MINIMUM FLOWS AND LEVELS ASSESSMENT

FOR THE

UPPER SUWANNEE RIVER

DRAFT FOR PEER REVIEW

DECEMBER 2022

Prepared for:

Suwannee River Water Management District
9225 County Road 49
Live Oak, Florida 32060

Prepared by:

HSW
15711 Mapledale Boulevard, Suite B
Tampa, Florida 33624

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EXECUTIVE SUMMARY

The Upper Suwannee River (USR) was evaluated to determine flow regimes that would be protective of fish and wildlife habitats and passage of fish, recreational activities, sediment loads, and water quality. The Suwannee River, including the study reach, is designated by the State of Florida as an Outstanding Florida Water (OFW), a water body that is designated by Section 403.061(27), *F.S. (Florida Statutes)* as worthy of special protection because of its natural attributes. The OFW designation is applied to certain waters and is intended to protect existing good water quality. The entire Suwannee River is also designated a “Special Water” pursuant to rule (62-302.700, F.A.C.). Special Water OFWs are listed in paragraph 62-302.700(9)(i), F.A.C. and are designated as OFWs after the Florida Environmental Regulation Commission makes a finding that the waters are of exceptional recreational or ecological significance.

The Suwannee River, at about 246 miles long, is the second largest river system in Florida. Originating in the Okefenokee Swamp in southeastern Georgia, the Suwannee River flows south and southwest to the Gulf of Mexico. The reach of Suwannee River from its headwaters to just below the confluence with the Withlacoochee River near Ellaville, Florida, is referred to as the USR. The Alapaha and Withlacoochee Rivers together with the USR drain much of south-central Georgia and comprise about 70% of the entire Suwannee River watershed. The focus area of this Minimum Flows and Levels (MFLs) study is the Florida portion of the USR; i.e., about 79 river miles between the State line and the confluence of the Withlacoochee River.

An essential element in establishing MFLs for the USR is identifying or developing baseline flow and Upper Floridan Aquifer (UFA) groundwater level records that reflect 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 North Florida Southeast Georgia (NFSEG) regional groundwater model to assist with estimating the impacts of withdrawals on historical flows and water levels. The baseline records, referred to as Reference Time Frame (RTF) records, were developed by adding calculated withdrawal impacts to the historical flow and groundwater-level records.

The Suwannee River at White Springs, Florida gage (USGS number 02315500), is most useful for characterizing regional trends because it has a long period of record (POR) that extends back to 1906 with continuous records from 1927. The gage was selected as a reference for threshold RTF streamflow and associated MFLs criteria evaluated for the USR. Because of the change in river character along the USR, a second site located about 21 miles downstream, the Suwannee River at Suwannee Springs, Florida gage (USGS number 023315550) also is used as a reference gage.

In developing MFLs, current State Water Policy (Rule 62-40.473, Florida Administrative Code [*F.A.C.*]) provides that consideration be given to natural seasonal fluctuations in water flows or levels, nonconsumptive uses, and environmental water resource values (WRVs). Four WRVs are relevant to the USR 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, and (4) Water Quality.

Recreation was evaluated in terms of paddling and motorized boating. Recreation and passage for Gulf sturgeon and the general fish community were evaluated using HEC-RAS flow profile modeling. Instream freshwater habitat was evaluated using habitat simulation models developed for four segments of the USR. Riparian bank and floodplain habitats were evaluated using a combination of HEC-RAS flow profile modeling and ArcGIS mapping of wetland vegetation communities. Sediment loads were evaluated for bankfull conditions, and water quality criteria associated with Gulf sturgeon spawning were evaluated.

The MFLs proposed for the White Springs and Suwannee Springs reference gages are based on the most restrictive hydrologic shifts from the baseline condition developed from the WRVs evaluated for the range of RTF flows in the USR river. The hydrologic shifts for the two references gages are applied at the median flow. The Minimum Flows proposed for the two reference gages are as follows:

- The minimum flow for the Suwannee River at White Springs, FL gage is a median flow of 594 cfs, which is 82.3 cfs (12.2%) less than the median reference timeframe flow of 676 cfs.
- The minimum flow for the Suwannee River at Suwannee Springs, FL gage is a median flow of 783 cfs, which is 96.8 cfs (11.0%) less than the median reference timeframe flow of 880 cfs.

The difference between the RTF and MFL flows represents a potential maximum shift in the hydrology of the USR as evaluated at the White Springs and Suwannee Springs gages.

There are 56 springs along the USR, nine of which have been identified by the District as priority springs for MFLs assessment. Most of the springs along the upper Suwannee River are located along a 21-mile long subreach between Suwannee Springs and Ellaville. MFLs for the nine priority springs are being developed and will be presented in a separate document.

1.0 INTRODUCTION

The Suwannee River Water Management District (SRWMD) is establishing and implementing Minimum Flows and Levels (MFLs) for certain lakes, rivers, springs, and other priority water body systems within the District by assessing the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area (Chapter 373.042, Florida Statutes). State Water Policy (Rule 62-40.473, Florida Administrative Code [*F.A.C.*]) provides guidance for MFLs development, stating that "…consideration be given to natural seasonal fluctuations in water flows or levels, non-consumptive uses, and environmental values associated with coastal, estuarine, riverine, spring, aquatic, and wetlands ecology. …" Ten important environmental or ecological Water Resource Values (WRVs) are identified in the Rule and summarized as follows.

- *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*

The SRWMD publishes a priority list of MFL waterbodies each year. The Upper Suwannee River (USR) and associated priority springs are on the SRWMD 2021 MFLs Priority List and Schedule (SRWMD, 2022). Data and analyses that provide technical support for establishing and adopting MFLs for the USR are presented in this document. A brief description of the USR is included in Sections 1.1 and 1.2, and Chapters 2 and 3 include detailed descriptions of the hydrology and biology of the river system. Chapter 4 includes a description of the analytical approaches for evaluating relevant WRVs, and Section 5 includes the evaluation of relevant WRVs. Chapter 6 is a summary and includes the proposed MFLs for the USR. Chapter 7 is a list of References.

1.1 Watershed and River Descriptions

The Suwannee River is the second largest river system in Florida by mean annual flow and drains approximately 9,950 square miles, of which about 57% is in Georgia. The river is about 246 miles long. Originating at its headwaters in the Okefenokee Swamp in southeastern Georgia, the Suwannee River flows south and southwest to its mouth at the Gulf of Mexico near Suwannee, Florida, about 15 miles northwest of Cedar Key (Figure 1).

The Suwannee River is the largest blackwater river system in the southeastern United States (Katz & Raabe, 2005). The watershed comprises a mixture of subtropical forests, wetlands, springs, blackwater rivers, and estuarine habitats. This variety of habitats supports a range of species from temperate to subtropical, including several endangered and protected species. The basin and estuary support an economy based primarily on forestry, agriculture, commercial and recreational fisheries, clam farming, and ecotourism.

1.2 Study Area

Portions of the Suwannee River encompass unique combinations of water sources, groundwater interactions, and aquatic and floodplain habitats. For this reason, the river was divided into three separate reaches for MFLs development (SRWMD, 2016a). The Upper Suwannee River (USR) refers to the portion of the Suwannee River upstream of the USGS gage near Ellaville to its headwaters in the Okefenokee Swamp in southeastern Georgia. The focus of this study is the reach of the USR that extends from the Florida-Georgia line to just downstream of the confluence with the Withlacoochee River near the historic site of Ellaville, Florida (Figure 1). The Alapaha River and Withlacoochee River are major tributaries that enter the USR near the downstream end of the study reach. The influence of those two rivers, each of which are scheduled for their own MFL, was not assessed in this study.

The Suwannee River, including the study reach, is designated by the State of Florida as an Outstanding Florida Water (OFW). The OFW designation is applied to certain waters and is intended to protect existing good water quality. The entire Suwannee River is also designated a “Special Water” pursuant to rule (62-302.700, F.A.C.). Special Water OFWs are listed in paragraph 62-302.700(9)(i), F.A.C. and are designated as OFWs after the Florida Environmental Regulation Commission makes a finding that the waters are of exceptional recreational or ecological significance.

At high flows, the river creates Florida’s only whitewater rapids, at Big Shoals, located several miles upstream of White Springs. The unspoiled nature of the river attracts nature enthusiasts, who enjoy boating, canoeing, kayaking, and sports fishing in the peaceful surroundings. The Suwannee River basin habit 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*), alligator snapping turtle (*Macrochelys temminckii*); migratory birds and mammals such as the swallowtail kite (*Elanoides forficatus*); and Florida black bear (*Ursus americanus floridanus*). The Gulf sturgeon and Suwannee bass are species of particular interest to this study.

The process of establishing MFLs requires a thorough understanding of the environmental and ecological characteristics of the river and its environmental constraints to identify WRVs of relevance to the study area. The process ends with a systematic analysis of possible flow reductions that would remain protective of these WRVs. As some WRVs are so closely linked to others, protection of the more highly relevant or sensitive WRVs serves to protect the related WRVs. In addition, establishing limits for flow reductions over the entire range of the hydrologic flow regime affords a level of protection to the relevant WRVs, including those not explicitly evaluated.

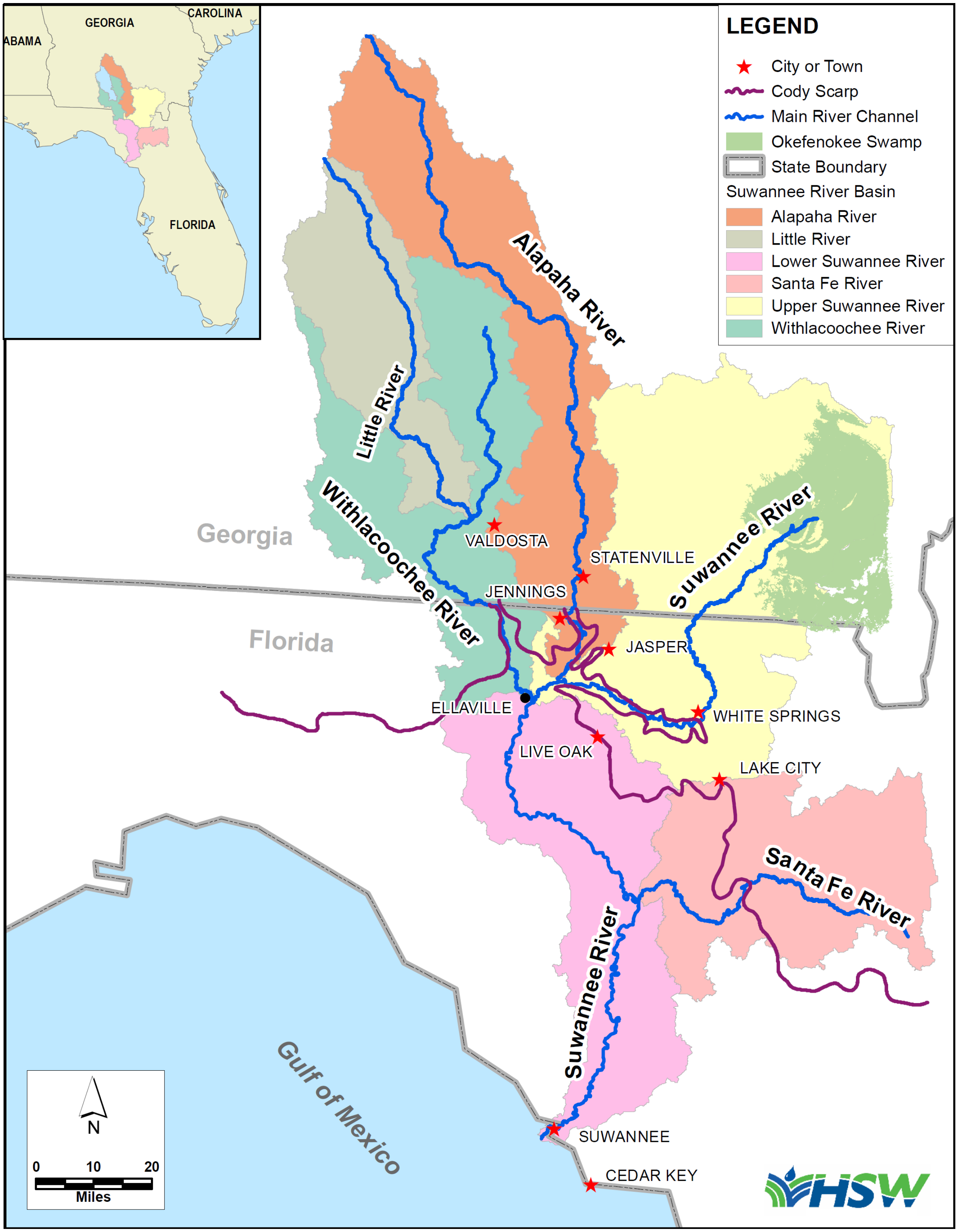


Figure 1. Suwannee River Basin in Florida and Georgia

2.0 HYDROLOGY

The hydrology of the USR, including regional characteristics of the USR watershed, climate, locations of gages, and extent of hydrometeorological records are described in this chapter. Hydrologic analyses of long-term hydrometeorological records were performed to characterize period of record conditions.

2.1 General Watershed Description

The Suwannee River, about 246 miles long, is the second largest river system in Florida. Originating in the Okefenokee Swamp in southeastern Georgia, the Suwannee River flows south and southwest to the Gulf of Mexico (Figure 2). The reach of the Suwannee River from its headwaters to just below the confluence with the Withlacoochee River near Ellaville, Florida, is referred to as the Upper Suwannee River (USR). The Alapaha and Withlacoochee Rivers together with the USR drain much of south-central Georgia. The area of the USR watershed, including the Alapaha and Withlacoochee River watersheds, comprises about 70% of the entire Suwannee River watershed.

Three regions of the Coastal Plain Physiographic Province define landforms and drainages in the upper Suwannee River basin (Figure 3). The Tifton Upland District in Georgia contains the headwaters of the Withlacoochee and Alapaha Rivers, and the Okefenokee Basin, a swampy area of low relief, is drained by the Suwannee River to the west and the St Mary's River to the east (Clark & Zisa, 1976). Regionally, the Cody Scarp denotes a transition between the Tallahassee Hills and Northern Highlands and the relatively flat coastal region of the Gulf Coastal Lowlands. The escarpment approximates the transition of the Floridan aquifer from a regionally confined to an unconfined system. Locally, and especially in the study area, the escarpment follows the major river valleys (Figure 2). In the river valleys and other drainage features, where the thin clastic cover is commonly breached by erosion, surface drainage either disappears underground through karst features (e.g., sinks on the Alapaha and Withlacoochee Rivers) or the river may lose or gain water depending on the relative groundwater and surface water levels (e.g., on the Suwannee River). Numerous springs and resurgences occur downstream of the escarpment. In the Upper Suwannee River valley, the Floridan aquifer becomes unconfined near White Springs upstream of the confluence of the Alapaha and Withlacoochee Rivers with the Suwannee River.

2.2 Monitoring Locations and Period of Record

2.2.1 Stream Discharge and Stage

Several U.S. Geological Survey (USGS) stream gage stations have been maintained on the rivers and creeks within the USR watershed. Five of the gage stations are on the USR (Figure 2), three of which (Fargo, White Springs, and Ellaville) have the longest concurrent period of continuous records, dating back to 1937 (Table 1).

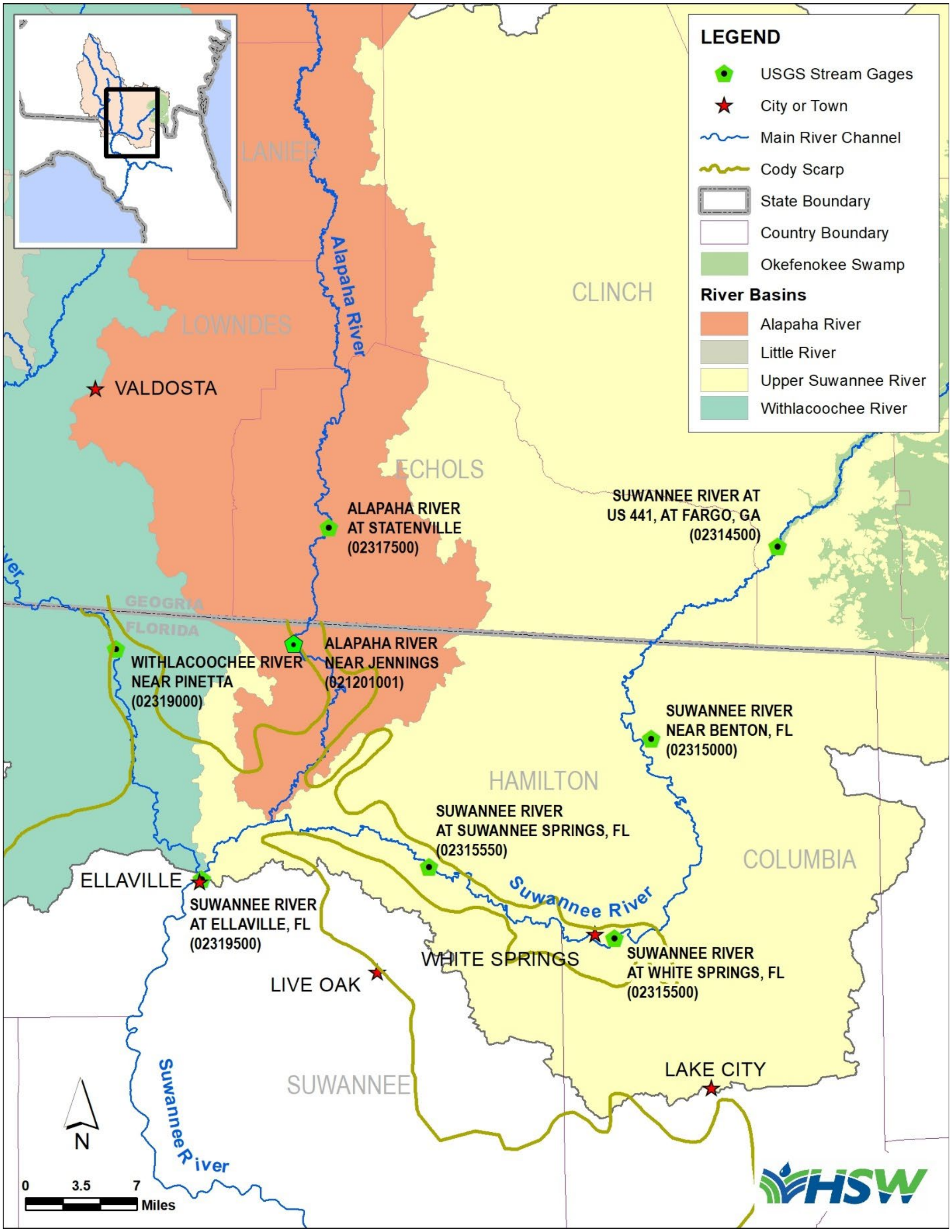


Figure 2. Upper Suwannee River watershed and adjacent areas

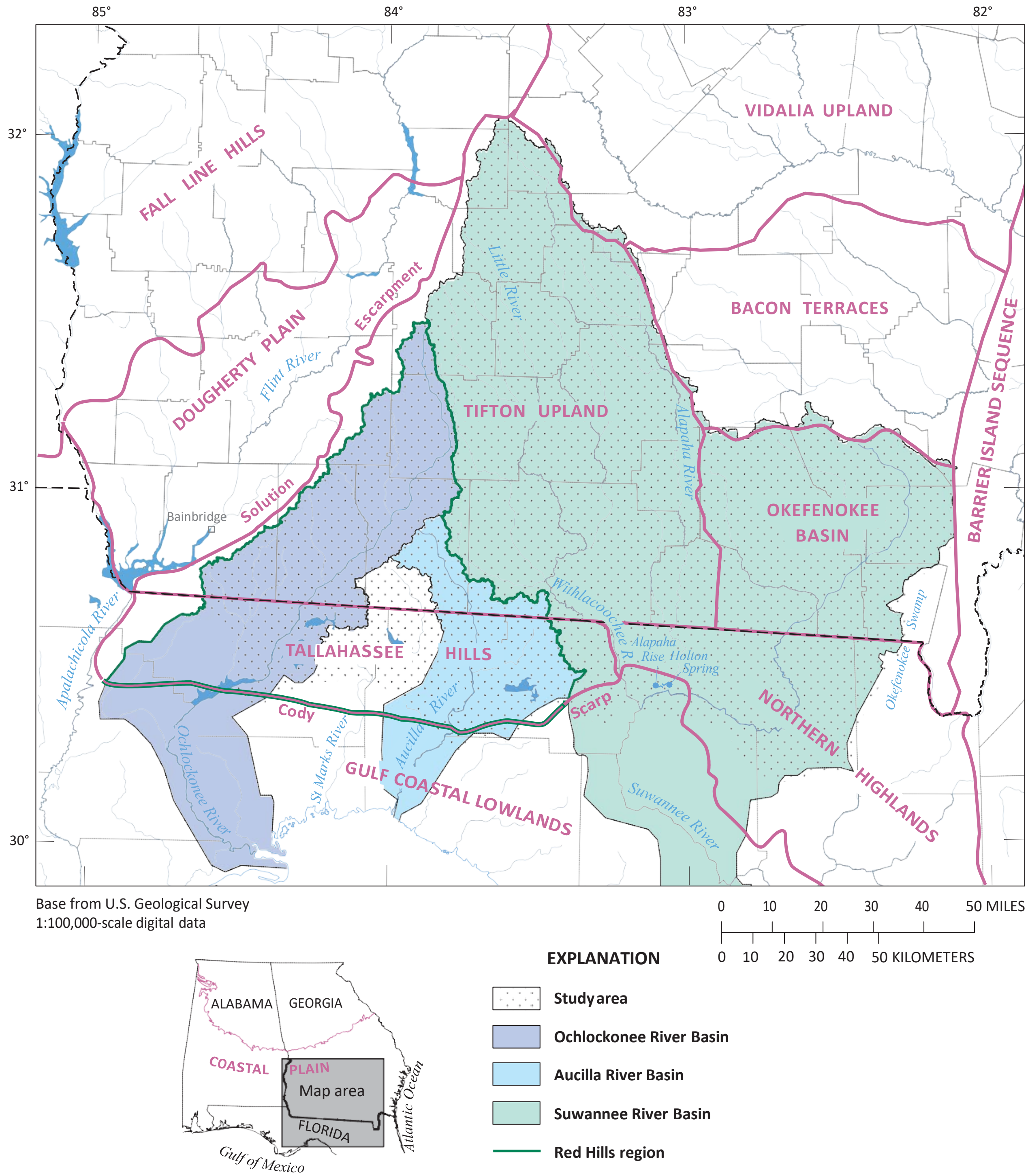


Figure 3. Physiographic divisions in the Aucilla-Suwannee-Ochlockonee River Basin [Source: (Torak, Painter, & Peck, 2010)]

Table 1. Summary of drainage areas and information for select USGS stream gage stations and locations in the USR watershed

USGS Site No.	Name	Abbreviation	Drainage Area (square miles)	Parameter	Period of Record[1]
02314500	Suwannee River at US 441, at Fargo, GA	Fargo	1,130	Flow	1/1927 - 12/1931; 4/1937 – current
				Stage	10/1986 – 4/1987; 10/1998 – current (intermittent)
02315000	Suwannee River near Benton, FL	Benton	2,090	Flow	1/1932 – 6/1934; 10/1975 – 10/2002; 10/2009 – 10/2015
				Stage	10/1975 – 10/2015
02315500	Suwannee River at White Springs, FL	White Springs	2,430	Flow and Stage	6/1906 - 12/1908; 2/1927 – 10/2020; 10/2020 – 12/2020 (intermittent); 12/2020 – current
02315550	Suwannee River at Suwannee Springs, FL	Suwannee Springs	2,630	Flow	10/1974 – 9/1996; 10/1997 – 8/2010 (intermittent); 10/2011 – current
				Stage	10/1974 – 9/1996; 10/2011 – current
02319500	Suwannee River at Ellaville, FL	Ellaville	6,970	Flow	4/1927 – current
				Stage	4/1927 – current (intermittent)

1. Continuous daily measurements except as noted. “Current” refers to the date on which this report was finalized.

2.2.2 Springs

There are 56 springs along the USR (FDEP, 2021), nine of which have been identified by the District for MFLs assessment (SRWMD, 2020). Most of the springs along the upper Suwannee River are located between Suwannee Springs and Ellaville (Figure 4). The MFLs springs assessment will be presented in a separate report.

Spring flow has been measured occasionally at the priority springs at different times. The earliest flow measurements were made in 1906 at Suwannee Springs and 1907 at White Sulphur Springs (Table 2). Although field flow measurements are made at the springs using standard methods, measurement accuracy is limited by site conditions such as irregularly shaped measurement locations and backwater conditions

Table 2. Springs within the USR watershed designated by the SRWMD for MFLs development

Name	SRWMD ID	USGS ID	Magnitude[1]	Period of Record[2]
Springs located between the White Springs and Suwannee Springs stream gages				
White Sulphur Springs	WHS010C1	02315503	2	2/1907 – 1/2021
Blue Sink near White Springs	--	02315512	2	5/1998 – 1/2021
Hamilton Unnamed Spring	HAM1023971	--	2	10/23/1997
Springs located between the Suwannee Springs stream gage and mouth of Alapaha River				
Suwannee Springs	SSS010C1	02315600	2	5/1906 – 1/2021
Blue Spring at Boys Ranch	SUW1017972	--	2	10/1997 – 1/2021
Holton Creek Rise	HOL010C1	02315620	1	2/1976 – 1/2021
Alapaha River Rise	ALR010C1	02315626	1	11/1975 – 9/2016
Springs located between mouth of Alapaha and Ellaville stream gage				
Seven Sisters Spring	HAM923971	--	2	4/1976 – 11/2020
Stevenson Spring	SUW923973	--	2	4/1976 – 1/2021

1. As listed in District's 2021 MFLs Priority List (SRWMD, 2022)
2. Intermittent field flow measurements at all springs. Daily flow records for Alapaha Rise for water years (WYs) 2013 and 2016. Only a single measurement for the Hamilton Unnamed Spring. See Chapter 7 for additional information regarding the flow measurements.

Figure 4. Location of priority springs within the USR watershed

2.2.3 Rainfall and Air Temperature

Parameter-elevation Relationships on Independent Slopes Model (PRISM) monthly time series rainfall data for the USR watershed were provided by the SRWMD. This gridded dataset was developed by the PRISM Climate Group at Oregon State University (PRISM Climate Group, 2014) using local and national resources such as the Florida Automated Weather Network (FAWN) and NOAA's Cooperative Observer Network (COOP).

Monthly average temperature data also were obtained using Parameter-elevation Relationships on Independent Slopes Model (PRISM) for a location near Fargo for general background climate information and for another location near the Nutrien phosphate mine near White Springs.

2.2.4 Groundwater Level

Databases maintained by the SRWMD and USGS were inventoried for records of groundwater level. Based on information provided by SRWMD from their database, representative monitoring wells with sufficient records to evaluate long-term water-level patterns were identified (Table 3). The wells are widely distributed throughout the USR watershed and vicinity in Florida and Georgia (Figure 5).

Table 3. Summary of select Floridan Aquifer groundwater-level monitoring well information

SRWMD Well ID	USGS Well ID	Owner / Site Name	Abbreviation	Period of Record[1]
--	304942082213801	USGS / 27E004 (at Okefenokee Swamp, GA)	Okefenokee	5/1978 – current (94% complete)
N021125001	303224083101785	Santa Deas	Santa Deas	3/1981 – current (93% complete)
N011316001	302959083015085	Carl I. Carter / Ivey Carter nr Jasper	Carter	11/1976 – current
N011608001	302957082441201	Irene Morgan / Camp Mallory	Irene Morgan	8/1976 – 6/2016 (monthly)
N011422007	302833082542985	Peter Deas	Peter Deas	3/1981 – current
S012003001	302620082173501	USGS / B-9 at Taylor, FL	B-9	10/1963 – current
S011232006	--	Falmouth	Falmouth	2/2000 – current
S011727001	302243082360201	USGS / ONF #1A	ONF	2/1978 – current (97% complete)
S011511001	--	PCS Phosphate Admin / MD4	MD4	5/1975 – current (monthly)
S011534001	302127082475801	Hilward Morgan well near Facil, FL	Hilward Morgan	11/1981 – 11/2015 (intermittent)
S011535004	--	Bullock Tower	Bullock	11/1981 – 2/8/2012 (monthly) 3/13/2012 – current

SRWMD Well ID	USGS Well ID	Owner / Site Name	Abbreviation	Period of Record[1]
S021516001	301909082490901	G E Poucher	Poucher	1/1961 – 12/2017
S021624001	301822082393901	Rebecca Nolin / New Hope School Well near White Springs	Nolin	11/1976 – current (monthly)
S021335001	301610082591585	Bobby Brickles / Church of God	Brickles	11/1976 – current (93% complete)
S031105006	--	Advent Christian Village	Advent	8/1981 – current
S031908001	301423082261185	USGS / Ocean Pond	Ocean Pond	12/1959 – 12/1994
S041705001	301031082381001	Lake City FDOT / Local No. 9	Lake City	6/1948 – current

1. Continuous daily level except as noted. “Current” refers to the date on which this report was finalized.

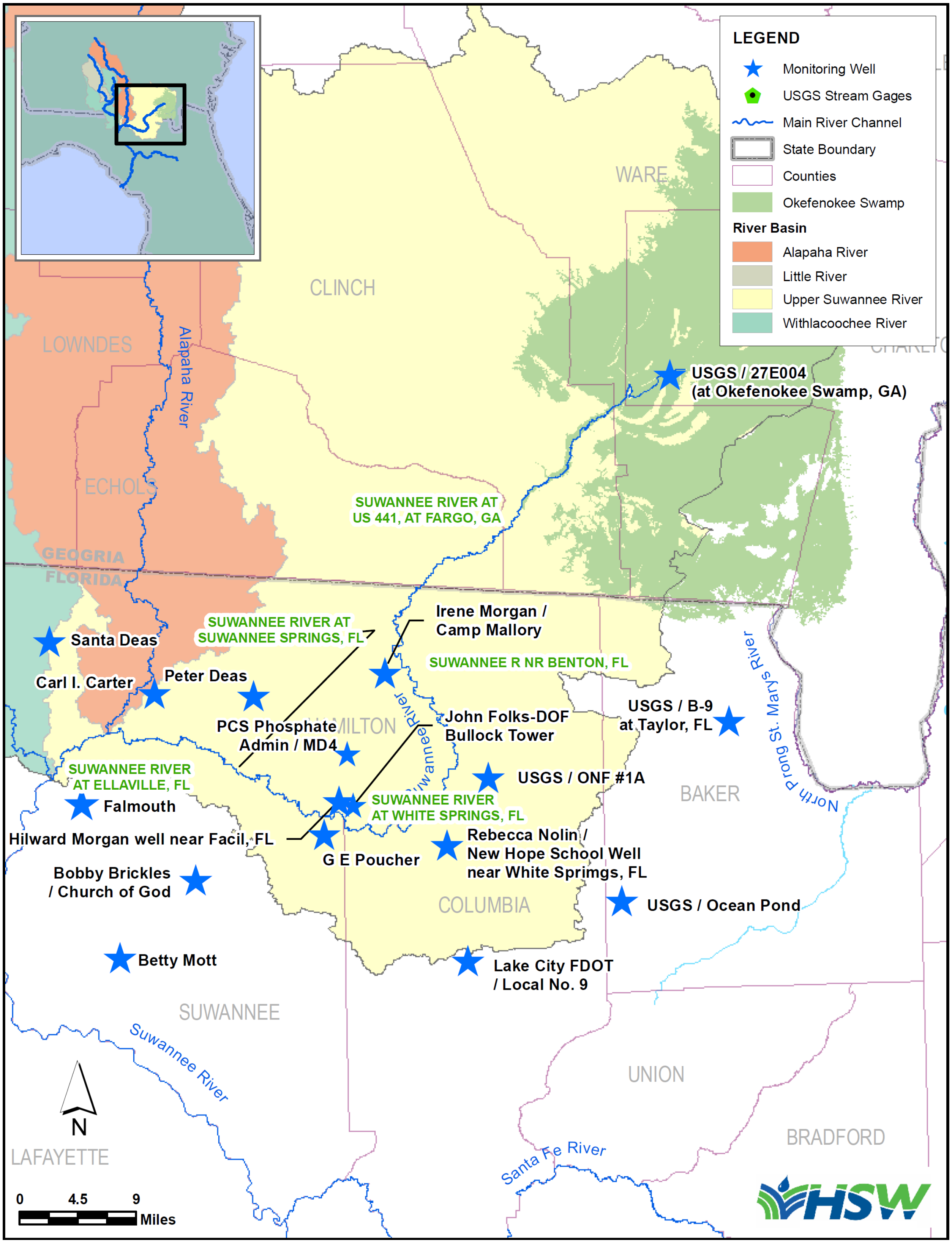


Figure 5. Location of groundwater-level monitoring wells proximal to the USR watershed with long-term record

2.3 Primary Gages, Drainage Areas, and Period for Analysis

Four stream-gaging stations on the USR were selected as the primary gages for hydrologic analysis (Figure 4).

- Fargo (02314500)
- White Springs (02315500)
- Suwannee Springs (02315550)
- Ellaville (02319500)

Except for Suwannee Springs, each of the gages has a nearly continuous period of record extending from Water Year (WY) 1938 through WY 2021 (i.e., October 1937 through September 2021) (Table 1). The Suwannee Springs gage was included as a reference gage because of its position below the Cody Scarp (Figure 4) and resulting baseflow signature.

Drainage areas were determined using the National Hydrography Dataset (NHD) watershed GIS shapefiles and information posted on the National Water Information System (NWIS). About two-thirds of the USR watershed is in Georgia (Table 4). Of the three primary rivers, the Alapaha River watershed has the least percentage of area in Florida (6%) and the USR watershed has the greatest percentage in Florida (34%). The USGS gages located at Fargo, Statenville, and Pinetta record runoff from a combined two-thirds of the USR gaged area at Ellaville (Table 5) and (Figure 2).

Water years 1938 through 2015 were selected as the period with best available data for hydrologic analysis. The period encompasses the longest period of concurrent streamflow record at the three primary gages and ancillary data, such as rainfall, that can be evaluated to characterize current, historic, and baseline streamflow conditions.

Table 4. Distribution of drainage area between Florida and Georgia
[Source: USGS National Hydrography Dataset, March 2016]

Watershed	Area (mi^2)			Relative Portion (%)	
	Georgia	Florida	Total	Georgia	Florida
Upper Suwannee River	1,747	898	2645	66%	34%
Alapaha River	1,693	109	1,802	94%	6%
Withlacoochee River	2,126	274	2,400	89%	11%
Total	5,566	1,281	6,847	81%	19%

Table 5. Distribution of primary gaged areas
[Source: USGS National Water Information System, May 2016]

River	Gage Location (USGS Site No.)	Gaged Area (mi^2)	Relative Portion (%)
Suwannee River	Fargo, GA (02314500)	1,130	16.2
Suwannee River	White Springs, FL (02315500)	2,430	34.9
Suwannee River	Suwannee Springs, FL (02315500)	2,630	37.7
Alapaha River	Statenville, GA (02317500)	1,370	19.7
Withlacoochee River	Pinetta, FL (02319000)	2,120	30.4
Intervening area	Below Suwannee Springs, Statenville, and Pinetta (partially gaged)	1,050	15.1
Suwannee River	Ellaville, FL (02319500)	6,970	100

2.3.1 Surface Water Quality

The SRWMD and USGS are primary sources of water quality data collected frequently on the USR. The Florida Department of Environmental Protection (FDEP) also collects data along the river in support of periodic water quality assessments, including water quality data collected monthly at Ellaville.

Water quality data dating back to 1989 were provided by SRWMD for over 400 monitored stations, including the USGS gages and gages monitored by FDEP on the USR. These stations are monitored at various frequencies depending on the purpose of the study and for a wide variety of water quality parameters including temperature, pH, conductivity, color, transparency, and dissolved oxygen, as well as inorganic analytes such as total and dissolved phosphorus, speciated nitrogen compounds, major anions and cations (e.g., calcium), and coliforms.

2.4 Missing Records and Record Extension

The equipment used to monitor streamflow and other environmental variables malfunctions at times or may be damaged by natural events or vandalism. Also, monitoring programs can change. Such occurrences may result in gaps in a particular time series. In addition, not all the monitored environmental variables have the same period of record. Appropriate techniques (e.g., interpolation and extraction, exceedance duration, and regression) were used in some instances to allow comparison of the White Springs and Suwannee Springs river gage data sets resulting in some infilling and record-extension of the Suwannee Springs record (Helsel & Hirsch, 2000).

Nearly continuous daily flow records are available for the Suwannee Springs river gage since 1974 with missing data during 1996 spanning multiple months. A scatter plot of Suwannee Springs with White Springs gage data shows good and nearly linear agreement for much of the flow record up to about 13,000 cfs (Figure 6). Various statistical procedures were used, and models were tested using the

Statistical Package for the Social Sciences (SPSS) to develop a rigorous relationship between the two flow records across the range of flows (Appendix A). Briefly, White Springs flow lagged one day offered slight improvement over no lag. In addition, based on inspection of the scatterplots (Figure 6), Cook's distance statistic was used along with a cubic polynomial regression equation to identify data values with substantial influence on coefficients. Observations with high Cook's Distances should encourage further investigation (Helsel & Hirsch, 2002), which was not undertaken with this USGS data set. These data are associated with very high flows, likely backwater on the Suwannee Springs gage imposed by the Alapaha River, and possibly other conditions such as rapidly changing flows and measurement anomalies that were not investigated further, and were omitted from the analyses – i.e., data values with Cook's Distance > 4/number of total data values were omitted https://www.statisticshowto.com/cooks-distance/). A total of 818 out of 16,026 values (about 5%) were excluded from further analysis.

To infill and extend the flow record for the Suwannee Springs gage, several multiple linear regression model forms were evaluated including linear, quadradic, cubic and piecewise linear regression (Figure 6). The piecewise linear regression model using White Springs lagged flow proved to be the most versatile, particularly at low flow (Figure 6 and Appendix A). This form is given by:

When lagged White Springs Q < knot2 (32.8 cfs, exceeded 93% of time)

Suwannee Springs Q = 45.4 + 2.358* lagged White Springs

When lagged White Springs Q >= knot2 and < knot3 (1,538 cfs, exceeded 31% of time)

Suwannee Springs Q = 45.4 + 2.358* lagged White Springs – 1.224*(lagged White Springs – knot2)

When lagged White Springs Q >= knot3 and < knot4 (11,544 cfs, exceeded 1% of time)

Suwannee Springs Q = 45.4 + 2.358* lagged White Springs – 1.224*(lagged White Springs – knot2) - 0.162*(lagged White Springs – knot3)

When lagged White Springs Q >= knot4

Suwannee Springs Q = 45.4 + 2.358* lagged White Springs – 1.224*(lagged White Springs – knot2) - 0.162*(lagged White Springs – knot3) – 0.304*(lagged White Springs – knot4)

with R-squared = 0.988. This regression model was used to infill and hindcast the Suwannee Springs daily flow record to WY1938, consistent with the record at White Springs.

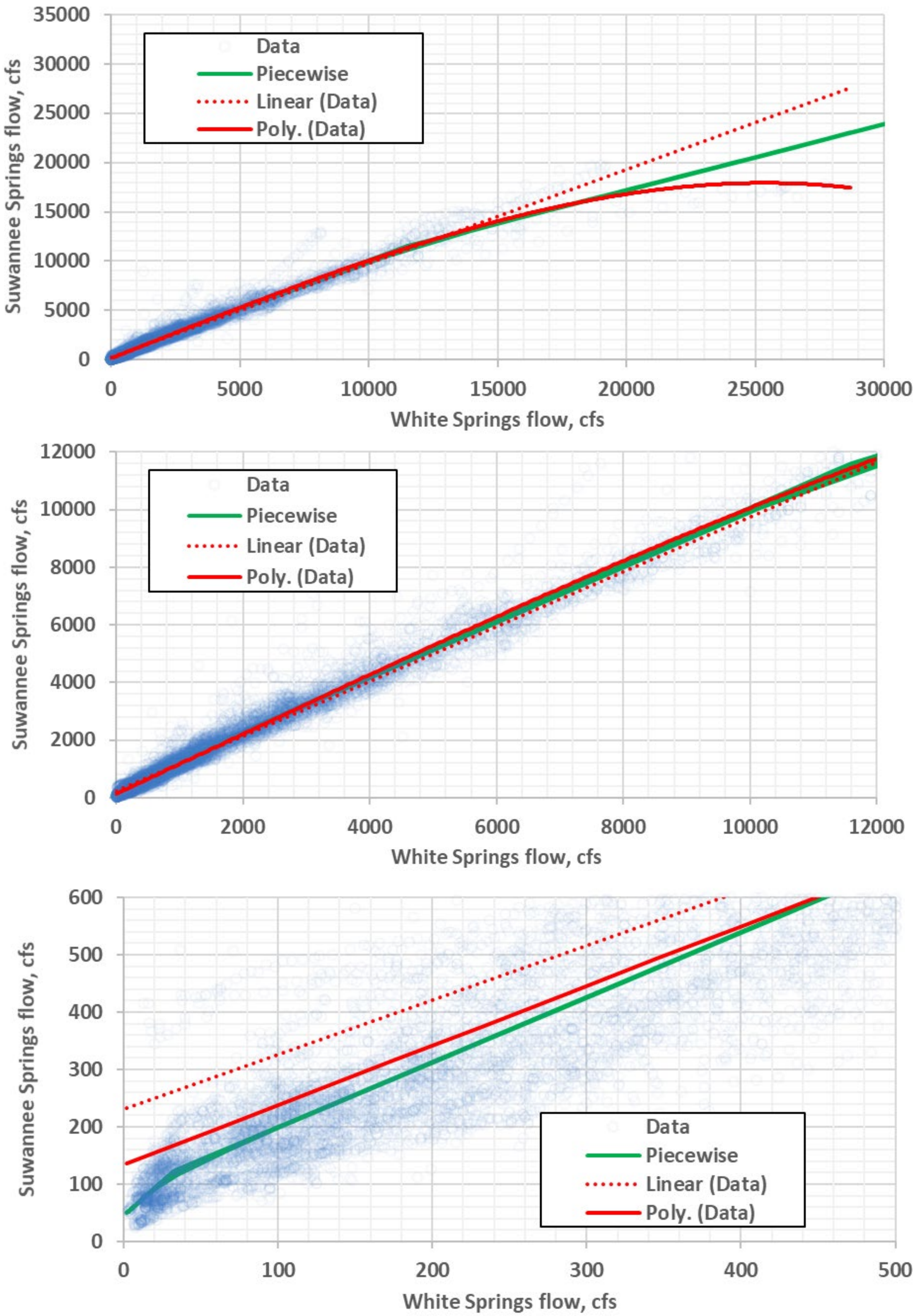


Figure 6. Scatterplots at different scales of Suwannee Springs versus one-day lag White Springs daily flows with linear, cubic and piecewise linear regression lines.

2.5 Historical Streamflow

2.5.1 Discharge Characteristics

Daily flows at the four primary USGS gages vary over a wide range individually and from gage to gage over the period of analysis (WYs 1938-2015). The median daily flow at White Springs is almost twice the median flow at Fargo, and the median flow at Ellaville is about ten times that at Fargo (Figure 7). The sustained greater flows at Ellaville (i.e., relatively flat flow duration curve) and, to a lesser degree, at the Suwannee Springs gage, reflect baseflow input to the river even during periods of little surface water runoff and contrast with the low-flow characteristics of the Suwannee River at Fargo and White Springs. At Suwannee Springs, the influence of baseflow (e.g., spring flow) is evident under low flow conditions while at extreme high flows, the river can lose water to groundwater resulting in greater flows at White Springs than Suwannee Springs.

Typical annual flow patterns are characterized by steady increases in discharges beginning in November and rise to a maximum in March to April (Figure 8). A second minor peak occurs in August.

The annual average discharge of the Suwannee River generally increased from 1938 until the late 1960s and has declined since then although some leveling of the LOESS curve is apparent over the last few years (Figure 9). A smoothing parameter of 0.33 is used for all LOESS curves. Similar patterns also are apparent in the annual minimum and maximum flow metrics (Figure 10).

