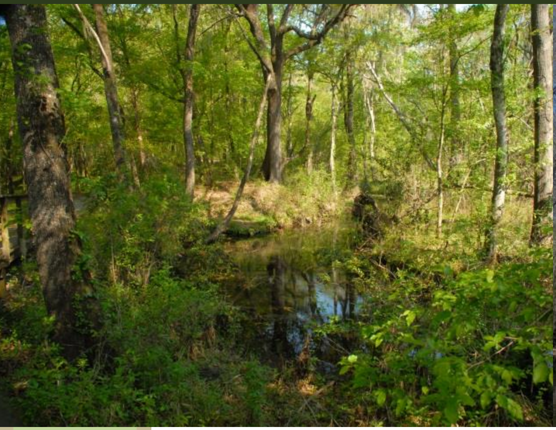
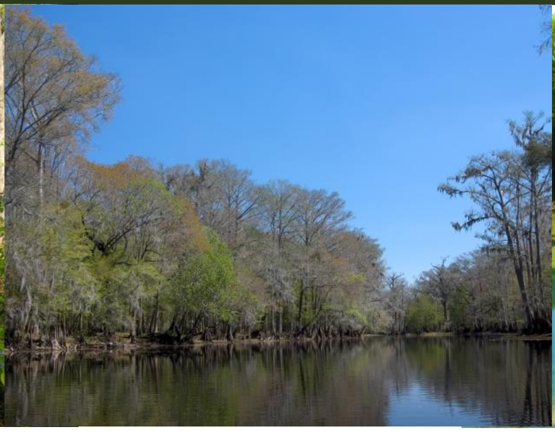




Minimum Flows and Levels for The Lower Santa Fe and Ichetucknee Rivers and Priority Springs

Suwannee River Water Management District
9225 CR 49, Live Oak, FL 32060
386.362.1001
www.mysuwanneeriver.com

November 22, 2013

ACKNOWLEDGEMENTS

This report was produced in collaboration with the staff of Janicki Environmental, Inc. (JEI) and INTERA Incorporated (INTERA), under contract to the Suwannee River Water Management District (SRWMD). The project database, hydraulic river model, and initial streamflow statistical models were developed by INTERA. The field biological data collection and assessments were performed by JEI with associated sub-contractors. Both INTERA and JEI contributed significant portions of the draft document text and JEI lead the team in production of the draft document.

Dr. Tony Janicki, Dr. Keith Hackett, Susan Janicki, and Steve West were the primary contributors for JEI. Patrick Tara, Renee Murch, and Julia Lukyanets were the primary contributors for INTERA. JEI subcontractors included Dr. Pam Latham (Atkins Global), Dr. David Hall and Wade Hurt.

The referenced geomorphological studies and analyses were done by Dr. John Keifer and Kristin Nowak (AMEC). HSW Engineering, Inc. (HSW) contributed statistical assistance. HSW's primary contributors included Dr. Ken Watson and Dean Mades.

Clay Coarsey, John Good, Trey Grubbs, Dale Jenkins, Robbie McKinney, and Daniel Simpson, were the primary contributors from the SRWMD. Additional technical assistance was provided by Louis Mantini, Dr. Erich Marzolf, and Dr. Marc Minno. Dr. Bill Spencer (University of Florida) provided initial floodplain study planning and field work while with the SRWMD.

The final report benefited from the constructive comments and recommendations of the peer review panel that reviewed the draft report for the SRWMD. Members of the panel included Dr. Wendy D. Graham (Panel Chair), Dr. Mark W. Clark, Dr. Matthew J. Cohen, Dr. Thomas K. Frazer, and Dr. Jonathan B. Martin, all with the UF Water Institute.

The report also benefited from comments received by various stakeholders and members of the public.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This report, entitled "Minimum Flows and Levels for the Lower Santa Fe and Ichetucknee Rivers and Priority Springs" (Report), presents the data and analyses that provide technical support for the establishment and adoption of Minimum Flows and Levels (MFLs) for the Lower Santa Fe and Ichetucknee rivers and priority springs.

The District's 2010 Water Supply Assessment (Assessment) concluded that water resources in the eastern and northeastern portions of the District are currently impacted or predicted to be impacted sometime before 2030. These resource impacts are directly related to reductions in the potentiometric surface of the Upper Floridan Aquifer (UFA), which has declined significantly since development of the Floridan Aquifer system (FAS) began in the late 1800s. Based on the Assessment, the Lower Santa Fe River and associated priority springs, already a high priority in the District's priority schedule, retained that position of emphasis. The 2012 MFL Priority List submittal noted the potential for cross-boundary impacts on the Lower Santa Fe River.

One essential element in establishing a MFL is the definition of a baseline period during which environmental characteristics are deemed appropriate. Guided by the projected impacts identified in the 2010 Assessment, analysis of observed flow data (Section 4.0 of the Report) identified a period of decreasing flow in the Lower Santa Fe and Ichetucknee rivers beginning in 1990. This information was used to develop a historical hydrologic condition (as referenced in Chapter 373.0421, F.S.), at the two selected MFL gages, the Santa Fe River near Fort White and the Ichetucknee River at Highway 27. This historical hydrologic condition was used as a flow reference point or baseline (called the Baseline Flows or Baseline Flow regime) from and with which MFLs are calculated.

State policy guidance regarding MFLs lists ten environmental and water resource values (WRVs) that must be considered in establishing MFLs. These WRVs were reviewed to determine their relevance to the study area and the amount of available information available for each. Two of the WRVs are both relevant to the study area and have sufficient available information to allow an evaluation of the relationship between the WRVs and system hydrology: (1) Recreation in and on the water, and (2) Fish and wildlife habitats and the passage of fish.

Given the characteristics of the rivers and the available flow data, MFLs have been developed at two gages; the predominant WRV metrics used include:

- Santa Fe River near Fort White – fish passage, floodplain vegetation inundation, hydric soils, bankfull flows, in-stream habitat;
- Ichetucknee River at US 27 – fish passage, recreation, bankfull flows, hydric soils, in-stream habitat.

An adjustment from the Baseline condition was developed establishing a continuous MFL flow regime that uses the most protective water resource at each flow on the flow duration curve. This allows development of a MFL time series. On an annual basis the 10 year frequency low flow allows reductions of 118 cfs (76.3 mgd) and 18 cfs (11.6 mgd) for the Lower Santa Fe and Ichetucknee rivers, respectively. It is important to note that although these values also represent the maximum water availability under the MFL regime, they do not necessarily represent the current water availability as they do not account for impacts from existing uses. After accounting for the existing uses, the Lower Santa Fe River is estimated to be in recovery with a deficit of 17 cfs (11 mgd) in 2010. The Ichetucknee River is estimated to be in recovery with a deficit 3 cfs (2 mgd) in 2010.

1.0 INTRODUCTION

This report, entitled "Minimum Flows and Levels for the Lower Santa Fe and Ichetucknee Rivers and Priority Springs" (Report), presents the data and analyses that provide technical support for the establishment and adoption of Minimum Flows and Levels (MFLs) for the Lower Santa Fe and Ichetucknee rivers and priority springs. Priority springs include all first magnitude springs (with flows greater than 100 cubic feet per second (cfs)) and second magnitude springs (with flows between 10 and 100 cfs) within state or federally owned lands purchased for conservation purposes (Florida Statutes [F.S] Chapter 373.042[2]). The immediate study area (Figure 1-1) includes the Lower Santa Fe River from River Rise just downstream of the land bridge and extends downstream to the mouth of the Santa Fe River, near Branford, Florida. This area also includes the Ichetucknee River and designated priority springs that discharge to the rivers. Figure 1-2 illustrates the priority springs of the Lower Santa Fe and Ichetucknee rivers.

Section 1.0 of the Report provides an overview of the requirement for establishing MFLs, the water policy framework and scope of the Lower Santa Fe and Ichetucknee rivers and priority springs MFLs, and regional context for the MFLs.

1.1 REQUIREMENT TO ESTABLISH MINIMUM FLOWS AND LEVELS

The Florida Legislature has directed the Suwannee River Water Management District (the District) to establish MFLs for streams, springs, rivers, lakes, and other priority water bodies within its boundaries (Section 373.042, F.S.).

Chapter 373.042, F.S., specifies that:

> (*1*) *Within each section, or the water management district as a whole, the Department (Florida Department of Environmental Protection) or the (District) Governing Board shall establish the following:*
>
> *(a) Minimum flows for all surface watercourses in the area. The minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.*
>
> *(b) Minimum water level. The minimum water level shall be the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area.*

The statute provides that MFLs shall be established using the best information available, that where appropriate, may reflect seasonal variations in flows and levels, and may provide for the protection of non-consumptive uses (Chapter 373.042[1], F.S.). In Section 373.0421, F.S., factors are provided that the Governing Board may consider when determining the appropriate reference point for MFL establishment. The statute recognizes that use of the historical hydrological condition of a water body may be an appropriate reference point for MFL establishment and allows certain exclusions when returning to those conditions may not be feasible.

Additional policy guidance regarding MFLs is provided in the State Water Resource Implementation Rule (Chapter 62-40.473, Florida Administrative Code [F.A.C.]), indicating that *"…consideration shall be given natural seasonal fluctuations in water flows or levels, nonconsumptive uses, and environmental values associated with coastal, estuarine, riverine, spring, aquatic, and wetlands ecology… These environmental and water resource values may include:*

1. *Recreation in and on the water,*
2. *Fish and wildlife habitats and the passage of fish,*
3. *Estuarine resources,*
4. *Transfer of detrital material,*
5. *Maintenance of freshwater storage and supply,*
6. *Aesthetic and scenic attributes,*
7. *Filtration and absorption of nutrients and other pollutants,*
8. *Sediment loads,*
9. *Water quality, and*
10. *Navigation."*

A discussion of the environmental and water resource values that are applicable to the Santa Fe and Ichetucknee rivers and associated priority springs is provided in Section 3.0.

Prior to the establishment of MFLs, the District may voluntarily subject technical work to independent scientific peer review (Section 373.042, F.S.). The purpose of the peer review is to conduct an independent examination of the scientific or technical data, methodologies, and models, including all scientific and technical assumptions employed in each model, used to establish each minimum flow or level. The District notified the FDEP, as part of its annual MFL priority list developed pursuant to Section 373.042, F.S. that the District intended to conduct a voluntary peer review on the MFLs for the Lower Santa Fe and Ichetucknee rivers and priority springs. In May 2013, the Suwannee River Water Management District Governing Board approved the contract for voluntary peer review of the MFLs. Subsequently, an independent peer review was conducted by the University of Florida Water Institute (Graham, Clark, Cohen, Frazer, & Martin, 2013). The resulting comments were evaluated and incorporated in this final report as appropriate.

Once the MFL has been determined, if the existing flow or level in a water body is below the applicable MFL, the District is required to develop and implement a recovery strategy. If the MFL is currently being met, but the water body is expected to fall below it within 20 years, a prevention strategy must be developed and implemented. Rule 62.40.473(5), F.A.C., requires that when recovery or prevention strategies are needed, they are to be simultaneously approved with the adoption of the MFL.

Once established by rule, MFLs are used in both the District's water supply planning and consumptive use permitting programs. In planning, MFLs are used to evaluate which water sources could be used while protecting the needed flows and levels for the water resource. In permitting, applicants must provide reasonable assurances that the proposed withdrawal will not violate an adopted MFL and is in accordance with any approved recovery or prevention strategy (Rule 62.40B-2.301 F.A.C.).

1.2 WATER POLICY FRAMEWORK

The District completed and adopted the 2010 Water Supply Assessment in December 2010 (SRWMD, 2010). The Water Supply Assessment report recommended designating the Lower Santa Fe River Basin as a Water Supply Planning Region because modeling analyses raised concern that the existing sources of water would not be able to meet increases in water use over the 20-year planning period while providing flows to sustain the river. The Assessment report also recommended that the District establish and implement MFLs.

The District's Governing Board designated the Upper and Lower Santa Fe River Basins (which includes the Ichetucknee River Basin) as Water Resource Caution Areas in October of 2011, in view of the findings and recommendations of the 2010 Water Supply Assessment.

In response to the need for regional coordination on water supply challenges, the Suwannee River Water Management District, St. Johns River Water Management District (SJRWMD), and the Florida Department of Environmental Protection (FDEP) entered into an interagency agreement in September 2011. The interagency agreement was the catalyst to the formation of the North Florida Regional Water Supply Partnership Stakeholder Advisory Committee (SAC). The SAC has been tasked to provide the districts with non-binding recommendations during the development of a joint regional water supply plan, which includes MFLs. The interagency agreement requires the two water management districts to develop consistency in the establishment of MFLs and any associated prevention and recovery strategies that are needed to ensure protection of priority water bodies. District staff have held a series of technical coordination meetings with SJRWMD and FDEP staff to facilitate consistency and understanding among the partners on establishment of MFLs for the Lower Santa Fe and Ichetucknee rivers and priority springs.

Adoption of MFLs for the Lower Santa Fe and Ichetucknee rivers and priority springs and associated prevention and recovery strategies will follow the process based on the passage by the Florida Legislature, of Senate Bill 244 in 2013. Senate Bill 244 allows for MFLs and associated recovery and prevention strategies that are adopted by the FDEP, to be applied by the water management districts without additional rulemaking by the districts. The Lower Santa Fe and Ichetucknee rivers and priority springs have the potential to be affected by withdrawals from outside District boundaries, thus, the District has requested that the FDEP adopt the MFLs and associated prevention and recovery strategies with technical support by District staff.

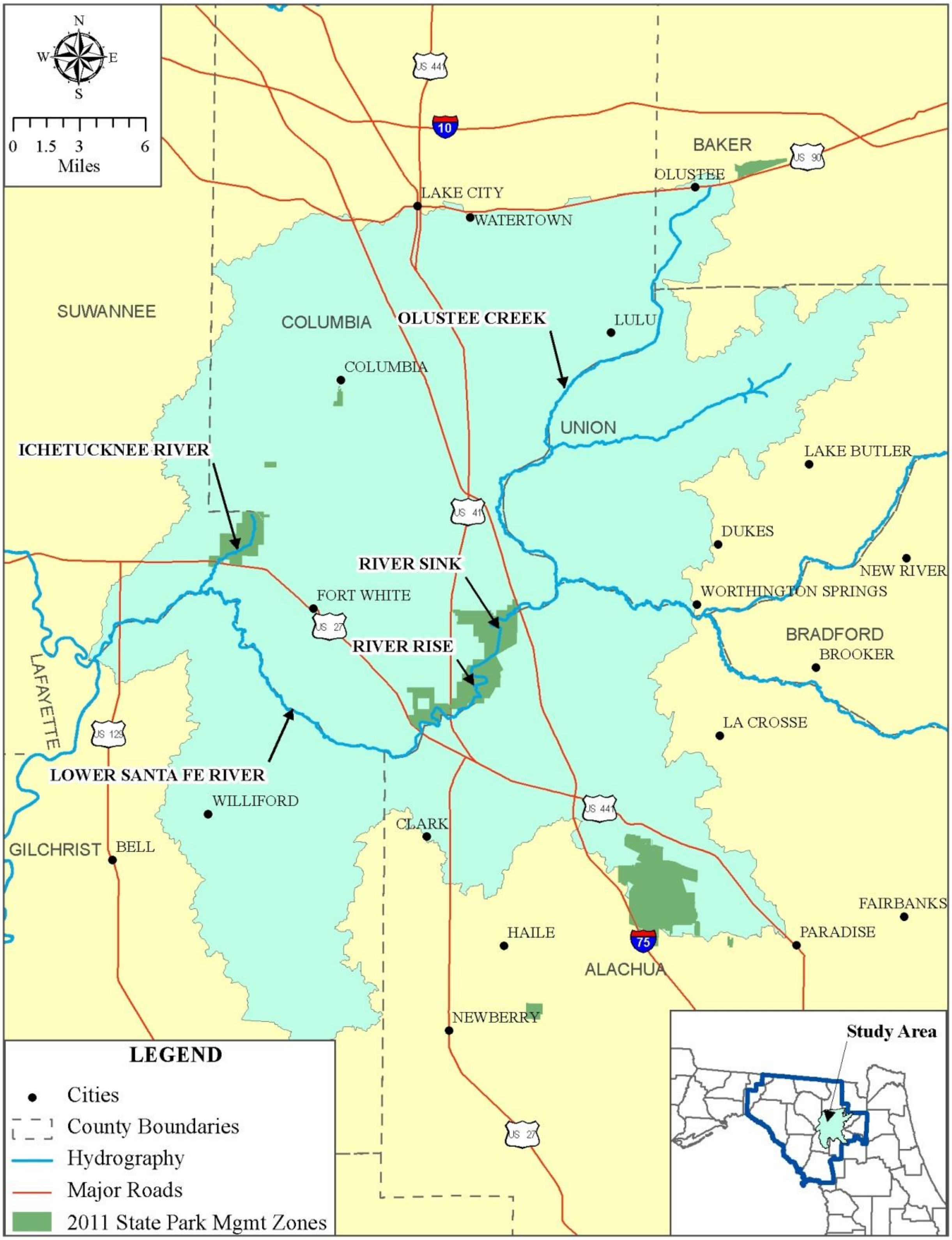


Figure 1-1. Location and extent of the Lower Santa Fe River system MFL study area, which coincides with the Lower Santa Fe sub-basin.

Figure 1-2. Priority springs within the Lower Santa Fe and Ichetucknee rivers. NOTE: Ichetucknee Spring Group includes: Ichetucknee Head Spring, Mission Spring, Devil's Eye, Grassy Hole, and Mill Pond

1.3 SCOPE OF THE LOWER SANTA FE RIVER AND ICHETUCKNEE RIVER MFLS

The Santa Fe River originates in the Santa Fe and Little Santa Fe lakes in the northeast corner of Alachua County, Florida. It flows westward along the Alachua County line and eventually goes completely underground at a large sinkhole known as the Santa Fe Sink (or River Sink), near O'Leno State Park (Hunn & Slack, 1983). The Santa Fe River travels underground for approximately three miles before it resurfaces several miles north of High Springs at the Santa Fe Rise (River Rise). The total length of the river is approximately 80 miles, while the length of the portion below the rise is approximately 30 miles. Because the Santa Fe River travels underground for such length, the natural land bridge acts as a divider forming two distinct reaches of the river: the Upper Santa Fe and the Lower Santa Fe.

The Lower Santa Fe River is fed mainly by groundwater discharge from the Upper Floridan aquifer. Multiple major springs, including the Ichetucknee River spring group which is one of the largest spring complexes in the state, occurs in the Lower Santa Fe River Basin. Flood events over a significant portion of the lower half of the system are sometimes a function of backwater effects of the Suwannee River (Appendix 4.1). In addition, the basin sits astride a climatic divide between the continent and peninsular Florida, which results in a marked bi-modal pattern with dual high water seasons in the spring and fall (Kelly M. , 2004).

The value of the Lower Santa Fe and Ichetucknee rivers and their springs is widely recognized. In a study using data from the National Rivers Inventory (NRI), Benke (1990) identified the Suwannee River system (including the Santa Fe and Ichetucknee rivers) as one of 42 "large, intact" river drainage systems remaining in the U.S. He defined these systems as rivers with more than 124.2 miles (200 km) of length that are unaffected by any major dams, flow diversions, or navigation projects. The 42 river systems cumulatively represented only 2% of the total length of river reaches in the NRI database. Based largely on Benke's work, Noss, et. al. (1995) designated large intact streams and rivers in the U.S. as "Endangered Ecosystems", which they defined as those ecosystem types that have experienced an 85-98% decline in the existence of high-quality, intact natural systems.

In similar fashion, a report on U.S. river ecosystems by the Nature Conservancy classified the Suwannee/Santa Fe drainages as "critical watersheds to protect freshwater biodiversity" (Master, Flack, & Stein, 1998).

The Lower Santa Fe River study area also includes a number of important conservation areas, including three state parks (Ichetucknee Springs, O'Leno, and River Rise Preserve [Figure 1-1]), and a number of county and District parks located at springs with public access. These lands provide important ecological and water supply values, as well as public recreation benefits including hiking, swimming, fishing, hunting, and kayaking. Additionally, the lands surrounding a number of other springs are highly utilized by long-term, for-profit recreational ventures, as well as for general use access of the river by outfitters and the general public.

In developing recommendations for MFLs for the Upper Santa Fe River (SRWMD, 2007), it was determined that the upper river's surface water system begins to exchange flows with groundwater sources via karst features above O'Leno State Park:

"…interactions of the river and groundwater system are complex in lower Olustee Creek and downstream of the confluence of Olustee Creek with the Santa Fe River. Portions of flow in both

reaches go underground via in-stream swallets and there are small resurgences within the Santa Fe River. The Santa Fe Spring appears to be one of these resurgences that discharges water derived from Olustee Creek and elsewhere. Swallets in the Santa Fe above O'Leno and the River Sink capture portions of the river water, some of which rejoins the river prior to reaching River Sink. The internal pathways of this system of swallets and resurgences, springs, and streams is unclear and some of the lost water appears to be gained by the river/ groundwater system as water passes from the River Sink to the River Rise. In addition, a number of first and second-magnitude springs immediately downstream from the River Rise may be discharging some water derived from upstream of the Sink. It is important that discharge from Olustee Creek and at O'Leno State Park be subjected to MFL development in order to prevent significant harm to these resources."

The interaction of the Upper Santa Fe River with the groundwater system necessitates that water from the Upper Santa Fe River is critical to maintaining the groundwater-driven flows in the Lower Santa Fe River.

The springs that drain to the Lower Santa Fe and Ichetucknee rivers can be classified as to their "historical magnitude." The term "historical" is used to designate the discharge of the spring as determined by measurements collected prior to the adoption of the Florida Springs Classification System (Copeland, 2003). First magnitude refers to a median historical discharge greater than 100 cfs, and second magnitude refers to a median historical discharge of 10 to 100 cfs (Meinzer, 1927; Copeland, 2003).

Chapter 373.042 F.S. states that *"...each water management district's priority list and schedule shall include all first magnitude springs, and all second magnitude springs within state or federally-owned lands purchased for conservation purposes."* The priority springs associated with the study area include:

1. Santa Fe Rise,
2. ALA112971 (Treehouse) Spring,
3. Hornsby Spring,
4. Columbia Spring,
5. Poe Spring,
6. COL101974 (Unnamed) Spring,
7. Rum Island Spring,
8. Devil's Ear Spring (Ginnie Spring Group),
9. July Spring,
10. GIL1012973 (Siphon Creek Rise),
11. Ichetucknee Head Spring,
12. Mission Spring,
13. Devil's Eye,
14. Grassy Hole,
15. Mill Pond, and
16. Blue Hole Spring.

These springs play a significant role in the riverine ecology and MFL development for the rivers. This is due to the fact that the Lower Santa Fe and Ichetucknee rivers have a close hydrologic relationship to each spring, and the springs act as subsurface conduits that carry water to or away from the river. The springs contribute significant baseflow to the river, and the stage of the river is one of the determining factors of spring discharge. Thus, a MFL that is protective of the river will also be protective of the associated springs; conversely, protecting spring flows will also protect the river system.

1.4 WATER RESOURCE ISSUES IN THE LOWER SANTA FE SYSTEM WATERSHED

Several on-going and emerging issues challenge water resource managers to balance the variety of competing interests, both societal and natural, in the Lower Santa Fe and Ichetucknee rivers and the north Florida region. The following presents a brief discussion of those issues relevant to the management of both water quantity and water quality in the rivers and associated springs.

The increasing regional use of groundwater is well-documented (Marella, 2013), and its effects are increasingly noticeable. There are still many uncertainties regarding the magnitude of existing groundwater withdrawals and the associated effects on the regional hydrology. However, the principles and processes are well understood. It is very unlikely that anthropogenic-related impacts to groundwater and associated surface water resources have not increased significantly over the past decades.

Decreases in flows in the Lower Santa Fe and Ichetucknee rivers are greater than can be explained by climatic patterns (see Section 6.0). Reduced spring and river flows impact water availability for other potential users, maintenance of aquatic and wetland ecosystems, and recreational activities. The effects of groundwater pumping on surface water systems can be significant whether the wells are located near the water body or outside the surface watershed. Increased monitoring and reporting of pumping rates from all significant users will help managers determine the level of consumptive use of water that is sustainable.

Managing local water resources is a multi-faceted task and setting MFLs is only one approach to protecting surface waters and groundwaters. Regulatory strategies, education and outreach programs, incentives, voluntary conservation, alternative water supplies, water resource development projects, and hydrologic restoration all play a role in the management of surface water and groundwater in the Lower Santa Fe and Ichetucknee rivers.

The Santa Fe River system is afforded particular water quality protection by the State of Florida by its designation as an Outstanding Florida Water (OFW). Rule 62-302.700, F.A.C., lists the Santa Fe River system as Special Waters, consisting of the Santa Fe River, Lake Santa Fe, Little Lake Santa Fe, Santa Fe Swamp, Olustee Creek, and the Ichetucknee River below S.R. 27, but excluding all other tributaries. The designation as an OFW is conferred to waters of the state with "*exceptional recreational or ecological significance*" (Chapter 62-302.700[3], F.A.C.).

Water quality management in the Lower Santa Fe and Ichetucknee rivers is unlike most other Florida rivers. Groundwater discharges significantly influence river flow both in terms of quantity and quality. Groundwater is in turn affected by the chemicals that leach into the aquifer from the land surface. Chemicals (nutrients, for example) are returned to the surface in spring discharge and can increase concentrations in river water.

Increased nutrient content in spring discharge has been associated with changes in Submerged Aquatic Vegetation (SAV) community structure in the Ichetucknee River spring run, and algae blooms in the Santa Fe River (Upchurch, Chen, & Cain, 2008), although algae blooms also occur during periods of low flow. Groundwater is a major source of nutrients in the Lower Santa Fe and Ichetucknee rivers because of upwelling from the locally unconfined aquifer. Therefore, for comprehensive water resource management, an understanding of the relationships between spring and river flows with water quality, particularly nitrogen concentrations, is critical.

To protect and restore the water quality of the Santa Fe River system, the FDEP has established Total Maximum Daily Loads (TMDLs) (Appendix 5.8). In 2008, the FDEP adopted TMDLs that provide numerical water quality restoration targets for the Santa Fe River. The TMDL requires reductions in nutrient concentrations of 35 percent. In 2012, the FDEP adopted the Santa Fe River Basin Management Action Plan (BMAP); the purpose of the BMAP is to identify actions and strategies to reduce nutrients in the Santa Fe River. The District is a partner with the FDEP in implementing the BMAP through state cost share funds to agriculture, to implement nutrient reduction and water conservation strategies.

There is also the need to balance protection of natural resources in state parks and other public lands with recreation needs of the public. The Ichetucknee Springs State Park, the O'Leno State Park, and the River Rise Preserve State Park all have approved management plans that guide park operations (FDEP, 2000). While all three areas have unique features, the Ichetucknee Springs park staff has the most challenging set of tasks; staff must facilitate the daily traffic of hundreds of visitors tubing on the river, while safeguarding the fragile and valuable SAV within the spring run. The park's management plan describes the impact of overuse on a spring-run stream as the bare sand and rock that remain after aquatic vegetation is trampled and dislodged by recreation. The park was purchased by the state in 1970, and a daily maximum limit of 3,000 tubing participants was set in 1979 for North Entrance access. That number was soon lowered to 1,500 per day and in 1989 and further lowered to its current standard of 750 per day (FDEP, 2000). Even with this significant reduction in tubing traffic, SAV monitoring by park personnel indicates that SAV coverage is reduced each season and regenerates mainly over the winter off-season. Additionally, when water levels are low, the existing exit platform for tubing participants is rendered unusable, as the water level may be too low for people to safely access the stairs and dock.

These are a few examples of competing uses for the same resource. Management of other public lands is just as challenging. Areas such as Poe Springs Park, Camp Kulaqua Conservation Easement, Mill Creek Preserve, and other sites above O'Leno Sink, including Alachua County's Odum Preserve, Santa Fe River Ranch, and others, all share similar issues involving preservation of resources versus facilitating recreational opportunities.

There are numerous opportunities for government agencies to act in concert to manage water resources in the Lower Santa Fe and Ichetucknee rivers and priority springs. Although individual agencies have focused priorities, there is much common ground from which to establish compatible management approaches and policies. One example is the sharing of information between the District and Ichetucknee Springs State Park personnel. Shared objectives of SAV protection have created an occasion to work together to minimize damage to the grasses while ensuring adequate recreational opportunities. Other examples include sharing environmental monitoring responsibilities, cooperating on modeling of hydrologic systems that cross jurisdictional boundaries, and developing policies that are sympathetic to all stakeholders. In particular, the Northern Florida Regional Water Supply Partnership (NFRWSP) has specific interests in conserving surface and groundwater resources for natural and societal uses.

1.5 CONTENT OF REMAINING SECTIONS

The remaining sections of this report contain the following:

- Section 2.0 – Provides an overview of the study area's geology, hydrogeology, surface water hydrology, riverine and wetland habitats, water use, and land use.
- Section 3.0 – Describes the conceptual model used to develop the proposed MFLs, including a discussion of the Water Resource Values (WRVs) of the system and the in-channel and out-of-bank WRVs in each river system.
- Section 4.0 – Describes the existing and new hydrologic data, baseline flow development, and hydrologic modeling efforts undertaken for MFL development.
- Section 5.0 – Provides the basis for the development of minimum flows for the Lower Santa Fe and Ichetucknee rivers and associated priority springs. Descriptions of data collection and analysis for the riverine and riparian habitats are included for each WRV.
- Section 6.0 – Summarizes much of the discussion from the previous sections and then uses that information to develop and recommend MFLs for the Lower Santa Fe and Ichetucknee rivers and priority springs.
- Section 7.0 – Acronyms and Glossary of Terms
- Section 8.0 – Literature Cited
- Appendices

2.0 DESCRIPTION OF THE LOWER SANTA FE AND ICHETUCKNEE RIVERS

This chapter provides a description of the Lower Santa Fe River and Ichetucknee River watersheds. Specifically, the geology and physiography, surface and ground water hydrology, riverine and riparian wetland habitats, and land use are discussed.

2.1 GEOLOGY, PHYSIOGRAPHY, AND HYDROGEOLOGY

The following sections summarize the physical setting of the Lower Santa Fe and Ichetucknee rivers. The regional geology and hydrogeology provide a foundation for surficial land features and surface water systems.

2.1.1 Geology

The Lower Santa Fe River Basin is characterized by a sequence of Tertiary-age sedimentary deposits. Figure 2-1 illustrates the surface or near-surface geology in the study area. These sedimentary deposits consist of (in ascending order) Eocene-age Ocala Limestone, Miocene-age Statenville Formation, Coosawhatchie Formation and undifferentiated Hawthorn Group sedimentary rocks, Plio-Pleistocene-age undifferentiated sediments, and Quaternary-age undifferentiated sediments and Beach Ridge and Dune deposits. The following geologic discussion is from Ceryak, et al. (1983); Evans, et al. (2004); Scott (2001), and Scott, et al. (2001).

OCALA LIMESTONE

The Ocala Limestone is generally composed of white to cream-colored, fine to coarse grained, poorly- to well-indurated, poorly sorted fossiliferous limestone. The lower portion of the Ocala Limestone may be partially to completely dolomitized, and may also include layers of chert (a hard, dense microcrystalline rock composed chiefly of quartz). The Ocala Limestone crops out along the Lower Santa Fe and Ichetucknee rivers and south of the Lower Santa Fe River (Figure 2-1). Many of the shoals in the Santa Fe River are exposures of more resistant limestone beds that often contain appreciable amounts of chert. The abundance of springs along this stretch of the river attests to the high permeability of the Ocala Limestone in the subsurface.

The Ocala Limestone is one of the most permeable units within the Upper Floridan aquifer (UFA). Extensive development of secondary porosity by karst processes (dissolution) has greatly enhanced the permeability of the limestone, especially in those areas where the overlying Miocene-age confining beds are breached or absent (Upchurch, 2007).

STATENVILLE FORMATION

The Miocene Statenville Formation is part of the Hawthorn Group (Scott, 1988). The formation occurs at or near the surface in the northern border of the Lower Santa Fe River Basin (Figure 2-1). The Statenville Formation consists of interbedded sands, clays, and dolostones with common to very abundant phosphate grains, which are present in economically important amounts (Scott, 2001). Permeability of these sediments is generally low, forming part of the intermediate aquifer system/intermediate confining unit (IAS/ICU).

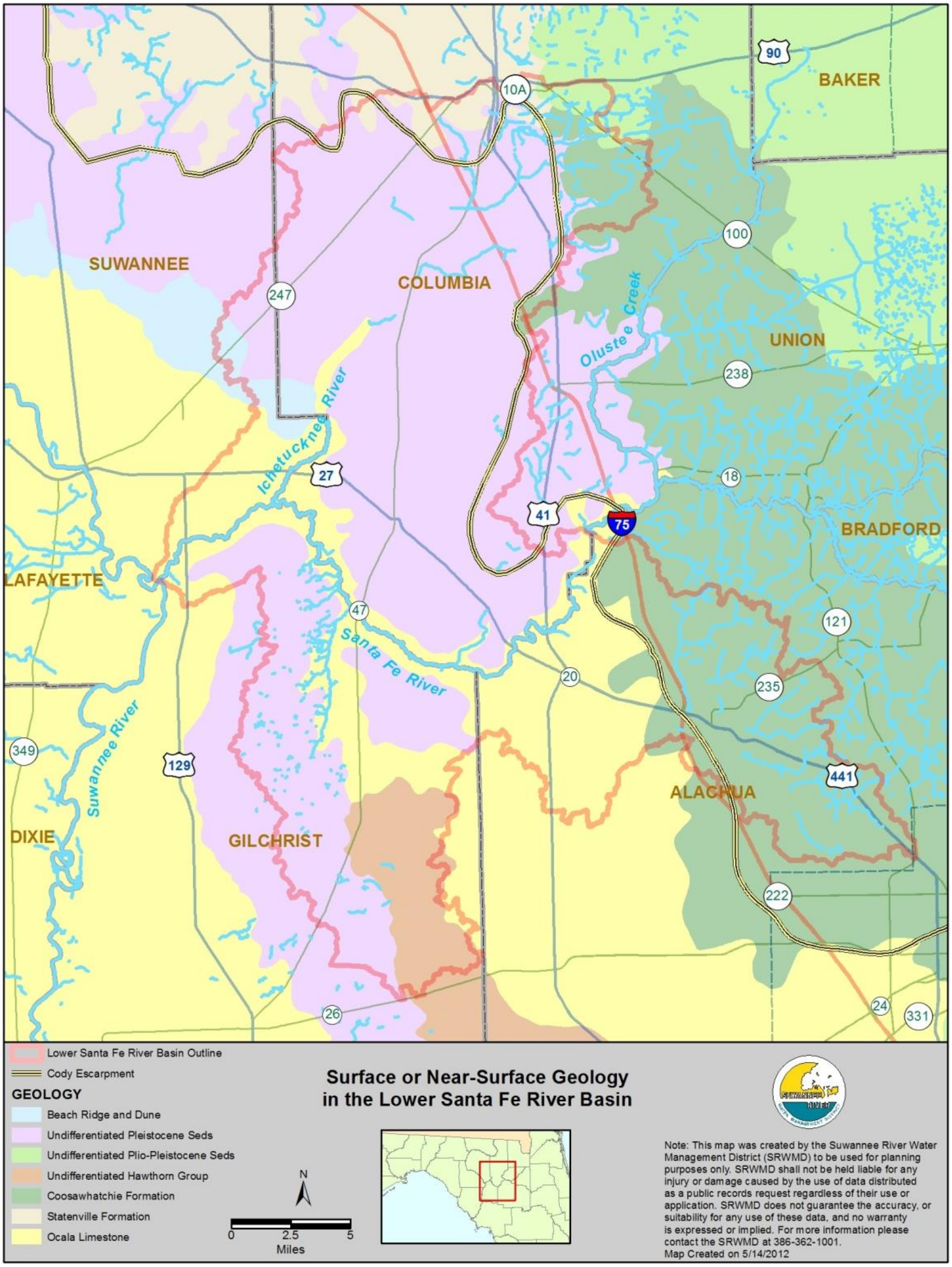


Figure 2-1. Surface and near-surface geology in the Lower Santa Fe River and Ichetucknee River basins.

COOSAWHATCHIE FORMATION

The Miocene Coosawhatchie Formation is part of the Hawthorn Group (Scott, 1988). This geologic unit is exposed at the surface above the floodplain on both sides of Olustee Creek and along the eastern margin of the Lower Santa Fe River Basin (Figure 2-1). The Coosawhatchie Formation consists of gray to bluish-gray sandy clay or clayey sand with phosphorite grains, and carbonate beds of limestone or dolomite (Evans III, Green, Bryan, & Paul, 2004). Lenses of relatively pure sand, clay, or limestone may also be present. Outcrops of the Coosawhatchie Formation in the Lower Santa Fe River Basin may consist of reddish-brown to white, clayey sands to sandy clays.

Locally, the carbonate beds of the Coosawhatchie Formation may be permeable enough to serve as an aquifer for small diameter wells (i.e., domestic self-supply wells). Furthermore, the clayey beds in the unit may impede recharge to the underlying UFA. The formation forms part of the IAS/ICU. The Coosawhatchie Formation begins to thin and become breached in the vicinity of the Cody Escarpment; therefore, recharge to the UFA increases and may be rapid through sinkholes.

UNDIFFERENTIATED HAWTHORN GROUP

The undifferentiated Hawthorn Group consists of sediments that may be residual from the weathering and erosion of the Hawthorn Group formations to the east and in the subsurface. Little phosphate is present in these sediments, and fossils are rare. The sediments are light olive gray to blue gray to reddish brown in deeply weathered sections and consist of poorly to moderately consolidated clayey sands to silty clays and relatively pure clays. Undifferentiated Hawthorn Group sediments exist south of the Lower Santa Fe River in eastern Gilchrist County extending into Alachua County (Figure 2-1).

UNDIFFERENTIATED PLIO-PLEISTOCENE SEDIMENTS

Undifferentiated Plio-Pleistocene sediments are present at the extreme northern edge of the Lower Santa Fe River Basin (Figure 2-1). These sediments are gray to blue-green, unconsolidated to poorly consolidated, fine to coarse-grained, clean to clayey, unfossiliferous sands, sandy clays, and clays (Scott, 2001). These sediments are part of the surficial aquifer system (SAS).

UNDIFFERENTIATED QUATERNARY SEDIMENTS AND BEACH RIDGE AND DUNE SEDIMENTS

The uppermost and youngest geologic units mapped in the study area consist primarily of undifferentiated sands of Quaternary (Pleistocene to Recent) age. The sand deposits were deposited during higher stands of sea level. These deposits consist of light brown to tan, medium-fine quartz sands with variable admixtures of clay and organics. The Quaternary sediments are prevalent throughout the northern portion of the Lower Santa Fe River Basin and along the southwestern margin of the Basin (Figure 2-1).

Quaternary sediments exhibiting discernible beach ridges and dunes have been mapped separately from the undifferentiated Quaternary sediments. These sediments consist of light gray to tan, fine to medium-grained quartz sand (Evans III, Green, Bryan, & Paul, 2004). These sediments (known as Quaternary Beach Ridge and Dune Deposits) are present northwest of the Ichetucknee River (Figure 2-1). These beach ridges were formed when land surface was uplifted to its current elevation through isostatic rebound following dissolution of underlying carbonate rocks (Opdyke, Spangler, Smith, Jones, & Lindquist, 1984). This occurs as limestone is dissolved by acid waters carried into the carbonate beds of the UFA. When this water re-emerges at the surface as spring flow, the water is carrying significant amounts of dissolved solids removed from the surrounding limestone. Due in part to the high concentration of springs in the north Florida region, it has been estimated that up to one meter of limestone may be lost every 12,500 years (Opdyke, Spangler, Smith, Jones, & Lindquist, 1984). The undifferentiated Quaternary and Beach Ridge and Dune sediments are part of the SAS.

2.1.2 Physiography

The Lower Santa Fe River Basin straddles two major physiographic provinces: the Northern Highlands and the Gulf Coastal Lowlands (White, 1970). A karst escarpment known as the Cody Scarp separates these two provinces (White, 1970; Upchurch, 2007). Figure 2-2 illustrates the physiographic provinces of the study area.

NORTHERN HIGHLANDS PROVINCE

The Northern Highlands (White, 1970) is present in the eastern and northern portions of the Lower Santa Fe River Basin, in portions of Columbia, Union, and Alachua Counties (Figure 2-2). This province consists of a moderately dissected plateau that is underlain by a thick sequence of relatively impermeable Miocene Hawthorn Group sediments, as well as undifferentiated Pleistocene-age sediments. The Northern Highlands contains numerous lakes, swamps and streams. Because of relatively low permeability sediments at or near the surface, the Upper Santa Fe River and its tributaries (such as Olustee Creek) convey runoff off the Highlands as evidenced by the drainage patterns (Figure 2-2).

GULF COASTAL LOWLANDS PROVINCE

The Gulf Coastal Lowlands extend inland from the Gulf of Mexico shoreline for a distance of approximately 50 miles, terminating in the western portion of the Lower Santa Fe River Basin (Figure 2-2). The Gulf Coastal Lowlands are characterized by broad and flat marine plains blanketed by thin Pleistocene sands which overlie the Ocala Limestone (Rupert, 1988). The sands were deposited by the regressing Gulf of Mexico.

As a result of the thin sediment cover over limestone, karst features are numerous in the Gulf Coastal Lowlands. Land surface elevations range from about 25 to 70 feet above sea level. Extensive karst development in the Gulf Coastal Lowlands creates an internal drainage pattern. Therefore, the physiographic province in the area of the Lower Santa Fe River Basin is largely devoid of stream channels, and punctuated by depressional features such as sinkholes.

CODY ESCARPMENT

The Cody Escarpment (Scarp) represents the largest continuous topographic break in Florida. The Scarp generally separates the Northern Highlands from the Gulf Coastal Lowlands (Figure 2-2). The Cody Scarp is the erosional edge of the Hawthorn Group rocks (Scott, 1988; 1992) and represents a location of intense recharge of surface water to the UFA via sinking streams and sinkholes, and in certain areas controls the water chemistry in and dissolution of the UFA (Lawrence & Upchurch, 1982). This recharge is an important source of water (mostly through spring discharge) to the Lower Santa Fe and Ichetucknee rivers.

The land surface typically contains sinkholes, sinking streams, and other large and well-developed karst features. In the vicinity of the Cody Scarp, the Santa Fe River flows into a swallet (a sinkhole where streams go underground) at O'Leno State Park (north of High Springs and just west of Interstate 75) and reappears (resurges) approximately three miles south-southwest at River Rise Preserve State Park. The source of water flowing to the River Rise alternates between two sources (surface water runoff from the Upper Santa Fe Basin where the Upper Floridan aquifer is confined, or diffuse recharge through near-surface karst where the Upper Floridan aquifer is unconfined) depending on the discharge of the Upper Santa Fe River (Martin and Dean, 1999; 2001).

WESTERN VALLEY

The Western Valley (White, 1970) is adjacent to the Northern Highlands, in the southeast portion of the Lower Santa Fe River Basin (Figure 2-2). This region is an area of subdued relief, underlain by a thin veneer of sandy cover over the Ocala Limestone. The Western Valley (typically between 25 and 75 feet above sea level) is a mature karst plain characterized by rapid recharge and numerous sinkholes.

Sinkholes in the region are typically small in area, but they are numerous (Upchurch, 2002; 2007). The physiography of the Western Valley is similar to the Gulf Coastal Lowlands, but it is separated from the Gulf Coastal Lowlands by the Brooksville Ridge and High Springs Gap (Figure 2-2).

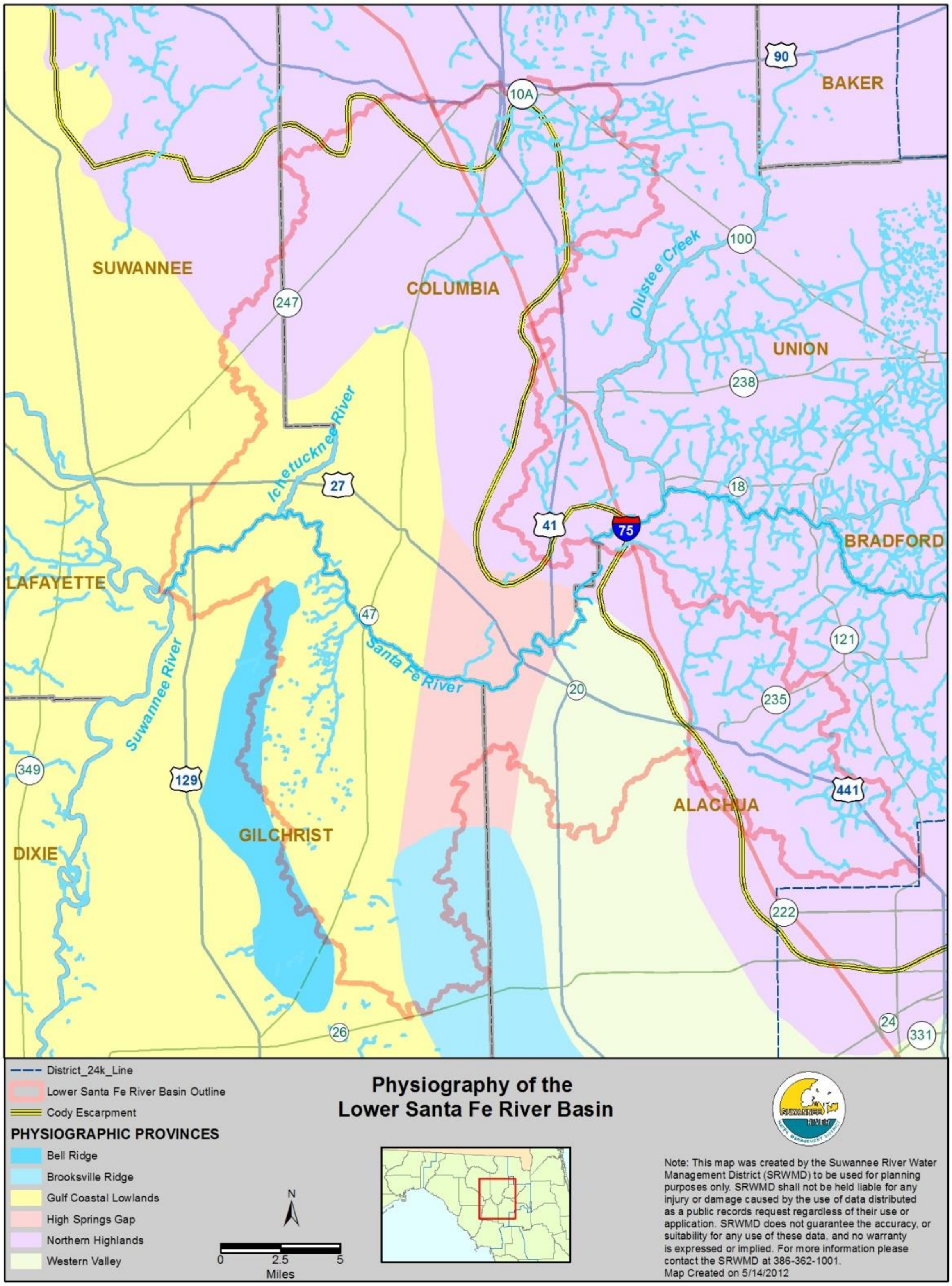


Figure 2-2. Physiography of the Lower Santa Fe River and Ichetucknee River basins.

BROOKSVILLE RIDGE

The Brooksville Ridge is present in the southernmost portion of the Lower Santa Fe River Basin (Figure 2-2). The ridge is a topographic highland composed primarily of Pleistocene-age siliciclastic sediments and capped by a depression-pocked rolling plain of marine terrace sand (Rupert, 1988). The Brooksville Ridge extends approximately 110 miles southeastward from its northern limit in eastern Gilchrist County to Pasco County in west-central Florida. Surface elevations approach 100 feet above sea level along the eastern edge of Gilchrist County.

BELL RIDGE

The Bell Ridge borders the western edge of the Lower Santa Fe River Basin (Figure 2-2) and is considered to be a Pleistocene beach ridge (Puri & Vernon, 1964). The elevations range from 80 to 100 feet above sea level. The sediments comprising the Bell Ridge are similar to the Brooksville Ridge, and (White, 1970) has suggested that the Bell Ridge is an outlier of the Brooksville Ridge.

WACCASASSA FLATS

Though not represented on Figure 2-2, the Waccasassa Flats is a geomorphologic feature that lies between the Brooksville Ridge and Bell Ridge within the Lower Santa Fe River Basin. The Waccasassa Flats is a subprovince of the Gulf Coastal Lowlands and extends from the Lower Santa Fe River southward to the town of Trenton and then southeastward terminating in north-central Levy County. The Flats are relatively flat and characterized by sand hills, pine flatwoods, wetlands, cypress ponds, and small lakes (Col, Enright, & Horvath, 1997). Undifferentiated Pleistocene-age sediments, composed of sands, clayey sands, and clays to a thickness of 50 feet, overlie the Ocala Limestone (Col, Enright, & Horvath, 1997). The presence of clays and clayey sands form perched ponds and lakes, also supports the SAS, particularly in the interior portion of the Waccasassa Flats.

HIGH SPRINGS GAP

The High Springs Gap is lowland in the southeast portion of the Lower Santa Fe River Basin, between the Western Valley and Gulf Coastal Lowlands (Figure 2-2). The High Springs Gap provides a drainage connection, via the Santa Fe River, between the northernmost limit of the Western Valley and Gulf Coastal Lowlands (Rupert, 1988). The Northern Highlands and Central Highlands of the Florida peninsula may have at one time been connected as one integrated highland, and were partitioned by erosion and solution of limestone as partially evidenced by the fact that the Northern Highlands are separated from the Brooksville Ridge by the High Springs Gap shown in Figure 2-2 (White, 1970).

2.1.3 Hydrogeology

Table 2-1 illustrates the hydrogeologic framework in the Lower Santa Fe River Basin (Scott, 2001). The presence of aquifers in the Lower Santa Fe River Basin are dependent on the presence or absence of Hawthorn Group sediments, which tend to retard the vertical movement of groundwater, thus leading to confined or semi-confined UFA conditions.

Figure 2-3 indicates the general areas in the Lower Santa Fe River Basin where the UFA is under confined, semi-confined, or unconfined conditions. In general, the UFA is under confined or semi-confined conditions where the Miocene sediments of the Hawthorn Group are present.

Examples of these areas in the Lower Santa Fe River Basin (Figure 2-2) include the Northern Highlands (confined) or Waccasassa Flats and the Cody Scarp areas (semi-confined). In these areas, the SAS and/or IAS/ICU are also present. The UFA is under unconfined conditions (i.e., open to atmospheric pressure) where Hawthorn Group sediments are absent. An example of this area is the Gulf Coastal Lowlands (Figure 2-2).

Table 2-1. General relationships between geologic and hydrogeologic units in the Lower Santa Fe River Basin.

<table>
<tr><th>SYSTEM</th><th>SERIES</th><th colspan="3">FORMATION</th><th>HYDROSTRATIGRAPHIC UNIT</th></tr>
<tr><td>Quaternary</td><td>Pleistocene</td><td colspan="3">Undifferentiated and Beach Ridge and Dune (25 - 75)*</td><td>Surficial Aquifer System (SAS)</td></tr>
<tr><td rowspan="3">Tertiary</td><td rowspan="2">Miocene</td><td>Statenville Formation (0 - 80)</td><td>Undifferentiated Hawthorn (0 - 25)</td><td rowspan="2">Hawthorn Group</td><td rowspan="2">Intermediate Aquifer System/Intermediate Confining Unit (IAS/ICU)</td></tr>
<tr><td colspan="2">Coosawhatchie Formation (25 - 75)</td></tr>
<tr><td>Eocene</td><td colspan="3">Ocala Limestone (150 - 275)</td><td>Upper Floridan aquifer (UFA)</td></tr>
</table>

*: values indicate range in thicknesses, in feet, in the Santa Fe Basin.

SURFICIAL AQUIFER SYSTEM

The uppermost aquifer in the area is the SAS. As mentioned above, the SAS is present only in areas where a confining or semi-confining unit separates surface or near-surface sediments from the underlying UFA. Therefore, the SAS is generally present only in the Northern Highlands and portions of the Waccasassa Flats (Figure 2-3). Where present, the SAS is composed of undifferentiated Pleistocene and Beach Ridge and Dune sediments. Because of its limited spatial and vertical extent, relatively poor water quality, and low yield to wells, the SAS is utilized only on a limited basis for water use.

INTERMEDIATE AQUIFER SYSTEM/INTERMEDIATE CONFINING UNIT

The IAS/ICU is composed of Hawthorn Group sediments and underlies the SAS. Within the IAS/ICU there may be localized and permeable, siliciclastic and carbonate beds that serve as low-yield aquifers within the Hawthorn Group. Where present, these permeable beds provide water for small diameter wells (e.g., domestic self-supply use).

For the most part, the sediments in the IAS/ICU consist of low permeability clays and clayey sands that limit the exchange of groundwater between the SAS and UFA. This condition exists in the Northern Highlands, where Hawthorn Group sediments serve as an effective confining unit. In the area of the Cody Scarp, Hawthorn Group sediments have thinned or have been breached to the extent that recharge to the UFA occurs. In this area, the lower permeable beds of the IAS/ICU may be in hydrologic connection with the UFA.

UPPER FLORIDAN AQUIFER

The Upper Floridan aquifer is the primary source of water supply for all water use types within the Lower Santa Fe River Basin. It also provides the base flow in the Lower Santa Fe River, primarily through springs. In the Lower Santa Fe River Basin, the UFA production zone (for supply and base flow to the river) is from the Ocala Limestone (Figure 2-3).

The transmissivity in the Ocala Limestone varies greatly. Groundwater flow is fairly sluggish through the matrix of the limestone, but can be very high where secondary porosity has been developed due to dissolution of the limestone. These high-flow zones typically develop along bedding planes (such as the contact between the Hawthorn Group and Ocala Limestone), fractures, and faults, and oftentimes, are located in the upper portion of the limestone where groundwater circulation is more dynamic due to water level fluctuations. As Figure 2-3 shows, the UFA is unconfined along the Lower Santa Fe and Ichetucknee rivers. In these areas, the UFA discharges (through springs and baseflow) to the rivers under most conditions (with the exception of flood events). The UFA discharge is expressed at the surface by the numerous first and second magnitude springs along the two rivers. As a result, maintaining UFA water levels in the Lower Santa Fe River Basin is critical to maintaining flow to the springs and to baseflow in the Lower Santa Fe and Ichetucknee rivers. Figure 2-3 also indicates that the UFA is confined along the eastern margin of the Lower Santa Fe River Basin and semi-confined in the southwest and northern portions of the Lower Santa Fe River Basin.

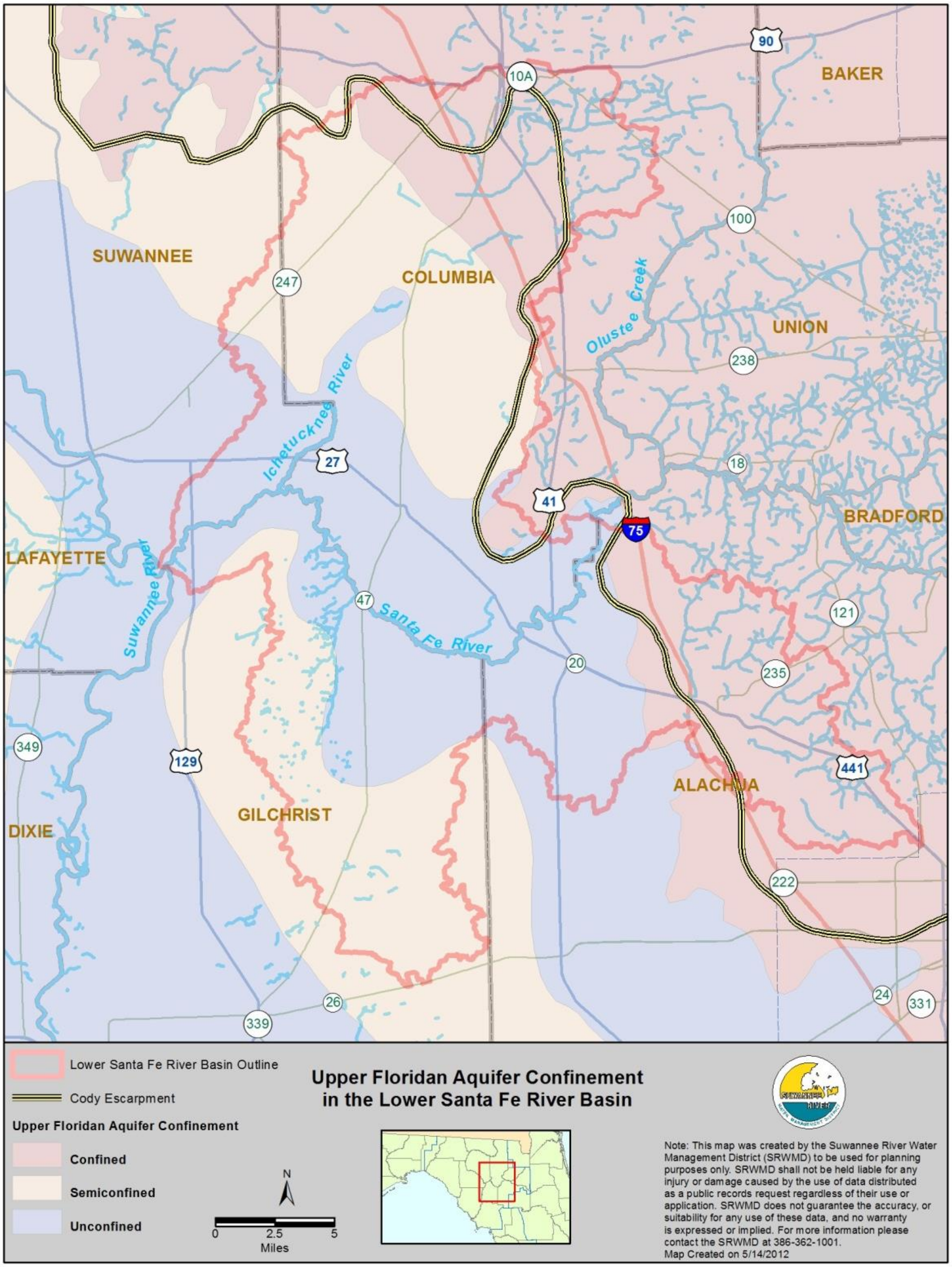


Figure 2-3. Upper Floridan aquifer confinement in the Lower Santa Fe River Basin.

2.1.4 Recharge to the Upper Floridan Aquifer

A spatial evaluation of recharge to the UFA is important to understand the overall water budget of the system. The UFA recharge potential was evaluated by the District using a ranking system for use in a geographic information system context (Figure 2-4). High recharge to the UFA occurs throughout most of the Lower Santa Fe River Basin and, as expected, correlates to areas where the UFA is unconfined to semi-confined (see Figure 2-3 and Figure 2-4). Figure 2-4 indicates that medium to medium-high recharge occurs along the southwest and northeast margins of the Lower Santa Fe River Basin (consistent with semi-confined areas – see Figure 2-3). Low-medium to low recharge occurs in the southwest portion of the Lower Santa Fe River Basin and to the east of the Basin (Figure 2-4). The UFA in the Waccasassa Flats (southwest portion of the Basin) is under semi-confined conditions, and the UFA in the Northern Highlands (east of the Basin) is under confined conditions.

2.1.5 Relationship of the Santa Fe River to the Underlying Aquifers

The Santa Fe River, both upper and lower portions, provides a local illustration of the variability in groundwater and surface water interaction across north-central Florida and is an apt example of the phrase “groundwater and surface water: a single resource” (USGS, 1998). The transition (described above in subsection 2.1) in the degree of confinement of the UFA near the Cody Scarp, described by Upchurch (2007), is pictured in Figure 2-4. A smoothed profile of the river bottom is shown, based on surveyed cross sections, and includes the land bridge at O’leno State Park. Superimposed on this are the estimated groundwater levels from May of 2005 and 2012. The 2005 period represents a high year, while District-wide groundwater conditions in May 2012 set a record-low. Together they depict the range of fluctuation in groundwater levels relative to the river profile, and portray the availability of gain in streamflow along the system.

Above the Worthington Springs gage, the Upper Floridan aquifer is considered confined and its groundwater levels remain below the river. Near Worthington Springs, in both wet and dry conditions, a local groundwater mound is observable, indicative of the initial ‘break’ in confinement that heralds the occurrence of sinks and springs downstream, and is likely caused by a localized increase in recharge, even during dryer periods. There are a number of sinks and rises that occur above O’leno State Park, including Santa Fe Spring (near River Mile [RM] 40), Vinzant Sink (near RM 39.5) and most notably the O’leno State Park river sink (near RM 35) that normally captures the entire river flow.

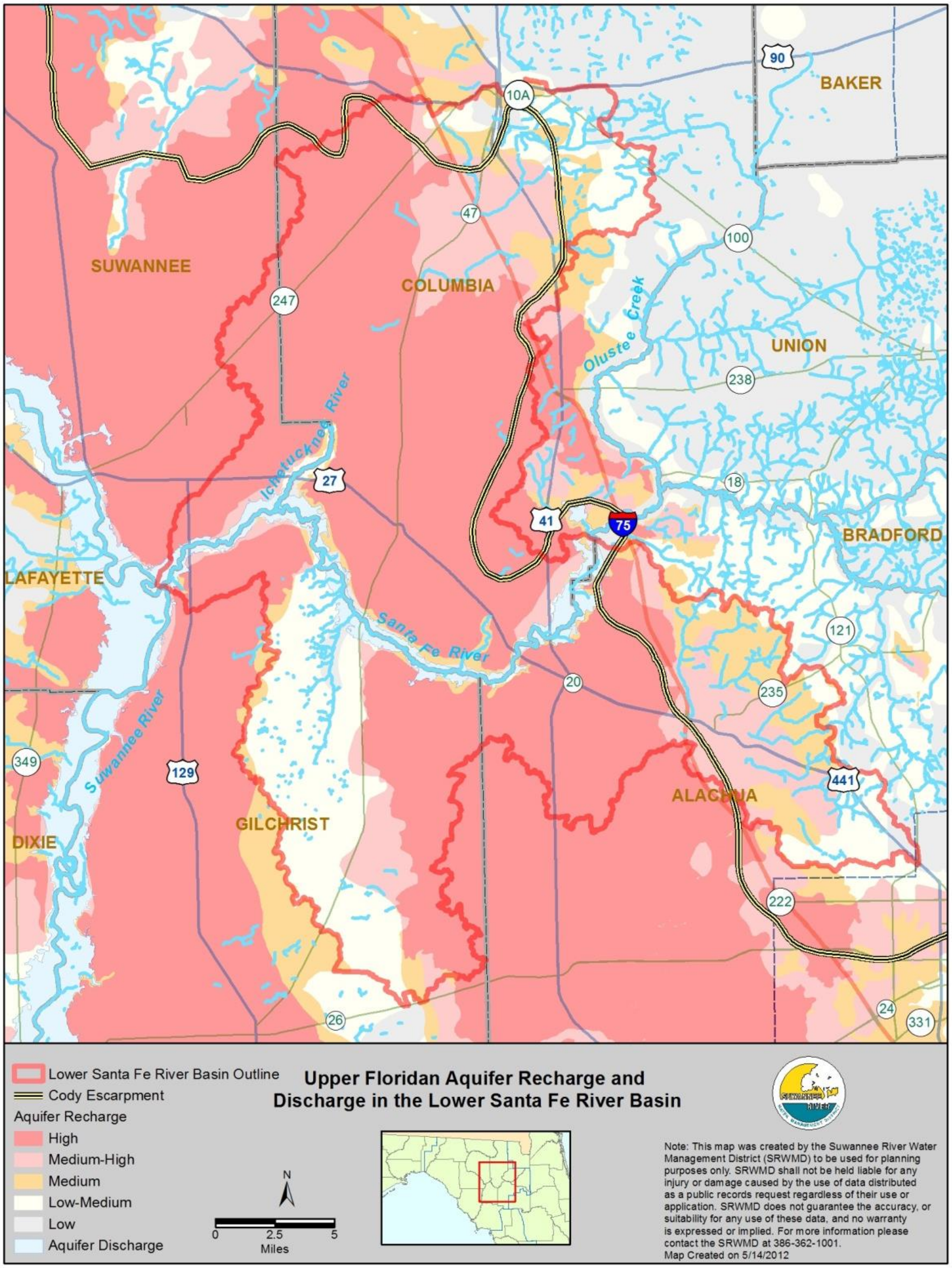


Figure 2-4. Upper Floridan aquifer recharge and discharge in the Lower Santa Fe River Basin.

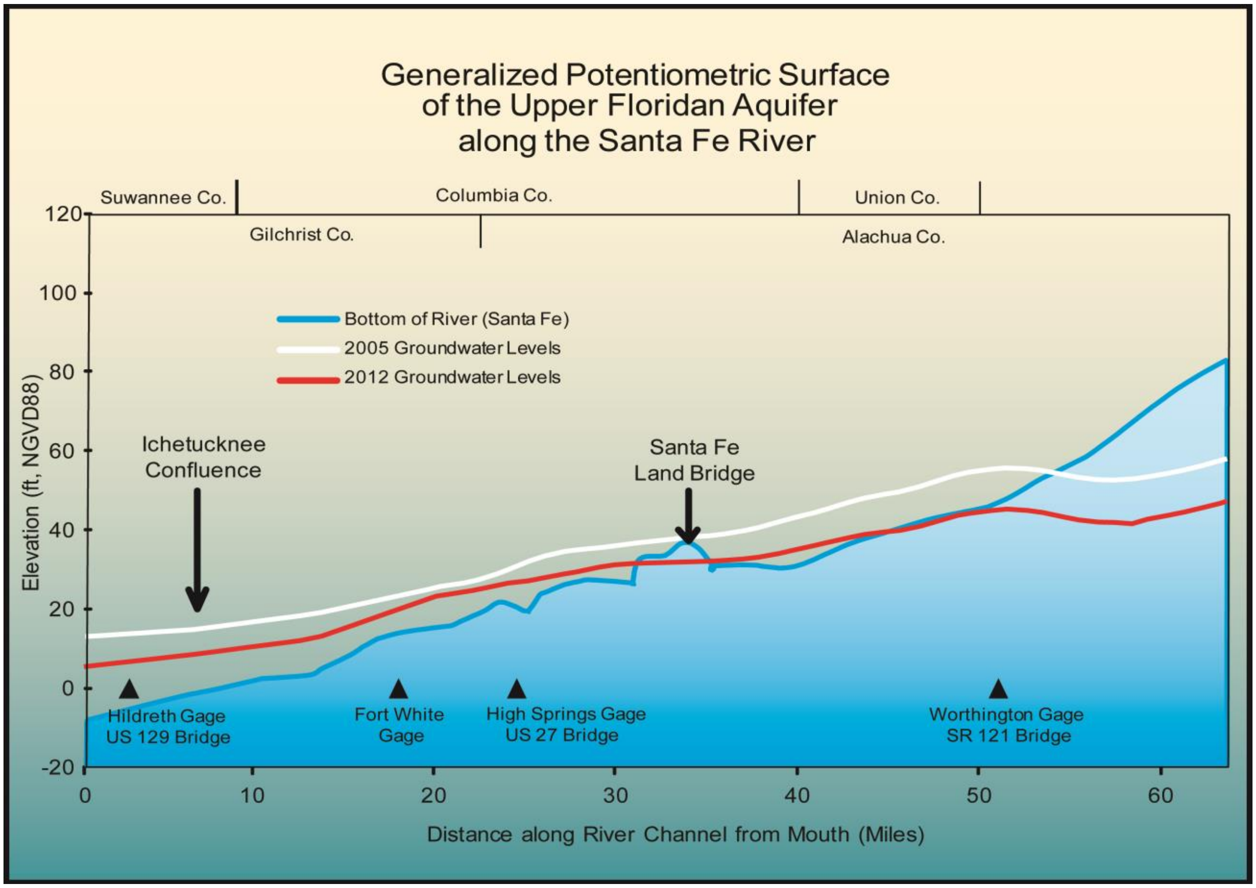


Figure 2-5. Generalized Potentiometric Surface of the Upper Florida aquifer along the Santa Fe River.
The Potentiometric Surface estimates are from data collected in May of each year. The bottom of the river is a smoothed representation based on surveyed cross sections. The divisions between county names along the top are location aids and indicate the position of the county boundary on the north bank (upper row) and south bank (lower row) of the river.
Note: this is not river levels but rather groundwater levels.

2.2 RIVERINE AND RIPARIAN WETLAND HABITATS

Understanding the relationship between streamflow and the resulting ecosystem responses is critical to the establishment of a MFL. The principal physical forces that influence river ecosystems are driven by hydrologic conditions (Poff, et al., 1997; Poff & Ward, 1988). Flow influences ecological integrity directly (Poff & Allen, 1995) or indirectly via other factors such as water quality, physical habitat availability, and fish passage (Schlosser, 1991; Poff, et al., 1997).

The previous subsection summarized hydrologic conditions in the Lower Santa Fe and Ichetucknee rivers. The local hydrologic system serves as the structural basis for the ecological communities of the rivers, including those in the river channel and adjacent floodplains. This subsection characterizes the riverine and riparian wetland habitats of the Lower Santa Fe and Ichetucknee rivers, describing the in-stream and floodplain communities that will be used to assess potential impacts associated with potential future water use.

2.2.1 Importance of Riverine Habitat Characteristics

The following subsection discusses those critical riverine habitat elements that can be affected by variation in river flow and provide a basis for MFL development.

The key to establishing defensible, protective MFLs is a clear understanding of the quantitative relationships between river flows and the critical ecological resources of concern. It is also recognized that these relationships can be confounded by the river's physical and chemical settings; therefore, knowledge of these settings is essential.

The Lower Santa Fe and Ichetucknee rivers support a wide variety of organisms that depend not only on adequate river flows but also on adequate in-stream habitats. Numerous physical, biological, and chemical characteristics of the river channels determine their suitability for local biota. The most significant physical features that determine habitat suitability include channel morphology, substrate type, channel slope, woody habitat, and the water sources for the rivers. These features are discussed below.

Channel morphology determines local flow patterns and the extent of riparian vegetation that the river banks can support. Channel slopes largely determine relative stream velocities, which in turn determine habitat suitability of both fish and benthic macroinvertebrate communities.

Substrate type largely influences the composition of the benthic macroinvertebrate community. Interstitial spaces among particles on the river bottom can provide habitat with reduced velocities. Conversely, bedrock substrates provide opportunities for attachment by those organisms that rely on river flow to provide a source of food. SAV is yet another habitat that can provide refuge from some predators (Figure 2-6). Various fish taxa depend upon specific substrates for nesting sites.

Woody habitats, i.e., both exposed tree roots and submerged wood, also provide habitat for a variety of aquatic organisms. These surfaces can support periphytic growth, a food source for upper trophic levels.

Water quality can also significantly influence the suitability on in-channel habitats. Critical water quality parameters include dissolved oxygen (DO), pH, specific conductance, and ionic composition. Excessive nutrient loading can result in excessive primary production that in turn can lead to wide diel variation in DO.

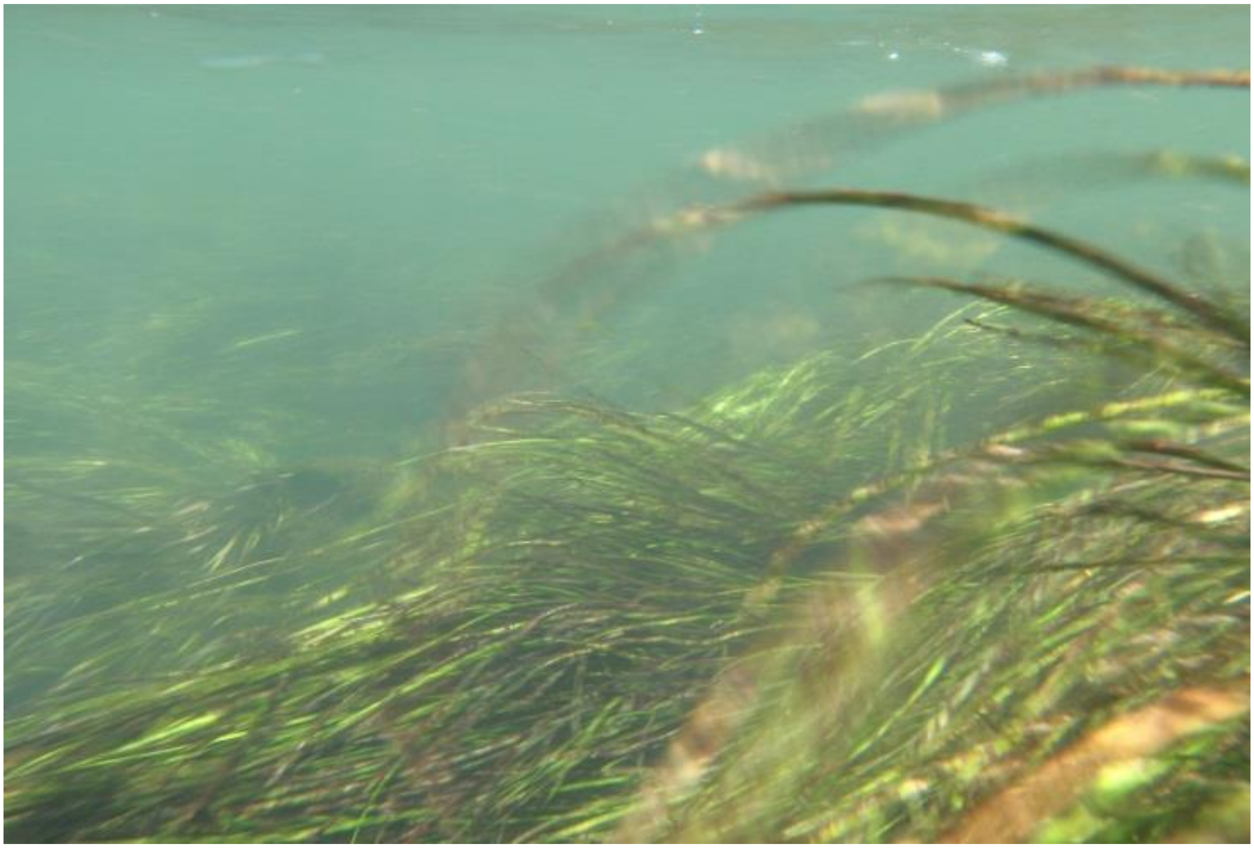


Figure 2-6. Submerged aquatic vegetation in the Lower Santa Fe River near Fort White.

2.2.2 Riverine Habitats in the Lower Santa Fe and Ichetucknee Rivers

The upper reaches of the Lower Santa Fe River are less incised and support a wide floodplain. Farther downstream (west of Fort White) the river banks become higher and steep, and the channel becomes wider and deeper. The upper portion of the Ichetucknee River run is narrow and lined by walls of limestone, eroded by the ceaseless spring flow. Downstream the high banks recede to be replaced by wooded floodplain.

LOWER SANTA FE RIVER

The channel of the Lower Santa Fe River is comprised of a combination of shoals, pools, and runs. River runs are relatively regular, unobstructed flow paths. Shoals (riffles) and pools, in contrast, present a diverse physical setting that provides numerous niches for fish and other biota. Shoals are higher than the surrounding channel bottom and can restrict flow which can result in the loss of hydraulic connection between reaches, present barriers to fish and manatee migration, or hamper recreational boating. Wharton (1978) describes a shoal as shallow, with oxygenated water, and as a swift flowing, rocky area that is abundant with life. The complex shoal bed sediment may consist of limerock ledges and boulders or gravel and cobble interspersed with sand. Many of the shoals in the rivers are exposures of more resistant limestone beds that often contain appreciable amounts of chert. Habitats within a shoal encompass shallow and deep pools, fast chutes, shallow runs, and riffles. The heterogeneous conditions in a shoal environment result in high species diversity compared to adjoining waters. Although pools typically do not support the variety of species as shoals, they do provide for low-water refuge and passage for aquatic fish and wildlife. Shoals are found in several sections of the Lower Santa Fe River (Figure 2-7).

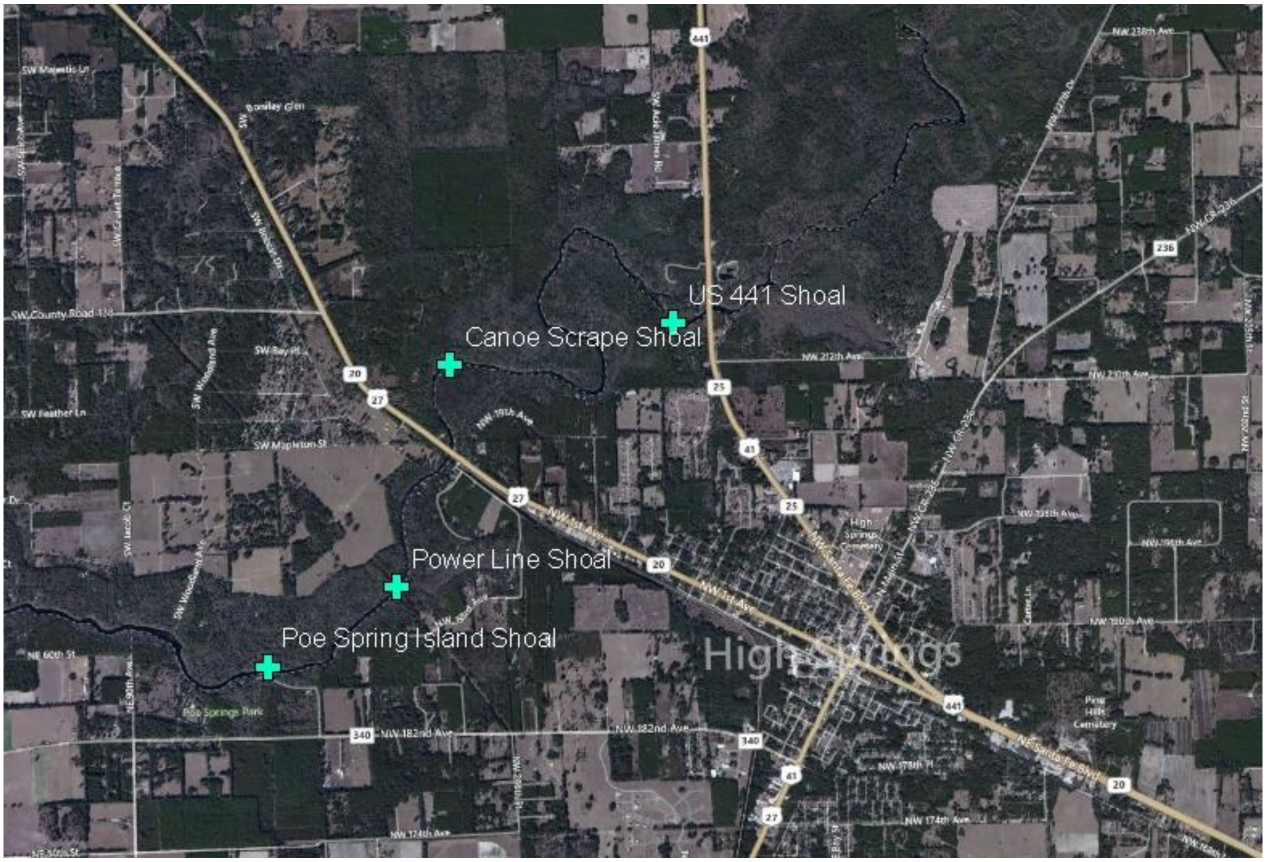


Figure 2-7. Shoals of the upper reach of the Lower Santa Fe River.

Just downstream of US 441, the river has a pool and riffle structure with well-developed shoals at intervals (Figure 2-8). Other shoals of interest have been identified approximately one mile upstream of Poe Springs, downstream of Highway 27 and two miles upstream of US 47 (Figure 2-9). A shoal nicknamed “canoe scrape” is another major shoal feature in this portion of the Lower Santa Fe River (Figure 2-10). In several areas of the river between Fort White and the Ichetucknee River, the stream channel is solid rock with many shoals.

Substrate type, which can be solid rock, boulder and cobble, gravel, sand, clay, or mud, is also a determining factor for habitat suitability. Finer grained sediments are more suitable for SAV growth. The Lower Santa Fe River features solid rock channel bottoms at shoals and other areas as well as unconsolidated, mainly sandy sediments. In the downstream-most section of the Lower Santa Fe River there are natural levees of Santa Fe marl along the bank, which may be several feet high.

Figure 2-8. Chert shoal at Columbia Spring outfall.

Figure 2-9. Shoals near the USGS gage near Fort White.

Figure 2-10. Canoe Scrape Shoal on the Lower Santa Fe River.

The sources of water that enter a river also influence in-stream habitat availability. Although the Lower Santa Fe River receives abundant groundwater inflow, it does have a significant surface water input (see Section 4.0). This results in a variable flow regime that reflects periods of high rainfall, although low flows are elevated by the more consistent groundwater inflows. The high flows act to physically shape the channel as well as transport sediment and nutrients. Variability in flows also results in periodic inundation of in-stream woody habitat as well as the floodplain.

ICHETUCKNEE RIVER

The channel slope of the Ichetucknee River is irregular, and is substantially steeper than the Lower Santa Fe River. The overall slope for the spring run is approximately 2.7 feet/mile. However, the upper portion of the channel, from RM 4.4 to 5.3 is much steeper at approximately 7.0 feet/mile, causing higher velocities in the narrow, upper river run.

The Ichetucknee River bottom is relatively more regular than seen on the Lower Santa Fe River with little evidence of an incised nature. Kurz, et al. (2004) reports that in the Ichetucknee River the majority of channel bottom material at sampling sites was sand (46%) and mud (23%) which facilitates SAV growth (Figure 2-11). Limerock outcrop shoals occur in the Ichetucknee River at several locations near the river mouth. These shoals can block passage of boats and animals, such as manatees, during moderate to low flow conditions. The middle reach on the Ichetucknee River is characterized by Grassy Flats, a broad marshy area. The Ichetucknee River receives almost all its water from springs. Although the flow does vary, the flow regime range is quite limited, as discussed in Section 4.0.

Figure 2-11. Submerged aquatic vegetation within the Ichetucknee River.

2.3 LAND USE WITHIN THE LOWER SANTA FE RIVER AND ICHETUCKNEE RIVER BASINS

Land use and land cover of the basin is a major contributor to defining the hydrologic response to rainfall. Changes in land use of a basin can contribute to changes in the water balance. The water budget can be further modified given water withdrawals to satisfy potable demands in the case of urbanization, or to offset evapotranspiration (ET) in the case of agricultural land use.

2.3.1 Land Use and Cover

The most recent available mapping of land cover/land use conditions for the basin was based on 2010 aerial photography. Mappings from the 1970s and 1988 were also obtained for analysis. Land use conditions for the Santa Fe River watershed in these time periods are shown in Figure 2-12 through Figure 2-14. Each land use coverage falls within the District boundary but not include a northern portion of the New River watershed and a portion of the Santa Fe River watershed outside of the District boundary. The 1970s land cover was developed by the U.S. Geological Survey (USGS) (Anderson, Hardy, Roach, & Witmer, 1976). The 1988 land cover was developed by the Suwannee River Water Management District (SRWMD, 1990). The 2010 land cover was developed by the FDEP (2011a). The coverages were developed at different resolutions; consequently, they were aggregated and grouped by generalized Florida Land Use, Land Cover Classification System (FLUCCS) codes, resulting in the summary shown in Table 2-2. These land use conditions were examined for changes from the 1970s to present times.

Forested land cover dominates the Lower Santa Fe River Basin, covering almost half of the basin. Some of the forested land use types include managed forest (or silviculture). The forested land cover, although heavily modified through silviculture, has little impact on the overall basin hydrologic response other than the possibility of increasing peak flows. The increase in peak flows are not a result of increased planting density but are a result of silviculture management practices of ditching and draining to facilitate seedling planting and timber harvesting (KBN Engineering, 1990) and the planted areas are certainly denser than natural forested areas. The increased forest density would tend to increase ET losses. The significance of increased ET loss is generally small compared to the overall water balance between natural forested areas and the planted forested area (KBN Engineering, 1990).

Major anthropogenic land covers within the Santa Fe River Basin include urban and agriculture. These two modified land covers together accounted for 31% and 27% of the basin area in the 1970s and 2010 respectively. Agricultural land cover is the larger portion of the total anthropogenic land cover. Agricultural land accounted for approximately 30% of the basin area in the 1970s and approximately 16% in 2010. A 3% decrease in the anthropogenic land cover between 1970s and 2010 is attributed to a significant reduction of the agricultural land cover (from 30% to 16%). Conversely, there was an increase in the urban land cover. In the 1970s, residential, commercial, industrial, and transportation land uses collectively comprised approximately 2% of the basin area. In 2010, it rose to 10%. A comparison of generalized land use within the Santa Fe and Ichetucknee River Basins from 1970, 1988, and 2010, is shown in Figure 2-15. In general, urban land uses have increased and agricultural land uses have decreased over time. The status of forest and wetlands is variable. It should be noted that different mapping methods, data sources, and interpretations were used for the three periods, so the comparison cannot be taken as absolute; furthermore, forest and rangeland classifications were combined to help compare differences in classifications across time.

Urbanized land cover is typically associated with increased runoff and therefore increases in stream discharges (peak flow). The increased discharges are related to the increase in directly connected impervious area (DCIA). The relatively small amount of urbanized land forms and the low degree of impervious area and DCIA would not be expected to produce significant increases in discharge. However, the coupled increase in water use would impact streamflows given the high inflow from groundwater sources.

Agricultural land cover can have an impact on the basin water balance when compared to natural conditions. Agricultural uses are often accompanied by water withdrawals for irrigation. Supplemental irrigation leads to changes in the ET rates and are the largest direct change to the water balance in areas of agricultural land use.

Review of land use data indicates that the basin is becoming more urbanized. Available evidence may also indicate a transition of natural forest land to silviculture. The upsurge in urbanization and silviculture increases runoff resulting in higher peak discharges. Higher discharges are caused by an increase of impervious surfaces in the urban areas and ditching and draining of silviculture lands. The basin is both internally drained and drained by sinking streams coming off the scarp. A small increase in peak discharges could occur as a result of anthropogenic changes to the land use. However, in the Lower Santa Fe River a possible increase in peak discharge would have little effect on the flow in the river. In both scenarios, the water eventually recharges the aquifer and flows to the river either through diffuse flow in the rock matrix or through a conduit. An increased rate of recharge in post development conditions would occur from the decreased time of concentration.

