

**MINIMUM FLOWS AND MINIMUM WATER LEVELS RE-EVALUATION
FOR THE
LOWER SANTA FE AND ICHETUCKNEE RIVERS
AND PRIORITY SPRINGS**

**FINAL
(with minor revisions)**

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EXECUTIVE SUMMARY

This Minimum Flows and Minimum Water Levels (MFLs) of the Lower Santa Fe River (LSFR) and Ichetucknee River (IR) and Priority Springs MFL re-evaluation is a substantive demonstration of adaptive management in which the original MFLs analysis (SRWMD 2013) was revisited pursuant to the Final Order Findings of Fact and Conclusions of Law (DOAH 2014) and further expanded to:

- a) create a Reference Timeframe Flow (RTF) record by adjusting historical flow records for groundwater withdrawal impacts on flow calculated using the North Florida-Southeast Georgia (NFSEG) Regional Groundwater Flow Model
- b) consider an additional 5 years of flow records for analysis beyond the prior analysis period of 1932-2010, providing a period of record through Water Year (WY) 2015
- c) update HEC-RAS model cross-section geometry data based on the latest available LiDAR data provided by the District and use the updated steady state model to determine additional (Water Resource Value) WRV evaluation metrics and input for habitat simulation modeling
- d) perform an expanded instream habitat evaluation using a more robust modeling software, the System for Environmental Flow Analysis (SEFA) software
- e) include a second MFL reference gage for the LSFR upstream of Fort White at US441

The Suwannee River Water Management District (District) did not change the methods for evaluating WRVs that were deliberated and defended in the previous review and hearing process (DOAH 2014), and resulted in the current MFL Rule 62-42.300, F.A.C.

The Santa Fe River (SFR), at about 80 miles in length, originates in the Santa Fe and Little Santa Fe Lakes in the northeast corner of Alachua County, Florida. The river flows westwards along the Alachua County line and eventually goes completely underground at a large sinkhole known as the Santa Fe Sink (or River Sink), within O'Leno State Park. The SFR travels underground for about 3.5 miles before it resurfaces several miles north of High Springs at the Santa Fe Rise (River Rise). The length of the reach from the rise to the confluence with the Suwannee River is about 30 miles.

The focus area of this MFLs study is the 30 river mile reach between the Santa Fe Rise and the confluence with the Suwannee River referred to as the LSFR. The study area also includes the IR, which is the main tributary of the LSFR. There are 17 Priority Springs along the LSFR/IR, eleven of which are located on LSFR and six of which are on IR.

An essential element in establishing MFLs is identifying or developing a baseline flow record that reflects unimpacted or minimally impacted historical conditions over representative long-term hydrometeorological cycles. To accomplish this task, the District, in collaboration with the St. Johns River Water Management District, developed the NFSEG regional groundwater model to assist with estimating the impacts of withdrawals on historical flows and water levels. The RTF records were developed by adding withdrawal impacts to the historical flow records. This is contrasted with 2013 MFL report that utilized a truncated historical flow record (WYs 1933 to 1990) as the baseline flow condition.

The Santa Fe River gage near Fort White, Florida (USGS number 02322500, Fort White), located about 18 miles upstream of the Suwannee River confluence, is useful for characterizing regional trends because it has a long continuous period of record (POR) that extends back to 1927. The gage was selected as a reference gage for threshold streamflows and associated MFLs criteria evaluated for the LSFR. Because of the change in river character along the LSFR, a second site, located about 10 miles further upstream, the Santa Fe River gage at US Highway 441 Near High Springs, Florida, (USGS number 02321975, US441) also is used as a reference gage. Similarly, the Ichetucknee River at Highway 27 gage near Hildreth, Florida, (USGS 02322700, Hwy 27) is used as a reference gage for threshold streamflow and associated MFLs criteria evaluated for the IR.

In developing MFLs, the current Water Resource Implementation Rule (62-40.473, F.A.C.) provides that consideration be given to natural seasonal fluctuations in water flows or levels, non-consumptive uses, and environmental WRVs. Three WRVs are relevant to the LSFR/IR system and have sufficient available information to develop relationships between the WRVs and system hydrology. These values include (1) Recreation In and On the Water, (2) Fish and Wildlife Habitats and the Passage of Fish, and (3) Sediment Loads. Fourteen WRV indicators were evaluated for the LSFR MFLs, and ten WRV indicators were evaluated for the IR MFLs. The WRV indicators for both rivers were evaluated to determine possible hydrologic shifts over a wide range of flows.

Recreation was evaluated in terms of paddling and motorized boating on the LSFR and tubing on the IR. Instream freshwater habitat was evaluated using habitat simulation models developed for four segments of the LSFR and two of the IR. Instream woody habitat was evaluated using roots and snag transect survey data. Submerged aquatic vegetation was evaluated using transect survey data collected along the IR. Floodplain habitats were evaluated using vegetation and soil transects survey data, and sediment loads were evaluated for bankfull conditions.

The MFLs proposed for the Fort White and Hwy 27 reference gages are based on the most restrictive hydrologic shifts from the baseline condition developed from the WRVs evaluated for the range of flows in each river. The MFL proposed for the US441 reference gage is a proportional adjustment of the hydrologic shift determined for the Fort White gage. The hydrologic shifts for all three reference gages are applied at the median flow. The MFLs associated with the three reference gages are as follows:

- LSFR at the Fort White gage - general fish passage is the most restrictive WRV, with a hydrologic shift of 103 cfs. For the median flow of 1,270 cfs the change is 103 cfs, or a reduction of about 8.1%.
- LSFR at the US441 gage - a proportional adjustment of the hydrologic shift determined for the Fort White gage for instream habitat applied to the median flow of 552 cfs is about 50 cfs, or a reduction of about 9.1%.
- IR at Hwy 27 gage - woody habitat and hydric soils are the most restrictive WRVs with a hydrologic shift of 10 cfs. For the median flow of 356 cfs the change is about 10 cfs (2.8%).

The differences between the RTF and MFL flows represent a potential maximum shift associated with withdrawals in the baseline hydrology that would remain protective of the LSFR/IR system WRVs as expressed at the Fort White, US441 and Hwy 27 gages.

Flow characteristic/Gage	Fort White	US441	Hwy 27
RTF median flow (cfs)	1,270	552	356
MFLs (cfs)	1,167	502	346
Difference (cfs)	103	50	10
Relative flow reduction (%)	8.1%	9.1%	2.8%

Because of the paucity of spring flow and other data relating flow to impacts on spring WRVs, Priority Springs are presumed to be protected from significant harm by treating them collectively for the LSFR and IR. In the absence of spring-specific metrics for evaluating WRVs, the presumption is that apportioning the hydrologic shift at a reference stream gage is protective of the WRVs for springs upstream from the reference gage. Allowable flow reductions due to withdrawals under median flow conditions in the LSFR and IR are 8.1% and 2.8% respectively. Therefore, spring flow reductions due to withdrawals are collectively limited to 9.1% for the four Priority Springs upstream of US441, 8.1% for seven other Priority Springs on the LSFR downstream of US441, and 2.8% for six Priority Springs on the IR.

I. INTRODUCTION

The Suwannee River Management District (SRWMD or District) initially developed Minimum Flows or Minimum Water Levels (MFLs) recommendations for the Lower Santa Fe River (LSFR) and Ichetucknee River (IR) and Priority Springs in 2013 (SRWMD 2013). Because these water bodies have the potential to be affected by withdrawals in the adjacent St. Johns River Water Management District (SJRWMD), the Florida Department of Environmental Protection (FDEP or Department) adopted the recommendations pursuant to Section 373.0421(3), F.S. (Florida Statutes). In such cases the water management districts are to provide the Department with technical information and staff support for the development of a minimum flow or minimum water level to be adopted by the department by rule, per Section 373.042(5), F.S.

SRWMD is re-evaluating the MFLs for the LSFR, the IR, and Priority Springs (SRWMD 2013) pursuant to Section 62-42.300 (1) (e), Florida Administrative Code (F.A.C), which states: *“Upon completion of the North Florida Southeast Georgia Regional Groundwater Flow Model currently under development, the Department, in coordination with the Suwannee River Water Management District and the St. Johns River Water Management District, shall re-evaluate the Minimum Flows and Minimum Water Levels and the present status of the Lower Santa Fe and Ichetucknee Rivers and Associated Priority Springs pursuant to Section 373.0421(3), F.S., using the best available scientific or technical data, methodologies, and models. No later than three years from the publication of the final peer review report on the North Florida Southeast Georgia Regional Groundwater Flow Model, or by December 31, 2019, whichever is earlier, the Department shall:*

- 1. Publish a Notice of Proposed Rule to strike paragraphs 62-42.300(1)(a) through (d), F.A.C., and re-propose for adoption Minimum Flows and Levels for the Lower Santa Fe and Ichetucknee Rivers and Associated Priority Springs and any associated recovery or prevention strategies; and,*
- 2. Adopt the proposed rule in accordance with the timeframes provided in section 120.54(3), F.S.”*

This MFL re-evaluation is a substantive demonstration of adaptive management in which the original MFLs analysis (SRWMD 2013) was completed pursuant to the Final Order Findings of Fact and Conclusions of Law (DOAH 2014) and further expanded to:

- a) create a Reference Timeframe Flow (RTF) record by adjusting historical flow records for groundwater withdrawal impacts on flow calculated using the North Florida Southeast Georgia (NFSEG) Regional Groundwater Flow Model
- b) consider an additional 5 years of flow records for analysis beyond the prior analysis period of 1932-2010, providing a period of record through WY 2015
- c) update HEC-RAS model cross-section geometry data based on the latest available LiDAR data provided by the District and use the steady state model to determine to determine additional Water Resource Value (WRV) evaluation metrics (Manatee Habitat and input for habitat simulation modeling)
- d) evaluate instream habitat using a more robust modeling software, the System for Environmental Flow Analysis (SEFA) software
- e) include a second MFL reference gage for the LSFR upstream of Fort White at US441

The District did not revisit methods for evaluating WRVs that were deliberated and defended in the previous review and hearing process, and resulted in the current MFL Rule 62-42.300, F.A.C.

The NFSEG regional groundwater flow model was developed by the SJRWMD and SRWMD to provide a shared tool to assess the impacts of groundwater withdrawals on water resources in north Florida. The NFSEG model was used by the District to generate a baseline flow record (i.e., RTF) that accounts for the historical influence of groundwater withdrawals. The RTF record (adjusted record through 2015) is contrasted with the baseline record used in the 2013 report (SRWMD 2013) which consisted of a truncated record from 1933 to 1990 based on an evaluation of the 1933 to 2010 historical record.

Ten important environmental or ecological Water Resource Values (WRVs) are identified in the Water Resource Implementation Rule (62-40.473, FAC), which provides guidance for MFLs development, and are summarized below.

- *WRV 1 Recreation In and On the Water*
- *WRV 2 Fish and Wildlife Habitat and the Passage of Fish*
- *WRV 3 Estuarine Resources*
- *WRV 4 Transfer of Detrital Material*
- *WRV 5 Maintenance of Freshwater Storage and Supply*
- *WRV 6 Aesthetic and Scenic Attributes*
- *WRV 7 Filtration and Absorption of Nutrients and other Pollutants*
- *WRV 8 Sediment Loads*
- *WRV 9 Water Quality*
- *WRV 10 Navigation*

This is a stand-alone MFLs document that describes a re-evaluation of MFLs on the LSFR, IR, and associated Priority Springs. Information updated from the previous MFL report (SRWMD 2013), as well as new information and analyses that provide technical support for re-evaluating MFLs for the LSFR, IR, and associated Priority Springs, are presented in this document. The relevant WRVs and many of the MFL evaluation metrics are the same as the initial MFLs assessment.

Following this introductory section, Sections 2 and 3 of this report include detailed descriptions of hydrology and biology of the riverine system. Section 4 includes an approach for setting MFLs, and Section 5 includes the evaluation of relevant WRVs. Section 6 is a summary and includes the proposed MFLs for the LSFR and IR. Section 7 presents the evaluation of the Priority Springs and spring MFLs. Section 8 is a list of literature cited.

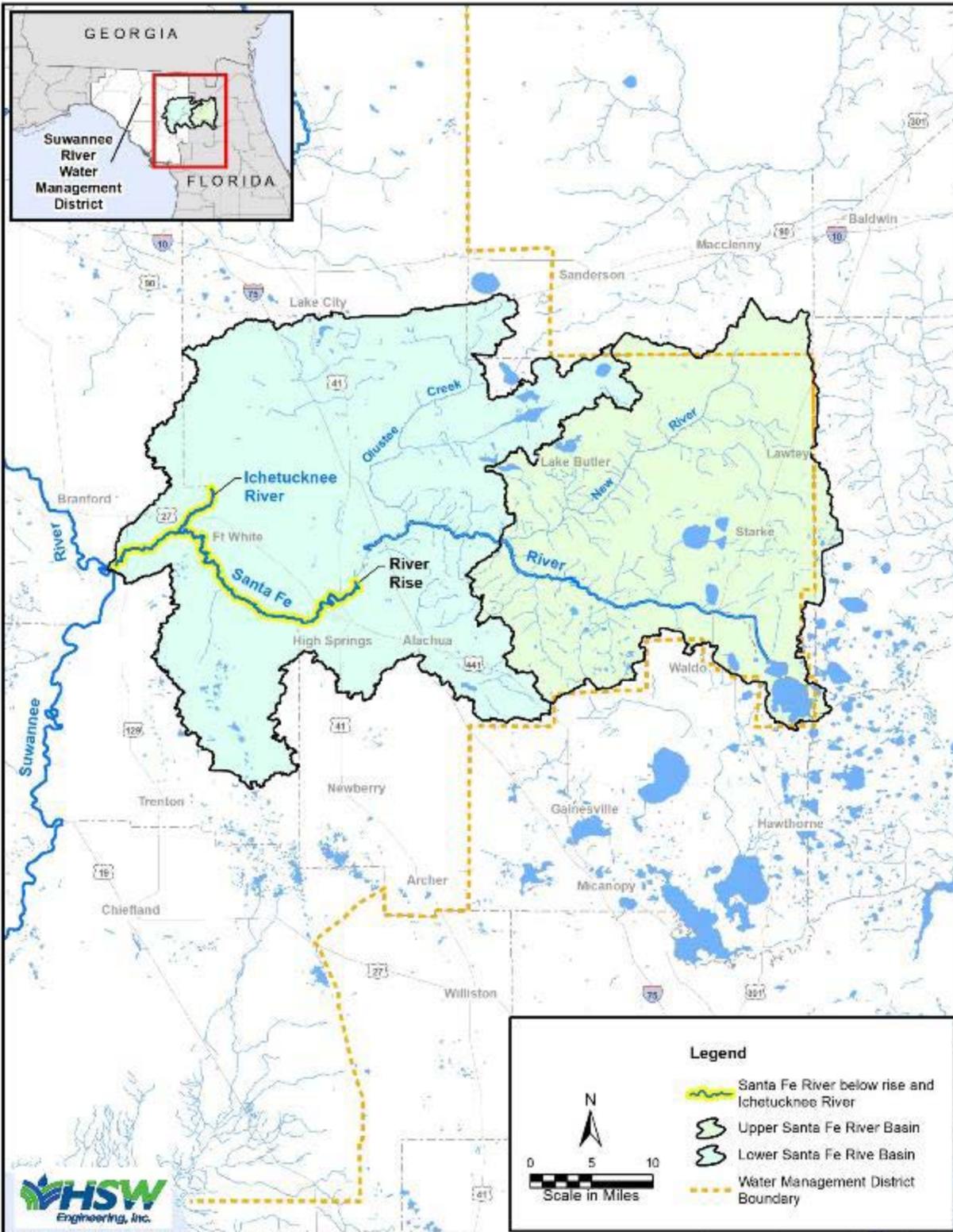
I.1 Watershed and River Descriptions

The Santa Fe River (SFR) Basin is approximately 1,380 square miles and is in the easternmost portion of the SRWMD. The basin primarily lies in Alachua, Columbia, Union, Bradford, and Gilchrist Counties, as well as smaller portions of Suwannee, Baker, Clay, and Putnam Counties (Figure 1). The SFR originates in the Santa Fe and Little Santa Fe Lakes in the northeast corner of Alachua County, Florida. The river flows westwards along the Alachua County line and eventually goes completely underground at a large sinkhole known as the Santa Fe Sink (or River Sink), in O’Leno State Park (Hunn and Slack 1983). The SFR travels underground for approximately 3.5 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.

The SFR basin features several popular recreational areas containing springs, swallets, and river rises, including Ichetucknee Springs State Park, O’Leno State Park, River Rise State Park, and private venues. Several Outstanding Florida Springs (OFS) are in the basin, including Ichetucknee Springs Group on the IR, and Columbia, Devils Ear, Hornsby, Poe, and Treehouse Springs along the SFR. The Ichetucknee Springs Group is a first magnitude spring complex, comprised of nine named and many unnamed springs that discharge into the spring-fed Ichetucknee River (Scott, et al. 2004) and (Florida Springs Institute 2012). The named springs in downstream order are: Ichetucknee (Head Spring), Cedar Head, Blue Hole (Jug), Mission Group (Roaring and Singing that are collectively referred to hereafter as Mission Springs), Devil’s Eye, Grassy Hole, Mill Pond, and Coffee. All but two of the nine springs (Cedar Head and Coffee) are identified by the District as Priority Springs.

1.2 Study Area

The LSFR basin MFL study area encompasses the SFR downstream from the Santa Fe River Rise, the IR, and the watersheds associated with these rivers (Figure 1). The Santa Fe River System, including the study reach, is designated by the State of Florida as an Outstanding Florida Water (OFW) and, as noted above, contains six OFS. Recreational uses of the LSFR and IR and their associated springs include tubing, snorkeling, fishing, cave diving, and the use of small watercraft, and represent an important economic resource in the region. The basin habitat supports several Federally- or State-protected species, including the threatened Gulf sturgeon (*Acipenser oxyrinchus desotoi*); the endangered West Indian manatee (*Trichechus manatus latirostris*); rare species of freshwater mussels, Suwannee bass (*Micropterus notius*), Suwannee cooter (*Pseudemys concinna suwanniensis*), and alligator snapping turtle (*Macrochelys temminckii*).



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Figure 1. Location and Extent of the Lower Santa Fe River Basin MFL Study Area (SRWMD 2014)

2. HYDROLOGY

The hydrology of the LSFR and IR, including regional characteristics of the LSFR/IR watershed, climate, locations of gages, and extent of hydrometeorological records are described in this section. Analyses of long-term hydrometeorological records were performed to characterize period of record (POR) conditions. A RTF flow record, an estimate of the flow record unimpacted by groundwater withdrawals, is used to establish the MFLs hydrology with which the aggregate effects of water withdrawals can be evaluated, and subsequent water supply assessments and plans can be developed.

2.1 Physiography

The LSFR 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) (S. Upchurch 2007).

The Northern Highlands (White 1970) is present in the eastern and northern portions of the LSFR Basin, in portions of Columbia, Union, and Alachua Counties (Figure 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 contain numerous lakes, swamps, and streams. Because of relatively low permeability sediments at or near the surface, the Upper Santa Fe River (USFR) and its tributaries (e.g., Olustee Creek) convey runoff from the Highlands as evidenced by the dendritic drainage pattern (Figure 2).

The Gulf Coastal Lowlands extend inland from the Gulf of Mexico shoreline for approximately 50 miles, terminating in the western portion of the LSFR basin (Figure 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). Because of the thin sediment cover over limestone, karst features are numerous in the Gulf Coastal Lowlands. Land surface elevation ranges from about 25 to 70 feet above sea level. Extensive karst development in the Gulf Coastal Lowlands creates an internal, largely subsurface drainage pattern. Therefore, the physiographic province near the LSFR basin is largely devoid of stream channels and punctuated by depressional features such as sinkholes.

The Cody Scarp or Cody Escarpment is a geomorphologic feature located through the north and central parts of Florida that roughly approximates an ancient shoreline of Florida when sea levels were much higher (Suwannee River Water Management District 2020). It represents the largest continuous topographic break in Florida with up to 100 feet of relief separating the highlands of the Okefenokee Basin and Tifton Uplands to north and east, from the Ocala Karst District to the west (Upchurch, et al. 2019). These areas correspond to areas within the major physiographic provinces of the Northern Highlands and Gulf Coastal Lowlands (Figure 2). The scarp is an example of fluviokarst formed by coastal processes and interaction between streams flowing off highlands, underlain by relatively low permeability siliciclastic sediments, onto a karst limestone plain. The highlands to the east are relatively flat and are underlain by surficial sands and the clays and carbonate strata of the Hawthorn Group. The presence of both primary and secondary porosity in the limestone and high level of aquifer confinement inland from the coast are important to the scarp development. The highlands near the margin of the scarp may have rock collapse sinkholes such as Devil's Millhopper in Alachua County. The toe of the scarp is characterized by limestone or dolostone that has been subject to dissolution by both surface water and groundwater at the scarp. The Cody Scarp is a complex of large dendritic valleys with many

karst features such as poljes, uvalas, sinkholes, sinking streams, siphons, and springs (Upchurch, et al. 2019). Every river that crosses the Cody Scarp in the SRWMD goes underground, and reemerges downstream as a spring, with the sole exception of the Suwannee River (Suwannee River Water Management District 2020).

Streams flowing off the highlands locally recharge the aquifer through swallets along the scarp formed by vertical karst conduits formed under sinkholes (Upchurch, et al. 2019). Olustee Creek, a major tributary to the Santa Fe, loses water through a series of swallets as it flows across the Cody Scarp and into the karst plain. The fate of this water is unknown but may discharge through a spring along the Santa Fe River or contribute to groundwater flow under the Santa Fe River.

The source of water flowing to the River Rise alternates between two sources: surface water runoff from the USFR basin where the UFA is confined, and diffuse recharge through near-surface karst limestone where the UFA is unconfined, depending on the discharge of the USFR (Martin and Dean 2001).

2.2 Hydrogeology

The LSFR basin includes the confined (Northern Highlands), semi-confined and unconfined (Gulf Coastal Lowlands) areas (Figure 2). The UFA is the primary source of water supply for all water use types in north-central Florida and south-east Georgia. It also provides the baseflow in the LSFR, primarily through springs.

The UFA is mostly unconfined along the LSFR and IR. In these areas, the UFA discharges (through springs and baseflow) to the rivers under most conditions (except for flood events). The UFA discharge is expressed at the surface by the numerous springs, some of which are first and second magnitude with flows greater than 10 cubic feet per second (cfs), along the two rivers. As a result, maintaining UFA water levels in the LSFR basin is critical to maintaining flow to the springs and to baseflow in the LSFR and IR.

A spatial evaluation of recharge to the UFA is important to understand the overall water budget of the system. The upper portion of the flow above the Cody Scarp is dominated by surficial drainage systems and the interaction of the surficial aquifer and the LSFR and small streams that drain into the LSFR. River discharge is dominated by groundwater downgradient of Cody Scarp, particularly under low flow conditions. The river becomes a gaining system where the UFA potentiometric surface is higher than river stage.

High recharge to the UFA occurs throughout most of the LSFR basin and, as expected, correlates to areas where the UFA is unconfined to semi-confined (Figure 3). Medium to medium-high recharge occurs along the southwest and northeast margins of the LSFR basin (consistent with semi-confined areas) and low-medium to low recharge occurs in the southwest portion of the LSFR basin and to the east of the basin (Figure 3). The UFA discharges to the LSFR/IR system via springs and distributed baseflow within the incised river valleys downstream from the Cody Scarp (Figure 3). During low-flow conditions the Lower Santa Fe River is essentially a spring run, with baseflow provided by artesian water inputs from the Floridan aquifer system (Florida Springs Institute 2012).

A smoothed section along the river thalweg was prepared using best available elevation data and includes the land bridge at O'Leno State Park (Figure 4). Superimposed on this are the estimated

groundwater potentials from May of 2005 and 2012 in the vicinity of the broader river corridor. The 2005 period represents high groundwater conditions, 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 UFA is considered confined and its potentiometric surface is below the river. Near Worthington Springs, under both wet and dry conditions, a local groundwater mound is observable, indicative of the initial ‘break’ in confinement and where sinks and springs occur further downstream, and is likely caused by localized increase in recharge, even during dryer periods. There are several sinks and rises that occur above O’Leno State Park, including Vinzant Sink (near RM 39.5) and, most notably, the SFR sink (near RM 35) that normally captures the entire river flow. The Santa Fe Land Bridge (Figure 4) spans the distance between the SFR Sink and River Rise.

2.3 Hydrologic Characteristics

2.3.1 Stream Discharge and Stage

Several U.S. Geological Survey (USGS) and District stream gaging stations have been maintained on the rivers and creeks within the LSFR/IR basin. Eight of the gages are on the LSFR (Figure 5), two of which (Santa Fe River at Worthington Springs and Santa Fe River Near Fort White) have the longest concurrent period of continuous daily records, dating back to water year (WY) 1932 (Table 1). The USGS-defined WY is from October 1 of previous year to September 30 of current year. For example, WY 2010 spans from October 1, 2009, to September 30, 2010. The Santa Fe River Near Fort White (02322500) and Santa Fe River at US Hwy 441 Near High Springs (02321975) gages on the LSFR (Fort White gage and US441 gage) and the Ichetucknee River at HWY27 Near Hildreth (02322700) gage on the IR (Hwy 27 gage) were selected as the reference gages for establishing MFLs. Throughout this report, these reference gages may also be referred to as Fort White, US441, and Hwy 27, respectively. The US441 gage was incorporated as a reference gage based on recommendations in the Upper Santa Fe River MFL report (Water Resource Associates, Inc. 2007). As stated in the Upper Santa Fe MFL evaluation:

“It is important that discharge from Olustee Creek and at O’Leno State Park be subjected to MFL development to prevent significant harm to these resources. However, it is suggested that setting a MFL downstream of the Rise and after the complex river/groundwater flow system becomes better defined be considered. The relationships of flow at O’Leno and the Santa Fe River at the U.S. 441 gage on the Lower Santa Fe have been explored as part of this report (Section 3.3.2.2.3). These relationships clearly indicate that setting a MFL at this gage (US441) will protect river discharge at O’Leno and Olustee Creek.”

Based on the flow data available, WY 1933-2015 was selected as the POR for this study. Unless specified otherwise, all flow values depicted in this report are rounded to two significant digits.

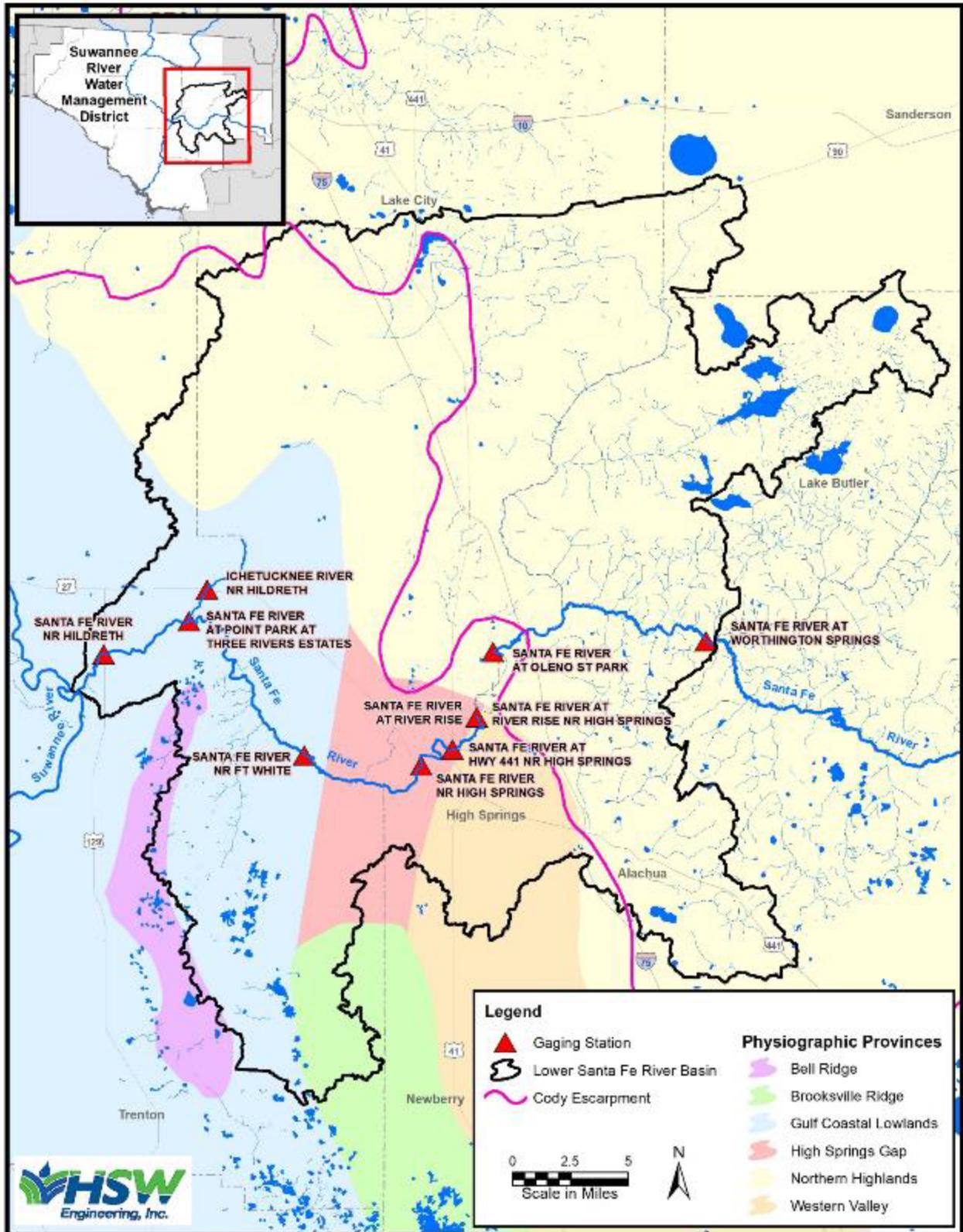


Figure 2. Physiography of the Lower Santa Fe River and Ichetucknee River Basins

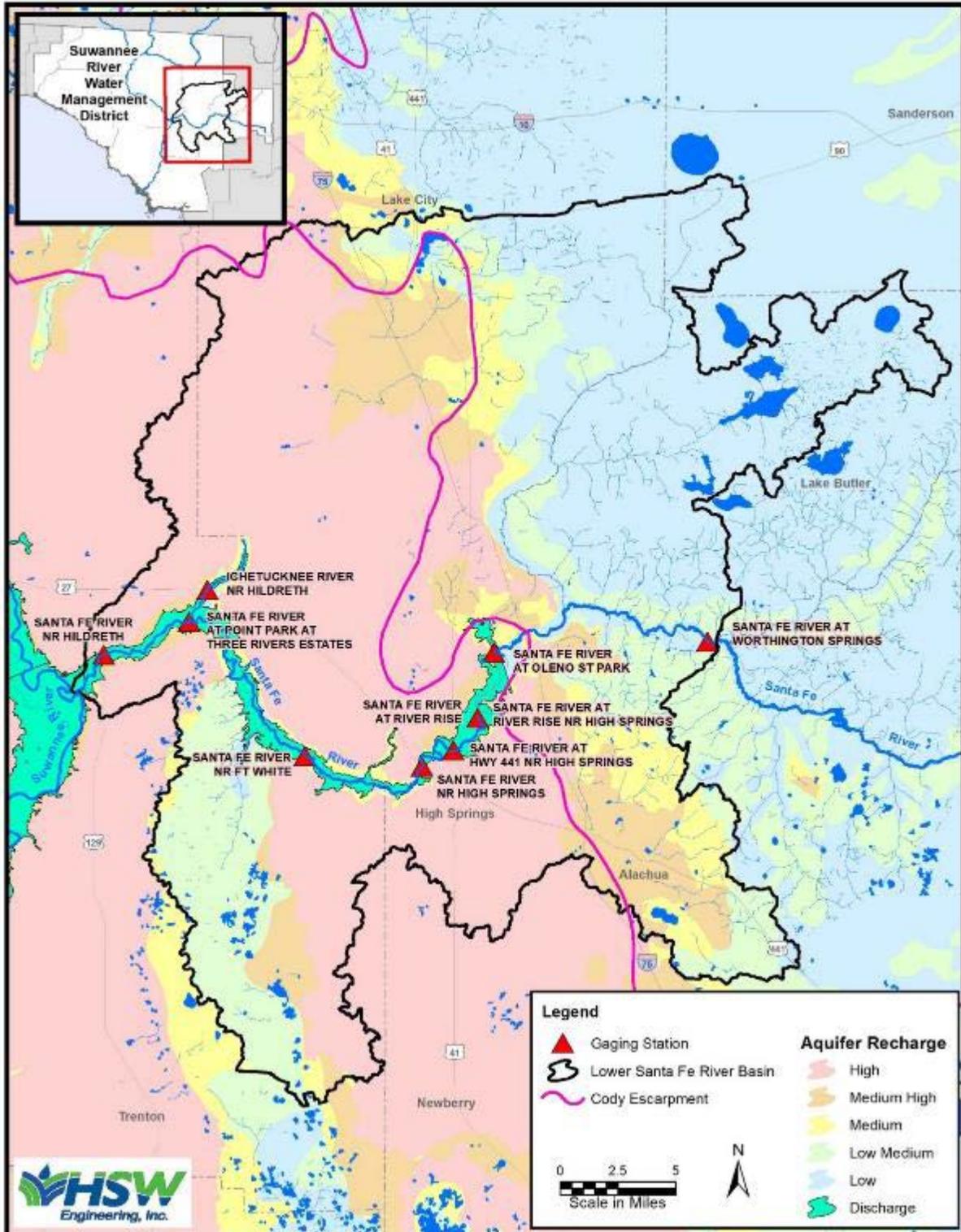


Figure 3. Upper Floridan aquifer recharge and discharge in the Lower Santa Fe River Basin [modified from SRWMD shape file]

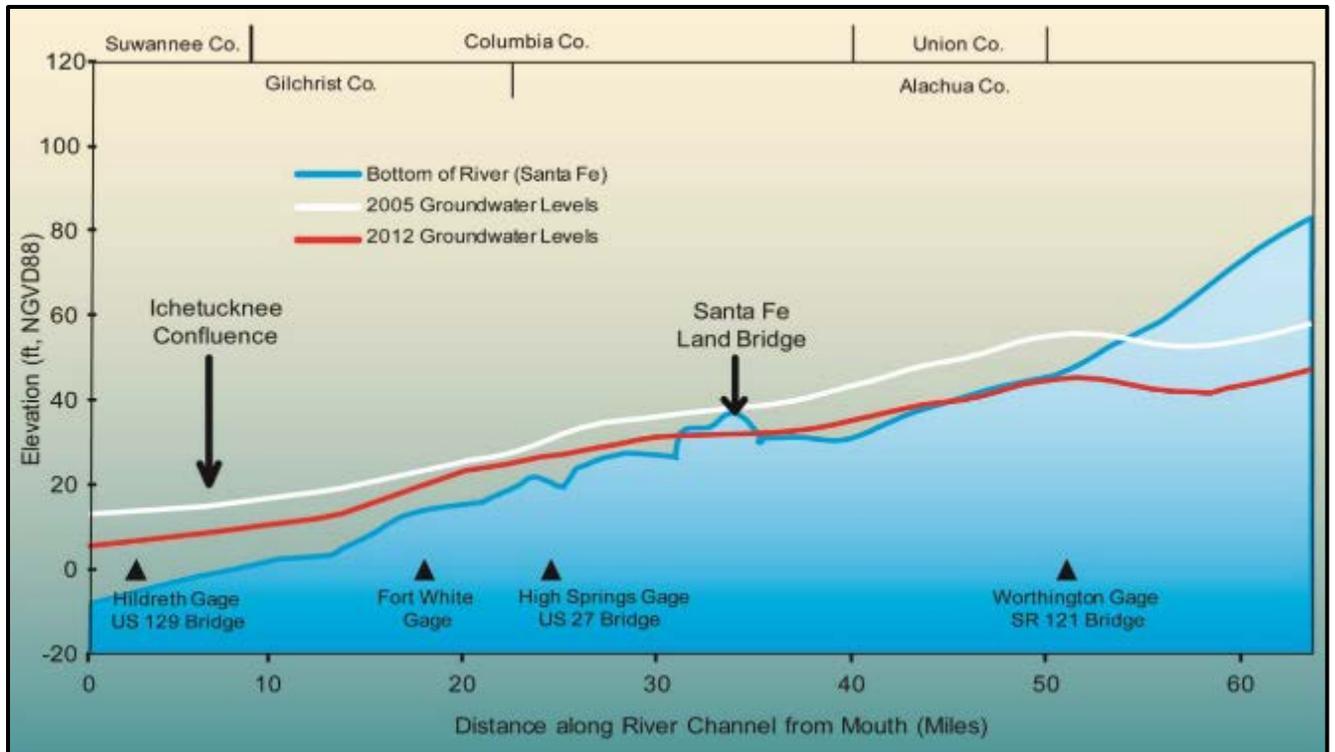


Figure 4. Generalized Potentiometric Surface of the Upper Floridan aquifer along the Santa Fe River [Source: (SRWMD 2013)]

Table 1. Summary of drainage areas and information for select continuous surface water gages on the Lower Santa Fe River and Ichetucknee River (listed by decreasing river mile, per river)

Site no. Drainage area (sq mi)*	Site name (River mile)*	Parameter	Period of Record Daily data		Total Percent Complete (%)
			Oldest	Newest	
02321500 (575)	SANTA FE RIVER AT WORTHINGTON SPRINGS, FLA. (51)	Flow	10/1/1931	9/30/2015	100.0%
		Stage	11/18/1931	9/30/2015	94.0%
02321898 (820)	SANTA FE RIVER AT O'LENO STATE PARK, FL	Flow	10/1/2011	9/30/2015	100.0%
		Stage	6/8/2010	9/30/2015	87.0%
02321958 (--)	SANTA FE RIVER AT RIVER RISE	Stage	5/23/2013	8/25/2015	100.0%
02321975 (859)	SANTA FE RIVER AT US HWY 441 NEAR HIGH SPRINGS, FL	Flow	10/1/1992	9/12/2015	96.1%
		Stage	2/27/1989	9/30/2015	52.4%
02322500 (1017)	SANTA FE RIVER NEAR FORT WHITE, FL (18)	Flow	10/1/1927	9/30/2015	97.3%
		Stage	1/21/1994	9/30/2015	56.7%

Site no. Drainage area (sq mi)*	Site name (River mile)*	Parameter	Period of Record Daily data		Total Percent Complete (%)
			Oldest	Newest	
02322703 (--)	SANTA FE RIVER AT POINT PARK AT 3 RIVER ESTATES	Stage	10/24/1998	9/30/2015	95.6%
02322800 (1374)	SANTA FE RIVER NR HILDRETH FL (1.7)	Flow	11/1/2000	9/30/2015	86.7%
		Stage	4/28/1947	9/30/2015	76.9%
02322700 (213)	ICHETUCKNEE R @ HWY27 NR HILDRETH, FL (1.5)	Flow	2/5/2002	9/30/2015	100.0%
		Stage	2/6/2002	9/30/2015	98.9%

* Site drainage area (in square miles) and river miles provided, where applicable, from the USGS National Water Information System website.

Daily average flow at the Fort White gage (Figure 6) varies over a wide range compared to the Hwy 27 gage on the IR (USGS 02322700). The daily average flow at the Fort White gage for the common POR (2/5/2002 through 9/30/2015) ranges from 342 cfs to 11,600 cfs, whereas the flow range at the Hwy 27 gage is from 124 cfs to 703 cfs. The lower range of flows at the Hwy 27 gage compared to Fort White gage reflects the different physiography and hydrogeology of the two river basins (Figure 2 and Figure 3) and a greater percentage of groundwater input to the IR as compared to the LSRF. The daily average flow at the US441 gage ranges from 0 cfs to 14,870 cfs for the same period.

Daily flows at the two LSRF gages with the longest period of record (Worthington Springs and Fort White) vary over a wide range individually and from gage to gage over the period of analysis (WYs 1933-2015). The median daily flow at the Fort White gage is almost ten times the median flow at Worthington Springs gage, whereas the Fort White gage is associated with just 1.8 times the Worthington Springs gage surface water drainage area. The sustained greater flows at Fort White (i.e., relatively flat flow duration curve) reflect baseflow input to the river even during periods of little surface water runoff and contrast sharply with the low-flow characteristics of the Worthington Springs gage (Figure 6).

The annual average discharge of the LSRF at the Fort White gage generally increased from 1933 until the late 1960s and has declined since then, although some leveling of discharge is apparent over the last few years (Figure 7). A non-parametric regression model, LOESS (LOcal RegrESSion), is fitted to depict a smoother variation in flow data (Cleveland and Devlin 1988). The smoothing parameter is the proportion of data used to fit the non-parametric regression model; for all LOESS curves presented in this report, a smoothing value of 0.33 was used.

Daily flow records are available for the US441 gage from 1993 until 2020 with missing data during 2000 and 2001 spanning multiple months. In the 2013 MFL report (SRWMD 2013) and 2019 draft MFL report, the POR flows for US441 gage (Q_{US441}) were infilled and extended using a Multiple Linear Regression (MLR) relationship with the flow at the Fort White and Worthington Springs gages (Q_{FW} and Q_{WS} , respectively) as explanatory variables. Several concerns were raised during the draft report review process related to the model used and residuals generated using this model form, generally related to assumptions regarding residuals and the overall model fit.

A number of assumptions may apply to the residuals of a regression model depending on the model application, including (1) homoskedasticity (i.e., residuals vary evenly over the range of predictions), (2) independence (i.e. residuals are minimally autocorrelated over time), and (3) normality (i.e., residuals should be normally distributed). Each of these assumptions relates to drawing inference into model coefficients and deriving prediction intervals. Residual assumptions are not required to predict y (i.e. flow at US 441) given x (i.e. flow at nearby gages) (see Table 9.1 in (Helsel and Hirsch 2002)). However, issues raised during peer review regarding residuals are addressed in the District response in the context of improving predictions.

To infill and extend the flow record for the US441 gage, several alternative modeling approaches were examined. These approaches included generalized least squares regression, Box-Cox transformation, weighted least squares regression, robust regression, and piecewise linear regression (Appendix A). In summary, modeling approaches that attempt to better satisfy residual assumptions generally did not improve predictions (Box-Cox, generalized least squares, and robust regression). However, a quadratic term introduced to reduce errors at greater flows and a lagged term for flow at Worthington Springs did improve model predictions. The piecewise linear regression using the linear form for flow at Fort White and lagged flow (3-days) at Worthington Springs proved to be the most versatile. The piecewise linear regression form was particularly useful because it allowed for zero flows at US441 to be estimated and marginally improved estimates at greater flows; therefore, all flow records were retained in the model. This form is given by:

$$\begin{aligned} &\text{When FtWhite_Q} < \text{knot1} \\ &\quad \text{US441_Q} = 0 + b3 * \text{Worthington_Q_lag3} \\ &\text{When FtWhite_Q} < \text{knot2} \\ &\quad \text{US441_Q} = 0 + b1 * (\text{FtWhite_Q} - \text{knot1}) + b3 * \text{Worthington_Q_lag3} \\ &\text{When FtWhite_Q} \geq \text{knot2} \\ &\quad \text{US441_Q} = 0 + b1 * (\text{FtWhite_Q} - \text{knot1}) + b2 * (\text{FtWhite_Q} - \text{knot2}) + \\ &\quad b3 * \text{Worthington_Q_lag3} \end{aligned} \tag{2}$$

with R-squared = 0.907 and

where

- US441_Q = daily flow at Santa Fe River at the US Hwy 441 Near High Springs, FL. (02321975)
- Worthington_Q_lag3 = daily flow at Santa Fe River at Worthington Springs gage (02321500), lagged three days,
- FtWhite_Q = daily flow at Santa Fe River at the Fort White gage (02322500),
- Knot1 (559 cfs) and knot2 (1,480 cfs) are inflection points for flow at Fort White where the linear form slope changes, and
- b1, b2, and b3 are regression coefficients.

It is notable that all forms resulted in similar estimates of median flow at US441, the primary goal of this exercise that will be discussed later in the report (Section 5.5). A more detailed discussion of model forms and approaches considered is provided in the District response to the peer review.

2.3.2 Infilling of Ichetucknee River Data at HWY 27 Near Hildreth Gage

The Hwy 27 gage has continuous flow records from February 5, 2002 until September 30, 2015. Additional sporadic data are available prior to 2002 from USGS field measurements. The USGS field measurements ranged in frequency from monthly to longer gaps spanning multiple months. Infilling of data from October 1, 1932 through February 5, 2002 was completed using multiple methods (INTERA 2013) and the dataset was provided by the District. Based on the availability of the observed data, the infilled dataset was broken up into two periods:

- prior to 1975 and after 2000 until 2002, when USGS field measurements were frequent, and
- From 1975 through 2000, when measurements were infrequent (with 54 measurements during the measurement period).

For the periods with high measurement frequency (prior to 1975 and after 2000), linear interpolation of flow data was used to produce a daily flow time series (INTERA 2013). A simple linear regression with groundwater level at a local monitoring well (DOT Lake City - S041705001) as an independent variable was used for the 1975 through 2000 period (INTERA 2013).

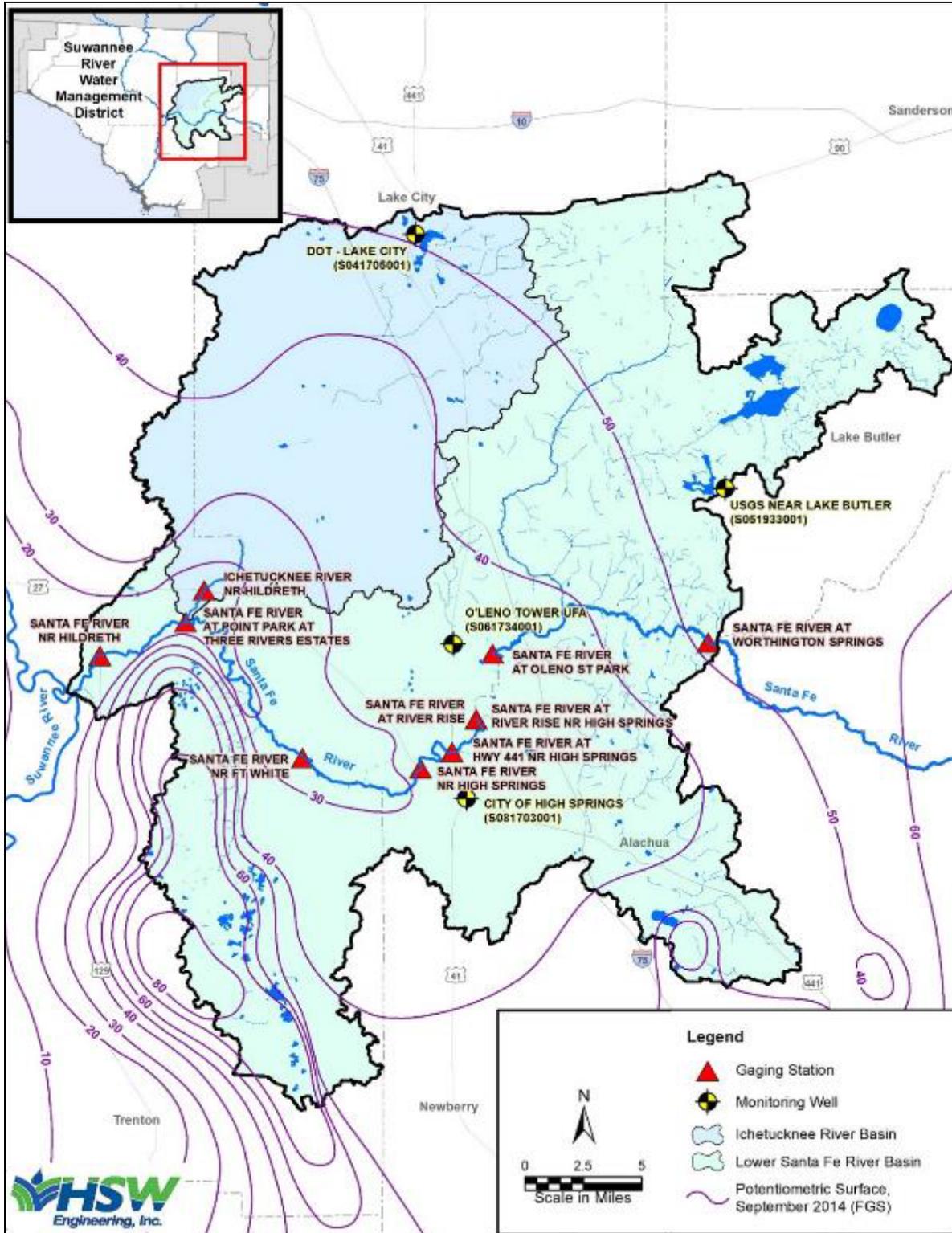


Figure 5. Location of surface water gages and monitoring wells

2.3.3 Watershed Yield

Watershed yield calculations are helpful for characterizing groundwater and surface water exchange as an initial step toward conceptualizing the stream-aquifer interaction. Regional factors such as geology, topography, local groundwater use, and temporary or permanent diversions of runoff typically influence the watershed yield.

