Minimum Flows and Minimum Water Levels Re-evaluation for the Lower Santa Fe and Ichetucknee Rivers and Priority Springs

Appendix E
HEC-RAS Model

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CONTENTS

ATTACHMENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

An existing transient HEC-RAS model of the Lower Santa Fe River (LSFR) and Ichetucknee River (IR) system was refined in support of a Minimum Flows and Minimum Water Levels (MFL) re-evaluation for the Suwannee River Water Management District (the District). Previous modeling efforts of the Lower Santa Fe River include:

- Hydraulic models developed by the U.S. Army Corps of Engineers (USACE) and (Taylor Engineering, Inc. 2002).
- In 2005, the Federal Emergency Management Agency (FEMA) modified a steady state HEC-RAS model of the Lower Santa Fe River (LSFR) for use in flood insurance rate mapping (FEMA 2006a) and (FEMA 2006b)
- In 2007, the steady state HEC-RAS model of the Lower Santa Fe River was modified to include a transient simulation and to represent low flow conditions (INTERA 2007).
- For the initial MFLs assessment (SRWMD 2013), the steady state model –developed by INTERA in 2007 – was geo-referenced and further modified to include new survey data and best available data from the existing models and executed using HEC-RAS version 4.1.0. Swallets, resurgences, and other karst features and their hydraulic relationships were modeled using the synthesized lateral inflows and the HEC-RAS pressurized conduit flow option.

Work performed by HSW to refine the initial MFLs assessment HEC-RAS model includes:

- Executing transient and steady state simulations using the current HEC-RAS version 5.0.6.
- Updating cross-section geometry data based on the latest available LiDAR data provided by the District. Hydraulic control areas in the Lower Santa Fe and Ichetucknee Rivers (e.g., shoals) observed during the field investigation conducted by HSW and the District on April 19 and 20, 2018, are depicted in the model. No additional hydrographic survey data were collected.
- Translating elevations represented in the model from the NGVD29 vertical datum to NAVD88. The geometry and stage data input to the updated model and calculated by the model are referenced to NAVD88.
- Revising steady state model input flow data to reflect the NFSEG-adjusted Reference Timeframe flow records considered for the MFLs re-evaluation.
- Resolving numerical instability issues so that transient and steady state simulations ran successfully.
- Evaluating transient model calibration and validation metrics for a 3,516 day simulation period from February 13, 2002, through September 29, 2011.
- Converting the calibrated transient model into a steady state model to represent a variety of probable flow conditions.
- Evaluating an alternative steady state model downstream boundary condition and the association between LSFR flow and stage at the junction of the Suwannee River (SR) and Santa Fe River (SFR) representing a condition when backwater effects are minimal relative to observed conditions.
- Simulating steady state profiles and velocity distributions for multiple Reference Timeframe flow exceedance frequencies for the period February 5, 2002, through September 30, 2015.

The updated transient model was validated by calculating values for the coefficient of model-fit efficiency, *E*, defined by (Nash and Sutcliffe 1970) and comparing the goodness-of-fit metric to literature values for model acceptability. Coefficient values were calculated for the discharges and water depths simulated and observed during the transient modeling period. Of the six locations evaluated for flow prediction accuracy, two were rated Very Good based on E values, one was Good, and three were Satisfactory. Of the seven locations evaluated for depth prediction accuracy, four were rated Very Good based on E values, one was Satisfactory, and two were Unsatisfactory. One gage rated Unsatisfactory is upstream from the area of interest (Santa Fe River Rise to mouth) and the other is at a location where there was a small variation in observed depths. Time series plots and frequency curves comparing simulated and observed daily discharges and depths during the nearly 10-year simulation period illustrate reasonable associations that are consistent with the model-fit efficiency values.

At Dampier's Landing on the Ichetucknee River, the simulated flow is consistently lower than the measured flow. The most likely cause of an apparent loss of flow in the upstream direction from the long-term gage at Highway 27 was from bias in the measurements at the upstream sites in areas with vegetation in the flow-measurement areas.

Considering the statistical and graphical validation results presented in this Appendix, it is concluded that the transient HEC-RAS model provides an acceptable simulation of flows and water depths in the Santa Fe and Ichetucknee Rivers over a wide range of flows, particularly in the area of interest for the MFLs re-evaluation. Relative to commonly applied model fit-quality criteria, the statistical results achieve at least satisfactory results throughout the study area with many of the results meeting good or very good fit quality. The parameterization of the calibrated transient HEC-RAS model is suitable for adaption as steady-state model of the Lower Santa Fe River system that can be used for the MFLs re-evaluation.

Predictive steady-state simulations were made for Reference Timeframe flow scenarios ranging in non-exceedance frequency from 2 to 98 percent. Model input flows were apportioned spatially as done in the initial MFLs assessment modeling.

A normal depth boundary condition was implemented in the updated steady state model using flow-dependent slopes prescribed at the most downstream SFR cross section. The boundary condition slopes were calculated using an empirical relation developed from daily stages measured on the Suwannee River near Branford and Bell, and daily discharges and stages measured on the Santa Fe River near Hildreth.

Detailed output from HEC-RAS was exported to an ASCII file for use in the ecological modeling of the Lower Santa Fe and Ichetucknee River (LSFR/IR) Systems. The output defines the velocities, depths, wetted perimeter, and other hydraulic properties for each cross section.

I. INTRODUCTION

The Santa Fe River, located within the Suwannee River Water Management District (the District), flows through Suwannee, Columbia, Union, Bradford, Alachua, and Gilchrist Counties until it reaches its confluence with the Suwannee River. Its primary tributaries include Ichetucknee River, New River, and Olustee Creek. A transient HEC-RAS model was developed of the Lower Santa Fe and Ichetucknee Rivers to support Minimum Flows and Levels (MFL) development and ecological modeling. The Lower Santa Fe River (LSFR) is defined in this report as the 50-mile long stretch of river that begins just upstream of State Road 121 near Worthington Springs and extends to the confluence with the Suwannee River (Figure 1).

The Lower Santa Fe and Ichetucknee Rivers were previously modeled and calibrated as separate systems. The previous modeling efforts for the Santa Fe River included the U.S. Army Corps of Engineers (USACE) development of a steady state HEC-2 model for the Federal Emergency Management Agency's (FEMA) flood insurance rate mapping (Taylor Engineering, Inc. 2002). In 2002, the District contracted with Taylor Engineering to convert the HEC-2 model of the Santa Fe River into a steady state HEC-RAS model (Taylor Engineering, Inc. 2002).

In 2005, FEMA further modified a steady state HEC-RAS model of the Santa Fe River system by updating some of the bridges and cross sectional information for use in flood insurance rate mapping (FEMA 2006a) and (FEMA 2006b).

Independently of the FEMA work, in 2007 INTERA modified the Taylor Engineering model of the Santa Fe River (Taylor Engineering, Inc. 2002) by adding a transient simulation and better representing low flow conditions (INTERA 2007). In 2007, INTERA also developed a transient georeferenced model of the Ichetucknee River, a tributary of the Santa Fe River (INTERA 2007).

The modeling efforts for the initial MFLs assessment utilized the best available information from the existing HEC-RAS models of the Lower Santa Fe and Ichetucknee Rivers and new survey data (INTERA 2012). The Lower Santa Fe and Ichetucknee Rivers were combined and calibrated as one system using HEC-RAS version 4.1.0. Digital elevation model (DEM) data provided by the District were combined with the existing and newly surveyed cross sectional data in order to develop cross sections for the HEC-RAS model. U.S. Geological Survey (USGS) and District flow and water level data were used in model development and calibration. The transient model was calibrated to observed stages and flows for the period February 13, 2002 until September 29, 2011. All work was performed in National Geodetic Vertical Datum of 1929 (NGVD29).

Work performed by HSW to refine the initial MFLs assessment HEC-RAS model includes:

- Executing transient and steady state simulations using the current HEC-RAS version 5.0.6.
- Updating cross-section geometry data based on the latest available LiDAR data provided by the District. Control areas in the Lower Santa Fe and Ichetucknee Rivers (e.g., shoals) observed during the field investigation conducted by HSW and the District on April 19 and 20, 2018, are well depicted in the model. No additional hydrographic survey data were collected.
- Translating elevations represented in the model from the NGVD29 vertical datum to NAVD88. The geometry and stage data input to the updated model and calculated by the model are referenced to NAVD88.

- Revising steady state model input flow data to reflect the NFSEG-adjusted Reference Timeframe flow records considered for the MFLs re-evaluation.
- Resolving numerical instability issues so that transient and steady state simulations ran successfully.
- Evaluating transient model calibration and validation metrics.
- Converting the calibrated transient model into a steady state model to represent a variety of probable flow conditions.
- Evaluating an alternative steady state model downstream boundary condition and the association between LSFR flow and stage at the junction of the Suwannee and Santa Fe Rivers to represent a condition when backwater effects are minimal.
- Simulating steady state profiles and velocity distributions for multiple Reference Timeframe flow exceedance frequencies.

The North Florida Southeast Georgia (NFSEG) groundwater model was developed by the St. Johns River Water Management District (SJRWMD) and SRWMD to provide a shared tool to assess the impacts of groundwater withdrawals on water resources in north Florida. The NFSEG model was used by the District to generate a flow record (Reference Timeframe Flow data) that accounts for the historical influence of groundwater withdrawals.[1]

Information collated from initial MFLs assessment HEC-RAS modeling (SRWMD 2013), some of which was updated, and new information and analyses that provide technical support for the Lower Santa Fe and Ichetucknee Rivers MFLs re-evaluation are presented in this appendix. Much of the information regarding model background, development, and calibration and the associated figures and tables are excerpts from the initial MFLs assessment HEC-RAS modeling report (INTERA 2012).

Following this introductory section, Section 2 includes descriptions of the model development, reaches of interest for the MFLs re-evaluation, boundary conditions, and parameterization. Section 3 includes descriptions of the transient model calibration and validation. Section 4 is a description of the steady state model parameterization and results of the predictive simulations that can be used to evaluate water resource values. A summary and conclusions are provided in Section 5.

[1] The North Florida Southeast Georgia (NFSEG) groundwater model was developed by the SRWMD and SJRWMD and used to generate a flow record (Reference Timeframe Flow data) that accounts for the historical influence of groundwater withdrawals.

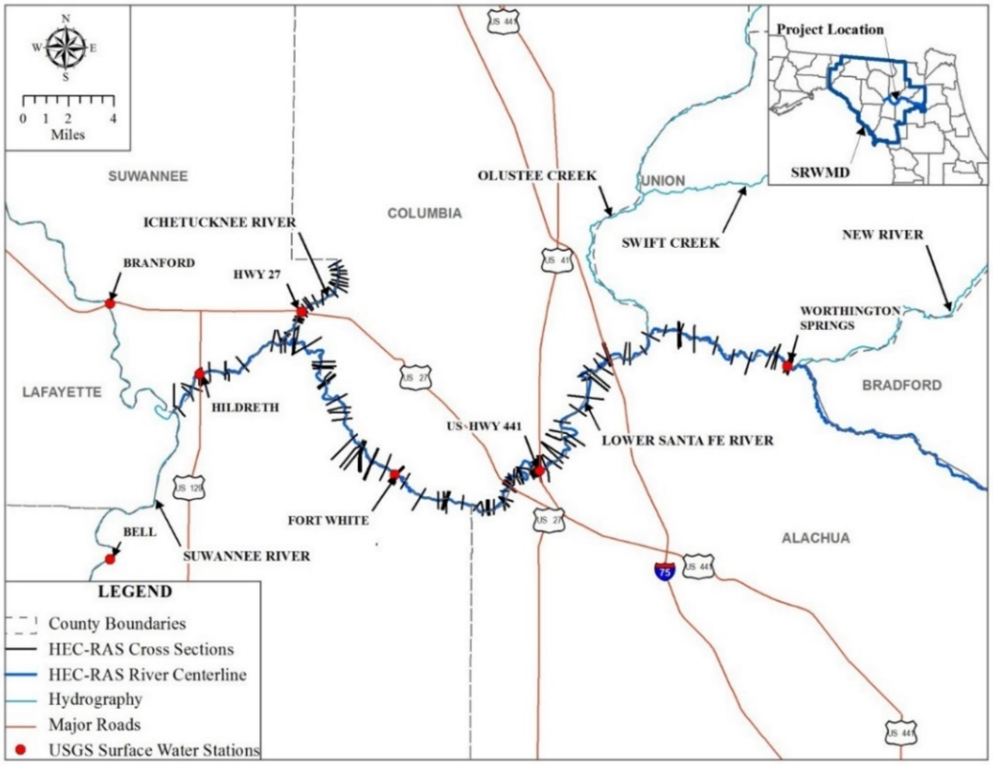


Figure 1. Location Map of the Lower Santa Fe and Ichetucknee Rivers HEC-RAS Model

2. HEC-RAS MODEL DEVELOPMENT

A transient HEC-RAS (HEC-RAS version 4.1.0) model of the Lower Santa Fe and Ichetucknee Rivers was developed by INTERA for the District in support of the initial MFLs development. The model was constructed using the best available data, including DEM, existing cross sectional data, and new survey data. HSW subsequently refined the initial assessment model for the MFLs re-evaluation.

2.1 Georeferencing

Georeferencing is a process of assigning real-world coordinates to a model so that it can be displayed in GIS (Hydrologic Engineering Center 2010). The earlier HEC-RAS models of the Lower Santa Fe River were not georeferenced. It was important for the District to have a spatially referenced model for visualization and overlay with other District data. The initial MFLs assessment HEC-RAS model was georeferenced using HEC- GeoRAS 10. Pre-processing in HEC-GeoRAS consisted of digitizing river centerlines, creating river banks and flow paths, and cutting cross sections. The river centerline was digitized using the aerial imagery, the Digital elevation model (DEM) data, and the National Hydrography Dataset (NHD). In digitizing efforts, the aerial imagery and the DEM took priority over the NHD except for the area near O'Leno State Park where the Santa Fe River disappears into the sink but eventually reappears downstream at the River Rise. In this portion of the river, the NHD was the best available source of data.

When assigning a top of bank in the HEC-RAS model, the top of bank elevations provided by Delta Land Surveyors, Inc. were utilized where available. Aerial imagery and DEM were used for assigning a top of bank where surveyed elevations were not available.

Site-specific shifts were applied for the updated HEC-RAS modeling to translate water-surface elevations measured at key U.S. Geological Survey (USGS) and District gages from NGVD29 to NAVD88 (Table 1). Based on those data, an average shift of -0.78 ft was determined and applied to all cross sections previously derived from the LiDAR data referenced to NGVD29 to make the updated HEC-RAS model consistent with NAVD88. Region specific adjustments were not warranted since the variation in the site-specific shifts is within the accuracy of the LiDAR data.

Table 1. Adjustments from National Geodetic Vertical Datum of 1929 to North American Vertical Datum of 1988 elevations for key gage locations in and near the Santa Fe and Ichetucknee river basins.

Station ID	Station name	Latitude	Longitude	Shift* (ft)	Relevance to Study
02320500	Suwanee River at Branford, FL	29˚57'20"	82˚55'40"	-0.751	Downstream Boundary Condition
02321500	Santa Fe River at Worthington Springs, FL	29˚55'18"	82˚25'35"	-0.832	Calibration, Upstream Boundary Condition
023218982	Santa Fe River at O'Leno State Park by Footbridge	29˚54'52"	82˚34'46"	-0.785	Calibration
02321898	Santa Fe River at O'Leno State Park	29˚55'36"	82˚33'35"	-0.791	Calibration
02321975	Santa Fe River at Highway 441 near High Springs, FL	29˚51'09"	82˚36'31"	-0.775	Calibration
02322500	Santa Fe River near Fort White, FL	29˚50'55"	82˚42'55"	-0.748	Calibration

Station ID	Station name	Latitude	Longitude	Shift* (ft)	Relevance to Study
02322698	Ichetucknee River at Dampier's Landing near Hildreth, FL	29˚57'37"	82˚46'20"	-0.764	Calibration
02322700	Ichetucknee River at Highway 27 near Hildreth, FL	29˚57'09"	82˚47'10"	-0.762	Calibration, Translated Upstream Boundary Condition
02322703	Santa Fe River at Ichetucknee River near Hildreth, FL	29˚55'57"	82˚47'57"	-0.758	Calibration
02322800	Santa Fe River near Hildreth, FL	29˚54'41"	82˚51'38"	-0.749	Calibration, Downstream Boundary Condition
02323000	Suwanee River near Bell, FL	29˚47'28"	82˚55'28"	-0.699	Downstream Boundary Condition
*Shifts were determined using the National Oceanic and Atmospheric Administration (NOAA) VERTCON software at the web site: https://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con2.prl and represent the difference between NAVD29 and NAVD88 such that Elevation (NAVD88) = shift + Elevation (NGVD29).					

2.2 Cross Section Data, DEM, Channel Geometry

Initial MFLs assessment

Steady state and transient HEC-RAS models of the Santa Fe and Ichetucknee Rivers were previously developed by INTERA for the District (INTERA 2007). The shapefile (river_cross_sections.shp) with the existing HEC-RAS model cross sections was provided to INTERA by the District. For the majority of the existing HEC-RAS model cross sections, shapes and lengths were preserved. Several existing cross sections were extended into the floodplain or modified to avoid conflict with new transects surveys. In addition, the existing cross sections were modified to be perpendicular to the direction of flow in the channel and in the floodplain. Channel data of the existing transects were combined with DEM data for input into the HEC-RAS model.

New surveyed elevations were provided to INTERA by the District in a shapefile format ("2012_01_30_LSFIR_FINAL.shp" and "RHABSIM_FINAL.shp"). All surveyed elevations were provided in NGVD29. The majority of transects were surveyed by Delta Land Surveyors, Inc; and several cross sections were surveyed by the District. RHABSIM (Thomas R. Payne and Associates 1998) cross sections, cross sections near Poe Island, cross sections downstream of the Ichetucknee River confluence, and cross sections near US Highway 27 bridge on the Ichetucknee River were surveyed by the District. The District surveyed elevations were used in the HEC-RAS model except for the US Highway 27 surveyed elevations. The US Highway 27 elevations were used to confirm the existing model cross sectional data in the area.

A total of 52 new cross sections were digitized to include the new surveyed data: 37 new surveyed cross sections on the Santa Fe River, 3 new surveyed cross sections on the Ichetucknee River, and 12 RHABSIM cross sections on the Lower Santa Fe River. Additional new transects included unsurveyed floodplain transects important for ecological evaluation, additional bridge or junction cross sections added for modeling purposes, and interpolated cross sections added for stability.

The District provided a 5-ft Light detection and ranging (LIDAR) raster surface and 10-meter Digital elevation model (DEM) in North American Vertical Datum of 1988 (NAVD88). The LIDAR coverage and a 10-meter DEM were merged into a single DEM file that was converted into NGVD29. The 5-ft LIDAR file was given priority over the 10-meter raster when merging these files into a single grid for use in the initial assessment HEC-RAS model. A majority of the Lower Santa Fe River model domain has the high-resolution coverage of the 5-ft raster file. However, a large portion of the Ichetucknee River DEM coverage had a lower resolution 10-meter DEM coverage that extends from the US Highway 27 bridge to the Ichetucknee Head Springs. The resultant DEM grid is shown in Figure 2.

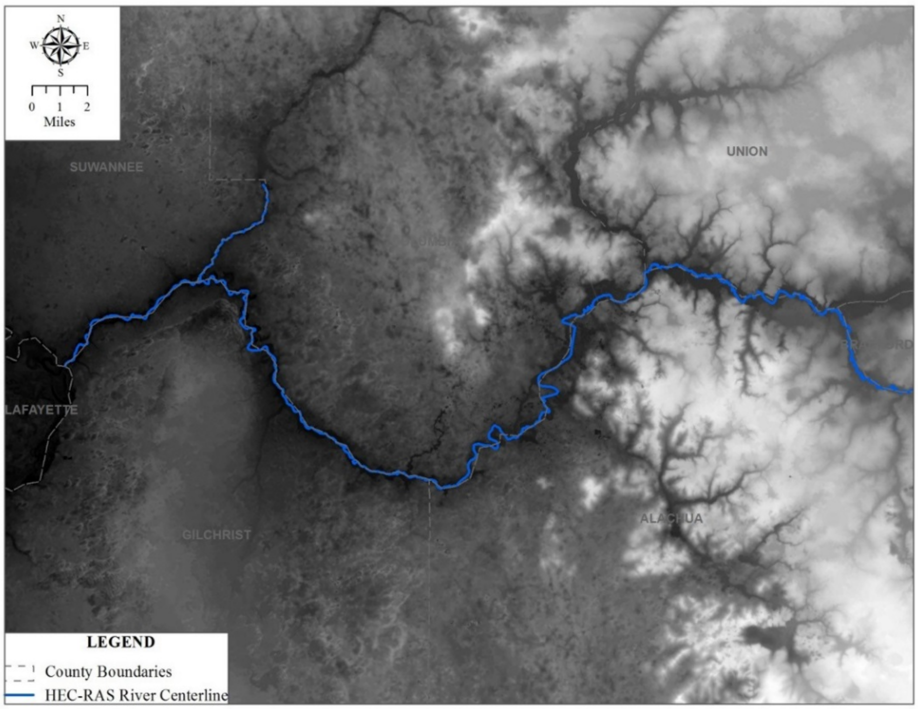


Figure 2. Resultant DEM Used in the Initial MFLs Assessment Lower Santa Fe and Ichetucknee Rivers HEC-RAS Model

The geometry of the model was constructed using HEC-GeoRAS in ArcMap Version 10 and HEC-RAS version 4.1.0. The channel centerline was digitized starting upstream at Santa Fe Lake to downstream until the confluence with the Suwannee River was reached. A total of 234 channel cross sections and 18 bridge cross sections were digitized. These included all of the cross sections from the Santa Fe Lake to the Suwannee River confluence. Since the Lower Santa Fe River was the focus of the modeling effort, cross sections upstream of State Road 121 were not imported into the HEC-RAS model.

Once the HEC-GeoRAS processing was completed, the geometry file, exported from HEC-GeoRAS, was imported into HEC-RAS. The DEM data in each cross section was replaced with the available survey data or the existing model data. For the newly surveyed cross sections, the DEM data and the surveyed data were aligned and merged in a spreadsheet. The survey data took priority over the DEM data. Generally, there was good agreement between the DEM data in the floodplain and the surveyed elevations in the river channel (Figure 3). Generally, there was poor agreement between the DEM data and the surveyed data on the Ichetucknee River due to the lower DEM resolution in this area.

The DEM data and the existing data were aligned and merged for the existing cross sections (Figure 4). Because the existing cross sectional data was not originally georeferenced, the DEM and the existing data were manually aligned in order to preserve the location of the channel bottom. The new DEM took priority when combining the data and in general, the channel bottom elevations were preserved from the existing cross sections.

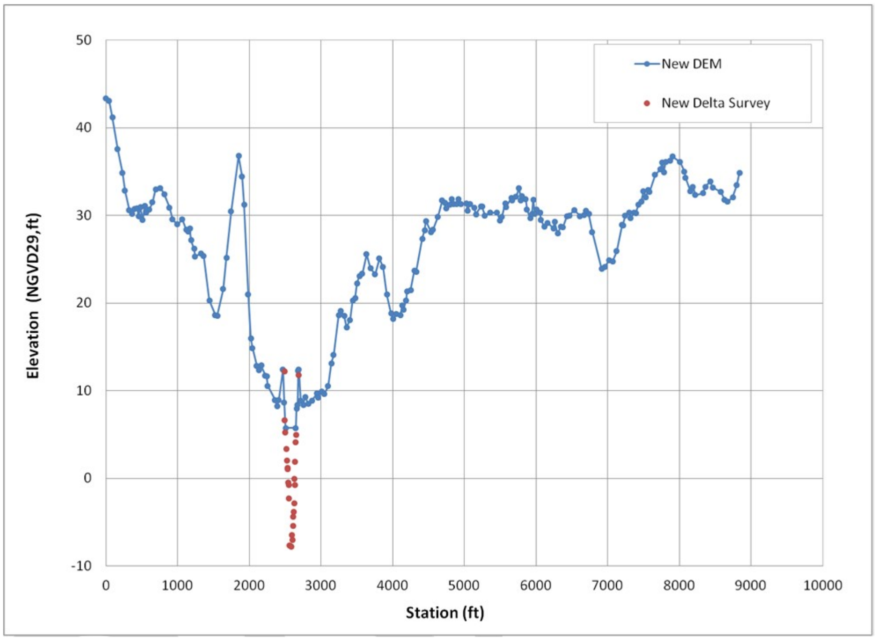


Figure 3. Alignment of the DEM and Survey Data

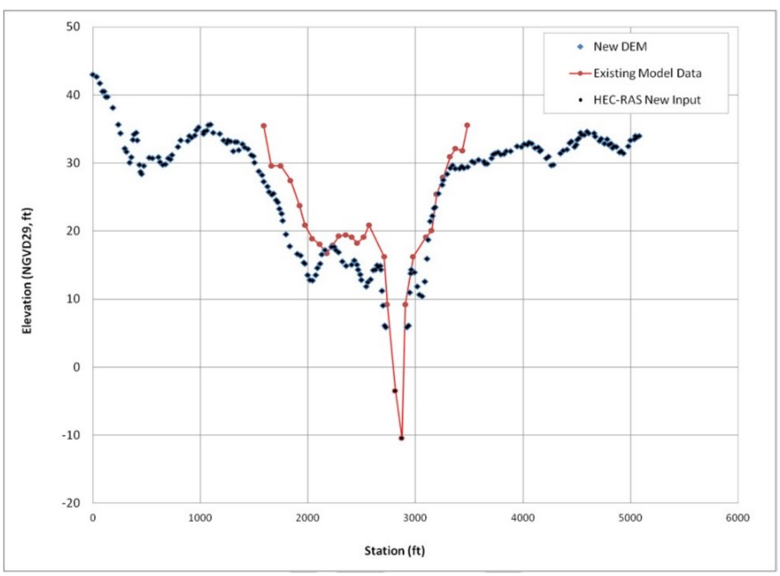


Figure 4. Alignment of the DEM and the Existing Cross Section Data

Cross section geometry for the three unsurveyed cross sections (“AA Downstream floodplain” transect on the Ichetucknee River and “D floodplain” and “8P floodplain” on the Santa Fe River) were obtained using DEM data in the floodplain and interpolating between bounding cross sections in the channel. Another special case were the cross sections located on the stretch of the Santa Fe River between the O'Leno Footbridge gaging station (near the Santa Fe River Sink) and the River Rise. This portion of the Santa Fe River, known as the Santa Fe Land Bridge, is where the river disappears underground (at the Santa Fe River Sink) and reappears about 3.5 miles down-gradient at the River Rise (Figure 5). No survey data were available on the Land Bridge, and the alignment with the U.S. Army Corps of Engineers (USACE) existing cross sections was poor. In this area of the river the DEM took precedence and was used to define the cross sections in the model. The cross section at the Vinzant Landing Swallet is another cross section where DEM data were not available. This cross section was added during the model calibration supplemented by District observations. The Vinzant Landing Swallet is described in the *Lateral Inflows* section (2.5.3).

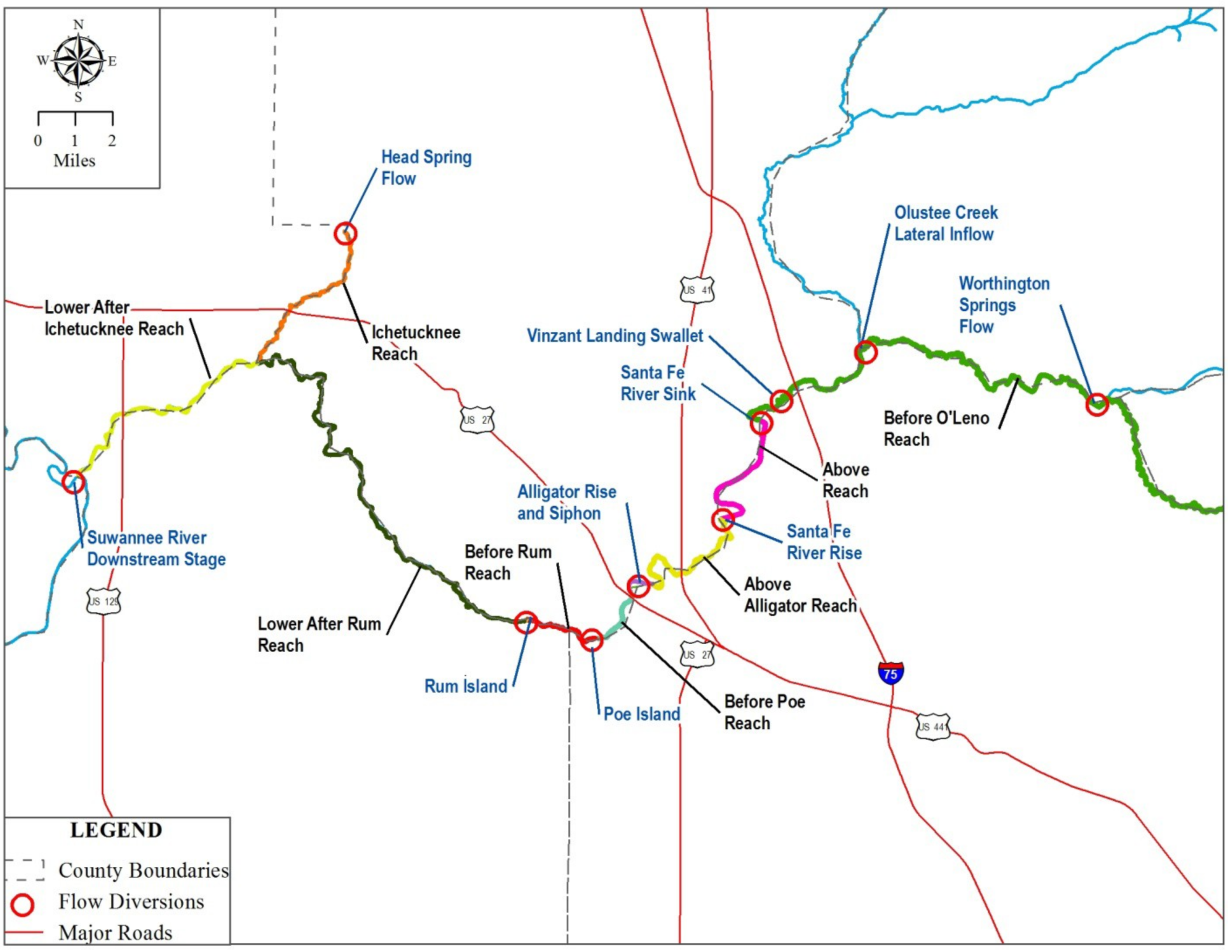


Figure 5. Santa Fe River / Ichetucknee River HEC-RAS Model Reaches

For MFL analyses, cross sections were assigned letter grades (A, B, C, D, or F) based on data quality (Table 2). Cross sections with a grade of A or B are well-aligned existing channel data, newly surveyed data, or previous contract survey data (Table 3 and Table 4). Cross sections with a grade of C were used with caution during MFL analyses. Cross sections with a grade of D are cross sections that define bridges or junctions in the model. Cross sections with a grade of F have old triangular channel data, are near the Land Bridge, or consist of only the DEM data.

Table 2. HEC-RAS Cross Section Assigned Grade Descriptions

Grade	Description
N/A	Bridge cross section
A	New survey data (Delta, RHABSIM, SRWMD) or previous contract survey data
B	USACE (existing model) channel data with good geometry and alignment
C	USACE (existing model) channel data with sufficient geometry and alignment
D	Bridge bounding cross sections or junctions defined for modeling purposes
F	Poor /"V-shape" channel geometry or data that only contains DEM points

Table 3. HEC-RAS Cross Sections Assigned Grades: Santa Fe River

River Station	Grade	River Station	Grade	River Station	Grade
267712.9	F	150850.2	D	112509.8	A
267340.3	F	150560.1	D	111186.1	F
267200.1	F	150453.2	F	106857.4	B
267117	N/A	150192.6	C	100692.3	F
267046.6	F	150082.7	A	96930.06	A
266658.9	F	149924.3	A	96791.79	A
262287.3	A	149708	A	96627.88	F
261880.7	A	149167.5	A	96532.88	A
260337.5	F	148387.7	A	93645.45	F
252404.1	F	144067	B	89916.23	A
246301.9	F	139200.9	A	89685.81	F
238298.1	F	138946	F	85420.27	F
229947.4	F	134136	F	85244.77	D
225360.8	C	138776.6	A	85178.48	N/A
225118.9	C	137783	A	85147.16	D
225097.9	D	137191	C	84962.8	F
225053.9	N/A	136066.5	A	84274.49	A
224986	D	135422.4	A	81719.97	F
224747	C	133585.8	F	76273.62	C
221123.8	F	133442.5	F	74474.53	A
214930.6	C	133397.5	N/A	73243.98	C
210688.8	C	133362.4	F	70536.88	F
206341	A	133290.6	F	61410.48	A
205072.2	F	133263.7	F	61124.27	C
200774.8	D	133241.4	N/A	61005	A
200676.6	D	133208.2	F	60515.43	A
200603.4	N/A	133079.4	F	55916.91	A
200430.1	D	131570.6	C	55732.9	A
200311.5	D	129819.5	F	55655.57	A
199608.7	C	129312.6	A	55566.83	A
195108.4	F	129212.6	A	55554.55	A
191737.7	F	129118.4	A	55203.61	A
191718.9	F	129082.4	A	54234.24	F

River Station	Grade	River Station	Grade	River Station	Grade
189142.1	A	126095.8	C	45429.38	F
186938.4	F	124915.7	D	42107.47	C
186917.6	F	124770.3	A	41168.91	A
164366	F	124713.2	A	37869.58	A
164296.4	F	124514.9	A	36841.84	A
186917.6	F	340.1572	A	34668.82	B
182234	F	264.3174	A	25348.59	B
178224	F	78.64378	A	19785.01	A
173231	F	124387.6	D	19201.19	B
166112.3	F	123484.8	A	15294.08	B
164296.4	F	121137	F	13258.14	B
164241.8	F	117559.8	F	13053.83	D
158286.6	A	113651.9	A	12970.11	N/A
156953	B	113265.1	D	12872.86	D
154931.4	A	112819.2	A	12685.32	F
152723.1	A	112684	D	8653.07	F
151090.1	D	936.5505	D	6723.73	A
150977.9	D	760.4809	A	1606.322	A
150908.6	N/A	94.66003	D		

Table 4. HEC-RAS Cross Sections Assigned Grades Ichetucknee River

River Station	Grade	River Station	Grade
27976.3	A	9938.649	N/A
26670.76	A	9901.374	D
26012.56	A	9873.696	A
25088.65	A	9801.898	D
24433.49	A	9782.468	N/A
23421.37	A	9752.88	D
22520.48	A	9705.355	A
21911.31	A	8311.143	A
20136.5	A	8101.876	A
16758.63	A	7268.683	A
14690.63	A	7087.178	A
13217.85	A	2909.323	A
12554.52	C	2545.087	A
11281.58	A	628.0969	A
10037.68	A	335.5512	A
9979.729	D		

The final HEC-RAS model developed for the initial MFLs assessment has 176 digitized cross sections, 10 bridge cross sections, and 145 interpolated cross sections. Interpolated cross sections were added directly in HEC-RAS for model stability or to define internal boundary conditions.

MFLs re-evaluation

In the initial MFLs assessment HEC-RAS model of the Santa Fe River, 51 cross sections are rated Grade F and 13 are rated Grade C (there also is one grade C cross section in the Ichetucknee River). Grade F indicated that a poor, ”V-shaped” channel geometry was assumed and/or the cross section data were only derived from the DEM (not LiDAR) data. (INTERA 2012) noted that the Grade C cross sections were used with caution during MFL analyses.

New 5-ft LiDAR data became available for the entire study area subsequent to the initial MFLs assessment, and the data were used to evaluate and, in some instances to refine, the geometry of cross sections in the initial assessment model. The 10-m DEM data were not considered in the updated model development. A shapefile with cross-section transects was superimposed on the LiDAR coverage and the ArcMap GIS utility was used to extract elevations along the lengths of the transects. No new cross sectional data were collected by field survey for the model update.

