
- Phase 2 – comprehensive baseline evaluation of existing conditions
- Phase 3 – development of a plan for specific restoration needs, costs, and responsible entities to fully restore the Santa Fe River and springs

The focus of the Phase 1 assessment is the river reach from Worthington Springs, the upstream-most named spring on the Santa Fe River; downstream to the confluence of the Santa Fe and Suwannee rivers. This river segment includes about 45 miles of the historic river channel. The purpose of the Phase 1 report is to summarize existing knowledge about the current and historic environmental conditions of the river and springs, to identify gaps in knowledge, and to develop a detailed scope for a Phase 2 study to provide a comprehensive baseline assessment.

The Phase 2 environmental baseline assessment is needed to develop recommendations for restoration, including specific resource acquisition and management actions that can be taken to reverse observed detrimental changes to the Santa Fe River and springs.

Completion of this Santa Fe River and Springs Restoration project includes two remaining phases: Phase 2 will include additional data collection needed to provide a complete and congruent baseline of existing environmental conditions, and Phase 3 will use that comprehensive data set as a foundation for developing a holistic, long-term, resource management plan.

This scope of services describes the tasks and estimated budget to complete Phases 2 and 3 of the Santa Fe River and Springs Study.

3.2 Phase 2 Scope

Work tasks proposed for Phase 2 include the following:

- Task 1 – Finalization of the Data Collection Plan with Responsible Parties
- Task 2 – Data Collection (physical, chemical, and biological for two or more years)
- Task 3 – Reporting and Public Input (quarterly data reports, annual summary reports, and final integrative report)
- Task 4 – Interactive database

Task 1 will result in a comprehensive data collection plan. This plan will include a list of responsible individuals/organizations, standard operating procedures, a quality assurance/quality control plan, sample stations, sampling frequency, and protocols for data management and analysis.

Task 2 consists of collection of physical, chemical, and biological data from the Santa Fe River and Springs Study Area. Sample collection will be continuous, monthly, and quarterly, depending on parameters sampled. Sampling duration will be a minimum of two to three years to reflect a range of inter-annual climatic variations. The river will be divided into four segments for the sampling events. The segments and their associated water quality sampling stations are as follows:

- Santa Fe River at Worthington Springs to River Sink in O'Leno State Park
    - Santa Fe River at Worthington Springs (US12 Bridge)
    - Worthington Springs
    - Santa Fe River above Olustee Creek
    - Olustee Creek
    - Santa Fe Spring
    - Santa Fe River at I-75 Bridge
    - Santa Fe River at O'Leno State park
- Santa Fe River Rise to US Hwy 27
    - Santa Fe River Rise
    - Hornsby Spring

  - Treehouse Spring
  - Santa Fe River at US 441
  - Columbia Spring
  - Alligator Spring/Rise
  - Santa Fe River at US Hwy 27
- US Hwy 27 to US Hwy 47
  - Poe Spring
  - Rum Island Spring
  - Gilchrist Blue Spring
  - Devil's Spring Run
  - Ginnie Spring Run
  - Santa Fe River at US Hwy 47
- US Hwy 47 to the confluence with the Suwannee River
  - Cow Creek
  - Wilson Spring
  - Jamison Spring
  - Sunbeam Spring
  - Ichetucknee confluence
  - Santa Fe River at US Hwy 129
  - Trail Spring
  - Campground Spring
  - Santa Fe River above Suwannee River confluence

Phase 2 recommended study components include the following tasks:

Physical and Water Quality Data Collection

Physical Setting

- Land use of the surface watershed (including waterfront houses and septic systems)
- Water balance (inflows and outflows of surface and ground water annually)
- Flow regime (velocity profiles quarterly)
- Sediment sampling (semi-annually) for texture, percent sand/silt/clay, percent solids, organic content, total nitrogen, total phosphorus, and occurrence of trace metals (arsenic, copper, and iron)
- Solar inputs and precipitation (continuous)

Water Quality

- Light transmittance (secchi depth and underwater photometer) – (monthly)
- Field parameters (temperature, pH, dissolved oxygen, specific conductance monthly)
  - vertical profiles
  - continuous (3-week deployment of multi-parameter data sondes quarterly)
- General analytical samples collected mid-depth in the water column (color, chloride, sulfate, arsenic, copper, iron, chlorophyll a, nitrate+nitrite nitrogen, total ammonia, total Kjeldahl nitrogen, total phosphorus, fecal coliforms, sucralose, and acetaminophen) – (monthly)
- Priority pollutants (suite of herbicides and insecticides quarterly)