Yield calculations were performed to determine gains and losses occurring in various reaches of the LSFR (Table 2). Yield gain was calculated using the ratio of flow gain to watershed area gain. The estimated Yield (Average Flow/Drainage Area) at US441 gage is lower than the estimated Yield at Worthington gage. However, the estimated Yield at Fort White gage is substantially greater than the Yield at US441 gage (Table 2). The gain between the US441 gage (02321975) and the Fort White gage compared to the gain between Worthington Springs gage and US441 gage, is evidence of a substantial increase in baseflow.

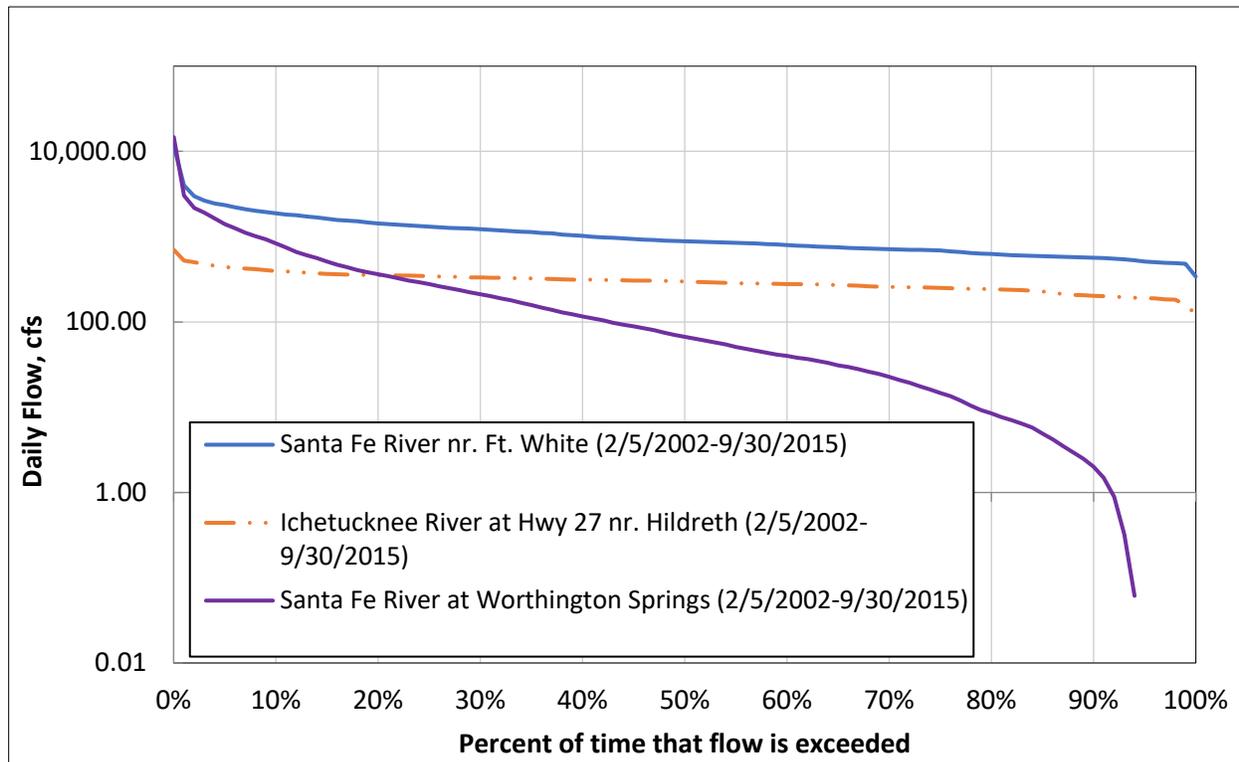


Figure 6. Flow exceedance curves for the Fort White, Worthington Springs, and Hwy 27 gages

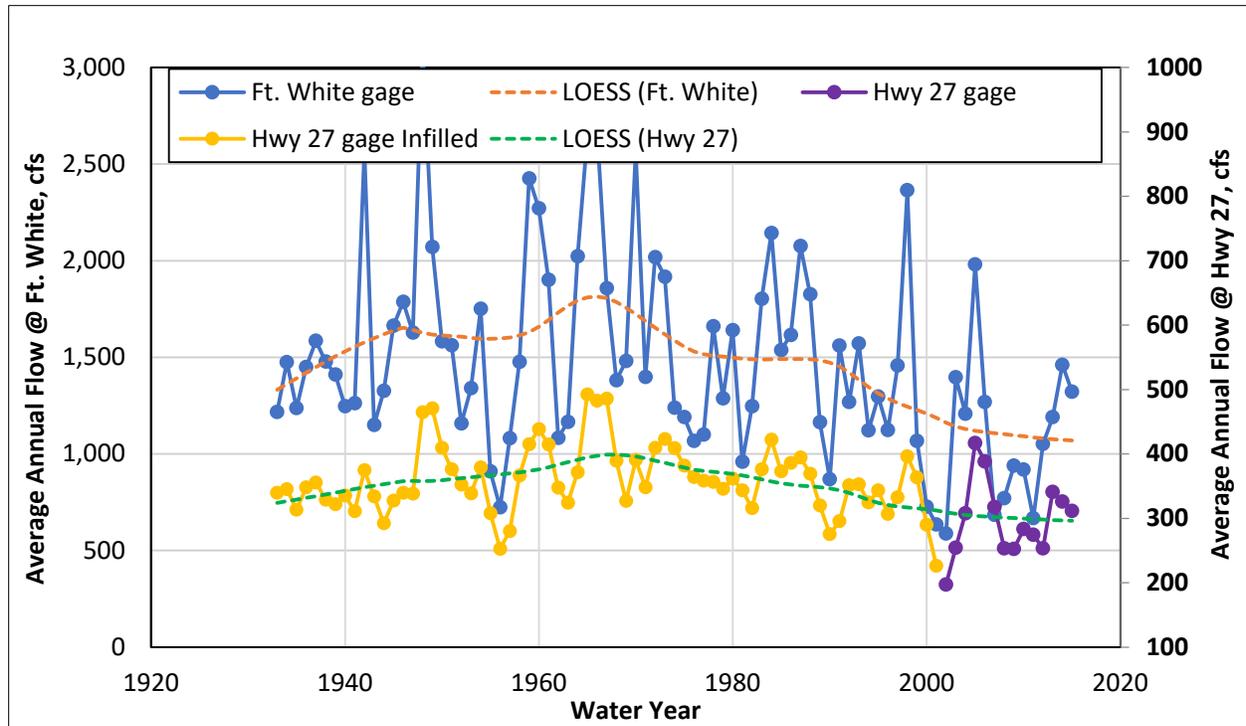


Figure 7. Annual average flows at the USGS Fort White gage and USGS Hwy 27 gage

Table 2. Yield gain along Lower Santa Fe River

Site no.	Site name	Watershed Area (Sq. miles)	(WY 1992-2010) Average Flow (cfs)	Yield (Flow /Area), in/yr	Watershed Area Gain (Sq. miles)	Flow Gain (cfs)	Yield (Flow Gain/Area Gain), in/yr
02321500	SANTA FE RIVER AT WORTHINGTON SPRINGS, FL	575	312	7.4	575	312	7.4
02321975	SANTA FE RIVER AT US HWY 441 NEAR HIGH SPRINGS, FL	859	410	6.5	284	98	4.7
02322500	SANTA FE RIVER NEAR FORT WHITE, FL	1017	1174	15.7	158	764	65.6

Notes:
Average flow was generated using daily average flow data.

2.3.4 Atlantic Multidecadal Oscillation

The Atlantic Multidecadal Oscillation (AMO) is a series of long-duration changes in the surface temperature of the North Atlantic Ocean. A cool or warm phase may last for 20 to 40 years (Figure 8). When rivers in peninsular Florida were in a multidecadal period of greater flows (1940-1969), rivers in the north to northwestern part of the state were in a low flow period. Conversely, flow was generally lower in peninsular Florida rivers (1970-1999) when rivers in the northern portion of the state exhibited greater flows (Kelly 2004). For the Santa Fe River, the daily flow duration curves for a generally wet period (WYs 1940-1969) are about the same as the curves for a generally dry period (WYs 1970-1999) (Figure 9).

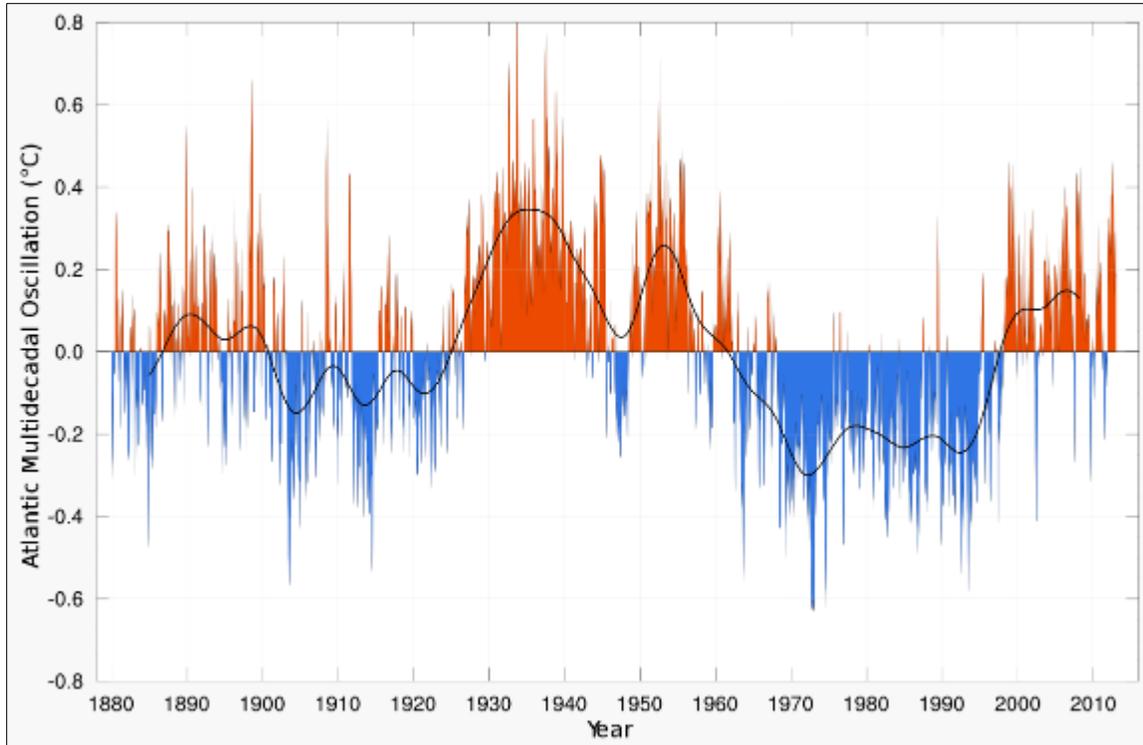


Figure 8. Departure of the Atlantic Ocean surface temperature from the long-term mean
 [Source: (McCarthy and Haigh 2015); periods of warm and cool Atlantic Ocean temperature depicted by red and blue bars, respectively]

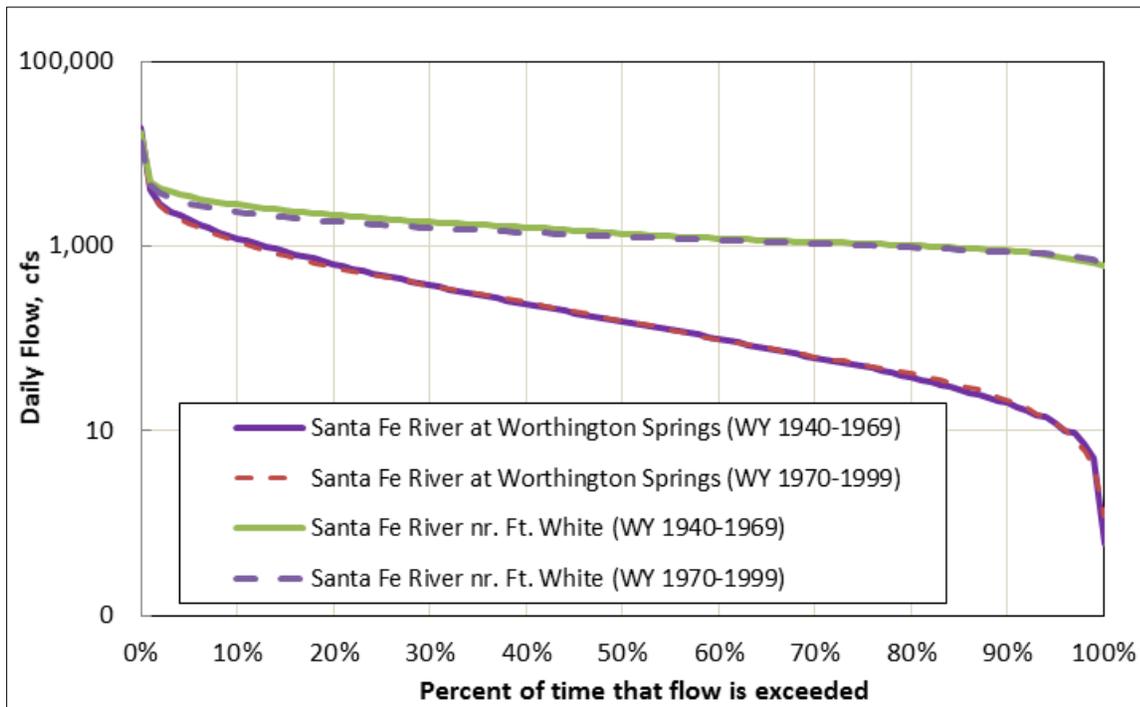


Figure 9. Flow exceedance curves for warm (1940-1969) and cool (1970-1999) AMO periods at the Fort White and Worthington gages

A distinct temporal bi-modal flow distribution apparent in the high-flow regime of the SFR is much less apparent in the low-flow regime (Figure 10). The high-flow regime reflects a greater proportion of surface runoff compared to the low-flow. The AMO appeared to influence the magnitude of flow but generally not the timing of low to median flows (Figure 11). The late summer/early fall period of high flows lasted several months longer during the wetter AMO cycle (1940-1969) compared to the dryer AMO cycle (1970-1999). Although a similar bi-modal flow distribution was observed during post-2000 of drier conditions, the timing of the flows was similar to the timing during the two AMO periods.

Seasonal flow patterns are apparent for flows greater than median flows (Figure 10). Groundwater withdrawal impacts on hydrology are relatively less on seasonal high flows compared to seasonal low flows. As such, evaluating seasonality for WRV metrics associated with high flows is not warranted (e.g. floodplain inundation/dewatering and the Gulf sturgeon spawn during March/April and September/October). However, for the smaller fish spawn that occurs primarily during March through August (Table 12), seasonality is an optional consideration.

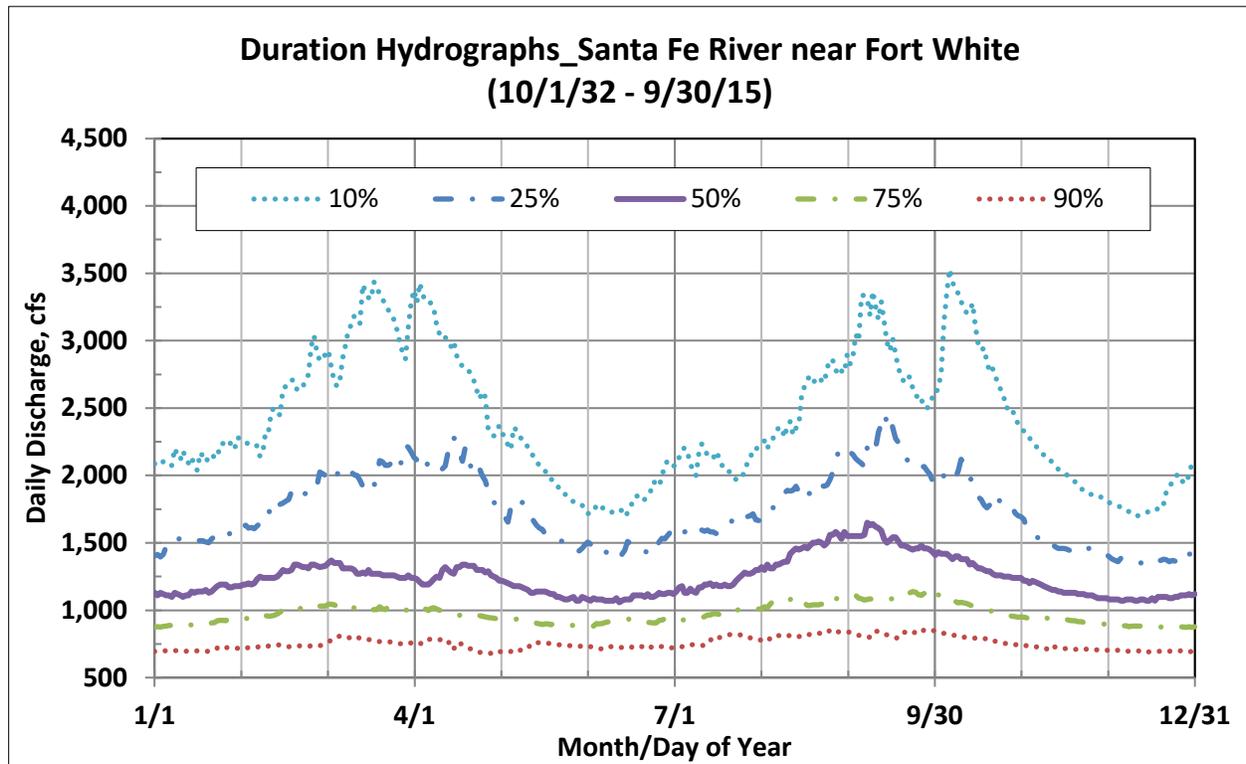


Figure 10. Flow duration hydrographs for Santa Fe River near Fort White for selected exceedance frequencies

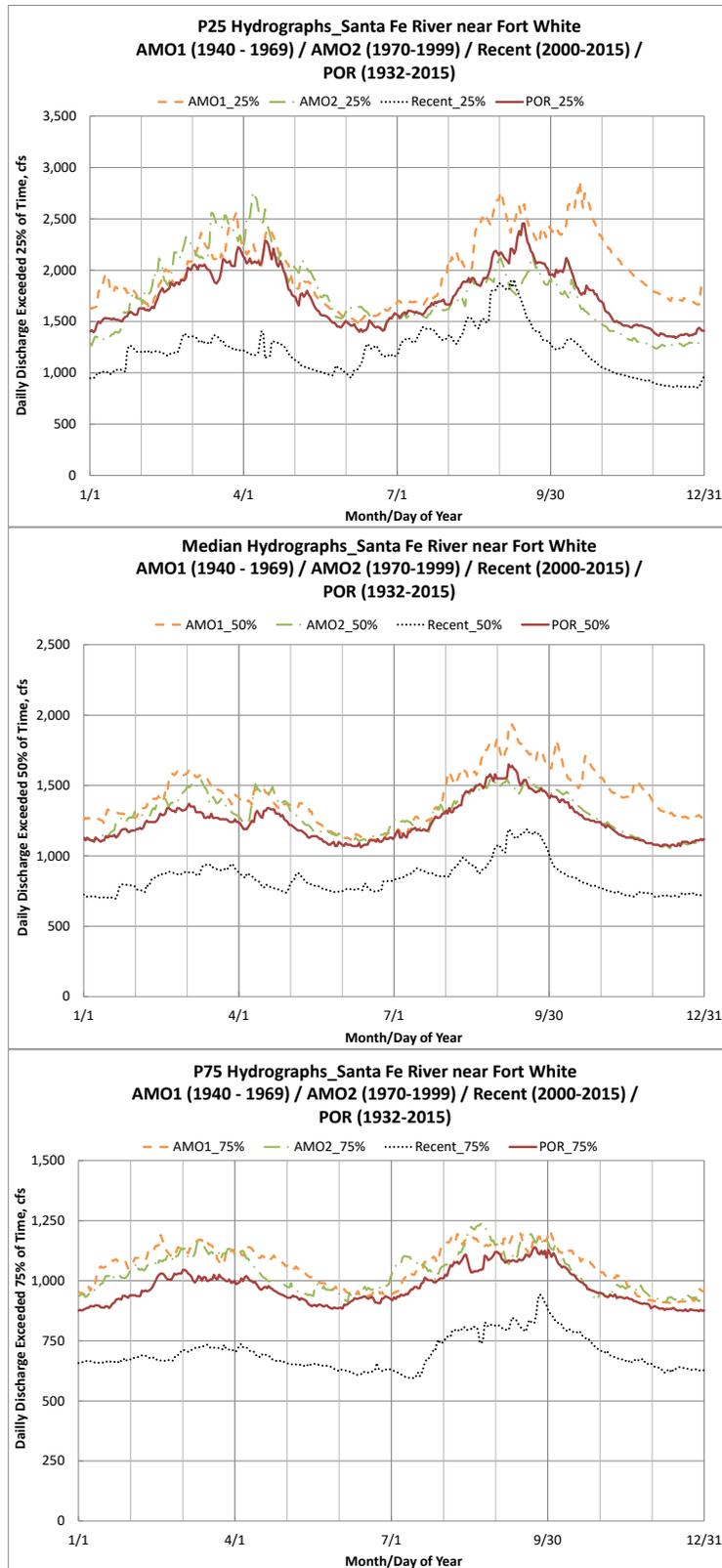


Figure 11. Quartile flow duration hydrographs for Santa Fe River near Fort White for select time periods of high flow (top), median (middle) and low flow (bottom).

2.3.5 Rainfall and Air Temperature

Rainfall and temperature data sets were extracted from a master dataset developed by the PRISM (Parameter-elevation Relationships on Independent Slopes Model) Climate Group at Oregon State University. The temperature data are for a location near the Fort White gage for general background climate information, whereas rainfall data were obtained by averaging the PRISM rainfall within the combined surface water and groundwater basin for the Fort White gage (Figure 12).

Average annual air temperature near the Fort White gage during WYs 1933-2015 ranged from 66.9 to 72.3 °F and averaged 68.8 °F (Figure 13). Basin-wide average annual rainfall during the period of analysis ranged between 39 and 72 inches and averaged 53.2 inches (Figure 14). With respect to the AMO, average rainfall during the early “wet” period (WY 1940 to 1969) was 53.88 inches per year versus 53.68 inches per year for the later “dry” period (WY 1970 to 1999).

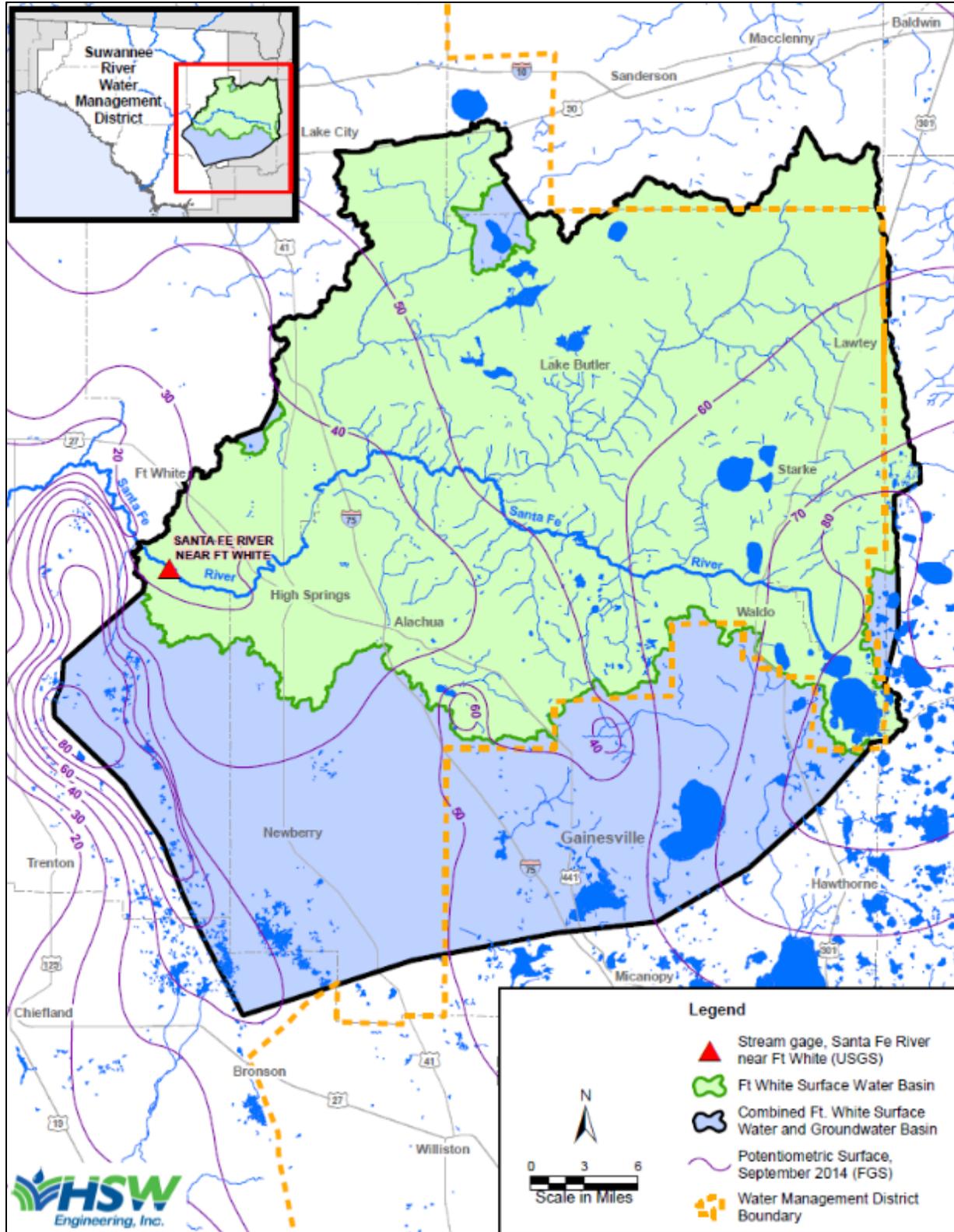


Figure 12. Combined Fort White surface water and ground water basin

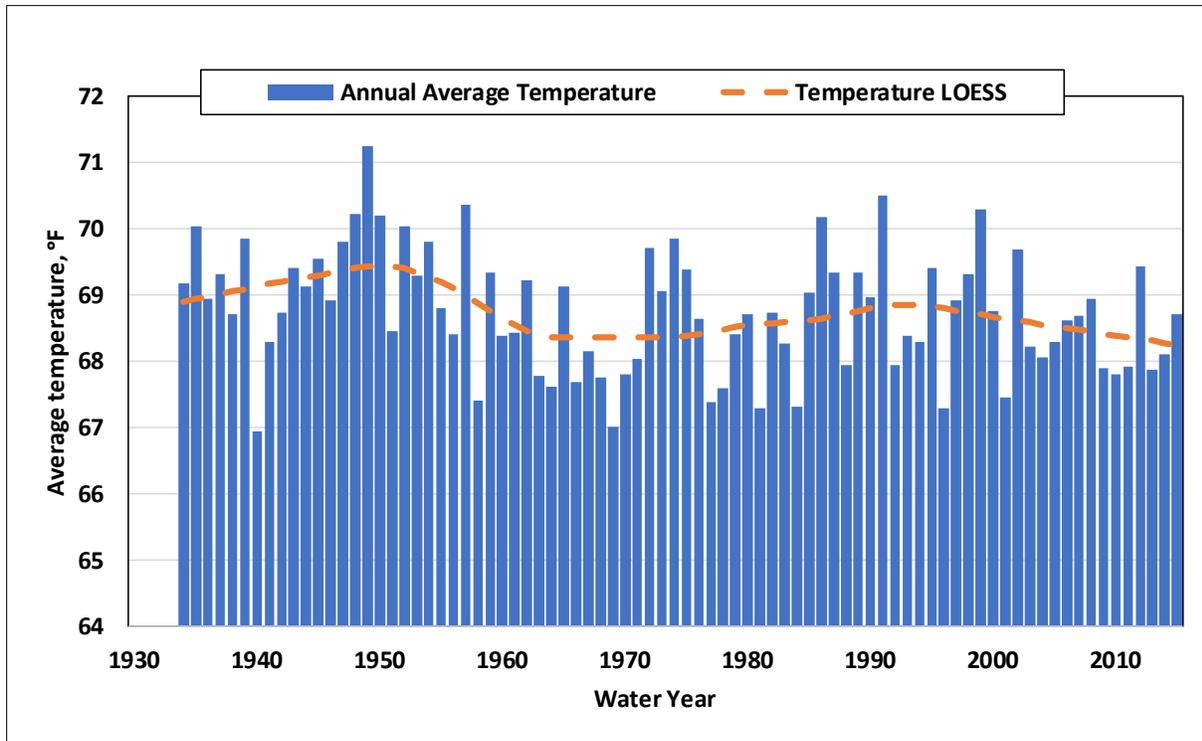


Figure 13. Historical average annual air temperature near Fort White gage, FL Water Years 1933-2015

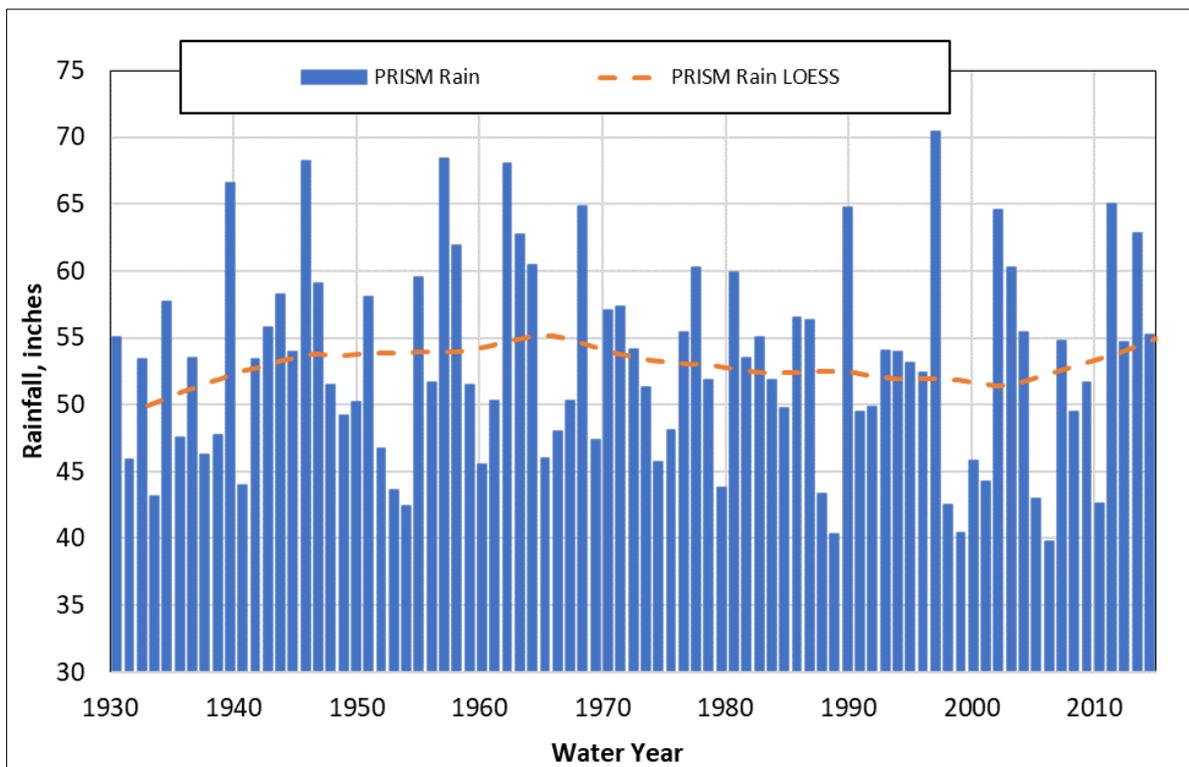


Figure 14. Total rainfall within Lower Santa Fe River watershed, Water Years 1933-2015

2.3.6 Groundwater level

Records of historical UFA groundwater levels dating back to 1948 are available to characterize long-term patterns within the LSFR and IR watershed. Groundwater flow generally is from northeast to southwest in the study area (Figure 5). Of all the wells near the LSFR and IR watersheds, the Florida Department of Transportation (DOT) monitoring well in DOT Lake City (DOT Lake City - S041705001) has the longest POR, which begins in June 1948 (Figure 5). Groundwater levels in the well have varied considerably over short periods of time; an annual variation of four feet or more is common. Groundwater levels have declined at the Lake City well since 1948 and appear to have stabilized after 2000. A similar trend is observed at UFA monitoring well USGS Near Lake Butler (S051933001) and City of High Springs well (S081703001), which are in the LSFR watershed (Figure 15).

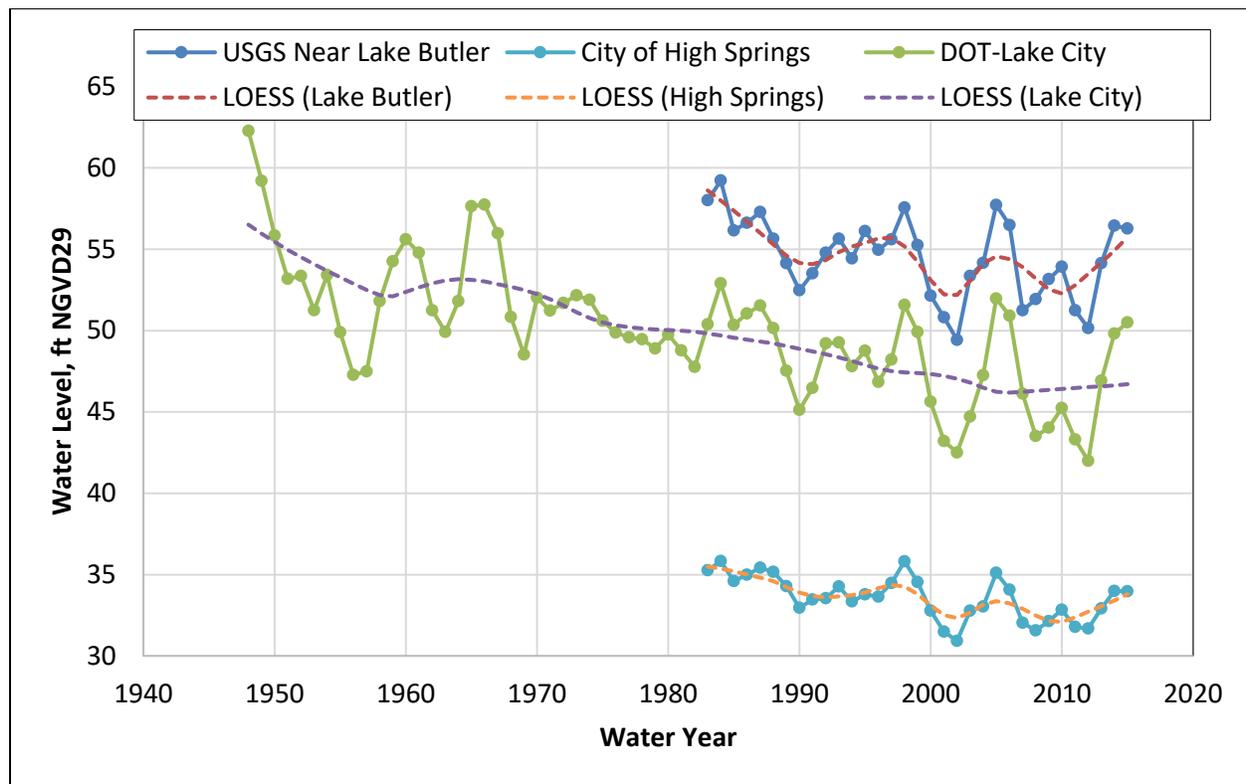


Figure 15. Historical annual average groundwater levels in the UFA at DOT Lake City, City of High Springs and USGS Near Lake Butler, Florida

2.4 Priority Springs

Eleven springs on the LSFR and six springs on the IR are identified by the District as Priority Springs (SRWMD 2019) and are included for MFLs assessment in this study (Figure 16, Figure 17; refer also to Appendix B for detailed information about each spring). Some of the springs are located within the floodplain forest of the river, while others are within the river itself or along the banks. Nine of the 17 springs are classified as historical first magnitude springs; i.e., with average flows of greater than 100 cfs (Copeland 2003) (Table 3). In addition, Hornsby, Treehouse, Columbia, Poe, and Devil’s Ear Springs on the LSFR and the Ichetucknee Spring Group on the IR are OFS. An OFS is a spring, or spring group, and

associated spring run designated by the Florida Legislature as worthy of special protection because of its natural attributes and quality.

The IR is essentially a large spring run as, under normal conditions, most of the water in the river is derived from springs along the upper extent of the river (Figure 17). Together, the springs and river have a median discharge of over 346 cfs.

Spring flow has been measured occasionally at the Priority Springs at different times, with frequent measurements at several locations occurring between 1995 and 2015 (Table 3 and Figure 16). The earliest flow measurements were made in 1898 for the IR and 1917 at Poe Springs. Although field flow measurements are made at the springs using standard methods, measurement accuracy for both manual and continuous flow measurements is limited by site conditions, such as irregularly shaped measurement locations (refer to Section 7 for more details regarding the evaluation of springs data).

Spring flow ratings for the Priority Springs are evaluated to calculate discharge based on other explanatory variables such as groundwater level, stream stage, and streamflow (Section 7). Recommended MFLs for the Priority Springs also have been developed (Section 7).

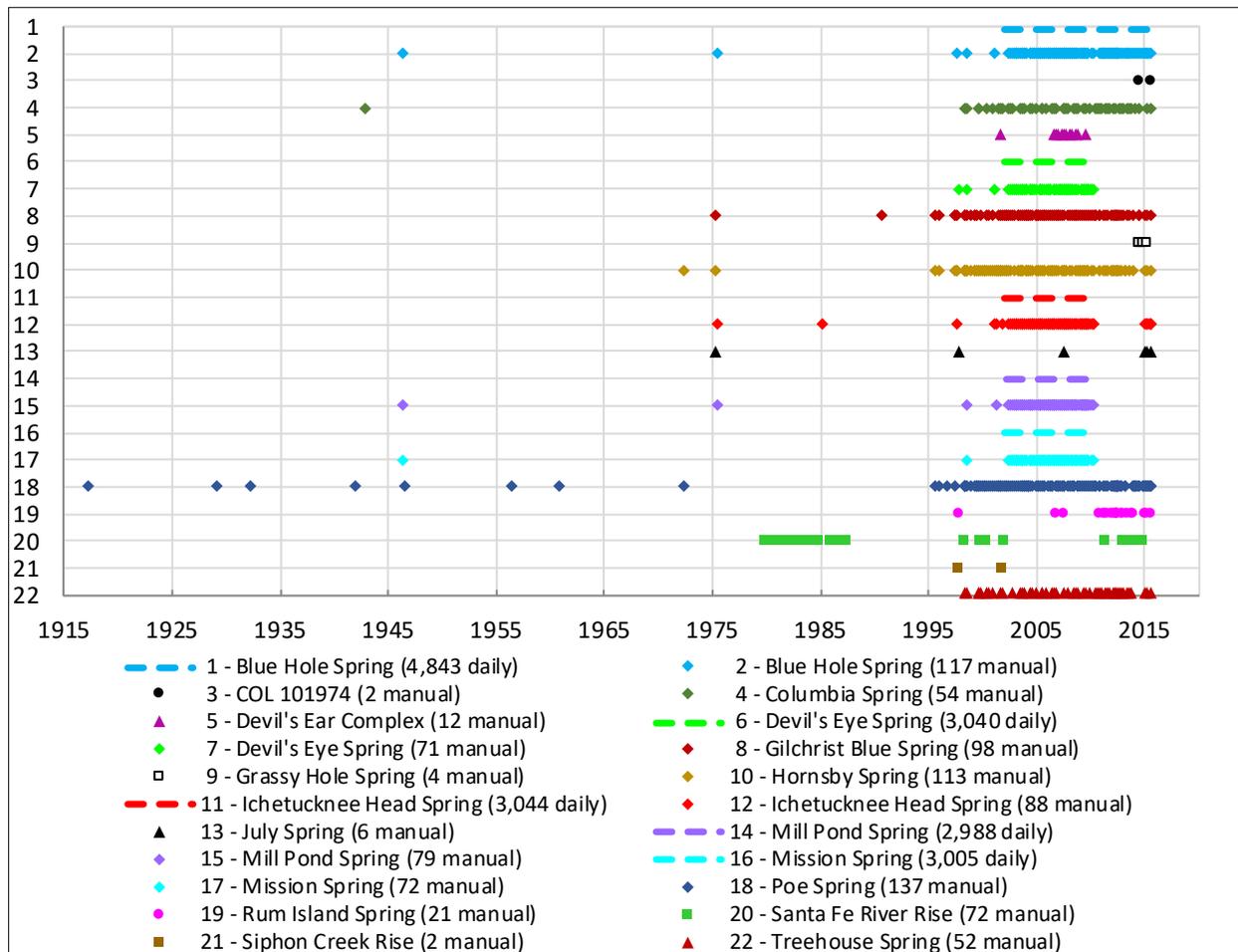


Figure 16. Timeline of flow measurements at Priority Springs located on the Lower Santa Fe River and Ichetucknee River

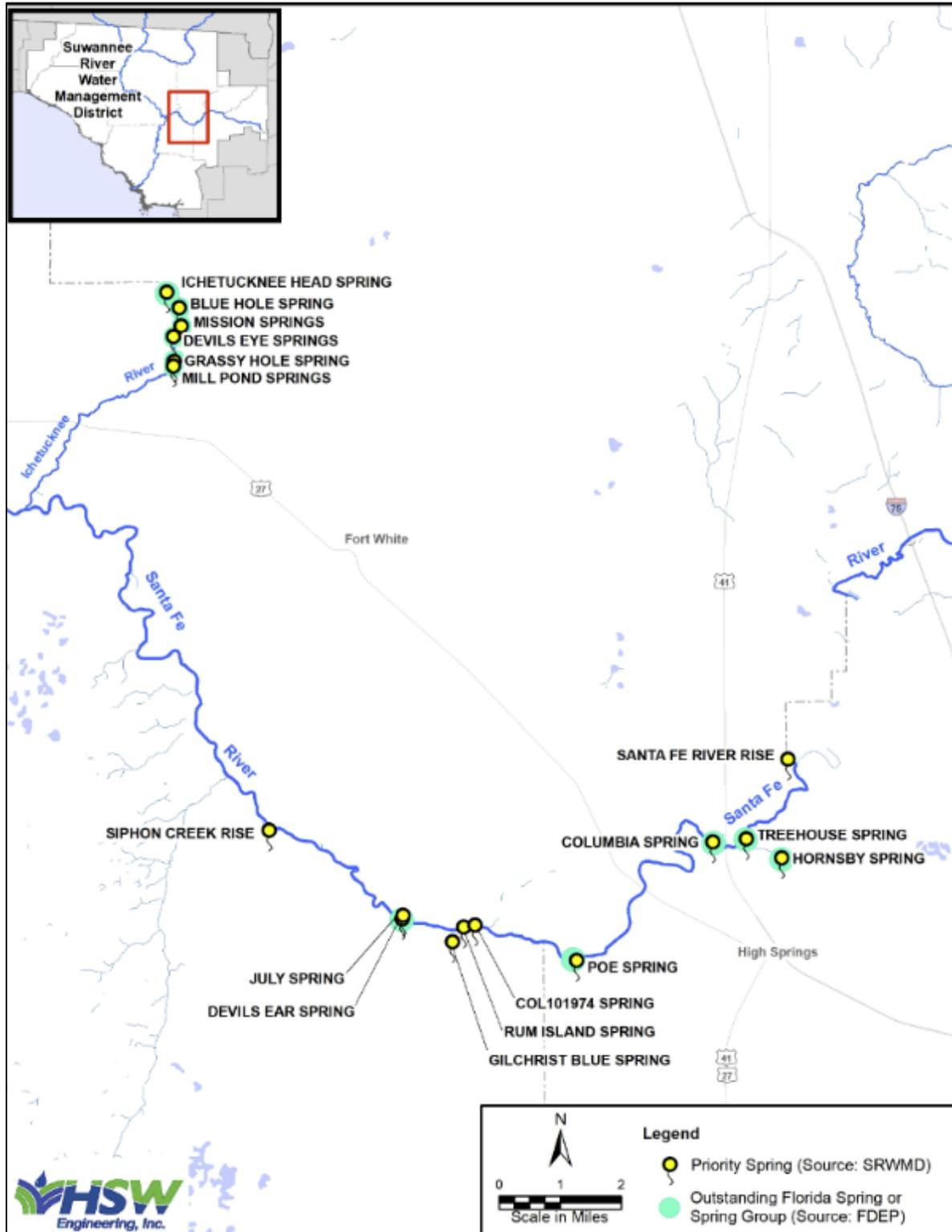


Figure 17. Location of Priority Springs on the Lower Santa Fe River and Ichetucknee River

Table 3. Priority Springs located on the Lower Santa Fe River and Ichetucknee River

Spring		Flow Measurements, cfs					
Name	ID	Type	Start and end date	Count	Minimum	Maximum	Median
Lower Santa Fe River							
Santa Fe River Rise	02321958	Manual	10/25/1979 10/8/2014	71	56	3,263	426
Treehouse	02321971	Manual	5/26/1998 7/8/2015	51	0	739	108
Hornsby	02321970	Manual	4/19/1972 7/16/2015	112	-18	352	42
Columbia	02321977	Manual	12/13/1942 7/8/2015	54	0.64	423	72
Poe	02322140	Manual	2/19/1917 8/11/2015	137	0.30	93	47
		Daily	11/30/2001 5/19/2010	3093	16	165	45
COL 101974	COL 101974	Manual	6/26/2014 7/9/2015	2	4.4	7.9	6.1
Rum Island	RUM010C1	Manual	10/15/1997 7/9/2015	21	5.0	61	17
Gilchrist Blue	02322350	Manual	4/28/1975 7/28/2015	98	8.4	87	39
Devil's Ear Complex**	--	Manual	9/5/2001 7/21/2009	12	72	472	144
July	02322390	Manual	5/12/1975 7/13/2015	6	28	117	51
Siphon Creek Rise	GIL1012973	Manual	10/12/1997 10/11/2001	2	120	370	245
Ichetucknee River							
Ichetucknee Head	02322685	Manual	7/11/1975 9/2/2015	88	20	85	47
		Daily	2/7/2002 6/8/2010	3044	5.9	80	46
Blue Hole	02322688	Daily	2/5/2002 9/30/2015	4843	29	294	107
		Manual	5/17/1946 8/4/2015	117	35	313	101
Mission	02322691	Daily	2/12/2002 5/5/2010	3005	12	165	88
		Manual	5/17/1946 4/1/2010	72	20	176	89
Devil's Eye	02322694	Daily	2/12/2002 6/9/2010	3040	19	77	48
		Manual	11/4/1997 4/29/2010	74	31	84	50
Grassy Hole	02322697	Manual	6/26/2014 3/31/2015	4	3.8	6.4	4.3
Mill Pond	02322695	Daily	2/14/2002 4/20/2010	2988	0.4	57	25
		Manual	5/17/1946 4/1/2010	79	0	60	23

**Includes Devil's Eye and Little Devil Springs.

Data obtained from SRWMD, USGS, and/or FGS.