HSW compared the cross sectional data in the initial MFLs assessment LSFR HEC-RAS model to the most recent LiDAR data for 7 selected “F-rated” cross sections—River Stations (RSs) 267340.3, 195108.4, 138946, 129819.5, 117559.8, 89685.81, and 54234.24. For the example of RS 129819.5 (Figure 6), there is no discernable difference in the most recent LiDAR data (Profile Graph in the figure) and the HEC-RAS input (rightmost graph in the figure) for the overbank areas. The same was found for the other “F-rated” cross sections selected for evaluation. Thus, for the Santa Fe River the cross-sectional data in the HEC-RAS model represent the best available data.

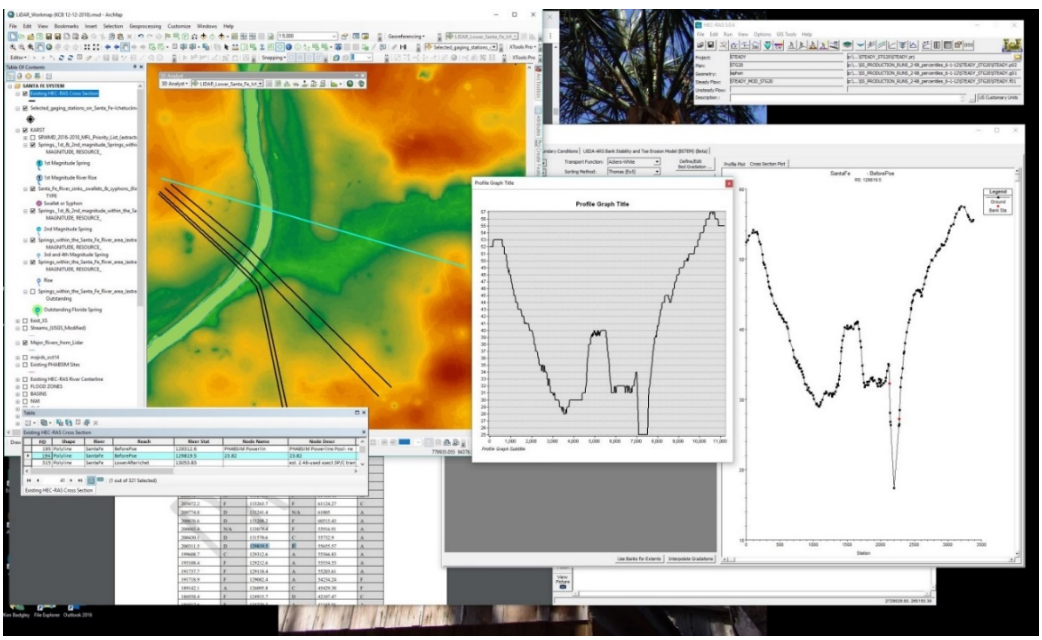


Figure 6. Comparison of the most recent LiDAR data (Profile Graph) and cross-sectional data in the HEC-RAS model (rightmost graph) for overbank areas for example River Station 129819.5.

HSW also compared the cross-section geometries in the initial MFLs assessment IR HEC-RAS model with geometries based on the new LiDAR data. Examples of the comparison are provided for four selected cross sections—two in the region where the new LiDAR data replaces the old DEM data and two in the region where the new LiDAR data are nearly the same as the LiDAR data used in developing the initial MFLs assessment HEC-RAS models (Figure 7).

RS 26012.56 is an example of a cross section where the boundaries between the main channel and the overbank areas have changed substantially and at low depths such that the simulated flow depths should be affected by these changes over a wide range of flows of interest for this and similar cross sections. RS 13217.85 also is an example of a cross section where the boundaries between the main channel and the overbank areas have changed substantially, but at higher depths such that for nearly all simulated flows of interest the water will remain in the main channel and the simulated depths should be unaffected by these changes for this and similar cross sections. RS 8311.143 is an example of a cross section where the new LiDAR and initial MFLs assessment HEC-RAS data are nearly identical. For RS 8311.143, and similar cross sections, the simulated flows and water depths will be unaffected by changes in the local geometric conditions. Even though RS 2545.087 is in the region where LiDAR data were available for the development of the initial MFLS assessment HEC-RAS model, some substantial differences in the cross-sectional data are evident.

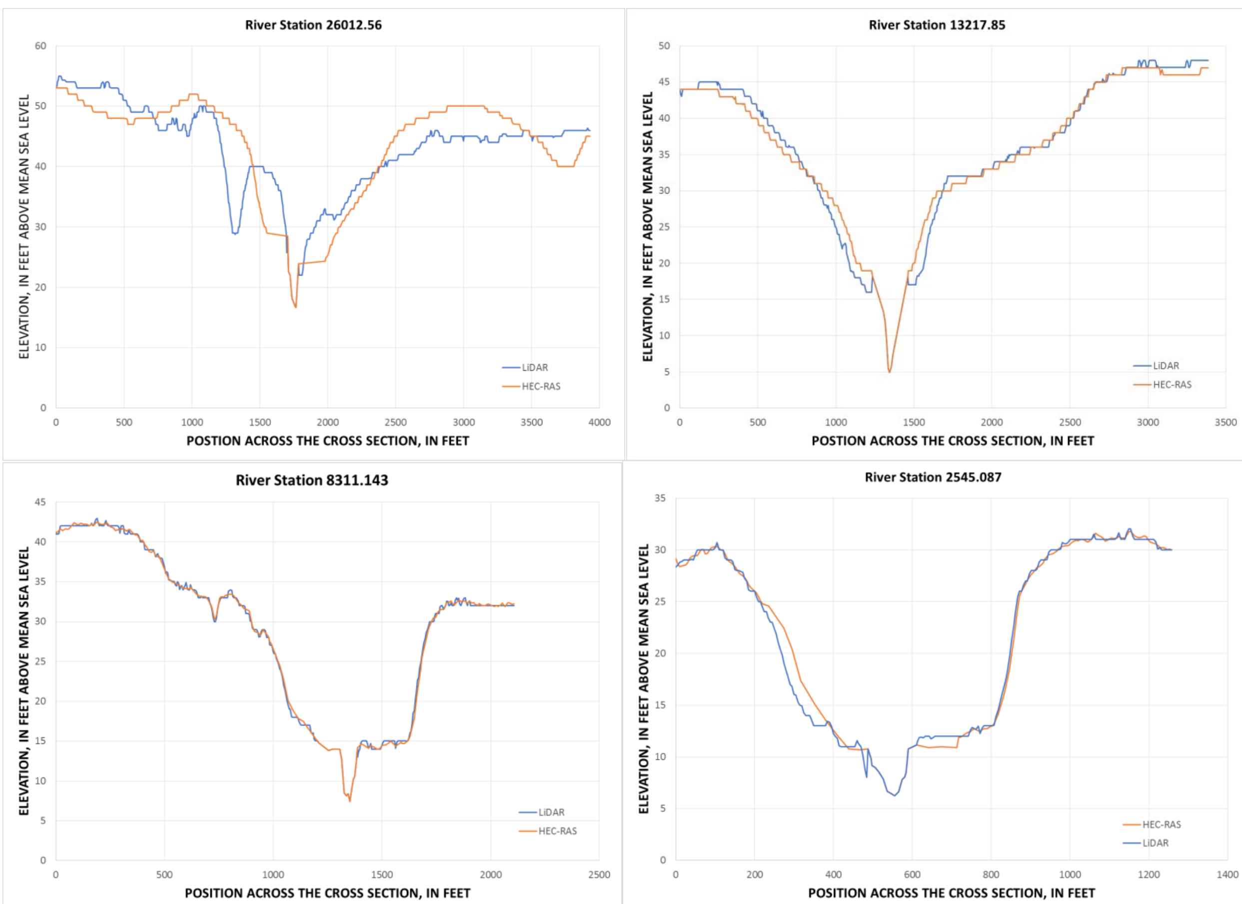


Figure 7. Comparisons of cross-section geometry based on the new 5 ft LiDAR data and the initial MFLs assessment HEC-RAS geometry input for selected cross sections along the Ichetucknee River.

2.3 Model Geometry

The geometry of 29 Ichetucknee River cross-sections was updated in HEC-RAS using the available 5-ft LiDAR data. Geometry updates were limited to areas outside of the main channel. No change was made during the MFLs re-evaluation to the LSFR HEC-RAS model geometry. The following subsections are excerpts from the initial assessment HEC-RAS modeling report (INTERA 2012).

2.3.1 Reach Characterization

The Lower Santa Fe River model comprises 15 reaches (Figure 8, Figure 9, Figure 10) named: Before O'Leno, Below, Above, Above Alligator, Siphon Above, Siphon Below, Before Poe, Poe Island North, Poe Island South, Before Rum, Rum Island South, Rum Island North, Lower After Rum, and Lower After Ichetucknee (Table 5). The Ichetucknee River is modeled as a single river reach named Ichetucknee Reach (Figure 8).

Karst features including swallets and resurgences and their hydraulic relationships are represented in HEC-RAS model using synthesized lateral inflows and the HEC-RAS pressurized conduit flow option. The Before O'Leno reach includes the cross sections from just upstream of the State Road 121 to the Santa Fe River Sink. The Santa Fe River is unique because it disappears underground into the Santa Fe River Sink in O'Leno State Park and reappears at Santa Fe River Rise (Figure 8, Figure 9). The Santa Fe River Sink is a large sinkhole that diverts the Santa Fe River flow underground; hence, the above-ground channel remains dry most of the time. For that reason, this portion of the river is modeled in HEC-RAS with two separate reaches, Above and Below, with the Below reach carrying most of the flow (Figure 8, Figure 9, Figure 10).

The Vinzant Landing Swallet is another sink located approximately 1 mile downstream of the I-75 bridge. The Alligator Siphon and the Alligator Rise are located approximately 5,600 feet and 750 feet upstream of the Highway 27 bridge, respectively (Figure 8 and Figure 9). The Alligator Siphon is a small siphon that forms a cave underground and diverts a significant amount of the Santa Fe River flow (Butt, Morris and Skiles 2007). The Alligator Siphon and Rise system is modeled with two reaches, Siphon Below and Above (Figure 9). The amount of flow taken in by the Alligator Siphon was adjusted during model calibration. The flow diversions at the Vinzant Landing Swallet and the Santa Fe River Sink are further described later in the report.

Poe and Rum Islands are represented in the model with paired reaches named Poe Island North and South, and Rum Island North and South (Figure 10). All four reaches represent above-ground features.

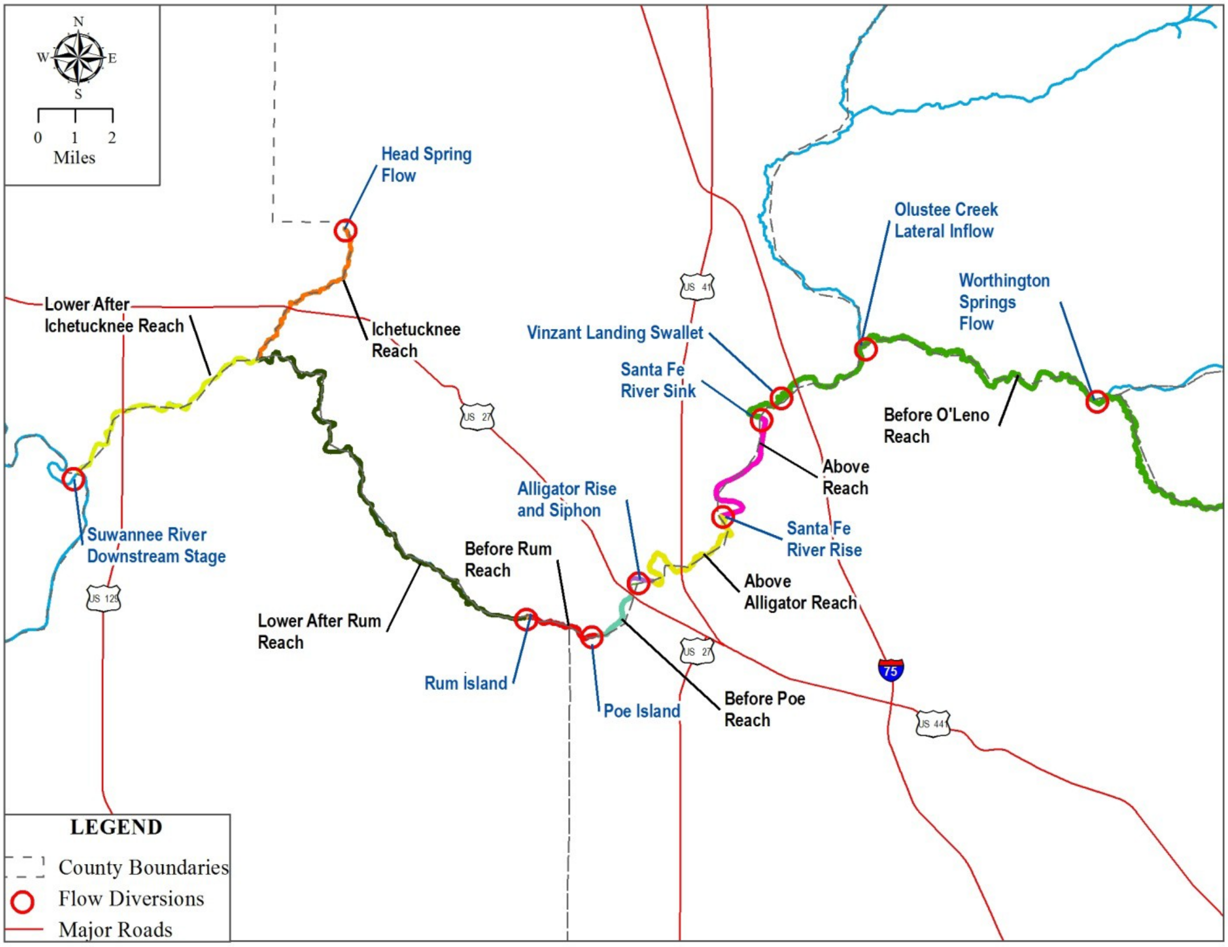


Figure 8. Santa Fe River / Ichetucknee River HEC-RAS Model Reaches

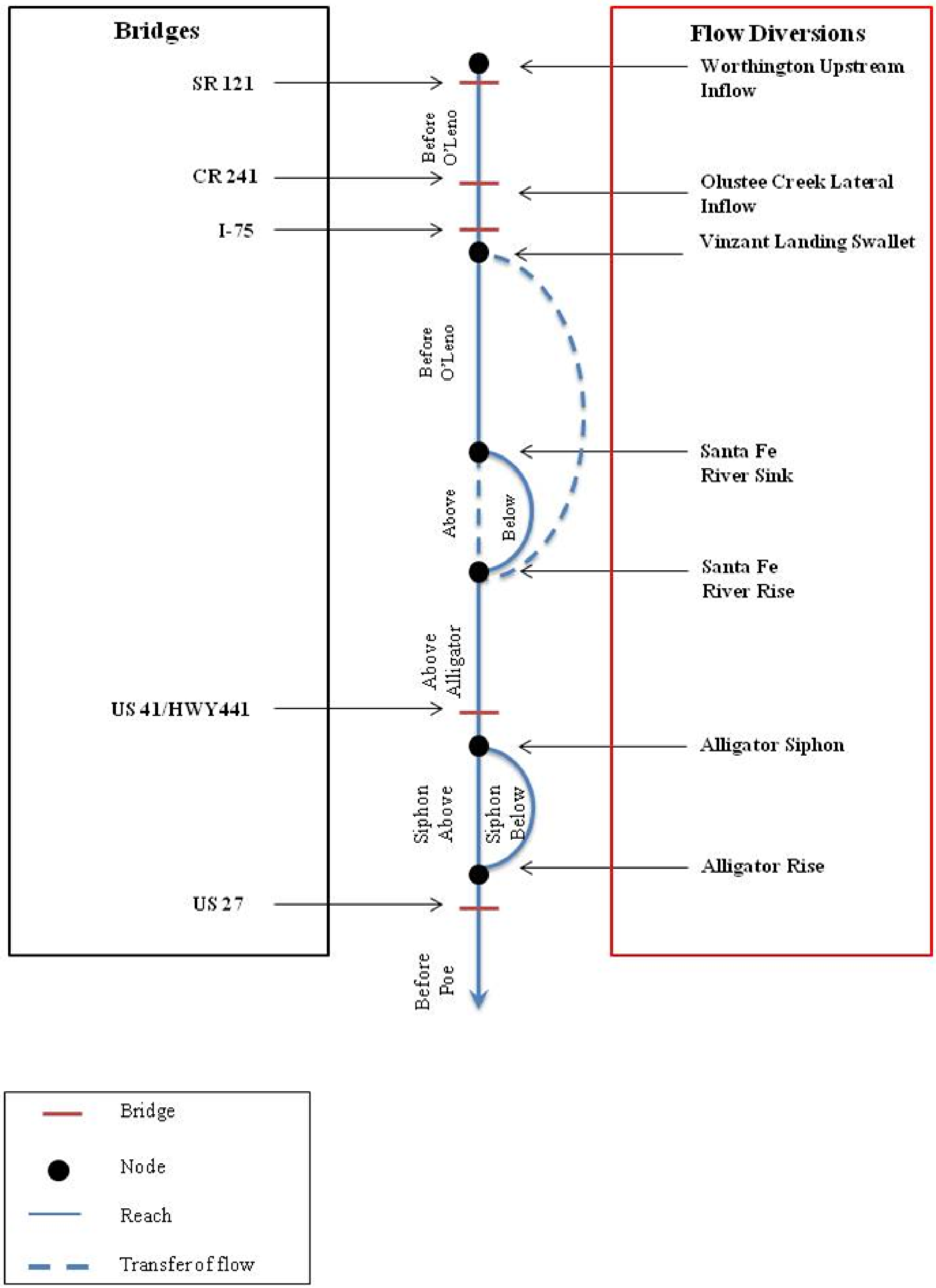


Figure 9. Schematic of the Santa Fe HEC-RAS Model: Upstream Reaches
[Not shown is Seaboard Coast Line railroad bridge in reach Before Poe just downstream from US27]

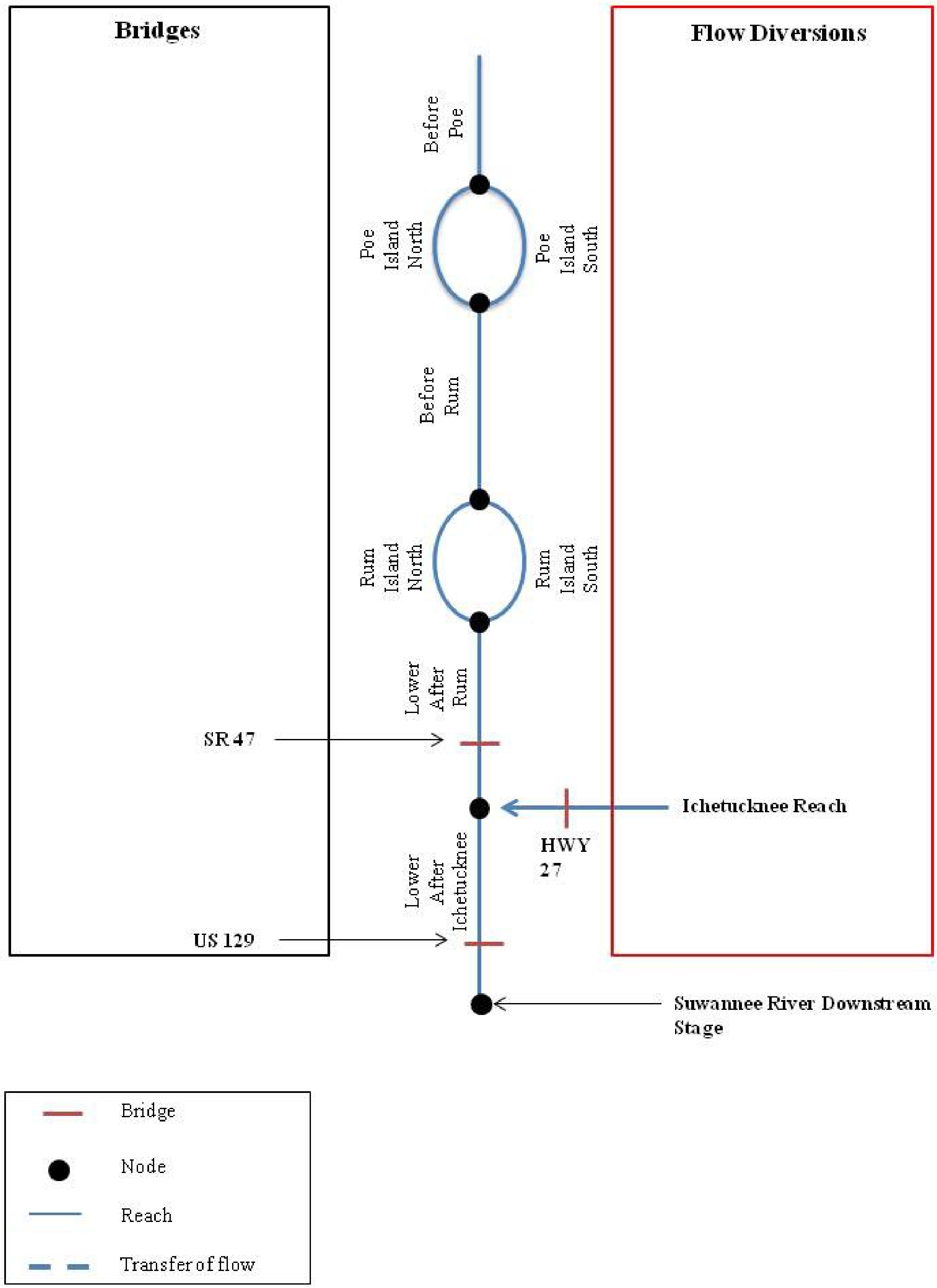


Figure 10. Schematic of the Santa Fe HEC-RAS Model: Downstream Reaches

Table 5. Lower Santa Fe and Ichetucknee River HEC-RAS Model Reaches and Stationing

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

Notes:
Shaded rows are reaches upstream from the area of interest for the MFLs assessment
*Approximate distance from river mouth, in feet
**Denotes interpolated cross section
**Denotes a coupled system

2.3.2 Junctions

A stream junction is necessary when a reach splits or joins with another reach. When digitizing the model transects, the cross sections that bounded each stream junction were placed as close to the junction as possible. Placing cross sections close to a junction allows for accurate calculation of the energy losses (Hydrologic Engineering Center 2010).

Various splits and joins on the Lower Santa Fe River are modeled as stream junctions (nodes in Figure 9 and Figure 10). There are nine stream junctions (computational nodes) in the model named (and representing) the following.

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

The Santa Fe Below and Siphon Below reaches represent subterranean karst conveyances that parallel the similarly named "Above" reaches and are not shown in Figure 8. The Santa Fe Above reach represents SFR along the natural Land Bridge (Figure 5, Figure 8). The flow in the Above Alligator reach splits at the Split junction to form the Siphon Above and the Siphon Below reaches (Figure 9). These two reaches join at the Siphon junction to form the Before Poe reach (Figure 9).

2.3.3 Bridges

There are 10 bridges in the model: 8 bridges on the Lower Santa Fe River and 2 bridges on the Ichetucknee River (Figure 9 and Figure 10). Three bridges on the Santa Fe River, Highway 441 bridge, I-75 bridge, and State Road 121 bridge, were revised using the most recent Florida Department of Transportation (FDOT) as- built plans, provided to INTERA by the Structures and Facilities Department of the FDOT District 2 office. The FDOT as-built plans provided more current information about the bridges. For the remaining bridges the existing data were used.

2.3.4 Alligator Rise and Siphon Representation in the Model

Alligator Siphon and Alligator Rise (Figure 11) are located approximately 5600 feet and 750 feet upstream of the US Highway 27 bridge, respectively (Butt, Morris and Skiles 2007). The Alligator Siphon is a small sinkhole that forms a cave underground (the Alligator Siphon Cave) and diverts a significant amount of the Santa Fe River flow (Butt, Morris and Skiles 2007). Synoptic flow measurements collected by the USGS Staff ("Summary of USGS May 2011 Data.xls") indicated that approximately 70 cfs of the Santa Fe River was diverted into the Alligator Siphon on May 4, 2011. The District estimated that the Alligator Siphon could take in about 200 cfs (Butt, Morris and Skiles 2007).

The Alligator Siphon Cave is modeled in HEC-RAS as a separate reach – Siphon Below reach – with two bounding cross sections and the HEC-RAS lid option. The Siphon Below reach (Figure 9) is not an actual path of the Alligator Siphon Cave and only its approximate representation. The lid option in HEC-RAS is used to model pressurized pipe flow (Hydrologic Engineering Center 2010). In this model the lid option made it possible to limit the amount of Santa Fe River flow diverted into the Alligator Siphon Cave. The amount of flow taken in by the Alligator Siphon was adjusted in calibration by adjusting the lid elevations and invert elevations of the cross sections on the Siphon Below reach. The amount of flow taken in by the Alligator Siphon (Siphon Below reach) was not to exceed 200 cfs but was to take in the majority of the Santa Fe River flow during low flow conditions.

The bounding cross sections of the Siphon Below reach were placed at STA. 138946 and STA. 134136, 4810 feet apart, in order to represent the approximate length of the Alligator Siphon Cave. The bounding cross sections of the Siphon Below reach (STA. 138946 and STA. 134136) are modified copies of the Siphon Above bounding cross section at STA. 138946*. This cross section was obtained by interpolating between the two surveyed cross sections at STA. 139200.9 and STA. 138776.6. Interpolation was necessary to place a cross section as close to the junction as possible. Additional interpolated cross sections were added for stability on the Above Siphon reach (Figure 11).

The Siphon Below reach bounding cross sections (STA. 138946 and STA. 134136) are copies of the Siphon Above cross section at STA. 138946* which was reduced by 50%, making the cross sectional area of the Alligator Siphon Cave approximately 400 square feet. This cross sectional area was the result of several iterations during model calibration.

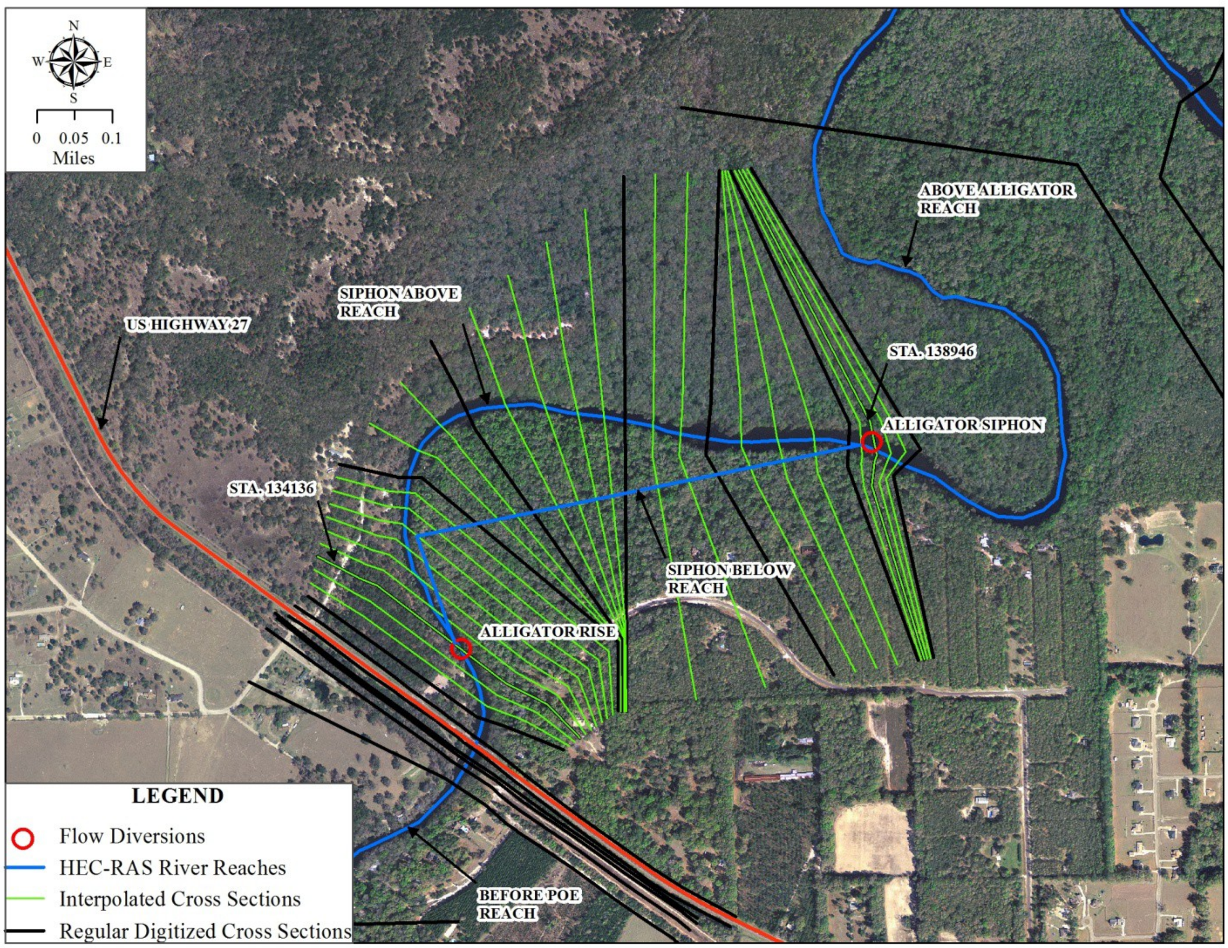


Figure 11. Map of Alligator Rise and Siphon and Cross Sections

2.4 Simulation Time Period and Computational Time Step

The simulation time period of the transient model is a 3,516-day period from February 14, 2002, through September 30, 2011. When choosing the simulation time period for the initial MFLs assessment, the purpose of the model and the availability of data were considered. The beginning of the simulation time period was limited to February 2002 because the USGS data collection at the springs on the Ichetucknee River and at the US Highway 27 gaging station (USGS #02322700) began in 2002. Extending the flow time series back to 1997 was considered but would have required relying on synthesized and interpolated values at the Ichetucknee US Highway 27 gaging station for internal and upstream flow boundary conditions, thus increasing model uncertainty.

Fort White, Worthington Springs, Santa Fe River near Hildreth, and Ichetucknee River at Highway 27 USGS gage discharge time series were used in developing the boundary conditions for the initial MFLs assessment model. Flow duration curves of the daily flows for the long and short-term periods of record at these USGS gaging stations were constructed (Figure 12 and Figure 13) to compare the percent of time the discharges were equaled or exceeded for the specified time periods. Although the short-term flow duration curves do not experience the extreme high flows shown in the long-term flow duration curves, both curves similarly represent the median and the low flows. Hence, the chosen simulation time period (short-term period of record) was appropriate for developing a model useful for assessing MFLs for the Lower Santa Fe River system.

The computational time step of the model was set to 30 seconds. Other computational time steps were utilized during model calibration but these time steps caused model instability.

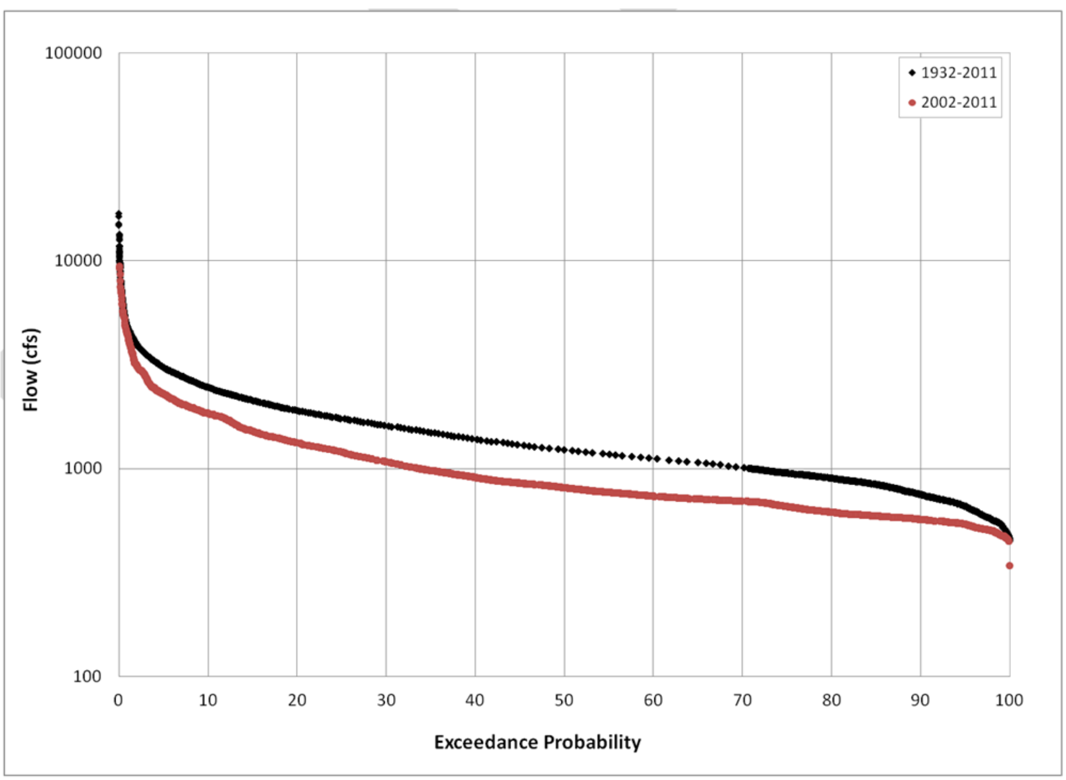


Figure 12. Flow Duration Curve for the Santa Fe River near Fort White (Semi-Log)

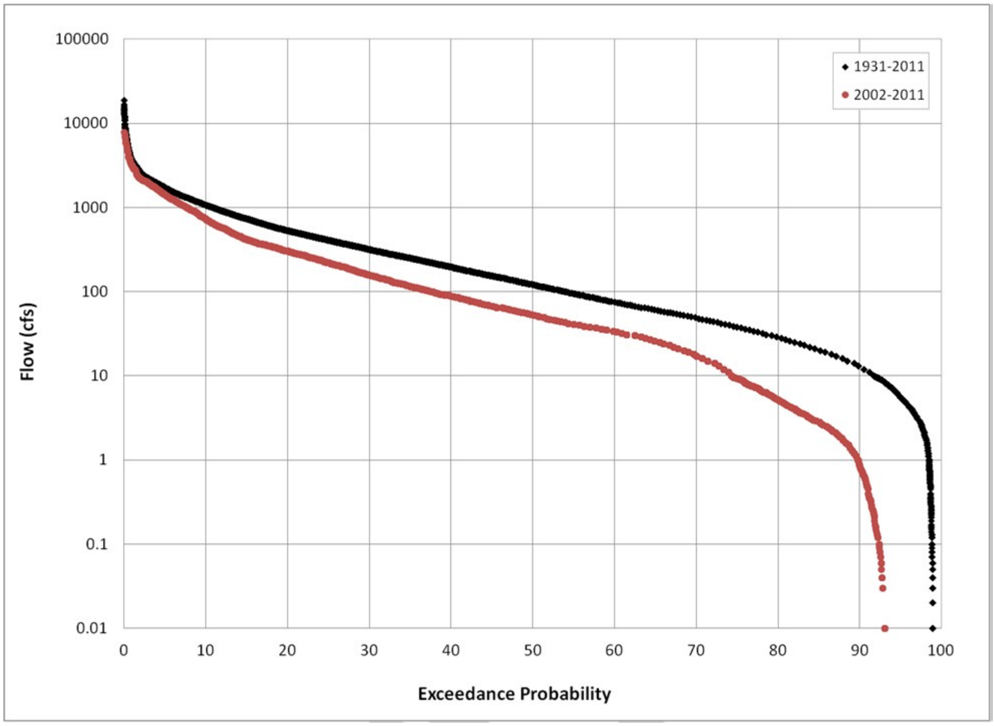


Figure 13 Flow Duration Curve for the Santa Fe River at Worthington Springs (Semi-Log)

2.5 Boundary Conditions

Boundary conditions of the LSFR/IR HEC-RAS model consist of the upstream flows on the Santa Fe and Ichetucknee Rivers, downstream stage near the Santa Fe River mouth, and various internal lateral inflows (both uniformly distributed and point inflows) on both rivers. Time series of daily values for the transient simulation period are used for transient model simulations. Steady, spatially varying flow values are used for steady state model simulations. The data are managed using the HEC-DSS (HEC Data Storage System) software. The boundary condition values are stored in the "Boundary.dss" file.