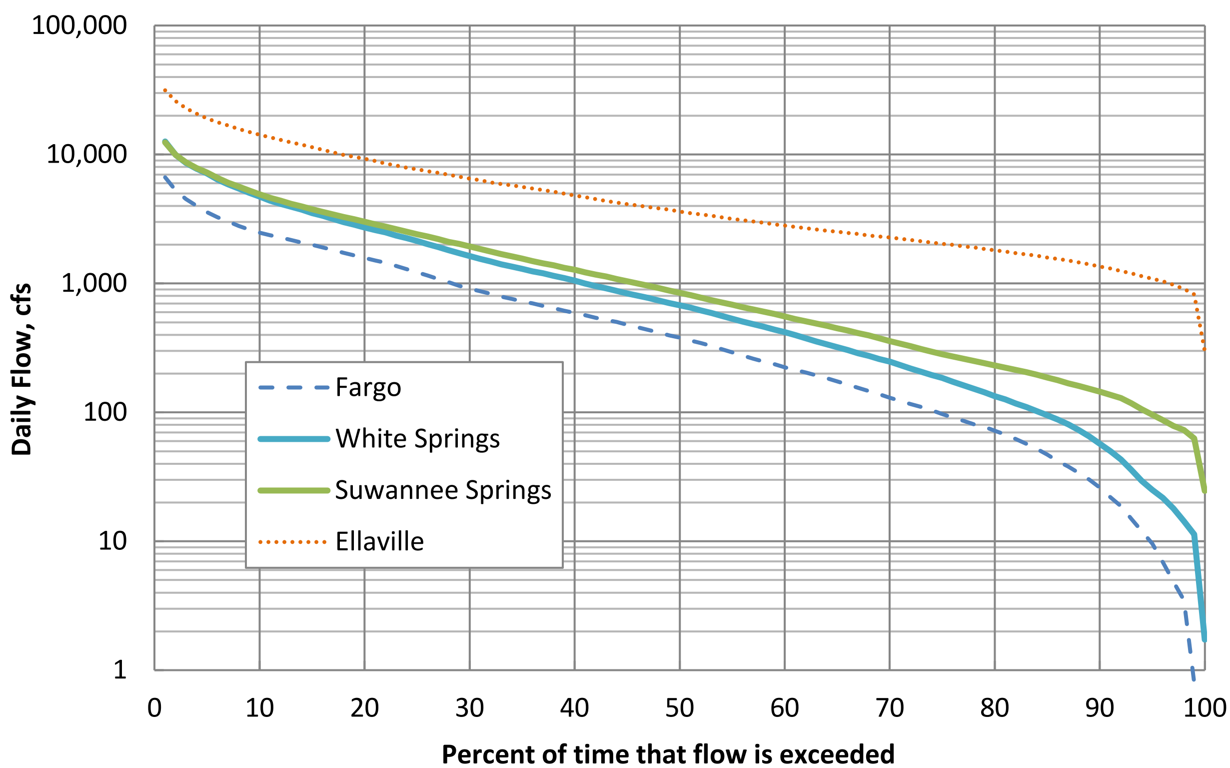


Figure 7. Daily flow duration curves for the four primary USGS gages, WYs 1938-2015

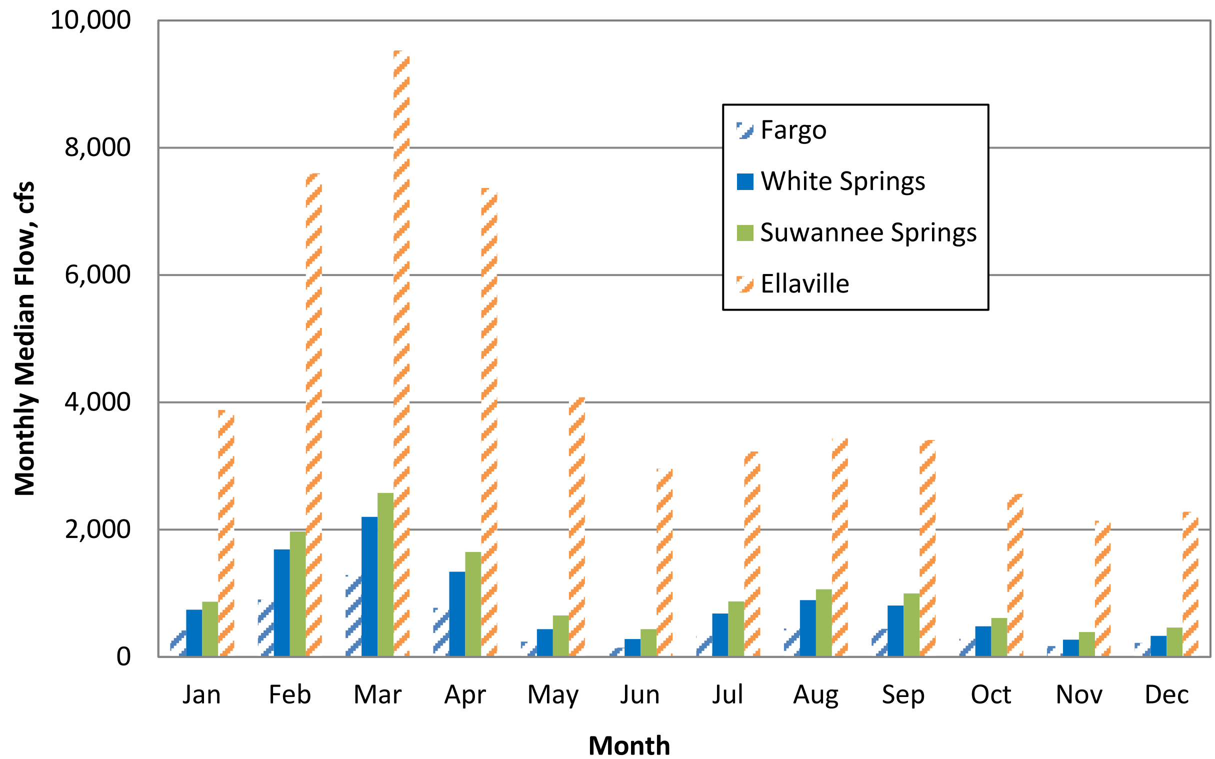


Figure 8. Monthly average historical flow for the four primary USGS gages WYs 1938-2015

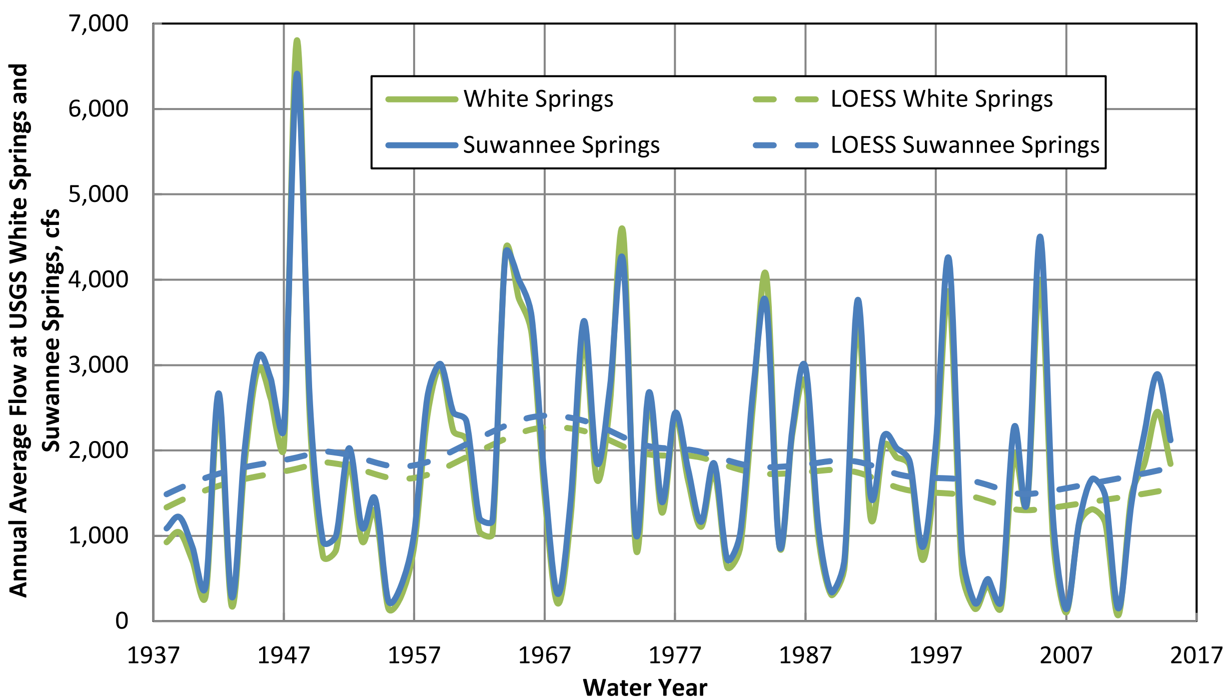
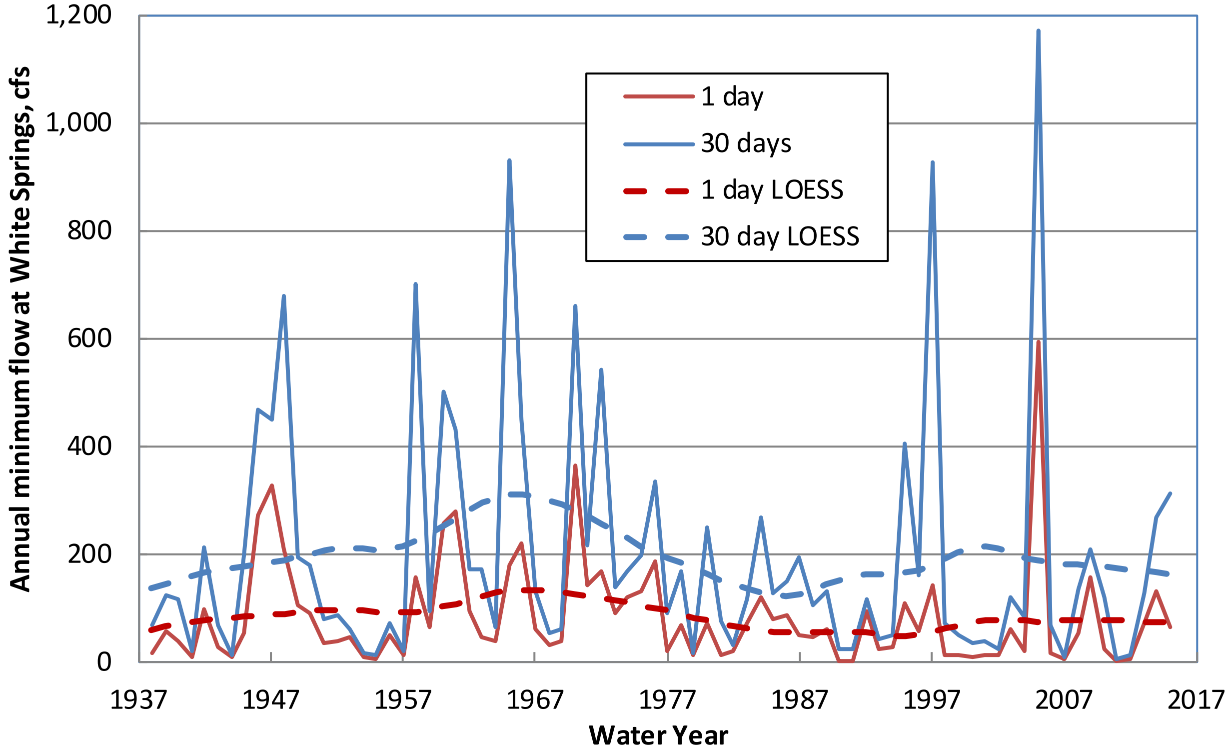


Figure 9. Annual average flows at the White Springs and Suwannee Springs gages, WYs 1938-2015



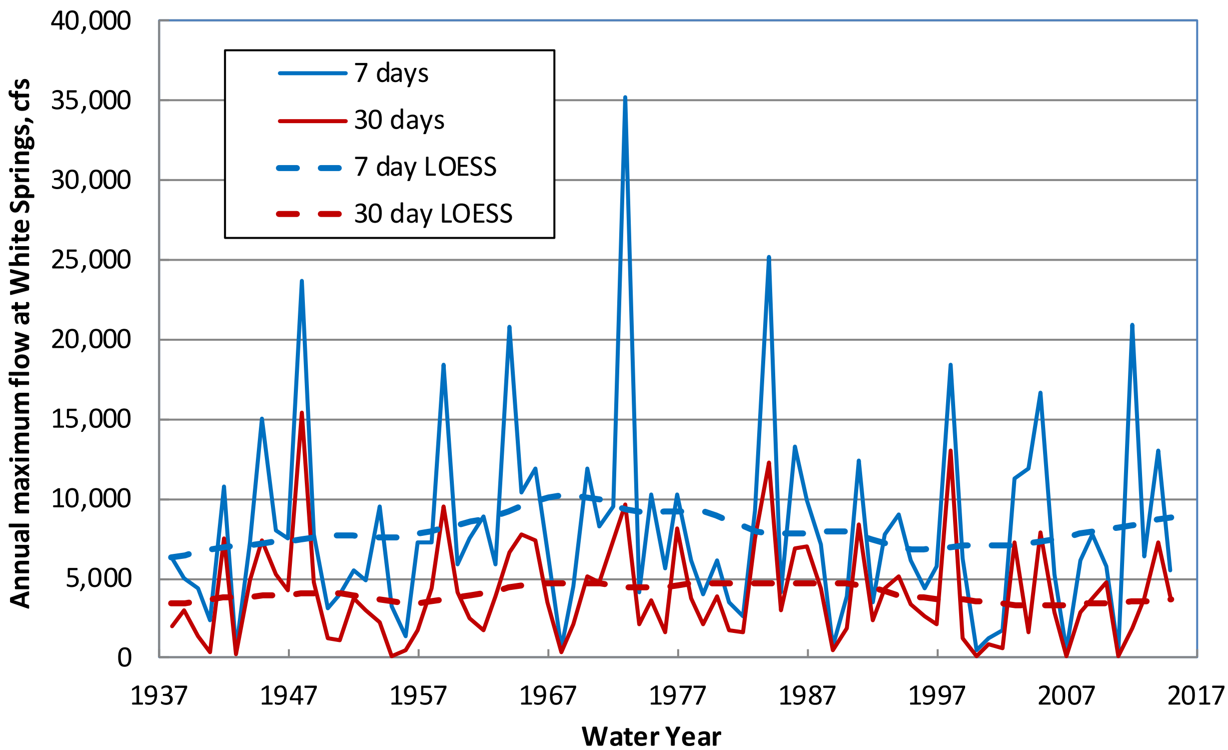


Figure 10. Historical annual minimum (top panel) and maximum (bottom panel) flows at White Springs gage for WYs 1938-2015

2.5.2 Atlantic Multidecadal Oscillation

The Atlantic Multidecadal Oscillation (AMO) is a series of long-duration changes in the surface temperature of the North Atlantic Ocean (NOAA, 2012). A cool or warm phase may last for 20 to 40 years at a time (Figure 11). The AMO reportedly affects Florida rainfall, with northern Florida experiencing less rainfall on land when the Atlantic Ocean is warm, and more rainfall on land when the ocean is cool (Kelly, 2004). This pattern is observable in the historical flow records for the three primary USR gages. The daily flow duration curves for a generally warm/dry period (WYs 1940-1969) are lower than the curves for a generally cool/wet period (WYs 1970-1999) (Figure 12), although the average flow difference is not great (e.g., 1,848 versus 1,903 cfs at the White Springs gage for the dry and wet periods). The period of record used for developing MFLs (WY 1938 -2015) covers portions of two warm periods and a complete cool period in the AMO cycle (Figure 11); hence differences between cool- and wet-period daily flow regimes are more evident in Figure 12 than the average annual flow times series in Figure 9.

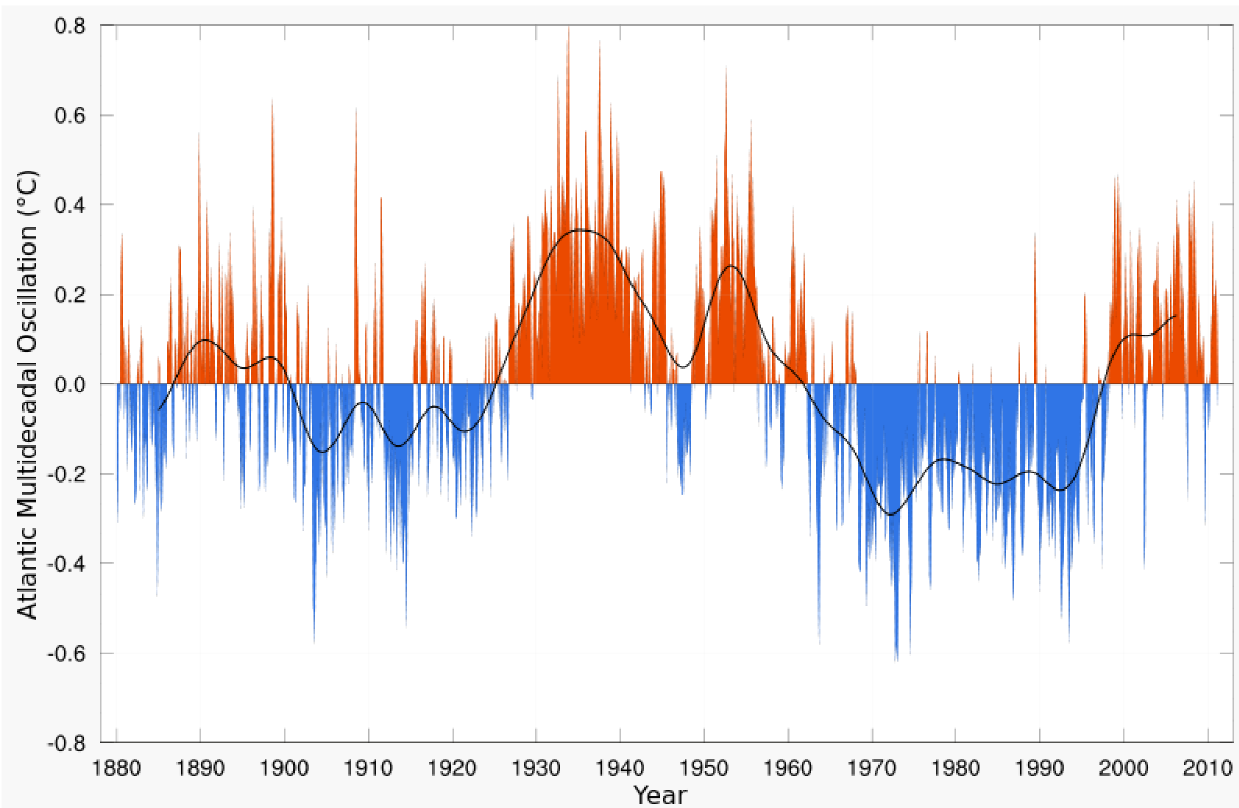


Figure 11. Departure of the Atlantic Ocean surface temperature from the long-term mean
[Source: (McCarthy & Haigh, 2015); periods of warm and cool Atlantic Ocean temperature depicted by red and blue bars, respectively.]

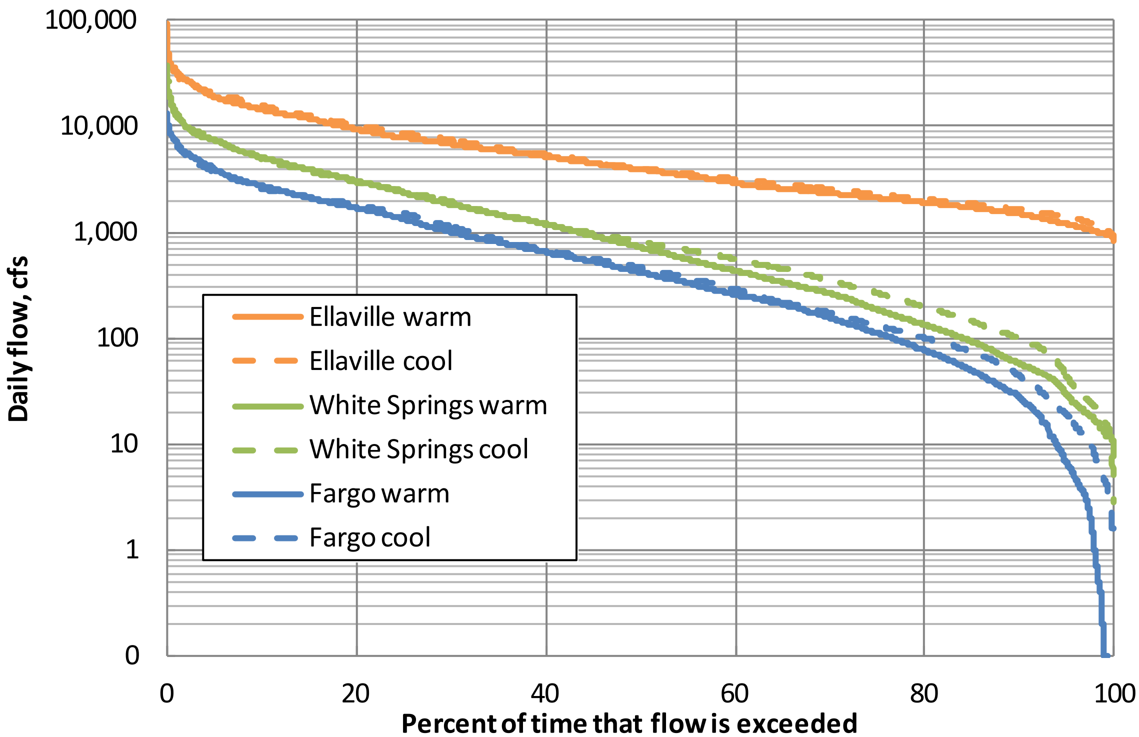


Figure 12. Daily flow duration curves for warm (1940-1969) and cool (1970-1999) periods at the Fargo, White Springs, and Ellaville gages

2.6 Historical Climatology

Monthly PRISM rainfall and temperature data, including minimum, maximum, and average temperature were acquired and processed for grid cells within the watershed area.

2.6.1 Rainfall Characteristics

Basin-wide average annual rainfall during the period of analysis ranged between 37 and 72 inches and averaged 51.4 inches for the 1938 to 2015 period (Figure 13). Rainfall peaked in the mid-1960s and was at a minimum around 2000 before increasing through 2015. With respect to the AMO, the average annual rainfall during the early AMO warm period (1940 to 1969) at 50.56 inches per year was not substantially different than the 50.63 inches per year for the later ”cool” period (1970 to 1999).

2.6.2 Temperature, PET, and Excess Rainfall

Average annual air temperature in the USR watershed during WYs 1938-2015 ranged from 66.6 to 70 ^{o}F and averaged 67.8 ^{o}F (Figure 14). The average monthly minimum temperature varied between about 38 and 73 ^{o}F and average monthly maximums varied between about 65 and 92 ^{o}F.

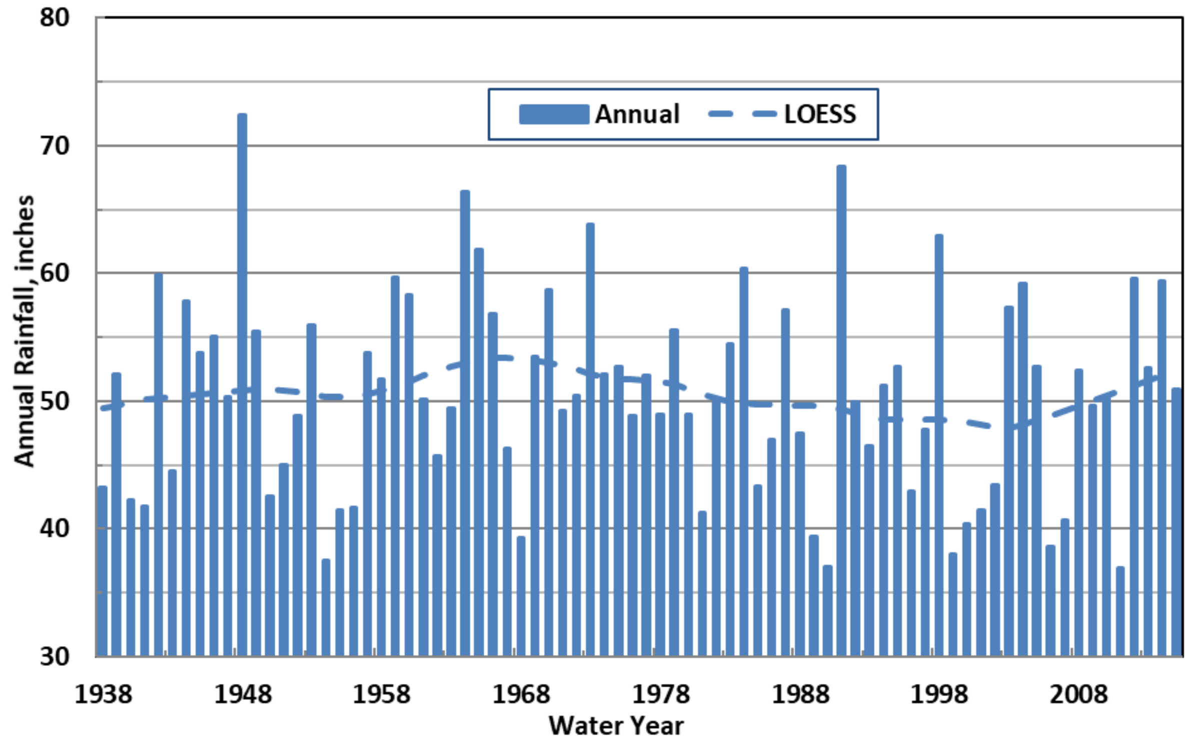


Figure 13. Average annual rainfall within the USR watershed above White Springs gage, WYs 1938-2015

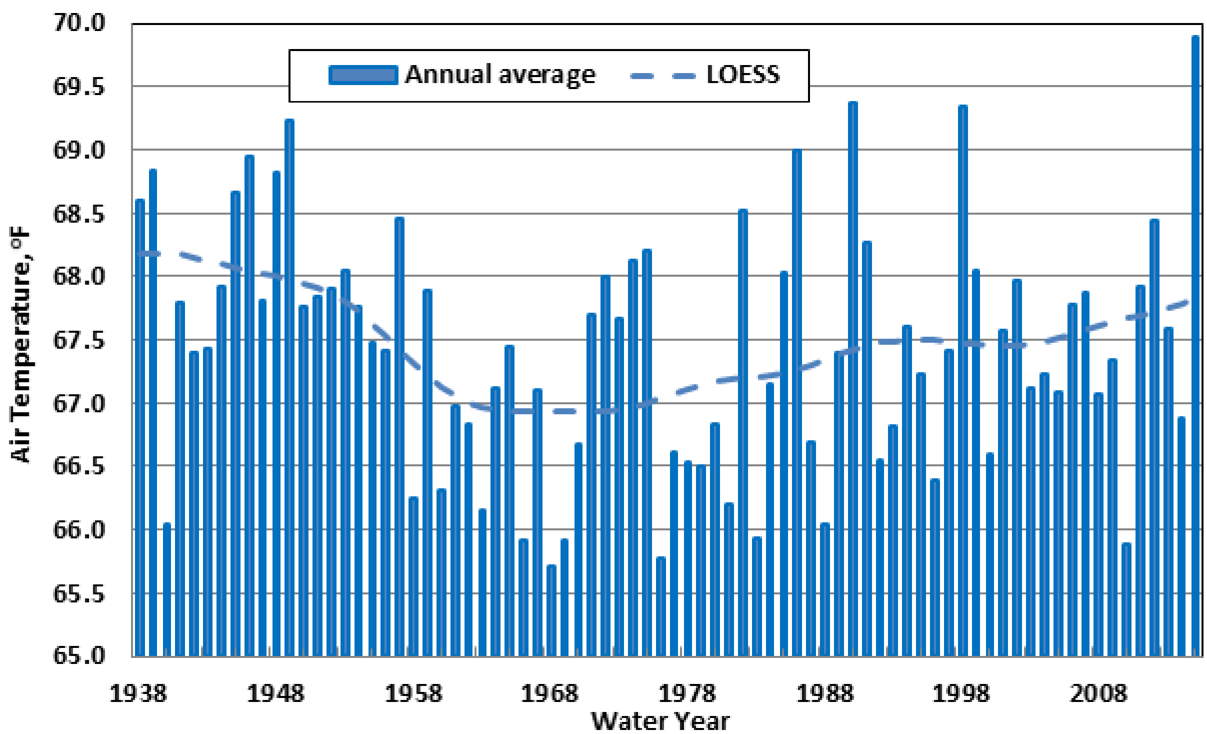


Figure 14. Historical average annual air temperature within the USR watershed above White Springs gage, GA WYs 1938-2015

Potential evapotranspiration (PET) is a measure of the atmospheric demand for moisture from a water surface when the supply of water is not limited (Eagleson, 1970). Monthly PET was estimated using PRISM monthly temperature data and a method developed by Thornthwaite (1948) because this method requires only temperature. Radiation-based methods are more comparable to pan evaporation measurements but also require more information that is not available historically. Average annual PET during WYs 1938-2015 ranged from 38.1 to 43.5 inches and averaged 40.3 inches (Figure 15). As with average air temperature, estimated PET has steadily increased since the mid-1960s.

PET varies seasonally with temperature and day length. Low PET occurs typically in the winter months of December and January and high PET occurs in the summer months of June through August. Average monthly PET varied historically between about 0.8 and 6.6 inches. Monthly minimums ranged between about 0.2 and 5.9 inches and maximums between about 2.2 and 7.7 inches.

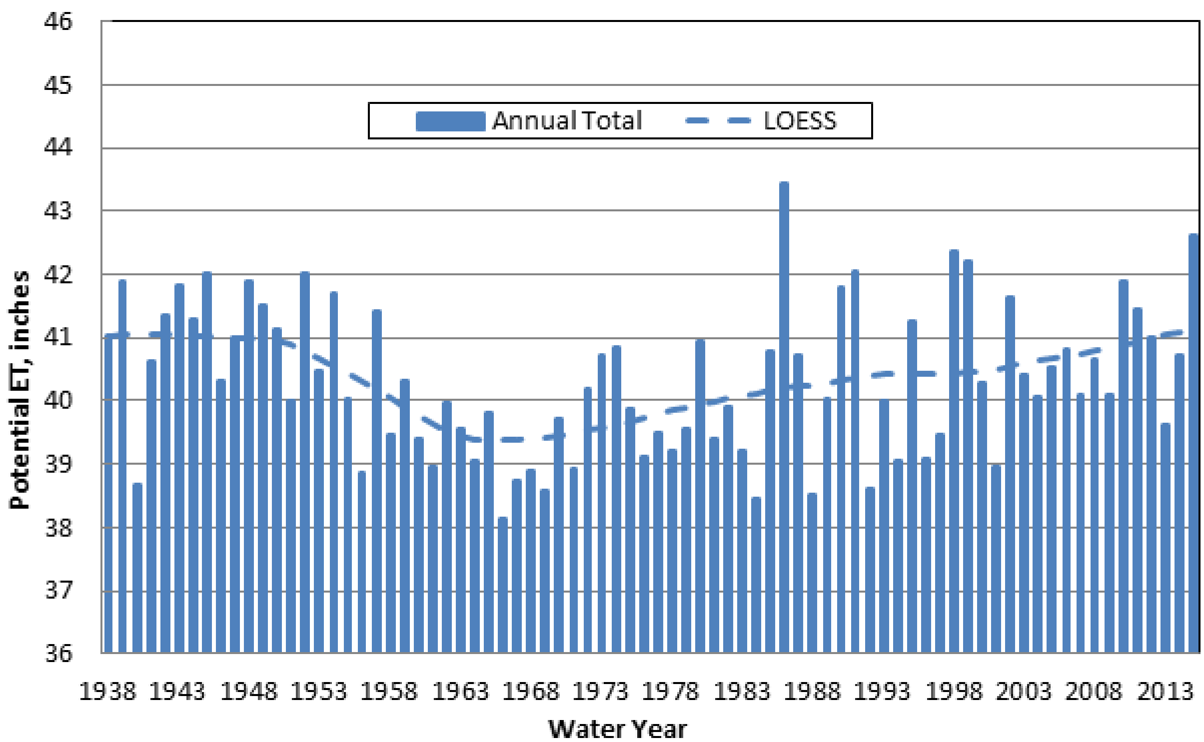


Figure 15. Historical average annual potential evapotranspiration within the USR watershed above White Springs gage, WYs 1938-2015

Excess rainfall is the difference between total rainfall and actual evapotranspiration (ET). A positive excess is a volume of water available for runoff, deep percolation, consumptive use, and accretion of water in storage. A negative excess rainfall results in the depletion of storage as water is lost to ET and other processes. Using PET as a surrogate for actual ET, the long-term average monthly excess rainfall for the USR watershed ranged between -1.3 and 3.0 inches and totaled about 10 inches for a year (Figure 16).

A surplus, or positive excesses, typically occurred between November and April. Monthly deficits typically occurred between May and September. PET was not adjusted for land cover and does not account for soil moistue deficits that may occur, so actual ET will be different; however, the rainfall excess pattern is expected to be similar.

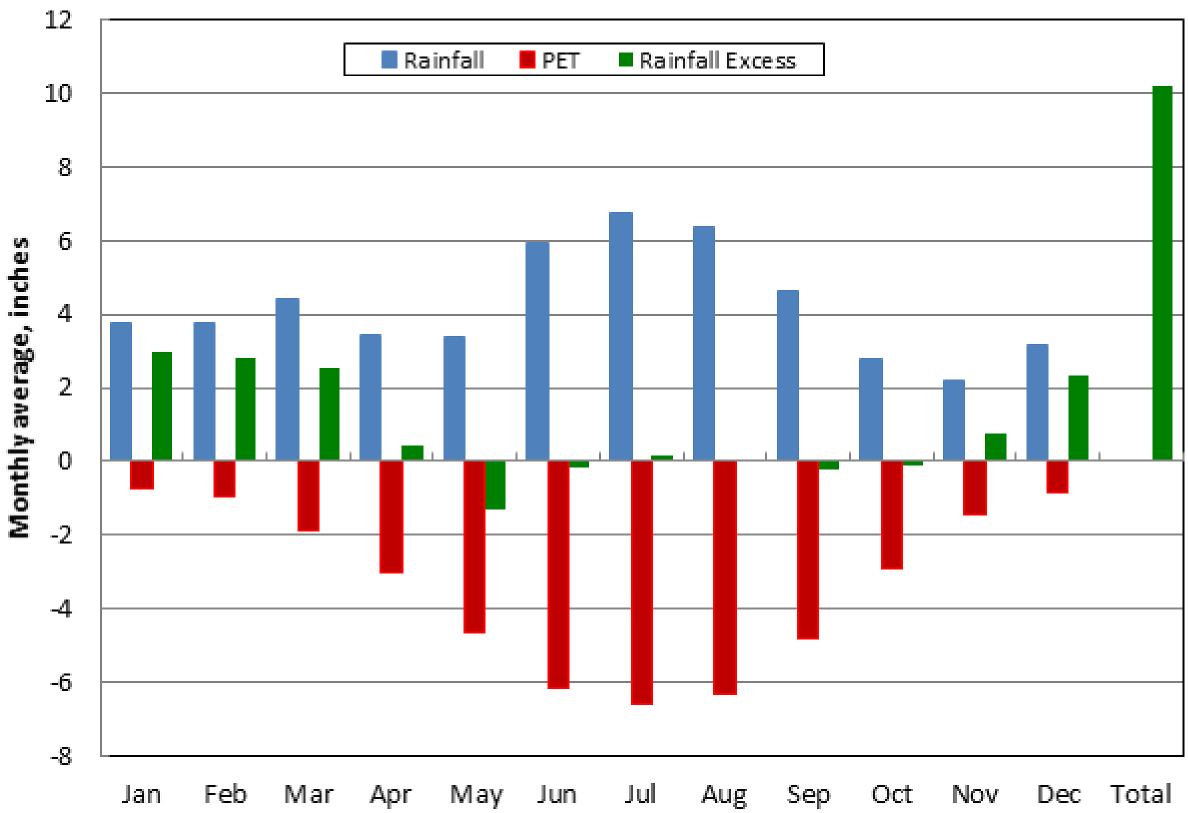


Figure 16. Long-term average monthly distribution of excess rainfall within the USR watershed above White Springs gage, WYs 1938-2015

2.7 Historical Trends

2.7.1 Hydrologic and Meteorological Data

Trends in observed hydrologic and meteorological variables and relationships between these variables are important in developing a conceptual model. One method for graphically examining trends in annual hydrometeorological variables is to plot the cumulative deviations of a variable from its mean value over the POR. The USGS gage at White Springs is very useful for characterizing regional trends because it has a long POR and is centrally located within the study area. From about WY 1942 to WY 1950 and from WY 1958 to WY 1973, annual rainfall and flow at White Springs exceeded the mean values calculated for these variables for the POR, i.e., above-average annual rainfall and flow over these intervals of time resulted in positive slopes of the cumulative deviation bars (Figure 17 and Figure 18). The cumulative

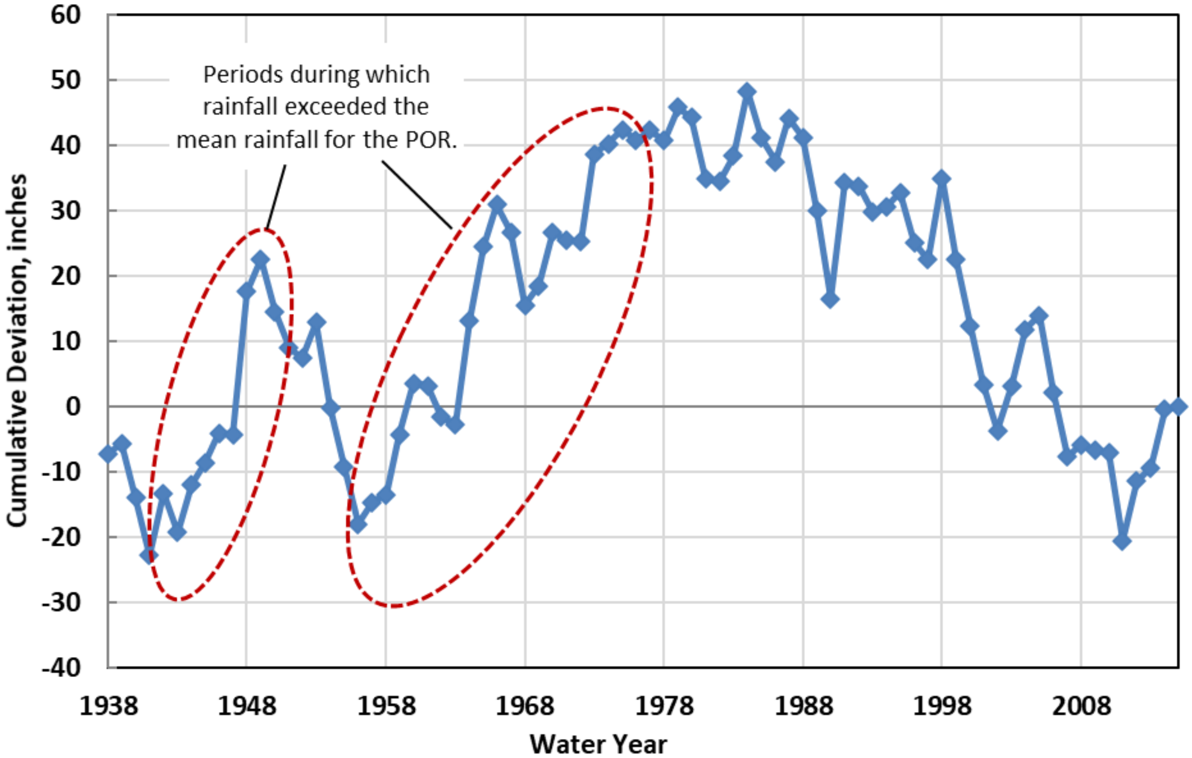


Figure 17. Cumulative deviation of annual average rainfall from long-term average within the USR above White Springs for WYs 1938-2015

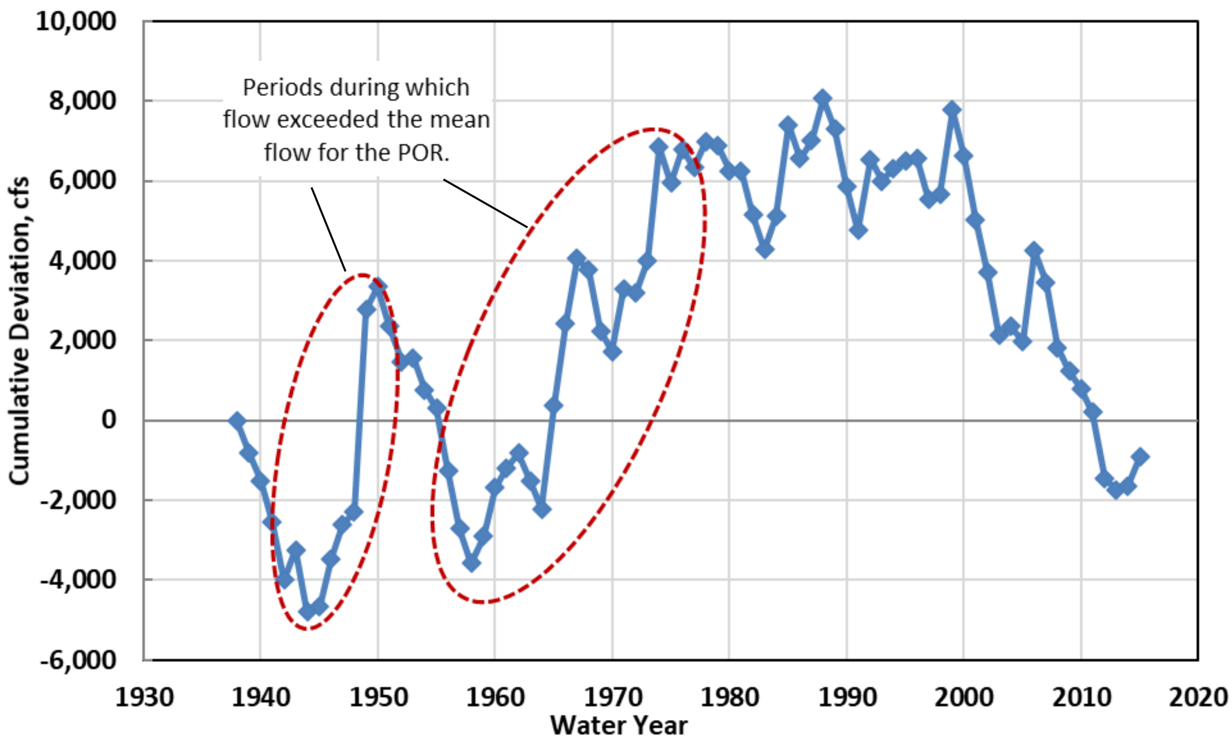


Figure 18. Cumulative deviation of annual average discharge for USGS gage Suwannee River at White Springs for WYs 1938-2015

deviations of rainfall and flow stabilized from about 1973 to 1998. A rainfall surplus of about 60 inches occurred between 1956 and 1976 and a deficit of about 55 inches occurred from 1998 to 2012.

2.7.2 Regional Groundwater Levels

The Upper Floridan Aquifer (UFA) potentiometric surface has declined regionally from levels estimated using computer modeling for predevelopment conditions circa 1880 (DePaul, Rice, & Zapecza, 2008). Predevelopment groundwater levels in the Georgia and Florida portion of the USR watershed including Okefenokee Swamp where the UFA is confined were estimated to be around 70 feet NGVD. The regional decline in the potentiometric surface from predevelopment to 1980 within the USR watershed is estimated to have ranged from less than 10 feet in the vicinity of Ellaville to less than 30 feet near Okefenokee Swamp (Figure 19).

The potentiometric surface in 2010 throughout much of the USR basin was relatively flat, ranging from 40 to 60 feet NGVD and average about 55 feet NGVD over most of the area of interest (Figure 20). The regional influence of the Suwannee River valley near and downstream of Cody Scarp is evident in the regional map of contoured groundwater levels measured in 2010.