2.5 Surface Water Quality

The water quality of the Santa Fe River transitions from a black-water, acidic, soft water river between the Santa Fe Swamp and O’Leno State Park, to a clear, spring-fed river with higher dissolved solids, pH, and nitrate nitrogen in the LSRF (Florida Springs Institute 2012).

Nitrate is a key indicator of surface water quality. Nitrate concentration in the LSRF below the IR has steadily increased since at least the 1960s, from estimated pre-development concentrations of less than 0.10 mg/L to about 0.40 mg/L in 2007 (FDEP 2008). In 2008, the FDEP determined, under the TMDL (total maximum daily load) requirements of the 1972 U.S. Environmental Protection Agency (EPA) Clean Water Act and the 1999 Florida Watershed Restoration Act, that the Santa Fe River Basin was impaired for nutrients and dissolved oxygen concentrations. FDEP adopted a nitrate TMDL of 0.35 mg/L for the basin (FDEP 2008).

Nitrate concentrations in the Santa Fe River at US 47 near Fort White averaged about 0.73 mg/L between 1989 and 2015 (Figure 18). The average nitrate levels are elevated but have not increased substantially at this location, with the concentration averaging 0.75 mg/L between 2010 and 2015. Nitrate concentrations at High Springs have been trending downward since 1989, averaging about 0.23 mg/L over this 25-year time period (Figure 18). The higher concentrations of nitrate recorded at Fort White than at High Springs may be due to the Fort White gage’s location farther down-river from the river’s reemergence at the River Rise than the High Springs gage; i.e., this area of the river may be more greatly impacted by non-point source nitrate loading from surface water runoff than the area around High Springs.

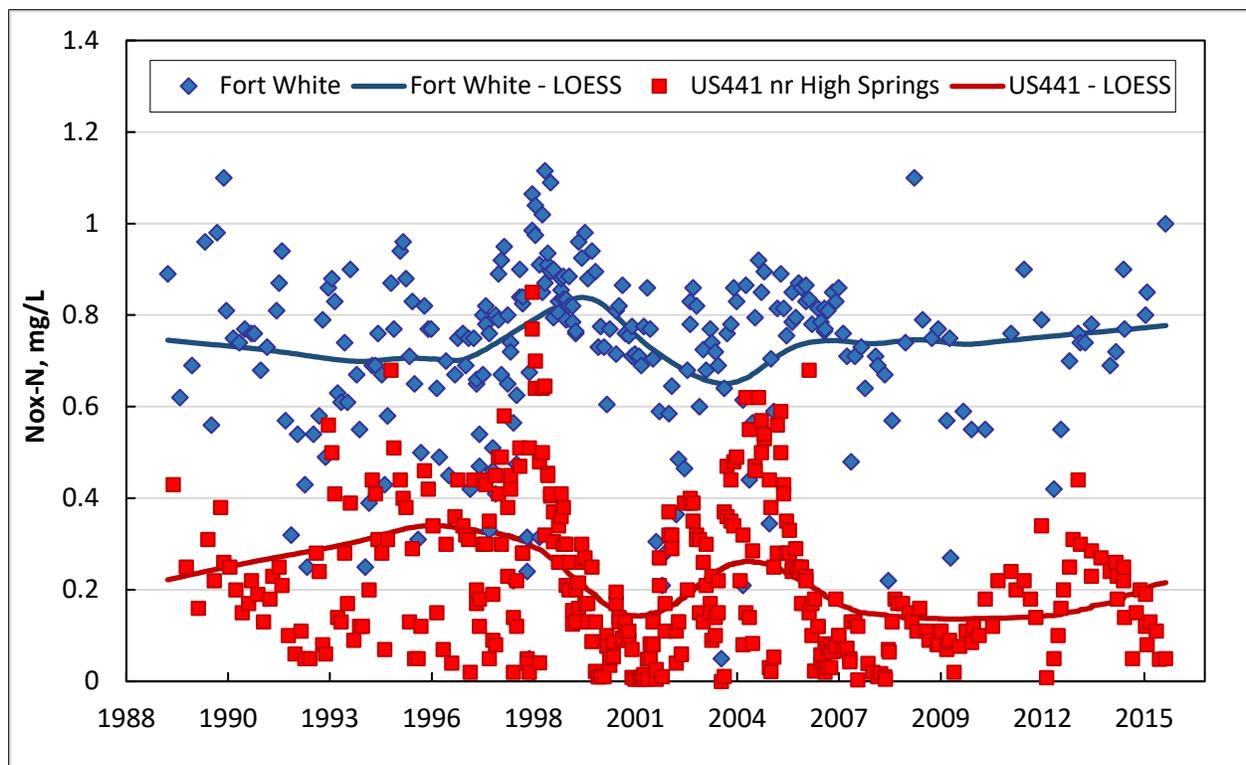


Figure 18. Nitrate concentration trends in the Lower Santa Fe River (SRWMD May 2020)

Various agencies, including the FDEP, SRWMD, and Alachua County, monitor water quality in the LSRF and its springs. Nitrate concentrations are not in compliance with the TMDL of 0.35 mg/L in downstream springs. Nitrate concentrations at Gilchrist Blue and Ginnie Springs are substantially greater than nitrate concentrations in five springs located further east/upstream (Columbia, Hornsby, Poe, Santa Fe, and Treehouse Springs) (Figure 17 and Figure 19). While average nitrate concentrations in four of these five springs (i.e., all but Santa Fe Spring) exceed the TMDL, the trendlines suggest that nitrate concentrations are stable or declining. Insufficient data were available for Santa Fe Spring to assess its current condition or generate a trendline.

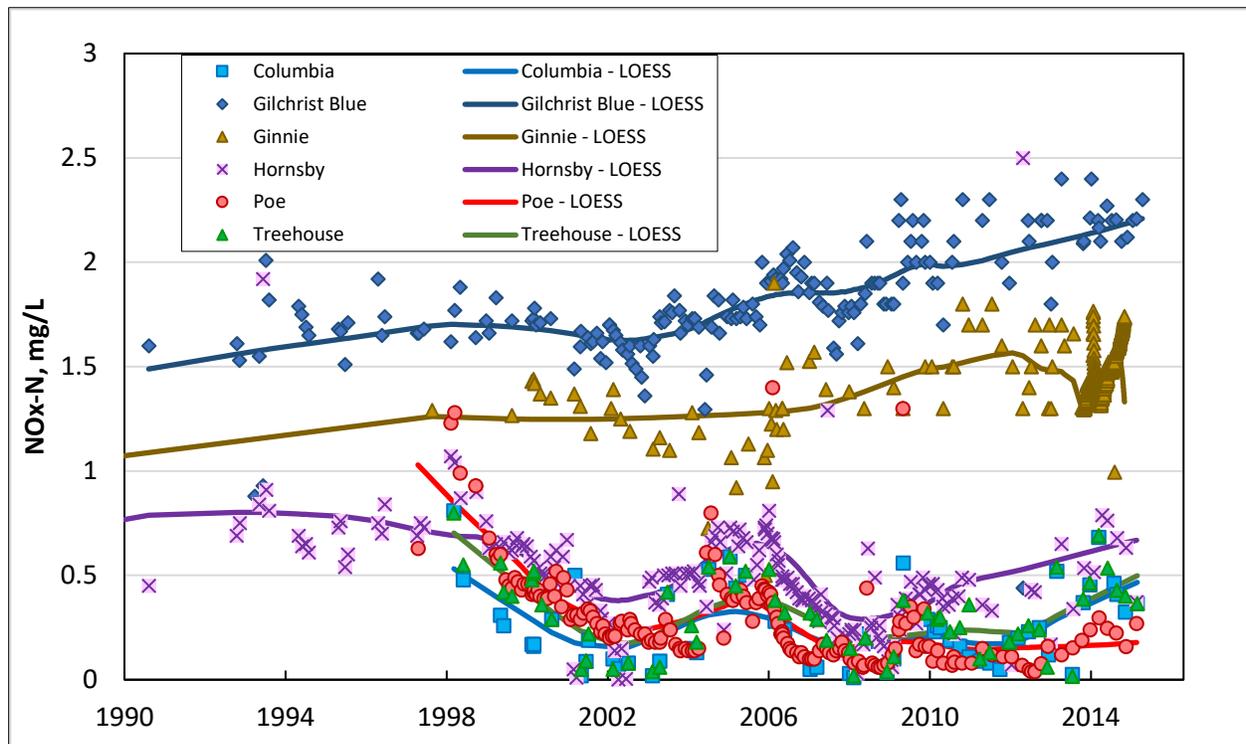


Figure 19. Nitrate concentrations at selected Santa Fe River springs in the study area (SRWMD May 2020)

2.6 Groundwater Use

In the counties encompassing the Santa Fe watershed, only about 1 cfs is withdrawn from surface water sources or about 1 percent of the total withdrawal (based on data reported in (Marell 2015)). Thus, groundwater is the source of most potable water used in the region of the LSRF/IR. Groundwater is withdrawn for public and domestic drinking water supplies, and for industrial, agricultural, and recreational uses. Water use in northeastern Florida and southeastern Georgia has increased substantially in the last 50 years, with groundwater supplying most of the water to meet demands in this region. In Florida, groundwater withdrawals within the North Florida Regional Water Supply Planning area (Figure 20) potentially influence flows along the LSRF and IR. The estimated groundwater use peaked in 1990 within the 1965-2015 period (Figure 21). Groundwater use increased prior to 1990 but has stabilized since then at about 500 million gallons per day (mgd). During 2015, public supply is the greatest water use category at 40%, followed by agriculture at 28% (Figure 22). Population growth and increases in agricultural groundwater withdrawals have contributed to the increase in groundwater use. Long-term historical water demands are summarized in Appendix C, Part 1.

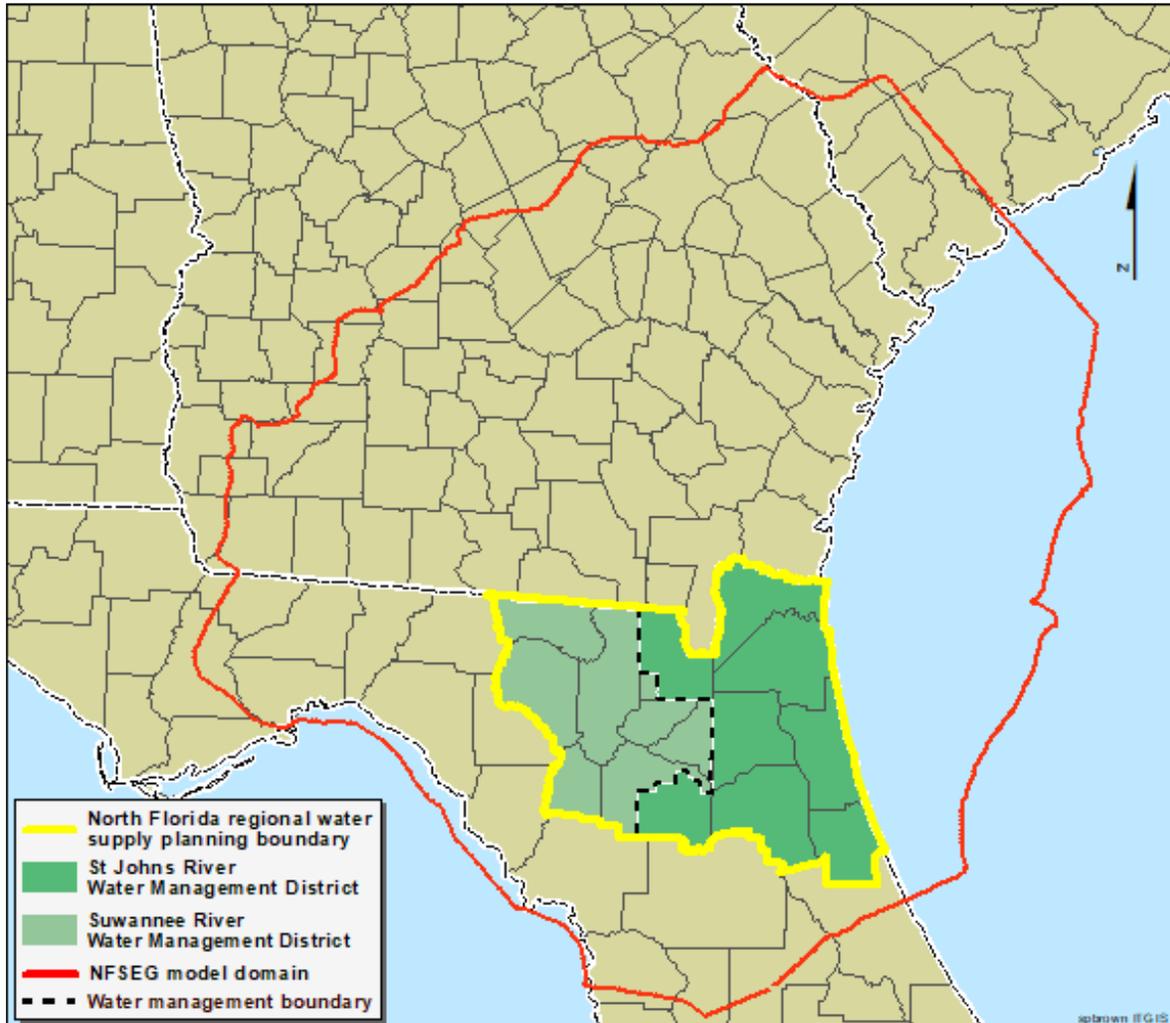


Figure 20. Area map showing the North Florida Southeast Georgia (NFSEG) model domain and the North Florida Regional Water Supply planning area boundary.

2.7 Reference Timeframe Flow

Evaluating the historic influence of water use on flows in regional rivers, springs, lakes, and estuaries is a component of the MFL process. As noted in Section 2.6, groundwater is the source of most potable water used in the region of the LSR/IR. To evaluate the historic influence of groundwater withdrawals, estimates of groundwater use over time were prepared for the area encompassed by the North Florida Southeast Georgia Model Domain (Figure 20).

The estimates were produced by county and by type of water use to capture the heterogeneous growth of groundwater demand through time. Estimates were prepared using published water use data, where available, and by estimating water use based on population where published water use estimates were not available.

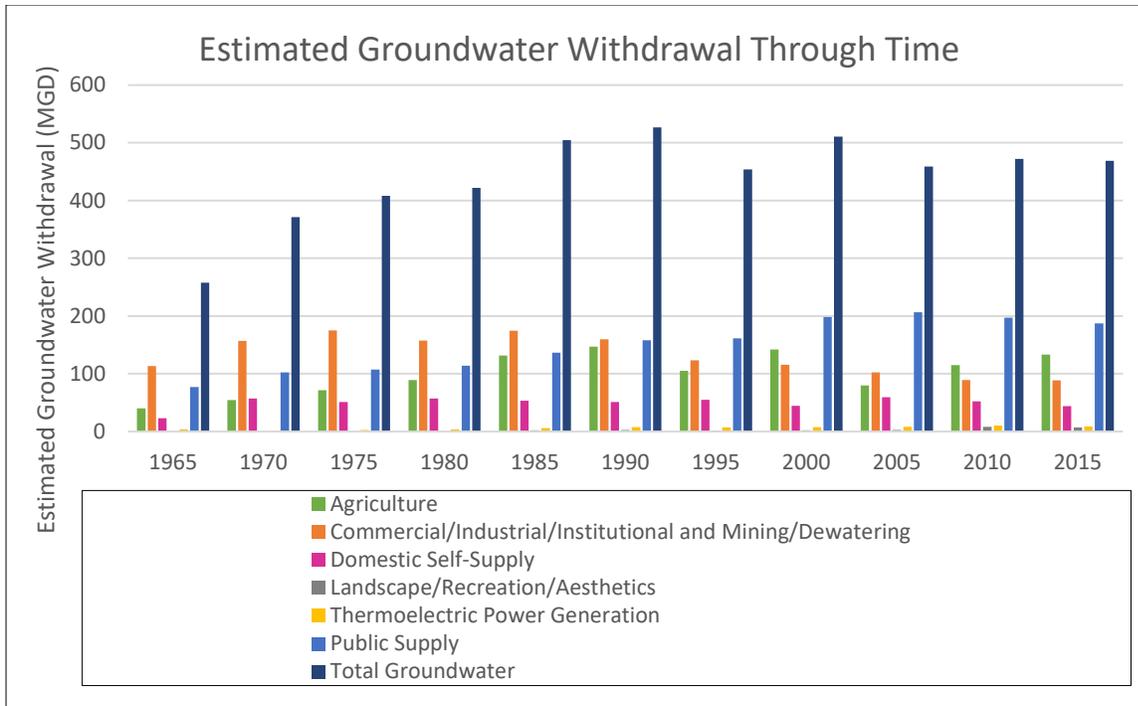


Figure 21. Estimated groundwater withdrawal for the planning area (1965-2015)

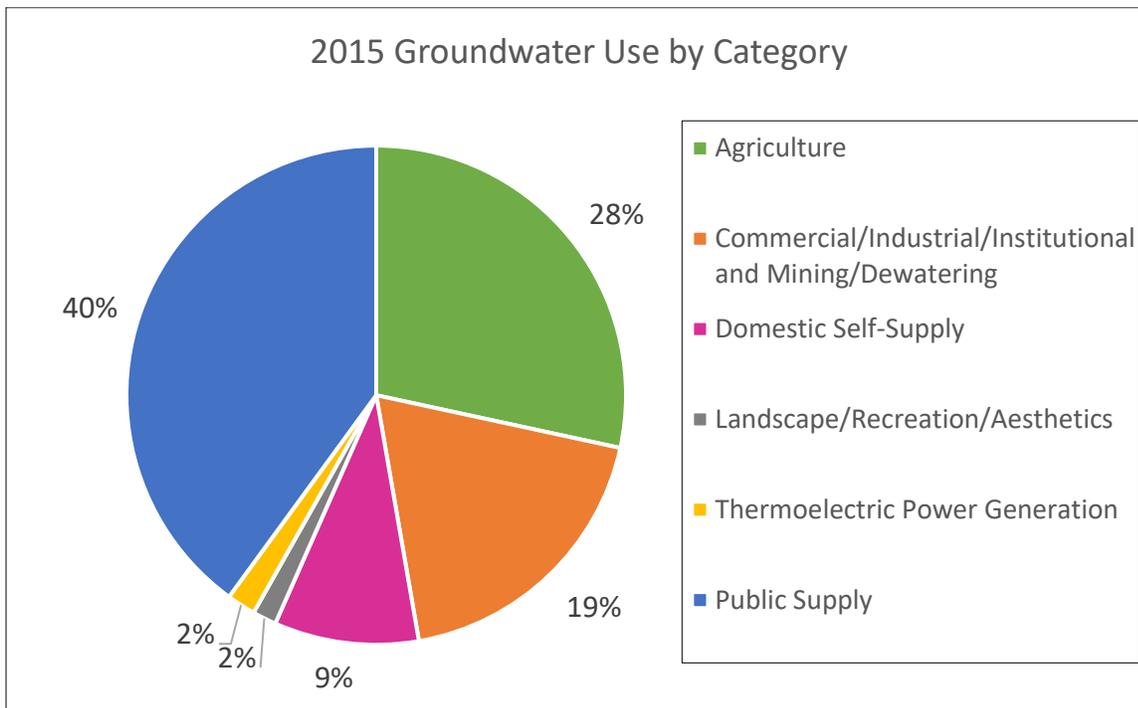


Figure 22. Estimated distribution of groundwater use in the planning area by category for 2015

These data were used to estimate the change in hydrologic conditions in the area due to groundwater withdrawals as a function of time. The estimates were then added to the observed record at selected

stream gage locations and at groundwater monitoring well sites. The result is an estimate of the historic time-series that would have been observed absent of any groundwater withdrawals; i.e., the resulting time-series is an estimate of the historic flow (or head) time-series from which impacts of groundwater withdrawals are removed. In this report, the term RTF flow is used to refer to these constructed time-series that would have been observed in the absence of groundwater withdrawals.

The maximum estimated daily historic net impacts at the Fort White, US441 and Hwy 27 (USGS 02322700) gages are about 75, 54 and 17 cfs, respectively (Figure 23). Appendix D outlines the process used to develop a RTF flow and/or groundwater-head (head) time-series at groundwater monitoring locations, springs and/or stream gage locations using NFSEG modeled data and the historic time-series of groundwater withdrawals.

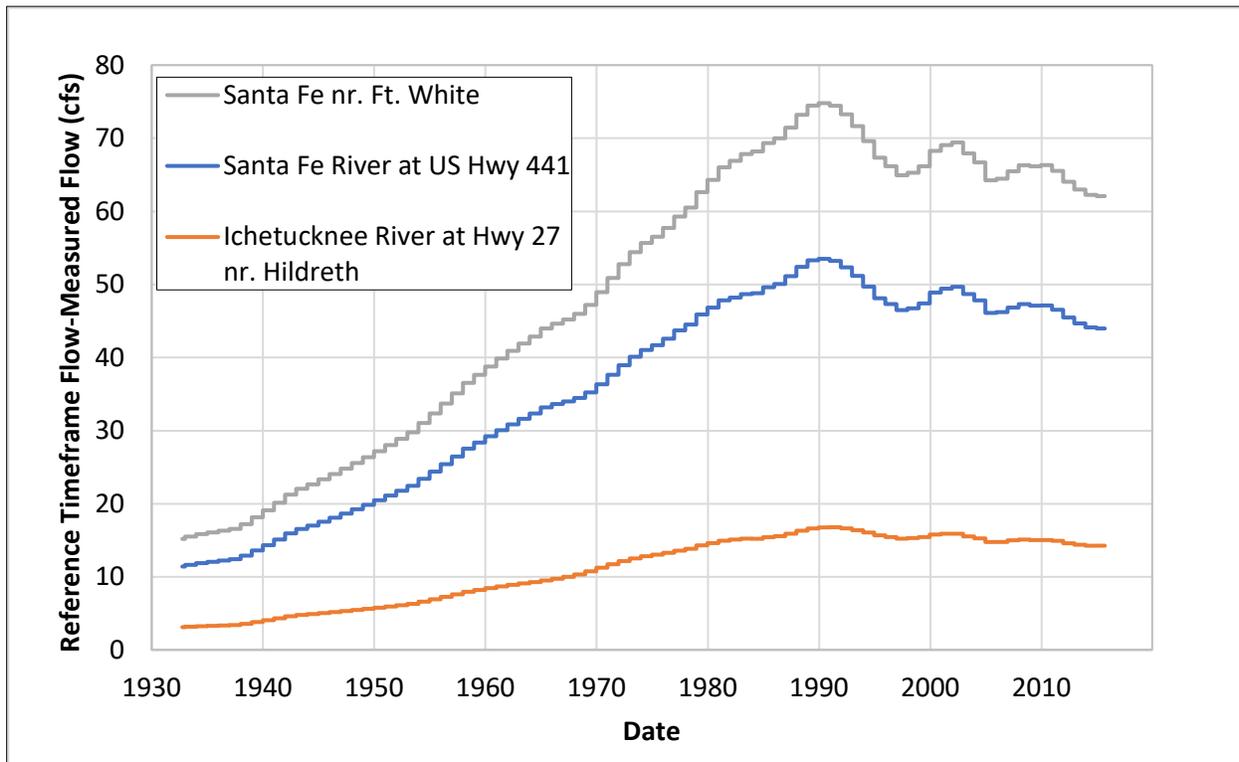


Figure 23. Estimated net groundwater withdrawal impacts at Fort White, US441 and Hwy 27 gages

2.7.1 Flow Characteristics

The difference between RTF and measured flows in the LSRF ranges from a minimum of 15.2 cfs to a maximum of about 75 cfs at the Fort White gage, and from 11.4 cfs to a maximum of about 55 cfs at US441 (Figure 24). The flow difference for the IR ranges from a minimum of 3.1 cfs to a maximum of about 17 cfs at the Hwy 27 gage (USGS 02322700) (Figure 25). The median RTF flows at Fort White, US 441, and Hildreth gages for the LSRF are 1,270 cfs, 552 cfs, and 1,819 cfs, respectively. The ratio of the median flow at US441 to Fort White is approximately 44% (Table 4). The relative flow difference at the Fort White gage, as a percent of RTF flow, ranges between 0.8% and 12.1% with an average of 3.4% (Figure 26). The relative flow difference for the IR Hwy 27 gage ranges between 0.2% and 18.2% with an average of 4.5% (Figure 26). The US441 graph is limited to 50% on y-axis because of zero flows within

US441 RTF and measured flow records. The maximum differences between the RTF and measured water levels at Lake City and High Springs wells are approximately 3.1 and 0.29 feet, respectively (Figure 27).

Table 4. RTF Median Flows at Fort White, US 441, and Hildreth gages

Gage	Hildreth (02322800)	Fort White (02322500)	US441 (02321975)	Worthington (02321500)
RTF Median	1,819 cfs	1,270 cfs	552 cfs	125 cfs
Ratio to Fort White	--	--	0.435	0.098

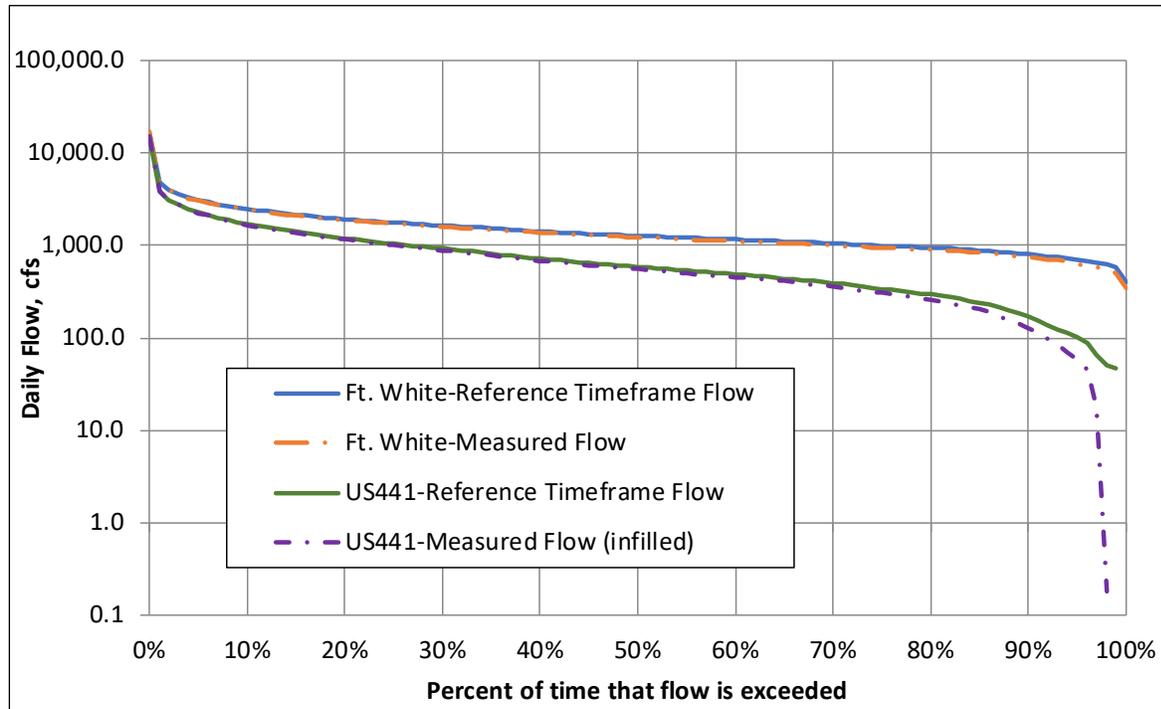


Figure 24. Flow Exceedance Curves (WY 1933-2015) for Santa Fe River Near Fort White (USGS 02322500), Santa Fe River at US Hwy 441 (USGS 02321975)

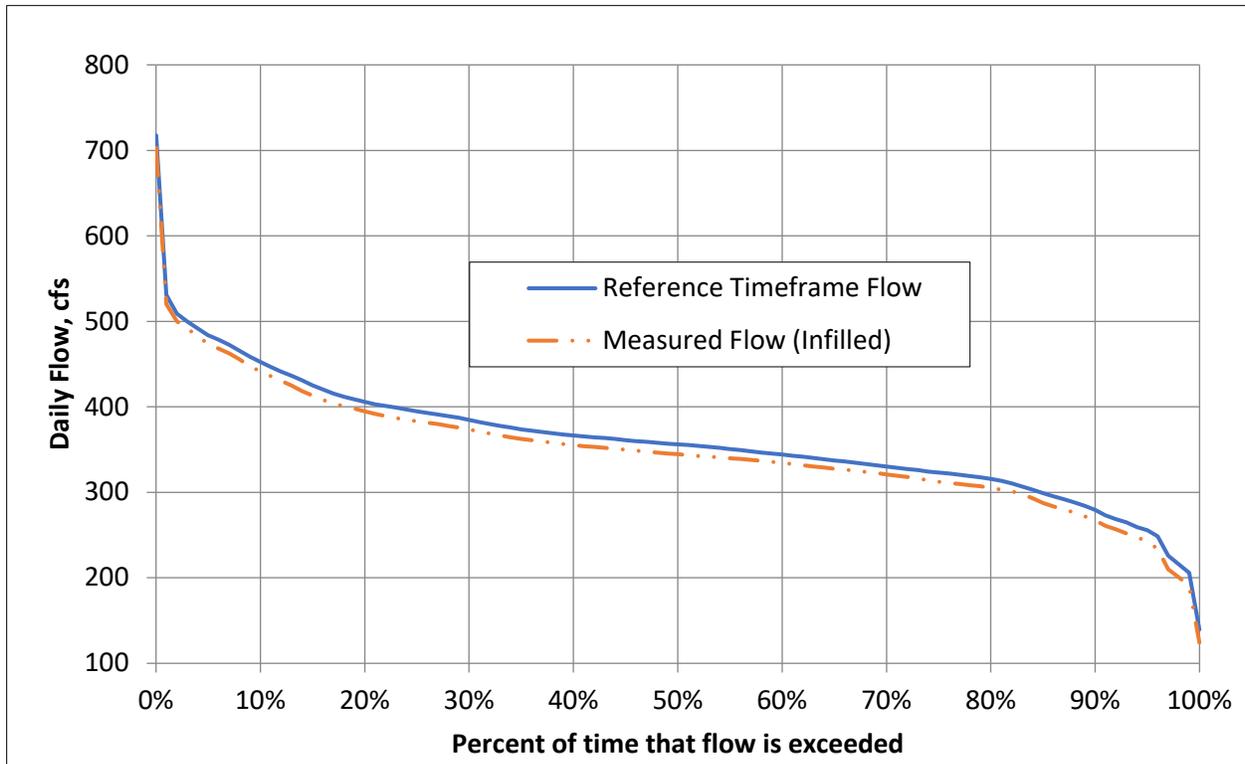


Figure 25. Flow Exceedance Curves for Ichetucknee River Near Hwy 27 (USGS 02322700)

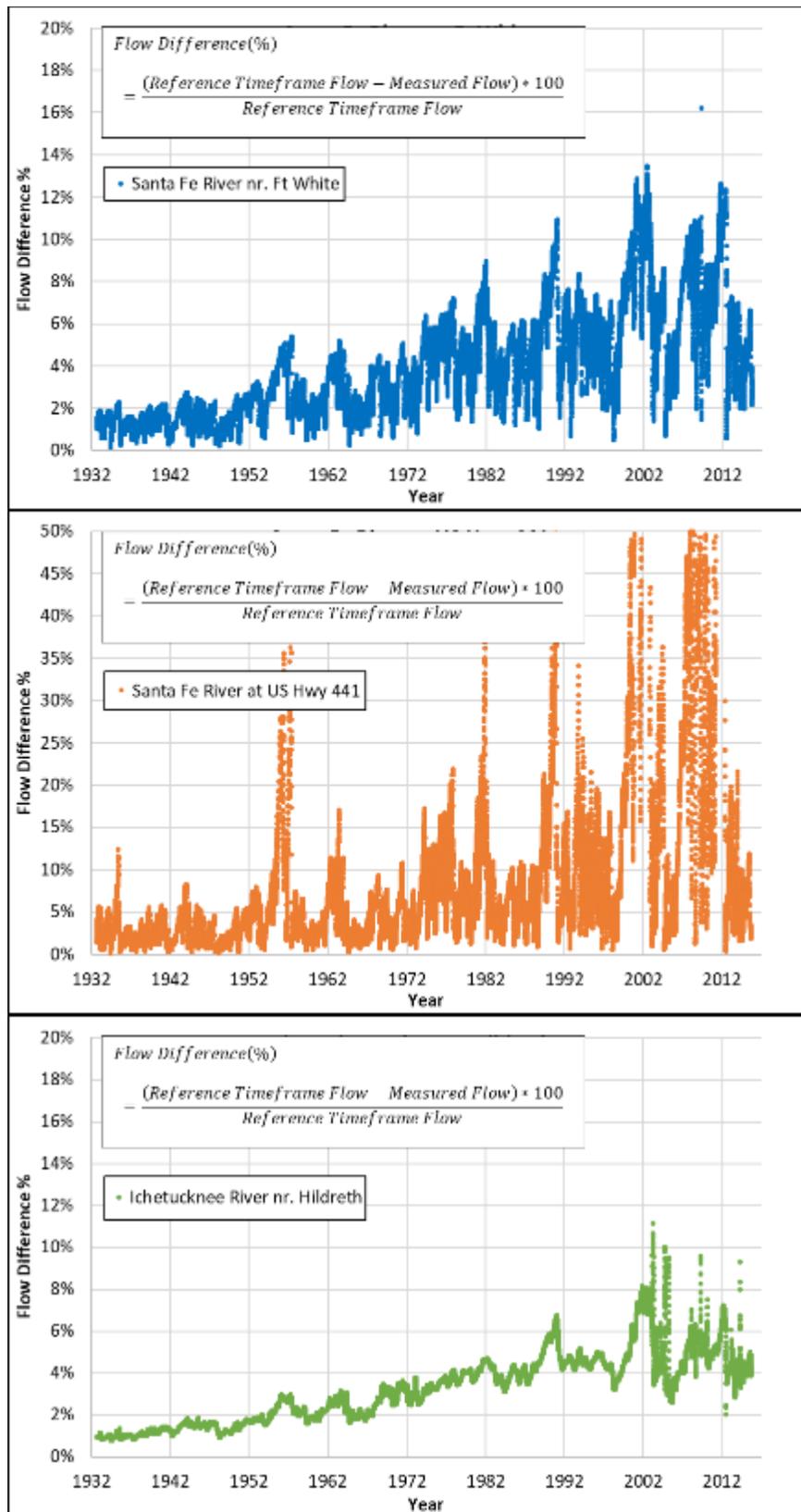


Figure 26. Temporal change in relative difference between RTF and measured flows at Fort White, US Hwy 441, and Hwy 27 gages.

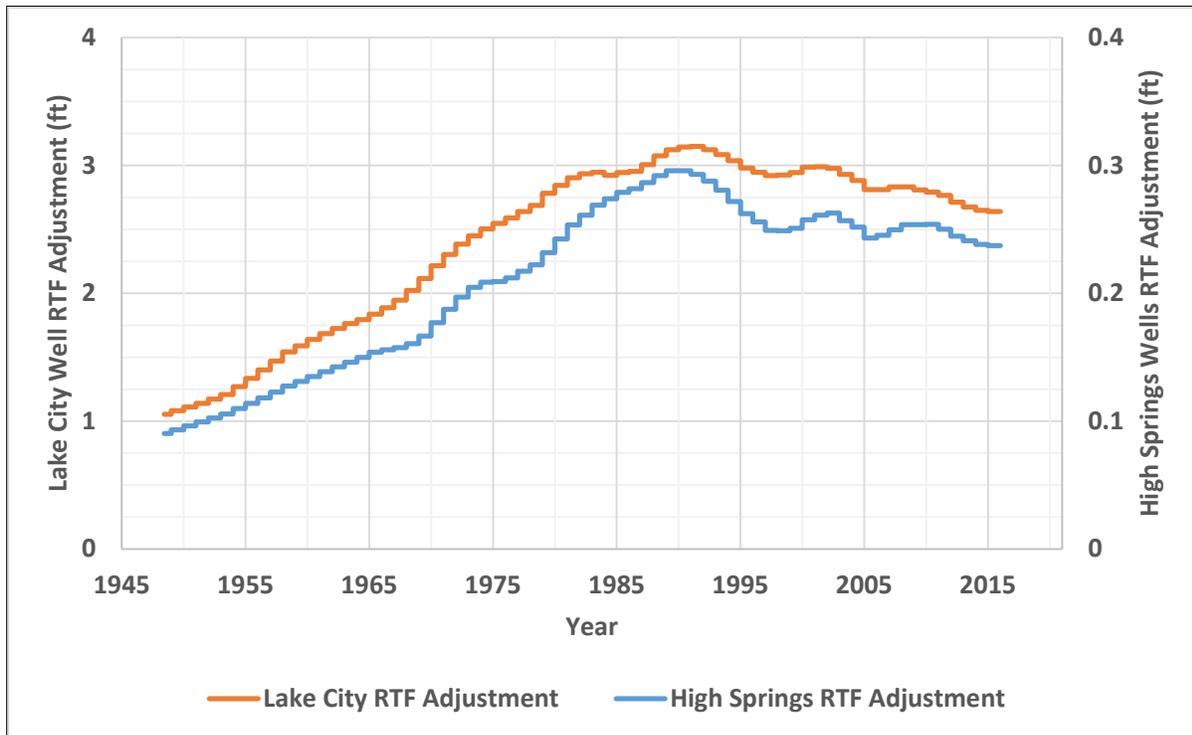


Figure 27. RTF Adjustments at Lake City and High Springs UFA Wells (1945 -2015)

3. BIOLOGY

Regionally significant riverine and floodplain ecological communities in and around the LSFR and IR are described in this section. Flow reductions in the LSFR/IR system have the potential to alter the hydrology of wetland habitats and instream aquatic habitats. Such alterations could potentially

- decrease the number and extent of semi-permanently inundated ponds;
- decrease the free-floating aquatic plants that grow only in riverine floodplain ponds;
- promote a shift to more upland species within the different riverine vegetative communities along the river;
- alter the percentage and cover of invasive species;
- reduce the type(s) and extent of aquatic habitats preferred/required by select invertebrate and vertebrate species; and
- increase residence time of water and potentially alter water chemistry including dissolved oxygen and temperature regimes.

3.1 Conceptual Ecological System Model

One goal of an MFLs assessment is to evaluate an allowable change in hydrology that would remain protective of the ecosystem and its component communities. 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 principal physical forces that influence river ecosystems are driven by hydrologic conditions (N. L. Poff, et al. 1997). Flow influences ecological integrity directly or indirectly via other factors such as water quality, physical habitat availability, and fish passage.

A simple Conceptual Ecological System Model (CESM) identifies the primary components of the LSFR/IR ecosystems, its major natural processes and characteristics that influence the river ecosystems, the geomorphological features affected by these processes, and biological attributes or indicators of these ecological responses (Figure 28). The climate of northern Florida and resulting hydrology influences the geometry and hydraulic characteristics of a river channel and floodplain. The resulting land surface topography and soil conditions influence the surrounding vegetation communities which are the habitats for the regional wildlife community.



Figure 28. Conceptual ecological system model variables

The primary CESM variables are as follows.

Hydrology — the volume and periodicity of water moving through the LSFR/IR system that is characterized frequently by a flow-duration curve.

Climate — the combined effects of precipitation, temperature, and other climatic factors that influence system hydrology.

Physiography — the physical geography of a watershed that influences system hydrology.

Channel / Floodplain Geometry — geomorphological features such as the channel and floodplain dimension, slope, and substrate which influence the association between hydrologic and hydraulic variables (i.e., stage-flow relation, stage-top width, etc.).

Vegetation Community — a group of plant populations that coexist in space and time within a defined area and interact directly or indirectly. Vegetation communities are distributed along a continuum and influenced by topography, soils, the amount and periodicity of water, and climate. In the study area, vegetation communities are grouped categorically by position relative to the main river channel, as follows.

Riverine – the LSFR/IR are ‘perennial streams,’ meaning they flow throughout the year, and, although water levels vary, there are plants that are highly water dependent and grow within the channel (e.g., submergent plants, such as the xanthophyte *Vaucheria sp.*; and emergent aquatic plants such as pennywort (*Hydrocotyle sp.*)).

Riparian zone – borders the river shorelines, where plants receive a constant supply of water at average flows. Rising above the river shoreline to the river top of bank are plant associations that vary in the amount of water they require and receive from the river when water levels are high, or from precipitation.

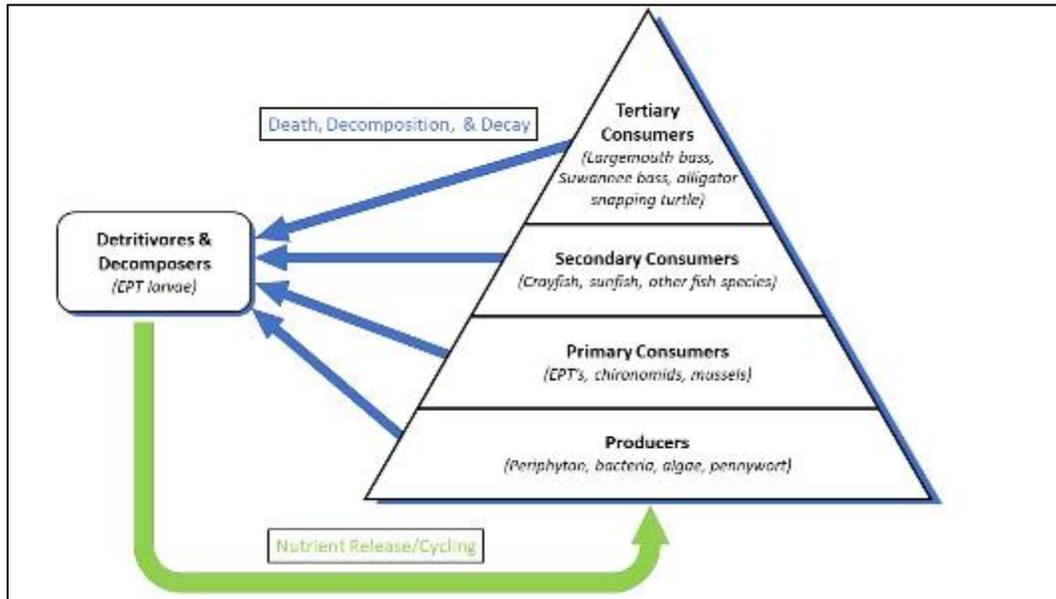
Floodplain – above the top of bank along much of the river, the floodway widens across the landscape and periodic flooding supports forested and emergent types of freshwater wetlands.

Habitat — places where an organism or a biological population normally lives or occurs (i.e., the location or environment where an organism is most likely to be found). For this MFLs assessment, habitat is grouped similarly to vegetation community by position relative to the river channel.

Wildlife Community — various species of invertebrate and vertebrate animal populations that coexist in space and time within a defined area and interact directly or indirectly. Because most species can move, the composition of the community can vary, often seasonally during migration, nesting, or spawning runs, or depending on forage availability. Wildlife species need space, shelter, and food, and are influenced by the habitats (topography, soils, and water), climate, and forage available to them.

Broad ecological functions, as well as species-specific needs, are considered for establishing MFLs. A simple conceptual model of the trophic relationships within the LSFR/IR system characterizes the roles of the aquatic organisms and relevance as forage for consumers (Figure 29). At the lowest level, plants and algae are producers that photosynthesize using the dissolved nutrients (nitrogen, phosphorus, etc.) in the water. At the next level, mussels and insects appear as primary consumers that consume bacteria, algae, and plants and produce detritus, while carnivorous (predatory) fish appear at the next level, the secondary consumers. The tertiary consumers are the top-level predaceous fish and reptiles in the river.

Organic matter produced by the decomposition of organisms at all four levels is recycled back to producers by detritivores and decomposers.



EPT – Ephemeroptera, Plecoptera and Trichoptera community

Figure 29. Conceptual trophic model

The multiple flow regimes considered when examining river flow requirements for instream and out-of-bank floodplain habitats are 1) flood flows that determine the boundaries of and shape the floodplain and valley features; 2) overbank or near-overbank flows that maintain riparian habitats; 3) in-channel flows that keep immediate stream banks and channels functioning; and 4) instream flows that sustain critical biota requirements such as fish passage, preferential habitat, and reproduction.

3.2 Riverine and Riparian Habitats

The initial MFLs report describes the riverine habitat characteristics of LSFR and IR (SRWMD 2013). The characteristics summarized in the report include the physical setting, substrate types and various important habitat areas (e.g. shoals), and much of that information is provided herein. The initial MFLs report peer review panel suggested additional focus on specific fish species that might be expected to be negatively affected by reduced flows (e.g. Suwannee bass) and emphasis on the effects of flow reduction on instream habitats, specifically vegetative habitats. Finally, the panel suggested additional emphasis and preliminary discussion on other species of interest such as Gulf sturgeon (*Acipenser oxyrinchus desotoi*), oval pigtoe, (*Pleurobema pyriforme*) and Ichetucknee siltsnail (*Floridobia mica*, formerly *Cincinnatia mica*), which are described in the following subsections.

Important fish habitat in the LSFR and IR channels include

- Littoral (submerged bank) areas, which may provide important fisheries habitat, particularly if vegetated with species of emergent or submergent aquatic plants or covered with tree roots and trunks.
- Submerged aquatic vegetation (SAV) beds. In the lower, spring-fed portion of the Santa Fe River, dense beds of eelgrass (*Vallisneria americana*), strapleaf sag (*Sagittaria kurziana*) and other

submerged aquatics provide important fish and invertebrate habitat (SRWMD, Surface Water Improvement and Management Plan 1995).