2.5.1 Upstream Flow

The discharge record of the Worthington Springs gaging station (USGS #02321500) was utilized as the upstream flow boundary condition on the Santa Fe River. The upstream boundary condition on the Santa Fe River was placed at the most upstream cross section, approximately 500 feet upstream of the State Road 121 bridge.

The discharge record of the Ichetucknee River at US Highway 27 near Hildreth gaging station (USGS #02322700) was translated and used to estimate the upstream flow boundary condition on the Ichetucknee River. The upstream boundary condition on the Ichetucknee River was placed at the most upstream cross section located near the Head Springs. This record was also used to develop internal lateral inflow boundary conditions on the Ichetucknee River. The development of the upstream flow boundary condition on the Ichetucknee River is discussed in the Lateral Inflows section (2.5.3).

2.5.2 Downstream Stage

A stage time series was developed during the initial MFLs assessment for use as the transient model downstream boundary condition at the confluence with the Suwannee River using the stages at Branford (USGS #02320500) and Bell (USGS #02323000) gaging station. The Branford and Bell gaging stations are 10.23 miles upstream and 9.79 miles downstream, respectively, from the Santa Fe River mouth. The downstream stage boundary condition is implemented at the most downstream LSFR model cross section, located approximately 1,600 feet upstream from the confluence.

The downstream boundary condition stage is a weighted sum of the stages at the two gages on the Suwannee River (SR). Time series using several combinations of weighing factors were developed and compared to the daily stages at the SFR Hildreth station (USGS #02322800), and the SR Branford and Bell gages for the simulation period (February 13, 2002 - September 29, 2011). The goal for the generated confluence time series was to have stages higher than the stages at Bell but lower than the stages at Branford. In addition, the generated confluence stage values were not to exceed the stages at Hildreth except for when a tailwater-controlled condition is present and the Suwannee River flows into the Santa Fe River during significant flood events.

The weighting equation determined for the initial MFLs assessment and used for the MFLs re-evaluation is:

Downstream Boundary Condition Stage = 0.4(SFR stage at Branford) + 0.6(SR stage near Bell)

The calculated daily confluence stages are lower than the SFR Hildreth stages most of the time, and the Hildreth stage was exceeded by the confluence stage 8.4% of the time (Figure 14). The calculated daily slope between the Hildreth gage and confluence during the transient simulation period averaged 0.000022 ft/ft (0.11 ft/mile), and typically ranged between about -0.00004 and 0.00006 ft/ft (Figure 15).

Four different “Known” water-surface elevations were considered for the initial MFLs assessment steady-state model. A stage-frequency relationship was developed for the calculated stages at the confluence during the calibration period (Figure 14), and stages associated with the 20^{th}, 40^{th}, 60^{th}, and 80^{th} exceedance frequencies were specified for each set of steady flow scenarios.

At the District’s request for the MFLs re-evaluation, HSW evaluated an alternative downstream boundary condition to characterize a condition when the backwater effect from the Suwannee River is minimal. The complete set of 3,516 calculated daily slopes were first parsed into two datasets, and the dataset with 3,220 values associated with positive slopes and discharge at the SFR Hildreth gaging station were evaluated further (Figure 15). The paired slope-Hildreth flow values were then sorted in order of increasing flow and parsed further into 21 subsets, twenty with 153 slope-flow pairs and one with 160 pairs, (Table 6). X-Y plotting positions for two relationships were calculated for the 21 subsets in which the average of the Hildreth flows associated with a subset are the X value. Average slopes were then calculated for all of the slopes associated with a subset and also for the slopes within the subset that were exceeded 20% of the time (Table 6).

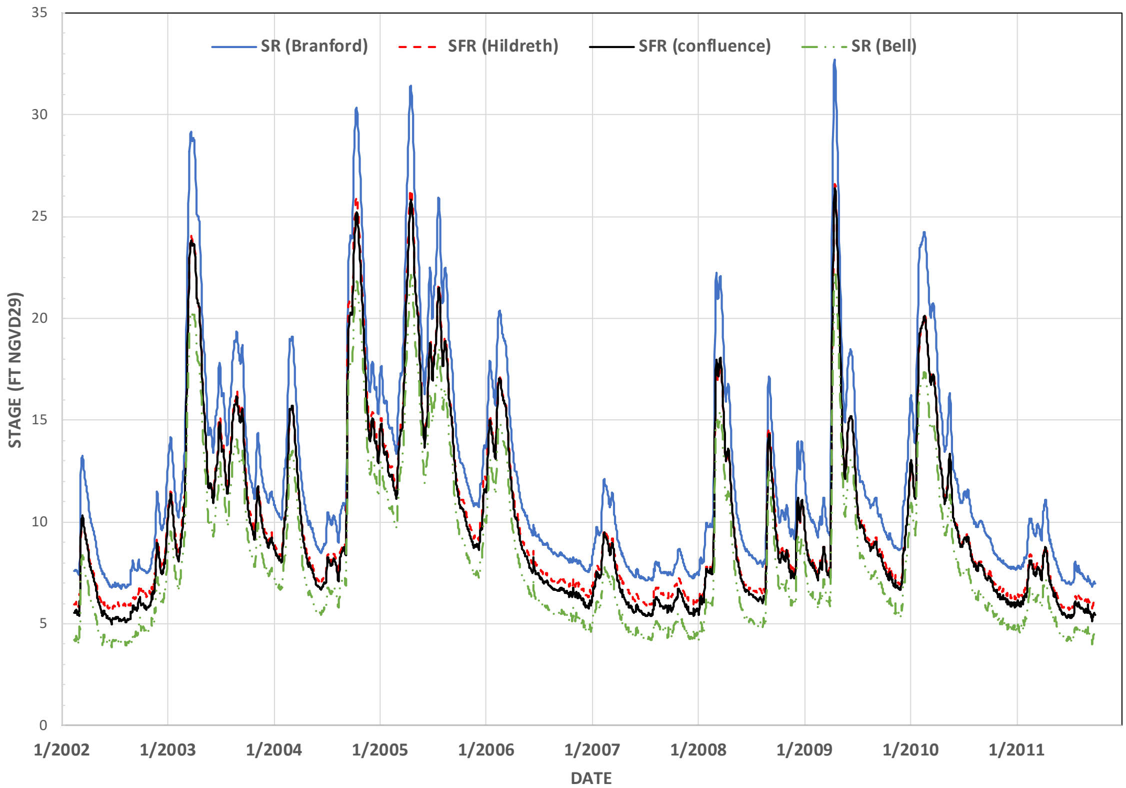


Figure 14. Daily Stages Measured on the Suwannee and Santa Fe Rivers and Calculated For the Confluence

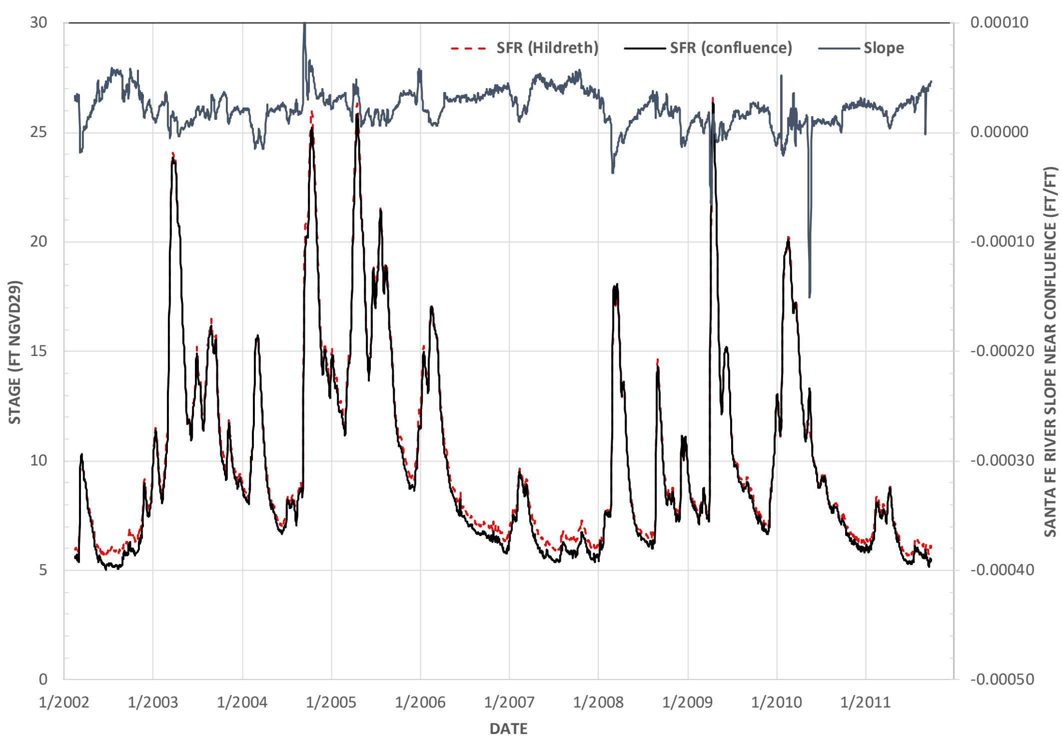


Figure 15. Daily Stages and Calculated Slope of the Santa Fe River Near Mouth

Table 6. Statistical Summary of Slope-Flow Pairs Evaluated to Characterize a Flow-Dependent Downstream Model Boundary Condition for Steady-State HEC-RAS Simulations

Subset No.	No. of Slope-Flow Pairs	Average Flow for Subset (cfs)	Average Slope for Subset (ft/ft)	Average of Subset Slopes Exceeded 20% of Time (ft/ft)
1	153	834	0.000033	0.000045
2	153	911	0.000026	0.000048
3	153	948	0.000032	0.000051
4	153	981	0.000030	0.000046
5	153	1007	0.000031	0.000049
6	153	1030	0.000029	0.000049
7	153	1056	0.000033	0.000052
8	153	1100	0.000029	0.000046
9	153	1143	0.000027	0.000044
10	153	1186	0.000025	0.000040
11	153	1208	0.000024	0.000039
12	153	1259	0.000021	0.000032
13	153	1365	0.000018	0.000029
14	153	1439	0.000016	0.000027
15	153	1522	0.000021	0.000036
16	153	1684	0.000026	0.000036
17	153	1854	0.000024	0.000039
18	153	2080	0.000020	0.000036
19	153	2304	0.000016	0.000028
20	153	2650	0.000017	0.000036
21	160	4085	0.000033	0.000067

Note: Flow is the Santa Fe River discharge at the Hildreth gaging station (USGS No. 02322800); slope is the calculated Santa Fe River slope between the Hildreth gage and confluence with the Suwannee River.

Power function trendlines were fit through the two sets of X-Y pairs (Figure 16). The 20% threshold was selected to define an envelope, or threshold, slope reflecting conditions when backwater effects from the Suwannee River were minimal. The following equation for the envelope curve was used to calculate the slope associated with the flow at the SFR Hildreth prescribed for each simulated steady-state flow condition.

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

In which

Slope = slope of Santa Fe River near confluence, ft/ft and

$Q_{Hildreth}$ = discharge of Santa Fe River at the Hildreth gaging station, cfs.

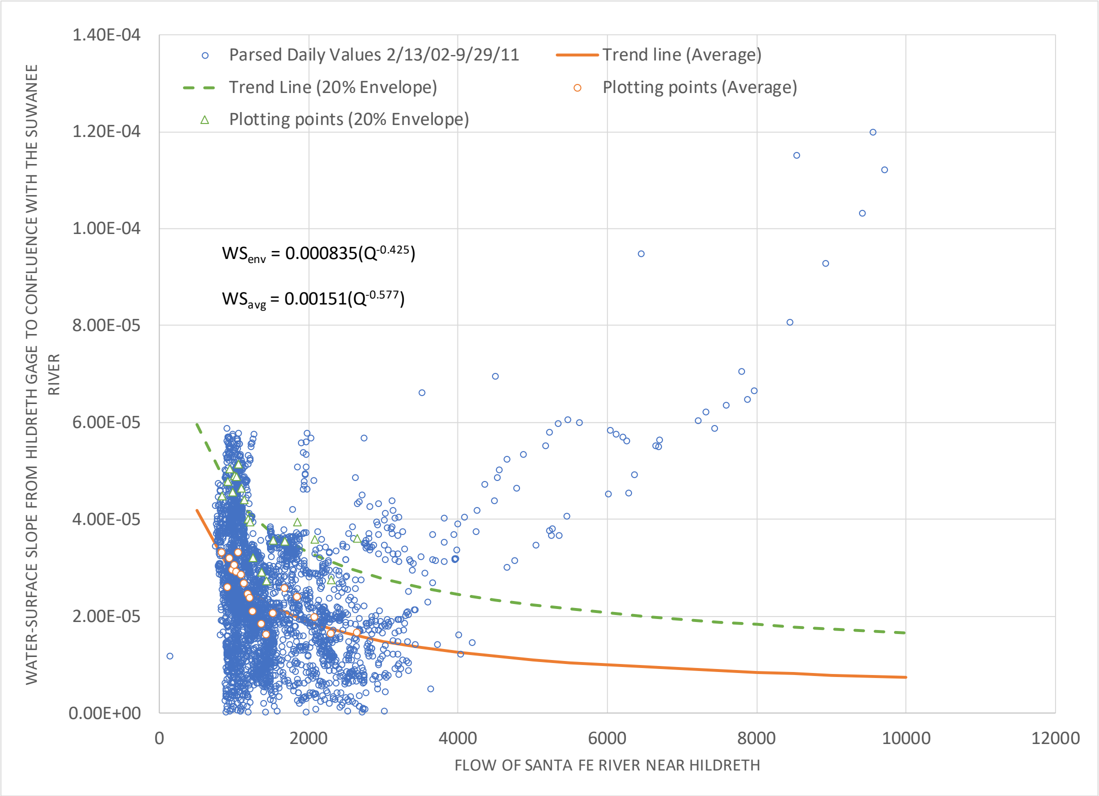


Figure 16. Slope-Discharge Relation for the Santa Fe River Near Its Mouth

2.5.3 Lateral Inflows

Various internal lateral inflows, both uniformly distributed and point inflows, were used in the model as internal boundary conditions. The lateral inflow option in HEC-RAS allows the assignment of a flow hydrograph at a specified point along a river reach. Uniform lateral inflow is another internal boundary condition that allows the specification of a flow hydrograph uniformly along a river (Hydrologic Engineering Center 2010). There are some limitations to how lateral inflows can be entered in HEC- RAS. Point lateral inflow cannot be attached to the most upstream cross section of a river reach.

Uniform lateral inflow cannot start on the most upstream cross section of a river reach or end on the most downstream cross section of a river reach. In addition, uniform lateral inflow cannot be uniformly distributed across a stream junction and has to terminate on a cross section before the junction. These limitations played a role when specifying uniform lateral inflows on the Lower Santa Fe River since the system consisted of several reaches that split and joined back together.

2.5.3.1 Santa Fe River System

The flow data at Worthington Springs (USGS #02321500) were used as the upstream flow boundary on the Lower Santa Fe River. The downstream boundary condition was a specified slope at STA. 1606.322 near the Suwannee River confluence.

The internal boundary conditions on the Santa Fe River consisted of lateral inflows simulating discharge from Olustee Creek and its contributing basin, lateral inflows simulating the loss of flow at the Santa Fe River Sink, and the gain of flow at the Santa Fe River Rise. Discharge pickup between Worthington

Springs and Fort White and between Fort White and Hildreth were additional uniformly distributed lateral inflows in the model.

Olustee Creek Lateral Inflow

The Olustee Creek near Providence (USGS #02321800) discharge record was limited to the period of record from 10/01/1957 to 09/30/1960. The New River near Lake Butler (USGS #02321000) USGS discharge time series was available from 01/01/1950 until present. The New River and the Olustee Creek basins have similar watershed characteristics and have not been significantly impacted by urban development (Figure 17) and flow records for the two gaging stations are similar (Figure 18).

A relationship between the Olustee Creek and New River discharge time series was developed using the discharge records for the common period (October 1, 1957 through September 30, 1960) as shown in Figure 19. The regression was used to generate the Olustee Creek time series of flow at the gaging station for the model simulation time period from February 13, 2002 through September 29, 2011.

The Olustee Creek near Providence USGS gage (USGS #02321800) is located approximately 6 river miles upstream from the confluence with the Santa Fe River. Since only an upstream portion of the Olustee Creek basin is gaged at the Olustee Creek near Providence USGS gage (Figure 17), flows from the basin downstream of the gage had to be accounted. A multiplier of 1.38 was developed by INTERA as part of the previous HEC-RAS modeling efforts of the Santa Fe River. The synthesized time series of flow at the gaging station was multiplied by 1.38 to account for all lateral inflows from Olustee Creek to estimate the discharge from the entire contributing basin (Figure 20).

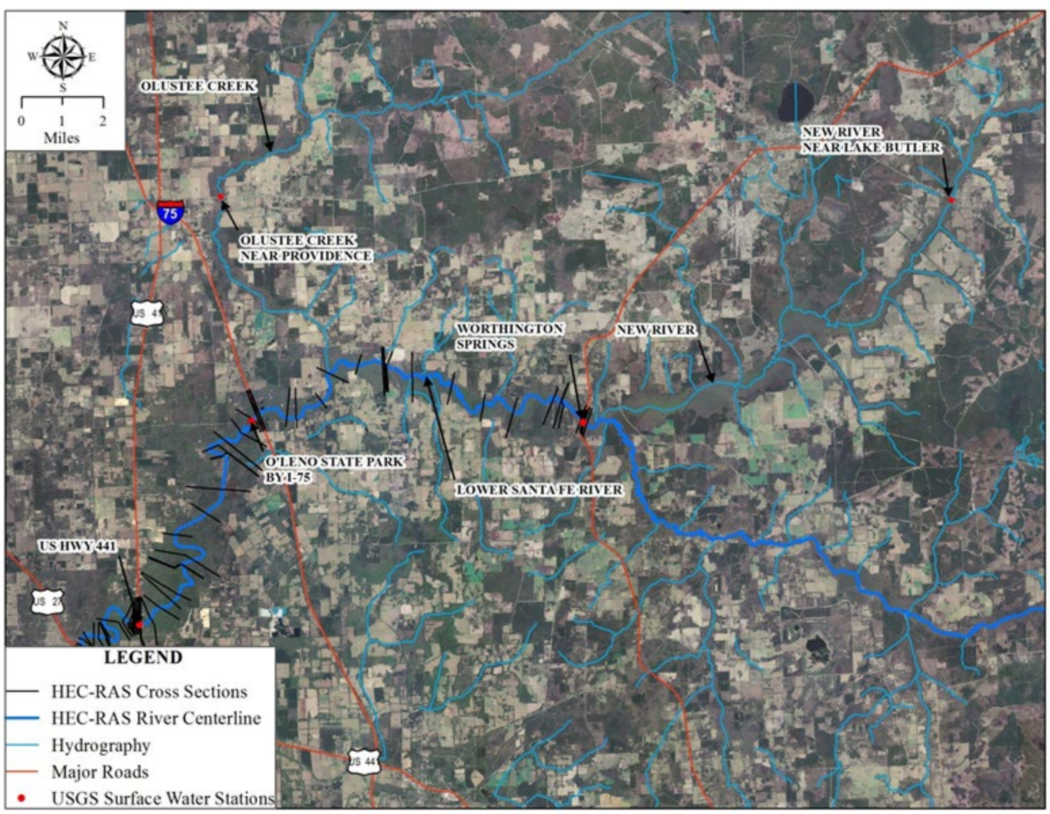


Figure 17. Location of Olustee Creek and New River

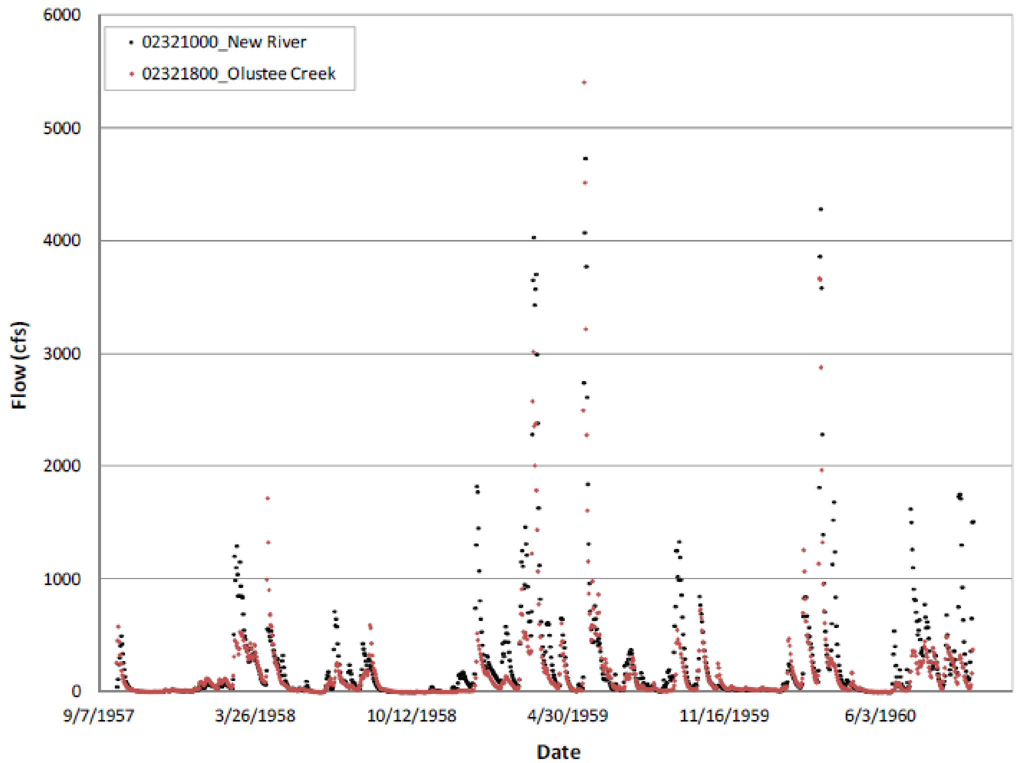


Figure 18. Discharged reported by USGS for Olustee Creek near Providence and New River near Lake Butler, October 1, 1957 – September 30, 1960

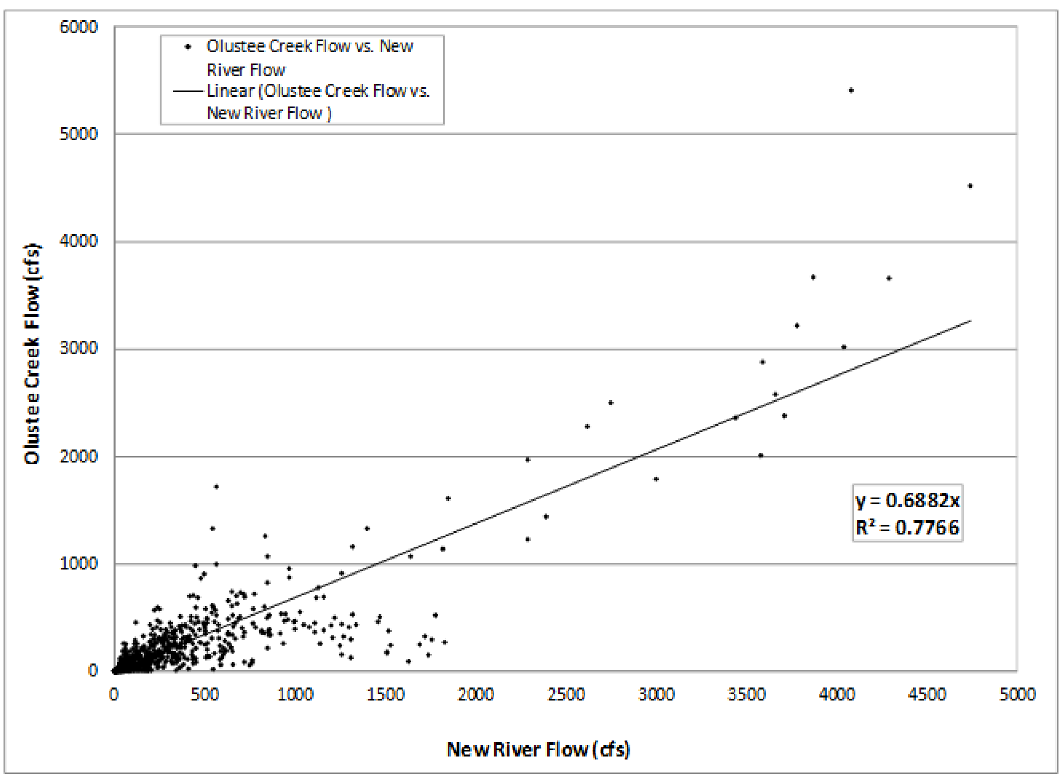


Figure 19. Relationship Between Flows of Olustee Creek near Providence and New River near Lake Butler

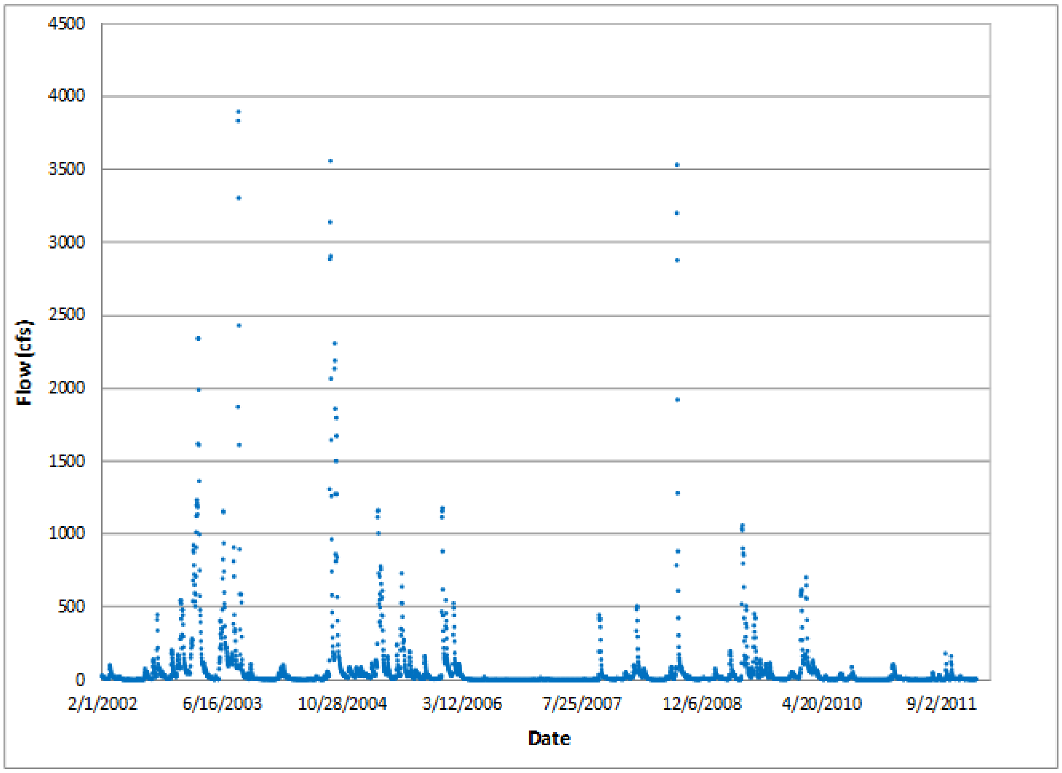


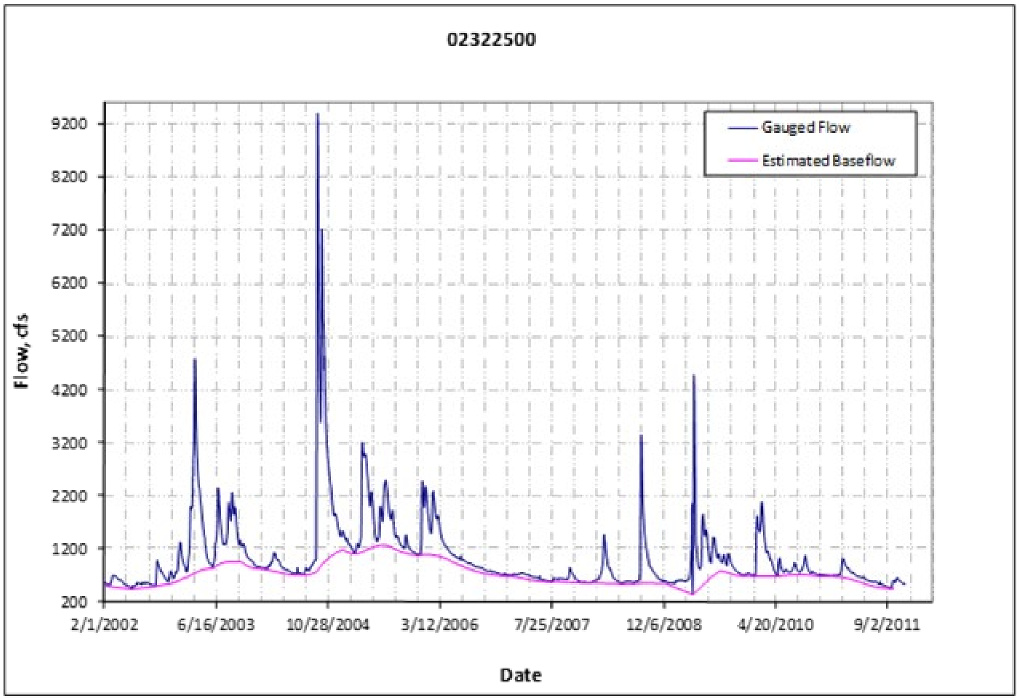
Figure 20. Olustee Creek Synthesized Discharge Time Series

Uniform Lateral Inflows Simulating the Discharge Pickup

Uniform lateral inflows simulating the discharge pickup on the Santa Fe River were developed from the generated baseflow time series at Worthington Springs (USGS #02321500), Fort White (USGS #02322500), Santa Fe River near Hildreth (USGS #02322800), Ichetucknee River at US Highway 27 near Hildreth (USGS #02322700), and Olustee Creek near Providence (USGS #02321800) gaging stations. Flow data at these stations was obtained from the USGS in order to develop baseflow time series to generate pickup between Worthington Springs and Fort White and between Fort White and Hildreth.

Baseflow was calculated using a low pass filter baseflow separation method. The low pass filter baseflow separation technique is a commonly used technique for determining the baseflow and runoff components of total streamflow (Perry 1995).

A moving 120-day window was utilized for baseflow separation at Fort White, Santa Fe River near Hildreth, Ichetucknee River at US Highway 27 near Hildreth, and Olustee Creek near Providence. For every given day, the minimum flow for a 120-day window (60 days prior and 60 after) was determined. Once the minimum 120-day flow was computed, the average of the minimum values was calculated for each 120-day period (60 days prior and 60 days after). A moving 270-day window was utilized for baseflow separation at Worthington Springs. Worthington Springs flow is characterized by flashy conditions and high peak discharges. A 270-day window generated lower overall baseflow conditions at Worthington Springs than a 120-day window. Negative streamflow values were deleted from the Santa Fe River near Hildreth (USGS #02322800) time series. In addition, flashy streamflow values were deleted from the Santa Fe River near Fort White time series (USGS #02322500). These manual adjustments were necessary for the baseflow algorithm to generate a baseflow component representative of the baseflow conditions at the Hildreth and Fort White streamflow gages. Examples of the baseflow separation at Fort White and Hildreth before and after streamflow adjustments are shown in Figure 21 through Figure 22. Final baseflow separation at Santa Fe River at Worthington Springs, Olustee Creek, and Ichetucknee River at Highway 27 are shown in Figure 23 through Figure 25.