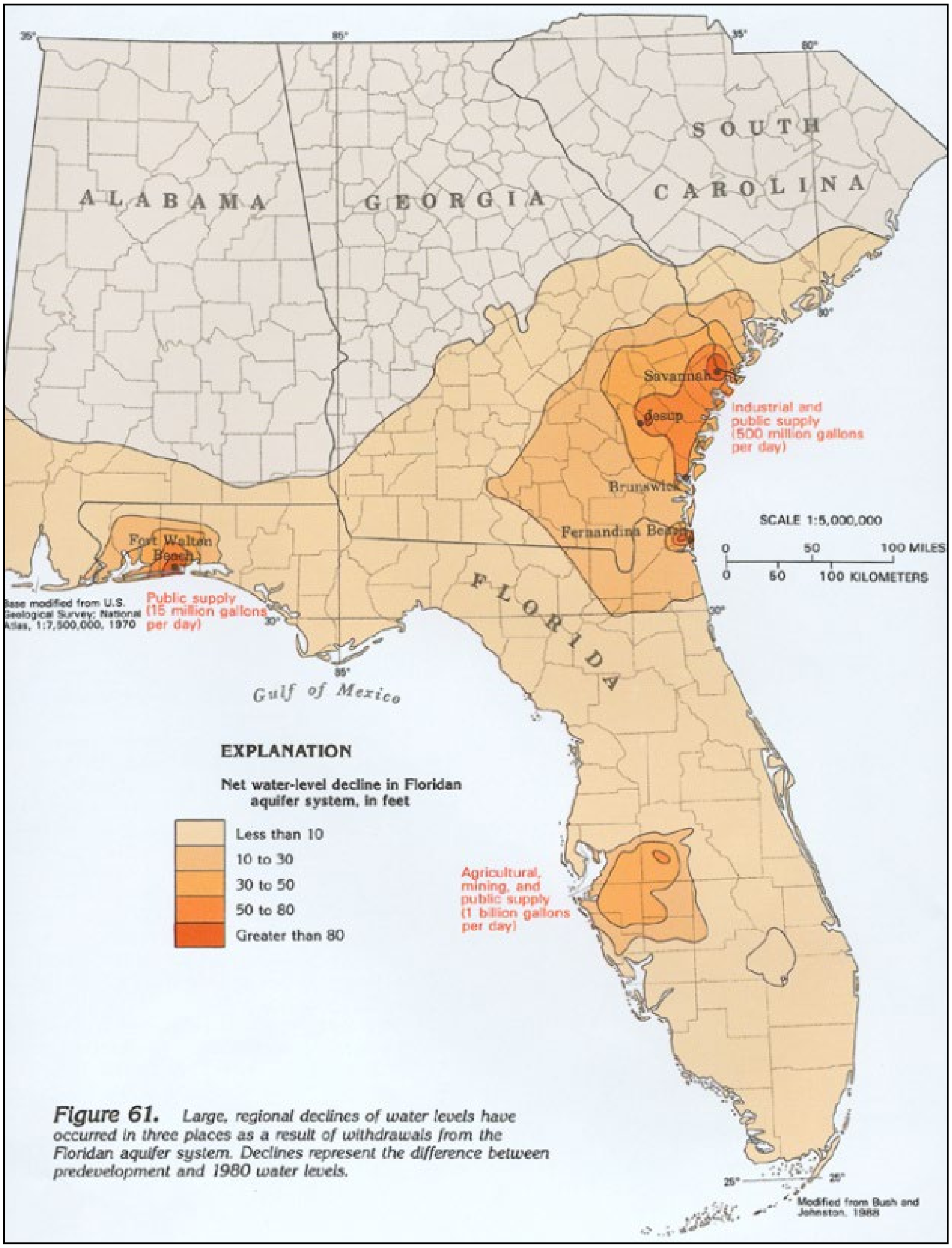


Figure 19. Estimated decline in the UFA potentiometric surface, predevelopment to 1980
[Source: (Miller, 1986)]

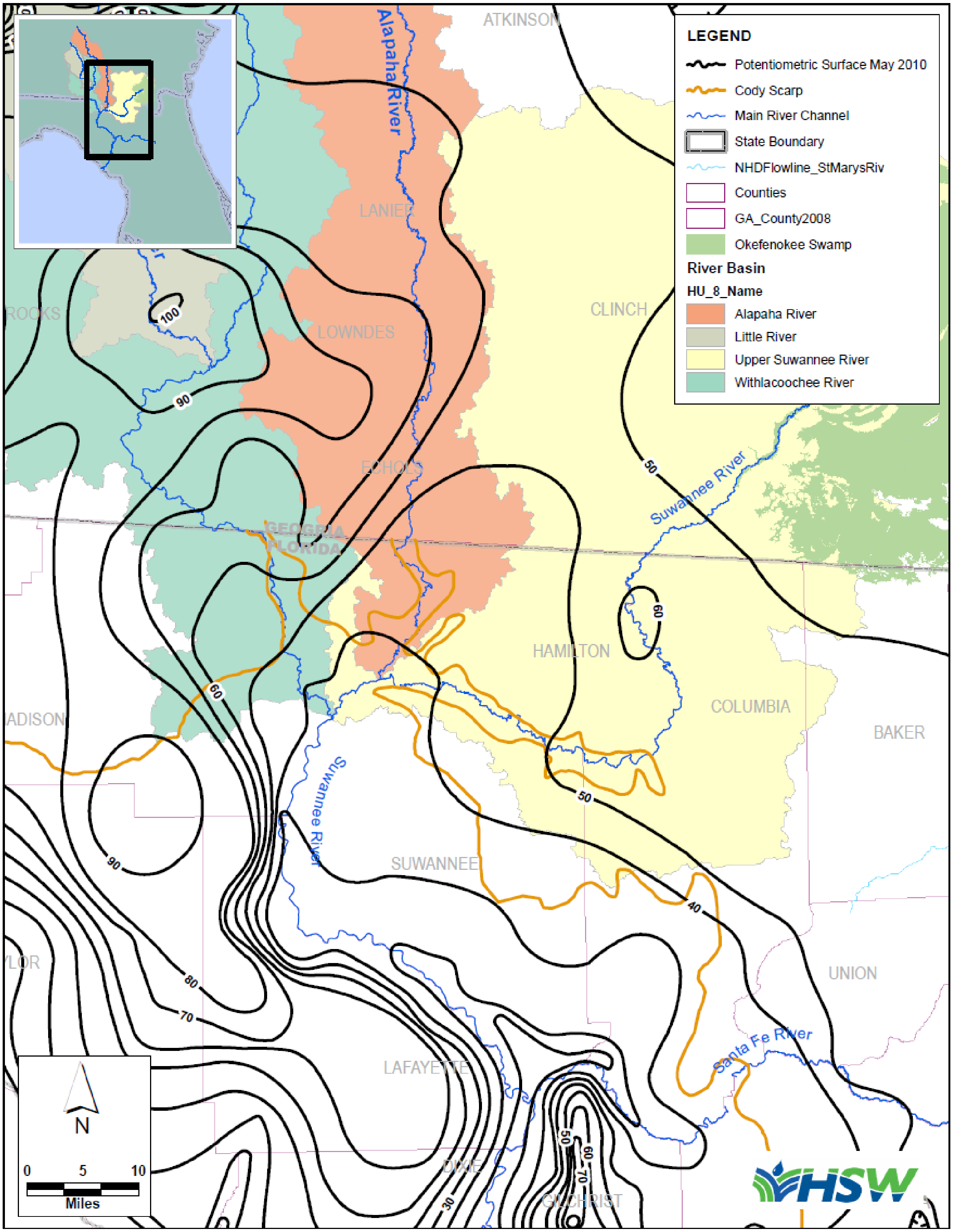


Figure 20. Upper Floridan Aquifer potentiometric surface in north Florida in 2010 [Source: (Bellino, Kuniansky, O'Reilly, & Dixon, 2018)]

2.7.3 Local Groundwater Levels

Records of historical UFA groundwater levels dating back to 1948 are available to characterize long-term patterns within the USR watershed (Table 3 and Figure 5). Of the 15 wells in the vicinity of the USR watershed, the Florida Department of Transportation (FDOT) monitoring well in Lake City has the longest period of record, which begins in June 1948. Groundwater levels in the well have varied considerably over short periods of time; an annual variation of four feet or more is common. The potentiometric surface at this location has declined at an average rate of about 0.12 feet per year (Figure 21), or nearly 8 feet over the 70 years of monitoring at this location. An increasing trend since 2006 is apparent.

Average annual water level records of select monitoring wells in the vicinity of the USR were extended (hindcast) using linear associations between the monitor well records and those for the FDOT Lake City well. Average annual groundwater levels have declined in the upper and central parts of the USR watershed (Figure 22). Groundwater levels near the White Springs gage that historically were greater than the river stage are more frequently less than the river stage; hence, White Sulphur Springs generally does not discharge.

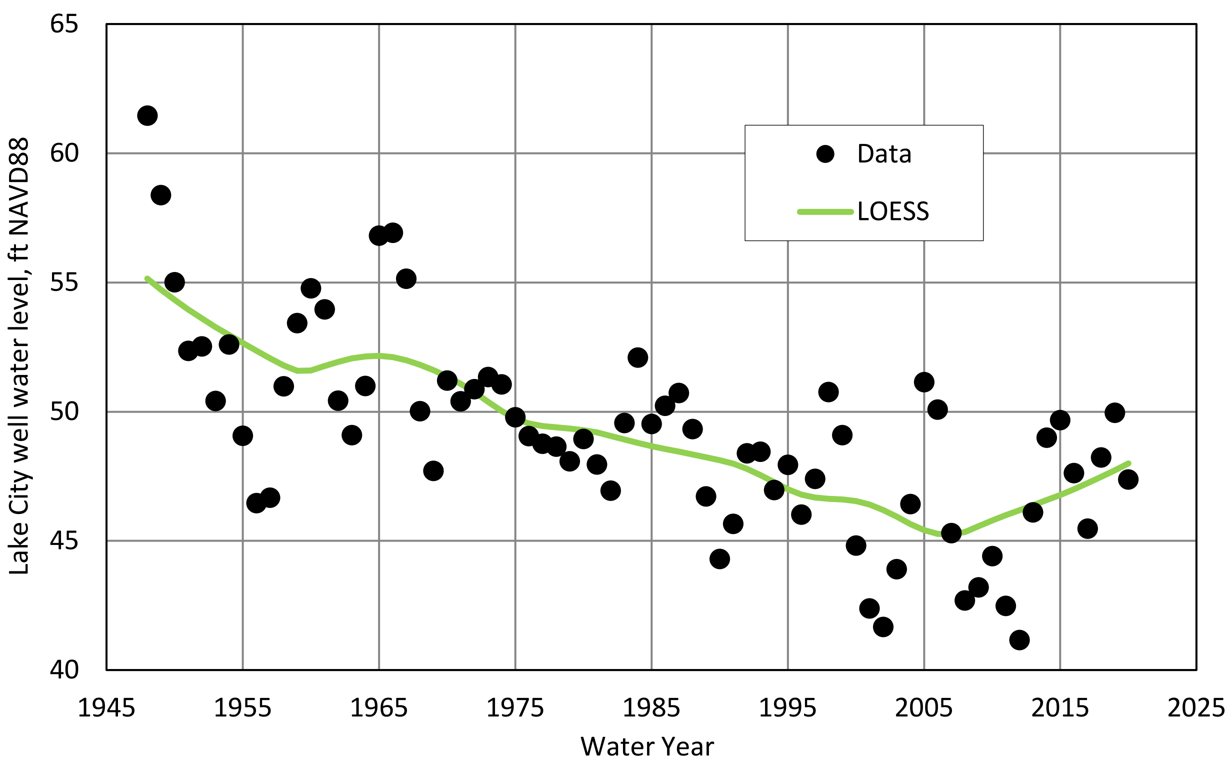


Figure 21. Historical annual average groundwater levels in the UFA at Lake City, Florida during WYs 1948-2020

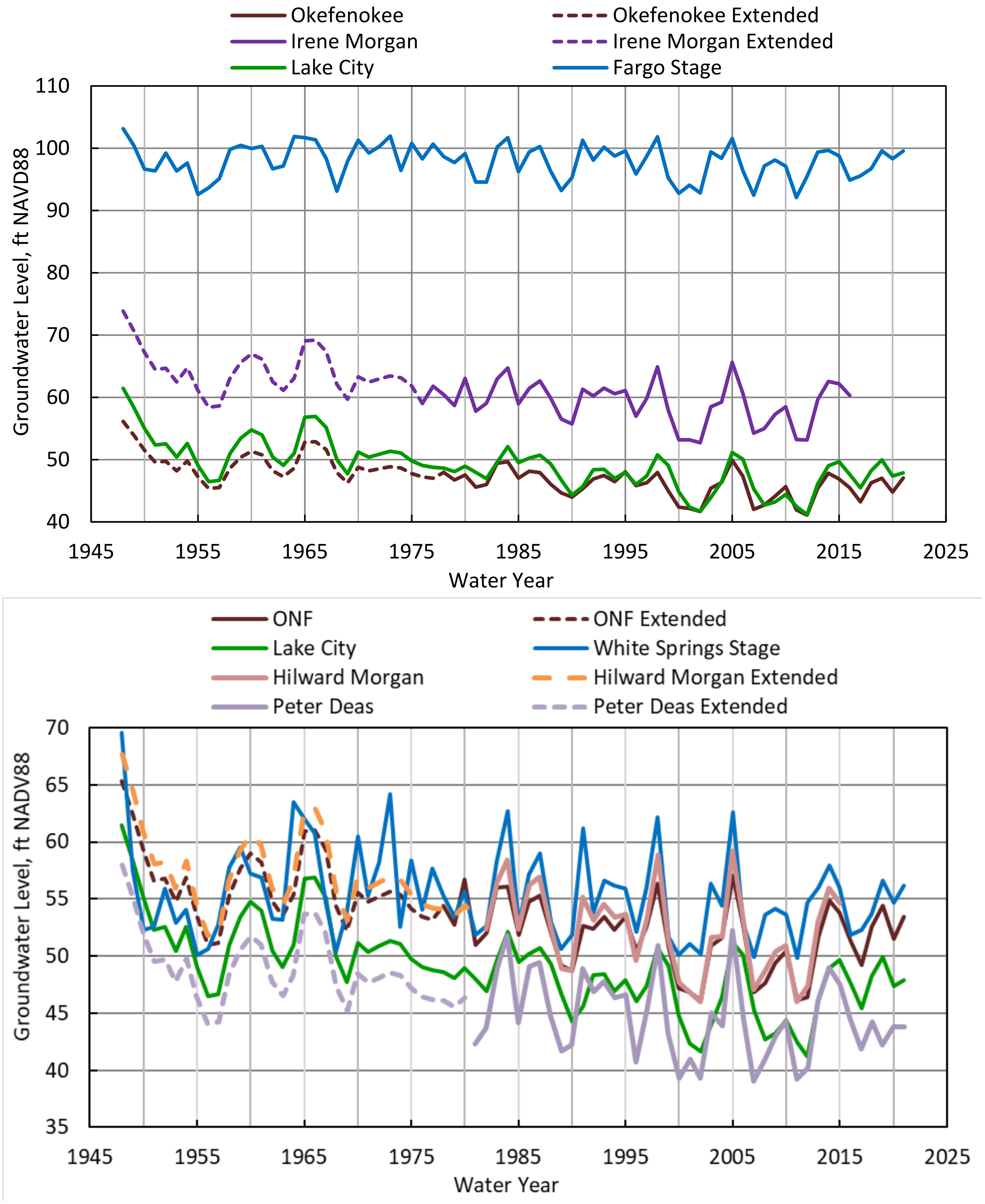


Figure 22. Annual average UFA potentiometric surface elevation at select wells compared to USR stage at the Fargo gage (top panel) and White Springs gage (bottom panel) for WYs 1948-2020

2.7.4 River Gains and Losses

The headwaters of the USR are dominated by the hydrology associated with the Okefenokee Swamp (USFWS, 2006). The Okefenokee Swamp is a 700-square mile palustrine wetland that serves as the headwaters of the Suwannee and St. Marys Rivers (Loftin, Aicher, & Kitchens, 2000). Water enters the swamp via precipitation and drainage of adjacent uplands and exits primarily via surface water drainage and ET.

Beginning in the late 19th century, the relatively untouched wetland was subjected to stresses such as timber harvesting, peat mining, and man-made drainage features. The swamp became a National Wildlife refuge in 1937, which afforded a level of protection to the wetland system. In 1962, a dam (Suwannee River Sill) was constructed to protect the swamp from fire damage. The sill was constructed across the main outflow channel where the Suwannee River exited the swamp. By the late 1980s, evidence was mounting that the sill was not serving this stated purpose and may have been having unintended impacts on hydrology and vegetation. As a result of investigations culminating in an Environmental Assessment by the U.S. Fish and Wildlife Service (Loftin C. , 1998) the sill was permanently breached in 2001.

About 80 percent or 40 inches of the approximately 50 inches of annual precipitation exits the swamp via ET (Yin, 1990) (Yin & Brook, 1992). The net amount of ET is a function of near-surface atmospheric conditions such as temperature and humidity, the degree of soil saturation, type of vegetation, and canopy cover. Alterations such as the sill and changes in vegetation and temperature can impact the amount of ET and, in turn, the amount of water available for discharge to surface water. Yin (1990) reported an average decrease in annual ET with-sill (1963-1986) compared to pre-sill (1937-1962) that he associated with temperature differences between the two time periods.

The potentiometric surface of the Floridan aquifer underlying the swamp reported declined more than 10 feet from predevelopment conditions to 1980 (Figure 19). From 1950 to 2015, the potentiometric surface at the Okefenokee well near Fargo also declined about 10 ft with little change in the river stage near Fargo over the same period (Figure 22).

The hydrology of the upper portion of the USR basin between the Okefenokee Swamp and Cody Scarp (upstream of White Springs) is dominated by surficial drainage systems and the interaction of the surficial aquifer and the USR and small streams that drain into the USR. Downstream of the Cody Scarp, internal drainage dominates. Near the Cody Scarp, the Floridan aquifer is considered semi-confined (medium recharge/discharge) to unconfined (high recharge/discharge) (Figure 23). Every river that crosses the Cody Scarp within the SRWMD goes underground and reemerges downstream as a spring, with the sole exception of the Suwannee River (SRWMD, 2016b).

River discharge is substantially influenced by groundwater inflow downgradient of the Cody Scarp, particularly under low flow conditions. The river becomes a gaining system where the UFA potentiometric surface is higher than river stage. The pre-1960s measurements of White Sulphur Springs discharge characterized a regional groundwater level that resulted in a gaining river system near White Springs at one time. However, hydrologic conditions since the 1970s are such that the USR has become a losing stream in the vicinity of White Springs, as evidenced by the substantial decline in spring flow. Downstream from White Springs, the USR that has been mapped as a gaining reach (Figure 23) and may be transitioning to a losing reach approaching Suwannee Springs, as discussed later in this chapter.

A geologic section along the river thalweg was prepared using the best available geology maps and channel thalweg elevations measured during recent HEC-RAS cross-section field surveys (Figure 24). The USR has cut a channel that gradually deepens from about 20 feet near Benton to about 45 feet near Ellaville. The updip limit of the Floridan aquifer system (Figure 24) occurs at about river mile 170; i.e., near White Springs (Miller, 1986). Downstream from this location, the river is directly connected to the UFA, and the rate of gains and losses from the river to the UFA are a function of the difference in hydraulic head (potentiometric surface minus river stage) associated with river stage and the UFA potentiometric surface.

Six pairs of monitoring wells (Table 6) were selected to generally characterize the temporal patterns in head difference on a longitudinal profile of six different locations along the river. Four locations are at, or near, the stream-gaging stations at Benton, White Springs, Suwannee Springs, and Ellaville, and two locations are just upstream and downstream from Big Shoals (i.e., river miles 175.5 and 180). Hydrographs of groundwater level measurements for the period of record were prepared and fit with a linear trend line. The trend lines were used to estimate mid-year (i.e., July 1) groundwater levels between 1940 and 2010 (Figure 24). The estimated groundwater level was then calculated as the average of the mid-year water levels for each pair of wells, weighted by the well distances from the river. The average mid-year groundwater levels, at 10-year intervals, were compared to long-term river stages calculated for each of the six locations.

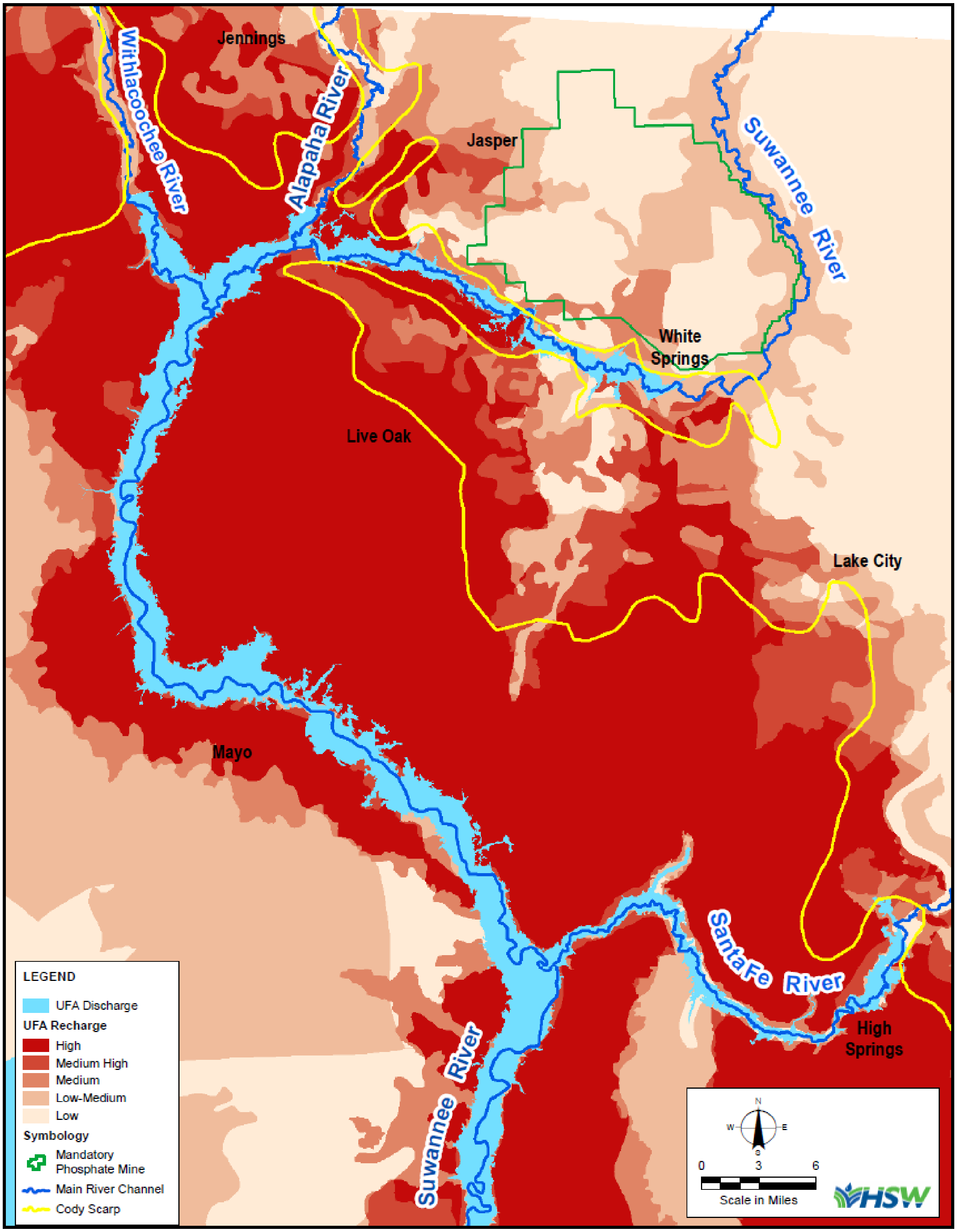


Figure 23. Upper Floridan Aquifer (UFA) discharge and recharge below the Cody Scarp
[Estimated for 1994. "Mandatory" refers to mines that became active after July 1, 1975, and which are required under Florida law to be reclaimed when closed.]

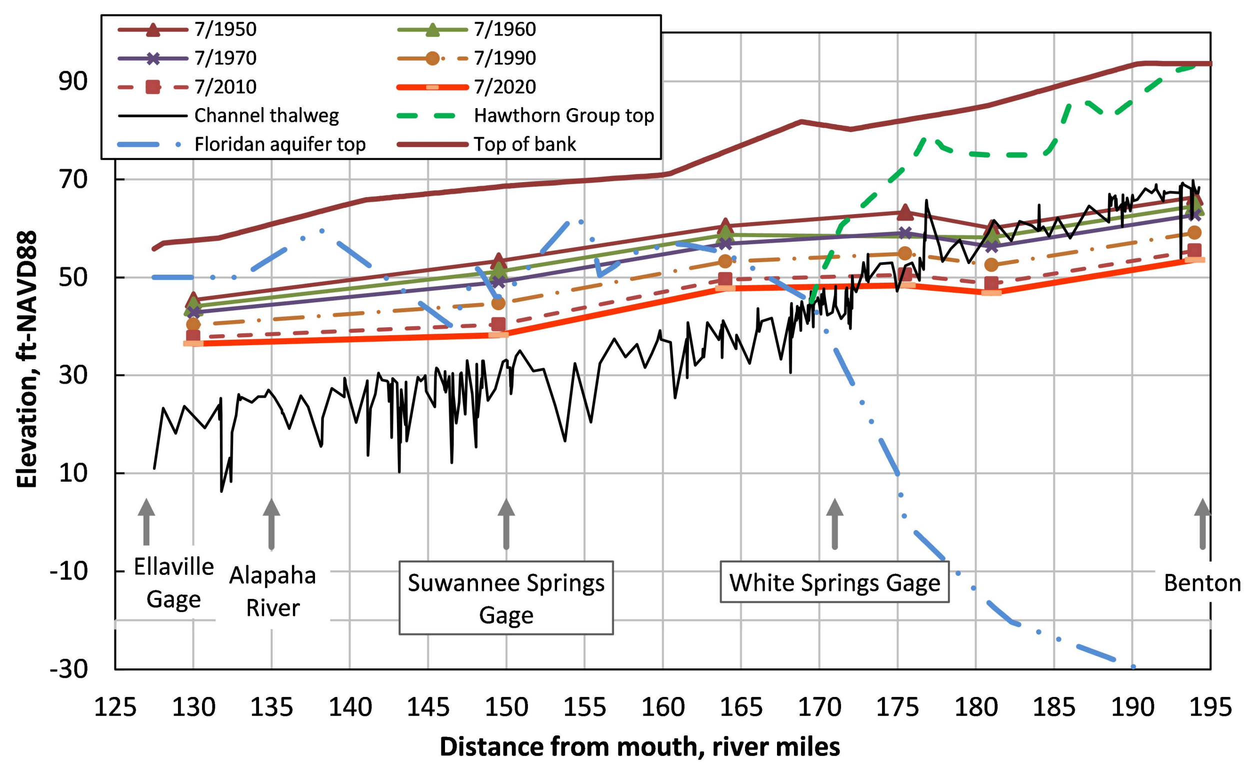


Figure 24. Generalized geologic section and estimated historical Floridan Aquifer potentiometric surface along the Upper Suwannee River

Table 6. Monitoring wells and select hydrogeologic characteristics of the USR watershed hydrogeology used to characterize river gains and losses

River mile	Well Pair		Channel Thalweg (ft - NAVD88)	Hawthorn group top elevation (ft - NAVD88)	UFA elevation (ft - NAVD88)
	Left side[1] of the river	Right side[1] of the river			
194	B-9	Irene Morgan	69.16	93.57	-34.12
180	ONF	MD4	59.06	75.00	-13.85
175.5	Nolin	MD4	52.36	72.53	0.06
164	Poucher	Hilward Morgan	41.16	—	55.00
149.5	Brickles	Peter Deas	32.76	—	45.00
130	Mott	Santa Deas	19.26	—	50.00

1. Side defined by looking downstream; see Table 3 and Figure 5 for well IDs and locations.

Head difference was calculated by subtracting the river stage from the groundwater level. Where the UFA is unconfined, a positive difference indicates a gain to the river and loss from the UFA. Before 1990, the head difference near the White Springs gage was positive (Figure 25) and subsequently the head difference has reversed as the river in this area transitioned from a gaining to a losing system. Groundwater declines south and west of White Springs have contributed to a similar decline in the head difference downstream from White Springs. Between 1970 and 2010, the average head difference declined between about 8.6 feet at the Suwannee Springs gage and 5.2 feet at the Ellaville gage. The decline observed at Suwannee Springs has approached the point where the vertical gradient may soon reverse and the river from this location upstream may persistently become a losing reach.

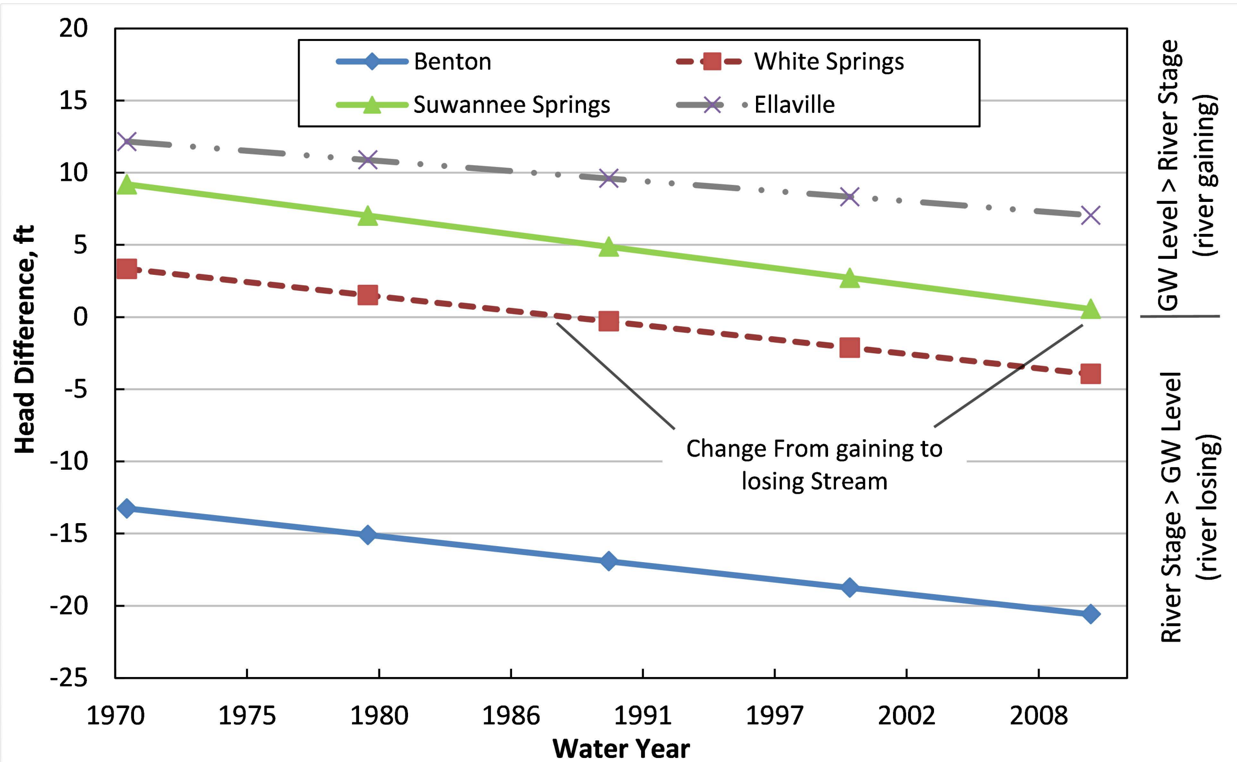


Figure 25. Historical difference along the river between the long-term midyear average groundwater levels and median river stage between 1970 and 2010

The year-to-year variability of the vertical head gradient was characterized for each of the three primary USR stream gages (Fargo, White Springs, and Ellaville) using a similar approach of paired wells. Each of the three locations exhibited a long-term decline in head difference, primarily due to declining groundwater levels (Figure 26). The reach downstream from White Springs to Suwannee Springs appears to be trending towards a persistent losing reach.

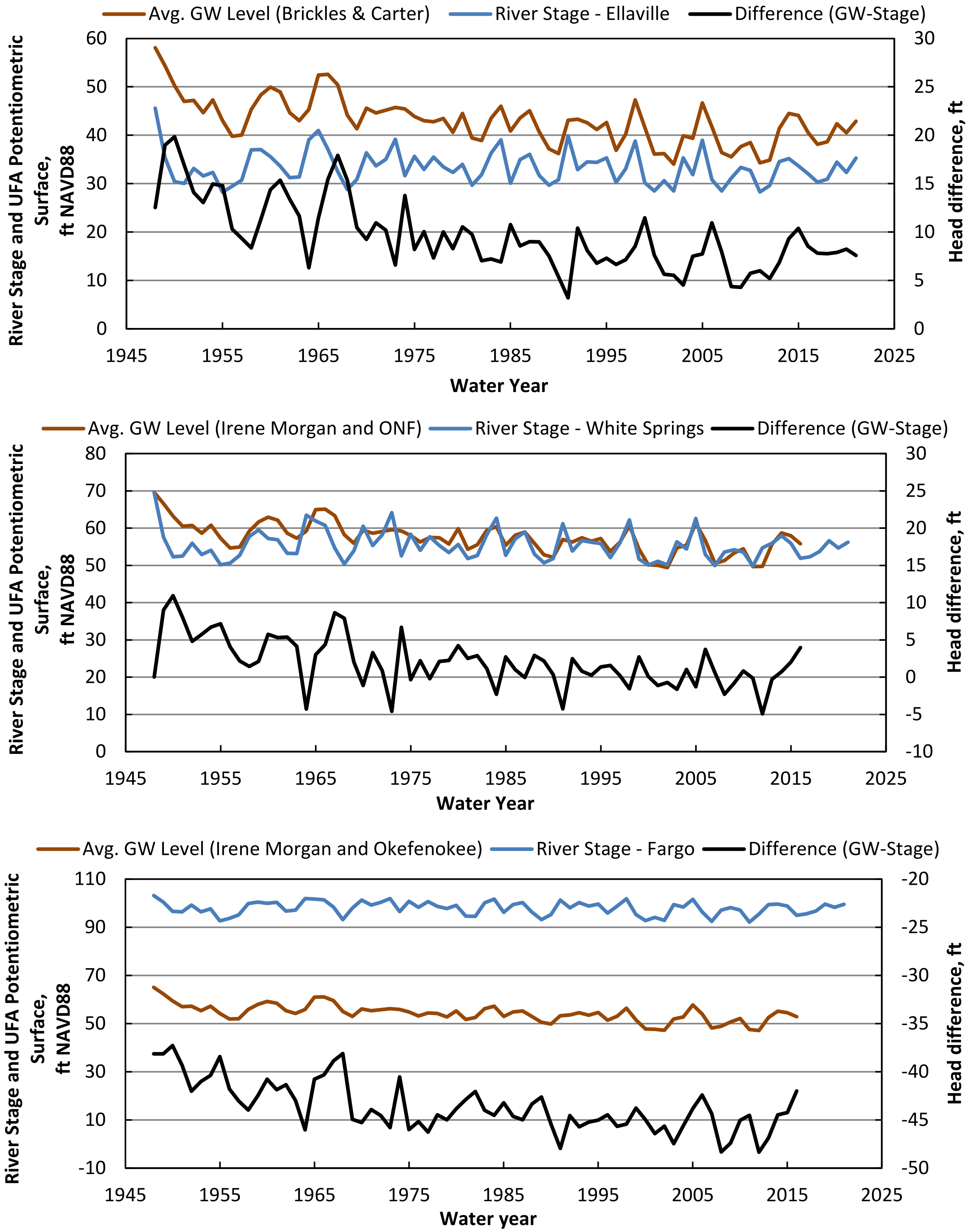


Figure 26. Long-term annual average river stage, groundwater levels and hydraulic head difference near the Fargo, White Springs, and Ellaville gages

2.8 Water Use

In the area encompassing the Upper Suwannee watershed and its tributaries in Florida and Georgia upstream of the Withlacoochee confluence (Figure 1), estimated net surface water withdrawals were about 0.17 cfs in 2015 based on data reported by Marella (USGS, 2015). Two proposed river MFL regulatory locations are the Suwannee River gages at White Springs and Suwannee Springs, which are located above the USR confluences with the Alapaha and Withlacoochee Rivers. The additional net surface water use represented by these two systems (approximately 15 cfs) is not included in this total.

Groundwater withdrawals within the North Florida Regional Water Supply Planning area in Florida and the Suwannee-Satilla Water Planning Region in Georgia (Figure 27) influence flows along the USR. Groundwater is withdrawn for public and domestic drinking water supplies, and for industrial, agricultural, and recreational uses. Groundwater use in northeastern Florida and southeastern Georgia increased substantially through 2015, with groundwater supplying most of the water to meet demands in this region. The estimated groundwater use in this combined area peaked in 2000 within the 1980-2015 period (Figure 28). Groundwater use in the combined region increased prior to 1990 but has stabilized since then at under 600 million gallons per day (mgd) or about 928 cfs. Thus, groundwater is the source of most potable water used in the region of the USR above the Alapaha confluence (Figure 29). Population growth and increases in agricultural groundwater withdrawals have contributed to the increase in groundwater use. Long-term historical water demands for the planning areas are summarized in Appendix B.

2.9 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 Chapter 2.8, groundwater is the source of most potable water used in the region of the USR. 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 (NFSEG) Model Domain (Figure 27).

The estimates were produced by county and by water use type 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.

Water use 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 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 reference time frame (RTF) flow (or baseline 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 flow impacts at the White Springs and Suwannee Springs river gages are about 1.3 and 51 cfs, respectively (Figure 30). The net impact at gages above White Springs (i.e., Benton and Fargo) was negligible while the impact at Ellaville was up to about 340 cfs. The estimated maximum groundwater elevation impacts at select wells ranged from about 0.6 ft at the Falmouth well to 5.5 ft at the Hilward Morgan well (Figure 31). Appendix C is an outline of the process used to develop an 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.

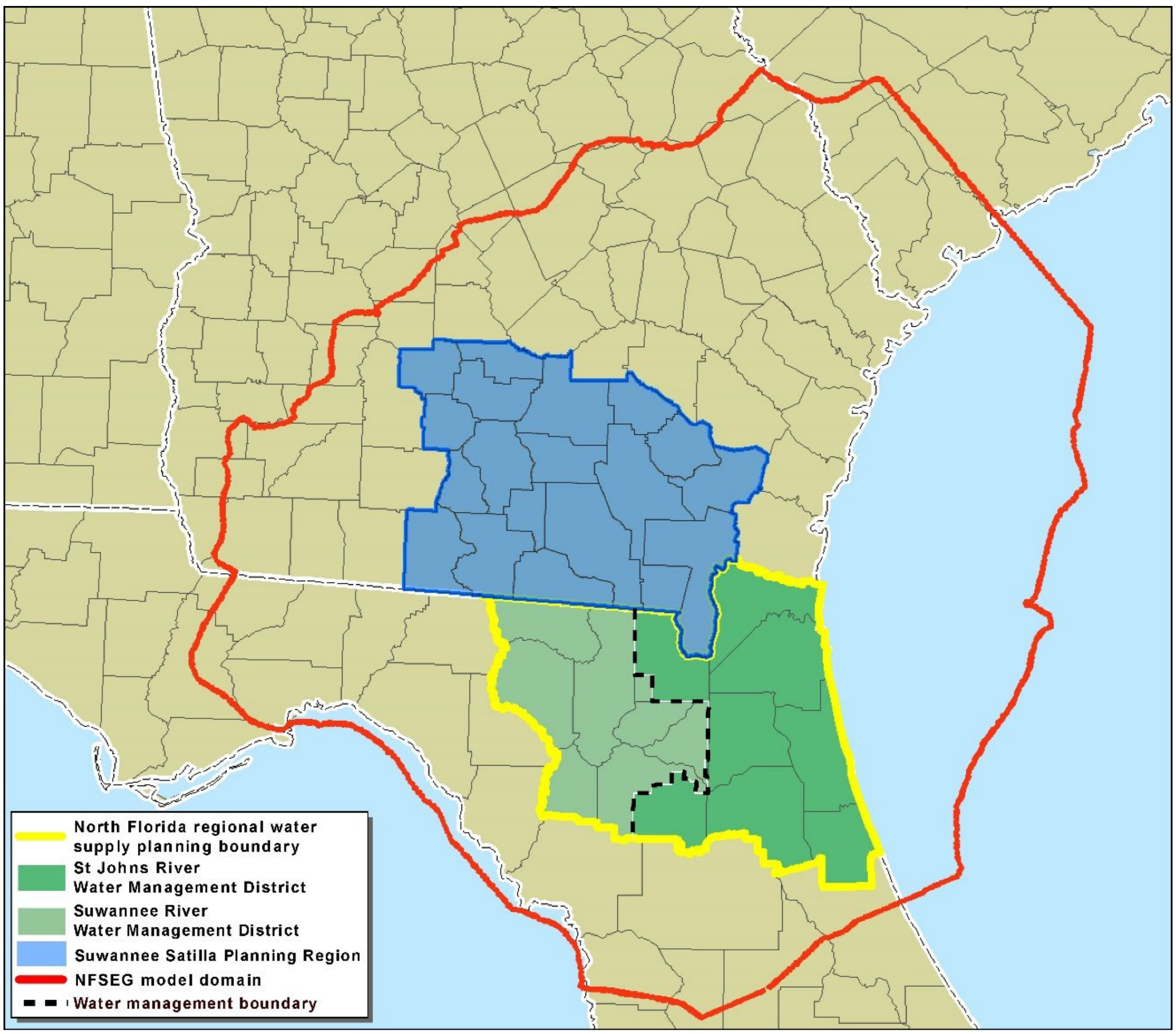


Figure 27. Area map showing the North Florida Southeast Georgia (NFSEG) model domain, the Suwannee Satilla Planning Region, and the North Florida Regional Water Supply planning area boundary.
[Adapted from Figure 4-92 of the North Florida Southeast Georgia Groundwater Model (NFSEG v1.1), (2019)]

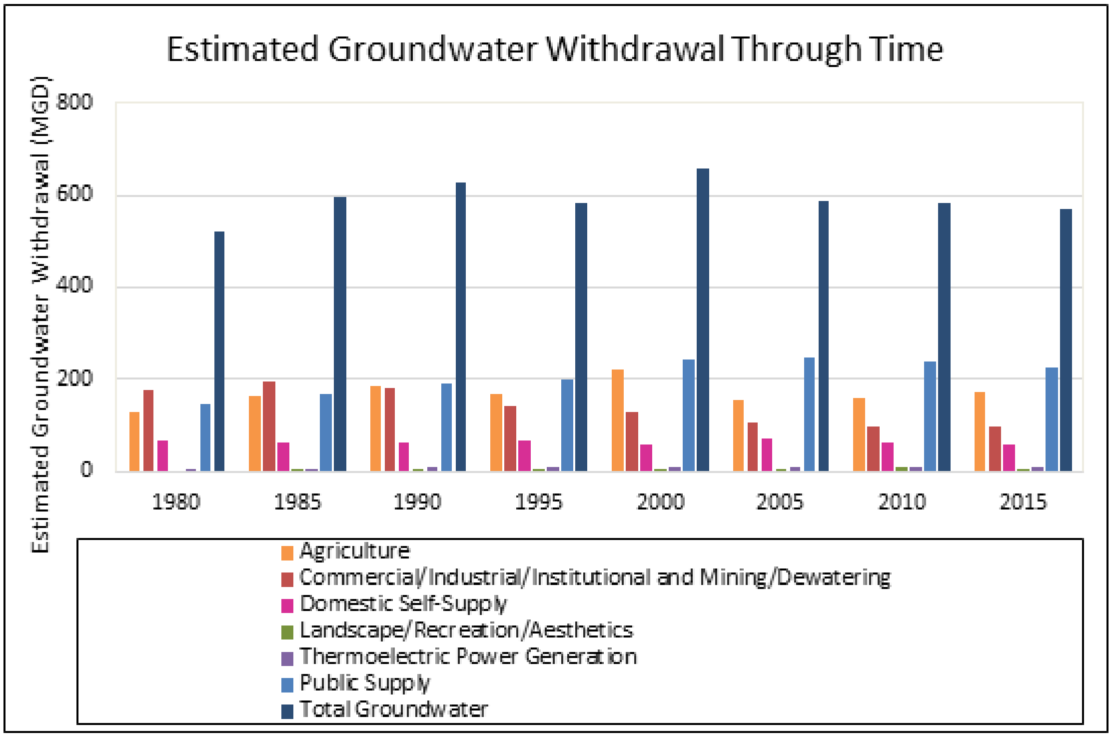


Figure 28. Estimated groundwater withdrawal for the Florida and Georgia planning areas (1980-2015)

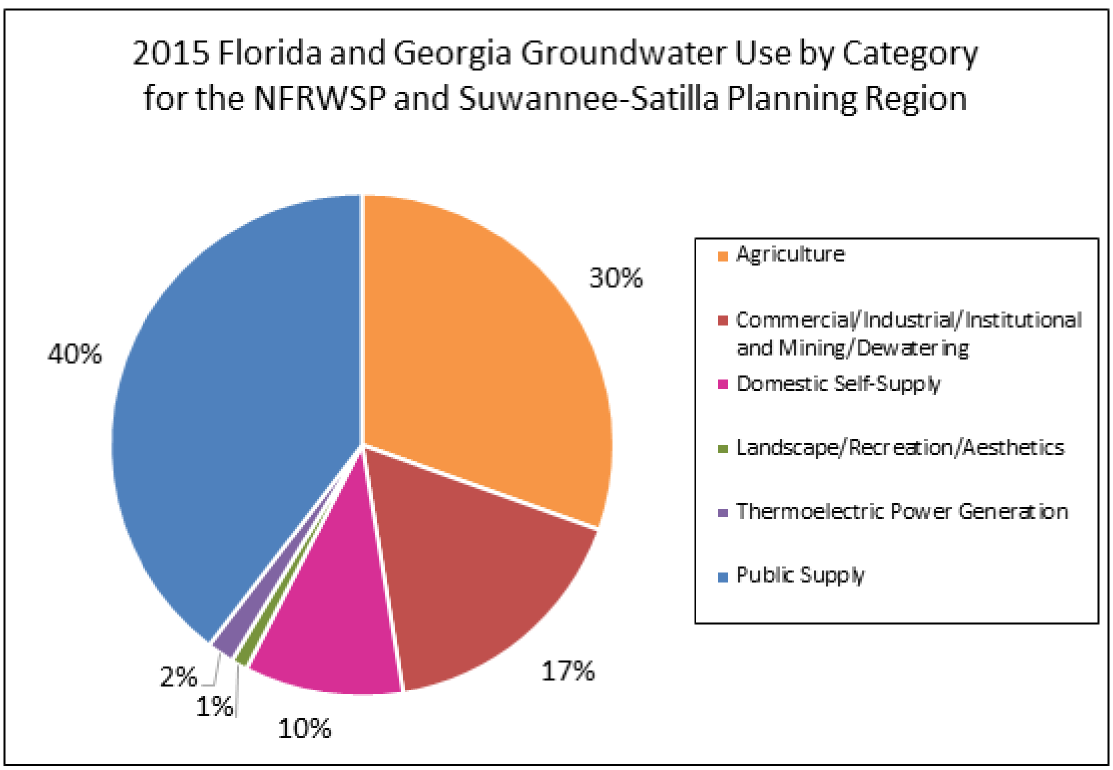


Figure 29. Estimated distribution of groundwater use in the Florida and Georgia Planning Areas by category for 2015

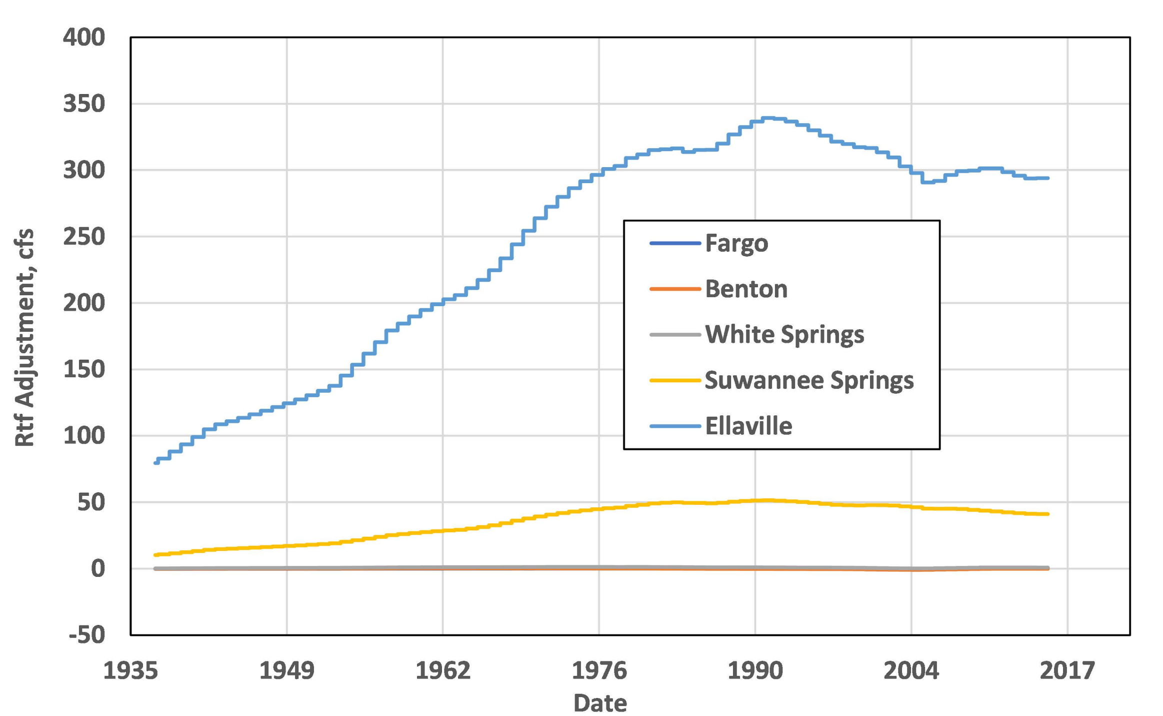


Figure 30. Estimated net yearly groundwater withdrawal impacts to the Suwannee River at five USGS gages [Fargo, Benton, and White Springs plot near or at zero and are indistinguishable from one another. Refer to Figure 5 for well locations.]