- Snag areas, submerged logs and brush, which have been shown to be important habitat areas for riverine invertebrates. Studies in other southeastern U.S. streams have shown that much of the invertebrate and fish production is associated with snags (SRWMD, Surface Water Improvement and Management Plan 1995).

The LSFR and IR support a wide variety of other organisms that depend on adequate river flows to sustain 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 water quality for the rivers.

Channel morphology determines local flow patterns and the extent of riparian vegetation that the river banks can support. Channel slope largely determines relative stream velocity, which in turn determines the suitability of habitat for 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 lower velocity. Conversely, hard-bottom, 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. Various fish taxa depend upon specific substrates for nesting sites.

Woody habitats (i.e., 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 (Figure 29).

Water quality can also influence the suitability of in-channel habitats. Critical water quality constituents 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 a wide variation in DO.

3.2.1 Lower Santa Fe River

The upper reaches of the LSFR are less incised and support a wide floodplain. Farther downstream (i.e., west of Fort White), the riverbanks become higher and steep, and the channel becomes broader and more incised. The channel of the LSFR is characterized by a combination of shoals, pools, and runs. Within a shoal there may be 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.

River runs are relatively regular with 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 at a higher elevation than the surrounding channel bottom and can restrict flow and promote 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. Shoals are found in several sections of the LSFR (Figure 30).

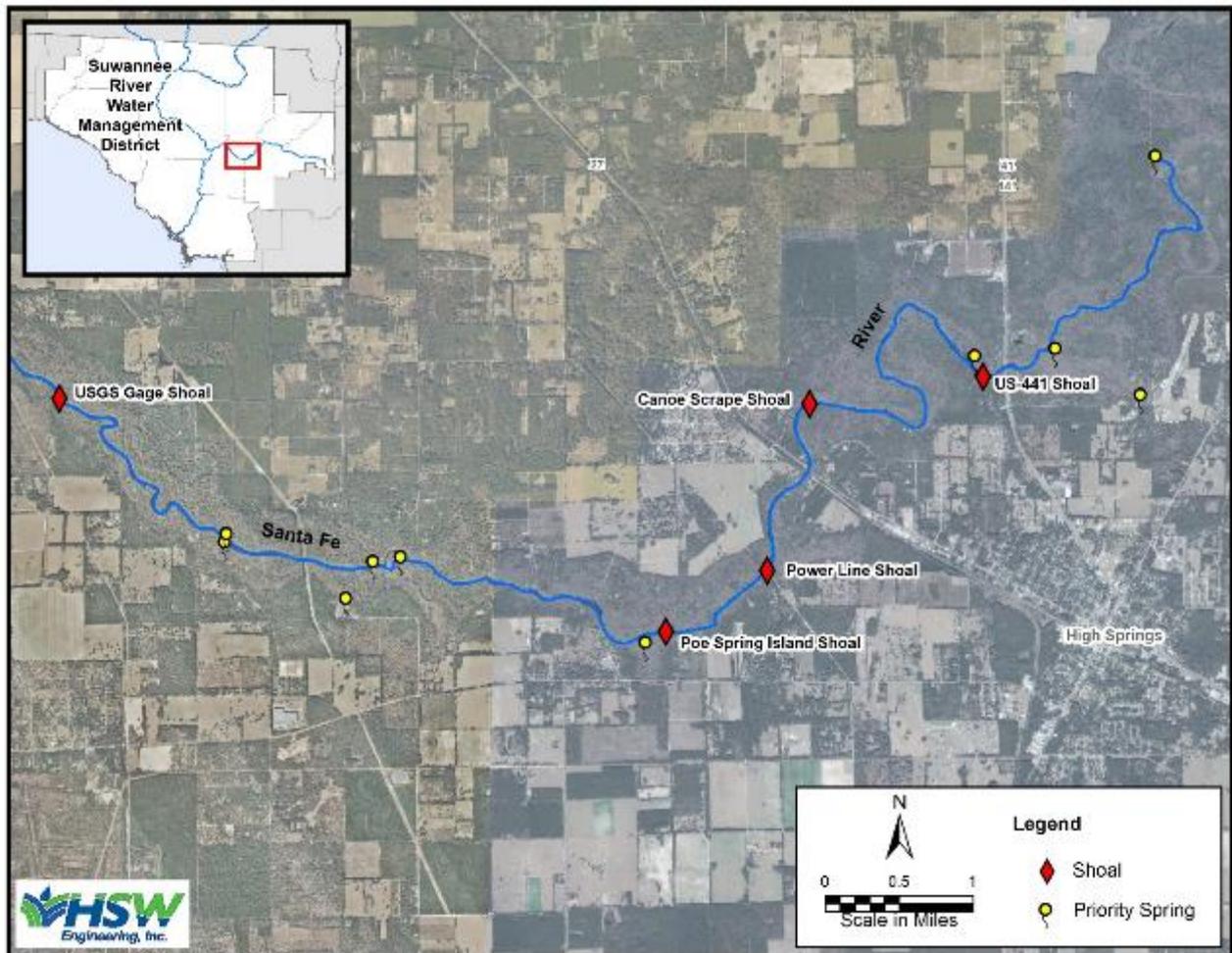


Figure 30. Shoals of interest in the upper reach of the Lower Santa Fe River

Just downstream of US 441 and near the Columbia Spring outfall, the river has a pool-and-riffle structure with well-developed shoals at intervals (Figure 31). Other shoals of interest have been identified just upstream of Poe Springs about 1.8 miles downstream of Highway 27, and about two miles upstream of SR 47 near the USGS Fort White gage (Figure 32). A shoal nicknamed “Canoe Scrape” is another major shoal feature in this portion of the LSFR (Figure 33). In several areas of the river between Fort White and the IR confluence, the river channel is composed of consolidated rock with many shoals.

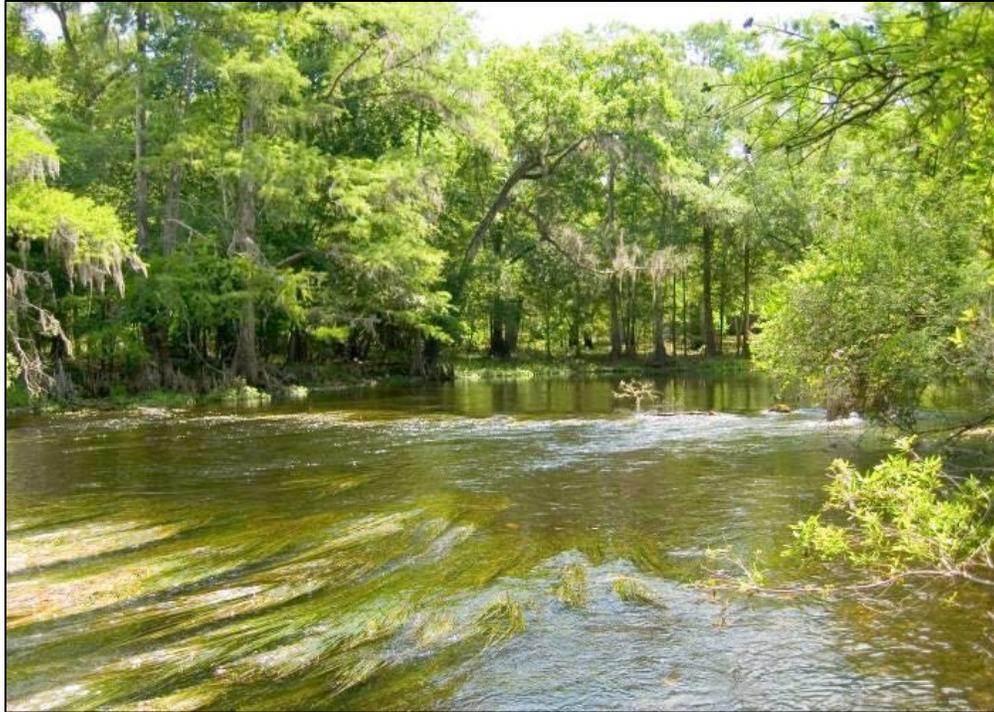


Figure 31. Chert (crystalline quartz rock) shoal on Lower Santa Fe River at Columbia Spring outfall.



Figure 32. Shoals on the Lower Santa Fe River near the USGS gage near Fort White



Figure 33. Canoe Scrape shoal on the Lower Santa Fe River.

Substrate type, which can be 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 (Figure 34). The LSFR features solid rock channel bottoms at shoals and other areas as well as unconsolidated, mainly sandy sediments. In the downstream-most section of the LSFR there are natural levees of Santa Fe marl along the bank, which may be several feet high.



Figure 34. Submerged aquatic vegetation in the Lower Santa Fe River near Fort White.

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 sedimentary rock composed of microcrystalline quartz (chert) (Figure 31).

The sources of water that enter a river also influence in-stream habitat availability. Although the LSFR receives abundant groundwater inflow, it does have a significant surface water input. 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.

3.2.2 Ichetucknee River

The upper portion of the IR run is narrow and confined in a limestone channel, eroded by the consistent spring flow. Downstream the high banks recede and are replaced by a wooded floodplain.

The channel slope of the IR is substantially steeper than the LSFR. 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.

Kurz, et al., 2004 (Kurz, R.C., Woithe and Notestein 2004) reports that in the IR the majority of channel bottom material at sampling sites was sands (46%) and mud (23%) which facilitates SAV growth (Figure 35). Limerock outcrop shoals occurs in the IR 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 IR is characterized by Grassy Flats, a broad marshy area. The IR receives almost all its water from springs. Although the flow does vary, the flow regime range is quite limited.

3.3 Floodplain habitat

Floodplains are unique environments that are subjected to saturation, inundation, and flow of surface water. All three of these hydrologic conditions are essential factors in the regeneration of floodplain species as well as the survival of established vegetation (Table 5). Although flooded conditions are generally unfavorable for terrestrial plant growth, tolerant species can benefit by the reduction of competition from flood-intolerant species. Other beneficial effects include the protection of submerged seeds from predation by terrestrial animals such as squirrels (H. M. Light, et al. 1993).

The ten-year floodplain of the LSFR, FEMA flood zone A for the IR, and wetland inventory data were evaluated to depict the general extent of wetland communities within the LSFR/IR floodplains. National Wetland Inventory data were used to be consistent with the 2013 MFLs analysis (SRWMD 2013). About 7,800 and 400 acres of combined Freshwater Emergent Wetlands and Freshwater Forested/Shrub Wetlands were characterized near the LSFR and IR (Figure 36 and Figure 37, respectively). The Natural Areas Inventory (FWC/FNAI) Florida Cooperative Land Cover (CLC) Map version 3.2 digital inventory of land cover was also used to examine floodplain wetland habitats near LSFR and IR. Based on the CLC V3.2 map, the more widespread floodplain wetland vegetation communities include Mixed Wetland Hardwoods, Floodplain Swamp, Other Wetland Forested Mixed, Bottomland Forest, Cypress, Bottomland Forest, Wet Prairie, and Other Hardwood Wetlands.

These floodplain forests fulfill a variety of ecological roles. When flooded, they constitute important nursery habitat for riverine fishes. These areas serve as massive flood detention areas, storing flood waters and “buffering” river flood peaks downstream. The floodplain forests contribute leaf litter and plant detritus which forms a basic food source in riverine food webs, consumed primarily by various invertebrates.

Table 5. Effects of hydrologic factors on floodplain vegetation

Hydrologic Factor	Beneficial effects on floodplain vegetation
Saturation	Acts as a selective factor for plants with either adaptations to anaerobic conditions or avoidance mechanisms which enable plant species to survive in areas where anaerobic conditions exist for at least part of the year. Within many forested wetlands, periods without standing water are necessary for the successful germination and growth of even the most inundation tolerant species of trees, such as cypress. Cypress seeds will not germinate underwater, hence periods of from 1 to 3 months without standing water are required for cypress regeneration.
Inundation	Has effects on plants beyond effects due to soil saturation; acts as a selective factor for species with seeds and seedlings that can survive submersion or that produce seeds and seedlings at favorable times of the year; protects submerged seeds and small plants from herbivores.
Flowing Water	Can damage or destroy some floodplain plants, but can benefit others by dispersing seeds, root pieces and small plants. Seeds that require bare mineral soils for germination benefit when flowing water scours the flood-plain surface. Some plants grow better in moving water than in stagnant water. Flowing water with sufficient velocity can select for those plants that can re-sprout after flood damage or select against species with shallow, poorly anchored root systems.

Sources: (Conner, Toliver and Sklar 1986), (H. M. Light, et al. 1993), (Fowells 1965)

3.4 Aquatic Biota

Best available data were used to identify aquatic species in the LSFR and IR and to evaluate the influence of flow reduction on their habitats. Taxonomic lists of invertebrates, vertebrates, and plants were reviewed to identify species dependent on the aquatic habitats and wetlands that could be affected by changes in river flows and levels.

3.4.1 Submerged Aquatic Vegetation

SAV in twelve spring pools and runs in the LSFR were surveyed during March 2017 for species composition, distribution, and relative abundance (Morris, Butt and Shemitz 2017). Twelve (12) species of higher taxa, two species of macrophytic algae, one species of aquatic moss and three types of filamentous algae were present in varying amounts (Table 6). Filamentous algae, Ludwigia, and Water pennywort were present at all the twelve (12) springs.

Approximately 78% of the IR bottom surface area upstream from US27 is covered by SAV. A comparison of inventories conducted in 1979 (Dutoit 1979) and in 2002 (Kurz, R.C., Sinphay, et al. 2003) indicated

that SAV coverage increased by 23 acres or 353% during the 24-year period (1979-2002). A follow-up re-mapping of the IR in 2004 showed a 2% decrease in SAV. The decrease was attributed to disturbances resulting from reconstruction of floating dock structures and changes in flow velocities caused by the installation of a new floating barrier across the river at the dock structures (Kurz, R.C., Woithe and Notestein 2004) (Figure 38). Findings from a FDEP survey in 2015 show percent coverage of aquatic vegetation increased from 46 percent in 1989 to 63 percent in 2015 while vegetation diversity decreased for the same period (Figure 39).



Figure 35. Submerged aquatic vegetation within the Ichetucknee River.

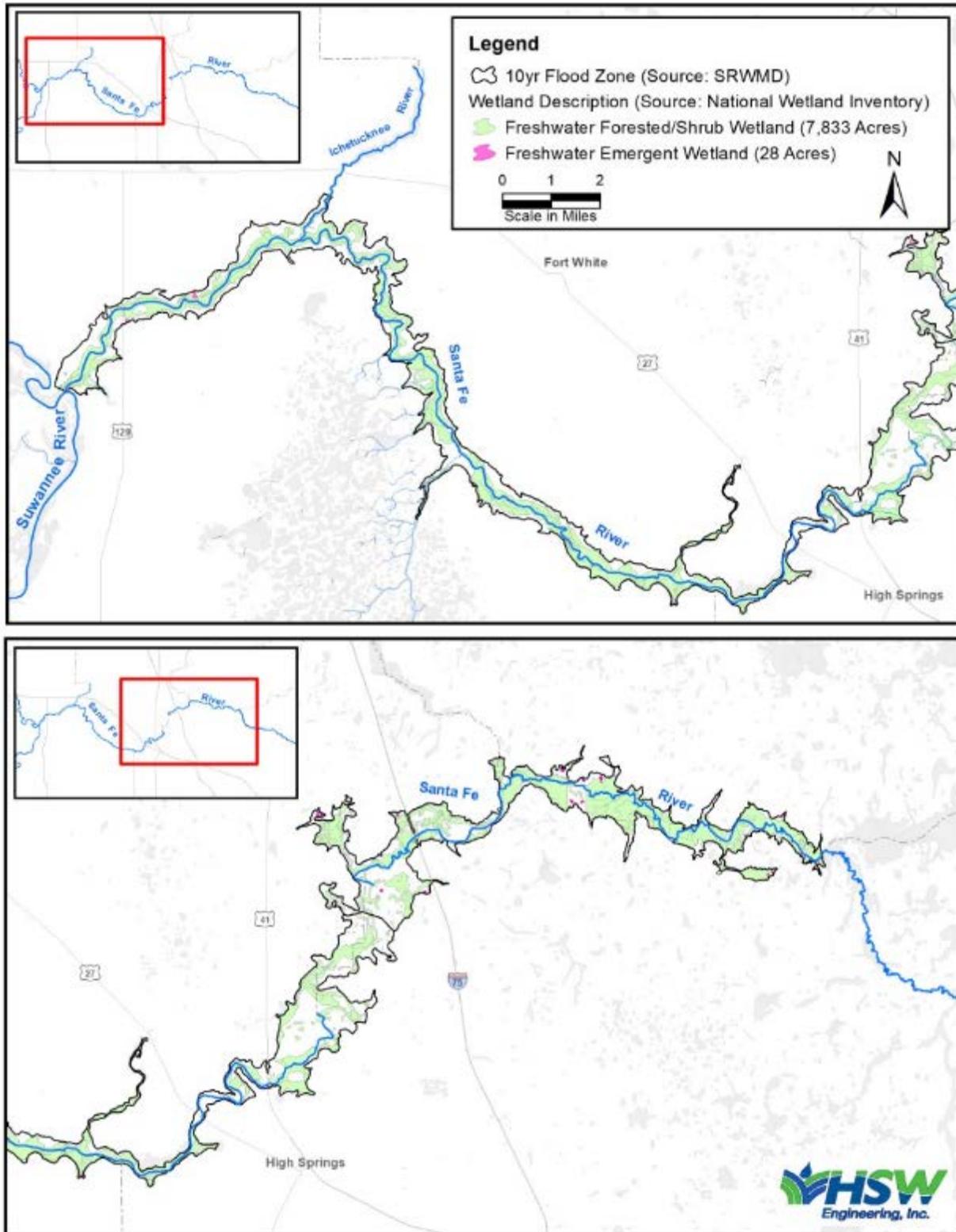


Figure 36. Extent of Lower Santa Fe River floodplain wetlands within the 10-year flood zone.

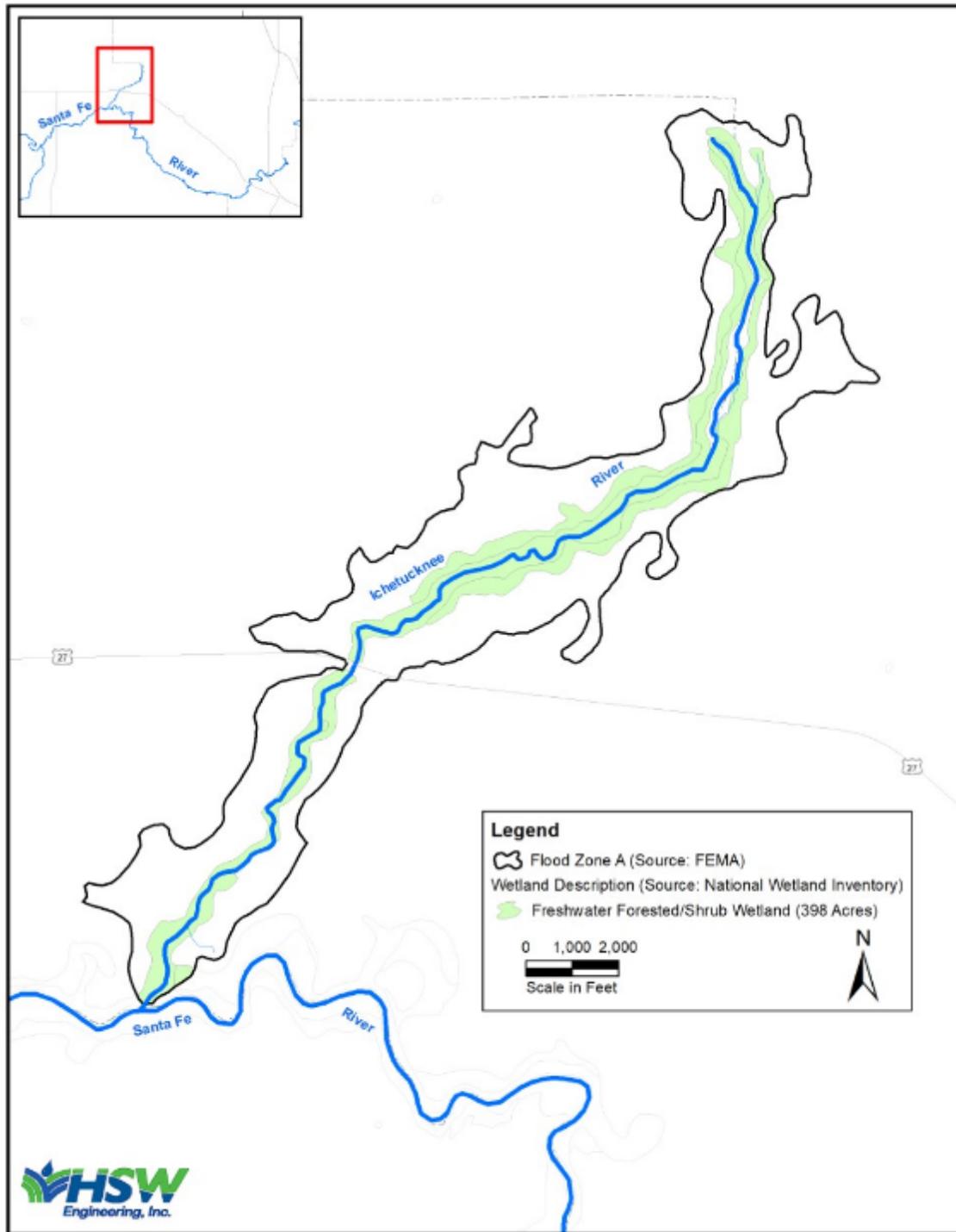


Figure 37. Extent of Ichetucknee River floodplain wetlands within Flood Zone A.

Table 6. Submerged aquatic vegetation species identified during a 2017 survey of the Lower Santa Fe River (Morris, Butt and Shemitz 2017)

Scientific name	Common name
Algae (Filamentous)	
<i>Vaucheria sp.</i>	Water felt
<i>Lyngbya wallei</i>	Lyngbya
<i>Spirogyra sp.</i>	Water silk
<i>Alternanthera philoxeroides</i>	Alligator weed
<i>Utricularia sp.</i>	Bladderwort
<i>Chara sp.</i>	Chara (Muskgrass)
<i>Ceratophyllum demersum</i>	Coontail
<i>Vallisneria americana</i>	Eelgrass
<i>Hydrilla verticillata</i>	Hydrilla
<i>Hygrophila polysperma</i>	Hygrophila
<i>Ludwigia repens</i>	Ludwigia (Purple ludwigia)
<i>Najas guadalupensis</i>	Naiad
<i>Nuphar advena</i>	Spatterdock
<i>Nitella sp.</i>	Stonewort
<i>Sagittaria kurziana</i>	Tapegrass
<i>Rorippa sp.</i>	Watercress
<i>Fontinalis sp.</i>	Water moss
<i>Hydrocotyle umbellata</i>	Water pennywort

The Ichetucknee System is dominated by the following species of submerged and emergent aquatic vegetation (Kurz, R.C., Sinphay, et al. 2003):

- Tapegrass (*Sagittaria kurziana*)
- Wild rice (*Zizania aquatica*)
- Eelgrass (*Vallisneria americana*)
- Stonewort (*Nitella sp.*)
- Water milfoil (*Myriophyllum heterophyllum*)
- Water primrose (*Ludwigia repens*)
- Water pennywort (*Hydrocotyle sp.*)

Other aquatic vegetation species identified by Florida Park Service staff include:

- Streambank spider lily (*Hymenocallis lirisome*)
- Cardinal flower (*Lobelia cardinalis*)
- Watercress (*Rorippa officinale*)
- Spotted water hemlock (*Cicuta maculata*)

Recreational use was a key factor in SAV abundance in the IR. Recreational impacts on SAV abundance are especially acute during low water level conditions caused by long-term drought conditions (Kurz, R.C., Sinphay, et al. 2003).



Figure 38. Location of submerged aquatic vegetation re-mapping transects in the Ichetucknee River. [Source: (Kurz, R.C., Woithe and Notestein 2004)]

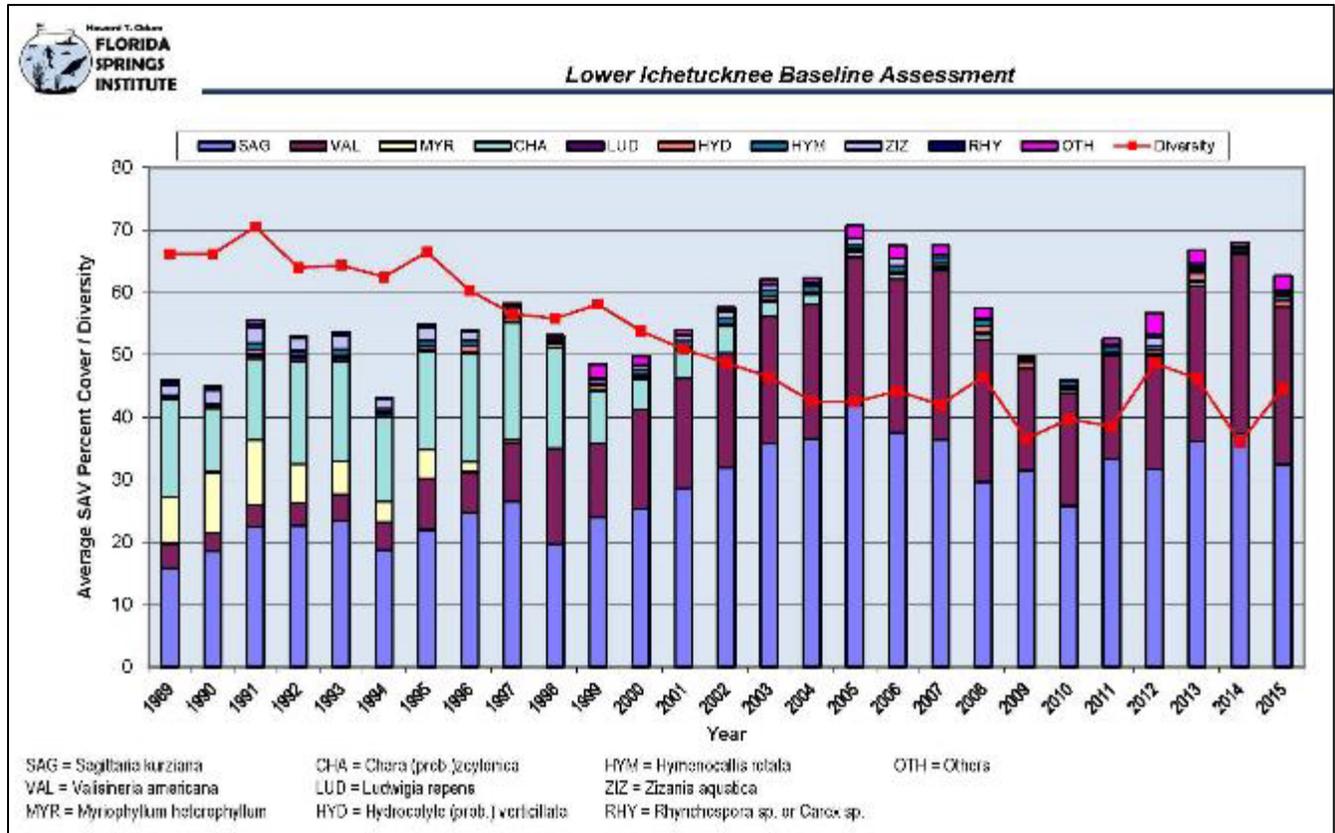


Figure 39. Upper Ichetucknee River aquatic vegetation transect summary [Source: (Florida Springs Institute 2016)]

The MFL re-evaluation is focused more on the presence/absence of SAV as a whole, rather than on particular species and their relative importance for habitat, forage, and streambed stabilization. As noted above, recreation is known to impact SAV abundance. Water quality changes such as ionic composition (e.g., calcium) may also play a role. Insufficient data were available for time period illustrated in Figure 39 to evaluate an association, but may be a valuable future line of inquiry.

King (2014) suggested that hydrodynamics could contribute to, or even dominate, the control of filamentous macroalgae on and attached to SAV in Florida spring runs (King 2014). An optimum velocity range of 0.8-2.3 ft/s for SAV in the Silver River was used below which the macrophyte beds are subject to invasion by macroalgae, and above which the macrophyte beds cannot withstand the drag forces.

In a recent study on spring flow reversal and effects on macrophytes (Hensley and Cohen 2017), the authors demonstrated that reversal pulses (episodic events) have increased in frequency and duration and posited that these changes may have created a “trophic cascade” within certain springs resulting in negative effects on algae consumers. This contrasts with the more frequently reported “press (i.e., persistent, chronic) disturbances” associated with nutrient enrichment of groundwater and surface water from anthropogenic activities. Springs susceptible are those with high DO concentrations and with short spring runs such that acidic, high organic carbon (DOC) rich river water can flood the springs and adjacent aquifer. Five springs in the Suwannee River basin were evaluated (White Sulphur, Troy, Fanning, Madison Blue, and Poe). Poe Spring is an OFS on the LSFR. Spring flow reversals occur when the river stage adjacent to the spring is greater than the spring sill (hydraulic control) and the adjacent

aquifer potential. By examining five-year intervals of hydrologic data (spring flow, river stage and groundwater potential data) from 1980 to 2014, the authors reported that flow reversals have increased in frequency and duration over time, while river stage remained relatively stable. The implication is that groundwater declines are the primary driver of temporal changes in flow reversal. They also reported that the increase in frequency and duration of flow reversals was “remarkably consistent” with the emergence of nuisance algal mats.

3.4.2 Aquatic Macroinvertebrates

The macroinvertebrate community in the LSFR is considered to be very healthy, based on water quality and biological samples collected during 2015 (Water and Air Research, Inc. 2015). The effects of stream velocity and other important environmental factors on the distribution, abundance, and diversity of aquatic macroinvertebrates in IR above US 27 were evaluated (Steigerwalt 2005). Statistical analyses indicated that overall macroinvertebrate density could be accurately predicted based on epiphyton biomass, dissolved oxygen, and canopy cover. Stream velocity was also important for explaining the biomass of some macroinvertebrate groups, especially the stoneflies (*Plecoptera*) and mayflies (*Ephemeroptera*). The author concluded that stream velocity may be most important to spring run macroinvertebrate fauna due to its effects on replenishing dissolved oxygen in areas of low concentrations (near spring boils). The most sensitive macroinvertebrate species based on dissolved oxygen requirements may be most affected by flow reductions and resulting decreases in stream velocity.

3.4.3 Fish

About 43 species of fish were reported circa 1967 in the blackwater river habitat of the LSFR. Mosquito fish (*Gambusia holbrooki*), brook silverside (*Labidesthes sicculus*), redbreast sunfish (*Lepomis 51alker51*), redear sunfish (*L. microlophus*), bluefin killifish (*Lucania goodei*), largemouth bass (*Micropterus salmoides*), and golden shiner (*Notemigonus crysoleucas*) were the most abundant species ((Hellier, Jr. 1967) and (Johnston, et al. 2016)).

Two sets of fisheries data collected by the FWC and provided by the District were reviewed. Sampling methods included electroshocking and seining. The historical database includes results from surveys conducted from 1972 through 1998, and the dataset from FWC’s statewide standardized long-term monitoring program includes surveys from 2015 to 2018. More than 60 fish species are included in the two databases (Table 7).

Table 7. Species of fish in the Santa Fe River reported by FWC from 1972 through 2018

Common name	Scientific name
Alabama shad	<i>Alosa alabamae</i>
mountain mullet	<i>Agonostomus monticola</i>
white catfish	<i>Ameiurus catus</i>
yellow bullhead	<i>Ameiurus natalis</i>
brown bullhead	<i>Ameiurus nebulosus</i>
spotted bullhead	<i>Ameiurus serracanthus</i>
bowfin	<i>Amia calva</i>

Common name	Scientific name
American eel	<i>Anguilla rostrata</i>
pirate perch	<i>Aphredoderus sayanus</i>
flier	<i>Centrarchus macropterus</i>
warmouth	<i>Chaenobryttus gulosus</i>
bannerfin shiner	<i>Cyprinella leedsii</i>
American gizzard shad	<i>Dorosoma cepedianum</i>
Everglades pygmy sunfish	<i>Elassoma evergladei</i>
Okefenokee pygmy sunfish	<i>Elassoma okefenokee</i>
banded pygmy sunfish	<i>Elassoma zonatum</i>
blue-spotted sunfish	<i>Enneacanthus gloriosus</i>
lake chubsucker	<i>Erimyzon sucetta</i>
redfin pickerel	<i>Esox americanus</i>
chain pickerel	<i>Esox niger</i>
brown darter	<i>Etheostoma edwini</i>
swamp darter	<i>Etheostoma fusiforme</i>
golden topminnow	<i>Fundulus chrysotus</i>
russetfin topminnow	<i>Fundulus escambiae</i>
lined topminnow	<i>Fundulus lineolatus</i>
Seminole killifish	<i>Fundulus seminolis</i>
Eastern mosquitofish	<i>Gambusia holbrooki</i>
least killifish	<i>Heterandria formosa</i>
channel catfish	<i>Ictalurus punctatus</i>
brook silverside	<i>Labidesthes sicculus</i>
spotted gar	<i>Lepisosteus oculatus</i>
longnose gar	<i>Lepisosteus osseus</i>
Florida gar	<i>Lepisosteus platyrhincus</i>
redbreast sunfish	<i>Lepomis auritus</i>
warmouth	<i>Lepomis gulosus</i>
bluegill	<i>Lepomis macrochirus</i>
dollar sunfish	<i>Lepomis marginatus</i>
redear sunfish	<i>Lepomis microlophus</i>
spotted sunfish	<i>Lepomis punctatus</i>
pygmy killifish	<i>Leptolucania ommata</i>
bluefin killifish	<i>Lucania goodei</i>
Suwannee bass	<i>Micropterus notius</i>
largemouth bass	<i>Micropterus salmoides</i>
spotted sucker	<i>Minytrema melanops</i>
striped mullet	<i>Mugil cephalus</i>
white mullet	<i>Mugil curema</i>
speckled worm eel	<i>Myrophis punctatus</i>
golden shiner	<i>Notemigonus crysoleucas</i>
ironcolor shiner	<i>Notropis chalybaeus</i>

Common name	Scientific name
redeye chub	<i>Notropis harperi</i>
taillight shiner	<i>Notropis maculatus</i>
coastal shiner	<i>Notropis petersoni</i>
weed shiner	<i>Notropis texanus</i>
tadpole madtom	<i>Noturus gyrinus</i>
speckled madtom	<i>Noturus leptacanthus</i>
pugnose minnow	<i>Opsopoeodus emiliae</i>
blackbanded darter	<i>Percina nigrofasciata</i>
sailfin molly	<i>Poecilia latipinna</i>
black crappie	<i>Pomoxis nigromaculatus</i>
metallic shiner	<i>Pteronotropis metallicus</i>
Atlantic needlefish	<i>Strongylura marina</i>
Gulf pipefish	<i>Syngnathus scovelli</i>
hogchoker	<i>Trinectes maculatus</i>

The Florida Springs Institute conducts visual fish counts monthly in the Lower IR. A total of 17 fish species (Table 8) were observed during the February 2018 fish surveys conducted on the IR (Florida Springs Institute 2018).

Table 8. Species of fish in the Ichetucknee River reported by Florida Springs Institute for 2018

Common name	Scientific name
pirate perch	<i>Aphredoderus sayanus</i>
lake chubsucker	<i>Erimyzon sucetta</i>
redfin pickerel	<i>Esox americanus</i>
darther sp.	<i>Etheostoma sp.</i>
Seminole killifish	<i>Fundulus seminolis</i>
killifish sp.	<i>Fundulus sp.</i>
Florida gar	<i>Lepisosteus platyrhincus</i>
sunfish sp.	<i>Lepomis sp.</i>
Suwannee bass	<i>Micropterus notius</i>
largemouth bass	<i>Micropterus salmoides</i>
spotted sucker	<i>Minytrema melanops</i>
striped mullet	<i>Mugil cephalus</i>
golden shiner	<i>Notemigonus crysoleucas</i>
minnows	<i>Notropis sp.</i>
Sailfin molly	<i>Poecilia latipinna</i>
Atlantic needlefish	<i>Strongylura marina</i>
hogchoker	<i>Trinectes maculatus</i>

3.4.4 Threatened and Endangered Species

Federally designated threatened and endangered (T&E) species are listed by the U.S. Fish and Wildlife Service (USFWS 2018). Florida state-designated endangered and threatened species of wildlife are listed by the Florida Fish and Wildlife Conservation Commission (FNAI 2018).

Six wading birds are listed of which only the wood stork (*Mycteria americana*) is designated by the state and federal government as threatened, and the remainder are state-designated species of special concern (Table 9). Three other state-designated species of special concern are the Santa Fe Cave crayfish (*Procambarus erythroptus*), alligator snapping turtle (*Macrochelys temminckii*), and Suwannee cooter (*Pseudemys concinna suwanniensis*). A key fish species of interest that depends on aquatic habitat within the LSFR/IR is Gulf sturgeon, which is listed as threatened by the U.S. Fish and Wildlife Service. Although the Suwannee moccasinshell (*Medionidus walkeri*) mussel is not currently listed at the state level, the federal government has listed it as a threatened species under the Endangered Species Act of 1973 (Table 9). Of the T&E species that are dependent on riverine or wetland habitats in the study area, habitat suitability criteria for Gulf sturgeon and surrogate host fish for mussels exist for developing representative hydrologic indicators for MFLs analysis.

Table 9. Species deemed likely at risk from Lower Santa Fe River /Ichetucknee River flow and water-level reductions.

Scientific name	Common name	Florida state status ¹ (FNAI rank ²)	Federal status ³
Birds			
<i>Aramus guarana</i>	Limpkin	N (S3)	---
<i>Egretta caerulea</i>	Little Blue Heron	ST (S4)	---
<i>Egretta thula</i>	Snowy Egret	N (S3)	---
<i>Egretta tricolor</i>	Tricolored Heron	ST (S4)	---
<i>Eudocimus albus</i>	White Ibis	N (S4)	---
<i>Mycteria americana</i>	Wood Stork	FT (S2)	T
Caddisflies			
<i>Chimarra florida</i>	Floridian Finger-net Caddisfly	N(S3S4)	---
<i>Hydroptila bernerii</i>	Berner's Microcaddisfly	N(S3)	---
Crustaceans			
<i>Procambarus erythroptus</i>	Santa Fe Cave crayfish	ST(S1)	
Mayflies			
<i>Asioplax dolani</i>	A Mayfly	N (S1S2)	---
<i>Pseudocentropiloides usa</i>	A Mayfly	N (S2S3)	---
<i>Siphloplecton simile</i>	A Mayfly	N (S1S2)	---
<i>Stenacron floridense</i>	A Mayfly	N (S3S4)	---
Fishes			
<i>Micropterus notius</i>	Suwannee Bass	N (S3)	---
<i>Acipenser oxyrinchus desotoi</i>	Gulf Sturgeon	FT (S2)	T
<i>Acantharchus pomotis</i>	Mud Sunfish	N (S3)	---
<i>Ameiurus serracanthus</i>	Spotted Bullhead	N (S3)	---
<i>Cyprinella leedsii</i>	Bannerfin Shiner	N (S3)	---
<i>Umbra pygmaea</i>	Eastern Mudminnow	N (S3)	---

Scientific name	Common name	Florida state status ¹ (FNAI rank ²)	Federal status ³
Mollusks			
<i>Pleurobema pyriforme</i>	Oval Pigtoe	FE (S1S2)	E
<i>Medionidus walkeri</i>	Suwannee Moccasinshell	FT (S1)	T
Snails			
<i>Floridobia mica</i>	Ichetucknee Siltsnail	N (S1)	---
Reptiles			
<i>Macrochelys temminckii</i>	Alligator Snapping Turtle	SSC (S2) ⁴	PT
<i>Pseudemys concinna suwanniensis</i>	Suwannee Cooter	SSC (S3)	---
Mammals			
<i>Trichechus manatus</i>	West Indian Manatee	FE (G2/S2)	T

1. State status designated as FE (Federally-designated Endangered), FT (Federally-designated Threatened), ST (State population listed as Threatened by the FWC), SSC (Species of Special Concern), and N (Not currently listed, nor currently being considered for listing);
2. Florida Natural Areas Inventory (FNAI) rank designated as:
 S1 = Critically imperiled in Florida because of extreme rarity (five or fewer occurrences or fewer than 1,000 individuals) or because of extreme vulnerability to extinction due to some natural or man-made factor,
 S2 = Imperiled in Florida because of rarity (six to 20 occurrences or fewer than 3,000 individuals or because of vulnerability to extinction due to some natural or man-made factor),
 S3 = Either very rare and local throughout its range (21-100 occurrences or fewer than 10,000 individuals) or found locally in a restricted range or vulnerable to extinction from other factors, and
 S4 = Apparently secure in Florida (may be rare in parts of range).
3. G2 = Imperiled globally because of rarity (6 to 20 occurrences or less than 3000 individuals) or because of vulnerability to extinction due to some natural or man-made factor. Federal status designated as PT (Proposed Threatened), E (Endangered) and T (Threatened).
4. FNAI designates the Suwannee alligator snapping turtle (*Macrochelys suwanniensis*) as N (S1S2).

3.4.5 Manatee

The Florida manatee (*Trichechus manatus latirostris*) is a subspecies of West Indian manatee that exists almost exclusively in the southeastern United States. Florida manatees, particularly juveniles, are vulnerable to death from cold stress when the water temperature falls below 68 °F for long periods of time, or to temperatures of 50 °F or less for short periods up to a few days (Bossart, et al. 2002). Manatees have been observed in the LSFR and IR, and sightings are reported to the Florida Parks Service and Florida Fish and Wildlife Conservation Commission. Although none of the springs in the LSFR/ IR system have been identified as significant thermal refugia for manatees (Warm Water Task Force 2004), the frequent manatee sightings suggest that the LSFR and IR are providing a seasonal habitat and food source for manatees.

The interaction of discharge, temperature, and morphology determine the suitability of rivers or springs as a thermal refuge. Many springs in Florida are known to provide important warm-water refuge during the winter for manatees when river water temperatures drop below 68 °F (Warm Water Task Force 2004). The District collected or obtained water temperature data during the recent winter months of December 2017 through February 2018. During this period, the IR water temperature occasionally dipped below 68 °F while spring discharges from Blue Hole spring remained at 72 °F. During the winter

months, the LSRF water temperature more frequently dipped below 68 °F and sometimes as low as 61 °F which would cause manatees to seek thermal refuge in spring vents (Figure 40). IR water temperature varied generally with season and longitudinally with a diminishing spring signature moving downstream from the spring sources towards the well-mixed water at the IR/SFR confluence.

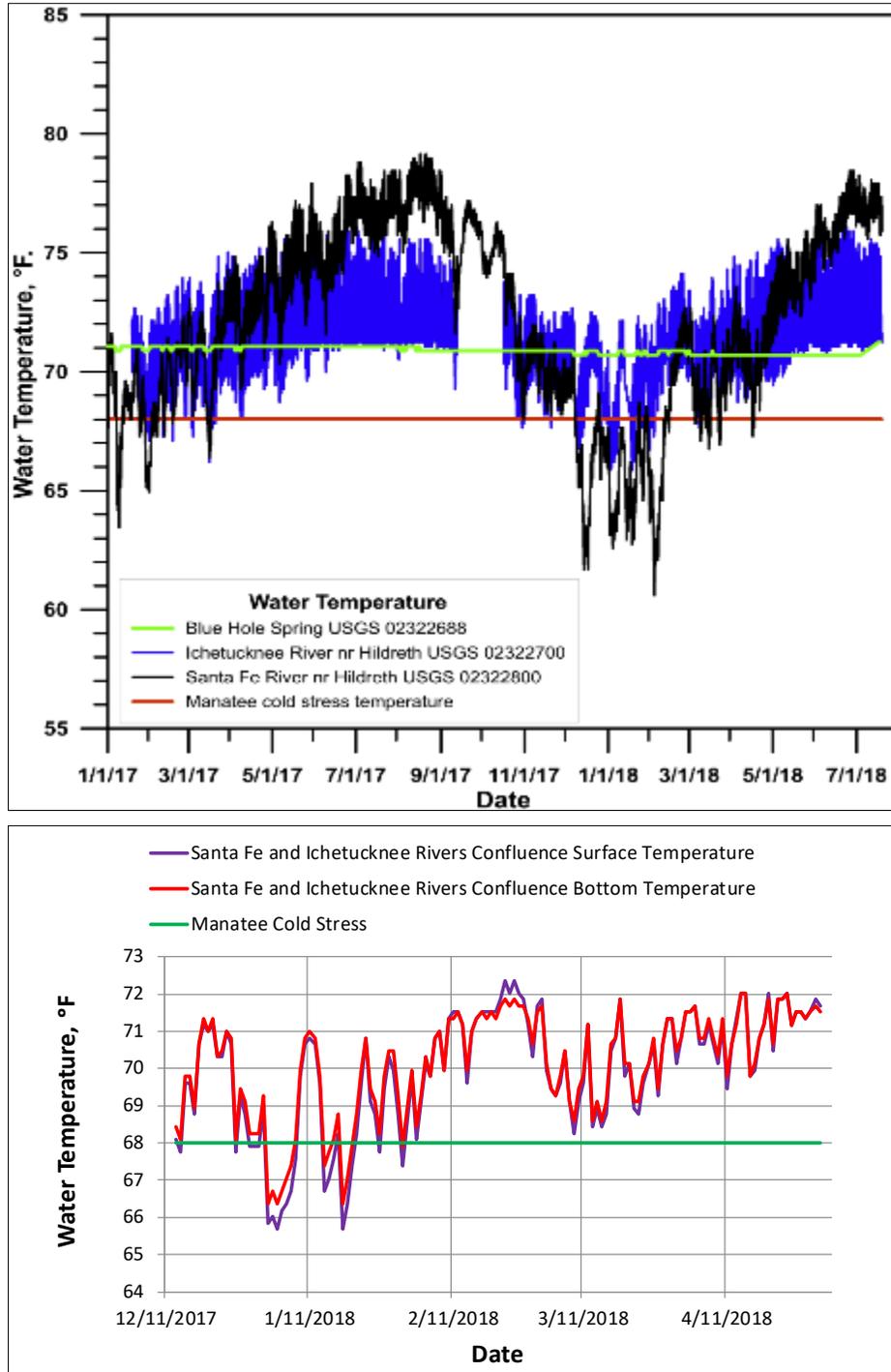


Figure 40. Comparison of water temperatures measured in 2017 and 2018 at Blue Hole Spring, and the Ichetucknee River and Lower Santa Fe River near Hildreth.

Anecdotal records of manatee sightings in the LSFR and IR are available from 1992 and 2005, respectively, through 2019. Recorded sighting counts through 2018 were obtained from the SRWMD through personal communication with Lars Andersen (<http://www.adventureoutpost.net/>) and Ichetucknee State Parks Department (personal communication, Sam Cole; Table 10 and Table 11, respectively). Manatee sightings are generally highest during winter and spring, particularly in the IR. However, manatee populations in these rivers have not been systematically counted, and there may be duplications in the sightings and locations.