Biological and Human Use Data Collection

Biological

- Benthic macroinvertebrates - Stream Condition Index and emergence sampling (semi-annually)
- Aquatic plants – Rapid Periphyton and Linear Vegetation Surveys and species and percent cover annually
- Fish (species and biomass by visual counts quarterly or when clear water conditions exist)
- Turtles (quarterly)
- Birds (monthly)
- Other fauna (mammals as observed)
- Ecosystem function (gross primary productivity, net productivity, particulate export, and community respiration, 3 weeks quarterly)

Human Use

- Creel/fishing survey (as observed)
- Boating survey (as observed)
- Park Admissions (Ginnie Springs, Gilchrist Blue, Poe Spring Park, Rum Island Park, etc.)
- Equipment Rental (Rum 138, Canoe Outpost, Outdoor Adventures, etc.)
- Visual human use surveys (quarterly)

Task 3 – Monitoring Report

Regular reports and oral presentations will be made to keep the public and agencies up-to-date on progress with the Santa Fe River and Springs Environmental Study. Data reports will be issued quarterly and public presentations will be made semi-annually. Annual reports will integrate all data collected up to that point and a full-day workshop will be held after the issuance of each annual report to discuss findings and to adaptively manage continuing data collection efforts.

A final integrative report will be prepared that preserves all of the information compiled during this baseline study.

Task 4 – Interactive Map

Task 4 of the Lower Santa Fe River Environmental Study Plan will include the development of an interactive map that will integrate available data on the Santa Fe River into a simple, user friendly interface. These data will include land use, septic tanks, house and dock mapping, spring locations, geology, springsheds, and conduit and caves systems. The purpose of this map is to guide readers through the report with an emphasis on illustrating the relationship of the river and springs with each other and the surrounding area.

3.3 Phase 3 Scope

Phase 3 of the Lower Santa Fe River Environmental Study plan includes development of a comprehensive restoration plan based on the findings from Phases 1 and 2, and on input from the affected community. The Lower Santa Fe River Restoration Plan will detail specific actions and projects needed to achieve a realistic level of restoration. Responsible entities to implement these actions and projects will be identified as will the estimated costs for implementation.

3.4 Proposed Project Budget

3.4.1 Estimated Cost

Table 23 summarizes estimated labor and expenses for each of the tasks noted above. Work will be conducted by a team to be assembled as part of Task 1 of Phase 2 and may include services provided by the following agencies and organizations:

- Florida Springs Institute, Inc.
- Karst Environmental Services, Inc.
- Our Santa Fe River, Inc.
- Florida Department of Environmental protection
- Suwannee River Water Management District
- Florida Fish and Wildlife Conservation Commission
- U.S. Geological Survey
- U.S. Fish and Wildlife Service

The estimated cost for a two-year Phase 2 study is $602,000. The estimated cost for the Phase 3 report is $75,000. The estimated total project cost is $677,000. Actual project costs may be substantially reduced through in-kind services provided by private and public entities. For example, a partnership that utilizes FDEP's analytical laboratory for sample analysis could reduce this projected budget by more than $400,000. Field assistance possibly provided by the Suwannee River Water Management District could reduce labor costs by about $50,000.

Table 23 – Estimated labor and expense budget for Phase 2 and 3

Task	Labor	Expenses	Total
Phase 2 Task 1 – Data Collection	$165,000	$260,000	$425,000
Task 1.1 – Physical Setting	$15,000	$10,000	$25,000
Task 1.2 – Water Quality	$150,000	$250,000	$400,000
Phase 2 Task 2 – Data Collection	$125,000	$12,000	$137,000
Task 2.1 – Biological	$100,000	$10,000	$110,000
Task 2.2 – Human Use	$25,000	$2,000	$27,000
Phase 2 Task 3 and 4– Monitoring Report and Interactive Map	$35,000	$5,000	$40,000
Phase 2 – Data Collection / Monitoring Report	**$325,000**	**$277,000**	**$602,000**
Phase 3 – Comprehensive Restoration Plan	**$65,000**	**$10,000**	**$75,000**
Total	**$390,000**	**$287,000**	**$677,000**

[a] Expenses include travel and equipment (listed under Task 1.2)

Section 4.0 References

Atkins, Inc. (2012). Technical Support for Establishing Minimum Flows and Levels for the Lower Santa Fe and Ichetucknee Rivers. Prepared for Janicki Environmental, Inc., and the Suwannee River Water Management District.