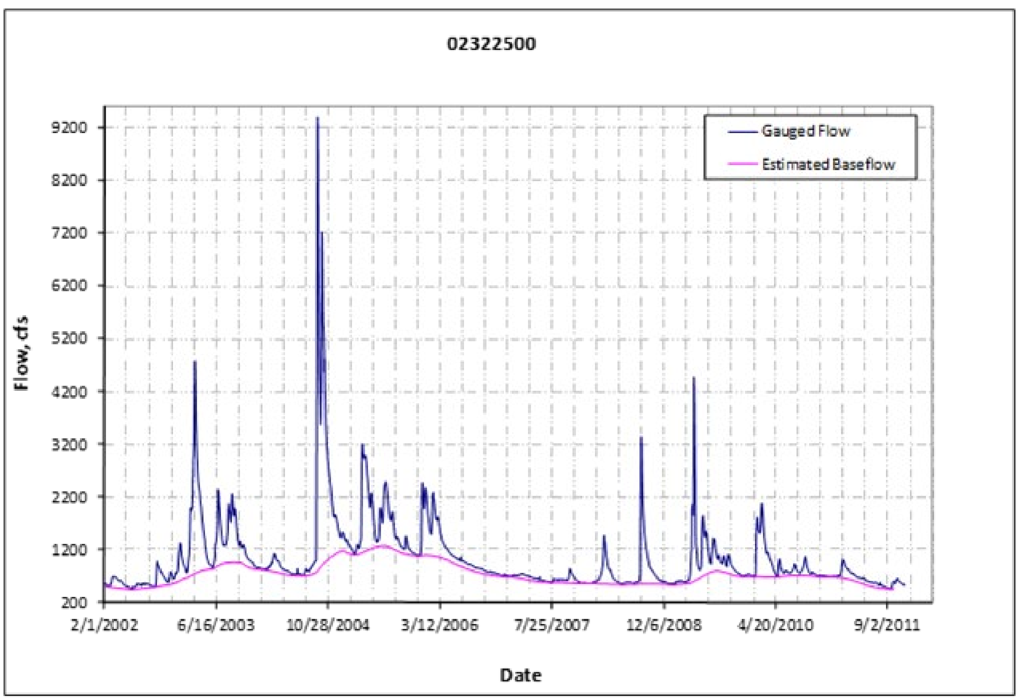
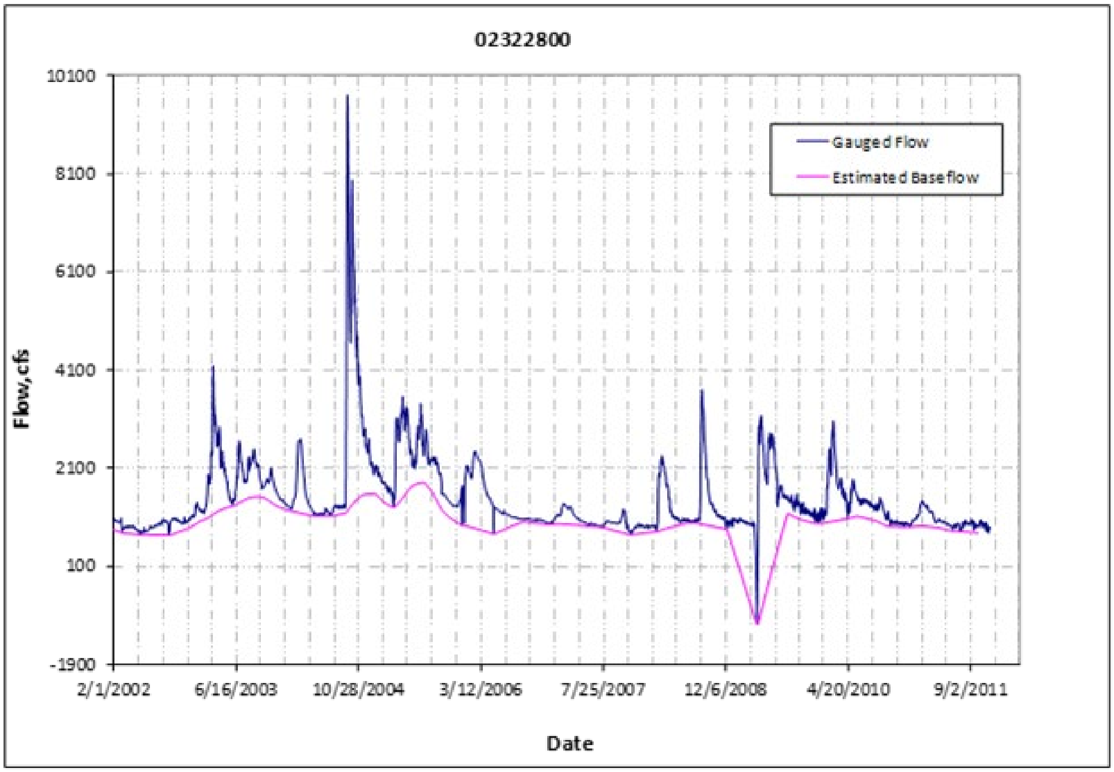


Figure 21. Baseflow Separation at Santa Fe River near Fort White (USGS #02322500): Before Streamflow Adjustments (top) and After Adjustments (bottom)



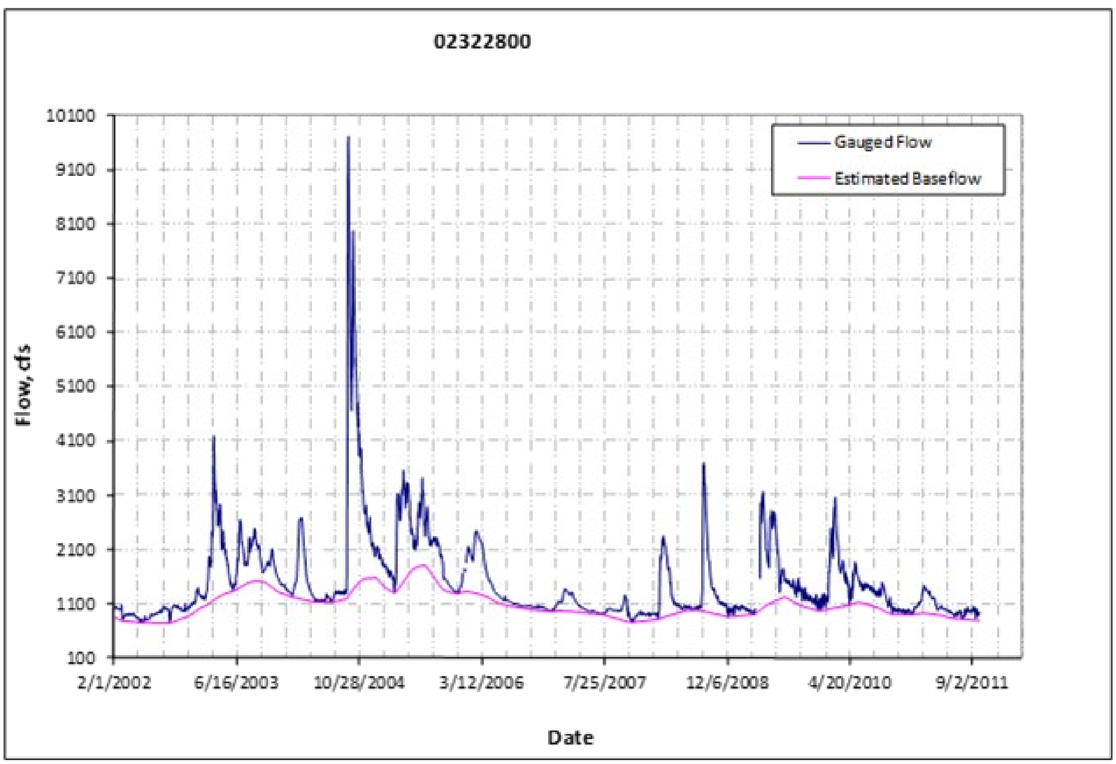


Figure 22. Baseflow Separation at Santa Fe River near Hildreth (USGS #02322800): Before Streamflow Adjustments (top) and After Adjustments (bottom)

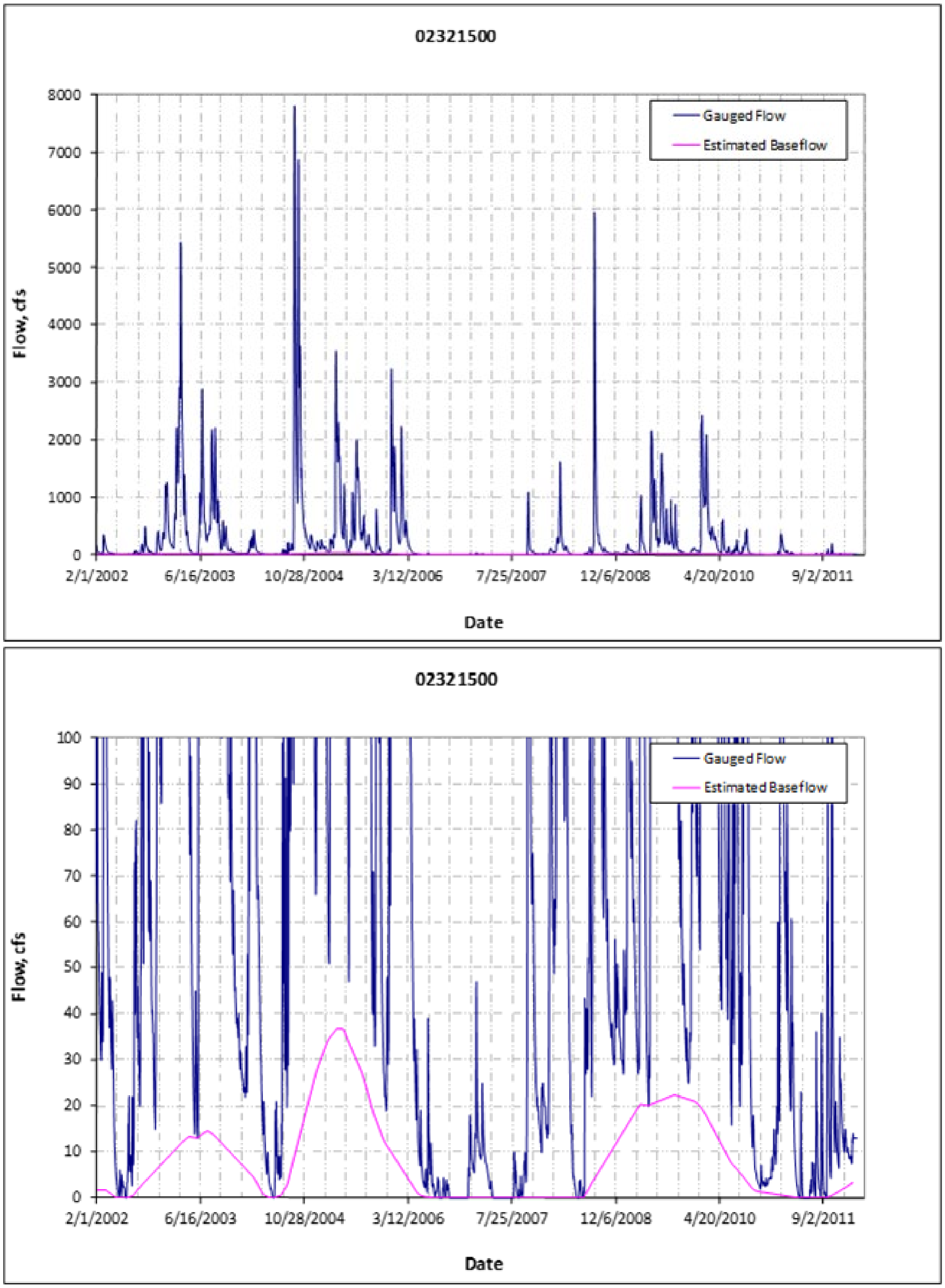
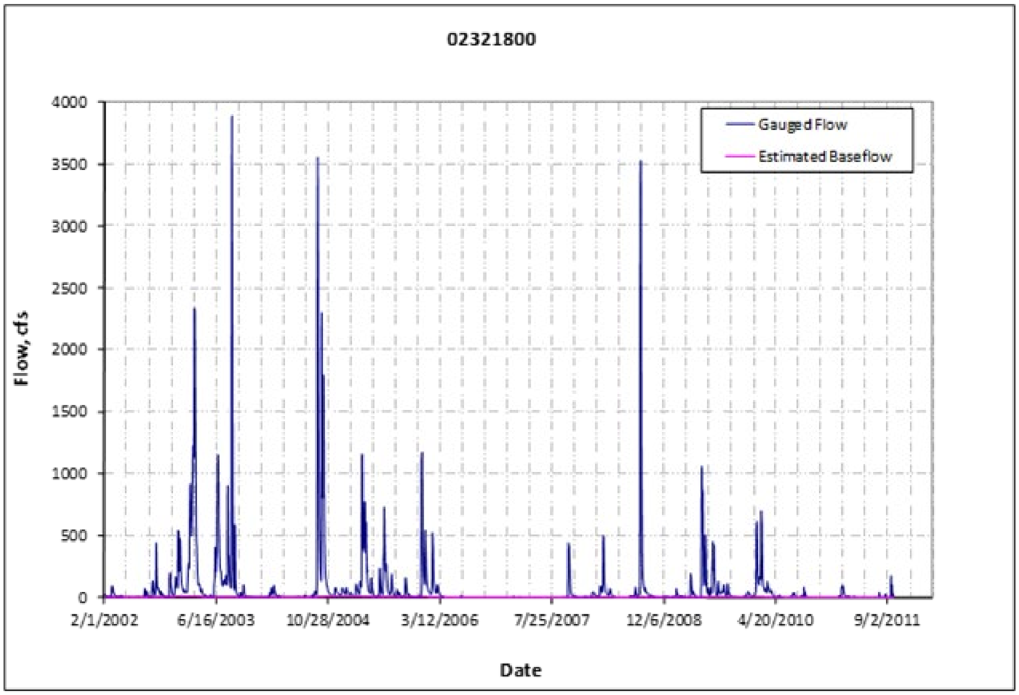


Figure 23 Final Baseflow Separation at Santa Fe River at Worthington Springs (USGS #02321500): Full Range (top) and Baseflow Range (bottom)



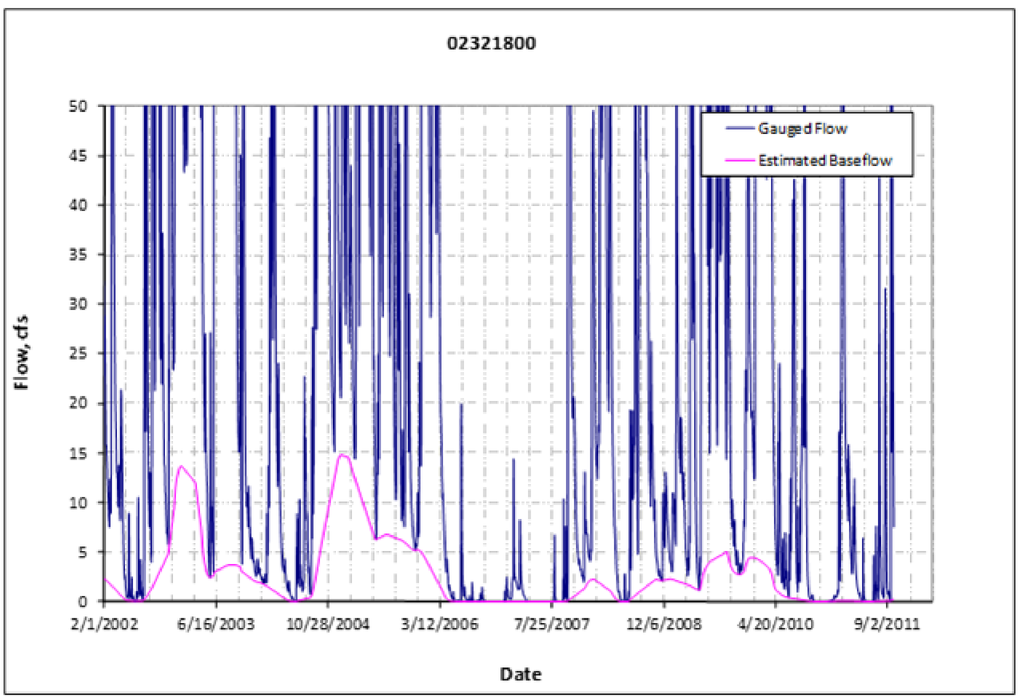


Figure 24. Final Baseflow Separation at Olustee Creek near Providence (USGS #02321800): Full Range (top) and Baseflow Range (bottom)

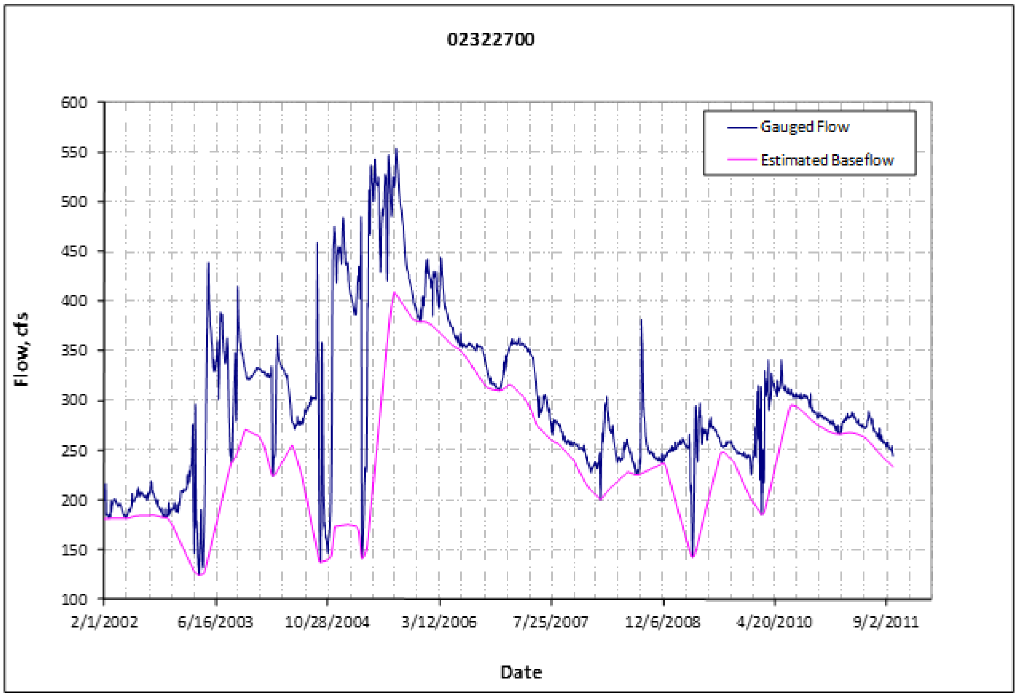


Figure 25. Baseflow Separation at Ichetucknee River at Highway 27 near Hildreth (USGS #02322700)

The discharge pickup between Worthington Springs and Fort White was developed by subtracting Worthington Springs baseflow and Olustee Creek baseflow from the Fort White baseflow time series. Similarly, the discharge pickup between Fort White and Hildreth was developed by subtracting Fort White baseflow and Ichetucknee River at US Highway 27 baseflow from the Hildreth baseflow time series. The Olustee Creek baseflow time series was subtracted from the pickup time series because the discharge from Olustee Creek and its contributing basin was entered as a lateral inflow in the model. Similarly, the Ichetucknee River at US Highway 27 baseflow was subtracted from the Fort White to Hildreth pickup since the Ichetucknee River is a tributary contributing flow to the overall system. The resultant discharge pickup time series are shown in Figure 26. These two time series were entered into HEC-DSS (“Boundary.dss”). Discharge pickup multipliers (factors) were applied to the time series (FWHITE_TO_HILDRETH and WORTH_TO_FWHITE) directly in the HEC-RAS model.

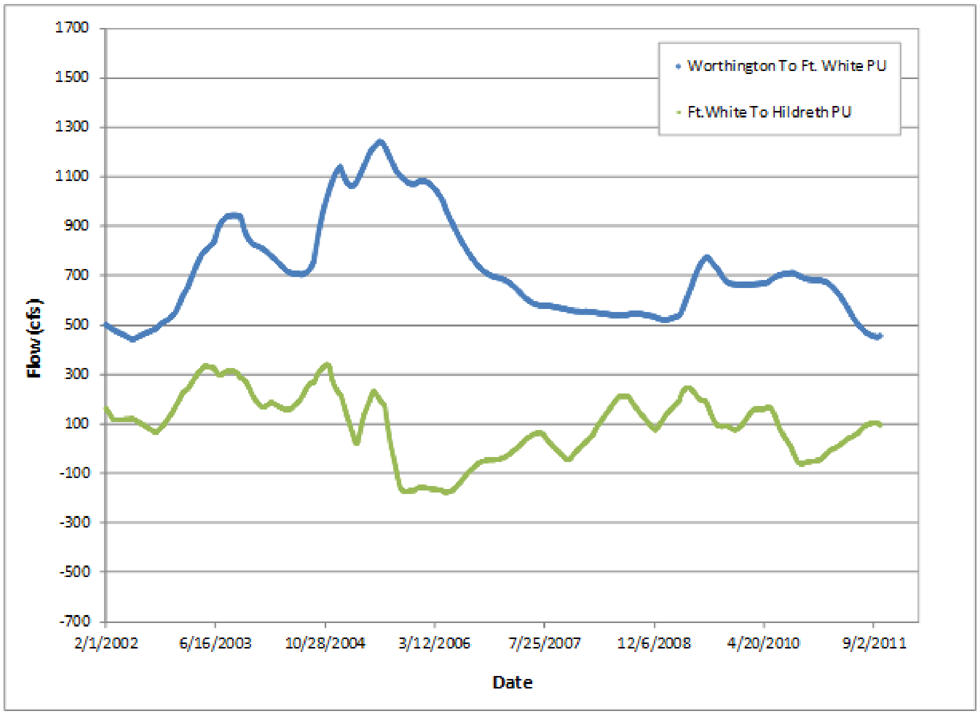


Figure 26. Discharge Pickup Time Series

The USGS National Water Information System (NWIS) discharge measurements, the USGS synoptic flow measurements, and the District discharge measurements were used in developing discharge pickup multipliers to model flow distribution along the Lower Santa Fe River.

The synoptic flow measurements were collected by the USGS Staff on May 4, 2011 ("Summary of USGS May 2011 Data.xls") along the Lower Santa Fe River (Figure 27). Flows at the Vinzant Landing Swallet and Worthington Springs were not part of the USGS synoptic discharge measurements. The flows at Worthington Springs were obtained from the USGS NWIS database. The District Staff measured the amount of flow entering the sinkhole at the Vinzant Landing Swallet on 2/21/2012 (30.3 cfs). The amount of flow entering the sinkhole on 2/21/2012 (30.3 cfs) was compared to the amount of flow at the Worthington Springs gaging station (USGS #02321500) on 2/21/2012 (10 cfs). The flow entering the sinkhole at the Vinzant Landing Swallet on 05/04/2011 was estimated by multiplying the flow at Worthington Springs on 5/4/2011 (0.96 cfs) by a factor of 3.03. The final Worthington to Fort White discharge pickup factors are shown in Table 7.

Other discharge pickup factors were also utilized during model calibration, with the factors shown below producing the best stage and flow results. In addition, various Fort White to Hildreth discharge pickup factors were utilized during model calibration. The best stage calibration was achieved when Fort White to Hildreth pickup discharge time series was distributed equally: half of the discharge pickup before the confluence with the Ichetucknee River and half of the discharge pickup after the confluence. A summary of the final internal boundary conditions on the Lower Santa Fe River, including pickup multipliers and their distribution along the Lower Santa Fe River, is provided in Table 7.

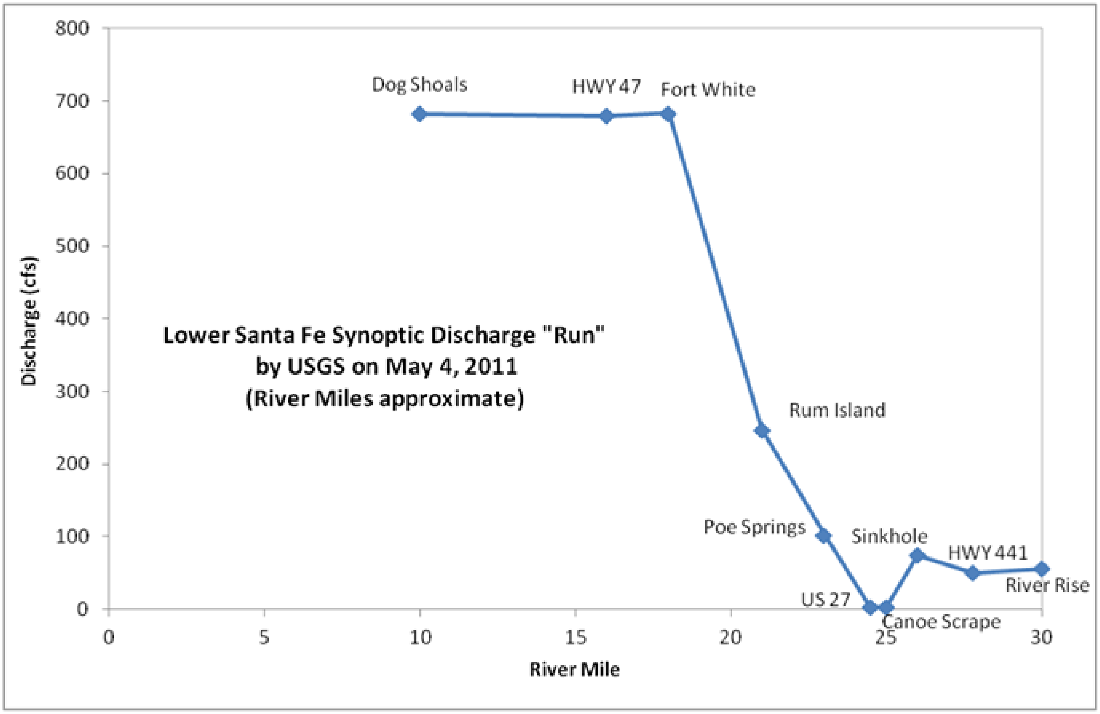


Figure 27. USGS Synoptic Discharge Measurements on the Lower Santa Fe River

Table 7. Worthington to Fort White Discharge Pickup Factors on the Lower Santa Fe River

Location	**River Mile (Approx.)**	**Discharge (cfs)**	**Source**	**Discharge Pickup (cfs)**	**Pickup Factors**
Worthington	49	0.96	USGS NWIS	0	
Vinzant Landing Swallet	37	2.90	Estimated	1.94	0.0028
Santa Fe River Rise	30	55.80	USGS Synoptic "Run"	52.90	0.0776
Sinkhole near High Springs	26	73.78	USGS Synoptic "Run"	17.98	0.0264
Poe Springs	23	102.00	USGS Synoptic "Run"	28.22	0.0414
Rum Island	21	247.00	USGS Synoptic "Run"	145.00	0.2126
Fort White	18	683.00	USGS Synoptic "Run"	436.00	0.6393
Fort White Q - Worthington Q		682.04		682.04	1

Vinzant Landing Swallet Lateral Inflow

The Vinzant Landing Swallet is another sink located approximately 1 mile downstream of the I-75 bridge (Figure 28). The Vinzant Landing Swallet cross section (STA. 195108) was added during calibration and was not surveyed; hence, this cross section consists of DEM points in both the floodplain and the channel (Figure 29). The bottom elevation of the cross section is 35.07 ft above NGVD29.

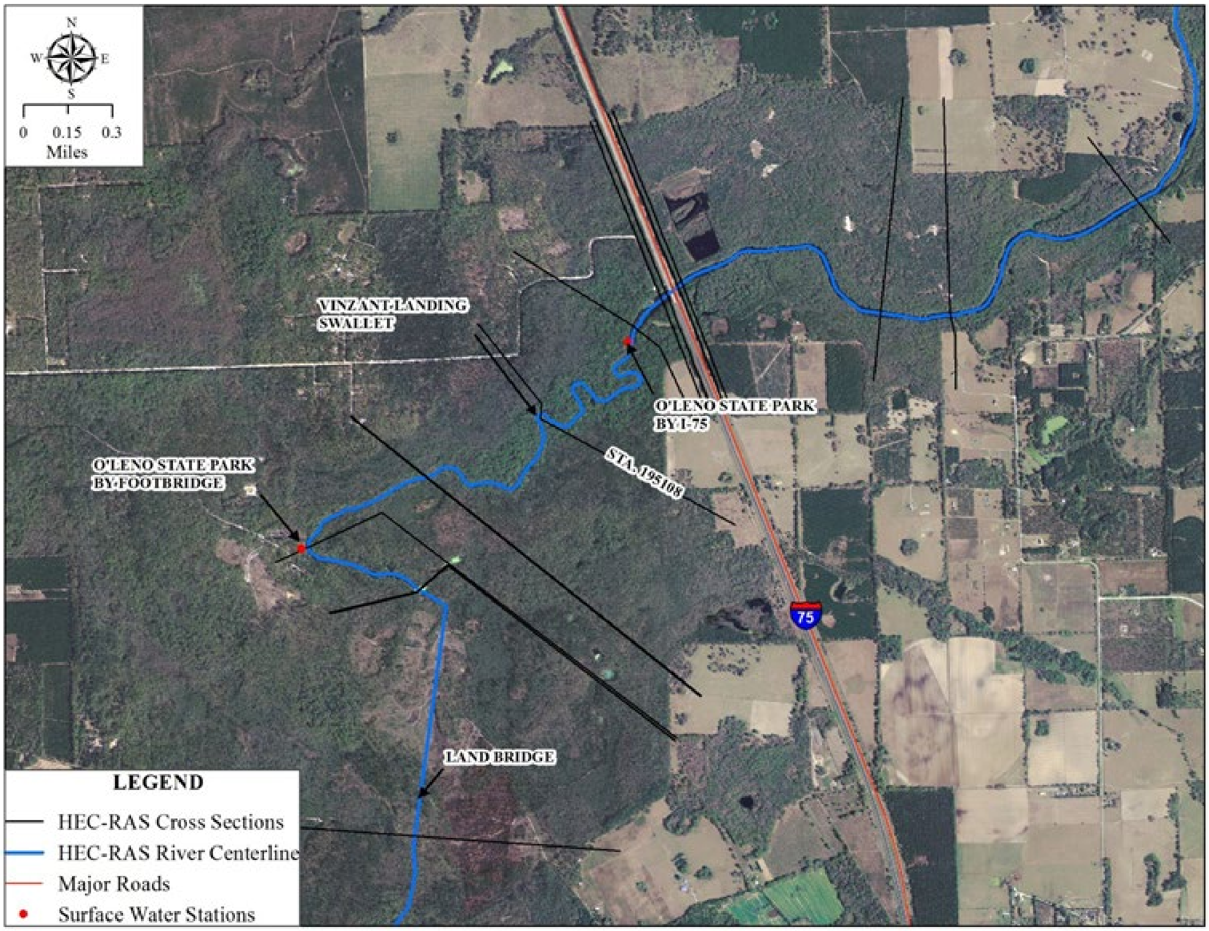


Figure 28. Vinzant Landing Swallet

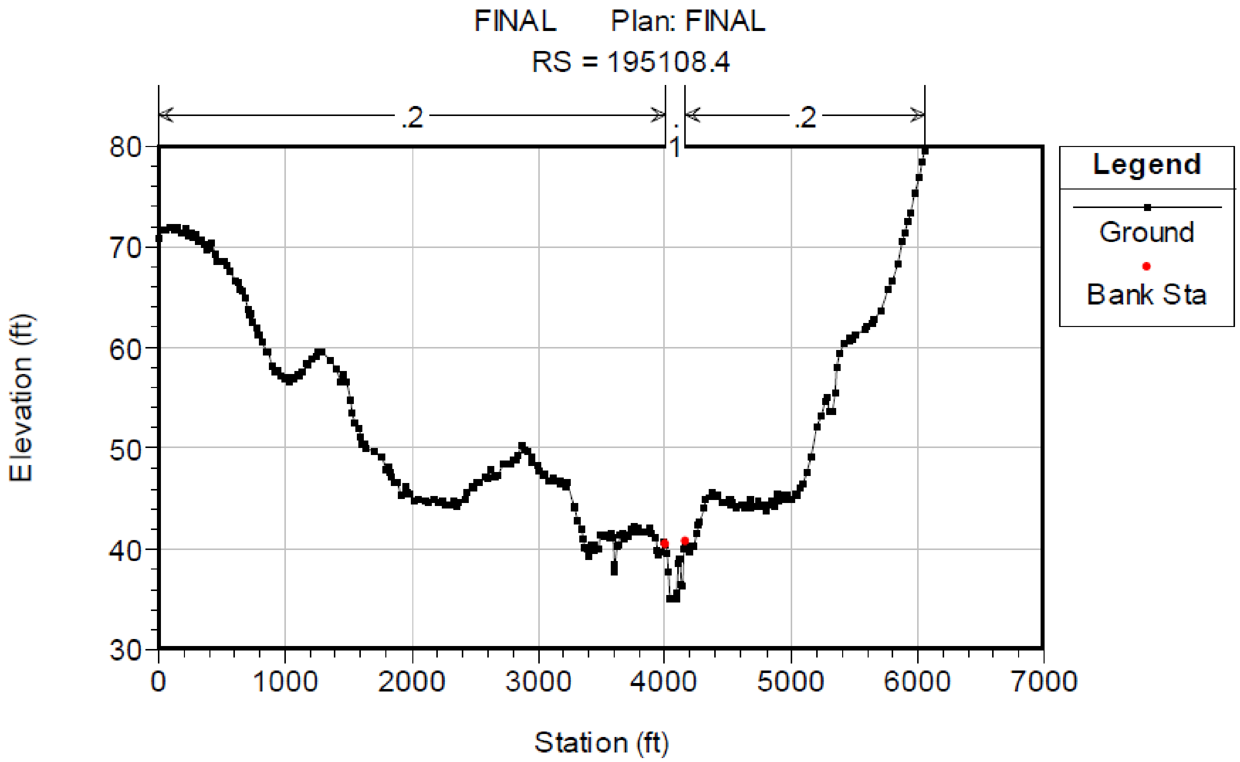


Figure 29. Vinzant Landing Swallet Cross Section

The District Staff kayaked the portion of the Lower Santa Fe downstream of I-75 and notified INTERA that a significant amount of water disappeared into the Vinzant Landing Swallet. The District Staff measured the amount of flow entering the sink at the Vinzant Landing to be 30.3 cfs on February 21, 2012. No additional measurements were made. The objective was to use the best available data to model the flow that disappeared into the Vinzant Landing Swallet. The loss of flow is modeled as a negative lateral inflow at the Vinzant Landing Swallet and as a positive lateral inflow at the Santa Fe River Rise. The positive lateral inflow is modeled at STA.164366 located immediately upstream of the Santa Fe River Rise (Figure 30). The underground channel of Land Bridge is modeled by the Below reach in the HEC-RAS model.

The Vinzant Landing Swallet lateral inflow is a synthesized time series in the HEC-RAS model. The lateral inflow was developed by first running the model without negative or positive inflows that account for the flows entering the Vinzant Landing Swallet and then taking the difference between the model simulated flow values and observed flow values at the O'Leno State Park by Footbridge gage (at STA. 189142). The O'Leno State Park by Footbridge flow measurements were provided by the District for the period of record from October 1, 1997 until September 30, 2009. Missing flow values from May 2, 2002, to August 2, 2002, and from September 30, 2009 to September 29, 2011, were filled using a linear regression between the O'Leno State Park by Footbridge flows and Worthington Springs flows (Figure 31).

Taking the difference between the model simulated flow values and observed flow values at the O'Leno State Park by the Footbridge (STA. 189142) generated a times series shown in Figure 32. The initially synthesized time series had flows values of nearly 8000 cfs and not representative of the physical conditions at the Vinzant Landing Swallet. The time series was further revised to ensure that no more than 200 cfs was diverted into the Vinzant Landing Swallet in the model (Figure 32).

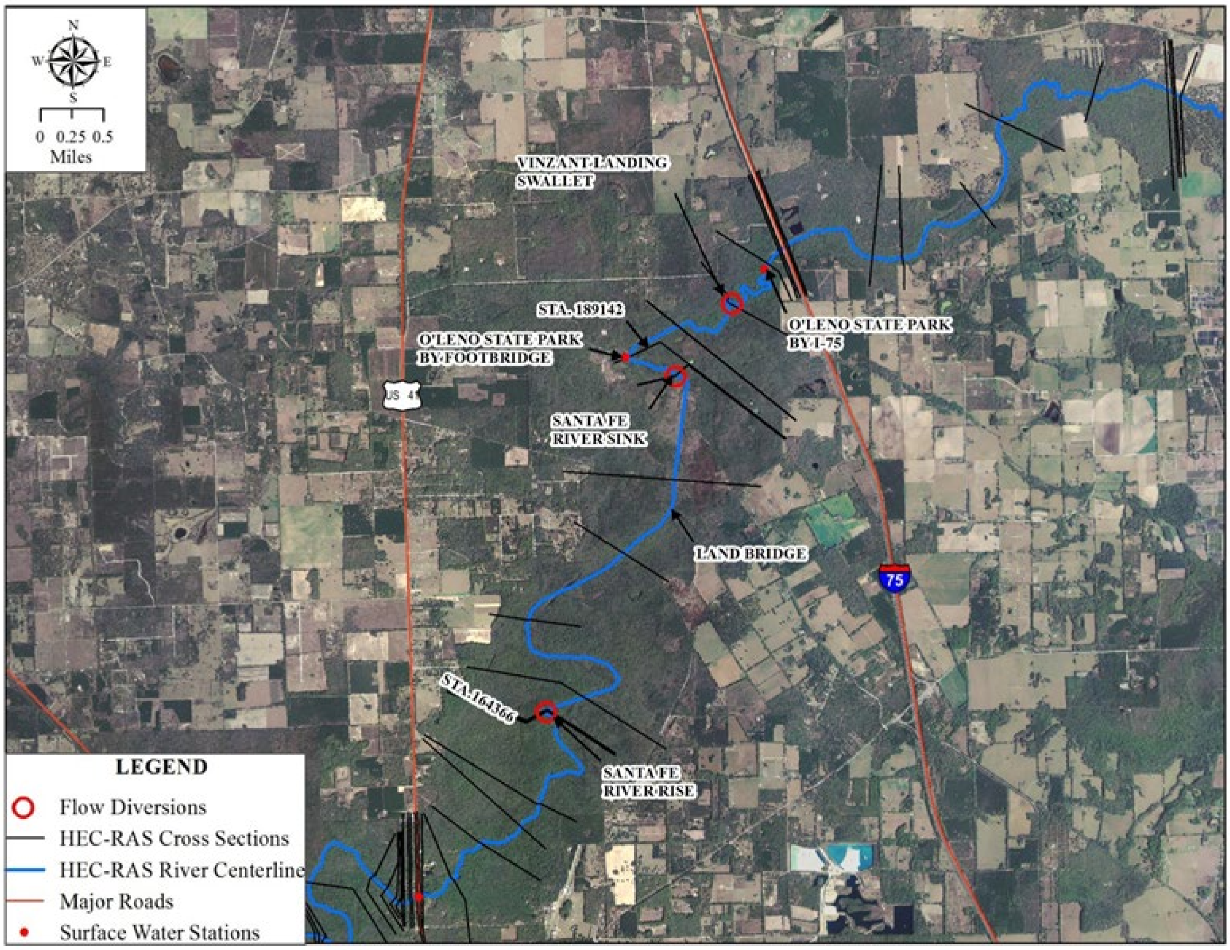
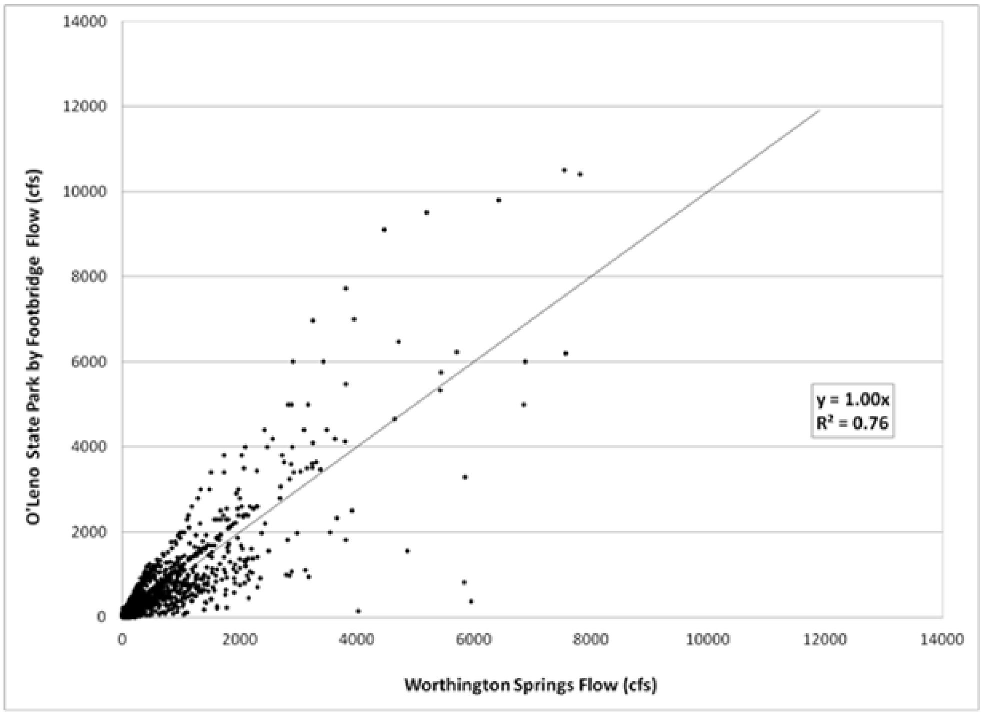


Figure 30. Vinzant Landing Swallet Lateral Inflows

The final Vinzant Landing Swallet synthesized time series is shown in Figure 32. A negative multiplier of 0.9 was applied in HEC-RAS to the synthesized time series to account for the flow loss into the sink at the Vinzant Landing. A positive multiplier of 0.9 was applied to the synthesized time series to ensure the flow loss was gained back at the Santa Fe River Rise. Although there was some uncertainty in how the Vinzant Landing Swallet lateral inflow was developed, the time series simulating the loss of flow at the Vinzant Landing Swallet improved calibration results at the O'Leno State Park by Footbridge calibration station (STA.189142.1).