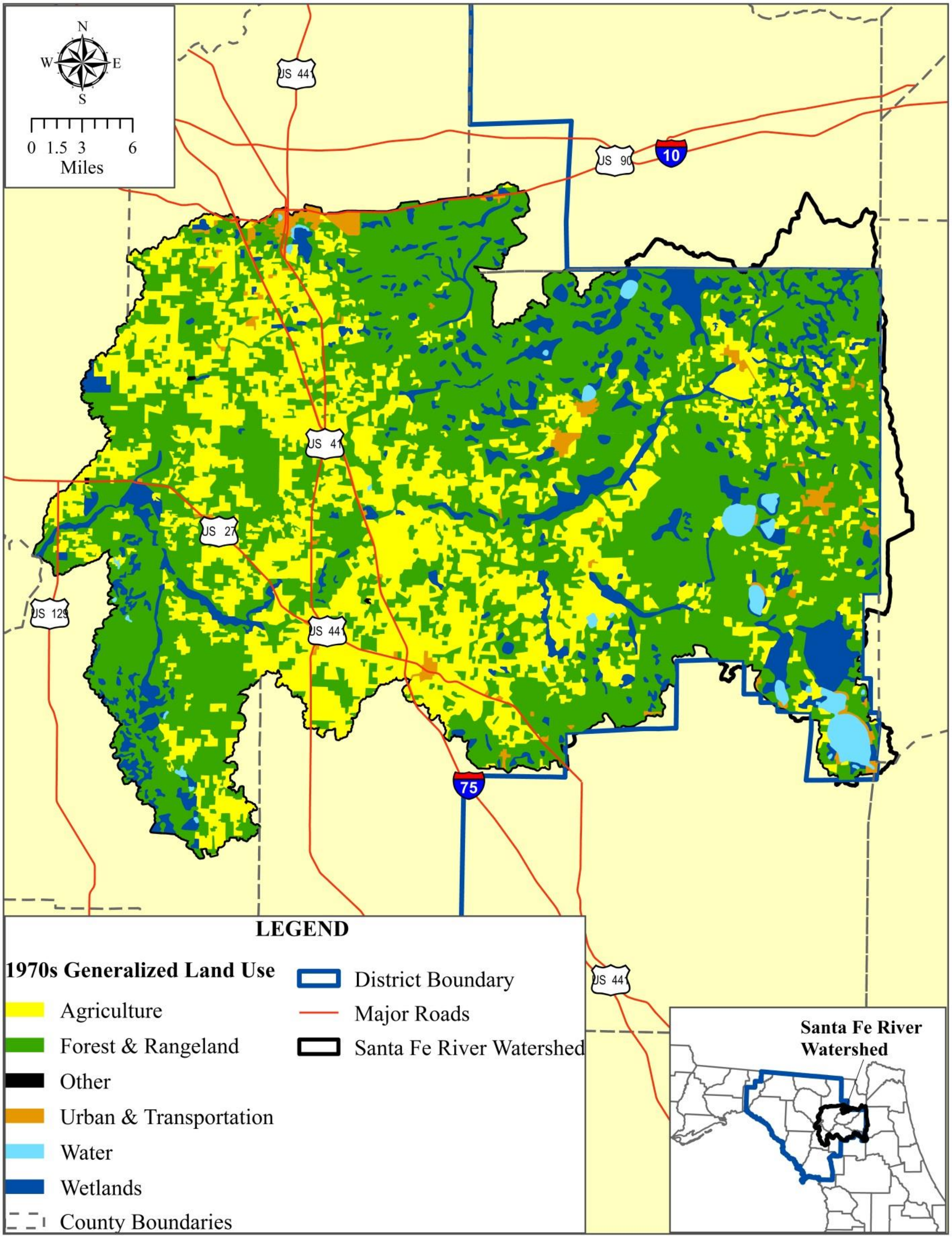


Figure 2-12. 1970s land use within the Lower Santa Fe River and Ichetucknee River basins.

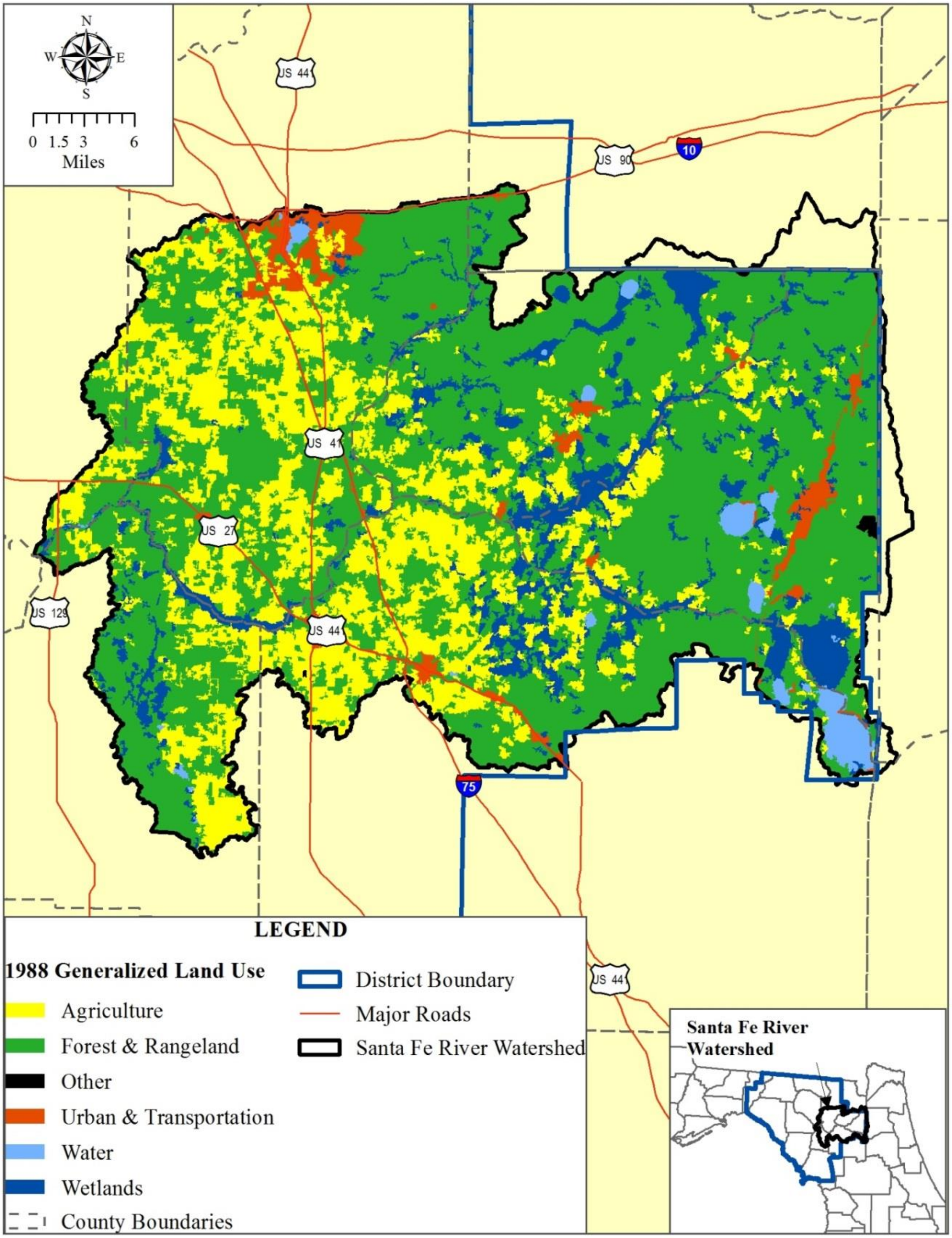


Figure 2-13. 1988 land use within the Lower Santa Fe River and Ichetucknee River basins.

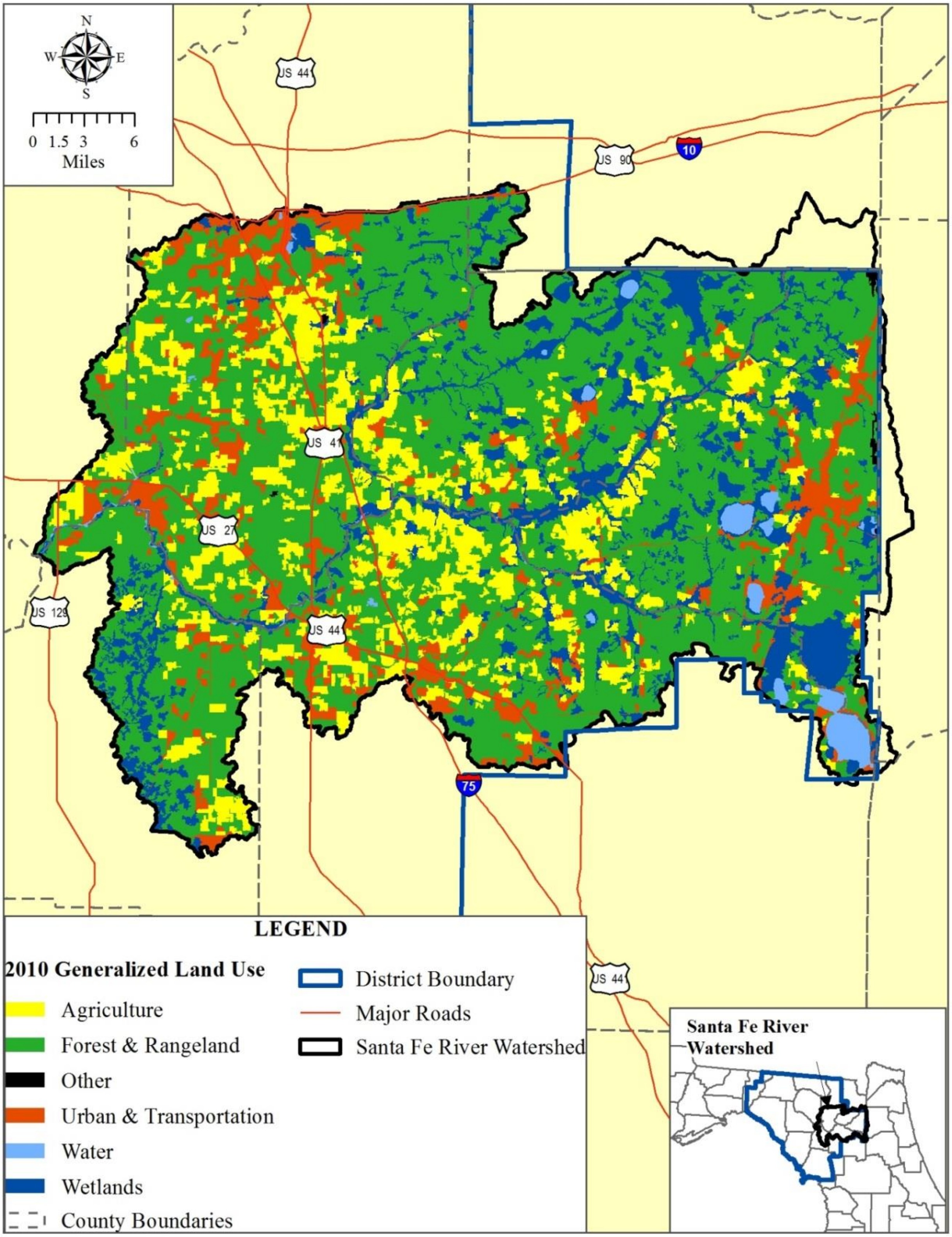


Figure 2-14. 2010 land use within the Lower Santa Fe River and Ichetucknee River basins.

Table 2-2. Land use within the Lower Santa Fe River and Ichetucknee River Basins in the 1970s, 1988, and 2010.

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**

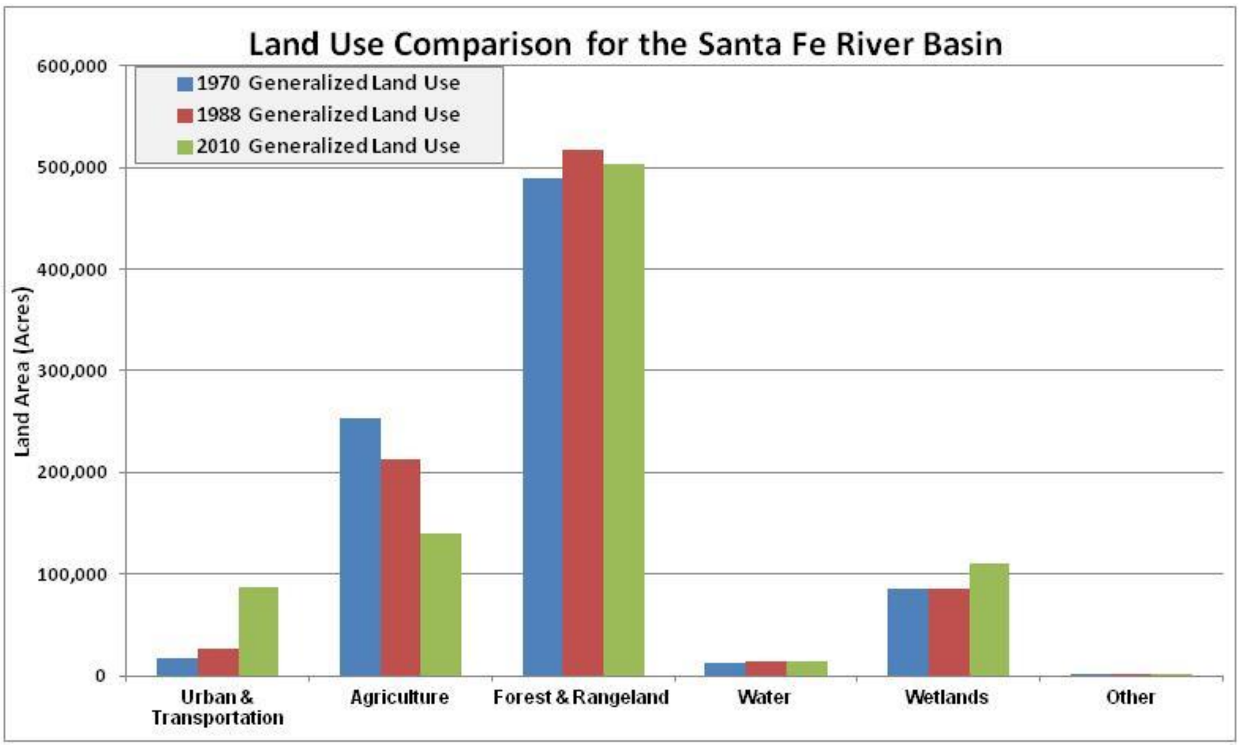


Figure 2-15. Land use comparison within the Lower Santa Fe River and Ichetucknee River basins: by land area.

2.3.2 Parks in the Lower Santa Fe and Ichetucknee Basins

Four state parks lie within the Lower Santa Fe River Basin (Figure 2-16). Three of the state parks include the Lower Santa Fe and Ichetucknee rivers within park borders. San Felasco State Park is located in Alachua County, south of the Santa Fe River. The Ichetucknee Springs State Park, O'Leno State Park, and River Rise State Park feature the rivers as a main attraction for visitors. The Ichetucknee Springs State Park includes the upper extent of the Ichetucknee River and includes many significant springs including Ichetucknee Head Springs, Blue Hole, Cedar Head Spring, Mission, Devil's Eye, Grassy, Mill Pond, and Coffee (Figure 2-17). The O'Leno and River Rise Preserve State Parks include significant features of the Santa Fe River such as the O'Leno Sink and River Rise, as well as the land bridge with many karst windows (Figure 2-18). All three parks rely on the maintenance of water levels for recreation as well as aesthetics. Recreation on the Santa Fe and Ichetucknee rivers includes small water craft, tubing, snorkeling, and swimming. In addition, Blue Hole supports cave diving. In the Ichetucknee River State Park low water levels associated with low flows have been attributed to damage to SAV from trampling action when it is shallow enough for tubing participants to walk. Additionally, certain structures, such as the existing tubing take-out at the Ichetucknee River near Highway 27, become unsafe or unusable when the water levels drop below a threshold. At O'Leno State Park the swimming area also closes during times of low flow.

In addition to state parks, county and private parks are located in the basin. Poe Springs and Rum Island are county-run park facilities directly impacted by discharge from the respective springs and water levels of the Santa Fe River. Private parks located in the basin and include Ginnie Springs campground and Blue Springs campground (FDEP, 2009).

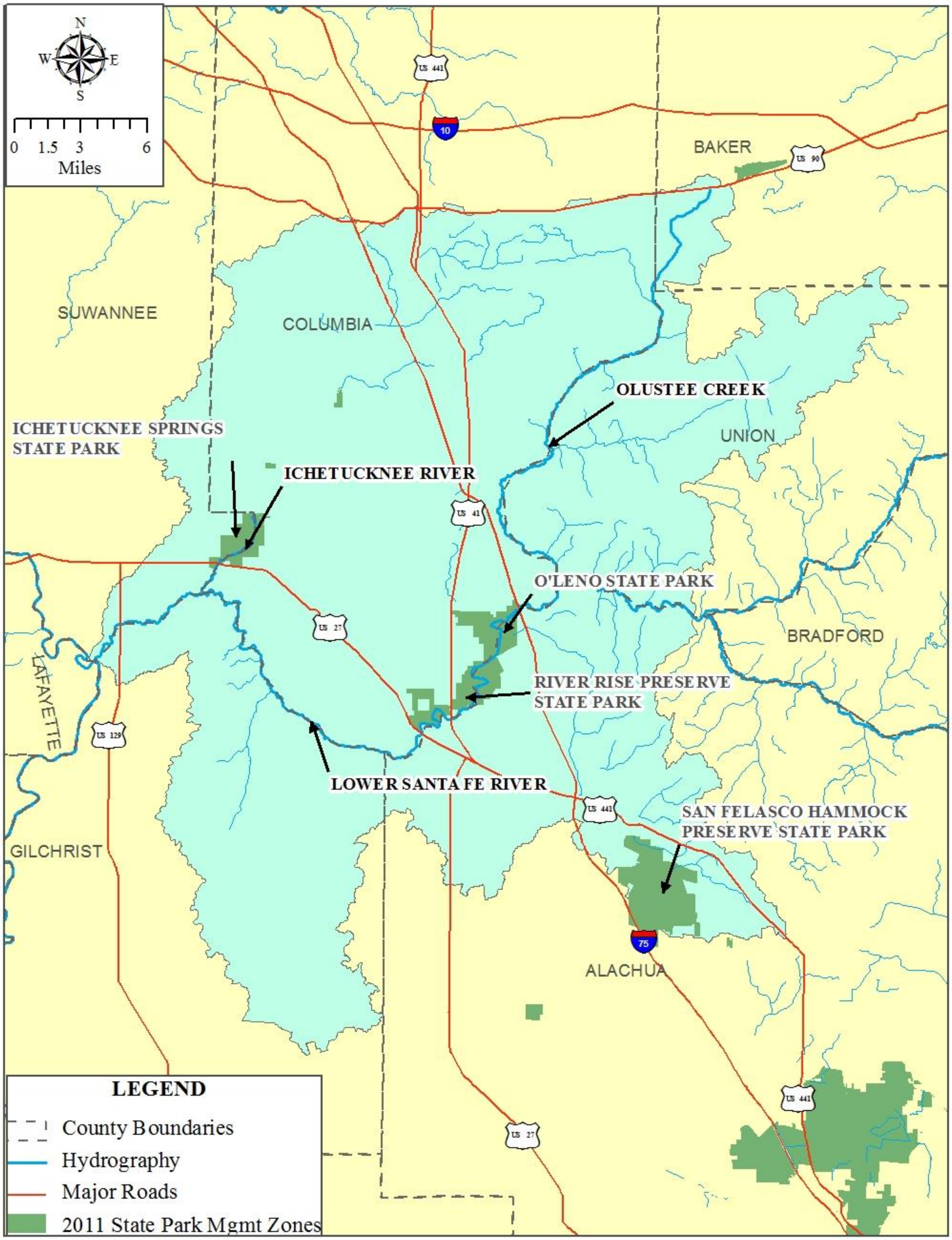


Figure 2-16. State parks within the Lower Santa Fe River and Ichetucknee River basins.

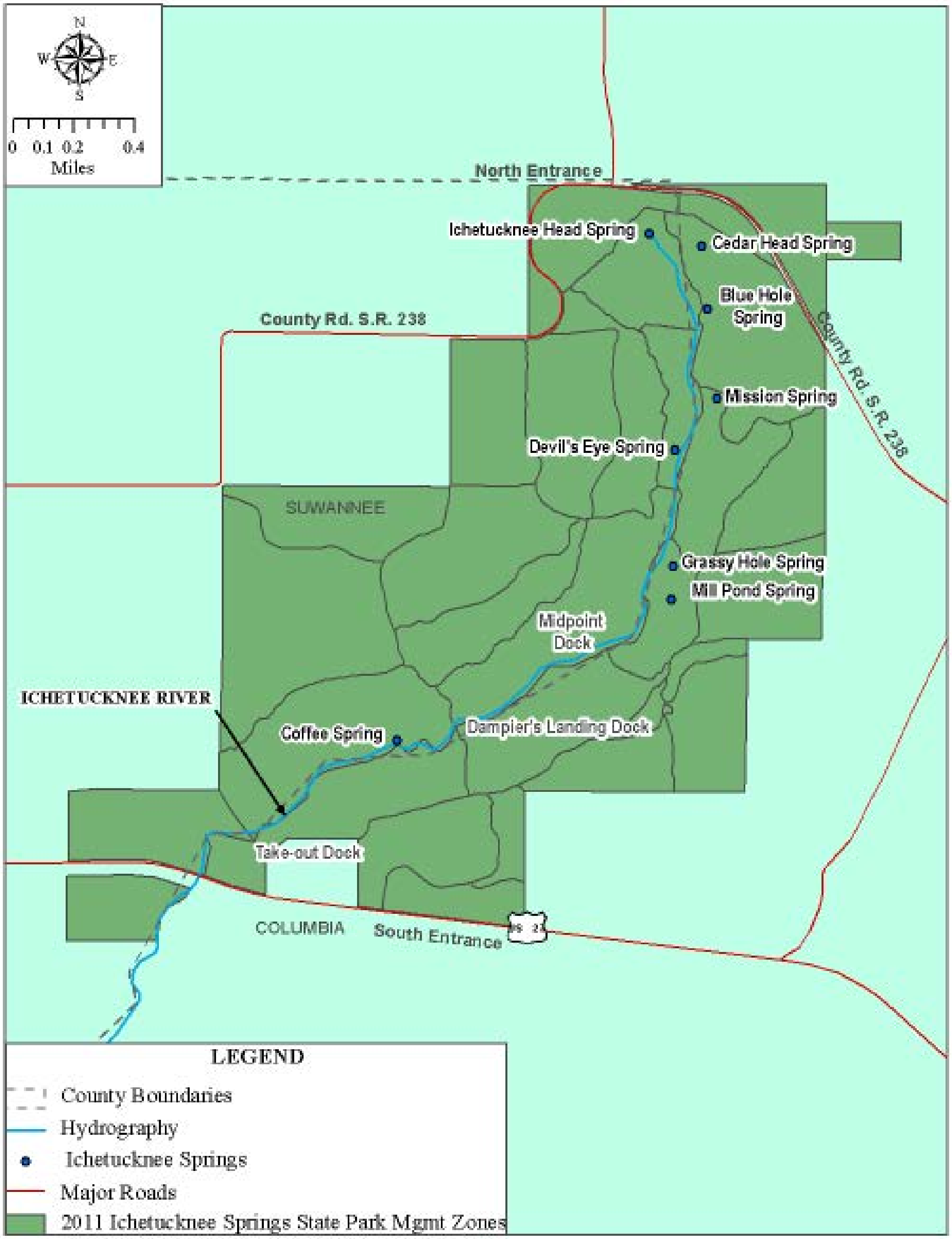


Figure 2-17. Ichetucknee Springs State Park.

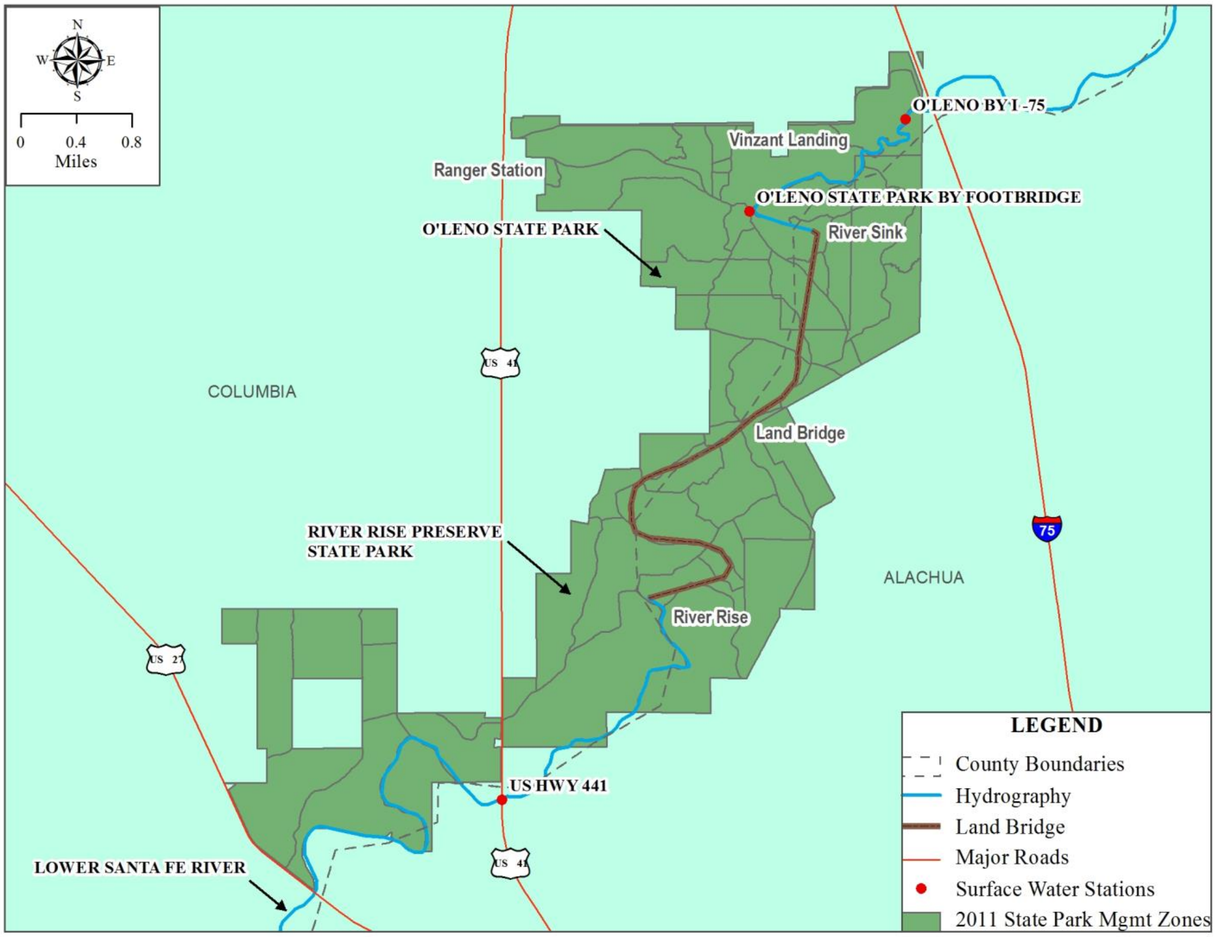


Figure 2-18. O'Leno State Park and River Rise Preserve State Park.

2.4 HYDROLOGY OF THE LOWER SANTA FE RIVER AND ICHETUCKNEE RIVER

The hydrology of the Lower Santa Fe River Basin is markedly influenced by karstic geology. The flows in the river consist of a combination of stormwater runoff and groundwater discharge. The Upper Santa Fe River, above Worthington Springs, is the source of most of the stormwater. The Upper Santa Fe River has prevalent tributaries and well-connected flat swampy areas and lakes.

Downstream of this upper reach, the river flows through a transitional area, with the lower portion of the Santa Fe River having a relative scarcity of tributaries below O'leno State Park and streamflow being dominated by spring discharge. Since the spring flow and a large portion of the river flows are derived from the UFA, they are more susceptible to impacts via groundwater pumping than systems driven by surface water runoff. Historically, there were direct treated wastewater discharges to a Santa Fe River tributary (the New River), but these point sources have been replaced with spray field irrigation.

The river emerges at River Rise State Preserve (near RM 30), downstream of O'leno State Park, and interacts with a series of sinks, rises, and springs for the next 12 miles (Butt, Morris, &

Skiles, 2007). A synoptic flow run in this reach conducted by the USGS on May 4, 2011, documented an increase in flow of approximately 680 cfs from the High Springs gage at the Highway 27 bridge to the Fort White gage and an average gain of 100 cfs per mile during near record low-flow conditions.

In general, the Lower Santa Fe River can be divided into distinct hydrologic regimes (Figure 2-19). From the confluence of the Suwannee River to a physiographic break at about RM 10, the Santa Fe River is often tailwater-controlled, heavily influenced by the stage conditions in the Suwannee River. Suwannee River tailwater influence also extends above the Highway 27 bridge on the Ichetucknee River.

From the Olustee Creek confluence and continuing downstream approximately 40 miles, the Lower Santa Fe River is dominated by interaction with the surrounding karst environment by way of springs, sinks, and resurgences. The upper portion of the Ichetucknee River also has a high degree of groundwater interaction. From upstream of the Olustee confluence to the Worthington Springs gage, the hydrology of the river is generally in transition from a karst-dominated system to one dominated by runoff processes from the surrounding basin.

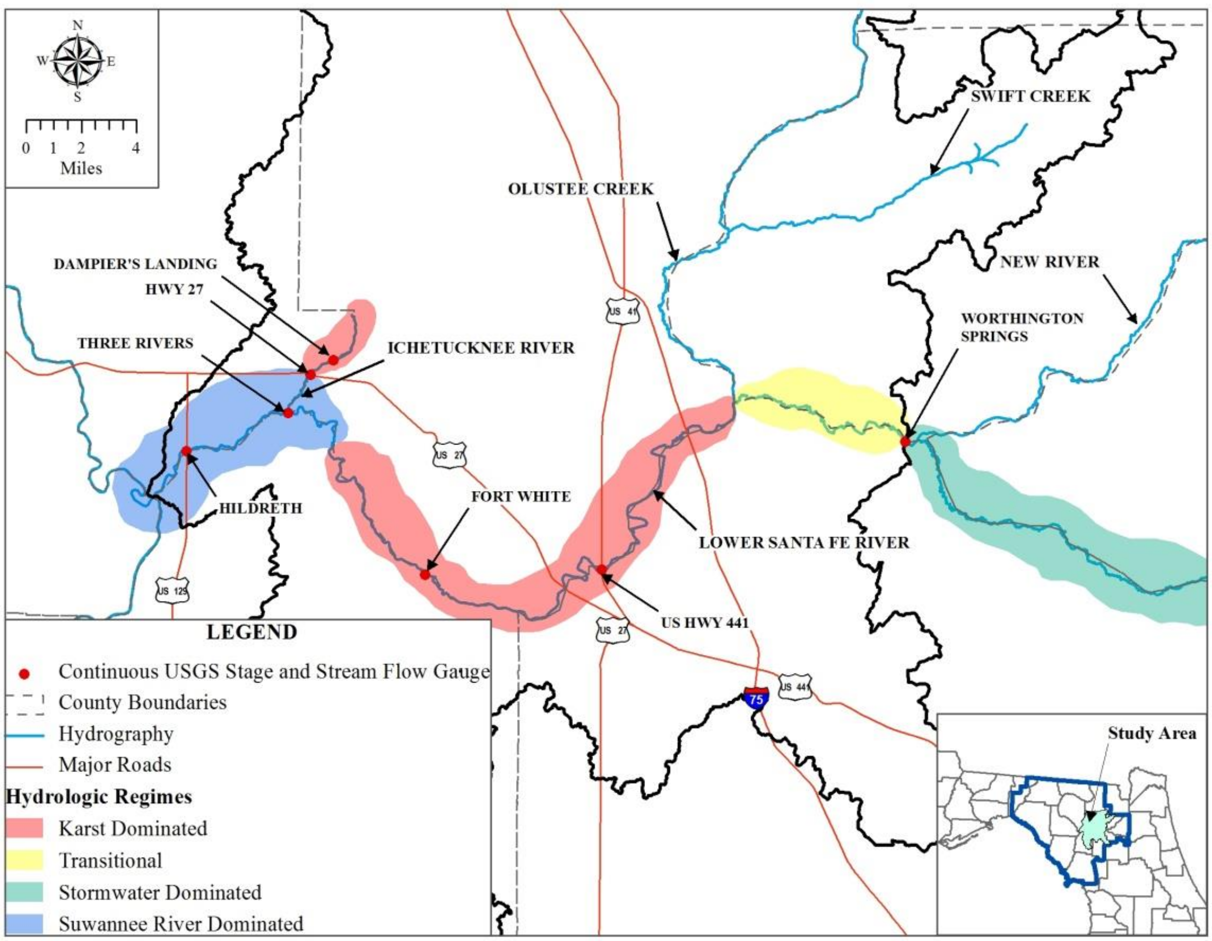


Figure 2-19. Hydrologic regimes of the Santa Fe River and Ichetucknee River basins.

2.4.1 Historical Rainfall Conditions

Ultimately, the source of all flow in the river is precipitation. Since rainfall is a primary explanatory variable that influences the hydrologic response of a region, changes to the relationship between rainfall and streamflow can indicate changes in the relationship between streamflow and other explanatory variables such as water use, impoundments, and land use changes. Of all the explanatory variables which contribute to streamflow, climatic variables such as rainfall offer the most complete historical data set.

Long-term rainfall records from the PRISM Climate Group (Daly, et al., 2008) were available for analysis. Monthly rainfall totals for the conterminous United States on a 4 kilometer (km) grid from 1895 to present were utilized. The PRISM grid cell rainfall monthly totals are based on rainfall from point rain gages similar to gages shown in Figure 2-20 through Figure 2-22.

An initial step in processing the PRISM data into a useful tool was the determination of the contributing area for the various USGS discharge sites. Groundwater contributing areas were delineated from the UFA potentiometric surface maps or existing springshed maps in the case of the Ichetucknee River (Figure 2-22). Figure 2-20 through Figure 2-22 show the combined groundwater and/or surface water contributing area for 3 gages. There interaction between the UFA and the Santa Fe River upstream of the Worthington Springs gage is limited compared to downstream of Worthington Springs. Therefore, the groundwater contributing area was not included in the total contributing area for the Worthington Springs gage (Figure 2-20). Conversely, there is very little surface water that enters the Ichetucknee River. Only the springshed was used in determining the rainfall contributing area for that gage (Figure 2-22). The Fort White gage is a mixture of both runoff from the surface water system and groundwater discharge from the UFA. The rainfall contributing area for the Fort White gage is the combination of the surface water and groundwater basin (Figure 2-21). All figures containing rainfall use the PRISM data as the source for rainfall.

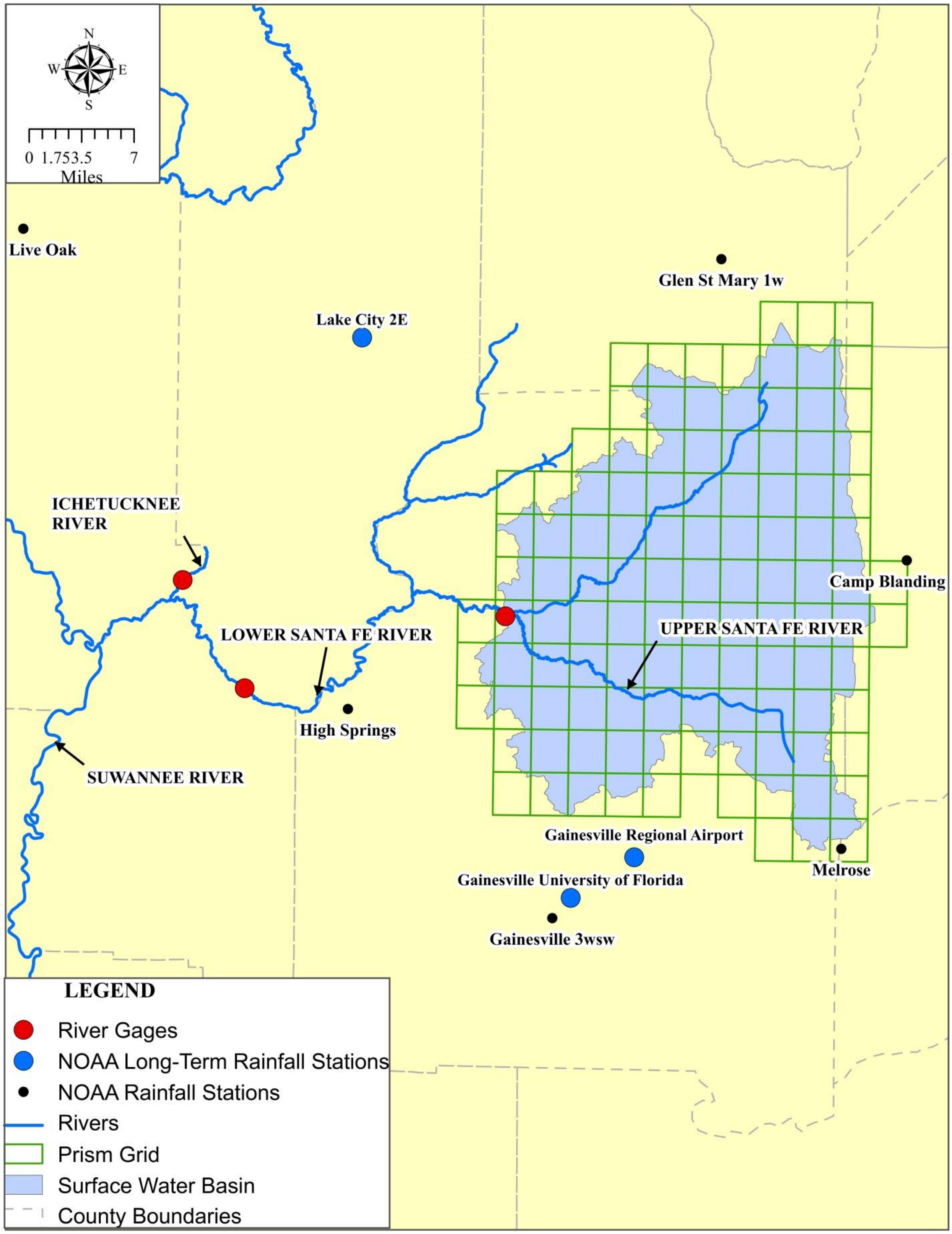


Figure 2-20. PRISM Grid for the Santa Fe River at Worthington Springs surface water basin (02321500).

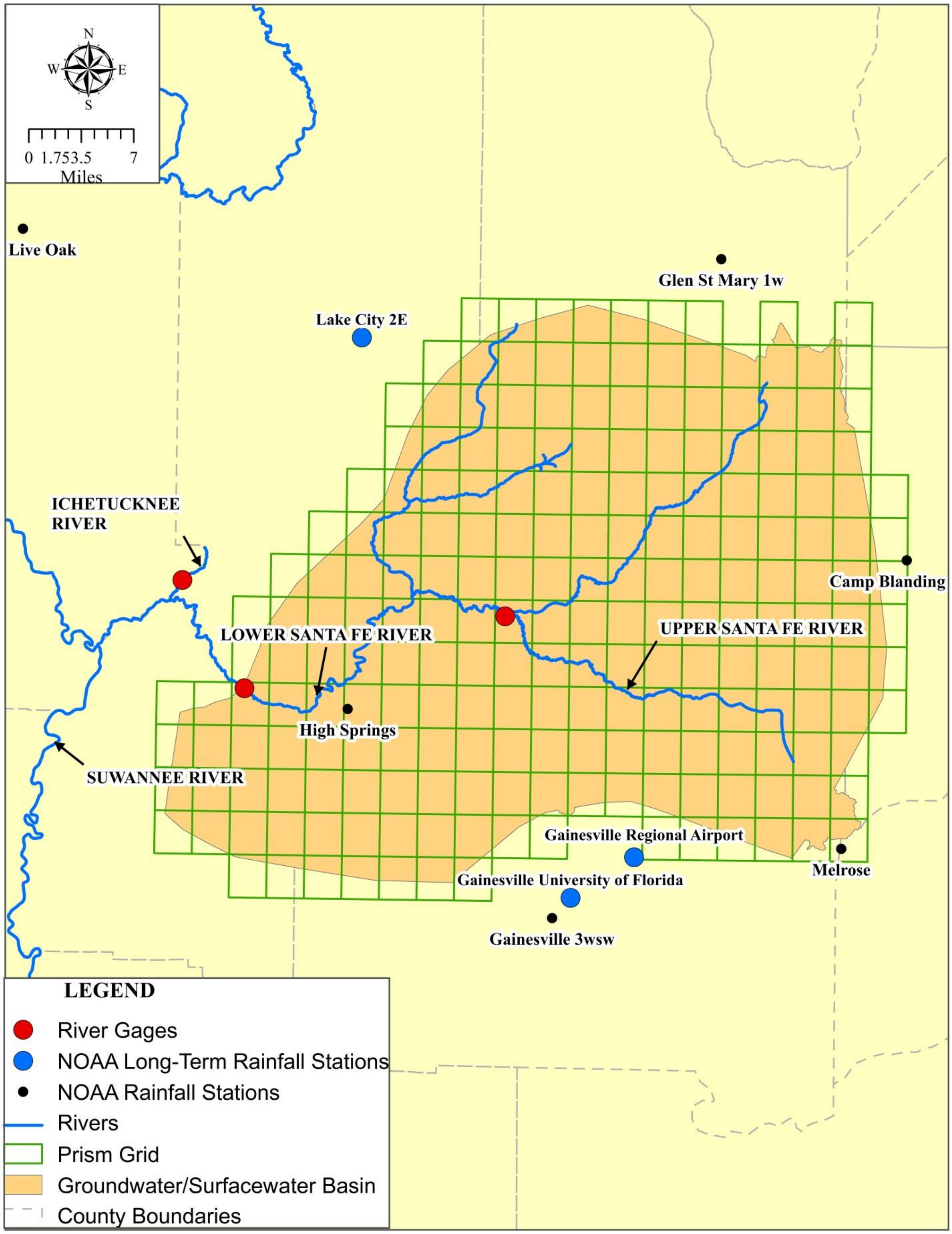


Figure 2-21. PRISM Grid for the Santa Fe River near Fort White combined groundwater and surface water basin (02322500).

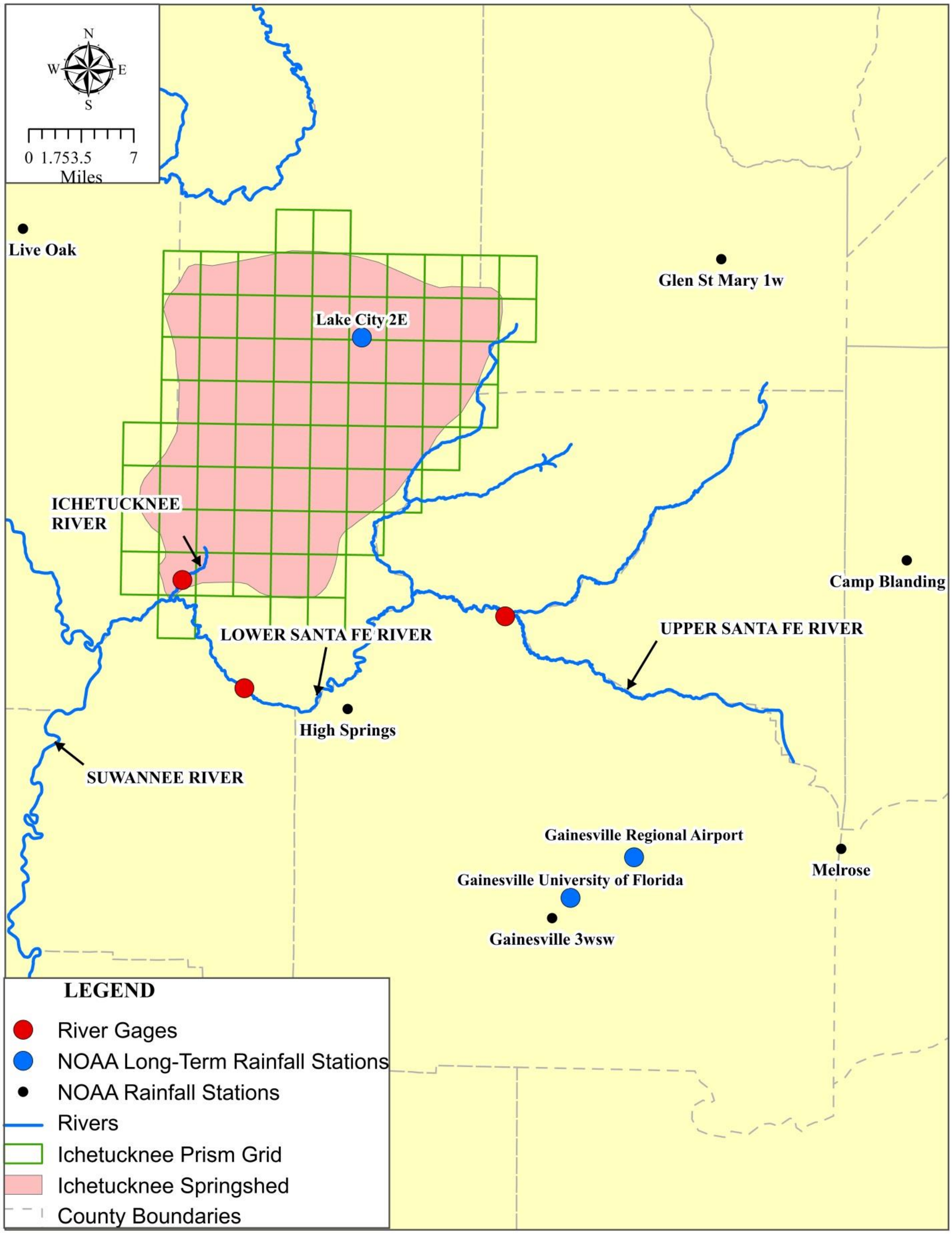


Figure 2-22. PRISM Grid for the Ichetucknee River at Highway 27 groundwater basin (02322700).

Rainfall annual totals for the period 1932 to 2010 for the Worthington Springs gage, Fort White gage, and Ichetucknee River gage contributing areas are shown in Figure 2-23 through Figure 2-25. Inter-annual variability in total rainfall can vary significantly from the annual precipitation average. The Worthington Springs gage contributing area annual (calendar year) rainfall ranges from 35.7 inches (1990) to 70.1 inches (1964). The Fort White gage contributing area annual rainfall varies from 37.3 inches (1990) to 71.5 inches (1964). The Ichetucknee River gage contributing area annual rainfall varies from 35.5 inches (1955) to 82.6 inches (1964).

As shown in Figure 2-26 through Figure 2-28, monthly precipitation is temporally variable for all three contributing areas, with highest monthly totals generally occurring June through September.

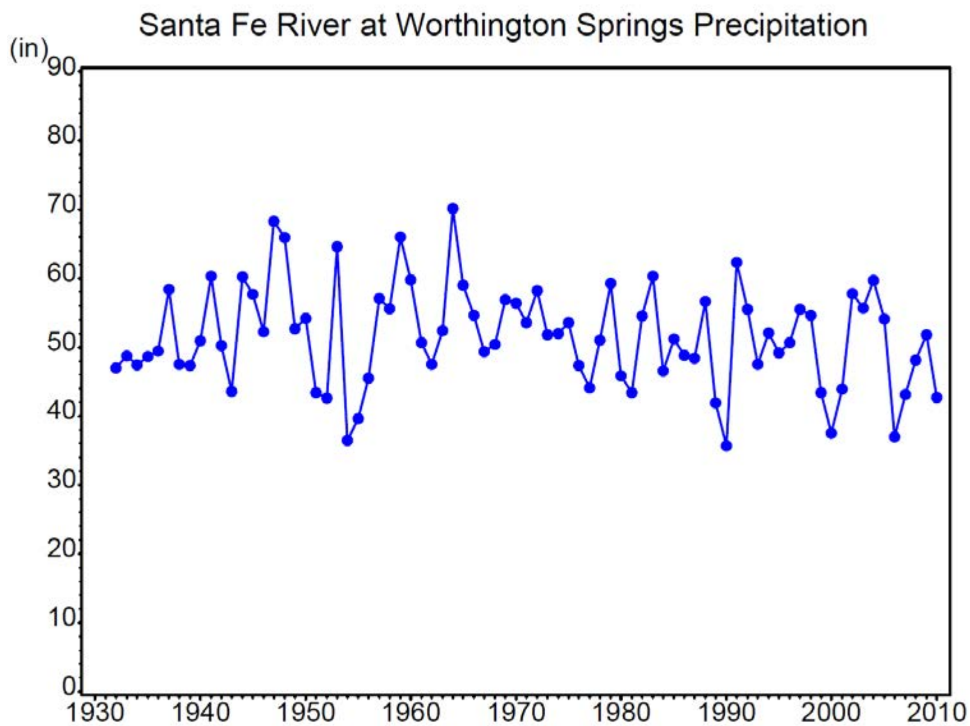


Figure 2-23. PRISM precipitation data for Santa Fe River at Worthington Springs gage (02321500).

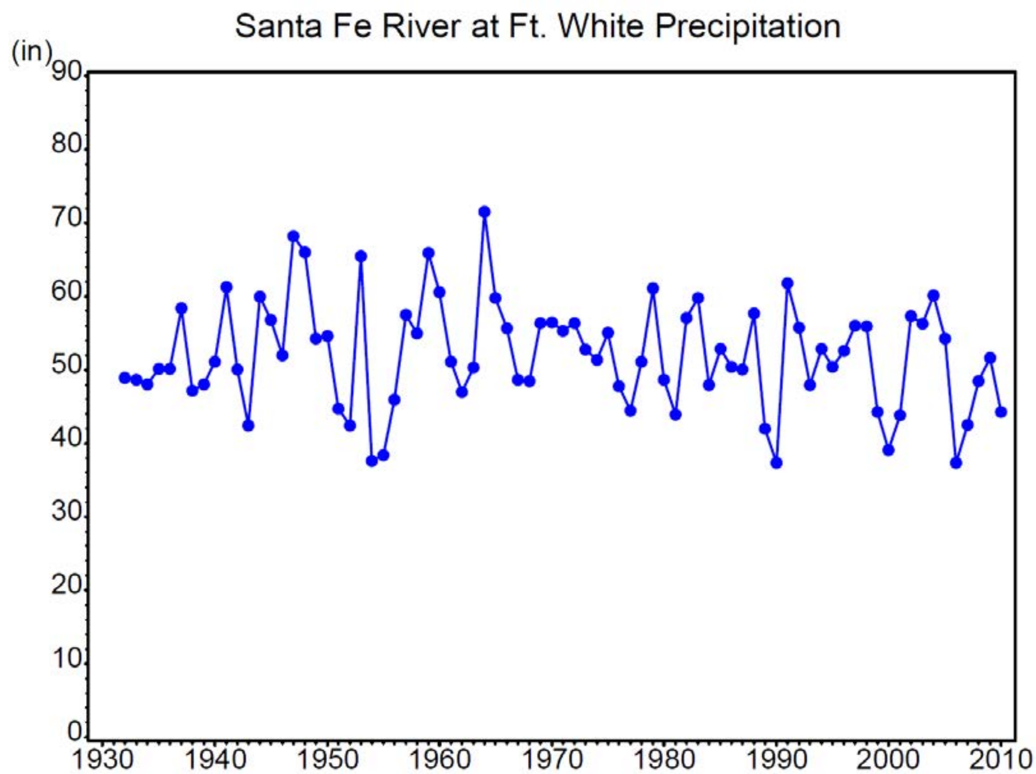


Figure 2-24. PRISM precipitation data for Santa Fe River near Fort White gage (02322500).

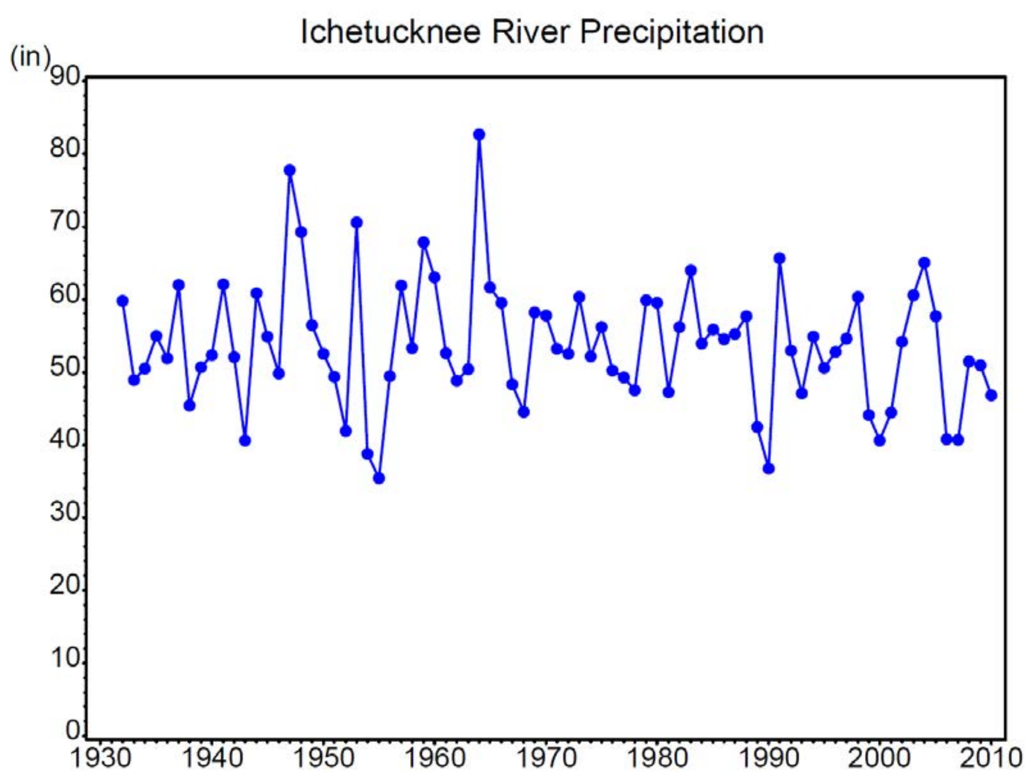


Figure 2-25. PRISM precipitation data for the Ichetucknee River at Highway 27 (02322700).

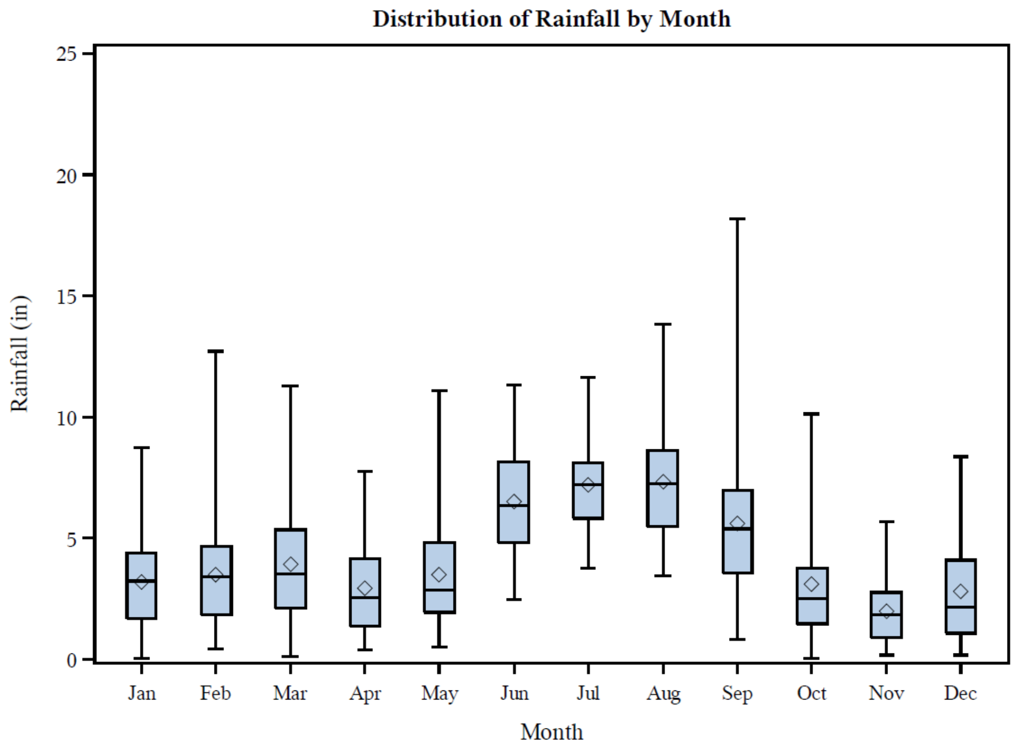


Figure 2-26. Distribution of rainfall by month for PRISM data at the Santa Fe River at Worthington Springs gage (02321500).

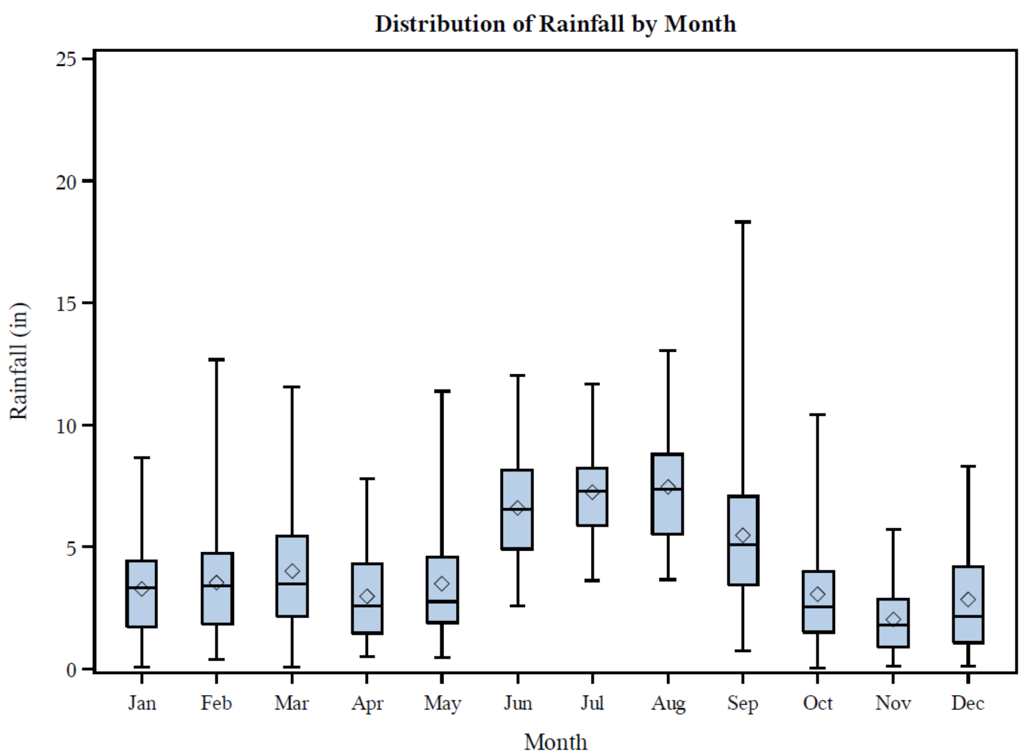


Figure 2-27. Distribution of rainfall by month for PRISM data at the Santa Fe River near Fort White gage (02322500).

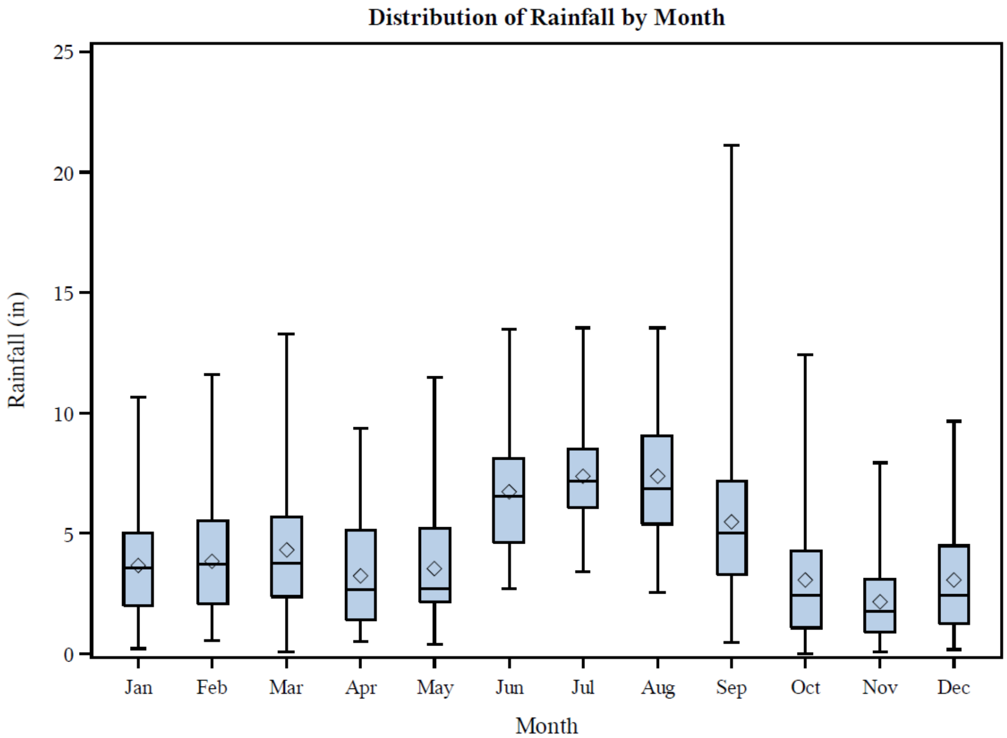


Figure 2-28. Distribution of rainfall by month for PRISM data at the Ichetucknee River at Highway 27 (02322700).

2.4.2 Existing Surface Water Data

RIVERS

Flow and stage data are available from several sources, including the District and the USGS. Available observed data for stage and flow are shown in Table 2-3 and Table 2-4, respectively. Gaging sites within the Lower Santa Fe River and Ichetucknee River are shown in Figure 2-29.

A comprehensive database of flow and stage for the Lower Santa Fe and Ichetucknee rivers was developed using these time series and used for all further analysis, including MFL establishment. As shown in Table 2-4, several stations (Suwannee River at Branford, Santa Fe River at Worthington Springs, and Santa Fe River at Fort White) contain long-term (~80 years) flow records with minor data gaps (<3%). These three sites are key locations in a gap filling and record extension process used to expand usefulness of multiple partial record sites. A detailed discussion on pre-processing of the data and database development can be found in Section 4.0.

Table 2-3. Period of gage height data at selected gaging stations.

Station ID	Station Name	Minimum Date	Maximum Date	Number of Observations	Period of Record (years)	Percent Complete
02320000	Suwannee River at Luraville, FL	10/1/1927	9/30/2011	9,120	84.0	29.7%
02320500	Suwannee River at Branford, F	7/9/1931	9/30/2011	29,188	80.2	99.6%
02321500	Santa Fe River at Worthington Springs, FL	11/18/1931	9/30/2011	27,478	79.9	94.2%
023218982	Santa Fe River at O'Leno State Park by Footbridge - District Gage	3/12/1980	11/30/2011	8,682	31.7	74.9%
02321898	Santa Fe River at O'Leno State Park	6/8/2010	9/30/2011	480	1.3	100.2%
02321975	Santa Fe River at Highway 441 near High Springs, FL	11/2/2002	9/30/2011	3,252	8.9	99.9%
02322500	Santa Fe River near Fort White, FL	10/1/1927	9/30/2011	25,368	84.0	82.7%
02322698	Ichetucknee River at Dampier's Landing near Hildreth, FL	2/15/2002	9/30/2011	3,302	9.6	94.0%
02322700	Ichetucknee River at Highway 27 near Hildreth, FL	1/23/1931	9/30/2011	3,930	80.7	13.3%
02322703	Santa Fe River at Ichetucknee River near Hildreth, FL	10/24/1998	9/30/2011	2,361	12.9	50.0%
02322800	Santa Fe River near Hildreth, FL	4/28/1947	9/30/2011	17,917	64.4	76.1%
02323000	Suwannee River near Bell, FL	6/1/1932	9/30/2011	13,343	79.3	46.1%

Table 2-4. Period of record of flow data at selected gaging stations.

Station ID	Station Name	Minimum Date	Maximum Date	Number of Observations	Period of Record (years)	Percent Complete
02320000	Suwannee River at Luraville, FL	10/1/1927	4/4/2011	9,048	83.5	29.7%
02320500	Suwannee River at Branford, FL	7/1/1931	3/29/2011	29,126	79.7	100.0%
02321500	Santa Fe River at Worthington Springs, FL	10/1/1931	11/21/2011	29,272	80.1	100.0%
023218982	Santa Fe River at O'Leno State Park at Footbridge - District Gage	10/1/1997	9/30/2009	3,806	12.0	86.9%
02321975	Santa Fe River at Highway 441 near High Springs, FL	10/1/1992	9/13/2010	6,419	17.9	97.9%
02322500	Santa Fe River near Fort White, FL	10/1/1927	11/21/2011	29,880	84.1	97.2%
02322698	Ichetucknee River at Dampier's Landing near Hildreth, FL	2/15/2002	4/3/2011	3,205	9.1	96.1%
02322700	Ichetucknee River at Highway 27 near Hildreth, FL	1/23/1931	4/4/2011	3,786	80.2	12.9%
02322800	Santa Fe River near Hildreth, FL	11/1/2000	11/21/2011	3,308	11.1	81.9%
02323000	Suwannee River near Bell, FL	6/1/1932	3/29/2011	12,869	78.8	44.7%

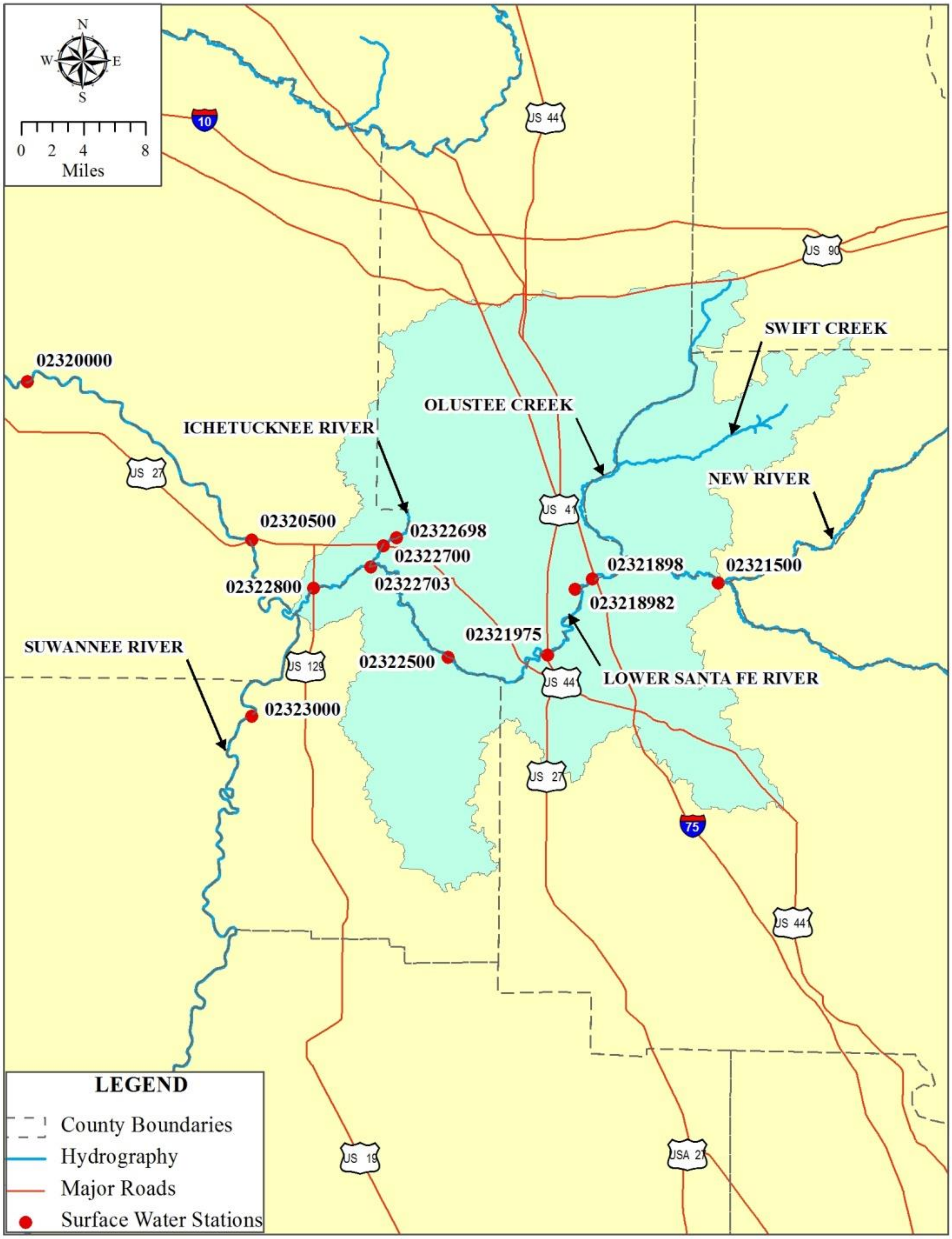


Figure 2-29. Location map of surface water gaging stations.

Basic statistics for the existing time series for selected Santa Fe and Ichetucknee stations are shown in Table 2-5. As shown, the Santa Fe River near Hildreth station experienced a flow reversal, resulting in a minimum flow of -1,070 cfs and was a result of high stages in the Suwannee River. Flows at the two Ichetucknee stations are very similar to each other. Since Dampier's Landing is upstream of Highway 27, it would be expected that the mean and median flows at Dampier's Landing would be slightly less than those at Highway 27. Instead, a flow loss from upstream to downstream exists in the observed record. These sites are maintained by the USGS. The most likely cause of the loss of flow was from bias in the measurements at the upstream site. All the upstream sites (above Highway 27) have a rating of poor due to additional error attributed to vegetation in the area of measurement. The only site without a significant amount of vegetative interference is Station 02322700 (Highway 27). Therefore, Station 02322700 (Highway 27) best approximates the actual flow in the Ichetucknee River (Rau, 2012).

Table 2-5. Selected Santa Fe and Ichetucknee stations: filled time series basic statistics.

USGS Station Number	Station Name	Mean (cfs)	Median (cfs)	Maximum (cfs)	Minimum (cfs)
02321500	Santa Fe River at Worthington Springs	404	120	19,000	0
02321975	Santa Fe River at Highway 441	497	280	9,150	0
02322500	Santa Fe River near Fort White, FL	1,497	1,240	16,900	342
02322698	Ichetucknee River near Dampier's Landing	314	298	609	138
02322700	Ichetucknee River Highway 27 near Hildreth, FL	305	296	578	124
02322800	Santa Fe River near Hildreth, FL	1,482	1,170	9,710	-1,070

Using the existing time series for each station, the month-to-month flow variability was characterized. Average monthly flow by river for a number of gages is shown in Figure 2-30, through Figure 2-32. As shown, the Suwannee River exhibits higher flow in the late winter and early spring (February, March and April), while the Santa Fe River exhibits bi-modal behavior, with two peak periods per year. The Ichetucknee River exhibits highest flows in May. The plotted data in Figure 2-32 are from the limited period of record shown in Table 2-3; long-term data may demonstrate a different pattern and means.

The presence of a climatic river basin divide in Florida has been observed by others (Heath & Conover, 1981). The location of the divide, shown in Figure 2-33, approximates the western and northern sub-basin boundaries of the Santa Fe River. Streams north and west of the divide (such as the selected Suwannee River gages) are characterized by high flows in the late winter and early spring and low flows in the late spring and fall. Streams lying south of the divide exhibit high flows in the late summer and fall, and low flows in the spring. Streams along the divide (i.e., the Santa Fe River) tend to exhibit a bi-modal pattern, with high flow in both the spring and fall. The Ichetucknee River, also along the boundary, is also influenced by significant springflow and therefore groundwater storage.

Rainfall is a major contributor to these seasonal flow patterns, with the Suwannee River Basin being more influenced by continental rainfall which is frontal in nature. The Lower Santa Fe River Basin is influenced by both the frontal activity typical of continental rainfall and the convective activity typical of peninsular Florida.

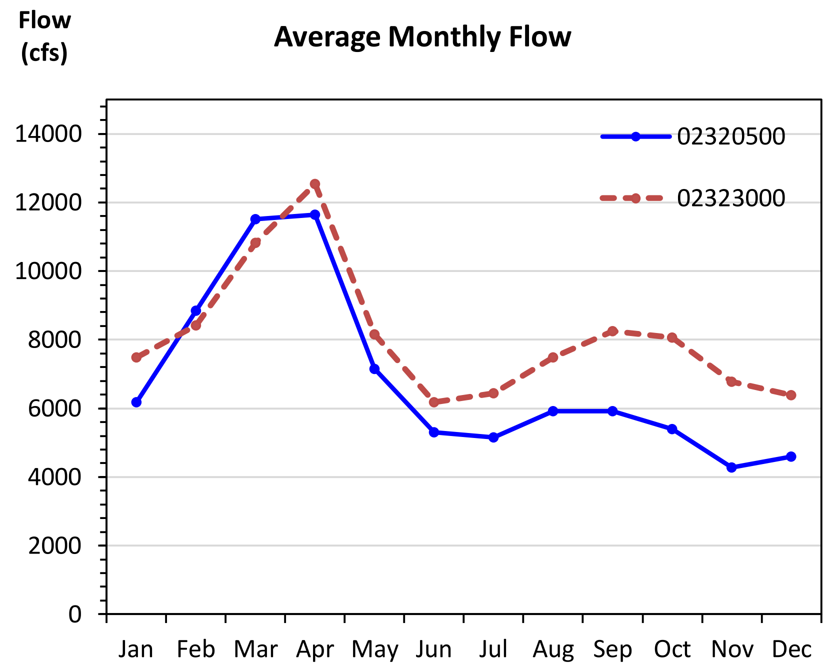


Figure 2-30. Mean monthly flows at USGS gage sites on the Suwannee River. Selected sites are 02320500 (Suwannee River at Branford) and 2323000 (Suwannee River near Bell).

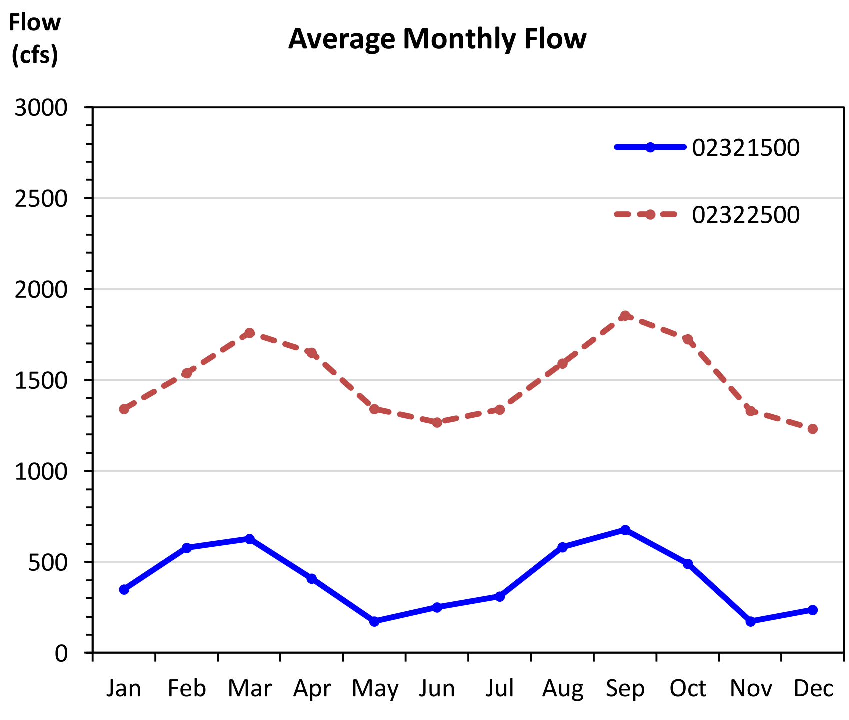


Figure 2-31. Mean monthly flow at USGS gage sites on the Lower Santa Fe River.
Selected sites are 02321500 (Santa Fe River at Worthington Springs) and 2322500 (Santa Fe River near Fort White).

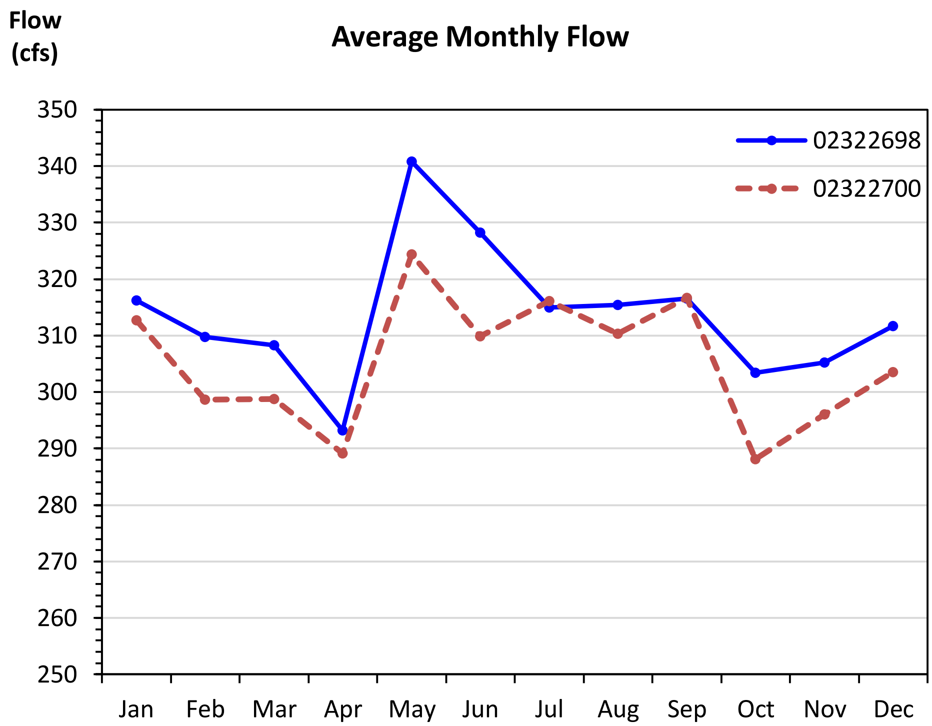


Figure 2-32. Mean monthly flow at USGS gage sites on the Ichetucknee River. Selected sites are 02322698 (Ichetucknee River near Dampier's Landing) and 02327000 (Ichetucknee River at Highway 27).

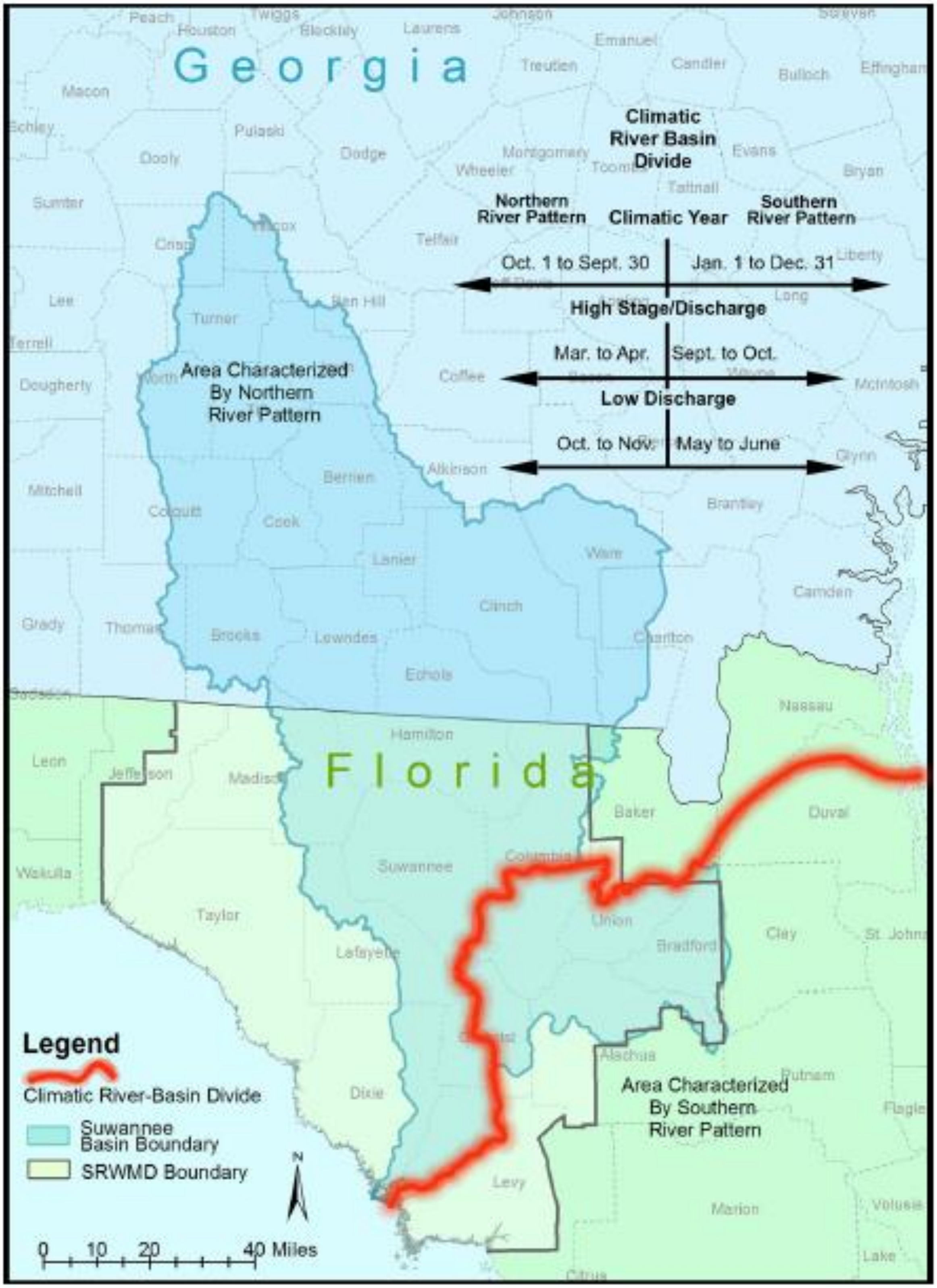


Figure 2-33. Climatic river-basin divide (Heath & Conover, 1981). River pattern data from (Kelly M. , 2004).

PRIORITY SPRINGS

The available priority spring discharge data are given in Table 2-6; spring locations are shown in Figure 2-34. Table 2-6 documents the minimal discharge data available at most priority springs. Discharge data at individual springs range from as little as 1 measurement per spring to as much as 3,930 measurements per spring. The latter are sites instrumented for daily data in February 2002 as part of a statewide Springs Monitoring Network, which began in 2001 when the Florida Legislature first provided funding for the Florida Springs Initiative. However, most site measurements are not only infrequent but also heavily weighted to the more recent time period. Therefore, available springs discharge data does not provide a good source for determining historical flow conditions at the priority springs or for establishing MFLs. See Appendix 2-2 for a more detailed discussion of available data at priority springs.

Table 2-6. Summary of discharge measurements at MFL Priority Springs.

Spring	Median Discharge (cfs)	Number of Measurements
Santa Fe Rise	395	58
Treehouse	103	45
Hornsby	51	98
Columbia	49	49
Poe	46	117
COL101974	10	1
Rum Island	14	15
July	58	3
Devil's Ear (Ginnie Group)	120	1
Siphon Creek Rise	245	2
Ichetucknee Head	46	3,135
Blue Hole	108	3,930
Mission	88	3,006
Devil's Eye	48	3,115
Grassy Hole	6.5	2
Mill Pond	24	3,077

Figure 2-34. Location of MFL Priority Springs.

2.4.3 Water Use

Water use is the rationale for the establishment of MFLs. Chapter 373.042, F.S. states that a MFL "*shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.*" Understanding the magnitude and location(s) of this component of north Florida's hydrology is important for understanding the establishment of MFLs for the Santa Fe Basin. Due to the connectedness of the basins groundwater and surface water systems, groundwater use is the most likely means of affecting the Lower Santa Fe and Ichetucknee rivers and springs. With one noted exception (Figure 2-35), all the figures and tables in this section are based on groundwater uses only. Surface water withdrawals are estimated to be less than one percent of total use in the District after accounting for once-through cooling (where the water withdrawn from a surface waterbody is returned to the same system after use).

This section presents several views of water use in the region. Presented first is information on water use within the District and the smaller area of the Lower Santa Fe Basin, both as permitted allocations (as of 2012) and estimates of actual water use. It should be noted that permitted and actual use are not synonymous. Water use permits are issued on a statistical basis such that the water allocations on the permit allow reasonable use under drought conditions as well as during more typical years (F.A.C. 40B-2). As such, water allocations, especially for agriculture, usually represent larger amounts of water than are actually used in most years. Second, a regional view of water use is included here because of the potential for cross-boundary impacts on the Lower Santa Fe Basin. The perspective is broadened to encompass estimates of actual water use within the North Florida Regional Water Supply Partnership (NFRWSP) area. All estimates of actual water use are based on USGS draft estimates for 2010 (Marella, 2013).

Existing permitted water allocations within the District, inside and outside of the Lower Santa Fe River basin is shown spatially in Figure 2-35. The uses in Figure 2-35 include both surface water and groundwater permits. Agricultural irrigation is currently the largest single water use type permitted in the District (see Table 2-8).

Table 2-7 shows a summary of permitted water allocations in the District and the Lower Santa Fe River basin for all use types. Permitted water allocations in the District total 872 million gallons per day (mgd), which equates to about 1,350 cfs. Permitted water allocations in the Lower Santa Fe River basin are 35.78 mgd, which equates to about 55 cfs. The Lower Santa Fe area encompasses 4.1% of the existing permitted groundwater allocation in the District.

Table 2-7. Summary of existing permitted groundwater allocation by region in 2012.

Region	Permitted Water Allocation (mgd)	Percent of Permitted Water Allocation
Inside the Lower Santa Fe Basin	35.78	4.1%
Outside of the Lower Santa Fe Basin	836.57	95.9%
District Total	872.35	100.0%

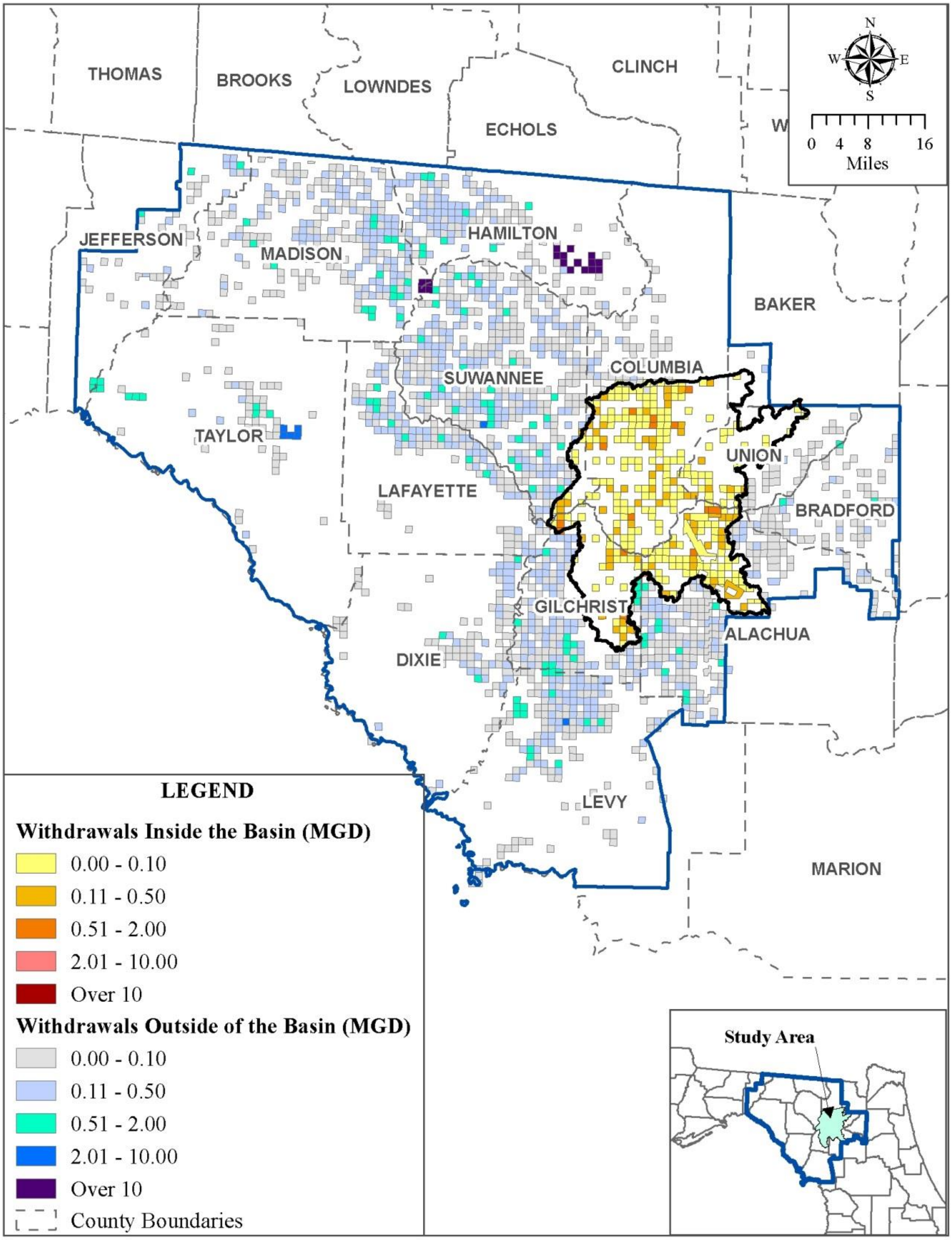


Figure 2-35. Existing permitted allocations.
Note: Surface water and groundwater within the District: inside and outside of the Lower Santa Fe River Basin (data as of 2012).