Table 10. Counts of manatee sightings in Lower Santa Fe River (2005–2018)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2005	-	-	-	-	-	-	-	-	-	-	-	-	0
2006	-	-	-	-	-	-	-	-	-	-	-	-	0
2007	-	-	-	-	-	-	-	-	-	-	-	-	0
2008	-	-	-	-	-	-	-	-	-	-	-	-	0
2009	-	-	-	-	-	-	-	-	-	-	-	-	0
2010	-	-	-	-	-	-	-	-	-	-	-	-	0
2011	-	-	-	-	-	-	14	-	-	-	-	-	14
2012	-	-	2	-	-	-	-	-	-	-	-	-	2
2013	-	-	-	-	-	-	-	-	-	-	-	1	1
2014	-	2	-	3	-	-	-	-	-	-	-	-	5
2015	-	-	-	-	-	-	-	-	-	-	-	-	0
2016	17	-	3	7	-	-	-	-	-	-	-	8	35
2017	-	-	-	-	-	-	-	-	-	-	-	1	1
2018	-	-	-	-	-	-	-	-	-	-	-	-	0
Totals	17	2	5	10	0	0	14	0	0	0	0	10	58

Source: Lars Andersen; Dash (-) indicates no data.

Table 11. Counts of manatee sightings in Ichetucknee River (1992-2018)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1992	-	1	-	-	-	-	-	-	-	-	-	1	2
1993	2	2	-	-	-	-	-	-	-	-	-	-	4
1994	-	-	11	-	-	-	-	-	-	1	-	-	12
1995	-	2	-	-	-	-	-	-	-	-	-	-	2
1996	-	-	-	-	-	-	-	-	-	-	-	-	0
1997	-	-	-	-	-	-	-	-	-	-	-	1	1
1998	17	29	-	-	-	-	-	-	-	-	-	-	46
1999	-	-	-	-	-	-	-	1	-	-	-	-	1
2000	-	-	-	-	-	-	-	-	3	-	-	-	3
2001	-	-	-	-	-	-	-	-	-	-	-	-	0
2002	-	-	-	-	-	1	-	-	-	-	-	-	1
2003	-	-	8	-	-	-	-	10	3	-	-	-	21
2004	-	2	2	-	-	-	-	-	-	3	1	1	9
2005	2	1	10	22	36	6	13	8	-	-	-	3	101

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2006	15	15	5	2	-	-	5	-	2	1	3	3	51
2007	8	3	3	8	9	-	5	2	10	2	-	-	50
2008	-	-	5	-	-	-	-	10	1	-	-	-	16
2009	-	-	-	45	3	5	-	-	-	-	-	-	53
2010	3	10	9	-	-	-	-	-	-	-	-	-	22
2011	-	-	-	-	-	-	-	-	-	-	-	-	0
2012	-	-	-	-	-	12	106	-	-	-	-	-	118
2013	-	-	47	41	18	-	9	1	3	-	-	-	119
2014	2	6	53	63	71	1	-	-	-	-	-	3	199
2015	33	35	28	3	5	-	-	-	-	-	-	-	104
2016	-	34	17	15	1	-	-	-	-	-	-	-	67
2017	2	57	7	-	-	-	-	-	5	1	-	-	72
2018	9	20	18	-	-	-	3	-	-	-	-	-	50
Totals	93	217	223	199	143	25	141	32	27	8	4	12	1124

Source: Ichetucknee River State Park; Dash (-) indicates no data

Evaluating the potential impacts of flow alteration on manatee thermal refuge would include considering two primary factors: (1) maintaining spring flows and/or stages necessary to preserve adequate volumes of warm water above the threshold temperature of 68 °F (20 °C), and (2) maintaining spring and river stages to provide depths >3 feet that allow for manatee passage (SWFWMD 2008).

3.4.6 Ichetucknee Siltsnail

The Ichetucknee siltsnail is a freshwater snail approximately 2-3 millimeters in size. It has a brown, translucent, iridescent shell (Figure 41). The Ichetucknee siltsnail is one of eleven snails of the genus *Floridobia* endemic to a single Florida spring system (Coffee Spring), and it is the lone endemic siltsnail known to occur in the Suwannee River Basin (Warren and Bernatis 2015). Since the Ichetucknee siltsnail inhabits only one location, its population is vulnerable to extinction from any environmental change that adversely affects water quality or its habitat.

Recent studies (Warren and Bernatis 2015) have quantified the Ichetucknee siltsnail population in Coffee Spring. The population is extremely variable with a clumped distribution in Coffee Spring. The population is dispersed throughout the spring in lower abundance in bottom sediments, algae mats, tree roots, wood debris, and flat stones. The highest population counts were associated with bryophytes, with eelgrass as the secondary substrate. The habitat area of Ichetucknee siltsnail is only 364 square meters at high pool, and small reductions in the stage of Coffee Spring could cause significant reductions in habitat area (Warren and Bernatis 2015). The Ichetucknee siltsnail breeding behavior and life cycle are poorly understood. Its diet is primarily periphyton and detritus from substrates, and it may be important to the maintenance of water quality in the spring. Siltsnails can tolerate low dissolved oxygen concentrations which provides some protection from predators. The population is also influenced by substrate, filamentous algae, submersed macrophytes, canopy cover and flooding (Warren and Bernatis 2015).



**Figure 41. Ichetucknee siltsnail on eelgrass at Coffee Spring
(Photograph by Jennifer Bernatis, FWC, 18 November 2015)**

The Ichetucknee siltsnail is categorized as S1 (critically imperiled) by the Florida Natural Areas Inventory (Figure 41). The snail is designated as a “Species of Greatest Conservation Need” by the Florida Fish and Wildlife Conservation Commission (FWC). It was one of species petitioned for federal listing as threatened or endangered by the Center for Biological Diversity, Tucson, Arizona, in their 2010 “megapetition” submitted to the U.S. Fish and Wildlife Service (Center for Biological Diversity 2010). The U.S. Fish and Wildlife Service announced their 12-month findings on July 6, 2016, on the petition to list the Ichetucknee siltsnail as endangered species or threatened species under the Endangered Species Act of 1973. After a review of the best available scientific and commercial information, they found that listing the Ichetucknee siltsnail was not warranted at this time. During the 2013 MFLs assessment, based on the results of the HEC-RAS model and the physical stage-area relationship, it is estimated that approximately 5% of the Coffee Spring Pool area always stays inundated (SRWMD 2013).

3.4.7 Oval Pigtoe

The oval pigtoe is a federally endangered species of freshwater mussel, an aquatic bivalve mollusk in the family Unionidae, the river mussels (Figure 42). This mussel is endemic to Georgia, Florida, and Alabama and occurs in river sediments that are characterized as muddy sands, and “mixed sand and gravel” (USFWS 2003).



**Figure 42. Photograph of oval pigtoe mussel
[Source: Jason Wisniewski, GA DNR]**

The oval pigtoe was added to the U.S. federal endangered species list in 1998 and a recovery plan was created for this species (USFWS 2003). The Santa Fe River is designated as a critical habitat, and the populations have declined significantly in the LSFR and IR (Cummings and Cordeiro 2012). The collapse of freshwater mussel fauna in general is by and large the result of habitat loss from anthropogenic degradation. This includes impoundments, channelization, pollution, and sedimentation that have altered or eliminated those habitats that are essential to the long-term viability of many riverine mussel populations. However, the histories of anthropogenic impacts to the mussel fauna of the Suwannee River drainages have not been summarized (USFWS 2003).

3.4.8 Gulf Sturgeon

The Gulf sturgeon is a subspecies of sturgeon that lives in the Gulf of Mexico and some rivers draining into it. The Gulf sturgeon is anadromous and spends a major part of the year in freshwater and migrates to saltwater in the fall. Adult sturgeon primarily feed during the winter months in marine or brackish water; however, they consume very little food during their spawning time in freshwater rivers. Movement from the Gulf of Mexico and up-river generally occurs between February and April for spawning, while down-river movement into the Gulf of Mexico occurs between September and November. Spawning occurs in areas with deeper water and rock, gravel, or sand bottoms (Federal Register 1991). Sturgeon attain sexual maturity in a minimum of eight years for females and seven for males, which makes any loss of breeders or spawning habitat a serious problem for the species (Wakeford 2001).

The Suwannee River contains the largest population of Gulf sturgeon, and the Suwannee River Basin is considered a critical habitat for the species (50 CFR 226.214 n.d.) (Figure 43). Gulf sturgeon was listed as a threatened species on October 30, 1991, pursuant to the Endangered Species Act of 1973 (Figure 43). Three specimens have been collected from the Santa Fe River, and the importance of the Santa Fe River as a habitat and breeding area for Gulf sturgeon needs further investigation (Flowers and Pine 2008).

3.4.9 Suwannee Bass

Suwannee bass is endemic to the Suwannee Basin and was considered a species of special concern by the states of Florida and Georgia (Gilbert 1992). Currently, it is not listed, nor is it currently being considered for listing. However, FNAI ranked the species as S3 (*Either very rare and local throughout its range or found locally in a restricted range or vulnerable to extinction from other factors*). Suwannee bass consume a variety of food organisms, but crayfish (*Procambarus spp.*) are their primary food source (Bass 1974) (Nagid, et al. 2015). Suwannee bass are often found in moderate to swift currents near limestone or woody structure, and spawning occurs from February to June (Cailteux, Nordaus and Dobbins 2002) and (Bonvechio, Allen and Cailteux 2005).

Largemouth bass and Suwannee bass were sampled in the LSFR upstream of the IR during May 1982 through March 1982 (Schramm and Maceina 1986). The authors determined that Suwannee bass and largemouth bass concomitantly occupied six prevalent habitat types in the LSFR, and relative abundance was highest for all size-groups in brush pile macrohabitats. Considering the restricted distribution of the Suwannee bass and the predominance of crayfish in their diet in the LSFR, a diverse forage resource including abundant crayfish is important to the maintenance of Suwannee bass population (Schramm and Maceina 1986) and (Nagid, et al. 2015).

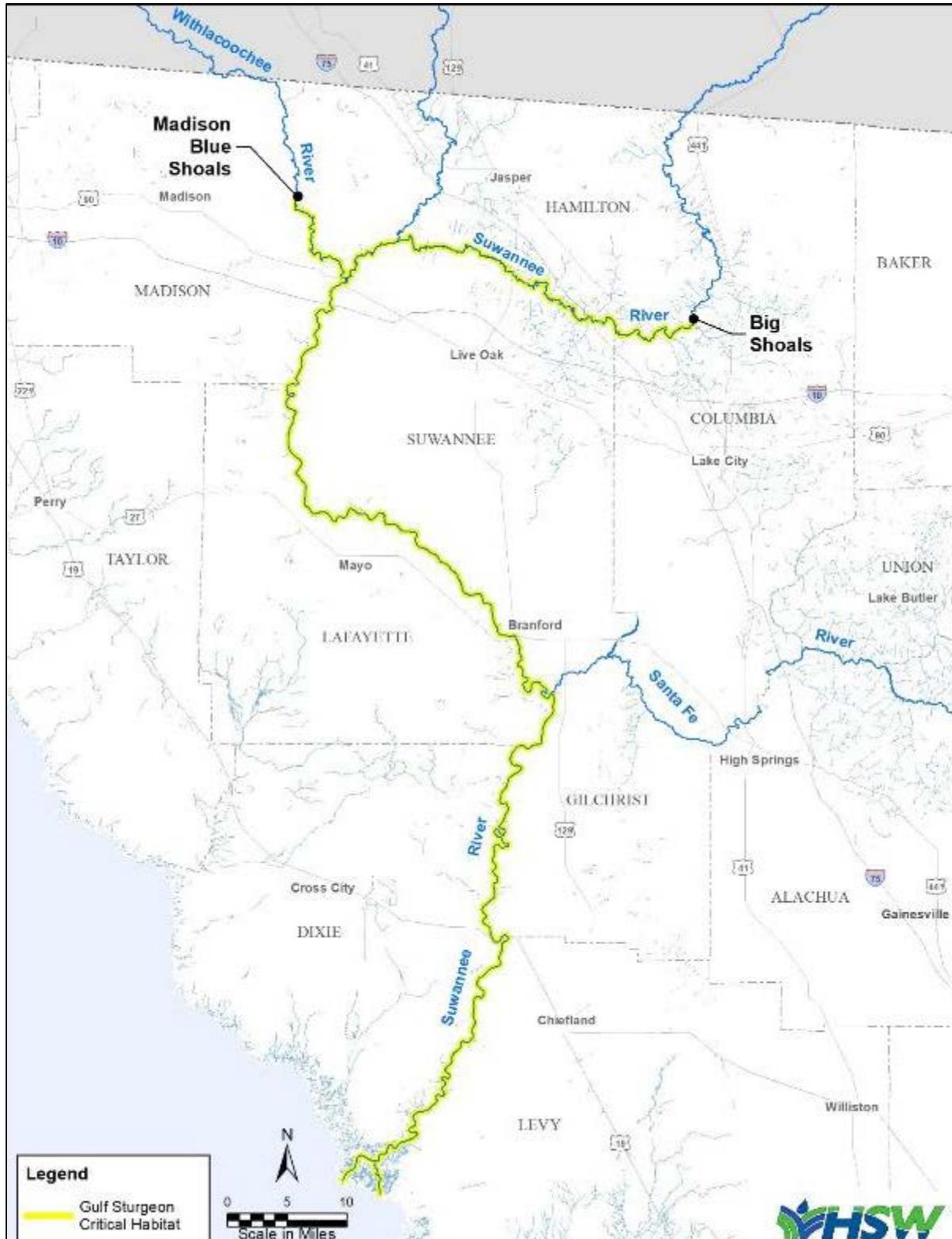


Figure 43. Extent of designated Gulf sturgeon critical habitat [Source: (50 CFR 226.214 n.d.)]

3.4.10 Seasonality

Many fish species in the LSFR/IR system spawn during three to five months during spring and summer that coincide with the several environmental factors that influence spawning. Such factors include water temperature, water depth, and water velocity. Other species, such as channel catfish, spawn during extended periods spanning six to eight months (Table 12).

Table 12. Seasonality of select fish spawning

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Reference
Largemouth bass			■	■	■	■							(Rogers and Allen 2010)
Suwannee bass		■	■	■	■	■							(FWC 2018)
Channel catfish			■	■	■	■	■	■	■				(Sutton 2006)
Bluegill sunfish					■	■	■						(Page and Burr 1991)
Redear sunfish			■	■	■	■	■	■					(Floridagofishing 2018)
Gulf sturgeon			■	■					■	■			(HSW 2010)

*Grey cell indicates spawning season

Maintenance of appropriate MFLs are necessary to maintain water temperature, depths, and velocities in LSFR/IR system for spawning habitat. Spawning habitats are needed for critical life-cycle stages for fish, and seasonality of spawning activities is considered for the habitat analysis in Chapter 4 and Chapter 5.

4. APPROACH TO SETTING MFLS

The results of the background literature review and hydrologic assessment are presented in previous sections of this report and form the basis for evaluating human use and water resource values and developing MFLs for the LSFR/IR. The technical approach makes use of the RTF flows presented in Section 2 and described in detail in Appendix D. It is assumed that the RTF flows are not only protective of water resource and human use values but that some water is available for beneficial use without causing significant harm to the resource. In some cases, sufficient data are available to identify flow characteristics (e.g., a flow of specific magnitude and duration) that are protective of a WRV with some level of confidence. More often, available data are insufficient to quantify the flow characteristics that are protective of a WRV, and assumptions and professional judgment are needed to develop protective criteria.

The overall approach for setting MFLs for the LSFR/IR is characterized as a weight-of-evidence approach that begins with identifying specific water resource values particularly relevant to the river, followed by an analysis of possible flow reductions that would remain protective of the WRVs. Not all WRVs are of equal relevance or sensitivity to flow reductions, and some are so closely linked to others that protection of the more highly-relevant or sensitive WRVs is assumed to protect a related WRV as well. Thus, limits established for flow reductions over the range of a flow duration curve afford a level of protection to all the relevant WRVs and are assumed to provide a level of protection to those not explicitly evaluated.

4.1 Identification of Relevant WRVs

A qualitative evaluation of risk and value was performed for each of the ten WRVs to identify those WRVs relevant to the LSFR/IR. The evaluation is described in this section and is based on reviewing available information.

4.1.1 Recreation in and On the Water (WRV 1)

Recreation along the LSFR/IR is an important WRV. The OFW designation of the river is based in part on its use for recreational activities such as swimming, recreational fishing, kayaking, and canoeing. Both river systems support public and private tubing, diving, and swimming facilities. There are four state parks and several county parks on the rivers, as well as commercial facilities that provide resource-based recreational opportunities.

4.1.2 Fish and Wildlife Habitats and the Passage of Fish (WRV 2)

This WRV is considered relevant for the LSFR and IR MFLs. 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 LSFR or IR have been identified as significant thermal refugia for manatees (Warm Water Task Force 2004). Both in-channel habitats and floodplain habitats are affected by river flows and are relevant for establishing the MFLs for these rivers.

The freshwater wetlands within the LSFR/IR floodplain (Figure 36 and Figure 37) are indicators of habitat influenced by high flows that inundate the floodplain. Roots provide refugia for fish during periods of medium and high flows. Snags are an organic substrate for detritivores and decomposers and serve as refugia for juvenile fish during low to medium flows.

A diverse assemblage of fish species and invertebrates are indicators of available habitat at low to medium flows. Based on the District's experience with species used for other river segments, the species occurring in the LSFR/IR study area, and HSW's review of listed species of high conservation interest, aquatic macroinvertebrates, and fish (both prey and predators) in a range of trophic levels were selected to use in the MFLs analysis.

4.1.3 Estuarine Resources (WRV 3)

This WRV is not directly relevant to the LSFR/IR because it is a freshwater system. However, MFLs were evaluated for the Lower Suwannee River and Estuary, and an MFL regime was established to protect freshwater flow to the estuary and maintain estuarine habitats (WRA 2005). The LSFR/IR watershed is a headwater source of freshwater flow to the estuary and, by this association, an allowable flow reduction prescribed for the Lower Suwannee River and Estuary could potentially influence an LSFR/IR MFL.

4.1.4 Transfer of Detrital Material (WRV 4)

Detrital material is a food source for detritivores, primary consumers that obtain nutrients by consuming decomposing plant and animal material that are crucial to benthic ecosystems. 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 LSFR/IR MFLs and is addressed by consideration of the frequency of overbank flows in establishing the MFLs for these rivers.

4.1.5 Maintenance of Freshwater Storage (WRV 5)

While this WRV is considered relevant, it is afforded protection by the permitting process, as well as by MFLs protective of the habitat in the surrounding floodplain, explicitly evaluated for WRV 2.

4.1.6 Aesthetic and Scenic Attributes (WRV 6)

This WRV is linked to the recreational use of the LSFR/IR and the Priority Springs and is considered relevant. Protection of this WRV therefore is incorporated into the selection of MFLs protecting recreational activities, explicitly evaluated for WRVs 1 and 2.

4.1.7 Filtration and Absorption of Nutrients and Other Pollutants (WRV 7)

WRV 7 refers to the reduction in concentration of nutrients and other pollutants through the process of filtration and absorption and is considered relevant to the LSFR/IR MFLs. The role of wetlands in the maintenance of water quality is well established (Mitsch and Gosselink 1986). Wetlands allow for settlement of suspended particulates, uptake of nutrients by plants, and sequestration of heavy metals and other contaminants in sediments (SRWMD 2013, Mitsch and Gosselink 1986). Hence, it is assumed that maintaining an acceptable level of ecological integrity for wetland ecosystems of the LSFR/IR will maintain this function. The presence of freshwater marl on the floodplain of the rivers provides for phosphorus sorption (p-sorption) and maintenance of locally alkaline soils (SRWMD 2013). 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 also is supported by out-of-bank flows.

4.1.8 Sediment Loads (WRV 8)

This WRV is considered relevant to the LSFR/IR MFLs although there is lack of data related to sediment loads 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 (SRWMD 2013). 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 - are considered relevant for setting the MFLs.

4.1.9 Water Quality (WRV 9)

Water quality refers to the chemical and physical properties of water not included in WRV 7. Healthy fish populations and a diversity of benthic organisms depend on sufficient levels of dissolved oxygen and an absence of elevated levels of pollutants. This WRV is important and is examined in some detail in this report (Section 2).

4.1.10 Navigation (WRV 10)

While navigation is directly related to flow, it is not a relevant WRV for the LSFR/IR because no commercial barges or other large commercial vessels utilize the river. Motorized boating, canoeing, and kayaking will be protected under an MFL associated with WRV 1 (Recreation In and On the Water).

4.1.11 WRV Summary

Eight of the ten WRVs were identified as being relevant values associated with the LSFR/IR and can be expected to be impacted to some degree by a reduction in freshwater flow. Four of these are considered highly relevant and are explicitly evaluated in this report: Recreation (WRV 1), Fish/Wildlife Habitat and Fish Passage (WRV 2), Sediment Loads (WRV 8), and Water Quality (WRV 9). However, because potential impacts across a wide range of flows will be evaluated and a consistent method is used to define allowable flow reductions, it is reasonable to assume that other WRVs that might be impacted by flow reductions will be afforded some level of protection.

4.2 Indicators and Response Functions

The proposed MFLs for LSFR/IR are based on the relationships between river flow and an indicator metric associated with the following:

- Out-of-bank and bankfull flows that
 - inundate floodplain vegetation communities,
 - inundate hydric soils,
 - provide access to floodplain habitat or food resources for fish and other organisms, and
 - maintain the appropriate geomorphology as indicated by bankfull flows.
- Instream 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, and
- maintain SAV.

The WRV indicator metrics are surrogate measures of water resource values that are relatable, directly or indirectly, to flow. A metric can be associated with a discrete location, such as known spawning beds for a species of special interest, or an accumulation along the length of these rivers. The association between flow (or stage or velocity) and a WRV metric is referred to as a response function.

WRV metrics can be expressed in terms of time, distance, area, or other measurable characteristics. For example, kayakers and other recreational users of the river are most likely to relate to a flow reduction and the associated change in the number of days available for boating/tubing. Likewise, the natural life cycle of a certain fish species may require some minimum hydrologic condition sufficient for spawning that must be maintained frequently enough and for a sufficient duration to sustain the population.

The WRV indicators, metrics, and associated response functions selected for the LSFR/IR MFLs assessment (Table 13) are based on consultations with District staff, subject matter experts with site-specific knowledge of the river, available literature, and data developed from this and previous studies (SRWMD 2013). Response functions also were developed from existing databases and by post-processing river hydraulic characteristics calculated using the steady state HEC-RAS model developed for the LSFR/IR MFL assessment.

Examples of response functions are as follows.

- Recreation in/on water and fish passage – stage-flow ratings are a response function frequently used to evaluate these metrics.
- Fish habitat – relationships between freshwater flow and the combination of depth, water velocity, and inundated substrate type are evaluated.
- In-stream and floodplain habitats – relationships between freshwater flow and areas of inundation and elevations of certain habitats are response functions for these habitats.
- Sediment loads – Stage-inundation curves are an appropriate tool for this metric.

Table 13. Selected indicators, response functions, and MFLs assessment metrics for WRVs

Indicator	Relevance	Response Function	Metric	Key Source
RECREATION (LSFR and IR)				
LSFR-Boating	Public interest; associated with aesthetics	Daily stage-duration curve	Amount of time that boating is not ideal (i.e., stage \leq 33.5 feet NGVD29 at US441 gage) due to low water conditions	Viable stage for kayaking / canoeing + 1.5 feet (average shaft length of short- and long-shaft small engines); (Iboats 2009)
LSFR-Kayaking / canoeing	Commercial and public interests; associated with aesthetics	Daily stage-duration curve	Amount of time that kayaking or canoeing is not ideal (i.e., stage \leq 32* feet NGVD29 at US441 gage) due to low water (Iboats 2009) conditions	Santa Fe River Paddling Guide (https://floridadep.gov/file/9210/download?token=Ayw75gXN)
IR-Tubing	Public interest; associated with aesthetics	Daily stage-duration curve	Amount of time that tubing is not ideal (i.e., flow \leq 282 cfs at Hwy 27 gage)	(SRWMD 2013)
FISH PASSAGE, FISH AND WILDLIFE HABITAT (LSFR and IR)				
Gulf sturgeon (adult)	Threatened and Endangered (T&E) species, migration	Depth-discharge curve assuming channel width exceeds 15 feet	Amount of time (during seasons) that Gulf sturgeon passage is not viable due to low water conditions (i.e., depth $<$ 3 feet and width $<$ 15 feet)	(Randall, Sulak and Rauschenberger 2012)
Gulf sturgeon (adult and juvenile)	T&E species, general habitat, holding cover	Habitat suitability curve	Area weighted suitability (AWS)**	(Randall, Sulak and Rauschenberger 2012)
General fish assemblage	Fish passage	Depth-discharge curve assuming channel width exceeds 5 feet	Amount of time that passage of a general fish assemblage is not viable due to low water conditions (i.e., depth $<$ 0.8 feet over 25% of the channel width)	(Neubauer, et al. 2008)
General fish assemblage	Fish habitat	Habitat suitability curves	Area Weighted Suitability	(Gore, McKinney and Nagid 2012)
Primary consumers (e.g. chironomids, EPTs, and mussels)	Forage for secondary consumers	Habitat suitability curves for species / taxonomic group	Area Weighted Suitability	(Gore, McKinney and Nagid 2012)

Indicator	Relevance	Response Function	Metric	Key Source
Secondary/Tertiary Consumers: (e.g. Guilds)	Refugia, spawning habitat	Habitat suitability curves for specific species and guild	Area Weighted Suitability	(Gore, McKinney and Nagid 2012)
Woody habitat (roots and snags)	Invertebrate cover and larval substrate, fish spawning and refugia	Stage-inundation area curve	Relative amount of time (or area) that threshold inundation area (inflection point) associated with large and fibrous roots and snags are inundated	(Fischenich and Morrow Jr. 2000); (Clifford 1982); (Berner and Pescador 1988)
Floodplain forest wetlands	Maintain wetland systems; represses succession	Forest stage-inundation area curve	Flow associated with a 15% reduction in floodplain habitat area.	(Cowardin, et al. 1979), (H. M. Light, et al. 2002)
			Amount of time flows associated with mean elevations for each floodplain vegetation type are exceeded.	(SRWMD 2013), (Munson and Delfino 2007)
SEDIMENT LOADS (LSFR and IR)				
Bank-full discharge	Channel maintenance; alkaline soil protection	Stage-inundation area	Amount of time that bank-full discharge is exceeded (number)	(Julien 2002), (SRWMD 2013), (Munson and Delfino 2007)
WATER QUALITY (LSFR and IR)				
Conductivity	Gulf sturgeon spawning	Flow-conductivity curve	Amount of time (seasons) that conductivity exceeds a limiting conductivity.	(HSW 2010)
AESTHETICS (LSFR and IR)				
Submerged Aquatic Vegetation (SAV)	Aesthetics and scenic attributes	Velocity vs. Flow	Amount of time optimal velocity (0.8 ft/s – 2.3 ft/s) suitable for SAV is maintained.	(University of Florida, Water Institute 2017)

Specific stage or flow conditions are referenced to the Fort White gage, 02322500 on LSFR and Hwy 27 gage, 02322700 on IR, unless otherwise indicated.

* As of 10/23/2019 Santa Fe Paddling, Guide included a paddling metric of 32 ft NGVD29.

** AWS – measure of habitat area in ft²/ft

4.3 Modeling

Statistical methods and numerical models are frequently used to develop response functions for MFLs assessments. The Army Corps of Engineer’s Hydraulic Engineering Center Riverine Analysis System (HEC-RAS) computer program is used to develop a stage-flow rating (i.e., response function) at ungaged locations. Results from the HEC-RAS model are used to develop a habitat analysis model, System for Environmental Flow Analysis (SEFA), and in GIS (i.e., floodplain mapping), to support MFL development.

4.3.1 HEC-RAS Modeling

HEC-RAS, River Analysis System, is a hydraulic modeling program developed by the U.S. Army Corps of Engineers Hydraulic Engineering Center (HEC). It is well documented, widely used, and considered an industry standard. The computer program was developed initially to perform one-dimensional steady and unsteady flow river hydraulics calculations for flood study purposes (Hydrologic Engineering Center 2010). HEC-RAS solves the one-dimensional energy equation by computing energy losses between two adjacent cross-sections. Water-surface profile computations begin at a cross-section with known or assumed starting conditions and proceed upstream for subcritical flow or downstream for supercritical flow.

A HEC-RAS model of the LSFR system developed for the initial MFLs assessment was updated for the current MFLs re-evaluation. The development, calibration, validation, and demonstration of the LSFR HEC-RAS model is described in detail in Appendix E. The following sections summarize the information provided in Appendix E.

4.3.1.1 Model Development

The updated LSFR system HEC-RAS model is a combination of SFR and IR HEC-RAS models dating back to 2002 that were combined and revised by others to improve the model predictive capabilities for a wide range of flows. For the initial MFLs assessment (SRWMD 2013), the steady state model developed by INTERA in 2007 was geo-referenced and further modified to include new survey data and best available data from the existing models and executed using HEC-RAS version 4.1.0. Swallets, resurgences, and other karst features and their hydraulic relationships were modeled using synthesized lateral inflows and the HEC-RAS pressurized conduit flow option (INTERA 2012).

The model was developed further for the current MFLs re-evaluation by:

- Updating cross-section geometry data for the IR based on the latest available LiDAR data provided by the District. No additional hydrographic or field survey data were collected.
- Translating elevations represented in the previous model from the NGVD29 vertical datum to NAVD88. The geometry and stage data input to the updated model and calculated by the model are referenced to NAVD88.
- Evaluating an alternative steady state model downstream boundary condition and the association between LSFR flow and stage at the junction of the Suwannee River (SR) and Santa Fe River, representative of a condition when backwater effects from Suwannee River are minimal relative to observed conditions.
- Executing transient and steady state simulations using the most recent HEC-RAS version 5.0.6.

The LSFR model represents the SFR from the Worthington Spring gaging station to 1,600 feet upstream from the confluence with the Suwannee River and the IR from Ichetucknee Head Spring to the confluence with SFR (Figure 44). The model is composed of 329 surveyed and interpolated cross sections -- 275 across the LSFR channel and floodplain and 54 across the IR channel and floodplain. The model extent is sufficiently large compared to the area of interest for the MFLs re-evaluation which begins at Santa Fe River Rise (Figure 45).

The SFR portion of the model is composed of ten model reaches (Figure 45) to represent the complex hydrology and hydraulics associated with swallets, resurgences, and other karst features. There are 10 bridges in the model; eight cross the SFR and two cross the IR. Various splits and joins representing key physiographic features are modeled as stream junctions. There are nine stream junctions (computational nodes) in the model named (and representing) the following.

- Santa Fe Split (Santa Fe River Sink and Vinzant Landings Swallet (or Sink) - split into Santa Fe Above and Santa Fe Below reaches near upstream side of Land Bridge)
- Santa Fe Join (Santa Fe River Rise - join of Santa Fe Above and Santa Fe Below reaches near downstream side of Land Bridge)
- Split (Alligator Swallet (or Siphon) - split into Siphon Above and Siphon Below reaches)
- Siphon (Alligator Rise - join of Siphon Above and Siphon Below reaches)
- Poe Split and Poe Join (north and south channels around Poe Island, respectively)
- Rum Split and Rum Join (north and south channels around Rum Island, respectively)
- Ichetucknee (SFR-IR confluence)

The Santa Fe Below and Siphon Below reaches represent subterranean karst conveyances that parallel the similarly named “Above” reaches and are not shown in Figure 45. The Santa Fe Above reach represents the SFR along the natural Land Bridge (Figure 4, Figure 45). The Ichetucknee River is treated as a single model reach.

4.3.1.2 HEC-RAS Model Calibration and Validation

The model was calibrated to observed stages and flows during the initial MFLs assessment in a transient state primarily by adjusting the channel friction and proportioning lateral inflows along the river reaches (INTERA 2012). The transient model simulation time period spans 3,516 days from February 14, 2002, through September 30, 2011. Daily records of flow and stage measured at the Santa Fe River gaging stations near Worthington Springs, Fort White, and Hildreth; Hwy 27 on IR; and Suwannee River near Branford and Bell were used to develop boundary conditions for the transient model.

The calibration approach and results are described in Appendix E and in a report prepared for the initial MFLs assessment (INTERA 2012). Daily stages simulated and measured at 22 locations (15 on the SFR and 7 on the IR) were considered during the calibration process. Simulated stages at 16 of the 22 locations were within 5% of the measured stages (Table 14).

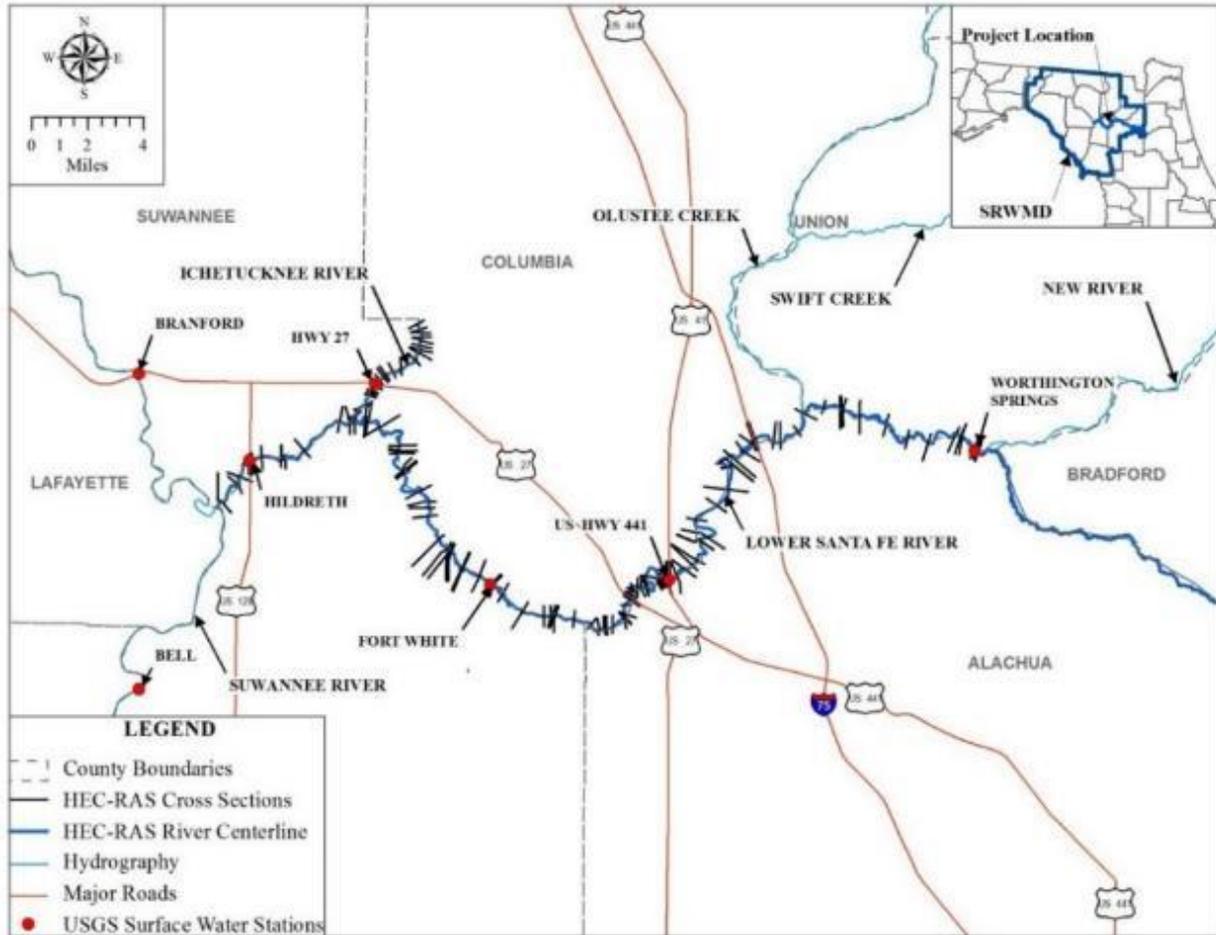


Figure 44. Location Map of the Lower Santa Fe River and Ichetucknee River HEC-RAS Model
 [Source: (INTERA 2012)]

The updated transient model was validated by calculating values for the coefficient of model-fit efficiency, E , defined by (Nash and Sutcliffe 1970) for the calibration period and comparing the goodness-of-fit metric to literature values for model acceptability.

$$E = 1 - \frac{\sum_{i=1}^n (Q_{mi} - Q_{si})^2}{\sum_{i=1}^n (Q_{mi} - \overline{Q_m})^2}$$

In which

- Q_{mi} = the measured discharge at time, i ,
- $\overline{Q_m}$ = the average measured discharge,
- Q_{si} = the simulated discharge at time, i , and
- n = the number of measured discharge values.

Moriasi, et al. (2007) proposed three descriptive ratings to characterize model-fit quality for model evaluation based on E : $E \geq 0.75$ – Very Good, $0.75 > E \geq 0.65$ – Good, and $0.65 > E \geq 0.5$ – Satisfactory. The fit quality is presumably Unsatisfactory when $E < 0.5$ (Moriasi, et al. 2007). These criteria are for a monthly interval.

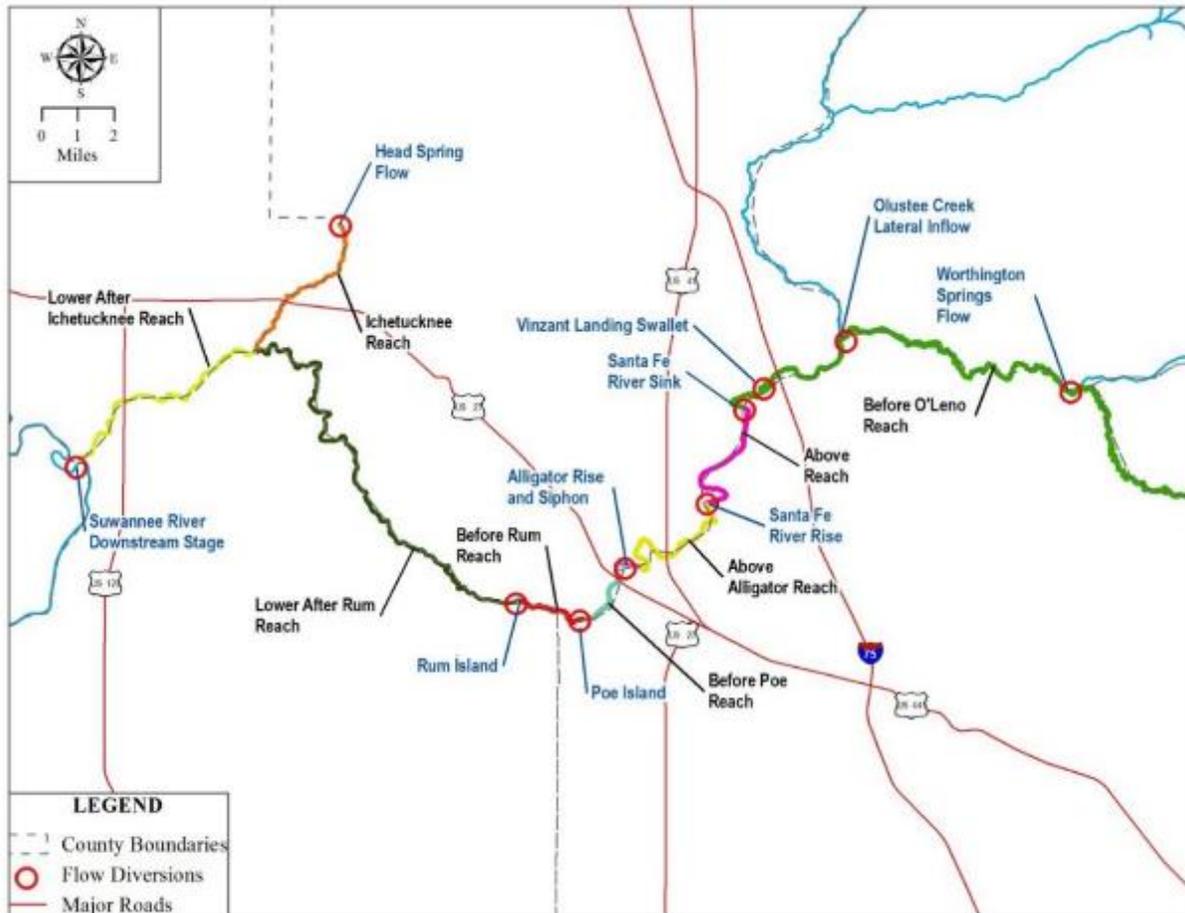


Figure 45. Santa Fe River / Ichetucknee River HEC-RAS Model Reaches
[Source: (INTERA 2012)]

Model fits were noted to typically be poorer for shorter time steps than for longer time steps; e.g., daily versus monthly or yearly, (Engel, et al. 2007). These fit criteria commonly are used to assess the quality of watershed models for continuous simulation of streamflow.

Efficiency coefficient values were calculated for the discharges and water depths simulated and observed during the transient modeling period. Of the six locations with long-term records that were evaluated for flow prediction accuracy, two were rated Very Good based on E values, one was Good, and three were Satisfactory (Table 15). Of the seven locations evaluated for depth prediction accuracy, four were rated Very Good based on E values, one was Satisfactory, and two were Unsatisfactory (Table 16). One gage rated Unsatisfactory is upstream from the area of interest (Santa Fe River Rise to mouth), and the other is at a location where there was a small variation in observed depths. Time series plots and frequency curves comparing simulated and observed daily discharges and depths during the nearly 10-year simulation period illustrate reasonable associations that are consistent with the model-fit efficiency values (Appendix E Attachment 1). At Dampier's Landing on the IR, the simulated flow is consistently lower than the measured flow. The most likely cause of an apparent loss of flow in the upstream direction from the long-term gage at Highway 27 was from bias in the measurements at the upstream sites in areas with vegetation in the flow-measurement areas.

Table 14. Final Transient Model Calibration Results

[Source: modified from (INTERA 2012); Simulation period from February 13, 2002, through September 29, 2011]

Name	River	Percent of Stage Residuals within 5%	Percent of Stage Residuals within 0.5 ft	Percent of Stage Residuals within 1 ft	% Stage Residuals within 0.5 ft at Low Flows
Worthington Springs	Santa Fe	98.76%	67.58%	88.72%	85.97%
O'Leno State Park by I-75	Santa Fe	99.79%	67.22%	96.24%	69.65%
O'Leno State Park by Footbridge -District Gage	Santa Fe	88.75%	32.13%	73.04%	34.36%
River Rise	Santa Fe	96.70%	65.35%	90.43%	78.53%
Santa Fe River at US441 near High Springs	Santa Fe	92.00%	60.81%	83.70%	79.79%
Logger Sinkhole near High Springs	Santa Fe	95.82%	53.97%	93.31%	57.92%
Logger Canoe Scrape	Santa Fe	98.33%	65.27%	94.98%	68.12%
Logger near High Springs	Santa Fe	97.50%	84.17%	92.50%	90.54%
Logger at Poe Springs	Santa Fe	100.00%	53.75%	100.00%	51.17%
Logger at Rum Island	Santa Fe	96.25%	66.25%	93.75%	71.30%
Fort White	Santa Fe	90.94%	75.80%	89.47%	90.38%
Logger at SR 47 near Fort White	Santa Fe	100.00%	21.99%	100.00%	15.66%
Logger Dog Leg Shoals	Santa Fe	60.21%	59.16%	91.10%	49.65%
Santa Fe Point Park (Three Rivers)	Santa Fe	66.34%	62.21%	91.00%	54.36%
Santa Fe River near Hildreth FL	Santa Fe	96.76%	96.16%	99.71%	99.09%
Head Spring	Ichetucknee	98.58%	95.43%	98.11%	94.94%
Blue Hole Spring	Ichetucknee	98.39%	94.19%	97.89%	93.50%
Mission Springs	Ichetucknee	98.37%	91.65%	97.80%	87.11%
Devil's Eye Spring	Ichetucknee	98.83%	91.28%	98.38%	88.14%
Mill Pond Spring	Ichetucknee	53.73%	29.65%	52.92%	8.13%
Dampier's Landing	Ichetucknee	98.79%	94.82%	98.76%	93.60%
Ichetucknee River at Hwy 27 near Hildreth	Ichetucknee	98.09%	92.74%	98.51%	93.84%

Table 15. Nash-Sutcliffe coefficient of model-fit efficiency E for daily flows for long term streamflow gages in the study watershed

Station ID	Station name	E	Rating
023218982	Santa Fe River at O’Leno State Park by Footbridge	0.696	Good
02321975	Santa Fe River at Highway 441 near High Springs, FL	0.602	Satisfactory
02322500	Santa Fe River near Fort White, FL	0.596	Satisfactory
02322800	Santa Fe River near Hildreth, FL	0.573	Satisfactory
02322698	Ichetucknee River at Dampier’s Landing near Hildreth, FL	0.762	Very Good
02322700	Ichetucknee River at Highway 27 near Hildreth, FL	0.994	Very Good

Table 16. Proportion of all the simulated daily water depths within 10, 15, and 25% of the measured daily water depth and the Nash-Sutcliffe coefficient of model-fit efficiency for the daily water depths

Gage	Difference Threshold				Rating
	<10%	<15%	<25%	E	
Santa Fe River at Worthington Springs, FL	0.911	0.927	0.934	0.909	Very Good
Santa Fe River at O’Leno State Park by Footbridge	0.186	0.299	0.521	0.162	Unsatisfactory
Santa Fe River at Highway 441 near High Springs, FL	0.629	0.800	0.906	0.271	Unsatisfactory
Santa Fe River near Fort White, FL	0.832	0.913	0.937	0.545	Satisfactory
Santa Fe River near Hildreth, FL	0.999	1.00	1.00	0.998	Very Good
Ichetucknee River at Dampier’s Landing near Hildreth, FL	0.960	0.989	0.996	0.961	Very Good
Ichetucknee River at Highway 27 near Hildreth, FL	0.913	0.978	0.987	0.976	Very Good

Considering the statistical and graphical validation results described here and in Appendix E, the updated transient HEC-RAS model overall provides an acceptable simulation of flows and water depths in the LSFR and IR over a wide range of flows. Relative to commonly applied model fit-quality criteria, the statistical results achieve at least satisfactory results throughout the study area with many of the results meeting good or very good fit quality. Changes to friction values, channel geometry, lateral inflows, and hydrologic features were unnecessary. The parameterization of the calibrated transient HEC-RAS model is suitable for adaption as a steady-state model of the LSFR system that can be used for the MFLs re-evaluation.

4.3.1.3 HEC-RAS Steady State Model Development and Predictive Simulations

A steady state model of the LSFR system was created by modifying two sets of boundary conditions in the calibrated transient state model; the first is the stage at the downstream end of the LSFR system model and the second is the spatially varying discharge. The downstream boundary was changed from the daily time series of stage used for transient simulations to a normal flow stage when backwater effects from Suwannee River are minimal.