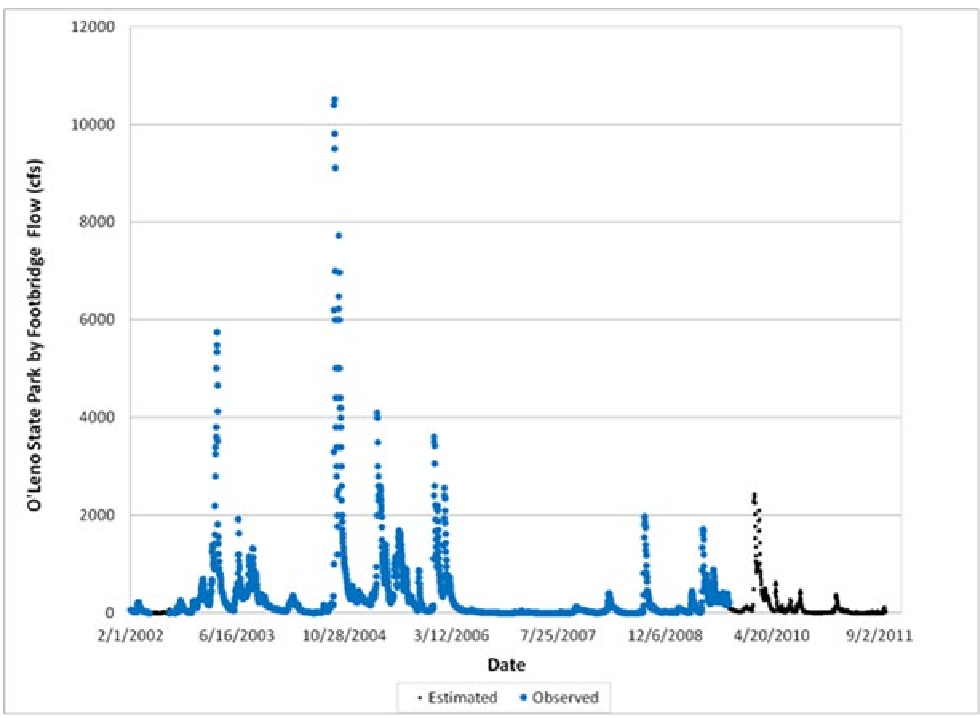


Figure 31. Linear Regression: O'Leno State Park by Footbridge: Linear Regression of Flow vs. Worthington Springs Flow (top) and Observed and Synthesized Flow Time Series (bottom)

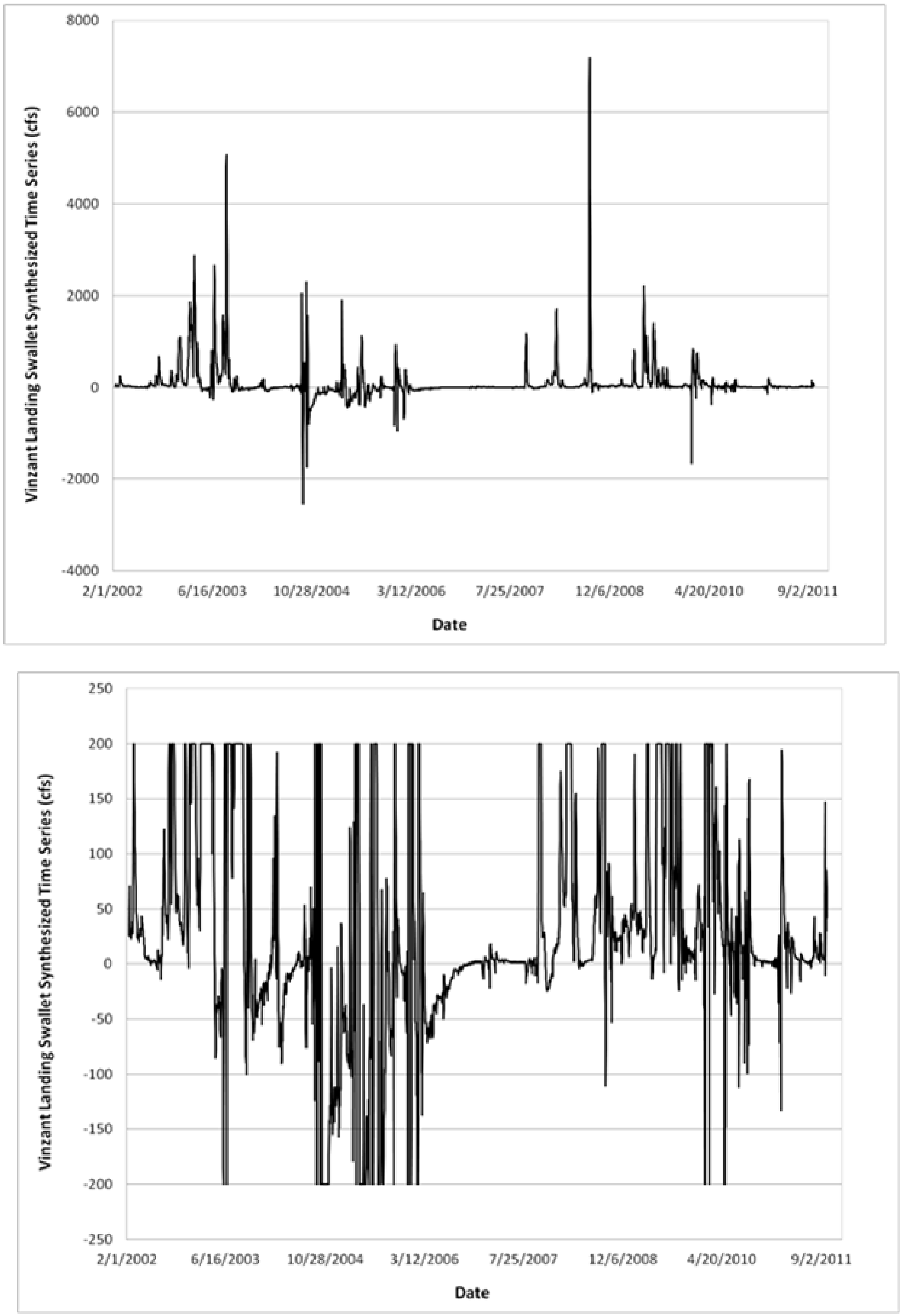


Figure 32. Vinzant Landing Swallet Synthesized Time Series: Before Adjustments (top) and After Adjustments (bottom)

Summary of Internal Boundary Conditions on the Santa Fe River

The model internal boundary conditions on the Santa Fe River are listed below:

- Uniform Lateral Inflow between STA. 267340.3 to STA. 199608.7 simulating the discharge pickup from Worthington Springs to just downstream of I-75 bridge (near O'Leno State Park by I-75 gaging station): 0.0028 of the Worthington to Fort White discharge pickup time series.
- Lateral Inflow at STA. 214930.6 simulating the discharge from Olustee Creek and its contributing basin: 1.38 times the Olustee Creek discharge time series.
- Lateral Inflow at STA. 196233* simulating the discharge loss at the Vinzant Landing Swallet: 0.9 times the Vinzant Landing Swallet synthesized time series.
- Lateral Inflow at STA. 164366 simulating the Vinzant Landing Swallet discharge gain in the underground channel of the Land Bridge: 0.9 times the Vinzant Landing Swallet synthesized time series.
- Lateral Inflow at STA. 164346* simulating the discharge pickup in the underground channel of the Land Bridge: 0.0776 of the Worthington to Fort White discharge pickup time series.
- Uniform Lateral Inflow between STA. 158286.6 to STA. 139200.9 simulating the discharge pickup from River Rise to just upstream of the Alligator Siphon: 0.0264 of the Worthington to Fort White discharge pickup time series.
- Uniform Lateral Inflow between STA. 133442.55 to STA. 126095.8 simulating the discharge pickup from Highway 27 bridge to Poe Springs Island: 0.0414 of the Worthington to Fort White discharge pickup time series. 133442.55 is located approximately 20 feet upstream of the upstream side of the Highway 27 bridge.
- Uniform Lateral Inflow between STA. 123484.8 to STA. 114628* simulating the discharge pickup from Poe Springs Island to Rum Island: 0.2126 of the Worthington to Fort White discharge pickup time series.
- Uniform Lateral Inflow between STA. 111186.1 to STA. 96627.88 simulating the discharge pickup from Rum Island to Fort White: 0.6393 of the Worthington to Fort White discharge pickup time series.
- Uniform Lateral Inflow between STA. 96627.88 to STA. 41168.91 simulating the discharge pickup from Fort White to just upstream of the confluence with the Ichetucknee River: 0.5 of the Fort White to Hildreth discharge pickup time series.
- Uniform Lateral Inflow between STA. 34668.82 to STA. 12872.86 simulating the discharge pickup from just downstream of the confluence with the Ichetucknee River to Hildreth gaging station: 0.5 of the Fort White to Hildreth discharge pickup time series.

2.5.3.2 Ichetucknee River System

The Ichetucknee River 2007 HEC-RAS model previously developed and calibrated by INTERA was used as a base for the Ichetucknee River portion of the HEC-RAS model of the Lower Santa Fe and Ichetucknee Rivers. The Ichetucknee River was combined subsequently with the Lower Santa Fe River for the initial MFLs assessment to be modeled as a single combined system.

The 2007 HEC-RAS model of the Ichetucknee River was constructed to simulate a five-year period between February 14, 2002 and March 3, 2007. The 2007 HEC-RAS model boundary conditions consisted of the following eight springs:

- Ichetucknee Head Spring (USGS #02322685) upstream boundary and lateral inflows from Cedar Head Spring (USGS #02322687)

- Blue Hole Spring (USGS #02322688)
- Mission Spring (USGS #02322691)
- Devil's Eye Spring (USGS #02322694)
- Coffee Spring
- Mill Pond Spring (USGS #02322695)
- Grassy Hole Spring

Lateral inflows simulating discharge pickup from Grassy Hole Spring and Coffee Springs were obtained using linear regressions with the Mill Pond Spring (USGS #02322695) discharge time series. Figure 33 shows the location of the modeled Ichetucknee River springs.

The daily hydrographs for the Ichetucknee Head Spring upstream boundary and lateral inflows at the springs were extended because the transient model simulation period is February 13, 2002 through September 29, 2011. The data collection at the springs on the Ichetucknee River was discontinued by the USGS on March 31, 2010. Initially, the decision was made to use the USGS measured flows at the springs until 2010 and fill the rest of the time series using regressions with the Ichetucknee River US Highway 27 flow (USGS #02322700).

Figure 34 shows daily flow hydrographs at US Highway 27 and the spring gages. Figure 35 compares the daily flows at the US Highway 27 gaging station with the sum of the spring discharge upstream of US Highway 27 and indicates that the sum of the spring discharge upstream of US Highway 27 exceeds the total flow at the US Highway 27 gaging station. The District was notified of the findings and discussed the discharge measurements on the Ichetucknee River with the USGS Staff. The USGS Staff attributed the loss of flow to a bias in the measurements and poor ratings at the spring gages. The USGS Staff confirmed that it was not appropriate to sum the Ichetucknee River springs' discharges to achieve total flow on the Ichetucknee River. According to the USGS Staff, the Highway 27 (USGS #02322700) flow was the best approximation of total flow on the Ichetucknee River (Coarsey, 2012).

Since it was confirmed by the USGS that the US Highway 27 flow was the best approximation of total flow on the Ichetucknee River, regressions were developed between each spring discharge and Highway 27 discharge to determine flow-proportioning factors representative of the total flow at each spring location. Grassy Hole Spring and Coffee Spring did not have daily discharge measurements. The Coffee Spring USGS intermittent field measurements were used to develop a relationship with the Highway 27 discharge time series. The Coffee Spring field measurements begin on May 31, 2002 and end on March 25, 2010. In the 2007 HEC- RAS model of the Ichetucknee River, lateral inflow simulating the discharge pickup from Grassy Hole Spring was obtained using linear regression with the Mill Pond Spring (USGS #02322695) discharge time series. In the 2007 HEC-RAS model Grassy Hole Spring lateral inflow was simply a factor (0.1053) of the Highway 27 discharge time series. For the revised model Grassy Hole Spring factor was obtained by relating the Mill Pond discharge times series and Highway 27 discharge time series. The developed linear regressions are shown in Figure 36 through Figure 43. Although there is some uncertainly in how the regressions for Coffee Spring and Grassy Hole Spring were developed, these springs contributed a very small portion of total flow on the Ichetucknee River.

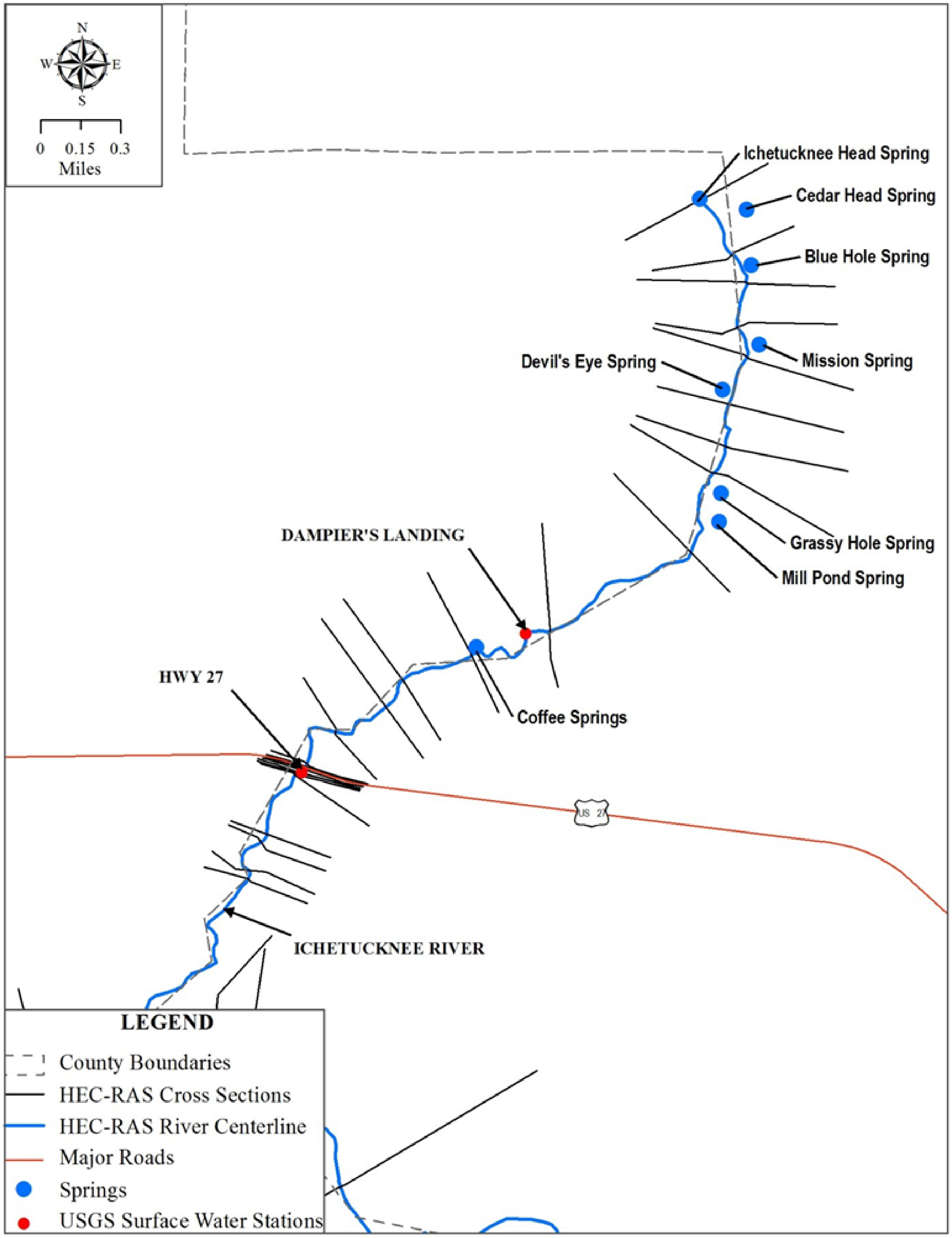


Figure 33. Ichetucknee River Springs and Cross Sections

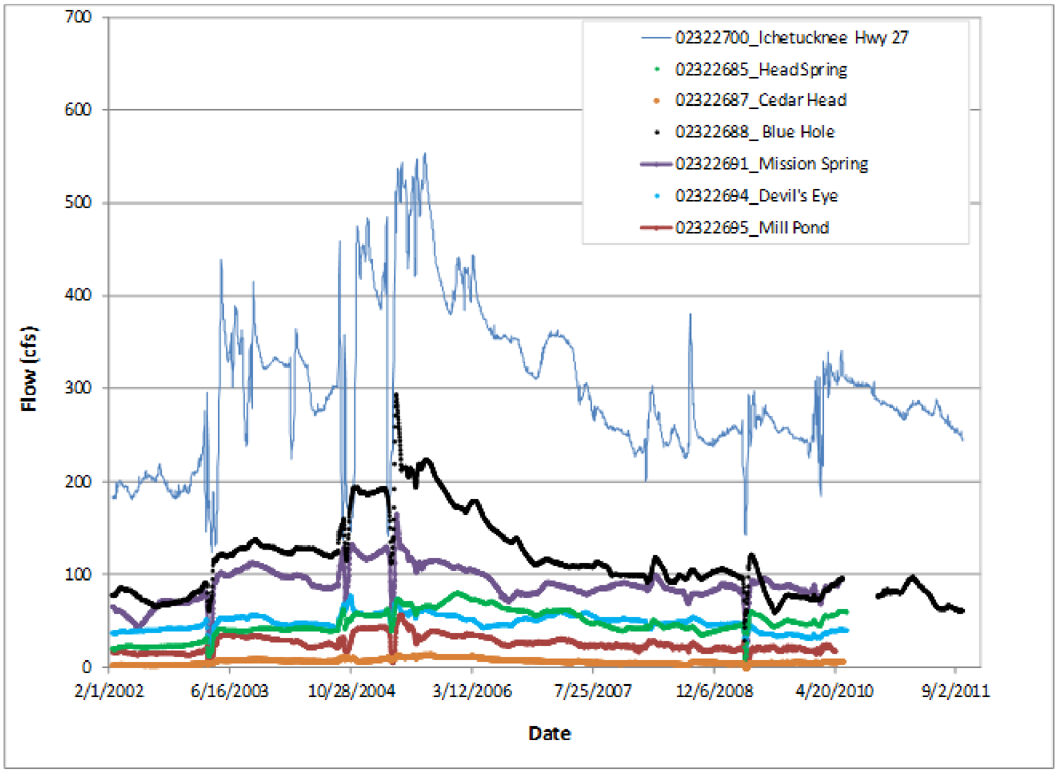


Figure 34. Daily Hydrographs at Highway 27 and Springs on the Ichetucknee River

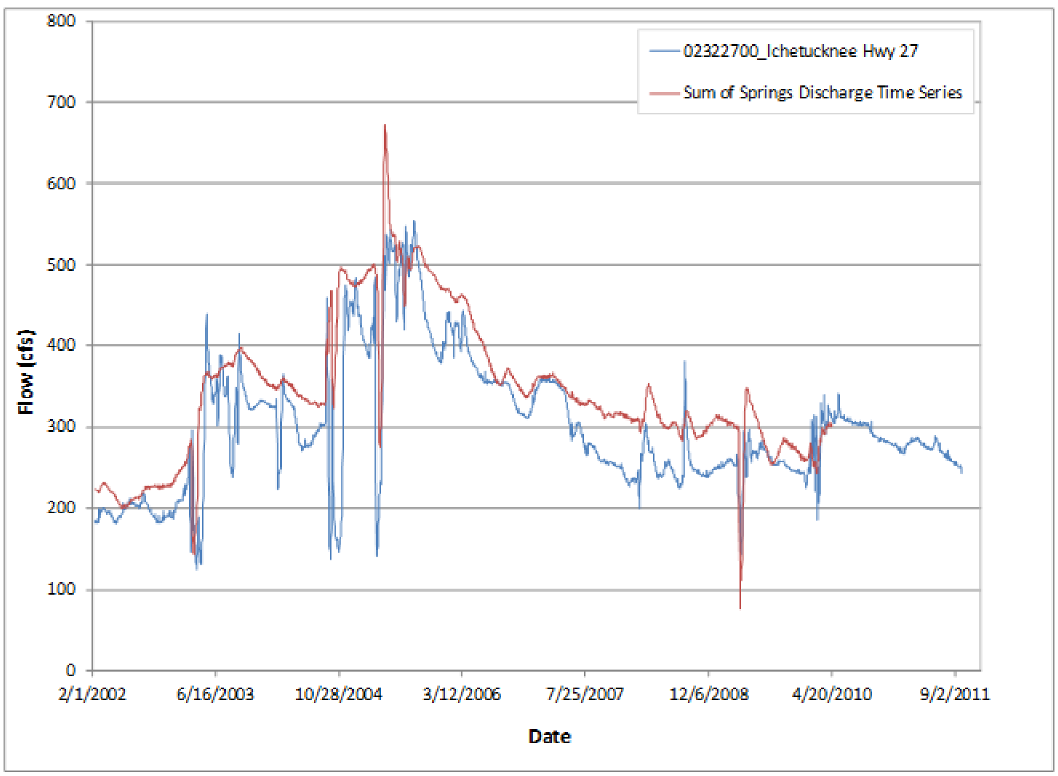


Figure 35. Sum of the Springs Discharge Time Series

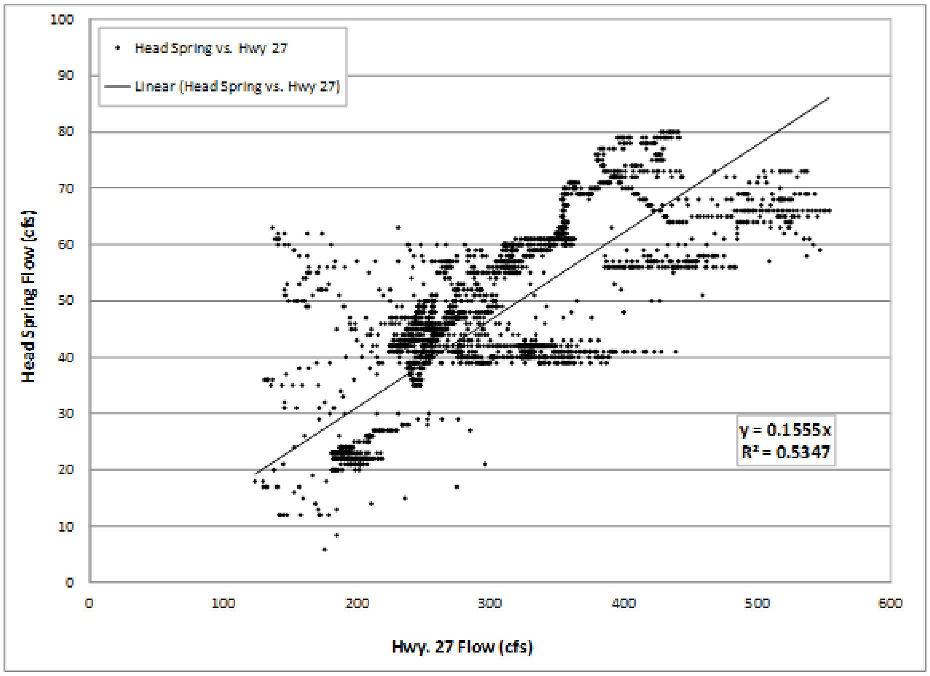


Figure 36. Ichetucknee Head Spring Flow vs. Highway 27 Flow

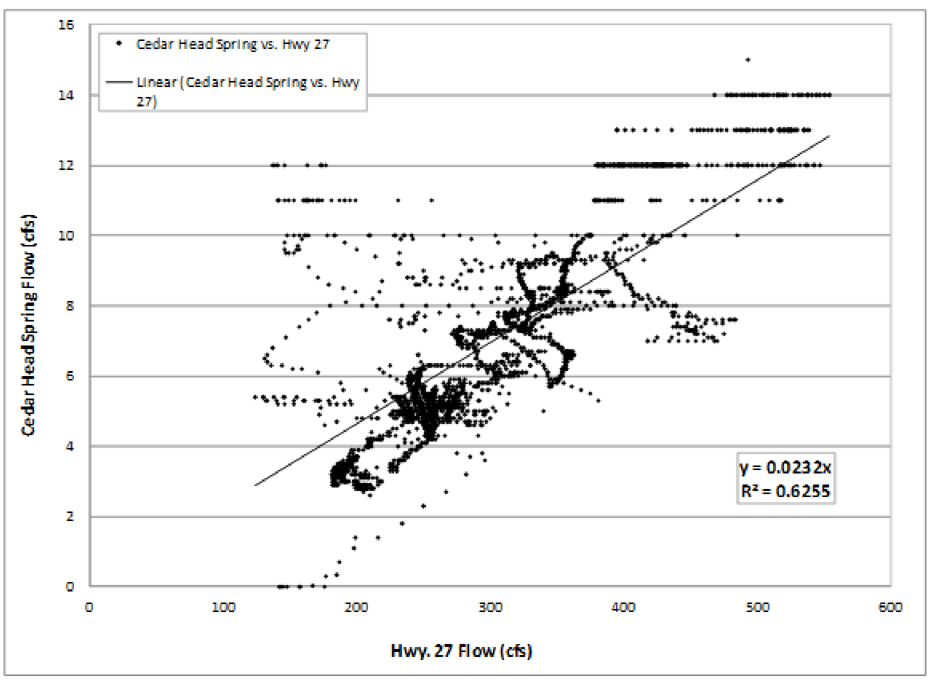


Figure 37. Cedar Head Spring Flow vs. Highway 27 Flow

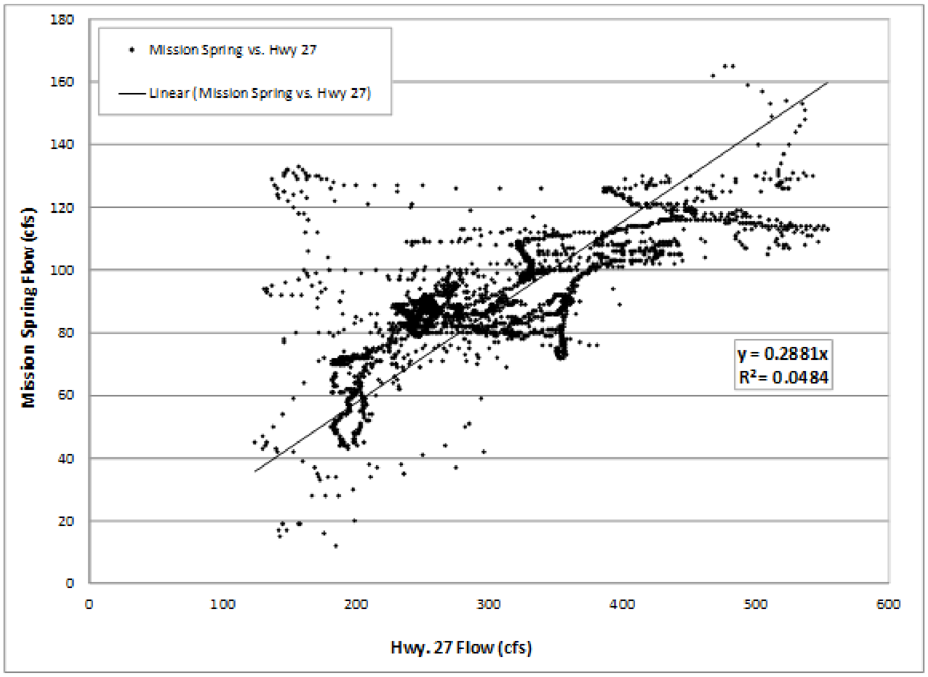


Figure 38. Blue Hole Spring Flow vs. Highway 27 Flow

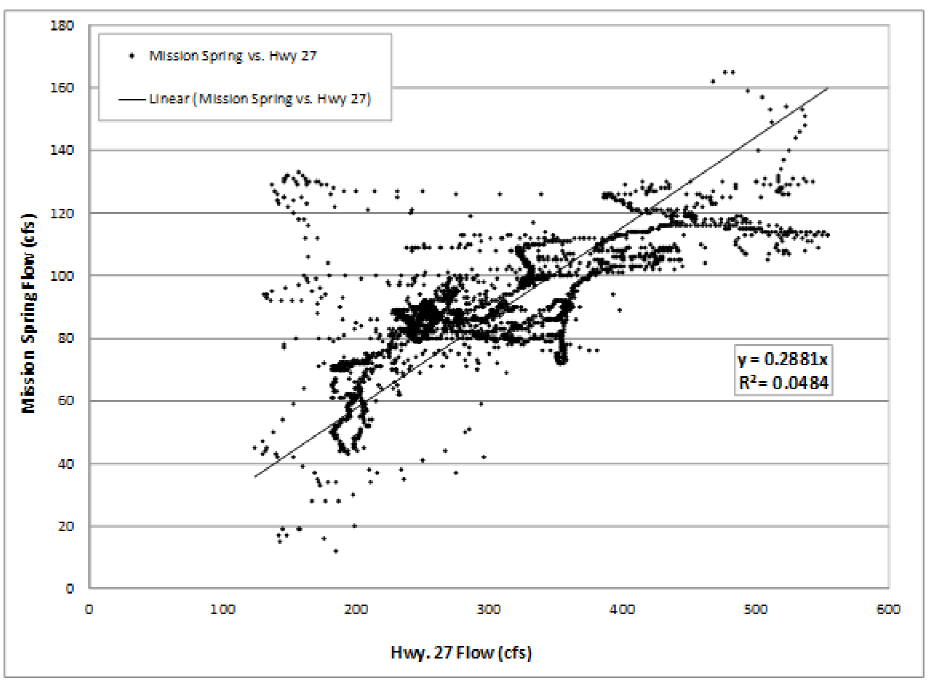


Figure 39. Mission Spring Flow vs. Highway 27 Flow

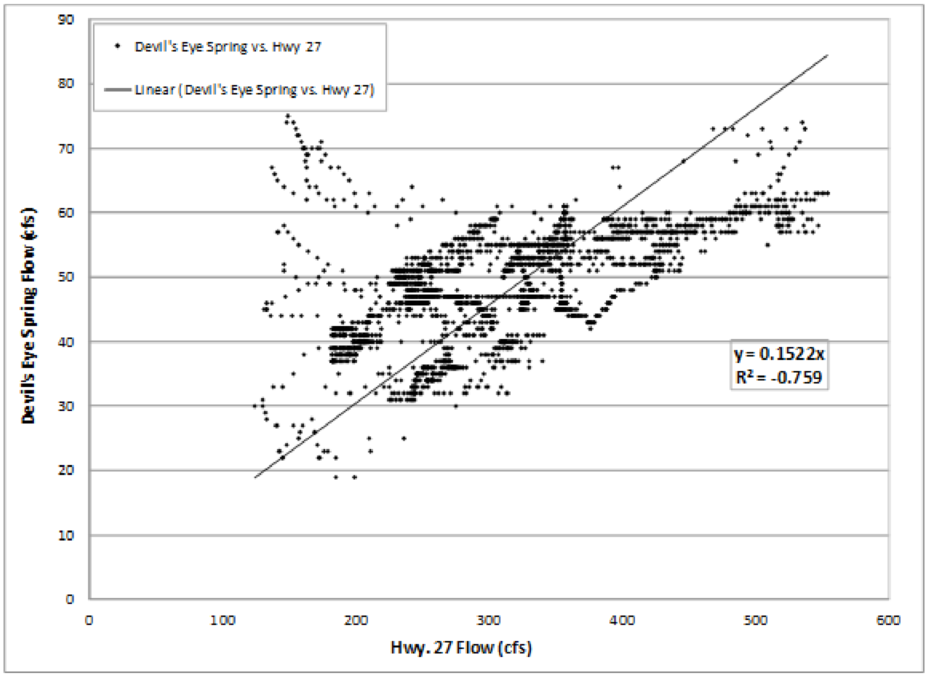


Figure 40. Devil's Eye Spring Flow vs. Highway 27 Flow

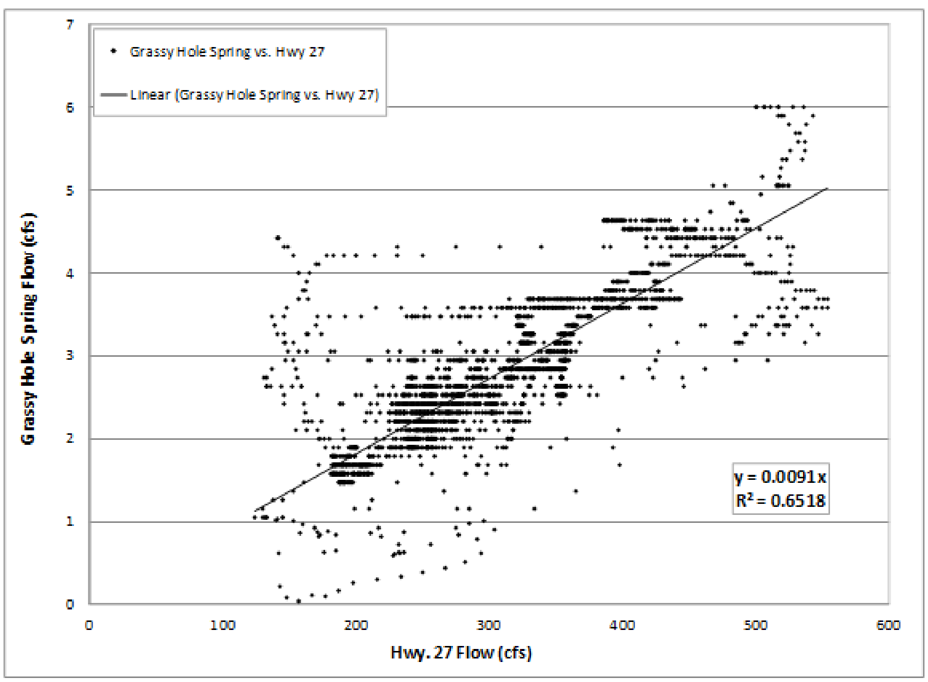


Figure 41. Grassy Hole Spring Flow vs. Highway 27 Flow

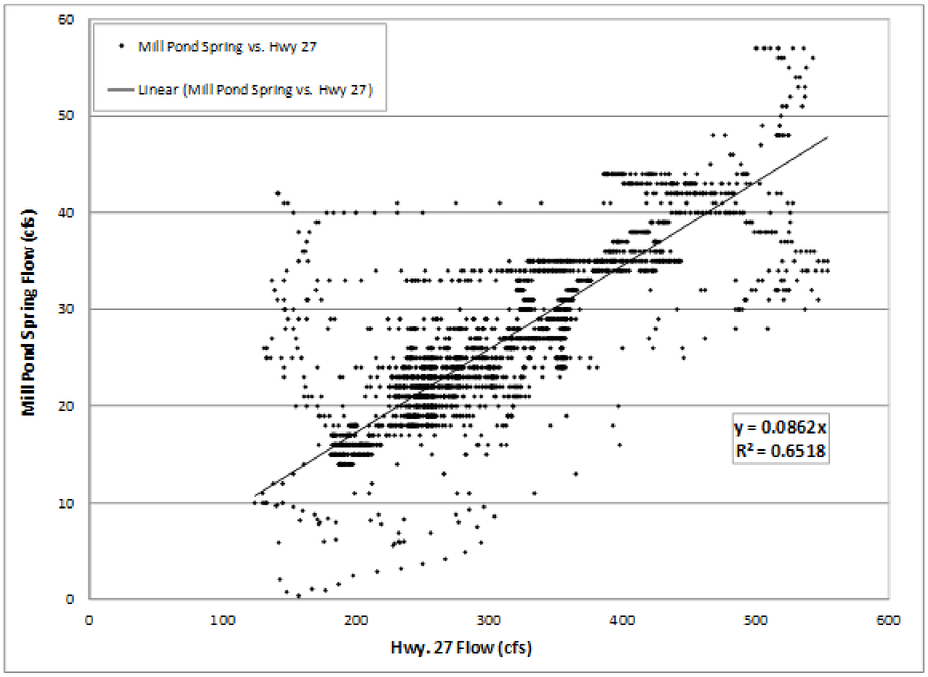


Figure 42. Mill Pond Spring Flow vs. Highway 27 Flow

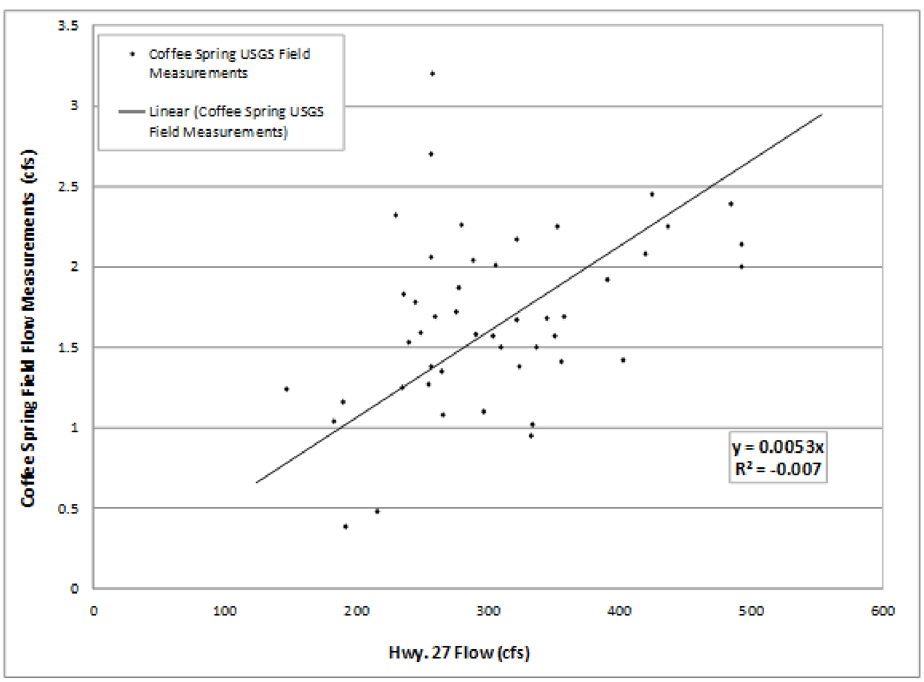


Figure 43 . Coffee Spring USGS Field Measurements vs. Highway 27 Flow

The factors from the regressions were adjusted so that their sum was 1 (Table 8). These factors were further reduced by 15%. The 15% of total flow at Highway 27 was distributed uniformly on the Ichetucknee River between the Ichetucknee Head Spring (Sta. 27649.9) and the cross section just upstream of Highway 27 bridge (Sta. 9979.729). Reducing the factors by 15% and redistributing 15% of total flow as uniform lateral inflow improved calibration results on the Ichetucknee River and accounted for additional inflows due to sources other than the named springs in the model.