Estimated actual groundwater withdrawals by category for the District, based on Marella (2013) are shown in Figure 2-36 and Table 2-8. As noted previously, permitted amounts and estimates of actual use in any given year are typically different. The totals presented include estimates for the following counties: Alachua, Baker, Bradford, Columbia, Dixie, Gilchrist, Hamilton, Jefferson, Lafayette, Levy, Madison, Suwannee, Taylor, and Union. All counties that were included in this analysis were located at least partially within District boundaries.

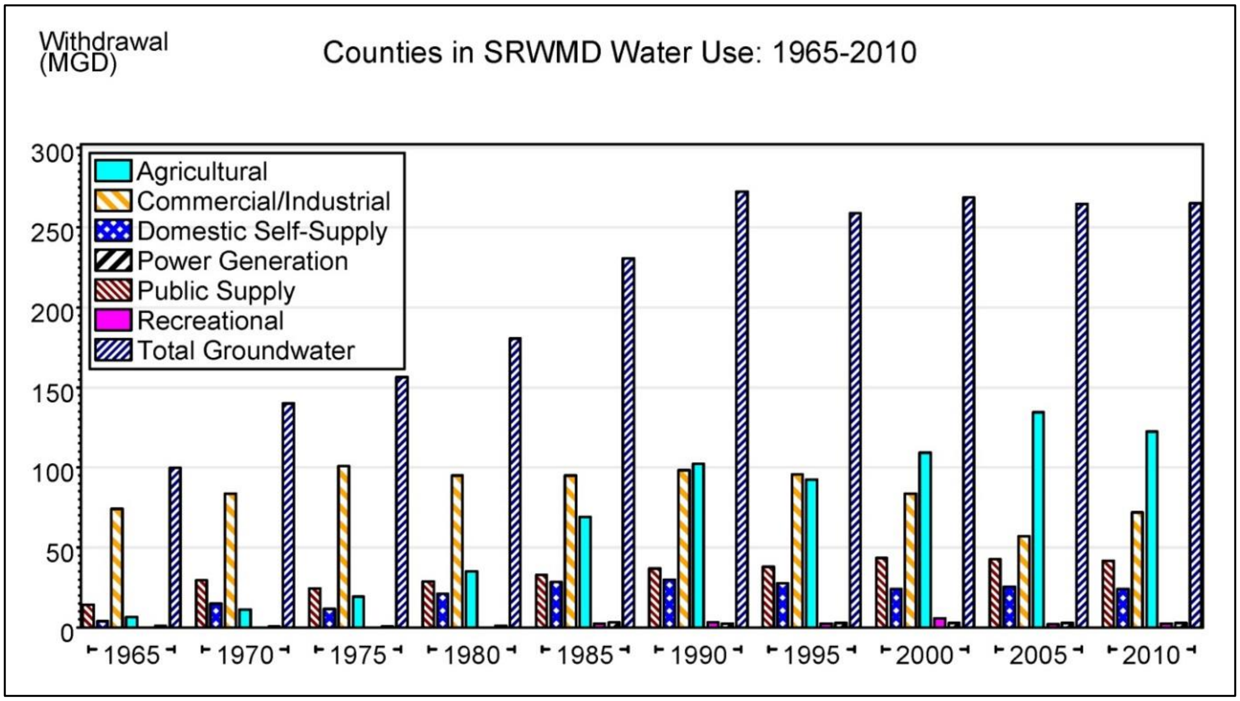


Figure 2-36. Estimated actual groundwater withdrawals by category in District counties. Based on (Marella, 2013).

As shown, commercial and industrial uses are a large component of total groundwater withdrawals. Agricultural use, which has generally been increasing since 1965, also accounts for a large portion of total groundwater withdrawals. Groundwater withdrawals by category for the counties within the Santa Fe Basin, based on Marella (2013), are shown in Table 2-9 and Figure 2-37. In recent years (2005 and 2010), agricultural use has comprised approximately half of the groundwater withdrawals. Public supply is generally the second highest groundwater withdrawal in the Lower Santa Fe Basin.

Table 2-8. Estimated actual groundwater withdrawals by category in the District
Note: Based on (Marella, 2013). All values in million gallons per day (mgd).

Year	Groundwater Withdrawals						
	Public Supply	Domestic Self-Supply	Commercial/ Industrial	Agricultural	Recreational	Power Generation	Total Ground Water
1965	14.05	4.04	74.17	6.57	0.00	1.09	99.92
1970	29.56	14.99	83.70	11.31	0.00	0.54	140.10
1975	24.53	11.54	100.85	19.17	0.00	0.51	156.60
1980	28.62	21.12	95.03	35.07	0.00	0.94	180.78
1985	32.84	28.39	94.98	69.10	2.27	3.34	230.92
1990	36.71	29.78	98.42	102.15	3.05	2.48	272.59
1995	38.07	27.79	95.57	92.52	2.34	2.67	258.96
2000	43.42	24.18	83.70	109.22	5.76	2.69	268.97
2005	42.75	25.58	56.79	134.69	2.21	2.77	264.79
2010	41.72	24.01	71.78	122.48	2.40	2.65	265.04

Table 2-9. Estimated actual groundwater withdrawals by category for counties within the Santa Fe Basin.
Note: Counties include: Alachua, Bradford, Columbia, Gilchrist, Suwannee, and Union. Based on (Marella, 2013). All values in million gallons per day (mgd).

Year	Groundwater Withdrawals						
	Public Supply	Domestic Self-Supply	Commercial/ Industrial	Agricultural	Recreational	Power Generation	Total Ground water
1965	10.95	2.36	13.85	3.60	0.00	1.08	31.84
1970	25.50	11.30	10.50	7.36	0.00	0.54	55.20
1975	19.49	8.32	13.03	8.86	0.00	0.51	50.21
1980	23.23	15.83	7.42	27.85	0.00	0.94	75.27
1985	26.77	19.71	9.09	38.32	2.07	3.34	99.30
1990	29.75	20.36	6.26	57.30	2.49	2.48	118.64
1995	30.31	17.13	7.46	51.21	1.58	2.67	110.36
2000	35.34	14.88	6.29	60.36	4.84	2.69	124.40
2005	34.70	17.36	5.35	63.01	1.29	2.77	124.48
2010	33.38	14.03	4.52	58.93	1.63	2.65	115.14

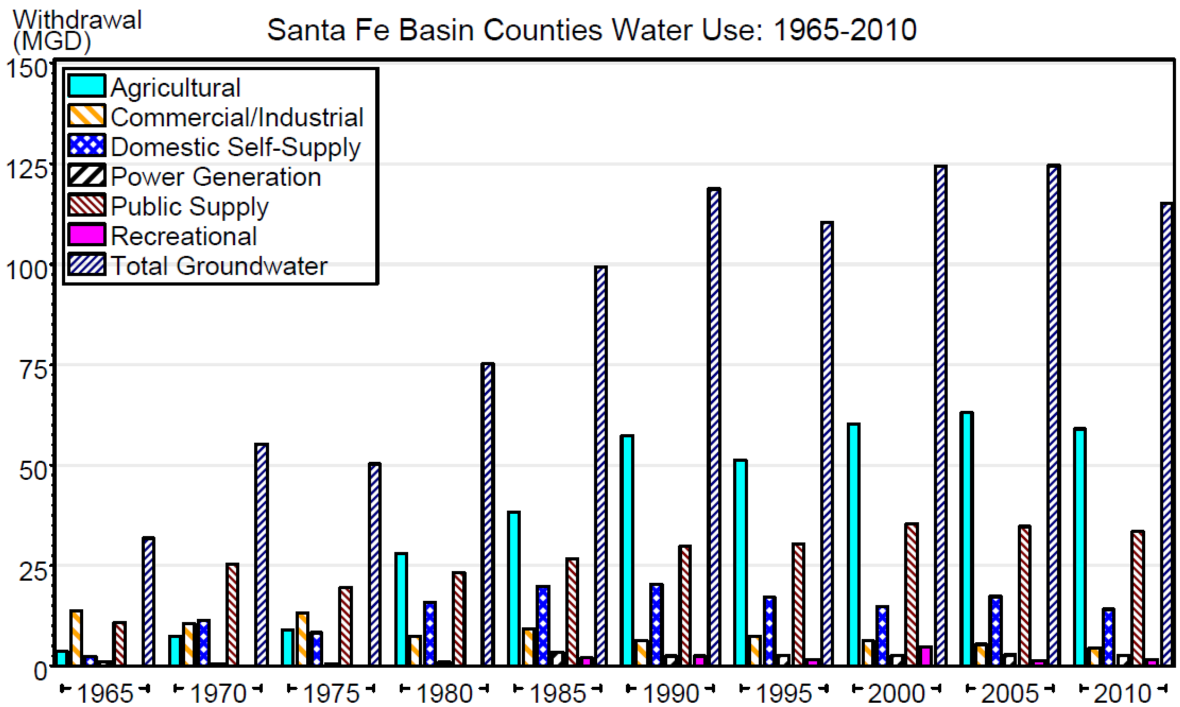


Figure 2-37. Estimated actual groundwater withdrawals by category in counties within the Santa Fe basin
Note: Based on (Marella, 2013).

As noted in Section 1.0 of this report, the effects of groundwater pumping on surface water systems can be significant, whether the wells are located near the water body, or outside the watershed. The NFRWSP was created, at least in part, with this reality in mind. Figure 2-38 shows the area encompassed within the NFRWSP and the 2010 water use by county. Table 2-10 presents the total estimated use in the District over time. This same information is presented graphically in Figure 2-39. The map and data indicate that the region has experienced growth in estimated water use over time. The growth rates for water use averaged between 8 to 10 mgd per year through 1990, and stabilized thereafter.

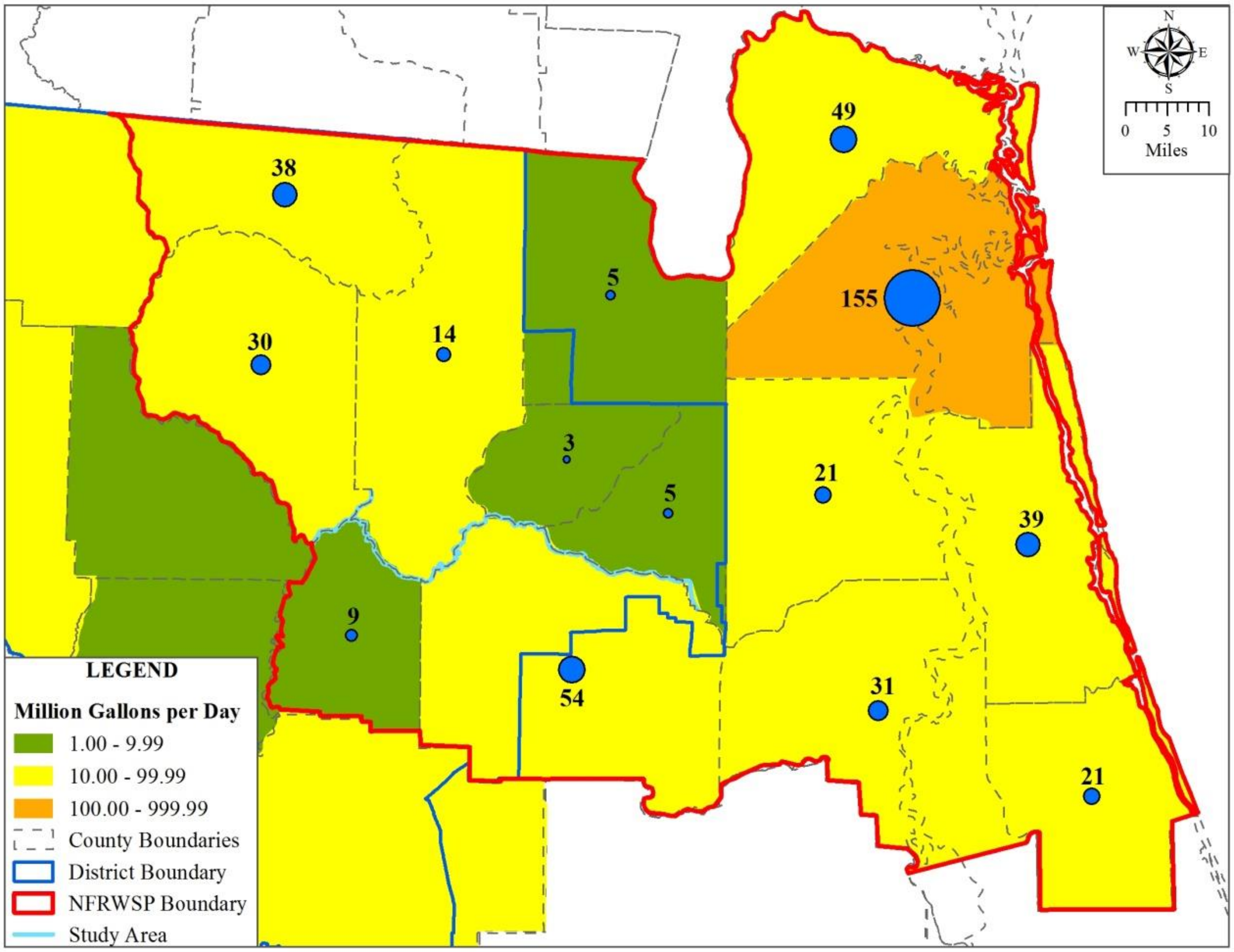


Figure 2-38. Estimated actual groundwater withdrawals in the District and in counties within the NFRWSP boundary.
Note: Based on (Marella, 2013). The NFRWSP region includes the eastern portion of the SRWMD and the northern portion of the SJRWMD.

Table 2-10. Estimated actual groundwater withdrawals within the NFRWSP boundary
Note: Based on (Marella, 2013). The NFRWSP region includes the SRWMD area.

Year	Groundwater Withdrawals (mgd)	
	SRWMD	NFRWSP Counties
1965	100	259
1970	140	374
1975	157	412
1980	181	431
1985	231	503
1990	273	534
1995	259	478
2000	269	533
2005	265	505
2010	265	488

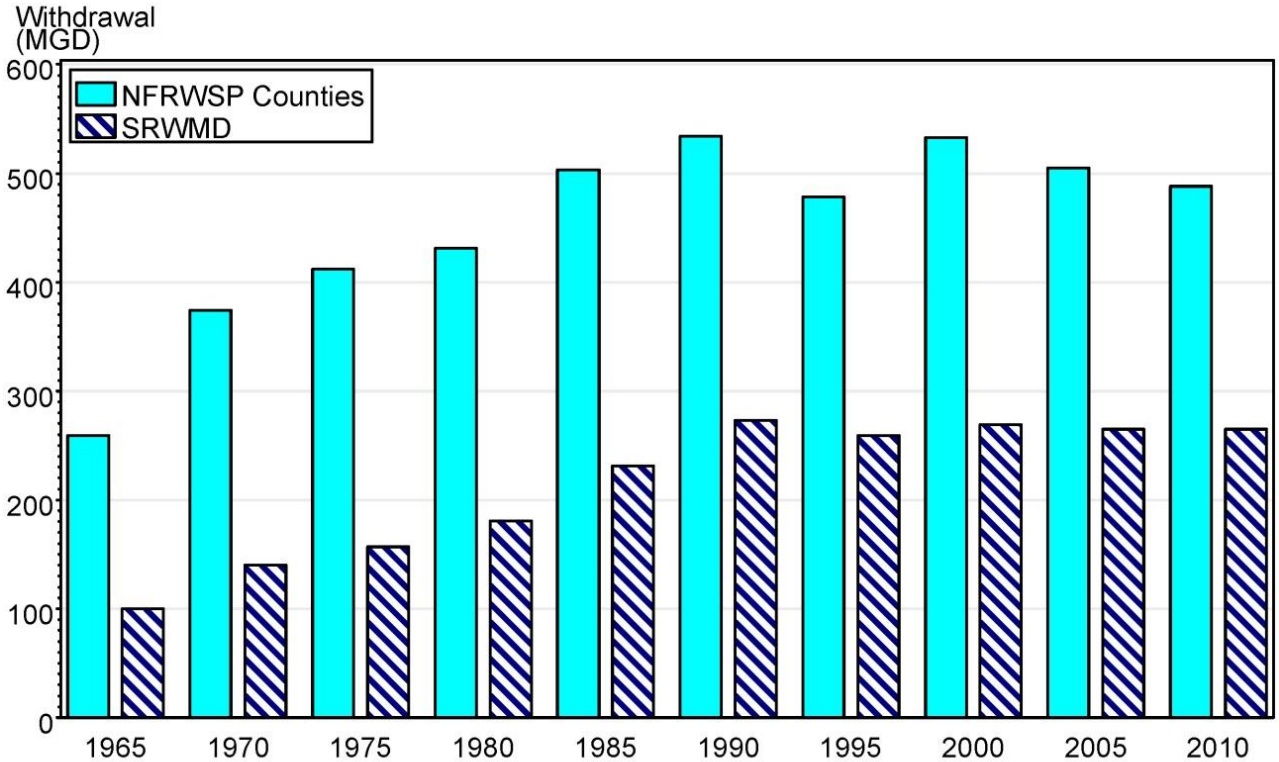


Figure 2-39. Groundwater withdrawals in the District and in counties within the NFRWSP boundary
Note: Based on (Marella, 2013). The NFRWSP region includes the SRWMD area.

3.0 CONCEPTUAL MODEL AND APPROACH TO THE ESTABLISHMENT OF MFLS

To be an effective water resource management tool, the establishment of MFLs must consider protection of the entire flow regime and not strictly low flow conditions. Thus, in some ways the term “minimum flow and level” may be a misleading.

The importance of protecting the full flow regime has been recognized by others and is reflected by multiple MFLs being set for various waterbodies. This became most apparent in cases where inline reservoirs could significantly affect both the low flow and high flow extremes. Richter, et al. (1996) concluded that both intra- and inter-annual variations in flow should be protected, thus, mimicking the natural flow regime. Postel and Richter (2003) also emphasized the critical nature of flood events in terms of both frequency and duration.

Stalnaker (1990) discussed the influence of flows on physical processes (e.g., sediment transport, channel formation) which, in turn, affect biological resources. This linkage was also apparent to Hill, et al. (1991) who identified four types of flows that should be considered when examining river flow requirements, both for in-stream and out-of-bank floodplain habitats:

- flood flows that determine the boundaries of and shape floodplain and valley features;
- overbank flows that maintain riparian habitats;
- in-channel flows that keep immediate streambanks and channels functioning; and
- in-stream flows that meet critical biota requirements.

Therefore, establishment of MFLs considers more than the species-specific needs of any particular taxon. Rather, broad ecological functions are included. As discussed in Section 1.0, the State Water Resources Implementation Rule regarding MFLs (Chapter 62-40.473, F.A.C.) indicates that *“. . . consideration shall be given natural seasonal fluctuations in water flows or levels, non-consumptive uses, and environmental values associated with coastal, estuarine, aquatic, and wetlands ecology. . .” These environmental and water resource values (WRVs) may include:*

- *recreation in and on the water,*
- *fish and wildlife habitats and the passage of fish,*
- *estuarine resources,*
- *transfer of detrital material,*
- *maintenance of freshwater storage and supply,*
- *aesthetic and scenic attributes,*
- *filtration and absorption of nutrients and other pollutants,*
- *sediment loads,*
- *water quality, and*
- *navigation.*

The following section discusses each of these WRVs.

3.1 WATER RESOURCE VALUES CONSIDERED IN THE ESTABLISHMENT OF MFLS

The following paragraphs discuss the WRVs for the Lower Santa Fe and Ichetucknee rivers.

3.1.1 Recreation In and On the Water

This WRC is considered relevant to the Lower Santa Fe River and the Ichetucknee River, and particularly the contributing springs. The Outstanding Florida Water designation of the rivers is, in part, based on the recreational significance of the system (Rule 62-302.700 F.A.C.). Uses include swimming, boating, diving, recreational fishing, kayaking, and canoeing. Both river systems support active, public and private tubing, diving, and swimming facilities. There are state parks on the rivers that provide resource-based recreational opportunities.

3.1.2 Fish and Wildlife Habitats and the Passage of Fish

This WRV is considered relevant for the Lower Santa Fe River and Ichetucknee River MFLs and a potential limiting factor in the establishment of a MFL. The SAV community of the rivers provides both an important structural habitat for a variety of fauna, as well as being a significant component of the rivers' primary production. In addition, SAV by its location on the bottom and high metabolic activity drives a variety of biochemical processes and cycles in the water column (Cohen, et al., 2013; McLaughlin, Kaplan, & Cohen, 2013; Hensley & Cohen, 2012; Heffernan & Cohen, 2010; Heffernan, Liebowitz, Frazer, Evans, & Cohen, 2010; Heffernan, et al., 2010; Heffernan, Albertin, Fork, Katz, & Cohen, 2012; De Montety, Martin, Cohen, Foster, & Kurz, 2011). Fish passage is a potential issue in the river channels during low flow, because of the shallow shoal areas in both rivers. Although the federally endangered West Indian manatees visit the springs, none of the springs of the Lower Santa Fe River or Ichetucknee River have been identified as significant thermal refugia for manatees (Warm Water Task Force, 2004). Manatee access across a shoal at the mouth of the Ichetucknee River; the availability of other high-quality thermal refugia downstream is another potentially limiting factor for manatee passage. Both in-channel habitats and floodplain habitats are affected by river flows and were also evaluated in the establishment of the MFLs for these rivers.

3.1.3 Estuarine Resources

This WRV was not considered relevant. MFLs have been established for the Lower Suwannee River and Estuary, and a MFL regime was established to protect flow to the estuary and maintain estuarine habitats. The Lower Suwannee MFL establishes protection of all riverine flows to the estuary, including flow from the Lower Santa Fe River.

3.1.4 Transfer of Detrital Material

It has been well-established that a principal food base in aquatic and wetland ecosystems is decaying plant material, collectively termed "plant detritus" or simply detritus. Transport of this material from the river floodplain wetlands to the river channel can be an important source of food material for riverine food webs. This WRV is relevant to the Lower Santa Fe River and Ichetucknee River MFLs, and is addressed by consideration of the frequency of overbank flows in the establishment of the MFLs for these rivers.

3.1.5 Maintenance of Freshwater Storage and Supply

This WRV refers to the long-term maintenance (i.e., sustainability) of water storage and supply capability of the water body. Freshwater storage and supply is considered relevant to the Lower Santa Fe River and Ichetucknee River MFLs. Establishment of a MFL for a water body implicitly establishes potential availability of that water. The result of the protection of this value by MFL establishment is to ensure that, over time, the ability of the water body to serve as a supply source for existing and future legal permitted users is preserved without causing “significant harm” to the water resource or ecology of the area.

3.1.6 Aesthetic and Scenic Attributes

This WRV is closely linked with the first WRV pertaining to recreation in that part of the recreational value of the Lower Santa Fe and Ichetucknee river and priority springs is the aesthetic experience. The accumulation of excessive algal biomass, either as phytoplankton, periphyton, or epiphyton, can alter the aesthetics of the river. These accumulations can occur from a variety of potential causes, operating separately or in combination, such as increased nutrient availability, reduced flow-induced scouring (King, 2012), increased disturbance, and/or changes in biological interactions (Brown, et al., 2008). King (2012) evaluated the role of flow and velocity and algal biomass for a Florida spring run. Generally, there is little quantitative information linking aesthetics and flow suitable for the establishment of MFL criteria.

3.1.7 Filtration and Absorption of Nutrients and Other Pollutants

This WRV is considered relevant to the Lower Santa Fe River and Ichetucknee River MFLs and was considered a potential limiting factor in the establishment of a MFL. The role of wetlands in the maintenance of water quality is well established (Mitsch & Gosselink, 1986). By allowing for settlement of suspended particulates, uptake of nutrients by plants, and sequestration of heavy metals and other contaminants in sediments, wetlands help protect water quality. Data from the scientific literature on nutrient cycling and other biochemical functions of wetlands were taken into consideration in establishing MFLs, with the assumption that maintaining an acceptable level of ecological integrity for wetland ecosystems of the Lower Santa Fe and Ichetucknee river would maintain this particular function. The presence of freshwater marl on the floodplain of the rivers provides for a substance for p-sorption and maintenance of locally alkaline soils. MFLs are recommended to protect the development of this soil type in the river system, which assists in nutrient (orthophosphate) fixation. Nitrogen fixation within the river floodplain is also supported by out-of-bank flows.

3.1.8 Sediment Loads

This WRV is considered relevant to the Lower Santa Fe River and Ichetucknee River MFLs although there is no available data relating sediment loads to flow for these rivers. Due to the physiography and soil types present in the basin, and the substantial groundwater contribution to flows, these rivers may be expected to carry lower sediment loads than many other similar-sized rivers. Despite this fact, the presence of alluvial features in the floodplain of the river indicates that the river does carry some sediment, which may include clay, organic silt, or sand. Thus, sediment transport is important in the maintenance of these geomorphic features and their associated ecological communities. It is probable that most of the river’s sediment load is carried at higher flows given the very clear water during baseflow periods. Riverine fluvial dynamics, specifically bankfull flows, were considered in setting the MFLs.

3.1.9 Water Quality

This WRV is considered relevant to setting MFLs on the Lower Santa Fe and Ichetucknee rivers. The primary water-quality consideration was nitrate-nitrogen loading, which has been attributed to the springs of the Lower Santa Fe (Pittman, Hatzell, & Oaksford, 1997; Katz, Hornsby, Bohlke, & Mokray, 1999; Upchurch, Chen, & Cain, 2008).

3.1.10 Navigation

This WRV applies to large commercial vessels and was not considered to be relevant to the Santa Fe and Ichetucknee rivers, or priority springs MFLs. However, passage by recreational vessels, such as canoes was considered under the "Recreation In and On the Water" value, above.

3.1.11 Summary

The series of metrics related to these WRVs and evaluated in the MFL development included:

- In-stream metrics – wetted perimeter, woody habitat, physical habitat suitability, fish passage, manatee passage, water quality, and recreation.
- Floodplain habitat – overbank flows, floodplain inundation, hydric soils and bankfull flows.

3.2 CONCEPTUAL MODEL FOR MFLS

The conceptual model utilized in the development of the MFLs for the Lower Santa Fe and Ichetucknee rivers and priority springs was envisioned by recognizing the physical setting of the rivers' in-channel and floodplain habitats and the specific locations of the available river flow data (i.e., USGS and District gages). Therefore, the intersection of these two elements, i.e., the physical setting of the rivers and the available flow data, became the framework for the conceptual model (Figure 3-1). Thus, the relationships between flows and habitat suitability/availability are the basis for the MFL development approach.

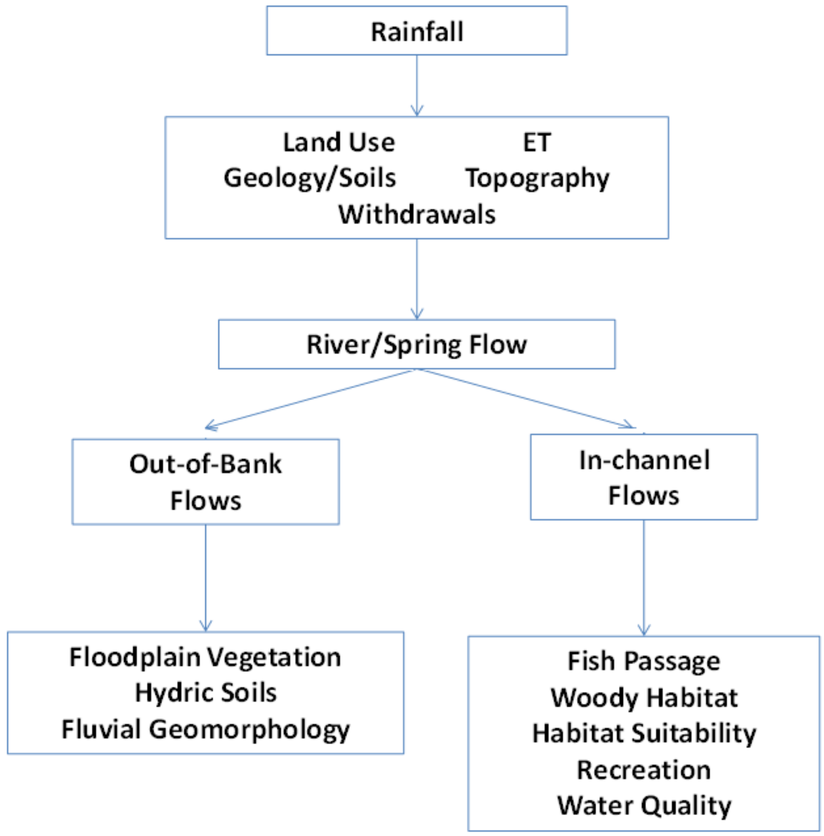


Figure 3-1. Conceptual model of the relationships between river flow with the physical and biological features of the rivers and their priority springs.

The in-channel and floodplain habitats vary significantly from the upper reach of the Lower Santa Fe near US 441 to the lower reach below the confluence with the Ichetucknee River. As discussed in Section 2.0, the channel in the upper reach is characterized by the land bridge and a series of very shallow shoals. The in-channel substrate is dominated by limestone outcroppings and extensive SAV. The floodplain in the upper reach is significantly more pronounced than in the lower reach. In a downstream direction approaching the USGS gage at Fort White, the Lower Santa Fe River becomes more incised and the floodplain narrows. The reach below the confluence with the Ichetucknee River is most incised, without the occurrence of rocky shoals and with a more varied substrate.

The substrates within the Ichetucknee River are relatively more homogenous than in the Lower Santa Fe River. The channel is comprised primarily of sandy substrate with extensive submerged aquatic vegetation. The middle reach on the Ichetucknee River is characterized by Grassy Flats, a broad, low velocity marshy area. Relative to the Lower Santa Fe River, the channel in the Ichetucknee River is far less incised with the floodplain being more pronounced than in the lower reaches of the Lower Santa Fe River.

In addition to the physical setting of the waterbodies of concern, an understanding of hydrologic characteristics is essential. Thus, there is an apparent need for a tool that allows comparison of different flow regimes. Flow Duration Curves (FDCs) are a convenient tool for visualization, simplification, and comparison of streamflow data. Searcy (1959) notes the curves are cumulative frequency curves "*combining in one curve the flow characteristics of a stream throughout the range of discharge*." They have had "*wide-spread application*" and a "*long history*" in a variety of hydrologic studies including in-stream flow assessments (Vogel & Fennessey, 1995). They show the percent of time specified discharges were equaled or exceeded for a continuous record in a given period. For example, during the period 1932 to 2010, the daily mean flow of the Santa Fe River near Fort White (Figure 3-2) was at least 767 cfs, 90 percent of the time. The curves are influenced by the period of record used in their creation, but for comparison purposes between different scenarios over a fixed time period they are extremely useful.

The vertical axis of a FDC is the streamflow rate in cfs and the horizontal axis is the exceedance probability expressed as a decimal. As can be observed in Figure 3-2, FDCs are constructed by sorting all of the daily data, from highest to lowest and assigning probability. The highest flow in the record corresponds to the lowest exceedance probability flow; the lowest flow in the record corresponds to the highest exceedance probability flow. The exceedance probability commonly used (and used here) is the Weibull plotting position (Jacobs & Ripo, 2001).

Flows and/or exceedance probabilities of interest can be plotted "on top" of the FDC. For example, the magnitude of a spring is of common interest to the public and is used in MFL priority list development. An exceedance probability of 0.5 (the median) is used to determine spring magnitude (Florida Geological Survey, 2005).

Given the characteristics of the rivers and the available flow data, MFLs have been developed at two USGS gages. These gages and the predominant metrics used include Santa Fe River near Fort White – fish passage, floodplain inundation, hydric soils, fluvial geomorphology, in-stream habitat; and Ichetucknee River at US 27 – fish passage, recreation, fluvial geomorphology, hydric soils, in-stream habitat.

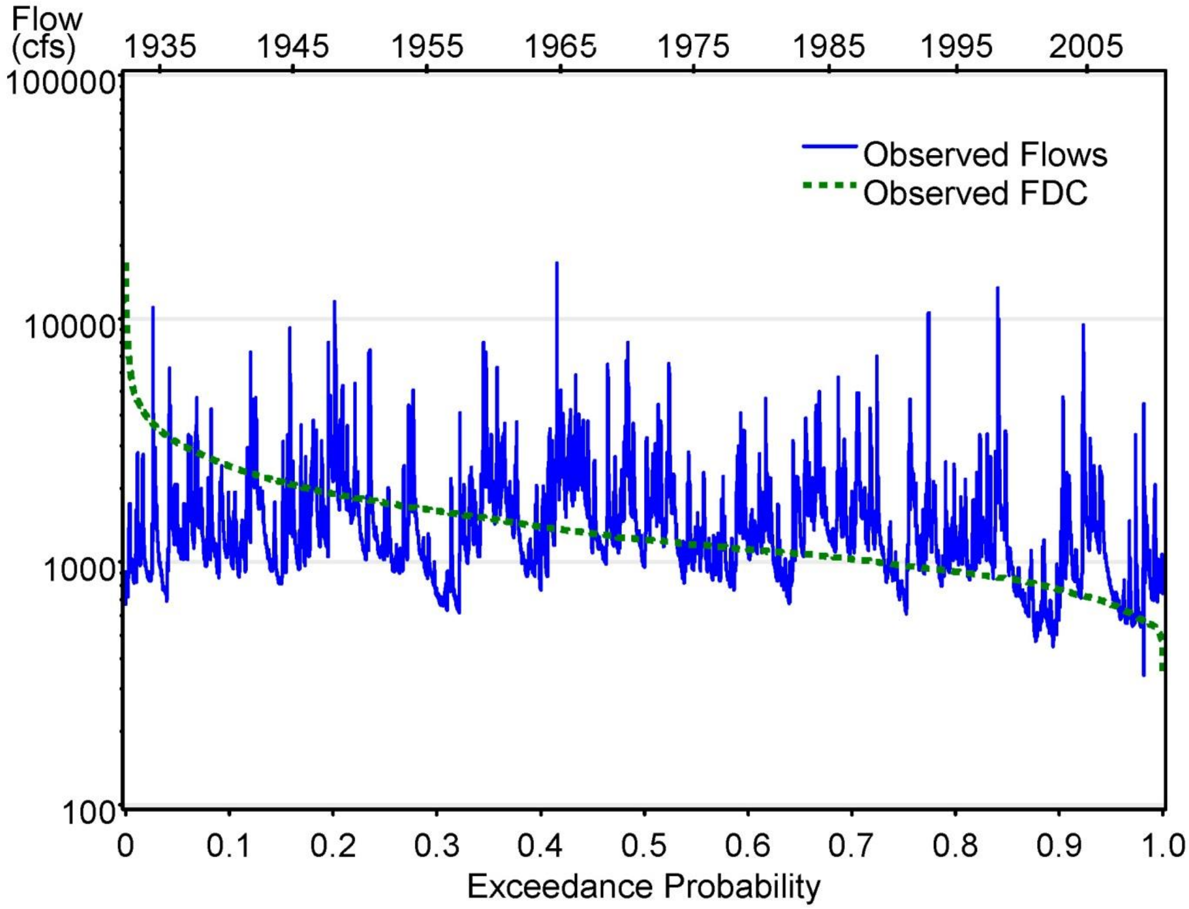


Figure 3-2. Comparison of hydrograph of the Lower Santa Fe River near Fort White with its flow duration curve (FDC).

Given the large contribution of springflow to river discharge in the Lower Santa Fe and Ichetucknee rivers, the maintenance of spring discharge is essential to continuation of historical water resource conditions in the Lower Santa Fe River Basin. The approach used to protect these resources is based on an allowable proportional change analysis for each priority spring based on median conditions under the MFL specified for each river. This will be used in determining cumulative changes at individual springs as assessed with analysis tools such as groundwater-flow models. This approach is further discussed in Section 6.0.

3.3 MFL DEVELOPMENT

As discussed in Section 1, the goal of a MFL determination is to protect the resource from significant harm due to water withdrawals, and was broadly defined in the enacting legislation as *"the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area."* However, as has been previously shown, significant harm is rarely depicted as a “bright line,” as habitat loss typically varies monotonically (without a clear inflection or break point) with flow (SWFWMD, 2005). Thus, there is a need for an operationally defined threshold that protects the WRVs used to establish the MFL. The proposed threshold for the development of Lower Santa Fe and Ichetucknee rivers and priority springs MFLs is a 15% habitat loss. The following provides justification for the proposed threshold.

The Southwest Florida Water Management District (SWFWMD, 2005) has implemented a 15% loss of habitat or resource as a threshold for significant harm that limits the withdrawal of water from the freshwater ecosystems. Instream flow determinations in other areas have been based on percent changes in habitat that ranged from 10% to 33% (Jones Edmunds and Associates, 2012). In their review of a SWFWMD MFL, Cichra, et al. (2005), stated:

"…the peer review panel for the Middle Peace found that use of the 15% threshold is reasonable and prudent (Shaw, Dahm, & Golladay, 2005), especially given the absence of clear guidance in statute or in the scientific literature on levels of change that would constitute significant harm. We acknowledge that percentage changes reported in the literature have ranged from 10-33% in other applications designed to prevent significant harm. The present panel affirms the use of the 15% threshold in the Alafia and Myakka rivers for similar reasons."

Jones Edmunds and Associates (JEA) (2012) conducted a literature review to allow examination of the 15% habitat loss criterion. The literature search resulted in the review and documentation of 366 articles. JEA concluded:

"In examining the literature, we have drawn several broad conclusions that are consistent with previous observations made by the water management districts of Florida in various MFL documents. Minimum flow recommendations should address a range of processes and the flow events that influence each process. Many programs employ assessment methods that rely heavily on the input of scientific experts to define flow-ecology relationships. To increase transparency and community acceptance, some programs have supplemented scientific expertise with input from local stakeholders through a workshop approach. The coupling of scientific experts and local stakeholders to arrive at a recommended flow regime is commonly referred to as a holistic method or approach."

The general approach taken in the development of the Lower Santa Fe and Ichetucknee rivers and priority springs MFLs includes the following steps:

- set a goal (for this MFL, protection from significant harm);
- identify the resources of interest to be protected (WRVs);
- define a unit of measure (e.g., flow in cubic feet per second, percent reduction in flow);
- define a baseline flow regime, and
- define a protection standard statistic (e.g., a prescribed percent reduction).

The following sections of this report present the above approach in greater detail.

4.0 HYDROLOGIC DATA ANALYSES AND MODELING

This chapter discusses the data collection, exploratory data analysis, trend analysis, Baseline Flow development, and hydrologic modeling efforts undertaken as a component of MFL development. A complete description of the statistical analysis and hydrologic modeling efforts are fully described in INTERA (2012a, 2012b) and HSW (2013a, 2013b) which are provided as Appendices 2-1, 4-1, 4-2, and 4-3 respectively.

4.1 INTRODUCTION

The Lower Santa Fe River system is a karst-influenced system populated with numerous springs, estavelles, sinks, resurgences, and rises (Butt, Morris, & Skiles, 2007). It is a natural system with no floodplain controls, dams, or impoundments. The flows in the river consist of a combination of stormwater runoff and groundwater discharge. The river transitions from a stormwater dominated system to a karst dominated system from the Worthington Springs gage downstream to the confluence with Olustee Creek (Figure 2-19). From the Olustee Creek confluence and continuing downstream approximately 40 miles the system is highly influenced by the surrounding karst environment.

Downstream of the Olustee confluence, baseflow contributions to total flow are more significant than those upstream. This is largely due to the presence of multiple springs along this section of the river (Figure 1-2). However, portions of the Santa Fe are tailwater controlled by the stage in the Suwannee River during high water events on that system. The Ichetucknee River is also dominated by high springflow contributions to total flow. Upstream of the Highway 27 gage, flow is dominated by springflow. Downstream of the Highway 27 gage, flow is also dominated by springflow, but flow conditions can be controlled by tailwater in the Suwannee or Santa Fe rivers.

The development of a comprehensive flow and stage database for the Lower Santa Fe River was an integral component of the Baseline Flow development, modeling efforts, statistical characterization of the Lower Santa Fe River, and MFL development (Appendices 2-1, 4-2, and 4-3). In order to investigate and account for the relative contributions of anthropogenic and climatic (i.e., rainfall) factors, trend analysis and exploratory data analysis were conducted on long-term stream monitoring stations and rain gages within the Santa Fe River Basin. The development of a single comprehensive hydrologic database preceded the analyses since it was desirable to have a single data source for flow and stage to increase efficiency for both the modeling effort and the statistical characterization of hydrologic data.

4.2 DATA COLLECTION, GAP FILLING, AND RECORD EXTENSION

4.2.1 Stage, Flow and Groundwater Levels

Daily stage and flow data for twelve (12) surface water stations on the Lower Santa Fe, Ichetucknee, and Suwannee rivers were collected (Table 2-3 and Table 2-4). Daily groundwater levels for one local groundwater well (site ID -41705001, located at the Florida Department of Transportation, Lake City) were also collected Figure 4-1. The period of record of the well was from 6/4/1948 to 10/7/2010.

The majority of flow and stage data for the surface water stations were imported from the USGS National Water Information System (NWIS) database. USGS field measurements were also imported for the Ichetucknee River at Highway 27 near Hildreth (USGS #02322700). Other hydrologic data were obtained from the District. USGS water-data reports were consulted to account for datum shifts. Figure 4-3 shows the location of the rainfall and surface water stations and the groundwater well.

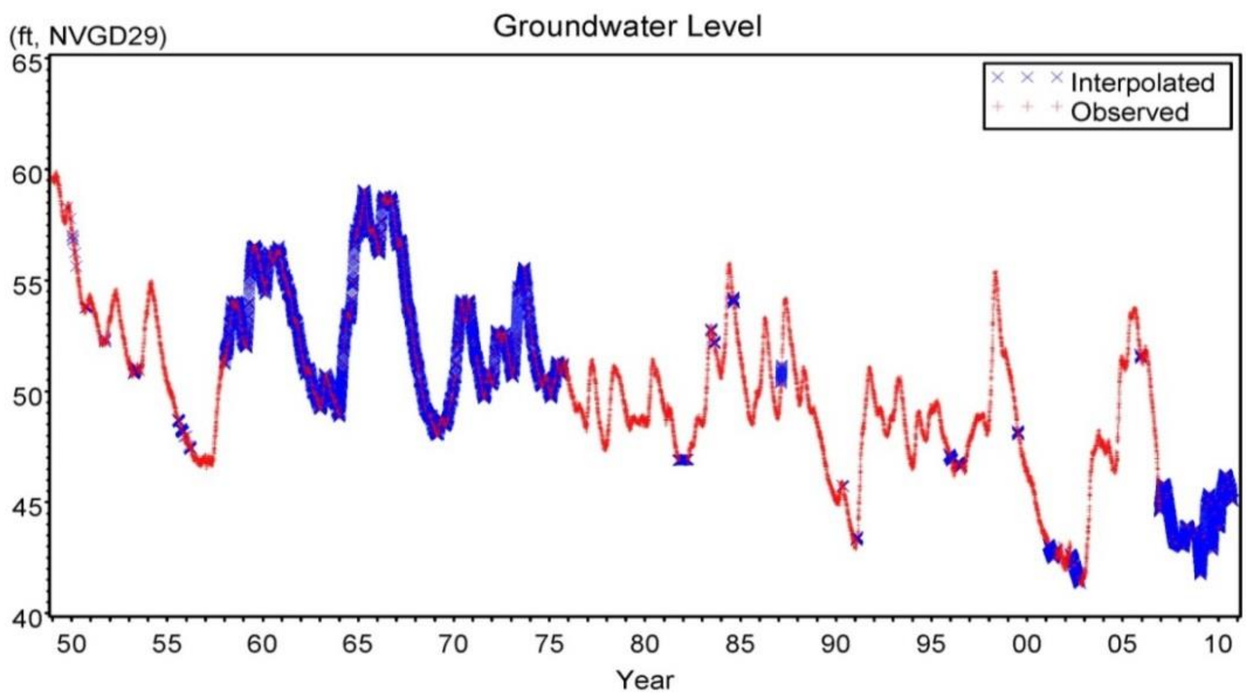


Figure 4-1. FDOT Lake City well (-41705001) observed and interpolated data.

Figure 4-2. Station locations.

4.2.2 Rainfall

Data from long-term rain gages, located in Lake City and Gainesville, were also added to the database. The Gainesville record is based on 2 rainfall gages: the University of Florida gage and the Gainesville Regional Airport gage. These locations are shown on Figure 4-2.

4.2.3 Database Development

A Microsoft Access© database consisting of stage and flow records was created based on the USGS data, the District data, and the filled data. The database contains ten tables which include a station list of the USGS surface water sites, gage height data, discharge data, well data, rainfall data for two nearby stations, discharge and gage height data history, and quality flags.

4.2.4 Gap Filling and Record Extension

The majority of the gage sites include data gaps in the observed flows and stages or had shorter record lengths than desirable for establishing relationships between sites or to establish quantitative relationships between environmental metrics and flow. Also, contemporaneous data were desired to allow comparisons across sites. Where possible record gaps at the sites were filled, or record length extended using various statistical methods. Since well -41705001 had the longest and the most complete record, it was utilized in statistical model development for data filling of stage and flow data, in particular for the Ichetucknee River. Existing gaps in this groundwater record were filled by linear interpolation. Consequently, the final contemporaneous period of record was from 6/4/1948 to 3/31/2011 due to data availability of groundwater levels.

A summary of the models developed for filling data is shown in Table 4-1. The models used for filling include simple linear regressions (SLRs), rating curves, multiple linear regressions (MLRs), and artificial neural networks (ANNs). For all cases, a general hierarchy was followed for statistical model development. First, a stage-discharge relationship was developed for the dependent variable of interest, if possible. If there were adequate data to develop this relationship and the fit of the relationship was strong, the stage-discharge relationship was utilized for filling. If it was not possible to develop a stage-discharge relationship, a nearby gage was examined in order to develop a simple linear regression between contemporaneous flow or stage records. If a simple linear regression did not adequately predict the response variable, a multiple linear regression or artificial neural network with multiple inputs was utilized to predict the response variable. For all models, the root mean squared error (RMSE), average residual, coefficient of determination (R^2) and graphical model fit were examined to ensure the goodness-of-fit of the statistical model for gap filling. Note that in this report, the completed, filled flow and stage time series are referred to as **observed** stages and flows in order to distinguish them from the **simulated** stages and flows from the HEC-RAS model.

Table 4-1. Statistical model summary by station.

Station Number	Station Name	Data Type	Model Type	Independent Variable(s)
02320500	Suwannee River at Branford	Gage height	SLR	Luraville (02320000) gage height
		Flow	Rating curve	Branford gage height
02323000	Suwannee River at Bell	Gage height	SLR	Branford gage height or Luraville (02320000) gage height
		Flow	Rating curve	Bell gage height
02321500	Santa Fe River at Worthington	Gage height	Rating curve	Worthington flow (4 flow regimes)
02321975	Santa Fe River at Highway 441	Gage height	MLR	Fort White gage height, flow; Worthington gage height, flow
		Flow	MLR	Fort White flow, Worthington flow
02322500	Santa Fe River near Fort White	Gage height	MLR	Bell gage height, Worthington flow
02322703	Santa Fe River above Ichetucknee near Hildreth (3 Rivers)	Gage height	SLR	Santa Fe Hildreth gage height
02322800	Santa Fe River near Hildreth	Gage height	MLR	Fort White gage height, Branford gage height
02322698	Ichetucknee River near Dampier's Landing	Gage height	ANN	FDOT well -41705001, Santa Fe Hildreth gage height
		Flow	SLR	Ichetucknee Highway 27 flow
02322700	Ichetucknee River Highway 27 near Hildreth	Gage height	ANN	FDOT well -41705001, Santa Fe Hildreth gage height
		Flow	SLR	FDOT well - 41705001

Note: SLR= simple linear regression; MLR = multiple linear regression; ANN = artificial neural network

4.2.5 Trend Analysis

An initial trend analysis was performed on the flow data to determine the magnitude and significance of the trends in the time series. The Mann-Kendall (MK) test is extensively utilized for the examination of trends in hydrologic and hydro-climatic time series (Birsan, Molnar, Burlando, & Pfaundler, 2005; Kahya & Kalayci, 2004; Tao, Gemmer, Su, Mao, & Bai, 2011). MK trend analysis was conducted on all stations in order to determine the significance of the trends over the common period of record (1948 through 2011).

The aggregation of data to annual average minimized the serial correlation present in the time series. The presence of serial correlation (or dependency of the data at time t on time t-1), can lead to a false positive test (i.e. concluding that there is a trend when in fact the trend is due to serial correlation). The outcome of the MK test is the decision of whether or not to reject the null hypothesis, (H_o). Failure to reject the null hypothesis does not indicate that there is no trend in the data, but rather that there is not sufficient evidence to conclude that there is a trend (Helsel & Hirsch, 2002).

Trend analysis was run on the annual average total flows and baseflow. Baseflow was estimated using a low pass filter with a 120-day average minimum flow for each station (Perry, 1995). Results for the trend analysis are summarized in Table 4-2. As shown in Table 4-2, all stations exhibited statistically significant decreasing trends in baseflow. The correlation coefficient, tau, is also shown. Tau, which ranges from -1 to 1, is a measure of the correlation between the data and time: a negative tau indicates that the data are decreasing as time increases, and a positive tau indicates that the data are increasing as time increases. For the MK test, the p-value corresponds to the probability of obtaining a tau value at least as extreme as the observed tau, assuming that the null hypothesis is true. The null hypothesis of the test is that there is no trend in the data. The null hypothesis is rejected when the p-value is less than the significance level, alpha. When the null hypothesis is rejected, it is concluded that the results of the test are statistically significant. Thus, given a 90% confidence level and the fact that the test is two-sided (because trends can be either positive or negative), the null hypothesis can be rejected when the p-value is less than the critical alpha (α) of 0.05. Based on a 90% confidence level, all stations have statistically significant negative trends in baseflow, while five of the eight stations have statistically significant trends in total flow. A discussion of this analysis and additional exploratory data analysis is provided in Appendix 2-1.

Table 4-2. Trend analysis results.

Site ID	Station Name	Total Flow			Baseflow		
		Mann Kendall p-value	Mann Kendall Sen Slope (cfs/year)	Mann Kendall tau	Mann Kendall p-value	Mann Kendall Sen Slope (cfs/year)	Mann Kendall tau
02321500	Santa Fe at Worthington Springs	0.073	-2.892	-0.154	0.005	-0.470	-0.240
02321975	Santa Fe at Highway 441	0.006	-7.900	-0.237	0.000	-5.658	-0.334
02322500	Santa Fe near Fort White, FL	0.002	-11.503	-0.263	0.000	-8.511	-0.371
02322700	Ichetucknee at Highway 27	0.000	-1.799	-0.352	0.000	-1.977	-0.397
02322800	Santa Fe near Hildreth, FL	0.004	-11.525	-0.246	0.000	-10.415	-0.360
02320500	Suwannee at Branford, FL	0.483	-18.169	-0.061	0.028	-20.057	-0.188
02323000	Suwannee near Bell, FL	0.196	-32.862	-0.111	0.008	-33.276	-0.227

Based on the results of the exploratory data analysis, it was noted that many stations exhibited increasing flows prior to approximately 1970 and decreasing trends after approximately 1970 as shown in the examples in Figure 4-3. As shown from the LOESS (Locally Weighted Scatterplot Smoothing) plots, the flows at the Santa Fe River at Fort White and Ichetucknee River at Highway 27 increase in the early portion of the record, and begin to decrease around 1970. Many other stations also exhibited similar break points in their time series. Note that although general trends in the data were seen, not all trends were statistically significant (as discussed in Appendix 2-1). Additionally, only streamflow was evaluated and the identified trends and do not incorporate the effects of all hydrologic conditions. In particular, the relationship between precipitation and basin yield is critical for understanding the basin characteristics and behavior relative to MFL establishment. This is developed further in subsection 4.4. The implications of these trends for establishment of MFLs for the Lower Santa Fe and Ichetucknee rivers are discussed in section 6.0.

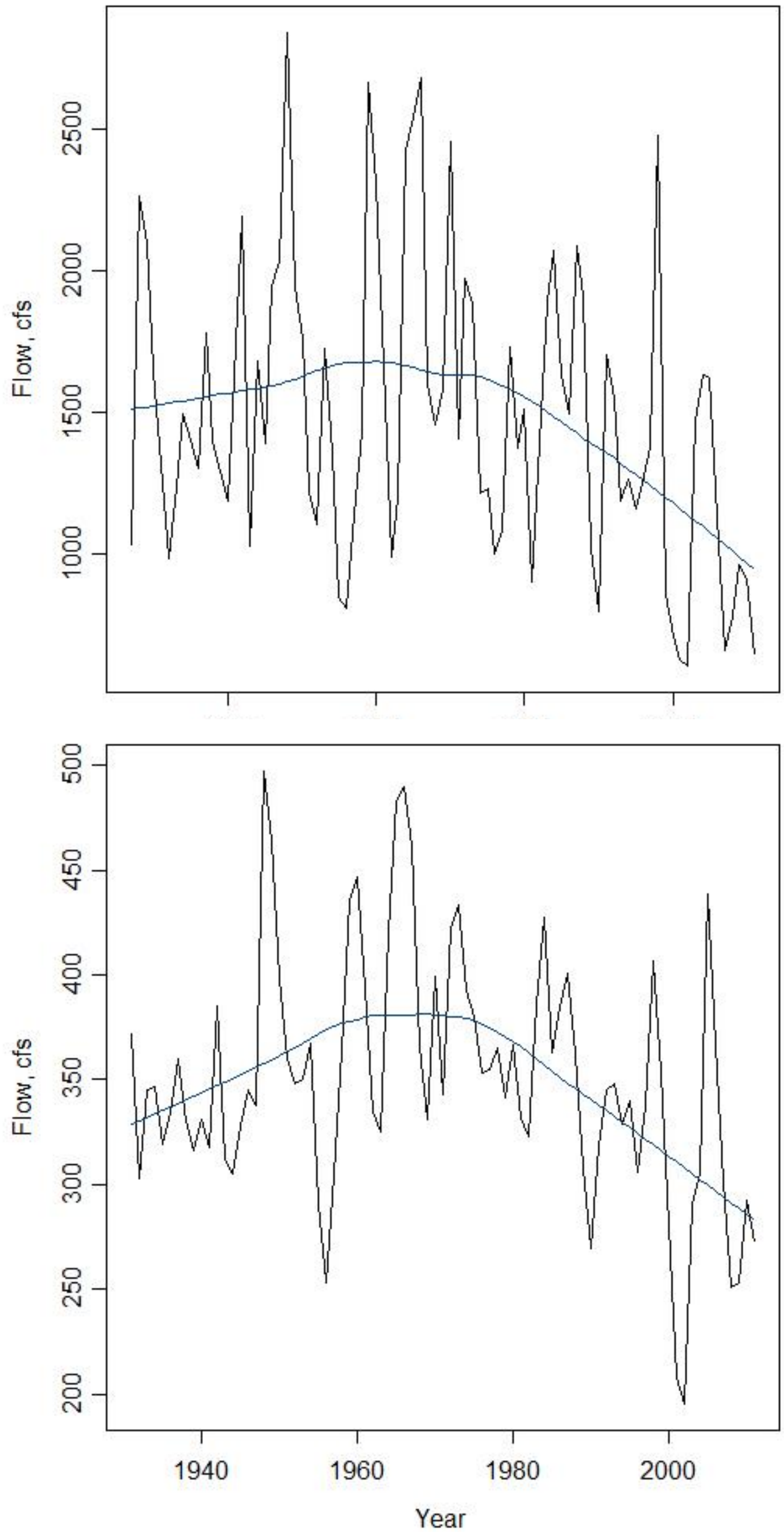


Figure 4-3. Santa Fe River at Fort White (top panel) and Ichetucknee River (bottom panel) LOESS analysis.

4.3 LOWER SANTA FE RIVER SIMULATION

The purpose of the HEC-RAS modeling effort was to create simulations of the Santa Fe and Ichetucknee rivers. These simulations were utilized to find the relationships of flow to stage throughout the entire lengths of the rivers and to translate water surface elevations at critical cross-sections to flows at the primary USGS gages: the Santa Fe River at Fort White (02322500) and the Ichetucknee River at US Highway 27 (02322700).

The HEC-RAS modeling effort utilized information from existing HEC-RAS transient models of the Santa Fe and Ichetucknee rivers (INTERA, 2007) previously prepared by INTERA for the District. The Lower Santa Fe River and Ichetucknee River systems, previously modeled separately, were combined and calibrated as one system (Figure 4-4) using the HEC-RAS open-channel flow modeling software (US Army Corps of Engineers, 2010). This model was developed using new elevation and bathymetric data, as follows (Appendix 4-1). The existing stand-alone Lower Santa Fe River model was geo-referenced, combined with the Ichetucknee River model, and modified to include the best available data from the existing models. Digital elevation model (DEM) data provided by the District were combined with the existing and newly surveyed cross section information in order to develop cross sections for the HEC-RAS model. United States Geological Survey (USGS) and District flow and water-level data were used for model development and calibration. The transient model was calibrated to observed stage data. All elevation data was referenced to the National Geodetic Vertical Datum of 1929 (NGVD29). The simulation time period of the model was from February 13, 2002 until September 29, 2011.

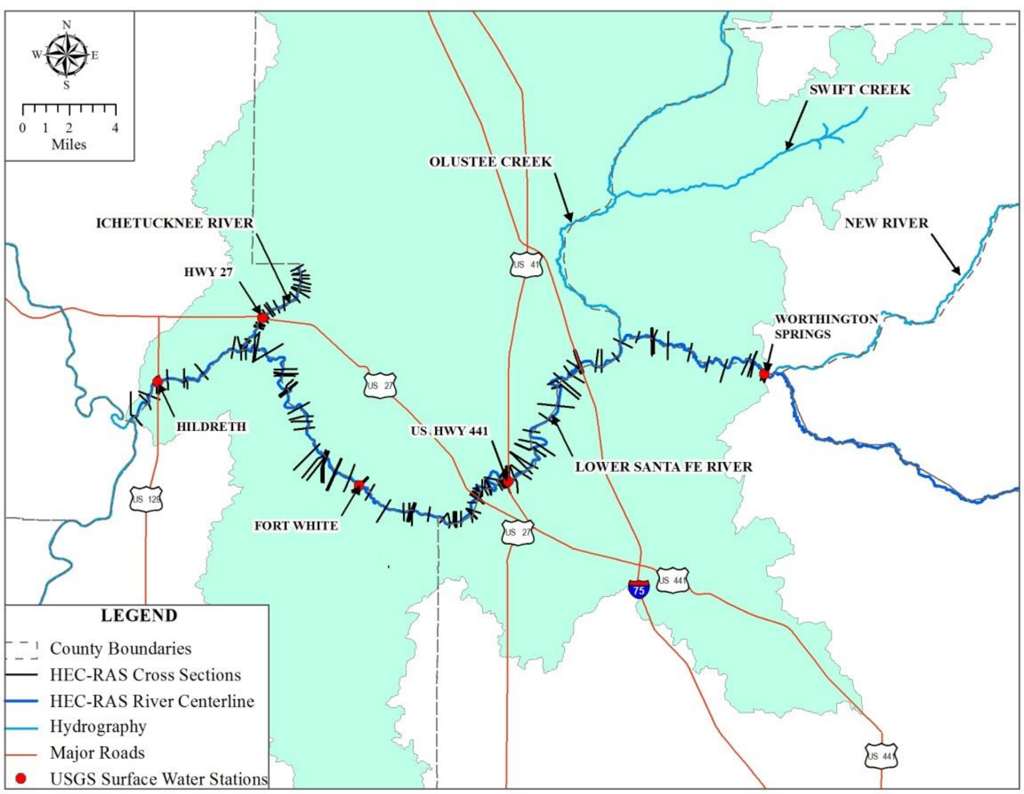


Figure 4-4. Location of the combined Santa Fe/Ichetucknee River Model.

4.3.1 Reach Segmentation

The geometry of the model was constructed using HEC-GeoRAS in ArcMap Version 10 and HEC-RAS v4.1.0. The channel centerline of the Santa Fe River was digitized starting upstream near the Worthington Springs gage working downstream until the confluence with the Suwannee River was reached. A total of 234 channel cross sections and 18 bridge cross sections were digitized. The Lower Santa Fe model system is comprised of 15 reaches (Figure 4-5 and Table 4-3).

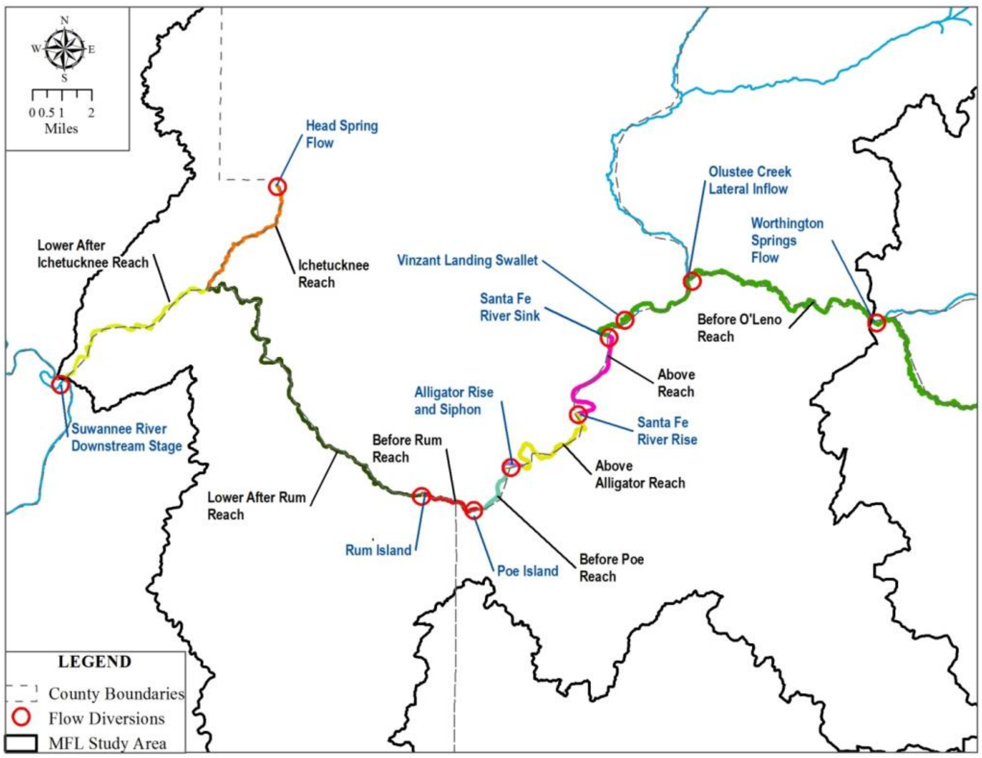


Figure 4-5. Santa Fe HEC-RAS Model reaches.

Table 4-3. Lower Santa Fe and Ichetucknee Model Reaches.

River	Reach	River Station Start	River Station End	Upstream Reach(es)	Downstream Reach(es)
Santa Fe	Before O'Leno	267712.9	186938.4	N/A	Below, Above
Santa Fe	Below	186917.6	164296.4	Before O'Leno	Above Alligator
Santa Fe	Above	186917.6	164296.4	Before O' Leno	Above Alligator
Santa Fe	Above Alligator	164241.8	139031*	Above, Below	Siphon Above, Siphon Below
Santa Fe	Siphon Above	138946*	134136*	Above Alligator	Before Poe
Santa Fe	Siphon Below	138946	134136	Above Alligator	Before Poe
Santa Fe	Before Poe	133953*	124915.7	Siphon Above, Siphon Below	Poe Island North, Poe Island South
Santa Fe	Poe Island North	124770.3	124514.9	Before Poe	Before Rum
Poe Island South	Poe Island South	340.2	78.6	Before Poe	Before Rum
Santa Fe	Before Rum	124387.6	113651.9	Poe Island North, Poe Island South	Rum Island South, Rum Island North
Santa Fe	Rum Island South	113265.1	112684.0	Before Rum	Lower After Rum
Rum Island North	Rum Island North	936.6	94.7	Before Rum	Lower After Rum
Santa Fe	Lower After Rum	112509.8	37869.6	Rum Island South, Rum Island North	Lower After Ichetucknee
Ichetucknee	Ichetucknee Reach	27976.3	335.5	N/A	Lower After Ichetucknee
Santa Fe	Lower After Ichetucknee	36841.8	1606.3	Lower After Rum	N/A

Note: * denotes interpolated cross section

One of the challenges of the HEC-RAS model was simulating interconnected karst formations including swallets and resurgences. The karst features and their hydraulic relationships were successfully modeled in HEC-RAS through use of the synthesized lateral inflows and the HEC-RAS pressurized conduit flow option. The "Before O'Leno" reach includes the cross sections from just upstream of State Road 121 to the Santa Fe River Sink. The Santa Fe River is unique because it disappears underground into the Santa Fe River Sink in the O'Leno State Park and reappears in the Santa Fe River Rise (Figure 4-5). The Santa Fe River Sink is a large sinkhole that diverts the Santa Fe River flow underground; hence, the aboveground channel remains dry most of the time. For that reason, this portion of the river was modeled in HEC-RAS with two separate reaches, "Above" and "Below", with the "Below" reach carrying most of the flow (Figure 4-6). The Alligator Siphon and the Alligator Rise are located approximately 5600 feet and 750 feet upstream of the Highway 27 bridge, respectively (Figure 4-7). The Alligator Siphon is a small siphon that is formed by an underground cave and diverts a significant amount of the Santa Fe River flow (Butt, Morris, & Skiles, 2007). The Alligator Siphon and Rise system was modeled with two reaches: "Siphon Below", to represent flow that is captured by the siphon (and routed through a conduit to a downstream location) and "Above", which carries the remaining flow in the Santa Fe River (Figure 4-7). The amount of flow taken in by the Alligator Siphon was adjusted in model calibration. The flows around Poe and Rum Islands were also represented in the model with two reaches (Figure 4-5). The Ichetucknee River was modeled as a single river reach (Ichetucknee Reach, Figure 4-5).

4.3.2 Boundary Conditions

The geographic extent of the model is defined by the upstream boundaries of the Santa Fe River at the gage near Worthington Springs and the Ichetucknee River Headspring, and by the downstream boundary at the confluence of the Santa Fe and Suwannee rivers. The boundary conditions of the model are defined by stream-flows at the upstream Santa Fe River and Ichetucknee River boundaries, river stage values at the downstream boundary at the Santa Fe-Suwannee River confluence, and various internal lateral inflows (both uniformly distributed and point inflows) on both rivers.

Observed daily stage and flow data from the USGS surface water stations were used as boundary conditions. Flow and stage data at Worthington Springs (USGS #02321500), Fort White (USGS #02322500), Hildreth (USGS #02322800), Branford (USGS #02320500), and Bell (USGS #02323000) were used in development of upstream, downstream, and internal boundary conditions. The Olustee Creek (USGS #02321800) flow record (10/1/1957 to 09/30/1960) and the New River near Lake Butler (USGS #02321000) flow record (1/1/1950 – 9/30/2011) were also obtained from the NWIS to be utilized in development of the lateral point inflow boundary condition at Olustee Creek. Development of boundary conditions for the HEC-RAS model is described in Appendix 4-1.

Flow-duration curves of the daily flows for the long-term (1932-2011) and short-term (2002-2011) periods of record at Worthington Springs and Fort White USGS gaging stations were constructed to compare the percent of time the discharges were equaled or exceeded for the specified time periods (Figure 4-6 and Figure 4-7). Although the short-term flow duration curves do not experience the extreme high flows shown in the long-term flow-duration curves, the short-term records generally capture the range and distribution of observed flows in the long-term period. The 2002 through 2011 time period represents the longest period of record where boundary condition flows were available and could be developed through gap filling for model development. Thus, although the model simulation period flow-duration curves show some differences in extreme events from the long term flow records, this short period represents the best available data for model development and calibration.

Hence, the chosen simulation time period (short-term period of record) was appropriate for the model developed in support of Lower Santa Fe River and Ichetucknee River MFLs.

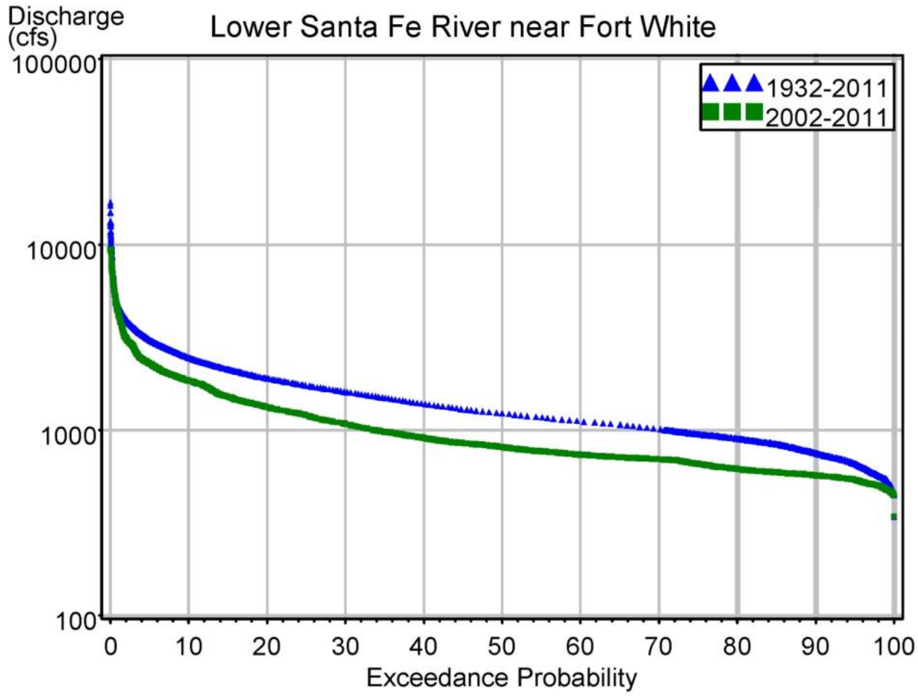


Figure 4-6. Flow duration curve (semi-log) for the Santa Fe River near Fort White (USGS Station Number 02322500).

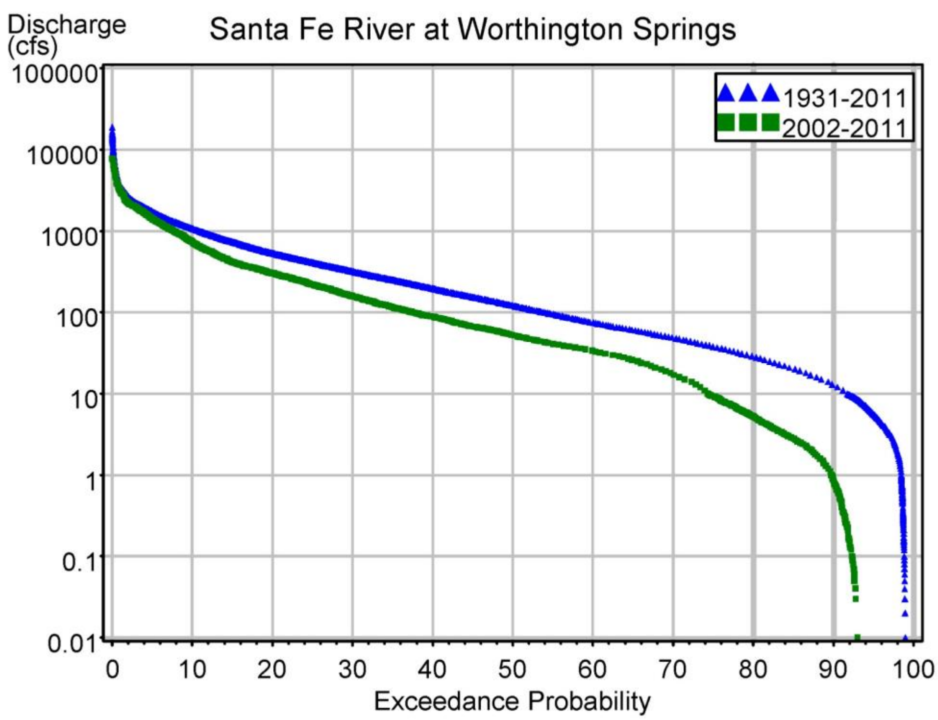


Figure 4-7. Flow duration curve (semi-log) for the Santa Fe River at Worthington Springs (USGS Station Number 02321500).
Note: Flow ceases in the highest exceedance probabilities.

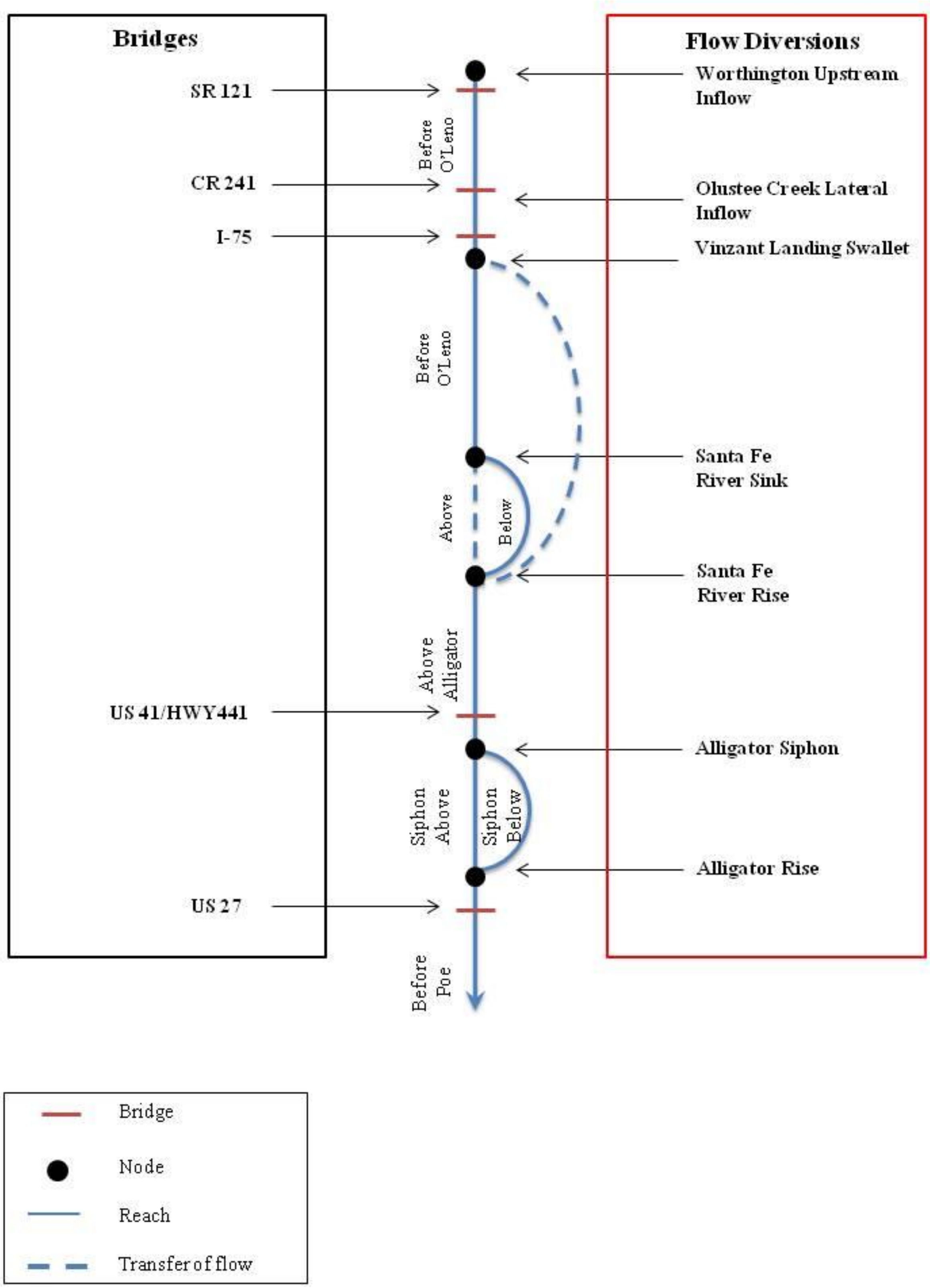


Figure 4-8. Schematic of the Santa Fe HEC-RAS model: Upstream.

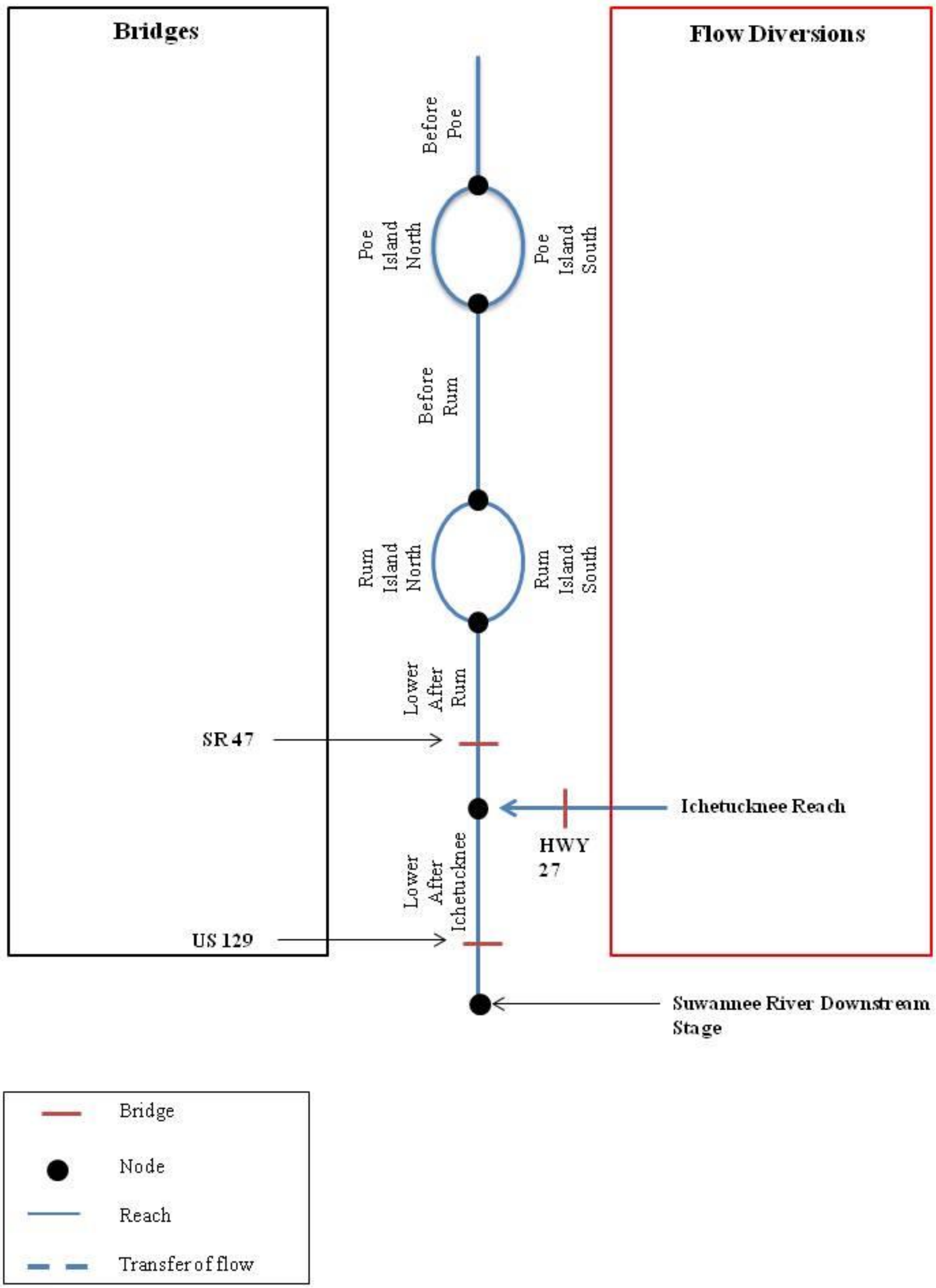


Figure 4-9. Schematic of the Santa Fe HEC-RAS model: Downstream.

4.3.3 Calibration

The HEC-RAS model was manually calibrated using the observed daily stage and flow data from the USGS surface water stations were utilized as calibration targets in the HEC-RAS model including additional flow and stage data for the Ichetucknee Spring Group. The period of record for the Ichetucknee Spring Group surface water stations extended from 2/13/2002 through 9/30/2011. District flow and water-level data at the data logger locations, established by the District during the study, were also utilized in calibration. The District level data loggers had available observed stage for several months (2/1/2011 - 10/6/2011) and were representative of low flow conditions. Daily stage data at the River Rise on the Santa Fe River, collected by the University of Florida for the period from 5/14/2010 to 5/23/2011, were also provided by the District.

Table 4-4 and Table 4-5 list calibration targets and their sources. An asterisk (“*”) denotes an interpolated HEC-RAS cross section. Figure 4-10 and Figure 4-11 show calibration targets on the Santa Fe and Ichetucknee rivers, respectively.

The model of the river was calibrated in a transient state allowing the friction to be adjusted to reproduce the observed stages and flows. Consistency in the friction factors was maintained, avoiding point calibration and increasing the model’s predictive capability. The model was calibrated to the observed stages. The simulated discharge values were compared to the observed discharge values at the stations with flow data. Table 4-6 summarizes final calibration results.

The USGS and the District flow and water-level data were used for calibration at the USGS gaging stations along the Santa Fe and Ichetucknee rivers and at other locations established by the District using temporary loggers during the study. The USGS calibration targets have a relatively long period of stage values representing low and high flow conditions, whereas the District level loggers have stage values of several months (02/01/2011 - 10/06/2011) representing low flow conditions only.

Table 4-4. Lower Santa Fe River calibration targets.

HEC-RAS Station	Name	Source
267046.6	Worthington Springs	USGS
199608.7	O'Leno State Park near I-75	USGS
189142.1	O'Leno State Park at Footbridge	SRWMD
164241.8	River Rise	UF
150850.2	Santa Fe River at US Highway 441 near High Springs	USGS
139200.9	Logger Suckhole near High Springs	SRWMD
136066.5	Logger Canoe Scrape	SRWMD
133585.8	Logger near High Springs	SRWMD
124387.6	Logger at Poe Springs	SRWMD
760.4809	Logger at Rum Island	SRWMD
96627.88	Fort White	USGS
85420.27	Logger at Highway 47 Near Fort White	SRWMD
55732.9	Logger Dog Leg Shoals	SRWMD
37869.58	Santa Fe Point Park (Three Rivers)	USGS
12872.86	Santa Fe River near Hildreth, FL	USGS

Table 4-5. Ichetucknee River calibration targets.

HEC-RAS Station	Name	Source
27976.3	Head Spring	USGS
26116.6*	Blue Hole Spring	USGS
24534.3*	Mission Springs	USGS
23529.4*	Devil's Eye Spring	USGS
20687.3*	Mill Pond Spring	USGS
16758.63	Dampier's Landing	USGS
9901.374	Ichetucknee River at Highway 27 near Hildreth	USGS

Figure 4-10. Lower Santa Fe River calibration targets.

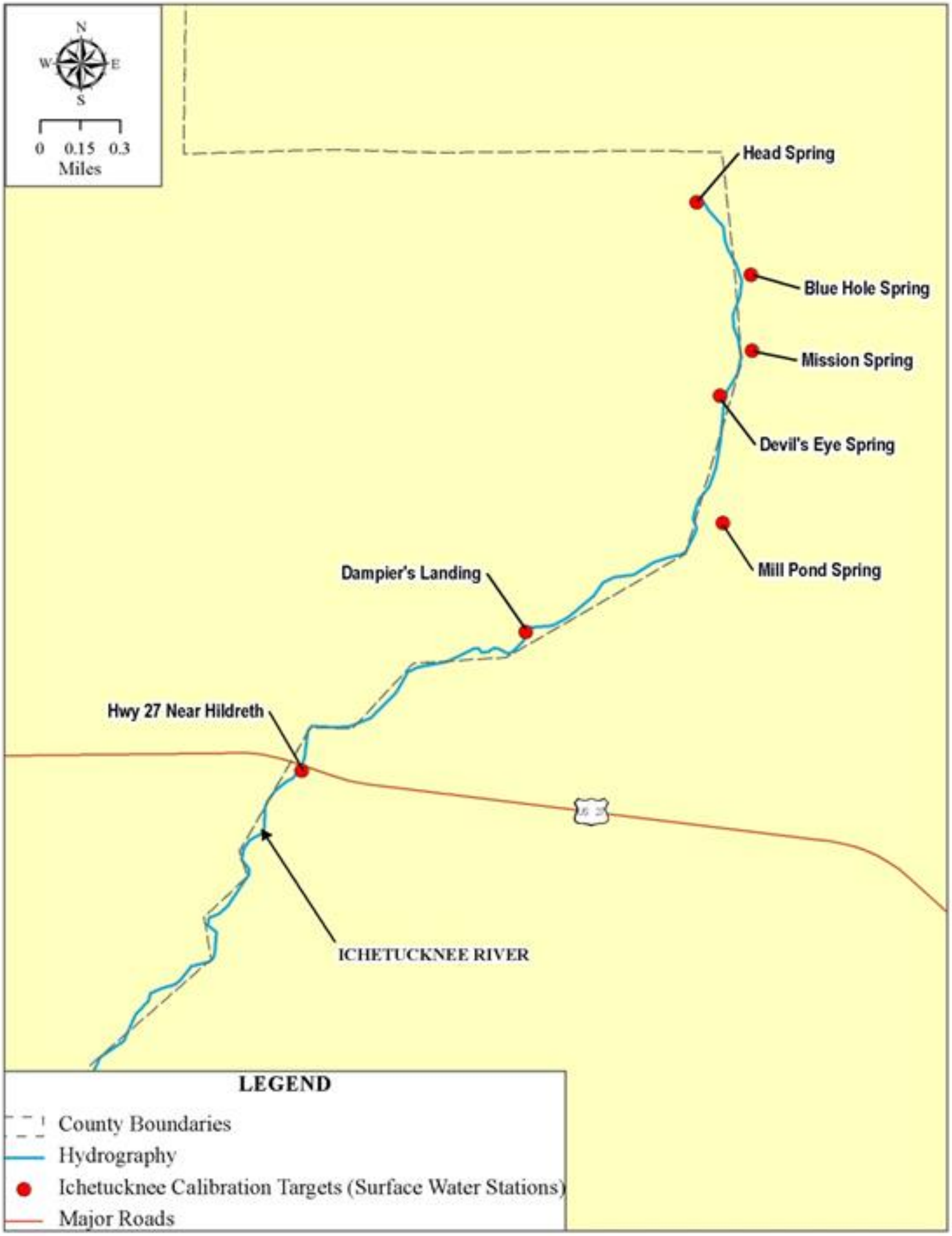


Figure 4-11. Ichetucknee River calibration targets.