Daily stages measured during the transient model calibration period on the Suwannee River near Branford and Bell, and daily discharges and stages measured on the Santa Fe River near Hildreth were evaluated to characterize conditions when backwater appeared minimal (Appendix E). Since predictive steady-state simulations are needed for a wide range of hydrologic conditions, the following empirical equation relating the slope of the SFR near the confluence to the SFR-Hildreth gaging station was developed. The slope varies inversely with SFR flow becoming steeper as flow diminishes or conversely, flatter as flow increases.

$$S = 0.000835 (Q_{\text{Hildreth}})^{-0.425}$$

In which,

S = water-surface slope of the SFR at the confluence with SR (ft/ft)

Q_{Hildreth} = flow at the SFR-Hildreth gaging station (cfs)

The second set of boundary conditions that was modified is the spatially varied flow that characterizes the hydrology of the LSFR system. Time series of lateral flow inputs determined from field measurements and stream gaging are used in the transient model to characterize the gain (i.e., pickup) or loss of flow along the two rivers. For a steady-state simulation, the time series are replaced with a table of flows prescribed for each model reach in downstream order. The flow specified for a cross section remains constant between that cross section and the next downstream section where a different flow is specified.

Model input flows were apportioned spatially as done in the initial MFLs assessment modeling (Appendix E) for RTF flow scenarios ranging in non-exceedance frequency from 2 to 98 percent, at a 2-percentile interval (49 scenarios). The flow scenarios are based on flow duration curves determined for the period February 5, 2002, through September 30, 2011, when daily flow records were available for the gaging stations on the LSFR and IR. The influence of the karstic system of swallets and resurgences is apparent in the upper reaches as is the pickup associated with spring flow in the IR (Figure 46).

Predictive steady-state simulations were made for the 49 RTF flow scenarios assuming a normal depth downstream boundary condition for each scenario. Detailed output from HEC-RAS was exported to an ASCII file for use in the ecological modeling of the LSFR and IR Systems. The detailed output defines the velocities, depths, wetted perimeter, and other hydraulic properties for each cross section.

The transition of the SFR from a pool-riffle system at low flow to a channel-control system at high flow is apparent in the water-surface profiles calculated for the various flow scenarios (Figure 47 and Figure 48). Backwater becomes more evident in the lower 70,000 feet of the SFR at flows greater than the median flow (Figure 47). The IR appears to be similarly affected in the lower 7,500 feet of the river (Figure 48). The pronounced “V” in the SFR profiles (Figure 46) between distances of about 166,000 and 185,000 feet is a plotting artifact that represents the Santa Fe Land Bridge (Figure 2, Figure 4) where the SFR flows underground and the above-ground channel is normally dry.

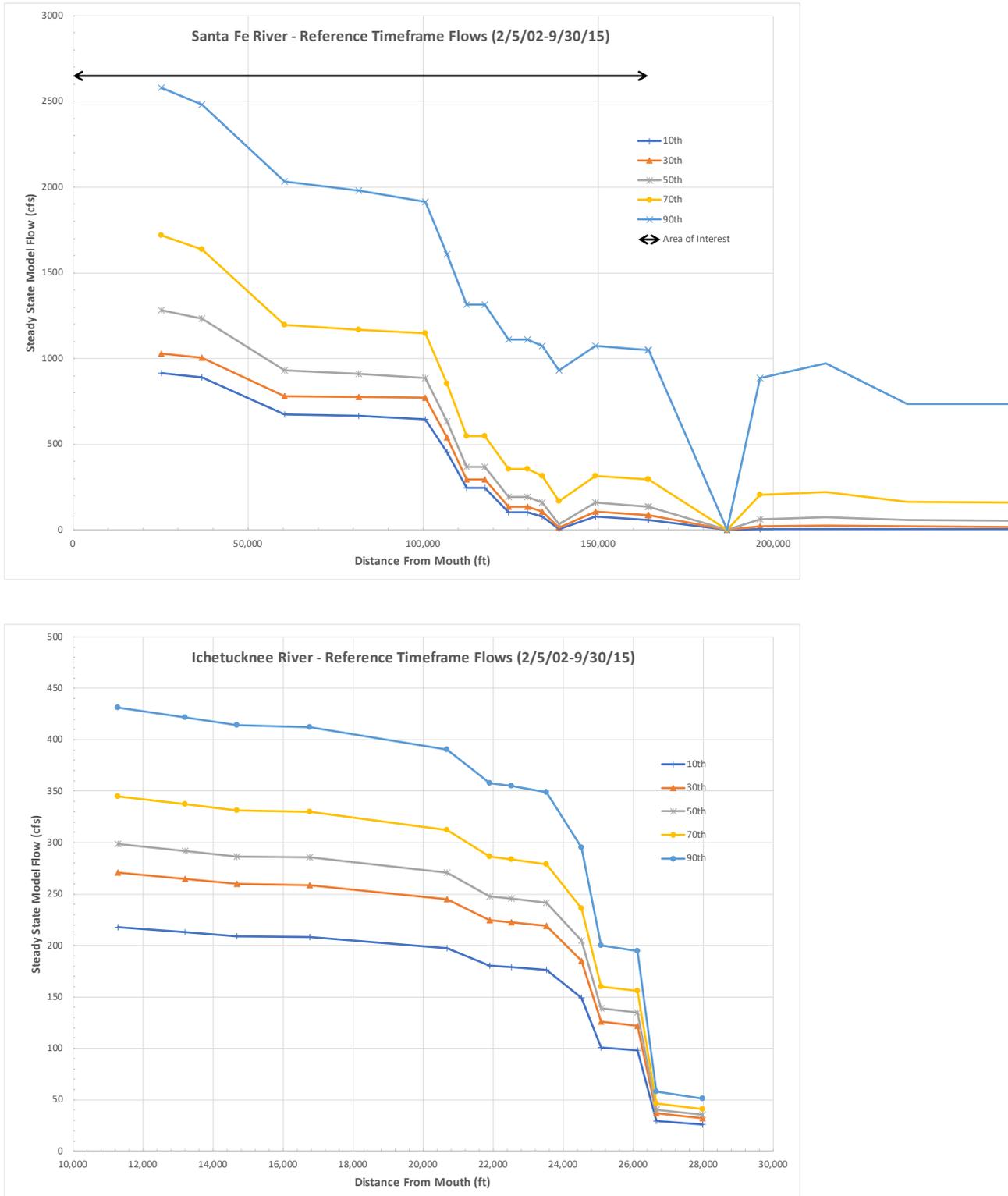


Figure 46. MFLs Re-evaluation Steady State Input Flow Profiles for Select Non-exceedance Frequencies: Lower Santa Fe River (top) and Ichetucknee River (bottom)

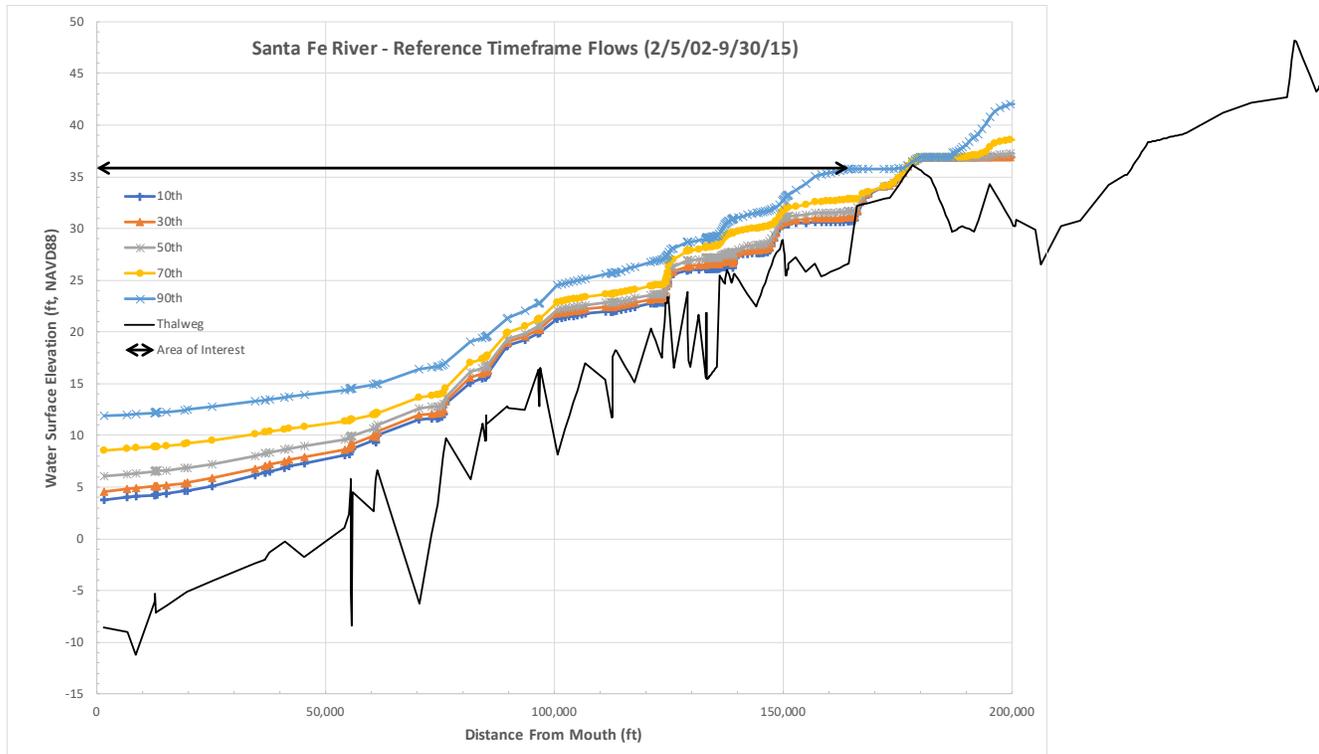


Figure 47. Steady State Water Surface Profiles Simulated For Select Flow Non-Exceedance Frequencies: Lower Santa Fe River

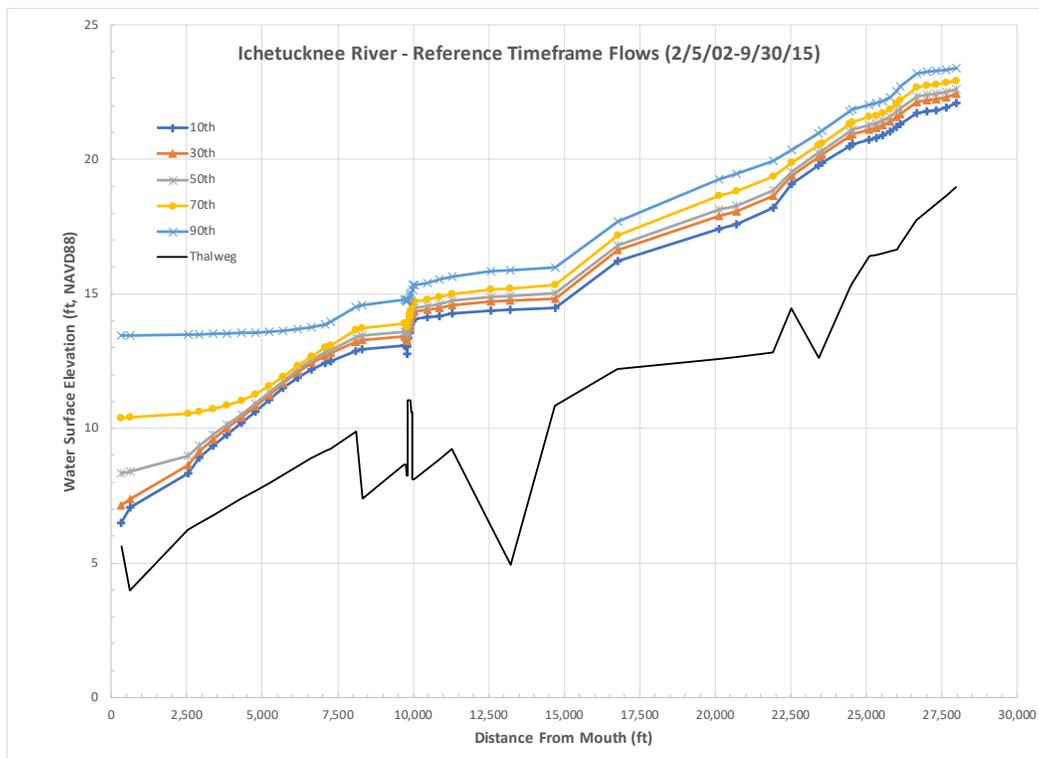


Figure 48. Steady State Water Surface Profiles Simulated For Select Flow Non-Exceedance Frequencies: Ichetucknee River

4.3.2 SEFA Modeling

SEFA (System for Environmental Flow Analysis) (Aquatic Habitat Analysts, Inc. 2012) is a program that simulates relationships between streamflow and a measure of physical habitat for selected fish or other aquatic life forms by guilds, species, and/or life stages. SEFA software utilizes hydraulic, instream habitat, and time series models to develop flow recommendations based on habitat suitability criteria for the evaluated aquatic organisms. The hydraulic characteristics and stage-discharge relationships within a stream sub-reach are key components of a SEFA model. The program allows for the alteration of flows to estimate their effects on the suitability of habitat (reported as area weighted suitability) for organisms of interest in the study system (Jowett, Payne and Milhouse 2014). The ability of SEFA modeling to evaluate relationships between streamflow and physical habitat for aquatic organisms is directly applicable to MFL evaluations.

Water velocity and depth and channel substrate are variables that characterize the physical habitat suitability of a location for aquatic organisms. The response functions needed to evaluate habitat suitability are the relationships between stream discharge and the combination of depth, water velocity, and inundated substrate type. SEFA calculates Area Weighted Suitability (AWS), which is a measure of suitable habitat available to aquatic life forms within the evaluated sub-reach under specified discharge conditions. The program translates an input time series of daily discharge (or other time increment) into a time series of daily AWS (by guild, species, and life stage) and then calculates statistics for each AWS frequency distribution. The output function of the SEFA program is the relation between stream discharge and AWS.

Four locations on the LSFR downstream of US441, and two locations on the IR were selected to provide input to the SEFA model (Figure 49). These locations were representative of the overall river segments and allow specific consideration of key habitat types (pool, shoal, and river run) for lotic organisms. Pools provide reduced velocity, deeper water refuges that some species preferentially select. Conversely, shoals provide greater velocity and shallower depth habitats that are also important to model as Shoals can limit fish passage during low flows. River runs represent typical intermediate velocity and depth habitats.

Habitat Suitability Curves (HSCs) provided by the District are the biological basis of SEFA modeling and represent the functional relationship between the selected physical habitat variable and the response of the selected guild/species/life stage. HSC index values vary between 0 (least suitable) and 1 (most suitable) and provide a probability measure on how suitable a habitat is for a target species. Based upon the relevant species identified in Section 3.4 and the availability of corresponding HSCs, forty-two HSCs of various guilds, species and/or life stages were incorporated into the SEFA modeling (Table 17). The velocity, depth, and substrate criteria for each species and life stage were utilized to calculate the AWS.

Four different SEFA models for the LSFR and two SEFA models for the IR, corresponding to each of the SEFA sites (Figure 49), were developed using appropriate flow input time series for each site. For the two IR sites the infilled flow data for Hwy 27 described in Section 2.3.2 was used as SEFA input. For the LSFR at the Fort White and US441 SEFA sites, the input flow records for the cognominal adjoining gages were used directly (Figure 49). For the remaining two SEFA sites, Powerline and Dog Leg, the steady-state HEC-RAS lateral inflows at selected frequencies were used for flow translation from Fort White (Appendix F). These flow relationships were used with the daily Fort White RTF flow record to develop input flow for the two sites. The steady-state HEC-RAS model was run to a maximum flow of 3,200 cfs

(5% exceedance) at Fort White gage. A set of stage-flow values (<3,200 cfs) derived from HEC-RAS calculated rating curves was used to establish log-log stage-flow relationships for each transect in the SEFA program (Appendix F). The maximum flows of 3,200 cfs at Fort White and 414 cfs at Hwy 27 for averaging the AWS were selected based on comparison of HEC-RAS and SEFA rating curves. The SEFA log-log rating differs from HEC-RAS ratings for flows greater than 3,200 cfs and 414 cfs at Fort White and Hwy 27, respectively.

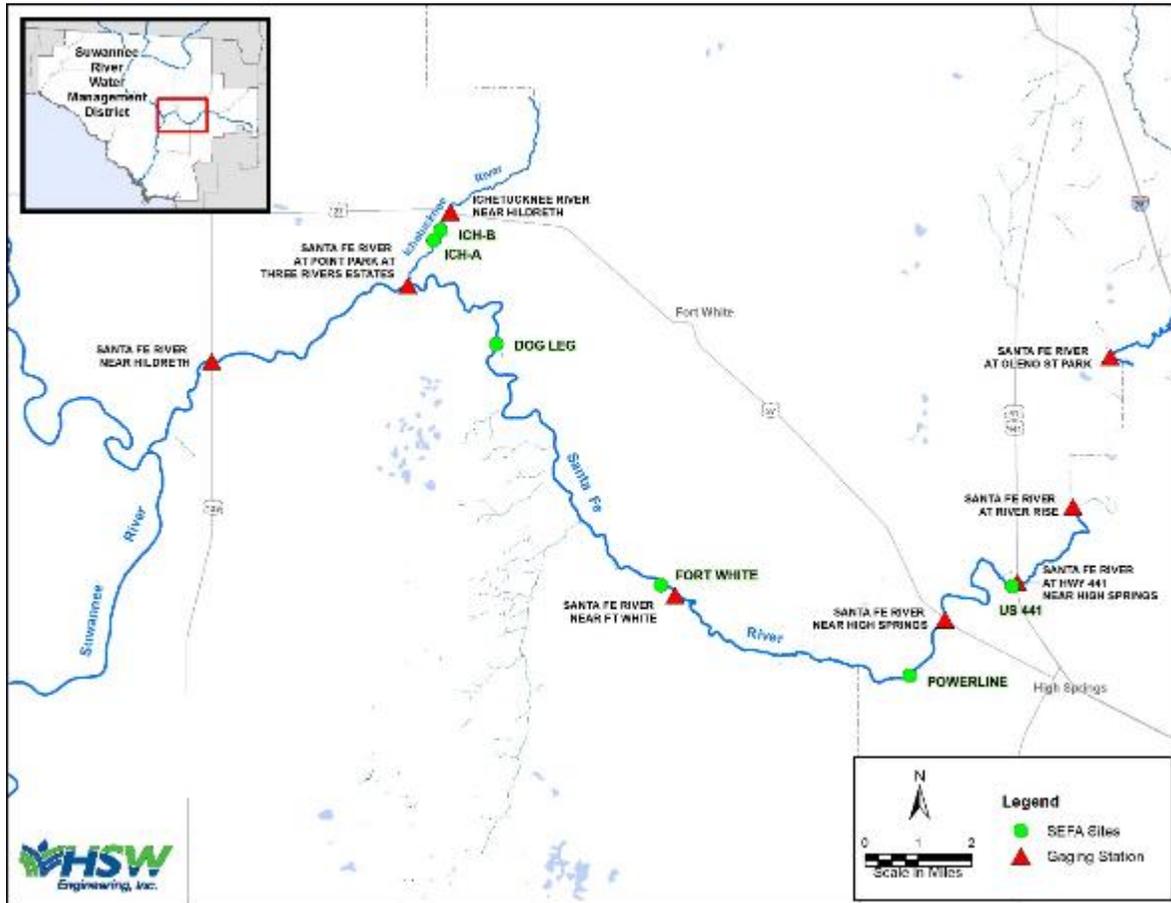


Figure 49. Location of SEFA sites on the Lower Santa Fe River and Ichetucknee River

Table 17. Guilds, species, and life stages considered in the SEFA analysis

Species or Group	Life stage
Suwannee Bass	Adult, Juvenile
Gulf Sturgeon	Adult, Juvenile
Redbreast Sunfish	Adult, Juvenile, Spawning, Fry
Habitat Guilds	Shallow/Slow, Shallow/Fast, Deep/Slow, Deep/Fast
Channel Catfish	Adult, Juvenile, Juvenile (spring, summer, fall, warm water), Spawning, Fry
Darters	Generic, Blackbanded

Species or Group	Life stage
Macroinvertebrates	Ephemeroptera, Plecoptera, Trichoptera, EPT Total <i>Pseudocloeon ehippiatum</i> , Hydropsychidae – total, <i>Tvetenia vitracies</i>
Largemouth Bass	Adult, Juvenile, Spawning, Fry
Bluegill	Adult, Juvenile, Spawning, Fry
Spotted Sunfish	Adult, Juvenile, Spawning, Fry
Cyprinidae	Adult
Note: Area weighted suitability (AWS) was evaluated for the entire year for all species, life stages and guilds, except for Spawning and Fry. AWS for the fry of select species (see Section 5.2.3) was evaluated for a 4-month period (April – July).	

4.4 MFLs Assessment Methods

Streamflow is strongly correlated with many critical characteristics of rivers and is often considered a “master variable” in regulating the physical, chemical, and biological features of riverine systems (N. L. Poff, et al. 1997). Relevant water resource and human use values are collectively protected from significant harm if a broad range of flows affecting hydrology, geomorphology, biology, water quality, and connectivity are maintained (Annear, et al. 2004). The approach used for setting MFLs makes use of several methods for estimating allowable flow reductions that are discussed in this section.

The methods developed to maintain a flow regime that sustains healthy river and riparian ecosystems can be categorized as top-down or bottom-up methods (Tharme 2003). The top-down methods consist of identifying a maximum acceptable departure from the natural flow regime that does not cause ecological degradation (Arthington 1998). The former (SRWMD 2013) and current LSF/IR MFLs assessment follow a top-down approach. A bottom-up approach starts with a static minimum flow and adds flows needed to meet various uses. It is a systematic construction-from-scratch approach, which may be more appropriate for highly altered streams unlikely to be restored to a more natural condition.

The guiding premise for MFLs assessments is that high flow occurrences are not decreased too much and low flow occurrences are not increased too much such that significant harm, due to withdrawals, is avoided. Florida’s water management districts have used different approaches to meet these objectives. Explicit in this guiding premise is that the percent of time (POT) that particular flows are exceeded (Munson and Delfino 2007) can be reduced as long as the reduction does not result in significant harm. Implicit in this premise is that there is an allowable change in inundated area (or some other physical feature) for a fixed amount of time that would remain protective (e.g., Instream Flow Incremental Methodology (IFIM)) – i.e., would not result in significant harm. A third inference is that the frequency that a particular flow event (e.g., flow of specified duration) is exceeded (or not exceeded) is not altered such that significant harm results. This is an event-based approach (Neubauer, et al. 2008). Regardless of the approach used, the result of the analyses is a hydrologic regime that differs from a reference regime (or RTF flow regime) by an amount such that the resource values are protected (N. L. Poff, et al. 1997) and significant harm is avoided.

The event approach was recommended in both the 2013 and 2020 peer reviews of the LSF MFL assessments. Where feasible, the SRWMD uses an event-based approach when developing MFLs for lakes because the systems are less complex than rivers, and information gained from similar types of

water bodies in a similar hydrogeologic setting often is transferable. Using an event-based approach for rivers systems should rely on site-specific data or Florida-specific data (Poff and Zimmerman 2010) targeted specifically for MFLs assessment.

The allowable flow reductions for this re-evaluation of the LSF are associated with either a 15% reduction in time that a WRV-specific flow is exceeded (Munson and Delfino 2007), or a 15% reduction in a modeled habitat area metric developed using SEFA. Either of these approaches may be applied seasonally. The application of the POT approach is presented in Section 5 and involves limiting the number of days a high flow is equaled or exceeded from being decreased by more than 15%. This can be thought of as not allowing the “good” days (high flow days) to occur substantially less often than occurred during the RTF period. The POT approach (Munson and Delfino 2007) has been used primarily for evaluating high flows, and SEFA (or more generally in-stream habitat modeling) has been used primarily for in-stream lower flows. The 15% threshold has been applied in many of the MFLs analyses performed by the SRWMD and SWFWMD for MFLs Rule development (Munson and Delfino 2007, SWFWMD 2005a, SWFWMD 2005b, SWFWMD 2010b, SWFWMD 2011). MFLs established by SRWMD using this approach include the prior MFL study of the LSFR/IR system, of which this work is a re-evaluation, the related Upper Santa Fe System River (Water Resource Associates, Inc. 2007), and more recently the Steinhatchee, Aucilla, and Wacissa Rivers, which are based on POT and/or modeled habitat-area reduction assessments and a 15% change threshold.

In addition to the methods described in this section for evaluating WRVs, it is important to maintain flow that prevents significant harm between successive reaches of the river. That is, MFLs established and referenced to the streamflow gage at Fort White and, by extension, allowable flow reductions, should be proportional to flow changes in the river reaches between the USGS gage at Fort White and US441 and above the US441 gage. This is analogous to the yield analysis of Table 2 but is being based only on the relationships of reach flows. The upstream MFL (i.e., above US441) is determined by apportioning water within and above the reaches based on the difference in median streamflow between the two. This approach is useful when sufficient data are unavailable or limited within a river reach and a full evaluation of water resource values is not possible.

As a back-check to the approach used to setting MFLs, two additional comparisons are employed:

1. Relative flow reductions associated with the proposed MFLs were compared to literature summarizing case studies of water management (Richter, et al. 2011) and
2. IHA software (The Nature Conservancy 2009) was used to characterize the differences in a variety of statistical streamflow characteristics between long-term time series of observed flow adjusted to account for groundwater withdrawals and the projected flows associated with the proposed MFLs at the Fort White gage.

4.5 Uncertainty and Adaptive Management

This re-evaluation of minimum flows in the LSF River System reflects the application of an adaptive management strategy for dealing with uncertainty in this complex, dynamic river system and associated stochastic processes. Uncertainty is an unavoidable consequence of the ever-changing natural and anthropogenic processes within and affecting the LSF River System. From both scientific and management perspectives, there is uncertainty associated with determining withdrawal impacts on

physical, biological, and chemical aspects of the system. Nonstationarity in climate and other environmental conditions such as temperature and nutrients and ecological features such as non-native species spread also represent challenges to environmental flow assessments (N. L. Poff 2017). The author notes that “a new imperative of managing for resilience is emerging” because of “shifting hydro-climatic and ecological conditions.”

Uncertainties are widely acknowledged but they are rarely quantified in the MFL setting process, and it is not the District’s intent to do so in this report. However, identifying sources of uncertainty can help with reducing uncertainty by collecting additional data and through additional targeted studies and adaptive management.

Some sources of uncertainty in the current re-evaluation are:

- Flow and stage data (error associated with collecting and processing basic hydrologic data).
- Infilling and record extension. Often data are not available for a complete or desired period of record for a particular gage/location and associations between flow/stage at one gage are used to estimate the flow/stage at another gage with a limited record. This source of error generally can be quantified using parametric (if certain criteria are met) or non-parametric (less restrictive criteria) means.
- Functional relationship between flow/stage and system response. For example, the SEFA model used for instream habitat modeling depends on a hydraulic model of the study area and an association between input variables (velocity, depth, and substrate) and habitat suitability indices (curves) for a variety of species and life stages. There are uncertainties associated with the input data, the model application, and the response functions.
- Varying influence of climatological variables (e.g., rainfall and air temperature) on surface and groundwater hydrology, ecosystems, primary productivity, and important water-quality constituents such as dissolved oxygen.

Adaptive management is a standard approach for reducing the inherent uncertainty associated with natural resource management (Williams and Brown 2014) and is recommended by the U.S. Department of the Interior for decision making in the face of uncertainty about management impacts (Williams, Szaro and Shapiro 2009). Adaptive management is a systematic, iterative approach to meeting management objectives in the face of uncertainty through continued monitoring and refinement of management actions based on consideration of alternatives and stakeholder input (Figure 50). The adoption of Rule 62-42.300, F.A.C., closed the loop for a single iteration of an adaptive management process maintained by the District.

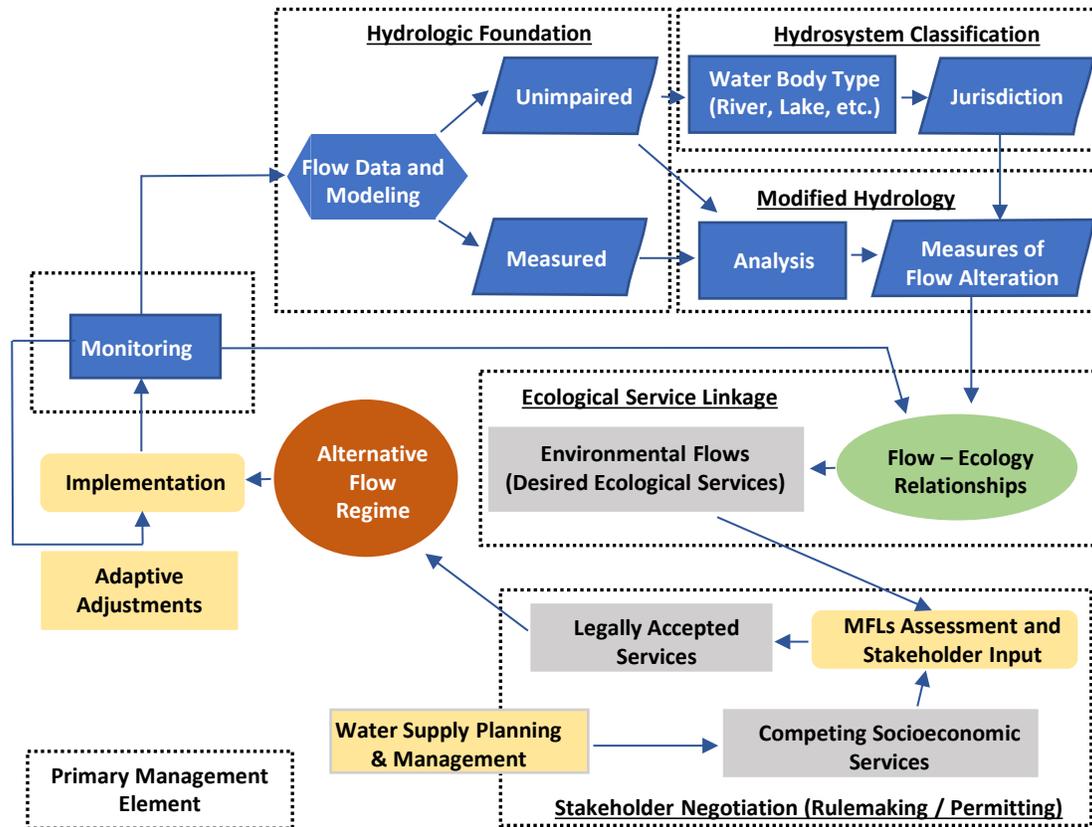


Figure 50. Conceptual holistic framework for the LSF River Systems Assessment
 [Modified from (N. Poff, J. Allan, et al. 2010)]

This 2019 re-evaluation of minimum flows is closing the loop on another iteration of the adaptive management process (Figure 50) by assembling, evaluating, and using the best information currently available to develop revised, recommended minimum flows for the LSF River System. The minimum flow recommendations resulting from this re-evaluation are made while acknowledging the continued, unavoidable uncertainty in our understanding of natural patterns and processes inherent to the system as well as uncertainty associated with predicting the consequences of future water withdrawals.

The continued adaptive management of the LSF River System will require ongoing monitoring, assessment, and periodic re-evaluation of minimum flows. Examples of future monitoring that could support future MFL assessments include:

- SEFA data collection and modeling upstream from US441
- Systematic stream- and spring-flow water quality monitoring tailored specifically to characterize changes in base flow that can be attributed to withdrawals
- Baseline and recurring synoptic surveys of floodplain vegetation, instream submerged aquatic vegetation, fish, and other aquatic biota of interest.

5. EVALUATION OF WRVS

Water Resource Values that are deemed most relevant to this study area of the LSFR/IR (Section 4) are evaluated further in this section. Flow scenarios that are protective of these WRVs are sufficient to protect the overall structure and function of the river system based on their prior use and acceptance in other systems in Florida (see Section 4.4).

Threshold flows for the LSFR are referenced to the Fort White gage. For example, paddling and boating WRV metrics are available for the US441 gage and the threshold flows for these WRVs were translated from US441 to the Fort White gage using common flow exceedance values (Figure 51). The same approach is used when the threshold flow is at a particular cross-section, i.e., steady-state HEC-RAS model output is used to translate flow from the transect to the Fort White reference gage.

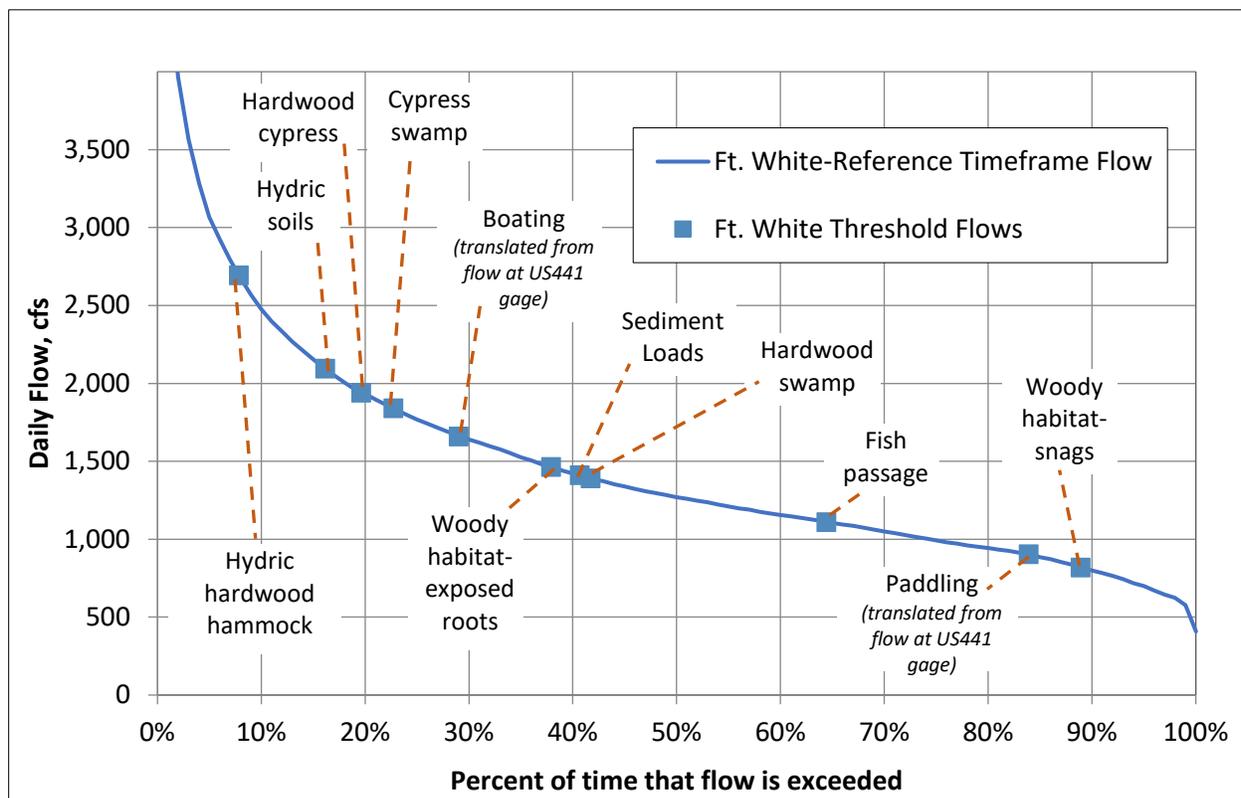


Figure 51. Threshold flows at Fort White

5.1 Recreation In and On the Water

Recreation is an important water resource value for the LSFR and IR. The Outstanding Florida Water designation of the rivers is, in part, based on the recreational importance of the system (Rule 62-302.700 F.A.C.). Uses include swimming, boating, diving, recreational fishing, kayaking, canoeing, and tubing. The rivers are bordered by many parks, and numerous boat ramps and docks allow access to the rivers for recreational activities.

Lower Santa Fe River (LSFR)

Generally, paddlers and boaters are advised to assess water conditions before accessing the river. The *Santa Fe River Paddling Trail Guide* published by the Florida Park Service recommends that river levels at the SRWMD gage at the US 441 Bridge (02321975) be 32 ft NGVD29 for adequate water between US 441 and US 27.

The amount of time that water level conditions preclude paddling or boating due to low-flow conditions was selected to assess protection of recreation on the LSFR, while the amount of time that water level conditions would result in damage to SAV from tubing was selected to assess protection of recreation on the IR. In these percent-of-time evaluations, it is the decrease in occurrence of a viable condition that is of interest.

Canoes and kayaks used on the river have lengths of about nine to 16 feet but require only about six inches of water depth for navigation. Typical fishing and pontoon propeller engine shaft lengths range from 20 to 25 inches, which includes the boat transom height above the water (Iboats 2009). Thus, a water depth of about two feet, or 1.5 feet more than required for paddling, is considered adequate for outboard motor clearance between the bottom of these vessels and the channel bottom to prevent prop scarring of SAV or physical damage to a boat motor.

The threshold stage used for evaluating canoeing or kayaking on the LSFR is 31.2 ft NAVD88 (listed as 32 ft NGVD29 in the paddling guide) at the 441 Bridge and is associated with a flow of about 253 cfs at the US441 gage. A flow of 253 cfs at the US441 gage translates to a flow of 903 cfs at the Fort White gage. Paddling is assumed to be impaired at a stage of less than 31.2 ft NAVD88 at 441 Bridge; therefore, a flow of 903 cfs at the Fort White gage is the threshold flow for assessing this recreation metric. A 15% decrease in time canoeists and kayakers would experience easy paddling due to low-flow conditions (306 days) would mean a decrease of about 46 days each year. Under RTF flow conditions, this exceedance corresponds to a flow of about 1,034 cfs at Fort White; i.e., a withdrawal of about 131 cfs at Fort White under these flow conditions decreases the viable paddling days by 15%, on average (Table 18) (Figure 53).

By similar reasoning and assuming that a minimum water level of 32.7 ft NAVD88 (31.2 ft NAVD88+1.5 ft) at the 441 Bridge (corresponding to flows of about 941 cfs at US441 and 1,659 cfs at Fort White) is needed for operation of small, motorized vessels, a 15% decrease in the number of viable boating days that would occur under reduced flow conditions would mean that easy boating on the river would not be viable for an additional 16 days each year, on average. This reduced-flow scenario permits a withdrawal of about 115 cfs at Fort White when discharge at Fort White gage is about 1,774 cfs (Table 18).

Ichetucknee River (IR)

An important water resource value for the IR is maintenance of recreation, particularly north of the Grassy Flats area (Figure 52). The SAV community provides both an important structural habitat and refuge for a variety of fauna, as well as being an important component of the river's primary production, and it can be damaged by trampling action when water levels are low enough for tubing participants to

stand in the water. The greatest damage to the grassy flats results from seasonal tubing, which is limited to the summer season (Memorial Day weekend to Labor Day).

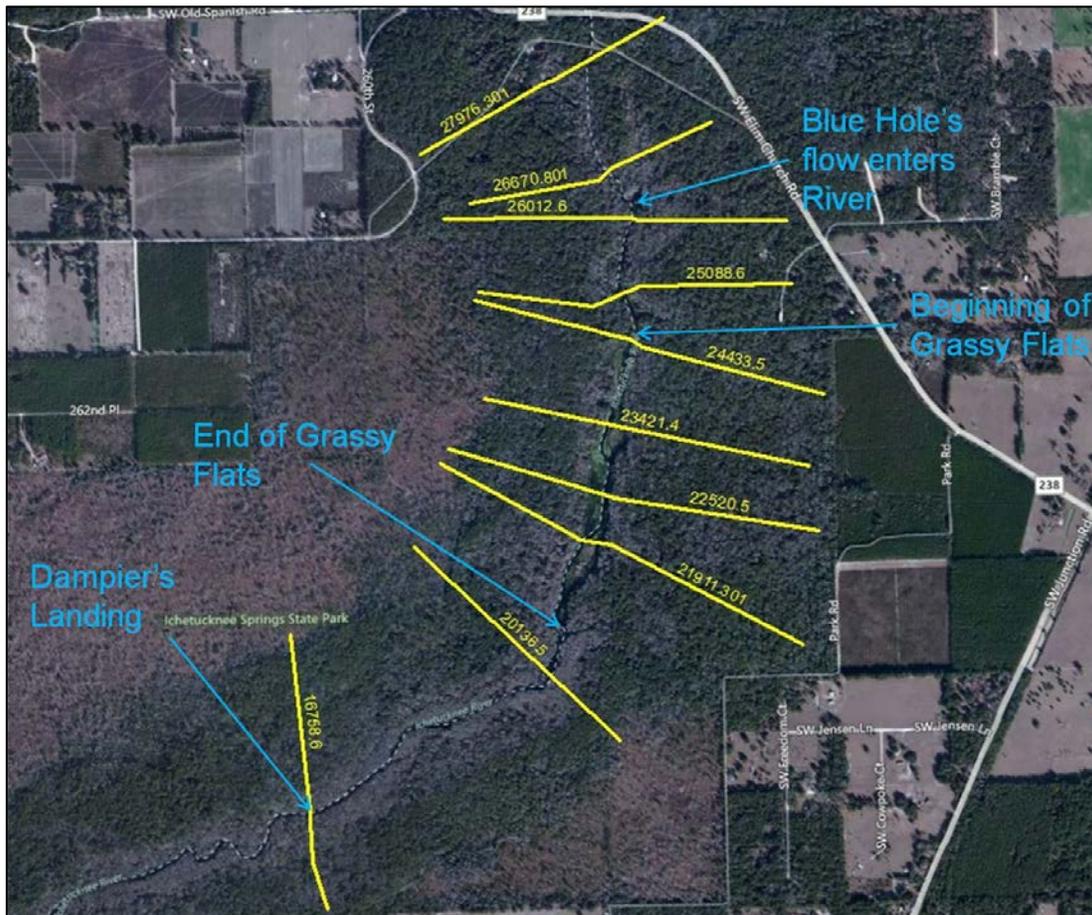


Figure 52. Ichetucknee River HEC-RAS Cross-sections

According to the Ichetucknee Springs State Park (Park) Approved Unit Management Plan (UMP), one of the stated goals is to preserve and protect SAV as a desirable natural resource and the abundance of SAV within the IR served as the basis for the existing carrying capacity numbers specified for daily recreational tubers in the upper portion of the IR. For this reason, the utilization of SAV as a WRV criterion is reasonable and is associated with significant harm. It is further stated in the park UMP: “Tuber (Recreational) damage to SAV is acute during years with extreme low water levels”. Reduced water levels may increase human recreational contact with SAV; which is a stressor to SAV (especially the desirable species – i.e., native, flowering macrophytes).

Current management of water recreation in this part of the IR is primarily based on research (Dutoit 1979) that presented impacts of tubing on SAV. The IR Park Staff and Florida Park Service also have documented the impact of tubing on SAV in the upper portion of the system. A threshold for tubing on the IR therefore was developed so that recreational access from the north entrance is maintained and the frequency of contact between tubing participants and SAV is limited (FDEP 2000) (SRWMD 2013).

An assessment of adequate conditions for tubing down the IR is based on the average individual being able to tube without damaging SAV. Field measurements conducted in February 2013 indicated that a

large tubing participant (>200 lbs.) in a typical, single-user tube requires about 1.05 ft of water above the threshold SAV elevation (SRWMD 2013). Based on field measurements of SAV at six transects between River Station 26671 and Dampier’s Landing, the stage at River Station 25088.7 was the most critical and is associated with a flow of 282 cfs at the Hwy 27 gage. Under RTF flow conditions, a flow of 282 cfs corresponds to a flow exceedance of 89.6%, or about 327 days per year on average.

A 15% decrease in time that conditions are conducive for tubing while allowing adequate SAV protection would result in a decrease of about 49 days per year, on average. Under such reduced-flow conditions, 40 cfs would be available for withdrawal at flows of about 322 cfs (Table 18) (Figure 53).

Table 18. Flow reductions associated with 15% decrease in exceedance for paddling/boating/tubing

Threshold flow and time exceeded			RTF flow and time exceeded resulting from a 15% decrease in time exceeded			Change in flow and time exceeded			
Description	Flow	Time flow exceeded		Time flow exceeded		RTF	Time	Flow	
	cfs	%	Average days/year	%	Average days/year	cfs	Average days/year	Cfs	%
Index ¹	A	B	C	D	E	F	G	H	I
Paddling on LSFR ²	903	83.9	306	71.3	260	1,034	46	131	12.7
Boating on LSFR ²	1,659	29.3	107	24.9	91	1,774	16	115	6.5
Tubing on IR ²	282	89.6	327	76.2	278	322	49	40	12.4

- 1 A=threshold stage (flow), B=% time threshold flow is exceeded, C=B*365, D=B*0.85, E=C*0.85, F=flow associated with 15% decrease in exceedance time, G=C-E, H=F-A, I=100*(F-A)/F.
- 2 Refer to Figures 1, 2, and 3 of Appendix G.
- 3 The flows indicated are rounded to nearest integer.

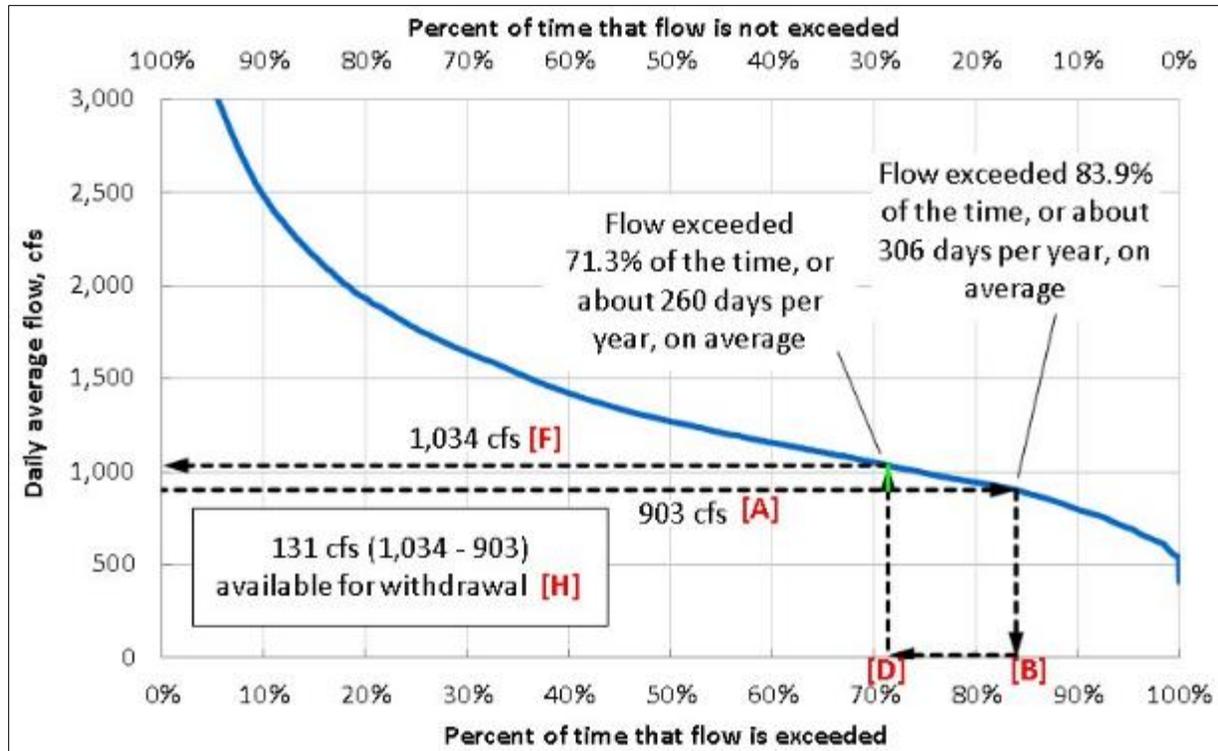


Figure 53. RTF Flow duration curve depicting threshold flows protective of paddling on the Lower Santa Fe River (Fort White gage)

5.2 Fish Passage and Fish and Wildlife Habitat

5.2.1 Fish Passage

Fish passage is a potential issue in the river channels during low flow because of shallow shoal areas in both the LSRF and the IR. Under low-flow conditions, water depth can be an obstruction to the longitudinal passage of fish. The passage of fish 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.