Table 8. Ichetucknee River Flow Proportioning Factors of Total Flow

Spring Name	Regression Factors	Modified Factors	Factors Reduced by 15%*
Ichetucknee Head Spring	0.1555	0.1402	0.1192
Cedar Head	0.0232	0.0209	0.0178
Blue Hole	0.3893	0.3511	0.2984
Mission Spring	0.2881	0.2598	0.2208
Devil's Eye	0.1522	0.1373	0.1167
Grassy Hole	0.0091	0.0082	0.0070
Mill Pond	0.0862	0.0777	0.0661
Coffee Spring	0.0053	0.0048	0.0041
Sum of Factors	**1.11**	**1.00**	**0.85**
*Used to calculate spring-specific lateral inflow.			

The developed factors were entered as multipliers in HEC-RAS to be applied to the US Highway 27 flow hydrograph stored in HEC-DSS ("Boundary.dss" file). Since cross sections were needed at all inflow points, interpolated cross sections were added at the spring locations in the HEC-RAS model. Additional interpolated cross sections were added to address model stability issues.

Summary of Internal Boundary Conditions on the Ichetucknee River

The processed model boundary conditions and the stations on the Ichetucknee River are listed in downstream order below. The interpolated cross-sections are denoted by a symbol"*."

- Upstream Boundary at STA. 27976.3 for Ichetucknee River at Head Spring: 0.1192 of the Highway 27 discharge time series.
- Uniform Lateral Inflow from STA. 27649.9* to STA. 9979.729 simulating the uniform discharge pickup along the Ichetucknee River: 0.15 of the Highway 27 discharge time series.
- Lateral Inflow at STA. 26116.6* simulating the discharge pickup from Cedar Spring and Blue Hole Spring: 0.3162 of the Highway 27 discharge time series.
- Lateral Inflow at STA. 24534.3* simulating the discharge pickup from Mission Spring: 0.2208 of the Highway 27 discharge time series.
- Lateral Inflow at STA. 23529.4* simulating the discharge pickup from Devil's Eye Spring: 0.1167 of the Highway 27 discharge time series.
- Lateral Inflow at STA. 21911.31* simulating the discharge pickup from Grassy Hole Spring: 0.007 of the Highway 27 discharge time series.
- Lateral Inflow at STA. 20687.3* simulating the discharge pickup from Mill Pond Spring: 0.0661 of the Highway 27 discharge time series.
- Lateral Inflow at STA. 14690.63 simulating the discharge pickup from Coffee Spring: 0.0041 of the Highway 27 discharge time series.

Note that the discharge pickup factors from Cedar Head Spring and Blue Hole Spring were added together and attached to the interpolated cross section in the vicinity of the Blue Hole Spring. This is because the Cedar Head Spring flows into the Ichetucknee River near the Blue Hole Spring.

3. TRANSIENT MODEL CALIBRATION AND VALIDATION

The model of the river was calibrated during the initial MFLs assessment in a transient state by adjusting the channel friction. The model was calibrated to observed stages and flows. The locations and data considered during model calibration are described in Section 3.1 followed by the calibration results in Section 3.2 These sections were excerpted from the peer reviewed initial MFLs assessment modeling report (INTERA 2012).

The transient model was validated during the MFLs re-evaluation subsequent to updating the geometry of select cross section and translating the reference elevation for elevation data from NGVD29 to NAVD88. The results of the validation analysis described in Section 3.3 demonstrated that the transient model is appropriately calibrated; thus, changes to friction values were unnecessary.

3.1 Calibration Targets

The USGS and the District flow and water-level data were used for calibration at the USGS gaging stations along the Santa Fe and Ichetucknee Rivers and at other locations established by the District during the study (Figure 44, Figure 45, Table 9, and Table 10). The calibration targets associated with several USGS stations have a long period of flow and stage values representing a wide range flow conditions, whereas the District level loggers have stage values of several months (02/01/2011 - 10/06/2011) during which low-flow conditions prevailed. The stations with long-term record are identified by their station number (Table 9 and Table 10).).

The HEC-RAS model of the Lower Santa Fe River system was calibrated by adjusting the channel Manning's n friction factors to increase the model's predictive capability. Consistency in the friction factors was maintained avoiding point calibration. Final Manning's n friction factors for each river reach, including the interpolated cross sections (denoted with an asterisk "*") are for the Santa Fe River (Table 11) and Ichetucknee River (Table 12). Some interpolated cross sections on the Ichetucknee River were associated with the locations of the springs' lateral inflows.

Table 9. Lower Santa Fe River Calibration Targets

Station	Name	Reach	Source (Station No.)
267046.6	Worthington Springs	Before O'Leno	*USGS (02321500)
199608.7	O'Leno State Park by I-75	Before O'Leno	USGS (02321898)
189142.1	O'Leno State Park by Footbridge - District Gage	Before O'Leno	SRWMD (023218982)
164241.8	River Rise	Above Alligator	UF (02321958)
150850.2	Santa Fe River at US Hwy 441 near High Springs	Above Alligator	USGS (02321975)
139200.9	Logger Sinkhole near High Springs	Above Alligator	SRWMD (02321990)
136066.5	Logger Canoe Scrape	Siphon Above	SRWMD (02321994)
133585.8	Logger near High Springs	Before Poe	SRWMD (02322000)
124387.6	Logger at Poe Springs	Before Rum	SRWMD (02322139)
760.4809	Logger at Rum Island	Rum Island North	SRWMD (02322300)
96627.88	Fort White	Lower After Rum	*USGS (02322500)
85420.27	Logger at SR 47 near Fort White	Lower After Rum	SRWMD (02322540)
55732.9	Logger Dog Leg Shoals	Lower After Rum	SRWMD (02322595)

Station	Name	Reach	Source (Station No.)
37869.58	Santa Fe Point Park (Three Rivers)	Lower After Rum	USGS (02322703)
12872.86	Santa Fe River near Hildreth FL	Lower After Ichetucknee	*USGS (02322800)
*Station number () for gage with long-term record.			

Table 10. Ichetucknee River Calibration Targets

Station	Name	Reach	Source*
27976.3	Head Spring	Ichetucknee	USGS (02322685)
26116.6*	Blue Hole Spring	Ichetucknee	USGS (02322688)
24534.3*	Mission Springs	Ichetucknee	USGS (02322691)
23529.4*	Devil's Eye Spring	Ichetucknee	USGS (02322694)
20687.3*	Mill Pond Spring	Ichetucknee	USGS (02322695)
16758.63	Dampier's Landing	Ichetucknee	USGS (02322698)
9901.374	Ichetucknee River at Hwy 27 near Hildreth	Ichetucknee	*USGS (02322700)
*Gaging station with long-term period of record.			

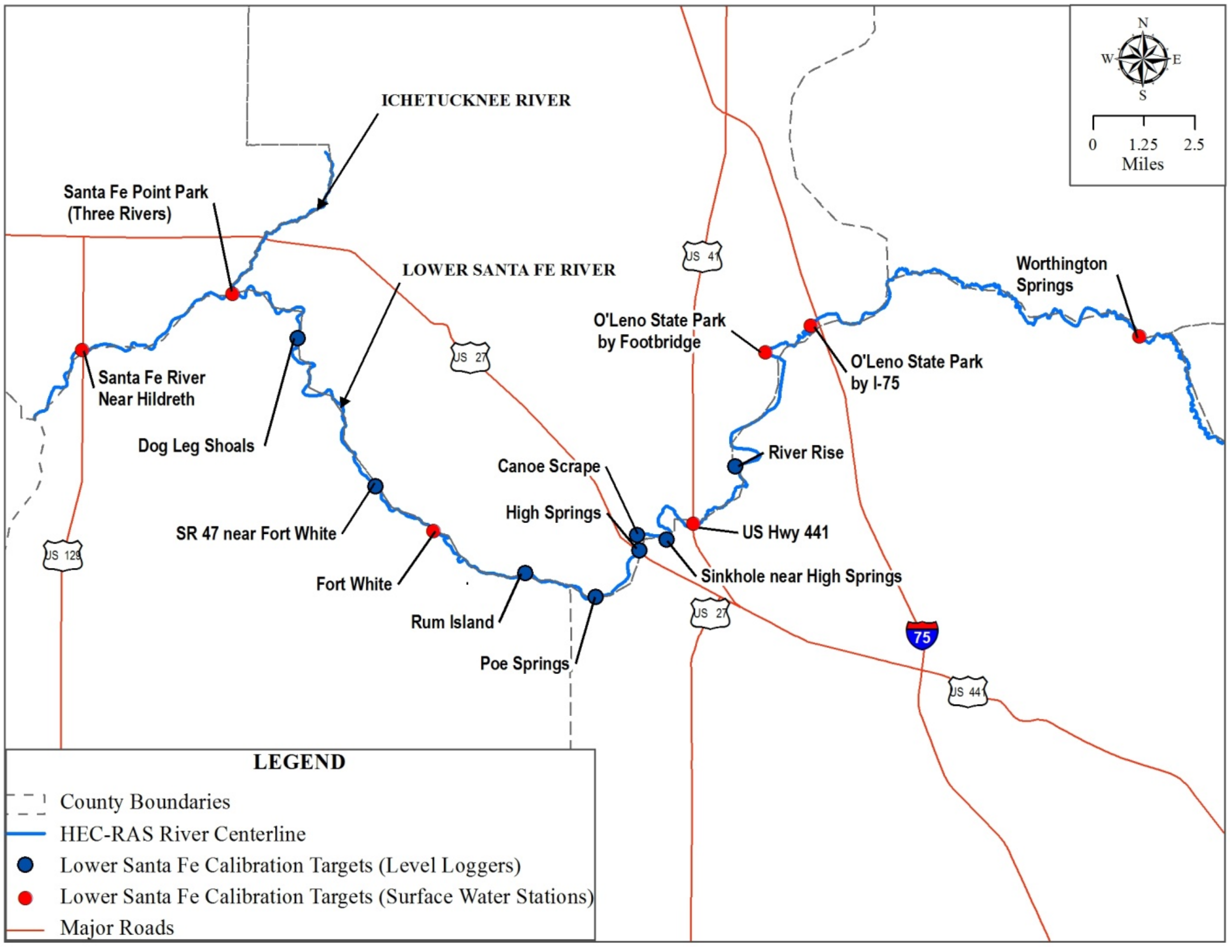


Figure 44. Lower Santa Fe River Calibration Targets

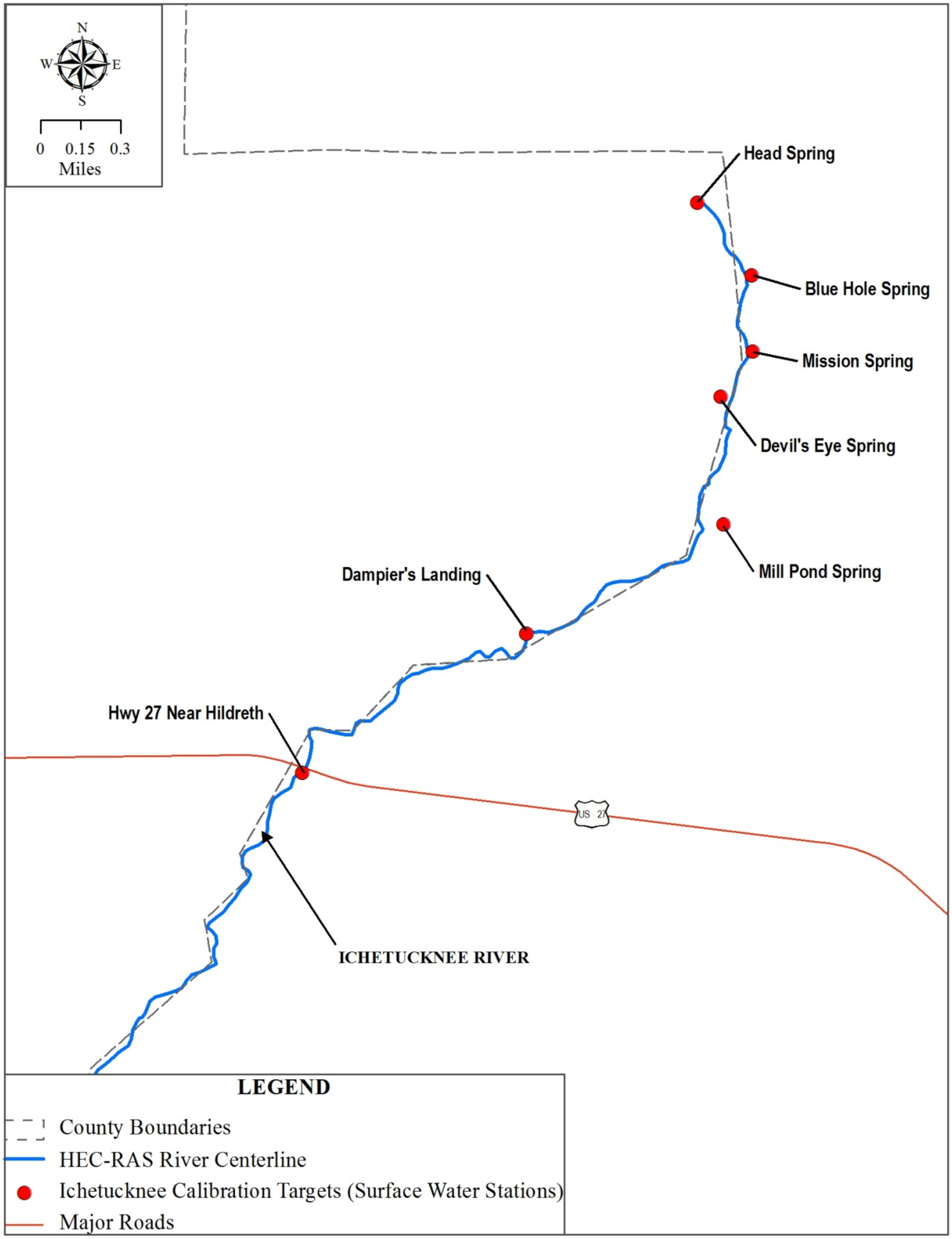


Figure 45. Ichetucknee River Calibration Targets

Table 11. Manning's n Factors Used in the Final Calibration: Lower Santa Fe River

River Station	Left Bank n	Channel n	Right Bank n
Before O'Leno Reach			
267712.9 49.38	0.2	0.06	0.2
267340.3	0.2	0.06	0.2
267200.1 SR 121 BU	0.2	0.06	0.2
267117 SR 121 BRIDGE	0.2	0.06	0.2
267046.6 SR 121 BD	0.2	0.06	0.2
266658.9 49.19	0.2	0.06	0.2
262287.3 Bridge Site	0.2	0.06	0.2
261880.7 Lime Rock Site	0.2	0.06	0.2
260337.5 48.04	0.2	0.06	0.2
252404.1 46.59	0.2	0.06	0.2
246301.9 45.48	0.2	0.06	0.2
238298.1 44.02	0.2	0.06	0.2
229947.4 42.54	0.2	0.06	0.2
225360.8	0.2	0.06	0.2
225118.9	0.2	0.06	0.2
225097.9 SR241 BU	0.2	0.06	0.2
225053.9 SR 241 BRIDGE	0.2	0.06	0.2
224986 SR241 BD	0.2	0.06	0.2
224747 41.56	0.2	0.06	0.2
221123.8 40.91	0.2	0.06	0.2
214930.6 39.81	0.2	0.06	0.2
210688.8 39.02	0.2	0.06	0.2
206341 NearGrahamSpring	0.2	0.06	0.2
205072.2 37.98	0.2	0.06	0.2
200774.8 at Lc from I-75	0.2	0.06	0.2
200676.6 I-75 BU	0.2	0.06	0.2
200603.4 I-75 BRIDGE	0.2	0.06	0.2
200430.1 I-75 BD	0.2	0.1	0.2
200311.5 at Le from I-75	0.2	0.1	0.2
199608.7	0.2	0.1	0.2
195108.4 Oleno Sinkhole	0.2	0.1	0.2
191737.7	0.2	0.1	0.2
191718.9 35.57	0.2	0.1	0.2
189142.1 Oleno	0.2	0.1	0.2
186938.4	0.2	0.1	0.2
Above Reach			
186917.6	0.2	0.4	0.2
182234 33.85	0.2	0.4	0.2

River Station	Left Bank n	Channel n	Right Bank n
178224.3 33.09	0.2	0.4	0.2
173231 32.18	0.2	0.4	0.2
166112.3 30.42	0.2	0.4	0.2
164296.4 Est. 30.31	0.2	0.4	0.2
Below Reach			
186917.6	0.2	0.04	0.2
164366	0.2	0.04	0.2
164296.4	0.2	0.04	0.2
Above Alligator Reach			
164241.8 Est. 30.3	0.2	0.06	0.2
158286.6	0.2	0.06	0.2
156953 28.94	0.2	0.06	0.2
154931.4 13P	0.2	0.06	0.2
152723.1 12P	0.2	0.06	0.2
151090.1 at Lc from HIGHWAY44	0.2	0.06	0.2
150977.9 441 bridge BU	0.2	0.06	0.2
150908.6 HIGHWAY 441 BRIDGE	0.2	0.06	0.2
150850.2 near 441 BD	0.2	0.06	0.2
150560.1 at Le from HIGHWAY44	0.2	0.06	0.2
150453.2 27.76	0.2	0.06	0.2
150192.6	0.2	0.06	0.2
150082.7 RHABSIM US441 Pool	0.2	0.04	0.2
149924.3 RHABSIM US441 Run	0.2	0.04	0.2
149708 RHABSIM US441 Shoal	0.2	0.04	0.2
149167.5 US441 upstream of Columbia	0.2	0.04	0.2
148387.7 US441 downstream of Columbia	0.2	0.04	0.2
144067 26.52	0.2	0.04	0.2
139200.9 Upstream of Sinkhole and Shoals	0.2	0.04	0.2
Siphon Above Reach			
138776.6 Downstream from Sinkhole1	0.2	0.06	0.2
137783 Downstream from Sinkhole2	0.2	0.06	0.2
137191.4 25.19	0.2	0.06	0.2
136066.5 Canoe Scrape Shoal	0.2	0.06	0.2
135422.4 Alligator Rise Upstream of US27	0.2	0.06	0.2
Siphon Below Reach			
138946 Alligator Siphon	0.2	0.04	0.2
134136 Alligator Rise	0.2	0.04	0.2
Before Poe Reach			
133585.8	0.2	0.04	0.2
133442.5 Taylor 24.52 -US27 bridge BU	0.2	0.04	0.2

River Station	Left Bank n	Channel n	Right Bank n
133397.5 US-27 BRIDGE	0.2	0.04	0.2
133362.4 US27 - BD	0.2	0.04	0.2
133290.6	0.2	0.04	0.2
133263.7 SEABOARD bridge BU	0.2	0.035	0.2
133241.4 SEABOARD COAST LINE RR BRIDGE	0.2	0.035	0.2
133208.2 SEABOARD bridge BD	0.2	0.035	0.2
133079.4	0.2	0.035	0.2
131570.6 24.15	0.2	0.035	0.2
129819.5 23.82	0.2	0.035	0.2
129312.6 RHABSIM Powerline Pool	0.2	0.035	0.2
129212.6 RHABSIM Powerline Run	0.2	0.035	0.2
129118.4 RHABSIM Powerline Shoal	0.2	0.035	0.2
129082.4 Powerline Shoals	0.2	0.035	0.2
126095.8 23.14	0.2	0.035	0.2
124915.7 Poe Island Junct	0.2	0.045	0.2
Poe Island North Reach			
124770.3 Poe Island Junct	0.2	0.045	0.2
124713.2 Poe Springs Island North	0.2	0.045	0.2
124514.9 Poe Island Junct	0.2	0.045	0.2
Poe Island South Reach			
340.1572 Poe Island Junct	0.2	0.05	0.2
264.3174 Poe Springs Island South	0.2	0.05	0.2
78.64378 Poe Island Junct	0.2	0.05	0.2
Before Rum Reach			
124387.6 Poe Island Junct	0.2	0.045	0.2
123484.8 Downstream from Poe Springs	0.2	0.045	0.2
121137 22.24	0.2	0.045	0.2
117559.8 21.59	0.2	0.045	0.2
113651.9 Rum Island Upstream	0.2	0.045	0.2
Rum Island South Reach			
113265.1 Rum Island Junct	0.2	0.045	0.2
112819.2 Rum Island South	0.2	0.045	0.2
112684 Rum Island Junct	0.2	0.045	0.2
Rum Island North Reach			
936.5505 Rum Island Junct	0.2	0.06	0.2
760.4809 Rum Island North	0.2	0.06	0.2
94.66003 Rum Island Junct	0.2	0.06	0.2
Lower After Rum Reach			
112509.8 Rum Island Downstream	0.4	0.045	0.4
111186.1 20.44	0.4	0.045	0.4

River Station	Left Bank n	Channel n	Right Bank n
106857.4 19.62	0.4	0.045	0.4
100692.3 18.49	0.4	0.04	0.4
96930.06 RHABSIM Fort White Gage Pool	0.4	0.04	0.4
96791.79 RHABSIM Fort White Gage Run	0.4	0.04	0.4
96627.88 17.78	0.4	0.04	0.4
96532.88 RHABSIM Fort White Gage Shoal	0.4	0.04	0.4
93645.45	0.4	0.04	0.4
89916.23 9P	0.4	0.04	0.4
89685.81 16.53	0.4	0.04	0.4
85420.27	0.4	0.04	0.4
85244.77 SR47 -BU	0.4	0.04	0.4
85178.48 STATE ROAD 47 BR	0.4	0.04	0.4
85147.16 SR47 - BD	0.4	0.04	0.4
84962.8	0.4	0.04	0.4
84274.49 SR47	0.4	0.04	0.4
81719.97 15.08	0.4	0.04	0.4
76273.62 14.08	0.4	0.04	0.4
74474.53 8P	0.4	0.04	0.4
73243.98 8P floodplain	0.4	0.04	0.4
70536.88 13.03	0.4	0.04	0.4
61410.48 PHS1 Upstream	0.4	0.04	0.4
61124.27 11.3	0.4	0.04	0.4
61005 PHS1 Island	0.4	0.04	0.4
60515.43 PHS1 Downstream	0.4	0.04	0.4
55916.91 Dog Leg Shoals Upstream	0.4	0.04	0.4
55732.9 RHABSIM Dog Leg Pool	0.4	0.04	0.4
55655.57 RHABSIM Dog Leg Run	0.4	0.04	0.4
55566.83 Dog Leg Shoals Middle Stream	0.4	0.04	0.4
55554.55 RHABSIM Dog Leg Shoal	0.4	0.04	0.4
55203.61 Dog Leg Shoals Downstream	0.4	0.04	0.4
54234.24 10.06	0.4	0.04	0.4
45429.38 8.43	0.4	0.04	0.4
42107.47 D floodplain	0.4	0.04	0.4
41168.91 7.64	0.4	0.04	0.4
37869.58 O	0.4	0.04	0.4
Lower After Ichetucknee Reach			
36841.84 Downstream of Ichetucknee	0.4	0.04	0.4
34668.82 6.46	0.4	0.04	0.4
25348.59 4.73	0.4	0.04	0.4
19785.01 3P	0.4	0.04	0.4

River Station	Left Bank n	Channel n	Right Bank n
19201.19 3.6	0.4	0.04	0.4
15294.08 2.88	0.4	0.04	0.4
13258.14	0.4	0.04	0.4
13053.83	0.4	0.04	0.4
12970.11 US-129 BRIDGE	0.4	0.04	0.4
12872.86 FEMA 2.42	0.4	0.04	0.4
12685.32	0.4	0.04	0.4
8653.07 1.61	0.4	0.04	0.4
6723.73 2P	0.4	0.04	0.4
1606.322 1P	0.4	0.04	0.4

Table 12. Manning's n Factors Used in the Final Calibration: Ichetucknee River

River Station	Left Bank n	Channel n	Right Bank n
27976.3 Head Spring	0.5	0.12	0.5
27649.9*	0.5	0.12	0.5
27323.5*	0.5	0.12	0.5
26997.1*	0.5	0.15	0.5
26670.76	0.5	0.15	0.5
26116.6* Blue Hole Spring	0.5	0.15	0.5
26012.56	0.5	0.15	0.5
25781.5*	0.5	0.15	0.5
25550.6*	0.5	0.15	0.5
25319.6*	0.5	0.15	0.5
25088.65 6P	0.5	0.15	0.5
24534.3* Mission Spring	0.5	0.2	0.5
24433.49	0.5	0.2	0.5
23529.4* Devil's Eye Spring	0.5	0.2	0.5
23421.37	0.5	0.2	0.5
22520.48 5P	0.5	0.2	0.5
21911.31	0.5	0.2	0.5
20687.3* Mill Pond Spring	0.5	0.08	0.5
20136.5	0.5	0.08	0.5
16758.63 Dampier's Landing	0.5	0.055	0.5
14690.63	0.5	0.055	0.5
13217.85 4P	0.5	0.055	0.5
12554.52 AA Downstream	0.5	0.055	0.5
11281.58	0.5	0.055	0.5
10866.9*	0.5	0.055	0.5
10452.3*	0.5	0.055	0.5
10037.68	0.5	0.055	0.5

River Station	Left Bank n	Channel n	Right Bank n
9979.729 US HIGHWAY 27 BU	0.5	0.055	0.5
9938.649 US HIGHWAY 27 Bridge	0.5	0.055	0.5
9901.374 US HIGHWAY 27 BD	0.5	0.055	0.5
9873.696	0.5	0.055	0.5
9837.79*	0.5	0.03	0.5
9801.898 Ichetucknee Rail BU	0.5	0.03	0.5
9782.468 Ichetucknee Rail Bridge	0.5	0.03	0.5
9752.88 Ichetucknee Rail BD	0.5	0.03	0.5
9705.355	0.5	0.03	0.5
8311.143	0.5	0.03	0.5
8101.876	0.5	0.03	0.5
7268.683	0.5	0.03	0.5
7087.178	0.5	0.03	0.5
2909.323	0.5	0.03	0.5
2545.087	0.5	0.03	0.5
628.0969	0.5	0.03	0.5
335.5512	0.5	0.03	0.5

For most of the Santa Fe River ("Below" through "Lower After Ichetucknee" reaches) Manning's n varies over a small range of 0.035 to 0.06, which is characteristic of typical river studies. These values are consistent with the limited Submerged Aquatic Vegetation (SAV) in these reaches as discussed by SRWMD (2013, p. 2-16):

> "Finer grained sediments are more suitable for SAV growth. The lower Santa Fe River features solid rock channel bottoms at shoals and other areas as well as unconsolidated, mainly sandy sediments. In the downstream-most section of the lower Santa Fe River there are natural levees of Santa Fe marl along the bank, which may be several feet high."

The use of Manning's n values for the overbank areas of 0.2 for the majority of the Santa Fe River and 0.4 for the lower reaches of the Santa Fe River also are reasonable compared with typical river studies where higher roughness is encountered for overbank flow areas. The "Above" reach has an unusually high Manning's n value because the vast majority of flow should pass through the "Below" reach, and flow should only pass above ground under unusually high flow conditions. The use of a high Manning's n value assists in the simulation of minimal flows in the "Above" reach. The higher values of Manning's n in the "Before O'Leno" reach are the result of the effects of SAV. SRWMD (2013, p 3-5) notes that in the Upper Reach of the Lower Santa Fe River "The in-channel substrate is dominated by limestone outcroppings and extensive SAV."

The large variation in Manning's n along the Ichetucknee River requires discussion and confirmation. The high values of Manning's n correspond to areas with high SAV. SRWMD (2013, p. 2-18) cites (Kurz, et al. 2004) as reporting

> "in the Ichetucknee River the majority of channel bottom material at sampling sites was sand (46%) and mud (23%) which facilitates SAV growth. The middle reach on the Ichetucknee River

is characterized by Grassy Flats, a broad marshy area. Limestone outcrop shoals occur in the Ichetucknee River at several locations near the river mouth."

Further, SRWMD (2013, p. 5-80) notes

> "Wild rice is dominant in the Ichetucknee Head Spring and approximately 200 m of the spring run. Downstream, and for the duration of the river channel, strap-leaf sagittaria is the most abundant type of SAV. Tape grass and muskgrass are also abundant throughout the Ichetucknee River."

Two photographs of the SAV in upper sections of the Ichetucknee River follow (Figure 46). Hence, the high Manning's n values in the upper and middle sections and the lower n values in the downstream sections of the Ichetucknee River are reasonable.

Figure 46. Submerged Aquatic Vegetation on and near the Ichetucknee River near Roaring Spring Run (part of Ichetucknee Spring Group, near RS 26000) [left] and at Devil's Eye Spring (near RS 23529.4) [right]

Flow roughness-change coefficients are discharge-dependent multiplication factors that adjust Manning's n friction factors with changes in flow (Hydrologic Engineering Center, 2010). Flow roughness-change factors were assigned to get a better match with the observed stage data at low flows at the Above Alligator, the Siphon Above and the Before Poe reach calibration targets.

Flow-roughness change factors (Table 13) were assigned to the Above Alligator reach (from downstream of the Highway 441 bridge to the Alligator Siphon), the Siphon Above reach (from the Alligator Siphon to the Alligator Rise), and Before Poe reach (from the Alligator Rise to Poe Springs Island).

Table 13. Flow Roughness-Change Factors on Above Alligator Reach (STA. 150850.2 – STA. 139031*)

Flow	Roughness-Change Factor
Above Alligator Reach (STA. 150850.2 – STA. 139031*)	
0	2
200	2
1000	1

Flow	Roughness-Change Factor
Siphon Above Reach (STA. 138946* – STA. 134136*)	
0	3
200	3
1000	1
Before Poe Reach (STA. 133953* – STA. 124915.7)	
0	3
200	3
1000	1

During the initial MFLs assessment calibration phase, adjustments were made to the cross sections from the previous model (INTERA 2007) on the river reach below the confluence with the Ichetucknee River (Lower After Ichetucknee Reach). The previous model was not calibrated to the observed stages at the Point Park gaging station also known as the Three Rivers gaging station (USGS #02322703), and differences between observed and simulated stages were noted particularly during low flow and stages below about 9.7 feet NGVD29 (Figure 47).