Table 4-6. Final Calibration Results.

Name	River	% Stage Residuals within 5%	% Stage Residuals within 0.5 ft	% Stage Residuals within 1 ft	% Stage Residuals within 0.5 ft at Low Flows	Low Flow (cfs)	Sim. Flow - Obs. Flow (%)
Worthington Springs	Santa Fe	98.76%	67.58%	88.72%	85.97%	100	0
O'leno By I-75	Santa Fe	99.79%	67.22%	96.24%	69.65%	100	
O'leno State Park By Footbridge	Santa Fe	88.75%	32.13%	73.04%	34.36%	100	27.0
River Rise	Santa Fe	96.70%	65.35%	90.43%	78.53%	100	
Santa Fe River At Us Highway 441	Santa Fe	92.00%	60.81%	83.70%	79.79%	200	11.9
Logger Suckhole Near High Springs	Santa Fe	95.82%	53.97%	93.31%	57.92%	200	
Logger Canoe Scrape	Santa Fe	98.33%	65.27%	94.98%	68.12%	200	
Logger Near High Springs	Santa Fe	97.50%	84.17%	92.50%	90.54%	200	
Logger At Poe Springs	Santa Fe	100.00%	53.75%	100.00%	51.17%	200	
Logger At Rum Island	Santa Fe	96.25%	66.25%	93.75%	71.30%	150	
Fort White	Santa Fe	90.94%	75.80%	89.47%	90.38%	700	4.8
Logger At Sr47 Near Fort White	Santa Fe	100.00%	21.99%	100.00%	15.66%	700	
Logger Dog Leg Shoals	Santa Fe	60.21%	59.16%	91.10%	49.65%	700	
Santa Fe Point Park (Three Rivers)	Santa Fe	66.34%	62.21%	91.00%	54.36%	800	
Santa Fe River Nr Hildreth FL	Santa Fe	96.76%	96.16%	99.71%	99.09%	1000	0
Head Spring	Ichetucknee	98.58%	95.43%	98.11%	94.94%	50	
Blue Hole Spring	Ichetucknee	98.39%	94.19%	97.89%	93.50%	50	
Mission Spring	Ichetucknee	98.37%	91.65%	97.80%	87.11%	150	
Devil's Eye Spring	Ichetucknee	98.83%	91.28%	98.38%	88.14%	200	
Mill Pond Spring	Ichetucknee	53.73%	29.65%	52.92%	8.13%	200	
Dampier's Landing	Ichetucknee	98.79%	94.82%	98.76%	93.60%	300	-10.1
Ichetucknee River At Highway27 Nr Hildreth	Ichetucknee	98.09%	92.74%	98.51%	93.84%	300	0

Plots of the calibration results include: plots of daily simulated and observed flows, where observed discharge measurements were available; plots of daily simulated and observed stages; plots of stage residuals (simulated stage verses observed stage); scatter plots comparing simulated and observed stages against a 45-degree line; and scatter plots comparing stage residuals and observed stages. The model adequately captures the hydrologic response to all inflows, and the overall hydrograph shape is generally replicated by the model at calibration locations. Refer to Figure 4-12 and Figure 4-13 for example hydrographs at Fort White (a calibration location).

As with any numerical model, instability at very low flows is a common issue in HEC-RAS; computationally, the model cannot simulate a zero flow condition. In HEC-RAS, the use of a pilot channel alleviates the dry channel instability (Hydrologic Engineering Center, 2010). The pilot channel is essentially a computational error in the model since the HEC-RAS pilot channel option cuts an artificial rectangular notch at the bottom of the cross section adding additional area and conveyance. The pilot channel is only active under dry channel conditions. The pilot channel is defined as a 1 foot-wide notch in the true channel cross section and is defined with higher roughness factors to reduce the pilot channel flow. At higher flows, when the depth gets higher, the original cross sectional area is used and the pilot channel is ignored (Hydrologic Engineering Center, 2010). Pilot channels were therefore utilized to keep the model from going unstable in extreme drought conditions

After thorough model calibration in the transient state, the steady state model was developed. The steady state model was utilized for predictive simulations and for use in the ecological modeling of the Lower Santa Fe system.

4.3.4 Steady State Model Simulations

Changes to the boundary conditions of the calibrated transient model were made to develop a steady state model. These steady state simulations were used to correlate critical water surface elevations (i.e. hydric soils), at a particular transect, to a critical flow at the primary gages: the Fort White Gage on the Santa Fe and Highway 27 on the Ichetucknee River. A steady state model requires a known water surface elevation as the downstream boundary condition and a known discharge value at every flow change location.

It was desired by the District to run predictive simulations for every 2nd incremental percentile flow, from the 2nd percentile through the 98th percentile. Therefore steady state input percentile flows at every flow change location were generated for every 2nd percentile from the observed flow and stage conditions. Establishment of appropriate downstream boundary stage conditions for the predictive simulations was an important consideration for MFL development. Stage results for the 20th and 80th percentile downstream boundary conditions are shown in Figure 4-14 and Figure 4-15 for the main Santa Fe River reach; they illustrate the 10 different flow scenarios and their relationship to stage.

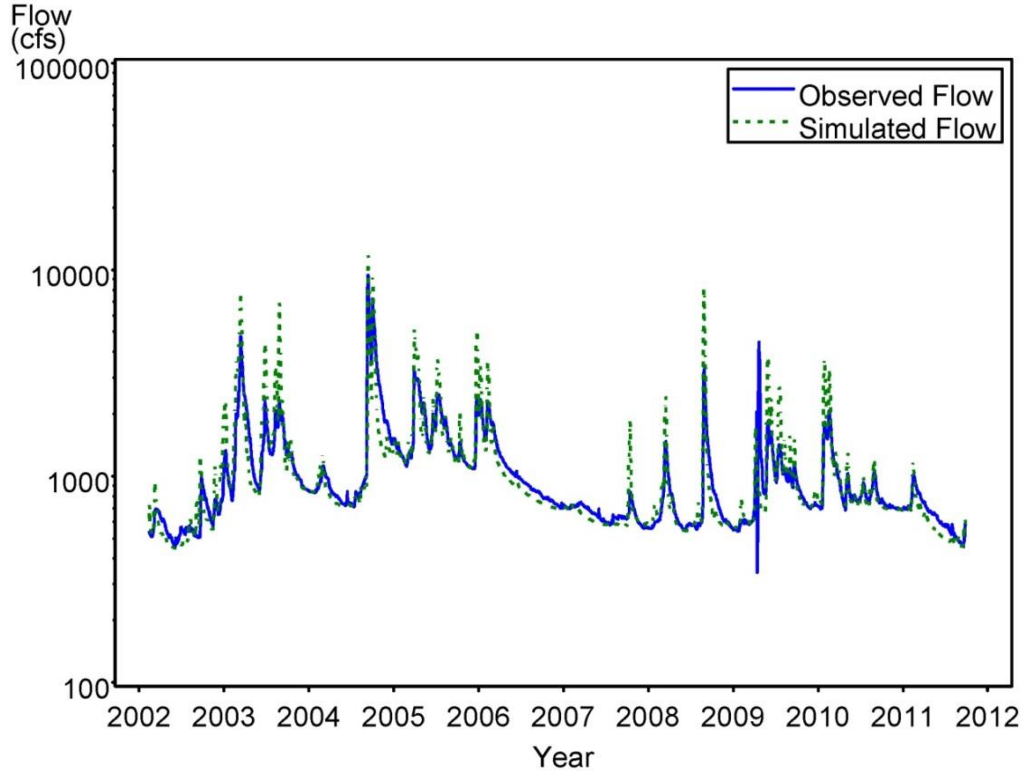


Figure 4-12. Semi-log plot of daily simulated and observed flows at Fort White.

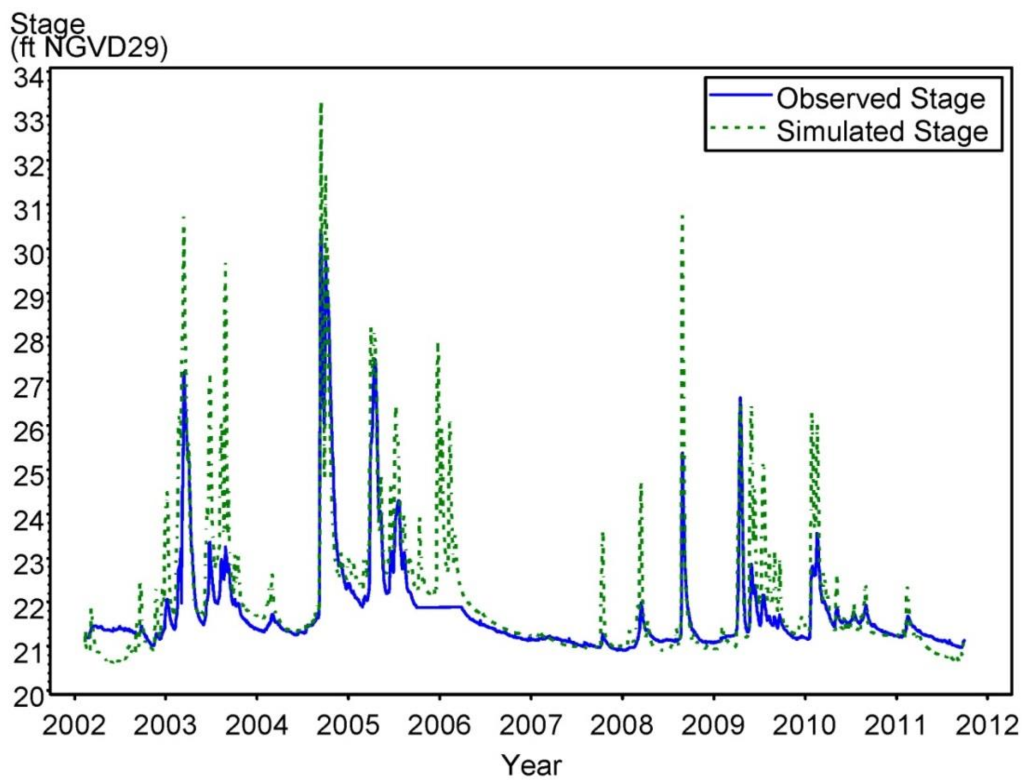


Figure 4-13. Daily simulate and observed stages at Fort White.

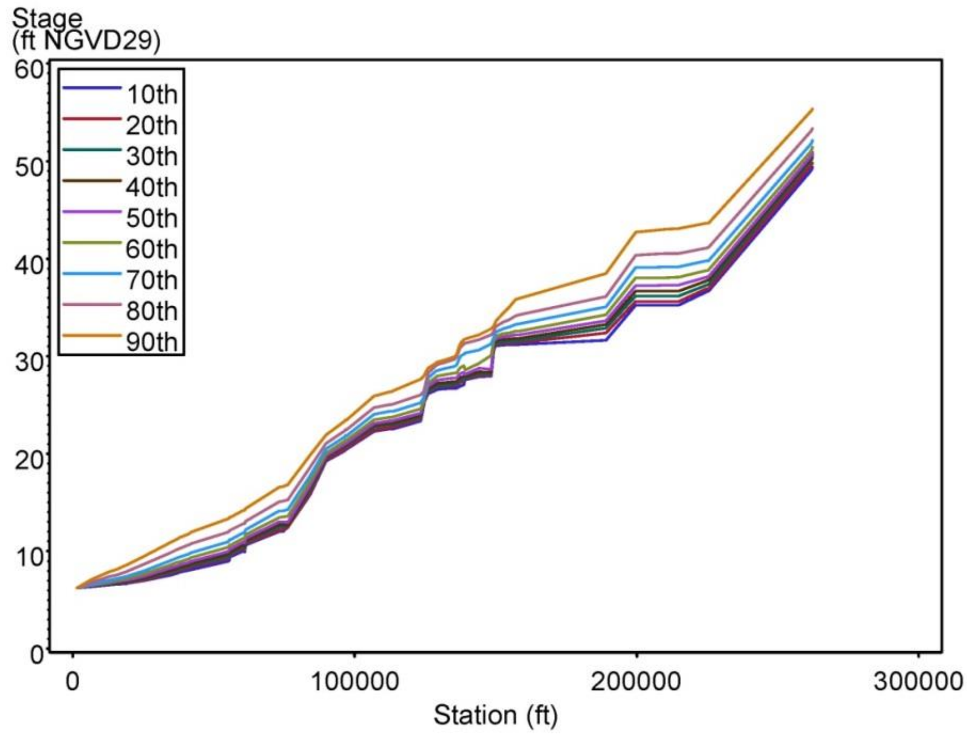


Figure 4-14. Santa Fe River (Main Reaches) water surface profile: STG20 boundary stage.

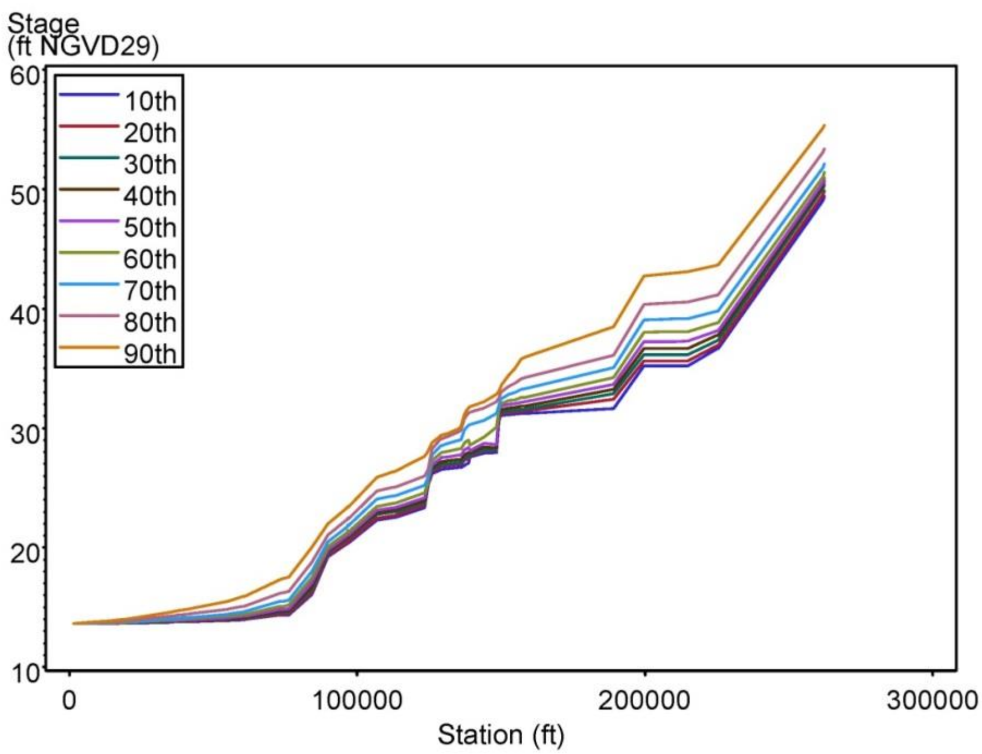


Figure 4-15. Santa Fe River (Main Reaches) water surface profile: STG80 boundary stage.

Results of the simulations show that the tailwater condition created by high stages (80th percentile and greater) in the Suwannee River influences the Santa Fe River as far upstream as (approximately) the Fort White gage (Figure 4-16) and the Ichetucknee River as far upstream as (approximately) Dampier's Landing (Figure 4-17). The 20th percentile (non-exceedance) downstream Boundary condition was used for all in-channel and out-of-channel WRV analyses. The selection of the 20th percentile Suwannee Stage was deemed most appropriate, since it minimized the influence of the Suwannee River backwater effects to the Santa Fe and Ichetucknee rivers. Using a low backwater effect best simulates what flows are needed to protect the Ichetucknee and Santa Fe River communities.

At the remaining percentile stages, tailwater conditions did not control the flow of the Santa Fe and Ichetucknee rivers. Each 2nd percentile flow and stage condition was run in steady state within HEC-RAS. The detailed output for each steady state run was exported to an ASCII output file in order to define the horizontal velocity distribution for ecological modeling and habitat suitability analysis in support of MFL development. The suite of model simulations and tabular output are fully described in Appendix 4-1.

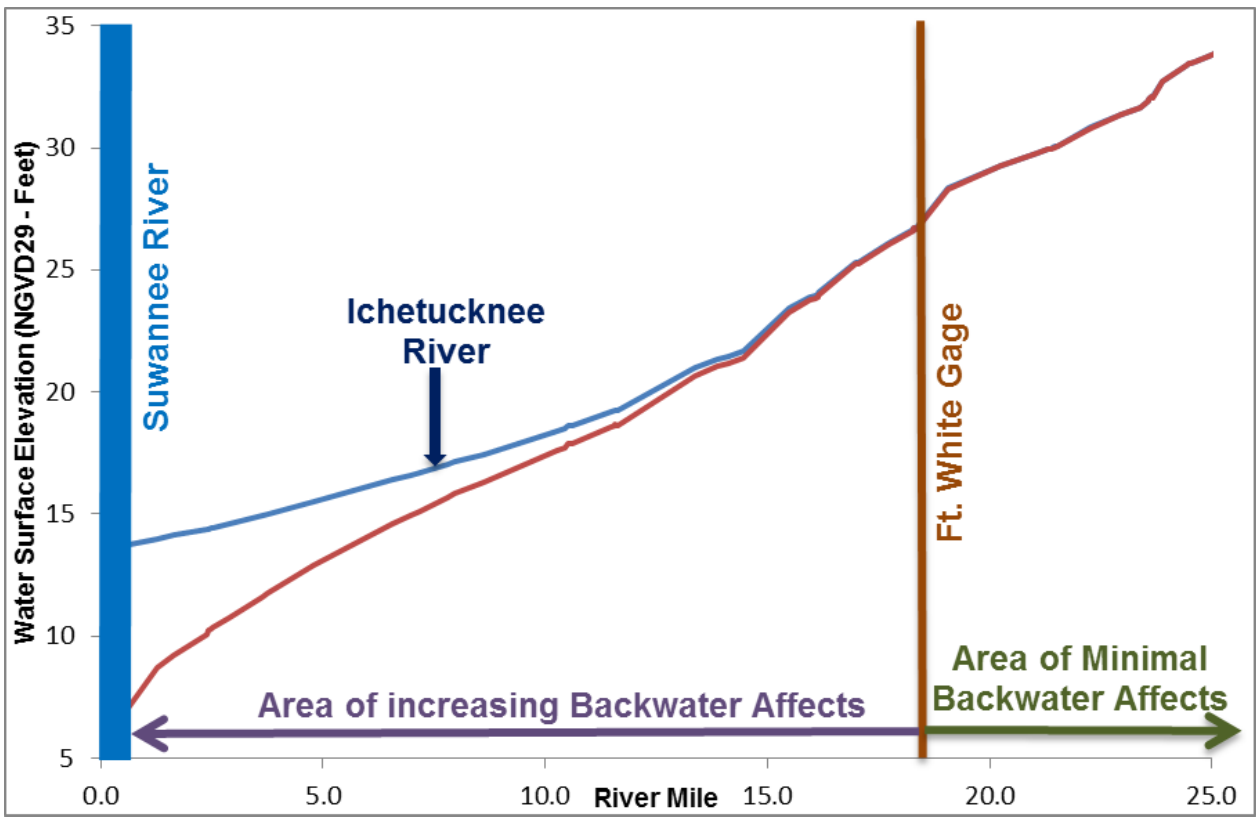


Figure 4-16. Suwannee River Tail water affects on the Santa Fe River.
Note: Graph depicts the 98% Santa Fe Flows, and the 80% Suwannee Stage (red), and the 20% Suwannee Stage (blue).

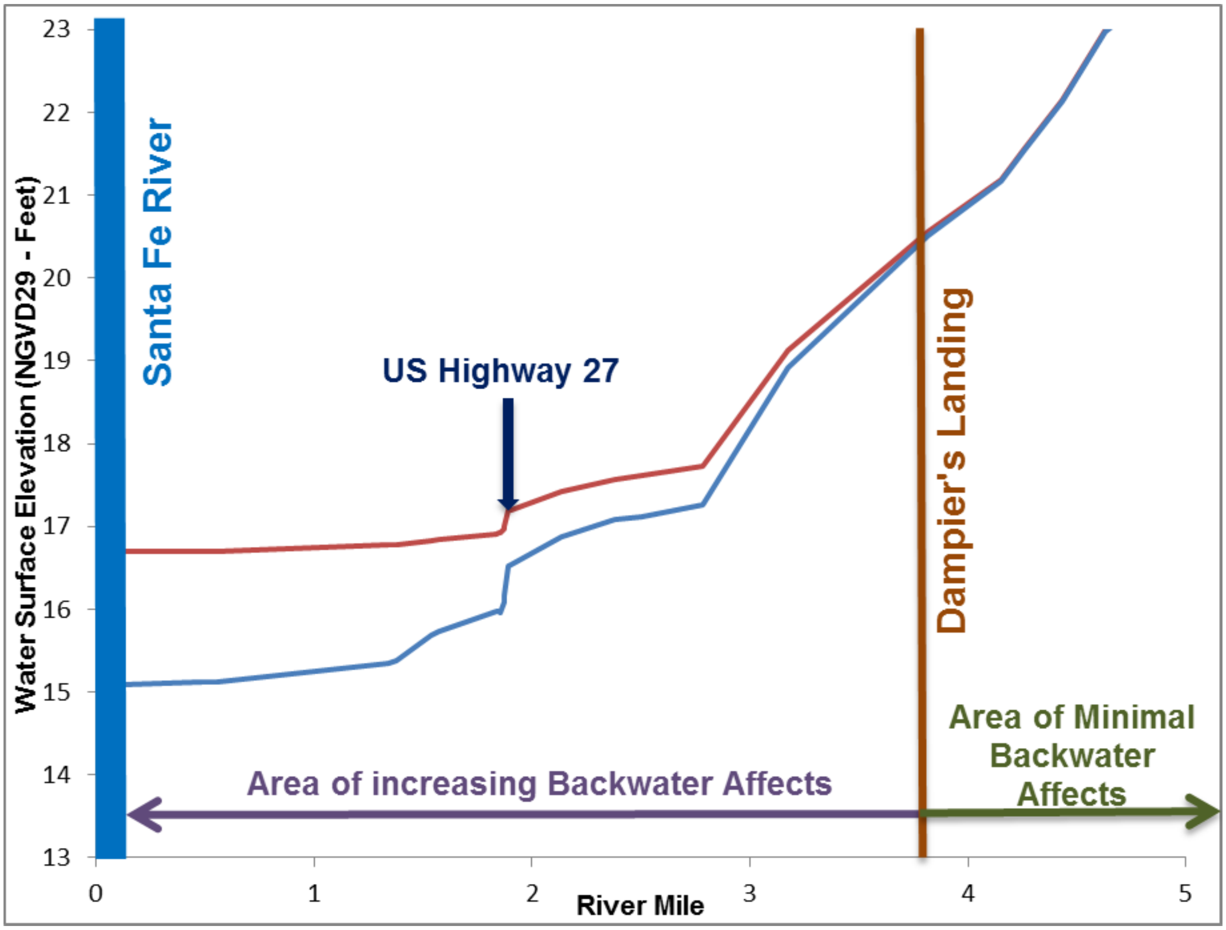


Figure 4-17. Tailwater affects on the Ichetucknee River
Note: Graph depicts the 98% Ichetucknee, and the 80% Suwannee Stage (red), and the 20% Suwannee Stage (blue).

4.3.5 Model Application in Critical Flow Determination

For many of the Water Resource values, a critical water surface elevation is determined (see Section 5.0), then converted into a flow at a gage; the HEC-RAS model is germane to this process. First a critical water surface elevation is determined at a transect for a water resource value of interest (i.e. inundation of hydric soils). This critical water surface elevation corresponds to a model exceedance probability at the cross-section. The model exceedance probability is then translated to a flow at the gage (Figure 4-18)

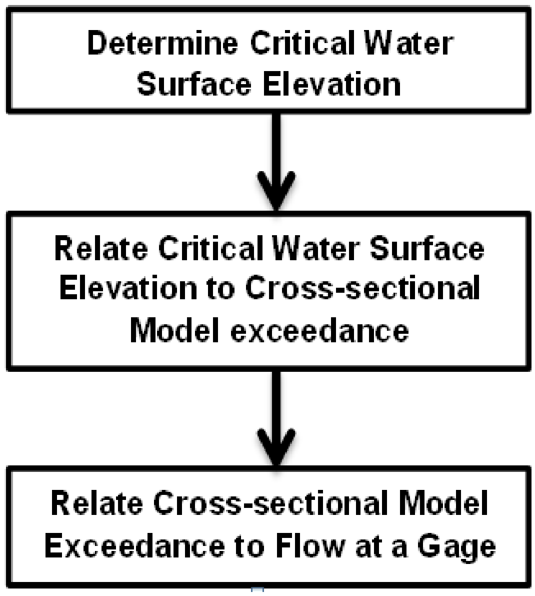


Figure 4-18. Critical elevations to Critical Flows Flow Chart using HEC-RAS

4.4 BASELINE DEVELOPMENT

4.4.1 Watershed Yield

Water yield has been defined as the annual yield of a basin (expressed in inches), which is obtained by dividing annual flow by drainage area (Carter, Driscoll, Williamson, & Lindquist, 2002). As used here watershed yield is defined as the ratio of annual mean discharge to total annual rainfall, the discharge having been transformed as described previously (Bales, 1996).

Watershed yield is a dimensionless term that provides a long-term estimate of the portion of precipitation that appears as streamflow. Watershed yield plots for three gages in or near the study area are provided as Figure 4-19, Figure 4-20 and Figure 4-21, for the Worthington Springs, Fort White and Ichetucknee at US27 sites. Examining how watershed yield changes through time is a useful exploratory analysis that can help in determining if the flow in the river is being influenced by factors other than rainfall. Based on this information it appears that the trend in yield is for the Santa Fe River system to produce less streamflow, on average, over the last 10-20 years than during the prior five-plus decades.

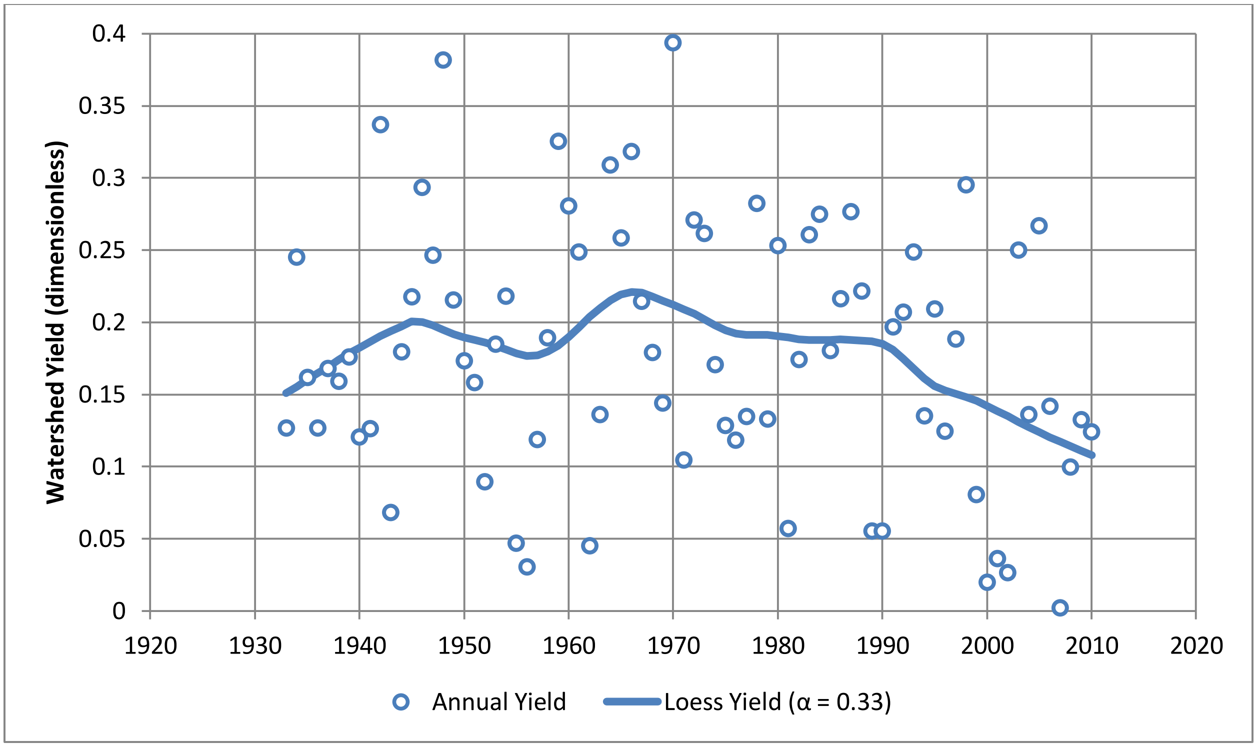


Figure 4-19. Worthington Springs Annual Yield

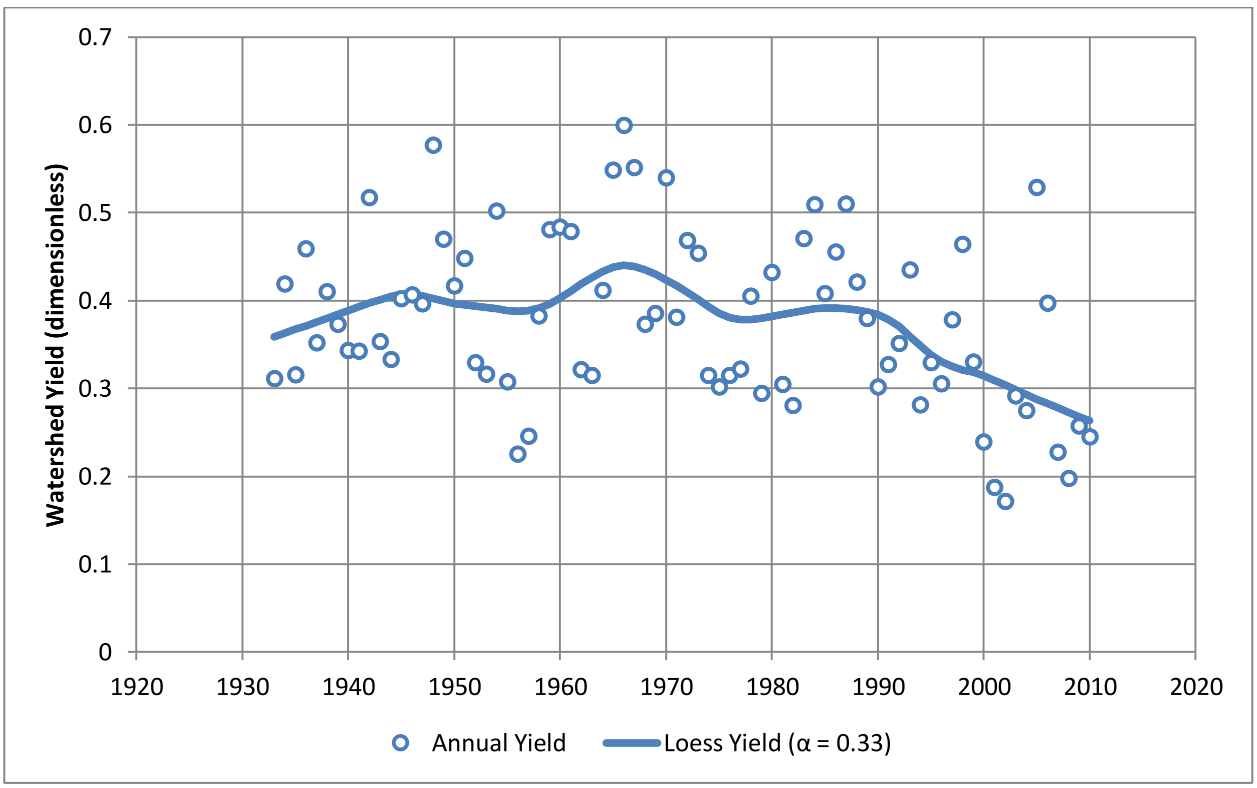


Figure 4-20. Fort White Annual Yield

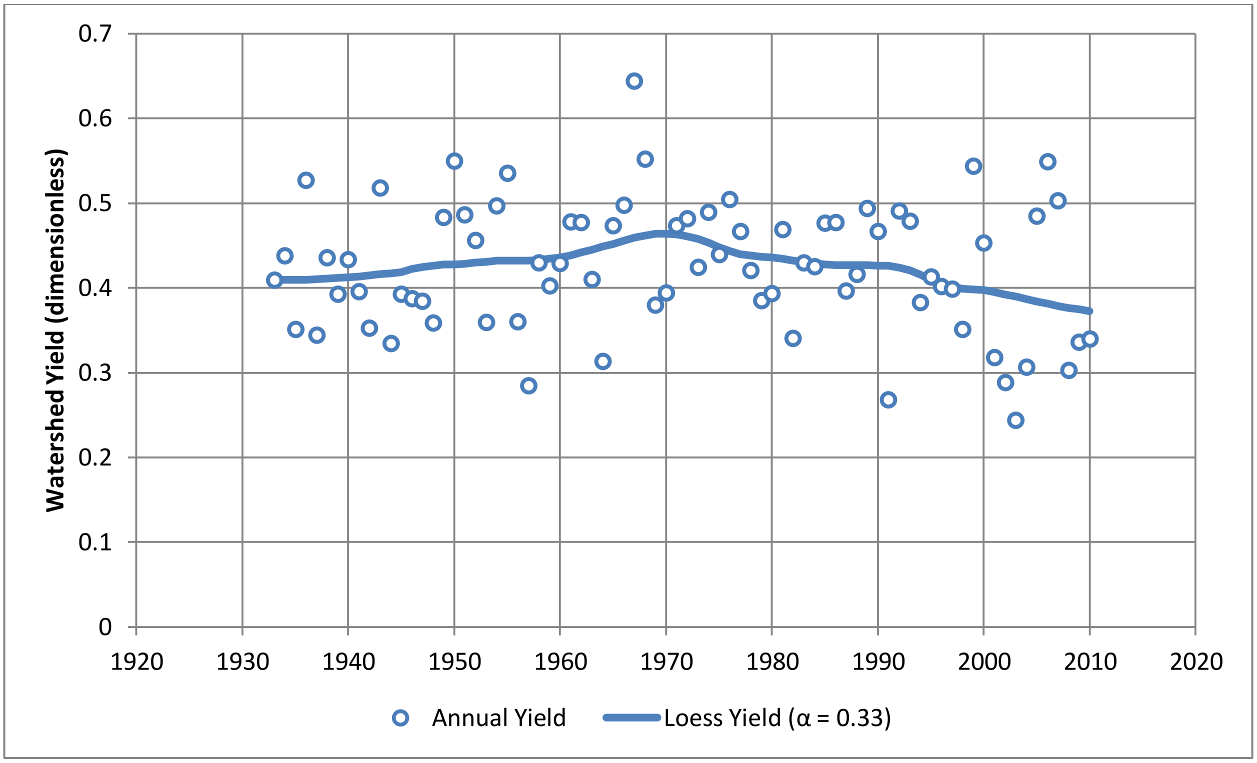


Figure 4-21. Ichetucknee Annual Yield.

4.4.2 Baseline

As pointed out by Beecher (1990), one essential element in establishing a MFL is the definition of a baseline period during which environmental characteristics are deemed appropriate. A combined analysis of flow and rainfall data were used to identify a baseline period. This period is defined as the historical hydrologic condition (as referenced in Chapter 373.0421, F.S.), at the two selected MFL gages, the Santa Fe River near Fort White and the Ichetucknee River at Highway 27.

To determine a specific baseline period the previous watershed yield information was confirmed with an analysis of the annual relationship between effective rainfall and streamflow. A model was developed that used the previous two years effective rainfall to predict the current year's average annual flow. The modeling results are summaries here; see Appendix 4-2 for a more detailed description. The initial model used data from water year 1933-2010 (Figure 4-22). The initial model displays a trend of increasing residuals up to about 1990 followed by a trend of decreasing residuals after 1990. After reviewing the results from the first model a second model was fit to data from 1933-1990. The cumulative residuals are fairly stable around zero with some deviations prior to 1990. However after 1990 the cumulative residuals decrease rapidly. Fitting a model to the 1933-1990 time period leads to overestimation of observed flows post 1990. This demonstrates that there has been a change in the rainfall runoff relationship after approximately 1990. If there were no change in the rainfall runoff relationship after 1990 the model fit to 1933-1990's cumulative residuals would aggregate near zero. See Appendix 4-2 for a more detailed description of the statistical modeling used for selection of the baseline period.

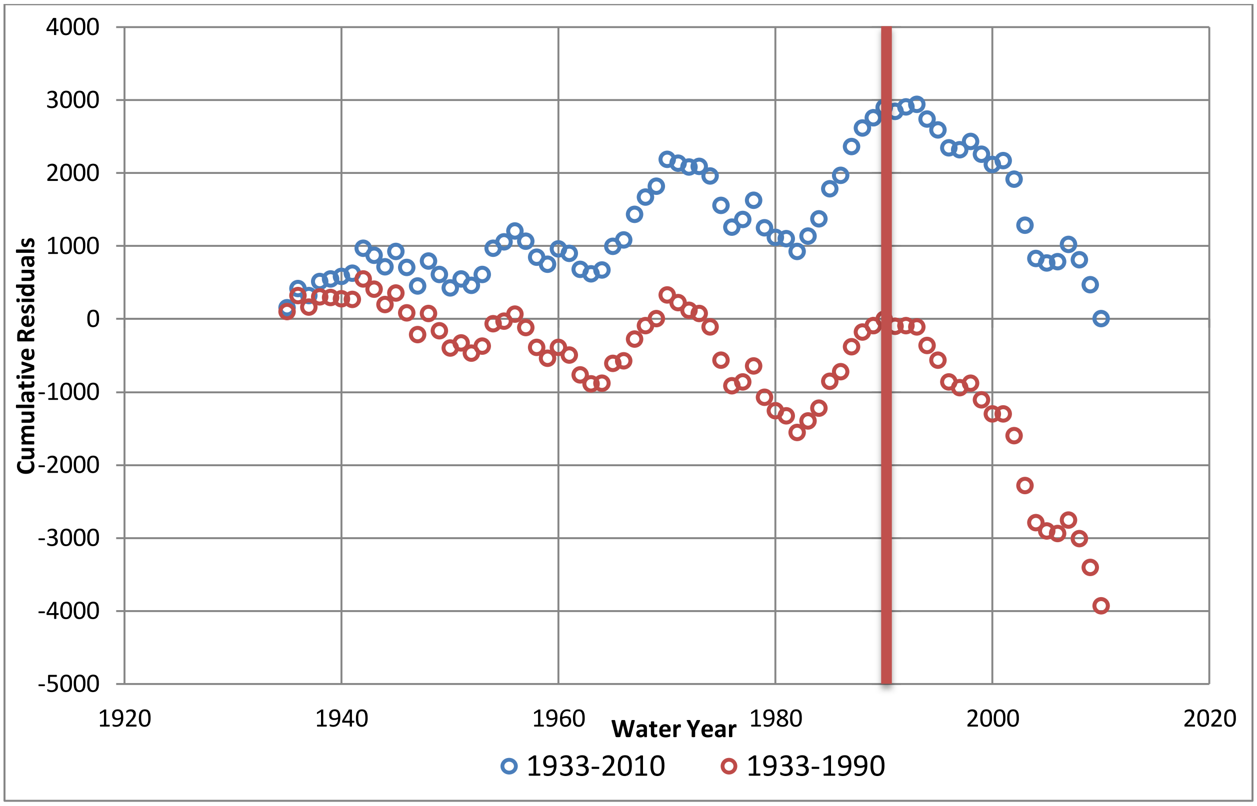


Figure 4-22. Cumulative Residuals for annual linear models for Santa Fe River at Fort White (02322500)

There is considerable uncertainty in synthesizing a baseline flow regime that lacks anthropogenic affects. Consideration of the uncertainty resulted in the selection of a baseline period of observed data for use in determining MFLs with no correction for anthropogenic affects applied to this period. This historical hydrologic condition was used as a flow baseline (called the Baseline Flows or Baseline Flow regime). The historical hydrologic condition is defined by the observed flows from water year 1933-1990 for both the Santa Fe and Ichetucknee rivers.

The selection of the Baseline Flow regime as the period from 1933 through 1990 does not imply that the period prior to 1991 had no impacts to river discharge. Instead it is used to define a period of time when the rainfall-streamflow relationships were relatively stable, with no reference to presumed anthropogenic effects. On average, during the period after 1990 the river responds with less discharge per unit of rainfall than it did prior to 1990.

5.0 DEVELOPMENT OF MINIMUM FLOWS AND LEVELS

This section provides the basis for the development of MFLs for the Lower Santa Fe and Ichetucknee rivers and associated priority springs.

5.1 BACKGROUND

As discussed in Section 1.0, according to state law, MFLs are to be established based upon the best available information (Section 373.042, F.S.). Also, according to the State Water Resources Implementation Rule (Chapter 62-40.473, Florida Administrative Code), "*consideration shall be given to the protection of water resources, natural seasonal fluctuations in water flows or levels, and environmental values associated with coastal, estuarine, aquatic, and wetlands ecology*." The following provides a discussion of the water resource values (WRVs) from Chapter 62-40 and the sources of information or data used in establishing the MFLs for the Lower Santa Fe and Ichetucknee rivers and priority springs.

5.1.1 Floodplain Vegetation and Soils

Watershed-wide vegetation and soils information was useful in characterizing the Lower Santa Fe and Ichetucknee rivers watersheds and local hydrology. Natural habitats and developed (urban or agricultural) land have very different characteristics with respect to influencing the hydrologic cycle, as described in Section 4.0. The following summarizes specific sources of data and the analyses in which the data were utilized.

Study area vegetation and land use information were obtained from the District as ARC-GIS shapefiles. The latest available data set reflects land use conditions during the 2006 through 2008 period and is based on the Florida Land Use and Cover Classification System (FLUCCS) (FDEP, 2009). Given the modest pace of land use change in the watershed, these data reasonably represent current conditions.

Soils data were obtained from the USDA Natural Resources Conservation Service (NRCS). NRCS data are the standard for soil classification and include numerous soil properties that are important to hydrologic and ecologic processes.

The floodplain analysis was a critical element in MFL development for the Lower Santa Fe and Ichetucknee rivers. Floodplain inundation is critical for both vegetation and biota. The development of transect topography for this analysis, and a description of specific sources of vegetation and soils data, and the analyses in which the data were utilized, follow. Information obtained at the floodplain transects was used to assess relationships between water levels and floodplain vegetation and soils elevations. Floodplain vegetation and soils information was obtained at 11 locations on the Lower Santa Fe River Figure 5-1 and six locations on the Ichetucknee River (Figure 5-2). The transect locations were identified based on site visits and a review of topographic and vegetation mapping, aerial photography, and practical considerations such as physical ease of access and land ownership. The surveyed transects were flagged in the field, and the ground elevations along the transects were then surveyed. The transects generally extended to the landward edge of floodplain wetland vegetation, which roughly coincided with the upland limit of the 10-year floodplain (Atkins, Inc., 2012). Hydrologic indicators of flooding were also surveyed. Ground level surveys were combined with Light

Detection and Ranging (LiDAR) data to develop an extended digital elevation model (DEM) for the analysis.

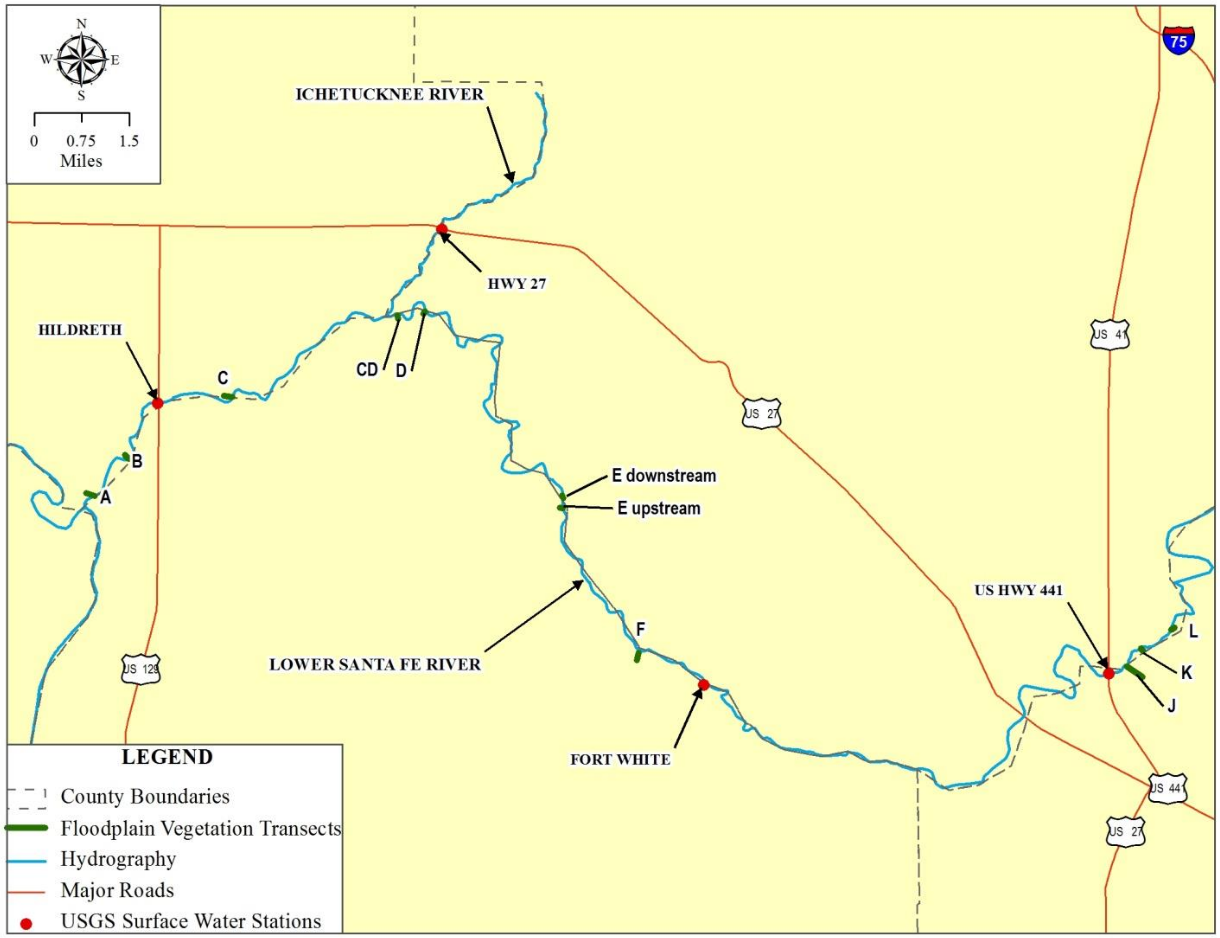


Figure 5-1. Location of floodplain vegetation transects on the Lower Santa Fe River.

Vegetative communities identified during the transect selection process were characterized by general community type, species cover, elevation, and soils (Atkins, Inc., 2012). Dominant tree species and their importance values were defined to further classify the vegetative assemblage. Identified vegetated communities included bay swamp, cypress popash swamp, cypress swamp, hardwood swamp, hydric hardwood hammock, hardwood cypress, and mesic hardwood hammock. The extent of the communities was mapped along the transects and average ground level elevations for each community were determined based on topographic surveys of the transects.

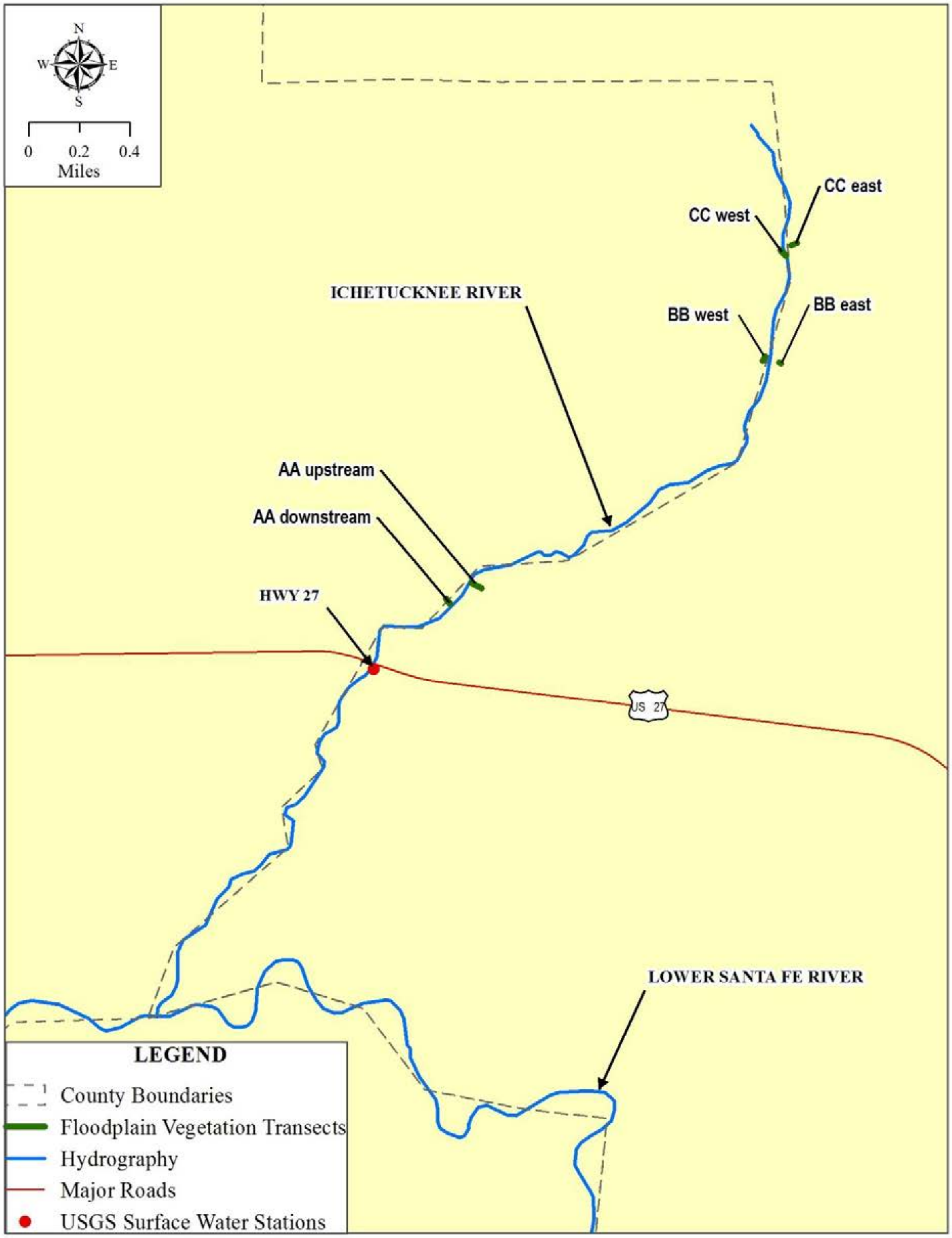


Figure 5-2. Location of floodplain vegetation transects on the Ichetucknee River.

Site-specific soils data were collected along the floodplain transects described above. Soil profiles were examined to identify hydric soils which are either saturated or flooded for a duration necessary to support a prevalence of wetland plant species, and non-hydric soils, which are not. Delineating hydric soils is a common approach to determining the extent of wetlands. In the field, the depth to seasonal high groundwater was estimated at locations along the transects, and soil cores were examined for evidence of hydric soil characteristics.

The transect-specific elevation, vegetation, and soils data were used as factors in the floodplain inundation analyses. The frequency of inundation of the wetland communities under baseline conditions was determined. The change in the inundation frequency was then examined using incrementally reduced flows, until a threshold indicating adverse impacts was reached. The threshold represented a percent reduction in floodplain inundation frequency caused by lower flows.

5.1.2 Instream Water Quality, Habitat, and Biota

The heart of the Lower Santa Fe and Ichetucknee rivers is their stream channels. The physical features of the channels influence instream water quality, habitat, and living resources. Water quality in turn affects habitat availability, which is critical for providing protective cover and food sources for aquatic flora and fauna. Thus water quality, habitat, and biota are all interdependent and equally important for sustaining a healthy river system. Data used to assess potential changes to instream water quality, habitat, and biota resulting from changes in the hydrologic regime are described in this section.

WATER QUALITY

Improving water quality is not the focus of the MFL program, but the hydrologic regime must be maintained to prevent degradation to current water quality conditions caused by excessive flow reductions. The following summarizes surface water quality data that were assessed in the development of the MFL for the Lower Santa Fe and Ichetucknee rivers.

The District provided all relevant water quality data for Lower Santa Fe River sampling sites (SFR050C1, SFR060C1, and SFR070C1), and Ichetucknee River sites ICH001C1 (at the Main Spring) and ICH010C1 (just upstream of the US 27 bridge) (Figure 5-3). Water quality data have been collected on a monthly basis from 1989 through 2013 for the Lower Santa Fe River sites, and from 1991 to 2002 for site ICH001C1. Sampling at the spring head was sporadic.

Water quality data obtained from grab samples collected in the Lower Santa Fe and Ichetucknee rivers were assessed to determine any relationships that may be evident between water quality and river discharge. Parameters investigated included specific conductance, pH, dissolved oxygen (DO), color, total Kjeldahl nitrogen (TKN), total nitrite + nitrate (NO_X), total ammonium (NH_4^+), total phosphorus (TP), dissolved orthophosphorus (PO_4), and chlorophyll a (CHL).

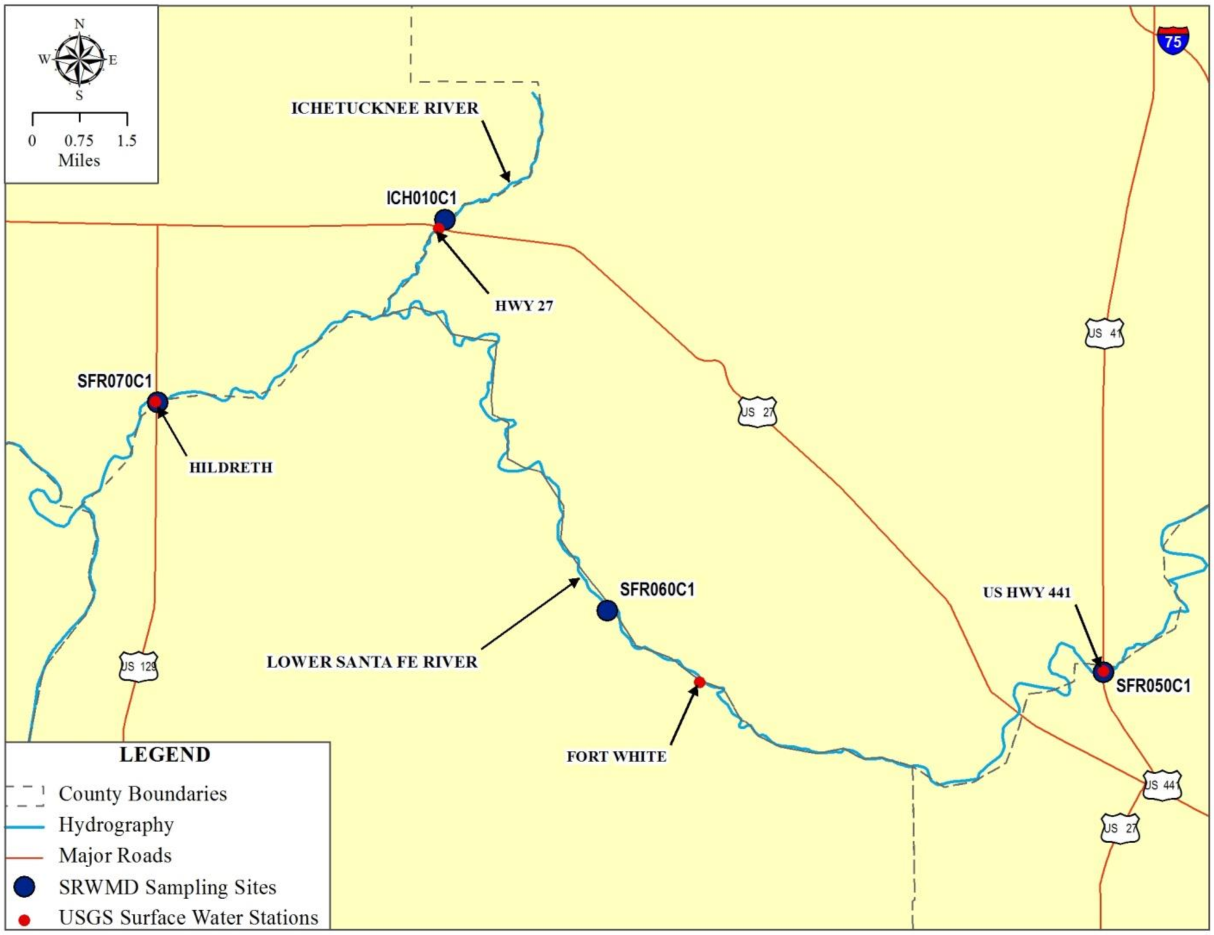


Figure 5-3. Location of District water quality sampling sites.

INSTREAM HABITAT

The availability of instream habitats is important for many fish and benthic macroinvertebrates, as it provides protective cover and sources of food. Instream habitats must be at least periodically inundated to be of use to aquatic organisms. Habitat data were collected to characterize the following features relevant to the development of the Lower Santa Fe and Ichetucknee rivers MFL:

- fish passage,
- habitat suitability, and
- woody habitat.

The following summarizes specific sources of data and the analyses in which the data were utilized.

Fish Passage

Under low-flow conditions, water depth can be an obstruction to the longitudinal passage of fish up and down a river. The Lower Santa Fe and Ichetucknee rivers are not known to be heavily used by anadromous fishes such as the Gulf sturgeon or American shad. However, the ability to move up and down a river is important for many fish species to escape predation or undesirable conditions, or to find food sources or spawning habitat.

Information used to examine the potential for limited fish passage under baseline and altered river flow conditions was obtained from HEC-RAS hydrologic model transect geometry data (developed by INTERA, Inc. and described in Subsection 4.3 and Appendix 4.1 (Figure 5-4)). Model input included river mile, and longitudinal distance and elevation coordinates for topographic transects arranged normal to the flow path along both rivers from the confluence of the Lower Santa Fe and Suwannee rivers upstream to above River Sink, and the entire length of the Ichetucknee River. The fish passage analysis required that the point of lowest elevation at each model transect (the thalweg) be identified. The river water level (stage) at each transect was compared to the thalweg elevation across a wide range of flow conditions. The flow resulting in a water depth of no less than 0.8 feet over 25% of the river channel at each transect was determined to be the Critical Flow for fish passage (SJRWMD, 2012).

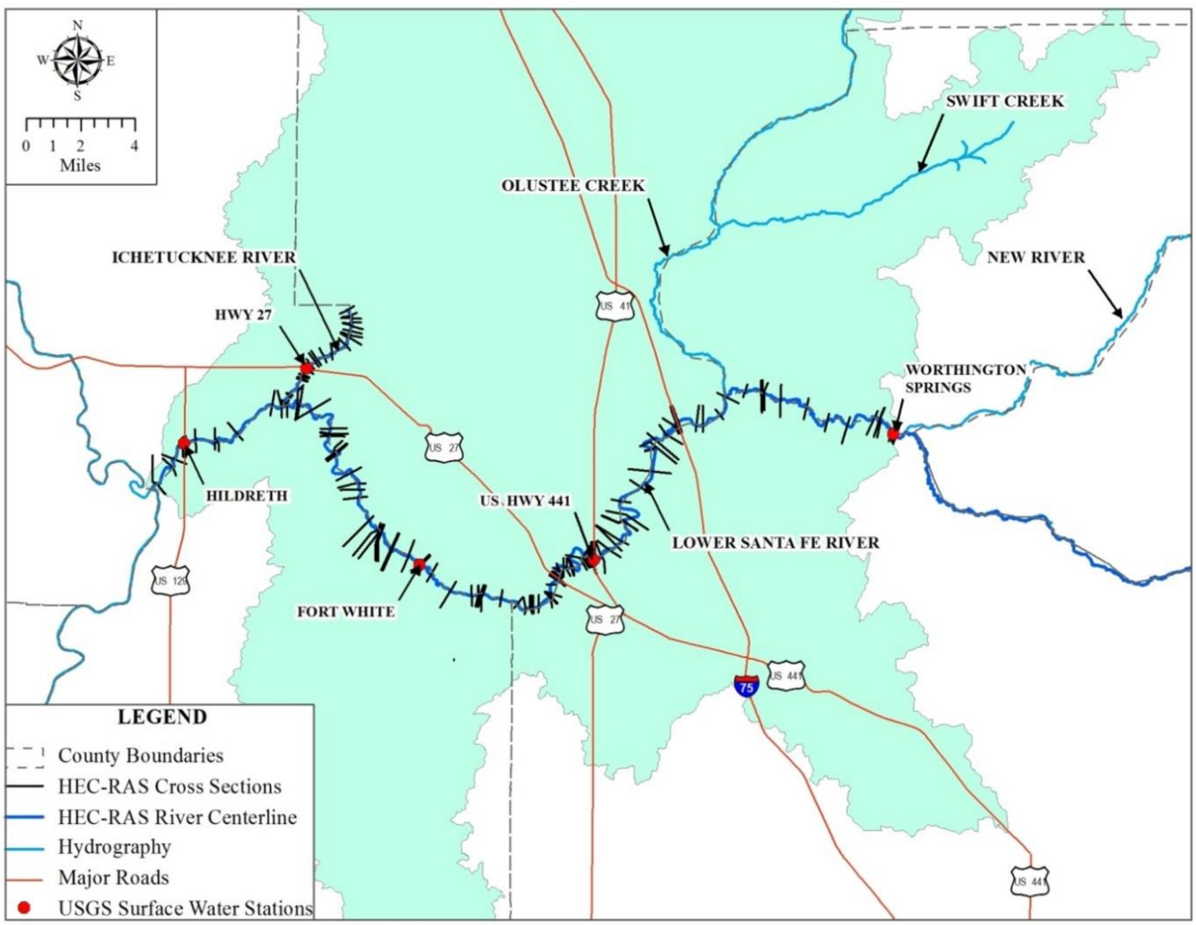


Figure 5-4. Location of the combined Lower Santa Fe/Ichetucknee River Model.

Habitat Suitability

It is critical to obtain information regarding existing instream conditions with respect to biological indicators' habitat preferences in order to assess the potential for impacts to the natural system based on hydrologic alterations. One approach to impact assessment is through ecologic modeling using the RHABSIM model (Thomas R. Payne & Associates, 1994). The habitat suitability assessment required the use of both field data describing local instream conditions and literature values of species' habitat condition preferences. These data are used as input to the RHABSIM ecologic model.

Environmental data used as RHABSIM input was obtained. Four locations were selected on the Lower Santa Fe River to provide information for the RHABSIM model (Figure 5-5). The locations were intended to represent larger river segments, with specific regard given to significant habitat types (pool, shoal, and river run). Pools provide deeper water refuges for fish. Shoals are important because they provide spawning grounds and, during low-flows, can be a limiting factor for species migration. River runs represent typical open flowing water conditions. Two locations downstream of the Fort White USGS gage were selected (the Fort White and Dog Leg locations). Two selected locations (Power Line and US 441) were upstream of Fort White and downstream of the USGS gage at US 441. The surveyed RHABSIM transect locations were included in the HEC-RAS geometry. Model transects have detailed topography, and the HEC-RAS model provided a range of flow estimates for each transect. Data were collected to obtain profiles of water velocity, water depth, and substrate classification at each transect.

The RHABSIM model compares field data with habitat preferences for a variety of biological indicators (fish species and life stages, and benthic macroinvertebrates). Habitat Suitability Indices (HSI) have been developed for each indicator that specify preferences for a range of flow velocities, water depth, and substrate type (sand, mud, vegetated, etc.). HSI for Florida-specific indicators have been developed through a variety of methods. Several were developed by the Southwest Florida Water Management District (SWFWMD) through the use of the Delphi method (using several expert biologists to give their best professional judgment). Others were developed by a SWFWMD contractor.

The HSIs were obtained from SWFWMD and used in RHABSIM, complimented by data collected in the field (appendix 5-5). The parameter, referred to as weighted usable area (WUA), was developed for each biological indicator over a range of flows. The maximum WUA for each indicator was identified, and the change in WUA resulting from incremental reductions in flows was assessed. The flow reduction resulting in a threshold reduction in WUA was determined to be the Critical Flow reduction for that indicator.

Figure 5-5. Location of the surveyed transects for RHABSIM and woody habitats.

Woody Habitat

Woody habitat provides both food sources and refuge for many types of biota. Water levels must be maintained to allow woody habitats within the stream channel to be periodically flooded. Woody habitat includes both submerged snags and exposed roots.

The District collected field data describing the elevation of woody habitat, including both submerged snags and exposed roots, at four locations along the Lower Santa Fe River channel. Data were collected at the same sites that were used for the habitat suitability modeling. Elevations of the top and bottom of the woody habitat features were measured at three transects at the four locations (Dog Leg, Fort White, Powerline, and US 441), shown in Figure 5-5 above.

The frequency of inundation of woody habitat under baseline conditions was determined. The change in the inundation frequency of woody habitat was then examined using flows that were reduced incrementally, until a threshold indicating adverse impacts was reached.

Biota

Physical and chemical features, as well as anthropogenic activities, within instream environments determine the distribution and composition of aquatic biota. The mosaic of conditions along the river reaches creates areas of varying suitability for plants and animals, which can vary on a daily, seasonal, or annual basis. Living resources that are ecologically, recreationally, and aesthetically important in the Lower Santa Fe and Ichetucknee rivers include:

- benthos,
- fisheries, and manatees, and
- submerged aquatic vegetation (SAV).

The following summarizes specific sources of data and the analyses in which the data were utilized.

Benthos

Benthic macroinvertebrates serve as an indicator of the ecological health of a water body. Because many species are sessile or have limited mobility, their survival is dependent on immediately surrounding conditions. Environmental factors that can influence benthos include physical habitat type (substrate, vegetation, and water body morphometry), flow regime in lotic systems, water quality (temperature, dissolved oxygen, clarity, nutrients, and contaminants), and the degree of anthropogenic disturbance, which can affect all the above factors. Thus, the conditions of the benthic community provide a synthesis of surrounding conditions.

Both raw data and summary statistics from benthic macroinvertebrate sampling in the Lower Santa Fe and Ichetucknee rivers were derived from the District database; the sampling sites in the Lower Santa Fe and Ichetucknee rivers with benthic macroinvertebrate data are SFR050C1 (at US 441) and SFR070C1 (at US 129) (Figure 5-3). Data were available from quarterly samples for the period 1990 through August 2010 for both sites. One sample was reported for site SFR050C1 in 1983. Taxa are identified to the species level as feasible. Summary statistics were also provided for each sample replicate, and for pooled replicates at the sample level. The statistics included number of individuals, number of species, and measures of diversity. Additionally, District staff provided a summary of dominant taxa at both sampling sites.

These data were used to identify relationships between benthic macroinvertebrate community characteristics and river flows. A series of flow conditions across the entire hydrologic regime was assessed. Same day, cumulative, and lag flows were compared to benthic invertebrate community structure.

FDEP provided data from their surface water monitoring program for the Stream Condition Index (SCI). The SCI represents an array of indicators of biological diversity to indicate whether a site is representative of natural conditions in its region based on benthic species composition, diversity, and community structure, and is a means of assessing water bodies impaired by human activity (FDEP, 2011b). SCI scores are calculated using different algorithms depending on the bioregion that the site is located in. The Santa Fe River watershed is unique, in that it is located in the Big Bend bioregion but is bounded by both the Peninsula and Northeast bioregions. Data from 10 sites on the Lower Santa Fe River were collected between 2004 and 2011, but only one site (SFR050) had more than two samples (Figure 5-6). On the Ichetucknee River, one site (ICHETUKN) had 13 samples taken between 2004 and 2008, and the two other sites had one sample each. As with the District's benthic data, the SCI information was compared to a variety of river flow conditions to identify any causative relationships.

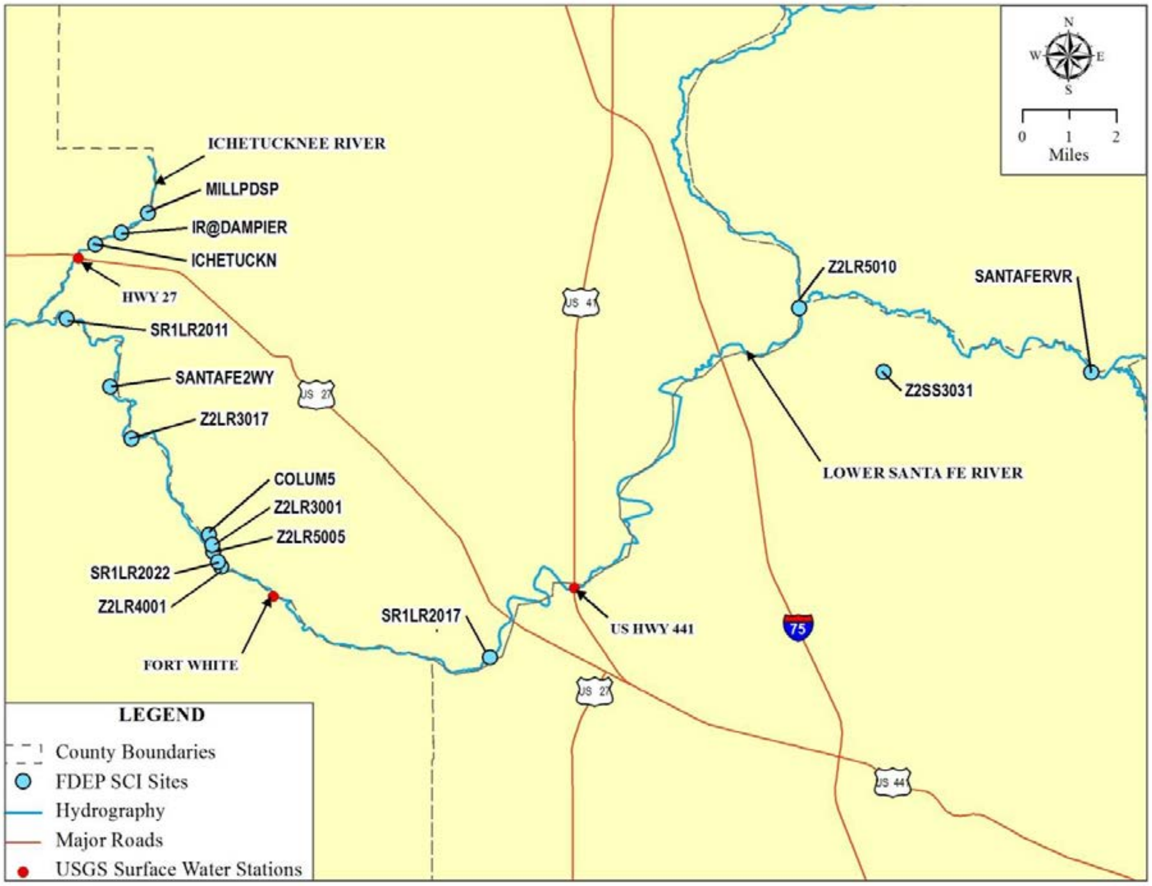


Figure 5-6. Location of FDEP Stream Condition Index sampling sites.

Fish

The abundance and distribution of fish also acts as an indicator of a river's ecological health. Fisheries sampling data can be used to identify conditions under which desirable species are most likely to thrive. Although river flows and water quality do influence fish survival, it is the water level (stage) that is most important to protecting fish physical habitat. Different species need, or prefer, instream or floodplain habitats that are only periodically flooded, thus it is critical to maintain an inundation frequency that allows for spawning and a protective habitat for fry and juveniles.

Fisheries data collected and reported by the Florida Fish and Wildlife Conservation Commission (FWC) were obtained and reviewed. Sampling methods included electroshocking and seining. Samples were collected between 2003 and 2012 at sites along the Lower Santa Fe River (). Fisheries data were not used directly in any quantitative analysis because of sparse temporal and spatial coverage. However the dominant species that were identified helped to characterize the river reaches. Habitat suitability modeling with RHABSIM was used to specify conditions most advantageous to important fish species including the largemouth and Suwannee bass, bluegill, and spotted sunfish.

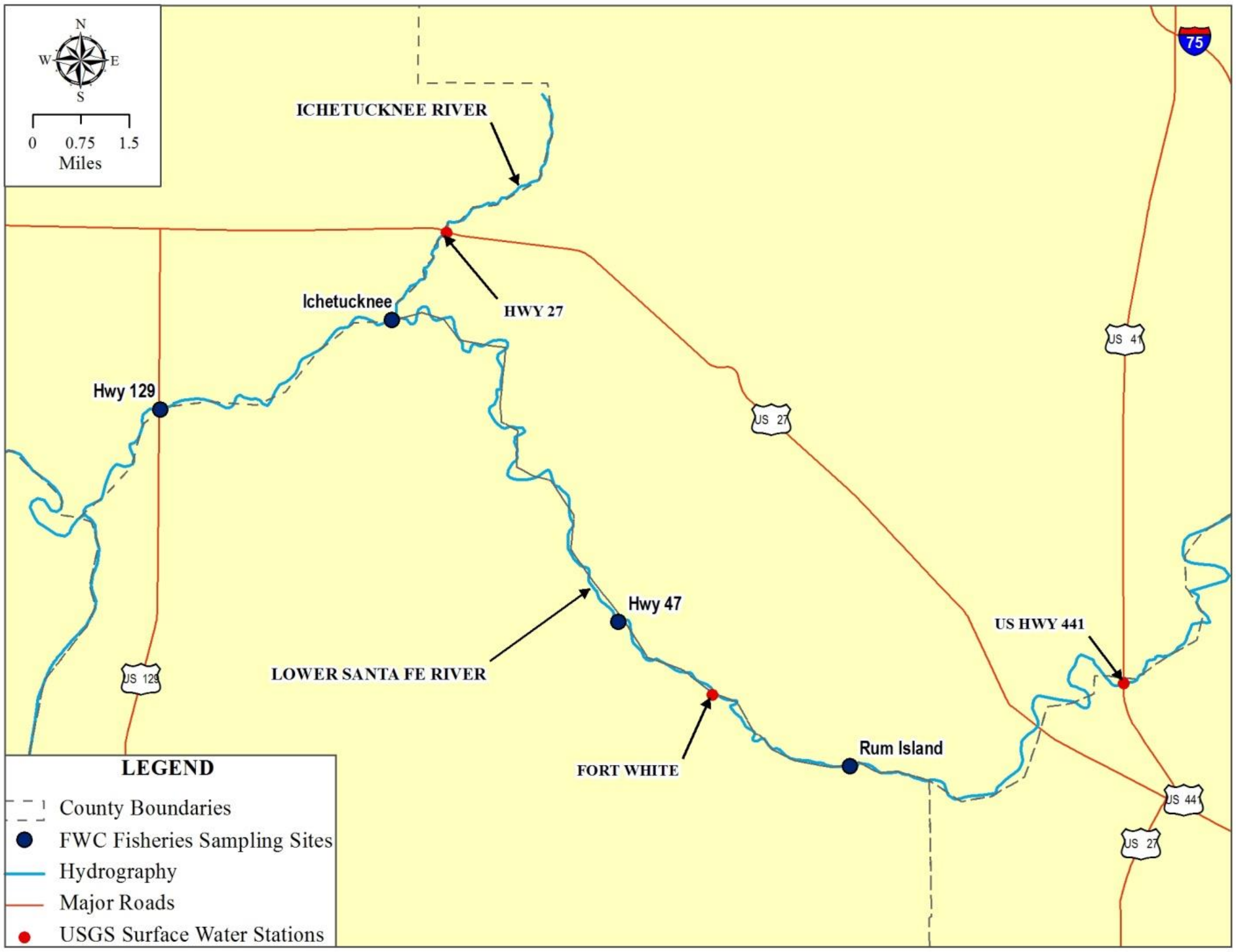


Figure 5-7. Location of FWC fisheries sampling sites.

The Gulf sturgeon, protected under state and federal law, frequents the Suwannee River but is rarely observed in the Lower Santa Fe. Flowers and Pine (2008) captured a juvenile in the river, but report only two other documented specimens taken from the Lower Santa Fe. Because of the lack of quantitative data and the relative scarcity of the species it was not included in any analysis.

Manatee

The Florida manatee (*Trichechus manatus latirostris*), a subspecies of the West Indian Manatee (*Trichechus manatus*), has been observed in the Lower Santa Fe and Ichetucknee river systems. Manatees have a wide tolerance for salinity and can be found in freshwater, brackish, and marine environments throughout the state (Ackerman, Wright, Bonde, Odell, & Banowetz, 1995). Manatees can be found year-round in other Gulf Coast states, and during times of migration in the warm summer months, have been found as far north as Rhode Island. Manatees are currently classified as endangered under the Federal Endangered Species Act (FWC (2007) and Haubold (2006)).

Despite the fact that this area has not been designated as a primary or secondary refuge, manatees have been found in these rivers. Anecdotal manatee sightings have been recorded by park personnel since 1992 and include sightings by park visitors, volunteers, and rangers. Each individual sighting event is recorded; therefore, the possibility exists that the same individual(s) could be counted multiple times. As such, these data do not represent the size of the Ichetucknee River manatee population; rather they are a general index of manatee occurrence in the river.

The protected Florida manatee is a noteworthy member of the Lower Santa Fe and Ichetucknee rivers community. Although the Florida Manatee Recovery Team (Warm Water Task Force, 2004) has not designated Ichetucknee River and its springs as a primary thermal refuge for manatees, there have been over 400 manatee sightings in the river since 1992.

Water depth is a critical factor in the ability of manatees to access upstream sources of warm water and food during cool weather. Thus, the number of manatee sightings is likely influenced by flows in the Ichetucknee, Lower Santa Fe, and Suwannee rivers which have inter-dependent hydrologic relationships. Flows and water levels in the Lower Santa Fe and Suwannee rivers influence the water depth in the Ichetucknee, which flows at a less variable rate due to its dependence on relatively steady spring flow.

Ichetucknee Springs State Park personnel provided records of manatee sightings in the park and downstream (date, number of individuals, observer, and location of sighting). Sightings were tabulated by month and year, and compared to monthly water depths to identify any correlation between river stage and sightings. The USGS provided a file of manatee sightings on the Lower Santa Fe River between 2001 and 2008. Submerged Aquatic Vegetation (SAV)

SAV is a crucial component of the mosaic of instream habitats and serves several diverse purposes. It provides forage to manatees and other aquatic species, shelter for fish and benthos, assimilates nutrients and other chemicals, and stabilizes the river channel to reduce erosion and turbidity. During low water levels, SAV is vulnerable to damage resulting from recreational activities such as boating, and especially tubing on the Ichetucknee River. Monitoring the condition of SAV can also help identify trends in water quality and flows. Maintaining water levels at sufficient depths to protect the SAV provides many benefits to the riverine ecosystem.

Ichetucknee Springs State Park provided files that summarize their work monitoring SAV coverage and speciation at multiple transects on the Ichetucknee River and spring runs. Information was obtained showing transect locations (Figure 5-8) and biannual transect monitoring of the SAV by park staff. Data include percent vegetative cover at each transect by species (linear feet covered by species along each transect line), water depth profiles, and bottom type (vegetated, sand, silt, or algae). Data were obtained for spring and fall monitoring from spring of 1989 through spring of 2012. Files from Ichetucknee Springs State Park personnel also contained records of daily park attendance and how frequently the maximum allowable number of visitors was present.

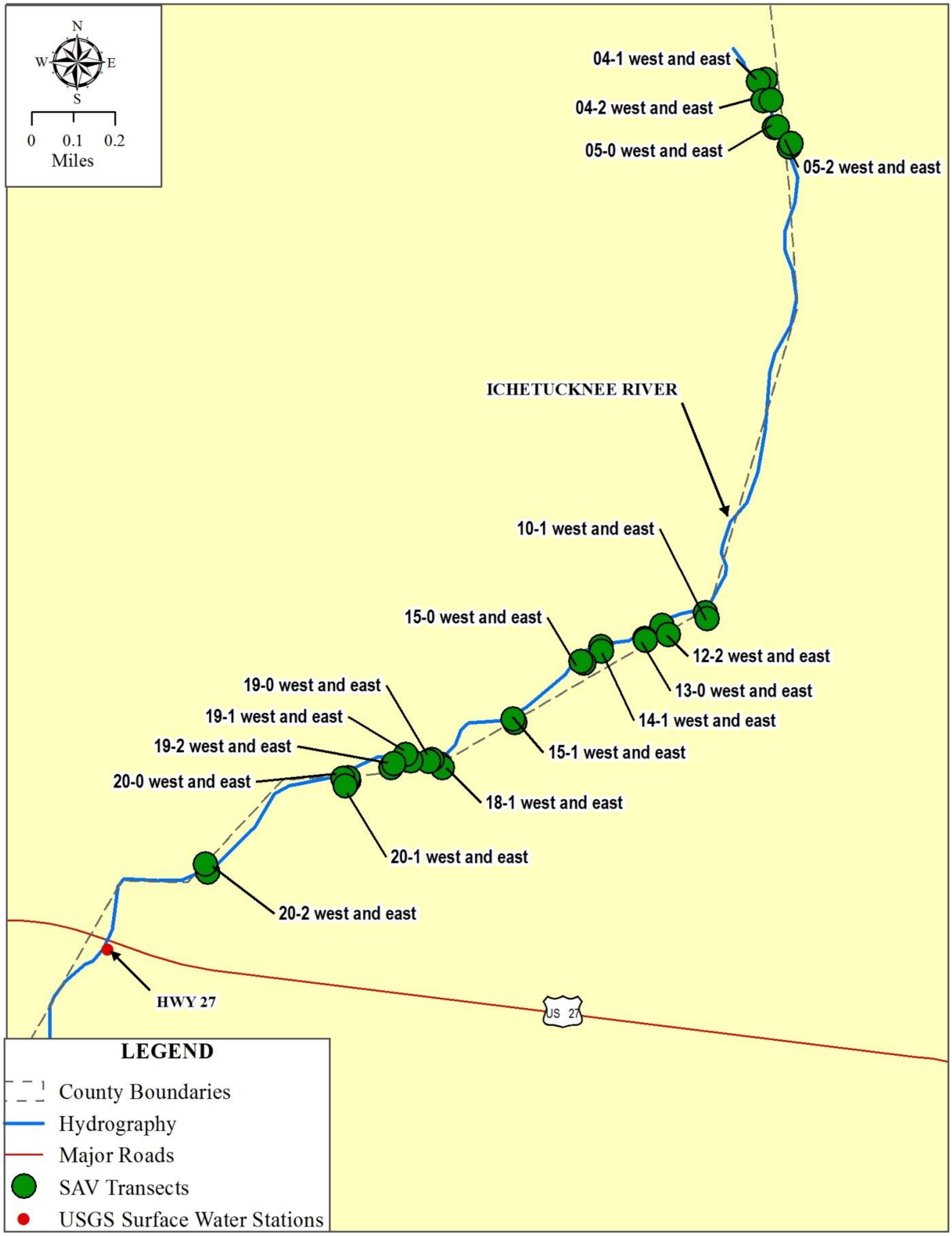


Figure 5-8. Location of SAV transects on the Ichetucknee River (ISSP, 2012).

Recreation

Recreation is a significant water resource value for the Lower Santa Fe and Ichetucknee rivers. The rivers border many parks including state, county, and private facilities. Numerous boat ramps and docks allow access to the river for recreational activities on the Lower Santa Fe River. These structures can become dangerous or unusable during low water conditions. In addition, navigation for motor boats and smaller water craft such as canoes and kayaks is another water resource value that can be impacted by low water. Boats require a minimum depth to safely navigate the river. In recent years, the state parks' docks have been known to create safety hazards and are in danger of being deemed unusable during low flows in the Santa Fe and Ichetucknee rivers. The tubing take-out dock at the Ichetucknee River near Highway 27 becomes unsafe when the water levels drop below a threshold. A portion of this dock was designed to be always submerged, but the low river levels have caused this portion of the dock to be exposed and caused safety concerns with tubing egress.

The level of submergence of the Ichetucknee River take out dock, safe boat navigation at the Three Rivers Shoal on the Ichetucknee River, and safe canoe navigation at the Canoe Scrape Shoal on the Santa Fe River were evaluated as criteria for developing MFLs. Detailed geographic references are provided for these two landmarks in the following sections addressing safe navigation. Recreational activities on the Ichetucknee River, especially during low flows, are known to contribute to damage to SAV due to trampling action when it is shallow enough for tubing participants to walk. Hence, damage to SAV due to trampling action on the Ichetucknee River was also evaluated as a possible criterion for developing MFLs.

Depth clearance of Ichetucknee River take-out dock - Engineering design plans of the dock (Jones Edmunds and Associates, Inc., 2002) were provided by the District. Take-out dock top elevation from the design plans was used in the analysis. The Lower Santa Fe River HEC-RAS model simulated water surface elevation was used to estimate depth over the take out dock top elevation.

The HEC-RAS transect, located approximately 140 feet upstream of the Ichetucknee take out dock, was used in the analysis (HEC-RAS Sta. 11281.58). Depth over the dock top elevation was compared to the depth clearance indicated on the dock design plans (8 inches of clearance).

Safe boat navigation at the Three Rivers Shoal on the Ichetucknee River - A shoal is located approximately 335 feet upstream of the Ichetucknee River confluence (HEC-RAS Sta. 335. 5512). Boats navigate from the Santa Fe River into the Ichetucknee River through this shoal. The HEC-RAS model simulated water surface elevation was used to estimate depth at the transect of interest (HEC-RAS Sta. 335. 5512) and compared to a) the stage associated with a safe boating operation water depth of 4 feet, and b) a canoeing depth of 1.5 feet (Coarsey, 2012b).

Safe canoe navigation at the Canoe Scrape Shoal on the Santa Fe River - A shoal is located approximately 300 feet upstream of the Canoe Scrape (HEC-RAS Sta. 136066.5). The HEC-RAS model simulated water surface elevation was used to estimate depth at the transect of interest (HEC-RAS Sta. 136066.5) and compare to a stage associated with safe boating operation (water depth of 4 feet) and a canoeing depth of 1.5 feet (Coarsey, 2012b).

5.2 MFL DEVELOPMENT

The paradigm upon which the proposed MFLs are based is that a single minimum flow is inadequate for the maintenance of a healthy river ecosystem (Stalnaker, 1990; Hill, Platts, & Beschta, 1991). Rather, a series of flows or a flow regime are needed to support and protect those physical processes within a river that ultimately affect the biological resources of that river. Richter (1996) noted that maintenance of the full range of natural variation in flows offers the best management approach to sustainable "natural biodiversity." For example, the St. Johns River Water Management District typically develops multiple flow requirements when establishing MFLs. The proposed MFLs, therefore, are intended to mimic, to the extent feasible, the natural flow regime. In other words, both in-streamflows and out-of-bank flows are critical, and within-year variation is also an important component. The establishment of MFLs in the priority springs involves protection of both critical resources within the springs and their spring runs as well as those resources within the receiving waterbodies, in this case the Lower Santa Fe and Ichetucknee rivers.