Bowes, G., A. S. Holaday, T. K. Van, and W. T. Haller. 1977. Photosynthetic and photorespiratory carbon metabolism in aquatic plants. Pp. 289–298 *in* D. O. Hall, J. Coombs, and T. W. Goodwin, eds. Proceedings of the Fourth International Congress on Photosynthesis. The Biochemical Society, London.

Butt, P. L., T. L. Morris, & W. C. Skiles. 2007. Swallet/resurgence relationships on the lower Santa Fe River, Florida. Prepared for Water Resource Associates, Inc., Tampa.

Cabana, G. and J.B. Rasmussen. 1996. Comparison of aquatic food chains using nitrogen isotopes. Proceedings of the National Academy of Sciences 93: 10844-10847.

Chasar, L., B. Katz, and D. Griffin. 2005. Evaluation of Nitrate Sources in Springs of the Santa Fe River Basin using Natural Traces: Geochemical, Specific Microbiological, and Multiple Stable Isotopic Indicators. U.S. Geological Survey. Tallahassee, Florida. 34 p.

Col, N., F. Rupert, and G. Horvath, 1997. Reappraisal of the Geology and Hydrogeology of Gilchrist County, Florida, with Emphasis on the Wacassassa Flats. Florida Geological Survey, Report of Investigations No. 99, 76 p

Faulkner, G.L., 1973. Geohydrology of the Cross-Florida Barge Canal Area with Special Reference to the Ocala Vicinity. U.S. Geological Survey, Water-Resources Investigations Report 1-73, 116 p. [Publication available at http://fl.water.usgs.gov/Orlando/legacy/legacy.htm]

Florida Department of Environmental Protection (FDEP) 2012. Basin Management Action Plan for the Implementation of Total Daily Maximum Loads for Nutrients. Adopted by the Florida Department of Environmental Protection in the Santa Fe River Basin. Division of Environmental Assessment and Restoration Bureau of Watershed Restoration Tallahassee, FL.

Florida Fish and Wildlife, 2011. Freshwater Mussel (Bivalvia:Unionidae) Assemblages of the Santa Fe River near O'Leno State Park and Worthington Springs, Florida.

Florida Springs Institute (FSI). 2017. Santa Fe River, Springs, and Tributaries: Current and Historical Observations. High Springs, Florida. March 2017.

Fry, B. 1999. Using stable isotopes to monitor watershed influences on aquatic trophodynamics. Canadian Journal of Fisheries and Aquatic Sciences 56:2167-2171.

Goericke, R., J.P. Montoya, and B. Fry. 1994. Physiology of isotopic fractionation in algae and cyanobacteria, in Stable Isotopes in Ecology and Environmental Science, Lajtha, K. and R.H. Michener, eds., Blackwell Scientific, Oxford, pp. 187-221.

Hellier, Thomas Robert. 1967. The fishes of the Santa Fe River system Bulletin of the Florida State Museum: biological Sciences v.2 no.1 http://ufdc.ufl.edu/UF00001536/00001

Kincaid, T.R., 1998. River water intrusion to the unconfined Floridan aquifer. Environmental & Engineering Geoscience, 4:361-374.

Knight, R.L. 2012. Nitrate Effects in Spring Ecosystems – A Working Hypothesis. Paper Presented to the UF Water Institute Nutrient Dynamics and Enrichment Impacts in Aquatic Ecosystems.

Knight, R.L. 2015. Silenced Springs – Moving from Tragedy to Hope. Howard T. Odum Florida Springs Institute press, High Springs, FL.

Lake, J., R. McKinney, F. Osterman, R. Pruell, J. Kiddon, S. Ryba, A. Libby. 2001. Stable nitrogen isotopes as indicators of anthropogenic activities in small freshwater systems. Canadian Journal of Fisheries and Aquatic Sciences 58: 870-878.

Odum, H.T. 1957. Trophic structure and productivity of Silver Springs, Florida. Ecological Monographs 27(1): 55-112.

Macko, S.A., and N.E. Ostrom. 1994. Pollution studies using stable isotopes, in Stable Isotopes in Ecology and Environmental Science, Lajtha, K. and R.H. Michener, eds., Blackwell Scientific, Oxford, pp. 45-62.

MACTEC. 2010. Sources of Nitrate and Estimated Groundwater Travel Times to Springs of the Santa Fe River Basin. Prepared for Alachua County Environmental Protection Department.