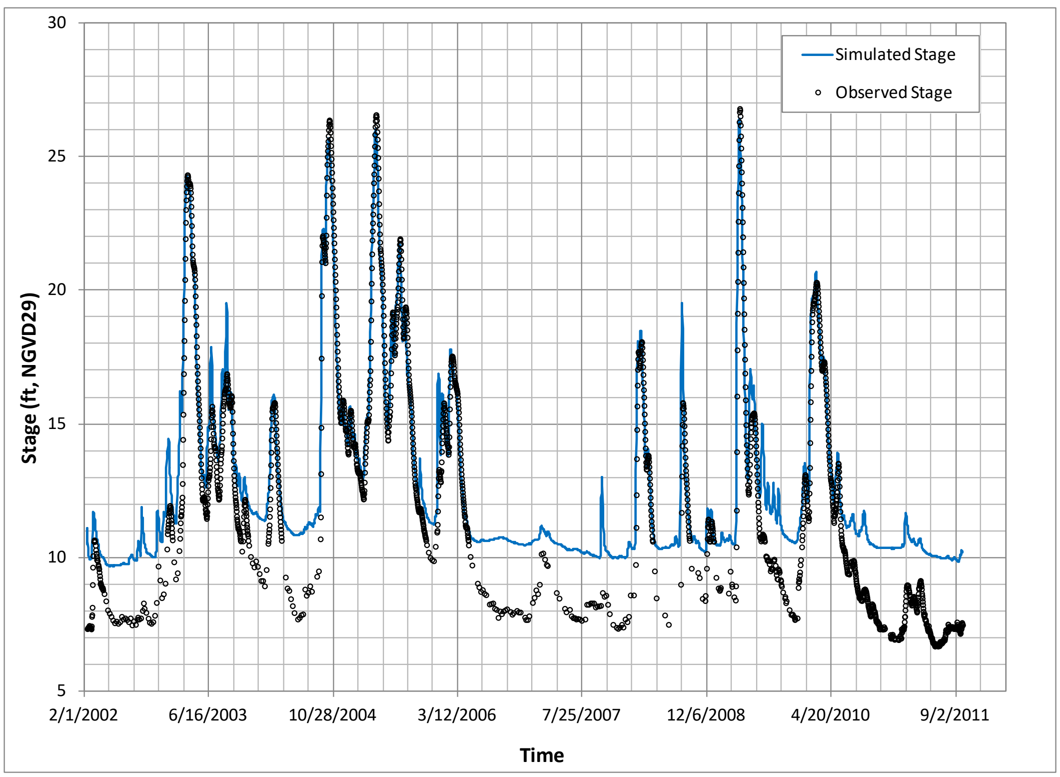
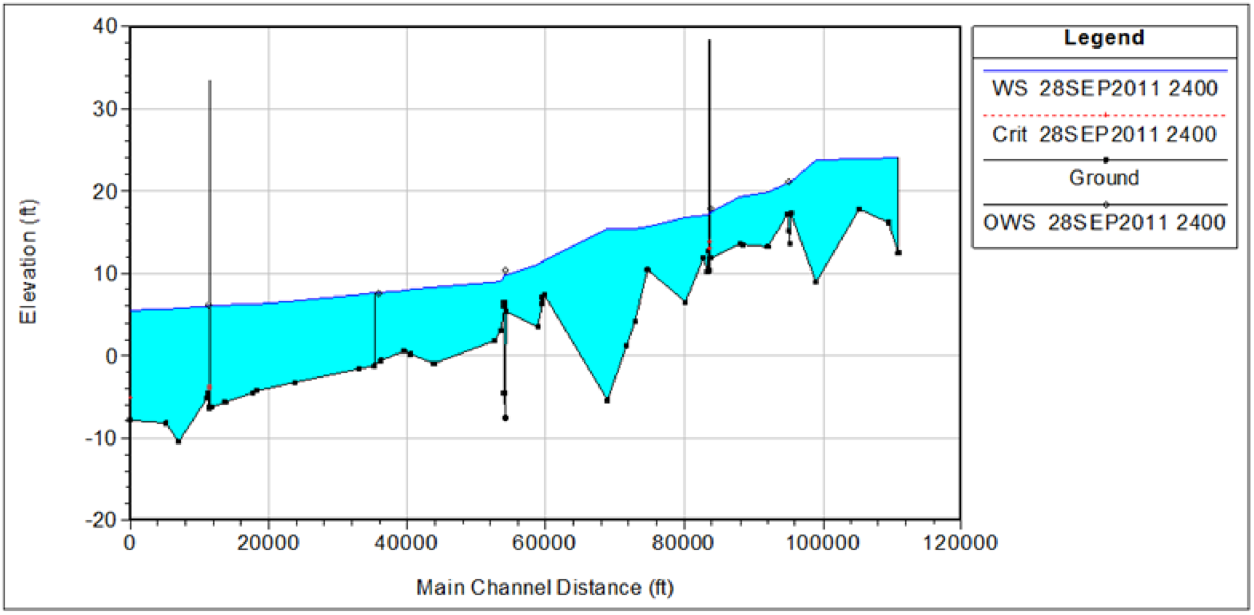


Figure 47. Daily Simulated and Observed Stages at Three Rivers Prior to Adjustments

New cross sections were surveyed by Delta Land Surveyors, Inc. to improve calibration at the Three Rivers gaging station. The new survey data had the channel much wider which conveys more flow at lower stages.

Channel elevations of the existing cross sections were replaced with interpolated data from the newly surveyed cross sections (Figure 48, Three Rivers gage location shown as a black circle). A better match to observed stages at the Three Rivers gage was obtained by modifying channel elevations in the existing cross sections. Final daily calibrated stages at the Three Rivers gage are shown in the Calibration Results section.



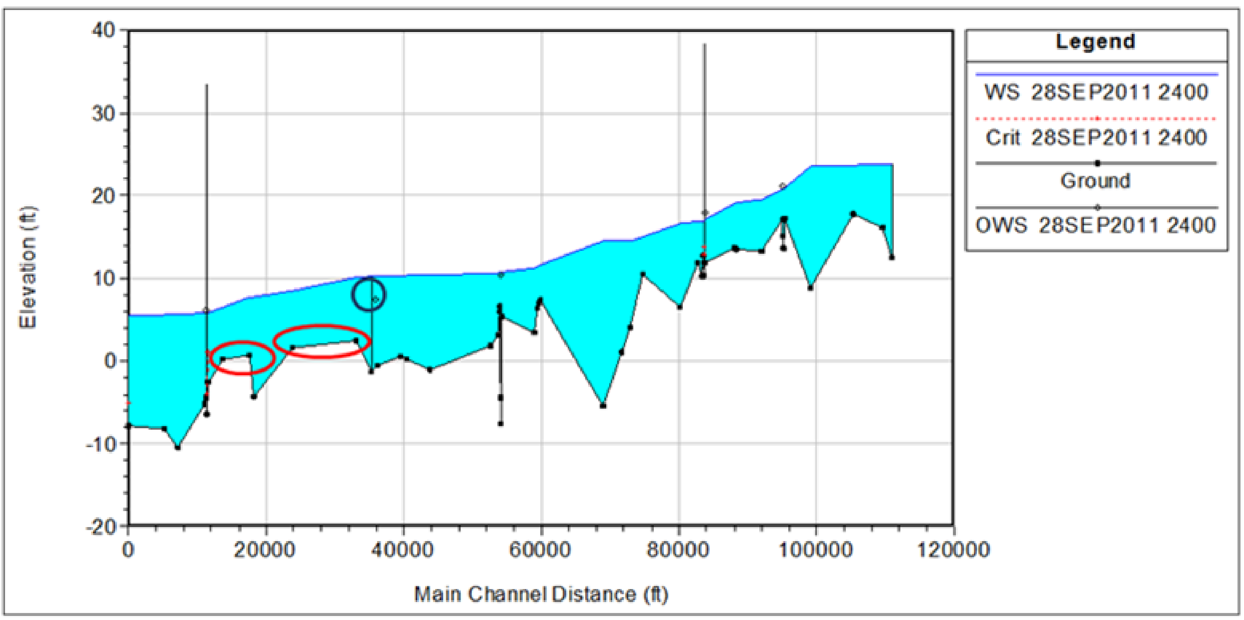


Figure 48. Ichetucknee River Thalweg Profile near Three Rivers Gage Prior to Adjustments (top) and After Adjustments Based on Field Survey (bottom)

3.2 Calibration Results

Calibration results are illustrated in plots comparing final simulated stages and flows at the calibration targets are compared to field measurements upstream to downstream (Attachment 1). Simulated and observed flows are only shown for the USGS gages that have observed discharge measurements. Plots of the calibration results include plots of daily simulated and observed flows (where observed discharge measurements are available), plots of daily simulated and observed stages, plots of stage residuals (simulated stage-observed stage), scatter plots comparing simulated and observed stages against a 45-degree line, and scatter plots comparing stage residuals and observed stages. Calibration plots for the Lower Santa Fe River are followed by the Ichetucknee River calibration plots. Table 14 summarizes final calibration results. As shown from the hydrographs, the model adequately captures the hydrologic response to all inflows and the overall hydrograph shape is generally replicated by the model at calibration locations.

As with any numerical model, instability at very low flows is a common issue in HEC-RAS; computationally, the model cannot simulate a zero flow condition. In HEC-RAS, the use of a pilot channel alleviates the dry channel instability. The pilot channel is essentially a computational error in the model since the HEC-RAS pilot channel option cuts an artificial rectangular notch at the bottom of the cross section adding additional area and conveyance. The pilot channel is only active under dry channel conditions. The pilot channel is defined as a 1 foot-wide notch in the true channel cross section and is defined with higher roughness factors to reduce the pilot channel flow. At higher flows, when the depth gets higher, the actual cross sectional area is used and the pilot channel is ignored (Hydrologic Engineering Center 2010). HSW deepened the pilot channel in the “Before O’Leno” reach by 3 feet so that the transient HEC-RAS models (for the initial and re-evaluation assessments) would run to completion without instability problems in HEC-RAS version 5.0.6. The pilot channel was not needed for the steady flow analysis described in Section 4.

Table 14. Final Transient Model Calibration Results
[Source: modified from (INTERA 2012); Simulation period from February 13, 2002 through September 29, 2011]

Name	River	Percent of Stage Residuals within 5%	Percent of Stage Residuals within 0.5 ft	Percent of Stage Residuals within 1 ft	% Stage Residuals within 0.5 ft at Low Flows	Low Flow (cfs)	Average Sim. Flow - Obs. Flow (%)
Worthington Springs	Santa Fe	98.76%	67.58%	88.72%	85.97%	100	0
O'Leno State Park by I-75	Santa Fe	99.79%	67.22%	96.24%	69.65%	100	
O'Leno State Park by Footbridge -District Gage	Santa Fe	88.75%	32.13%	73.04%	34.36%	100	27.0
River Rise	Santa Fe	96.70%	65.35%	90.43%	78.53%	100	
Santa Fe River at US Hwy 441 near High Springs	Santa Fe	92.00%	60.81%	83.70%	79.79%	200	11.9
Logger Sinkhole near High Springs	Santa Fe	95.82%	53.97%	93.31%	57.92%	200	
Logger Canoe Scrape	Santa Fe	98.33%	65.27%	94.98%	68.12%	200	
Logger near High Springs	Santa Fe	97.50%	84.17%	92.50%	90.54%	200	
Logger at Poe Springs	Santa Fe	100.00%	53.75%	100.00%	51.17%	200	
Logger at Rum Island	Santa Fe	96.25%	66.25%	93.75%	71.30%	150	
Fort White	Santa Fe	90.94%	75.80%	89.47%	90.38%	700	4.8
Logger at SR 47 near Fort White	Santa Fe	100.00%	21.99%	100.00%	15.66%	700	
Logger Dog Leg Shoals	Santa Fe	60.21%	59.16%	91.10%	49.65%	700	
Santa Fe Point Park (Three Rivers)	Santa Fe	66.34%	62.21%	91.00%	54.36%	800	
Santa Fe River near Hildreth FL	Santa Fe	96.76%	96.16%	99.71%	99.09%	1000	0
Head Spring	Ichetucknee	98.58%	95.43%	98.11%	94.94%	50	
Blue Hole Spring	Ichetucknee	98.39%	94.19%	97.89%	93.50%	50	
Mission Springs	Ichetucknee	98.37%	91.65%	97.80%	87.11%	150	
Devil's Eye Spring	Ichetucknee	98.83%	91.28%	98.38%	88.14%	200	
Mill Pond Spring	Ichetucknee	53.73%	29.65%	52.92%	8.13%	200	
Dampier's Landing	Ichetucknee	98.79%	94.82%	98.76%	93.60%	300	-10.1
Ichetucknee River at Hwy 27 near Hildreth	Ichetucknee	98.09%	92.74%	98.51%	93.84%	300	0

3.3 Validation Results

The concept of calibrating the HEC-RAS model for unsteady flows over a nearly 10-year period (February 13, 2002 to September 29, 2011) and then using the "calibrated" hydraulic coefficients (Manning's n roughness) and intermediate flow apportionment along the rivers to simulate water-surface profiles over a wide range of steady flows is a sound approach for characterizing relations between flow, depth, and velocity throughout the river system.

The HSW team reviewed the development, calibration, and application of the transient and steady-state HEC-RAS models prepared for the initial MFLS assessment (INTERA 2012). The hydrologic model results presented in the Section 3.2 are the basis for the hydrology represented in the transient state model. The flow apportionment for the Santa Fe River between the Worthington Springs and Fort White streamflow gages was based on synoptic flow measurements taken during low flows on May 4, 2011. None of these flow apportionment factors were adjusted in the process of calibrating the transient HEC-RAS model. Only the flow apportionment for the lateral inflows (i.e. flow pickup) between the Fort White and Hildreth streamflow gages on the Santa Fe River were adjusted in calibration. INTERA (2012, p. 40) states "The best stage calibration was achieved when Fort White to Hildreth pickup discharge time series was distributed equally: half of the discharge pickup before the confluence with the Ichetucknee River and half of the discharge pickup after the confluence." Thus, the majority of the flow comparisons reported in Section 3.2 are a validation of the hydrologic models used in this study. The flow apportionment for the Ichetucknee River was derived from linear regression relations between the measured flow at the Highway 27 streamflow gage and the gages at the various springs in the Ichetucknee watershed.

The hydraulic aspects of the transient and steady-state HEC-RAS models were not verified with an independent dataset during the initial MFLs assessment. All the available hydraulic data were utilized to calibrate the model to ensure that the calibration considered a wide range of flows that would be relevant for an MFLs analysis.

Model Hydrology and Hydrologic Fit Quality Criteria

The Lower Santa Fe and Ichetucknee Rivers are fed by a combination of surface runoff and complex subsurface flows from a karst area . The hydrologic representation of those flows in the model is based on empirical evidence, i.e. measurements of flow and stage, in lieu of alternative methods for characterizing hydrology, such as drainage-area ratios and rainfall-runoff models (e.g., Hydrological Simulation Program—Fortran (HSPF). Flow proportioning for the various model reaches representing the LSFR and IR is described in Sections 2.5.3.1 and 2.5.3.2, respectively. An evaluation of the reasonableness of the flow proportioning follows.

The Conservation Effects Assessment Project-Watershed Assessment Study (CEAP-WAS) is a project that quantified the environmental benefits of conservation practices supported by the U.S. Department of Agriculture. One of the CEAP-WAS goals was to formulate guidelines for calibration, validation, and application of watershed models used in CEAP-WAS to simulate the effects of conservation practices. Moriasi et al. (2007) reviewed many watershed modeling case studies for the CEAP-WAS and proposed statistical criteria for acceptable performance of watershed models used to estimate the effects of conservation practices.

They determined that one of the most powerful measures of fit quality is the coefficient of model-fit efficiency, *E*, defined by Nash and Sutcliffe (1970) as follows:

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

In which

Q_{mi} = the measured discharge at time, *i*,
$aveQ_m$= the average measured discharge,
Q_{si} = the simulated discharge at time, *i*, and
n = the number of measured discharge values.

Moriasi et al. (2007) proposed three descriptive ratings to characterize model-fit quality for model evaluation based on *E*: $E \geq 0.75$ –Very Good, $0.75 > E \geq 0.65$ – Good, and $0.65 > E \geq 0.5$ – Satisfactory. The fit quality is presumably Unsatisfactory when $E < 0.5$. These criteria are for a monthly evaluation and (Engel, et al. 2007) noted typically, model simulations are poorer for shorter time steps than for longer time steps (e.g., daily versus monthly or yearly). These criteria commonly are used to assess the quality of watershed models for continuous simulation of streamflow.

Fit quality for the Santa Fe River and Ichetucknee River

Values of the Nash-Sutcliffe coefficient of model-fit efficiency (E) were calculated for the time series of daily simulated and observed discharges during the calibration period. The calculated E values for seven stream gages in the study watershed range between 0.573 and 0.994 (Table 15). The high value of E for the Ichetucknee River at Highway 27 would be expected because all flows are proportioned to equal the flow at this gage, thus, only the effects of travel time between the various springs and the gage cause the small decrease from a perfect fit (i.e., E = 1.0). The gage at Dampier's Landing on the Ichetucknee River shows very good results (E > 0.75) in part because of its proximity to the Highway 27 gage.

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

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

The performance of the hydrologic model for the Santa Fe River is lower than that for the Ichetucknee River, but still achieves satisfactory performance for 3 locations and good performance at one location. This quality of performance is similar to that obtained for monthly simulations using HSPF for complex wetland dominated watersheds in Florida and Wisconsin (Table 16). Wicklein and Schiffer (2002) reported the following for a sub-watershed in their study area with the largest number of wetlands:

> "After many attempts to simulate discharge from Cypress Creek with HSPF, it was determined that the best approach to modeling the entire Reedy Creek watershed was to use the observed flow and periodic water-quality data from the USGS gaging station at Cypress Creek near Vineland as a point source for use in the hydrologic and water-quality parts of the HSPF model.

Land areas within the Cypress Creek drainage were excluded from the model, and daily discharge values were input as a point source of inflow to the stream reach downstream from the USGS gaging station at Cypress Creek near Vineland."

Thus, the simple hydrologic models applied in modeling the Santa Fe and Ichetucknee Rivers perform similarly to more complex continuous rainfall-runoff models applied to wetland dominated watersheds.

Table 16. Nash-Sutcliffe coefficient of model-fit efficiency (E) for monthly flows for wetland dominated watersheds simulated with the Hydrological Simulation Program—Fortran software.

Watershed	Wetland (%)	E	Source
Whittenhorse Creek near Vineland, FL	43.6	0.717	1
Davenport Creek near Loughman, FL	26.7	0.754	1
Reedy Creek near Vineland, FL	34.4	0.785**	1
Bonnet Creek near Vineland, FL	40.1*	0.678**	1
Reedy Creek near Loughman, FL	37.3*	0.774**	1
Swamp Creek above Rice Lake at Mole Lake, WI (calibration)	25.5	0.680	2
Swamp Creek above Rice Lake at Mole Lake, WI (validation)	25.5	0.522	2
Swamp Creek below Rice Lake at Mole Lake, WI (calibration)	26.6	0.539	2
Swamp Creek below Rice Lake at Mole Lake, WI (validation)	26.6	0.527	2

Notes:
Source: (1) - (Wicklein and Schiffer 2002); (2) - (Chriscicki, et al. 2003)
*Does not include land areas in the Cypress Creek basin; **Spatial validation results

A common way to visually compare simulated and measured flows is to graph them in a time series plot. The comparison of measured and simulated flows for the Santa Fe River (Figure 49) show general agreement between the values, and it is apparent why the Nash-Sutcliffe E evaluation indicated satisfactory agreement at Hildreth, Fort White, and Highway 441 and good agreement at O'Leno State Park by Footbridge.

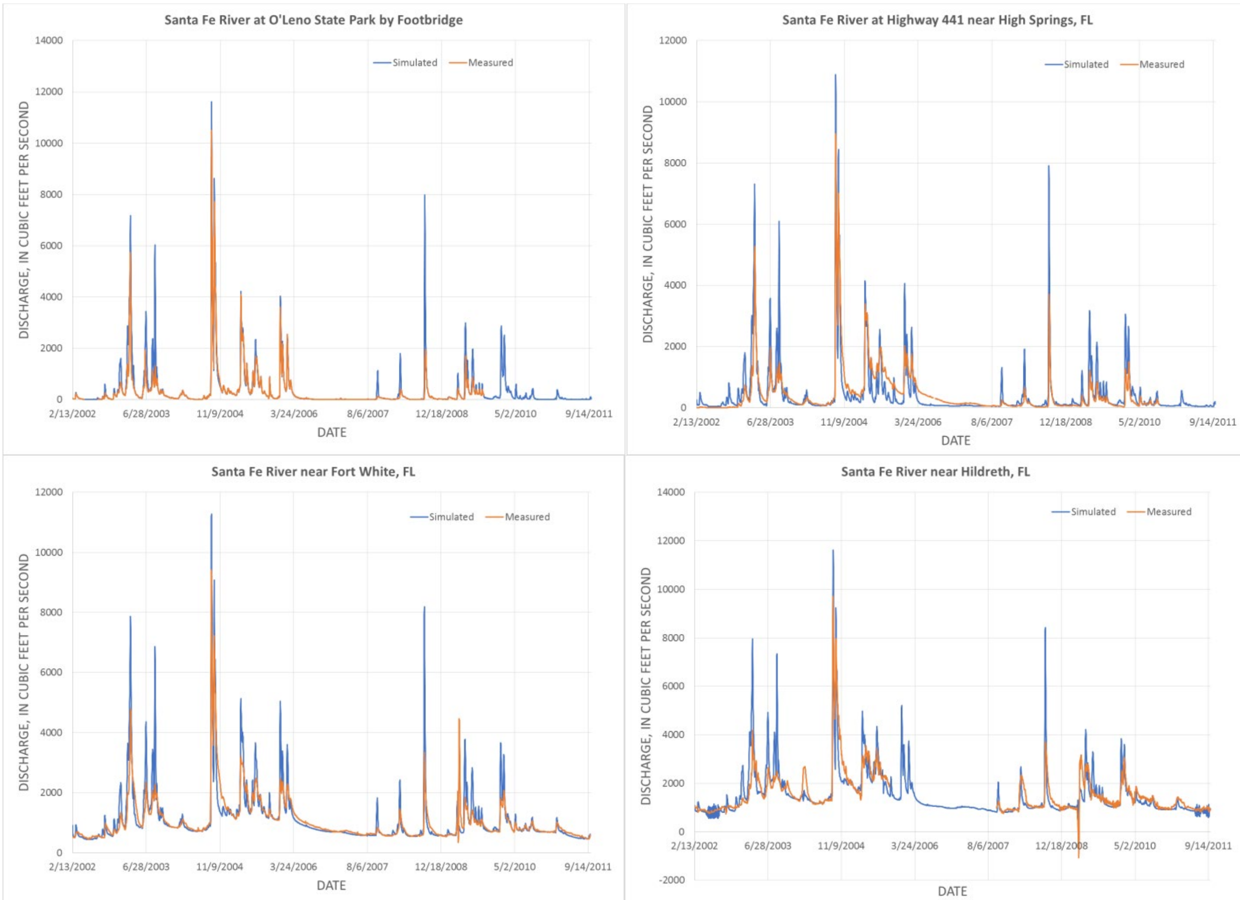


Figure 49. Time series plots of measured and simulated flows on the Santa Fe River.

The measured and simulated flows are nearly identical for the Ichetucknee River at Highway 27 (Figure 50). Daily flows were proportioned to equal the flow at this gage, thus, only the effects of traveltime between the various springs and the gage cause the differences illustrated in Figure 50.

At Dampier’s Landing on the Ichetucknee River the simulated flow is consistently lower than the measured flow which is reportedly attributable to flow measurement accuracy at Dampier’s Landing and the fact that simulated flows are closely tied to the measured flows at Highway 27. Flow measurement accuracy at the gage is discussed on page 2-41 of the initial MFLs assessment report (SRWMD 2013) as follows:

> “Since Dampier’s Landing is upstream of Highway 27, it would be expected that the mean and median flows at Dampier’s Landing would be slightly less than those at Highway 27. Instead, a flow loss from upstream to downstream exists in the observed record. These sites are maintained by the USGS. The most likely cause of the loss of flow was from bias in the measurements at the upstream site. All the upstream sites (above Highway 27) have a rating of poor due to additional error attributed to vegetation in the area of measurement. The only site without a significant amount of vegetative interference is Station 02322700 (Highway 27). Therefore, Station 02322700 (Highway 27) best approximates the actual flow in the Ichetucknee River …”

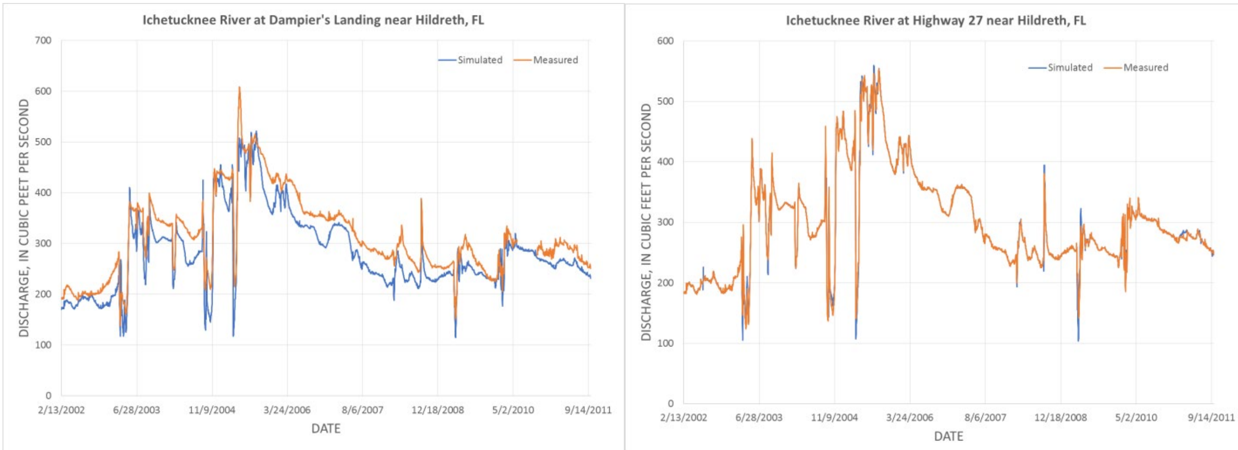


Figure 50. Time series plots of measured and simulated flows for the Ichetucknee River.

Another way to evaluate the quality of the hydrologic model is to compare the flow duration curves (FDCs) for measured and simulated daily flows. At the upstream sites on the Santa Fe River (O'Leno State Park by Footbridge and Highway 441), the FDCs for measured and simulated daily flows are very close except for the lowest flows, i.e. the flows exceeded 85% or more of the time (Figure 51). At Fort White on the Santa Fe River the FDCs for measured and simulated daily flows are nearly identical. Finally, at Hildreth on the Santa Fe River the FDCs for measured and simulated daily flows also are quite close. The FDCs for measured and simulated flows are nearly identical for the Ichetucknee River at Highway 27 (Figure 52). At Dampier's Landing on the Ichetucknee River the simulated flow is consistently lower than the measured flow for reasons previously discussed.

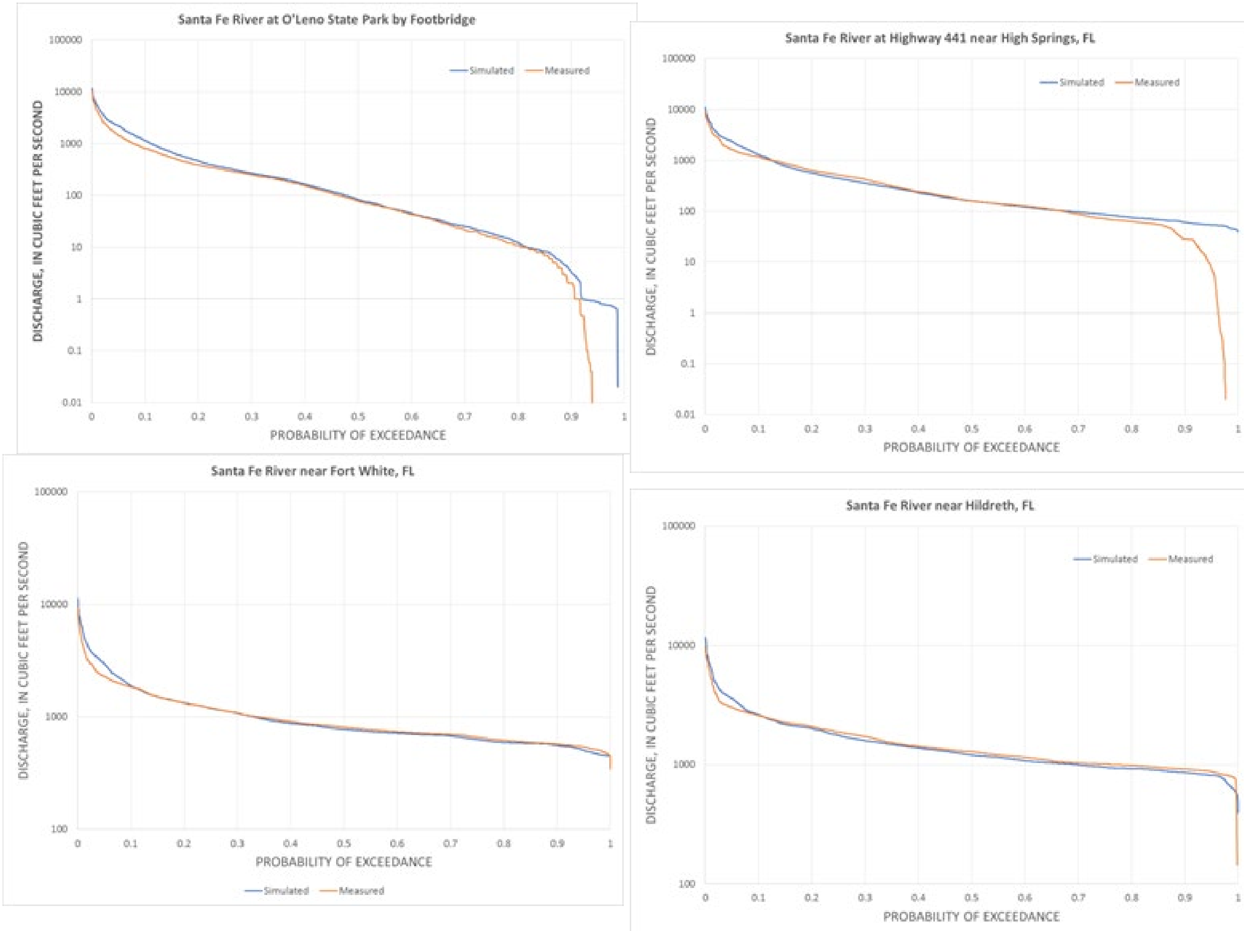


Figure 51. Flow duration curves for measured and simulated daily flows on the Santa Fe River.

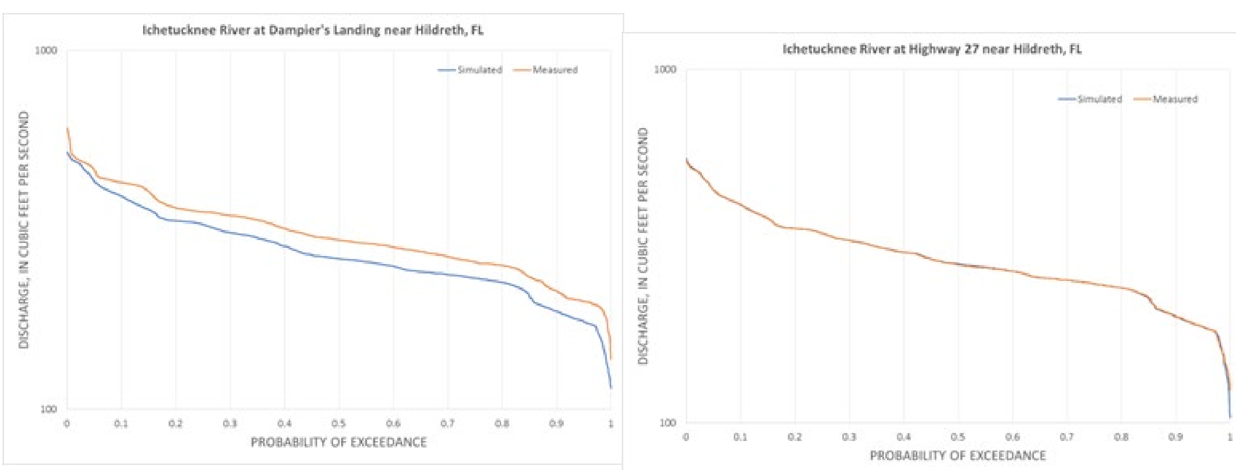


Figure 52. Flow duration curves for measured and simulated daily flows on the Ichetucknee River.

In summary, considering the satisfactory model-fit efficiency of the simulated daily flows (especially, relative to the performance of complex rainfall-runoff models applied to similar wetland dominated watersheds) and the good agreement between FDCs for measured and simulated daily flows, it can be concluded that the simple hydrologic models applied to the Ichetucknee and Santa Fe Rivers are adequate for the calibration and testing of the HEC-RAS model.

Simulation accuracy for water depth

INTERA (2012) compared the measured and simulated water stages to illustrate the accuracy of the transient HEC-RAS model (Section 3.2). However, the comparison of stage may be misleading because of the influence of the local bed elevation at the comparison point. Another useful comparison is to consider the simulated and measured water depths, determined by subtracting the thalweg elevation for the measurement cross section from the measured or simulated water-surface elevation (i.e. stage).

Two forms of statistical evaluation of the simulated water depths are applied here. The first is the Nash-Sutcliffe coefficient of model-fit efficiency (E) applied to the daily water depths. The second is the determination of the fraction of the simulated daily water depths that are within certain percentages of the actual water depth. Donigian et al. (1984, p. 114) state that for HSPF simulation the annual or monthly fit is very good when the error is less than 10%, good when the error is between 10 and 15%, and fair when the fit is between 15 and 25%. These cut-offs for very good, good, and fair are often used to evaluate other model output (and other models) including water depth.

The proportions of simulated daily depths that meet at least the very good (within 10%), good (within 15%), and fair (within 25%) criteria and the Nash-Sutcliffe efficiency statistic, *E*, for the daily water depths were calculated for seven gaging station (Table 17). The three most downstream sites—all near Hildreth, FL—show very strong agreement between measured and simulated water depths with E values greater than 0.96 and more than 90% of the simulated depths within 10% of the measured depth. The upstream boundary of the Santa Fe River at Worthington Springs also shows very strong agreement between measured and simulated water depths with E greater than 0.90 and more than 90% of the simulated depths within 10% of the measured depth. Worthington Springs provides a confirmation of the accuracy of the hydraulic model because even though the measured flows are applied at this location as an upstream model boundary condition, the water depths are calculated through the hydraulic routines in HEC-RAS. The *E* value for Fort White meets the satisfactory level, and 83.2% of the simulated depths are within 10% of the measured depths indicating reliable estimates of depth at Fort White. The *E* value for the Santa Fe River at Highway 441 is unsatisfactory, but with 62.9% of the simulated depths within 10% of the measured depths HEC-RAS can be considered to yield reasonable estimates of depth at Highway 441.

Table 17. Proportion of all the simulated daily water depths within 10, 15, and 25% of the measured daily water depth and the Nash-Sutcliffe coefficient of model-fit efficiency for the daily water depths

Gage	Difference Threshold				
	<10%	**<15%**	**<25%**	***E***	**Rating**
Santa Fe River at Worthington Springs, FL	0.911	0.927	0.934	0.909	Very Good
Santa Fe River at O'Leno State Park by Footbridge	0.186	0.299	0.521	0.162	Unsatisfactory
Santa Fe River at Highway 441 near High Springs, FL	0.629	0.800	0.906	0.271	Unsatisfactory
Santa Fe River near Fort White, FL	0.832	0.913	0.937	0.545	Satisfactory

Gage	Difference Threshold				
	<10%	**<15%**	**<25%**	***E***	**Rating**
Santa Fe River near Hildreth, FL	0.999	1.000	1.000	0.998	Very Good
Ichetucknee River at Dampier's Landing near Hildreth, FL	0.960	0.989	0.996	0.961	Very Good
Ichetucknee River at Highway 27 near Hildreth, FL	0.913	0.978	0.987	0.976	Very Good

The quality of the calculated water depths at O'Leno State Park by Footbridge is unsatisfactory. Given that the hydrologic results at this location were good (*E* = 0.696), the poor stage results could be affected by the large number of cross sections (16 and 6, respectively) in the "Before O'Leno" reach with ratings of F and C. The area of interest for the MFLs assessment is downstream from River Rise which is nearly 25,000 feet downstream from the footbridge gage. Better cross sectional data would be needed for the F and C rated cross sections to improve the reliability of simulated water depths in the "Before O'Leno" reach.

On the Santa Fe River, the measured and simulated water depths are very close for the Santa Fe River at Worthington Springs with the only substantial differences occurring during periods of zero or near zero flow at Worthington Springs (e.g., April 25 to August 1, 2007 the measured daily flow at Worthington Springs was zero (Figure 53). The agreement between measured and simulated water depths at Fort White generally is good and reflects the satisfactory Nash-Sutcliffe E obtained. While the differences between measured and simulated water depths at Highway 441 is not as good as at Fort White. Larger differences between measured and simulated depths occurred at O'Leno State Park near Footbridge which is upstream from the primary area of interest for the MFLs re-evaluation. The measured and simulated water depths are very close for the Ichetucknee River at Dampier's Landing and Highway 27 and for the Santa Fe River near Hildreth (Figure 54).