The development of lotic MFLs in Florida requires a MFL prevent "significant harm" to the state's rivers. Therefore, "significant harm" must be defined so MFL compliance can be assessed. The prevention of significant harm need not require strict agreement (i.e., no change) with an historical hydrologic regime. Rather, a MFL should be based on the establishment of Critical Flows from which modifications to the flow regime can be considered.

Similar to the approach taken by the Southwest Florida Water Management District, and as put forward by Beecher (1990), the proposed MFLs for the Lower Santa Fe and Ichetucknee rivers have the following elements:

- a goal (i.e., protection from "significant harm");
- identification of the resources of interest to be protected;
- a unit of measure (e.g., flow in cubic feet per second, percent reduction in flow);
- a benchmark flow regime, and
- a protection standard statistic (e.g., a prescribed percent reduction).

The establishment of MFLs ultimately depends upon the quantitative relationship between river and spring flows and the WRVs of concern. For a variety of reasons, and despite the availability of generally accepted conceptual models, much of the research that addresses these relationships has not been conducted. Therefore, the following analyses use the best available data to derive the MFLs for the Lower Santa Fe and Ichetucknee rivers and their springs.

The proposed MFLs for Lower Santa Fe and Ichetucknee rivers are based on the relationships between river flow and the following:

- out-of-bank flows that:
    - inundate floodplain vegetation communities,
    - inundate hydric soils, and
    - provide access to floodplain habitat or food resources for fish and other organisms,
    - maintain the appropriate geomorphology as indicated by bankfull flows, and
- in-channel flows that:
    - maintain water quality for aquatic life support,

- allow fish passage over shoals,
- inundate woody habitats (snags and exposed roots),
- maintain physical habitat suitability for fish and benthic macroinvertebrates,
- maintain recreational opportunities.

A MFL metric has been identified for each WRV where adequate data exist for the development of a MFL. A Critical Flow, i.e., the flow that is the threshold for a given MFL metric, has been defined for each metric. The MFL for a given metric is the flow that considers modifications to the baseline, in this case, the Baseline Flows time series. The specific MFL metrics and the analyses used to derive their Critical Flows follows. The methodology for the development of spring MFLs is presented in Section 6.0.

5.2.1 Out-of-bank and Bankfull Flows

Establishing out-of-bank or high flow MFLs on the Lower Santa Fe and Ichetucknee rivers is vital to preserving the ecological health of the entire ecosystem, since high-flows support the extent and integrity of floodplain vegetation and soils necessary to support these communities (Hynes, 1970; Allan, 1995). Floodplains are known to represent an important riverine habitat that is created on a seasonal basis during higher flows (i.e., out-of-bank flows) (Light, Darst, & Grubbs, 1998; Light, Lewis, Darst, & Howell, 2002; Kelly, Munson, Morales, & Leeper, 2005; Mitsch & Gosselink, 1986). The floodplains contain unique wetland communities that are formed in relation to the frequency and duration of inundation. Additionally, it has been shown that the overall biological productivity of river ecosystems is linked to the predictable seasonal inundation of the floodplains (Crance, 1988; Junk, Bayley, & Sparks, 1989). Fish and other organisms that inhabit the river channel benefit from the expanded habitat provided by access to inundated floodplains (Wharton, Kitchens, Pendleton, & Sipe, 1982; Ainsle, et al., 1999; Hill & Cichra, 2002). The inundation of the floodplain also provides a nutrient subsidy to the river, by introducing a new source of detrital matter. Thus, the resource of concern identified for selecting a high-flow MFL for the Lower Santa Fe and Ichetucknee rivers is inundation of floodplain vegetation communities and hydric soils.

The importance of bankfull flows has become increasingly recognized (Rosgen, 1996). Bankfull flow is that flow associated with the bankfull stage ("the flow that just fills the river channel to the top of its banks"). Dunne and Leopold (1978) defined bankfull stage as the stage "*that corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels*".

FLOODPLAIN VEGETATION

The following presents the methods and results of the analyses for out-of-bank flows with respect to floodplain vegetation, hydric soils, and fluvial geomorphology (i.e., bankfull flows).

Floodplain vegetative communities were identified along a series of eleven (11) transects along the Lower Santa Fe River (Figure 5-1) and six (6) transects along the Ichetucknee River (Figure 5-2). The general vegetative community type, species cover, elevation, and soils were recorded (Atkins, Inc., 2012). Of the seven floodplain vegetation communities listed in Section 5.1, four predominant floodplain vegetation types were found in the Santa Fe and Ichetucknee rivers floodplains: cypress swamp, hardwood cypress, hardwood swamp, and hydric hardwood hammock.

The elevations along vegetation transects were measured by a Florida professional land surveyor (see Appendix 5-1), and the mean elevations for each of the four predominant floodplain vegetation types along each transect were calculated. The relationships between water surface elevations at each transect and river flow, measured at Fort White and Highway 27 in the Lower Santa Fe River and Ichetucknee River, respectively, can be found in Appendix 5-2. Comparison of mean elevations for the predominant floodplain vegetation types found in the Ichetucknee River and the maximum water surface elevations identified by the HEC-RAS model indicates that the out-of-bank flows do not support the riparian vegetation. Therefore, this suggests that the floodplain vegetation is supported by local hydrologic factors and analysis of the out-of-bank flows for this metric, as a function of river channel flows is not presented. Using the relationships between river flow and water surface elevations at each of the vegetation transects on the Lower Santa Fe River, the flows at which the mean elevations for each floodplain vegetation type occur were identified. The Critical Flow for each predominant vegetation type was calculated as the mean of the flows occurring at the mean elevations of respective vegetation types.

Recent and Long-term Positional Hydrograph (RALPH) analyses have been used by the Southwest Florida Water Management District to illustrate the number of days during a defined period of record that a specific flow, such as the Critical Flows defined for the predominant vegetation types, was equaled or exceeded (SWFWMD, 2002). Using the Lower Santa Fe River Baseline Flows time series (see Section 4.1), RALPH plots of the number of days in each year from October 1, 1932, to September 30, 1990, were developed (Figure 5-9 through Figure 5-12).

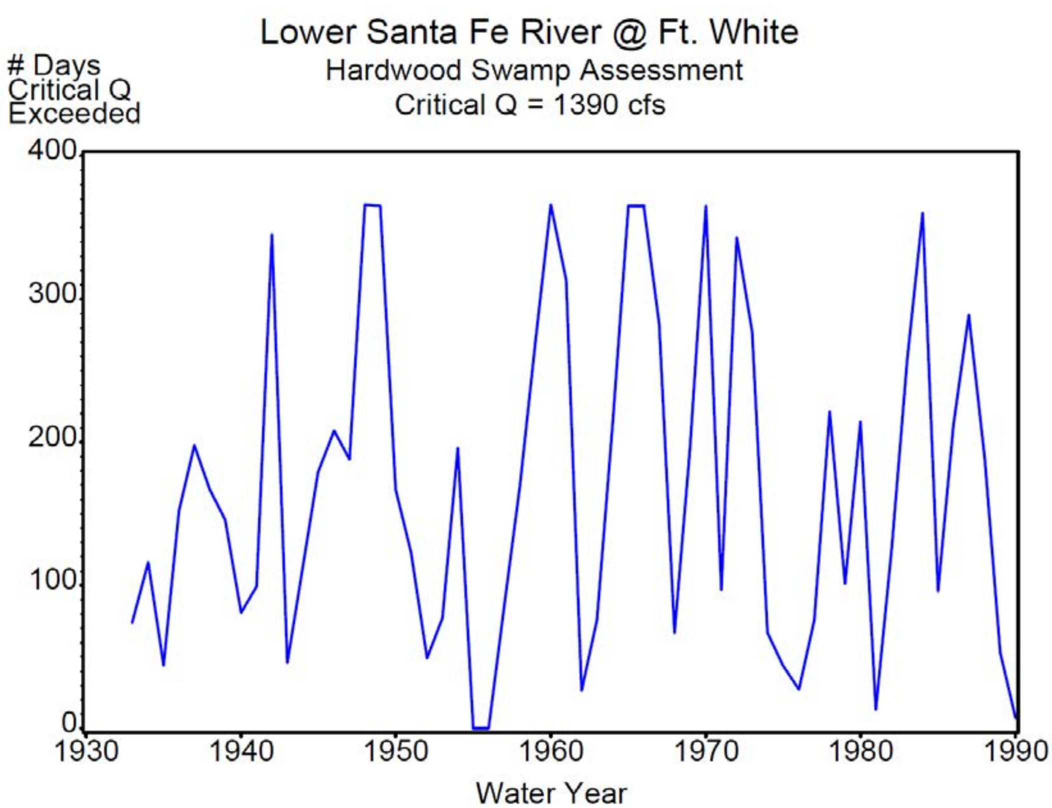


Figure 5-9. RALPH plot for hardwood swamp in the Lower Santa Fe River.

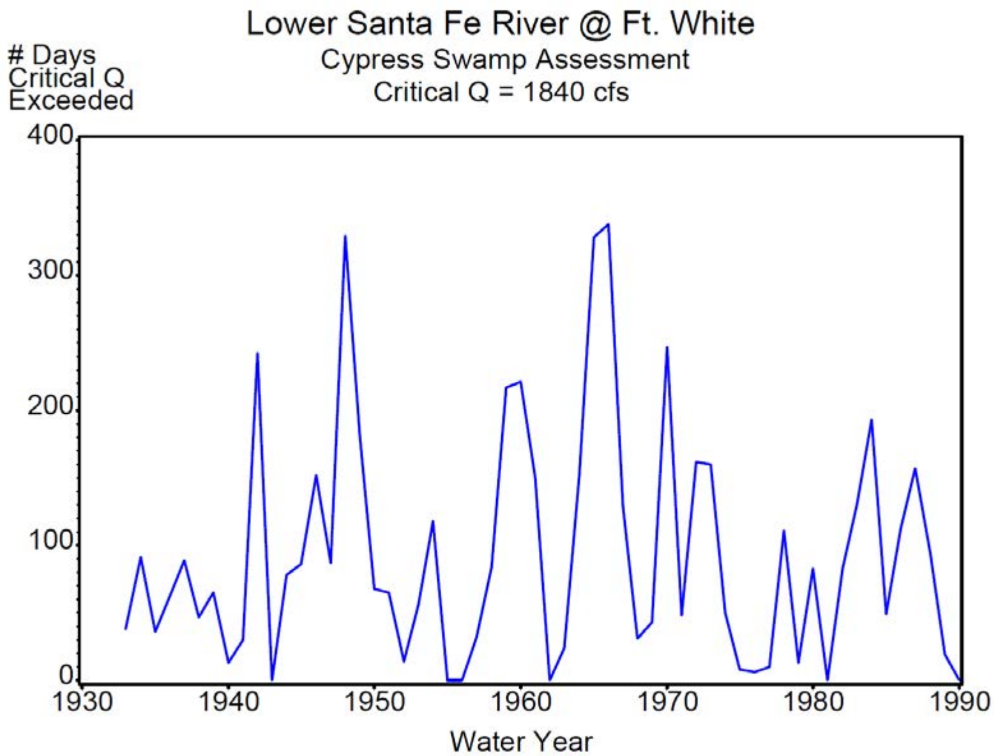


Figure 5-10. RALPH plot for cypress swamp in the Lower Santa Fe River.

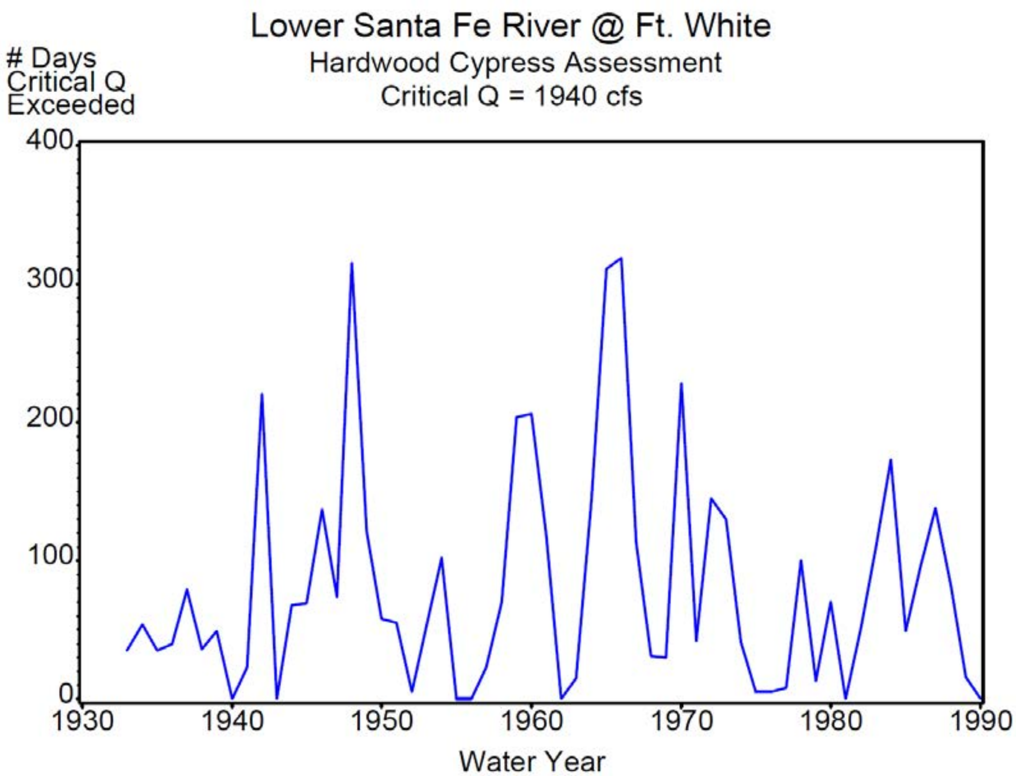


Figure 5-11. RALPH plot for hardwood cypress in the Lower Santa Fe River.

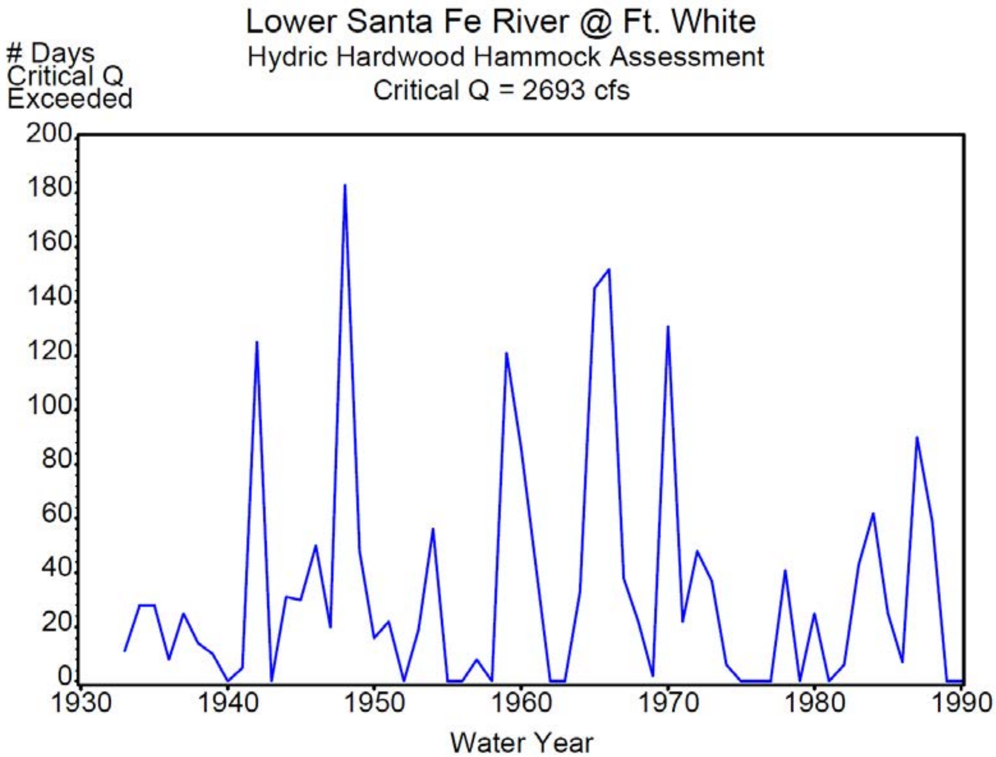


Figure 5-12. RALPH plot for hydric hardwood hammock in the Lower Santa Fe River.

The Critical Flow (the optimal flow that maintains the specific metric) for each of the predominant vegetation types was estimated by iteratively reducing the daily flows from the Baseline Flows time series in 1% increments. The allowable percent reduction is that percent reduction in river flow that results in a 15% reduction in the number of days when the Critical Flow was equaled or exceeded. Justification for the use of a 15% reduction in habitat, either temporal or spatial, is presented in Section 3.0. Multiplying the Critical Flow by this allowable percent reduction in flow provides an estimate of the Resulting Metric Flow. Figure 5-13 through Figure 5-16 present the results of this iterative analysis of flow reductions. These plots depict the number of days that the Critical Flow was equaled or exceeded for the series of 1% flow reduction increments. The plots also depict a horizontal green line which depicts the 15% reduction in the number of days that the Critical Flow is met. The lowest flow reduction that lies below this green line, therefore, is the allowable percent reduction or shift from the Baseline Flows. RALPH plots (Figure 5-17 through Figure 5-20) can also be used to compare the number of days in each year that the Critical Flow is met during the Baseline Flows time series and the time series of daily flows with the allowable percent reductions identified from Figure 5-13 through Figure 5-16.

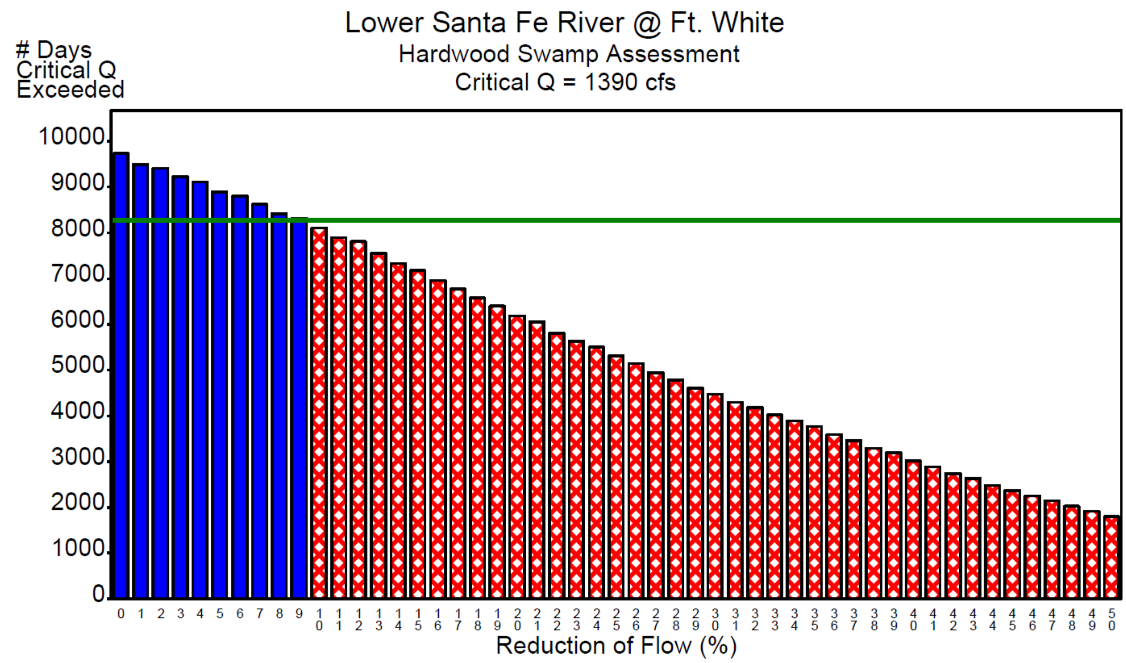


Figure 5-13. Results of the iterative reductions in flow and the resulting number of days that the Critical Flow for hardwood swamp in the Lower Santa Fe River was equaled or exceeded.
Horizontal green line indicates a 15% reduction in the number of days from the maximum value.

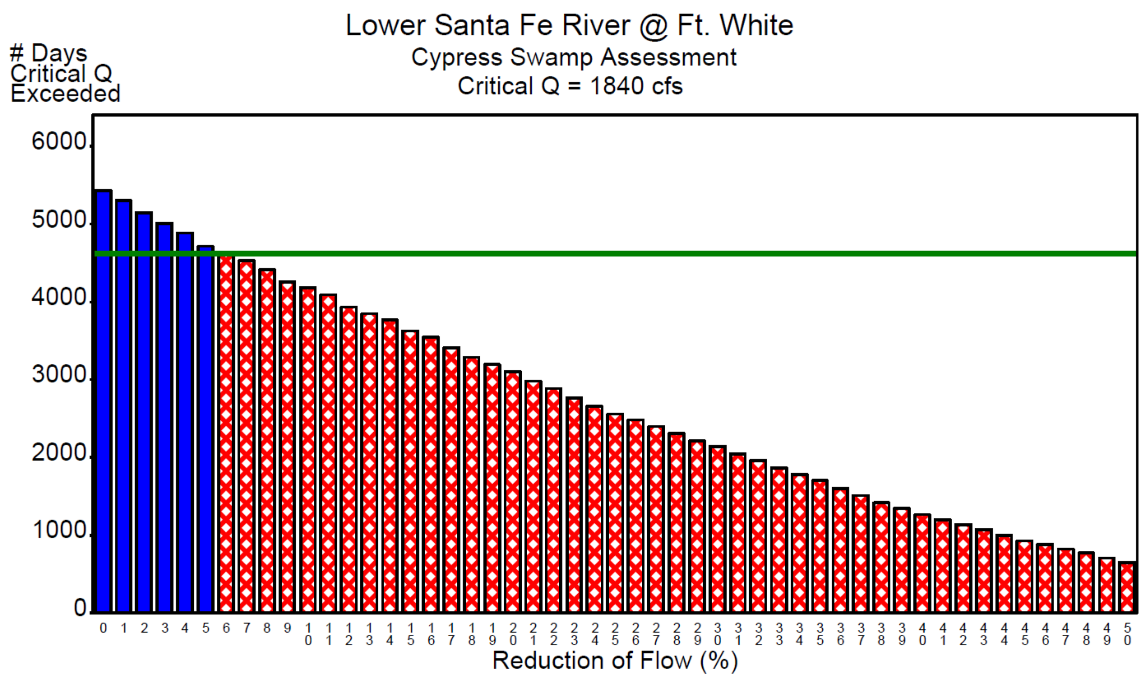


Figure 5-14. Results of the iterative reductions in flow and the resulting number of days that the Critical Flow for cypress swamp in the Lower Santa Fe River was equaled or exceeded.
Horizontal green line indicates a 15% reduction in the number of days from the maximum value.

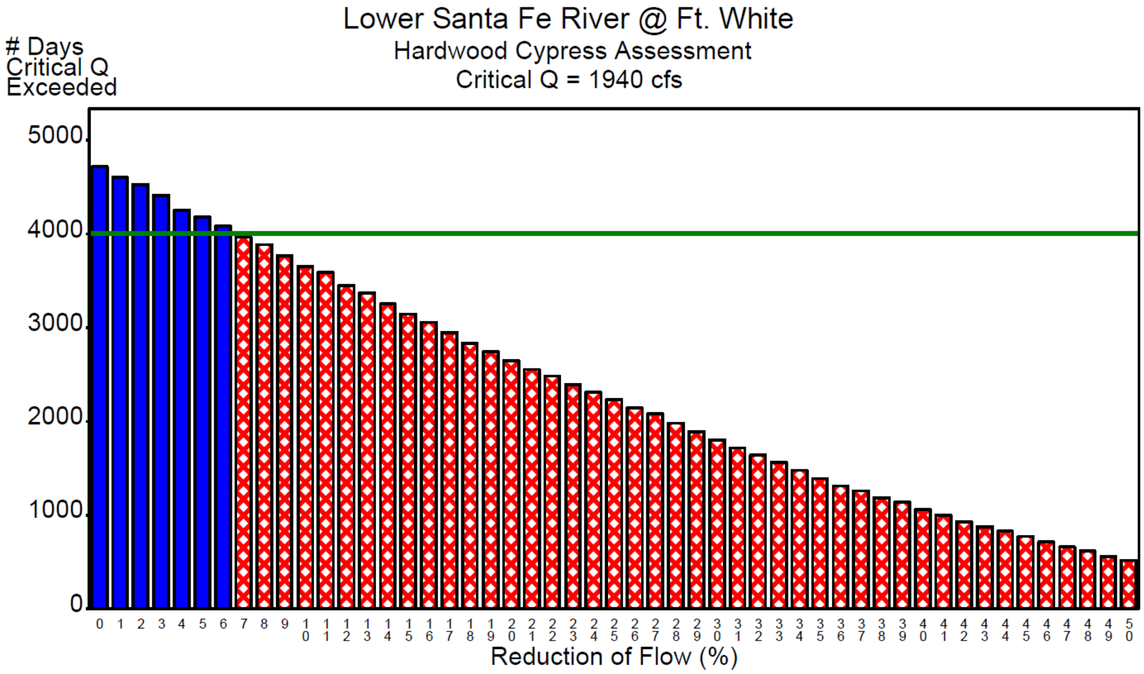


Figure 5-15. Results of the iterative reductions in flow and the resulting number of days that the Critical Flow for hardwood cypress in the Lower Santa Fe River was equaled or exceeded.
Horizontal green line indicates a 15% reduction in the number of days from the maximum value.

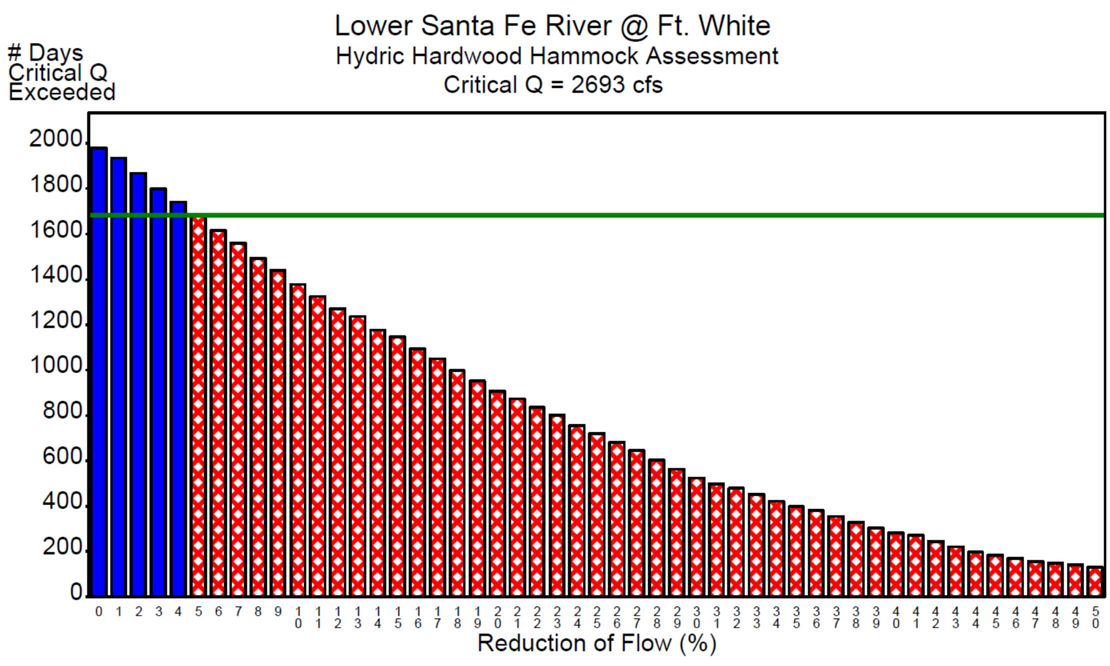


Figure 5-16. Results of the iterative reductions in flow and the resulting number of days that the Critical Flow for hydric hardwood hammock in the Lower Santa Fe River was equaled or exceeded.
Horizontal green line indicates a 15% reduction in the number of days from the maximum value.

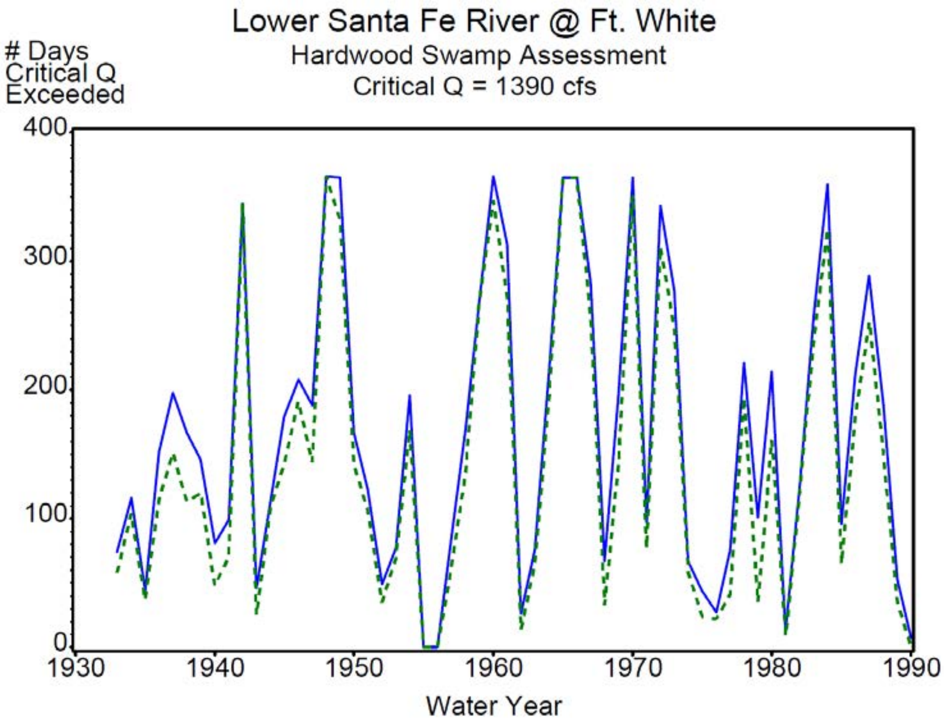


Figure 5-17. RALPH plot for hardwood swamp in the Lower Santa Fe River. A Comparison of the results from the Baseline Flows (blue line) and the allowable percent reduction from Figure 5-13 (dashed green line).

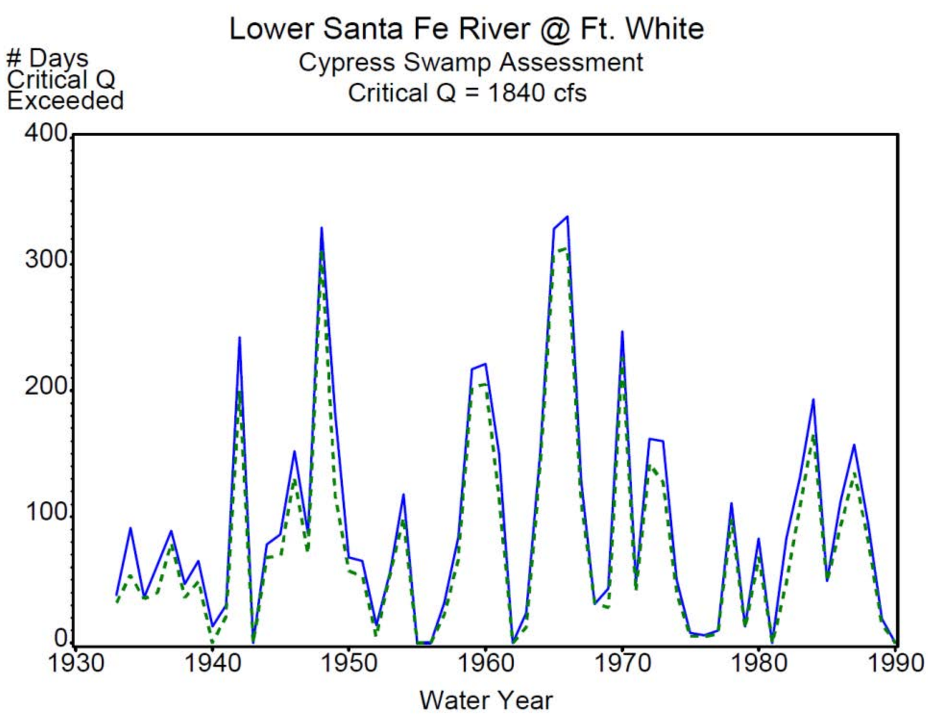


Figure 5-18. RALPH plot for cypress swamp in the Lower Santa Fe River A Comparison of the results from the Baseline Flows (blue line) and the allowable percent reduction from Figure 5-14 (dashed green line).

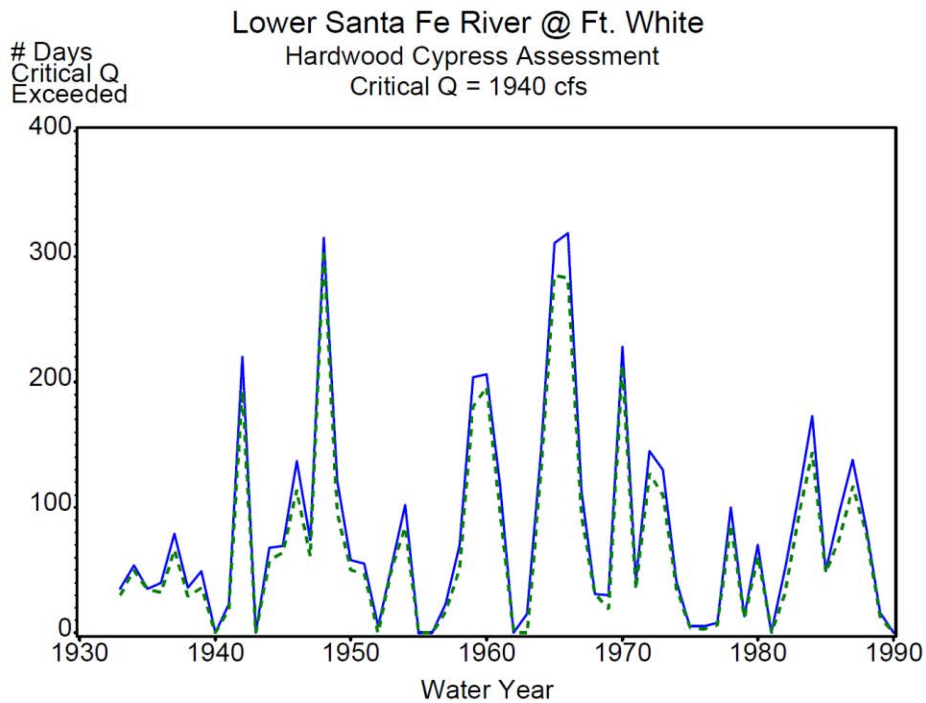


Figure 5-19. RALPH plot for hardwood cypress in the Lower Santa Fe River A Comparison of the results from the Baseline Flows (blue line) and the allowable percent reduction from Figure 5-15 (dashed green line).

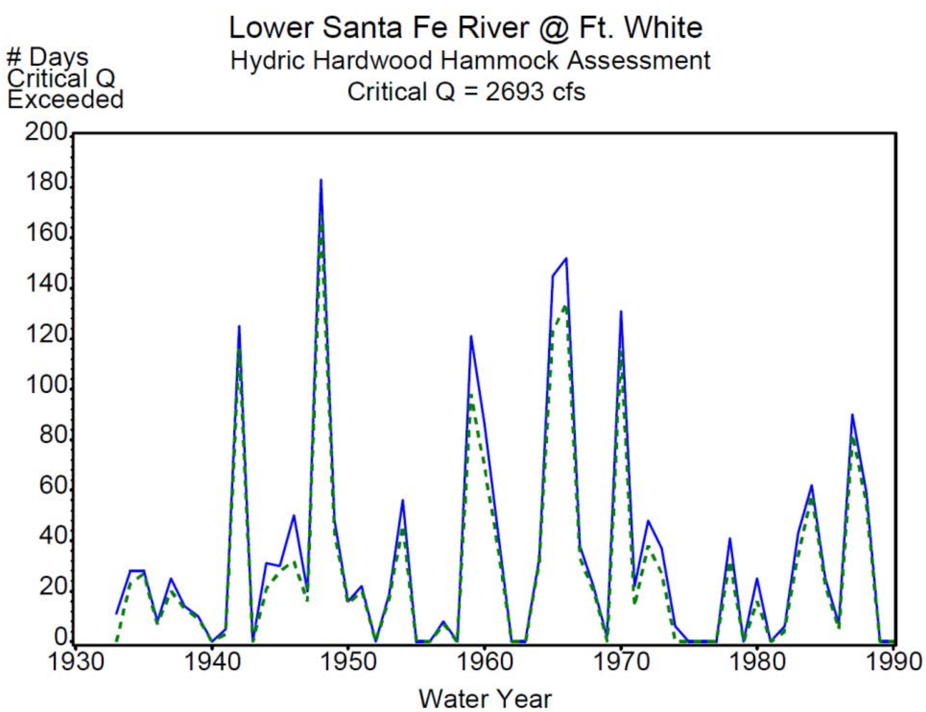


Figure 5-20. RALPH plot for hydric hardwood hammock in the Lower Santa Fe River A comparison of the results from the Baseline Flows (blue line) and the allowable percent reduction from Figure 5-16 (dashed green line).

Table 5-1 summarizes the Critical Flows, the allowable percent reductions, and the Resulting Metric Flows for each predominant vegetation type. The Critical Flows varied and are in agreement with the different elevations where the four floodplain vegetation types were found. The allowable percent reductions were very similar, ranging from 4% to 9%.

Table 5-1. Critical Flows (cfs), percent reductions, and Resulting Metric Flows for the four predominant vegetation types from the Lower Santa Fe River.

Vegetation Type	Critical Flow (cfs)	Allowable Percent Reduction	Resulting Metric Flow (cfs)
Hardwood swamp	1390	9%	1265
Cypress swamp	1840	5%	1748
Hardwood cypress	1940	6%	1824
Hydric hardwood hammock	2693	4%	2585

HYDRIC SOILS

The Critical Flows, allowable percent reductions, and Resulting Metric Flows were estimated for the hydric soils along both rivers following the same approach as described for the predominant vegetation types. The Critical Flows for hydric soils (i.e., the flows associated the mean elevation of those soils) are 2094 cfs and 407 cfs for the Lower Santa Fe River and Ichetucknee River, respectively. Figure 5-21 and Figure 5-22 present the RALPH plots that present the number of days in each year that the Critical Flow was equaled or exceeded. The results of the iterative reductions in river flow and resulting number of days that the Critical Flow for hydric soils was met are shown in Figure 5-23 and Figure 5-24.

RALPH plots (Figure 5-25 and Figure 5-26) can also be used to compare the number of days in each year that the Critical Flow is met during the Baseline Flows time series and the time series of daily flows with the allowable percent reductions identified from Figure 5-23 and Figure 5-24.

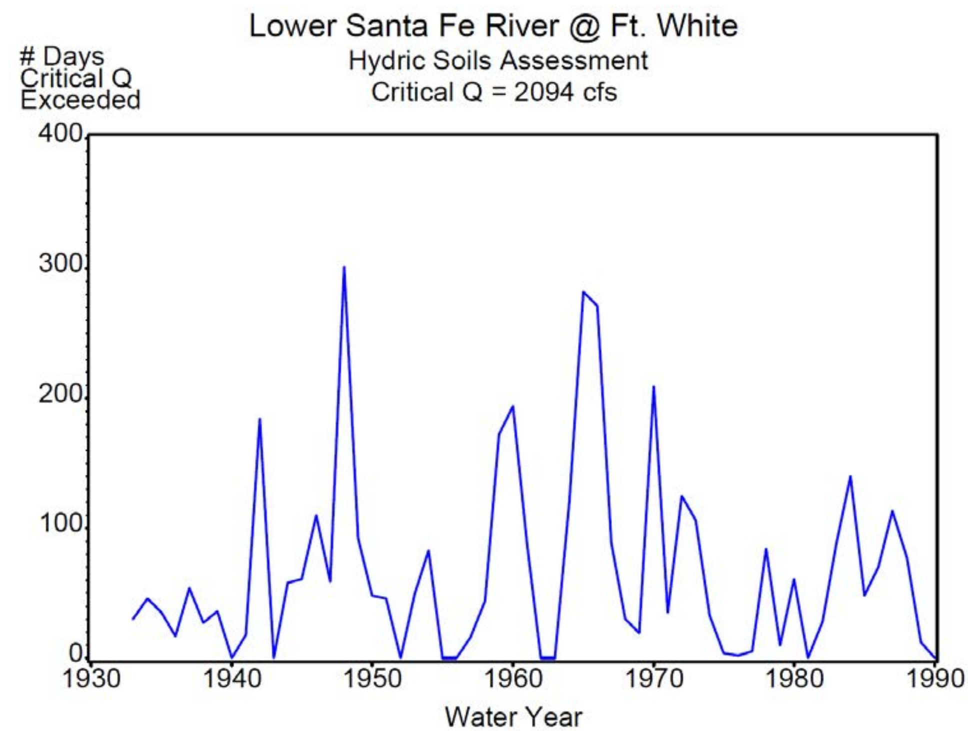


Figure 5-21. RALPH plot for hydric soils in the Lower Santa Fe River.

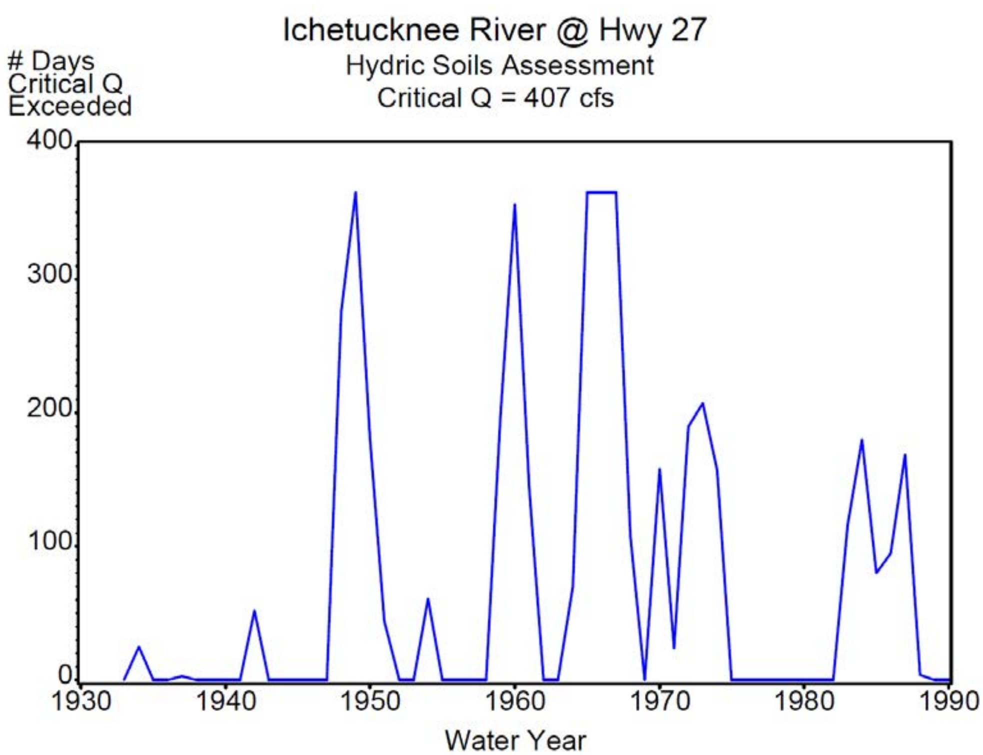


Figure 5-22. RALPH plot for hydric soils in the Ichetucknee River.

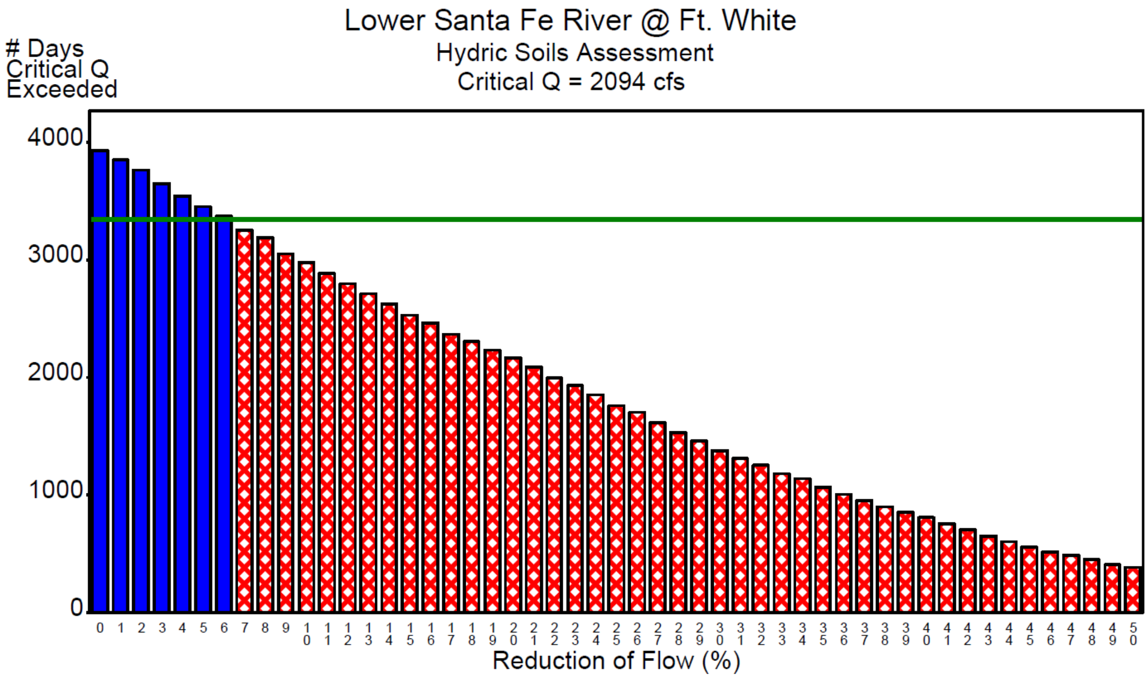


Figure 5-23. Results of the iterative reductions in flow and the resulting number of days that the Critical Flow for hydric soils in the Lower Santa Fe River was equaled or exceeded.
Horizontal green line indicates a 15% reduction in the number of days from the maximum value.

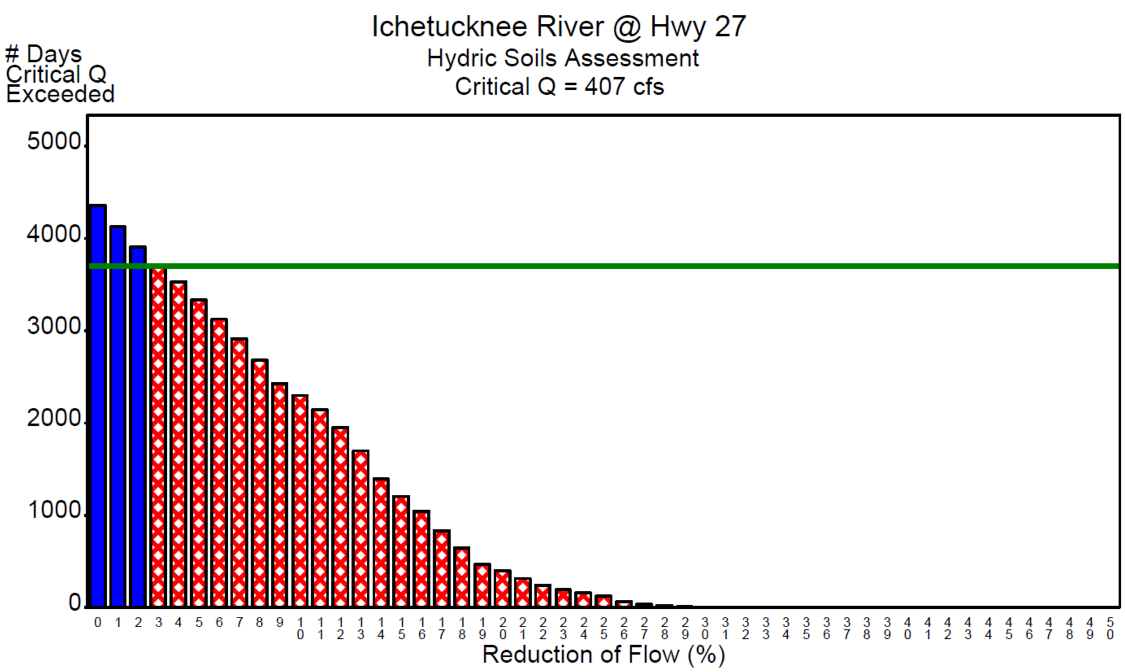


Figure 5-24. Results of the iterative reductions in flow and the resulting number of days that the Critical Flow for hydric soils in the Ichetucknee River was equaled or exceeded.
Horizontal green line indicates a 15% reduction in the number of days from the maximum value.

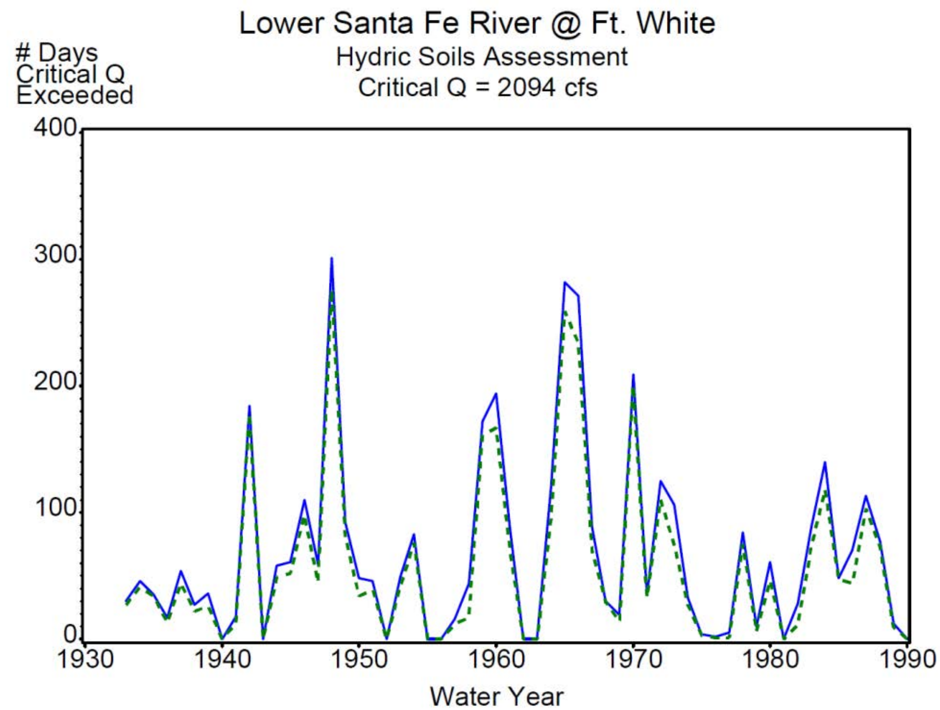


Figure 5-25. RALPH plot for hydric soils in the Lower Santa Fe River. A Comparison of the results from the Baseline Flows (blue line) and the allowable percent reduction from Figure 5-21 (dashed green line).

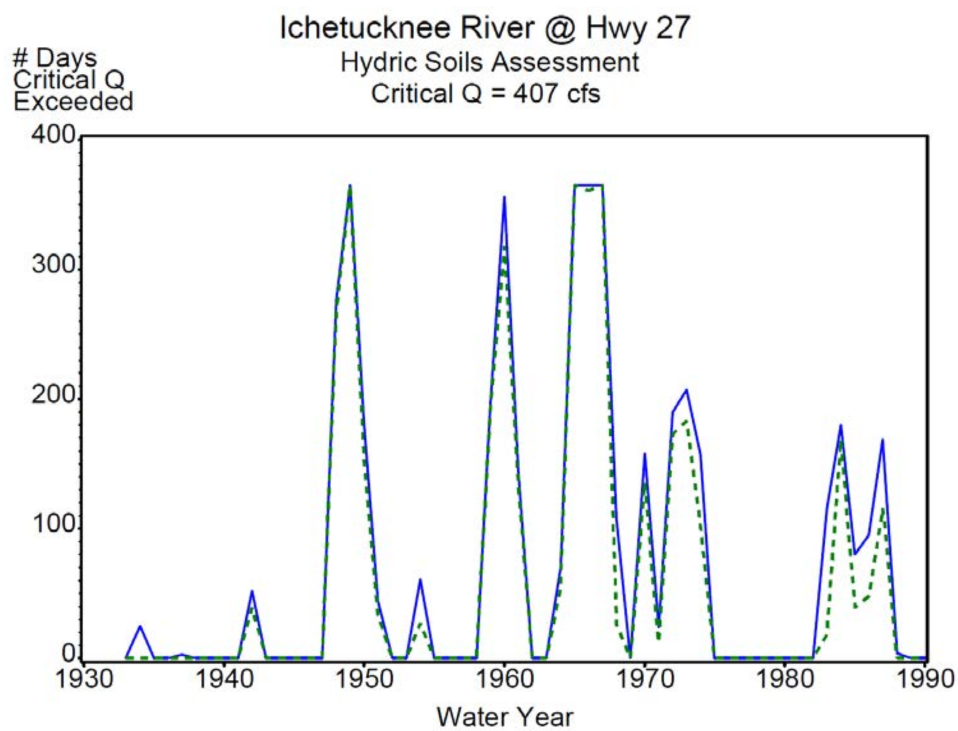


Figure 5-26. RALPH plot for hydric soils in the Ichetucknee River. A Comparison of the results from the Baseline Flows (blue line) and the percent reduction from Figure 5-22 (dashed green line).

Table 5-2 summarizes the Critical Flows, the allowable percent flow reductions, and the Resulting Metric Flows for hydric soils in each river. As was found for the floodplain vegetation, the allowable percent reductions are relatively low, 6% and 2% for the Lower Santa Fe River and Ichetucknee River, respectively.

Table 5-2. Critical Flows (cfs), allowable percent reductions, and Resulting Metric Flows for the hydric soils from the Lower Santa Fe River and Ichetucknee River.

River	Critical Flow (cfs)	Allowable Percent Reduction	Resulting Metric Flow (cfs)
Lower Santa Fe	2094	6%	1968
Ichetucknee	407	2%	399

FLUVIAL GEOMORPHOLOGY (BANKFULL FLOWS)

AMEC (2012) conducted a study that identified the bankfull discharges and stages that currently maintain channel dimension and habitat structure and some thresholds necessary to maintain alluvial features in the floodplain. The specific methods used to estimate the bankfull stage and flow are presented in (AMEC, 2012).

The calculated bankfull discharges were 1,410 cubic feet per second (cfs) in the Lower Santa Fe River at Fort White and 328 cfs in the Ichetucknee River at Highway 27. Therefore, these are the Critical Flows for the bankfull flow metric.

Using the respective Baseline Flows time series, RALPH plots of the number of days in each year, from October 1, 1932, to September 30, 1990 that the critical bankfull flows were equaled or exceeded are shown in (Figure 5-27 and Figure 5-28).

The Resulting Metric Flow for the bankfull flows was estimated by iteratively reducing the daily flows from the Baseline Flows time series in 1% increments. The percent reduction that resulted in a 15% reduction in the number of days when the Critical Flow was equaled or exceeded defined the Resulting Metric Flow. Figure 5-29 and Figure 5-30 present the results of this iterative analysis of flow reductions. These plots depict the number of days that the Critical Flow was equaled or exceeded for the series of 1% flow reduction increments. The plots also depict a green line which indicates the 15% reduction in the number of days that the Critical Flow is met. The lowest flow reduction that lies below this green line, therefore, is the allowable percent reduction. RALPH plots (Figure 5-31 and Figure 5-32) can also be used to compare the number of days in each year that the Critical Flow is met during the Baseline Flows time series and the time series of daily flows with the percent reductions identified from Figure 5-29 and Figure 5-30.

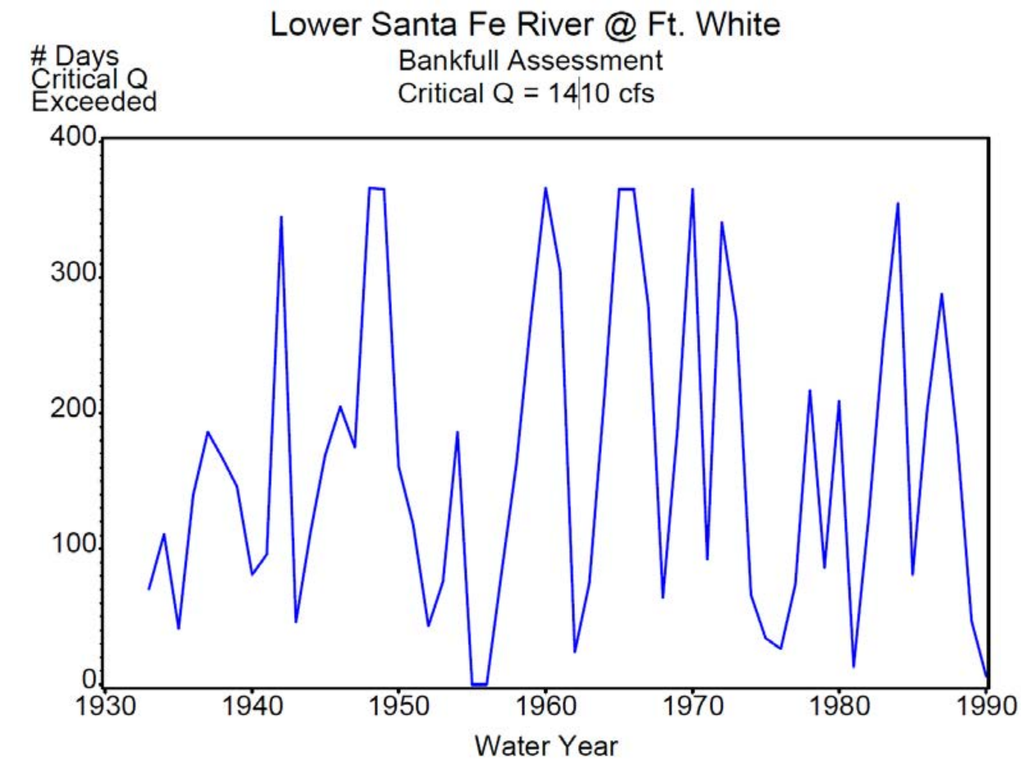


Figure 5-27. RALPH plot for bankfull flows in the Lower Santa Fe River.

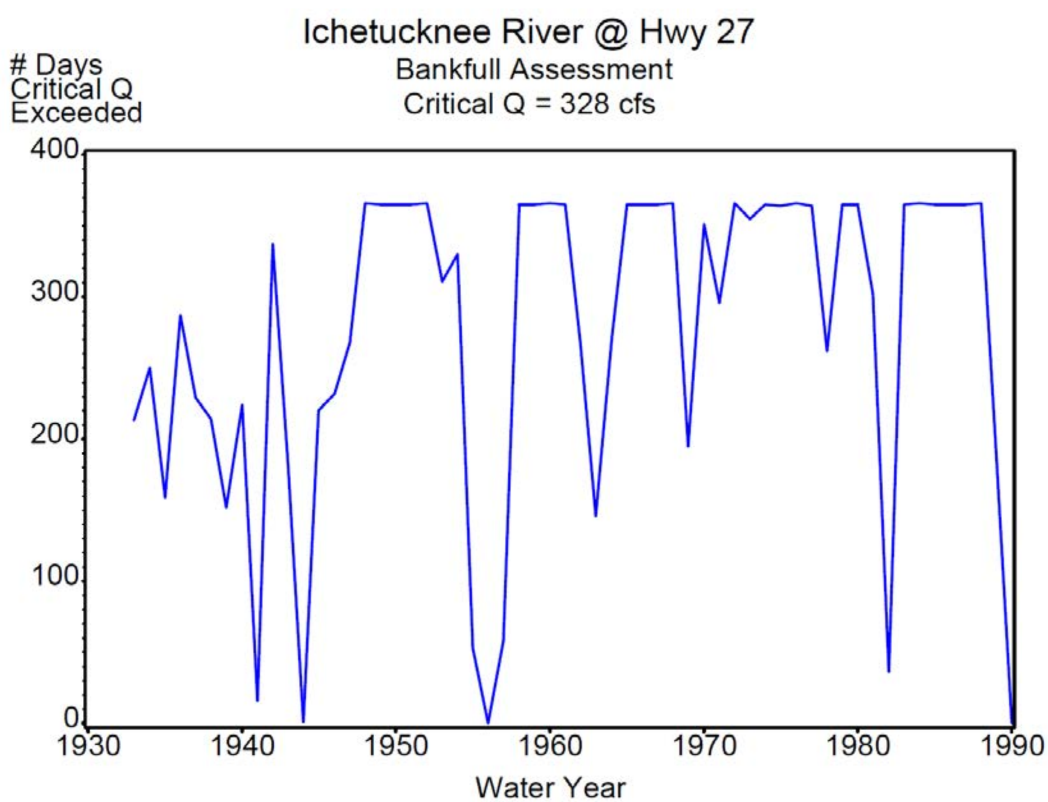


Figure 5-28. RALPH plot for bankfull flows in the Ichetucknee River.

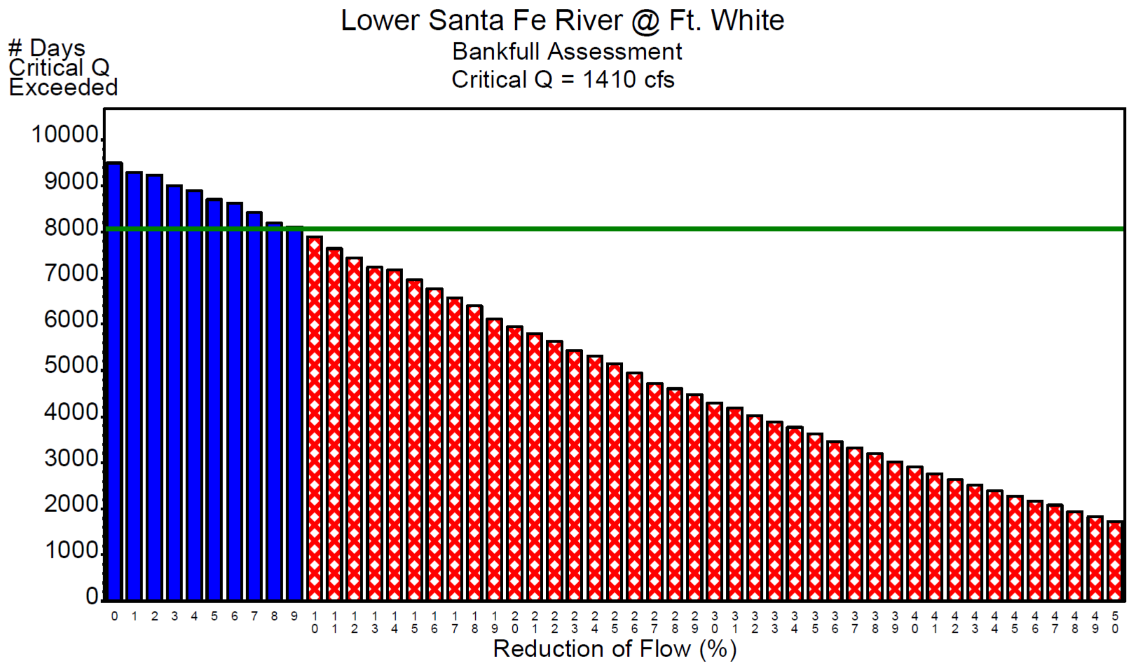


Figure 5-29. Results of the iterative reductions in flow and the resulting number of days that the Critical Flow for bankfull flows in the Lower Santa Fe River was equaled or exceeded.
Horizontal green line indicates a 15% reduction in the number of days from the maximum value.

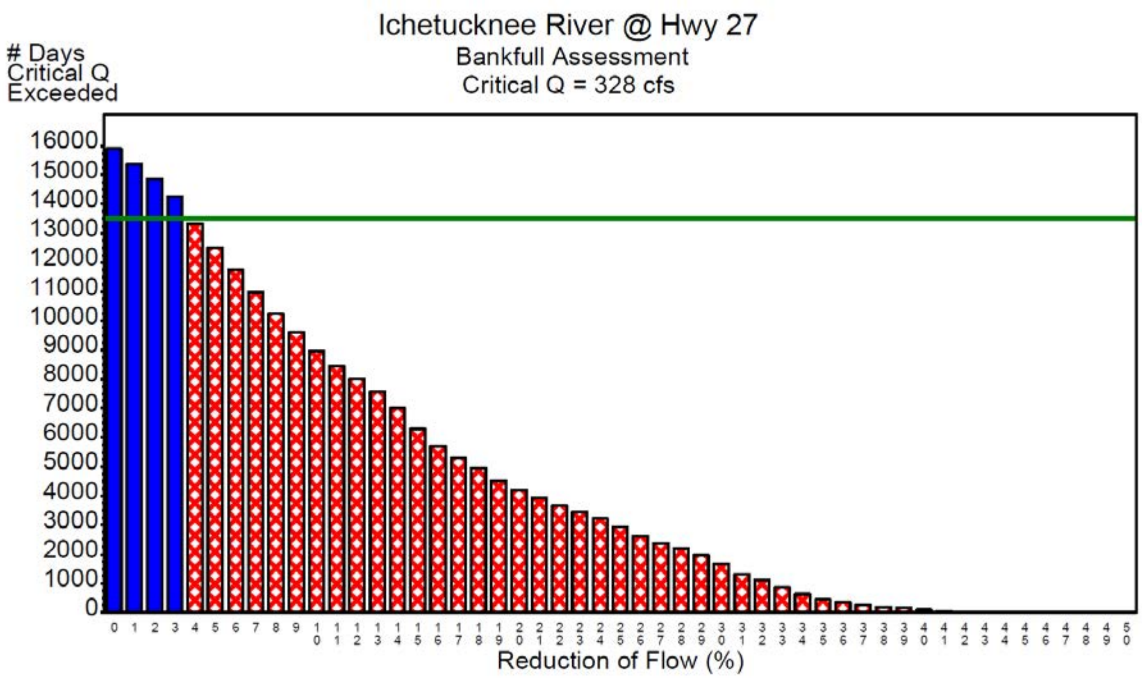


Figure 5-30. Results of the iterative reductions in flow and the resulting number of days that the Critical Flow for bankfull flows in the Ichetucknee River was equaled or exceeded.
Horizontal green line indicates a 15% reduction in the number of days from the maximum value.

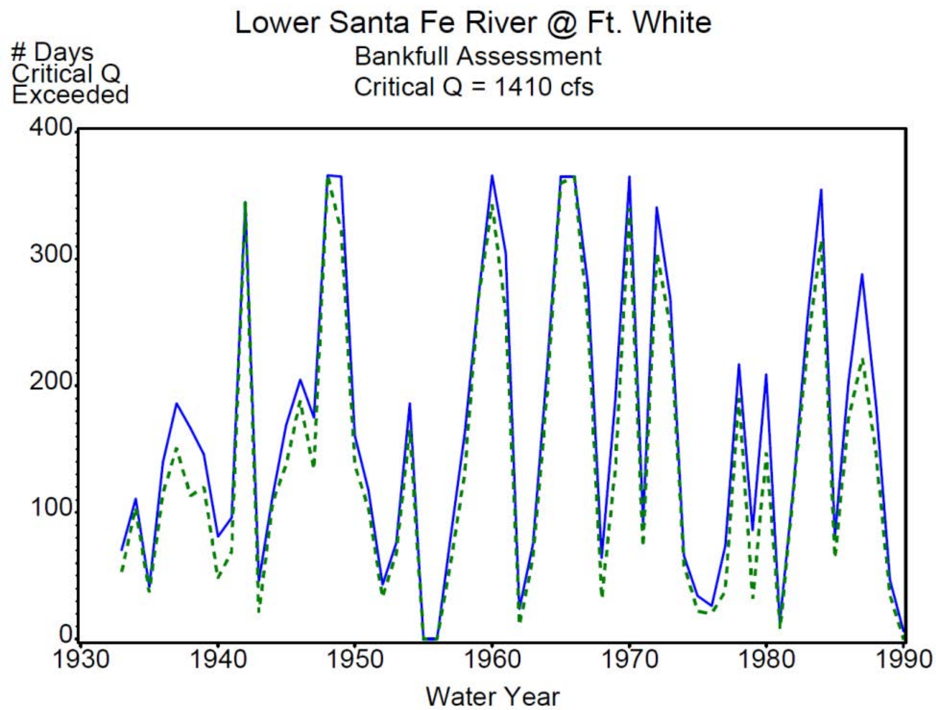


Figure 5-31. RALPH plot for bankfull flows in the Lower Santa Fe River A Comparison of the results from the Baseline Flows (blue line) and the allowable percent reduction from Figure 5-27 (dashed green line).

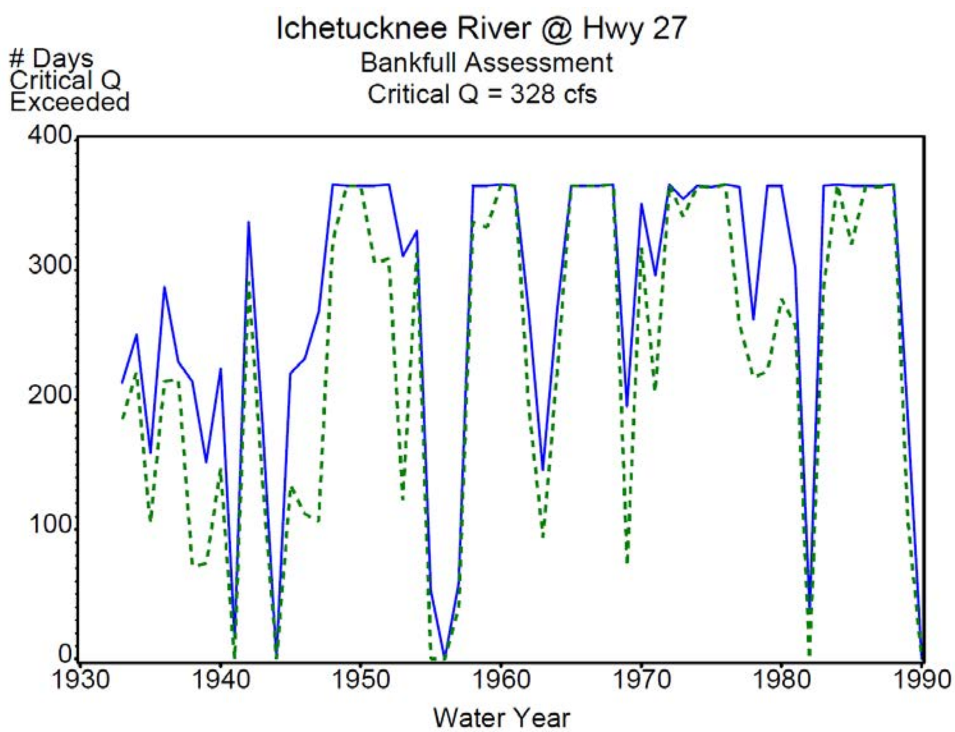


Figure 5-32. RALPH plot for bankfull flows in the Ichetucknee River A Comparison of the results from the Baseline Flows (blue line) and the allowable percent reduction from Figure 5-28 (dashed green line).

Table 5-3 summarizes the Critical Flows, the allowable percent flow reductions, and the Resulting Metric Flows for bankfull flows in each river. As was found for the floodplain vegetation and hydric soils, the allowable percent reductions are relatively low, 9% and 3% for the Lower Santa Fe River and Ichetucknee River, respectively.

Table 5-3. Critical Flows (cfs), allowable percent reductions, and Resulting Metric Flows for the bankfull flows from the Lower Santa Fe River and Ichetucknee River.

River	Critical Flow (cfs)	Allowable Percent Reduction	Resulting Metric Flow (cfs)
Lower Santa Fe	1410	9%	1283
Ichetucknee	328	3%	318

5.2.2 In-channel Water Resource Values

The Critical Flows associated with in-channel flows are based on several features of the river ecosystem that are significantly affected by these flows. These features include water quality, fish passage, physical habitat suitability, woody debris and recreation. The following presents how the Critical Flows and Resulting Metric Flows were defined with respect to these river features.

WATER QUALITY

Improving water quality is not the focus of the MFL program, but the hydrologic regime must be maintained to prevent degradation to current water quality conditions caused by excessive flow reductions. The following summarizes surface water quality data that were assessed in the development of the MFL for the Lower Santa Fe and Ichetucknee rivers.

The District provided all relevant water quality data for Lower Santa Fe River sampling sites (SFR050C1, SFR060C1, and SFR070C1), and Ichetucknee River sites ICH001C1 (at the Main Spring) and ICH010C1 (just upstream of the US 27 bridge) (Figure 5-33). Water quality data have been collected on a monthly basis from 1989 through the current year for the Lower Santa Fe River sites, and from 1991 to 2002 for site ICH001C1. Sampling at the spring head was sporadic. The water quality data include but are not limited to physical parameters (temperature, clarity), nutrients, dissolved oxygen (DO), chlorophyll *a* (CHL), pH, conductance, alkalinity, organic carbon, suspended solids, bacteria, and some metals.

Water quality data obtained from grab samples collected in the Lower Santa Fe and Ichetucknee rivers were assessed to determine any relationships that may be evident between water quality and river discharge. Parameters investigated included specific conductance, pH, dissolved oxygen (DO), color, total Kjeldahl nitrogen (TKN), total nitrite + nitrate (NO_X), total ammonium (NH_4), total phosphorus (TP), dissolved orthophosphorus (PO_4), and chlorophyll (CHL-A).

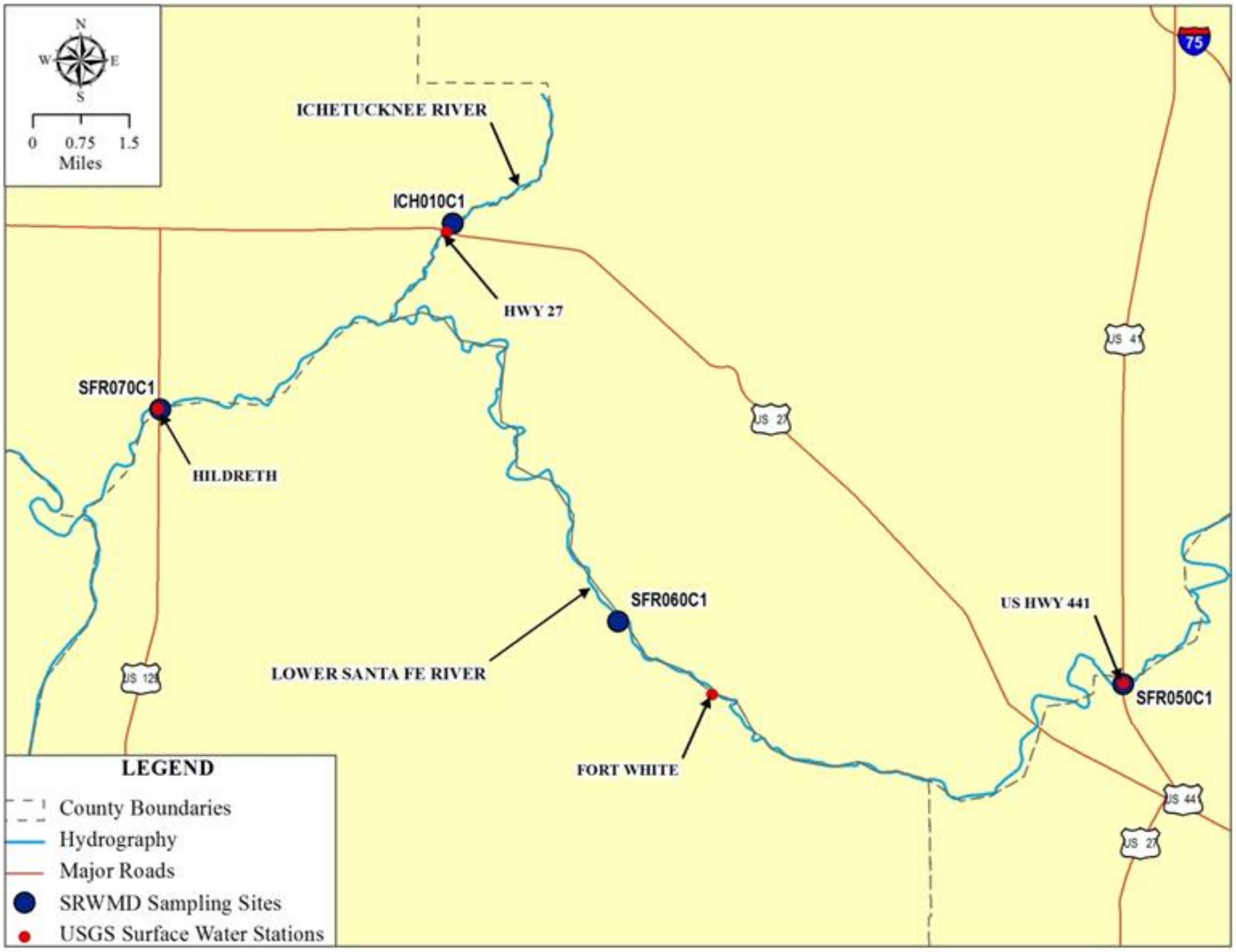


Figure 5-33. Locations of the Water Quality sampling sites on the Lower Santa Fe and Ichetucknee rivers

Significant relationships were determined using primarily linear regression with statistical significance determined by a p-value less than 0.05. In addition to statistical significance, to be useful for MFL criterion development relationships need explain a considerable proportion of the variation (R^2). Therefore, while there were some relationships that were statistically significant, they explained too little of the water quality parameter's variance to be useful in determining a MFL criterion. For parameters which the desired condition is a lower value, ie. nutrients, chlorophyll a, a positive relationship to flow means the condition becomes more undesirable with increasing flows. For these situations, the parameter does not lend itself to further consideration of MFL criterion development.

While there are similarities between the Ichetucknee and Santa Fe rivers, there are important differences that are apparent in the water quality data. The largest differences are due to the amount of surface runoff to the rivers. The Ichetucknee River is dominated by springflow nearly at all times with very little surface runoff. As a result the water quality of the Ichetucknee reflects groundwater at nearly all flow conditions. The groundwater influence is expressed by less variable flows, high water clarity, low color and suspended solids, higher calcium and pH. In contrast, the Santa Fe River, receives significant surface runoff, especially in the upper portion of the river. This surface runoff takes on the characteristics of rainfall and the decomposition of natural organic matter which imparts the typical tea color of warm southern rivers. The water quality of these rainfall driven systems tend to be low in dissolved minerals, low in pH and high in color. As a result, the Santa Fe River fluctuates between a system dominated by surface runoff at high flows to one dominated by groundwater during dry periods.

Due to changes in the relative contribution of surface runoff to the rivers, the rivers fluctuate between systems dominated by surface runoff and are dominated by naturally occurring organic compounds generated as part of the decomposition of organic matter. These organic compounds in the poorly buffered rainwater generate low pH water. During high flow periods, when the relative contribution of groundwater from springs is small the Santa Fe River appears as a typical colored system. However, during dry periods as surface runoff declines the relative contribution of groundwater increases. During the groundwater's contact time with the limestone aquifer some of the calcium carbonate matrix is dissolved and the water increases in both its pH and buffering capacity. As the groundwater enters the river, it tends to increase the calcium content, increase the pH and increase water's clarity. These naturally hydrologically driven processes do not create conditions where pH, calcium or color change beyond typical levels and are not useful for MFL development.

Conductivity in both rivers tends to be highest under low flow conditions when the rivers are dominated by groundwater. Even at the lowest flows, the rivers do not approach the state's conductivity standard of 1275 µS/cm. For this reason, this standard cannot be used for MFL development.

Dissolved oxygen is an important water quality constituent that reflects the metabolism of the river's biota and physical processes. The DO content of the Ichetucknee River is relatively stable due to dominance of groundwater flow. Within many springs, there is a positive relationship between discharge and DO, with lower DO occurring during periods of lower flows. The general mechanism behind this relationship is that springflows are generally a mix of shallow, younger groundwater and deeper, older groundwater (Copeland, Doran, White, & Upchurch, 2009). During dry periods it is the young, shallow contribution which tends to decline the most, which increases the relative contribution of older, less DO enriched water which tends to decrease the overall DO concentration in the flow. This relationship varies tremendously between springs and does not amend itself to setting MFL criteria. In the rivers themselves, the responses can be quite different due to the processes of photosynthesis and reaeration which add oxygen to the river's water. In the Ichetucknee River there is no significant relationship between discharge and DO, so DO not suited for MFL criterion development. Similarly, the Santa Fe River at High Springs did not show a significant relationship between DO and flow. In the Santa Fe River near Fort White, there is a significant negative relationship between flow and DO. However this relationship only explains about 11% of the variation in DO. This is likely due to the fact that these DO data were collected only during daylight hours and do not reflect the typical diel cycles of DO. For this reason, DO was not useful to determine a MFL criterion.

In the Ichetucknee River, apparent water color does not vary much because the water is nearly entirely groundwater, with very little surface water contribution. Not surprisingly there was no significant relationship between flow and color. In the Santa Fe River (both locations) there was a strong significant positive relationship between color and flow. This relationship exists because flow in the Santa Fe River is a mixture of clear groundwater and colored surface water. The greatest variability in flow is due to changes in surface flow. The relationship does not appear to be linear over the entire range. At low flows, the relationship appears more linear, while at higher flows the relationship becomes non-linear as color typically reaches a maximum of around 500. A decrease in groundwater contributions relative to surface flow could result in higher color per unit total flow. However given the slope of the relationship between color and flow (~0.11) means that it would take a 100 cfs change in groundwater flow to achieve a 11 color unit decline in color in the river. This change is seen as too small to be a meaningful criterion to develop a MFL.

Nitrogen is an important macronutrient for algal and plant growth. Nitrogen in the river exists in a variety forms in the river, and these forms cycle between forms driven largely biologically mediated. For this assessment three forms are considered. The first is total Kjeldahl nitrogen (TKN) which is a measurement technique which quantifies the organic nitrogen-containing compounds and ammonium. Second is ammonium (NH_4), a reduced inorganic form of nitrogen readily available for uptake by plants. The last is nitrate (NO_3), an oxygenated form of inorganic nitrogen also readily available for uptake by plants. Nitrate (NO_2), another oxidized form is commonly found a concentrations lower than nitrate, but the two are often measured together as NO_x to reflect that often vary together. Here nitrate (NO_x) is intended to represent the sum of both NO_3 and NO_2. Due to increased nitrogen loading to the Santa Fe basin by a variety of human activities, nitrogen is in excess in the rivers and there are ongoing efforts to reduce nitrogen abundance in the systems (FDEP, 2008, 2012).

The total Kjeldahl nitrogen (TKN) concentration in the Ichetucknee River is uncorrelated with flow and therefore not useful for MFL development. In the Santa Fe River there is a significant positive relationship between TKN and flow. Since this relationship is positive it is not a useful criterion for MFL development, assuming that lower TKN is beneficial.

Nitrate is an important water quality constituent for springs and spring run rivers. The State has recently adopted a numeric nutrient criterion for nitrate of 0.35 mg N-NO_x. In the Ichetucknee River there is no significant relationship between nitrate and flow so it is not useful for MFL criterion development. In the Santa Fe River the relationship between flow and nitrate is complicated due to the presence of both surface and groundwater contributions. As is typically observed in surface runoff dominated systems, nitrate declines with flow due to dilution. However the relationship between nitrate and spring flows is variable, with some springs having a positive relationship, some having a no relationship and one (Blue Hole) having a negative relationship. The relationship for Blue Hole is weak and based upon a very limited dataset and should be considered preliminary. These relationships exist independently of any temporal trends of nitrate in these same springs. Within the lower Santa Fe basin there are springs with increasing trends, decreasing trends or no trend in nitrate over time.

Nitrate concentrations in the Ichetucknee River are positively correlated with flow, however the relationship is weak, explaining less than 3% of the variation in nitrate. This positive relationship is indicative of the small volume of surface water entering this system. The low percentage of nitrate variation explained by flow makes the relationship unsuited for MFL criterion development. At the Highway 441 site on the Santa Fe River, there was not a significant relationship between flow and nitrate, so nitrate could not be used for MFL criterion development. At the Fort White site on the Santa Fe River, there was significant, strong negative linear relationship between nitrate and flow which explains about 29% of the variation in nitrate. An exponential fit explains about 50% of the variation, however there is considerable uncertainty in the relationship near the 0.35 criterion, thus the no nitrate criterion for MFL development was pursued, Figure 5-34.

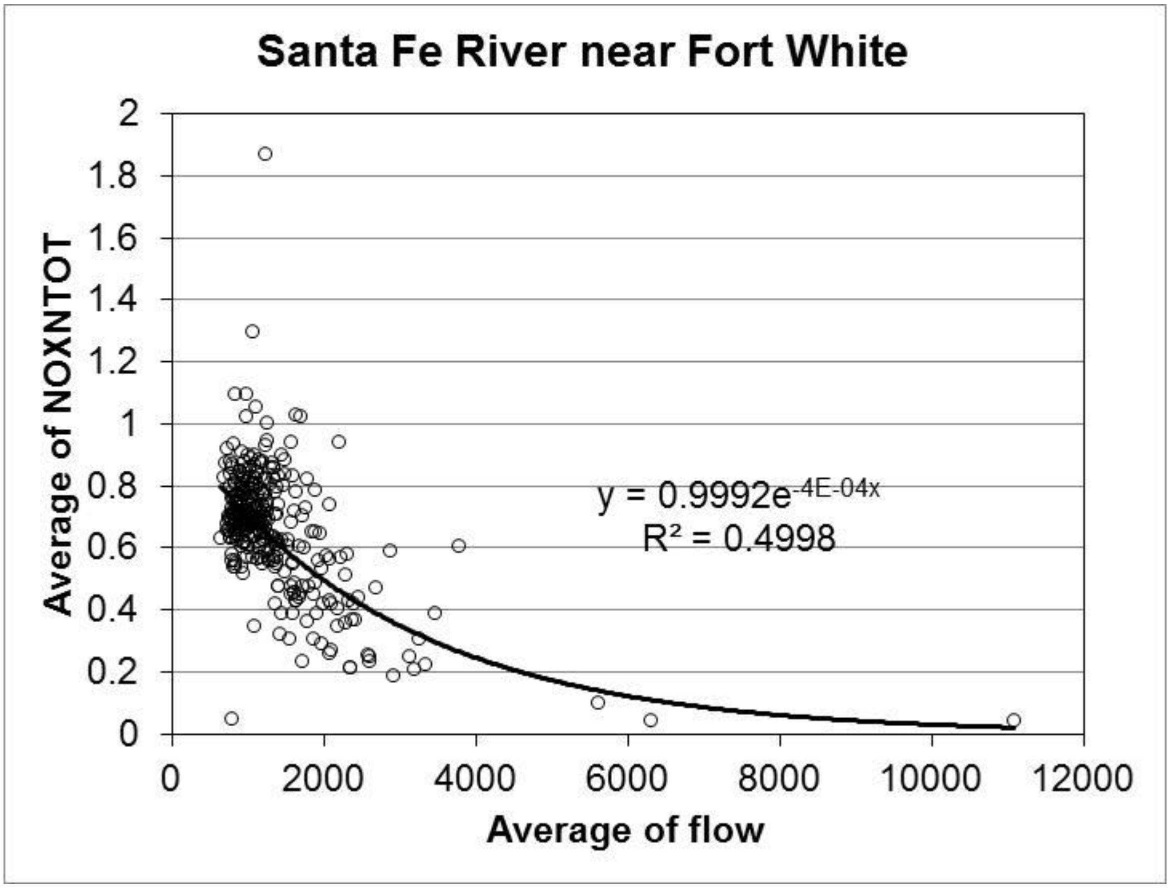


Figure 5-34. Plot of Nitrate vs. Flow for the Santa Fe River at Fort White (02322500)

While the exponential fit explains more of the variation in nitrate than a linear fit. There is considerable range in flow at which a nitrate concentration of 0.35 mg N-NOx/L would be observed (~1,000 to 3,500 cfs).