Flow duration curves for historic and RTF flows are nearly coincident for the White Springs gage but there is a notable departure for the Suwannee Springs gage (Figure 32). The relative difference in average daily flows ((RTF flow - historic flow)/historic flow * 100) has increased with time, most noticeably at the Suwannee Springs gage (Figure 33). As expected, the relative difference is greater at low flow and is notable in more recent years Figure 33). When flow is low, the relative differences can exceed 10% when flow is less than about 20 and 500 cfs at the White Springs and Suwannee gages, respectively (Figure 34).

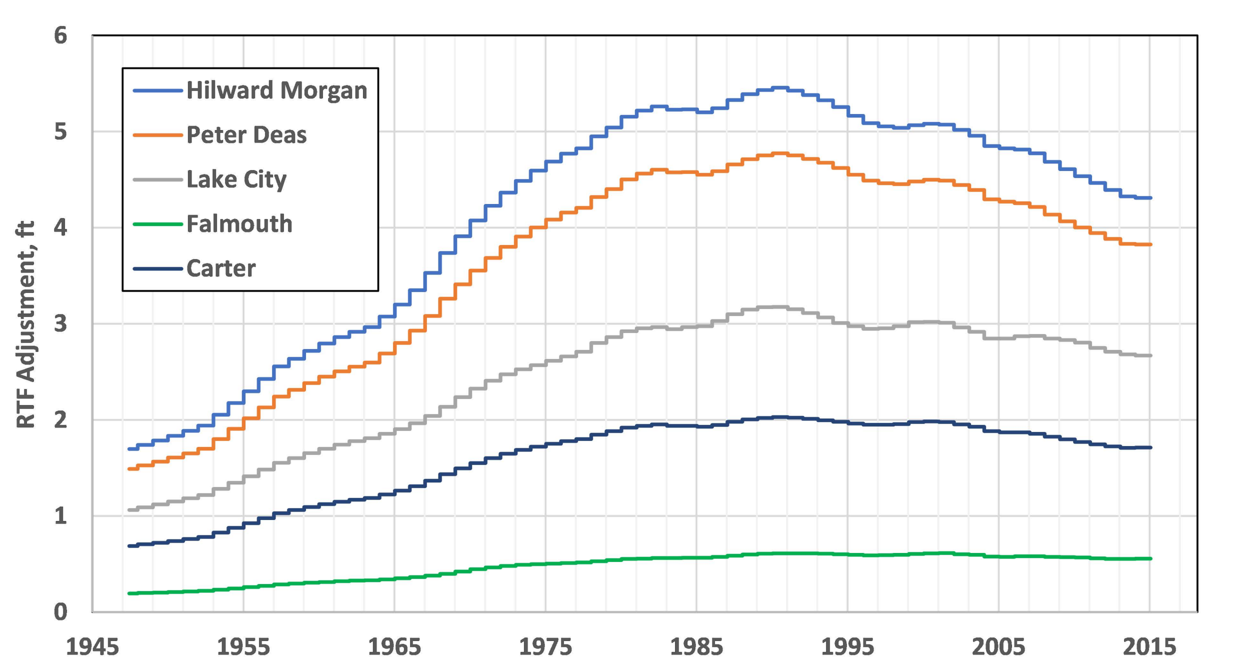


Figure 31. Estimated yearly groundwater level impacts at select wells
[Refer to Figure 5 for well locations.]

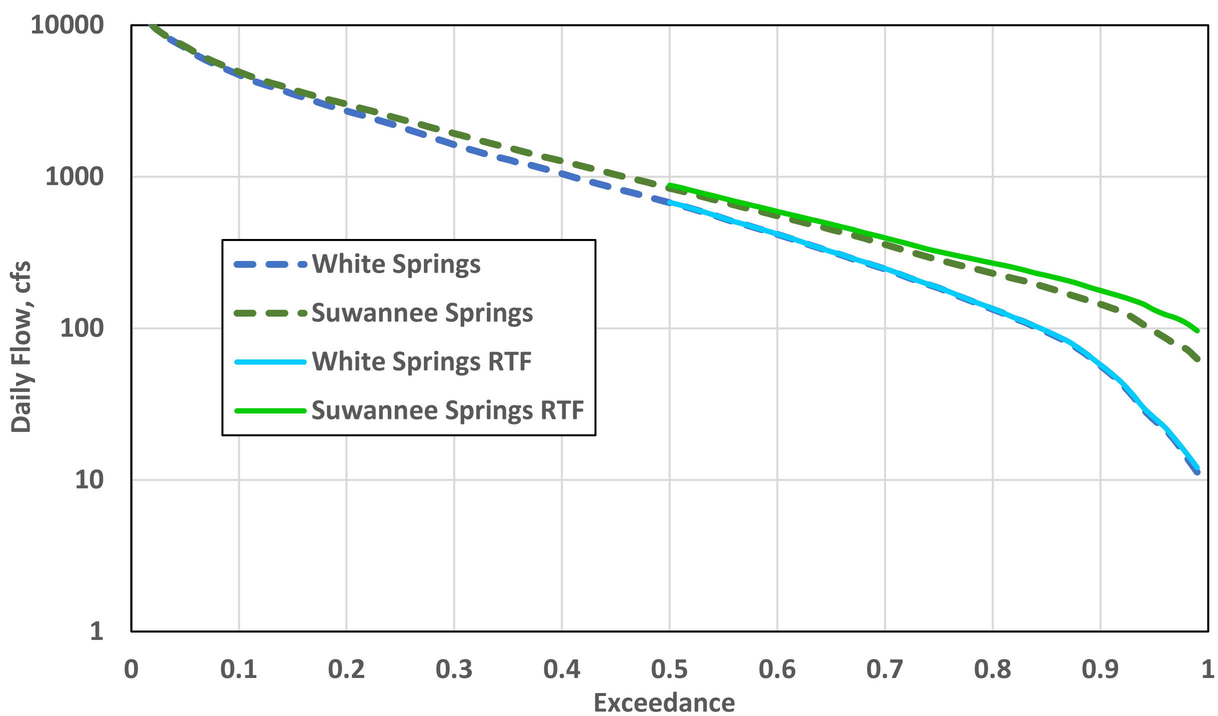
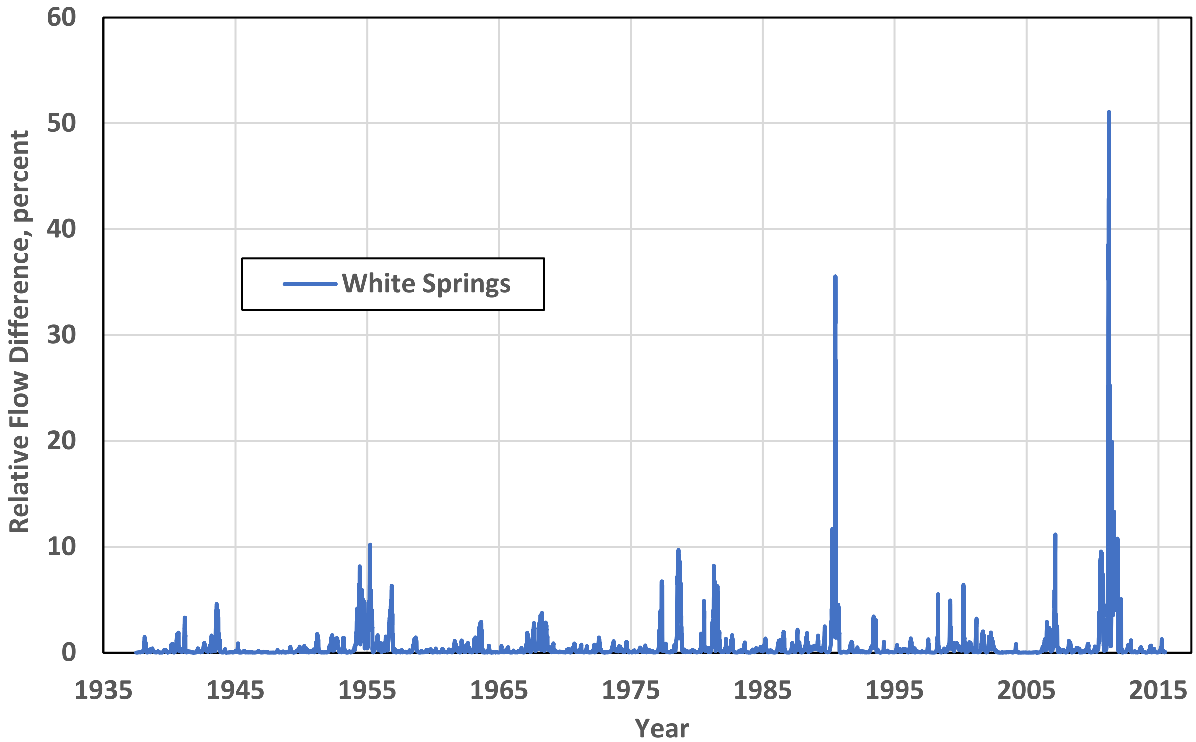


Figure 32. Flow Exceedance Curves (WY 1938-2015) for historical and RTF adjusted flows at the White **Springs and Suwannee Springs gages**
[White Springs historical and RTF adjusted flows are nearly indistinguishable from one another.]



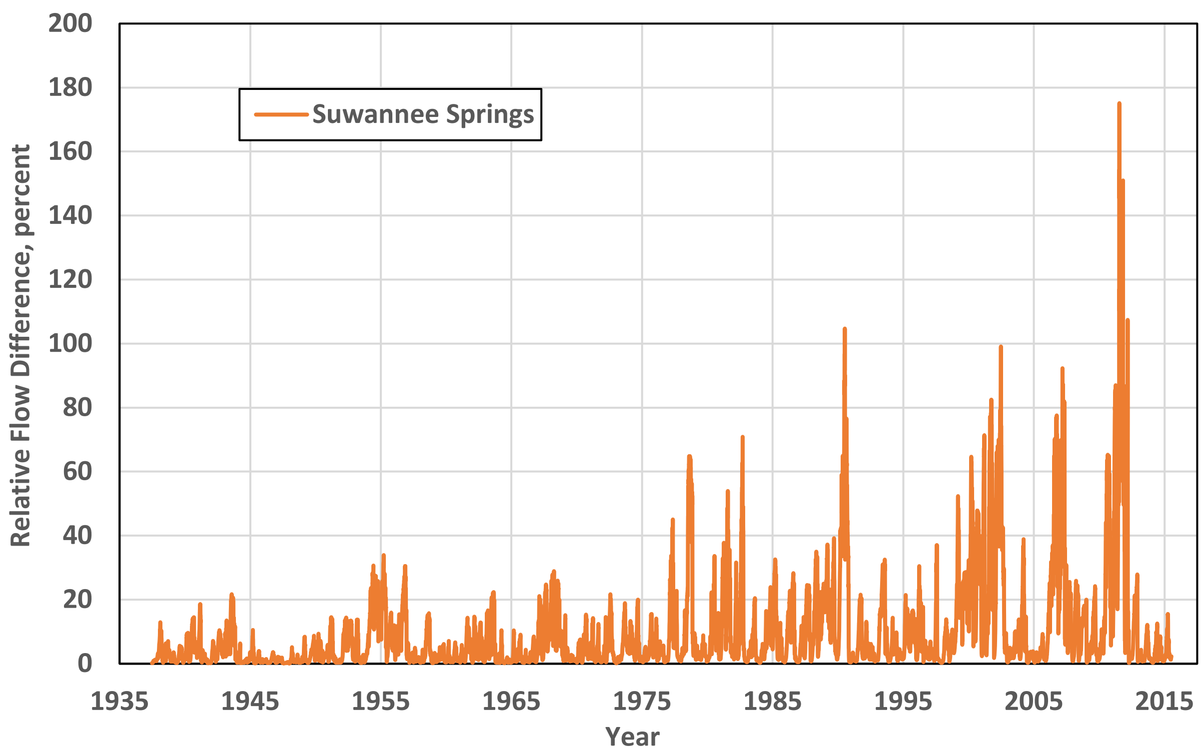


Figure 33. Temporal change in relative difference between RTF and measured flows at White Springs (top) and Suwannee Springs (bottom) gages

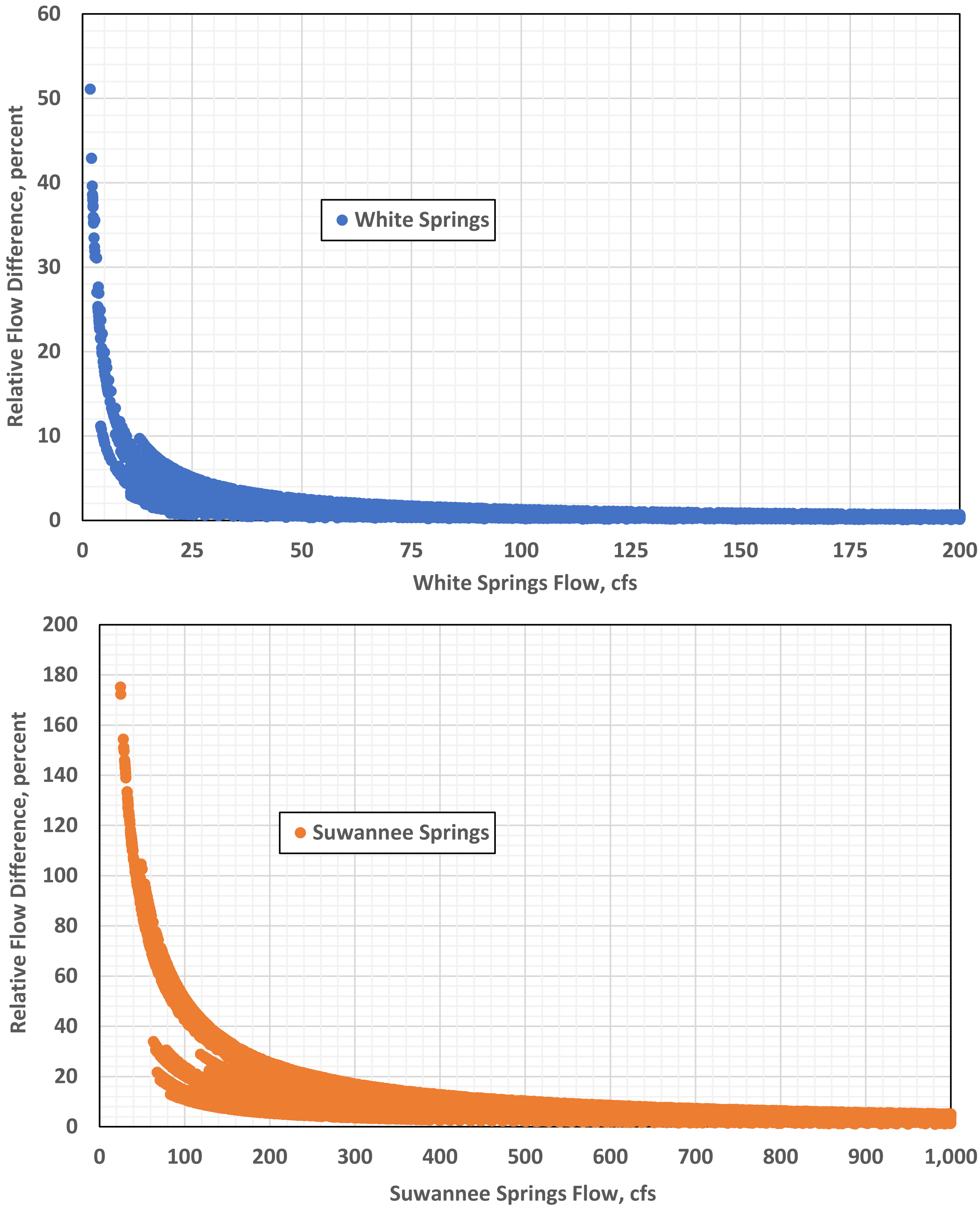


Figure 34. Relative difference between RTF and measured flows at White Springs (top) and Suwannee Springs (bottom) gages during WYs 1938-2015

3.0 BIOLOGY

Regionally significant riverine and floodplain ecological communities occur in and around the upper Suwannee River. Flow reductions in the USR have the potential to alter the hydrology of wetland habitats and instream aquatic habitats (Darst, Light, & Lewis, 2002). Such alterations could potentially

- decrease the number and extent of semi-permanently inundated ponds
- promote a shift to more upland species within the different riverine vegetative communities
- alter the percentage and cover of invasive species
- reduce the type(s) of aquatic habitats preferred/required by select invertebrate and vertebrate species
- increase residence time of water within locations of slower flow rates (potentially altering dissolved oxygen and temperature regimes).

The MFLs assessment of fish and wildlife habitat was performed within the context of a Conceptual Ecological System Model (CESM) that is representative of the upper Suwannee River system. The CESM is described in the next section, followed by descriptions of regional ecosystems and species of interest more sensitive to potential reductions in flows and/or levels.

3.1 Conceptual Ecological System Model

One goal of a MFLs assessment is to evaluate an allowable change in hydrology that would remain protective of the ecosystem and its component communities. A simple Conceptual Ecological System Model (CESM) was developed to help identify the primary components of the upper Suwannee River ecosystems, its major natural processes that drive or stress the river ecosystems, the ecological effects of these processes, and biological attributes or indicators of these ecological responses (Figure 35). The climate of northern Florida and resulting hydrology influences the geometry of the Suwannee 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 35. Conceptual ecological system model variables

The primary CESM variables are as follows.

Hydrology — the volume and periodicity of water moving through the USR system; this may be characterized by a flow-duration curve.

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

Channel / Floodplain Geometry — geomorphological features such as the channel and floodplain dimension, slope, and substrate which influence the association between 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, influenced by topography, soils, the amount and periodicity of water, and climate. In the study area, vegetative communities are grouped categorically by position relative to the main river channel (Figure 36):

Riverine – the USR within the boundaries of Florida is a perennial stream, meaning it flows throughout the year (except upstream from Benton in years of severe drought) and, although water levels vary, there are plants that are highly water dependent and grow within the channel (e.g., submergent plants, such as coontail (*Ceratophyllum demersum*), naiad (*Najas* spp.), and green algae (*Vaucheria sp.*), and emergent aquatic plants such as pennywort (*Hydrocotyle sp.*)).

Riparian zone – borders the river shorelines and plants receive a constant supply of water at average flows, and obligate wetland trees and shrubs such as bald cypress (*Taxodium distichum*), Ogeechee tupelo (*Nyssa ogeche*), coastal plain willow (*Salix caroliniana*), black willow (*Salix nigra*), or river birch (*Betula nigra*) are found. 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 (Figure 36).

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.

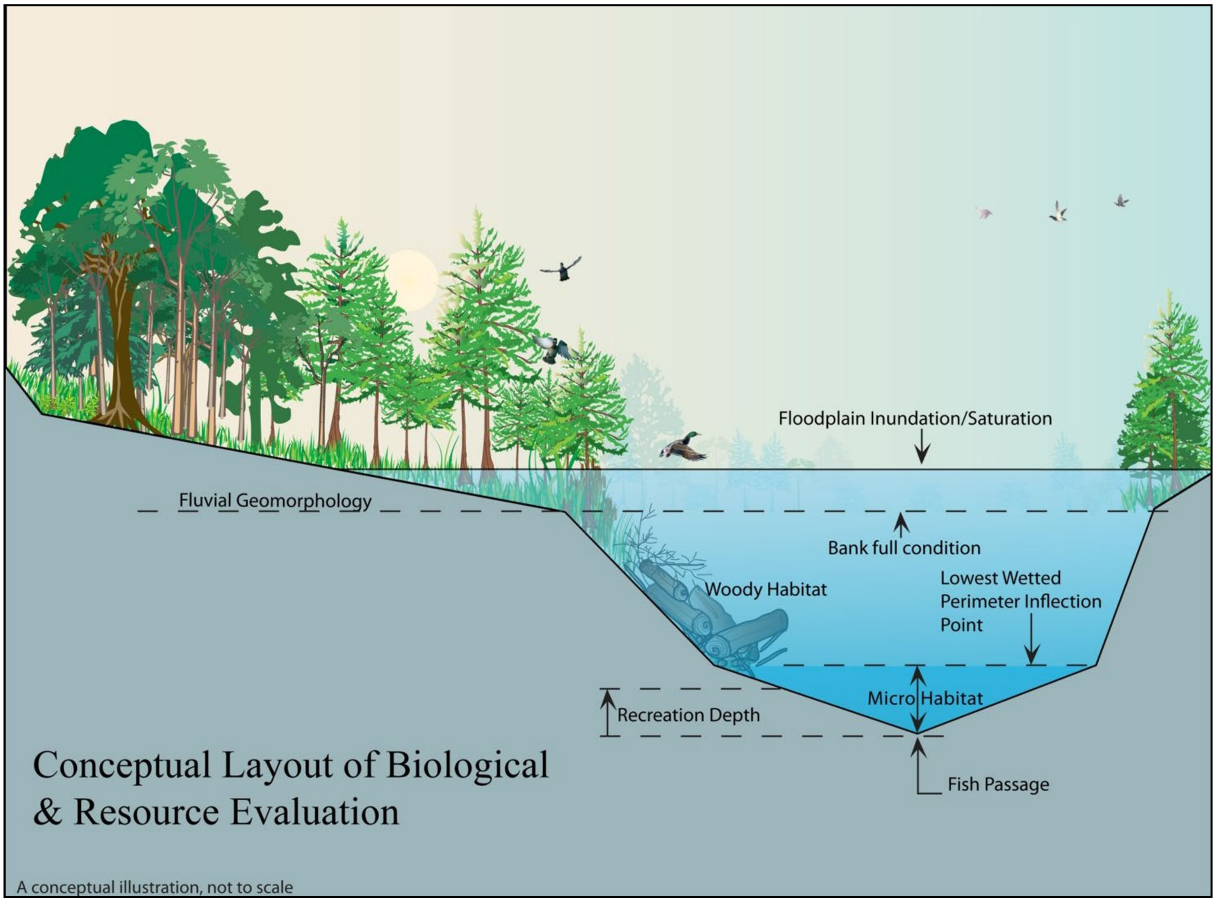


Figure 36. Conceptual cross-section of wetted perimeter and habitat availability in the USR ecosystem [Layout provided by the SRWMD]

A simple conceptual model of the trophic relationships within the USR characterizes the roles of aquatic organisms and relevance as forage for consumers (Figure 37). 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.

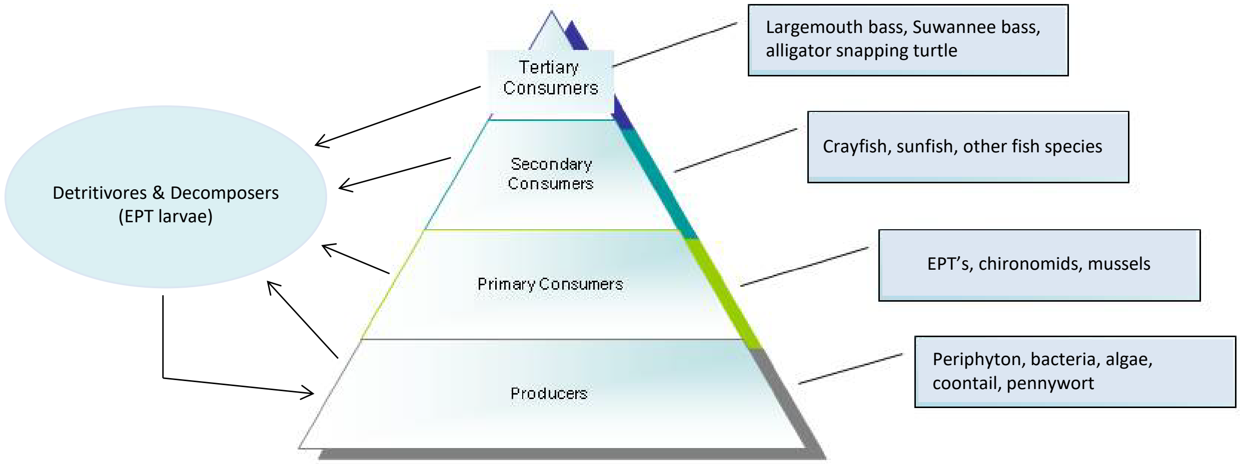


Figure 37. Conceptual trophic model for the USR riverine ecosystem
[EPT designates the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)]

General fish assemblages can be categorized using a four-way matrix of water velocity and water depth to encompass groups of fish in ecological guilds; i.e., species that exploit similar habitat (Table 7). The species guild identifiers are designated using a 4-letter sequence that denotes water velocity and water depth best suited for the species. For example, the identifier "VSDS" designates a preference for slow velocity, shallow depth environment. The guilds VSDS, VFDS, and VSDD are spatially dominant within the study area.

Table 7. Generalized ecological guilds and identifiers for fishes in the USR

Water Depth (D)	Water Velocity (V)	
	Slow (S)	Fast (F)
Shallow (S)	Species Guild VSDS	Species Guild VFDS
Deep (D)	Species Guild VSDD	Species Guild VFDD

3.2 Riverine Ecoregions and Flow Regimes

The USR represents the two most upstream of five ecological reaches in the Suwannee River as characterized by water quality within the reach (Hornsby, Mattson, & Mirti, 2000) and unpublished SRWMD data (Figure 38). For a general description of the regional ecology see WRA (2005) and HSW (2010). The approximately 79 river-mile study area is divided into an upstream reach (Reach 1), which extends from the state line south about 56 river-miles to Suwannee Springs and is referred to as the Upper River Blackwater. The next ecological downstream reach (Reach 2) extends about 37 river-miles from Suwannee Springs south to Dowling Park, about 14 river-miles downstream of Ellaville, and is referred to as Cody Scarp Transitional. Both ecological reaches are characterized as having low mineral content (low hardness), high color, and acidic blackwater.

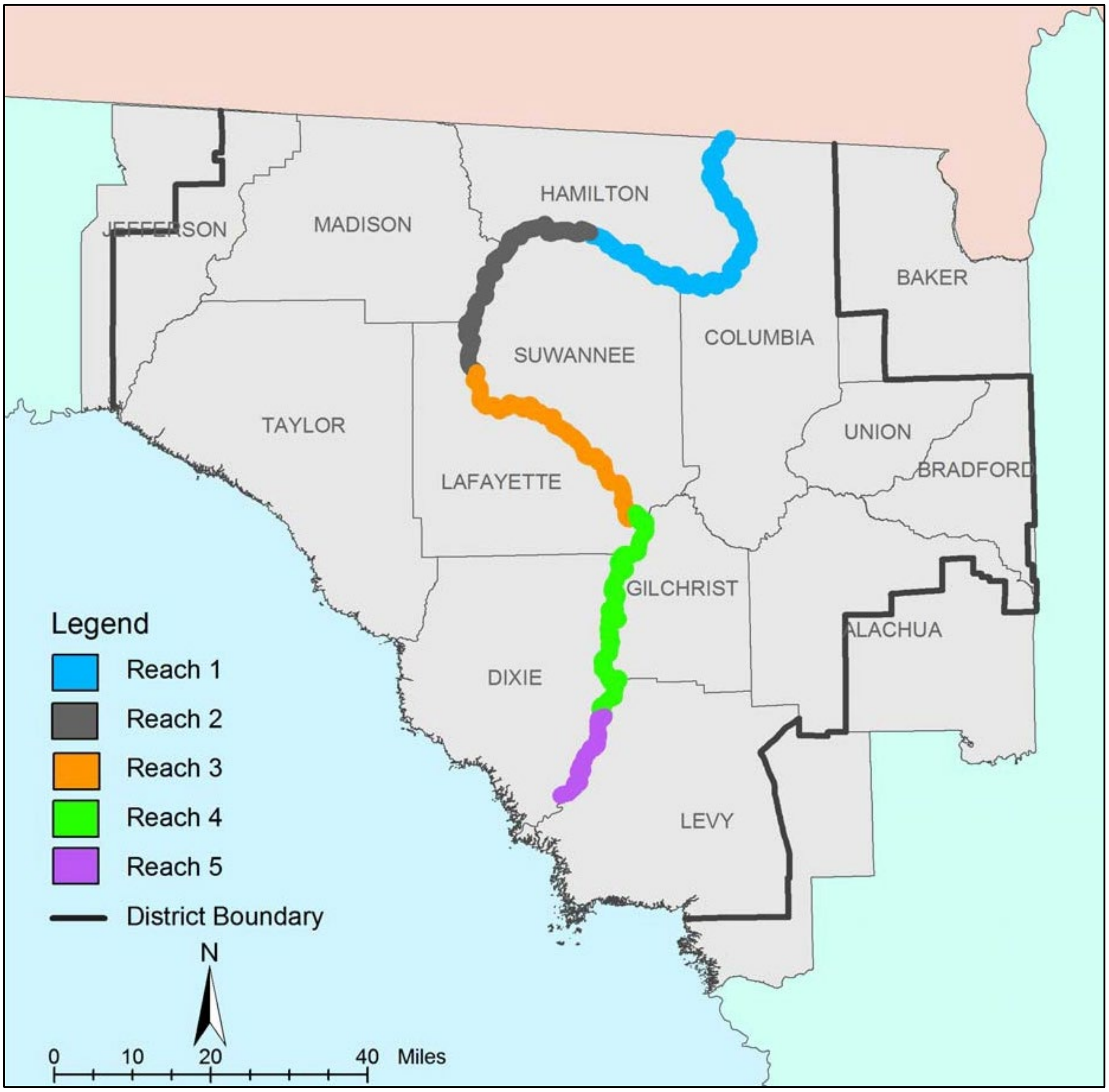


Figure 38. Ecological reaches of the Suwannee River in Florida
[SRWMD data and Hornsby et al., 2000]

Four flow regimes that should be 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 floodplain and valley features; 2) overbank or near overbank flows that maintain riparian habitats; 3) in-channel flows that keep immediate streambanks and channels functioning; and 4) instream flows that meet critical biota requirements such as fish passage and reproduction. Thus, broad ecological functions, as well as species-specific needs, are considered in the establishment of MFLs (Hill, Platts, & Beschta, 1991).

3.3 Floodplain Vegetation and Soils

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 39).

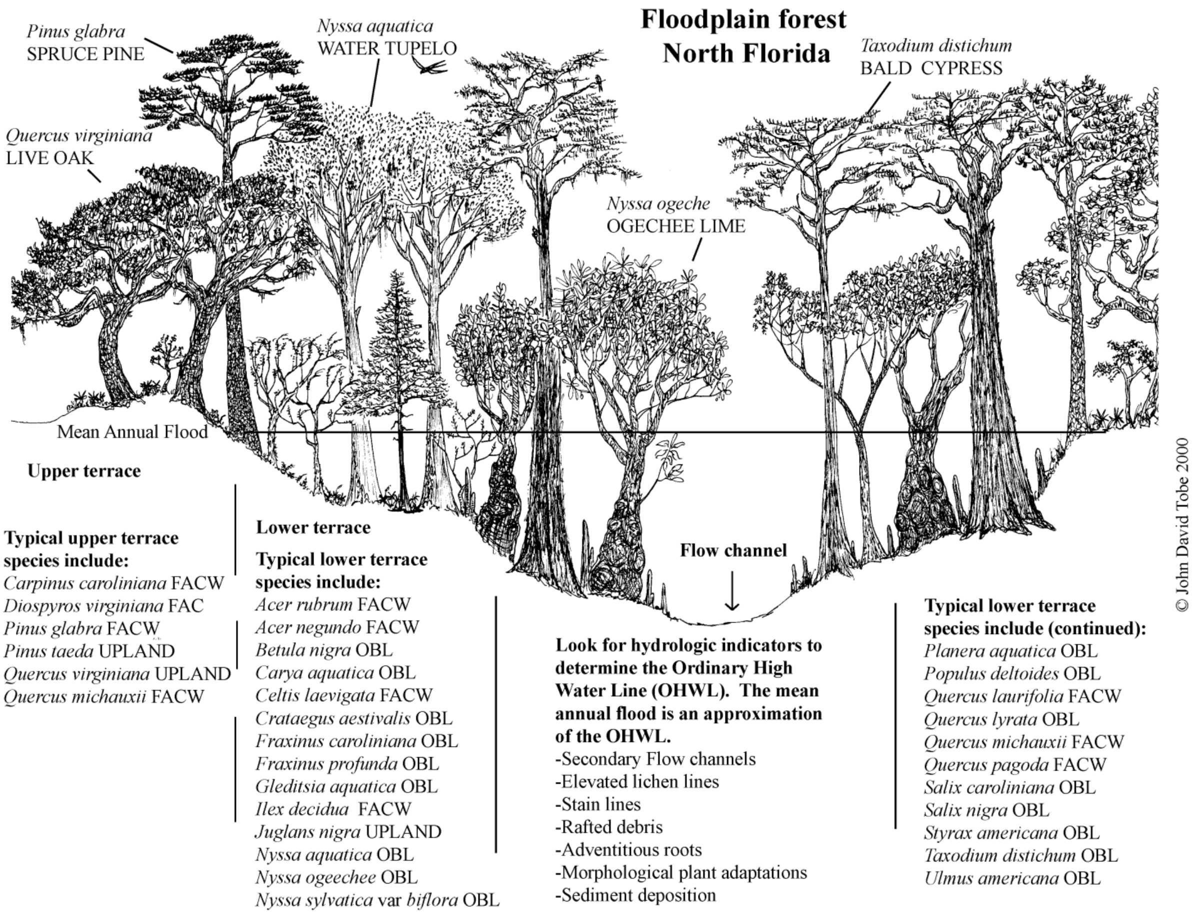


Figure 39. Conceptual diagram of floodplain forest of north Florida
[Source: (FDEP, 2012); (Cowardin, Carter, Golet, & LaRoe, 1979)]

The general floodplain characteristics of the upper Suwannee River are summarized in an earlier assessment of environmental resource constraints (HSW, 2010).

Reach 1 - Upper River Blackwater Reach: The river channel in ecological Reach 1 (Figure 38, Figure 40 top panel, and Figure 41) is more deeply incised into the landscape, as compared to the downstream Reach 2 (Figure 40 bottom panel) and varies from 100-160 feet in width. At lower flows, depths in the channel are mostly less than 3 feet. Shoals of exposed clay and shallow sandy runs are a prominent habitat feature in the river channel along this reach, and the river-channel bottom is generally coarse sand or exposed clay. Because surficial drainage is better developed in this part of the basin, numerous small tributary creeks branch off the river channel.

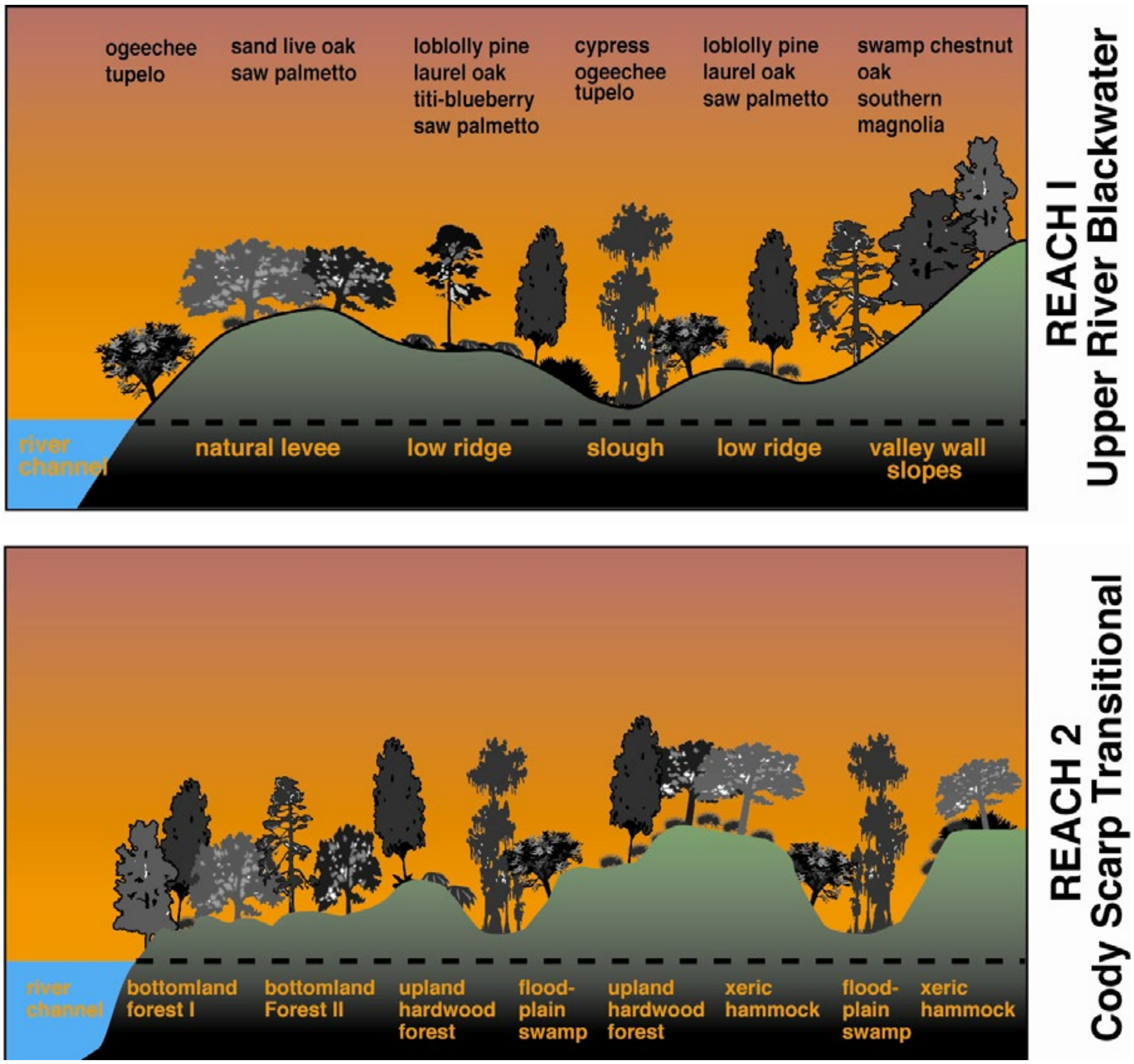


Figure 40. Basic geomorphology of the river channel and floodplain and typical plant communities in the two ecological reaches of the upper Suwannee River study area
[Source: (WRA, 2005)]

The river floodplain is inundated only by larger floods (i.e., floods with 5-10 year recurrence intervals), and flooding duration is often less than 30 continuous days. Plant communities in the floodplain are mostly upland forests, dominated by natural or planted pine, oaks, magnolia and hickory. Wetlands in the floodplain are mainly associated with the tributary creeks branching off the main channel and consist of cypress and deciduous hardwoods such as swamp tupelo (*Nyssa sylvatica* var. *biflora*), river birch, Ogeechee tupelo, and others. The Suwannee in this reach is a classic, southeastern blackwater stream. Benthic invertebrate communities are dominated by caddisflies and chironomids. Highest invertebrate densities are found in the shoal habitats (Bass & Cox, 1985).

Figure 41. Typical view of ecological Reach 1 of the upper Suwannee River in Florida
[Photograph taken by HSW on June 16, 2012; note a large Ogeechee tupelo tree appears in the riparian zone on the right bank]

Reach 2 - Cody Scarp Transitional Reach: The river channel in ecological Reach 2 (Figure 38, Figure 40 bottom panel, Figure 42, and Figure 43) is incised into the landscape and varies from 130-260 feet in width. The channel bottom is dominated by shallow water habitat, with depths of 3-6 feet or less and numerous areas of sandy or rocky shoals. Channel bottom substrates include medium to coarse sand, exposed clay, and rock (limestone, chert, dolostone). Some of these shoal areas in the region of Big Shoals to the Alapaha Rise and confluence are critical spawning habitat for the Gulf sturgeon (*Acipenser oxyrinchus desotoi*) (Sulak & Randall, 2004). Portions of the channel are embedded within steep limestone walls rising vertically from the water surface. The upper elevations of these walls support bald cypress and river birch trees, anchored onto the limestone with networks of main roots and mats of fibrous roots that extend through the limestone to an elevation which allows water transport during low river flows. In this region, the river crosses the Cody Scarp (Ceryak, Knapp, & Burnson, 1983), a region with numerous sinkholes (karst features) that are sprinkled across the river floodplain. Limestone outcrops are prominent along the river channel throughout this reach, and the increasing karst nature of the landscape has resulted in a variety of large- or small-scale features both on the surface and beneath that support unique plant assemblages within the dolines. This reach includes the confluences of the Alapaha and Withlacoochee Rivers with the Suwannee River. Several springs discharge groundwater to the river throughout this reach, and historically major springs include White Springs, Suwannee Springs, Holton Creek Rise, Alapaha River Rise, Ellaville Spring, and Lime Spring (see also WRA 2008).

Figure 42. Typical view of ecological Reach 2 of the upper Suwannee River in Florida
[Photo taken by HSW on October 31, 2011; note bald cypress growing in the riparian zone on the right bank downstream; the Cody Scarp partially dominates the bank]

Digital inventory of land use and cover was obtained from the District GIS database and used to evaluate floodplain habitats (HSW, 2010). Approximately 3,700 acres within the 10-year floodplain of the USR are mapped as wetland vegetation (Table 8). Approximately 90 percent of the wetland vegetation is categorized as forested wetlands: “Mixed Wetland Hardwoods” (2,400 acres) and “Wetland Forested Mixed” (901 acres). These two forest types have varying dominance of hardwood tree species tolerant of hydric conditions. Both are associated with limited areas of floodplain along USR levees and tributary confluences and are inundated only during higher floods. “Cypress,” the third most common type (148 acres), and gum swamps (4.3 acres) are associated with a semi-permanently flooded hydrologic regime (Cowardin, Carter, Golet, & LaRoe, 1979).

Figure 43. Typical view of ecological Reach 2 of the upper Suwannee River in Florida
[Photo taken by HSW on November 3, 2011; the Cody Scarp forms the right riverbank]

In the USR floodplain, much of the forested wetlands are saturated or inundated primarily from precipitation after heavy prolonged rains that pond over the poorly draining soils or from stormwater inflow from the surrounding watershed. In areas where wetlands lie above the intermediate confining unit (clayey sands) and the potentiometric surface is high, there is little infiltration and wetland conditions are sustained. Karst sinkholes, particularly on the lower reach of the USR, are apparently linked through aquifer connection to the river (Beck, Ceryak, Jenkins, Scott, & Spangler, 1985) (Figure 44).

Table 8. Distribution of wetland vegetation in the 10-year floodplain of the Upper Suwannee River watershed

Land Cover Code[1]	Description	Area (acres)	Relative Amount (%)
6170	Mixed Wetland Hardwoods	2,400	65.0
6300	Wetland Forested Mixed	901	24.4
6210	Cypress	148	4.0
6430	Wet Prairies	118	3.2
6250	Hydric Pine Flatwoods	56.8	1.5
6460	Mixed Scrub-Shrub Wetland	55.1	1.5
6410	Freshwater Marshes	5.24	<0.1
6130	Gum Swamps	4.33	<0.1
6440	Emergent Aquatic Vegetation	1.06	<0.1
Total		3,690	100.0

1. The wetland maps used in the analysis are referenced to the FDOT (1999) FLUCCS (Florida Land Use and Cover Classification System) codes (FDOT, 1999).

Figure 44. Sinkhole with exposed limestone layer and water surface elevation similar to river water surface elevation
[Photo taken by HSW on April 4, 2012]

Soil surveys produced by the USDA Natural Resources Conservation Service (NRCS) are the standard for soil classification and include information on numerous soil properties that are important to hydrologic and ecologic processes. The Columbia, Hamilton, and Suwannee County surveys describe the soil types in the three counties (Howell, 1984), (Baldwin, Howell, & Weatherspoon, 2004), and (Weatherspoon, 2006). Because soil functioning can vary at a regional level based on local soil morphology, county-specific lists of hydric soils (soils that are inundated or saturated long enough to support wetland plant communities, typically with poor drainage and a shallow seasonal high groundwater table) were obtained to confirm the presence of hydric soils in the study area (Ellis, 2012). The NRCS digital Soil Survey Geographic Database (SSURGO) was obtained from the District GIS database as an ArcGIS shapefile (NRCS, 2011a) (NRCS, 2011b) (NRCS, 2011c).