Fish passage throughout the LSRF and IR is assumed to require water depths of at least 0.8 feet over at least 25% of the most-limiting HEC-RAS transect channel width (Thompson 1972). The flow resulting in a water depth of no less than 0.8 feet over 25% of the stream top width at the most limiting transect was determined to be the threshold flow for fish passage (Table 19).

Table 19. Fish Passage Threshold Flow

	Lower Santa Fe River	Ichetucknee River
Restrictive HEC-RAS XS	124713.2	7087.18
Threshold flow for Fish Passage at the MFL gage	Fort White – 1,110 cfs	Highway 27 - 284 cfs

The transect limiting the fish passage in the LSRF section of the HEC-RAS model is near River Station 124713.2 located upstream of the Fort White gage. The flow condition that provides the required cross-

sectional area for fish passage is about 1,110 cfs at the Fort White gage. A 15% decrease in the number of days that this flow condition is exceeded would allow a flow reduction of about 103 cfs, or 8.5%, when flow is about 1,213 cfs (Table 20). Similarly, the most restrictive cross-section on the IR is River Station 7087.18. The flow condition that provides the required fish passage cross-sectional area is about 284 cfs at the Hwy 27 gage. A 15% decrease in the number of days that this flow condition is not exceeded would allow a flow reduction of about 38 cfs (Table 20).

Table 20. Flow reductions associated with 15% decreases in the time that the threshold stages for fish passage on the LSRF and IR are exceeded

Threshold flow and time exceeded			RTF flow and time exceeded resulting from a 15% decrease in time exceeded			Change in flow and time exceeded			
Description	Flow		Time flow exceeded		RTF	Time	Flow		
	cfs	%	Average days/year	%			Average days/year	Average days/year	cfs
Index ¹	A	B	C	D	E	F	G	H	I
Fish Passage – LSRF ²	1,110	64.4	235	54.7	200	1,213	35	103	8.5
Fish Passage – IR ²	284	89.1	325	75.7	276	322	49	38	11.9

- 1 A=threshold stage (flow), B=% time threshold flow is exceeded, C=B*365, D=B*0.85, E=C*0.85, F=flow associated with 15% decrease in exceedance time, G=C-E, H=F-A, I=100*(F-A)/F.
- 2 Refer to Figures 4 and 5 of Appendix G.
- 3 The flows indicated are rounded to nearest integer.

5.2.2 Gulf Sturgeon Passage

Gulf sturgeon have been sighted in the LSRF and three specimens have been collected from the Santa Fe River. Movement of Gulf sturgeon from the Gulf of Mexico up the Suwannee River generally occurs during a primary spring spawning period in March and April, and a second period of spawning occurs from early September through October (Randall and Sulak 2007). Gulf sturgeon, including juveniles, typically remain in their spawning areas throughout the summer and fall, although they often travel extensively in these areas, including further upstream. When river waters begin to cool in the fall, sturgeon of all ages migrate during September and October to estuarine and coastal waters for winter feeding (USFWS/NMFS 2009). The USGS has recommended a minimum depth of three feet, or about twice the maximum body depth of an adult female sturgeon, for fish passage (M. Randall, Personal Communication 2013). A channel width of no less than 15 feet, or about twice the body length of a large female adult, would allow adult sturgeon to turn in the river.

The critical HEC-RAS cross-section in the LSRF is 264.3174 where the minimum width of 15 feet and depth of three feet could limit sturgeon passage. The flow at Fort White associated with these threshold criteria is 1,627 cfs. Both sturgeon migration periods at this gaging location were evaluated using the percent-of-time method; specifically, the flow reduction associated with a 15% decrease in time that flow is greater than 1,627 cfs at Fort White (Table 21).

Table 21. Flow reductions associated with 15% decreases in the time that the threshold flows for Gulf Sturgeon passage on the LSFR are exceeded

Threshold flow and time exceeded			RTF flow and time exceeded resulting from a 15% decrease in time exceeded			Decrease in flow and time exceeded			
Description	Flow	Time flow exceeded		Time flow exceeded		RTF	Time	Flow	
	cfs	%	Average days/year	%	Average days/year	cfs	Average days/year	cfs	%
Index ¹	A	B	C	D	E	F	G	H	I
Sturgeon passage (March-April) ²	1,627	37.6	137	31.9	117	1,810	21	183	10.1
Sturgeon Passage (Sept-October) ²	1,627	41.0	150	34.9	127	1,776	22	149	8.4

- 1 A=threshold stage (flow), B=% time threshold flow is exceeded, C=B*365, D=B*0.85, E=C*0.85, F=flow associated with 15% decrease in exceedance time, G=C-E, H=F-A, I=100*(F-A)/F.
- 2 Refer to Figures 6 and 7 in Appendix G.
- 3 The flows indicated are rounded to nearest integer.

5.2.3 Instream Habitat

As discussed in Section 4.3.2, SEFA was used to evaluate potential changes in physical habitat for fish and other biota associated with the variation of flows at selected sites in the LSFR/IR. The sites and aquatic biota selected for SEFA modeling are representative of the different trophic levels, hydraulic conditions, and substrate found in the LSFR/IR. Four sites (Dog Leg, Fort White, Powerline, US441) on the LSFR and two sites (IchA, IchB) on the IR were selected during the 2013 MFLs assessment to represent pool-riffle-run habitat characteristics of the LSFR/IR system (SRWMD 2013) (Figure 49).

SEFA Site Characteristics

A regional perspective of the LSFR morphology is described in Section 3.2.1. The upper reaches of the LSFR are less incised and support a wide floodplain. Farther downstream (west of Fort White) the river banks become higher and steeper, and the channel becomes broader and more incised. The LSFR features solid rock channel bottoms at shoals and other areas as well as unconsolidated, mainly sandy sediments. In the downstream-most section of the LSFR there are natural levees of Santa Fe marl along the bank, which may be several feet high. The US441 and Powerline sites are located in the upper portion of the LSFR where the channel bottom elevations and channel width-to-depth ratios are greater and more variable than at the Fort White and Dog Leg sites (Figure 54 and Table 22).

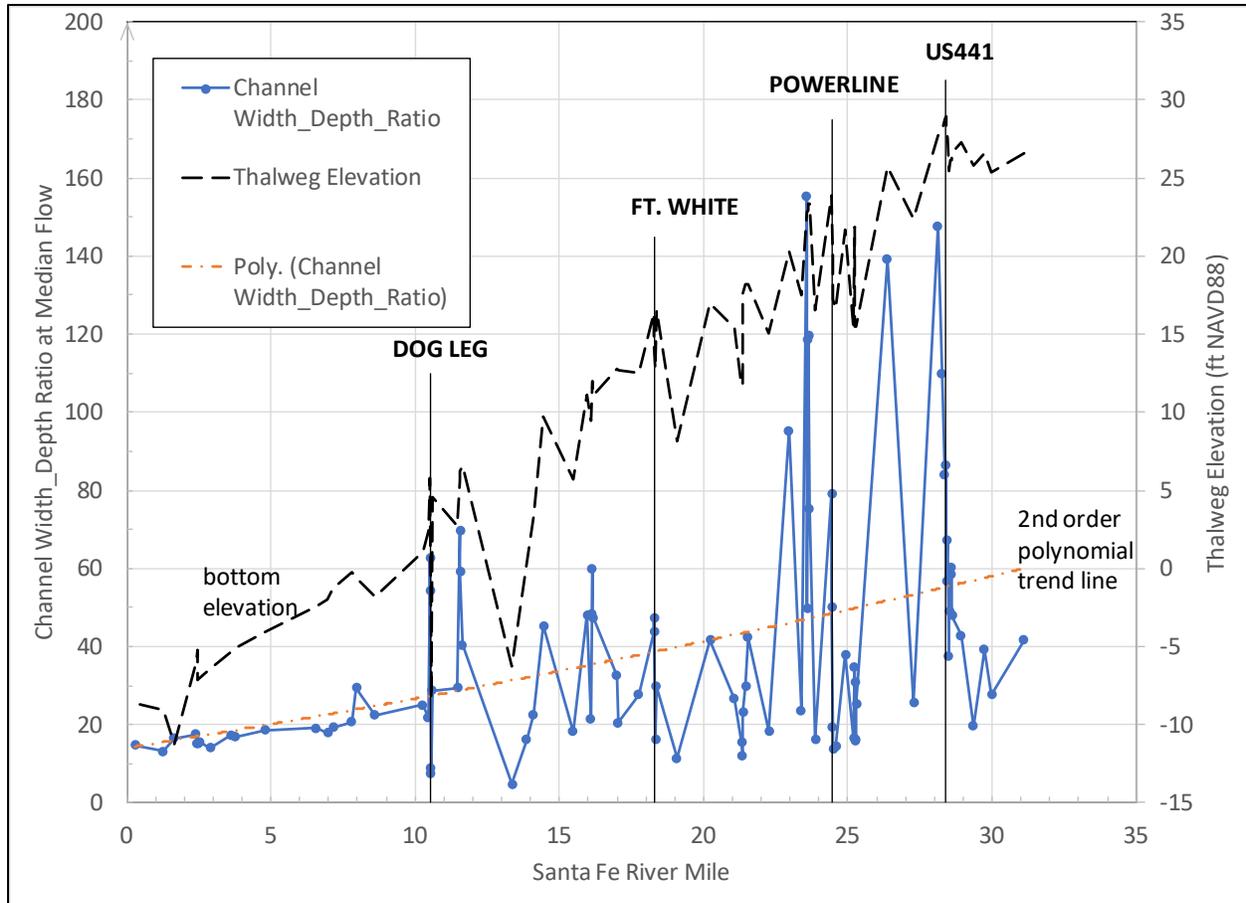


Figure 54. Morphological characteristics of the LSRF and SEFA Sites

Table 22. General characteristics of the Lower Santa Fe River SEFA sites

HEC-RAS Station Descriptor	River Mile	Channel Width-Depth Ratio	Thalweg Elev. (ft NAVD88)	Predominant Channel Bottom Substrate
150082.7 PHABSIM US441	28.42	56.75	28.0	Cobble
149924.3 PHABSIM US441	28.39	86.51	28.9	Gravel, Cobble
149708 PHABSIM US441	28.35	83.89	28.8	Gravel, Cobble
129312.6 PHABSIM Powerline	24.49	13.91	17.2	Cobble
129212.6 PHABSIM Powerline	24.47	19.48	20.0	Gravel, Cobble, Small Boulder
129118.4 PHABSIM Powerline	24.45	50.19	23.7	Gravel, Cobble, Small Boulder, Sand
96930.06 PHABSIM Fort White	18.36	29.74	16.5	Gravel, Cobble
96791.79 PHABSIM Fort White	18.33	16.20	12.8	Bolder, Flat & Angled Bedrock
96532.88 PHABSIM Fort White	18.28	43.84	16.4	Cobble
55732.9 PHABSIM Dog Leg	10.56	7.35	-8.4	Angled Bedrock, some Sand

HEC-RAS Station Descriptor	River Mile	Channel Width-Depth Ratio	Thalweg Elev. (ft NAVD88)	Predominant Channel Bottom Substrate
55655.57 PHABSIM Dog Leg	10.54	8.78	-5.2	Bolder, Flat & Angled Bedrock
55554.55 PHABSIM Dog Leg	10.52	54.19	5.2	Bolder, Flat & Angled Bedrock

These regional substrate characteristics of the LSFR are apparent in the substrate types recorded during the field surveys performed for the initial MFLs assessment. The predominant bottom substrates at the US441 and Powerline sites are gravel, cobble, and small boulders. The predominant substrates at the most downstream site (Dog Leg) are flat and angled bedrock, bolder, and some sand. Substrates at the Fort White site reflect a transition with a combination of gravel, cobble, and flat and angled bedrock.

The sources of water that enter the river also influence the in-stream habitat availability. The LSFR at the two more downstream SEFA sites (Fort White and Dog Leg) receive abundant groundwater inflow compared to the upstream sites (US441 and Powerline). In summary, it appears that the US441 and Powerline SEFA sites are representative of the upper 8.2 miles of the LSFR (river miles 22.9 – 31.1), which is about 25% of two combined sub-reaches. The Fort White and Dog Leg sites are representative of the lower 22.9 river miles, or about 75% of the combined sub-reaches.

Flow Reduction Assessment

For the relevant species and life stages described in Section 4, daily AWS values were calculated using daily RTF flow values and then averaged for a wide range of flows to explicitly characterize instream habitat in the LSFR and the IR. SEFA simulations were performed for each SEFA site using a constant relative flow reduction, i.e. percent-of-flow reduction (POFR), and the USGS gage at Fort White as the reference gage. Daily RTF flows at the Dog Leg and Powerline sites were derived using daily Fort White RTF flows and HEC-RAS flow apportionment. Daily RTF flows at the Fort White and the US441 SEFA sites are the same as those at the respective USGS gages. The daily AWS values simulated for the period of record daily flows, up to a maximum of 3,200 cfs at the LSFR Fort White gage and 414 cfs at the IR Hwy 27 gage, were then averaged to characterize in-channel habitat suitability. Daily AWS values for flows greater than 3,200 cfs (exceedance frequency of about 5%) at the Fort White gage were not used for this analysis.

Multiple SEFA simulations were made to determine the POFRs resulting in a 15% decrease in average AWS for each species and life stage at each SEFA site. A weighted average AWS was computed based on geomorphologic characteristics of the rivers. The upper SFR reach (with the US441 and Dog Leg sites) was weighted as 0.25 and the lower SFR reach (with the Fort White and Powerline sites) as 0.75, based on linear miles of the two sub-reaches. The two sites on IR (Ich A and Ich B) have similar substrate characteristics, and the SEFA results for those sites were weighted equally.

Based on the initial SEFA model results, the fry of largemouth bass, a valued game fish, was determined to be sensitive at the four sites on LSFR (Dog Leg, Fort White, US441, and Powerline) (Appendix F). Largemouth bass juvenile life stage was the most sensitive on IR. Weighted average AWS for largemouth bass fry was evaluated further considering seasonality and water management approaches. AWS sensitivity for largemouth bass fry was evaluated using a subset of daily flows for the 4-month period from April through July when largemouth bass spawn and mature into juvenile fish. Given the substantial groundwater component that sustains low to medium flows in both rivers, seasonal

largemouth bass AWS sensitivity was also evaluated for both POFR and constant flow reduction (CFR) management approaches.

All four SFR SEFA sites are downstream of the US441 gage, hence the sensitivity to flow reduction of instream habitat upstream from the US441 gage was evaluated implicitly using apportionment as described in Section 4.4. The hydrologic shifts (i.e., POFR or CFR) determined for the Fort White gage were assessed at median flow conditions to maintain similar hydrology upstream of the US441 gage. The hydrologic shift determined for the Fort White gage was used to compute the shift at the US441 gage by multiplying the shift at Fort White by 0.435 (the ratio of the 552 and 1,270 cfs median RTF flows at the gages) similar to the method described by Jacobs (Jacobs and Romesser 2006).

The weighted average POFR at the Fort White gage associated with a 15% decrease in AWS at the four LSFR SEFA sites is 7.8%, which equals a 99 cfs shift when applied to the POR RTF median flow at Fort White (Table 23). The CFR shift associated with a 15% decrease in AWS is 115 cfs. The hydrologic shifts at the US441 gage corresponding to a 15% decrease in average AWS downstream from the US441 gage equal the shifts determined at the Fort White gage. This assumed translation is analogous to pipe flow such that a reduction of flow into the pipe (US441) will result in the same reduction of discharge at Fort White and locations in between.

The hydrologic shifts that consider instream habitat upstream from the US441 gage are 46 and 53 cfs, respectively, for POFR and CFR management approaches (Table 23). Those shifts are based on the apportionment of hydrologic shifts determined for the Fort White gage.

The average of the IR percent of flow reductions associated with a 15% decrease in average AWS at the Ich A and Ich B sites is about 18 cfs, which is about 5% of the 356 cfs median POR RTF flow at the Hwy 27 gage.

5.2.4 Woody habitat

Woody habitats are important in low-gradient rivers and streams, such as the LSFR and IR, and are widely recognized as among the most important of habitat types in the southeastern U.S. (Benke, Van Arsdall, Jr., et al. 1984) (Thorp, et al. 1990) (Benke and Wallace, Wood Dynamics in Coastal Plain Backwater Streams 2011). The woody habitats, consisting of emergent niches, exposed roots, and submerged snags, are important for maintaining ecosystem integrity. They provide protective spaces that are important for spawning and juvenile fish protection. Woody habitats also are relatively stable under diverse flows and are resistant to smothering by sand and silt (Edwards and Meyer 1987). These features can create additional habitat and substrate for microbial growth, by trapping organic material such as leaf litter and loose wood debris.

Table 23. Basis for SEFA-based hydrologic shifts determined for SFR at the Fort White

SEFA Site	Fort White gage (1); RTF median flow = 1,270 cfs	
	Constant % (APR-JUL)	Constant cfs (APR-JUL)
Dog Leg	9.4%	126
Fort White	4.0%	83
Power Line	12.0%	159
US441	10.0%	133
Average	8.9%	125
Weighted average (2)	7.8%	115
Shift at median (3)	99	115

1. Daily flows are referenced to Fort White gage. Percent flows are determined by multiplying daily flow by a constant percent; constant flows are determined by subtracting a constant value from daily flow.
2. Weighted average POFR and CFR results are given by (US441 + Powerline) x 0.125 + (Fort White + Dog Leg) x 0.375.
3. Hydrologic shift at the median flow; POFR shift equals median flow x weighed average % flow reduction.

The functionality of woody habitats in rivers is best realized when these habitats 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 also is 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 habitats and their potential for use in development of an MFL, inundation patterns were examined for exposed root and snag habitats at in-stream locations, with three transects at each location.

The threshold flow for exposed roots (i.e., the flow associated the mean elevation of exposed roots) is 1,463 cfs for the LSFR at the Fort White gage and 368 cfs for the IR at the Hwy 27 gage. The threshold flow for inundated snags for the LSFR is 819 cfs at the Fort White gage (SRWMD 2013). A 15% decrease in exceedance time corresponding to flows of 1,463 cfs and 819 cfs on the LSFR at Fort White would allow flow withdrawals of 131 and 167 cfs. For the IR, a 15% decrease when flow is 368 cfs would allow a withdrawal of 10 cfs (Table 24).

Table 24. Flow reductions associated with 15% decreases in the time that the threshold flows for woody habitat sustainability on the LSFR and IR are exceeded

Threshold flow and time exceeded			RTF flow and time exceeded resulting from a 15% decrease in time exceeded			Decrease in flow and time exceeded				
Description	Flow	Time flow exceeded		Time flow exceeded		RTF	Time		Flow	
	cfs	%	Average days/year	%	Average days/year	cfs	Average days/year	cfs	%	
Index ¹	A	B	C	D	E	F	G	H	I	
Exposed Roots – LSFR ²	1,463	37.9	138	32.2	118	1,594	21	131	8.2	
Inundated Snags – LSFR ²	819	88.9	325	75.6	276	986	49	167	16.9	
Exposed Roots – IR ²	368	38.9	142	33.0	121	378	21	10	2.6	

- 1 A=threshold stage (flow), B=% time threshold flow exceeded, C=B*365, D=B*0.85, E=C*0.85, F=flow associated with 15% decrease in exceedance time, G=C-E, H=F-A, I=100*(F-A)/F.
- 2 Refer to Figures 8, 9, and 10 in Appendix G.
- 3 The flows indicated are rounded to nearest integer.

5.2.5 Manatee Thermal Refuge

The District has collected water temperature data at the confluence of the IR and LSFR since December 2017. The confluence area could potentially serve as a thermal refuge to manatees when the water levels on the IR are low, partially due to water levels in the Suwannee River, and shallower depths prevent the passage of manatees to the Springs on the IR. The confluence water temperature data during January-February 2018 were compared to the average daily flow at the Hwy 27 gage on the IR, and the data are correlated (Figure 55). A linear regression relationship was used to select a threshold flow of 297 cfs that corresponds to a manatee cold stress temperature of 68°F (Section 3.4.5).

Under RTF conditions, the threshold flow of 297 cfs at the Hwy 27 gage is exceeded about 85.6% of the time, or about 312 days per year on average. A 15% decrease in exceedance would allow withdrawals of about 29 cfs when flows are at 326 cfs (Table 25).

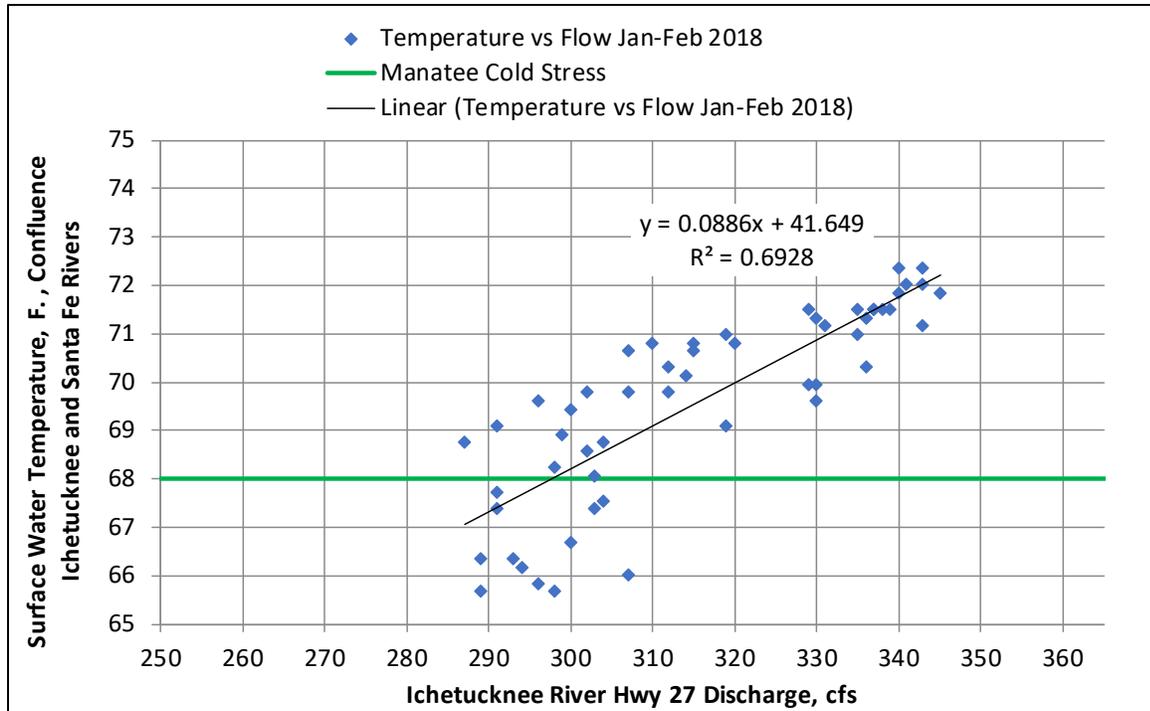


Figure 55. Confluence water temperature vs. Flow at Hwy 27 gage on the Ichetucknee River

Table 25. Flow reductions associated with 15% decrease in exceedance corresponding to manatee thermal refuge threshold flow on the IR

Threshold flow and time exceeded			RTF flow and time exceeded resulting from a 15% decrease in time exceeded			change in flow and time exceeded				
Description	Flow	Time flow exceeded		Time flow exceeded		RTF	Time		Flow	
	cfs	%	Average days/year	%	Average days/year	cfs	Average days/year	cfs	%	
Index ¹	A	B	C	D	E	F	G	H	I	
Manatee Thermal Refuge – IR ²	297	85.6	312	72.7	265	326	47	29	9.0	

- 1 A=threshold stage (flow), B=% time threshold flow exceeded, C=B*365, D=B*0.85, E=C*0.85, F=flow associated with 15% decrease in exceedance time, G=C-E, H=F-A, I=100*(F-A)/F.
- 2 Refer to Figure 11 in Appendix G.
- 3 The flows indicated are rounded to nearest integer.

5.2.6 Floodplain Habitat

In a typical floodplain forest of north Florida, riparian habitats border the river channel, and associations of trees grouped into vegetative communities extend across the floodplain. Soil and land-surface topography vary across the floodplain, creating an irregular distribution of wetland communities based on soils and water requirements. Trees common to the hydrology of the lower and upper terraces may be found also within sloughs and swamps behind the confining levees of the river channel (Figure 56).

Four predominant floodplain vegetative types have been identified in the LSFR and IR floodplains: hardwood swamp, cypress swamp, hardwood cypress, and hydric hardwood hammock (SRWMD 2013). Mean elevations for each of these four vegetative types were calculated for 11 transects along the LSFR and six transects along the IR. Comparison of mean elevations for the predominant floodplain vegetation types found near the IR and maximum water surface elevations identified by HEC-RAS modeling indicated that out-of-bank flows do not support the riparian vegetation but rather that it is supported by local hydrologic factors (SRWMD 2013). Hence, floodplain vegetation is not evaluated for the IR. The flows at which the mean elevations for each floodplain vegetative type occurring on the LSFR were identified as the threshold flows for maintaining vegetative health.

Each of these four threshold flows associated with vegetative types was evaluated using the percent-of-time approach; i.e., the percent of time in which the threshold flow would be exceeded was reduced by 15%. Under these scenarios, the allowable percent reductions are 8.4%, 5.6%, 6.2%, and 5.2%, respectively, at the Fort White (Table 26 and Table 27).

Table 26. Threshold flows for four predominant vegetative types in the Lower Santa Fe River floodplain

Vegetative Type	Threshold Flow (cfs)
Hardwood swamp	1,390
Cypress swamp	1,840
Hardwood cypress	1,940
Hydric hardwood hammock	2,680*

*Corrected value; the threshold flow of 2,693 cfs considered in the initial MFLs assessment was determined based on an erroneous elevation reported for transect CD which was excluded from this re-evaluation

Source: (SRWMD 2013)

5.2.7 Hydric Soils

Hydric soils are those that are permanently or seasonally flooded with water. In addition to helping maintain hydric soils, periodic river flooding also benefits floodplain ecosystems, recharges the groundwater, and limits community degradation (Figure 57). When they occur, floods introduce additional nutrients and sediments and trigger episodic biological productivity (HSW 2016).

The threshold flows for hydric soils along the LSFR and IR were previously determined following the same approach as for the four predominant vegetative types (SRWMD 2013). Based on this analysis, the threshold flows at the Fort White gage on the LSFR and at the Hwy 27 gage on the IR are 2,094 cfs and 407 cfs, respectively. Proposed 15% reductions in the time these threshold flows are exceeded allows withdrawals of 131 cfs at Fort White and 10 cfs from the IR (Table 28).

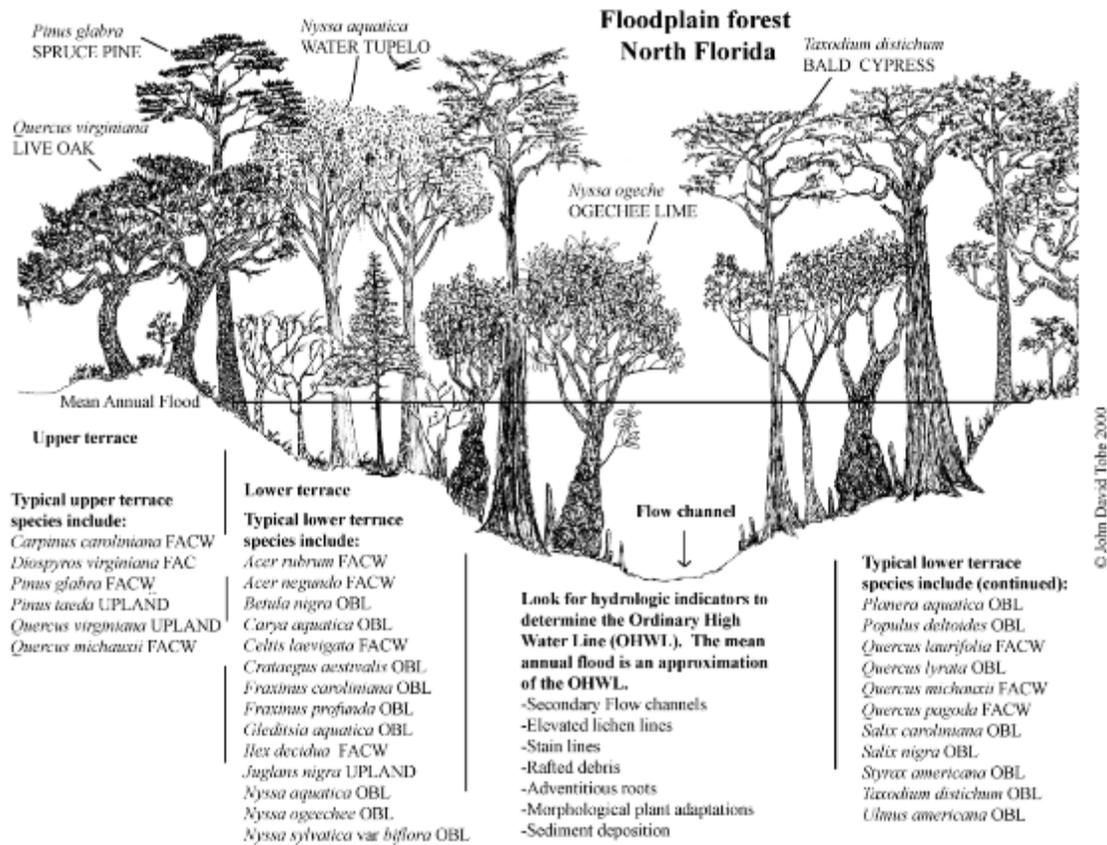


Figure 56. Conceptual diagram of floodplain forest of north Florida (FDEP 2012); (Cowardin, et al. 1979)

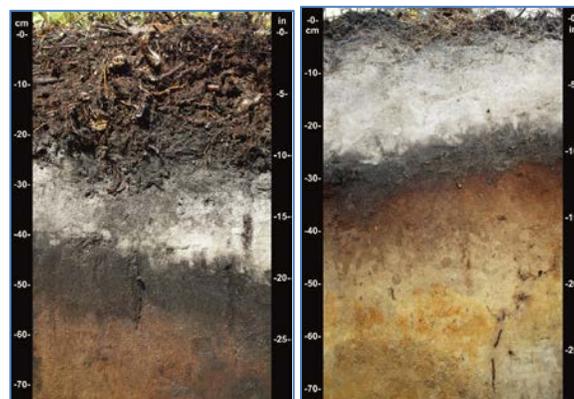


Figure 57. Comparison of hydric (left) and non-hydric (right) soil profiles (U.S. Department of Agriculture 2018)

Table 27. Flow reductions associated with 15% decreases in the time that the threshold flows for four predominant vegetative types in the LSFR floodplain are exceeded

Threshold flow and time exceeded			RTF flow and time exceeded resulting from a 15% decrease in time exceeded			Decrease in flow and time exceeded			
Description	Flow	Time flow exceeded		Time flow exceeded		RTF	Time	Flow	
	cfs	%	Average days/year	%	Average days/year	cfs	Average days/year	cfs	%
Index ¹	A	B	C	D	E	F	G	H	I
Hardwood swamp ²	1,390	41.7	152	35.5	130	1,517	23	127	8.4
Cypress swamp ²	1,840	22.8	83	19.3	71	1,950	12	110	5.6
Hardwood cypress ²	1,940	19.7	72	16.7	61	2,068	11	128	6.2
Hydric hardwood hammock ²	2,680	7.9	29	6.8	25	2,826	4.4	146	5.2

- 1 A=threshold stage (flow), B=% time threshold flow exceeded, C=B*365, D=B*0.85, E=C*0.85, F=flow associated with 15% decrease in exceedance time, G=C-E, H=F-A, I=100*(F-A)/F.
- 2 Refer to Figures 12, 13, 14, and 15 of Appendix G.
- 3 The flows indicated are rounded to nearest integer.

Table 28. Flow reductions associated with 15% decreases in the time that the threshold flows for hydric soils in the LSFR and IR floodplains are exceeded

Threshold flow and time exceeded			RTF flow and time exceeded resulting from a 15% decrease in time exceeded			Decrease in flow and time exceeded			
Description	Flow	Time flow exceeded		Time flow exceeded		RTF	Time	Flow	
	cfs	%	Average days/year	%	Average days/year	cfs	Average days/year	cfs	%
Index ¹	A	B	C	D	E	F	G	H	I
Hydric soils – LSFR ²	2,094	16.1	59	13.7	50	2,225	8.6	131	5.9
Hydric soils – IR ²	407	19.6	71	16.6	61	417	11	10	2.4

- 1 A=threshold stage (flow), B=% time threshold flow exceeded, C=B*365, D=B*0.85, E=C*0.85, F=flow associated with 15% decrease in exceedance time, G=C-E, H=F-A, I=100*(F-A)/F.
- 2 Refer to Figures 16 and 17 of Appendix G.
- 3 The flows indicated are rounded to nearest integer.

5.2.8 Submerged Aquatic Vegetation

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. 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.

A hydrodynamic analysis of velocity, discharge, and stage in the Silver River was completed to determine whether velocity is an important non-nitrate factor influencing the community structure and function of primary producers in the system (University of Florida, Water Institute 2017). King (2014) suggested that hydrodynamics could contribute to, or even dominate, the control of filamentous macroalgae on and attached to SAV in Florida spring runs. Increases in velocity tend to increase growth rates of SAV by thinning the diffusive boundary layer over the plant surface (Biggs, Goring and Nikora 1998). At too high a velocity, however, the plants suffer stress from excessive drag and are ultimately uprooted as velocity increases. In general, SAV in streams require low absolute velocity, low velocity variability and stable substrates (B. Biggs 1996). An optimum velocity range of 0.8-2.3 ft/s for SAV in the Silver River was used below which the macrophyte beds are subject to invasion by macroalgae, and above which the macrophyte beds cannot withstand the drag forces.

The District completed multiple SAV transect surveys on the IR, but no data related to SAV on the LSFR is available. Hence, the SAV optimal velocity analysis is presented for the IR only. Based on the HEC-RAS steady-state model output, three HEC-RAS transects (stations 26012.56, 20136.50, and 10037.68) were selected along the IR that had average velocities decrease below 0.8 ft/s due to flow reduction. The threshold flows at which the average velocity decreases below 0.8 ft/s at the stations 20136.50, 10037.68, and 26012.56 are 271, 301, and 431 cfs, respectively, at the Hwy 27 gage. A 15% decrease in exceedance time for these flows would allow withdrawals of about 49, 27, and 11 cfs (Table 29). The flow reduction associated with a threshold flow of 271 cfs is illustrated as an example in Figure 18 of Appendix G.

Table 29. Flow reductions associated with the threshold flows for SAV on the Ichetucknee River

Threshold flow and time exceeded			RTF flow and time exceeded resulting from a 15% decrease in time exceeded			Change in flow and time exceeded			
Description	Flow	Time flow exceeded	Time flow exceeded	RTF	Time	Flow			
	cfs	%	Average days/year	%	Average days/year	cfs	Average days/year	cfs	%
Index ¹	A	B	C	D	E	F	G	H	I
SAV – IR ² (Station 26012.56)	271	91.5	334	77.8	284	319	50	49.0	15.3
SAV – IR (Station 20136.50)	301	84.5	308	71.8	262	328	46	27.0	8.1
SAV – IR (Station 10037.68)	431	13.9	51	11.9	43	442	7.6	11.0	2.4

- 1 A=threshold stage (flow), B=% time threshold flow exceeded, C=B*365, D=B*0.85, E=C*0.85, F=flow associated with 15% decrease in exceedance time, G=C-E, H=F-A, I=100*(F-A)/F.
- 2 Refer to Figure 18 of Appendix G.
- 3 The flows indicated are rounded to nearest integer.

5.3 Sediment Loads

A common definition of sediment transport is the sub-aqueous movement of particles (Vanoni 1977). The movement of particles, or transport, is a function of flow condition, sediment material composition, and supply (i.e., source of particulate matter), with classification systems based on either means of transport or particle size (Figure 58). Sediment transport amount, or “sediment load,” is then conveyed as a mass or weight per unit time (e.g., tons/day or kilograms/second).

The primary sediment-load related features of the LSFR and IR to be protected are the hydraulic stage, velocity, and bed shear stress associated with maintaining the main channel geomorphology, with a focus on the transport of inorganic sediment. Rivers are naturally dynamic and subject to a range of normal flow conditions and durations that support morphological functions. Lane’s Diagram (Figure 59) depicts a natural system as a scale with sediment load and sediment size on one side and stream discharge and slope on the other. If any one of these variables persists beyond the natural dynamic equilibrium (Schumm 1977), the scale tips and then either sediment aggradation or degradation will occur to reestablish dynamic equilibrium. This concept of dynamic equilibrium has been used by geomorphologists to analyze the response and recovery of natural streams, and bankfull discharge is recognized as being important to channel geomorphology (FISRWG 1998).

If a bankfull flow event occurs too frequently, excess shear stress can cause channel incision, which can separate the channel from the floodplains. If a bankfull flow event occurs too infrequently, the result could be sediment accretion and subsequent vegetation growth on bars and banks. Either of these conditions will cause an imbalance on the dynamic nature of a river system as represented in Lane’s Diagram (Figure 59).

		Classification System	
		Based on Mechanism of Transport	Based on Particle Size
Total sediment load	Wash load	Suspended load	Wash load
	Suspended bed-material load		Bed-material load
	Bed load	Bed load	

Figure 58. Sediment load classification categories (FISRWG 1998)

In addition to considering threshold shear stress and velocity, it also is important to protect connectivity between the river and the adjacent floodplains. The connectivity between the river and the adjacent floodplain can be defined by bankfull stage for which modest increases in water level will cause proportionally larger increases in wetted perimeter associated with floodplain inundation. By protecting the bankfull condition, both detrital transfers associated with floodplain connectivity and channel geomorphology are protected.

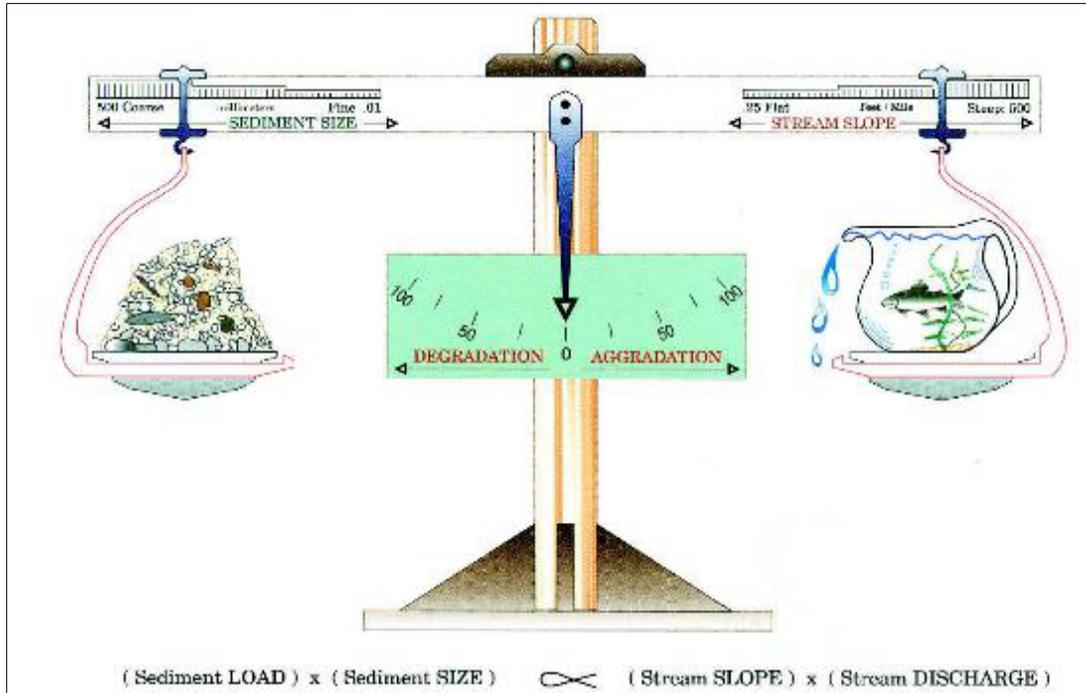


Figure 59. Lane’s Diagram representing the balance of dynamic river forces (Rosgen 1996)

Bankfull discharges for LSFR and IR that maintain channel dimension and habitat structure were identified as 1,410 cfs (Fort White) and 709 cfs (US441) for LSFR and 328 cfs for IR (AMEC 2012). A 15% decrease in exceedance time for these flows would allow withdrawals of about 8.4% on the LSFR and 4.4% on the IR (Table 30).

Table 30. Flow reductions associated with 15% decreases in the time that viable bankfull flows in the Lower Santa Fe River and Ichetucknee River are exceeded

Threshold flow and time exceeded			RTF flow and time exceeded resulting from a 15% decrease in time exceeded			Decrease in flow and time exceeded				
Description	Flow	Time flow exceeded		Time flow exceeded		RTF	Time		Flow	
	cfs	%	Average days/year	%	Average days/year	cfs	Average days/year	cfs	%	
Index ¹	A	B	C	D	E	F	G	H	I	
Bankfull condition – LSFR ²	1,410	40.7	148	34.6	126	1,539	22	129	8.4	
Bankfull condition – IR ²	328	71.5	261	60.8	222	343	39	15	4.4	

- 1 A=threshold stage (flow), B=% time threshold flow exceeded, C=B*365, D=B*0.85, E=C*0.85, F=flow associated with 15% decrease in exceedance time, G=C-E, H=F-A, I=100*(F-A)/F.
- 2 Refer to Figures 19 and 20 of Appendix G.
- 3 The flows indicated are rounded to nearest integer.

5.4 Water Quality

Surface water quality data were assessed in the development of the MFL for the LSFR and IR. Parameters investigated included specific conductance, pH, dissolved oxygen (DO), color, total Kjeldahl nitrogen (TKN), total nitrite + nitrate (NO_x), total ammonium (NH₄), total phosphorus (TP), dissolved orthophosphorus (PO₄), and chlorophyll-a. Significant relationships between individual parameters and flow were evaluated primarily with linear regression, with statistical significance determined by p-values of less than 0.05.

The relationships for some parameters explained too little of the water quality parameter's variance to be useful in determining an MFL criterion. For other parameters for which the desired condition is a lower value (e.g., nutrients, chlorophyll-a), a positive relationship between parameter value and flow means the condition becomes more desirable as flow decreases. For these situations, the parameter does not lend itself to further consideration of MFL criterion development.

The relationships between flow and concentrations of water quality parameters in four priority springs along the LSFR (Gilchrist Blue, Hornsby, Poe, and Rum Island) were investigated using data provided by SRWMD (memorandum to John Good, SRWMD, dated November 20, 2019). No strong correlations with flow were noted for most of these parameters (DO, conductivity, TDS, turbidity, color, and temperature), while a positive relationship was indicated for NO_x for three of the four springs (i.e., all but Gilchrist Blue). These relationships also were explored extensively in the District's 2013 MFLs report, with none able to serve as strong explanatory variables.

Despite the lack of correlation between flow and water quality parameters for the particular dataset evaluated for the MFL, water quality in the LSFR and IR is a concern, and it is widely recognized that Florida's springs have become impaired over the past few decades. While NO_x concentrations do not appear to be increasing in the LSFR, the TMDL of 0.35 mg/L has been exceeded continuously at the Fort White gage since 1989, and NO_x concentrations have steadily increased in Gilchrist Blue and Ginnee Springs over this same time period (Section 2.5).

5.5 Resources Upstream from US441

There is a need to consider water resources between the US441 gage and the next upstream MFLs reference gage on the Santa Fe River at Worthington Springs. Three OFSs (Hornsby, Treehouse, and Santa Fe River Rise) are present upstream of the US441 gage. O'Leno State Park and River Rise Preserve State Park are also located upstream from the US441 gage (Figure 60). The 2007 MFLs assessment for the Upper Santa Fe River recognized the importance of discharge from Olustee Creek and at O'Leno State Park but lacked the data to support a quantitative assessment of MFLs for those reaches (Water Resource Associates, Inc. 2007). Olustee Creek is a substantial tributary that joins the Santa Fe River between the Worthington Springs and US441 gages (Figure 2).

A Unit Management Plan (UMP) was developed by FDEP as the basic statement of policy and direction for the management of O'Leno State Park and River Rise Preserve State Park as a unit of Florida's state park system (FDEP 2017). The plan "identifies the goals, objectives, actions and criteria or standards that guide each aspect of park administration and sets forth the specific measures that will be implemented

to meet management objectives and provide balanced public utilization”. The plan is intended to meet the requirements of Sections 253.034 and 259.032, Florida Statutes, Chapter 18-2, FAC, and is intended to be consistent with the State Lands Management Plan.

The parks are significant for the following reasons stated in the Unit Management Plan.

- The parks provide recreational access to one of Florida’s most diverse riverine ecosystems, including an extensive network of trails for hiking, biking, and equestrian use and outstanding areas for camping, swimming, picnicking, fishing, canoeing/kayaking, and nature study.
- O’Leno State Park was originally developed in the 1930s by the Civilian Conservation Corps and the Works Progress Administration as a Florida Forest Service training camp at the previous site of the mill town of Leno.
- The natural land bridge, created where the Santa Fe River flows underground for several miles from River Sink to River Rise, served as the crossing point for major land transportation routes, including the Spanish Mission Trail from St. Augustine to Pensacola, Florida and the Bellamy Road, the first federally-funded road in Florida.
- The parks protect prominent hydrological features of the Santa Fe River system, including the world-renowned Old Bellamy Cave System, a vast underground system of aquatic caves.
- O’Leno State Park and River Rise Preserve State Park are home to 21 distinct natural communities and 128 cultural sites that span the continuum of Florida’s history.

The UMP indicates that the O’Leno park manager uses river level measurements as a reference in making decisions about swimming area closures at the park. During periods of very low flow when the Vinzant Swallet completely captures the Santa Fe River well upstream of the swimming area, the river level at the suspension bridge ranges between 32.50 and 33.50 ft NGVD29. The water is stagnant during these low flow periods and becomes unsuitable for swimming activities.

The UMP identifies two species, Suwannee moccasinshell and the oval pigtoe, as imperiled mussels whose ranges extend into O’Leno State Park along a stretch of the Santa Fe River just below the I-75 bridge. The oval pigtoe is a federally endangered species, and the Suwannee moccasinshell is a federally threatened species (Section 3.4.4). The UMP also identifies 25 fish species including largemouth bass, a species that SEFA modeling determined to be sensitive to flow reduction that are known to occur in the two parks.