It should be noted that the nitrate impairment of the Santa Fe basin has been determined by FDEP in its Total Maximum Daily Load TMDL for the system (FDEP, 2008). This impairment is also the subject of FDEP's adopted Basin Management Action Plan (BMAP) whose purpose is to reduce nitrate concentrations in the system's springs and spring runs to 0.35 mg N-NO_x/L (FDEP, 2012). Addressing the nitrate impairment of these rivers will also likely result in addressing any impairments of the new numeric nutrient criterion for total nitrogen (TKN + NO_x) which for these rivers is 1.87 mg N/L.

Phosphorus is the other macronutrient commonly found to be limiting algal production in freshwater systems. Total phosphorus in the Ichetucknee River is not significantly related to flow, not surprising for this groundwater dominated system. Within the aquifer matrix there are abundant opportunities for phosphorus to exchange, thus smoothing out variations in concentration. The lack of a relationship to flow eliminates it for potential MFL criterion development. In the Santa Fe River where surface water contributes to high flow conditions total phosphorus is positively related to flow. These positive relationships make total phosphorus concentrations unsuitable for MFL criterion development. During high flow conditions, the increased flushing and higher water color reduce the stimulatory growth effects of phosphorus within the rivers. The new numeric nutrient criterion for total phosphorus applicable to these rivers is 0.30 mg TP/L. This criterion is infrequently exceeded in either river and phosphorus was not included in the TMDL for the system (FDEP, 2008).

The form of phosphorus most readily available to stimulate algal growth is orthophosphorus or phosphate (PO_4). As was found for total phosphorus, in the Ichetucknee River there is a negative relationship between PO_4 and flow, however the relationship is weak, explaining less than 3% of the variation and therefore not suitable for MFL criterion development. At both of the Santa Fe River locations there is positive relationship between PO_4 and flow, not surprising for a system influenced by surface runoff. The positive relationship makes the PO_4 unsuitable for MFL criterion development.

The measurement of chlorophyll a (CHL-A) is often used as in index for algal biomass as this pigment is found in all common algal taxa. Chlorophyll in the water column could represent either planktonic algae living in the water column or algae which were originally growing on the river's bottom on other substrate and have been scoured suspended in the water column. In the Ichetucknee River there was no relationship between CHL-A and flow, making CHL-A unsuitable for MFL criterion development. At both the Santa Fe River locations there was no significant relationship between CHL-A and flow, thus CHL-A was unsuitable for MFL criterion development. In spite of the lack of a linear relationship between CHL-A and flow, it is clear that the highest CHL-A values occur during periods of low flow. This reflect the relatively low flushing rates allowing phytoplankton biomass to accumulate under the clear water, long hydraulic residence times which exist at low flows. It is important to note that at low flows, most of the CHL-A measurements are less than 4 µg/L, thus flow alone is a unreliable predictor of CHL-A. To assess the role the duration of flow conditions on CHL-A flows were averaged over a variety of durations ranging from 7 to 60 days. Even at the longest averaging period of 60 days, the majority of CHL-A measurements are less than 4 µg/L. The unreliability of the relationships between CHL-A and flow do not support MFL criterion development. None of the values exceed the threshold of CHL-A > 20 µg/L commonly used to identify excessive algal biomass in rivers.

Another water quality constituent which can be indicative of degraded conditions is turbidity, which is a measure of the water's clarity and is important as it relates to the ability of sunlight to penetrate the river's water column and reach the bottom to provide sufficient light for submersed aquatic vegetation to grow. There was no relationship between turbidity and flow for the Ichetucknee River and Santa Fe River at Highway 441. For the Santa Fe River at Fort White there was a positive relationship which explained less than 4% of the variation in turbidity. These turbidity data could not be used for MFL criterion development.

A detailed examination of turbidity in the Ichetucknee River provided high frequency data to examine the potential for turbidity to be used as a MFL criterion (Wetland Solutions Inc., 2011). Continuous turbidity data were collected during a portion of 2010. Daily averages were calculated and analyzed against daily flow data. Days of the week were examined separately to evaluate the potential that weekend days with high number of recreational tubers might have a different relationship to flow. Overall there was a strong positive relationship between turbidity and flow. While there is some indication that weekend days have relatively higher turbidity compared to week days at similar flows, the influence was relatively minor (Figure 5-35). The positive relationship makes the turbidity unsuitable for MFL criterion development.

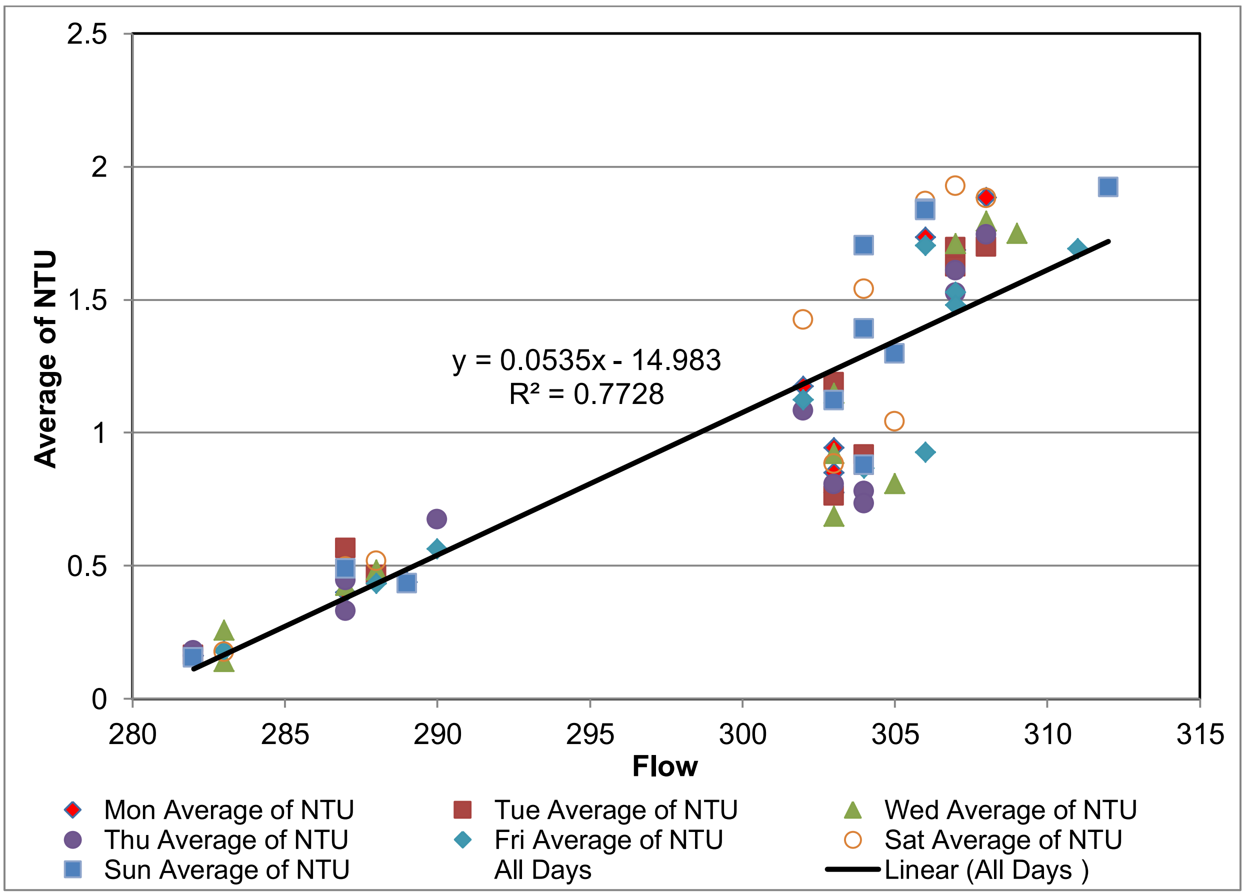


Figure 5-35. Plot of Turbidity vs. Flow for the Ichetucknee River
Note: Daily means for ever day of the week are separated. The best fit line is for all days of the week combined. There is no obvious pattern indicating weekend days are higher than week days for a given flow.

There were no quantitative data on attached or periphytic algae that would allow examination of potential MFL criterion. Like nutrients, the overabundance of either periphyton or phytoplankton either evaluated via numeric data or narrative criteria are addressed as part of the nutrient impairment assessment and restoration that are occurring as part of the TMDL and BMAP processes currently underway by FDEP in the Santa Fe River basin.

As discussed earlier in Chapter 3.0, King (2012) evaluated the role of flow and velocity on algal biomass for a Florida spring run. There are two potential sources of velocity data in the Ichetucknee River that could be used to evaluate the development of a velocity-based MFL criterion related to algal biomass accumulation. The first source would be using data collected by the USGS during their discharge measurements at the US 27 gage. While the USGS velocity measurements contain detailed velocity profiles, the measurements occur at small number of locations and are not spatially distributed along the river. The second source would be to use the HEC-RAS model as a source of an estimated velocity distribution. However the exported velocity distributions contain only one vertical velocity for each velocity distribution at each cross section. Finally, there are no algal abundance data to compare against either velocity dataset. Therefore use of velocity for preventing accumulation of algal biomass was not used for MFL criterion development due to the lack of necessary data.

FISH PASSAGE

The maintenance of a minimum water depth sufficient for the movement and passage of fish upstream and downstream throughout the entire river study area is an important consideration in setting MFLs, and is one of the criteria used to protect in-stream habitat. Providing water deep enough for fish passage maintains the longitudinal connectivity of the river that is necessary for successful foraging, spawning, and migration by local and transient species.

Guidelines for fish passage are typically based on body dimension measurements of several fish species (Hupalo, Neubauer, Keenan, Clapp, & Lowe, 1994). Few studies have actually documented minimum water depths required to maintain fish passage, and it is unknown how many shallow obstructions can be navigated by fish before health and vitality are compromised (Hupalo, Neubauer, Keenan, Clapp, & Lowe, 1994). However, minimum water depths of at least 0.6 feet have been applied previously in Florida (SRWMD, 2007; SWFWMD, 2002; SWFWMD, 2004). Most recently, the St. Johns River Water Management District has used a depth of 0.8 feet over 25% of the channel width as the criterion for fish passage (SJRWMD, 2012).

In accordance with the St. Johns River WMD criterion, fish passage throughout the Lower Santa Fe and Ichetucknee rivers was assumed to require water depths of at least 0.8 feet over at least 25% of the most limiting HEC-RAS transect. The Lower Santa Fe River HEC-RAS model is an appropriate tool to estimate water depths at various locations throughout the river. The HEC-RAS model was used to develop relationships between river flow and water surface elevation (stage), at each of the model's transects. Using the HEC–RAS model, the flow-stage relationships were defined for a series of downstream condition scenarios (Suwannee River stages – 20th, 40th, 60th, and 80th percentiles) that represented varying downstream boundary conditions. The boundary conditions reflected different water levels on the Suwannee River, which can affect flows and water surface elevations in the Lower Santa Fe and Ichetucknee rivers. The HEC-RAS model results using the 20th percentile Suwannee River stage was chosen for analysis as this downstream condition has the least impact on the stage-discharge relationships both in the Lower Santa Fe and Ichetucknee rivers.

Figure 5-36 provides an example of a graphical tool that aids in the identification of the flow that allows fish passage at all transects. For each HEC-RAS transect, the depth of water over the channel bottom is estimated for a given flow. Z represents the difference between this depth and the depth required to maintain fish passage (i.e., 0.8 feet over 25% of the channel). Therefore, for a given flow, this plot shows all transects that allow fish passage (i.e., where Z is greater than 0) and transects where the water depth is too shallow to allow fish passage (i.e., where Z is less than 0). This graphical approach was applied to flows in 2% flow intervals for both rivers and these plots can be found in Appendix 5-4.

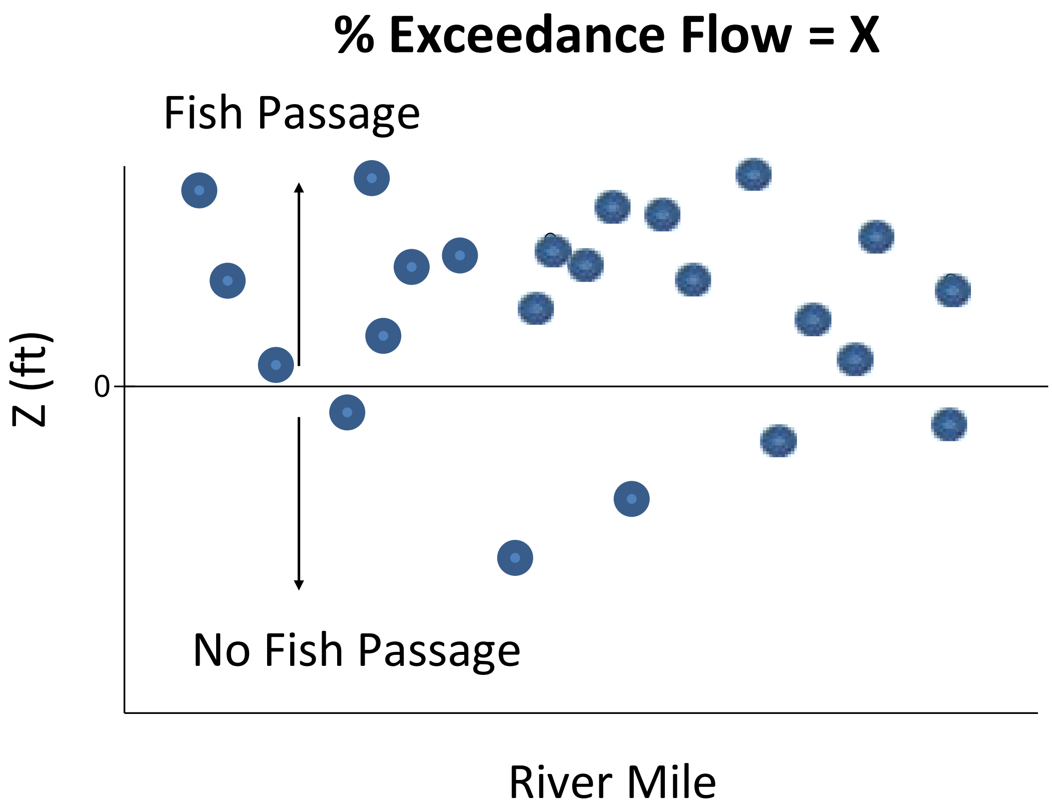
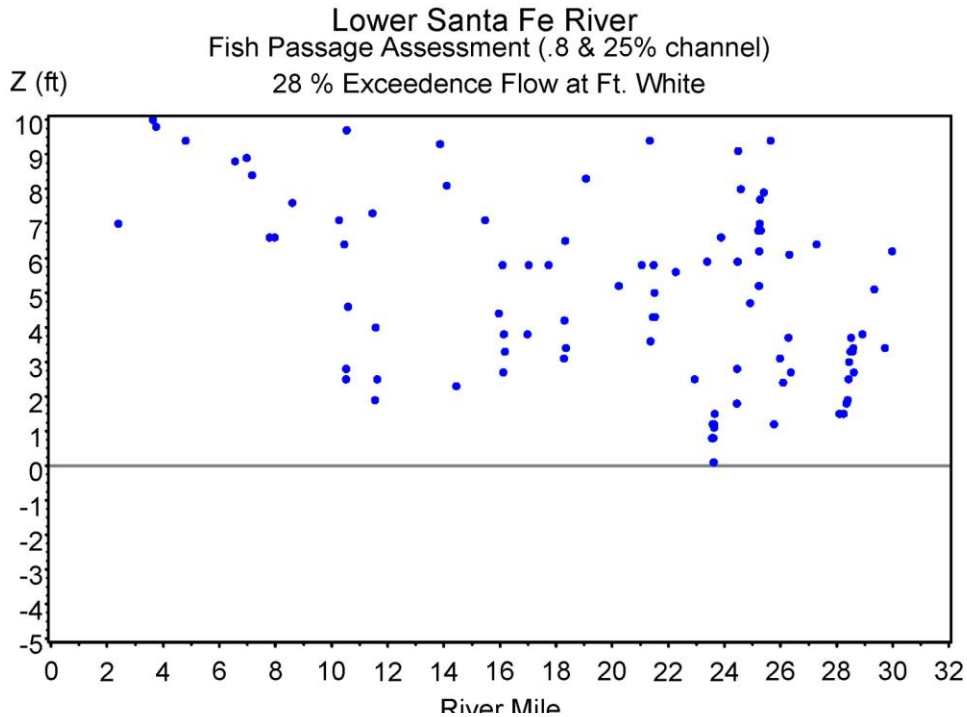


Figure 5-36. Conceptual diagram showing fish passage.
Note: Z is defined as the maximum simulated depth at a transect (River Mile) minus the critical depth necessary for fish passage. When Z > 0, fish passage is ensured at flow condition X. When Z < 0, fish passage is precluded at flow condition X.

It follows that when any transect takes on a negative value for Z (i.e., prevents fish passage), the Critical Flow for fish passage is at or between that flow and the preceding percentile flow. Using this approach, examination of the plots in Appendix 5-4 shows that the Critical Flow for fish passage was between the 28th and 30th percent exceedance flows in the Lower Santa Fe River (Figure 5-37) and between the 48th and 50th percent exceedance flows in the Ichetucknee River (Figure 5-38).



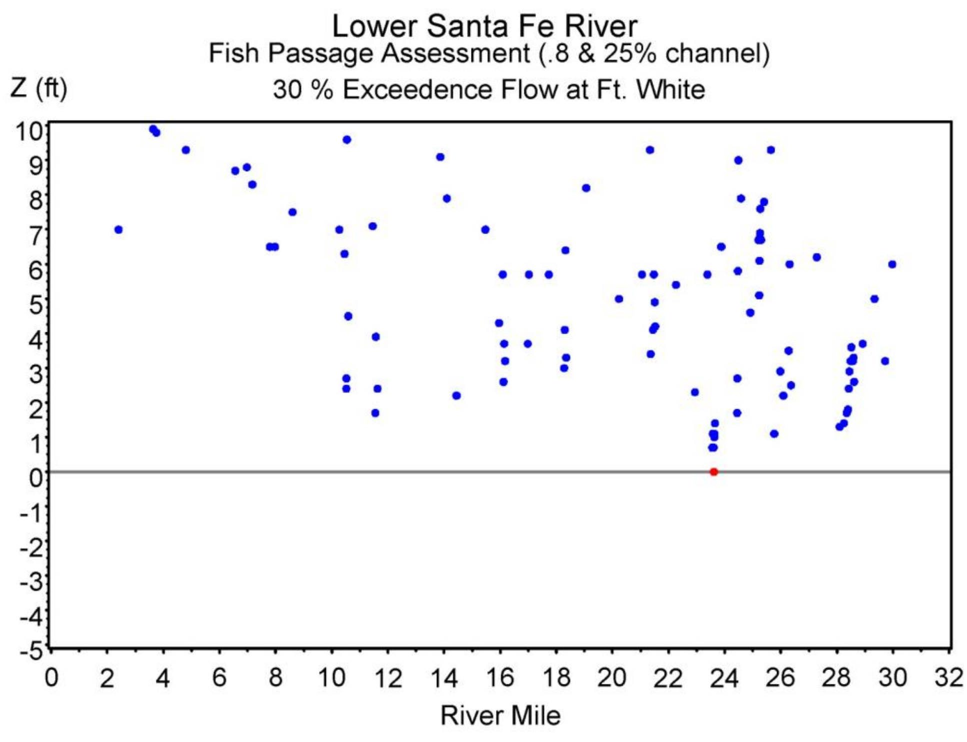


Figure 5-37. Results of the fish passage assessment on the Lower Santa Fe River.
Each point represents the maximum water depth at a HEC-RAS transect at the 28% (above) and 30% (below) exceedance flows minus the 0.8 feet fish passage criterion. The Suwannee River boundary condition is at the 20th percentile stage.

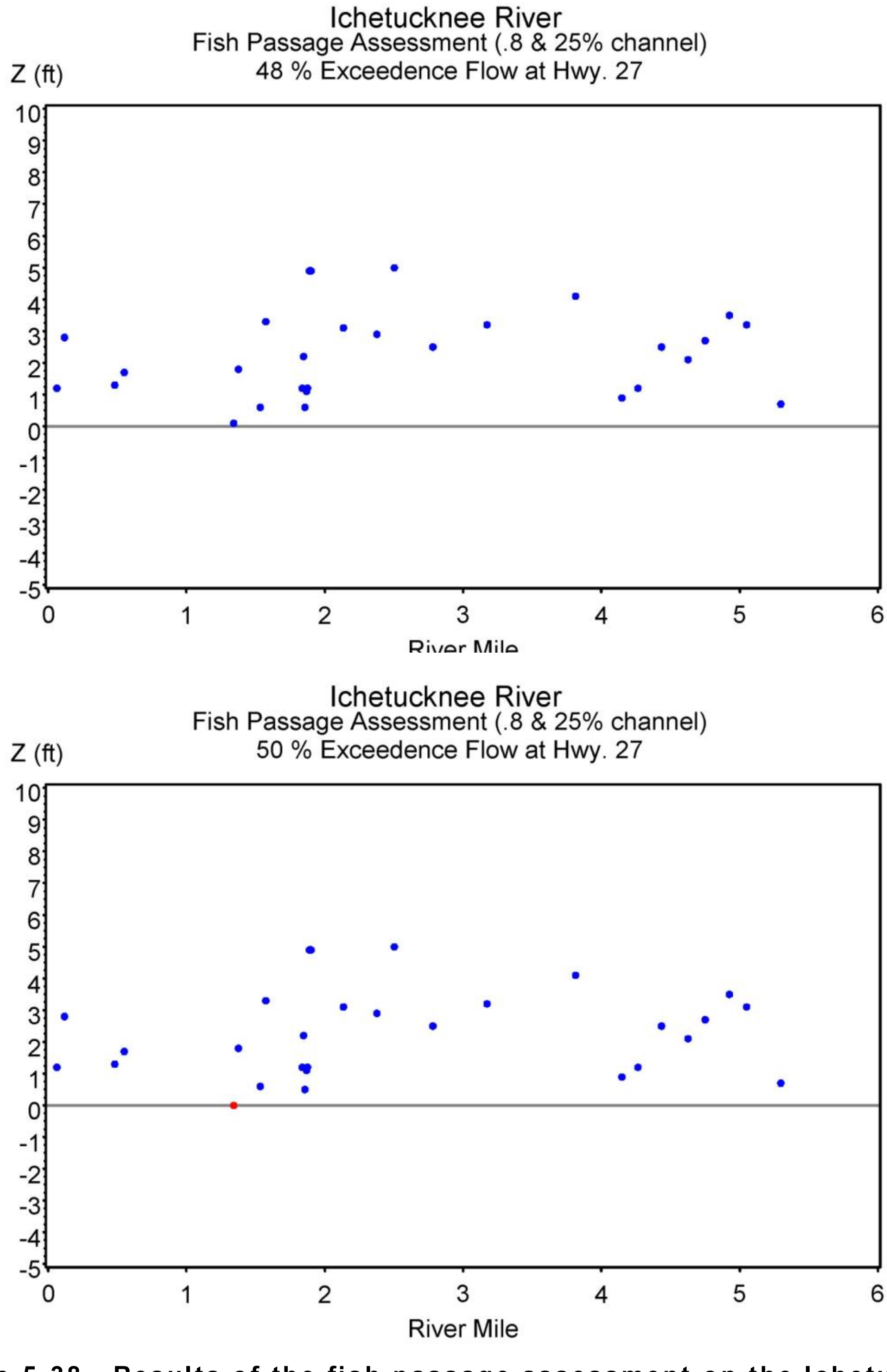


Figure 5-38. Results of the fish passage assessment on the Ichetucknee River.
Each point represents the maximum water depth at a HEC-RAS transect at the 48% (above) and 50% (below) exceedance flows minus the 0.8 feet fish passage criterion. The Suwannee River boundary condition is at the 20th percentile stage.

Based on these results, the Critical Flows for fish passage are 1110 cfs and 284 cfs in the Lower Santa Fe River and Ichetucknee River, respectively. Using the respective Baseline Flows time series, RALPH plots of the number of days in each year from October 1, 1932, to September 30, 1990, that the Critical Flows associated with fish passage were equaled or exceeded are shown in (Figure 5-39 and Figure 5-40).

The Resulting Metric Flow for fish passage was estimated by iteratively reducing the daily flows from the Baseline Flows time series in 1% increments. The percent reduction that resulted in a 15% reduction in the number of days when the Critical Flow was equaled or exceeded defined the Resulting Metric Flow. Figure 5-41 and Figure 5-42 present the results of this iterative analysis of flow reductions. These plots depict the number of days that the Critical Flow was equaled or exceeded for the series of 1% flow reduction increments. The plots also depict a green line which indicates the 15% reduction in the number of days that the Critical Flow is met. The lowest flow reduction that lies below this green line, therefore, is the allowable percent reduction. RALPH plots (Figure 5-43 and Figure 5-44) can also be used to compare the number of days in each year that the Critical Flow is met during the Baseline Flows time series and the time series of daily flows with the percent reductions identified from Figure 5-41 and Figure 5-42.

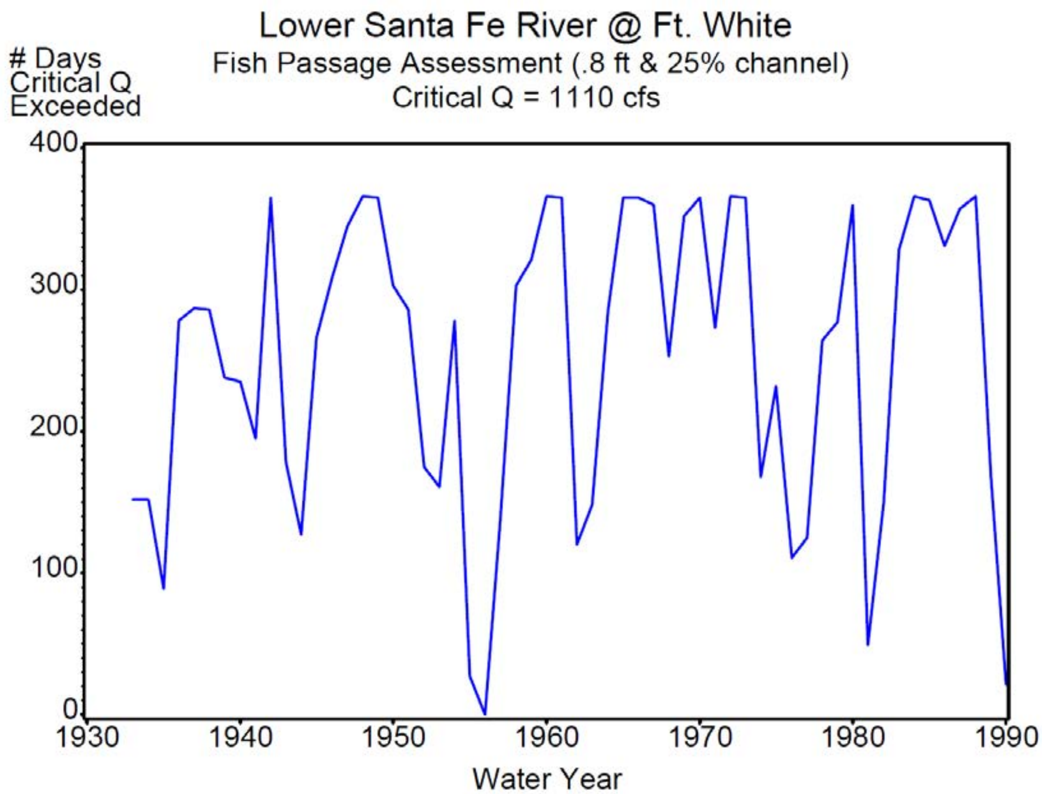


Figure 5-39. RALPH plot for fish passage in the Lower Santa Fe River.

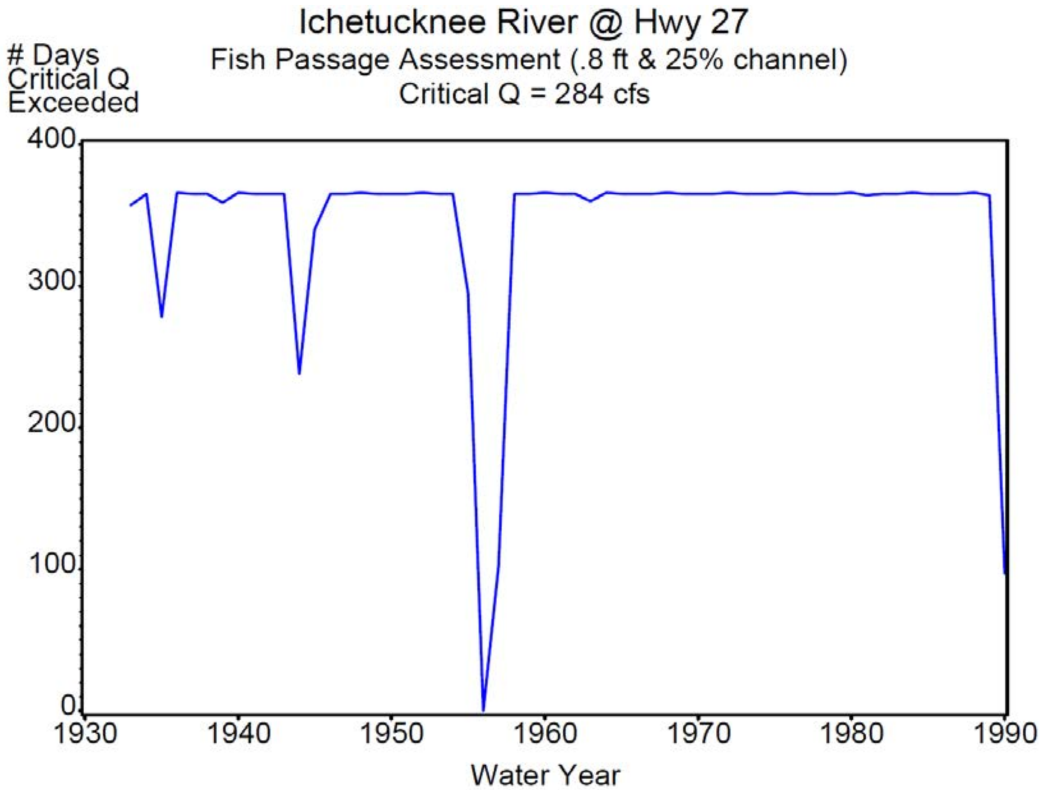


Figure 5-40. RALPH plot for fish passage in the Ichetucknee River.

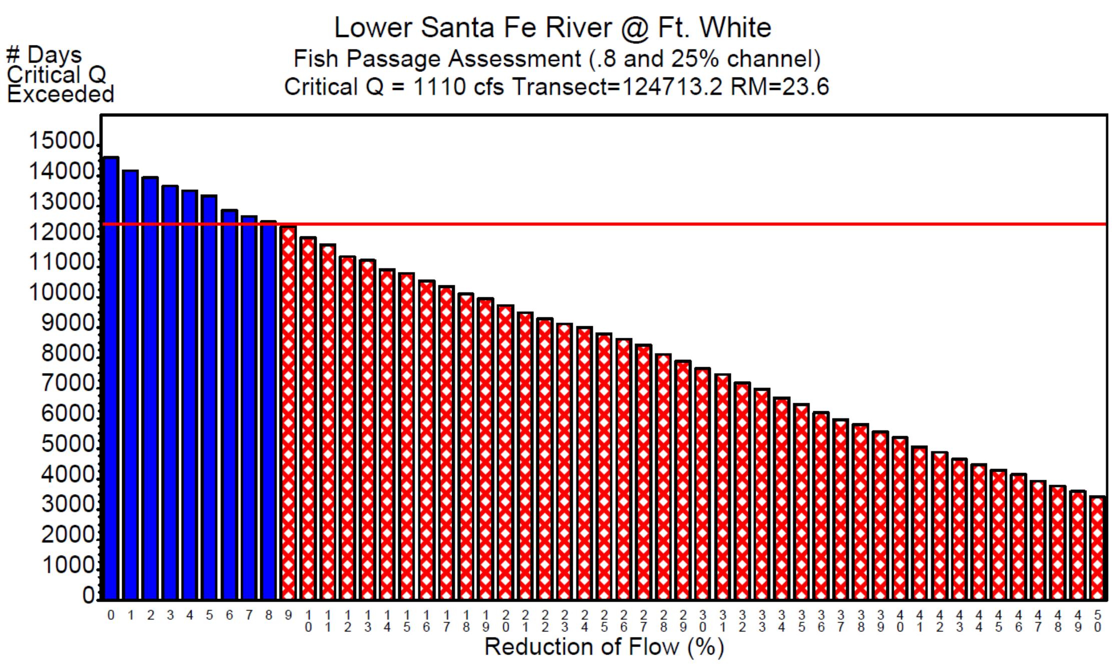


Figure 5-41. Results of the iterative reductions in flow and the resulting number of days that the Critical Flow for fish passage in the Lower Santa Fe River was equaled or exceeded.
Horizontal red line indicates a 15% reduction in the number of days from the maximum value.

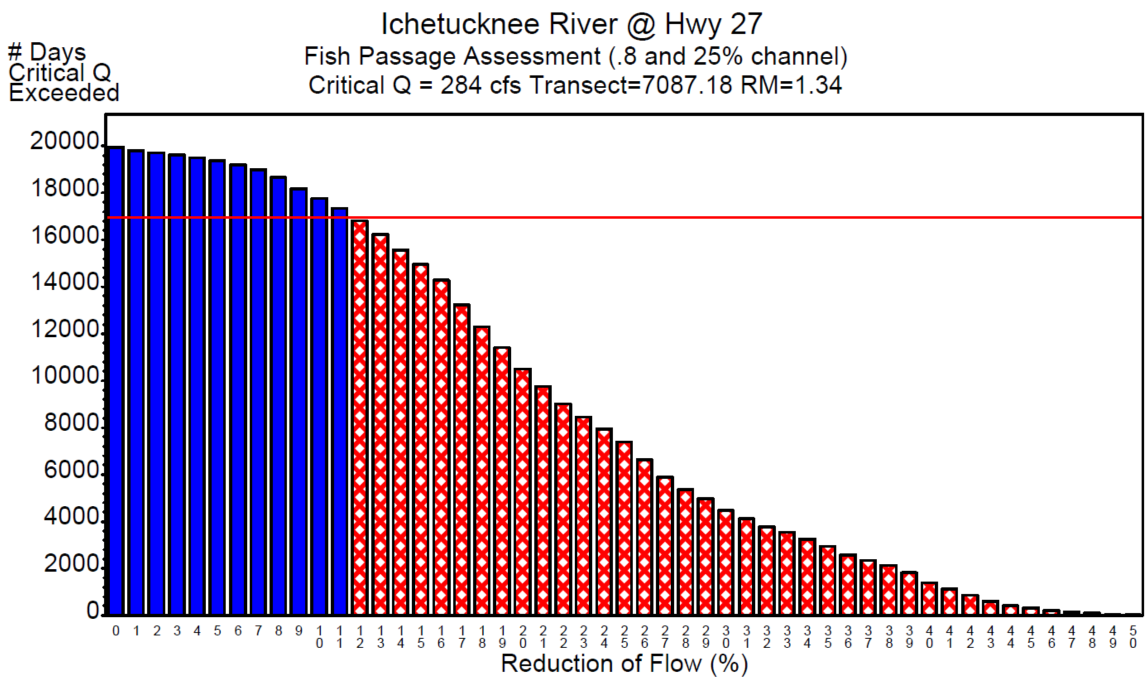


Figure 5-42. Results of the iterative reductions in flow and the resulting number of days that the Critical Flow for fish passage in the Ichetucknee River was equaled or exceeded.
Horizontal red line indicates a 15% reduction in the number of days from the maximum value.

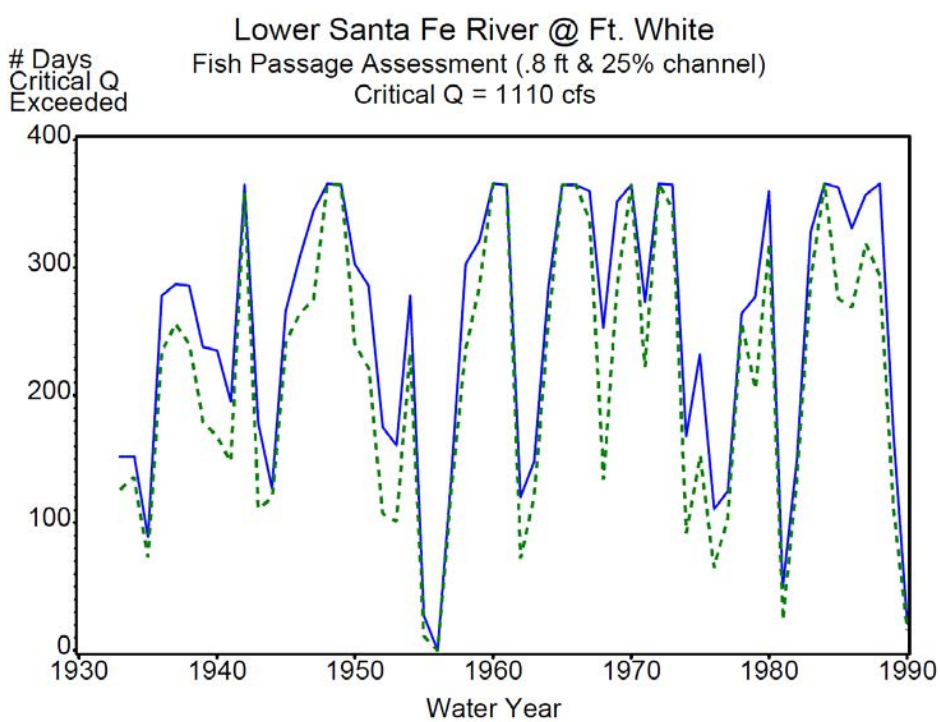


Figure 5-43. RALPH plot for fish passage in the Lower Santa Fe River A Comparison of the results from the Baseline Flows (blue line) and the allowable percent reduction from Figure 5-39 (dashed green line).

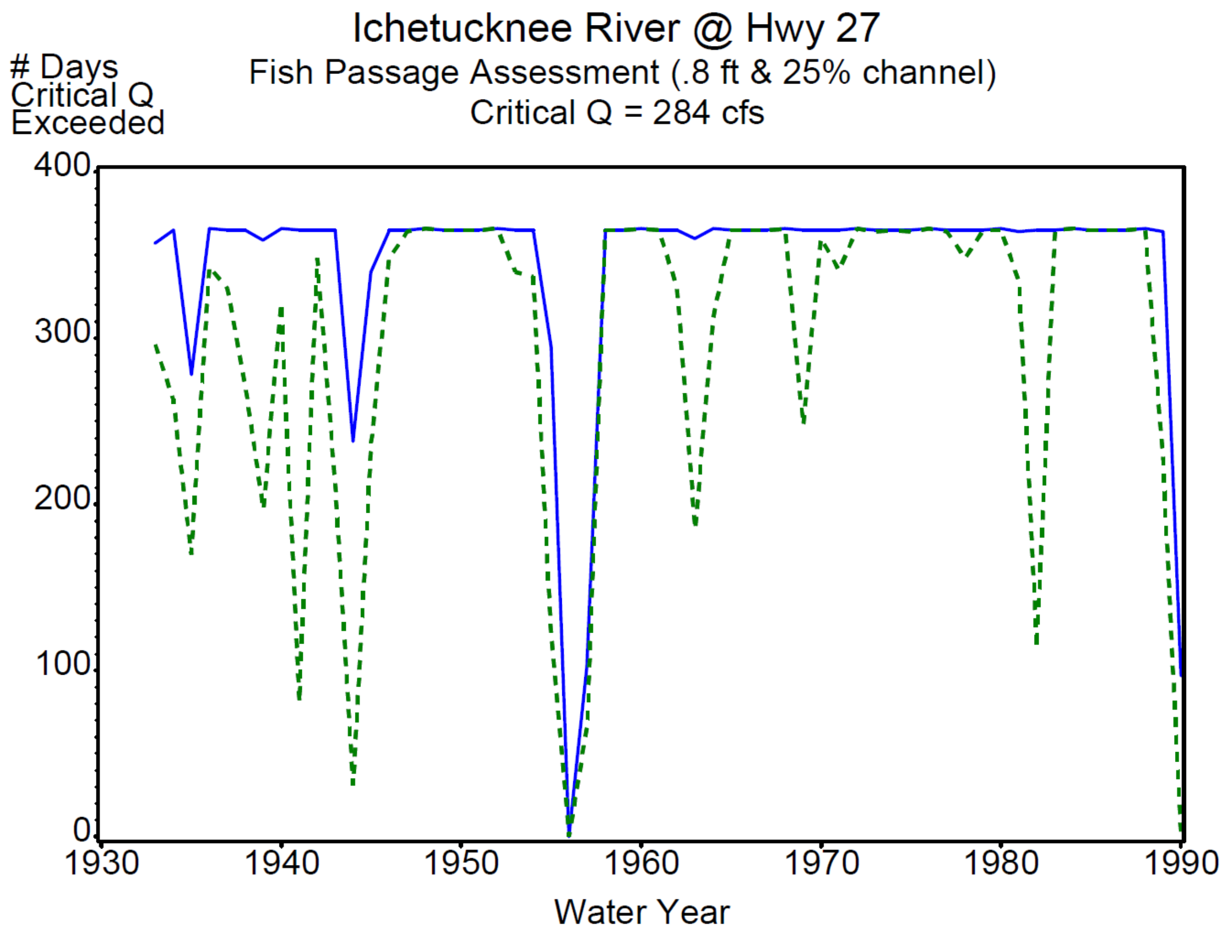


Figure 5-44. RALPH plot for fish passage in the Ichetucknee River A Comparison of the results from the Baseline Flows (blue line) and the allowable percent reduction from Figure 5-40 (dashed green line).

Table 5-4 summarizes the Critical Flows, the allowable percent flow reductions, and the Resulting Metric Flows for fish passage in each river. As was found for the floodplain vegetation, hydric soils, the allowable percent reductions are relatively low, 8% and 11% for the Lower Santa Fe River and Ichetucknee River, respectively.

Table 5-4. Critical Flows (cfs), allowable percent reductions, and Resulting Metric Flows for the fish passage from the Lower Santa Fe River and Ichetucknee River.

River	Critical Flow (cfs)	Allowable Percent Reduction	Resulting Metric Flow (cfs)
Lower Santa Fe	1110	8%	1021
Ichetucknee	284	11%	253

HABITAT SUITABILITY

Instream Flow Incremental Methodology (IFIM) is a widely-used suite of tools used for setting MFLs (Bovee, et al., 1998). The Physical Habitat Simulation (PHABSIM) module of IFIM is a predictive tool that models microhabitat variability associated with flow alterations and has been used by regulatory agencies around the world (Gore, Layzer, & Mead, 2001). In Florida, PHABSIM has been used to set MFLs on several rivers, including the Alafia, Peace, and Upper Myakka rivers (SWFWMD, 2004).

IFIM is a multi-faceted process for evaluating the instream flow requirements of lotic organisms, particularly fishes (Bovee, et al., 1998). The IFIM approach considers hydraulic conditions, water quality, temperature regime, morphology and morphometry of the channel, as well as the physical microhabitat requirements of the biota in terms of depth, velocity, substrate and cover (Bovee, et al., 1998). The microhabitat requirements for the biota are considered in the PHABSIM element of IFIM (Bovee, et al., 1998).

PHABSIM is a component of IFIM which is based on the assumption that aquatic biota respond to alterations to instream flow. The PHABSIM model relies on water surface profile data collected through a selected channel reach over a range of discharges. The profiles provide information on water depths and velocities at a single discharge, which allows other variables, such as widths, depths, and velocities to be estimated at a variety of river flows. Knowing the optimum conditions for instream uses, such as fish spawning, allows for the weighted-usable-area (WUA) at each discharge to be computed.

In the case of the Lower Santa Fe River and Ichetucknee River, field data were collected under a relatively narrow range of flows that were typically low. When the PHABSIM model was applied and WUA values were estimated, the maxima that were developed were such that the 15% habitat reduction criterion was unable to be used. Thus, due to the small range of flows that was observed during the field data collection portion of the study, an alternative was chosen instead.

RHABSIM (Riverine HABitat SIMulation) was chosen as an alternative to PHABSIM due to the inability to collect field data that covered an adequate range of flows in order to evaluate a minimum flow for critical habitat availability. RHABSIM is a fully integrated program for river hydraulics and aquatic habitat modeling using the Instream Flow Incremental Methodology (IFIM) developed by Thomas R. Payne and Associates of Arcata, CA. Running in Microsoft Windows and DOS, it is an extensive conversion of the PHABSIM hydraulic and habitat simulation system developed by the U.S. Fish and Wildlife Service. RHABSIM allows for the import of ASCII text input files that contain transect data, including bed elevation, velocity and other attribute data such as substrate and cover type.

RHABSIM predicts changes in the extent of available microhabitat as instream flow regimes change. The assumption is that the temporal and spatial extents of specific microhabitats are affected by streamflow, which is associated with the carrying capacity of the stream. Therefore, biotic communities are assumed to be affected by changes in the flow regime. The amount of available habitat varies with changes in velocity, depth, or substrate type. It also examines how aquatic biota respond to modeled alterations in the flow regime and the attendant effects on physical habitat, as measured by WUA. WUA, a combination of physical microhabitat quantity and quality, is the typical output of the RHABSIM process. Microhabitat quality is weighted by the probabilistic range of the species' preferences in velocity, depth, and substrate type, as estimated in Habitat Suitability Indices (HSIs). Usable area is suitable for a species' presence, but WUA gives greater weight to the species' preferences. As depths and velocities vary with flow, the area and quality of habitat may change.

As an alternative approach, input files for use in RHABSIM were created from HEC-RAS steady-state model output, which includes the same depth and velocity estimates required to run PHABSIM. Additionally, RHABSIM has a number of other advantages over other habitat suitability model alternatives, including compatibility with the previously developed habitat suitability indices (HSIs) that have been applied elsewhere in the SRWMD and very similar algorithms in the estimation of WUA, the commonly used and understood model output type from PHABSIM. Due to its compatibility with the HEC-RAS hydraulic model, in addition to its familiar output, the RHABSIM model was chosen as the best alternative to PHABSIM for setting minimum flows for the Lower Santa Fe and Ichetucknee rivers.

To apply the RHABSIM model, the following steps were necessary:

- Development of a calibrated HEC-RAS model (*see subsection 4.3 or Appendix 4.1 for further details*) - Application of the RHABSIM model requires the selection of transects from a calibrated HEC-RAS model, which are chosen to represent larger river segments, with specific regard given to significant habitat types. Snag and shoal habitats have particular importance for the application of a habitat suitability model. The snag habitat provides a preponderance of protective spaces in the submerged vegetation which are important for spawning and juvenile fish, while the shoals are important as they provide spawning grounds and, during low-flows, can be a limiting factor for species migration (Burgess, 2008). The selected HEC-RAS model transects was based on the locations of the transects visited during the field data collection (Figure 5-45).

- Output of data at a series of flows - The HEC-RAS model was run at a series of flows that ranged from the 2nd through the 98th percentile flows in 2-percentile flow increments. Data were estimated at regular distance intervals across each transect. These data included velocity and water surface elevation. Model output also included channel bed elevation data, which is necessary to estimate depth as a function of flow in the habitat suitability model.

- Identification of sensitive taxa - Key biota were identified for inclusion in the habitat suitability modeling effort. Preferences for depth, velocity, and substrate for each of these taxa, at various critical life stages, have been determined and were included in the application of the model using Habitat Suitability Indices (HSI). The HSI curves were obtained from the Southwest Florida Water Management District and can be found in Appendix 5-5. It should be noted that the critical flows represented on each graphic are those determined at transect locations prior to adaptation to a long term gage.

The key taxa and their life stages (spawning, fry. juvenile, and larvae) included spotted sunfish (*Lepomis punctatus*), largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), Cyprinidae (minnows), fish habitat guilds (shallow-fast and shallow-slow), benthic diversity (low flow), and *Tvetenia* (a genus of non-biting midges of the family Chironomidae.

- Application of the model – The HEC-RAS model was run as a steady-state for flows in two (2) percentile increments from the 2nd through the 98th percentiles. The velocity, water surface elevation data, and channel bed elevation data, which were estimated by the HEC-RAS model, were converted into ASCII text files and input to the habitat suitability model. The HSIs from the previous step were also input to the model. The habitat simulation model was run for each taxon and life stage combination. WUA curves were examined. For each curve, the maximum WUA value was identified. The Critical Flow for each taxon and life stage was then estimated as that flow that resulted in a 15% reduction in WUA. The WUA-flow curves are presented in Appendix 5-6.

Figure 5-45. Location of RHABSIM transects on the Lower Santa Fe River and the Ichetucknee River.

The Resulting Metric Flows, Critical Flows, and the allowable percent reduction to reach the Resulting Metric Flows varied across the various taxon-life stage variables. There are clearly a number of taxon-life stage variables that are more sensitive to changes in flow. Selection of these taxon-life stage variables to establish the MFLs for the two rivers assures that the habitat requirements of the less sensitive are protected. The following taxon-life stage variables were selected for the Lower Santa Fe River - spotted sunfish (spawning, fry, juvenile, larvae); Cyprinidae (composite); and Tvetenia (larvae). These organisms displayed both a maximum WUA and decreasing WUA with decreasing flows. Other organisms either displayed a monotonically increasing WUA with increasing flows or did not display a decreasing WUA with decreasing flows. In the Ichetucknee River, the Tvetenia (larvae) variable was chosen. Figures

Figure 5-46 through Figure 5-52 present the reduction in WUA associated with river flow reductions, in 1% increments from 0 to 50%, for both rivers.

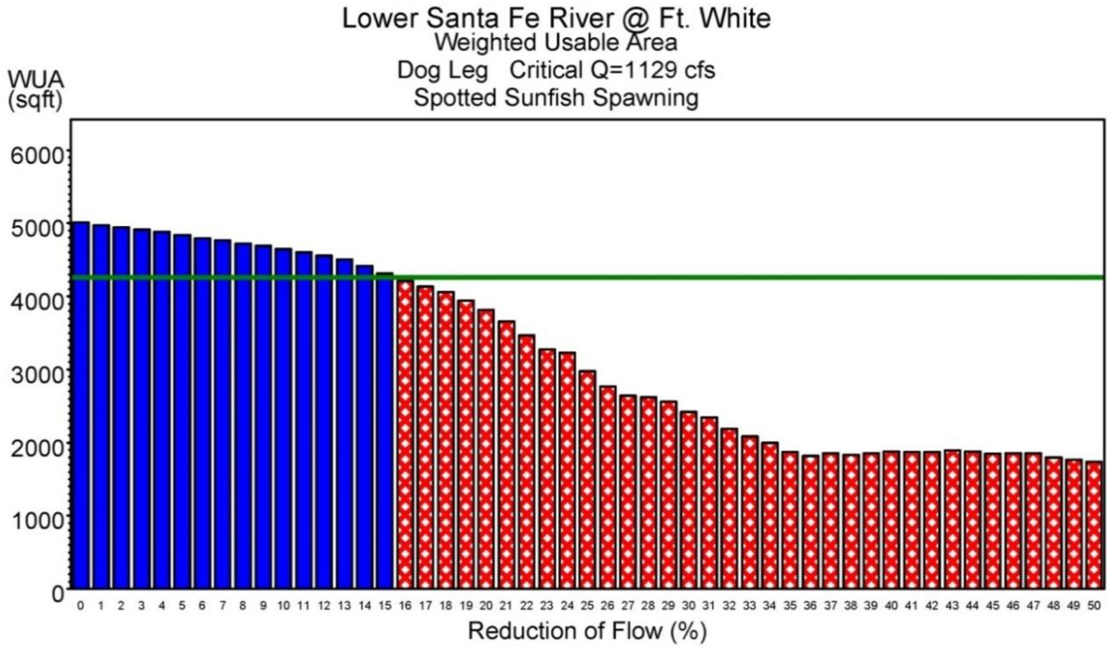


Figure 5-46. Reductions in WUA for spotted sunfish spawning associated with river flow reductions in 1% increments from 0 to 50% in the Lower Santa Fe River.
Horizontal green line indicates a 15% reduction in the WUA from the maximum value.

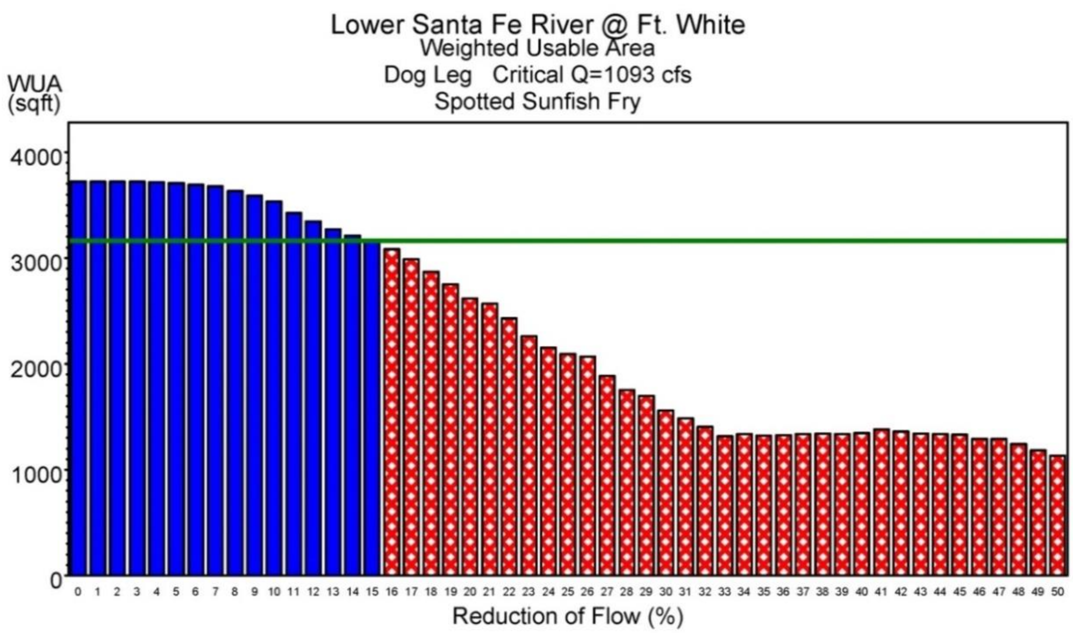


Figure 5-47. Reductions in WUA for spotted sunfish fry associated with river flow reductions in 1% increments from 0 to 50% in the Lower Santa Fe River. Horizontal green line indicates a 15% reduction in the WUA from the maximum value.

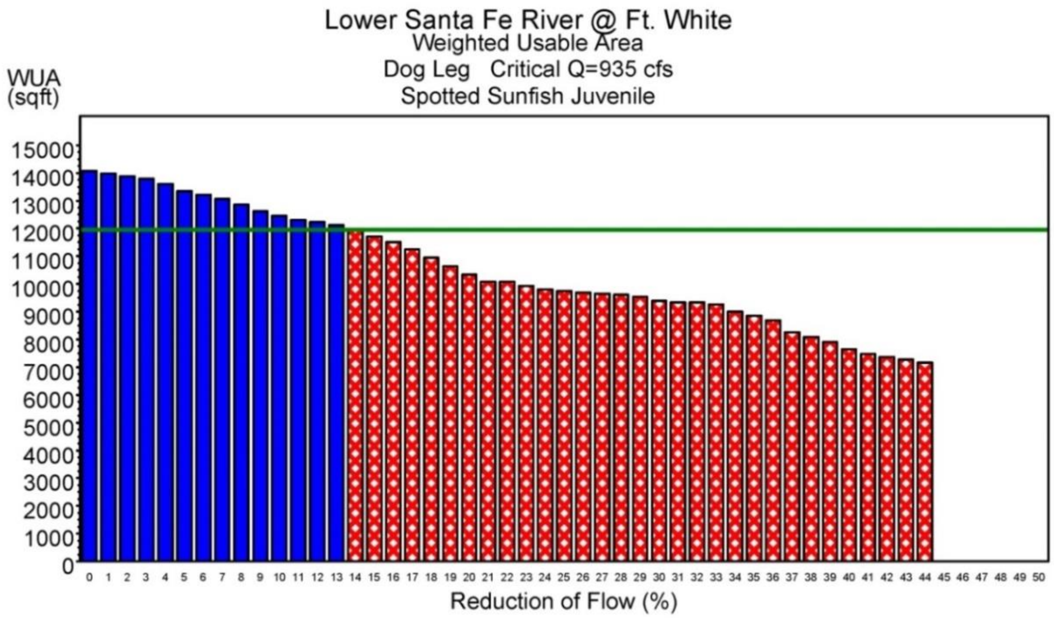


**Figure 5-48. Reductions in WUA for spotted sunfish juvenile associated with river flow reductions in 1% increments from 0 to 50% in the Lower Santa Fe River.
Horizontal green line indicates a 15% reduction in the WUA from the maximum value.**

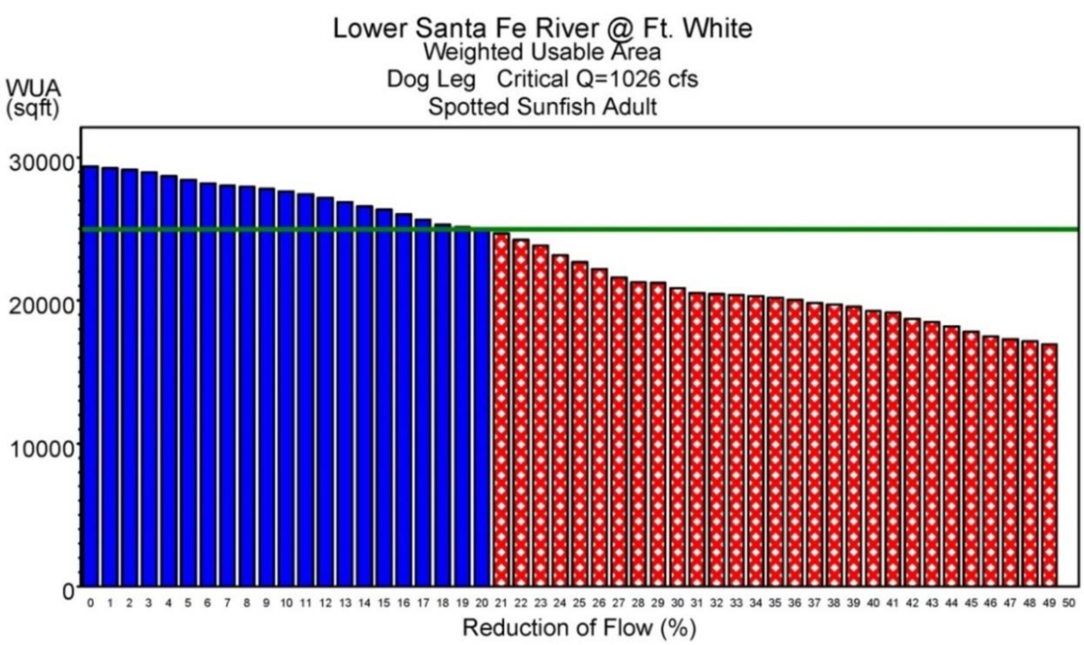


Figure 5-49. Reductions in WUA for spotted sunfish adult associated with river flow reductions in 1% increments from 0 to 50% in the Lower Santa Fe River. Horizontal green line indicates a 15% reduction in the WUA from the maximum value.

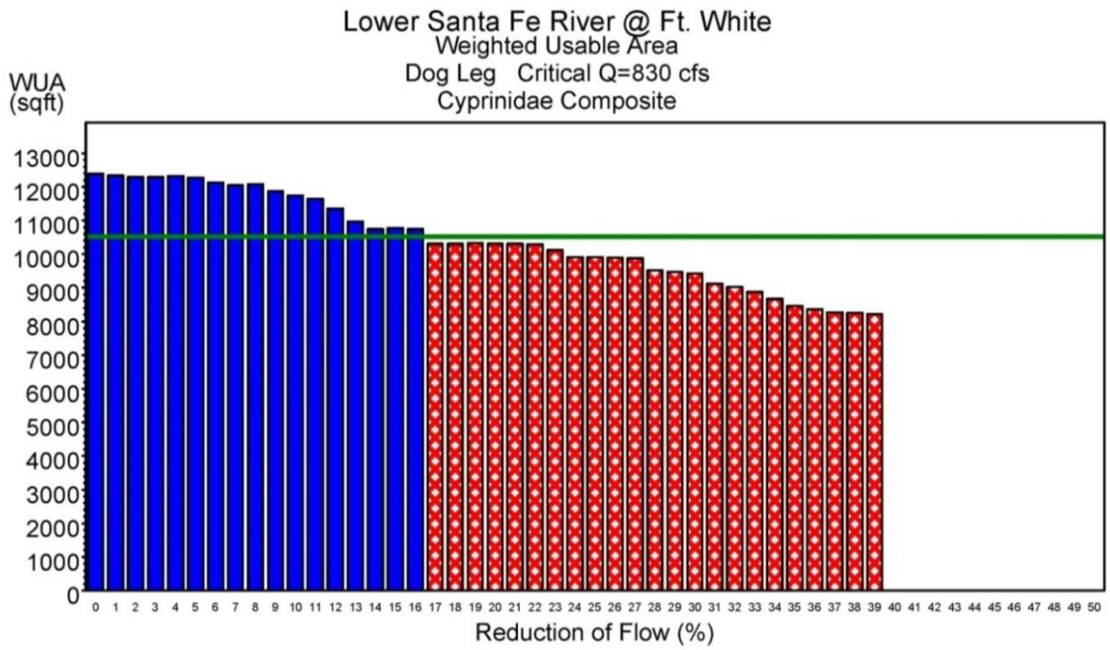


Figure 5-50. Reductions in WUA for Cyprinidae associated with river flow reductions in 1% increments from 0 to 50% in the Lower Santa Fe River. Horizontal green line indicates a 15% reduction in the WUA from the maximum value.

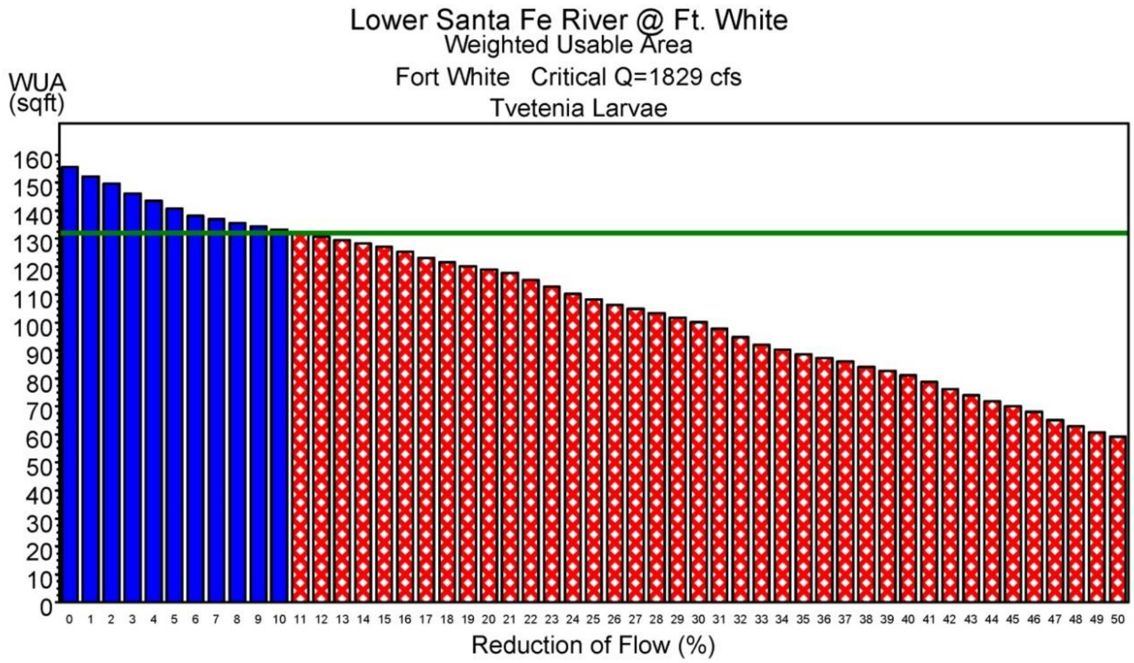


Figure 5-51. Reductions in WUA for Tvetenia larvae associated with river flow reductions in 1% increments from 0 to 50% in the Lower Santa Fe River. Horizontal green line indicates a 15% reduction in the WUA from the maximum value.

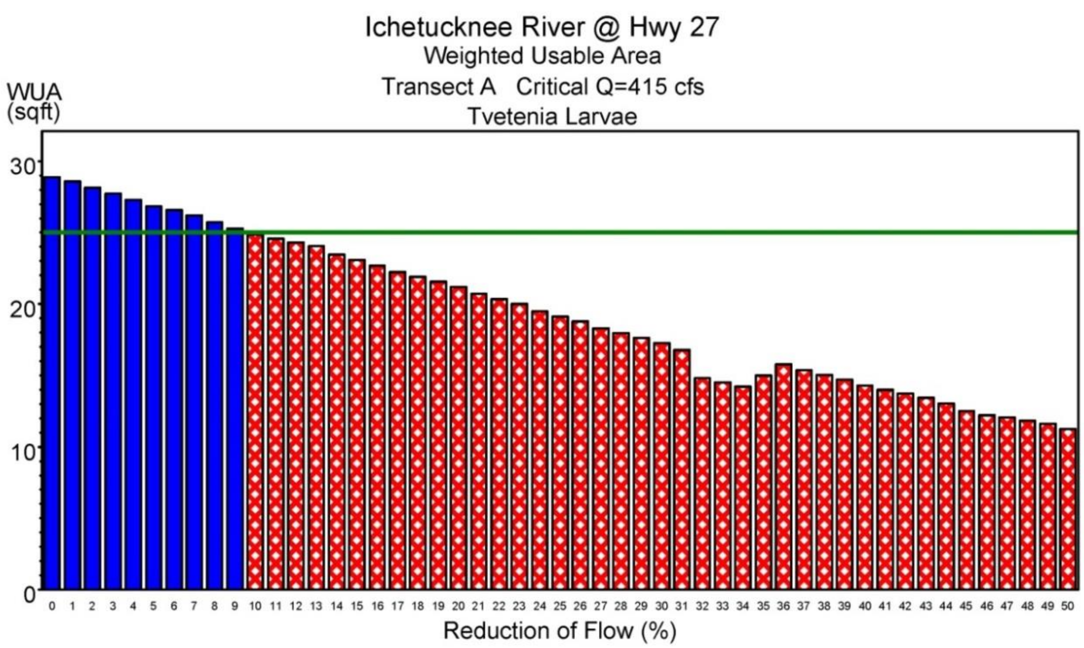


Figure 5-52. Reductions in WUA for Tvetenia larvae associated with river flow reductions in 1% increments from 0 to 50% in the Ichetucknee River. Horizontal green line indicates a 15% reduction in the WUA from the maximum value.

Table 5-5 presents the Critical Flow, allowable percent reduction, and Resulting Metric Flow for the taxon-life stage variables used in the habitat suitability analyses from the Lower Santa Fe River and Ichetucknee River. In the Lower Santa Fe River, the allowable percent reductions range between 10% and 20% and the Critical Flows vary from 830 cfs to 1829 cfs.

Table 5-5. Critical Flows (cfs), allowable percent reductions, and Resulting Metric Flows for the taxon-life stage variables used in the habitat suitability analyses from the Lower Santa Fe River and Ichetucknee River.

River	Critical Flow (cfs)	Allowable Percent Reduction	Resulting Metric Flow (cfs)
Lower Santa Fe			
Spotted sunfish spawning	1129	15%	960
Spotted sunfish fry	1093	15%	929
Spotted sunfish juvenile	935	13%	813
Spotted sunfish adult	1026	20%	821
Cyprinidae	830	16%	697
Tvetenia larvae	1829	10%	1646
Ichetucknee			
Tvetenia Larvae	415	9%	378

WOODY HABITATS

Riverine woody habitats provide a vertical continuum of protective areas during a wide range of river flows and stages. These habitats are one of a mosaic of in-stream environments that help ensure fish and macroinvertebrate species survival. The composition and functions of in-stream biotic communities are in part dependent on the relative abundance of different habitat regimes, which are shaped by river geomorphology and flow.

Woody habitats are especially important in low-gradient rivers and streams such as the Lower Santa Fe and Ichetucknee rivers, and are widely recognized as among the most important of habitat types in the southeastern U.S. (Benke, Van Arsdall, Jr., Gillespie, & Parrish, 1984; Wallace & Benke, 1984; Thorp, McEwan, Flynn, & Hauer, 1990; Benke & Wallace, 1990; Benke & Wallace, 2011). The woody habitats, consisting of both emergent niches - exposed roots and submerged snags have particular importance for maintaining ecosystem integrity. These provide a preponderance of protective spaces which are important for spawning and juvenile fish and which, during medium and high flows, can be a limiting factor for species sustainability. Woody habitats are also relatively stable under diverse flows, and are resistant to smothering by sand and silt (Edwards & Meyer, 1987). These can also create additional habitat and substrate for microbial growth through trapping organic material such as leaf litter and loose wood debris.

The functionality of woody habitats in rivers are best realized when they are submerged. Periodic inundation must occur at reasonable frequencies, and the length of inundation must be sufficient to facilitate the full range of benefits to species and the aquatic food web. The timing of inundation is also important, as diverse species use the habitats during different seasons and for different purposes. If a fish species depends on woody habitats for food, then inundation must occur on a schedule that allows the food (algae, macroinvertebrates, etc.) to become established.

Thus, it is desirable to maintain a river's flow regime to be protective of both submerged and emergent woody habitats. This MFL metric is based on limiting the reduction in the number of days that the habitat is inundated under a range of flows. Based on the ecological importance of woody habitat and its potential for use in development of a MFL, inundation patterns were examined for exposed root and snag habitats at in-stream locations, with three transects at each location. The selection of locations to be assessed in the woody habitat analysis on the Lower Santa Fe River and Ichetucknee River was based on the location of sites evaluated for the habitat suitability modeling (Figure 5-45). The mean elevations (ft. NGVD) of each woody habitat (i.e., snags and exposed roots (tops)) were averaged in each river. The Critical Flows for each woody habitat type were identified by relating these mean elevations to flows at the Fort White gage and Highway 27 gage in the Lower Santa Fe and Ichetucknee rivers, respectively.

The Critical Flows, allowable percent reductions, and Resulting Metric Flows were estimated for the woody habitats along both rivers following the same approach as described for the predominant vegetation types. The Critical Flows for exposed roots (i.e., the flows associated the mean elevation of exposed roots) are 1463 cfs and 368 cfs for the Lower Santa Fe River and Ichetucknee River, respectively. Figure 5-53 and Figure 5-54 present the RALPH plots that present the number of days in each year that the Critical Flow was equaled or exceeded. The results of the iterative reductions in river flow and resulting number of days that the Critical Flow for exposed roots was met are shown in Figure 5-55 and Figure 5-56. RALPH plots (Figure 5-57 and Figure 5-58) can also be used to compare the number of days in each year that the Critical Flow is met during the Baseline Flows time series and the time series of daily flows with the allowable percent reductions identified from Figure 5-55 and Figure 5-56.

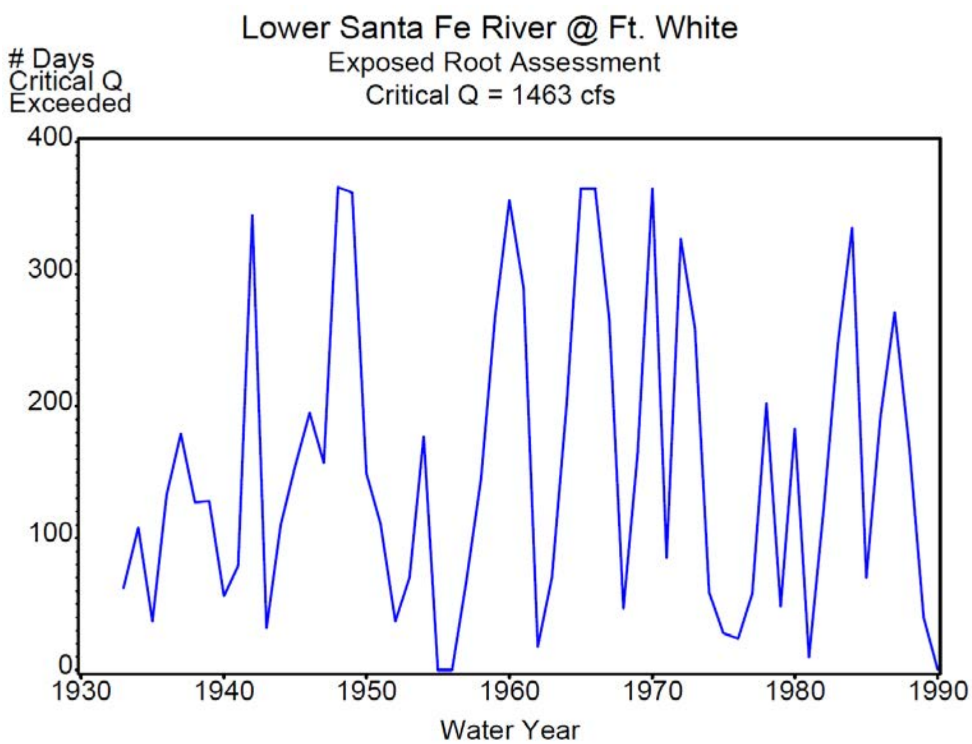


Figure 5-53. RALPH plot for exposed roots in the Lower Santa Fe River.

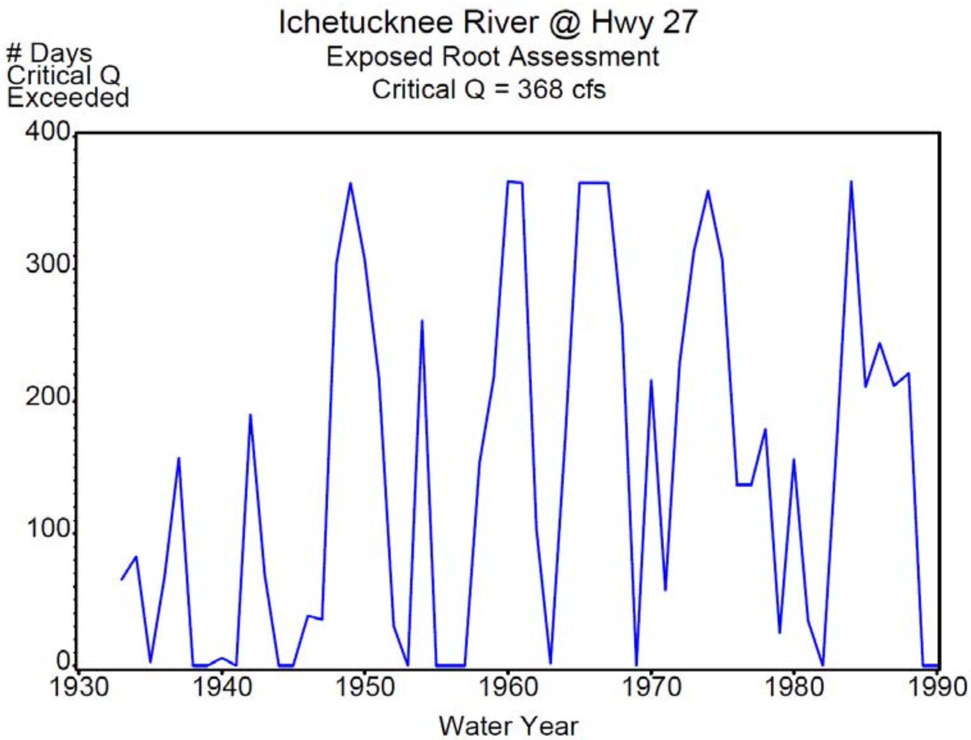


Figure 5-54. RALPH plot for exposed roots in the Ichetucknee River.

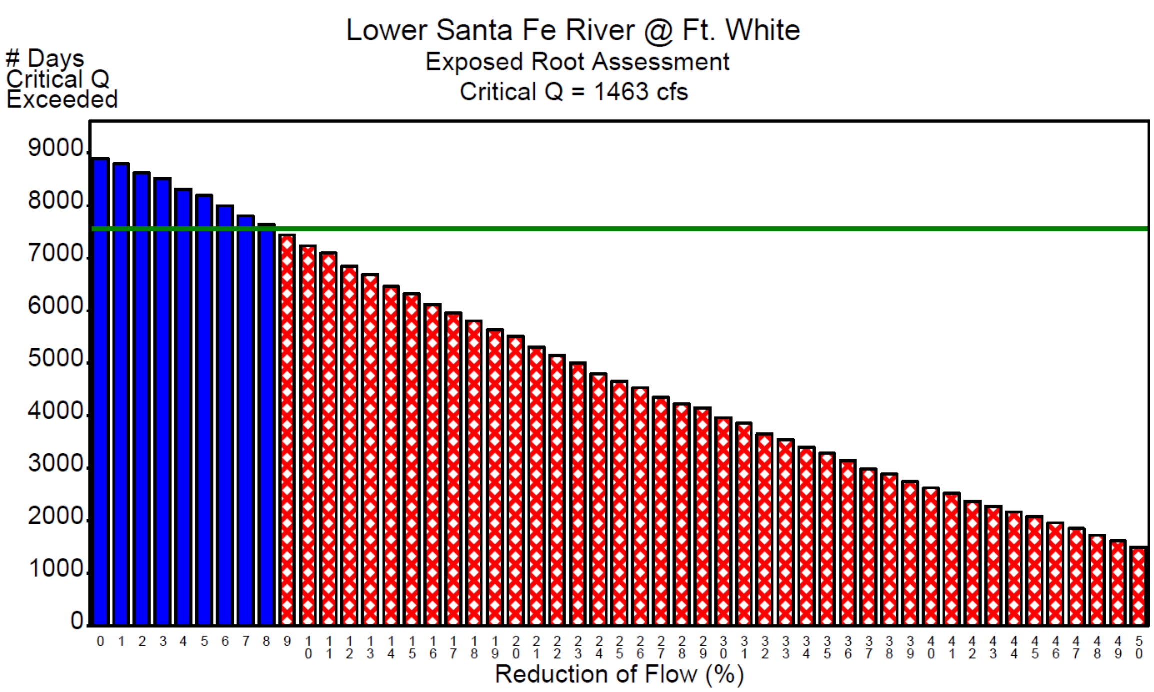


Figure 5-55. Results of the iterative reductions in flow and the resulting number of days that the Critical Flow for exposed roots in the Lower Santa Fe River was equaled or exceeded.
Horizontal green line indicates a 15% reduction in the number of days from the maximum value.

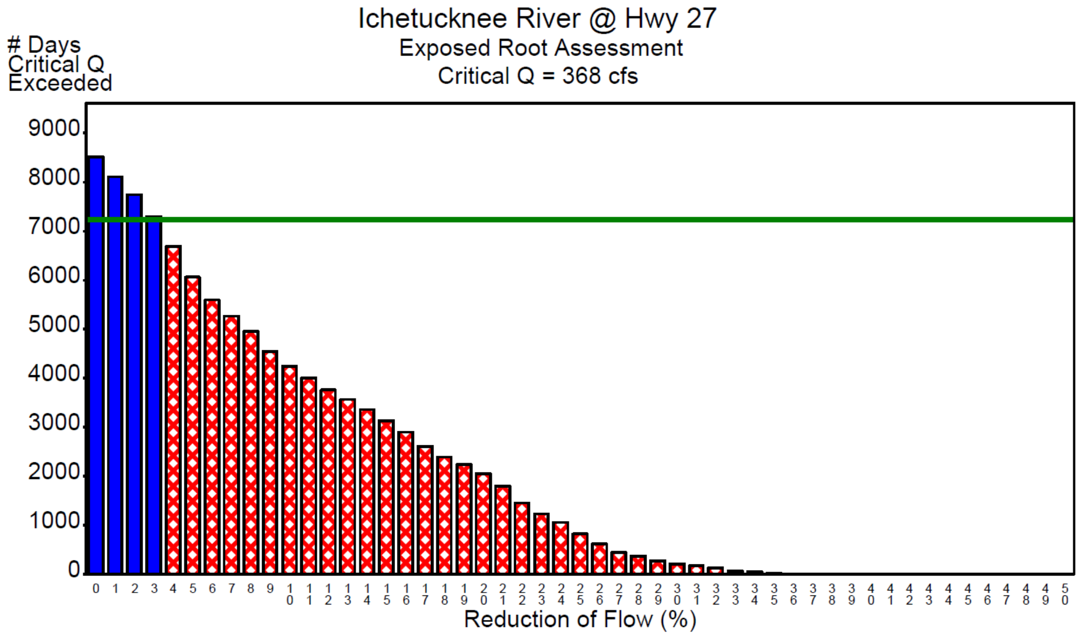


Figure 5-56. Results of the iterative reductions in flow and the resulting number of days that the Critical Flow for exposed roots in the Ichetucknee River was equaled or exceeded.
Horizontal green line indicates a 15% reduction in the number of days from the maximum value.

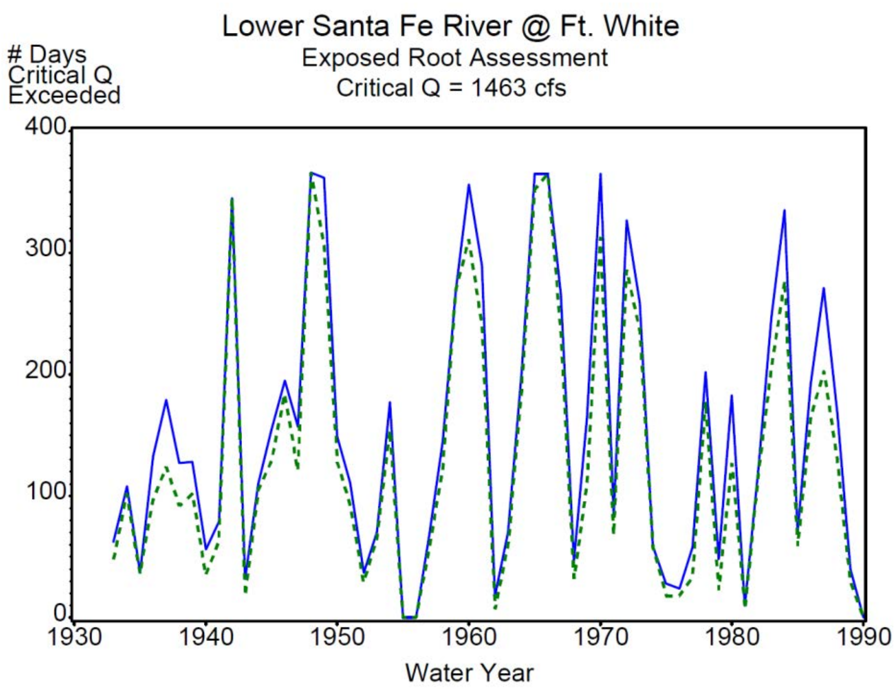


Figure 5-57. RALPH plot for exposed roots in the Lower Santa Fe River A comparison of the results from the time series from the Baseline Flows (blue line) and the allowable percent reduction from Figure 5-53 (dashed green line).

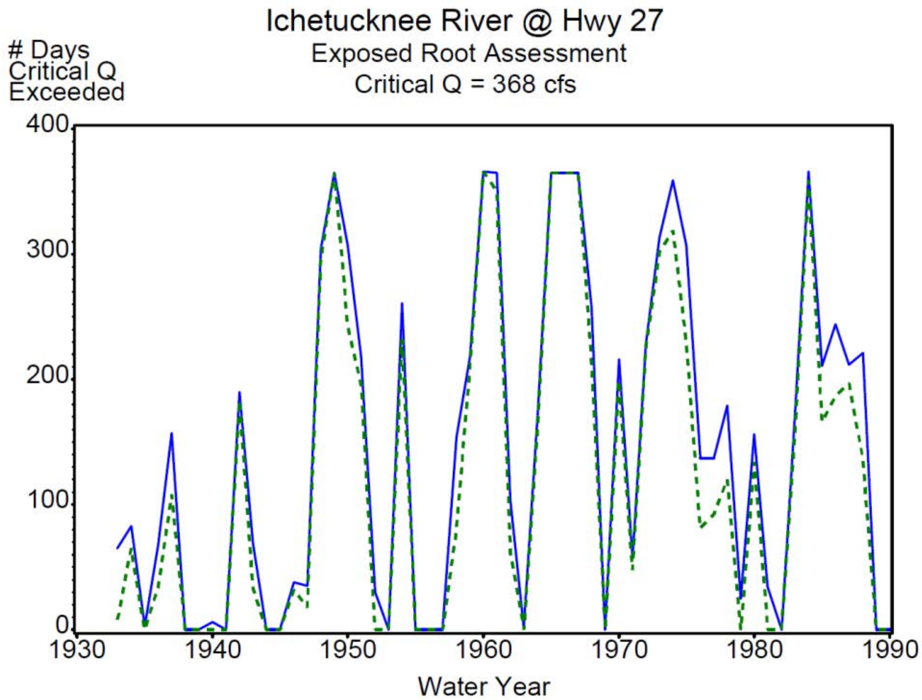


Figure 5-58. RALPH plot for exposed roots in the Ichetucknee River A Comparison of the results from the time series from the Baseline Flows (blue line) and the allowable percent reduction from Figure 5-54 (dashed green line).

The Critical Flow for snags is 819 cfs in the Lower Santa Fe River. Figure 5-60 presents the RALPH plot that presents the number of days in each year that the Critical Flow was equaled or exceeded. The results of the iterative reductions in river flow and resulting number of days that the Critical Flow for snags was met are shown in Figure 5-60. A RALPH plot (Figure 5-59) can also be used to compare the number of days in each year that the Critical Flow is met during the Baseline Flows time series and the time series of daily flows with the allowable percent reductions identified from Figure 5-61. The snags in the Ichetucknee River were at significantly lower elevations than the exposed roots, therefore, the Resulting Metric Flow for exposed roots in the Ichetucknee River will be protective of the snags in that river.