3.4 Riverine and Riparian Habitat

Riverine, or instream, habitats provide protective cover and sources of food for many benthic macroinvertebrates, fish, and other aquatic wildlife. Benthic substrates in the river are generally sand and limestone shelves with pebbly gravel. Aquatic vegetation consists of patches of rooted or floating aquatic vegetation, such as coontail and pennywort, often encircling submerged snags. At very low flows, filamentous algae (like *Vaucheria* sp.) grows profusely, and terrestrial plants temporarily colonize the river bottom during prolonged droughts (Figure 45).

Figure 45. Filamentous algae and terrestrial plants covering the rocks of Big Shoals during low flow in the river channel
[Photo taken by HSW on November 2, 2011]

Naturally occurring snags, characterized as large woody debris greater than 10 centimeters (cm) in diameter and at least 2 meters (m) in length, are an important habitat component (Figure 46). Snags provide protection from strong currents and overhead cover for fishes, habitat for aquatic invertebrates, and basking sites for aquatic turtles (Figure 47). Snags can be an important source of particulate organic matter adding to primary productivity of a stream (Fischenich & Morrow Jr., 2000). Snags also play a role in defining channel morphology, by enhancing scouring and producing pools that provide fish holding cover.

Inundated snags provide attachment substrate and a source of forage for many aquatic invertebrates. The length of time for larval development is quite variable. For example, many types of Northern Hemisphere mayfly nymphs hatch out to become adults in periods ranging from 4 to 24 months (Clifford, 1982). In Florida, larval instars are developing almost continuously, and all species of mayflies emerge throughout the year except during short cold spells (Berner & Pescador, 1988).

Riparian vegetation, the plant habitats and communities along the banks of the river, are characterized by plants having varying water requirements for optimal growth. Bald cypress and Ogeechee tupelo (both obligate wetland species[1]) are iconic species that grow in the riparian zone along the shorelines of the USR. Ogeechee tupelo, which occur south to approximately Stephen Foster State Park at White Springs, generally grow best and are most abundant at just above the average water level and are infrequently found more than 1 to 2 feet above this elevation of the streams along which it grows (USFS, 1965). Bald cypress grow under a wider range of hydrologic conditions in the riparian zone and throughout the upper floodplain, frequently in wetlands mixed with hardwoods. Often, those trees growing higher on the bluff face are anchored into the limestone or sandy banks by fibrous root mats. At higher flows, the exposed live roots of trees growing in the riparian zone along the river's edge provide habitat functions for invertebrate production and fish cover similar to snags (Figure 48). River birch, another common type of riparian tree, occur along the lower banks and occasionally in wetlands higher on the floodplain.

Figure 46. Snags lying partially submerged in the river channel
[Photo taken by HSW on March 8, 2012]

[1] Plants are assigned a "wetland indicator status (WIS)" based on their water tolerance, which is used to determine the wetland type. Trees, shrubs, and groundcover in the "facultative wet (FACW)" and "obligate (OBL)" categories are typically wetland species. Wetland indicator status is listed in the National Wetland Plant List, Region 2 (Lichvar & Kartesz, 2009), (NRCS, 2012), and the Florida Department of Environmental Protection Wetland Evaluation and Delineation Program vegetative index (FDEP, 2011). Plant names are based on the Florida Atlas of Vascular Plants (Wunderlin & Hansen, 2008).

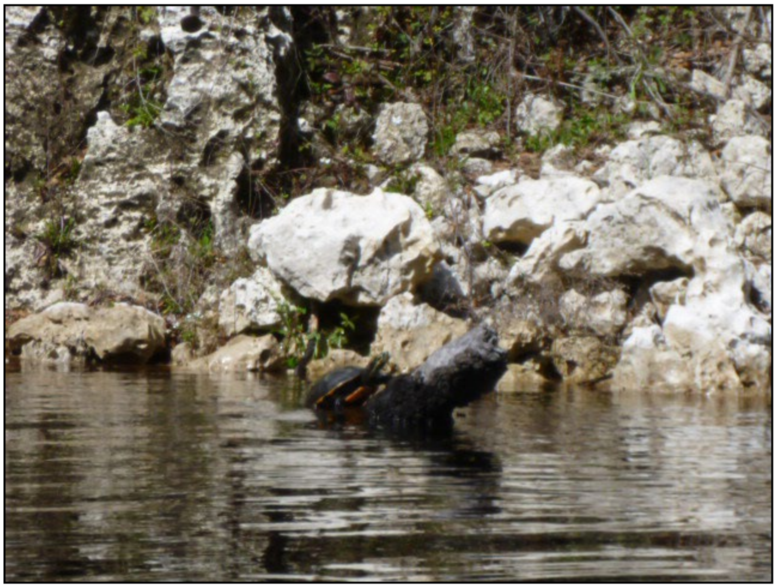


Figure 47. Turtle basking on a snag on the Upper Suwannee River
[Photo taken by HSW on March 8, 2012]

Figure 48. Live roots of a cypress tree near the Deese-Howard ramp on the Upper Suwannee River
[photo taken by HSW on November 11, 2011]

3.5 Aquatic Biota

The best available data were used to describe the biotic species in the USR and evaluate their habitats. Taxonomic lists of invertebrates, vertebrates, and plants were reviewed to identify species dependent on the river's aquatic habitats and wetlands that could be affected by changes in river flows and levels.

3.5.1 Periphyton

Samples collected by SRWMD from 1990 to 2003 showed the periphyton assemblage to be generally similar in composition to that of the 1980s. Species richness varied between sampling stations. The upper reach had the greatest species evenness and the highest percentage of blue-green bacteria (Cyanobacteria), while diatoms (Bacillarophycea) became dominant (>80% of the composition) at stations lower in the river (Janicki, 2004). Because these data sets varied in sampling intensity and periodicity, they were not relied on in the MFLs analysis.

3.5.2 Aquatic Macroinvertebrates

Macroinvertebrate's species richness was similar in studies conducted in the 1950s, 1970s, and 1980s (FDER, 1985). Data from 1989 through 2003 showed that non-biting midges (Chironomidae) and worms (Oligochaetes) were dominant and sub-dominant, respectively, in the upper sampling stations, and mayflies (Ephemeroptera) and caddisflies (Trichoptera) became dominant at sampling stations lower in the river (Janicki, 2004). Benthic macroinvertebrates samples from 2004 to 2010 were not analyzed (Suwannee River Water Management District, unpublished data), and additional sampling was not conducted for the MFLs analysis. Overall, the various studies indicate that caddisflies and chironomids dominate the upper reach, while the lower reach is dominated by caddisflies, chironomids, and mayflies. Data had variable statistical treatments and, because these data sets varied in sampling intensity and periodicity, they were not relied on in the MFLs analysis. Instead, habitat availability for selected invertebrates under a range of flow conditions was analyzed using the System for Environmental Flow Analysis (SEFA) software (Aquatic Habitat Analysts, 2012).

3.5.3 Freshwater Mussels

Mussels are long-lived (30-70 years for some species) bivalve mollusks that occur commonly in river ecosystems. The group is presently of high conservation interest with an apparently declining but generally unknown population status in much of their range. Around 30 species have been collected in the Suwannee River region (Butler, Williams, & Wisniewski, 2010). Of these, at least three species, Florida rainbow (*Villosa amygdala*), Suwannee moccasinshell (*Medionidus walkeri*), and Suwannee pigtoe (*Quadrula kleiniana*), are listed as species of high conservation concern in the three-county study area (FNAI, 2019a) (FNAI, 2019b) (FNAI, 2019c). Although their distribution and abundance are not well documented, in 2012, the Suwannee Moccasinshell was rediscovered after a 16-year hiatus between collections. Subsequently, this species was listed as federally threatened under the Endangered Species Act in October 2016 (81 FR 69417). In 2019, the USFWS proposed designating the mainstem Suwannee River, additional portions of the Santa Fe River, and the Withlacoochee River, as critical habitat for the Suwannee Moccasinshell (84 FR 65325).

The larvae (glochidia) of mussels are parasitic typically on the gills or fins of a host fish, although the host fishes are not completely known for most species (Watters, 1994). Because listed mussels or mussel species proposed for listing may occur more widely in the USR than presently known, host fish such as the blackbanded darter (*Percina nigrofasciata*) and brown darter (*Etheostoma edwini*) may be used as surrogates for the possible occurrence of the moccasinshell. The metallic shiner (*Pteronotropis* *metallicus*), a host fish for the oval pigtoe (*Pleurobema pyriforme*) in the contiguous Middle Suwannee River may also be considered for protection as part of the USR MFL. Selected host fish were used as surrogates for the mussel(s) for a biological assessment of the Withlacoochee River (Warren & Nagid, 2008).

3.5.4 Fish

Fisheries surveys conducted by the Florida Fish and Wildlife Conservation Commission (FWC) in 2003, 2010, and 2011 showed that the fish assemblage was dominated by anadromous Gulf sturgeon, largemouth bass (*Micropterus salmoides*), Suwannee bass (*Micropterus notius*), channel catfish (*Ictalurus punctatus*), warmouth (*Lepomis gulosus*), bluegill (*Lepomis macrochirus*), redear sunfish (*Lepomis microlophus*), spotted sunfish (*Lepomis punctatus),* redbreast sunfish (*Lepomis auritus*), and other species (Krummrich, 2010). A key fish species of interest that depends on aquatic habitat in the USR is Gulf sturgeon, a federally-designated threatened species (FWC, 2021). Sturgeon spawning-like activity has been monitored at select sites as far upstream as Woods Ferry near White Springs (Randall, Personal communication; USGS, 2016). Suwannee bass are uncommon in the upper reach of the river, and species richness and numbers tend to increase as the river descends towards Ellaville (Hellier, 1967), (Bass & Hitt, 1974), (Swift, Gilbert, Bortone, Burgess, & Yerger, 1986), (WRA, 2008), (FMNH, 2013).

Supplemental data from about 10 km above the Florida state line (contiguous with the upper MFL study area) indicated that sunfish including flier (*Centrarchus macropterus*), warmouth, bluegill; chain pickerel (*Esox niger*) and redfin pickerel (*E. americanus americanus*); and largemouth bass dominated the fish assemblage (Hodgson & Harrison, 2012). Suwannee bass were not present, probably because they are intolerant of the low pH typical of this river reach (Hodgson & Harrison, 2012).

Many fish species are important because they are fished recreationally (e.g., largemouth bass, Suwannee bass, sunfish, channel catfish, spotted bullhead (*Ameiurus serracanthus*), longnose gar (*Lepisosteus osseus*), bowfin (*Amia calva*), etc.), while others fill a trophic level as forage species for other fish or serve as possible hosts for larval mussels (e.g., brown darter (*Etheostoma edwini*) or blackbanded darter). The habitat suitable for selected species was modeled in the MFLs assessment (Chapter 5).

3.5.5 Threatened and Endangered Species

Multiple sources were reviewed to identify listed species that are likely at risk from reductions in flow and water level (Table 9). Federally-designated threatened and endangered (T&E) species are listed by the U.S. Fish and Wildlife Service (USFWS, 2020a) (USFWS, 2020b) (USFWS, 2020c). Florida state-designated endangered and threatened species of wildlife are listed by the Florida Fish and Wildlife Conservation Commission (FWC, 2021) . State-designated endangered, threatened, and commercially exploited plants are listed by the Florida Department of Agriculture and Consumer Services (FDACS, 2016). Species without formal listing status were also reviewed (FNAI, 2019a) (FNAI, 2019b) (FNAI, 2019c).

Three 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 (*Procamburas erythrops*), alligator snapping turtle (*Macrochelys temminckii*), and Suwannee cooter (*Pseudemys concinna suwanniensis*). The Center for Biological Diversity (2014) notified the USFWS of recent research that the alligator snapping turtle in the Suwannee River system in Florida is an individual species (*Macrochelys suwanniensis*) (CBD, 2014).

In November 2016, the Imperiled Species Management Plan (ISMP) was approved by the FWC with the goal to conserve or improve the status of threatened species to effectively reduce the risk of extinction (FWC, 2021). The IMPC includes changes in listing status for 23 species (Rule 68A-27.003, *F.A.C.*), some of which exist within the USR river and Holton Creek Rise spring run. The goal of Florida's ISMP is "With broad public and partner support, conserve or improve the status of threatened species to effectively reduce the risk of extinction" for 57 fish and wildlife species over the next 10 years. The ISMP is supported by several key components, including Species Action Plans, Species Conservation Measures and Permitting Guidelines, and several policies (FWC, 2021).

A key fish species of interest that depends on aquatic habitat within the USR is Gulf sturgeon, which is listed as threatened by the U.S. Fish and Wildlife Service (USFWS). Although the Suwannee moccasinshell (*Medionidus walkeri*) mussel is not currently listed at the state level, the federal government lists 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 were used to analyze habitat availability and develop representative hydrologic indicators for the MFLs analysis.

In October 2016, USFWS proposed changing the designation of the Suwannee moccasinshell from proposed threatened (PT) to threatened (T). This designation became final with the rule published on November 7, 2016, and was based on several factors, including degradation of habitat, small population size and range, and competition and disturbance from the introduced Asian clam. The Suwannee moccasinshell is dependent on host fish such as the blackbanded and brown darters, with the glochidia (larvae) attaching themselves to the gills of these fish as temporary parasites.

Table 9. Listed species deemed likely at risk from flow and water-level reductions

Species	Common Name	Florida State Status[1] (FNAI Rank[2])	Federal Status[3]
Birds			
Egretta caerulea	Little Blue Heron	T (S4)	---
Egretta tricolor	Tricolored heron	T (S4)	---
Mycteria americana	Wood stork	FT (S2)	T
Crustaceans			
Procamburas erythrops	Santa Fe Cave crayfish	T (S1)	PT[4]
Remasellus parvus	Swimming Little Florida Cave isopod	N (S1S2)	---
Procambarus pallidus	Pallid Cave crayfish	N (S2S3)	---
Fish			
Acipenser oxyrinchus desotoi	Gulf sturgeon	FT (S2)	T
Mollusks			
Medionidus walkeri	Suwannee moccasinshell	FT (S1)	T[5]
Reptiles			
Macrochelys suwanniensis	Suwannee alligator snapping turtle	T (S2)[6]	---

1. State status designated as FT (Federally designated Threatened), SSC (Species of Special Concern), and N (Not currently listed, nor currently being considered for listing); (FWC, 2021).
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); (FNAI, 2019a) (FNAI, 2019b) (FNAI, 2019c).
3. Federal status designated as PT (Proposed Threatened) and T (Threatened); (USFWS, 2020a) (USFWS, 2020b) (USFWS, 2020c).
4. Federal Register Vol. 76 (No. 187) September 27, 2011: 59836- 59862.
5. Federal Register Vol. 81 November 7, 2016: 69417-69425.
6. FNAI designates Suwannee alligator snapping turtle (*Macrochelys suwanniensis*) as N (S1S2).

3.6 Biological Water Resource Value Indicators

The freshwater wetlands within the USR floodplain (Table 8) 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 refugia for juvenile fish during low to medium flows and are a basking site for turtles during low flows.

A variety of fish species and invertebrates are indicators for low to medium flows. Based on the District's experience with species used for other river segments, the species occurring in the USR 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. Recommendations by federal (USGS Coastal Ecology and Conservation Research Group, and USFWS

Endangered Species) and state (SRWMD and FWC) agencies with species conservation responsibilities guided the selection of the study organisms.

Fish species selected for this study: The iconic fish of the USR is the Gulf sturgeon, currently a protected fish species listed as threatened by the USFWS, and a key indicator for the environmental value relating to fish habitat and fish passage in the USR. Sturgeon have been studied extensively, and a comprehensive review of the habitat requirements for adult and juvenile life stages of Gulf sturgeon was conducted previously (HSW, 2010). The Suwannee bass is a black bass that generally is confined to fluvial systems east of the Ochlocknee River and west of the Suwannee River. It is an important species for recreational angling. The largemouth bass, also a black bass, is highly valued by recreational anglers. It is widely considered a habitat generalist and was selected to potentially elucidate habitat utilization similarities or differences with Suwannee bass. The channel catfish is predominantly a fluvial species often considered sensitive to poor water quality and with an affinity to limerock environments. Spotted sunfish are a feisty panfish whose preferred habitat is slow-moving, heavily vegetated streams and rivers with limestone, sand, or gravel substrates. Redbreast sunfish are common in rivers of north Florida in backwater areas with less flow, especially where there are sandy bottoms. Cyprinidae (minnows, shiners) prefer pools and streams with clear, cool water, a moderate current, and unvegetated gravel to rubble bottom. Blackbanded darter occurs in a variety of habitats, ranging from silty streams with vegetation to medium streams with sand, gravel, or rubble). As a host fish, it may be used as a surrogate for the possible occurrence of mussels.

Guilds of fishes are based on their preferences for water depth and water velocity (Table 7). Fish species reported from the FWC surveys were aggregated to add redundant analysis to the ecosystem modeling.

Invertebrates selected for this study: A suite of invertebrates similar to those used for the Withlacoochee River (Warren & Nagid, 2008) was selected based on recommendations from FWC and Dr. James Gore with the University of Tampa (Gore, McKinney, & Nagid, 2012) to evaluate flow and water level reduction impacts in the water-level sensitive snag, cobble/gravel riffle, and tree root system habitats of the USR. The general guild representing low gradient benthic diversity was used as an overall community indicator. Among those taxa most dependent upon flows are many species of mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera), typically grouped together as the EPTs. Larvae of the Hydropsychidae, the net-spinning caddisfly family, are ecologically important invertebrate taxa that are dependent upon flow for survival and often associated with snag habitat. *Pseudocloeon ephippiatum*, larvae of the baetid mayfly, also are ecologically important invertebrate taxa that are dependent upon flow for survival but show a preference for cobble/gravel riffle habitat. The non-biting midges (Chironomidae), commonly a forage species for larval insects and fish, are represented by the species *Tvetenia vitracies*, which is also flow dependent.

4.0 APPROACH TO SETTING MFLS

The results of the background literature review and hydrologic assessment were presented in previous chapters of this report and by others (EAS, 2013). In addition to the background information presented in this report, earlier work by HSW (2010) forms the basis for evaluating human use and water resource values and developing MFLs for the USR. Water years 1938 through 2015 were identified as baseline water years based on the availability of information to develop the RTF flows as described in Section 2.9 and Appendix C.

When developing an MFL from a baseline condition, it is assumed that the baseline condition is 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 technical approach makes use of the baseline flows as adjusted to RTF flows and groundwater levels as described in Section 2.9 and in-stream and floodplain field work and analyses presented in this chapter. The overall approach for setting MFLs for the USR 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 WRV is assumed to protect a related WRV as well. Thus, establishing limits for flow reductions over the entire range of the flow duration curve affords a level of protection to all the relevant WRVs and is assumed to provide a level of protection to those not explicitly evaluated.

4.1 Identification of Relevant WRVs

The process used to identify water resource and human use values for analysis is based on a qualitative evaluation of risk and value, availability of information, and association with one or more flow-reduction scenarios. Eight of the ten WRVs listed below were identified as being "*relevant*" values associated with the USR 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. These include Recreation (WRV 1), Fish/Wildlife Habitat and Fish Passage (WRV 2), Sediment Loads (WRV 8), and Water Quality (WRV 9).

1. Recreation in and on the water (WRV 1). This WRV is considered highly relevant. The Outstanding Florida Water (OFW) designation of the river is based in part on its use for recreational activities such as swimming, recreational fishing, kayaking and canoeing. SRWMD and FDEP worked to create the Suwannee Wilderness Trail, a 207-mile canoe trail on the Suwannee River that links together a network of camping and cabin facilities located on State and District lands. There are 15 public canoe and boat ramps and two public camps and two state parks equipped with cabins within the

study reach (http://www.srwmd.state.fl.us/). Additionally, camping is available at other locations (water access only), by pre-issued permit, on District lands above the ordinary high-water line.

2. Fish and wildlife habitats and the passage of fish (WRV 2). This WRV is considered highly relevant. The river provides habitat to Suwannee bass and Gulf sturgeon, both of which are listed species of special interest in the study reach. Due to the steep channel slope and number of shoals in the USR that must be traversed by these and other riverine animal species, this WRV requires evaluation of MFLs under a wide range of flows and several flow-reduction scenarios.

3. Estuarine resources (WRV 3). This WRV was not considered relevant. MFLs have been established for the Lower Suwannee River and Estuary, and a MFL regime was established to protect flow to the estuary and maintain estuarine habitats. The Lower Suwannee MFL establishes protection of all riverine flows to the estuary, including flow from the USR.

4. Transfer of detrital material (WRV 4). While it has been well established that decaying plant material is a principal food base in aquatic and wetland ecosystems, this WRV is considered not relevant to the USR for this study. Particulate detrital transfer appears to be limited, due to the hydraulic separation of the deeply incised channel of the USR and its floodplain sloughs, which are dominated with vegetation associated with infrequent inundation. The blackwater characteristic of the river upstream from White Springs, however, is a clear indication of high concentrations of humic substances associated with dissolved detritus.

5. Maintenance of freshwater storage and supply (WRV 5). Spring flow makes up an increasing contribution of river flow downstream from White Sulphur Springs. Spring flow is an indicator of groundwater storage; hence, WRV 5 is relevant primarily to the spring MFLs that are being developed and will be presented in a separate document.

6. Aesthetic and scenic attributes (WRV 6). This WRV is linked to the recreational use of the USR and is considered relevant. Protection of this WRV therefore is incorporated into the selection of MFLs protecting recreational activities, explicitly evaluated for WRV 1.

7. Filtration and absorption of nutrients and other pollutants (WRV 7). This WRV is considered relevant to the USR in a complex way. The steep-sided, bedrock channel and bottom composed primarily of rock and clay with localized deposits of sand and gravel is a relatively poor substrate for grass-like submerged aquatic vegetation. However, it reportedly supports thick mats and ropes of the filamentous alga *Vaucheria* (Sulak & Randall, 2004) that appear to be increasing in density in response to increasing nitrogen loadings to the USR. Increasing algal density may lead to increased oxygen depletion due to nocturnal algal respiration and result in eradication of optimal spawning habitat for listed species such as the Gulf sturgeon and diminished foraging habitat for juvenile fish. Thus, a tradeoff exists between the benefit of nutrient assimilation and potential detriment to fish habitat. Protection of this WRV therefore is afforded in MFLs established for fish and wildlife habitat and fish passage, explicitly evaluated under several scenarios for WRV 2.

8. Sediment loads (WRV 8). This WRV is considered highly relevant to the USR for this study. Sandbars are prevalent along the length of the USR, particularly on the inside of the many bends in the river.

Although an impediment to canoes, kayaks, and boats at low flow, the sandbars are enjoyed as beaches and campsites. The sandbars also serve as substrate to shoreline and submerged aquatic vegetation not found on the predominantly rock bottom.

9. Water quality (WRV 9). This WRV is considered highly relevant to the USR, as reflected by its designation as an OFW and influence on the spawning of Gulf sturgeon. Its relevance is further supported by the direct bearing water quality has on water-based recreation, maintenance of healthy stocks of fish, the recreational and aesthetic appeal of the estuary, as well as the estuary's continued role as a specialized habitat and seasonal haven.
10. Navigation (WRV 10). This WRV is considered not relevant to the USR, which is too shallow to support safe passage of commercial watercraft such as boats and ships. The passage of recreational vessels such as small boats, canoes, and kayaks is considered in the recreation-related WRV.

4.2 Indicators and Response Functions

The WRV indicators are a collection of human activities, hydrogeomorphic processes, and flora and fauna that are characteristic of the USR. 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 the USR. 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. Likewise, the natural life cycle of a certain fish species (e.g., Gulf sturgeon) may require some minimum hydrologic condition sufficient for spawning that must be maintained frequently enough and for a sufficient duration on an annual basis to sustain the population.

The selection of WRV indicators, metrics, and associated response functions for the USR MFLs assessment was based on consultations with District staff, subject matter experts with site-specific knowledge of the river, available literature, and data developed from this study. Representatives from the FDEP, Florida Fish and Wildlife Conservation Commission (FWC), U.S. Fish and Wildlife Service (USFWS), and USGS also were consulted.

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 USR MFL assessment. Many of the Habitat Suitability Curves (HSCs) prescribed as input to the System for Environmental Flow Analysis (SEFA) model are from a library of HSCs maintained by Dr. James Gore (University of Tampa) that are based on velocity, depth, and substrate. HSCs for the Gulf sturgeon are based on the HSCs published by ICF Jones and Stokes (2009), supplemented by a velocity curve for adult sturgeon developed by HSW and reviewed by USGS, USFWS, and FFWCC (ICF Jones and Stokes, Inc, 2009).

Indicators, response functions, and MFL assessment metrics are identified for six relevant or highly relevant WRV metrics for this study (Table 10). One relevant WRV not listed (filtration/absorption of nutrients and other pollutants) is captured to some degree by the metrics given for one or more of the six that are listed, as discussed earlier in Section 4.1.

A summary of needed response functions is 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 certain habitats are response functions for these habitats.
- Sediment loads – stage-inundation curves are an appropriate tool for this metric.
- Gulf sturgeon spawning – flow-conductivity curves can be used to evaluate water quality as it relates to maintaining water quality conditions conducive to successful Gulf sturgeon spawning.

Table 10. Indicators, response functions, and MFLs assessment metrics for USR WRVs
[Specific stage or flow conditions are referenced to the White Springs gage (USGS 02315500) unless otherwise indicated]

Indicator	Relevance	Response Function	Metric	Key Source
Upper Suwannee River				
RECREATION				
Boating	Public interest; associated with aesthetics	Daily stage-duration curve	Amount of time that boating is not viable (i.e., stage ≤ 52.5 feet NGVD) 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)
Kayaking / canoeing	Commercial and public interests; associated with aesthetics	Daily stage-duration curve	Amount of time that kayaking or canoeing is not viable (i.e., stage ≤ 51.0 feet NGVD) due to low water (Iboats, 2009) conditions	SRWMD signage and pers. comm. 2012 with E. McCook (SRWMD) and outfitters (Paddle Florida, Inc., Suwannee Guides and Outfitter, American Canoe Adventures)
FISH PASSAGE, FISH AND WILDLIFE HABITAT				
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 gravid Gulf sturgeon passage is not viable due to low water conditions (i.e., depth < 3 feet and width < 15 feet)	(Randall, Sulak, & Rauschenberger, 2012)
Gulf sturgeon (adult)	T&E species, spawning habitat	Depth-discharge curve	Amount of time (during seasons) that gravid Gulf sturgeon passage over spawning reefs is not viable due to low water conditions (i.e., depth < 6 feet over spawning reef)	(Randall, Sulak, & Rauschenberger, 2012)
Gulf sturgeon (adult and juvenile)	T&E species, general habitat, holding cover	Habitat suitability curve	Area weighted suitability (AWS)	(Randall, Sulak, & 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)

Indicator	Relevance	Response Function	Metric	Key Source
General fish assemblage	Adult, juvenile, fry, spawning, or seasonal holding habitat	Habitat suitability curves	Area Weighted Suitability	(Gore, McKinney, & Nagid, 2012)
Primary consumers (e.g., chironomids, EPTs, and mussels)	Forage for secondary consumers, possible T&E species (mussel)	Habitat suitability curves for species / taxonomic group	Area Weighted Suitability	(Gore, McKinney, & Nagid, 2012)
Secondary/Tertiary Consumers: Shallow-Slow Guild (e.g., crayfish, spotted sunfish, bluegill, Suwannee bass)	Refugia, spawning habitat, forage for tertiary consumers	Habitat suitability curves for specific species and guild associated with 0.33 feet<depth<1.83 feet and velocity<0.89 ft/sec	Area Weighted Suitability	(Gore, McKinney, & Nagid, 2012)
Secondary/Tertiary Consumers: Shallow-Fast Guild (e.g., darters, macroinvertebrates)	Refugia, mussel host, spawning habitat, forage for tertiary consumers	Habitat suitability curves for specific species and guild associated with 0.33 feet<depth<3.78 feet and 0.39 ft/sec<velocity<1.56 ft/sec	Area Weighted Suitability	(Gore, McKinney, & Nagid, 2012)
Secondary/Tertiary Consumers: Deep-Slow Guild (e.g., Gulf sturgeon, bass, catfish)	Refugia, spawning habitat	Habitat suitability curves for specific species and guild associated with 0.2 feet<depth<8.2 feet and velocity<3 ft/sec	Area Weighted Suitability	(Gore, McKinney, & Nagid, 2012)
Secondary/Tertiary Consumers: Deep-Fast Guild (e.g., Gulf sturgeon)	Refugia, holding cover	Habitat suitability curves for specific species and guild associated with 0.9 feet<depth<10 feet and velocity<3.6 ft/sec	Area Weighted Suitability	(Gore, McKinney, & Nagid, 2012)

Indicator	Relevance	Response Function	Metric	Key Source
Floodplain Swamp	Maintain wetland systems; repress succession	Forest stage-inundation area curve	Average inundation area for a selected vegetation community, amount of time that flow associated with average is exceeded, and annual flood frequency associated with average	(Cowardin, Carter, Golet, & LaRoe, 1979), (Light, Darst, Lewis, & Howell, 2002), (Sutherland, et al., 2017)
SEDIMENT LOADS				
Bank-full discharge	Channel maintenance	Stage-inundation area	Amount of time that bank-full discharge is exceeded	(Julien, 2002)
WATER QUALITY				
Conductivity	Gulf sturgeon spawning	Stage-conductivity curve at Suwannee Springs gage	Amount of time (seasons) that conductivity exceeds a limiting conductivity.	(HSW, 2010)

4.3 Field Surveys

Two types of field surveys were performed to support the USR MFLs assessment. First, existing GIS coverages of vegetative and soil types within the USR floodplain were verified by the field inspection of select transects that span the river corridor. The results of this survey support the assessment of floodplain habitat. Second, instream habitat was characterized by measuring channel geometry, substrate, and flow during three sets of synoptic surveys conducted during different flow conditions at four locations. The data collected were used to calibrate a SEFA model for each location and evaluate area weighted suitability (AWS) of instream habitat for a variety of species.

4.3.1 Floodplain Vegetation and Soil Verifications

A field reconnaissance effort was undertaken during April 20-27, June 15-17, and June 22, 2012, along much of the length of the USR. The purpose of this field effort was to verify the vegetative community maps, determine general plant species compositions, and verify SSURGO hydric soils maps. The best available digital information for mapped floodplain vegetation communities within the USR 10-year floodplain[2] was used to verify the distribution and extent of wetlands and hydric soils.

Wetlands mapped previously by the National Wetlands Inventory (NWI)[3] and FLUCCS methods and soil types[4] mapped by the SSURGO dataset were compared with current site conditions by field-verifying the mapped boundaries along 15 pre-selected transect alignments throughout the study area (HSW, 2012a) (Figure 49). The transects generally extended to the edge of the 10-year floodplain, which coincided roughly with the upland limit of floodplain wetland vegetation.

Forested wetland vegetative community types, characterized by dominant tree species and hydric soils, observed along the transects were compared to the expected wetland or soil type based on digital information. Forest composition in the floodplain is primarily determined by duration of inundation and saturation, and depth and frequency of floods. Four predominant floodplain forested wetland types occur: Gum Swamps, Mixed Wetland Hardwood, Cypress Swamp, and Wetland Forested Mixed.

[2] The 10-year floodplain digitized by SRWMD from unpublished map data prepared during a Suwannee River flood study by the U.S. Army Corps of Engineers in 1989.

[3] Wetlands were mapped using the U. S. Fish and Wildlife Service National Wetland Inventory [NWI] digital mapping coverage based on the Cowardin classification scheme (Cowardin, Carter, Golet, & LaRoe, 1979), supplemented by the Florida Land Use, Cover and Forms Classification System (FDOT, 1999) and SRWMD wetlands coverage.

[4] The U. S. Natural Resource Conservation Service (NRCS) digital Soil Survey Geographic Database (SSURGO) for each county was used as the soils theme in the project GIS analysis (NRCS, 2011a), (NRCS, 2011d), (NRCS, 2011e).

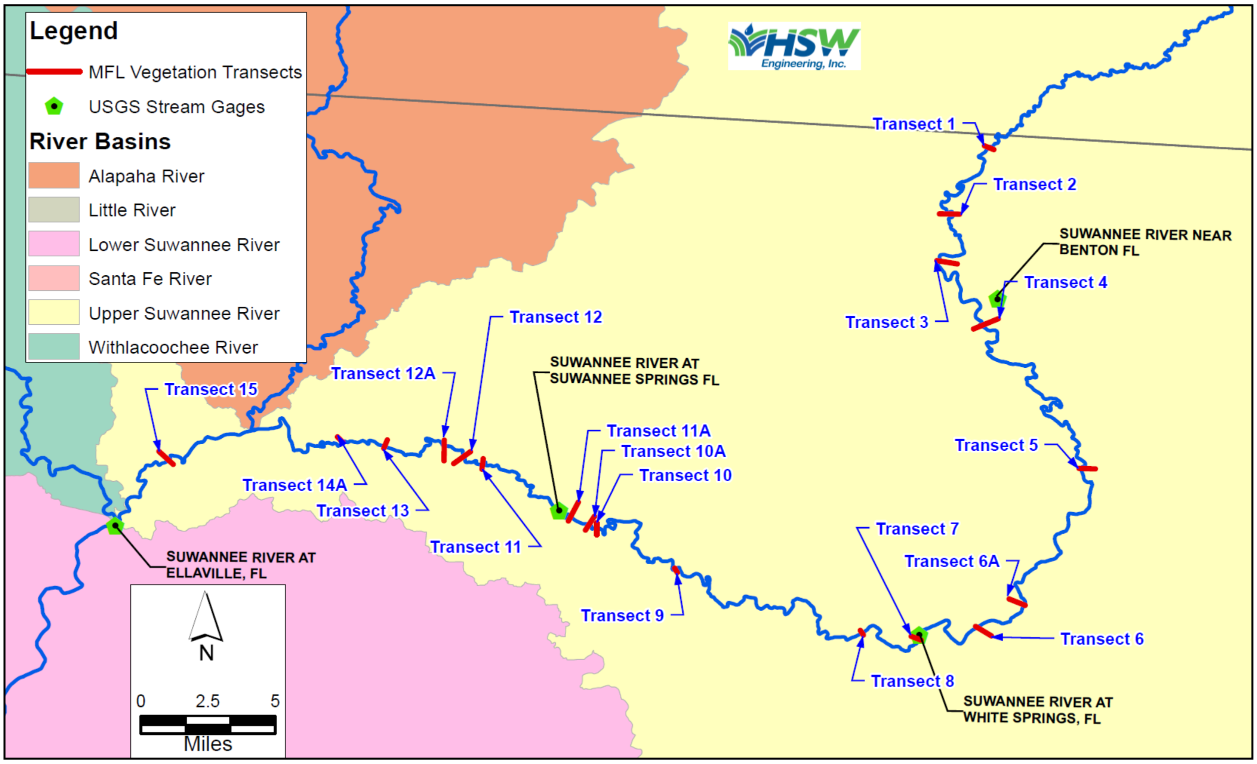


Figure 49. Vegetation transect locations of surveyed transects
[Transect 1 is farthest upstream, near the State line, and 15 is closest to the USGS gage near Ellaville]

Soils underlying these communities are flooded generally about one in ten years for 30 days or longer in March – April (NRCS, 2010). Thus, most of the wetlands on the floodplain are inundated infrequently by river flows; instead, they are sustained by precipitation and surficial drainage from the watershed. However, even infrequently-occurring high flows contribute to maintaining the ecological integrity of the entire ecosystem by supporting the extent and integrity of floodplain vegetation and the soils necessary to support these communities (Allan, 2007) (Hynes, 1970). Periodic river flooding benefits the floodplain ecosystem, recharges groundwater, helps to maintain hydric soils, and limits community degradation. When they occur, floods introduce additional nutrients and sediments and trigger episodic biological productivity.

Hydric soils were identified on all 15 inspected floodplain vegetation transects (HSW, 2012c). Both mineral and organic hydric soils were encountered on six of the transects, while only mineral hydric soils were encountered on nine transects.

Floodplain hydric soils in swales nearest the channel are inundated regularly; however, the inundation frequency diminishes quickly farther from the river. Depressional wetlands in the broad floodplain are flooded rarely by the river; instead, these areas appear to be maintained generally by precipitation and drainage from the surrounding watershed. In the lower part of the study area around transects 12, 13, 14, and 15, depressed karst solution features became increasingly abundant in the landscape. These features are observable on the LIDAR topography but are not mapped individually within the NWI, SSURGO, and FLUCCS coverages.

4.3.2 Instream Habitat Monitoring

SEFA is a Windows-based program (Aquatic Habitat Analysts, 2012) that was developed as a tool for use in studies that utilize the Instream Flow Incremental Methodology, or IFIM (Bovee, 1982) (Stalnaker, Lamb, Henriksen, & Bartholow, 1995). SEFA was used to evaluate the effects of multiple flow reduction scenarios on available riverine habitat and is described in a subsequent section. Field data were collected to calibrate SEFA models of four locations (I2, I3, I5, and I8) within the USR (Figure 50).

The four locations are characteristic of the heterogeneity of the river with pool-riffle sequences, even and uneven bottom geometry, and sand and/or rock bottom. The three most upstream sites (I2, I3, and I5) typify the USR. Site I2 is located immediately upstream from the County Road 6 bridge and the Benton gage. Site I3 is located immediately downstream from the canoe/kayak launch at Stephen Foster Park, about three miles downstream from the White Springs gage. Site I5 is located about midway between the Suwannee Springs gage and Gibson County Park boat ramp near the SW County Road 751 bridge. The fourth site (I8) is the Indian Shoal Gulf sturgeon spawning site, located about midway between the Gibson County Park boat ramp and Ellaville gage. Field methods are described in a work plan prepared for the collection of data (HSW, 2012b).

During 2012, 27 measurements were made at the four instream monitoring sites (HSW, 2012d). Flows measured during the site visits in March and May are characteristic of average- and low-flow conditions, respectively (Figure 51). During those site visits, flow characteristics were measured at each of the three transects at each instream monitoring site. During July 2012, high-flow conditions were measured on the recession of flooding associated with Tropical Storm Debby, and flow was measured at only one transect at each monitoring site.

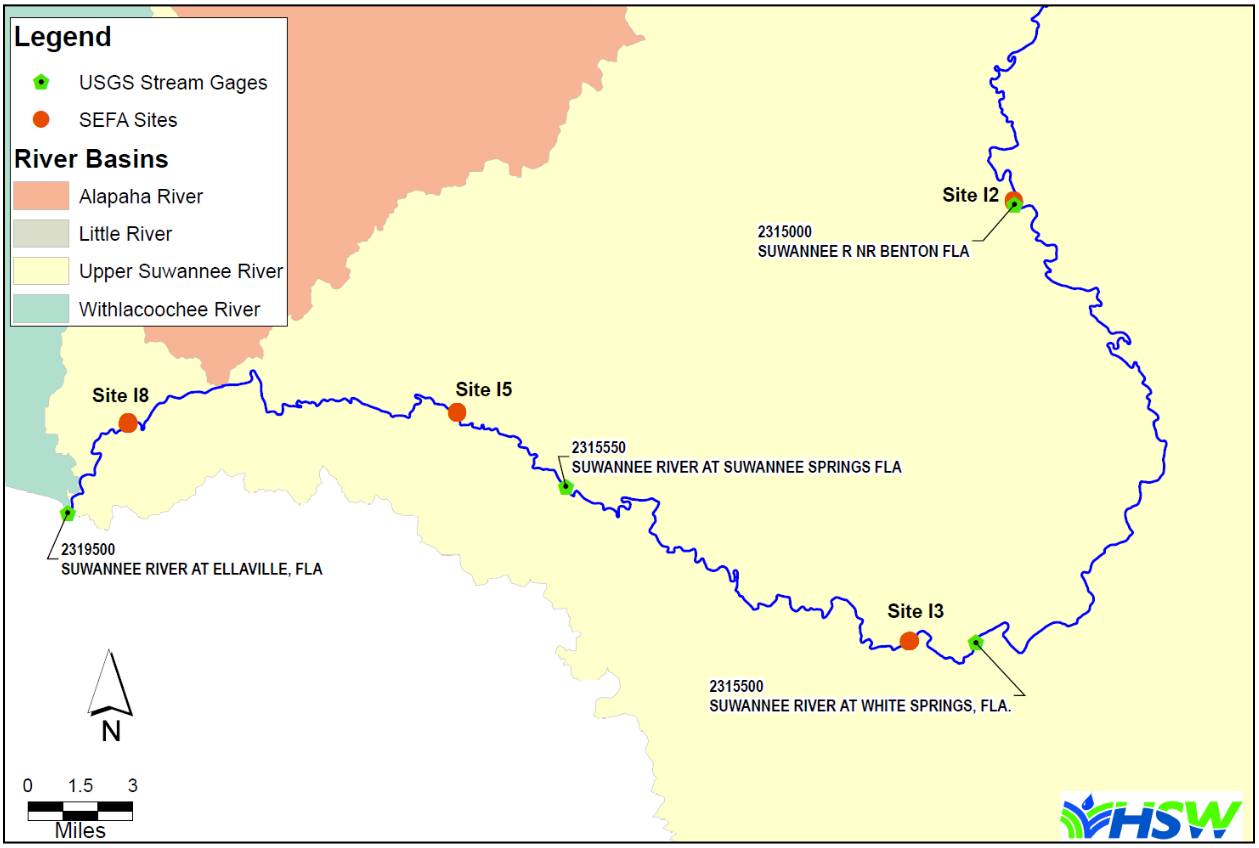


Figure 50. Location of instream monitoring sites, USGS gage stations on the upper Suwannee River

Instream monitoring site I2 on May 15, 2012, during low flow looking downstream at CR6 bridge

[Photo by HSW]

Instream monitoring site I3 during low flow on May 16, 2012, looking downstream from right bank

[Photo by HSW]

Instream monitoring site I5 during low flow on May 16, 2012, looking downstream from right bank

[Photo by HSW]

Instream monitoring site I8 looking from right bank during low flow across the exposed spawning site at Indian Shoal

[Undated photo courtesy of M. Randall (USGS) on March 14, 2016]

Figure 51. Photographs of instream habitat monitoring sites

4.4 Modeling

The approach for developing some of the response functions used for evaluating potential flow reductions makes use of the HEC-RAS hydraulic model and SEFA physical habitat model. These or other numerical models (e.g., estuarine), as well as statistical methods, are frequently used to develop response functions for MFLs assessments. Empirical data, such as measured flow/stage and river geometry, are needed to ensure that the response functions are characteristic of the target water body. Models also can be used to transfer observed data to distal locations on the water body through time.

Site-specific response functions were developed using data collected from fixed-station monitoring performed at prescribed locations. Multiple sites were investigated to adequately characterize the USR for the MFLs assessment because of variability in the attributes of the USR (e.g., water quality and substrate).

GIS analysis of hydraulic model results were used to develop regional response functions; i.e., relationships between freshwater flow and a WRV metric representing an area along the length of the target water body. In such cases, empirical data were collected to characterize the spatial distribution of a WRV metric, such as a floodplain wetland forest type. The data were collected using synoptic and fixed-station field surveys or remote sensing technology.

4.4.1 HEC-RAS Modeling

HEC-RAS is a one-dimensional hydraulic modeling program developed by the U.S. Army Corps of Engineers Hydraulic Engineering Center. It was developed to perform one-dimensional steady and unsteady flow river hydraulics calculations for flood study purposes (HEC, 2002). Profile computations begin at a cross-section with known or assumed starting conditions and proceed upstream for subcritical flow or downstream for supercritical flow.

The HEC-RAS model solves the one-dimensional energy equation by allowing computation of energy losses between two neighboring cross-sections. Version 4.1.0 of HEC-RAS was released in January 2010 and was used by Engineering & Applied Science, Inc., (EAS) to calculate water surface profiles along the length of the USR. EAS modified an existing hydraulic model to provide a dynamic flow and stage calibration with an emphasis on model utility for low-flow MFLs assessment (EAS, 2013). The calibration process required a detailed method for apportioning the intervening flow that enters the river between two gaged locations. The model is extremely useful for translating flow conditions at one location to another location.

The District retained licensed professional surveyors to perform field surveys and develop numerous additional river cross-sections to supplement those in the original model of the USR. Recommended survey locations were provided by EAS to enhance model accuracy under low-flow conditions and by HSW to supplement the floodplain vegetation survey (Figure 52). The 12 cross-sections selected during the instream flow monitoring for developing SEFA models also were included in the HEC-RAS model.

EAS simulated 20 steady-state flow scenarios that cover low, medium, and high river flow conditions. The flow scenarios range from 3.7 cfs to 12,500 cfs at the White Springs gage, with exceedance frequencies ranging from 1.11 to 99.97 percent (Table 11 and Figure 53).

HEC-RAS output was processed to characterize associations among hydraulic characteristics such as flow, water-surface elevation, depths, top width, wetted perimeter, and velocity at cross-sections. Low flow scenarios then were used to analyze water resource values associated with low flow conditions, such as recreation and fish passage. Bankfull and higher flow scenarios were used to evaluate channel geomorphology and floodplain habitat.

The development, calibration, validation, and demonstration of the USR HEC-RAS model is described in detail in Appendix D. The following sections summarize the information provided in Appendix D.

4.4.2 HEC-GeoRAS Geospatial Data Processing

HEC-GeoRAS is a set of tools specifically designed to process geospatial data and support hydraulic model development and analysis of water-surface profile modeling results (HEC, 2005). HEC-GeoRAS is used to analyze or transform datasets (collectively referred to as RAS Layers) in ArcGIS and extract information essential for hydraulic modeling. EAS used HEC-GeoRAS version 4.2.92 for ArcGIS version 9.2 to process USGS LiDAR topographic data and update the river floodplain geometric data within the study area.