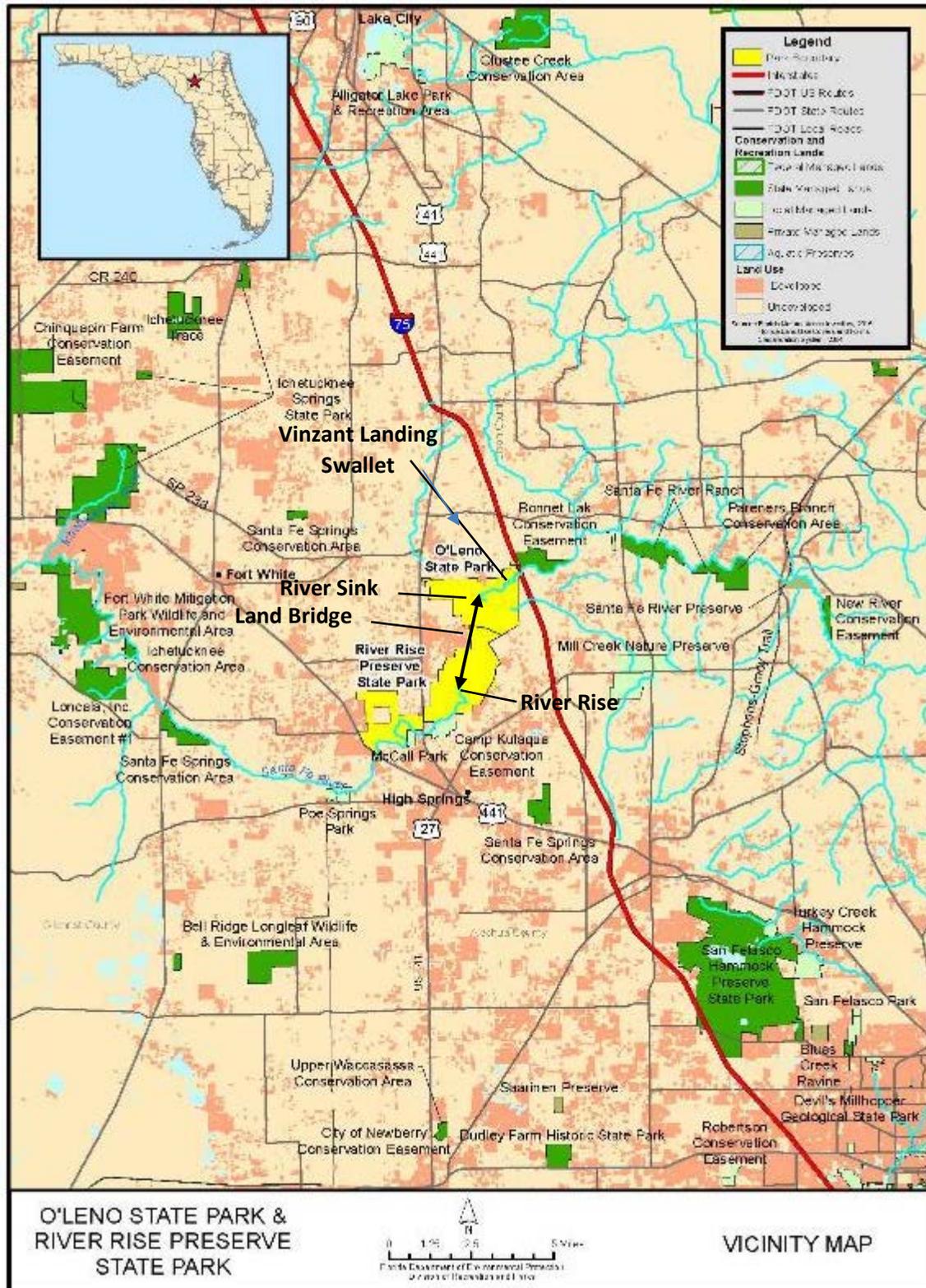


Figure 60. Location of O'Leno and River Rise State Parks (FDEP 2017)

There is a paucity of hydrologic data available for the Santa Fe River near the parks during the RTF period on which to base a WRV-specific assessment of flow metrics similar to those evaluated for the reach between the US441 and Fort White gages. Daily flow and stage records are available beginning in October 2011 for stream-gaging stations No. 02321898 (Santa Fe River at O'Leno State Park) and for River Rise beginning in May 2013 at No. 02321958 (Santa Fe River at River Rise), (Table 1). Given the absence of long-term hydrologic data to characterize RTF flows within the O'Leno/River Rise Parks, an apportionment approach was used to adjust the hydrologic shift determined for the Fort White gage to a shift at the US441 gage that maintains hydrology that is protective of WRVs upstream at the O'Leno/River Rise Parks. The apportionment approach comprises the following steps for this application:

- Determine a reference downstream FDC, i.e., the RTF flow FDC for the USGS gage at Fort White.
- Represent the downstream MFL FDC as the reference downstream RTF flow FDC less the hydrologic shift determined through an evaluation of control points (i.e., specific flow measures) that protect instream processes and critical instream functions.
- Determine the RTF flow FDC for the US441 gage.
- Determine the water available above the USGS gage at US441 using a proportional adjustment of the hydrologic shift applied at the Fort White gage based on the relative difference in the median RTF flows at the Fort White and US441 gages. The adjusted shift equals the product of the hydrologic shift at Fort White and the ratio of median RTF flows at US441 and Fort White which are 552 and 1,270 cfs, respectively (Table 4).

The proportioning factor of 0.435 (i.e., $552/1,270$) was applied to the two most restrictive hydrologic shifts determined for the Fort White gage, 103 and 115 cfs, that are associated, respectively, with the maintenance of fish passage and instream habitat in the reach between the Fort White and US441 gages. The O'Leno/River Rise Parks UMP indicates that those WRVs are relevant to the reach upstream from the US441 gage. The corresponding adjusted shifts at the US441 gage that consider similarly relevant resource values upstream from the US441 gage are 45 and 50 cfs, respectively, for fish passage and instream habitat. Instream habitat index (AWS) uses depth, velocity, and substrate and is more broadly applicable to the upstream habitat than fish passage, which uses only depth and is very site specific. Hence, instream habitat evaluated downstream of US441 using SEFA is used for the application of this approach and presented in Section 6.

As a back-check on the reasonableness of this approach, the method was applied to the Worthington Springs gage on the upper Santa Fe River for which an MFL has been determined previously (Water Resource Associates, Inc. 2007). The median RTF flow at the Worthington Springs gage is 123 cfs. The MFL adopted by rule for the median flow condition is 111 cfs, which implies that 12 cfs would be available at the median flow condition. The WRVs that provided the best opportunity to establish an MFL protective of all the applicable water resource values identified for the upper SFR are fish and wildlife habitats and the passage of fish.

The ratio of the median RTF flows at the Fort White and Worthington Springs gages is 0.0969 (i.e., $123/1,270$). Applying this adjustment factor to the most applicable hydrologic shift determined for the Fort White gage (115 cfs), yields an adjusted shift of 11 cfs for instream habitat. The adjusted shift is close to the available water associated with the MFL established for the Worthington Springs gage (i.e., 12 cfs). The results support the conclusion that in the absence of site-specific resource information at the O'Leno/River Rise Parks, the apportionment of hydrologic shifts is a reasonable approach for

determining a hydrologic shift at the US441 gage that is protective of water resources values upstream from the gage such that significant harm, due to withdrawals, is avoided. Additional work efforts are recommended in Section 6.2.3.

6. RIVER MFLS DEVELOPMENT

6.1 Introduction

The LSFR and IR are run-of-river systems with no large-capacity reservoirs (instream or off stream) that can be regulated to temporarily store withdrawals during high-flow conditions for subsequent release during low-flow conditions. The UFA is a natural storage system, and groundwater discharge from the UFA, particularly down-gradient from Cody Scarp, is the primary source of LSFR and IR base flow. A run-of-river MFL approach which considers WRVs associated with a wide range of hydrologic conditions was performed for the initial MFLs assessment and is applied in the current re-evaluation.

The LSFR and IR were evaluated to determine flow regimes that would provide the necessary level of protection to prevent significant harm for recreational activities, fish passage, fish and wildlife habitat, and sediment loads. Best available information was used to identify specific indicators for evaluating flow-reduction scenarios that would prevent significant harm. Multiple locations within each of the two rivers and a range of flows for each were evaluated. A RTF time series of daily flows for an 83-year period, from WY 1933 through WY 2015, was developed for the Fort White and US441 gages on the LSFR and for the Hwy 27 gage on the IR and used for the LSFR/IR MFLs assessment (Figure 24 and Figure 25).

Threshold flow is a flow, or flow range, at which the metric for a specified WRV is deemed to provide the necessary level of protection to prevent significant harm to the specified resource. Threshold flows at locations along the LSFR and IR were translated into equivalent flows at the Fort White gage (USGS 02322500) and Hwy 27 gage (USGS 02322700) on the IR. The MFL proposed for the US441 reference gage is a proportional adjustment of the most restrictive hydrologic shift determined for the Fort White gage (see Section 5.5).

Flow reductions, or hydrologic shifts, from the RTF flow hydrology were evaluated (Section 5) at the threshold flows associated with recreational activities, fish passage, fish and wildlife habitat, and sediment loads for both rivers (Table 31 for the LSFR and Table 32 for the IR). Some WRVs, such as for recreational paddling and fish passage, are associated with discrete threshold flows. Others, such as the AWS for instream habitat, are associated with an evaluation of a range of flows. When plotted at the exceedance frequencies evaluated, the threshold flows are lower than the corresponding RTF flows (Figure 61, Figure 62), and the hydrologic shifts assessed collectively for each station vary over the range of flows evaluated (Figure 63 and Figure 64). The most limiting flow reduction determined for each station would shift the RTF flow duration curve downward to the threshold flow associated with the limiting WRV (Figure 61 and Figure 62).

6.2 Fort White, US441, and Hwy 27 MFLs

The MFLs recommended for the LSFR and IR are based on best available information, supported by the weight of evidence from analyses of flow reductions that would prevent significant harm to the river, riverine and floodplain habitat, and sediment loads (Figure 61 and Figure 62). The MFLs proposed for the LSFR are referenced to the Fort White and US441 gages and for the IR are referenced to the Hwy 27 gage.

Fort White gage (Table 31)

For the LSFR at the Fort White gage, general fish passage is the most restrictive WRV, with a hydrologic shift of 103 cfs.

US441 gage

The UMP of O’Leno State Park developed by FDEP identifies 25 fish species known to occur in the two parks and two other species, Suwannee moccasinshell and oval pigtoe, as imperiled mussels whose ranges extend into O’Leno State Park along a stretch of the Santa Fe River just below the I-75 bridge. In the absence of sufficient hydrologic and habitat data to characterize RTF flows at O’Leno State Park, instream habitat upstream from US441 is assessed by a proportional adjustment of the instream habitat hydrologic shift at Fort White and is about 50 cfs (115 x (552/1,270)).

The hydrologic shift associated with the proportional adjustment of the hydrologic shift determined for the Fort White gage for upstream habitat (i.e., 50 cfs) was selected for the US441 gage.

Hwy27 gage (Table 32)

Woody habitat/hydric soils are the most restrictive WRVs with hydrologic shifts of 10 cfs at the Hwy 27 gage.

Table 31. Summary of WRV metrics and hydrologic shifts for the LSFR at the Fort White gage

Resource Value and Indicator		WRV Assessment Method	Threshold Flow (cfs)	RTF Flow ¹ (cfs)	Hydrologic Shift ² (cfs)
Recreation In and On the Water	Paddling	Percent-of-time	903	1,034	131
	Boating	Percent-of-time	1,659	1,774	115
Fish and Wildlife Habitat and Fish Passage	Gulf sturgeon passage	Mar-Apr	1,627	1,810	183
		Sep-Oct	1,627	1,776	149
	General fish passage and instream habitat	Percent-of-time	1,110	1,213	103
		SEFA	1,155	1,270 ³	115
	Woody habitat – exposed roots	Percent-of-time	1,463	1,594	131
	Woody habitat – snags	Percent-of-time	819	986	167
	Floodplain habitat	Hardwood swamp, Percent-of-time	1,390	1,517	127
		Cypress swamp, Percent-of-time	1,840	1,950	110
		Hardwood cypress, Percent-of-time	1,940	2,068	128
		Hydric hardwood hammock, Percent-of-time	2,680	2,826	146
Hydric soils, Percent-of-time		2,094	2,225	131	
Sediment Loads (Bankfull condition)		Percent-of-time	1,410	1,539	129

1-RTF denotes reference timeframe, 2-RTF flow – Threshold flow, 3 – Median RTF flow

Table 32. Summary of WRV metrics and hydrologic shifts for the IR at the Hwy 27 gage

Resource Value and Indicator		WRV Assessment Method	Threshold Flow (cfs)	RTF Flow ¹ (cfs)	Hydrologic Shift ² (cfs)
Recreation In and On the Water	Tubing	Percent-of-time	282	322	40
Fish and Wildlife Habitat and Fish Passage	General fish passage and instream habitat	Percent-of-time	284	322	38
		SEFA	338	356 ³	18
	Woody Habitat – Exposed roots	Percent-of-time	368	378	10
	Manatee – Thermal refuge	Percent-of-time	297	326	29
	Floodplain habitat	Hydric soils, Percent-of-time	407	417	10
Sediment Loads (Bankfull condition)		Percent-of-time	328	343	15
Submerged aquatic vegetation		Percent-of-time	271	319	49
			301	328	27
			431	442	11

1-RTF denotes reference timeframe

2-RTF flow – Threshold flow

3-Median RTF flow

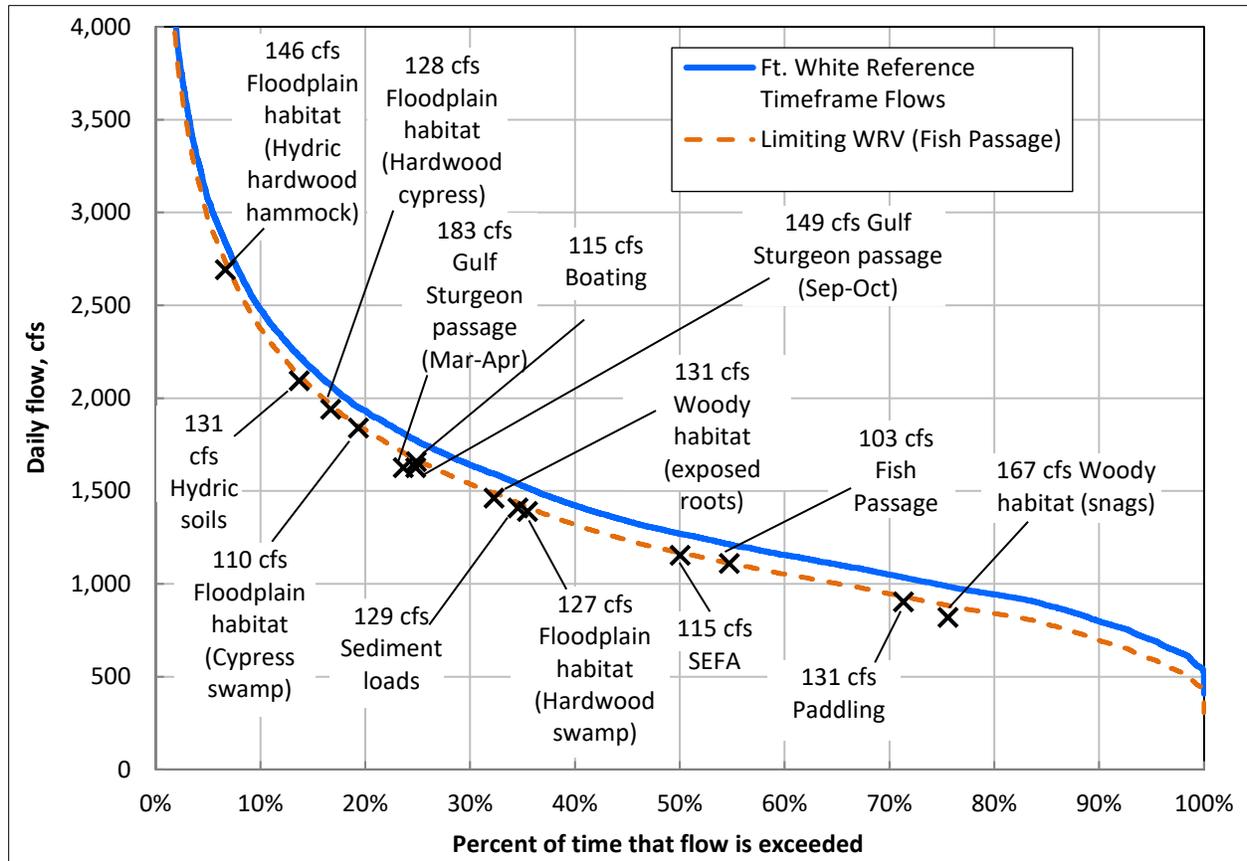


Figure 61. Flow duration curves and WRV metrics determined for Lower Santa Fe River at the Fort White gage

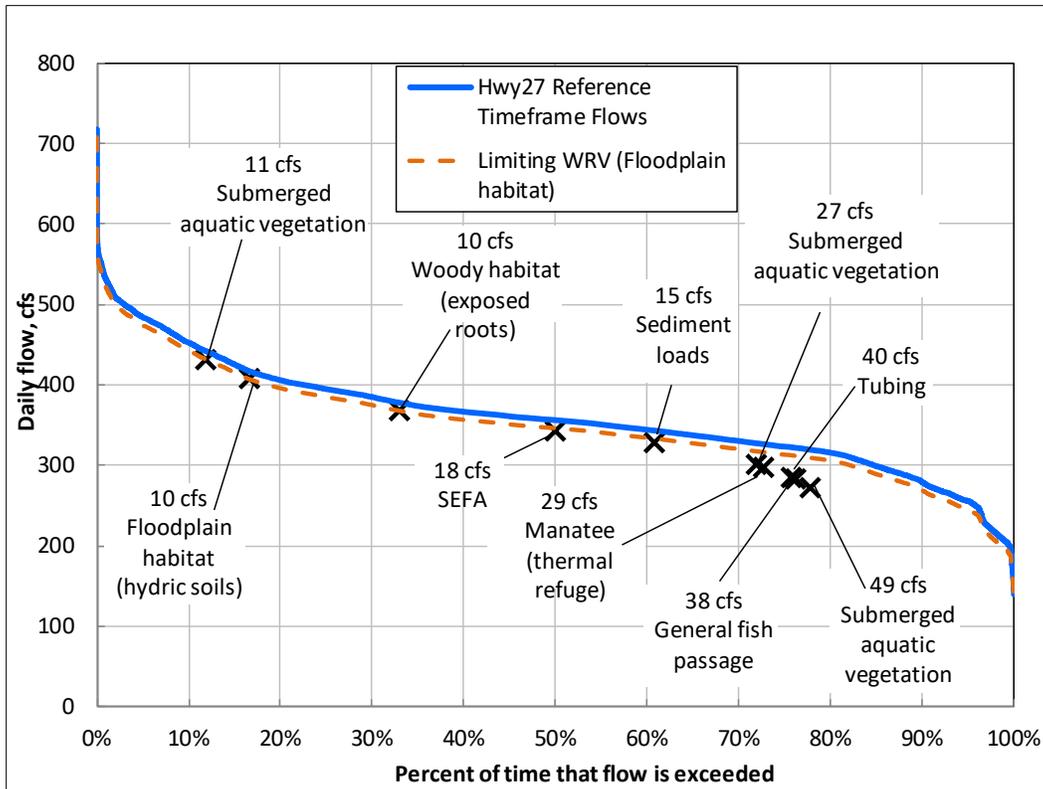


Figure 62. Flow duration curves and WRV metrics determined for IR at Hwy 27 gage

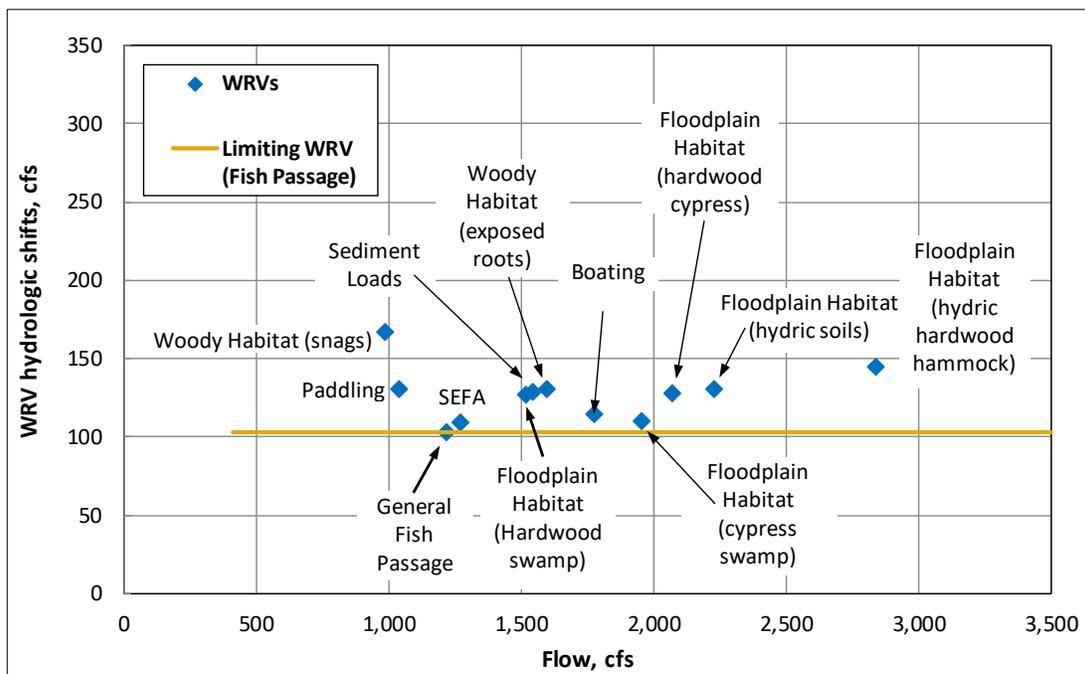


Figure 63. WRV hydrologic shifts at the Fort White gage

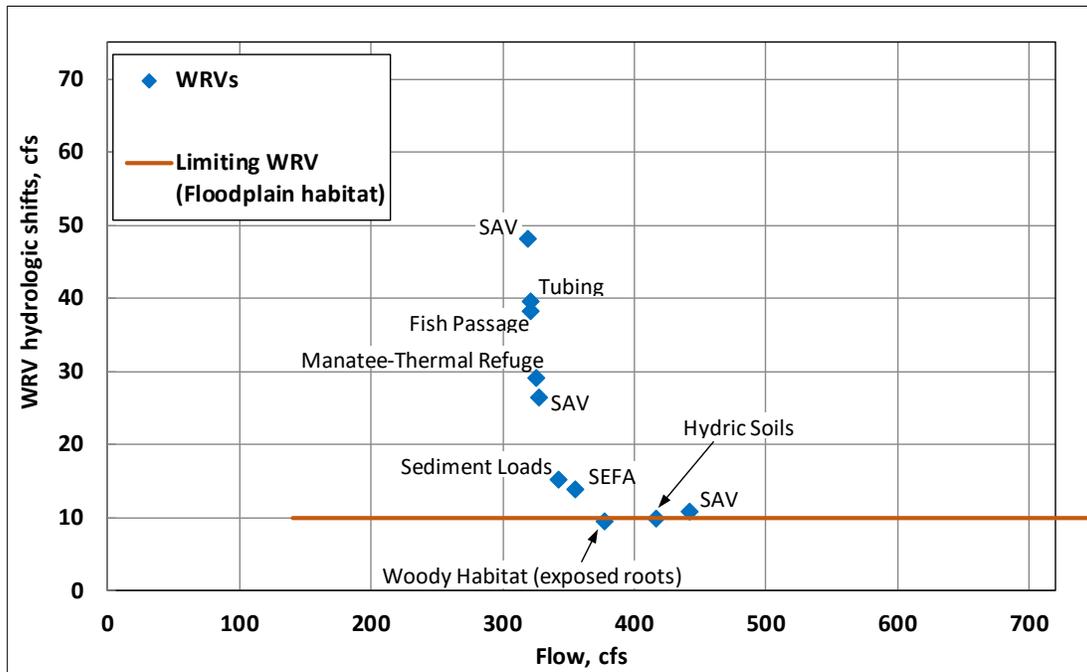


Figure 64. WRV hydrologic shifts at the Hwy 27 gage

The MFL proposed for a station is based on the most restrictive hydrologic shift developed from the WRVs evaluated and is applied at the median flow (Table 33).

- Fort White gage - median flow of 1,270 cfs the change is 103 cfs, or a reduction of about 8.1%.
- US441 gage - median flow of 552 cfs the change is about 50 cfs, or a reduction of about 9.1%.
- Hwy 27 gage - median flow of 356 cfs the change is about 10 cfs (2.8%).

The difference between the RTF and MFL flows represents a potential maximum shift in the hydrology of the LSFR as expressed at the Fort White and Hwy 27 gages.

Table 33. RTF and MFL flow values at the medians for the Lower Santa Fe River and Ichetucknee River

	Fort White	US441	Hwy 27
RTF median flow (cfs)	1,270	552	356
MFLs (cfs)	1,167	502	346
Difference (cfs)	103	50	10
Relative flow reduction (%)	8.1%	9.1%	2.8%

6.2.1 Summary

The hydrologic shifts for this re-evaluation are associated with either a 15% reduction in time that a WRV-specific flow is exceeded (Munson and Delfino 2007), or a 15% reduction in a modeled AWS modeled by SEFA. The MFLs are based on the more restrictive WRVs and, assessed collectively over a wide range of hydrologic conditions (Table 31 and Table 32), are less than 10% of the median RTF flows (Table 33).

While arguments can be made for designating MFLs for multiple flow conditions for a location, there is efficacy from a water management perspective in prescribing a single flow condition at a location. As such, a minimum surface water flow associated with the median flow condition is proposed for each of the reference stream-gaging stations considered in this re-evaluation study (Table 33). The information provided in this report can be used by water managers to further assess water withdrawals as the need may arise.

As a back-check, the relative flow reductions associated with the proposed MFLs were compared to literature summarizing case studies of water management. The percent-of-flow reduction (POFR) approach is a management approach that limits withdrawals from a river or groundwater (baseflow) to a percentage of flow at the time of withdrawal. The POFR approach reportedly has several strong advantages over other approaches (Richter, et al. 2011). It is more protective of flow variability than minimum threshold standards that can allow flow variability to become ‘flat-lined’ as water allocation pressure increases, and results, for an unregulated system, in a pattern of flow change that maintains the natural intra-annual seasonality and inter-annual periodicity of the resource. Following a case study review (Richter, et al. 2011), the following tiers of protection of natural structure and function, based on percent-of-flow reductions and risk tolerance, were proposed as a presumptive standard “...intended for application only where detailed scientific assessments of environmental flow needs (MFLs) cannot be undertaken in the near term.”

- < 10% – high level of protection, low risk
- 10-20% – moderate level of protection, moderate risk
- > 20% – low protection, high risk

In this section, MFLs for the LSFR and IR are developed and proposed that, in providing for allowable hydrologic shifts, would collectively protect relevant water resource values from significant harm. The relative differences between the RTF and MFL median flows on the LSFR and IR are less than 10% of the flow (Table 33). Such flow reductions would provide adequate protection under the paradigm proposed by Richter, et al. for which a reduction of less than 10% of daily flows provides a high level of protection; i.e., low risk to the ecosystem. A high-level of protection means that the natural structure and function of the riverine ecosystem will be maintained with minimal change (Richter, et al. 2011).

The IHA software (The Nature Conservancy 2009) was used to characterize the differences in a variety of statistical streamflow characteristics between RTF and MFL time series at the Fort White gage. The proposed MFL is implemented as a constant withdrawal, thus the hydrologic alteration was most apparent in the low- to moderately low flow statistics (Appendix H).

6.2.2 Proposed MFL Language

The minimum flow for the Santa Fe River near Fort White, FL gage is a median flow of 1,167 cfs, which is 103 cfs (8.1 percent) less than the median reference timeframe flow of 1,270 cfs.

The minimum flow for the Santa Fe River at US HWY 441 Near High Springs, FL gage is a median flow of 502 cfs, which is 50 cfs (9.1 percent) less than the median reference timeframe flow of 552 cfs.

The minimum flow for the Ichetucknee River at HWY 27 Near Hildreth, FL gage is a median flow of 346 cfs, which is 10 cfs (2.8 percent) less than the median reference timeframe flow of 356 cfs.

6.2.3 Future Considerations

Work has been ongoing and should continue to expand the body of evidence that would support an update of the MFL proposed for the US441 gage; several examples of which follow.

- Continue to maintain continuous recording stream-gaging stations to monitor stage and flow on the Santa Fe River at O'Leno State Park (No. 02321898) and the Santa Fe River at River Rise (No. 02321958).
- Develop a daily flow record beginning in May 2013 for the River Rise gage.
- Develop an RTF flow record for the O'Leno Park and River Rise gages based on a hydrologic assessment of the short-term records developed for the O'Leno Park and River Rise gages based on the long-term flow records available for the Santa Fe River at the Worthington Springs and Fort White gages.
- Coordinate with the Florida Division of Recreation and Parks on the collection of site-specific data, such as SEFA/instream habitat site(s), threshold stages and/or flows relevant to recreational activities and species of interest, and other information that supports the O'Leno/River Rise Parks UMP objectives (FDEP 2017).

7. PRIORITY SPRINGS ASSESSMENT AND MFLS DEVELOPMENT

7.1 Priority Springs Description

Nine of the 17 Priority Springs on the LSFR and IR are classified as historical first-magnitude springs with flows that have exceeded 100 cfs (SRWMD 2019 Priority List and Schedule). Seven are second-magnitude springs with flows historically between 10 and 100 cfs. One spring (Grassy Hole), with flows less than 10 cfs, is a third-magnitude spring.

Summary statistics for the manual measurements of LSFR/IR priority spring flows are listed in geographical order from upstream to downstream along the LSFR/IR in Table 34. Excerpts of descriptions from Springs Bulletin No. 66 (Scott, et al. 2004) and SRWMD Publication WR99-02 (Hornsby and Ceryak 1998) for the Priority Springs are included in Appendix B.

Table 34. Summary of priority spring flows measured manually during water years 1917-2015

Spring	Total spring flow observations	Minimum flow (cfs)	Median flow (cfs)	Mean flow (cfs)	Maximum flow (cfs)	Spring Magnitude
LSFR						
Santa Fe River Rise	71	56	426	552	3,263	1
Treehouse	51	0	108	202	739	1
Hornsby	112	-18	42	67	352	1
Columbia	54	0.64	72	117	423	1
Poe	137	0.30	47	46	93	2
COL 101974	2.0	4.4	6.1	6.1	7.9	2
Rum Island	21	5.0	17	20	61	2
Gilchrist Blue	98	8.4	39	43	87	2
Devil's Ear Complex**	12	72	144	174	472	1
July	6	28	36	51	117	1
Siphon Creek Rise	2	120	245	245	370	1
IR/Spring Group						
Ichetucknee Head	88	20	47	49	85	1
Blue Hole	117	35	101	107	313	1
Mission	72	20	89	91	176	2
Devil's Eye	74	31	50	49	84	2
Grassy Hole	4	3.8	4.3	4.7	6.4	3
Mill Pond	79	0	23	26	60	2
**Includes Devil's Ear and Little Devil Springs.						

Among the Priority Springs, Santa Fe River Rise is a re-emergence of the underground Santa Fe River (Figure 17) and has an average measured flow of about 552 cfs and a maximum measured flow of 3,263 cfs. Siphon Creek Rise is a re-emergence of Siphon Creek and has two flow measurements of 120 and

370 cfs. Flow data are available at Poe Springs from 1917. However, only eight intermittent flow measurements are available prior to 1995. Sufficient manual spring-flow measurements are available for Hornsby, Poe, and Blue Hole Springs from 1995 to 2015 to characterize trends (Appendix I). The flow trends are similar to average annual groundwater levels for the same time period (Figure 15).

7.2 Spring-Flow Ratings

Rating curves were developed for the Priority Springs with at least 12 manual flow measurements and were used to develop estimates of historic spring flows. The ratings were evaluated for their utility in establishing MFLs at these important features. Conceptual hydraulic models of spring flow are described as the basis for evaluating spring-flow ratings and assessing historic spring flow.

Four hydraulic conditions defined by groundwater level and river stage at, or near, the spring are presumed to control the spring-flow rating for an estavelle or river rise. Spring flow will be either positive, negative, or zero depending on the elevations of these two hydraulic variables relative to a Point of Zero Flow (PZF) and to each other. For this discussion, the terms PZF and hydraulic control elevation are synonymous and for a spring-flow rating may represent the spring sill.

Positive spring flow occurs when the groundwater level exceeds both the PZF and the river stage. Spring flow will increase as groundwater level increases and be relatively unaffected by river conditions when the river stage is less than the PZF (Category 1 in Figure 65).

As the river level increases above the PZF, the river exerts backwater on the spring vent causing spring flow to decline as conditions shift from Category 1 to Category 2 (Figure 65). Increasing river stages can cause spring flow to reverse and become negative. For negative spring flow to occur, the river stage must be higher than the PZF and the groundwater level at, or near, the spring vent (Category 3 in Figure 65). During certain conditions, a spring may not discharge. Prolonged periods of zero spring flow occur when both the groundwater level and river stage are lower than the PZF (Category 4 in Figure 65). Near zero flow may occur for very brief periods of time during transient flood conditions as river stage rises to the point that backwater causes positive spring flow to diminish and then reverse, i.e., a transition from Category 1 to Category 2 (Figure 65), and vice-versa during the flood recession, i.e., a transition from Category 2 to Category 1. Positive spring flows (Category 1 and 2) were used for rating analysis.

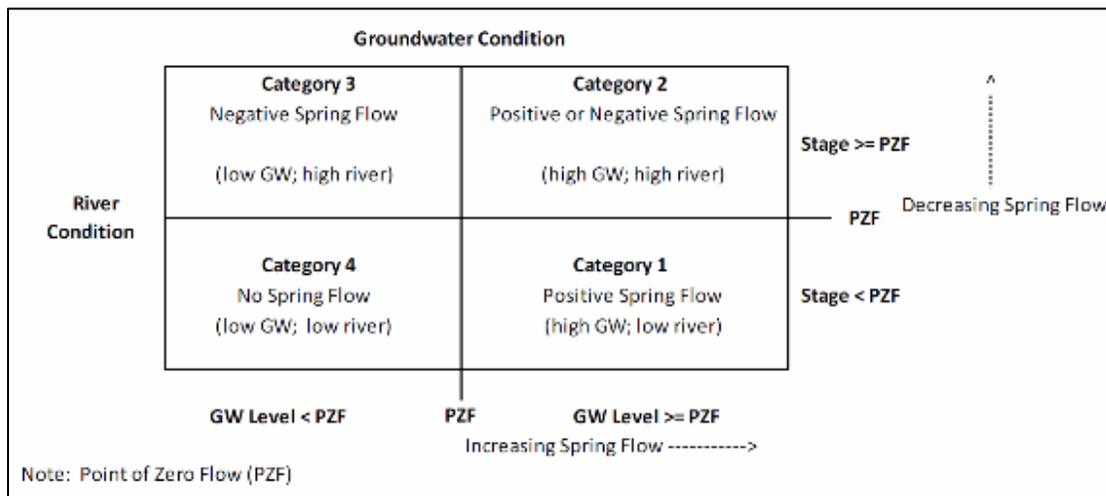


Figure 65. Conceptual model of hydraulic spring-flow regimes

The USGS has standard methods for characterizing stage-discharge ratings, relationships between stream (or spring) discharge and water level (Rantz 1982). The following relationship, that plots as a straight line on logarithmic paper, is represented by a power function with three fitting parameters and is used to develop ratings.

Power function:

$$Q = K(WL - C)^n$$

In which:

Q is discharge.

WL is groundwater level

C is the offset determined by measurement or fitting analysis.

K and n are fitting parameters determined through analysis.

Other functional forms evaluated for Priority Springs ratings include multiple linear regression (MLR) equation forms with river flow, river stage, and groundwater level as the independent variables. MLR and nonlinear regression analyses were performed using the R programming language.

MLR Functions:

$$Q = a1 \times RF1 + a2 \times RF2 + a3$$

$$Q = a1 \times RF + a2$$

In which:

Q is discharge.

RF is river flow

a1, a2, and a3 are fitting parameters

The spring-flow ratings were used to assess MFLs for 11 of the 17 Priority Springs with enough data (see Table 36 for rating equations and Appendix I for the 8 univariate model rating plots and goodness-of-fit plots for all 11 models). No ratings were developed for COL101974, July Spring, and Siphon Creek Rise on the LSFR and Grassy Hole Spring on the IR because of insufficient flow measurements. The rating equations did not result in a reasonable fit for Rum Island Spring on the LSFR or Devil's Eye Spring on the IR. Ratings that use a MLR equation with USGS gage flows as independent variables resulted in the best fit on both the LSFR and the IR.

An increasing river stage can cause the river to exert backwater on the spring vent causing spring flow to decline as conditions shift from Category 1 to Category 2 (Figure 65). If the river stage rises higher than the point of zero flow and the groundwater level at, or near, the spring vent then negative spring flow occurs. The zero flow and negative flow data were reviewed for each spring (Table 35). Negative flow has been measured at one (Hornsby) of the 17 springs, and zero flow has been observed at three springs (Treehouse, Hornsby, and Mill Pond), although generally such conditions were not measured.

The observations of zero flow reported for the three springs were difficult to assimilate in the rating analysis because stage data are lacking in the spring pool or run immediately downstream from the pool. Zero flow occurs when the river stage and groundwater level are lower than the sill. This condition

covers a range of groundwater levels, so it is difficult to include in a single equation. Zero flows were omitted from the regression analysis.

Table 35. Number of zero and negative spring flow measurements

Spring	Total spring flow observations	Number of Zero flows	Number of Negative flows
Santa Fe River Rise	71	-	-
Treehouse	51	3	
Hornsby	112	10	3
Columbia	54	-	-
Poe	137	-	-
COL 101974	2	-	-
Rum Island	21	-	-
Gilchrist Blue	98	-	-
Devil's Ear Complex	12	-	-
July	6	-	-
Siphon Creek Rise	2	-	-
Ichetucknee Head	88	-	-
Blue Hole	117	-	-
Mission	72	-	-
Devil's Eye	74	-	-
Grassy Hole	4	-	-
Mill Pond	79	1	-

7.3 Springs MFLs Development

Spring flow provides an increasing contribution to the LSFR downstream from Santa Fe Rise that sustains baseflow. The maintenance of flow from the Priority Springs is essential to protecting water resource conditions and values of springs and the LSFR and IR streams downstream from each spring. While it is desirable to designate spring-specific MFLs, it is impractical to do so at this time. The available data are inadequate to clearly demonstrate quantifiable impacts attributable strictly to flow reductions due to withdrawals with the accuracy and precision warranted to establish spring-specific MFLs.

Daily RTF flows at the USGS stream gages and the MLR rating equations (Table 36) were used to calculate daily RTF spring flows for the period from October 1, 1932, through September 30, 2015. Estimated median daily RTF spring flows during the RTF period for the Priority Springs range from 31 cfs at Mill Pond on IR to 447 cfs at Santa Fe Rise on LSFR (Table 37). Relative to the median RTF flows, the uncertainty in the individual spring-flow ratings ranges between 12 and 35 percent for the LSFR springs and between 15 and 21 percent for the IR springs (Table 37). These relative uncertainties are substantially greater than the corresponding flow reductions associated with the proposed LSFR and IR MFLs (8.1% and 9% for the LSF and 2.8%, respectively, at median river flow).

Table 36. Priority Spring Ratings

Spring	Total No. of Measurements	No. of Measurements Used	Rating Equation ¹	Explanatory Variables ²	R ²	Adjusted R ²	RMSE ³	Range-Normalized RMSE ⁴
							(cfs)	
LSFR Priority Springs								
Santa Fe Rise	71	71	-608 + 0.831*RF	USGS 02322500 SANTA FE RIVER NR FORT WHITE, FLA.	0.92	0.92	158.00	5%
Treehouse Spring	51	48	-274 + 0.497*RF	USGS 02322500 SANTA FE RIVER NR FORT WHITE, FLA.	0.96	0.96	42.67	6%
Hornsby	112	64	-142 + 0.0697*RF1 + 0.425*RF2	RF1-USGS 02322500 SANTA FE RIVER NR FORT WHITE, FLA., RF2-USGS 02322700 ICHETUCKNEE R AT HWY27 NR HILDRETH, FL	0.83	0.83	24.16	10%
Columbia	54	54	-143 - 0.0334*RF1 + 0.274*RF2	RF1-USGS 02321500 SANTA FE RIVER AT WORTHINGTON SPRINGS, FLA., RF2-USGS 02322500 SANTA FE RIVER NR FORT WHITE, FLA.	0.88	0.87	40.38	10%
Poe	137	134	12.5 - 0.0158*RF1 + 0.0349*RF2	RF1-USGS 02321500 SANTA FE RIVER AT WORTHINGTON SPRINGS, FLA., RF2-USGS 02322500 SANTA FE RIVER NR FORT WHITE, FLA.	0.56	0.55	13.76	15%
Gilchrist Blue	98	98	6.05 + 0.0353*RF	USGS 02322500 SANTA FE RIVER NR FORT WHITE, FLA.	0.63	0.62	12.86	16%
Devil's Ear Complex	12	12	10.9 + 0.0555*RF1	USGS 02320500 SUWANNEE RIVER AT BRANFORD, FLA.	0.92	0.90	28.43	7%
IR Priority Springs								
Blue Hole	117	112	-29.8 + 0.454*RF	USGS 02322700 ICHETUCKNEE R AT HWY27 NR HILDRETH, FL	0.60	0.59	27.54	10%
Ichetucknee Head	88	82	12.7 + 0.121*RF	USGS 02322700 ICHETUCKNEE R AT HWY27 NR HILDRETH, FL	0.55	0.54	8.96	14%
Mission Spring	72	70	44+0.153*RF	USGS 02322700 ICHETUCKNEE R AT HWY27 NR HILDRETH, FL	0.46	0.44	14.57	9%
Mill Pond	79	74	0.158 + 0.0861*RF	USGS 02322700 ICHETUCKNEE R AT HWY27 NR HILDRETH, FL	0.65	0.64	5.31	10%
<ol style="list-style-type: none"> 1. RF-River flow (cfs) 2. District ID's of explanatory variables 3. RMSE denotes Root Mean Square Error 4. Range-Normalized RMSE = RMSE/Range in measured flow × 100% 								

Table 37. Spring flow rating reliability compared to median period of record RTF spring flows

Spring	Median RTF Flow (cfs)	Flow Rating Reliability, RMSE from Table 36 (cfs)	Rating Reliability Relative to Median RTF
Lower Santa Fe River Priority Springs			
Santa Fe Rise	447	158	35%
Treehouse Spring	357	42.7	12%
Hornsby	101	24.2	24%
Columbia	199	40.4	20%
Poe	53	13.8	26%
COL 101974*	-	-	-
Rum Island*	-	-	-
Gilchrist Blue	51	12.9	25%
Devil's Ear Complex**	-	28.4	-
July*	-	-	-
Siphon Creek Rise*	-	-	-
Ichetucknee River Priority Springs			
Ichetucknee Head	56	8.96	16%
Blue Hole	132	27.5	21%
Mission	98	14.6	15%
Devil's Eye*	-	-	-
Grassy Hole*	-	-	-
Mill Pond	31	5.31	17%
*Insufficient data available to develop a flow rating.			
**Not evaluated because flow rating is based on daily flow of Suwannee River at Branford for which RTF flows were not available.			

Relatively short periods of continuous spring-flow monitoring records are available since about 2002 for just 5 of the 17 Priority Springs (Table 3). And as previously discussed, there is a relatively high degree of uncertainty associated with the daily POR RTF flows for springs calculated for the current re-evaluation.

With due consideration of the best data available and the uncertainties previously described, an appropriate way to afford protection from significant harm at this time is to treat the Priority Springs collectively for a defined river reach such that river hydrology at a reference gage downstream from the springs is maintained.

7.3.1 Proposed MFL Rule Language

- The cumulative minimum surface water flows for the Lower Santa Fe River Priority Springs between the Fort White and US441 gages (Poe, COL 101974, Rum Island, Gilchrist Blue, Devil’s Ear Complex, July, and Siphon Creek Rise), as measured at the Santa Fe River near Fort White, FL gage, is a median flow of 1,167 cfs, which is 103 cfs (8.1 percent) less than the median reference timeframe flow of 1,270.
- The cumulative minimum surface water flows for the Lower Santa Fe River Priority Springs upstream of the US441 gage (Santa Fe River Rise, Columbia, Treehouse, and Hornsby), as measured at the Santa Fe River at US HWY 441 Near High Springs, FL gage, is a median flow of 502 cfs, which is 50 cfs (9.1 percent) less than the median reference timeframe flow of 552 cfs.
- The following cumulative minimum surface water flows for the Ichetucknee River Priority Springs (Ichetucknee Head, Blue Hole, Mission, Devil’s Eye, Grassy Hole, and Mill Pond), as measured at the Ichetucknee River at HWY 27 Near Hildreth, FL gage, is a median flow of 346 cfs, which is 10 cfs (2.8 percent) less than the median reference timeframe flow of 356 cfs.

7.3.2 Future Considerations to Support Spring-Specific MFLs

Work has been ongoing to expand the body of evidence that would support future spring-specific MFLs; several examples of which follow.

- Median spring RTF flows could be developed, with sufficient confidence, for six springs (COL101974, Rum Island, July, Siphon Creek Rise, Devil’s Eye and Grassy Hole) after additional field data are collected to support a rating analysis.
- Median spring RTF flows could be developed for Devil’s Ear Complex after RTF flows are developed for the Branford gage on the Suwannee River.
- A recent study (Hensley and Cohen 2017) provides a potential metric by relating the increase in the frequency and duration of flow reversals (e.g., at Poe Spring) to the proliferation of nuisance algal mats (Section 3.4.1). Flow reversals were tied to groundwater levels and the associated hydraulic gradient between the river and groundwater potentials and provides a potential MFL metric related to groundwater levels.
- Few direct measurements of negative spring flow exist for estavelles such as Poe Spring and Hornsby Spring (Table 35) and will continue to be difficult to obtain without additional instrumentation. Flow reversals often occur during high-streamflow events when conditions conducive to accurately measuring spring flow safely may not exist and water velocity in the spring run and vent is influenced by backwater. An acoustic velocity meter (AVM) installed within the spring vent would afford a direct indication of flow reversal. Field measurements could be facilitated if the AVM is equipped with telemetry.
- Water quality is an ongoing concern for the priority springs, which are vitally important to the State of Florida from both an aesthetic and economic perspective. Systematic sampling of spring water quality therefore should not only continue but should be expanded to include other water quality parameters, such as bacteria, that can serve as sentinel indicators of water quality degradation or flow reversal. Increasing the number of locations for continuous monitoring of indicator parameters such as nitrate and conductivity, as well as increasing the collection

frequency of grab samples for confirmation purposes and for supplemental analyses of other indicators of water quality, will yield more complete datasets and allow trends to be recognized and acted upon more quickly. The benefits of larger datasets in reducing uncertainty and allowing more sensitive trend analysis are believed to outweigh the costs associated with expanding the scope of systematic monitoring of spring water quality.

- Systematic monitoring to characterize the nature and extent of aquatic vegetation in the springs and spring runs will be beneficial for tracking the effects of TMDL Best Management Action Plans implemented within the watershed to address impairment by nutrients.

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