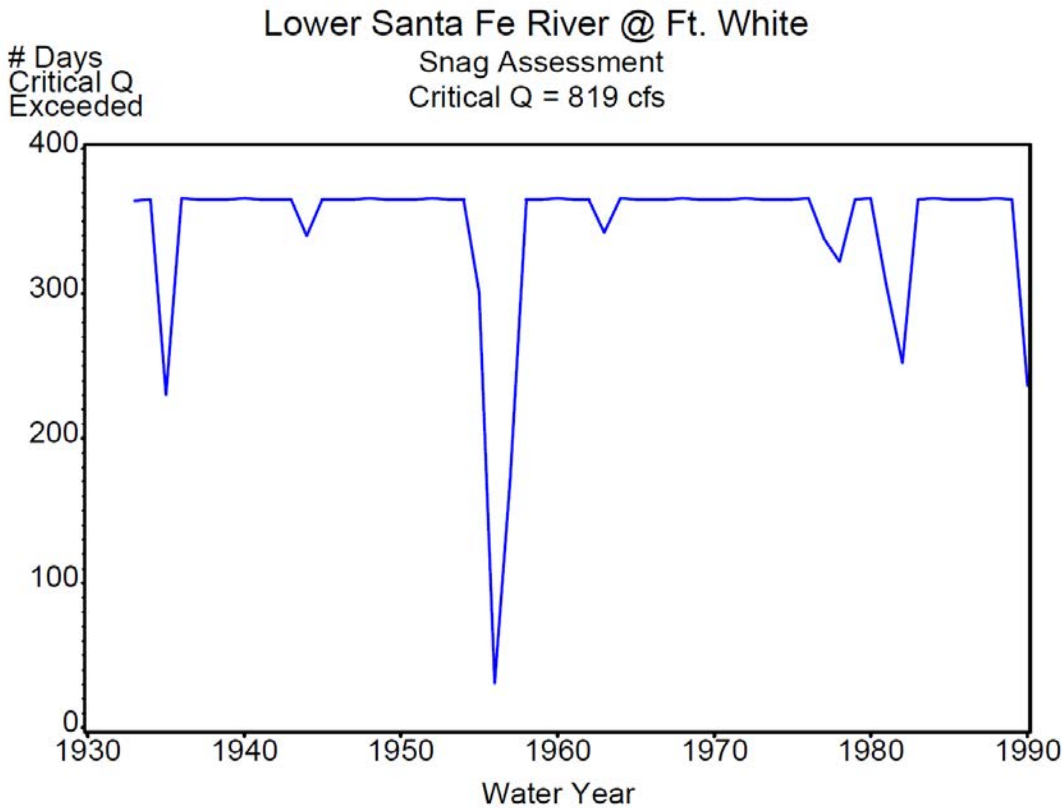


Figure 5-59. RALPH plot for snags in the Lower Santa Fe River.

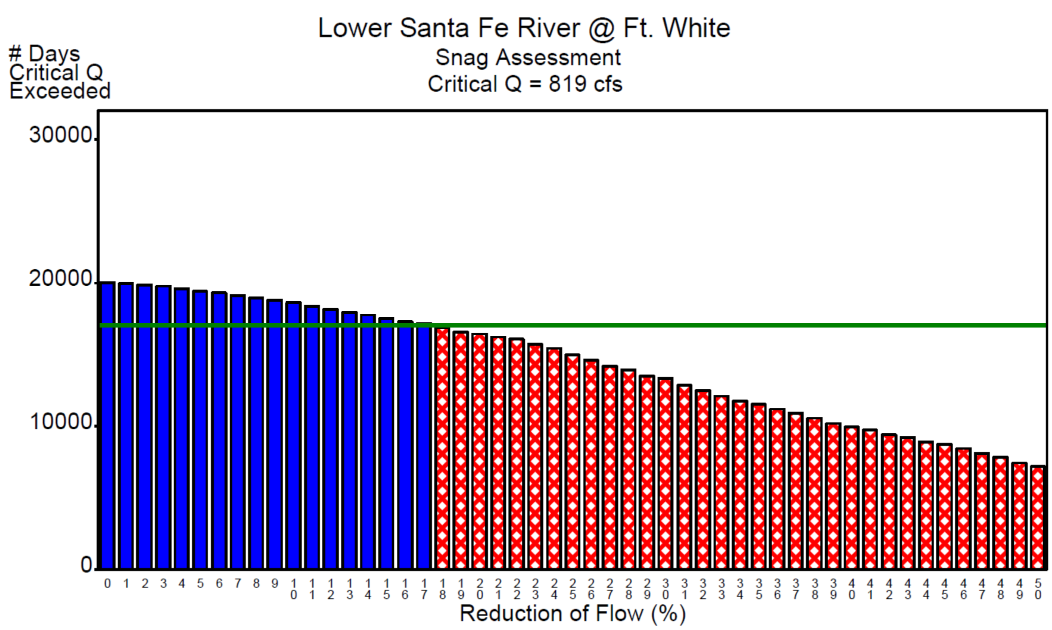


Figure 5-60. Results of the iterative reductions in flow and the resulting number of days that the Critical Flow for snags in the Lower Santa Fe River was equaled or exceeded.
Horizontal green line indicates a 15% reduction in the number of days from the maximum value.

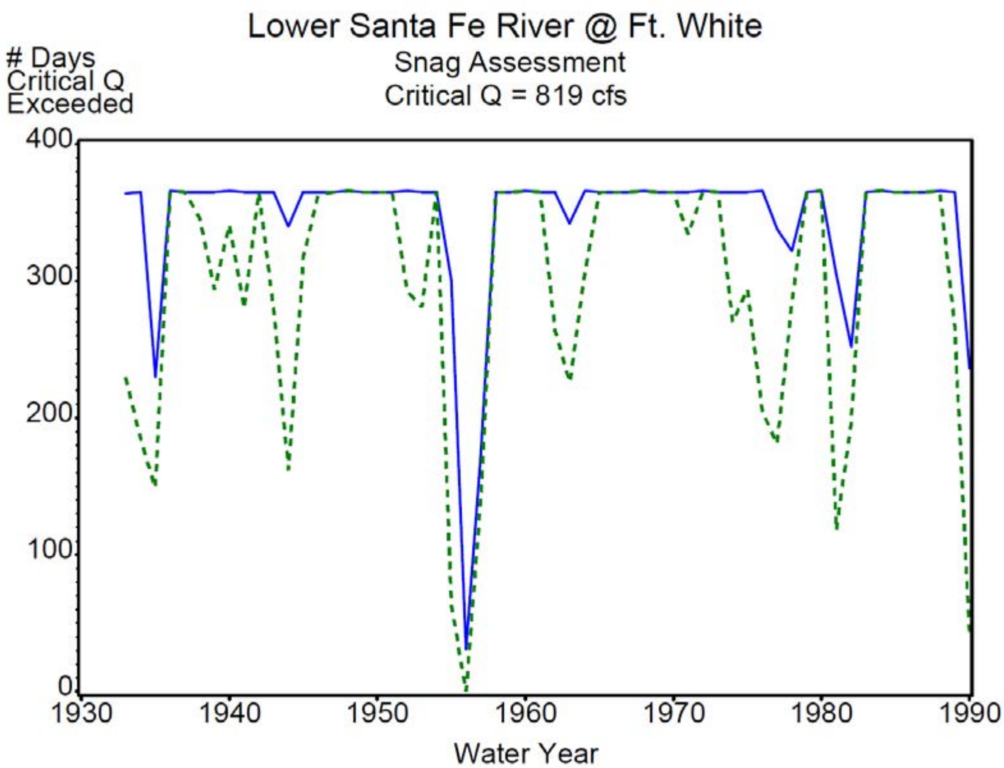


Figure 5-61. RALPH plot for snags in the Lower Santa Fe River comparing the results from the time series from the Baseline Flows (blue line) and the allowable percent reduction from Figure 5-52 (dashed green line).

Table 5-6 summarizes the Critical Flows, the allowable percent flow reductions, and the Resulting Metric Flows for woody habitats in each river. The allowable percent reductions are relatively low, 17% and 8% for the Lower Santa Fe River, and 3% for the Ichetucknee River.

Table 5-6. Critical Flows (cfs), allowable percent reductions, and Resulting Metric Flows for the woody habitats from the Lower Santa Fe River and Ichetucknee River.

River	Critical Flow (cfs)	Allowable Percent Reduction	Resulting Metric Flow (cfs)
Lower Santa Fe			
Exposed Roots	1463	8%	1346
Snags	819	17%	680
Ichetucknee			
Exposed Roots	368	3%	357

RECREATION

An important water resource value for the Ichetucknee River is maintenance of recreation, particularly north of the Grassy Flats area. This area experiences the greatest damage from seasonal tubing which is limited to the summer season (Memorial Day weekend to Labor Day).

Current management of water recreation in this part of the Ichetucknee River is in large measure based on research by Dutoit (1979) that presented impacts of tubing on submerged aquatic vegetation. The Ichetucknee River Park Staff and Florida Park Service have also documented the impact of tubing on submerged aquatic vegetation (SAV) in the upper portion of the system. A threshold for tubing on the Ichetucknee River was developed to ensure that recreational access from the north entrance is maintained and limit the frequency and duration of contact between tubing participants and SAV. The study area is from the Head Spring (RM 5.30) to Dampier's Landing (RM 3.17) (Figure 5-62). Information was collected at existing cross sections as represented in the HEC-RAS model (Appendix 4-1). There are 10 potentially applicable HEC-RAS cross sections in this area (Figure 5-62).

The data collection steps were as follows. First, a *physical tubing depth* was determined. This was accomplished by measuring a large tubing participant (>200 lbs.) in a typical single-person tube from the water surface to their lowest clearance point (Figure 5-63). This value was 1.05 feet.

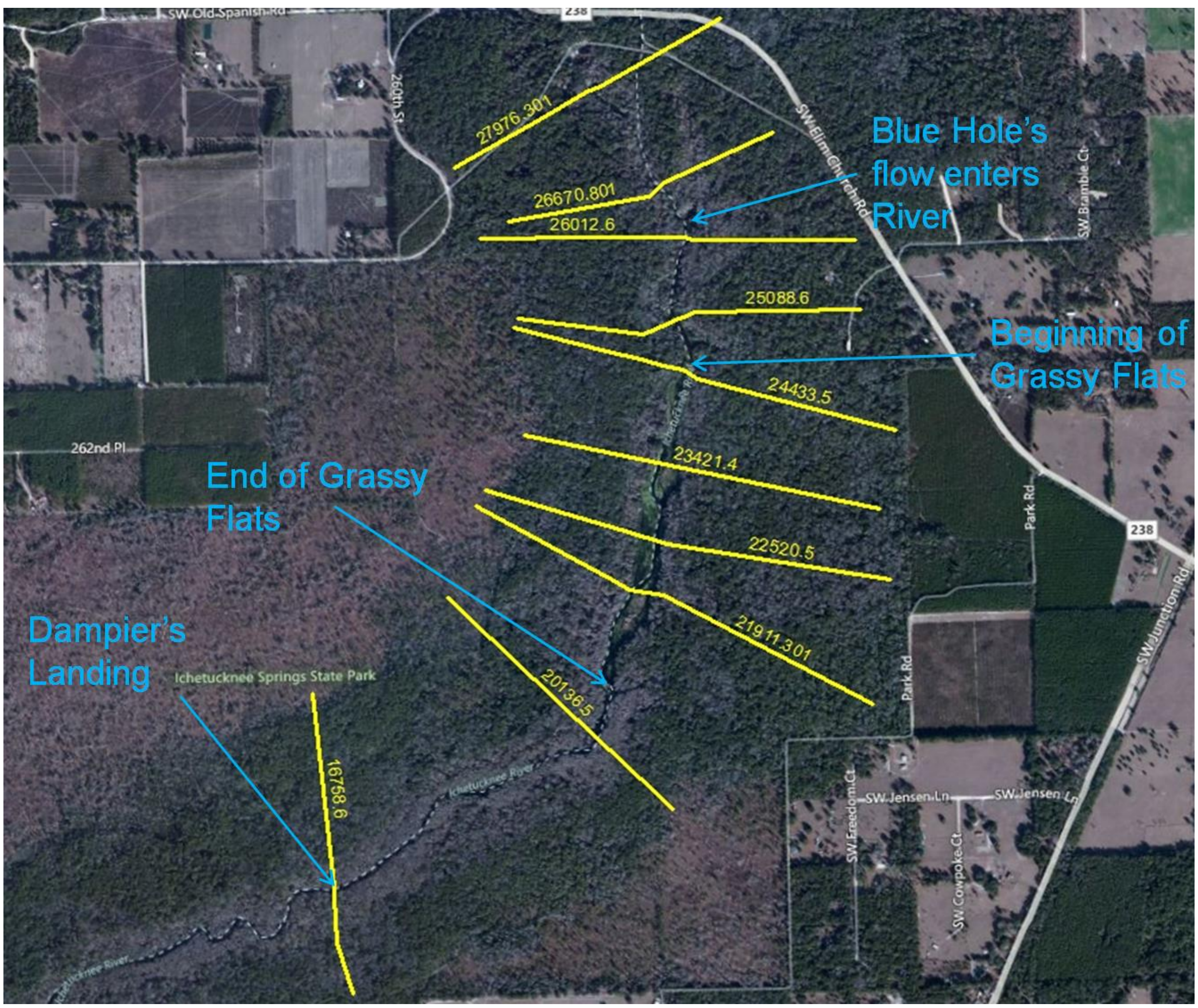


Figure 5-62. Ichetucknee River HEC-RAS cross sections.

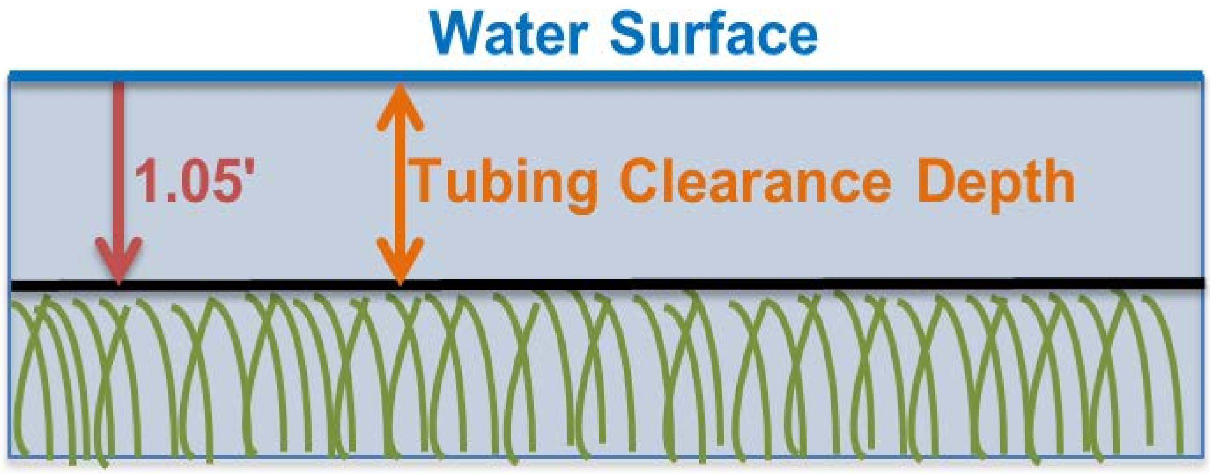


Figure 5-63. Tubing diagram.

Second, at each HEC-RAS cross section four measurements were taken from the water surface to the top of the SAV (Figure 5-64). For each cross section the four measurements were averaged and the standard deviation was calculated (Table 5-7). The standard deviation was subtracted from the mean depth to produce an effective SAV Depth. HEC-RAS river station 27976 was not measured because it was in an area where recreation is not permitted. HEC-RAS river stations 22521, 21911, and 16759 were not analyzed because the depth at these sites was greater than four feet, and would not restrict tubing in any way, even under low flow conditions.

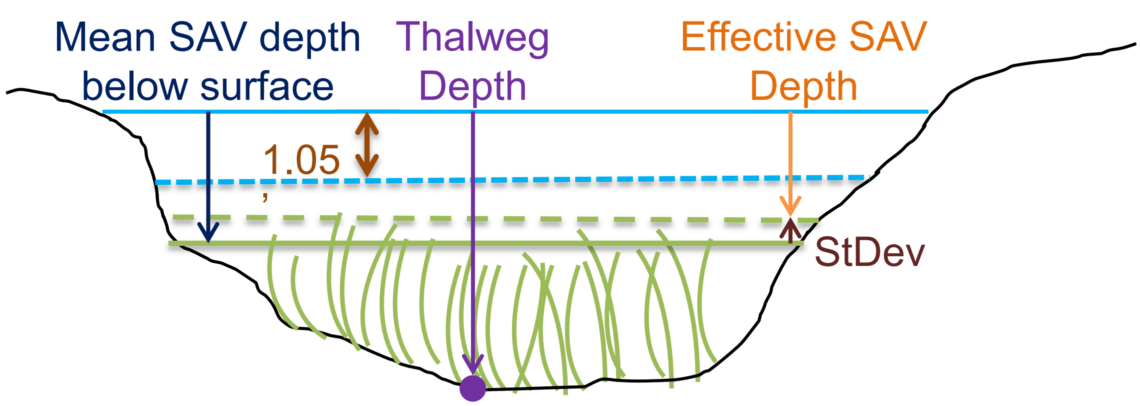


Figure 5-64. Cross-sectional model.

The data were collected on February 15, 2013. Table 5-7 summarizes the collected data. The top of all SAV were fully submerged. The flow at the USGS Highway 27 gage was 313 cfs. This flow corresponds to the 64 percent non-exceedance flow scenario from the Lower Santa Fe and Ichetucknee River steady state HEC-RAS model (20% Suwannee backwater condition). The water surface (WS) elevation and the thalweg depth were extracted from HEC-RAS for this flow profile. The thalweg elevation was calculated by subtracting the thalweg depth from the water surface elevation (Equation 1). The lengths of the SAV strands were estimated by subtracting the effective SAV depth from the thalweg depth (Equation 2). The critical SAV elevation was calculated by adding the length of SAV to the thalweg elevation (Equation 3).

Table 5-7. Summary of field measurements.

River Station	River Mile	Location	Measure 1	Measure 2	Measure 3	Measure 4	Mean	Standard Deviation	Effective SAV Depth
26671	5.05	1st transect of recreation	2.3	2.5	1.5	1.9	2.1	0.443471	1.6
26013	4.93	Just DS of Blue Hole	2.3	3.3	3.5	2.4	2.9	0.613052	2.3
25089	4.75	Last transect Grassy Flats	1.5	1.6	1.4	1.2	1.4	0.170783	1.3
24434	4.63	Grassy Flat 1	1.6	1.8	1.8	2.2	1.9	0.251661	1.6
23421	4.44	Grassy Flat 2	3.6	3.7	3.7	3.5	3.6	0.095743	3.5
22521	4.27	Grassy Flat 3	>4.0	>4.0	3.4	3.8	3.6	NA	NA
21911	4.15	Grassy Flat 4	3.0	>4.0	3.3	4.0	3.4	NA	NA
20137	3.81	Near midpoint	3.7	4.0	3.6	3.6	3.7	.189297	3.5
16759	3.17	Dampier's Landing	3.8	>4.0	>4.0	>4.0	3.8	NA	NA

Finally, the critical water surface elevation was calculated by adding the 1.05 *physical tubing depth* to the critical SAV elevation (Equation 4). The critical water surface elevation is the value that must be maintained in the river in order to protect tubing. These results of these calculations are summarized below in Table 5-8.

Equation 1:

$$Thalweg\ Elevation = WS\ Elevation - Thalweg\ Depth$$

Equation 2:

$$Length\ of\ SAV = Thalweg\ Depth - \ Effective\ SAV\ Depth$$

Equation 3:

$$Critical\ SAV\ Elevation = Length\ of\ SAV + Thalewg\ Elevation$$

Equation 4:

$$Critical\ WS\ Elevation = Critical\ SAV\ Elevation + \ 1.05'$$

Using HEC-RAS output, the critical water surface elevation at each cross section was related to a model non-exceedance scenario (Table 5-8). These non-exceedance scenarios were related to flows at Highway 27. River stations 26012.6, 23421.4, 20136.5, were below the lowest modeled flow. River station 25088.7 was the most critical cross-section, which corresponded to a Highway 27 Critical Flow of 282 cfs. This corresponds to the 88.9% exceedance flow scenario for the Baseline flow condition.

Table 5-8. HEC-RAS model output for flow of 313 cfs at Highway 27 gage.

River Station	River Mile	WS Elevation	Thalweg Depth	Thalweg Elevation	Effective SAV Depth	Length of SAV	Critical SAV Elevation	Critical WS Elevation
26671	5.05	23.2	4.68	18.52	1.6	3.07	21.59	22.64
26013	4.93	22.64	5.22	17.42	2.3	2.96	20.38	21.43
25089	4.75	22.15	4.97	17.17	1.3	3.73	20.90	21.95

24434	4.63	21.9	5.93	15.97	1.6	4.33	20.30	21.35
23421	4.44	21.09	7.71	13.38	3.5	4.18	17.56	18.61
20137	3.81	19.02	5.64	13.37	3.5	2.11	15.48	16.53

A 15% reduction in the number of days that the Critical Flow was met was used to estimate the Resulting Metric Flows for recreation (Table 5-9). At a flow of 282 cfs, a 15% temporal reduction corresponds to an 12% reduction in flow. The Resulting Metric Flow is 248 cfs for recreation on the Ichetucknee River.

Table 5-9. Baseline Flow Exceedances.

River Station	River Mile	Critical Flow (cfs)	MFL Percent Reduction	MFL Flows (cfs)
26671	5.05	241	22%	188
26013	4.93	< 169.3	45%	93
25089	4.75	282	12%	248
24434	4.63	231	26%	171
23421	4.44	< 169.3	45%	93
20137	3.81	< 169.3	45%	93

Figure 5-65 presents the RALPH plot that presents the number of days in each year that the Critical Flow was equaled or exceeded. The results of the iterative reductions in river flow and resulting number of days that the Critical Flow for recreation was met are shown in Figure 5-66. A RALPH plot (Figure 5-67) can also be used to compare the number of days in each year that the Critical Flow is met during the Baseline Flows time series and the time series of daily flows with the allowable percent reductions identified from Figure 5-65.

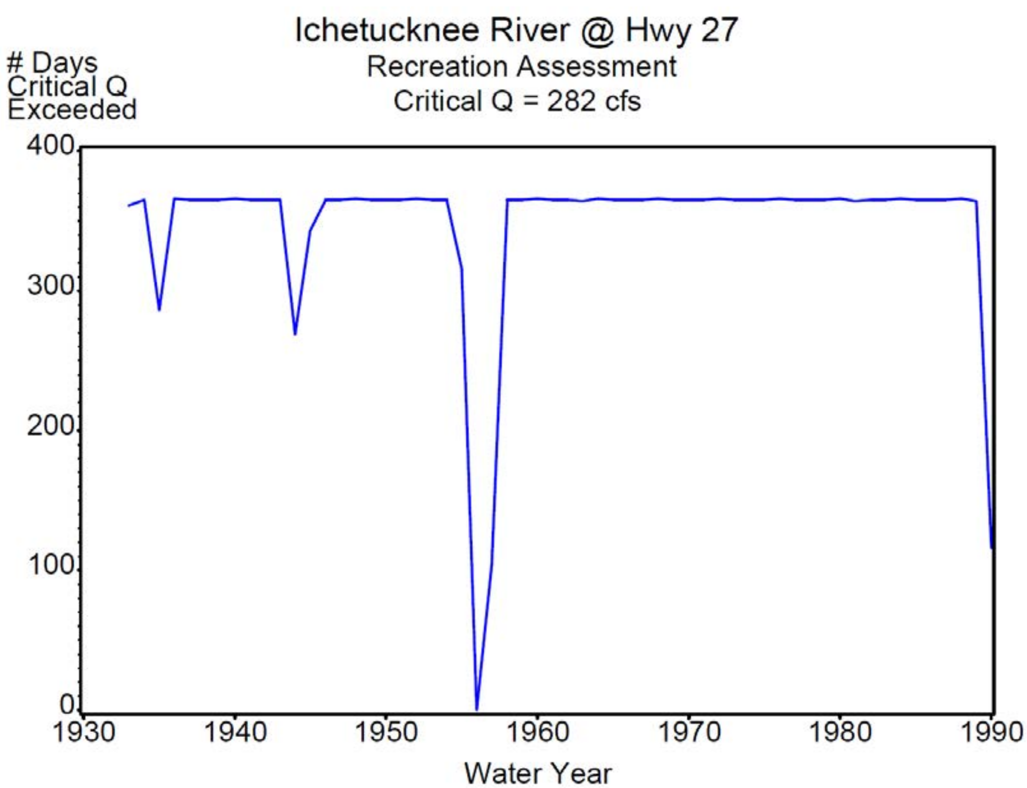


Figure 5-65. RALPH plot for recreation use in the Ichetucknee River.

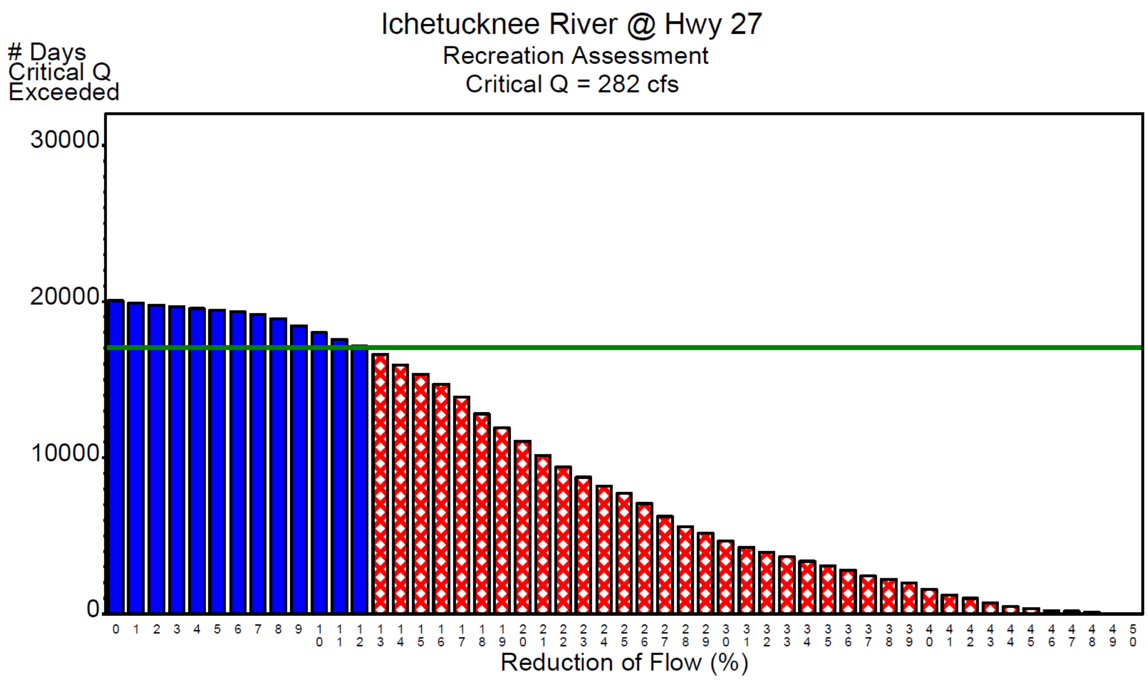


Figure 5-66. Results of the iterative reductions in flow and the resulting number of days that the Critical Flow for recreation in the Lower Santa Fe River was equaled or exceeded.
Horizontal green line indicates a 15% reduction in the number of days from the maximum value.

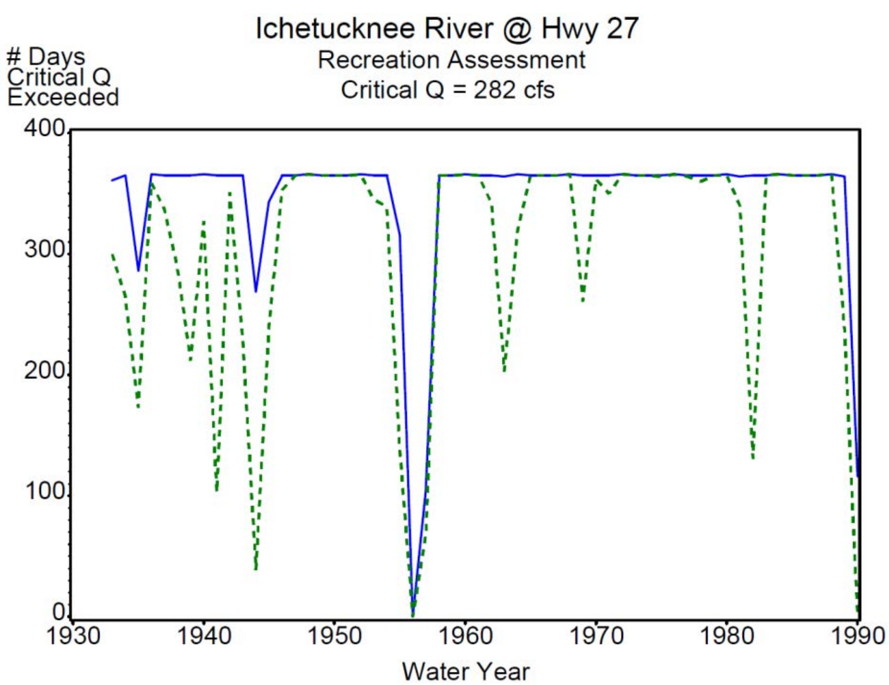


Figure 5-67. RALPH plot for recreation in the Lower Santa Fe River
A comparison of the results from the time series from the Baseline Flows (blue line) and the allowable percent reduction from Figure 5-65 (dashed green line).

Table 5-10 summarizes the Critical Flows, the allowable percent flow reductions, and the Resulting Metric Flows for the recreation assessment in the Ichetucknee River.

Table 5-10. Critical Flows (cfs), allowable percent reductions, and Resulting Metric Flows for the recreation assessment for the Ichetucknee River.

Critical Flow (cfs)	Allowable Percent Reduction	Resulting Metric Flow (cfs)
282	12%	248

OTHER CONSIDERATIONS

In addition to the various WRVs addressed above, several potential additional WRVs were considered in the process of developing the MFLs for the Lower Santa Fe and Ichetucknee rivers. These included the Ichetucknee Siltsnail, manatees, and nitrate trends in groundwater.

Ichetucknee Siltsnail

One of the species that makes the Ichetucknee River unique and is of particular importance to the ecosystem is the Ichetucknee Siltsnail (*Cincinnatia mica*), which was first described by Thompson (1968) from Coffee Spring (Figure 5-68).

Figure 5-68. Ichetucknee Siltsnail. (Thompson F. G., 2004)

This species is only found in Coffee Spring and the actual microhabitat encompasses approximately 10 square yards (FDEP, 2000). The snail does not enter the river proper, but is confined to the “immediate outflow area of the spring,” as seen in Figure 5-69 where it lives among aquatic mosses and, contrary to its common name, does not live on fine-grained substrata (Thompson F. G., Personal Interview, 2008).

Figure 5-69. Photograph of the Coffee Spring run and the immediate outfall area where the sole habitat of the Ichetucknee Silt Snail is located.

Members of the family Hydrobiidae, of which *Cincinnatia mica* is included, are commonly referred to as "spring snails" in reference to the type of habitat in which they are found. These snails measure only a few millimeters in size (i.e., generally between 2.0 - 3.5 mm), have highly restricted ranges and high rates of endemism to specific drainages or springs (Walsh, 2001; Shelton, 2005).

Hydrobiids are grazers and scrape algae off of rocks and other substrates; their feeding habits help to keep the water clean and clear (Frest & Johannes, 1995). These snails generally breed only once a year (Thompson F. G., The Aquatic Snails of the Family Hydrobiidae of Peninsular Florida, 1968) and are annual species (Thompson F. G., Personal Interview, 2008).

Although there are numerous reports of the apparent relationship between water quality and hydrobiid snails (Shelton, 2005; Gutierrez, Perrera, Yong, & Yong, 2001; Walsh, 2001; Frest & Johannes, 1995), United States Fish and Wildlife Service (1992) published accounts of sensitivity or threshold levels for these snails are lacking. With respect to *Cincinnatia mica*, Thompson (2008) did posit that "low" nutrient levels are required.

Hydrobiids in general are also sensitive to oxygen deficits, elevated water temperatures, and sedimentation. pH and calcium are known to be important parameters in shell development and, in some, cases reproduction. Although the exact ranges or threshold values are not known (Thompson F. G., Personal Interview, 2008) a pH range of 7.0-7.6 appears to be optimal for shell development. Acidic waters can facilitate shell erosion.

Habitat suitability for the Ichetucknee Siltsnail was considered during development of MFLs for the Ichetucknee River. The Coffee Spring Pool on the Ichetucknee River (Figure 5-70) is the only known habitat of *Cincinnatia mica*; hence, maintaining adequate physical habitat for the species was assessed as a possible MFL metric. The analysis was performed to identify the magnitude of flow reduction that would cause a 15% reduction in the Coffee Spring Pool area.

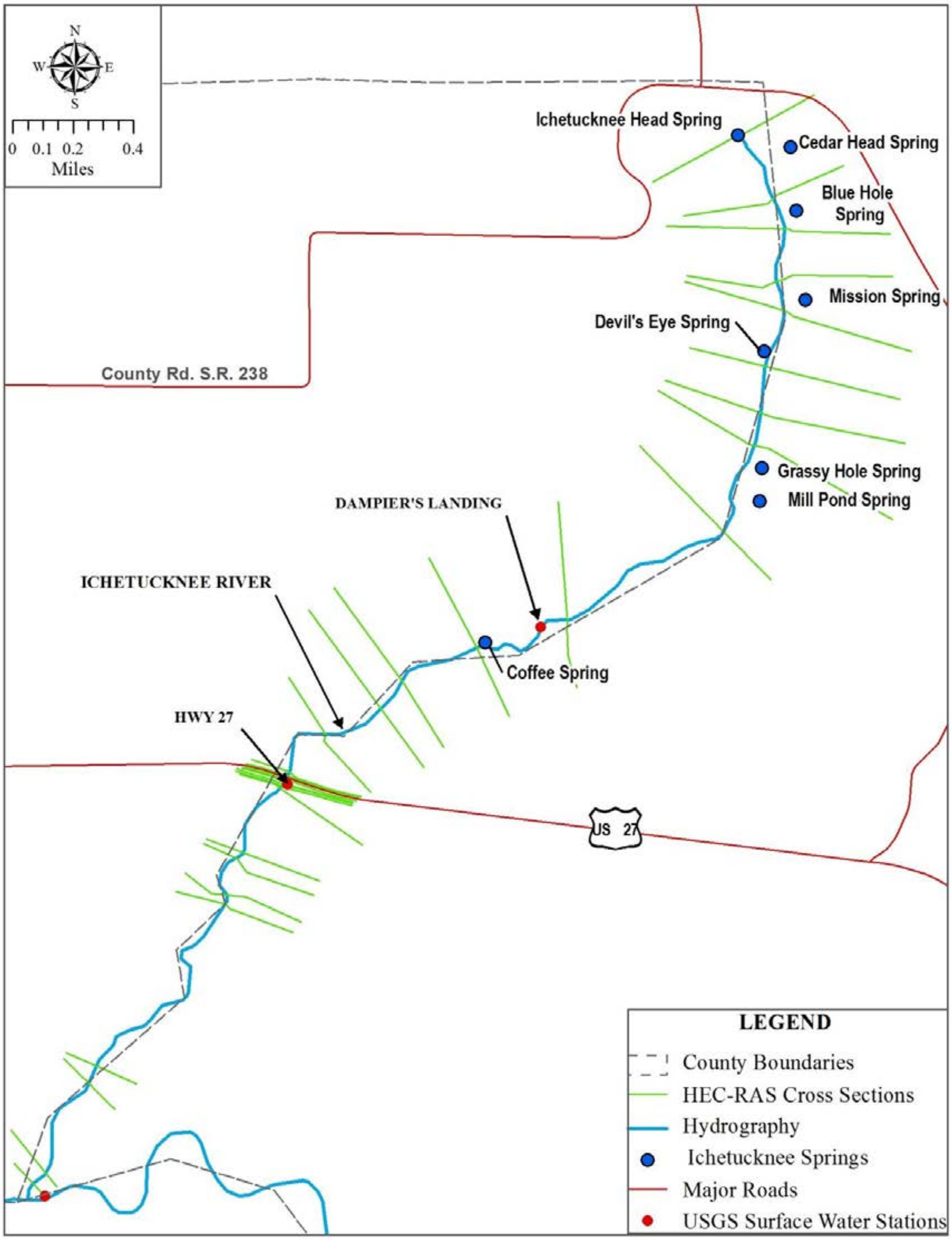


Figure 5-70. HEC-RAS model cross sections and Coffee Spring.

Coffee Spring Pool is located approximately 2.8 miles upstream of the Ichetucknee River confluence and approximately 150 feet upstream of the HEC-RAS model cross section at station 14690.63 (Figure 5-71). The Coffee Spring Pool ground elevations were surveyed by the District and converted to a shapefile format (Figure 5-71). The surveyed points (303 surveyed points) were used to develop a triangulated irregular network (TIN) model, which subsequently was used to obtain 0.2-ft elevation contours in ArcGIS. The elevation contours were further used to calculate corresponding areas at the Coffee Spring Pool. The developed contours ranged from 15.28 feet to 18 feet NGVD29, where the 15.28-ft contour corresponded to the lowest surveyed elevation at the pool. Although the highest surveyed elevation at the pool was approximately 22 feet, the 18-ft contour was the last contour that formed an enclosed surface and was relevant for the analysis. The developed relationship between pool area and stage at Coffee Spring Pool is shown in and Figure 5-72. As shown in Table 5-11, the 18-ft contour corresponding area (3920.35 ft^2) was considered 100% inundated whereas the lowest 15.28-ft contour corresponding area (0 ft^2) was considered 0% inundated. In other words, the assumption was made that at the 18-ft contour the bowl-shaped habitat of the snails at the Coffee Spring Pool (Table 5-11) becomes completely inundated. Hence, as shown in Figure 5-72 an inundated area of 50% (1960.18 ft^2) corresponds to a stage of 16.90 ft.

Figure 5-71. Coffee Spring Pool survey elevation points

Table 5-11. Developed stage-area relationship at Coffee Spring Pool.

Coffee Spring Pool Stage (ft, NGVD29)	Coffee Spring Pool Area (ft^2)	Area Inundated (%)
15.28	0.00	0.0
15.48	6.59	0.2
15.68	58.36	1.5
15.88	202.94	5.2
16.08	430.94	11.0
16.28	700.05	17.9
16.48	1178.03	30.0
16.68	1560.31	39.8
16.88	1922.73	49.0
16.90	1960.18	50.0
17.08	2295.98	58.6
17.28	2626.54	67.0
17.48	2954.85	75.4
17.68	3242.74	82.7
17.88	3681.48	93.9
18.08	3920.35	100.0

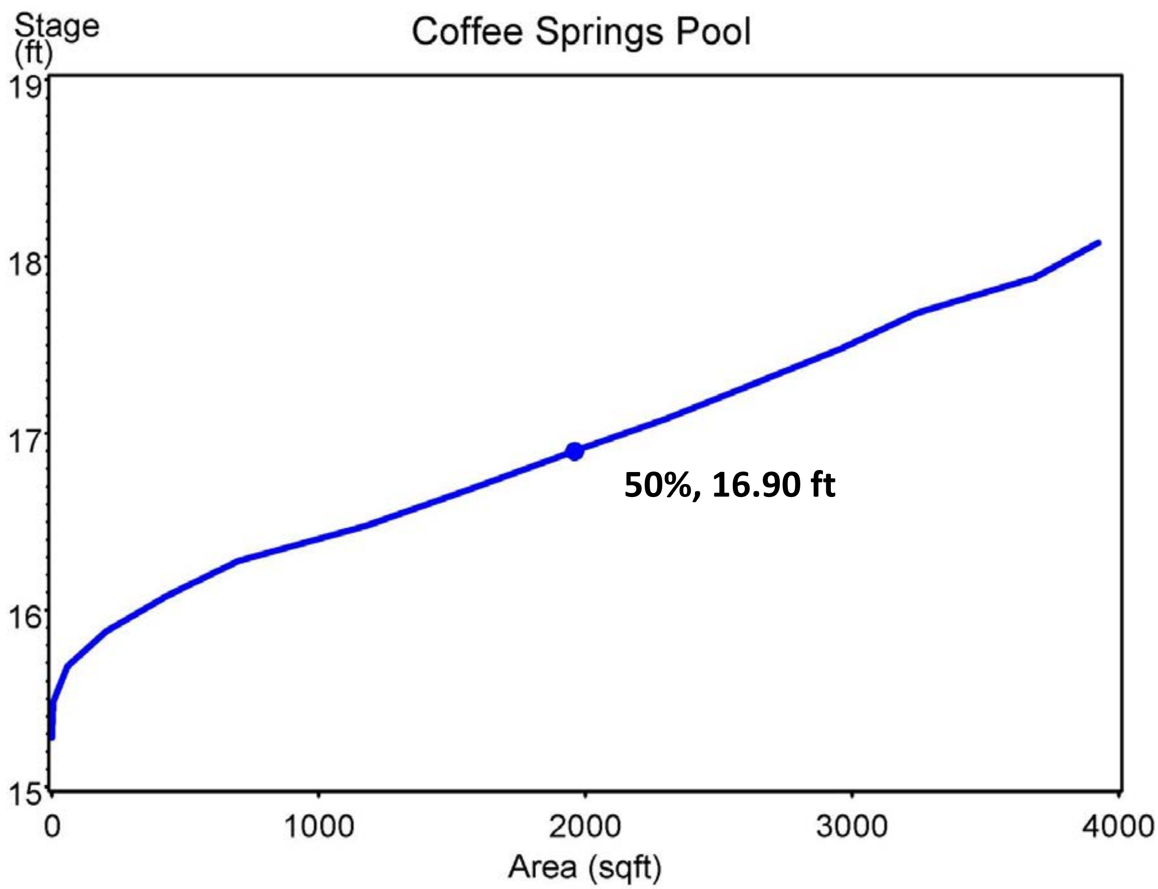


Figure 5-72. Relationship between area and stage at Coffee Spring Pool.

A relationship between observed flow at the USGS gage at Highway 27 and HEC-RAS model simulated stage at Coffee Spring Pool was also developed (Figure 5-73). Coffee Spring Pool simulated stage was obtained using linear interpolation and HEC-RAS model output stage values at HEC-RAS stations station 14690.63 and station 16758.63 (Figure 5-71). A simulated stage of 16.90 feet at Coffee Spring Pool corresponds to a streamflow of 351 cfs (Figure 5-73).

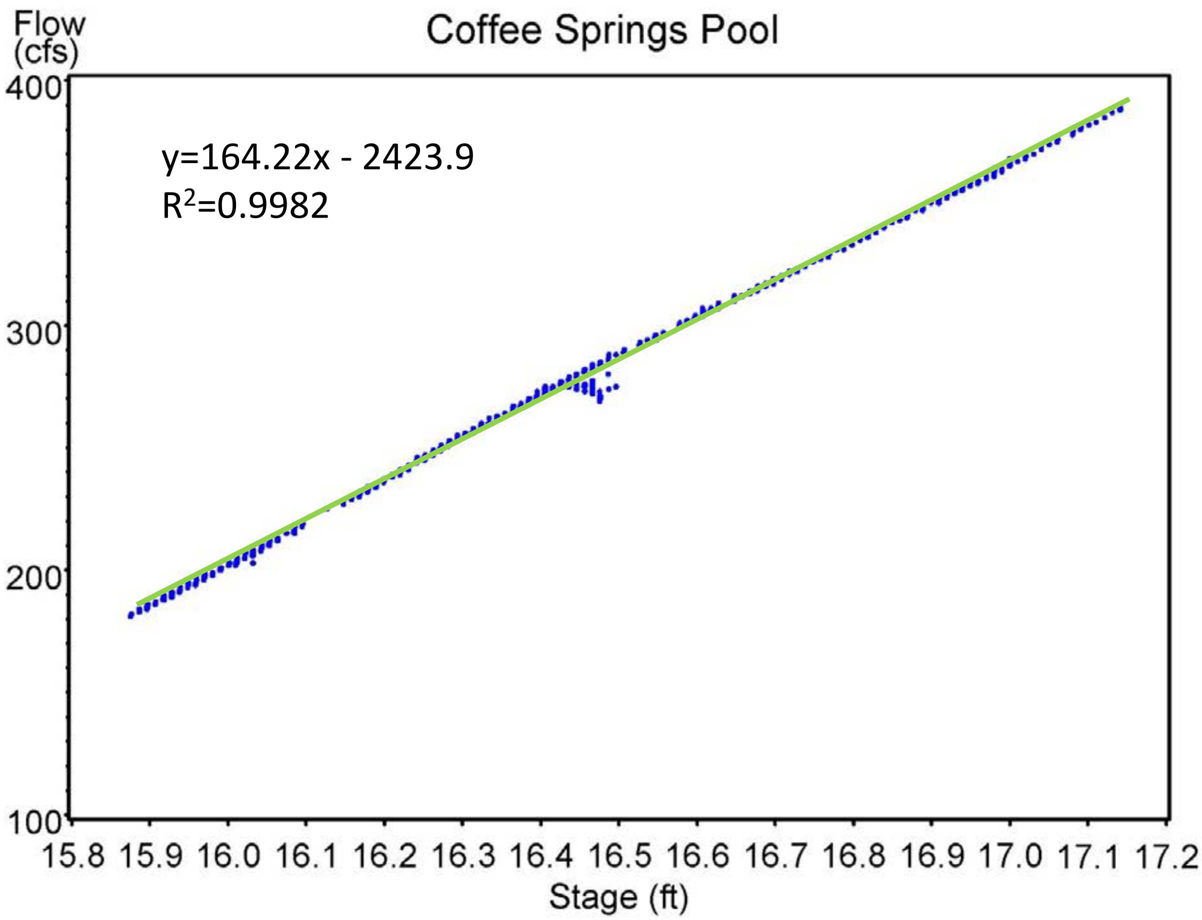


Figure 5-73. Relationship between Highway 27 observed flow and HEC-RAS model simulated stage at Coffee Spring Pool.

A stage of 16.90 feet (corresponds to an inundated area of 50% and a streamflow of 351 cfs) corresponds to probability exceedances of 53% on the flow duration curves for the Baseline Flow time series (Figure 5 74). A 15% loss of inundation area from 1960.18 ft2 would result in a pool area of 1666.15 ft2, which corresponds to a 16.74-ft stage (Figure 5 72) and 325 cfs flow (Figure 5 73). The exceedance probabilities for this flow are summarized in Table 5-12. Areas, stages, flows, and exceedance probabilities as a result of 15% area reduction are summarized in Table 5-13.

Table 5-12. Exceedance probabilities at Coffee Spring Pool.

MFL criteria	Area (ft^2)	Corresponding stage (ft, NGVD29)	Corresponding flow (cfs)	Baseline Exceedance Probability	Observed Exceedance Probability (2002-2011)
Inundated area of 50%	1960.18	16.90	351	0.53	0.25
15% reduction in inundated area	1666.15	16.74	325	0.77	0.33

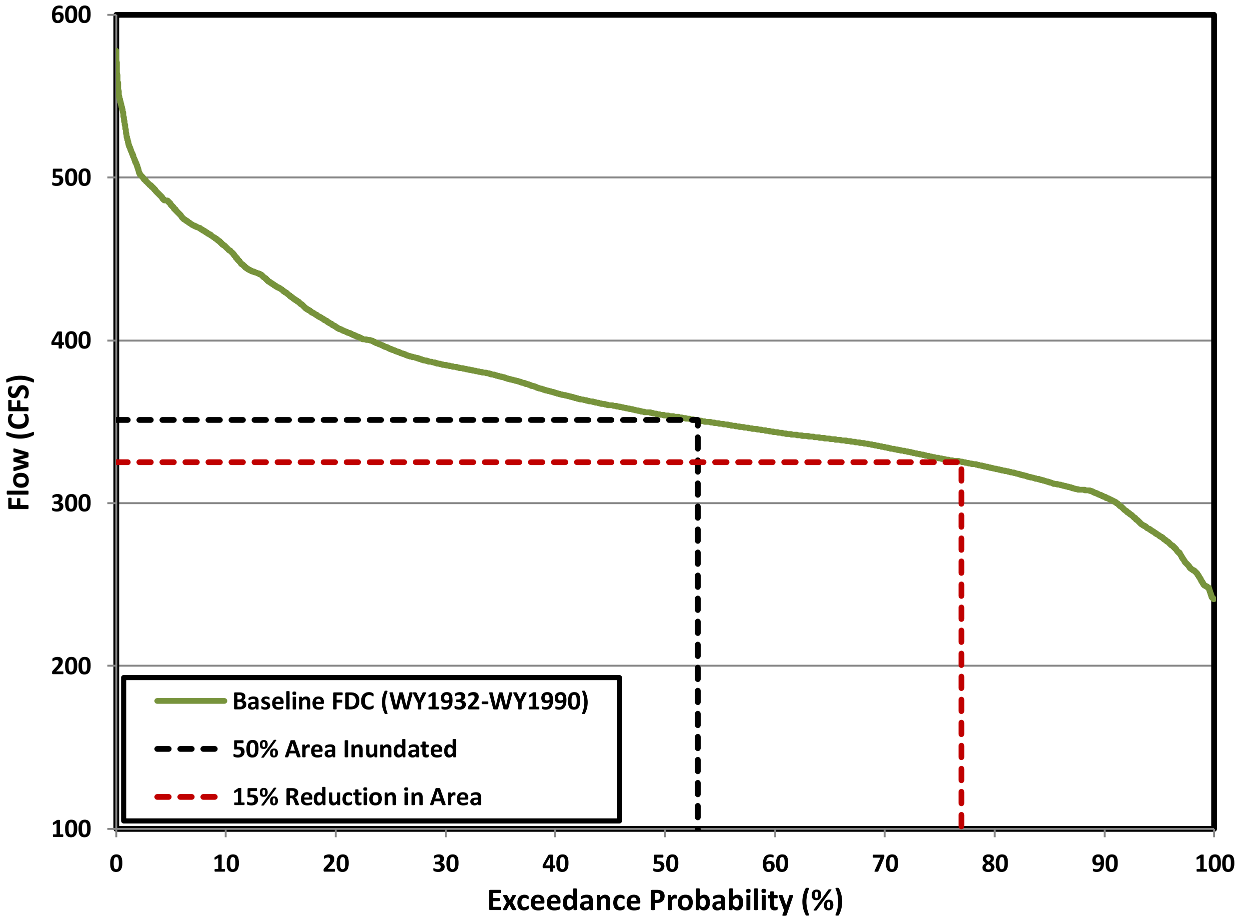


Figure 5-74. Flow duration curve for the Ichetucknee River at Highway 27 (USGS station number 2322700).

Table 5-13. Summary of 15% area reduction at Coffee Spring Pool: Flows, stages, and exceedance probabilities.

Coffee Spring Pool Area (ft^2)	Coffee Spring Pool Stage (ft, NGVD29)	Highway. 27 Flow (cfs)	Baseline Highway. 27 Flow (cfs)	Reduced Coffee Spring Pool Area (ft^2)	Reduced Coffee Spring Pool Stage (ft, NGVD29)	Reduced Highway. 27 Flow (cfs)	Baseline Highway. 27 Flow (cfs)	Difference in Flow (cfs)
202.94	15.88	183.91	>99.99%	172.50	15.84	177.00	>99.99%	6.91
430.94	16.08	216.76	>99.99%	366.30	16.02	207.45	>99.99%	9.31
700.05	16.28	249.60	99.10%	595.04	16.20	236.79	>99.99%	12.81
1178.03	16.48	282.45	94.47%	1001.32	16.41	270.30	96.68%	12.15
1560.31	16.68	315.29	83.65%	1326.27	16.56	295.18	91.98%	20.11
1922.73	16.88	348.13	55.77%	1634.32	16.72	322.00	79.44%	26.13
1960.18	16.90	351.42	52.52%	1666.15	16.74	324.88	77.38%	26.54
2295.98	17.08	380.98	32.96%	1951.58	16.90	350.67	53.18%	30.31
2626.54	17.28	413.82	18.72%	2232.56	17.05	375.40	36.29%	38.42
2954.85	17.48	446.67	11.48%	2511.62	17.21	402.40	21.94%	44.27
3242.74	17.68	479.51	5.51%	2756.33	17.36	426.81	15.94%	52.7
3681.48	17.88	512.35	1.61%	3129.26	17.60	466.56	8.19%	45.79
3920.35	18.08	545.20	0.45%	3332.30	17.72	486.21	4.39%	58.99

It is important to note that based on the results of the dynamic HEC-RAS model, the Coffee Spring Pool simulated stage does not fall below 15.88 feet (Figure 5-75 and Table 5-14). From the Coffee Spring Pool stage-area relationship (Table 5-11), this stage (15.88 feet) corresponds to an area of 202.94 square feet. Hence, based on the results of the HEC-RAS model and the physical stage-area relationship, approximately 5% of the Coffee Spring Pool area always stays inundated.

Table 5-14. HEC-RAS model stage summary at Coffee Spring Pool (2002 - 2011).

HEC-RAS Model Stage (ft, NGVD29) Summary at Coffee Spring Pool (2002 - 2011)	
Minimum Stage	15.88
Maximum Stage	26.40
Average Stage	17.08

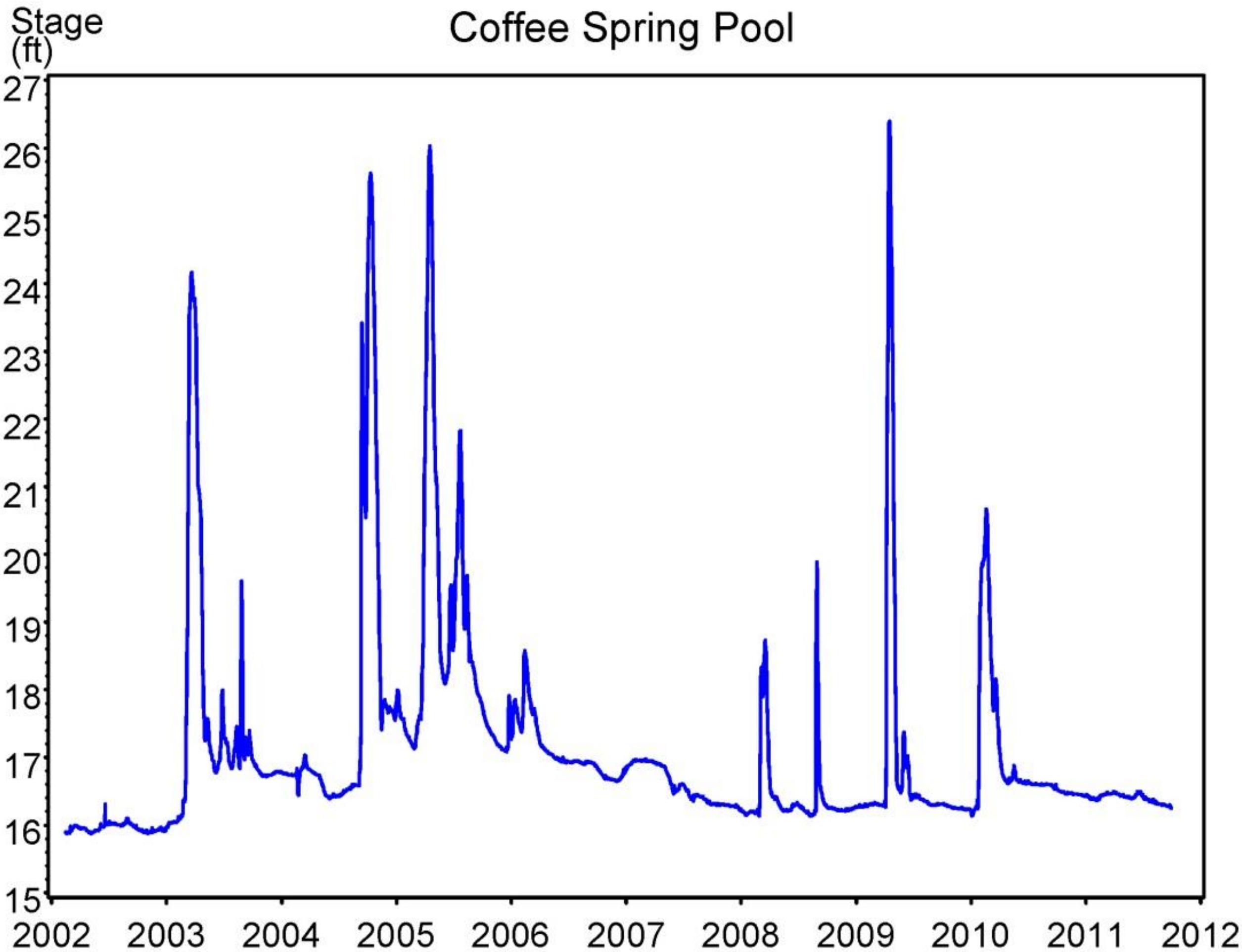


Figure 5-75. HEC-RAS stage at Coffee Spring Pool
Note: Coffee Spring Pool stage was obtained using linear interpolation and model output stage values at station 14690.63 and station 16758.63.

Oval Pigtoe Mussel

The oval pigtoe mussel (*Pleurobema pyriforme*) is an endangered unionid mussel that has been found historically in the Santa Fe River and more recently found by Florida Fish and Wildlife Conservation Commission (2011).

The oval pigtoe occurs in small to medium-sized creeks to small rivers where it inhabits silty sand to sand and gravel substrates, usually in slow to moderate current (Williams & Butler, 1994). Stream channels appear to offer the best habitat for this species. The basin status survey located 85% of the specimens in sandy substrates associated with either detritus, or clay, or silt, or cobble (Brim & Williams, 2000). In the Suwannee River drainage, specimens of the oval pigtoe were associated with sandy mud and coarse sand sediments with little to no detritus (Blalock-Herod, 2000).

Little is known regarding the habitat requirements of the oval pigtoe, thus precluding using this taxon to establish MFLs in either the Lower Santa Fe or Ichetucknee rivers.

Florida Manatee

The endangered Florida Manatee (*Trichechus manatus latirostris*) utilizes portions of the Santa Fe and Ichetucknee rivers. While the US Fish and Wildlife Service has not established any portion of the Santa Fe or Ichetucknee rivers as critical habitat, the basin's springs and submerged aquatic vegetation are important resources available for manatees.

Ichetucknee Springs State Park personnel provided records of manatee sightings in the park and downstream (date, number of individuals, observer, and location of sighting). Sightings were tabulated by month and year, and compared to monthly water depths to identify any correlation between river stage and sightings. The USGS provided a file of manatee sightings on the Lower Santa Fe River between 2001 and 2008.

Manatee passage in the Ichetucknee River appears to be restricted by two shoals along the river. The first is near the confluence with the Santa Fe River at cross section 335.5. The second, known as railroad shoal is located at cross section 9801.9. The SWFWMD used a minimum passage depth of 3 feet for manatees in the Weeki Wachee spring MFL (SWFWMD, 2008). Conditions which determine the water's depth at these shoals is a combination of flow in the Ichetucknee River and the elevation of the Santa Fe or Suwannee rivers. When excess rainfall elevates water levels in the Suwannee and Santa Fe, the rivers can create tailwater conditions on the Ichetucknee River and elevate the water level beyond what the Ichetucknee River's flow alone would support.

There have been over 400 manatee sightings in the river since 1992 (Figure 5-76). Based upon wildlife observations from Ichetucknee State Park staff, manatee utilization of the Ichetucknee River is highest during the winter months January – March (Table 5-15). It is during these same months that water elevations are highest based upon monthly box plots (Figure 5-77).

Table 5-15. Ichetucknee Springs State Park wildlife observation synopsis for Florida Manatee sightings
(1 indicates a month in which at least one observation occurred)

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
1992													0
1993		1											1
1994			1							1			2
1995		1											1
1996												1	1
1997													0
1998	1	1											2
1999													0
2000									1				1
2001													0
2002						1							1
2003			1					1	1				3
2004		1	1							1	1	1	5
2005	1	1	1	1	1	1	1	1					8
2006	1	1	1	1									4
2007		1											1
2008			1					1					2
2009				1	1								2
Totals	3	7	6	3	2	2	1	3	2	2	1	2	34

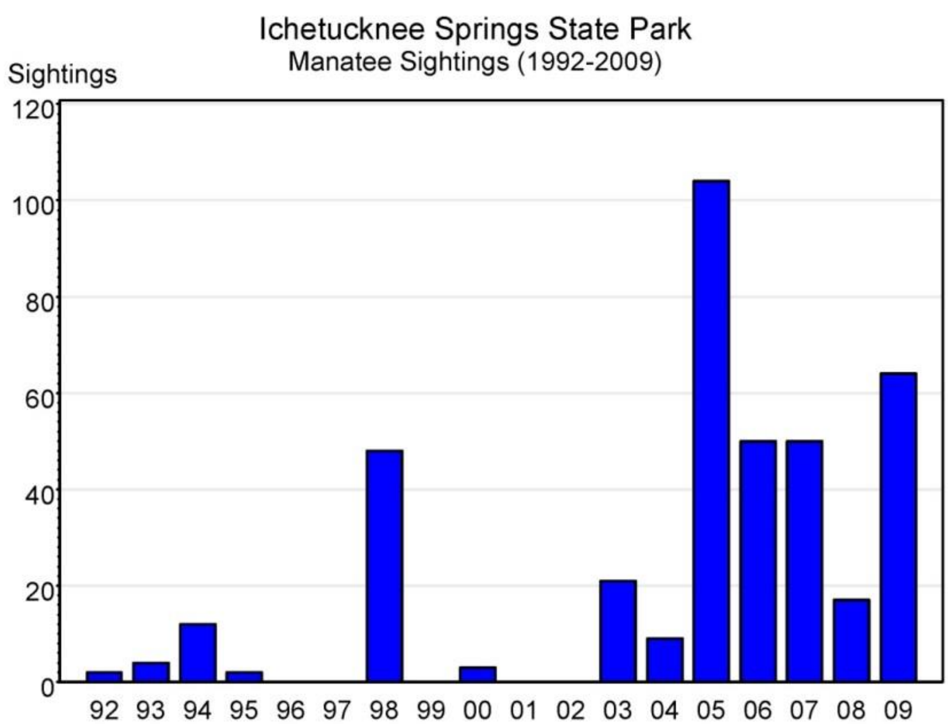


Figure 5-76. Total manatee sightings, by year.
Reported by the Florida State Park Service, 1992-2009.

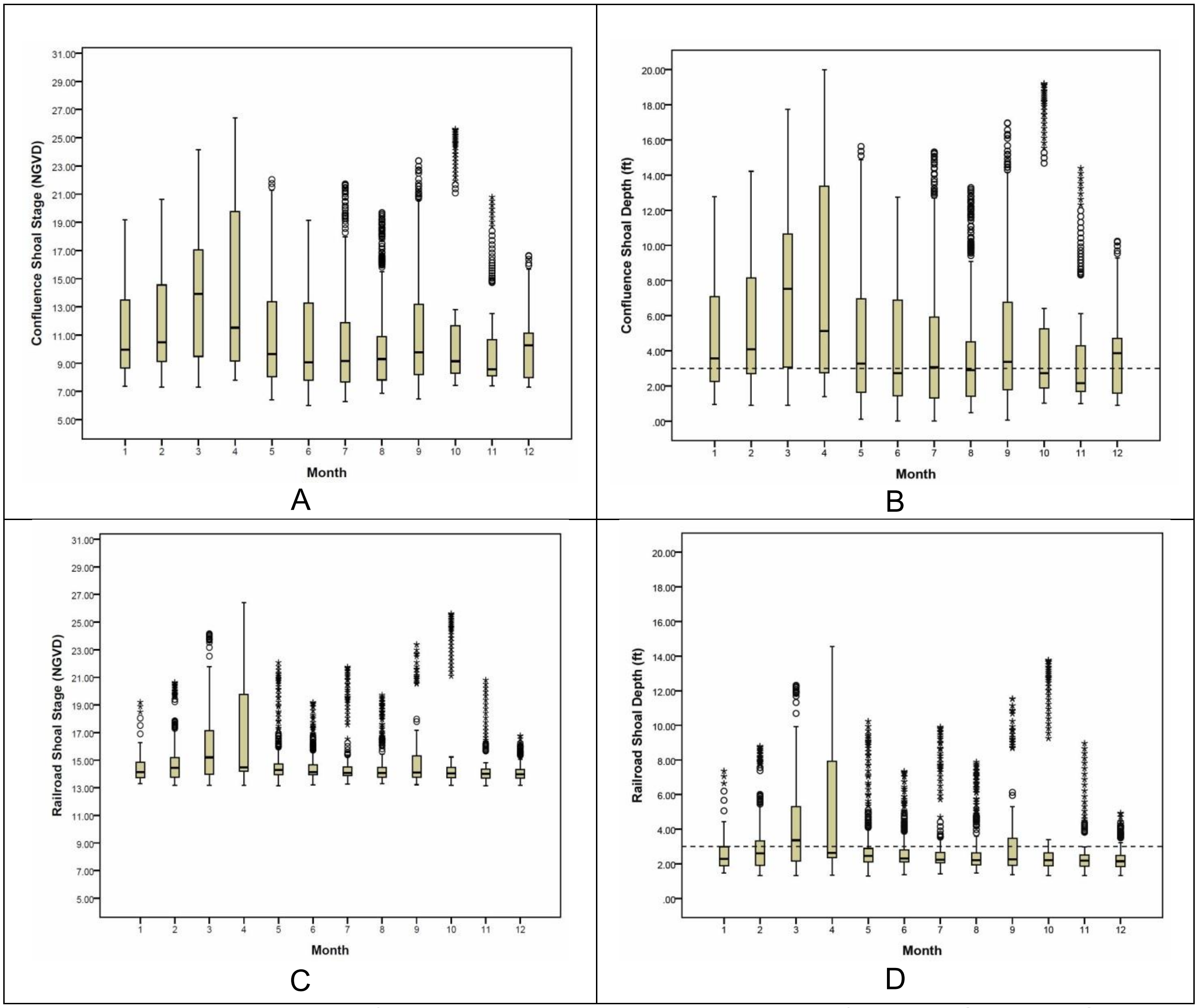


Figure 5-77. Box plot of water levels and depths at confluence (A and B) and railroad (C and D) shoals.

To evaluate the relative contribution of Ichetucknee River flow from flows on the Santa Fe and Suwannee rivers creating a tailwater condition, plots of stage vs. flow in the three rivers were evaluated. Figure 5-78 illustrates the relationships for depth at the confluence (Figure 5-77A) and railroad (Figure 5-77B) shoals for Ichetucknee flow at US27, Santa Fe River flow at Fort White and the Suwannee River at Branford. Ichetucknee River flows are generally poor predictors of stage at either of the shoals, but the flow does set the minimum depth of the water at each shoal, Figure 5-78A and Figure 5-78B. The Santa Fe River's flow at Fort White is a poor predictor of depth at either shoal, Figure 5-78C and Figure 5-78D. The Suwannee River's flow at Branford provides the best overall predictor of water levels at both shoals, supporting the strong role which tailwater conditions can have on Ichetucknee River water levels, Figure 5-78E and Figure 5-78F. Thus, Ichetucknee River flows set the minimum depths at the shoals and departures from this minimum are better explained by flows on the Suwannee River. Note that the lowest Ichetucknee River flows occur when elevations at the shoals are the highest, indicating that flows presumably from the river's springs can be reduced due to the hydrostatic pressure of high elevations generated by tailwater conditions from the Suwannee River. Thus the times when manatee access over the shoals is easiest (lowest flow and greatest water depth) occurs due to flows on the Suwannee River, independent of the Ichetucknee River's conditions.

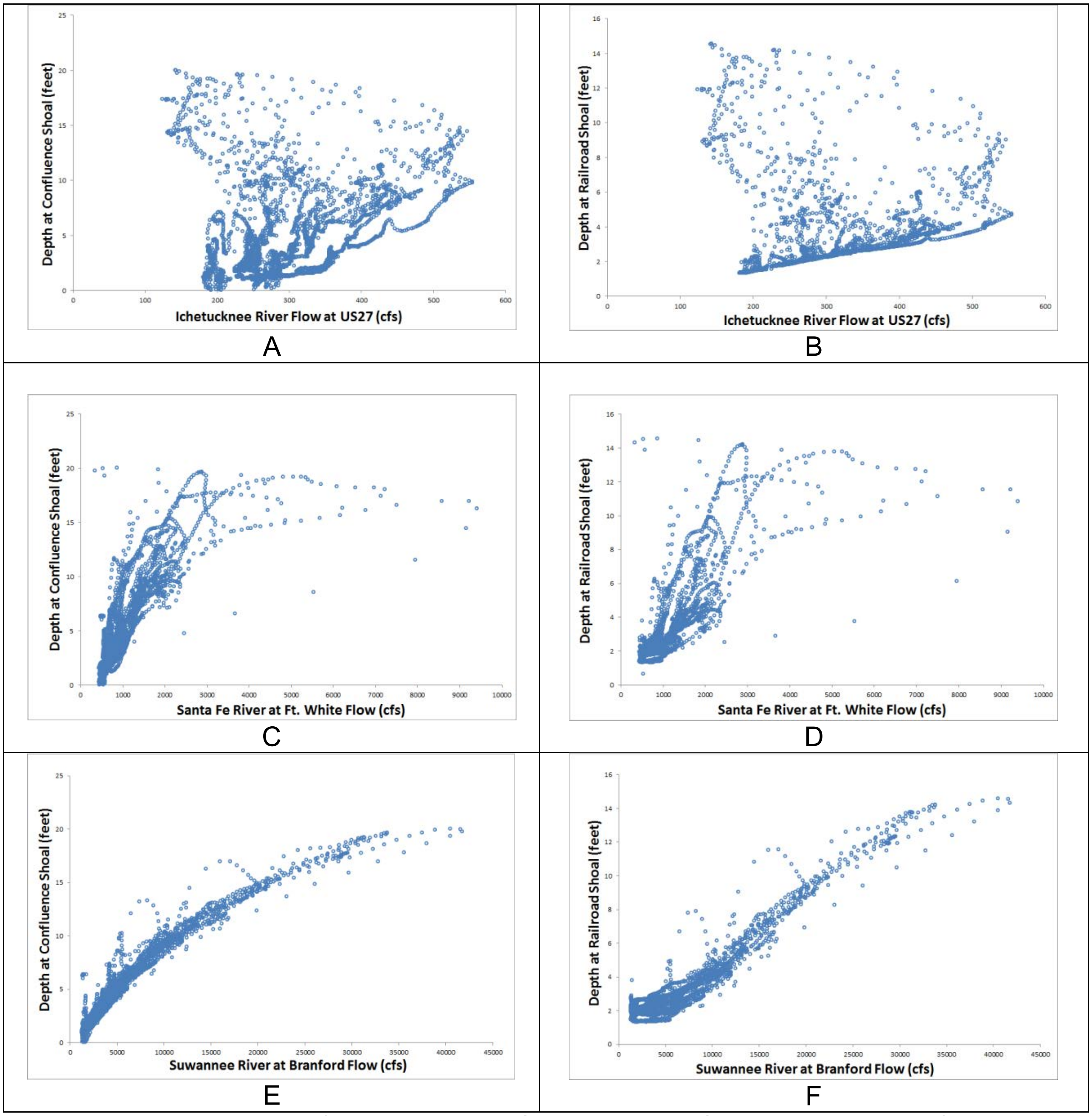


Figure 5-78. Plots of Ichetucknee, Santa Fe and Suwannee rivers' flow vs. depth at the confluence and railroad shoals of the Ichetucknee River.

Submerged Aquatic Vegetation (SAV)

Submerged aquatic vegetation (SAV) is prevalent throughout both the Lower Santa Fe and Ichetucknee rivers. SAV is important for nutrient attenuation, providing habitat for fish, especially juveniles, stabilizing sediments in the channel and banks, and in maintenance of streamflow velocity (Hynes, 1970). Many of the key taxa in these systems prefer low velocity habitats; an abundance of SAV provides friction and moderates velocities.

Aquatic vegetation types were described in the Ichetucknee River by Kurz, et al. (2004), (Figure 5-79). Wild-rice (*Zizania aquatic*) is dominant in the Ichetucknee Head Spring and approximately 200 m of the spring run (Kurz, et al., 2004). Downstream, and for the duration of the river channel, strap-leaf sagittaria (*Sagittaria kurziana*), is the most abundant type of SAV. Tape grass (*Vallisneria Americana)* and muskgrass (*Chara sp.*) are also abundant throughout the Ichetucknee River (Kurz, et al., 2004). Approximately 600 m downstream of the Ichetucknee Head Spring, the river channel widens into the rice marsh reach of the river (Kurz, et al., 2004). This reach of the river has little to no SAV cover. The channel then narrows once more approximately 1500 m further downstream where the canopy typically covers the entire river channel. While the river bottom is predominantly populated by SAV (~78%), 3.3% of the channel is bare; substrata include coarse sand and gravel (Kurz, et al., 2004).

Figure 5-79. SAV in the Ichetucknee River.

Stevenson et al. (2004) completed a comprehensive survey of 59 of Florida's springs, including eight on the Ichetucknee River, for FDEP. The investigators found a lack of correlation amongst TN, TP, and conductivity, results that were considered surprising with respect to previous studies. Upon removal of the sites with the highest conductivity, it was found that TN and TP were negatively correlated at most sites in Florida springs, including those on the Ichetucknee River (Stevenson, Pinowska, & Wang, 2004). Typically, TN and TP are positively correlated, and are correlated with conductivity, chloride, and anthropogenic activity. In low conductivity waters, spikes in conductivity can be linked to watershed perturbation and increased eutrophication.

Stevenson, et al. (2004) also correlated biological indicators with conductivity and nutrient inputs. Similar relationships between environmental variables and diatom species composition were observed as in previous studies, but conductivity was responsible for more variation in these communities than nutrients (Stevenson, Pinowska, & Wang, 2004). The researchers also ranked each spring in the survey on a variety of water quality issues. Based on these rankings, it was found that Blue Hole Spring is in the worst 5% of Florida springs in terms of algal matting, while Mission Spring ranks in the worst 7% of Florida springs concerning epiphytic algal growth. Stevenson, et al. (2004) go on to state that macroalgal biomass is limited by phosphorus in two springs in the Ichetucknee River (Mill Pond Spring and an unnamed spring identified as "before bridge" at US-27), a relationship observed at only four other sites in the survey.

The potential influence of water quality on the health of SAV in the Ichetucknee River has been raised. Specifically, the question is whether MFLs provide a means to mitigate nitrate loadings from springs. Upchurch, Chen & Cain, (2008) addressed this question for the District. They utilized data obtained by the District's Water Assessment Regional Network (WARN) in their analyses. The analyses included spring discharge, nitrate + nitrite, and specific conductance. These data were obtained from all first and most of the second magnitude springs within the District. They concluded –"*The clear conclusion from this analysis is that minimum flows and levels (MFLs) cannot be utilized to control nitrate discharging from the springs by promoting high discharge. Data from 50% of the springs show that nitrate concentrations increase as discharge from the spring increases. Forty-five percent of the remaining springs show no correlation between discharge and nitrate, and only 5% (2 springs with poor data) have relationships where high discharge was related to lower nitrate concentrations*".

Given the results from the Stevenson (2004) and Upchurch, et al. (2008), studies using nitrate loading as a metric in the development of MFLs for the Ichetucknee River is not warranted.

Lastly, the potential influence of tubing on SAV in the Ichetucknee River has been raised as a variable in MFL development. This issue was addressed previously in the discussion on recreation. The Park staff has been monitoring SAV cover since 1989. The percent cover is estimated at a series of transects (Figure 5-80) for both Spring and Fall of each year. Figure 5-81 presents the results from two transects that have been monitored since 1991. These data show that the Fall percent cover estimates were generally lower than the Spring estimates. This may indicate that whatever effects of tubing that occurred during the tubing season are not long-lived since there is an apparent return to higher percent covers in the Spring surveys.

SANTA FE RIVER TOTAL MAXIMUM LOADS AND BASIN MANAGEMENT PLAN

The Santa Fe River has been deemed impaired by the FDEP. The impairments include elevated chlorophyll levels and depressed dissolved (DO), and these impairments have been attributed to nutrient loading. Given these impairments, FDEP developed a Total Maximum Daily Load (TMDL). The purpose of setting a TMDL is to determine the maximum pollutant load that a water body can assimilate and retain its designated use and ecological health. The nutrient TMDL for the Santa Fe River was adopted December 7, 2008.

Subsequent to setting a TMDL, FDEP worked with local stakeholders to establish a Basin Management Action Plan (BMAP). A BMAP is a framework through which TMDLs can be implemented. The BMAP for the Santa Fe River was adopted by FDEP February 2012, and was developed in partnership with the Suwannee River Partnership; Alachua, Colombia, Gilchrist, Union, Bradford Counties; the Florida Department of Agriculture and Consumer Services, the Florida Department of Transportation, the District, and the Springs Working Groups for Ichetucknee and Santa Fe rivers. The purpose of the BMAP is to reduce nitrate concentrations in waters of the Suwannee River Basin (FDEP, Undated). A summary of the results from the FDEP TMDL and BMAP is given in Appendix 5-8.

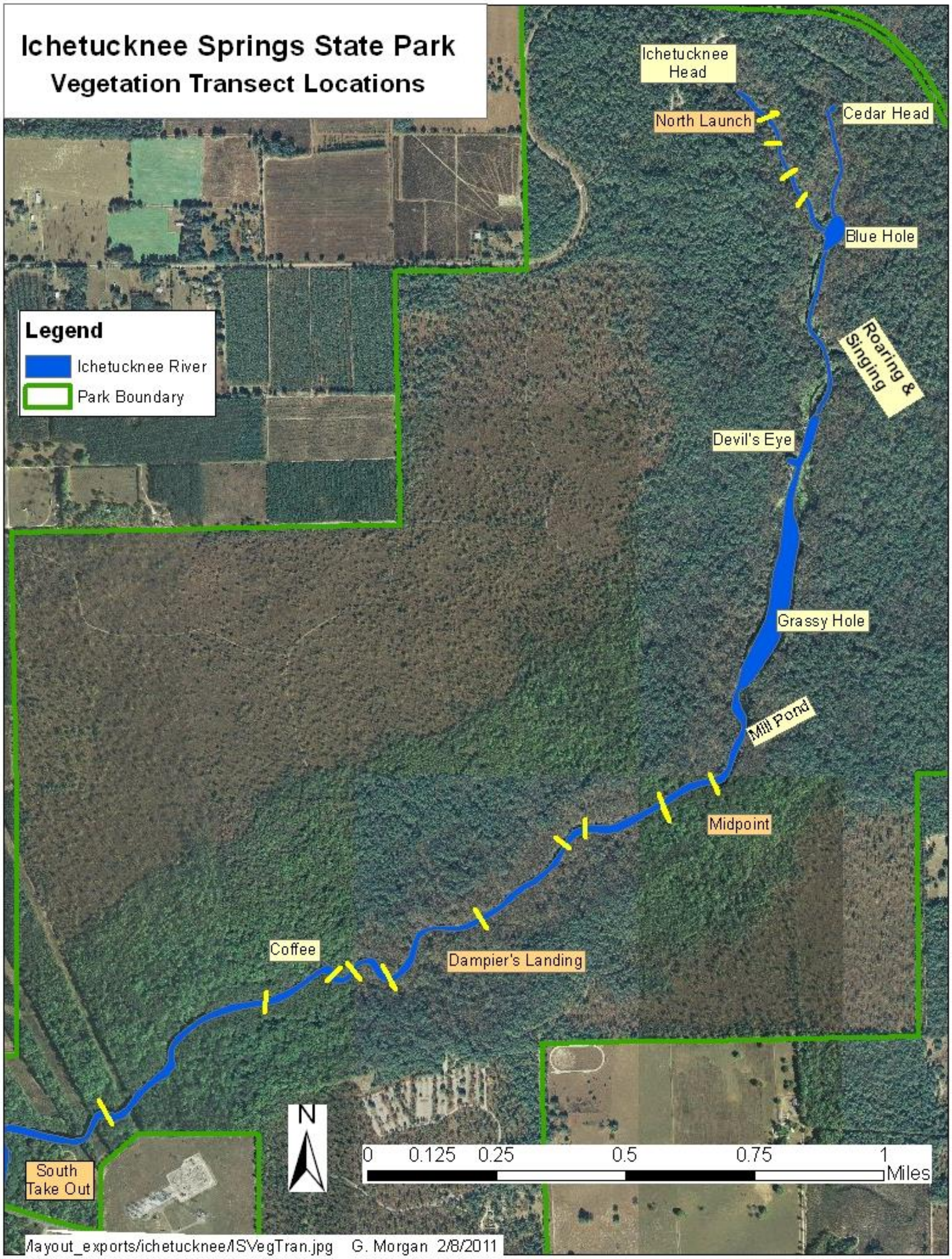


Figure 5-80. SAV survey transects on the Ichetucknee River.

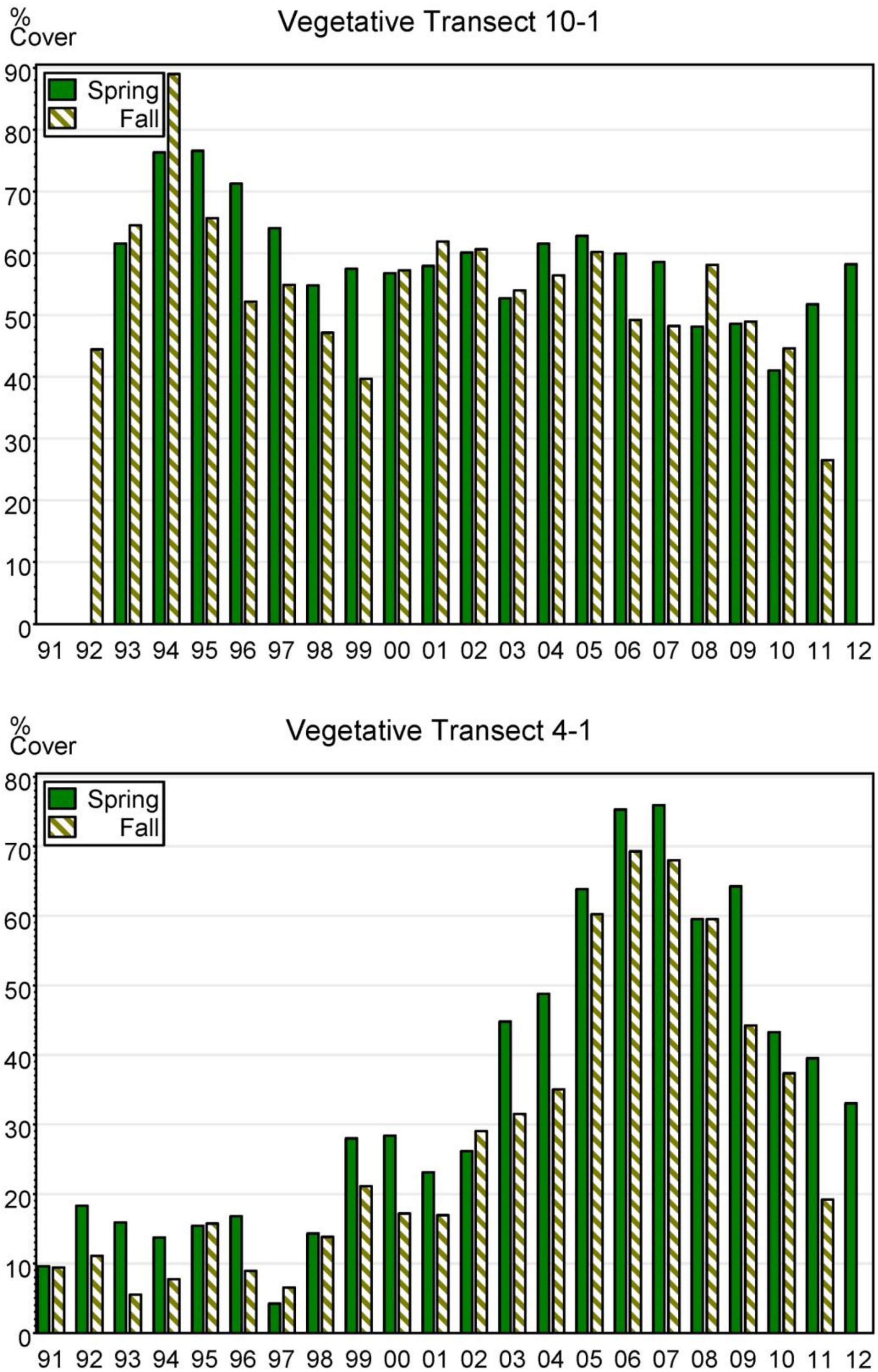


Figure 5-81. SAV percent cover estimates from two survey transects on the Ichetucknee River.

6.0 MFL DEVELOPMENT AND RECOMMENDATIONS

This section summarizes much of the discussion from the previous sections, and uses that information to develop and recommend MFLs for the Lower Santa Fe and Ichetucknee rivers and priority springs, and to determine the current basin status relative to the proposed MFLs. Section 6.0 topics are as follows (with reference to prior sections for further detail):

6.1 Lower Santa Fe and Ichetucknee Rivers and Priority Springs Study Area - - See Section 2.0.

6.2 Water Supply Issues in the Lower Santa Fe Region - - See Sections 2.0 and 4.0.

6.3 Baseline Hydrology and Flows for Water Resource Value (WRV) Metrics - - See Sections 3.0 and 5.0.

6.4 Proposed River MFL Flow Regimes and Results

6.5 Proposed Priority Spring MFLs

6.6 Current Basin Status in Relation to the Recommended MFLs

6.1 LOWER SANTA FE AND ICHETUCKNEE RIVERS AND PRIORITY SPRINGS STUDY AREA

The Santa Fe River originates in Santa Fe and Little Santa Fe lakes in the northeast corner of Alachua County, Florida. The river flows westward along the Alachua County line and eventually goes completely underground at a large sinkhole known as the Santa Fe Sink (or River Sink), near O'Leno State Park (Hunn & Slack, 1983). The Santa Fe River travels underground for approximately three miles before it resurfaces several miles north of High Springs at the Santa Fe Rise (River Rise). A natural land bridge between River Sink and River Rise acts as a divider forming two distinct reaches of the river: the Upper Santa Fe and the Lower Santa Fe. The total length of the river is approximately 80 miles, with approximately 30 miles below River Rise, prior to the confluence with the Suwannee River.

Flow in the Lower Santa Fe River consists mainly of groundwater discharge from the UFA, mixed with resurgence of surface water from the upper river at Santa Fe Rise. The groundwater component sustains the flow of the river during periods of deficit rainfall. Multiple, major springs occur in the Lower Santa Fe River Basin, including the Ichetucknee River Spring Group, which is one of the largest spring complexes in the state. Backwater from flooding on the Suwannee River affects a significant portion of the lower half of the system. The Lower Santa Fe River Basin is located in an area that spans a climatic divide separating the continent and peninsular Florida, and is evidenced by a marked, bi-modal pattern of spring and fall high water seasons.

The Ichetucknee River hydrology follows the "spring-dominated" pattern described by Kelly (2004). With eight named springs, including the source at Ichetucknee Head Spring, the river is almost completely driven by springflow (Stevenson, Pinowska, & Wang, 2004). Some "flashiness" (rapid increases and decreases in flow) can be observed during periods following heavy precipitation events, but the overall flow pattern is dictated by the springs. For this reason, the Ichetucknee River flows are less variable than those of the Lower Santa Fe River. Backwater conditions can also occur over much of the lower reach of the Ichetucknee River when flooding occurs near its confluence with the Lower Santa Fe River.

6.2 WATER SUPPLY ISSUES IN THE LOWER SANTA FE REGION

In 2010, the District published a Water Supply Assessment (Assessment) to determine whether water demands could be met for the 2010 through 2030 planning period (SRWMD, 2010) without adversely impacting the natural systems within the District. The 20-year water demand assessment assumed fresh groundwater would be the source water used to meet all reasonable and beneficial future demands. Fresh groundwater within the District is derived nearly exclusively from the UFA. The Assessment concluded that water resources in the eastern and northeastern portions of the District are currently impacted or predicted to be impacted sometime before 2030. These resource impacts are directly related to reductions in the potentiometric surface of the UFA, which has declined significantly since development of the Floridan Aquifer system (FAS) began in the late 1800s.