HSW used HEC-GeoRAS version 10 for ArcGIS 10.2.2 to analyze the HEC-RAS results. The 20 steady-state water-surface profiles calculated by HEC-RAS were associated with LiDAR data using ArcGIS to calculate the wetted area that inundates wetland plant communities.

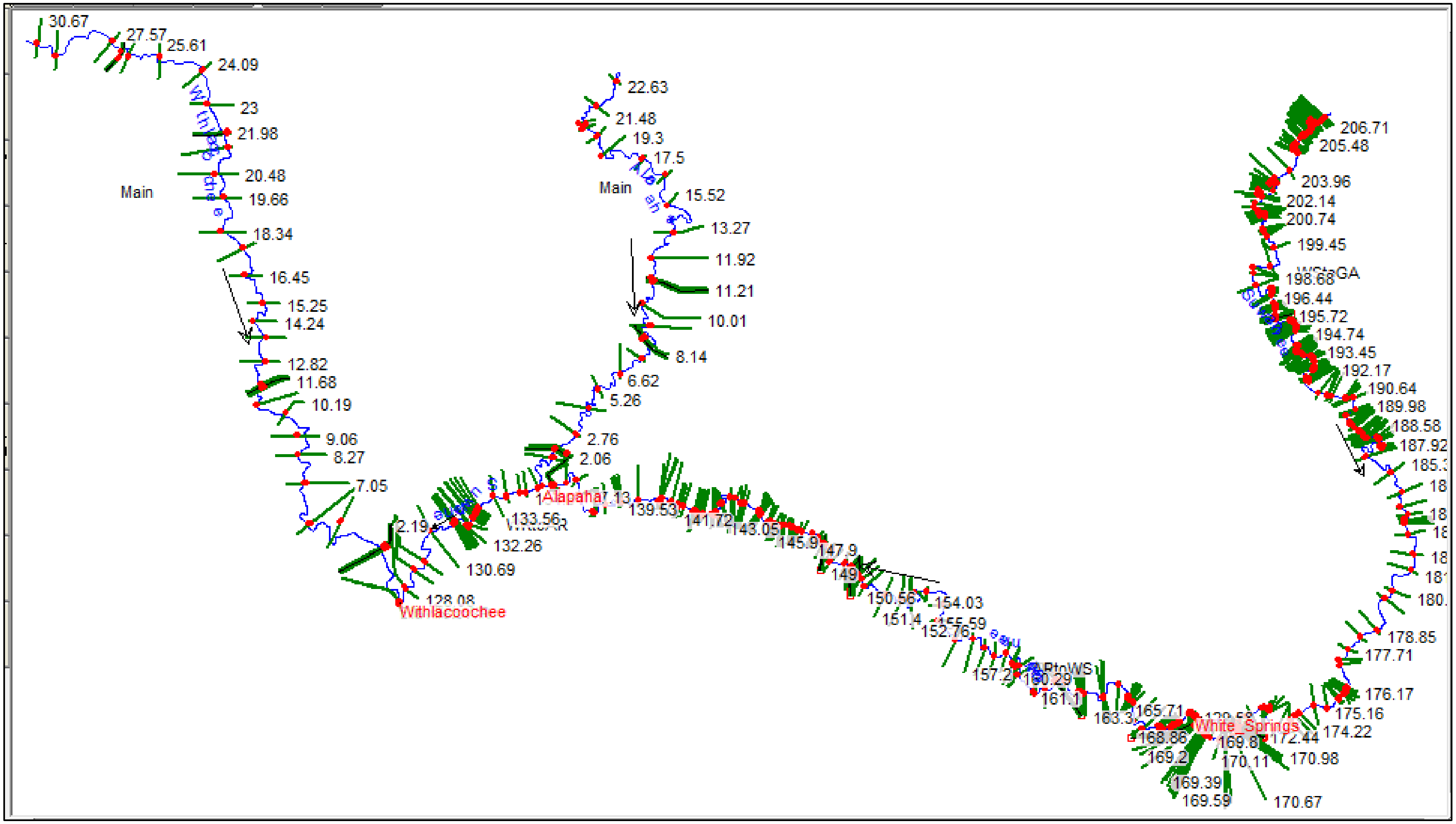


Figure 52. Cross-sections in the HEC-RAS model of the Upper Suwannee River

Table 11. Steady state flow scenarios simulated for the Upper Suwannee River

Flow Scenarios	Flow at White springs (cfs)	Stage at White Springs (ft)	Percent exceedance during baseline period
PF 1	4.63	48.61	99.90%
PF 2	5.88	48.64	99.80%
PF 3	9.94	48.71	99.50%
PF 4	12.07	48.74	99.00%
PF 5	15.02	48.79	98.00%
PF 6	25.77	48.95	95.00%
PF 7	57.58	49.34	90.00%
PF 8	96.20	49.68	85.00%
PF 9	135.08	49.97	80.00%
PF 10	247.87	50.73	70.00%
PF 11	419.08	51.7	60.00%
PF 12	676.81	52.9	50.00%
PF 13	1,050.66	54.37	40.00%
PF 14	1,630.81	56.29	30.00%
PF 15	2,721.28	59.62	20.00%
PF 16	3,520.93	61.85	15.00%
PF 17	4,720.82	64.78	10.00%
PF 18	7,120.53	70.21	5.00%
PF 19	9,954.38	76.01	2.00%
PF 20	12,601.1	79.88	1.00%

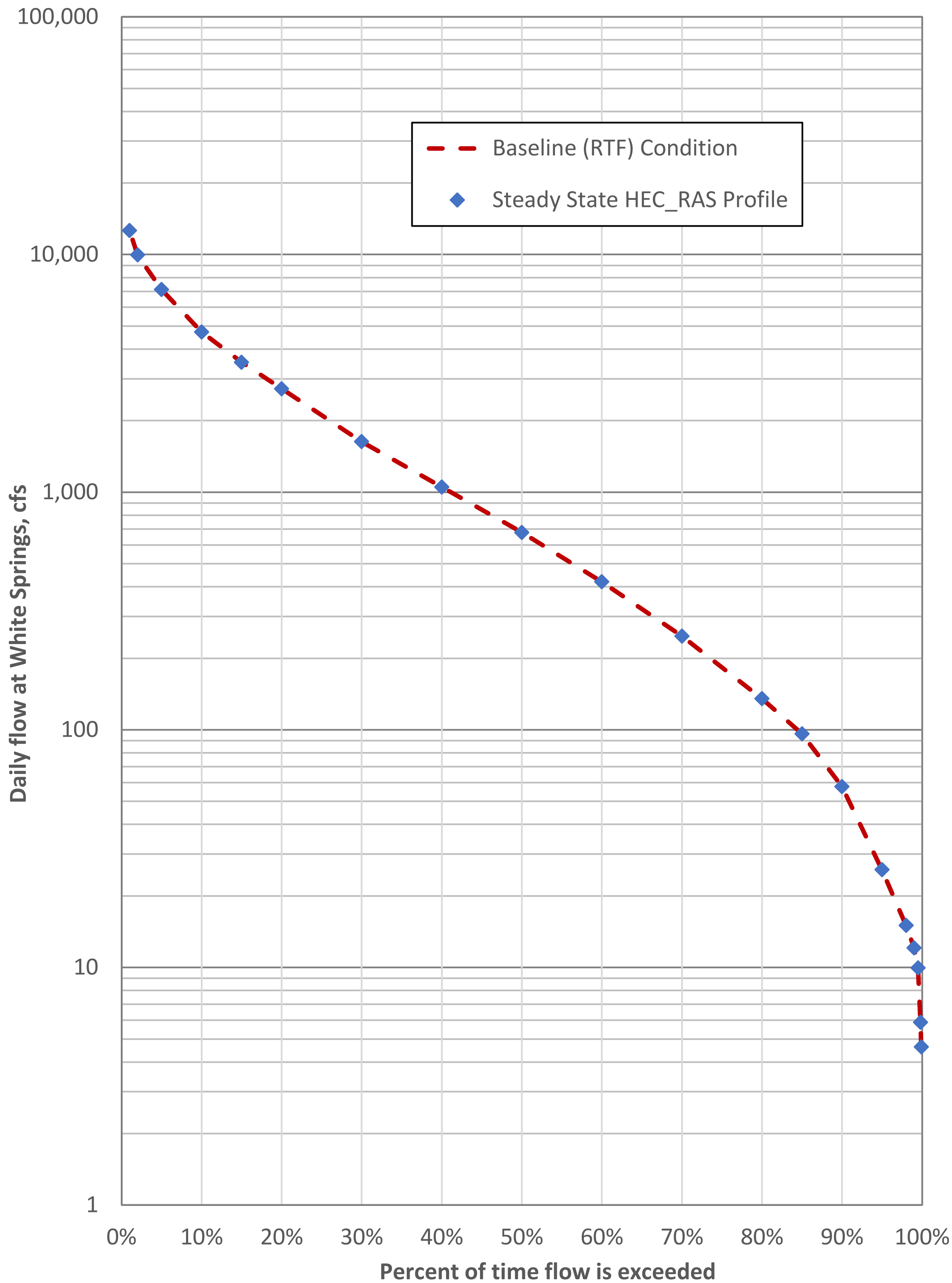


Figure 53. Baseline (RTF) condition White Springs flow duration curve and HEC-RAS simulated profiles (WYs 1938-2015)

4.4.3 SEFA Modeling

SEFA is a computer program that simulates a relationship between streamflow and physical habitat for various life stages of a species of fish or other aquatic organisms. Unlike the regional HEC-RAS model that spans the length of the USR, the four SEFA models developed for the USR are site-specific and each characterize the microhabitat within a short subreach of the river. The hydraulic characteristics and stage-discharge relationship within the subreach are key components of a SEFA model.

SEFA contains hydraulic, instream habitat, and time series models and can be used in the development of flow recommendations. The program allows for the alteration of flows to estimate the effects on the availability of habitat (shown as area weighted suitability) for species of interest in the body of water (Jowett, Payne, & Milhous, 2014).

SEFA calculates Area Weighted Suitability (AWS), which is a measure of suitable habitat available to a target organism within the model subreach for a specific discharge condition (Chapter 3.0). The program translates an input time series of daily discharge into a time series of daily AWSs (by species) and then calculates statistics for each AWS frequency distribution. The response function in a SEFA application is the association between flow and AWS.

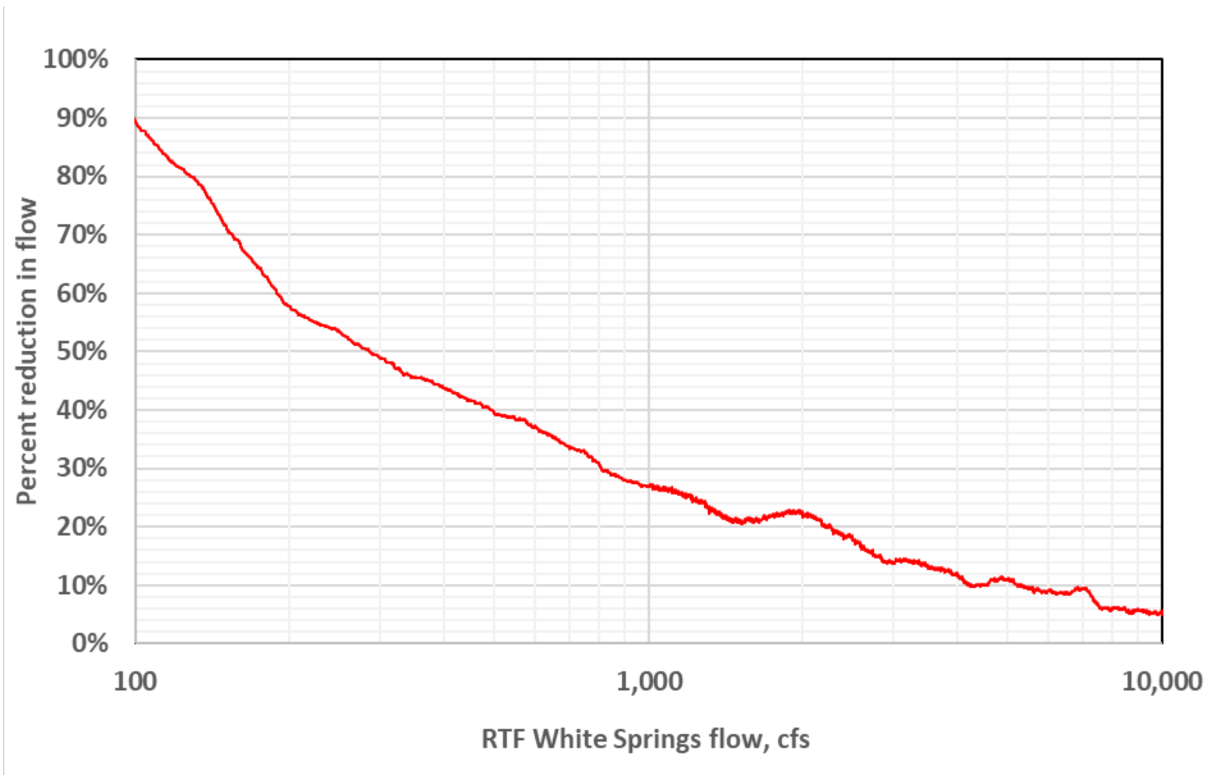
4.5 MFLs Assessment Methods

Water resource and human use values are collectively protected if a broad range of flows are maintained. The guiding premise is that some water withdrawal is acceptable as long as high flow occurrences are not decreased too much and low flow occurrences are not increased too much such that significant harm occurs. The determination of what constitutes significant harm often cannot be known with certainty and may be based on acceptance by the scientific community of some prudent but practical "placeholder" value that is subject to on-going monitoring and reassessment.

Most instream flow analysts assume that a change in duration or frequency of hydrologic events or loss in available habitat of greater than 15% from baseline or current conditions will result in significant harm to the resource (Gore & Mead, 2002). The 15% threshold has been applied in many, if not most, of the MFLs analyses performed in the State of Florida for MFLs Rule development (e.g., (Munson & Delfino, 2007), (SRWMD, 2005), (SWFWMD, 2010), (SWFWMD, 2011)) and was the subject of a first-phase literature comparison study with annotated bibliography produced for SWFWMD in which over 300 documents supportive of or allowing comparison with the 15% criterion were identified (Jones Edmunds and Associates, 2012). The 15% threshold also is applied in the USR MFLs analysis with the understanding that additional research and follow-up data collection to verify that the resources are protected are important elements of the MFLs process, and that this *de facto* significant harm criterion remains presumptive until it is rigorously demonstrated as protective (Cichra, Dahm, & Locke, 2007).

Different approaches have been used by Florida's water management districts to meet these objectives. Explicit in this premise is an allowable change in time that a particular flow rate is exceeded (Munson & Delfino, 2007). Implicit in this premise is an allowable change in area that is inundated for a fixed amount of time (e.g., application of floodplain inundation). A third consideration is an allowable change in the amount of time (i.e., the duration or number of consecutive days) that a particular flow is exceeded (or not exceeded), or an event-based approach (Neubauer, et al., 2008). Regardless of the method used, the result of the analyses is a set of threshold hydrologic conditions that differs from baseline conditions by no more than an amount that allows the resource values to remain protected. A multitude of environmental flow methodologies exist globally (Tharme, 2003), and often result in identification of a low-flow cutoff; i.e., a flow below which no withdrawals would be allowed. In addition, any of these criteria may be applied seasonally. The MFLs thus are established such that the threshold hydrologic conditions, selected to represent a broad range of the duration curve, are met.

The allowable-change-in-time approach has been used to define a threshold flow for preventing significant harm; i.e., to allow no more than 15% reduction in habitat from the baseline condition. A 15% reduction in habitat has traditionally been quantified as a 15% reduction in area, length, or volume of the habitat. Often, data are not readily available to assess a relationship between flow and area, length, or volume of the habitat. In those instances, a 15% change in time that a flow is exceeded or not exceeded has been used as a surrogate for area. SWFWMD (2005) has applied 15% reductions in both habitat area and time. The percent of time approach typically involves preventing the number of days a high flow occurs from being decreased by more than 15%. This can be thought of as not allowing the "good" days (high flow days) to become substantially less frequent than occurred during the baseline period (Figure 54).



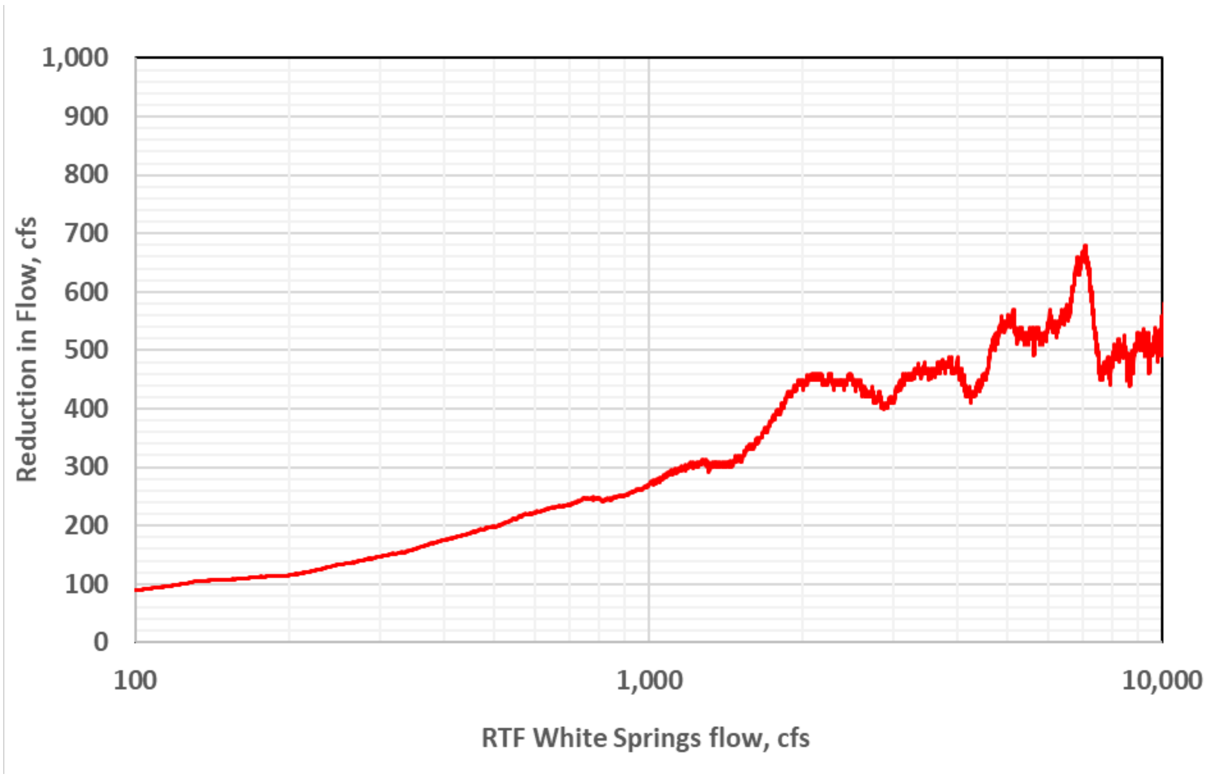


Figure 54. Percent reduction (top) and reduction (bottom) in RTF flow at White Springs associated with a 15% decrease in the number of days flow is exceeded

An in-stream evaluation using the Instream Flow Incremental Methodology (IFIM) approach, including SEFA and similar programs, is an example of a change-in-area approach. For the USR, each SEFA model was used to process a time series of daily flows and calculate average AWS for the baseline period.

After average AWSs for the baseline condition are computed, the input flow sequence is reduced by some prescribed percentage, another set of AWSs is calculated for the reduced-flow condition, and the change in AWSs relative to the baseline AWSs is calculated. The process is repeated for any number of flow-reduction scenarios until some unacceptable change in AWSs from the baseline condition is reached. Reductions of 10, 20, 30, and 40% in average daily flow were considered in the USR SEFA analysis.

This multi-faceted approach to the MFLs assessment utilizing alternative methods and multiple lines of evidence is robust and provides meaningful information regarding the sensitivity of the WRV value metrics to flow reductions. In the following example, the change-in-area (or reduction-in-area) approach and change-in-time (or percent-of-time) approach are used to develop a potential MFL flow reduction at a flow essential to maintaining floodplain habitat. In addition, for some WRVs, best available data may provide evidence that there is a threshold flow (or stage) magnitude that must persist for some finite duration and occur with some minimum (or maximum) frequency to protect the WRV from degradation. Frequency analysis of flood events that have occurred over the period of record therefore is included as a third approach to identifying conditions under which the WRV might suffer significant harm.

The results determined from using these three different methods are compared to illustrate the sensitivity of the assessment methodology and, in combination, provide greater evidence to support the MFL and protection of the WRV. However, it also is important to maintain flow that prevents significant harm downstream of the USR (i.e., middle and lower reaches of the Suwannee River). That is, MFLs established for the USR should not contribute disproportionately to allowable flow changes downstream. This approach also is useful when sufficient data are unavailable or limited within a river reach and a full evaluation of water resource values is not possible (e.g., for springs with limited data).

As a back-check to the approaches used to set MFLs, two additional comparisons were employed.

1. Relative flow reductions associated with the proposed MFLs were compared to literature summarizing case studies of water management (Richter, Davis, Apse, & Konrad, 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 White Springs and Suwannee Springs gages.

4.6 MFLs Assessment Example

The USR is surrounded by a nearly mile-wide floodplain made up of a complex landscape of forested cypress and mixed hardwood wetlands, intertwined in a matrix of pine and hardwood forests and agricultural uplands. Each of these four community types is dominated by characteristic tree species and has a typical hydrologic regime that sustains the community, and successively higher flows inundate greater areas of floodplain vegetation.

The two primary data sources of GIS shapefiles that illustrate the extent of the USR wetland communities are the FLUCCS (Florida Land Use and Cover Classification System) and Cooperative Land Cover (CLC) databases. The CLC database and codes are a more recently developed cross-walk that incorporates classifications currently used by the FWC, FNAI, and Florida's water management districts and the historic FLUCCS database (Kawula & Redner, 2018). The CLC floodplain vegetation communities were used to assess possible flow reductions that would remain protective of floodplain habitat and associated forest composition, wetland biogeochemical processes, and fish and wildlife habitat using the three different approaches previously described.

4.6.1 Reduction in Area

The areas of inundated wetland vegetation community types were determined using ArcGIS by overlaying the HEC-RAS derived inundation area shapefile for a select flow regime on CLC shapefiles over the length of the USR. The nature and extent of the community inundations upstream from Cody Scarp (Figure 55a) are different than those mapped downstream from the scarp (Figure 55b) and reflect the regional change in hydrogeomorphology along the USR. The process was performed for each of the 20 simulated flow regimes (Table 11) to characterize the association between flow and different floodplain wetland vegetation areas inundated.

Three CLC vegetation communities were selected for analysis: Bottomland Forest, Mixed Wetland Hardwoods, and Floodplain Swamp (Figure 56). Floodplain swamp is the dominant community in the upper portion of the USR (Figure 55a).

Bottomland Forest (CLC State code 22331) is a subset of the Mixed Wetland Hardwood community (CLC State code 2233) and is more prevalent in the lower portion of the USR (Figure 55b). On Figure 56, two inflection points are apparent on the inundation lines for Floodplain Swamp and Mixed Wetland Hardwoods, i.e., the first where each curve begins to rise substantially, and the second where each curve begins to depart from a line tangent to the curve. This second inflection point for these two curves represents a stage of 76.01 ft NAVD88, which corresponds to a flow of 9,954 cfs at the White Springs gage (Figure 56). The slope of the plotted line for Floodplain Swamp is steeper than for Mixed Wetland Hardwoods, so a reduction in flow results in a lower reduction in inundated area relative to the other two communities (and thus would be the most limiting loss in inundated area). Bottomland Forest is the drier of the communities, and the area curve is still rising at the upper end of the model runs.

Relatively smaller increases in inundated wetland area occur at flows exceeding 9,954 cfs because there are fewer wetlands at the elevations associated with these high and less frequent flows. The change in wetland inundation area is much more sensitive to reduction in flows of between 4,721 cfs and 9,954 cfs, and the flow associated with the midpoint elevation of the floodplain swamp between these two inflection points (70.4 ft NAVD88) was identified as a threshold flow condition. The flow at the White Springs gage is 7,531 cfs when the stage is 70.4 ft NAVD88. The total inundated floodplain swamp when flow at the White Springs gage is 7,531 cfs is about 2.96 square miles (Figure 56).

These vegetation communities are assumed to be protected if the inundated Floodplain Swamp area at the threshold flow is not reduced by more than 15%. A reduction of 15% to a threshold condition of 2.96 square miles and an associated flow of 7,531 cfs allows a flow reduction of 740 cfs from a flow of 8,271 cfs, or 9.0% (Table 12). The area change represents a potential loss of the vegetation community as it functioned under a baseline hydrologic condition and does not represent a predicted loss in wetland area.

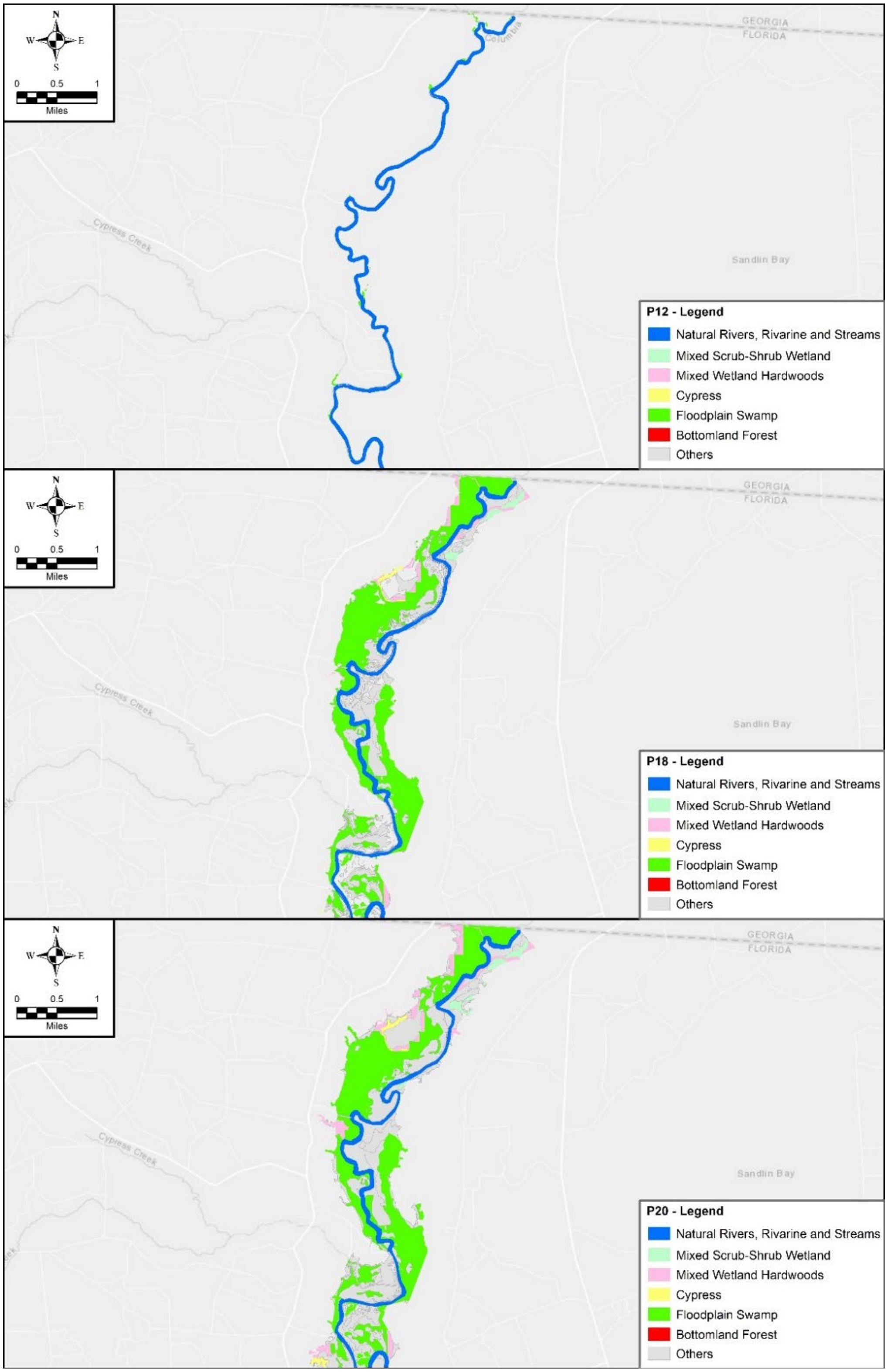


Figure 55a. Inundation maps (upstream from Cody Scarp between HEC-RAS stations 196 and 207) at flows of 4,670 cfs (top panel), 7,219 cfs (middle panel), and 9,947 cfs (bottom panel), with vegetative communities indicated by CLC coverage

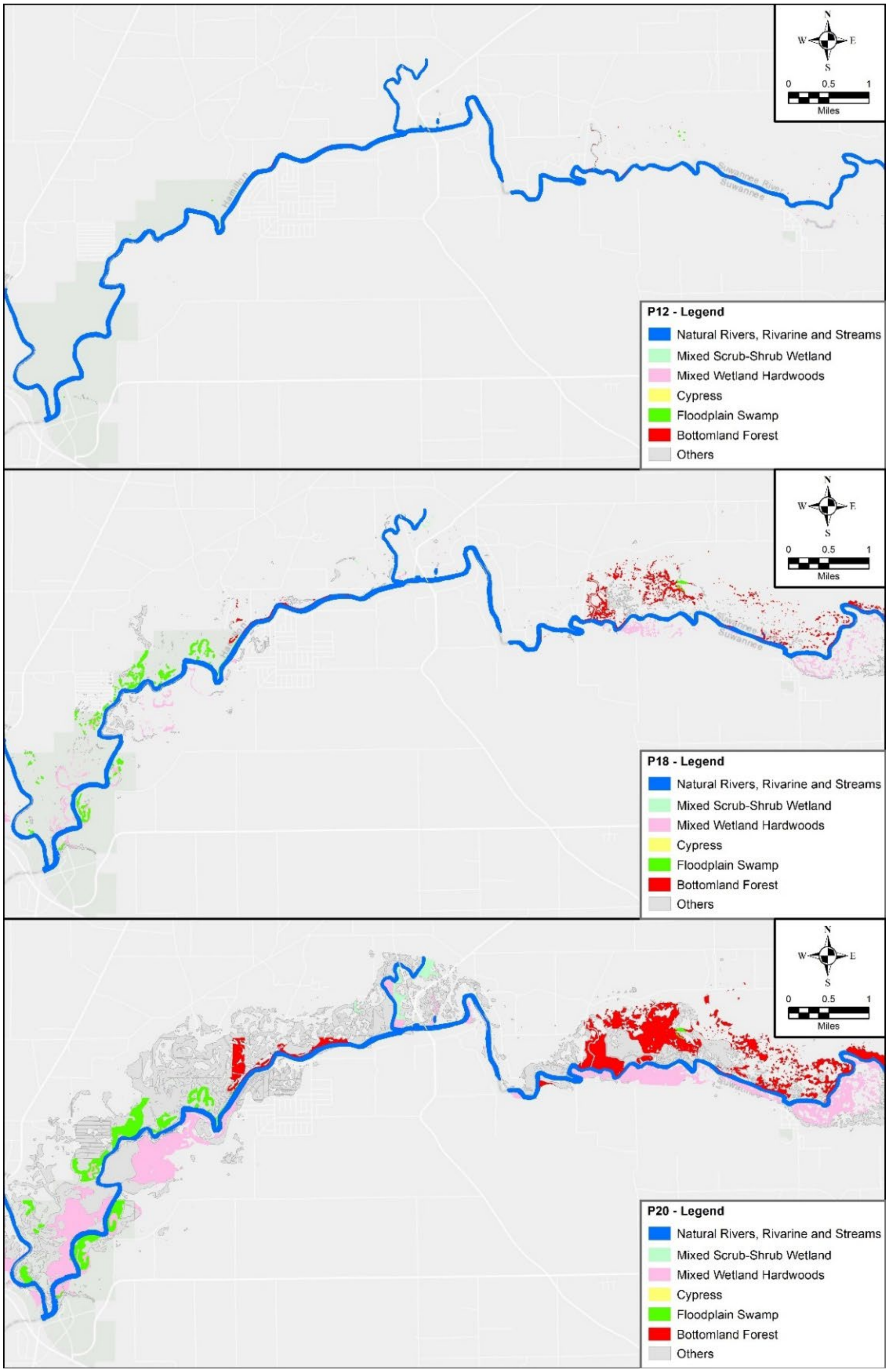


Figure 55b. Inundation maps (downstream from Cody Scarp between HEC-RAS river stations 128 and 143) at flows of 4,670 cfs (top panel), 7,219 cfs (middle panel), and 9,947 cfs (bottom panel), with vegetative communities indicated by CLC coverage

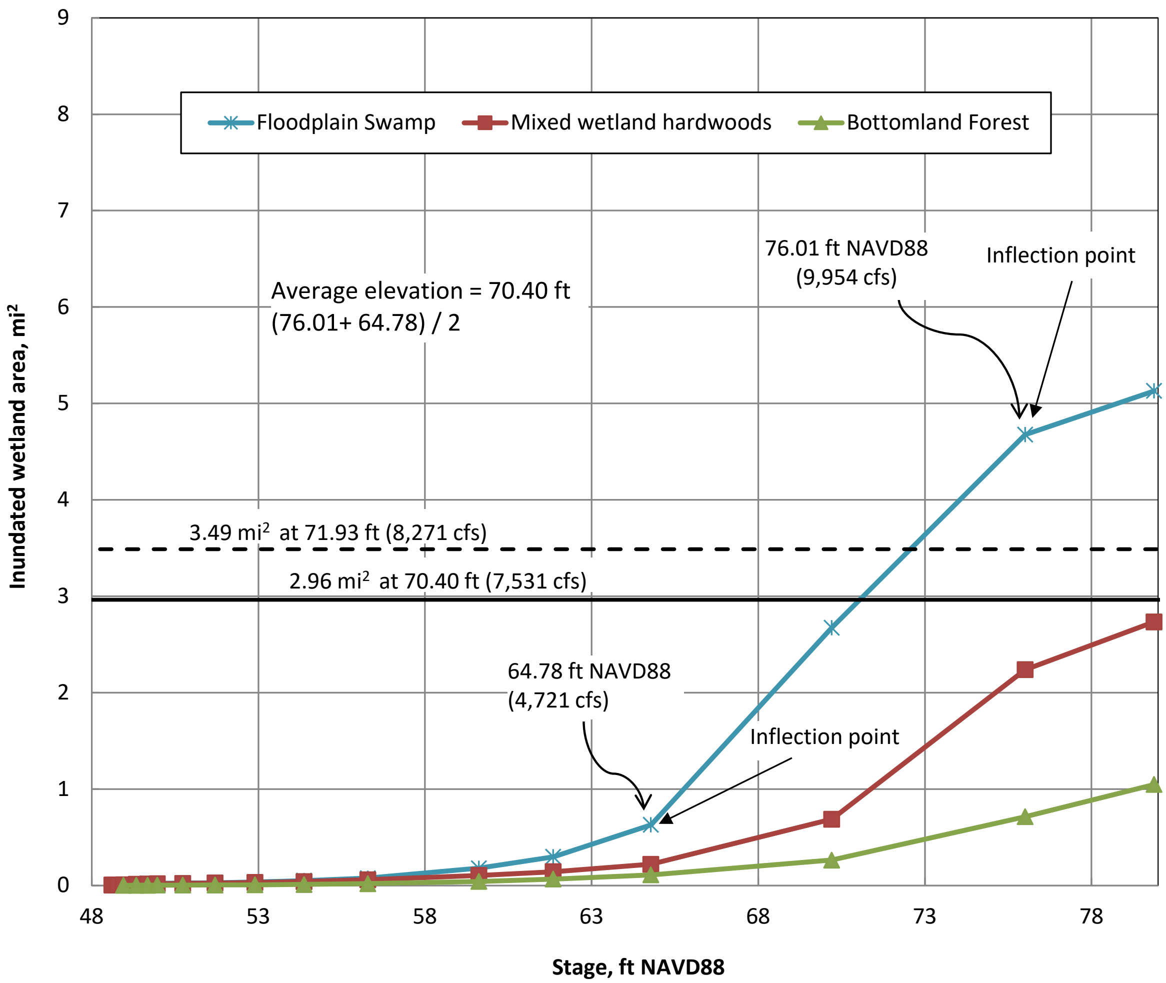


Figure 56. Association between USR stage at White Springs and selected inundated wetland areas

Table 12. Change in flow (available withdrawal) resulting from a 15% decrease in Floodplain Swamp inundated area

Threshold condition		Flow and area allowing a 15% reduction in area to the threshold condition		Decrease in inundated Floodplain Swamp area and flow		
Flow (cfs)	Inundated Floodplain Swamp area (mi^2)	Flow (cfs)	Inundated Floodplain Swamp area (mi^2)	Area (mi^2)	Flow (cfs)	Flow (%)
7,531	2.96	8,271	3.49	0.52	740	9.0

4.6.2 Percent of Time

The percent-of-time (or change in time) approach was used to assess the potential impacts to floodplain habitat resulting from a decrease in the frequency of floodplain inundation from what has historically occurred. Under baseline (RTF) conditions, the threshold flow of 7,531 cfs at White Springs is exceeded 4.4% of the time, or about 16 days per year, on average (Figure 57). A 15% reduction in the time that flow equals or exceeds the threshold condition results in an exceedance of 7,956 cfs about 3.7% of the time. This reduced flow exceedance scenario is associated with a flow reduction of 425 cfs when discharge at the White Springs gage is 7,956 cfs (Table 13 and Figure 57), a flow reduction of 5.3%. The inundation time is reduced by about 2 days per year, on average.

The relatively small allowable flow reduction (and change in inundation duration) is a function of the method used to calculate the change in inundation time and the shape of the duration curve as described in Section 4.5. A 15% reduction in the time a flow is exceeded will be greater for a flow that is exceeded often than for a flow that is exceeded infrequently. For example, a 15% reduction in the time for a flow exceeded 10% of the time is associated with a flow exceeded 8.5% of the time, or a difference of 5 days per year, on average. Conversely, a 15% reduction in time for a flow exceeded 50% of the time (the median flow) is associated with a flow exceeded 42.5% of the time, or a difference of 27 days per year, on average. While the change in inundation time at median flow versus high flow is relatively large, the change in flow per change in time is less at the median than at the extremes due to the flatter shape of the duration curve at the median.

Table 13. Change in flow (allowable withdrawal) resulting from a 15% decrease in the time flow is greater than the threshold condition for Floodplain Swamp inundation

Floodplain habitat metrics				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		Flow	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
Floodplain Swamp inundation	7,531	4.4	16	3.7	14	7,956	2	425	5.3

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% reduction in exceedance time, G=E-C, H=F-A, I=100*(F-A)/F. Refer to Figure 57.

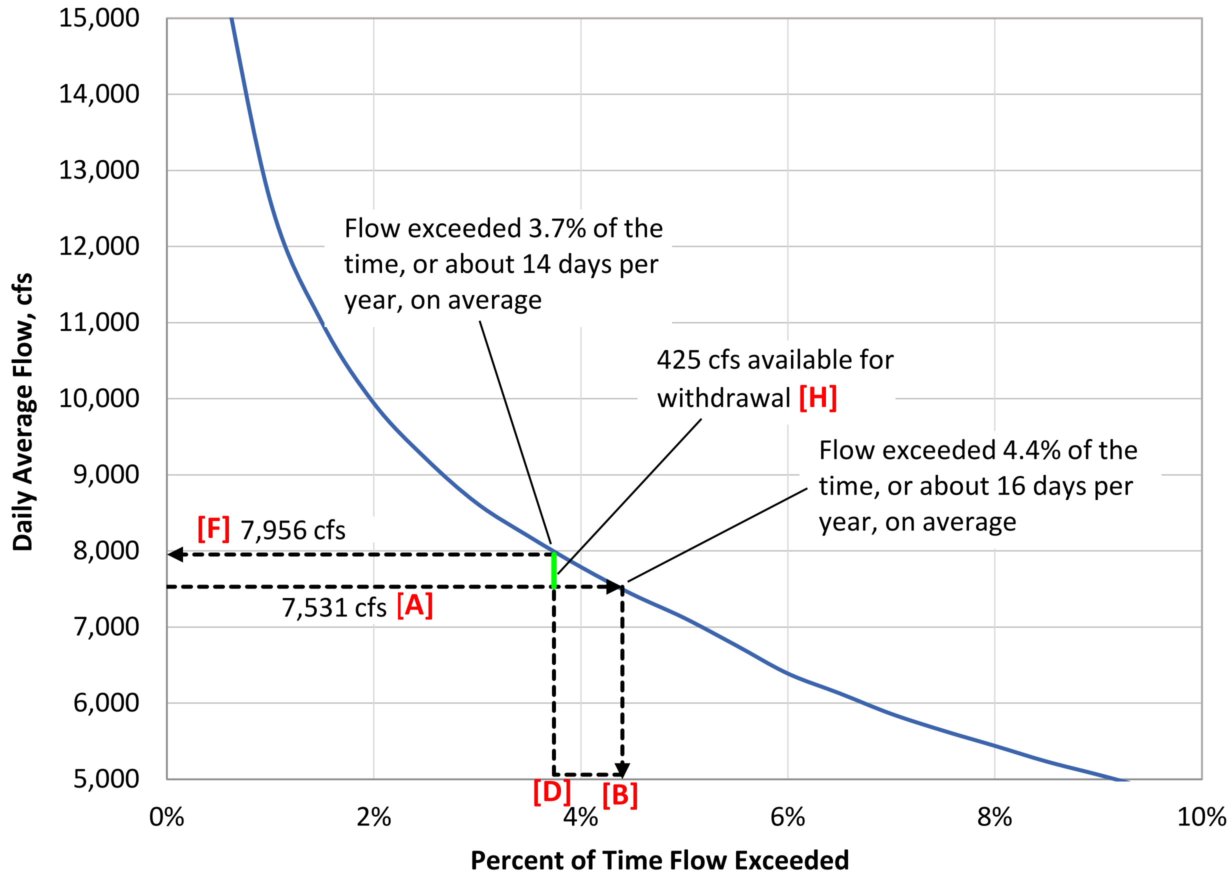


Figure 57. RTF (baseline) flow duration curve and exceedance frequencies associated with the USR Floodplain Swamp vegetation community

4.6.3 Event-Based Analysis

Wetland plant community function is influenced by sustained periods of dry conditions and sustained periods of wet conditions. The inflection points and median elevations of the individual wetland vegetation community area curves (Figure 56) generally reflect the community associations with stage (and flow). The median elevation of Floodplain Swamp identifies a community that requires wetter conditions than the Bottomland Forest (Florida Natural Areas Inventory (NFAI), 2010), which is at an elevation associated with a greater flow that occurs less frequently than 7,531 cfs.

Flood depths maintained continuously for a period of 14 days that occur every 2 to 5 years were determined to be important descriptors of general flood conditions affecting tree regeneration in riverine floodplain forests of the lower Suwannee River (Light, Darst, Lewis, & Howell, 2002) (Figure 58). More frequent flooding events will be associated with communities at lower relative elevations and nearer to the river (e.g., Floodplain Swamp – Rsw1 and RSW2 forest types) and less frequent flooding events will tend to support communities farther from the river or at higher elevations (e.g., Bottomland Forest – Rblh1, Rblh2, and Rblh3). These floods restrict regeneration of undesirable plant species in wetland forests because seedlings of exotic invasives and opportunistic hardwoods are unable to gain enough height during the period to survive the next flood. Floods greater in magnitude occur less frequently, thus allowing more time for young trees to reach heights that exceed flood depths. Note that the metric used for evaluating the WRV is not the flood occurrence itself but the time between the flood events (i.e., recurrence interval) that restricts the growth of invasive plant species.

The recurrence interval (RI) of an inundation event for Floodplain Swamp on the Upper Suwannee in which flow equals or exceeds 7,531 cfs for 14 consecutive days is 3.0 years under RTF (baseline) conditions (Figure 59). In the referenced Light work (Light, Darst, Lewis, & Howell, 2002), the riverine swamp communities in the lower Suwannee River (designated Rsw1 and Rsw2), appear to be inundated at a greater frequency than 33 years per century (RI = 3 years) (Figure 58). Flow reductions would shift the annual-exceedance frequency distribution in Figure 59 downward, thus increasing the recurrence interval and reducing the event frequency for any given flow magnitude.

When applying the event-based approach, it is important to view the results of analysis in the context of the information that supports the magnitude, duration, and recurrence interval of the threshold event. For example, the substantial work of Light and others (2002) on lower portions of the Suwannee River may or may not be directly transferable to the USR. The floodplain vegetation communities along the USR may have formed and or adapted under RTF conditions to a threshold recurrence interval or duration time somewhat different than the 14-day duration exceedance, two- to five-year return interval considered in this example. For example, the lower Suwannee River hydrology is characterized by direct communication between the river and the Upper Floridan aquifer (UFA), so the inundation of the floodplain communities is directly related to the river stage. Similarly, as the river stage changes, the response in the floodplain communities is rapid due to direct UFA communication. The USR, particularly above White Springs, is not directly connected to the UFA so, once inundated, communities may stay inundated and or saturated for a longer period. Also, wetland communities that exist at higher elevations relative to the river stage may be related to seepage faces in the landscape and soil confinement that results in moisture retention and longer periods of saturation.