Martin, J.B., and E.J. Screaton, 2001, Exchange of Matrix and Conduit Water with Examples from the Floridan Aquifer, in U.S. Geological Survey Karst Interest Group Proceedings, St. Petersburg, Florida, Water-Resources Investigations Report 01-4011, p. 38-44.

Mattson, R. A., J. H. Epler, and M. K. Hein. 1995. Description of benthic communities in karst, springfed streams of north central Florida. Journal of the Kansas Entomological Society 68: 18–41.

Mitchell, J. C., and G. R. Johnston. 2012. *Stern-otherus minor minor* (Loggerhead Musk Turtle). predation. Herpetological Review 43:128.

Nico, L. G., P. L. Butt, G. R. Johnston, H. L. Jelks, M. Kail, and S. J. Walsh. 2012. Discovery of South American suckermouth armored catfishes (Loricariidae, *Pterygoplichthys* spp.) in the Santa Fe River drainage, Suwannee River basin, USA. Bioinvasions Records 1:179–200.

Nordlie, F. G. 1990. Rivers and springs. Pp 392–425 *in* R. L. Myers and J. J. Ewel, eds. Ecosystems of Florida. University of Central Florida Press, Orlando, Florida.

Puri, H.S., and R.O. Vernon, 1964. Summary of the Geology of Florida and a Guidebook to the Classic Exposures. Florida Geological Survey Special Publication No. 5 (Revised), 312 p., plus plates.

SDII. 2011. Springsheds of the Santa Fe River. Prepared for Alachua County. July 8, 2008, Revised September 30,2009.

Smock, L. A., and E. Gilinsky. 1992. Coastal Plain blackwater streams. Pp. 271–311 *in* C. T. Hackney, S. M. Adams, and W. H. Martin, eds., Biodiversity of the Southeastern States, Aquatic Communities. John Wiley and Sons, New York, New York.

Spencer, W., and G. Bowes. 1985. *Limnophila* and *Hygrophila*: A review and physiological assessment of their weed potential in Florida. Journal of Aquatic Plant Management 23:7–16.

Tucker, J., J. Sheats, A.E. Giblin, C.S. Hopkinson, and J.P. Montoya. 1999. Using stable isotopes to trace sewage-derived material through Boston Harbor and Massachusetts Bay. Marine Environmental Research 48(4-5): 353-375.

Upchurch, S.B. 2007. An Introduction to the Cody Escarpment, North-central Florida. Prepared for the Suwannee River Water Management District. Sam B. Upchurch, SDII Global Corporation. September 2007. 17 p.

Upchurch, S.B. 2011. Peer Review of Sources of Nitrate and Estimated Groundwater Travel Times to Springs of the Santa Fe River Basin by MACTEC. SDII Project No. 3017152B. October 28, 2011.

Upchurch, S.B., 2002. Hydrogeochemistry of a karst escarpment. In J.B. Martin, C.M. Wicks, and I.D. Sasowsky (eds.), Hydrogeology and Biology of Post-Paleozoic Carbonate Aquifers. Charles Town, WV, Karst Waters Institute, Special Publication 7, pp. 73-75.

Upchurch, S.B., 2007. An Introduction to the Cody Escarpment, North-Central Florida. Live Oak, Florida, Suwannee River Water Management District, 16 p.

Upchurch, S.B., and F.W. Lawrence, 1984. Impact of ground-water chemistry on sinkhole development along a retreating scarp. In B.F. Beck (ed.), Sinkholes: Their Geology, Engineering & Environmental Impact. Rotterdam, A.A. Balkema, pp. 23-28.

Wetland Solutions, Inc. (WSI) 2010. An Ecosystem-Level Study of Florida's Springs. Final Report to the Florida Fish and Wildlife Conservation Commission, St. Johns River Water Management District, Southwest Florida Water Management District, Florida Park Service, Florida Springs Initiative, and Three Rivers Trust, Inc., Gainesville, FL.

Wetland Solutions, Inc. (WSI) 2013. Ginnie Springs Ecological Analysis (July 2012 – May 2013). Prepared for Ginnie Springs Outdoors.

White, W.A., 1970. The Geomorphology of the Florida Peninsula. Florida Department of Natural Resources, Bureau of Geology, Geological Bulletin 51, 164 p.

Wilson, W.L., and W. C. Skiles, 1988. Aquifer characterization by quantitative dye tracing at Ginnie Spring, northern Florida. Proceedings, Second Conference on Environmental Problems in Karst Terranes and Their Solutions, Association of Ground Water Scientists and Engineers, pp. 121-141.