The decline in regional groundwater levels in the northeastern portion of the District has led to actual or predicted impacts to flows in a number of its rivers and springs during the 2010–2030 planning period, including the Lower Santa Fe River. As a result, the Lower Santa Fe River Basin (which includes the Ichetucknee River) was designated as one of four Water Supply Planning Regions (WSPRs). In October 2011, the District Governing Board designated the four WSPRs as Water Resource Caution Areas (WRCAs) which are areas where existing water sources (i.e., fresh groundwater) may not be adequate to satisfy future water demands and sustain water resources during the 2010–2030 planning period.

Information from the 2010 Assessment was used to review the annual MFL Priority List submitted to the FDEP in October 2011. The Lower Santa Fe River and associated priority springs, already a high priority in the schedule, retained that position of emphasis. The 2012 MFL Priority List submittal noted the potential for “cross-boundary” impacts on the Lower Santa Fe River, meaning withdrawals outside the District, in addition to those within the District, may impact flows in the system.

6.3 BASELINE HYDROLOGY AND FLOWS FOR WRV METRICS

Conceptually, the development of MFLs for the Lower Santa Fe and Ichetucknee rivers and priority springs consisted of the following four steps:

- First - develop Baseline Flow period at the river gages,
- Second - identify relevant Water Resource Values (WRVs) found in the Lower Santa Fe River and Ichetucknee River systems and screen these for the sufficiency of available information. Determine appropriate metrics for the two river systems and identify a Critical Flow unique to each metric with sufficient available information. The Critical Flow is the optimal flow that maintains a WRV. Determine the reduction for each Critical Flow that can occur without causing significant harm, which is depicted as the Resulting Metric Flow. A Resulting Metric Flow is derived by multiplying the Critical Flow by the corresponding allowable percent reduction,

- Third - combine the individual Resulting Metric Flows from the multiple metrics into an integrated MFL Flow regime that is protective of the WRVs, and

- Fourth - use of the Observed, Baseline, and MFL flows in the two rivers to establish MFLs for the priority springs contributing groundwater to each river system.

This subsection, 6.3, summarizes the first and second steps, which were presented in detail in earlier section 4.0.

6.3.1 Historical Baseline Flow Period

As pointed out by Beecher (1990), one essential element in establishing a MFL is the definition of a baseline period during which environmental characteristics are deemed appropriate. Guided by the projected impacts identified in the 2010 Assessment, further detailed statistical analysis of Observed Flow and rainfall data identified a period of time, beginning around 1990 where the flow decreased disproportionality to rainfall in the Lower Santa Fe and Ichetucknee rivers. This information was used to define a historical hydrologic condition (as referenced in Chapter 373.0421, F.S.), at the two selected MFL gages, the Santa Fe River near Fort White and the Ichetucknee River at Highway 27. The historical hydrologic condition was used as a Baseline flow regime.

BASELINE FLOW PERIOD

The Baseline Flow period was developed for the two selected MFL gages using statistical methods to evaluate the relationship and rate of decline in estimated flow relative to rainfall before and after 1990 (Section 4.0). Statistical modeling was used to identify 1990 as a break point in the rainfall discharge relationship. Prior to 1990 the rainfall discharge relationship was relatively stable. After 1990 less discharge occurred per unit of rainfall. Section 4 describes the statistical modeling and adjustments to flow. The Baseline Flow period was used for all subsequent analysis of MFLs for the Lower Santa Fe and Ichetucknee rivers and priority springs.

FLOW DURATION CURVES

Figure 6-1 and Figure 6-2 summarize the Baseline flows (1933-1990) and the period of time after the baseline (1991-2010) as FDCs for the Lower Santa Fe River near Fort White and Ichetucknee River at Highway 27 gages, respectively. Although the FDCs do not show the chronological sequence of flows, they are useful for comparing the differences in cumulative frequency of flows between conditions. The distinction between the Baseline and 1991-2010 period flow curves is discernible across most of the distribution. For the Santa Fe River the lowest exceedance probability level, the difference between the Baseline and 1991-2010 period is minimized, because the effect of groundwater use on groundwater contributions to the system is dwarfed by the rates of surface water contributions at extreme high river conditions.

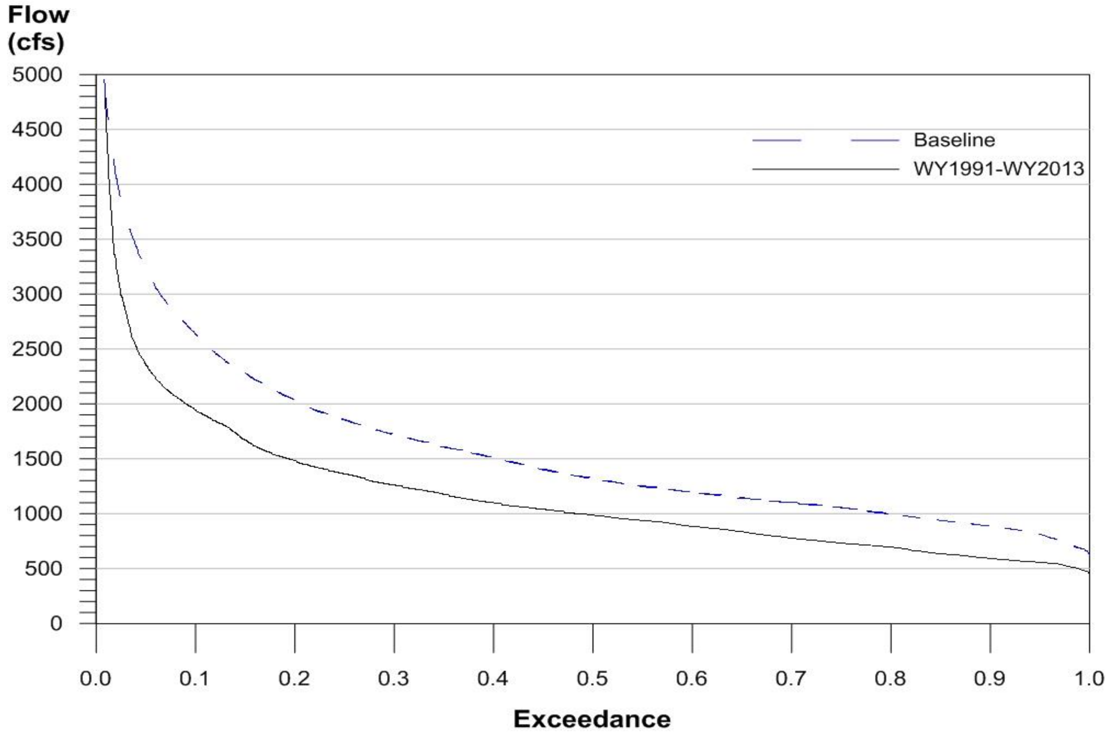


Figure 6-1. Baseline and WY1991-WY2010 flow duration curves for the Santa Fe River near Fort White (USGS ID 02322500)

Note: The period of record maximum observed flow was 16,900 cfs; the flow axis is truncated at 5,000 cfs for presentation purposes.

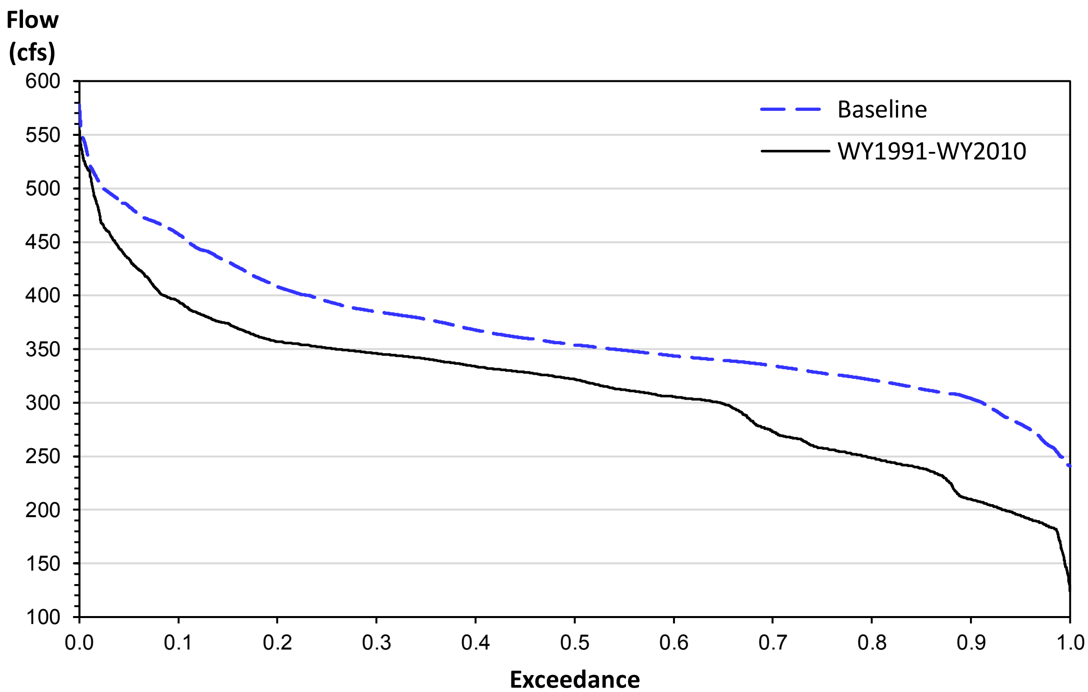


Figure 6-2. Baseline and WY1991-WY2010 flow duration curves for the Ichetucknee River at Highway 27 (USGS ID 02322700)

6.3.2 WRV Metrics and their Critical and Shifted Flows

MFLs for the Lower Santa Fe and Ichetucknee rivers were developed using a procedure that assessed a series of environmental metrics that describe a number of the WRVs listed in Chapter 62-40, F.A.C., and are found in the Lower Santa Fe and Ichetucknee rivers and priority springs. These metrics included several features that depend on out-of-bank flows (floodplain vegetation, hydric soils, and bankfull flows) and in-channel flows (fish passage, habitat suitability, recreation, and woody habitats). A series of data collection and analysis techniques were used to estimate Critical Flows that were applied to the Baseline Flow as described in Section 5.0.

Shift in the Critical Flow that did not cause significant harm was determined for each metric. Two types of allowable shifts were computed depending on the type of metric, a shift in maximum weighted useable area for habitat suitability, and for all other metrics, a shift in time using the number of days in the Baseline Flow period that the Critical Flows were equaled or exceeded. Determining the allowable shifts produced the Resulting Metric Flows. In both cases the Resulting Metric Flows were estimated based on a 15% reduction in each metric, either expressed as a percent of time or a percent of area. Justification for the 15% reduction was discussed in Section 3.3. The method by which the Resulting Metric Flows were combined to establish an integrated MFL Flow regime is described in Subsection 6.4.

Section 5.0 presented the development of WRV metrics and the associated Critical Flows. Also developed were the allowable changes from each metric's Critical Flow to its Resulting Metric Flow. Table 6-1 and Table 6-2 summarize the Critical Flows and Resulting Metric Flows for the Lower Santa Fe and Ichetucknee rivers, respectively. Figure 6-3 (for the Lower Santa Fe near Fort White gage) and Figure 6-4 (for the Ichetucknee River at Highway 27 gage) present this information on a FDC showing the location of each Critical Flow on the exceedance probability continuum, and the relative allowable shift to each Resulting Metric Flow.

Figure 6-3 and Figure 6-4 also show the "spread" of the Critical and Resulting Metric Flows across the Baseline Flow period and demonstrate the degree to which the selected WRV metrics provide protection across the full flow regime. The identified Resulting Metric Flows span a range of flows from approximately the 10^{th} percentile exceedance to the 90^{th} percentile exceedance.

Table 6-1. Critical and Resulting Metric Flows for the Lower Santa Fe River.

WRV Metrics	Critical Flow (cfs)	Percent Reduction from Critical Flow to Resulting Metric Flow	Resulting Metric Flow (cfs)
Floodplain Vegetation			
Hardwood Swamp	1,390	9%	1265
Cypress Swamp	1,840	5%	1748
Hardwood Cypress	1,940	6%	1824
Hydric Hardwood Hammock	2,693	4%	2585
Hydric Soils	2,094	6%	1968
Bankfull Flows	1,410	9%	1283
Fish Passage	1,110	8%	1021
Habitat Suitability			
Spotted Sunfish Spawning	1,129	15%	960
Spotted Sunfish Fry	1,093	15%	929
Spotted Sunfish Juvenile	935	13%	813
Spotted Sunfish Adult	1,026	20%	821
Cyprinidae	830	16%	697
Tvetenia Larvae	1,829	10%	1646
Woody Habitats			
Exposed Roots	1,463	8%	1346
Snags	819	17%	680

Table 6-2. Critical and Resulting Metric Flows for the Ichetucknee River

WRV Metrics	Critical Flow (cfs)	Percent Reduction from Critical Flow to Resulting Metric Flow	Resulting Metric Flow (cfs)
Hydric Soils	407	2%	399
Bankfull Flow	328	3%	318
Fish Passage	284	11%	253
Habitat Suitability			
Tvetenia Larvae	415	9%	378
Woody Habitats			
Exposed Roots	368	3%	357
Recreation	282	12%	248

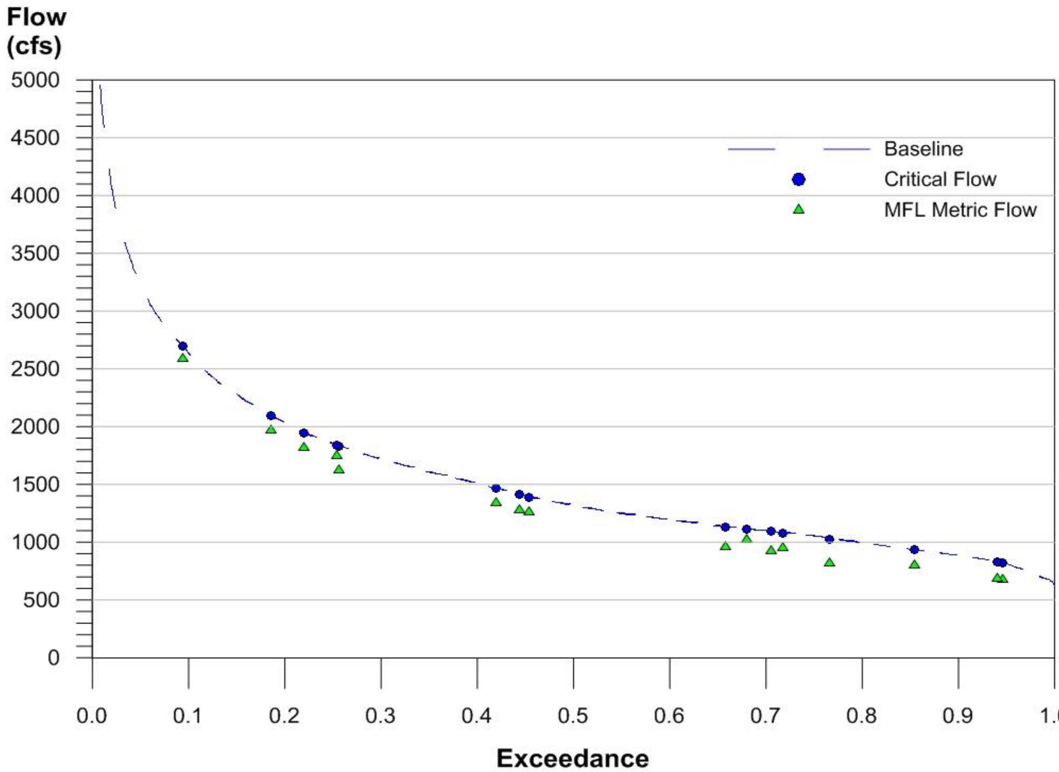


Figure 6-3. Baseline Flow duration curve for the Santa Fe River near Fort White gage (USGS ID 02322500)
Note: The period of record maximum observed flow was 16,900 cfs; the flow axis is truncated at 5,000 cfs for presentation purposes.

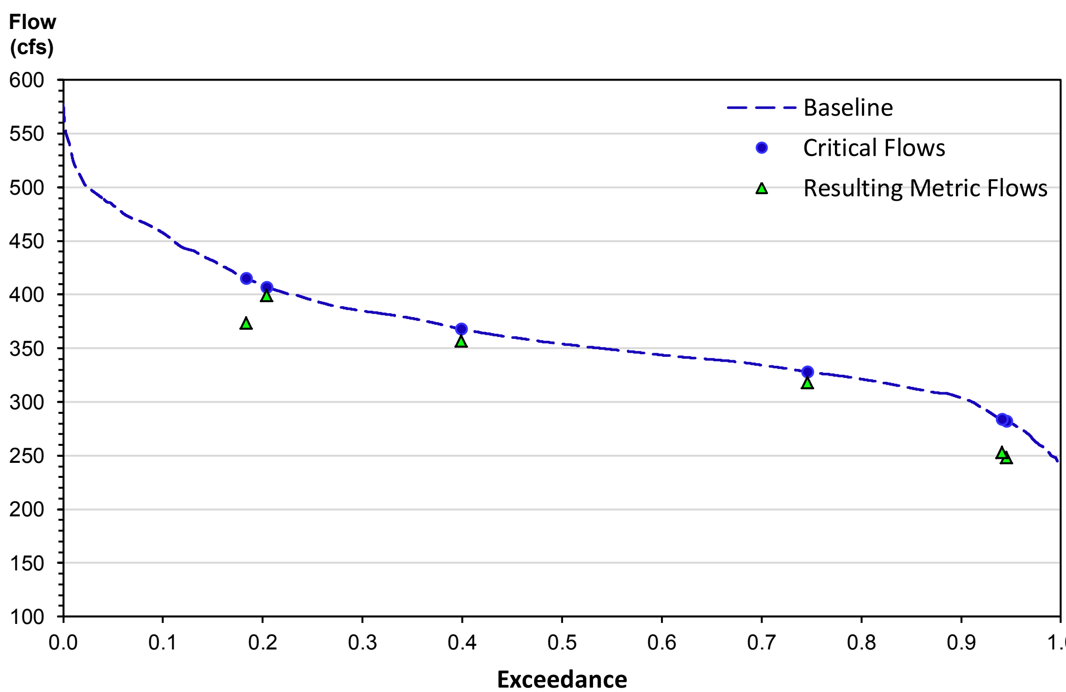


Figure 6-4. Baseline Flow duration curve for the Ichetucknee River at Highway 27 gage (USGS ID 02322700)

6.4 PROPOSED RIVER MFL FLOW REGIMES

As discussed previously, the development of a Baseline Flow period is the first of four steps in the MFL development method used for the Lower Santa Fe and Ichetucknee rivers and priority Springs. The second step is the independent determination of the shift from the Baseline period that can occur without causing significant harm for each metric. In step three, the WRV metrics are synthesized into a MFL regime that is protective of the WRVs. Section 6.4 presents and summarizes this process; details are provided in Appendix 6-1.

The initial step is to identify the allowable percent reduction or shift for each Critical Flow as a percent reduction to flow that varies based on the metric. This process was described in Section 5. The next step identifies the potential overlapping Critical Flows, frequencies and percent reductions, and gaps between Critical Flows. Based on these findings, the “controlling” Critical Flow points, or control points (CP), are identified. The control points are the sub-set of selected critical flows that encompass all remaining critical flows such that the critical flow requirements of all WRVs are protected.

Figure 6-5 and Figure 6-6 present the Baseline and proposed MFL FDCs for the Lower Santa Fe River at Fort White and the Ichetucknee River at Highway 27 and show the result of determining the CPs. Selected exceedances that describe the two FDCs are given in Table 6-3 and Table 6-4. The difference between the Baseline and Fitted MFL values in both Table 6-3 and Table 6-4 are variable flow reductions ranging from 92 cfs to 138 cfs and from 9 cfs to 34 cfs for the Lower Santa Fe and Ichetucknee rivers respectively. These reductions translate to an overall reduction of average flow of seven percent and three percent respectively. It is important to note that although these values also represent the water availability under the MFL regime, they do not necessarily represent the current water availability as they do not account for reductions in flow which have already taken place from existing uses; this is addressed in Subsection 6.6.

As noted in Section 1.0, the District is part of the NFRWSP, jointly with the SJRWMD, the FDEP, and various stakeholders to facilitate water supply planning in north Florida. As a check on the proposed MFL for the Lower Santa Fe and Ichetucknee rivers, the final Baseline and MFL time series were processed using the statistical event-based process used by the SJRWMD. For all compared WRVs, the proposed MFL also maintains the event-based criteria.

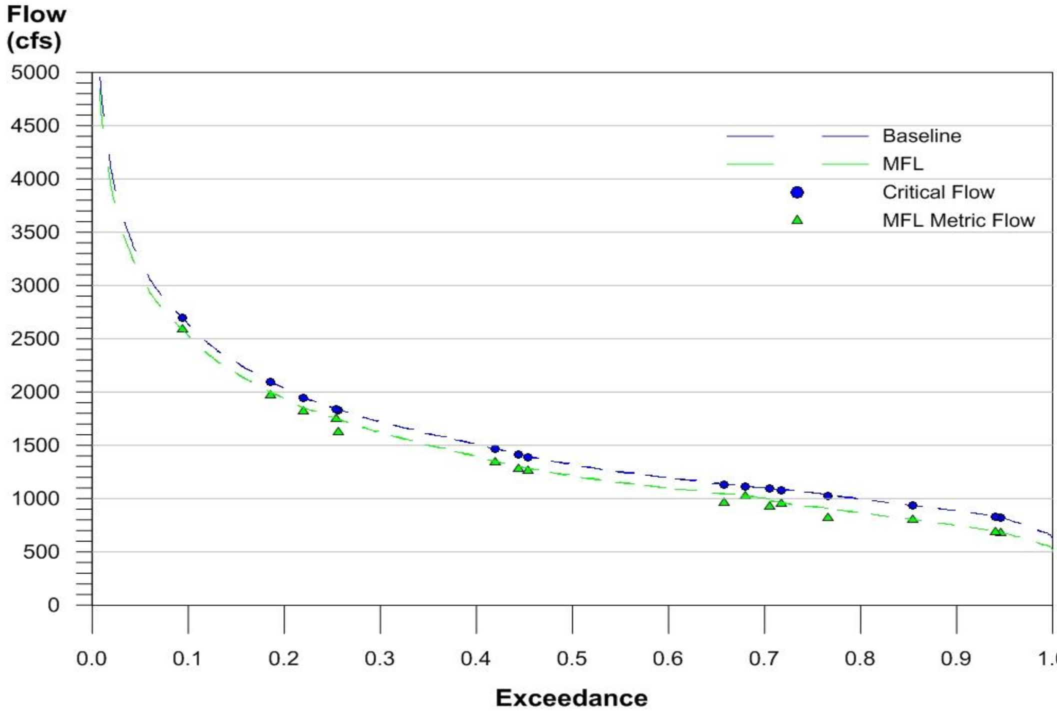


Figure 6-5. Flow duration curves for the Santa Fe River near Fort White gage (USGS ID 02322500)
Note: The period of record maximum observed flow was 16,900 cfs; the flow axis is truncated at 5,000 cfs for presentation purposes.

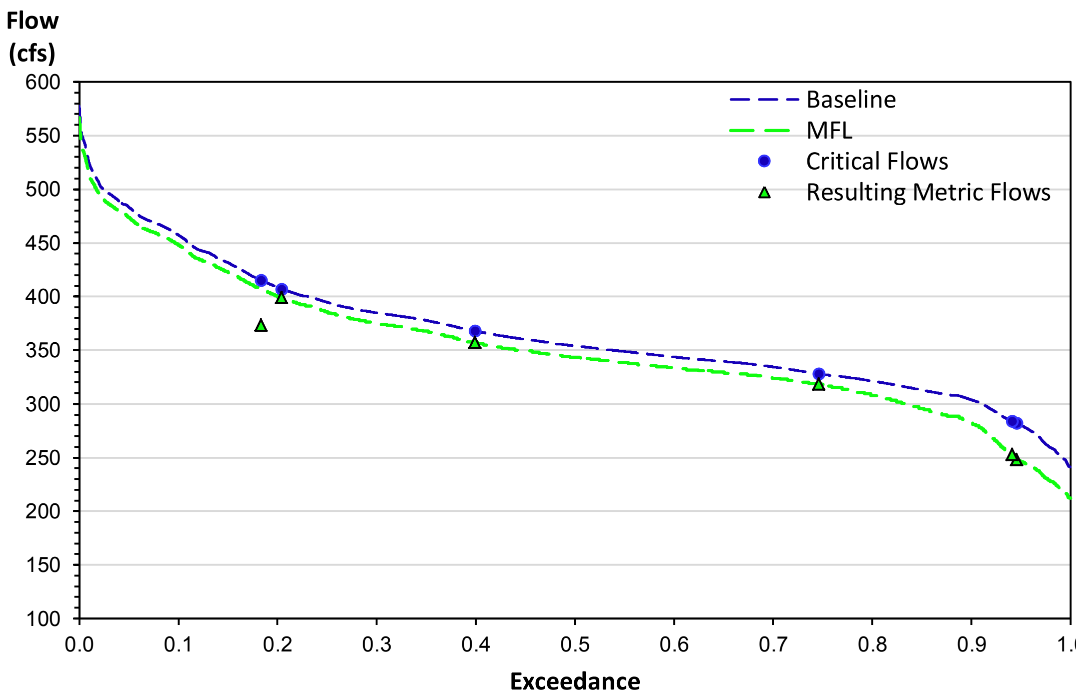


Figure 6-6. Flow duration curves for the Ichetucknee River at Highway 27 gage (USGS ID 02322700).

Table 6-3. Comparison of Baseline and Fitted MFL flow values for the Lower Santa Fe River near Fort White at selected probabilities of exceedance.

	Discharge Exceedance Amounts (cfs)						
FDC	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**
Baseline	3,230	2,630	1,860	1,320	1,050	885	810
MFL	3,101	2,523	1,768	1,214	920	749	672

Table 6-4. Comparison of Baseline and Fitted MFL flow values for the Ichetucknee River at Highway 27 at selected probabilities of exceedance.

FDC	Discharge Exceedance Amounts (cfs)						
	5%	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**
Baseline	483	457	395	354	328	304	280
MFL	473	448	386	343	318	282	246

6.5 PROPOSED PRIORITY SPRING MFLS

Given the large contribution of springflow to river discharge in the Lower Santa Fe and Ichetucknee rivers, maintenance of spring discharge is essential to the protection of water resource conditions in the Lower Santa Fe River Basin. Thus, protecting streamflows in the Lower Santa Fe and Ichetucknee rivers also required setting MFLs to protect flows from the contributing springs. As noted in Section 2.0, minimal discharge data are available at most priority springs. The measurements are not only infrequent but also heavily weighted to the more recent time period. Therefore, available springs discharge data does not provide a good source for determining historical flow conditions at the priority springs for establishing MFLs. Consequently, the MFLs developed for the priority springs were determined by applying a uniform percent reduction to the springs, based on the median percent MFL reduction in the streamflows for the rivers. As a result priority spring MFLs are protective of the same WRV metrics used to establish river MFLs, and to the same degree.

This approach will protect the priority springs by ensuring that any individual priority spring contributing to flow in either river will continue to provide the same proportional flow contribution under the MFL regime as it did under baseline conditions. Protecting the MFL streamflows measured at the two river gages will also protect cumulative flow for all springs that contribute to the rivers under the MFL Regime. The allowable reductions in priority springflows are provided in Table 6-5. A summary of the proportional change analysis conducted to implement this approach is provided below.

Table 6-5. Allowable percent change in baseline for priority springs on the Santa Fe and Ichetucknee rivers

Spring	Allowable Reduction
Santa Fe Rise	8%
ALA112971 (Treehouse)	
Hornsby	
Columbia	
Poe	
COL101974	
Rum Island	
July	
Devil's Ear (Ginnie Group)	
Siphon Creek Rise	
Ichetucknee Head	3%
Blue Hole	
Mission	
Devil's Eye	
Grassy Hole	
Mill Pond	

The median flow values for the river gages were determined from the Baseline and MFL FDCs (Figure 6-7 and Figure 6-8). An allowable percent change for priority listed springs was developed, by river gage, based on the percent shift from the river Baseline flow to the river MFL flow at median conditions (i.e., at the 0.5 exceedance probability). For each spring, these flow reductions would be applied to a cumulative impact assessment from all uses.

The median baseline discharge for the period of record data for the Santa Fe River near Fort White gage is 1,320 cfs (Figure 6-7, Table 6-3). The median MFL discharge at this location is 1,214 cfs. The difference between these values expressed as a percent of the baseline discharge is the recommended cumulative allowable change of eight percent. The median baseline discharge for the period of record data for the Ichetucknee River at Highway 27 gage is 354 cfs (Figure 6-8, Table 6-4). The median MFL discharge at this location is 343 cfs. This represents a three percent change from baseline discharge. Use of these values ensures that the maximum change at any individual priority spring contributing to flow in either river will continue to provide the same proportional flow contribution under the MFL regime as it did under baseline conditions. Table 6-5 above summarizes this information.

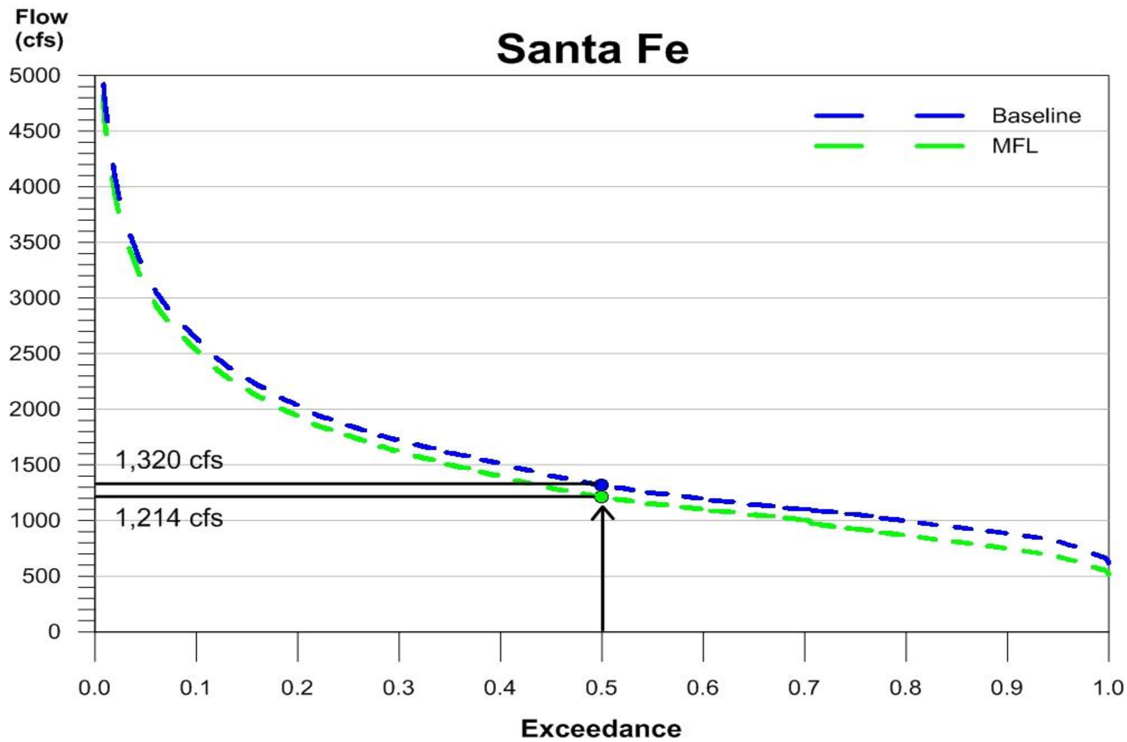


Figure 6-7. Baseline Period flow duration curves for the Santa Fe River near Fort White gage (USGS ID 02322500).

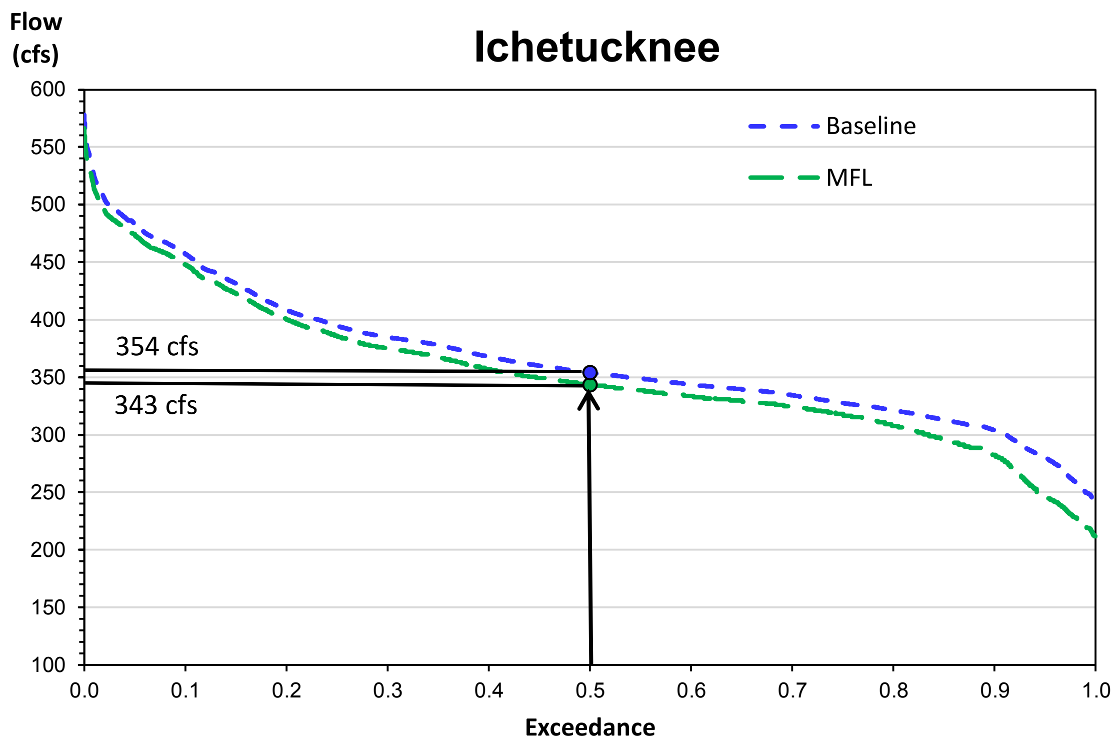


Figure 6-8. Baseline Period flow duration curves for the Ichetucknee River at Highway 27 gage (USGS ID 02322700).

6.6 CURRENT BASIN STATUS IN RELATION TO THE RECOMMENDED MFL

6.6.1 Determination of Impacts

There is considerable evidence of anthropogenic effects on the discharge of the Lower Santa Fe and Ichetucknee rivers (SRWMD, 2010). Subsequent to development of the recommended MFL flows, the magnitude of these effects was estimated and is described in this section.

Two types of methods were used to estimate the degree to which anthropogenic effects impacted stream and spring flow. A statistical model of streamflow and/or baseflow as a function of precipitation and other climatic variables is one possible method to estimate anthropogenic effects; another is the application of a groundwater model using appropriately specified boundary conditions and withdrawal stresses. Both methods were employed and are described in detail in Appendices 4-2 and 6-2. The results of the analyses provides a weight-of-evidence for impact during the post-baseline period of 1991-2010 (the analysis period) and were compared to the estimated available water resulting from the proposed MFL to arrive at an estimate of basin status.

ANNUAL LINEAR MODEL WITH EFFECTIVE PRECIPITATION

An annual linear model was developed that relates the current and previous year's effective rainfall to the average streamflow of the current year. Appendices 4-2 contains a complete discussion of the development of the annual linear model. The residuals of the annual linear model, as corrected for residual trends, were averaged over the analysis period to provide an estimate of the impact to the rivers. The resulting reduction in streamflow at Fort White was 130 cfs and on the Ichetucknee River it was 6 cfs.

MONTHLY MULTIPLE LINEAR REGRESSION (MLR) WITH BASEFLOW

A MLR model was developed for monthly rainfall and baseflow for the baseline period. The baseflow model was developed to isolate the estimated impacts due to groundwater pumping. The MLR used is based on the model described in Appendix 2-1 with three changes; the changes are documented in Appendix 6-2. The residuals of the annual linear model, as corrected for residual trends, were averaged over the analysis period to provide an estimate of the impact to the rivers. The resulting reduction in streamflow at Fort White was 129 cfs and on the Ichetucknee River it was 24 cfs.

GROUNDWATER MODELING

Groundwater modeling simulations using the North Florida Model (NFM) (Schneider, Upchurch, Chen, & Cain, 2008) version 1.03 were run to help assess the reasonableness of flow reduction estimates from the statistical models. District staff completed two runs with the NFM. The first run was a simple "pumps off" simulation with no other changes to the calibrated model. With the pumps turned off, the simulated groundwater discharge to the Santa Fe River upstream from the Fort White gage increased by approximately 77 cfs, and the groundwater discharge to the Ichetucknee River upstream from the Highway 27 gage increased by approximately 19 cfs.

The second simulation was identical to the first, except the groundwater levels provided as input to the General Head boundary condition were adjusted in an effort to better represent the historic changes that occurred to groundwater levels along the lateral boundaries of the model. The simulated increase in groundwater discharge to the Santa Fe River upstream from the Fort White gage in this second simulation was approximately 204 cfs, and the groundwater discharge to the Ichetucknee River upstream from the Highway 27 gage increased by approximately 33 cfs.

SUMMARY OF ESTIMATED IMPACT

Due to the uncertainty associated with determining the amount of anthropogenic effects on the rivers the average of the four estimates described above was used to determine the current level of flow reductions in a weight-or-evidence approach. Table 6-6 summarizes the range of results and the average, which is used as the best current estimate of the effects.

Table 6-6. Summary of estimated anthropogenic effects to streamflow on the Lower Santa Fe and Ichetucknee rivers.

Model/Method	Santa Fe River	Ichetucknee River
Annual Linear - Corrected	130	6
24 Month Linear - Corrected	129	24
NFM v.1 (PreDev Boundary)	204	33
NFM v.1 (Current Boundary)	77	19
AVERAGE	135	21

Chapter 373.0421(2), F.S., provides direction in the event the existing flow in a water body is below, or is projected to fall below the applicable minimum flow within 20 years. An analysis of the current condition of the Lower Santa Fe and Ichetucknee rivers based on the proposed MFLs follows.

To determine the current condition of the Lower Santa Fe and Ichetucknee rivers with respect to recommended MFLs an estimate of the available water was calculated. The available water was determined from the difference in the 10-year annual low flow for the Baseline and MFL from 1933-1990 (Figure 6-9 and Figure 6-10). To facilitate this analysis, the Baseline and MFL flow regimes were each aggregated into annual means. This analysis resulted in 118 cfs of available water at Fort White and 18 cfs of available water on the Ichetucknee River.

The available water for each system was compared to the average of the estimated reductions in flow not related to rainfall (Table 6-7). The Lower Santa Fe River has an estimated flow deficit of 17 cfs in 2010. Thus the MFLs being proposed for the Lower Santa Fe River are currently not being met. The Ichetucknee River has an estimated flow deficit of 3 cfs in 2010. Therefore, the District has determined that both rivers are in recovery. Consistent with Section 373.0421, F.S., these circumstances necessitate the development of a Recovery Strategy for these rivers and their associated springs.

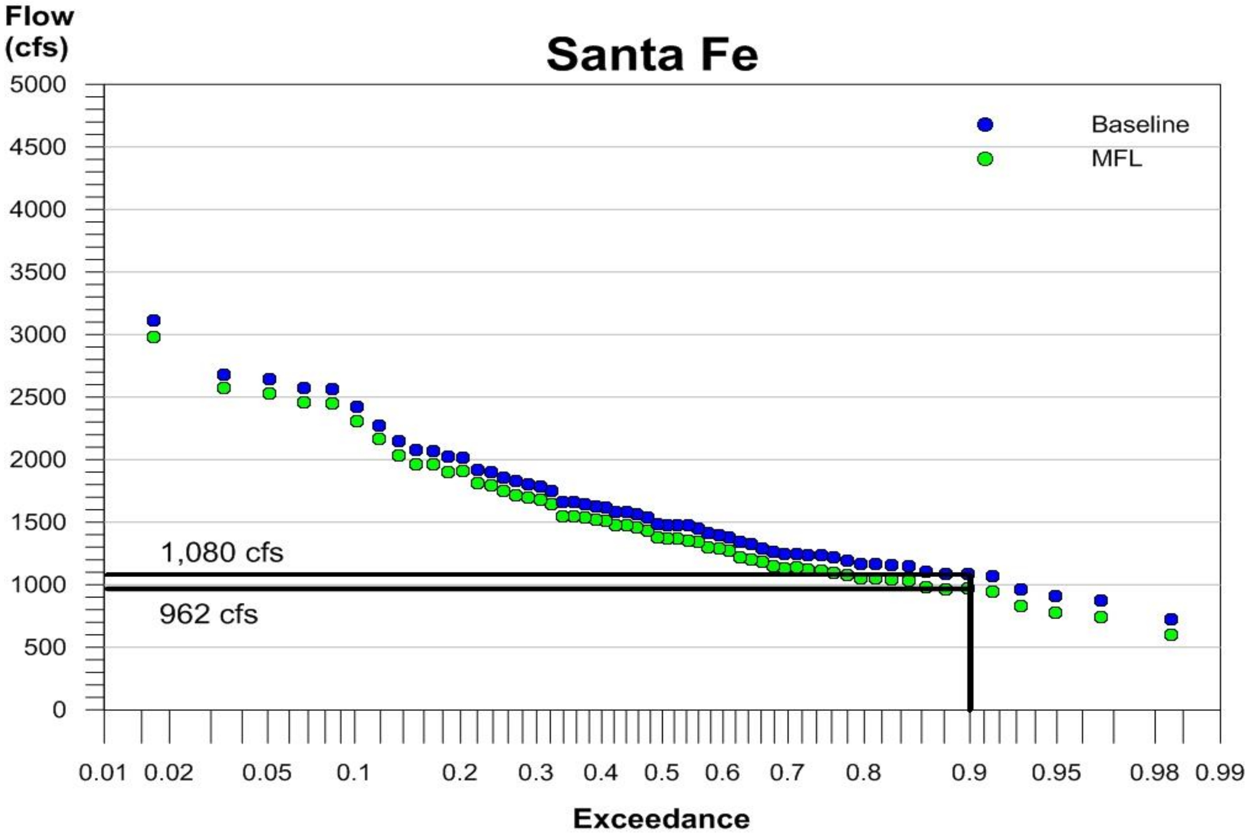


Figure 6-9. Mean annual flow exceedance for the Santa Fe River near Fort White gage.
Note: 10-Year annual low flow was used to calculate available water.

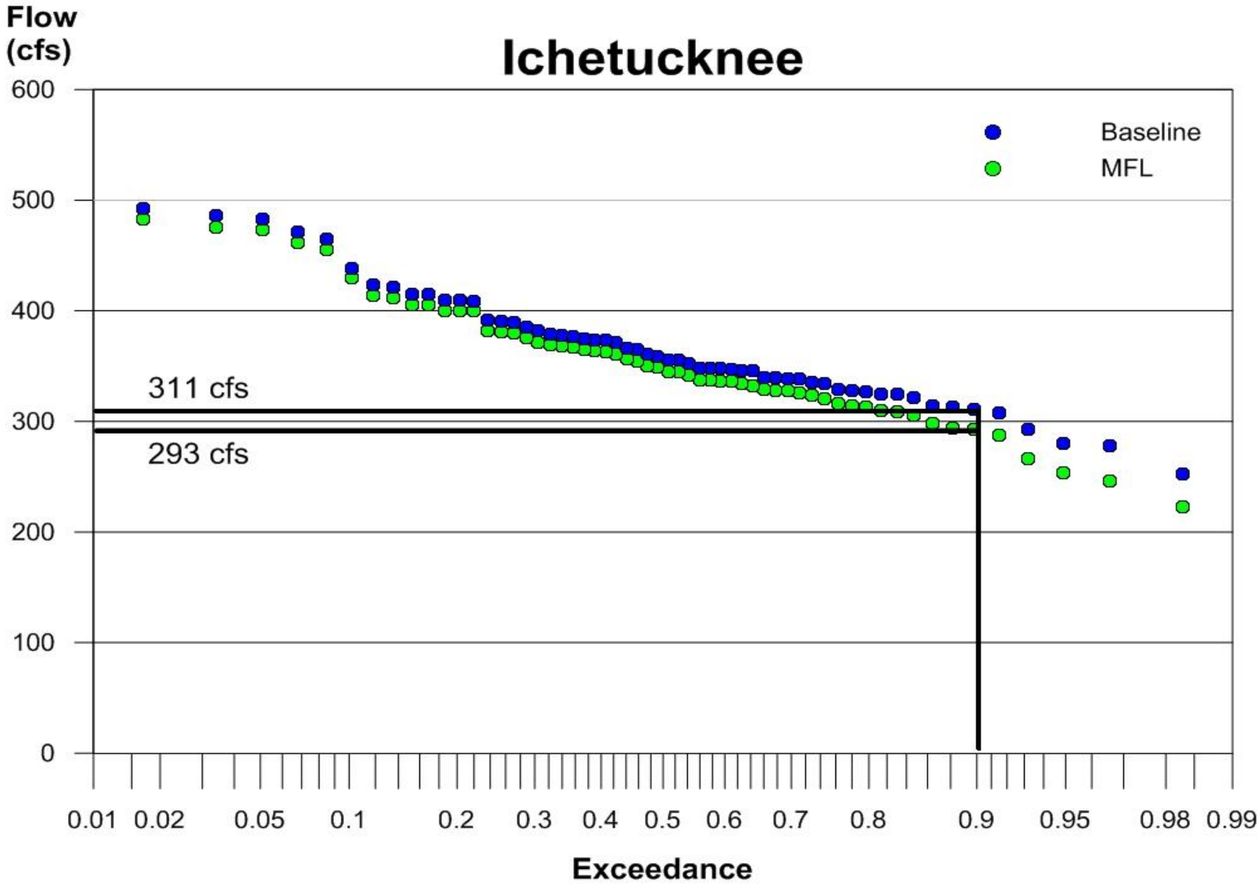


Figure 6-10. Mean annual flow exceedance for the Ichetucknee River at Highway 27 gage.
Note: 10-Year annual low flow was used to calculate available water.

Table 6-7. Summary of estimated anthropgenic effects to streamflow on the Lower Santa Fe and Ichetucknee rivers.

	Santa Fe River (cfs)	Santa Fe River (MGD)	Ichetucknee River (cfs)	Ichetucknee River (MGD)
Available Water	118	76	18	12
Estimated Non-Rainfall Related Reduction in Discharge	135	87	21	14
Recovery	17	11	3	2

7.0 GLOSSARY AND ACRONYMS

7.1 ACRONYMS

AMO – Atlantic Multidecadal Oscillation

ANN – Artificial Neural Network

BMAP – Basin Management Action Plans

CFS – Cubic Feet per Second

DEM – Digital Elevation Model

DCIA – Directly Connected Impervious Area

DO – Dissolved Oxygen

ET – Evapotranspiration

F.A.C. – Florida Administrative Code

FAS – Floridan Aquifer System

FDC – Flow Duration Curve

F.S. – Florida Statutes

HEC-RAS – Hydraulic Engineering Center-River Analysis System

HIS – Habitat Suitability Indices

IAS – Intermediate Aquifer System

ICU – Intermediate Confining Unit

IFIM – Instream Flow Incremental Methodology

LiDAR – Light Detection and Ranging

LOESS – Locally Weighted Scatterplot smoothing

MFL – Minimum Flows & Levels

MGD – Million Gallons Day

MK – Mann-Kendall

MLR – Multiple Linear Regression

NFRWSP – North Florida Regional Water Supply Partnership

NOAA – National Oceanic and Atmospheric Administration

NWIS – National Water Information System

OFW – Outstanding Florida Water

PHABSIM – Physical Habitat Simulation

RHABSIM – Riverine Habitat Simulation

RM – River Mile

SAS – Surficial Aquifer System

SAV – Submerged Aquatic Vegetation

SCI – Stream Condition Index

TMDL – Total Maximum Daily Load

UFA – Upper Floridan Aquifer

USGS – United States Geologic Survey

WRCA – Water Resource Caution Areas

WRV – Water Resource Values

WSPR – Water Supply Planning Region

WS – Water Surface

WY – Water Year

WUA – Weighted Useable Area

7.2 GLOSSARY

Atlantic Multidecadal Oscillation (AMO) – A natural multidecadal cyclic variation in large-scale atmospheric flow and ocean currents in the North Atlantic Ocean that combine to alternately increase and decrease Atlantic sea surface temperatures. The cool and warm phases last for 25-45 years at a time, with a difference of about 1°F (0.6°C) between extremes.

Anadromous fishes – a species of fish that migrate from salt water to spawn in fresh water.

Artificial Neural Network (ANN) – a mathematical computer model consisting of an interconnected group of artificial neurons. Neural networks are used for modeling complex relationships between inputs and outputs or to find patterns in data.

Backwater – water backed up in its course by an obstruction, an opposing current, or the tide.

Baseflow – Is flow in a channel sustained by ground-water discharge in the absence of direct runoff.

Baseline Flow – estimate of flow that would have been measured at a gage had anthropogenic impacts not been present in the observed flow

Benthos – Organisms that live on or in the channel bottom.

Block bootstrap – statistical method used for determining range of trends in data by randomly removing portions of the data and rerunning trend analyses repeatedly removing portions of the data

Basin Management Action Plans (BMAP) – a comprehensive set of strategies for restoring impaired waters by reducing pollutant loadings to meet the allowable loadings established in a Total Maximum Daily Load (TMDL).

Critical flow – flow required to meet a MFL metric

Delphi method – Structured communication and decision making technique using a panel of experts.

Digital Elevation Model (DEM) – an array of numbers representing spatial distribution of elevations for a specific area, in digital form.

Detritus – Dead organic matter and the decomposers that live on it; when broken up by decomposers, detritus provides energy to many coastal ecosystems.

Directly Connected Impervious Area (DCIA) – impervious area that drains directly into a drainage system.

Dissolved Oxygen (DO) – The amount of free (not chemically combined) oxygen in water, which is an indication of the degree of health of a waterbody and its ability to support a balanced aquatic ecosystem.

Epiphytic – a plant that grows above the ground, supported nonparasitically by another plant or object, and deriving its nutrients and water from rain, the air, dust, etc.

Estavelle – A spring that reverses flow because of relative changes in the elevation of groundwater levels and stream stage

Eutrophication – Generally, the natural or man-induced process by which a body of water becomes enriched in dissolved mineral nutrients (particularly phosphorus and nitrogen) that stimulate the growth of aquatic plants and enhances organic production of the water body. Excessive enrichment may result in the depletion of dissolved oxygen and eventually to species mortality.

Evapotranspiration (ET) – the combined process of evaporation and transpiration through vegetation.

Exceedance (Exceedance Probability) – That probability of at least a minimal expectation being met, often measured in terms of annual probability of occurrence.

Flow Duration Curves (FDC) – Plot of magnitude versus percent of time the magnitude is equaled or exceeded.

Fluvial Geomorphology – Study of the shape of streams to understand how they interact with the land around them.

Hydraulic Engineering Center – River Analysis System (HEC-RAS) – It is a water-surface profile model for river simulation. In this report it is utilized to evaluate steady, one-dimensional, gradually varied flow.

Habitat Suitability Indices (HSI) – Set of data that provides information about organism's predisposition for certain water depth, velocities and substrate.

Hydric Soils – Any one of a class of soils usually formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part that favor the growth and regeneration of hydrophytic vegetation.

Intermediate Aquifer System (IAS)/Intermediate Confining Unit (ICU) – An area composed of Hawthorn Group sediments that underlies the Surficial Aquifer System (SAS) and limits the exchange of groundwater between the SAS and Upper Floridan Aquifer (UFA).

Instream Flow Incremental Methodology (IFIM) – Analysis that incorporates fish habitat, recreational opportunity, and woody vegetation response to alternative water management schemes. Information is presented as a time series of flow and habitat at selected points within a river system for various existing and proposed water system operation alternatives.

Impacted Flow – Flow that would be expected to have occurred through period of observed data had current level of impact been present during the entire period of record.

Karst – an area of limestone terrain characterized by sinks, ravines, and underground streams.

LiDAR (Light Detection and Ranging) – Method of spatial elevation data collection.

Locally Weighted Scatterplot smoothing (LOESS) – a method for fitting a function to a scatterplot to find the central tendency of a set of data.

MFL Priority List – A list of water bodies in which MFLs will be developed and a schedule to complete the MFLs.

Mann-Kendall (MK) – statistical test used to determine if a trend in data is significant.

Multiple Linear Regression (MLR) – The extension of simple linear regression (SLR) to the case of multiple explanatory variables.

Observed Flow – Flow measured or simulated through statistical techniques at the gages.

Physical Habitat Simulation (PHABSIM) – 1. A specific model designed to calculate an index to the amount of microhabitat available for different faunal life stages at different flow levels. PHABSIM has two major analytical components: stream hydraulics and life stage-specific habitat requirements. 2. This extensive set of programs is designed to predict the micro-habitat (depth, velocities, and channel indices) conditions in rivers as a function of streamflow, and the relative suitability of those conditions to aquatic life.

Potentiometric Surface – Level to which water would rise in a well for an unconfined aquifer or the level of the water surface in an unconfined aquifer.

Resurgence – re-emergence of groundwater through a karst feature, a part or all of whose waters are derived from surface inflow into ponors at higher levels

Riverine Habitat Simulation (RHABSIM) – See definition for PHABSIM; the major difference being that the hydraulic model utilizes the results from an external model whereas the hydraulics are calibrated in the PHABSIM model.

Riparian vegetation – Vegetation that is dependent upon an excess of moisture during a portion of the growing season on a site that is perceptively moister than the surrounding areas.

Riparian Zone – The transitional zone or area between a body of water and the adjacent upland identified by soil characteristics and distinctive vegetation that requires an excess of water. It includes wetlands and those portions of floodplains that support riparian vegetation.

River Mile (RM) – Distance in miles measured from downstream to upstream from the terminus of the river to the start of the river.

Sink – A landform created by subsidence of soil, sediment, or rock as underlying strata are dissolved by ground water.

Sinking stream – A creek, stream or river that does not connect to another creek stream or river at the terminus of the creek but instead terminates at a sink.

Siphon – 1. In speleology, a cave passage in which the ceiling dips below a water surface. 2. A flooded cave passage. A gallery (conduit) in the form of a “U” with water moving only under pressure when the siphon is completely filled. 3. Site and origin of an intermittent spring; section of a flooded cave or sump flooded passage.

Spring Magnitude – A category based on the volume of flow from a spring per unit time.

Magnitude	English Units
1	≥ 100 cfs (≥ 64.6 mgd)
2	≥ 10 to100 cfs (≥ 6.46 to 64.6 mgd)
3	≥ 1 to 10 cfs (≥ 0.646 to 6.46 mgd)
4	≥ 100 gpm to 1 cfs (≥ 100 to 448gpm)
5	≥ 10 to 100 gpm
6	≥ 1 to 10 gpm
7	≥ 1 pint/min to 1 gpm
8	< 1 pint/min

Swallet – A place where water disappears underground in a limestone region. A swallow hole generally implies water loss in a closed depression or blind valley, whereas a swallet may refer to water loss into alluvium at a streambed, even though there is no depression.

Tailwater – reference to condition of water elevations downstream that may affect flow and elevations of water surfaces upstream

Thalweg – the lowest elevation in a cross section perpendicular to flow of a river channel

Water Year (WY) – The USGS defined water year is from October 1 of previous year and ends on September 30 of current year. A water year is referenced to the year the data collection ends. For example water WY 2010 ranges from October 1, 2009 – September 30, 2010.

Weighted Useable Area (WUA) – A component of PHABSIM which is an indicator of the net suitability of use of a given stream reach by a certain life stage of a certain species.

Woody habitats – Any of the various living (e.g., exposed roots) or dead/decaying (e.g., snags) substrata composed of wood, usually originating from riparian vegetation that serve as habitation for various instream biota.

8.0 WORKS CITED

Ackerman, B. B., Wright, R. K., Bonde, R. K., Odell, D. K., & Banowetz, D. J. (1995). Trends and Patterns in Mortality of Manatees in Florida, 1974-1991. 223-258.

Ainsle, W. B., Pruitt, B. A., Smith, R. D., Roberts, T. H., Sparks, E. J., & Miller, M. (1999). *A Regional Guidebook for Assessing the Functions of Low Gradient Riverine Wetlands in Western Kentucky. Technical Report WRP-DE-17.* U.S. Army COE Waterways Experiment Station.

Allan, J. D. (1995). *Stream Ecology: Structure and Function of Running Waters.* Dordrecht, The Netherlands: Kluwer Academic Publishers.

AMEC. (2012). *Fluvial Geomorphic Investigation of the Upper Santa Fe River, Lower Santa Fe River and Ichetucknee River. Prepared for the Suwannee River Water Management District.*

Anderson, J. R., Hardy, E. E., Roach, J. T., & Witmer, R. E. (1976). *A Land Use and Land Cover Classification System for Use with Remote Sensor Data.* U.S. Geologic Survey. Professional Paper 964.

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.

Bales, J. D. (1996). *Streamflow Characteristics of the Waccamaw River at Freeland, North Carolina, 1940-1994.* U.S. Geological Survey Water-Resources Investigations Report 96-4093.

Beecher, H. (1990). Standards for Instream Flows. Rivers. 1:97-109.

Benke, A. C. (1990). A Perspective on America's Vanishing Stream. *Journal of the North American Benthological Society*, 15:77-88.

Benke, A. C., & Wallace, J. B. (1990). Wood Dynamics in Coastal Plain Blackwater Streams. *Canadian Journal of Fisheries and Aquatic Sciences*, 47:92-99.

Benke, A. C., & Wallace, J. B. (2011). Wood Dynamics in Coastal Plain Blackwater Streams. *Canadian Journal of Fisheries and Aquatic Sciences*, 47:92-99.

Benke, A. C., Van Arsdall, Jr., T. C., Gillespie, D. M., & Parrish, F. K. (1984). Invertebrate Productivity in a Subtropical Blackwater River: The Importance of Habitat and Life History. *Monographs*, pp. 54:25-63.

Birsan, M. V., Molnar, P., Burlando, P., & Pfaundler, M. (2005). Streamflow Trends in Switzerland. *Journal of Hydrology*, 314:312-329.

Blalock-Herod, H. N. (2000). *Community Ecology of Three Freshwater Mussel Species (Bivalvia: Unionidae) from the New River, Suwannee Drainage, Florida.* University of Florida. Gainesville, FL: Unpublished Master's Thesis.

Bovee, K. D., Lamb, B. L., Bartholow, J. M., Stalnaker, C. B., Taylor, J., & Henriksen, J. (1998). Stream Habitat Analysis Using the Instream Flow Incremental Methodology: U.S. Geological Survey Information and Technology Report 1998-0004. 130.

Box, G. E., Hunter, W. G., & Hunter, J. S. (1977). *Statistics for Experimenters- An Introduction to Design, Data Analysis, and Model Building.* New York, Chichester, Brisbane, Toronto: John Wiley & Sons.

Brim, B. J., & Williams, J. D. (2000). *Unionid Mollusks of the Apalachicola Basin in Alabama, Florida, and Georgia.* Bulletin of the Alabama Museum of Natural History No. 22.

Brown, M., Reiss, K., Cohen, M., Evans, J., Inglett, P., Inglett, K., . . . McKee, K. (2008). *Summary and dynthesis of the available literature on the effects of nutrient on spring organisms and systemsq.* Gainesville, FL: University of Florida Water Institute. Retrieved from http://www.dep.state.fl.us/springs/reports/files/UF_SpringsNutrients_Report.pdf

Burgess, M. A. (2008). Quantification and Ecological Role of Snag Habitat in the Apalachicola River, Florida. A thesis presented to the Graduate School of the University of Florida in partial fulfillment of the requirements for the Degree of Master of Science. 98pp.

Butt, P. L., Morris, T. L., & Skiles, W. C. (2007). *Swallet/Resurgence Relationships on the Lower Santa Fe River, Florida.* Prepared for Water Resource Associates, Inc.

Carter, J. M., Driscoll, D. G., Williamson, J. E., & Lindquist, V. A. (2002). *Atlas of Water Resources in the Black Hills Area, South Dakota.* US Geological Survey and West Dakota Water Development District, Hydologic Investigations Atlas HA-747.

Ceryak, R., Knapp, M. S., & Burnson, T. (1983). *The Geology and Water Resources of the Upper Suwannee River Basin, Florida.* Florida Bureau of Geology. Report of Investigations No. 87.

Cichra, C. E., Dahm, C. N., & Shaw, D. T. (2005). A Review of "Alafia River Minimum Flows and Levels Freshwater Segment including Lithia and Buckhorn Springs", and "Proposed Minimum Flows and Levels for the Upper Segment of the Myakka River, from Myakka City to SR 72". 33 pp.

Coarsey, C. (2012a). Ichetucknee River Discharge Measurement Discussion with USGS. Interoffice Memorandum to John C. Good, Suwannee River Water Management District.

Coarsey, C. (2012b). "Re: Boat and Tuber Passage." Message to the Author. 24 May 2012. Email.

Cohen, M. J., Kurz, M. J., Heffernan, J. B., Martin, J. B., Douglass, R. L., Foster, C. R., & Thomas, R. G. (2013). Diel Phosphorus Variation and the Stoichiometry of Ecosystem Metabolism in a Large Spring Fed River. *Ecological Monograph*, pp. 155-176. Retrieved from http://dx.doi.org/10.1890/12-1497.1

Col, N. F., Enright, M., & Horvath, G. (1997). *Reappraisal of the Geology and Hydrogeology of Gilchrist County, Florida, with Emphasis on the Waccasassa Flats.* Tallahassee, FL: Florida Geological Survey, Report of Investigation No. 99.

Copeland, R. (2003). *Florida Spring Classification System and Spring Glossary.* Florida Geological Survey Special Publication No. 52.

Copeland, R., Doran, N. A., White, A. J., & Upchurch, S. B. (2009). *Regional and Statewide Trends in Florida's Spring and Well Groundwater Quality (1991-2003). Florida Geological Survey Bulletin No. 69.* Tallahassee, FL: Florida Department of Environmental Protection.

Crance, J. H. (1988). *Relationships Between Palustrine Forested Wetlands of Forested Riparian Floodplains and Fishery Resources: A Review.* Washington, D.C.: Biological Report 88(32) U.S. Fish and Wildlife Service.

Daly, C., Halbeleib, M., Smith, J. I., Gibson, W. P., Doggett, M. K., Taylor, G. H., . . . Pasteris, P. P. (2008). Physiographically Sensitive Mapping of Climatological Temperature and Precipitation Across the Conterminous United States. *International Journal of Climatology*.

De Montety, V., Martin, J. B., Cohen, M. J., Foster, C., & Kurz, M. J. (2011). Influence of diel biogeochemical cycles on carbonate equilibrium in a karst river. *Chemical Geology*(283), pp. 31-43.

Dunne, T., & Leopold, L. B. (1978). *Water in Environmental Planning.* San Francisco: W. H. Freeman. xxvii + 818.

Dutoit, C. H. (1979). *The Carrying Capacity of the Ichetucknee Springs and River. Master of Science Thesis.* University of Florida. Gainesville, FL.

Edwards, R. T., & Meyer, J. L. (1987). Metabolism of a subtropical low-gradient blackwater river. *Fresh Water Biology*, 251-263.

Evans III, W. L., Green, R. C., Bryan, J. R., & Paul, D. T. (2004). Geologic Map of the Western Portion of the U.S.G.S. 1:100,000 Scale Gainesville Quadrangle, Northern Florida. *Florida Geological Survey, Open File Map Series No. 93-01*.

Florida Department of Enironmental Protection. (2009). SRWMD 2006-2008 Land Use.

Florida Department of Environmental Protection. (2000). *Ichetucknee Springs State Park Approved Unit Management Plan.* Division of Recreation and Parks.

Florida Department of Environmental Protection. (2008). *Nutrient and Dissolved Oxygen TMDL for the Suwannee River, Santa Fe River, Manatee Springs (3422R), Fanning Springs (3422S), Branford Spring (3422J), Ruth Spring (3422L), Troy Spring (3422T), Royal Spring (3422U), and Falmouth Spring (3422Z)*. Retrieved from http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp1/suwanneebasinnutrienttmdl.pdf

Florida Department of Environmental Protection. (2011a). SRWMD 2010-2011 Land Use.

Florida Department of Environmental Protection. (2011b). *SCI 1000. Stream Condition Index Methods*. Retrieved June 19, 2013, from Florida Department of Environmental Protection: http://www.dep.state.fl.us/water/bioassess/docs/sci_1000.pdf

Florida Department of Environmental Protection. (2012). *Basin Management Action Plan for the Implementation of Total Daily Maximum Loads for Nutrients in the Santa Fe River Basin*. Retrieved from http://www.dep.state.fl.us/water/watersheds/docs/bmap/sfr-nutrient-bmap-final.pdf

Florida Department of Environmental Protection. (Undated). *FACT SHEET: Santa Fe Basin TMDLs.* Tallahassee, FL.

Florida Fish and Wildlife Conservation Commission. (2007). *Florida Manatee Management Plan (Trichechus Manatus Latirostris).* Tallahassee, FL.

Florida Fish and Wildlife Conservation Commission. (2011). *Freshwater Mussel (Bivalvia: Unionidae) Asemblages of the Santa Fe River near O'Leno State Park and Worthing Springs, Florida.* Gainesville, FL.

Florida Geological Survey. (2005). *Revisions to Florida Geological Survey Special Publication 52.* Florida Springs Nomenclature Committee.

Flowers, J. H., & Pine III, W. E. (2008). Observation of a Juvenile Gulf Sturgeon in the Santa Fe River, Florida. *Southeastern naturalist*, 559-561.

Frest, T. J., & Johannes, E. J. (1995). *Interior Columbia Basin Mollusk Species of Special Concern. Final Report.* Prepared for the Interior Columbia Basin Ecosystem Management Project, Walla Walla, WA. Contract #43-0E00-4-9112.

Gore, J. A., Layzer, J. B., & Mead, J. (2001). *Macroinvertebrate Instream Flow Studies After 20 Years: A Role in Stream Management and Restoration.* Regul. Rivers: Res. Mgmt. 17:527-542.

Graham, W. D., Clark, M. W., Cohen, M. J., Frazer, T. K., & Martin, J. B. (2013). *Peer Review of the Proposed Minimum Flows and Levels for the Lower Santa Fe and Ichetucknee Rivers and Associated Priority Springs.* Gainesville, FL: University of Florida Water Institute.

Grubbs, J. W. (2011). *Analysis of Long-Term Trends in Flow from a Large Spring Complex in Northern Florida. U.S. Geological Survey Karst Interest Group Proceedings.* Fayetteville, AK, April 26-29, 2011: Scientific Investigations Report 2011-5031. 160-167.

Gutierrez, A., Perrera, G., Yong, M., & Yong, L. (2001). *The Effects of Isolation on the Life History Traits of Pseudosuccinea Columella (Pulmonata: Lymnaeidae).* Mem. Inst. Oswaldo Cruz. 96:577-581.

Haubold, E. M., Deutsch, C., & Fonnesbeck, C. (2006). *Final Biological Status Review of the Florida Manatee (Trichechus Manatus Latirostris).* Retrieved from http://www.fwc.state.fl.us/docs/CommissionMeetings/2006/2006_Jun_ManateeBSwithAppendicesCompressed.pdf

Heath, R. C., & Conover, C. S. (1981). *Hydrologic Almanac of Florida.* U.S. Geological Survey Open File Report 81-1107.

Heffernan, J. B., & Cohen, M. J. (2010). Direct and indirect coupling of primary production and diel nitrate dynamics in a sub-tropical spring fed river. *Limnology and Oceanography*, pp. 677-688.

Heffernan, J. B., Albertin, A. R., Fork, M. L., Katz, B. G., & Cohen, M. J. (2012). Denitrification and inference of nitrogen sources in the karstic Floridan Aquifer. *Biogeosciences*, pp. 1671-1690.

Heffernan, J. B., Cohen, M. J., Frazer, T. K., Thomas, R. G., Rayfield, T. J., Gulley, J., . . . Graham, W. D. (2010). Hydrologic and biotic influences on nitrate removal in a subtropical spring-fed river. *Limnology and Oceanography*(55), pp. 249-263.

Heffernan, J. B., Liebowitz, D. M., Frazer, T. K., Evans, J. M., & Cohen, M. J. (2010). Algal blooms and the nitrogen-enrichment hypothesis in Florida springs: Evidence, alternatives and adaptive management. *Ecological Applications*, pp. 816-829.

Helsel, D. R., & Hirsch, R. M. (2002). Statistical Methods in Water Resources. Techniques of Water Resources Investigations, Book 4, Chapter A3. *U.S. Geological Survey*, 522 pages.

Hensley, R. T., & Cohen, M. J. (2012). Controls on solute transport in large spring-fed karst rivers. *Limnology and Oceanography*, pp. 912-924.

Hill, J. E., & Cichra, C. E. (2002). *Minimum Flows and Levels Criteria Development - Evaluation of the Importance of Water Depth and Frequency of Water Levels/Flows on Fish Population Dynamics: Literature Review/Summary and Annotated Bibliography for Water Level Effects on Fish Populations.* Prepared for St. Johns River Water Management District. Palatka, FL: Special Publication SJ2002-SP2.

Hill, M. T., Platts, W. S., & Beschta, R. L. (1991). Ecological and Geological Concepts for Instream and Out-of-Channel Flow Requirements. *Rivers 2:198-210*.

Hornsby, D., & Ceryak, R. (1998). *Springs of the Suwannee River Basin in Florida.* Suwannee River Water Management District, Live Oak, FL.

HSW Engineering. (2013a). *Lower Santa Fe and Ichetucknee River daily flow and rainfall analysis.* Technical Memorandum, Tampa, FL.

HSW Engineering. (2013b). *Lower Santa Fe and Ichetucknee River Analysis of Annual Flow and Rainfall.* Technical Memorandum, Tampa, FL.

Hunn, J. D., & Slack, L. J. (1983). *Water Resources of the Santa Fe River Basin, Florida.* Water-Resources Investigations Report: 83-4075.

Hupalo, R., Neubauer, C., Keenan, L., Clapp, D., & Lowe, E. (1994). *Establishment of Minimum Flows and Levels for the Wekiva River System.* Technical Publication SJ94-1, St. Johns River Water Management District, Palatka, FL.

Hydrologic Engineering Center. (2010). *HEC-RAS River Analysis System, User's Manual.* U.S. Army Corps of Engineers, Davis, CA.

Hynes, H. (1970). *The Ecology of Running Waters.* Caldwell, NJ: The Blackburn Press.

Instream Flow Council. (2008). Integrated Approaches to Riverine Resource Stewardship: Case Studies, Science, Law, People and Policy. 411pp.

INTERA. (2007). *HEC-RAS Models of the Santa Fe and Ichetucknee Rivers.* Live Oak, FL: Prepared for the Suwannee River Water Management District.

INTERA. (2012a). *Hydrologic Database, Statistical Analysis, and Adjusted Historical Flow Development of Select Surface Water Stations on the Lower Santa Fe and Ichetucknee Rivers.* Prepared for the Suwannee River Water Management District, Live Oak, FL.

INTERA. (2012b). *HEC-RAS Model Development and Calibration of the Lower Santa Fe and Ichetucknee Rivers.* Prepared for the Suwannee River Water Management District, Live Oak, FL.

ISSP. (2012). *Location of SAV transects on the Ichetucknee River.* Shapefile.

Jacobs, J. M., & Ripo, G. (2001). *Minimum Flows and Levels for the Lower Suwannee River - Implementation and Methodology.* Gainesvilee: University of Florida.

Johnson, P. M., Liner, A. E., Golladay, S. W., & Michener, W. K. (2001). *Effects of Drought on Freshwater Mussels and Instream Habitat in Coastal Plain Tributaries of the Flint River, Southwest Georgia (July-October, 2000). .* Final Report.

Jones Edmunds and Associates. (2012). *Draft Minimum Flows Literature Comparison.* Gainesville: SWFWMD.

Jones Edmunds and Associates, Inc. (2002). *Ichetucknee Springs State Park South Access Point Take-out Dock.* Construction Documents Submittal. Prepared for the Department of Environmental Protection. Office of Parks and Recreation.

Junk, W. P., Bayley, P. B., & Sparks, R. E. (1989). The Flood Pulse Concept in River Floodplain Systems. (D. P. Dodge, Ed.) *Special Publication of the Canadian Journal of Fisheries and Aquatic Sciences 106*, 110-127.

Kahya, E., & Kalayci, S. (2004). Trend Analysis of Streamflow in Turkey. *Journal of Hydrology*, 289:128-144.

Katz, B. G., Hornsby, H. D., Bohlke, J. F., & Mokray, M. F. (1999). *Sources and Chronology of Nitrate Contamination in Spring Water, Suwanne River Basin, Florida.* Reston, VA: U.S. Geological Survey Water Resources Investigations Report 99-4252.

KBN Engineering and Applied Sciences, Applied Technology and Management, Burgess, G., & E&S Environmental Chemistry. (1990). *Steinhatchee River Basin Management Plan.* Gainesville, FL.

Kelly, M. (2004). *Florida River Flow Patterns and the Atlantic Multidecadal Oscillation.* Draft Report. Ecologic Evaluation Section, Southwest Florida Water Management District, Brooksville, FL. 80pp.

Kelly, M. H., Munson, A. B., Morales, J., & Leeper, D. L. (2005). *Proposed Minimum Flows for the Middle Segment of the Peace River from Zolfo Springs to Arcadia.* Ecologic Evaluation Section. Southwest Florida Water Management District. Brooksville, FL. 165pp + appendix.

King, S. A. (2012). *Effects of flow on filamentous algae and nutrient limition in systems.* Gainesville: University of Florida.

Kurz, R. C., Woithe, C. D., Notestein, S. K., Frazer, T. K., Hale, J. A., & Keller, S. R. (2004). *Mapping and Monitoring Submerged Aquatic Vegetation in Ichetucknee Springs.* Contract 02/03-180.

Lawrence, F. W., & Upchurch, S. B. (1982). Identification of recharge areas using geochemical factor analysis. *Ground Water*, 680--687.

Light, H. M., Darst, M. R., & Grubbs, J. W. (1998). Acquatic Habitats in Relation to River Flow in the Apalachicola River. U.S. Geological Survey Professional Paper 1594. *U.S. Department of Interior, U.S. Geological Survey. Woods and F.E. Sergi (eds) Biogeography of the West Indies: Patterns and Perspectives, 2nd ed. CRW Press, Boca Raton, FL. 425-474*.

Light, H. M., Lewis, L. J., Darst, M. R., & Howell, D. A. (2002). *Hydrology, Vegetation and Soils of Riverine and Tidal Floodplain Forests of the Lower Suwannee River, Florida, and Potential Impacts of Flow Reductions.* U.S. Geological Survey Professional Paper 1656A .

Marella, K. (2013). *Water-Use Data Tables, 2010.* Retrieved from Florida Water Science Center: http://fl.water.usgs.gov/infodata/wateruse/datatables2010.html

Marmontel, M., Humphrey, S. R., & O'Shea, T. J. (1997). Population Viability Analysis of the Florida Manatee (Trichechus Manatus Latrirostris). 1976-1991. *Conservation Biology, 11:467-481*.

Martin, J. B., & Dean, R. W. (1999). *Temperature as a natural Tracer of short residence times for ground water in karst aquifers. In: Palmer, A.N. Palmer, M.V., Sasowsky, I.D. (Eds.), Karst Modeling.* Karst Waters Institute Special Publication #5.

Martin, J. B., & Dean, R. W. (2001). Exchange of water between conduits and matrix in the Floridan Aquifer. *Chemical Geology*, 145-165.

Master, L. L., Flack, S. R., & Stein, B. A. (1998). Rivers of Life. *The Nature Conservancy, in Cooperation with Natural Heritage Programs and the Association for Biodiversity Information Critical Watersheds for Protecting Freshwater Biodiversity*.

McLaughlin, D. L., Kaplan, D. R., & Cohen, M. J. (2013). Managing forests for increased regional water yield. *Journal of the American Water Resources Association*, pp. 953-965.

Meinzer, O. E. (1927). Large Springs in the United States: U.S. Geological Survey Water Supply Paper 557. 94pp.

Mitsch, W. J., & Gosselink, J. G. (1986). Wetlands.

Noss, R. F., LaRoe, E. T., & Scott, J. M. (1995). Endangered Ecosystems of the United States: A Preliminary Assessment of Loss and Degradation. *28*.

O'Brien, C. A., & Williams, J. D. (2002). Reproductive Biology of Four Freshwater Mussels (Bivalvai:Uniondae) Endemic to the Eastern Gulf Coastal Plain Drainages of Alabama, Florida, and Georgia. *American Malacological Bulletin*, 17:14-158.

Opdyke, N. D., Spangler, D. P., Smith, D. L., Jones, D. S., & Lindquist, R. C. (1984). Origin of the epeirogenic uplift of Pliocene-Pleistocene beach ridges in Florida and development of the Florida karst. *Geology*, 12:226-228.

Payne, T. R. (1998). *User's Manual, RHABSIM 2.0 TRPA.* Arcata, CA.

Perry, R. (1995). *Regional Assessment of Land Use Loading to Unconfined Aquifers. A Dissertation Submitted to the Department of Civil and Environmental Engineering.* University of South Florida.

Pescador, M. L., Rasmussen, A. K., & Harris, S. C. (1995). *Identification Manual for the Caddisfly (Trichoptera) Larvae of Florida, Final Report for DEP Contract Numbers WM543 and WM581.*

Pittman, J. R., Hatzell, H. H., & Oaksford, E. T. (1997). *Spring Contributions to Water Quality and Nitrate Loads in the Suwannee River During Baseflow in July 1995.* Reston, VA: U.S. Geological Survey Water Resources Investigation Report 97-4152.

Poff, L. N., Allan, J. D., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., . . . Stombert, J. C. (1997). The Natural FLow Regime: A Paradigm for River Conservation and Restoration. *BioScience*, 47:769-784.

Poff, N. L., & Allen, J. D. (1995). Functionsl Organization of Stream Fish Assemblages in Relation to Hydolofical Variability. *Ecology 76(2)*, 606-627.

Poff, N. L., & Ward, J. V. (1988). Implications of Streamflow Vaiability and Predictability fir Lotic Community Structure: A Regional Analysis of Streamflow Patterns. *Can. J. Fish and Aquat. Sci*, 46:1805-1818.

Postel, S., & Richter, B. (2003). *Rivers for Life: Managing Water for People and Nature.* Washington, D.C.: Island Press.

Puri, H. S., & Vernon, R. O. (1964). Summary of the Geology of Florida and a Guidebook to the Classic Exposures. *Florida Geological Survey, Special Publication No. 5, Tallahassee, FL*.

Rau, E. (2012). (C. Coarsey, Interviewer)

Richter, B. D., Baumgartner, J. V., Powell, J., & Braun, D. P. (1996). A Method for Assessing Hydrologic Alteration within Ecosystems. *Conservation Biology*, 10:1163-1174.

Rosgen, D. (1996). Applied River Morphology. *Wildland Hydrology*.

Rupert, F. R. (1988). The Geology and Geomorphology of Gilchrist County, Florida. *Florida Geological Survey, Open File Report 18*.

Schlosser, I. J. (1991). Stream Fish Ecology: A Landscape Perspective. *BioScience*, 41:704-712.

Schneider, J. W., Upchurch, S., Chen, J., & Cain, C. (2008). *Simulation of Groundwater Flow in North Florida and South-central Georgia. Prepared for the Suwannee River Water Management District.*

Scott, T. M. (1988). The Lithostratigraphy of the Hawthorn Group (Miocene) of Florida. *Florida Geological Survey, Bulletin No. 59*.

Scott, T. M. (1992). *A Geological Overview of Florida, Open File Report No. 50 Florida Geological Survey Bulletin.*

Scott, T. M. (2001). Text to Accompany the Geologic Map of Florida. *Florida Geological Survey, Open-File Report 80*.

Scott, T. M., Campbell, K. M., Rupert, F. R., Arthur, J. D., Missimer, T. M., Lloyd, J. M., . . . Duncan, J. G. (2001). Geologic Map of the State of Florida. *Florida Geological Survey in Cooperation with the Florida Department of Environmental Protection, Map Series 146*.

Searcy, J. K. (1959). *Flow Duration Curves. Manual of Hydrology: Part 2. Low-Flow Techniques.* Geological Survey Water Supply Paper 1542-A (1963 Reprint).

Shaw, D. T., Dahm, C. N., & Golladay, S. W. (2005). *A Review of "Proposed Minimum Flows and Levels for the Middle Segment of the Peace River from Zolfo Springs to Arcadia".* A Report Prepared for Southwest Florida Water Management District, June 2005, 23pp.

Shelton, D. N. (2005). *The Rare and Endemic Snails of Selected Springs within the St. Johns River Water Management District.* Prepared for the St. Johns River Water Management District. Special Publication SJ2006-SP17.

Southwest Florida Water Management District. (2004). *Alafia River Minimum Flows and Levels Freshwater Segment Including Lithia and Buckhorn Springs.* Ecologic Evaluation Section, Brooksville, FL.

Southwest Florida Water Management District. (2005). *Proposed Minimum Flows and Levels for the Upper Segment of the Myakka River from Myakka City to SR 72.* Ecologic Evaluation Section, Resource Conservation and Development Department, Brooksville, FL.

Southwest Florida Water Management District. (2008). *Weeki Wachee River recommended minimum flows and levels.* Brooksville, FL.

Southwest Florida Water Mangement District. (2002). *Upper Peace River: An Analysis of Minimum Flows and Levels.* Brooksville, FL: Resource Conservation and Development Department, Ecologic Evaluation Section.

St. Johns River Water Management District. (2007a). *Technical Publication SJ2007-1 Minimum Flows and Levels Determination: St. Johns River at State Road 50, Orange and Brevard Counties, Florida .* Palatka, FL.

St. Johns River Water Management District. (2012). *Evaluation of the Effects of Hypothetical Flow Reductions on Water Resource Values of Silver Springs and the Silver River, Marion County.* 2012.

Stalnaker, C. B. (1990). *Minimum Flow is a Myth. In M.B. Bain (ed.), Ecology and Assessment of Warmwater Streams: Workshop Synopsis.* Biological Report 90(5), U.S. Fish and Wildlife Service, Washington, DC.

Stevenson, J. A., Pinowska, A., & Wang, Y.-K. (2004). *Ecological Condition of Algae and Nutrients in Florida Springs.* Florida Department of Environmental Protection, Tallahassee, FL.

Suwannee River Water Management District. (1990). Land Cover 1988.

Suwannee River Water Management District. (1998). *Suwannee River Water Management District's 1994-95 Land Use and Cover Manual including a Lineage Report.* Live Oak, FL.

Suwannee River Water Management District. (2007). *Technical Report - MFL Establishment for the Upper Santa Fe River.* Live Oak, FL.

Suwannee River Water Management District. (2010). *Water Supply Assessment 2010.* Live Oak, FL.

Tao, H., Gemmer, M., Su, B., Mao, W., & Bai, Y. (2011). Trends of Streamflow in the Tarim River Basin During the Past 50 Years: Human Impact or Climate Change? *Journal of Hydrology, 400:1-9*.

Taylor, C. R. (2006). *A Survey of Florida Springs to Determine Accessibility to Florida Manatees (Trichechus Manatus Latirostris): Developing a Sustainable Thermal Network.* Final Report. Submitted to the U.S. Marine Mammal Commission.

Thomas R. Payne & Associates. (1994). RHABSIM 2.0 for DOS and Windows. Arcata, CA.

Thompson, F. G. (1968). The Aquatic Snails of the Family Hydrobiidae of Peninsular Florida.

Thompson, F. G. (2004). *An Identification Manual for the Freshwater Snails of Florida.* Gainesville, FL: Florida Museum of Natural History at the University of Florida.

Thompson, F. G. (2008). Personal Interview. (S. Grabe, Interviewer)

Thorp, J. H., McEwan, E. M., Flynn, M. F., & Hauer, F. R. (1990). Invertebrate Colonization of Submerged Wood in a Cypress-tupelo Swamp and Blackwater Stream. *American Midland Naturalist, 113:56-68*.

United States Fish and Wildlife Service. (1992). *Endangered and Threatened Wildlife and Plants: Determination of Endangered Status for Five Aquatic Snails in South Central Idaho.* Federal Register 59244-59257.

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. *Karst Water Institute. Special Publication 7*.

Upchurch, S. B. (2007). *An Introduction to the Cody Escarpment, North-Central Florida.* Suwannee River Water Management District, Live Oak, FL.

Upchurch, S. B., Chen, J., & Cain, C. (2008). *Trends of Nitrate Concentrations in Waters of the Suwannee River Water Management District.* Contract Report Prepared by SDII Global Corporation, Tampa, FL.

US Army Corps of Engineers. (2010). *HEC-RAS River Analysis System.* Institute for Water Resources, Hydrologic Engineering Center.

USGS. (1998). *Ground Water and Surface Water A Single Resource.* Circular 1139, Denver.

Vogel, R. M., & Fennessey, N. M. (1995). *Flow Duration Curves II: A Review of Applications in Water Resources Planning.* Water Res. Bull. 31(6): 1029-1039.

Wallace, J. B., & Benke, A. C. (1984). Quantification of Wood Habitat in Subtropical Coastal Plain Streams. *Ca. J. Fish and Aquatic Science, 41:1643-1652*.

Walsh, S. J. (2001). *Freshwater Macrofauna of Florida Karst Habitats. In: E. Kuniansky (eds.) U. S. Geological Survey Karst Interest Group Proceedings, St. Petersburg, Florida, February 13-16, 2001. p 78-88.* USGS Water Resources Investigations Report 01-4011.

Warm Water Task Force. (2004). *Draft Recommendations for Future Manatee Warm-Water Habitat.* Report by the Florida Manatee Warm Water Task Force, Florida Fish and Wildlife Conservation Commission, Tallahassee, FL.

Water Resources Associates. (2005). *MFL Establishment for Lower Suwannee River & Estuary, Fanning & Manatee Springs.* Prepared for the Suwannee River Water Management District, Live Oak, FL.

Wetland Solutions Inc. (2011). *Ichetucknee River, Florida Assesment of the Effects of Human Use on Turbidity*. Retrieved from http://wetlandsolutionsinc.com/files/paper_reports/Ichetucknee%20Turbidity%20Study%20Final%20Report.pdf

Wharton, C. H. (1978). *The Natural Environments of Georgia.* Georgia Department of Natural Resources, Environmental Protection Division, Geological Survey Branch.

Wharton, C. H., Kitchens, W. M., Pendleton, E. C., & Sipe, T. W. (1982). *The Ecology of Bottomland Hardwood Swamps of the Southeast: A Community Profile.* U.S. Fish and Wildlife Service FWX/OBS-81/37.

White, W. A. (1970). *The Geomorphology of the Florida Peninsula.* Geological Bulletin No. 51, State of Florida, Department of Natural Resources, Bureau of Geology.

Williams, J. D., & Butler, R. S. (1994). *Class Bivalvia, Freshwater Bivalves. pp 53-128, pp 740-742 in R. Ashton, ed., Rare and Endangered Biota of Florida* (Vol. 6. Invertebrates). Gainesville, FL: University of Florida Press.

Winter, T. C., Harvey, J. W., Franke, O. L., & Alley, W. M. (1998). Ground Water and Surface Water - A Single Source. *U.S. Geological Survey Circular 1139*.

Yu, S., & Pilon, P. (2004). A Comparison of the Power of the t Test, Mann-Kendall and Bootstrap Tests for Trend Detection. *Hydrological Sciences Journal, 41:21-37*.