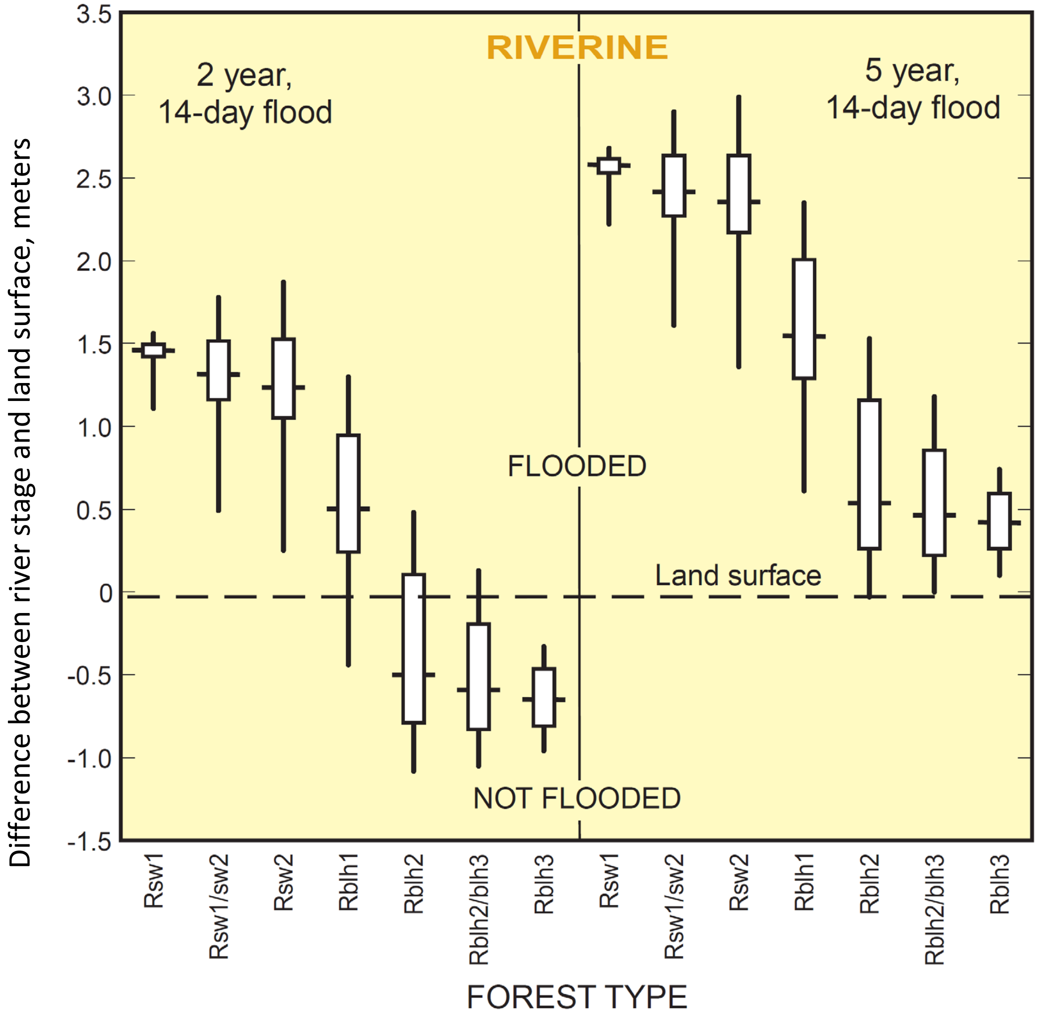


Figure 58. Flood depths in riverine and upper tidal forest types in the floodplain of the lower Suwannee River [Figure 51 of Light, Darst, Lewis, & Howell, 2002]

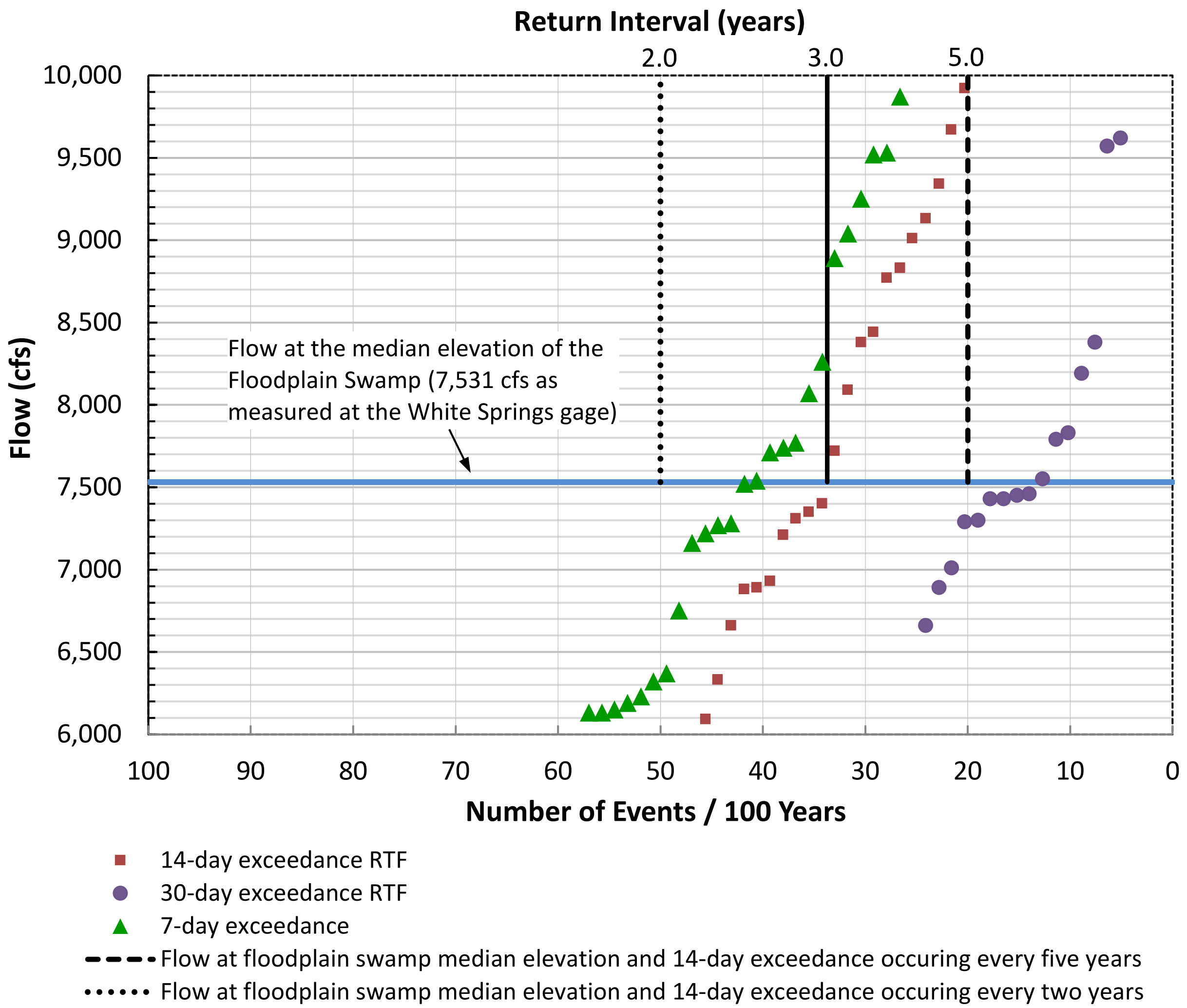


Figure 59. Frequency plots of 7-, 14- and 30-day duration high-flow events and flow threshold associated with the average area of Floodplain Swamp inundation with no area reduction

4.6.4 Summary

Using the inundation of the median elevation of the Floodplain Swamp vegetation community along the length of the USR as an example, a range of potential flow reductions was determined for a threshold flow of 7,531 cfs using three different MFLs assessment approaches that have been used frequently to evaluate MFLs for water bodies throughout central and north Florida (Table 14). Using a 15% reduced-area method results in a potential allowable flow reduction of 9.0%, while a 15% reduced-time method results in a potential allowable flow reduction of 5.3%.

The approaches used to evaluate WRVs are subject to discussion and professional judgment, but generally are based on available information (e.g., site specific and literature sources), what is most applicable to the indicator being analyzed, and supporting precedence. The event-based method is frequently used in MFLs evaluations, but sufficient site-specific information was not available for the

USR to define Surface Water Inundation Duration Signatures (SWIDs) and technically defensible parameters for a threshold event (Sutherland, et al., 2017).

While site specific information is not available to define an event threshold, the event approach was used as a check on the conclusion that the reduction-in-area approach is protective. A 9% allowable flow reduction would result in 740 cfs of available water (Table 12 and Table 14). A shift of the 14-day exceedance frequency curve of 740 cfs results in a RI of about 3.2 years versus 3.0 years under the RTF condition, or an increase of about three months. This RI shift of three months, or about 9% of the RTF condition, does not appear excessive. The RI shift based on a 425 cfs flow reduction (Percent-of-time method) would be less the 3 months.

The event approach is typically applied using either literature sourced information (e.g., (Light, Darst, Lewis, & Howell, 2002)) or site-specific information collected to support a return interval limit (e.g., (Sutherland, et al., 2017)). The work by Light on the lower portion of the Suwannee River does not appear to represent similar floodplain habitat on the USR. Collecting site-specific information to support an event analysis is discussed further in the following section.

Table 14. Summary of approaches used to assess possible flow reductions protective of floodplain habitat and associated forest composition, wetland biogeochemical processes, and fish and wildlife habitat

Approach	Threshold condition[1]	Governing Metric	Available for Withdrawal (cfs)	Reduction in flow (%)
Reduction-in-area	7,531 cfs	15% decrease in inundated area (0.52 mi^2)	740	9.0
Percent-of-time		15% decrease in inundation time (2 days)	425	5.3
Event-based		Increase in return interval of 14-day inundation[2]	--	--

1 Flow at the White Springs gage corresponding to the median stage of the Floodplain Swamp.

2 Insufficient data and literature information are available to apply an event approach to determine available water.

4.7 Uncertainty and Adaptive Management

Setting and periodically re-evaluating minimum flows in the USR 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 USR system. From both scientific and management perspectives, there is uncertainty associated with determining withdrawal impacts on physical, biological, and chemical aspects of the system. Non-stationarity 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 (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 evaluation are:

- Flow and stage data (error associated with collecting and processing basic hydrologic data).
- Parameters and calibration targets for the HEC-RAS model.
- 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.
- Parameters and calibration targets for the MODFLOW and HSPF models that comprise the NFSEG model.
- Translation of the lower Suwannee River riverine floodplain vegetation mapping and associated hydrology to the USR.

Adaptive management is a standard approach for reducing the inherent uncertainty associated with natural resource management (Williams & 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, & 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 60).

This evaluation of minimum flows is closing the loop on an iteration of the adaptive management process (Figure 60) by assembling, evaluating, and using the best information currently available to develop recommended minimum flows for the USR system. The minimum flow recommendations resulting from this 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 USR system will require ongoing monitoring, assessment, and periodic re-evaluation of minimum flows. The following are examples of future monitoring that could support future MFL assessments.

- Systematic stream and spring flow and water quality and groundwater level monitoring tailored specifically to characterize changes in base flow that can be attributed to withdrawals.
- Baseline and recurring synoptic surveys of floodplain and spring run vegetation, instream submerged aquatic vegetation, fish, and other aquatic biota of interest.
- Subregional modeling of the USR at a more discrete scale than the NFSEG model and sensitivity analysis of groundwater withdrawals, particularly in Hamilton County and within the phosphate mining area.
- Regional and subregional ground- and surface-water modeling that considers the influence of changing hydrometeorological variables such as rainfall, temperature and ET on aquifer recharge (Kumar, 2012) and phosphate mine reclamation alternatives.
- Floodplain vegetation mapping and association with hydrology similar to the investigation of the lower Suwannee River (Light, Darst, Lewis, & Howell, 2002).

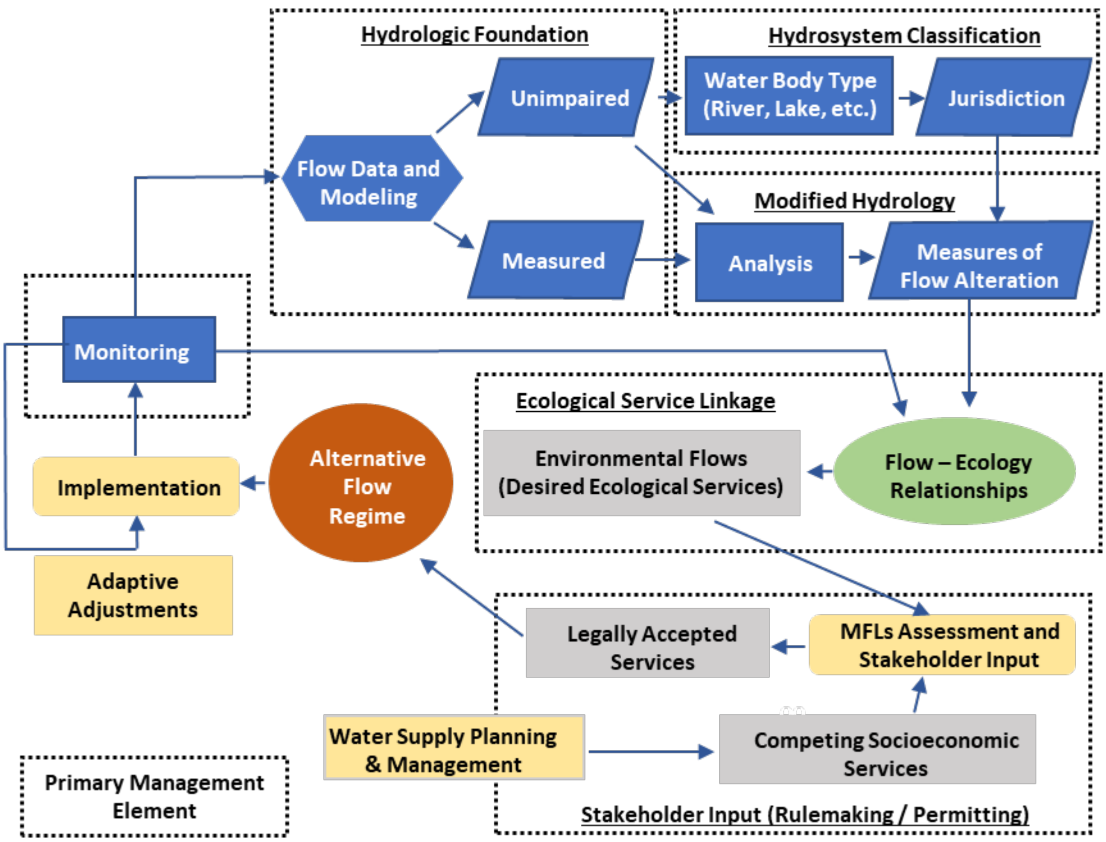


Figure 60. Conceptual holistic framework for the Upper Suwannee River adaptive management [Modified from (Williams & Brown, 2014)]

5.0 EVALUATION OF WRVS

As described in Chapter 4.0, water resource values involving recreation, fish and wildlife habitat and fish passage, sediment loads, and water quality deemed most relevant to this study area of the USR are evaluated further in this section of the report. The hydrologic shifts described in this section are an allowable withdrawal from the RTF flow condition (sometimes referred to as baseline), and are associated with either a 15% change in time that a WRV-specific flow is exceeded (Munson & Delfino, 2007) or not exceeded, a 15% decrease in area associated with a habitat, or a 15% reduction in an AWS modeled by SEFA. Recreation, fish passage, and water quality (instream conditions) are more likely to be adversely affected by low flow conditions, and, therefore, the extent to which an adverse low flow condition may increase is examined (Table 15). Conversely, fish and wildlife habitat and sediment transport are driven by high flow conditions, and so the extent to which the beneficial high flow condition may decrease is examined (Table 15). SEFA models developed for the USR at four sites along the river were used to characterize the microhabitat within a short subreach of the river and determine the change in habitat area over a range of flows. The hydraulic, instream habitat, and time series models contained in SEFA also were used in the development of flow recommendations discussed in this chapter. Flow scenarios that are protective of the values given in Table 14, Table 15, Table 16, and Table 17, are assumed to be sufficient to protect the overall structure and function of the river system.

5.1 Recreation In and On the Water

The USR is acknowledged as one of the most scenic and pristine sections of the Suwannee River. The roughly 79 river-mile Florida reach is framed by mature pines and cypress trees, high bluffs with limestone outcroppings, and white sandy beaches. At moderate water levels, it also includes Florida’s only Class III whitewater rapids, at Big Shoals, located roughly five miles upriver from White Springs. These unique attributes are enhanced by the rural, small-town nature of much of north-central Florida. Together, the USR and surrounding areas play an important role in the region’s water-based recreational activities and economy.

The subsection of the USR from the Stephen Foster Folk Culture Center State Park at White Springs to Suwannee River State Park at Ellaville comprises the first part of the 170-mile Suwannee River Wilderness State Trail (Figure 61). The trail, which continues along the river to its endpoint at the Gulf of Mexico near the town of Suwannee, is a network of natural, recreational, cultural, and historical sites created and maintained through cooperative efforts by the FDEP, SRWMD, local municipalities and businesses, and private citizens. Important features of the Suwannee River Wilderness State Trail are the camping sites and parks that dot the river, including five river camps with screened sleeping platforms, power, and hot water for showers, accessible only by hikers and boaters.

Table 15. Flow reductions associated with decrease in the time that the threshold stages are exceeded (White Springs gage)

Threshold stage (flow) and time exceeded				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		Flow	Time	Flow	
	cfs	%	Average days/year or season	%	Average days/year	cfs	Average days/year or season	cfs	%
Index:	A	B	C	D	E	F	G	H	I
WRV 1. Recreation in and on the water									
Paddling	172	76.3	278	64.9	237	323	41.8	151	46.9
Boating	476	57.4	210	48.8	178	713	31.4	237	33.3
WRV 2. Fish and wildlife habitat and fish passage									
General fish passage	352	63.3	231	53.8	196	569	34.7	217	38.1
Gulf sturgeon passage (Feb-May)	45.3	98.0	87.5	83.3	74.3	276	13.1	231	83.6
Gulf sturgeon passage (Sep-Nov)	45.3	89.4	81.4	76.0	69.2	128	12.2	82.3	64.5
WRV 2. Fish and wildlife habitat and fish passage									
Gulf sturgeon spawning (6-ft depth) (Mar-Apr)	1,931	47.4	28.9	40.3	24.6	2,571	4.3	640	24.9
Gulf sturgeon spawning (6-ft depth) (Sep-Oct)	1,931	24.3	14.8	20.7	12.6	2,301	2.2	370	16.1
Floodplain inundation	7,531	4.4	16.1	3.7	13.7	7,956	2.4	425	5.3
WRV 7. Sediment transport									
Bankfull condition	7,040	5.2	19.0	4.4	16.1	7,491	2.8	451	6.0
WRV 8. Water Quality									
Gulf Sturgeon spawning (conductivity, Mar-Apr)	566	74.4	45.4	63.2	38.6	1,051	6.8	485	46.1
Gulf Sturgeon spawning (conductivity, Sep-Oct)	566	54.0	32.9	45.9	28.0	753	4.9	187	24.9

A=threshold 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=E-C, H=F-A, I=100*(F-A)/F. Refer to Figure 72.

Table 16. Flow reductions associated with decreases in the time that the threshold stages are exceeded (Suwannee Springs gage)

Threshold stage (flow) and time exceeded				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		Flow	Time	Flow	
	cfs	%	Average days/year or season	%	Average days/year	cfs	Average days/year or season	cfs	%
Index:	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
WRV 1. Recreation in and on the water									
Paddling	306	76.3	278	64.9	237	488	41.8	182	37.3
Boating	655	57.4	210	48.8	178	926	31.4	271	29.3
WRV 2. Fish and wildlife habitat and fish passage									
General fish passage	520	63.3	231	53.8	196	758	34.7	238	31.4
Gulf sturgeon passage (Feb-Apr)	164	97.6	87.1	82.9	74.0	426	13.1	262	61.6
Gulf sturgeon passage (Sep-Nov)	164	89.6	81.5	76.2	69.3	260	12.2	96.8	37.2
WRV 2. Fish and wildlife habitat and fish passage									
Gulf sturgeon spawning (6-ft depth) (Mar-Apr)	2,251	48.1	29.4	40.9	25.0	2,910	4.4	659	22.6
Gulf sturgeon spawning (6-ft depth) (Sep-Oct)	2,251	23.9	14.6	20.3	12.4	2,619	2.2	368	14.0
Floodplain inundation	7,641	4.4	16.1	3.7	13.7	8,087	2.4	446	5.5
WRV 7. Sediment transport									
Bankfull condition	7,158	5.2	19.0	4.4	16.1	7,631	2.8	473	6.2
WRV 8. Water Quality									
Gulf Sturgeon spawning (conductivity) (Mar-Apr)	767	74.2	45.3	63.1	38.5	1,329	6.8	562	42.3
Gulf Sturgeon spawning (conductivity) (Sep-Oct)	767	51.5	31.4	43.7	26.7	1,010	4.7	243	24.1

A=threshold 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=E-C, H=F-A, I=100*(F-A)/F. Refer to Figure 73.

Recreational boating on the USR consists largely of canoeing and kayaking, with small powerboats also common downstream from White Springs. Fishing from small, shallow-draft motorized vessels also is a popular activity. Before accessing the river, paddlers and boaters are advised to assess water conditions based on water levels measured at White Springs. These readings are posted daily on the SRWMD website. Water level measurements at this location serve as an indicator of paddling conditions throughout the river reach. 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 submerged aquatic vegetation or physical damage to a boat motor.

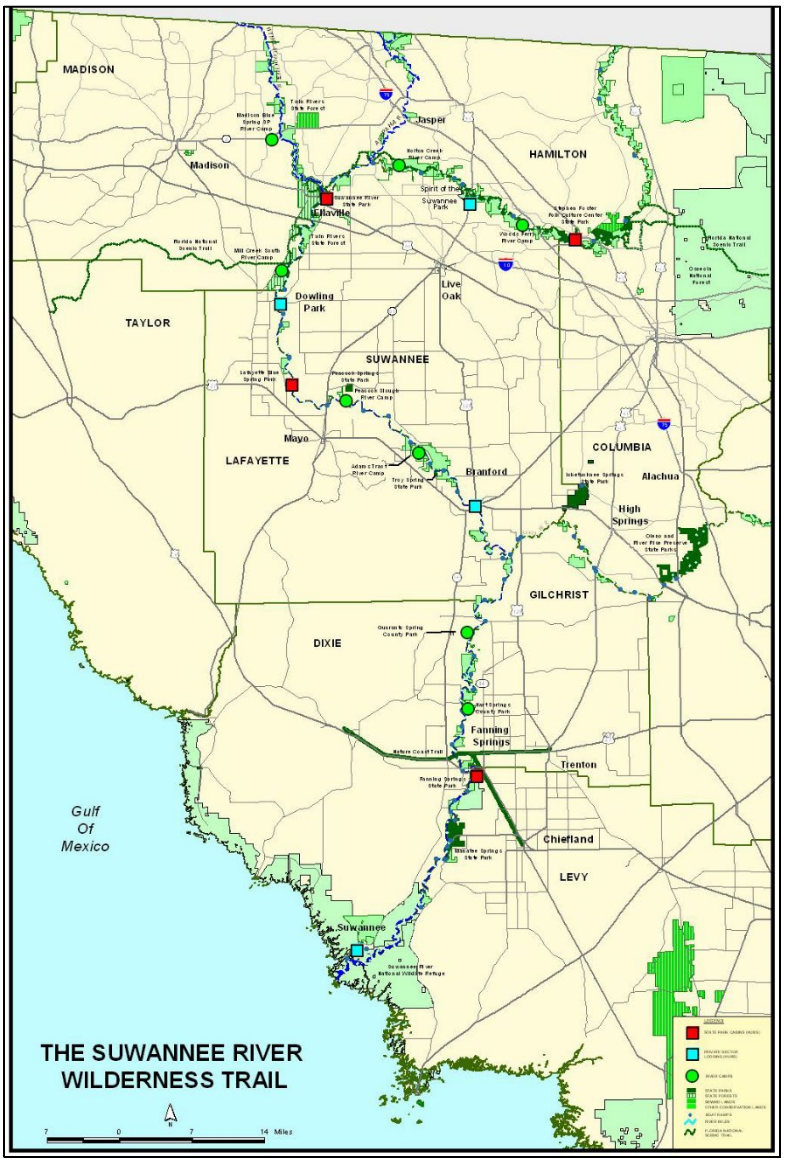


Figure 61. Map of the Suwannee River Wilderness State Trail
[Maps | Suwannee River Water Management District (mysuwanneeriver.com)]

Based on the advisory at White Springs (Figure 62), suitable water conditions for most paddlers are associated with water levels at the White Springs gage between 51 and 60 ft NGVD29. At lower levels, rocks and sandbars may make the river difficult for paddling and impassable for small boats. Most commercial outfitters indicated that they would not enter the water at White Springs at levels of less than 51 ft NGVD29 (50.17 NAVD88), although some stated that paddling would still be possible if launching from the public canoe launch at Suwannee Springs, north of Live Oak, or Suwannee River State Park, and several commented that the scenery is particularly attractive at lower water levels. Paddling and river camping are said to be optimal when the White Spring gage reading is about 51 to 59 ft NGVD29; above this level, there are fewer camping beaches and more tree branches hanging into the river that can trap boats and cause capsizing. At about 65 ft NGVD29 or higher, there are no camping beaches, and the current in the river is swift, with powerful eddies and undercurrents. At 77 ft NGVD29 (about 10,400 cfs), the Suwannee River is at flood stage and well over the top of bank.

The amount of time that water level conditions preclude easy paddling or small motorized vessel passage and clearance due to low-flow conditions was selected to assess protection of recreation on the river. The potentially available water under an MFLs scenario is the change in flow associated with an increase in the number of non-ideal paddling or boating days. This is the percent-of-time approach introduced in Chapter 4 and, in this case, it is the time a particular threshold condition is not exceeded that is of interest (i.e., an increase in the occurrence of a low-flow condition).

Figure 62. Water level advisory sign at Stephen Foster Folk Culture Center State Park [provided by SRWMD on May 14, 2013; 50 ft NAVD88 currently used for recommendation]

The critical stage for canoeing / kayaking is 51 ft NGVD29 and is associated with a flow of 172 cfs at the White Springs gage (Figure 62 and Table 15) and 307 cfs at the Suwannee Springs gage. Paddling is more difficult at a stage of less than 51 ft NGVD29; hence, 172 cfs is the threshold flow for assessment of the recreation metric. The flow duration curve (Figure 63) crosses the 172 cfs horizontal line at an exceedance flow of 76.38% under baseline conditions; i.e., a flow of 172 cfs is exceeded 76.3% of the time, or about 278 days per year, on average, under baseline conditions (Table 15). Under reduced flow conditions that would decrease the time exceeded by 15%, canoeists and kayakers be able to comfortably about 64.9 % of the time, i.e., about 237 days each year on average, or about 42 days less than under RTF conditions. This reduced-flow scenario permits a withdrawal of 151 cfs when discharge at the White Springs gage is 323 cfs, or an 46.9 % reduction in flow (Table 15 and Figure 63).

By the same reasoning and assuming that a minimum water level of 52.5 ft NGVD29 and flow of 476 cfs at the White Springs gage is needed for operation of small motorized vessels (see Table 10, Chapter 4), 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 be viable for 31 days less each year, on average, or about 48.8% of the time (Table 15). This reduced-flow scenario permits a withdrawal of about 237 cfs when discharge at the White Springs gage is 713 cfs, or a 33.3% reduction in flow.

Allowable flow reductions associated with the Suwannee Springs gage are 182 cfs for paddling and 172 cfs for boating (Table 16).

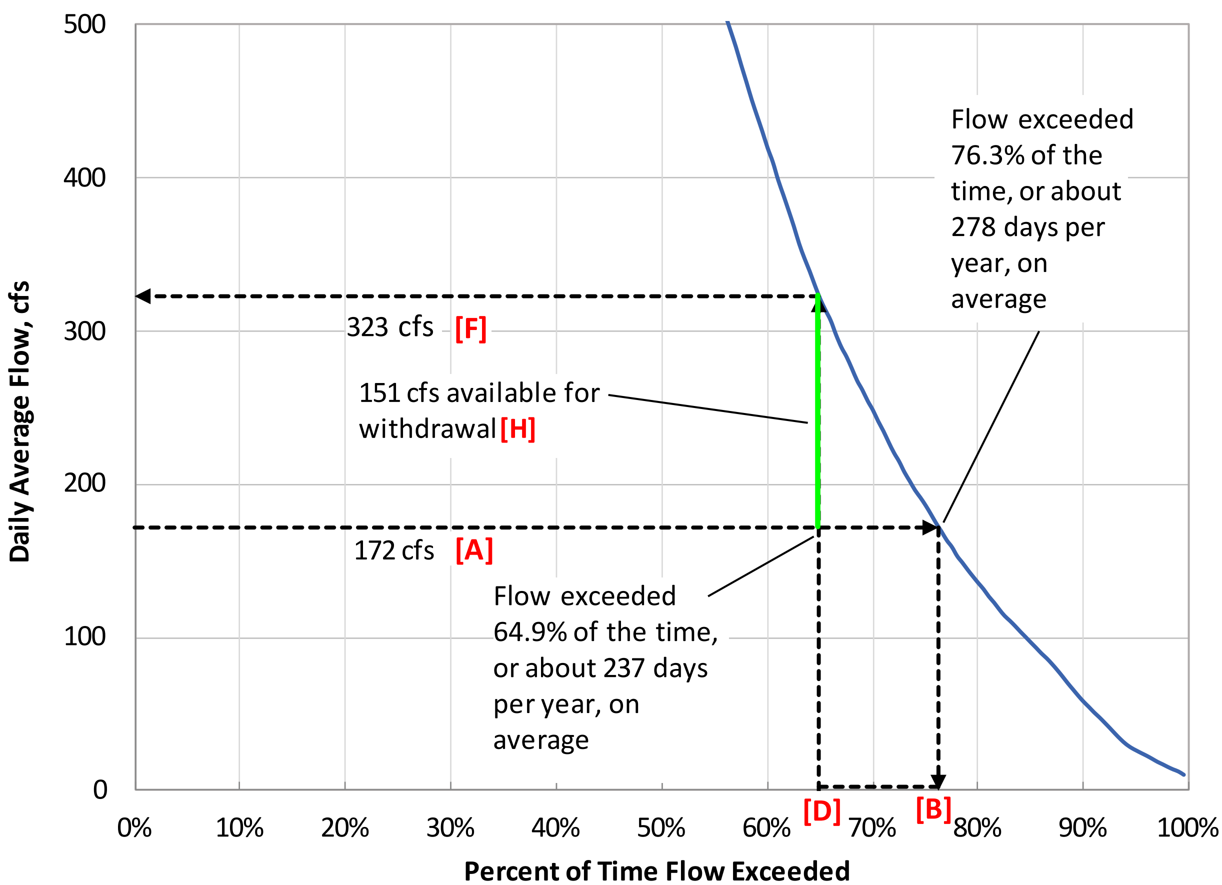


Figure 63. RTF flow duration curve for White Springs gage depicting threshold flows protective of recreational aspects of the USR

5.2 Fish Passage and Fish and Wildlife Habitat

Four flow regimes are considered to determine river flow requirements for in-stream and out-of-bank floodplain habitats. These include

- in-stream flows that meet critical biota requirements such as fish passage and reproduction;
- in-channel flows that maintain immediate stream banks and channels and inundate snags;
- overbank or near-overbank flows that maintain riparian habitats; and
- flood flows that determine the boundaries and shape of floodplain and valley features.

5.2.1 Fish Passage for Gulf Sturgeon and the General Fish Community

Gulf Sturgeon Passage

The iconic fish of the upper Suwannee River is the Gulf sturgeon, currently a protected fish species listed as threatened by the USFWS and a key indicator for the environmental value relating to fish habitat and fish passage in the USR. Adult Gulf sturgeon migrate upstream from Suwannee Sound to spawning areas near Nobles Ferry at Gibson County Park, Indian Shoals, and Trillium Bluff (Figure 64). Federally designated critical habitat extends to the confluence of the Suwannee River and Long Branch Creek, about 0.5 river miles upstream from Big Shoals in Big Shoals State Park, although sturgeon have been sighted occasionally upriver as far as Cone Bridge Road (Randall, Written communication; USGS, 2016).

The primary spring spawning period is from the beginning of March through the end of April, with many adults remaining in the river through the summer. A second period of spawning occurs from early September through October (Randall & Sulak, 2012). Based on recent communication with the USGS (Randall M. , 2022), the sturgeon passage period is extended one month from the spawning periods (i.e., February – April and September – November). After fall spawning, as the water temperature cools, the fish migrate downriver to the Sound. Gulf sturgeon are sexually dimorphic and females are larger than males. Large, gravid females grow to total lengths of 7.5 to 8.0 feet, can weigh up to 300 pounds, and have dorsoventral body depths of 12 to 18 inches (Sulak K. , 2010). These features generally define the passage depth and channel width requirements for Gulf sturgeon.

Fish passage for sturgeon was not addressed in the Gulf sturgeon 5-Year Review (USFWS/NMFS, 2009), so the water depth needed for passage of adult sturgeon was approximated using the estimated dorsoventral body depth of adult female sturgeon. 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 (Randall, 2013). A channel width of no less than 15 feet, or about double the body length of a large female adult, would allow adult sturgeon to turn in the river.

The critical cross-section in the USR reach is at RM 134.61, just downstream from Nobles Ferry, where the minimum width of 15 feet and depth of three feet would limit sturgeon passage would be first encountered when traveling upstream. Based on the HEC-RAS output, a maximum depth of four feet (i.e., three-ft minimum plus safety factor of one ft) at the shallowest cross-section (RM 134.61) between Ellaville (RM 127.49) and Trillium Bluff (RM 138.01) ensures that the proposed condition for passage of the Gulf sturgeon is met (Figure 65) for the 15-foot turning width. This condition is met when the flow at White Springs is about 45.3 cfs and the flow at Suwannee Springs is about 164 cfs (Table 15).

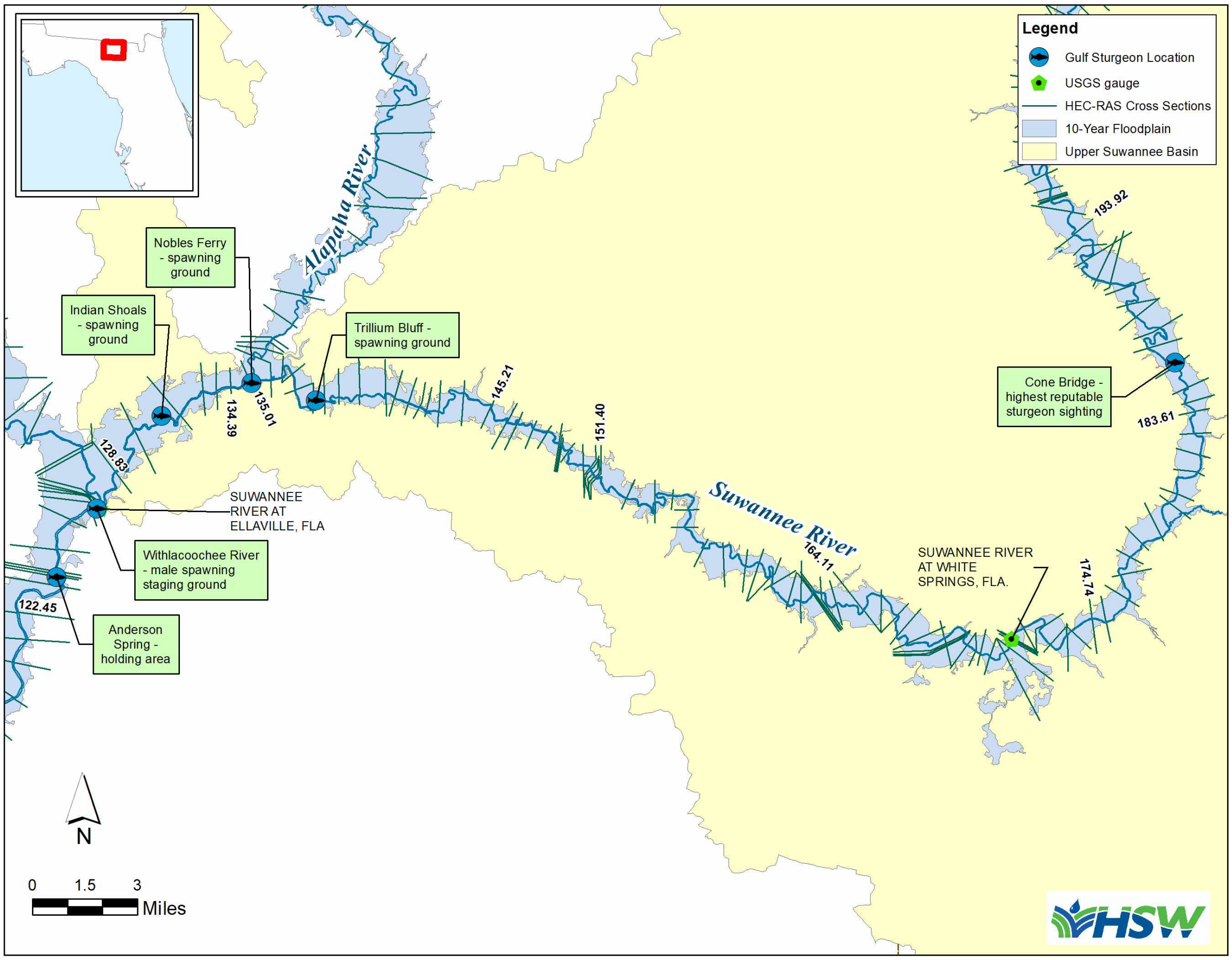


Figure 64. Locations of Gulf sturgeon spawning grounds in the USR

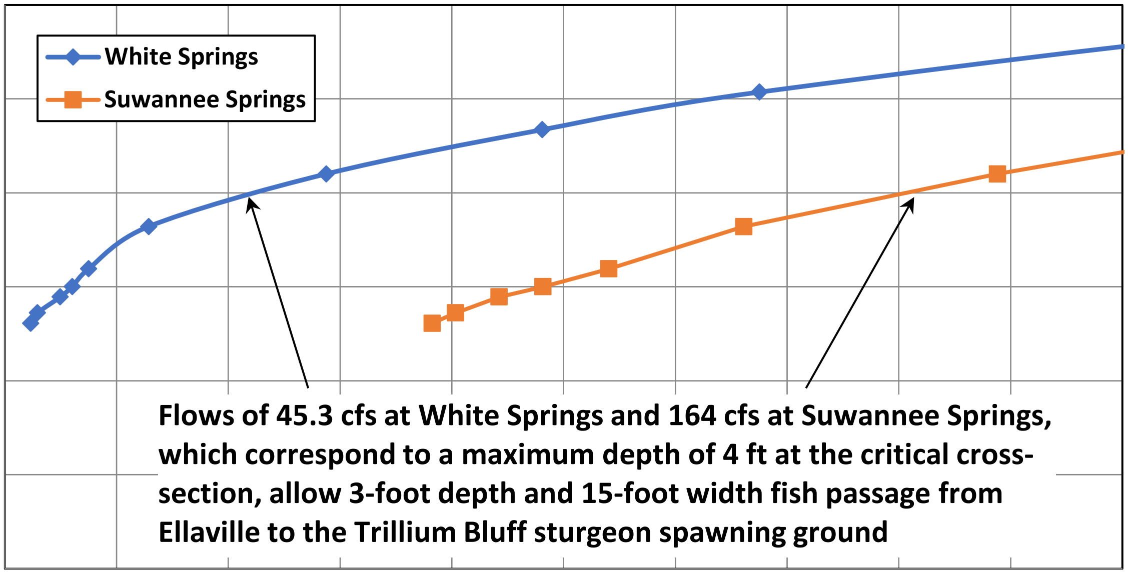


Figure 65. Maximum depth versus flow at the White Springs and Suwannee Springs gages at the limiting cross-section for determining conditions for adult Gulf sturgeon passage

Both sturgeon migration periods relative to the White Springs and Suwannee Springs gages were evaluated using the percent-of-time method; specifically, the flow reduction associated with a 15% decrease in time that flow is greater than 45.3 cfs and 164 cfs, respectively, during each migration period (Table 15). While the percent allowable change in flow is large as measured at both gages, the decrease in passage days is only 12-13 days during the spring and fall migration periods, and 74 (Spring) to 69 (Fall) days remain available for passage. Gulf sturgeon have been monitored in the Suwannee River moving upstream at an average speed of 3.5 km/d (2.2 mi/d) and downstream at an average speed of 6.2 km/d (3.9 mi/d) (Foster & Clugston, 1997) giving ample time to reach spawning areas.

Gulf Sturgeon Spawning

At the spawning areas (Figure 64), the USGS has recommended a minimum depth of 6 feet, or about four times the maximum body depth of an adult female sturgeon, for cover to shade the spawning site and afford protection from predators (Randall, 2013).

HEC-RAS cross-sections exist for the spawning sites at Indian Shoals (RM 131.60) and Nobles Ferry (RM 135.01). The HEC-RAS modeled discharge ratings for RM 131.60 and RM 135.549 indicate that flows of 4,945 cfs and greater at Indian Shoals and 2,641 cfs or greater at Nobles Ferry would inundate each spawning site at least six feet. When translated to the White Springs gage, the critical flows for the Indian Shoals and Nobles Ferry spawning sites are equivalent to 1,931 and 1,585 cfs, respectively. The greater of these two flows (Indian Shoals) would be protective of both spawning sites and was selected for the MFLs assessment. The spawning ground at the Indian Shoals site becomes inundated as flow, referenced to the White Springs gage, begins to exceed about 245 cfs (Figure 66).

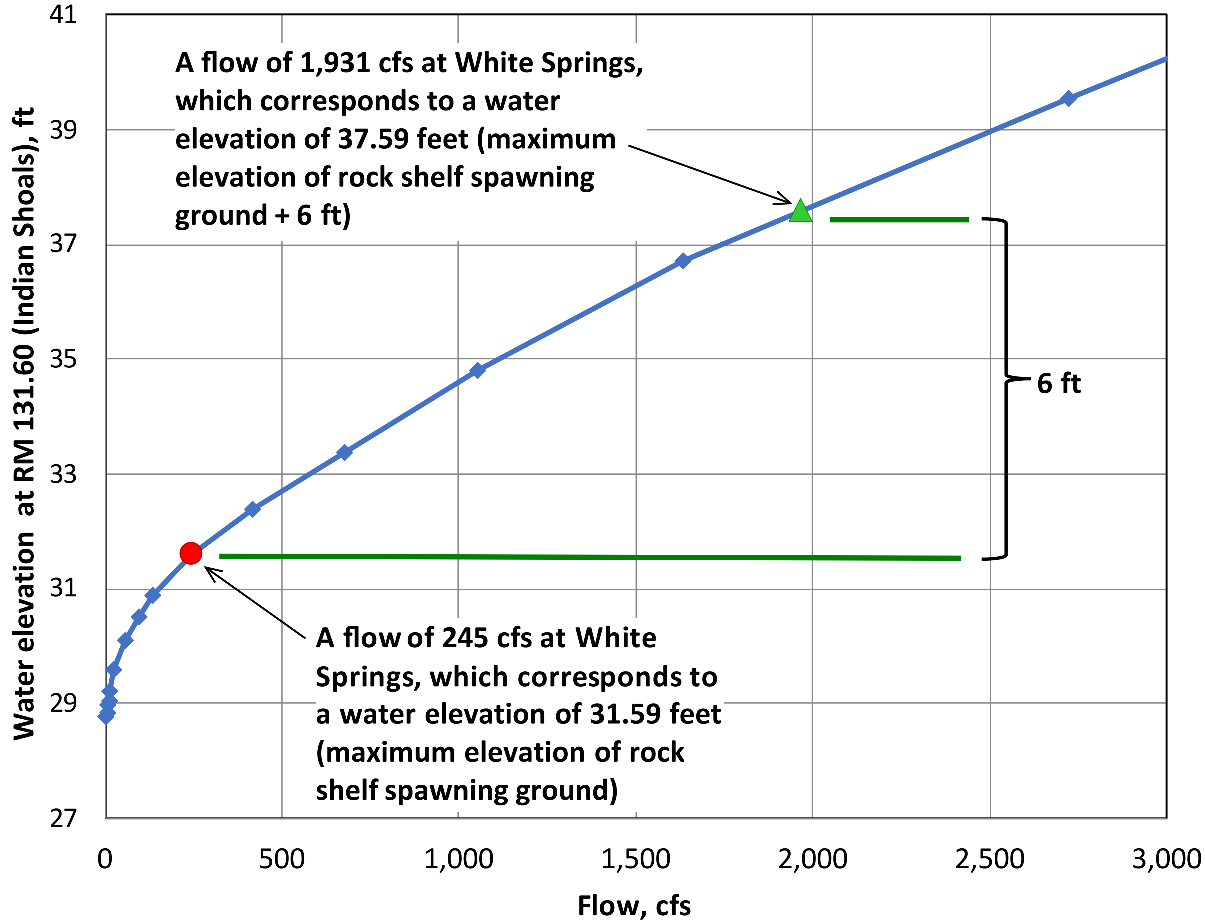


Figure 66. Water elevation versus flow at the limiting cross-section for determining conditions for adult Gulf sturgeon spawning

Both sturgeon migration periods were evaluated using the percent-of-time method; i.e., the flow reduction associated with a 15% decrease in time during each migration period that flows exceed 1,931 cfs. The associated changes in flow at the White Springs gage are 24.9% (640 cfs) and 16.1% (368 cfs) in the spring and fall periods, respectively (Table 15). Similar percent flow reductions were estimated at the Suwannee Springs gage with spring and fall flow reductions of 659 cfs and 368 cfs, respectively.

Fish Passage

Of the approximately 30 fish species other than Gulf sturgeon that generally are resident in the USR, adults of several species (e.g., largemouth bass, bowfin, chain pickerel, channel catfish, and longnose gar) achieve the largest body size. Thompson's (1972) study on minimum depth criteria (0.6 ft – 0.8 ft) for passage of fish has been widely used throughout Florida in assessing MFLs (SWFWMD, 2002), (Kelly, Munson, Morales, & Leeper, 2005); (Munson & Delfino, 2007). Given that Thompson's work was based upon fish species and streams dissimilar to Florida rivers (e.g., large species such as Chinook salmon in cold, well-oxygenated water), some fishery resource managers in Florida have cautioned against the direct use of Thompson's minimum depth range for Florida rivers and streams (Warren G. , 2004; HSW Engineering, Inc. (HSW), 2007; 2008). doubled Thompson's 0.8 ft criterion to provide a conservative safety factor when assessing MFLs within different portions of the St. Johns River. Neubauer et al. (2008) used a fish passage criterion of 0.8 ft depth over 25% of the channel as a low flow non-exceedance event, which means that the significant harm criterion is associated with an increase in the frequency of low-flow events. The SJRWMD criterion was used by the SRWMD for recent MFLs developed for the Lower Santa Fe River (SRWMD, 2013) and was used in fish passage analysis for the Aucilla River (HSW, 2016). This same criterion is used in fish passage analysis for the USR.

Based on the HEC-RAS output, the most restrictive cross-section for a depth of 0.8 ft is RM 176.15 at Big Shoals (Figure 67). The channel width at RM 176.15 is about 243.12 ft and, hence, fish species need a depth of 0.8 ft over a width of 60.8 ft (25% of 243.12 ft) at RM 176.15. The flow condition at RM 176.15 that provides the required cross-sectional area (60.8 ft × 0.8 ft) is about 340 cfs (352 cfs at the White Springs gage, RM 171.13, and about 520 cfs at the Suwannee Springs gage, RM 150.32). A 15% decrease in the number of days that this flow condition is exceeded results in an allowable flow reduction of about 217 cfs, or 38.1%, when flow is 569 cfs at the White Springs gage and 238 cfs at the Suwannee Springs gage (Table 15).

The fish passage analysis identified two flow scenarios that bracket the viable passage of a large fish (gravid Gulf sturgeon) within a subreach of the USR and smaller fish within the entire length of the USR. The endpoints for the viable flow range (i.e., 45.3 and 352 cfs at the White Springs gage) are attributable to two unique characteristics of the USR. First, the Gulf sturgeon analysis considered the most downstream 10.5 river miles that extend from Ellaville to the most upstream known Gulf sturgeon spawning bed at Trillium Bluff (Figure 64). Second, the USR thalweg is highly irregular and numerous shoals and pools exist within the study reach (Section 3.3). Located 48.7 river miles upstream from the Ellaville gage, Big Shoals is the largest shoal (i.e., it creates the longest pool) and most restrictive location for general fish passage throughout the length of the USR. As flow at White Springs declines below 352 cfs, general fish passage would be restricted at an increasing number of shoals. Similarly, as flow increases above 45.3 cfs, the passage of adult Gulf sturgeon upstream from Trillium Bluff would become more viable.

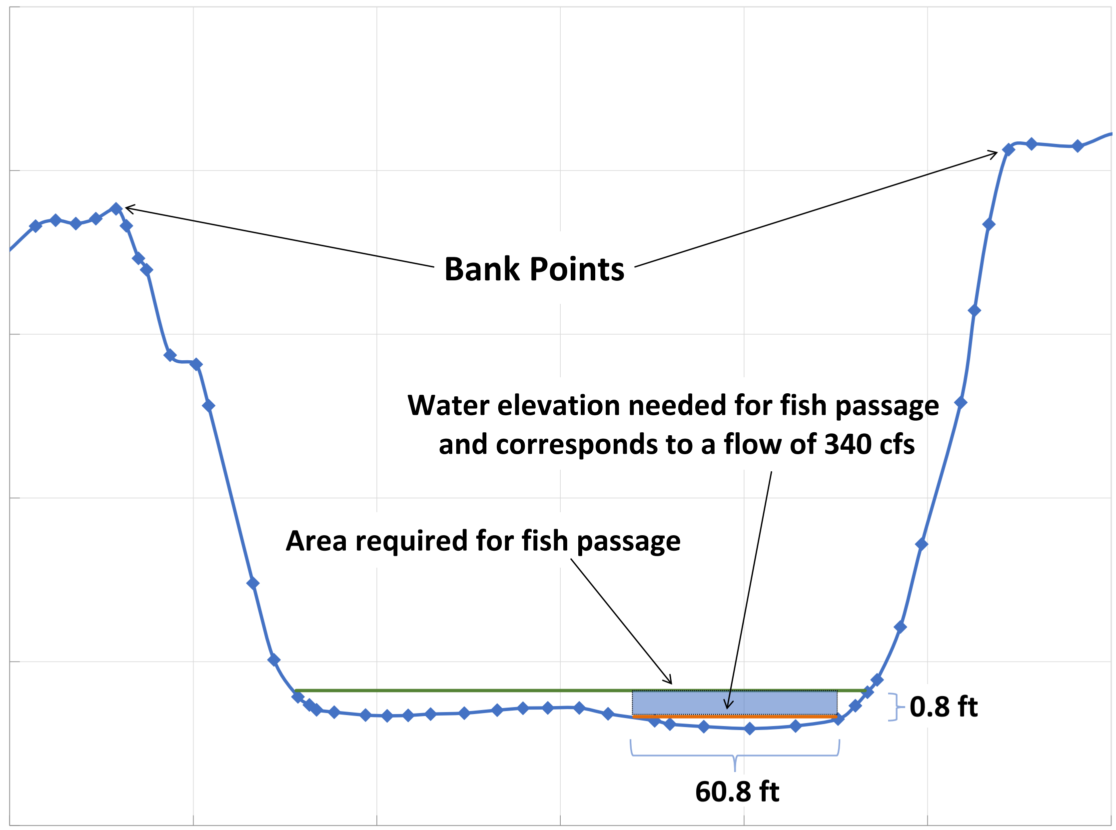


Figure 67. Critical cross-section for fish passage (RM 176.15)

5.2.2 In-Stream Habitat

5.2.2.1 Suitable Habitat Area

As previously discussed in Sections 3.4 and 4.3.3, SEFA was used to evaluate potential changes in habitat for fish and other biota associated with the variation of flows at selected sites in the USR. The sites and aquatic biota selected for SEFA modeling were representative of the different trophic levels, hydraulic conditions, and substrate found in the USR. Four sites (I2, I3, I5, and I8) were selected along the USR and survey data were collected at three transects (T1, T2, and T3) during three different flow/stage conditions at each of the four sites (Figure 50). I2 is the upstream site located near the CR6 Bridge, and I8 is the downstream site at the Indian Shoals Gulf sturgeon spawning site, located 1.3 miles upstream of Road 141 boat launch in Hamilton County (http://www.mysuwanneeriver.org/launches/index.html). Necessary data needed to calibrate SEFA, such as channel geometry, velocity, discharge, depth, and substrate, were collected during three field surveys performed on March 13-16, 2012; May 15-16, 2012; and July 23-25; 2012, at all four sites.

A single SEFA model was developed using the data collected at the four sites for a total of 12 transects in the model. In addition, a single SEFA model was run for Gulf sturgeon using only data collected at site I8. The three sets of stage and flow measurements were used to establish log-log rating relationships for each transect in the SEFA program. The rating curves were each calculated using the same method applied in the Physical Habitat Simulation Model (PHABSIM) (Jowett, Payne, & Milhous, 2014) (Milhous & Waddle, 2001). Forty-three habitat suitability curves of various species and life stages were incorporated into the SEFA models.

The velocity, depth, and habitat preference criteria (bottom substrate) for each species and life stage were utilized in the calculation of the AWS (Chapter 4), which is a measure of suitable habitat available to a target organism within the model reach. Site I8 also is a Gulf sturgeon spawning ground in the USR; therefore, Gulf sturgeon-juvenile/adult habitat suitability curves were used in the Site I8 SEFA model. Area Weighted Suitability time series corresponding to the daily time series of flow were developed for each of the target organisms. The flow change associated with a 15% change in AWS for each target species was determined using a non-linear solver routine.

A reliable range of instream habitat model applicability is between 0.5 and 2.0 times the lowest and highest measured flows, respectively, observed during a targeted flow regime to calibrate the habitat model (Gore, McKinney, & Nagid, 2012). Two model scenarios were run – one using a constant percent change in flow across the model flow range and a second using a constant flow reduction across the flow range. Based on the constant flow reduction scenario, Largemouth Bass-fry is the most restrictive species/life stage with a 111 cfs and 126 cfs reduction associated with a 15% reduction in AWS as referenced to the White Springs and Suwannee Springs gages, respectively (Table 17). Other species and life stages, including Gulf sturgeon, were not sensitive to flow reductions up to 40% of the RTF flow (Appendix E).

Table 17. Habitat suitability curves used in the MFL analysis

Species	Change in Flow (%)	Constant Change in Flow (cfs)	Months analyzed
White Springs gage			
Largemouth Bass – fry	8.1	111	March-July
Suwannee Bass - Spawning	7.2	114	March-June
Largemouth Bass – adult	11	130	Jan-Dec
Suwannee Springs gage			
Largemouth Bass – fry	7.8	126	March-July
Suwannee Bass - Spawning	6.9	129	March-June
Largemouth Bass – adult	10.2	143	Jan-Dec

5.2.3 Floodplain Habitat

Three approaches for developing a potential MFL flow reduction are described in Section 4.5, with floodplain habitat used as the example. The communities were used as metrics for assessing possible flow reductions that would remain protective of floodplain habitat and associated forest composition, wetland biogeochemical processes, and fish and wildlife habitat. The change-in-area method, under which the inundated wetland area would be reduced by 15%, resulted in an allowable flow reduction of 740 cfs (9.0%) when RTF flow is 8,271 cfs at the White Springs gage (Table 14). Translated to the Suwannee Springs gage, the available water is 698 cfs when flow is 8,339 cfs.

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 68). Sediment transport amount, or sediment load, is then conveyed as a mass or weight per unit time such as tons/day or kilograms/second.

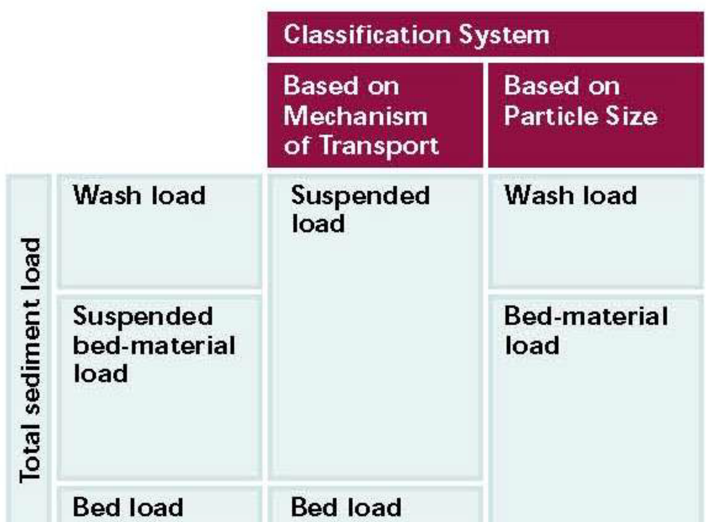


Figure 68. Sediment load classification categories (FISRWG, 1998)

The primary sediment load related features of the USR 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 69) 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 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 of the dynamic nature of a river system as represented in Lane's Diagram (Figure 69).

The long-term frequency of those events can change (relative to the baseline or historical frequency) by some amount due to anthropogenic activities, but not so much as to cause significant harm to the water resource and ecology. The implication is that there is a frequency range of hydrologic events that will protect the functions and processes that are beneficial to the river system. For example, a bankfull discharge event with a return interval on the order of 1.5 to 2 years is consistent with certain channel formation processes (Julien, 2002).

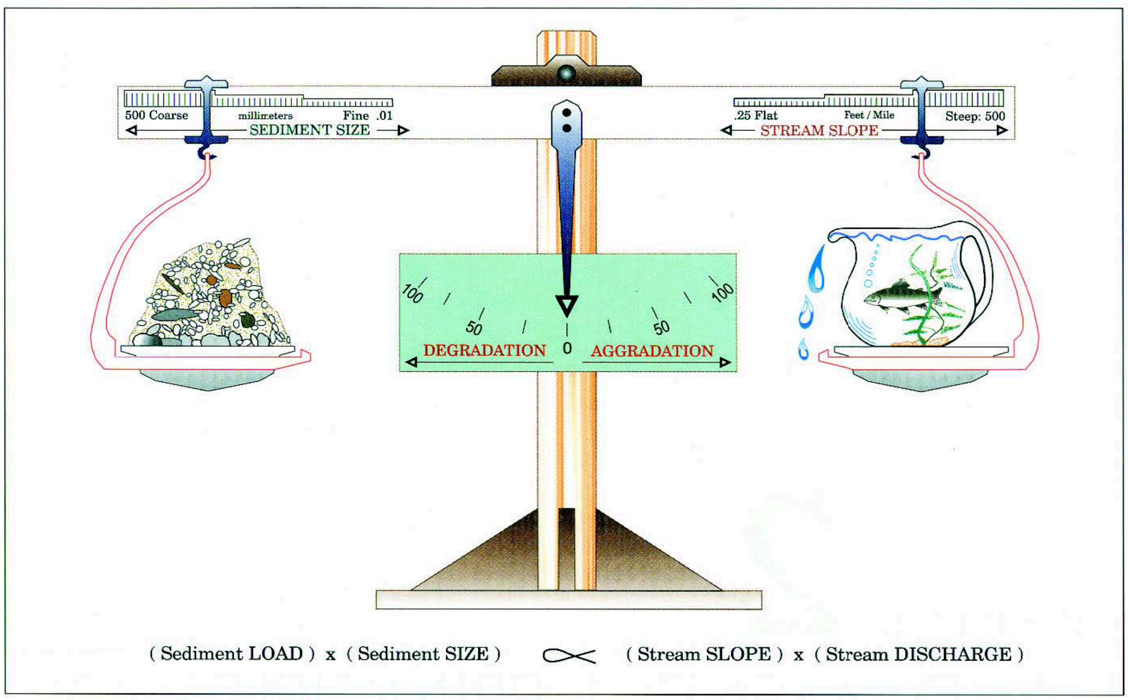


Figure 69. Lane's Diagram representing the balance of dynamic river forces (Rosgen, 1996)

In addition to considering critical 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 transfer associated with floodplain connectivity and channel geomorphology are protected.

The channel geometry data determined by field surveys and the steady state HEC-RAS model of the river are the best information available for characterizing bankfull conditions. The bankfull condition characteristic of the entire study reach is indicated by the distinct change in slope of the flow-area association (Figure 70). The inundation area is the area of the water surface for the length of the study reach associated with a prescribed flow condition at White Springs that was simulated using HEC-RAS. While the actual stage at any location associated with the bankfull condition may be higher or lower than the top of bank, the graph depicts an overall condition for the entire study reach.

Under RTF flow conditions, the bankfull flow of 7,040 cfs at White Springs is exceeded 5.2% of the time, or about 19 days per year on average. A 15% reduction in the time that flow equals or exceeds the bankfull condition results in an exceedance of 7,491 cfs about 4.4% of the time. This reduced exceedance scenario permits a withdrawal of about 451 cfs when discharge at the White Springs gage is 7,491 cfs, about a 6.0% flow reduction (Table 15). The available water is 473 cfs when flow is 7,631 cfs at the Suwannee Springs gage.

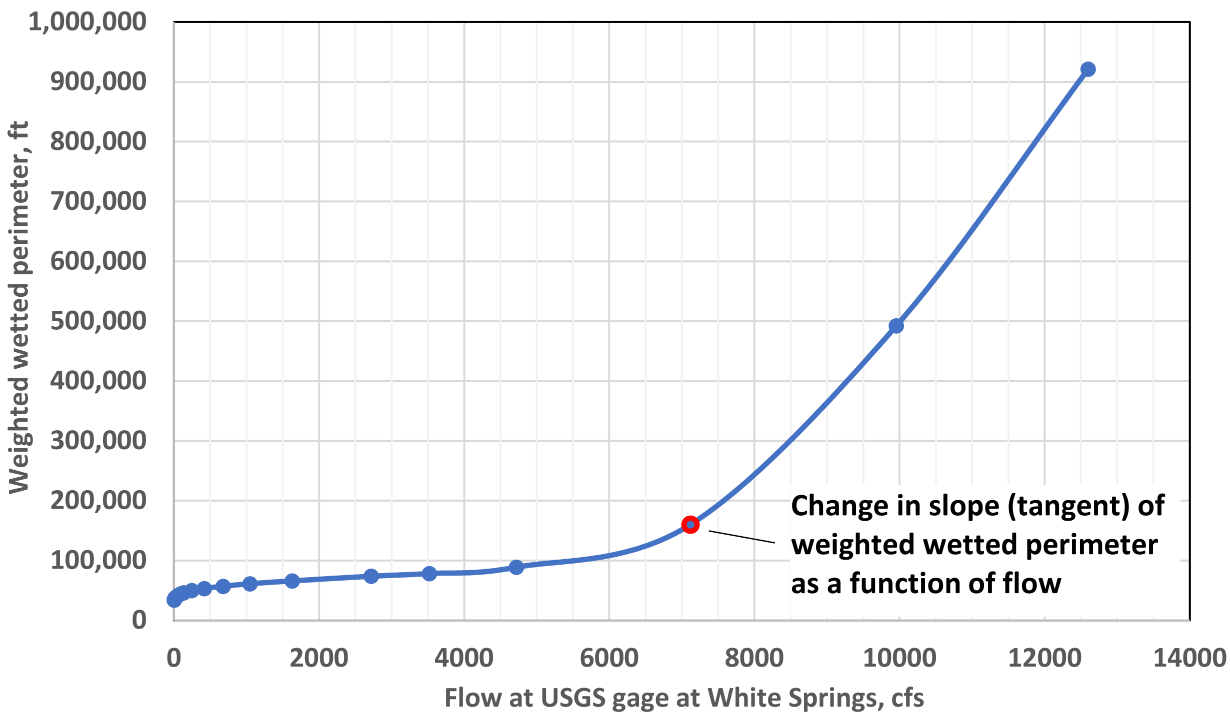


Figure 70. Weighted wetted perimeter versus flow at the USGS gage at White Springs

5.4 Water Quality

For this analysis, water quality is defined as the chemical and physical properties of the aqueous phase within the USR. The chemical and physical properties of the water that support the aquatic community serve as indicators for protection of water quality.

Section 403.061(27), *F.S. (Florida Statutes)*, grants the FDEP the authority to establish rules that provide for a special category of waterbodies within the state, referred to as Outstanding Florida Waters (OFWs), that are worthy of special protection because of their natural attributes. The Suwannee River, including this MFLs study reach, is designated as an OFW. The Gulf sturgeon and Suwannee bass are species of particular interest to this MFLs assessment.

The specific indicators of protection are the concentrations of key water quality parameters influenced by flow. Water quality parameters known to influence the fecundity of key species are of particular interest.

5.4.1 Conductivity and Gulf Sturgeon Habitat

Dissolved oxygen (DO), calcium ions, conductivity, and pH are the major water quality parameters of concern for the Gulf sturgeon in the USR (HSW, 2010). The current State DO criteria (62-302.533. F.A.C) and associated Technical Derivation Document identify a baseline DO concentration of 5.7 mg/L within the Ellaville to White Sulphur Springs reach (i.e., WBID 3341) below which young Gulf sturgeon may become stressed. The District maintains a water quality monitoring station (SUW070C1) in this reach that has substantially more DO measurements than any other monitoring location within the reach. The station is located at the old bridge just downstream from the Suwannee Springs spring and river gage (HEC-RAS RM 149.9). DO measurements (296 in total) for this station were downloaded from WinStoret for the period 2/1989 – 2/2017, and daily river flows at the Suwannee Springs gage were obtained for those dates. Although DO is known to be positively correlated with flow, no meaningful relation between flow and DO concentration, or flow and DO saturation, is apparent in this dataset.

Clugston and Sulak (1999) examined water quality characteristics at Suwannee River sturgeon spawning sites. They determined that a slightly alkaline pH, calcium concentration between 6-18 milligrams per liter (mg/L), conductivity between 40 and 110 µS/cm (microsiemens per centimeter at 25 °C), and a steady flow rate (to provide a more predictable and adequate DO supply) were characteristics within the areas of the river containing known spawning beds (Table 18). The authors found that spawning appears to cease when water temperatures climb to 21-22 °C. Gulf sturgeon in the Apalachicola River spawn at slightly higher temperatures (Parauka & Scollan, 2008) and at slightly higher conductivities than in the Suwannee (Clugston & Sulak, 1999) (HSW, 2010).

Conductivity, calcium, pH, and Secchi transparency depth are associated with flow (HSW, 2010). If a suitable relationship exists between flow and a specific parameter, the endpoints of a range represent indicators that can be used to determine a range in flow suitable for spawning.

The water quality data used to evaluate the relationships of these four water quality parameters of interest and flow were collected independently by SRWMD at gage SUW070C1 from 1979 through 2015 and by the USGS at gage 02315550 (also located at Suwannee Springs) from 1956 through 1988. The data were examined to confirm consistency and eliminate duplicate records then combined into a single dataset to determine the relationship between a given water quality parameter and flow.

Table 18. Range in water quality for successful Gulf sturgeon spawning

Water quality characteristic	Range for successful Gulf sturgeon spawning	Limiting value for lowest flow	Limiting value for highest flow
Conductivity, umhos/cm	40 to 110	110	40
Calcium, mg/L	6 to 18	18	6.0
pH	7.0 to 7.5	7.5	7.0
Secchi depth, m	0.6 to 1.4	1.4	0.6

[Source: Clugston & Sulak, 1999]

Associations relating each of these four water quality parameters to flow previously were evaluated (HSW, 2010). Of these, conductivity was determined to be the most relevant to Gulf sturgeon, i.e., the low limiting indicator flows for calcium and pH were determined to be outside the range for conductivity and, hence, are not limiting. Using the combined dataset described in the preceding paragraph, the relationship of conductivity with flow at the Suwannee Springs gage (Figure 71), as expressed by the LOESS curve, indicates that the flows associated with conductivity limits of 40 and 110 uS/cm conducive to Gulf sturgeon spawning are about 17,000 and 767 cfs, respectively. Conductivity increases much more quickly as flow declines below 767 cfs and changes very little at flows of about 2,000 cfs or higher. Thus, the critical value relevant to Gulf sturgeon spawning is a flow of 767 cfs at Suwannee Springs. This is translated to an equivalent flow of 566 cfs at the White Springs gage.

Under RTF flow conditions, a flow of 566 cfs at White Springs is exceeded about 74.4% of the time during the early Gulf sturgeon spawn in March and April (about 45 days in March-April of each year). A 15% decrease in the number of days when conductivity exceeds the 110 µS/cm threshold conductivity is associated with a non-exceedance frequency of 63.2%, or about 39 days for the season. This reduced-flow scenario for baseline March/April conditions allows a withdrawal of 485 cfs when discharge at the White Springs gage is 1,051 cfs (Table 15). Using a similar approach, the baseline September/October conditions would allow a withdrawal of 187 cfs when discharge at the White Springs gage is 753 cfs (Table 15). The available water is 562 and 243 cfs at the Suwannee Springs gage for the spring and fall seasons, respectively.

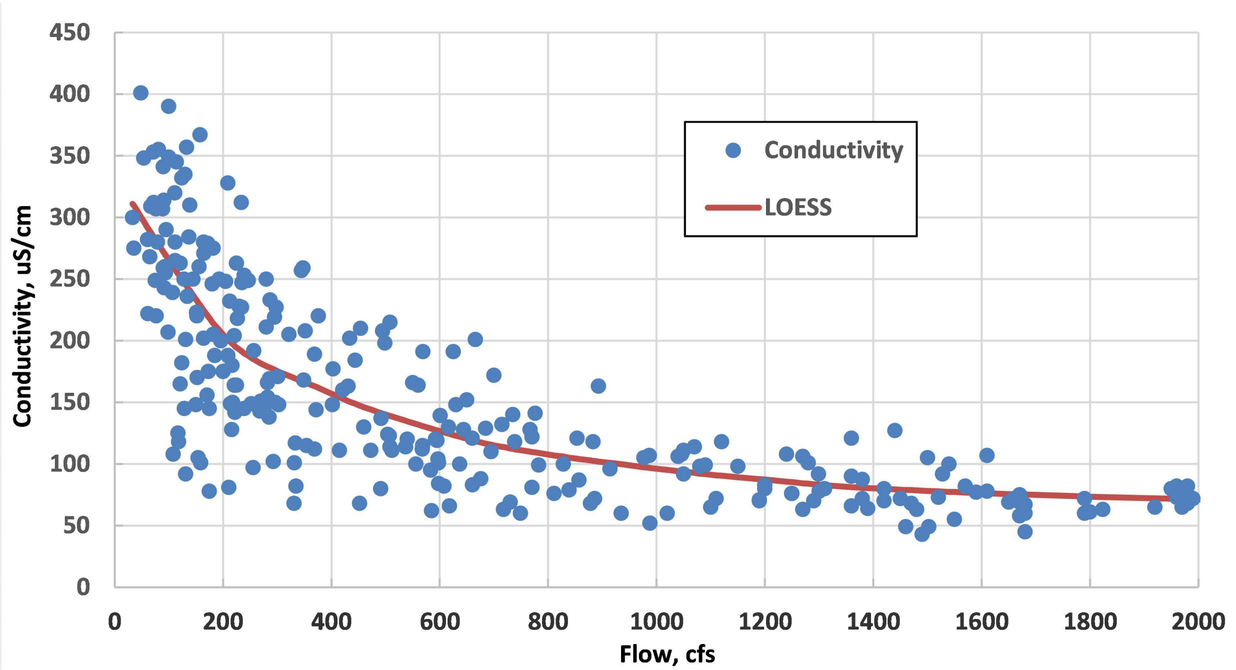


Figure 71. Association between field conductivity and flow of Suwannee River at Suwannee Springs

6.0 RIVER MFLS

6.1 Introduction

The USR is a run-of-river system 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 downgradient from Cody Scarp, is the primary source of USR base flow. Therefore, an approach that considers WRVs associated with a wide range of naturally occurring hydrologic conditions was performed for this MFL assessment.

The USR was evaluated to determine a flow regime that would provide the necessary level of protection to prevent significant harm to recreational activities, fish passage, fish and wildlife habitat, sediment loads, and water quality. The best available information was used to identify specific indicators for evaluating flow-reduction scenarios that would protect these resources. Multiple locations within the study area and a range of flows were evaluated.

An RTF time series of daily flows (baseline flow record), as described in Section 2.9, reflects estimated flow conditions unimpacted or minimally impacted by groundwater withdrawals. This RTF time series of daily flows spans a 78-year period from WY 1938 through WY 2015 and was evaluated as the starting point for the USR MFLs assessment. Because of the lack of specific information regarding a flow reduction that would no longer be protective of the selected resources, a flow reduction from the RTF condition that results in no greater than a 15% reduction in a metric, such as usable area and/or inundation time, was an allowable flow reduction for the resources evaluated.

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 USR were translated into equivalent flows at the White Springs and Suwannee Springs river gages.

Flow reductions, or hydrologic shifts, from the RTF flow hydrology were evaluated (Chapter 5.0) at the threshold flows associated with recreational activities, fish passage, fish and wildlife habitat, sediment loads, and water quality on the USR (Table 19 and Table 20). Most metrics used to evaluate WRVs, such as recreational paddling and fish passage, are associated with discrete RTF flows. Others, such as the AWS for instream habitat, are associated with a range of flows. The percent-of-flow reductions associated with these threshold flow regimes would shift the RTF flow duration curves at the White Springs and Suwannee Springs gages by varying amounts (Figure 72 and Figure 73). The discrete threshold flows are represented by X's on the graphs, and the metrics associated with a range of threshold flows are represented by the dashed lines (Figure 72 and Figure 73). When plotted at the exceedance frequencies evaluated, the threshold flows are lower than the corresponding RTF flows, and the hydrologic shifts assessed collectively for each station vary over the range of flows evaluated. When the hydrologic shifts are plotted at the RTF flow for the two gages, the shifts generally increase with flow (Figure 74 and Figure 75). The limiting flow reduction determined for each station would shift the RTF flow duration curves downward to the threshold flow associated with the limiting WRVs.

6.2 Proposed MFLs

The MFLs recommended for the USR are based on professional judgment, reflective of the river's designation as a Special Water OFW (Section 1.2), and supported by the weight of evidence from analyses of flow reductions (hydrologic shifts) that would remain protective of recreation on the river, riverine and floodplain habitat, sediment loads, and water quality (Figure 72 and Figure 73). The hydrologic shifts evaluated for the USR are referenced to the White Springs and Suwannee Springs gages and ranged from 82.3 to 740 cfs (Table 19) and from 96.8 to 698 cfs (Table 20).

White Springs gage (Table 19)
For the USR at the White Springs gage, Gulf Sturgeon passage during the fall spawning period, as determined using the percent-of-time method, is recommended as the restrictive WRV, with a hydrologic shift of 82.3 cfs.

Suwannee Springs gage (Table 20)
For the USR at the Suwannee Springs gage, Gulf Sturgeon passage during the fall spawning period, as determined using the percent-of-time method, is recommended as the restrictive WRV, with a hydrologic shift of 96.8 cfs.

The MFL proposed for a gaging station is based on a restrictive hydrologic shift developed from the WRVs evaluated and is applied at the median flow (Table 21).

- White Springs gage – at median flow of 676 cfs the change is 82.3 cfs, or a reduction of 12.2%.
- Suwannee Springs gage - median flow of 880 cfs the change is 96.8 cfs, or a reduction of 11.0%.

The difference between the RTF and MFL flows represents a potential maximum shift in the hydrology of the USR as measured at the White Springs and Suwannee Springs gages.

Table 19. Summary of WRV metrics and hydrologic shifts for the USR at the White Springs 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	172	323	151
	Boating		Percent-of-time	476	713	237
Fish and Wildlife Habitat and Fish Passage	Gulf sturgeon spawning passage	Feb-Apr	Percent-of-time	45	276	231
		Sep-Nov			128	82.3
	Gulf sturgeon spawning (6-ft depth)	Mar-Apr	Percent-of-time	1931	2571	640
		Sep-Oct			2301	370
	General fish passage and instream habitat		Percent-of-time	352	569	217
			SEFA (Largemouth Bass - fry)	565	676 [3]	111
	Floodplain habitat		Percent-of-time	7531	7956	425
			Percent-of-area	7531	8271	740
Bankfull condition (sediment loads)			Percent-of-time	7040	7491	451
Water Quality	Gulf sturgeon spawning (conductivity)	Mar-Apr	Percent-of-time	566	1051	485
		Sep-Oct			753	187

1. Reference timeframe
2. RTF flow minus threshold flow
3. Median RTF flow

Table 20. Summary of WRV metrics and hydrologic shifts for the USR at the Suwannee Springs 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	306	488	182
	Boating		Percent-of-time	655	926	271
Fish and Wildlife Habitat and Fish Passage	Gulf sturgeon spawning passage	Feb-Apr	Percent-of-time	164	426	262
		Sep-Nov			260	96.8
	Gulf sturgeon spawning (6-ft depth)	Mar-Apr	Percent-of-time	2251	2910	659
		Sep-Oct			2619	368
	General fish passage and instream habitat		Percent-of-time	520	758	238
			SEFA (Largemouth bass fry)	754	880 [3]	126
	Floodplain habitat		Percent-of-time	7641	8087	446
			Percent-of-area	7641	8339	698
Bankfull condition (sediment loads)			Percent-of-time	7158	7631	473
Water Quality	Gulf sturgeon spawning (conductivity)	Mar-Apr	Percent-of-time	767	1329	562
		Sep-Oct			1010	243

1. Reference timeframe
2. RTF flow minus threshold flow
3. Median RTF flow

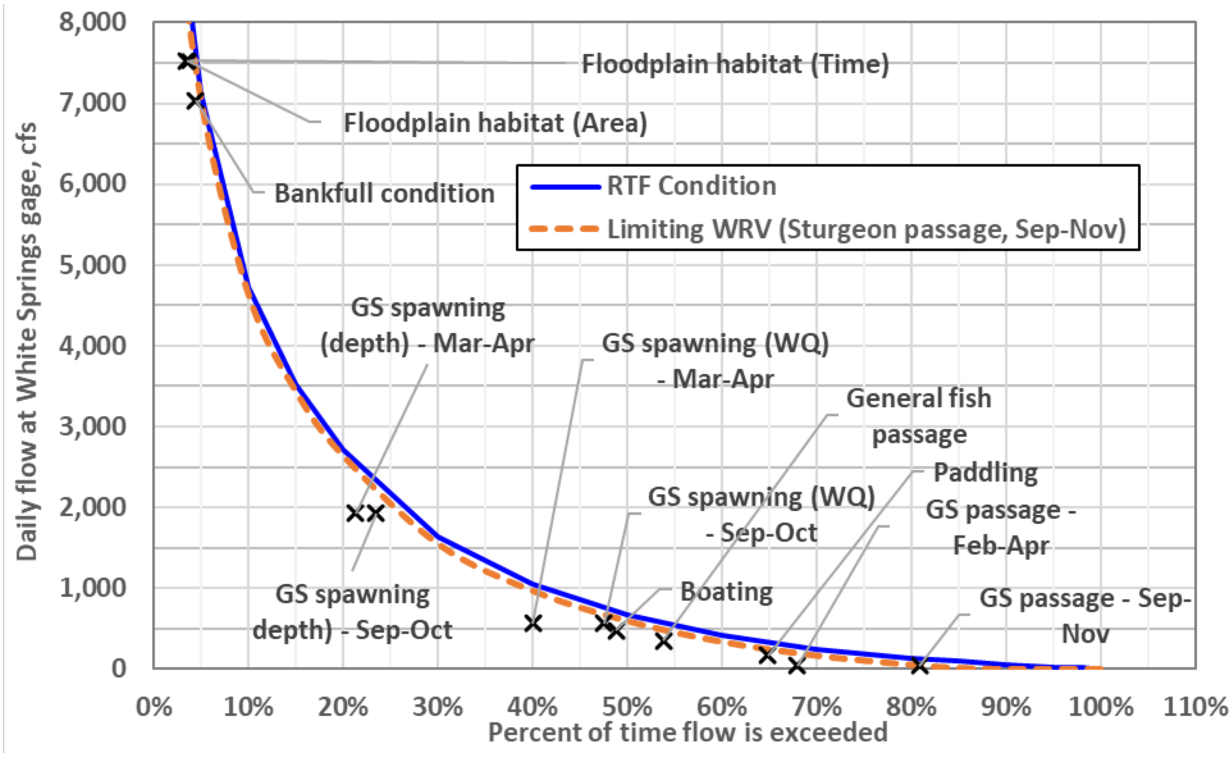


Figure 72. Flow reduction scenarios for the USR at the White Springs gage

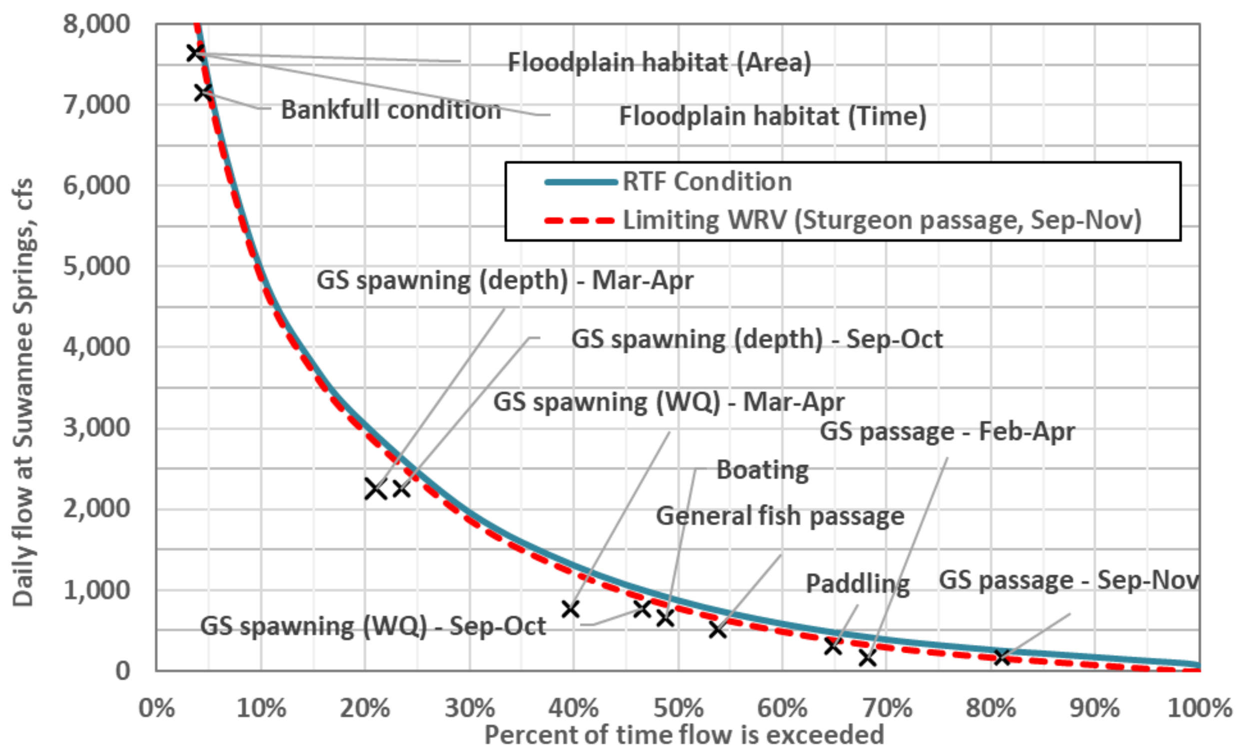


Figure 73. Flow reduction scenarios for the USR at the Suwannee Springs gage

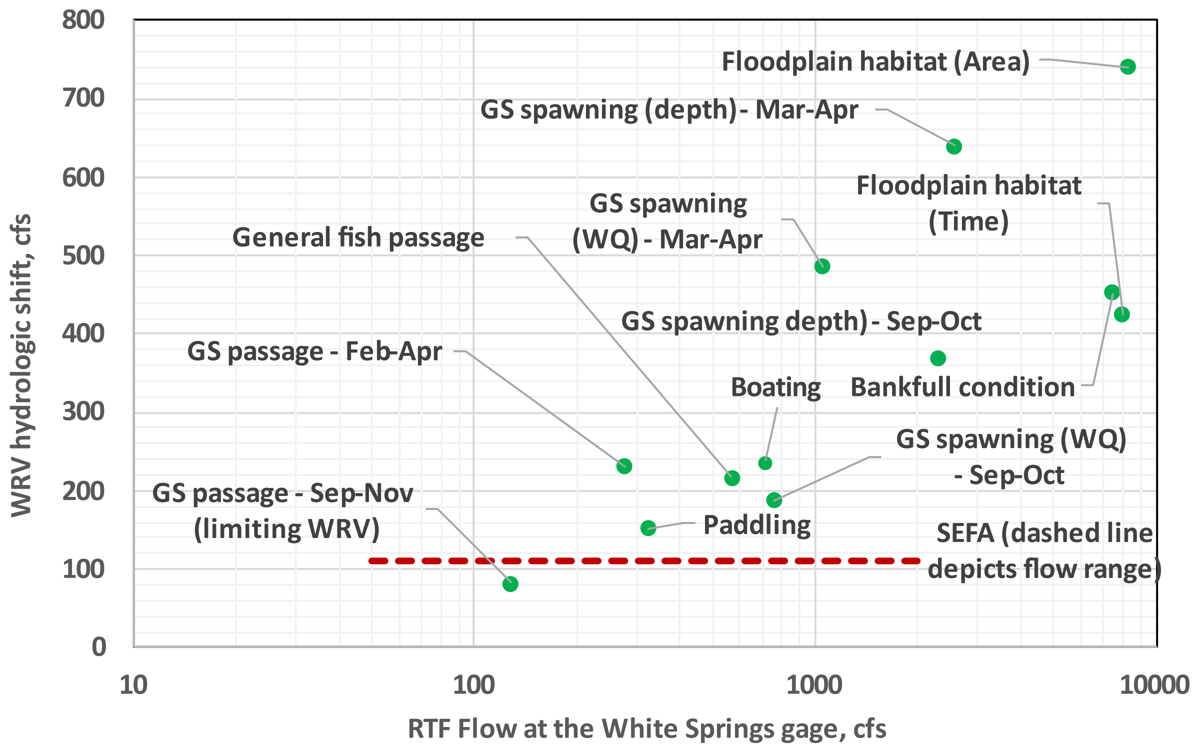


Figure 74. Flow available for withdrawal referenced to the White Springs gage

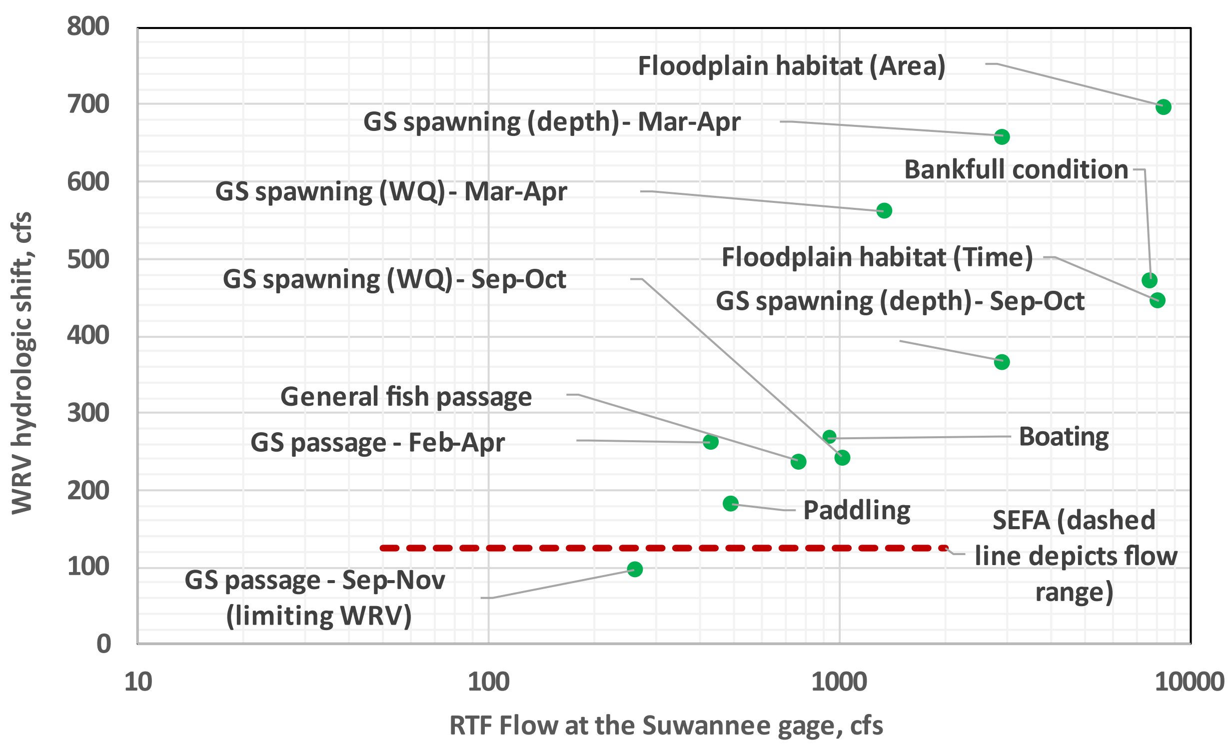


Figure 75. Flow available for withdrawal referenced to the Suwannee Springs gage

Table 21. RTF and MFL median flow at the upper Suwannee River White Springs and Suwannee Springs gages

Parameter/ gage	White Springs	Suwannee Springs
RTF median flow (cfs)	676	880
RTF average flow (cfs)	1730	1911
Hydrologic shift (cfs)	82.3	96.8
MFLs at median (cfs)	594	783
Relative flow reduction at median flow (average flow) (%)	12.2 (4.8)	11.0 (5.1)

6.2.1 Summary

The hydrologic shifts for this MFL evaluation are associated with a 15% reduction in time that a WRV-specific flow is exceeded (Munson & Delfino, 2007), a 15% reduction in inundated floodplain area, or a 15% reduction in AWS modeled by SEFA. The proposed MFLs are based on the most restrictive WRV evaluated for the White Springs and Suwannee Springs gages (Table 19 and Table 20) and are associated with hydrologic shifts of about 6% of the average RTF flows (Table 21).

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 MFL 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 21). 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, Davis, Apse, & Konrad, 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 (Richter, Davis, Apse, & Konrad, 2011). The following tiers of protection of natural structure and function were proposed as a presumptive standard that were based on percent-of-flow reductions and risk tolerance. These tiers are meant to be used when in-depth scientific analysis of environmental flows cannot be effectively completed within a timeline that supports the overall effort (Richter, et al. 2011).

- < 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 USR 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 and average flows at both gages on the USR are less than 10% of the average flow and between 10 and 20 % of the median flows (Table 21). Such flow reductions would provide adequate protection under the paradigm proposed by Richter, et al. (2011) 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, Davis, Apse, & Konrad, 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 White Springs 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 F).

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