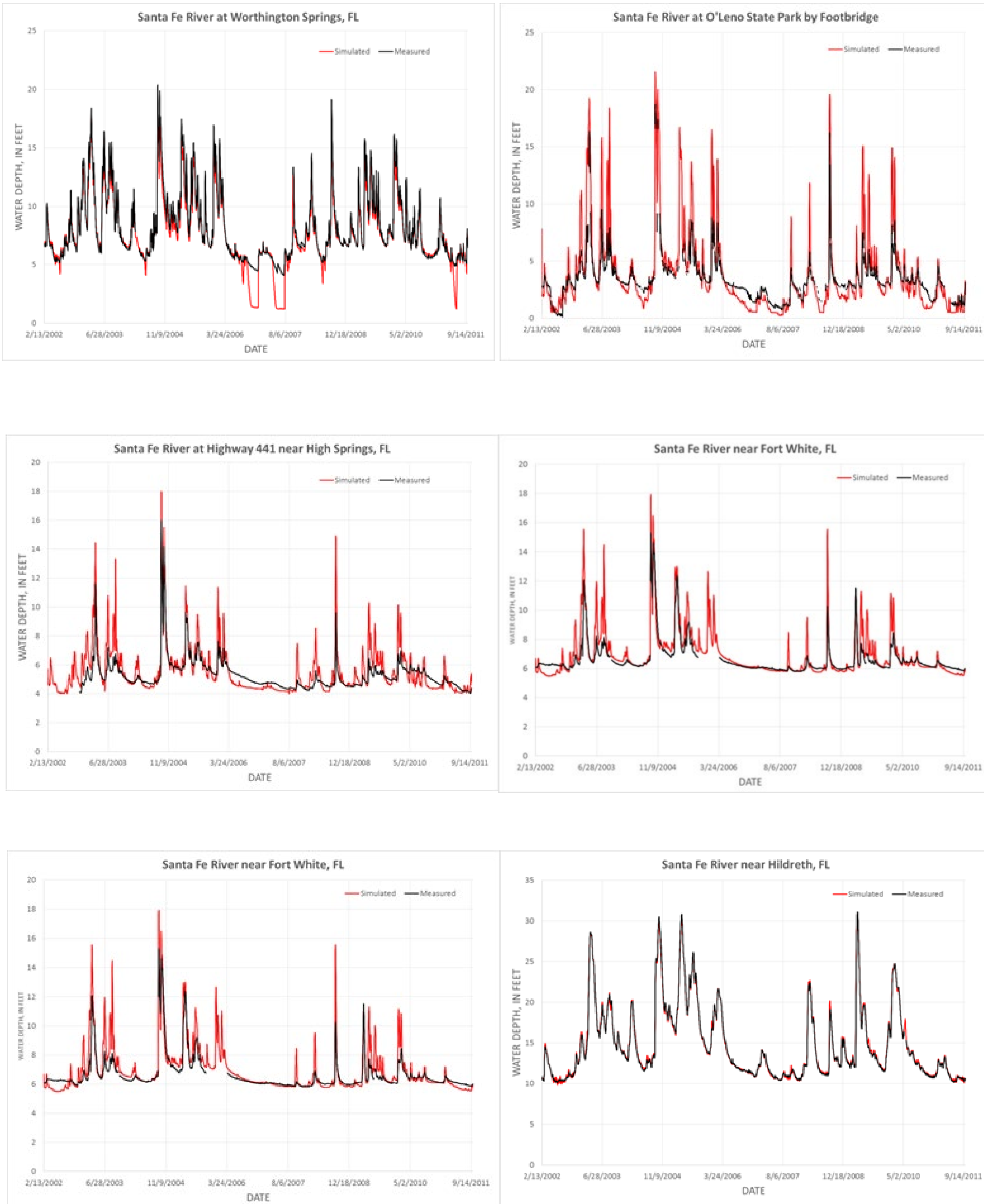


Figure 53. Time series plots of measured and simulated water depths for the Santa Fe River.

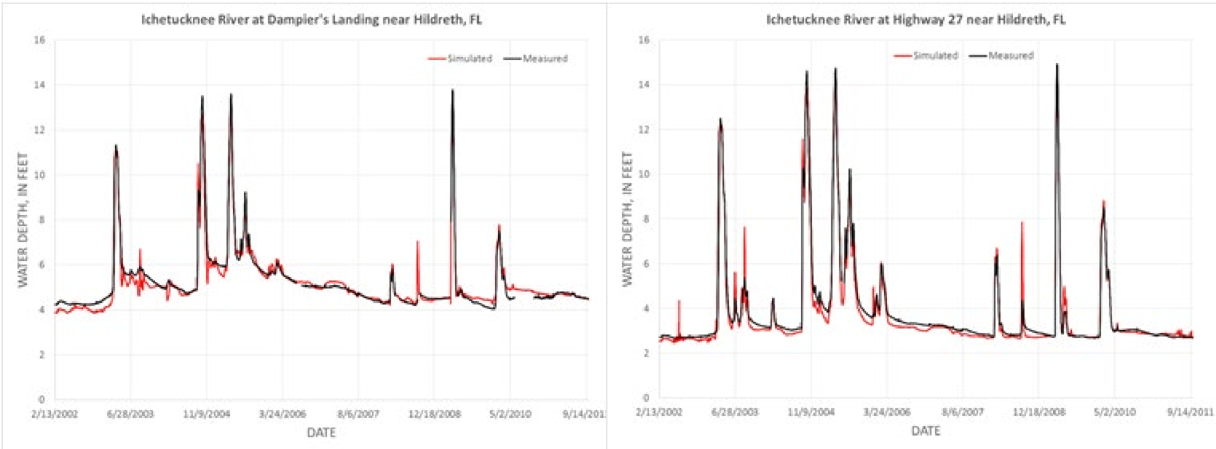


Figure 54. Time series plots of measured and simulated water depths for the Ichetucknee River.

Another way to characterize the quality of the hydraulic model (HEC-RAS) is to compare the Depth Duration Curves (DDCs) for measured and simulated daily water depths Santa Fe and Ichetucknee Rivers, respectively (Figure 55 and Figure 56). The DDCs for measured and simulated water depths are nearly identical for the Ichetucknee River at Dampier's Landing and Highway 27 and for the Santa Fe River near Hildreth. For the Santa Fe River at Worthington Springs the DDCs for measured and simulated daily water depths are very close except for the lowest depths, i.e. the depths exceeded 90% or more of the time. For the Santa Fe River at Highway 441 and near Fort White, the measured and simulated DDCs show excellent agreement for shallower depths that are exceeded 40% or more of the time. The agreement is also good for flows exceeded 20 to 40% of the time, and only for the highest flows (exceeded less than 20% of the time) is the agreement poorer.

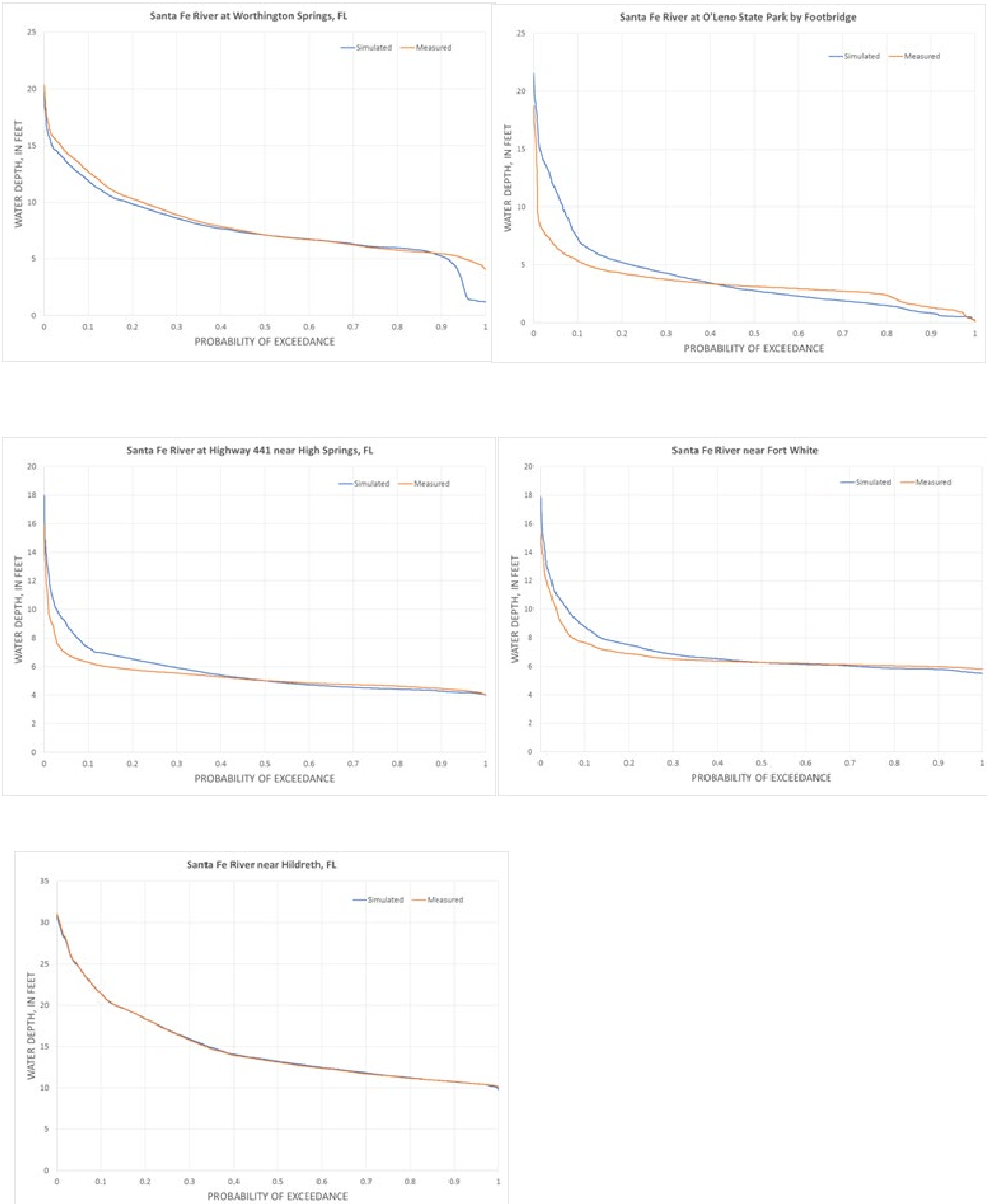


Figure 55. Depth duration curves for measured and simulated daily water depths on the Santa Fe River.

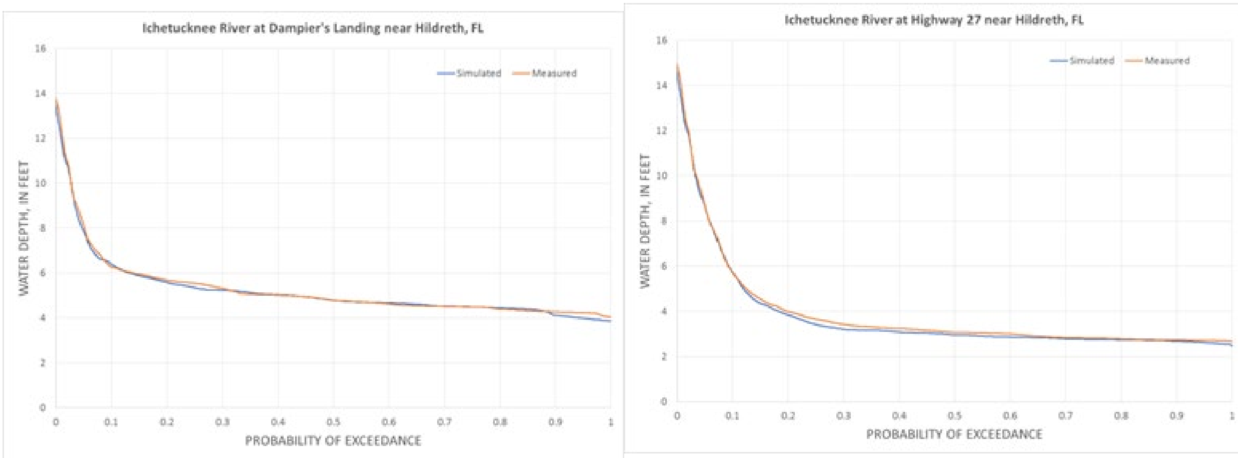


Figure 56. Depth duration curves for measured and simulated daily water depths on the Ichetucknee River.

Summary

In the calibration of continuous hydrologic simulation models, such as HSPF or its predecessor the Stanford Watershed Model, the length of record recommended as the minimum for adequate model calibration is 3 to 5 years ((Donigian, et al. 1984); (Linsley, Kohler and Paulhus 1982)). Given that the calibration period used for the transient HEC-RAS model is nearly double (i.e. nearly 10 years) the record length typically recommended for adequate calibration, it is reasonable to consider that the “unverified” HEC-RAS model has been tested over a wide range of flow conditions.

Validation metrics determined for the calibrated unsteady flow model demonstrate it is accurate over a wide range of flows that might be considered in the MFLs re-evaluation. The quality of the fit of the simulated flows and depths to the measured flows and depths met statistical criteria commonly applied in the calibration of hydrologic and hydraulic models of river systems

Some of the scatterplots comparing measured and simulated stages in Section 3.2 show differences between the measured and simulated stages that may cast doubt on the quality of the calibrated transient HEC-RAS model.

The differences between the measured and simulated stages are attributable primarily to two factors – inaccurate cross-section geometry and the prescribed flow distribution in time and space entering the Santa Fe and Ichetucknee rivers. The calibration quality of the hydrological models used to drive the transient HEC-RAS model and the HEC-RAS hydraulic model is described in the following paragraphs. The statistics and graphics presented are nearly identical to those for the initial MFLs assessment transient HEC-RAS model.

Considering the statistical and graphical validation results presented in this section, it is concluded that the transient HEC-RAS model was appropriately applied and calibrated during the initial MFLs assessment to the available flow and water-surface elevation data for the Santa Fe and Ichetucknee Rivers. Relative to commonly applied model fit-quality criteria, the statistical results achieve at least satisfactory results throughout the study area with many of the results meeting good or very good fit quality. The transient HEC-RAS model provides an acceptable simulation of flows and water depths in the Santa Fe and Ichetucknee Rivers over a wide range of flows, especially in the areas of areas of interest for the MFLs assessment and is suitable for use in the MFLs re-evaluation.

4. STEADY STATE MODEL AND PREDICTIVE SIMULATIONS

Two inputs were provided so that output from a steady state HEC-RAS model could be used to evaluate MFLs -- the simulated flow rates and the downstream boundary condition. When using HEC-RAS to simulate spatially varying flow conditions, flow values are applied in a reach-wise procedure which accounts for increases in flows along the river.

4.1 Spatially Varied Flow Apportionment

During the initial MFLs assessment, predictive simulations were made for every 2nd incremental percentile flow from the 2nd through the 98th exceedance frequencies (Table 18) based on measured daily flows for the calibration period of February 14, 2002 to September 30, 2011 (INTERA 2012). For the Santa Fe River, flows associated with those exceedance frequencies were determined for each of the Worthington Springs, Fort White, and Hildreth gages. Flow apportioning factors were then applied to the differences in flows between the Worthington Spring and Fort White gages and the Fort White and Hildreth gages for each of the flow percentiles to calculate the flow at intermediate locations between the gaging stations (Table 19). Included in the table are four locations on the SFR reaches where flow is split between two conveyances.

For the Ichetucknee River, the flows were based on the flow at the Highway 27 gaging station. The flows were then proportioned out to the Ichetucknee model reaches (Table 20) on the basis of the linear regression based weighting factors (see Section 2.5.3.2 and Table 21).

Table 18. Initial MFLs Assessment Steady Sate Input Percentile Flows at the Flow Change Locations: Santa Fe River

Station	Reach	10th	20th	30th	40th	50th	60th	70th	80th	90th
267712.9	Before O'Leno	0.87	5.20	17.00	33.00	52.00	88.00	157.50	304.00	732.00
238298.1	Before O'Leno	2.52	6.98	18.67	35.01	53.96	90.24	160.13	305.87	733.74
214930.6	Before O'Leno	3.18	8.45	23.72	43.98	69.17	116.79	213.17	395.03	954.16
196233	Before O'Leno	1.16	7.67	18.85	34.70	57.72	105.78	198.71	362.27	873.92
186917.6	Below	1.16	7.67	18.85	34.70	57.72	105.78	198.71	362.27	873.92
186917.6	Above	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
164366	Below	3.18	8.45	23.72	43.98	69.17	116.79	213.17	395.03	954.16
164346*	Below	49.15	62.04	76.04	94.99	123.83	173.38	278.98	460.02	1027.01
164241.8	Above Alligator	49.15	62.04	76.04	94.99	123.83	173.38	278.98	460.02	1027.01
149167.5	Above Alligator	64.36	79.49	92.67	112.66	143.02	193.38	300.61	481.55	1048.86
138946	Siphon Below	61.14	72.99	82.53	95.60	112.25	131.32	140.20	140.20	140.20
138946*	Siphon Above	3.21	6.50	10.14	17.06	30.77	62.06	160.41	341.35	908.66
133953*	Before Poe	64.36	79.49	92.67	112.66	143.02	193.38	300.61	481.55	1048.86
129819.5	Before Poe	88.10	107.06	119.11	140.37	171.56	224.15	334.60	518.94	1082.41
340.1572	Poe Island South	37.00	44.97	50.02	58.96	72.05	94.14	140.53	217.95	454.61
124770.3	Poe Island North	51.10	62.09	69.08	81.41	99.50	130.01	194.07	300.99	627.79

Station	Reach	10th	20th	30th	40th	50th	60th	70th	80th	90th
124387.6	Before Rum	88.10	107.06	119.11	140.37	171.56	224.15	334.60	518.94	1082.41
117559.8	Before Rum	210.64	237.14	257.58	283.38	323.40	389.51	511.74	707.50	1273.27
113265.1	Rum Island South	119.91	136.31	149.04	165.21	190.47	232.62	311.66	440.47	822.52
936.5505	Rum Island North	90.72	100.83	108.53	118.17	132.93	156.89	200.08	267.03	450.75
112509.8	Lower After Rum	210.64	237.14	257.58	283.38	323.40	389.51	511.74	707.50	1273.27
106857.4	Lower After Rum	388.54	413.08	470.56	495.65	550.92	629.06	792.59	1001.25	1547.91
100692.3	Lower After Rum	555.23	591.08	672.36	714.47	770.30	869.07	1059.07	1323.38	1831.16
81719.97	Lower After Rum	580.49	612.26	677.52	726.27	793.22	902.98	1072.93	1358.43	1879.43
60515.43	Lower After Rum	588.49	638.14	684.80	739.93	816.43	935.24	1094.22	1393.21	1920.20
36841.84	Lower After Ichetucknee	829.98	899.99	959.02	1030.06	1110.47	1237.29	1416.49	1781.23	2253.74
25348.59	Lower After Ichetucknee	856.65	925.87	988.80	1046.49	1155.55	1289.13	1476.59	1840.33	2328.64
Shaded rows indicate locations where flow is split between two channels.										

Table 19. Apportioning Factors Determined from the Initial MFLs Assessment Steady Sate Input Percentile Flows at the Flow Change Locations: Santa Fe River

Station	Reach	10th	20th	30th	40th	50th	60th	70th	80th	90th
267712.9	Before O'Leno	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
238298.1	Before O'Leno	0.0030	0.0030	0.0025	0.0029	0.0027	0.0029	0.0029	0.0018	0.0016
214930.6	Before O'Leno	0.0042	0.0055	0.0103	0.0161	0.0239	0.0369	0.0617	0.0893	0.2021
196233	Before O'Leno	0.0005	0.0042	0.0028	0.0025	0.0080	0.0228	0.0457	0.0572	0.1291
186917.6	Below [1]	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
186917.6	Above [1]	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
164366	Below [2]	--	--	--	--	--	--	--	--	--
164346*	Below	0.0871	0.0970	0.0901	0.0910	0.1000	0.1093	0.1347	0.1531	0.2684
164241.8	Above Alligator [3]	--	--	--	--	--	--	--	--	--
149167.5	Above Alligator	0.1145	0.1268	0.1155	0.1169	0.1267	0.1349	0.1587	0.1742	0.2883
138946	Siphon Below [4]	0.9500	0.9182	0.8906	0.8486	0.7849	0.6791	0.4664	0.2911	0.1337
138946*	Siphon Above [4]	0.0499	0.0818	0.1094	0.1514	0.2151	0.3209	0.5336	0.7089	0.8663
133953*	Before Poe	0.1145	0.1268	0.1155	0.1169	0.1267	0.1349	0.1587	0.1742	0.2883
129819.5	Before Poe	0.1574	0.1739	0.1558	0.1576	0.1664	0.1743	0.1964	0.2109	0.3188
340.1572	Poe Island South [5]	0.5800	0.5800	0.5800	0.5800	0.5800	0.5800	0.5800	0.5800	0.5800
124770.3	Poe Island North [5]	0.4200	0.4200	0.4199	0.4200	0.4200	0.4200	0.4200	0.4200	0.4200
124387.6	Before Rum	0.1574	0.1739	0.1558	0.1576	0.1664	0.1743	0.1964	0.2109	0.3188
117559.8	Before Rum	0.3784	0.3959	0.3671	0.3674	0.3778	0.3860	0.3929	0.3958	0.4924
113265.1	Rum Island South [6]	0.4307	0.4252	0.4213	0.4170	0.4110	0.4028	0.3910	0.3774	0.3540
936.5505	Rum Island North [6]	0.5693	0.5748	0.5786	0.5830	0.5890	0.5972	0.6090	0.6226	0.6460
112509.8	Lower After Rum	0.3784	0.3959	0.3671	0.3674	0.3778	0.3860	0.3929	0.3958	0.4924
106857.4	Lower After Rum	0.6993	0.6962	0.6921	0.6789	0.6946	0.6927	0.7044	0.6840	0.7423

Station	Reach	10th	20th	30th	40th	50th	60th	70th	80th	90th
100692.3	Lower After Rum	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
100692.3	Lower After Rum	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
81719.97	Lower After Rum	0.0838	0.0633	0.0163	0.0355	0.0595	0.0807	0.0332	0.0678	0.0970
60515.43	Lower After Rum	0.1103	0.1406	0.0393	0.0767	0.1197	0.1575	0.0842	0.1351	0.1790
36841.84	Lower After Ichetucknee	0.9115	0.9227	0.9059	0.9505	0.8830	0.8766	0.8561	0.8857	0.8494
25348.59	Lower After Ichetucknee	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Notes:
Shaded rows indicate locations where flow is split between two channels.
The Santa Fe River gaging stations near Worthington Springs and Fort White are located near Stations 267712.9 and 100692.3, respectively
[1]Apportioning factor is applied to flow determined for Station 196233.
[2]Apportioning factor not used. Flow equals flow determined for Station 214930.6.
[3]Apportioning factor not used. Flow equals flow determined for Station 164346*.
[4]Apportioning factor is applied to flow determined for Station 149167.5.
[5]Apportioning factor is applied to flow determined for Station 129819.5.
[6]Apportioning factor is applied to flow determined for Station 129819.5.

Table 20. Initial MFLs Assessment Steady State Input Percentile Flows at the Flow Change Locations: Ichetucknee River

Station	Reach	10th	20th	30th	40th	50th	60th	70th	80th	90th
27976.3	Ichetucknee	23.84	28.73	30.28	31.95	33.61	36.24	39.10	42.44	49.47
26670.76	Ichetucknee	27.04	32.59	34.34	36.24	38.12	41.10	44.35	48.14	56.11
26116.6*	Ichetucknee	90.28	108.79	114.65	120.98	127.29	137.22	148.06	160.71	187.33
25088.65	Ichetucknee	92.88	111.92	117.96	124.46	130.96	141.18	152.32	165.33	192.73
24534.3*	Ichetucknee	137.04	165.13	174.04	183.63	193.23	208.30	224.74	243.93	284.36
23529.4*	Ichetucknee	161.98	195.18	205.71	217.05	228.39	246.20	265.64	288.33	336.11
22520.48	Ichetucknee	164.58	198.31	209.01	220.54	232.06	250.16	269.91	292.96	341.50
21911.3	Ichetucknee	165.98	200.00	210.79	222.42	234.03	252.29	272.21	295.45	344.41
20687.3*	Ichetucknee	181.20	218.34	230.12	242.81	255.49	275.42	297.17	322.54	375.99
16758.63	Ichetucknee	191.20	230.39	242.82	256.21	269.59	290.62	313.57	340.34	396.74
14690.6	Ichetucknee	192.02	231.38	243.86	257.31	270.75	291.87	314.91	341.80	398.44
13217.85	Ichetucknee	195.62	235.72	248.43	262.13	275.83	297.34	320.81	348.20	405.91
11281.58	Ichetucknee	200.00	241.00	254.00	268.00	282.00	304.00	328.00	356.00	415.00

Table 21. Apportioning Factors Determined from the Initial MFLs Assessment Steady Sate Input Percentile Flows at the Flow Change Locations: Ichetucknee River

Station	Reach	10th	20th	30th	40th	50th	60th	70th	80th	90th
27976.3	Ichetucknee	0.1192	0.1192	0.1192	0.1192	0.1192	0.1192	0.1192	0.1192	0.1192
26670.76	Ichetucknee	0.1352	0.1352	0.1352	0.1352	0.1352	0.1352	0.1352	0.1352	0.1352
26116.6*	Ichetucknee	0.4514	0.4514	0.4514	0.4514	0.4514	0.4514	0.4514	0.4514	0.4514

25088.65	Ichetucknee	0.4644	0.4644	0.4644	0.4644	0.4644	0.4644	0.4644	0.4644	0.4644
24534.3*	Ichetucknee	0.6852	0.6852	0.6852	0.6852	0.6852	0.6852	0.6852	0.6852	0.6852
23529.4*	Ichetucknee	0.8099	0.8099	0.8099	0.8099	0.8099	0.8099	0.8099	0.8099	0.8099
22520.48	Ichetucknee	0.8229	0.8229	0.8229	0.8229	0.8229	0.8229	0.8229	0.8229	0.8229
21911.3	Ichetucknee	0.8299	0.8299	0.8299	0.8299	0.8299	0.8299	0.8299	0.8299	0.8299
20687.3*	Ichetucknee	0.9060	0.9060	0.9060	0.9060	0.9060	0.9060	0.9060	0.9060	0.9060
16758.63	Ichetucknee	0.9560	0.9560	0.9560	0.9560	0.9560	0.9560	0.9560	0.9560	0.9560
14690.6	Ichetucknee	0.9601	0.9601	0.9601	0.9601	0.9601	0.9601	0.9601	0.9601	0.9601
13217.85	Ichetucknee	0.9781	0.9781	0.9781	0.9781	0.9781	0.9781	0.9781	0.9781	0.9781
11281.58	Ichetucknee	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

The flow apportionments developed for the MFLs update steady state HEC-RAS modeling are based on Reference Timeframe flows (Section 2.7) and the relative gain in flow between gaging stations determined for the initial MFLs assessment. A 4-step process was used to calculate the apportionments.

Step 1.

Flow duration curves were created for the transient model simulation period and compared as a back-check on the flows assigned in the initial MFLs assessment steady state model for four gaging stations:

- Santa Fe River at Worthington Springs: model Station No. 267046.6
- Santa Fe River near Fort White: model Station No. 85420.27
- Santa Fe River near Hildreth: model Station No. 12872.86
- Ichetucknee River near Hildreth: model Station No. 9901.374

The percentile flows HSW computed are identical to those used by INTERA (2012) for the Santa Fe River at Worthington Springs and the Ichetucknee River near Hildreth. Differences were noted, however, in the percentile flows for the Santa Fe River near Fort White and Hildreth gages (Table 22). Work files with calculations of the steady-state flow apportionment for the initial MFLs assessment steady-state model could not be located, thus there is no apparent explanation for the differences.

The relative differences between the two datasets are cumulative. For example, the relative differences between the median (50th percentile) flows determined for the Worthington Springs and Fort White gages increased from 0 to 5.1 percent, and another 5.9 percent from the Fort White gage to the Hildreth gage (Table 22). When distributed along the length of the various model reaches (Table 5), the relative differences are comparable to other sources of uncertainty in hydrologic data, such as field discharge measurement accuracy, and did not warrant further investigation.

Table 22. Differences in Select percentile flows for the Santa Fe River near Fort White and Ichetucknee River near Hildreth gages for daily flows during February 5, 2002 to September 30, 2015.

Percentile	Fort White Flow (cfs)			Hildreth Flow (cfs)		
	INTERA*	HSW**	Relative Difference (%)	INTERA*	HSW**	Relative Difference (%)
10	555	568	2.3	857	915	6.8
20	591	616	4.2	926	980	5.8
30	672	695	3.4	989	1030	4.1
40	714	736	3.1	1046	1150	9.9
50	770	809	5.1	1156	1280	11

60	869	906	4.3	1289	1420	10
70	1059	1070	1.0	1477	1720	16
80	1323	1320	0.0	1840	2090	13
90	1831	1840	0.5	2329	2580	11
*Extracted from the initial MFLs assessment HEC-RAS model input dataset. **Calculated for the daily flow record evaluated for the re-evaluation MFLs assessment.						

Step 2.

For each exceedance frequency evaluated, flow-portioned pickup factors were calculated for each model reach using the spatially distributed flows determined for the initial MFLs assessment modeling (Table 18 and Table 20). Using the median (P50) flow and SFR gages at Fort White and near Hildreth gages as an example, the total pickup between the two gages simulated during the initial MFLs assessment modeling is 385.25 cfs (Table 23) . Beginning at the Fort White gage, the pickup simulated for successive reaches increases from 22.92 at Station 100692.3 to 385.25 cfs at Station 25348.59. The pickup factor similarly increases, in relative proportion of the total pickup, from 5.95 percent (22.92/385.25) at Station 100692.3 to 100% at Station 25348.59.

Table 23. Flow Apportionment Example For Santa Fe River Model Reaches Bracketed by the Fort White and Hildreth Gages

Station	Reach	Initial Assessment P50 Flow (cfs)	Pickup Between Station and Upstream Long-term Gage (cfs)	Pickup Factor	Re-evaluation P50 Flow (cfs)
100692.3* (Fort White)	Lower After Rum	770.30	0	0.0	875.74
81719.97	Lower After Rum	793.22	22.92	0.0595	904.83
60515.43	Lower After Rum	816.43	46.13	0.120	934.28
36841.84	Lower After Ichetucknee	1110.47	340.17	0.883	1307.45
25348.59** (Hildreth)	Lower After Ichetucknee	1155.55	385.25	1.0	1334.10

Step 3.

For the MFLs re-evaluation, the flows associated with select exceedance frequencies were determined from flow duration curves based on the long-term period of Reference Timeframe flows developed for the four aforementioned gaging stations. In this example, the median reference timeframe flows at the Fort White and Hildreth gages are 886 and 1280 cfs, respectively (Table 23) and the total simulated pickup between the two gages is 394 cfs. The P50 flows prescribed for the MFLs re-evaluation model are calculated as the sum of the P50 flow at Fort White (886 cfs) and the product of the Pickup Factor and total pickup between the two gages. For this example, the P50 for Station 60515.43 equals 886 + (0.1197)(394) = 933 cfs.

Spatially varied flow inputs for the MFLs update steady state model were prepared for the same suite of flow exceedances considered in the initial MFLs assessment (Figure 57). Examples of those percentile flows are listed in Table 24 and Table 25 for the Santa Fe and Ichetucknee Rivers, respectively.

Table 24. MFLs Re-evaluation Steady state input non-exceedance percentile flows at the flow change locations: Santa Fe River

Station	Reach	10th	20th	30th	40th	50th	60th	70th	80th	90th
267712.9	BeforeOLeno	2.71	7.07	18.93	35.01	53.98	89.96	159.49	305.82	733.99
238298.1	BeforeOLeno	4.6	9.12	20.82	37.27	56.23	92.49	162.34	307.81	735.84
214930.6	BeforeOLeno	5.35	10.82	26.54	47.37	73.63	122.46	219.9	402.46	970.54
196233.*	BeforeOLeno	3.05	9.92	21.03	36.92	60.53	110.03	204.21	367.68	885.1
186917.6	Below	3.05	9.92	21.03	36.92	60.53	110.03	204.21	367.68	885.1
186917.6	Above [1]	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
164366	Below	5.35	10.82	26.54	47.37	73.63	122.46	219.9	402.46	970.54
164346.*	Below	57.81	72.68	85.82	104.81	136.16	186.35	291.32	471.44	1048.11
186917.6	Above [1]	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
164241.8	Above Alligator	57.81	72.68	85.82	104.81	136.16	186.35	291.32	471.44	1048.11
149167.5	Above Alligator	75.17	92.82	104.66	124.7	158.11	208.92	314.8	494.3	1071.37
138946	Siphon Below	71.41	85.23	93.21	105.82	124.1	141.87	146.82	143.91	143.21
138946.*	Siphon Above	3.75	7.59	11.45	18.88	34.02	67.05	167.98	350.39	928.16
133953.*	BeforePoe	75.17	92.82	104.66	124.7	158.11	208.92	314.8	494.3	1071.37
129819.5	BeforePoe	102.26	124.64	134.62	155.9	190.76	243.66	351.69	533.99	1107.1
340.1572	PoeIslandSouth	42.95	52.35	56.53	65.48	80.12	102.33	147.71	224.27	464.98
124770.3	PoeIslandNorth	59.32	72.28	78.07	90.42	110.64	141.33	203.98	309.72	642.11
124387.6	BeforeRum	102.26	124.64	134.62	155.9	190.76	243.66	351.69	533.99	1107.1
117559.8	BeforeRum	242.11	274.78	291.5	316.92	364.47	430.33	543.93	734.15	1310.32
113265.1	RumIslandSouth	137.82	157.95	168.67	184.76	214.66	257	331.26	457.06	846.45
936.5505	RumIslandNorth	104.27	116.83	122.82	132.16	149.81	173.33	212.67	277.09	463.87
112509.8	LowerAfterRum	242.11	274.78	291.5	316.92	364.47	430.33	543.93	734.15	1310.32
106857.4	LowerAfterRum	445.13	477.84	532.8	555.92	624.76	700.75	848.73	1045.98	1602.75
100692.3	LowerAfterRum	635.37	683.30	761.43	802.30	875.74	971.69	1137.93	1387.93	1904.35
81719.97	LowerAfterRum	665.93	707.4	767.24	817.65	904.83	1014.72	1160.08	1441.25	1977.88
60515.43	LowerAfterRum	675.61	736.84	775.45	835.42	934.28	1055.65	1194.12	1494.15	2039.98
36841.84	LowerAfterIchet	976.85	1034.72	1084.53	1212.76	1307.45	1438.89	1709.29	2084.42	2548.02
25348.59	LowerAfterIchet	1000.1	1064.2	1118.1	1234.1	1364.7	1504.7	1805.4	2174.3	2662.1

Shaded rows indicate locations where flow is split between two channels.
[1]Flow of 2 cfs designated to resolve numerical instability when channel is dry or nearly dry.

Table 25. MFLs Re-evaluation Steady state input non-exceedance percentile flows at the flow change locations: Ichetucknee River

Station	10th	20th	30th	40th	50th	60th	70th	80th	90th
27976.3	25.74	30.53	32.06	33.75	35.39	38.03	40.92	44.2	51.23
26670.76	29.19	34.63	36.36	38.28	40.14	43.13	46.41	50.14	58.11
26116.6	97.46	115.61	121.39	127.8	134.03	144.01	154.95	167.38	194
25088.65	100.27	118.94	124.9	131.48	137.9	148.16	159.41	172.19	199.59
24534.3	147.94	175.48	184.27	193.98	203.46	218.6	235.2	254.05	294.48
23529.4	174.86	207.41	217.8	229.28	240.49	258.38	278.01	300.3	348.07
22520.48	177.67	210.74	221.3	232.97	244.35	262.54	282.48	305.12	353.66
21911.31	179.18	212.54	223.18	234.96	246.42	264.77	284.88	307.71	356.67
20687.3	195.61	232.03	243.65	256.5	269.02	289.04	311	335.93	389.37
16758.63	206.4	244.83	257.1	270.65	283.87	305	328.17	354.47	410.86
14690.63	207.29	245.88	258.2	271.81	285.09	306.31	329.57	355.99	412.62
13217.85	211.17	250.5	263.04	276.91	290.44	312.05	335.74	362.65	420.36
11281.58	215.9	256.11	268.93	283.11	296.93	319.04	343.27	370.78	429.77

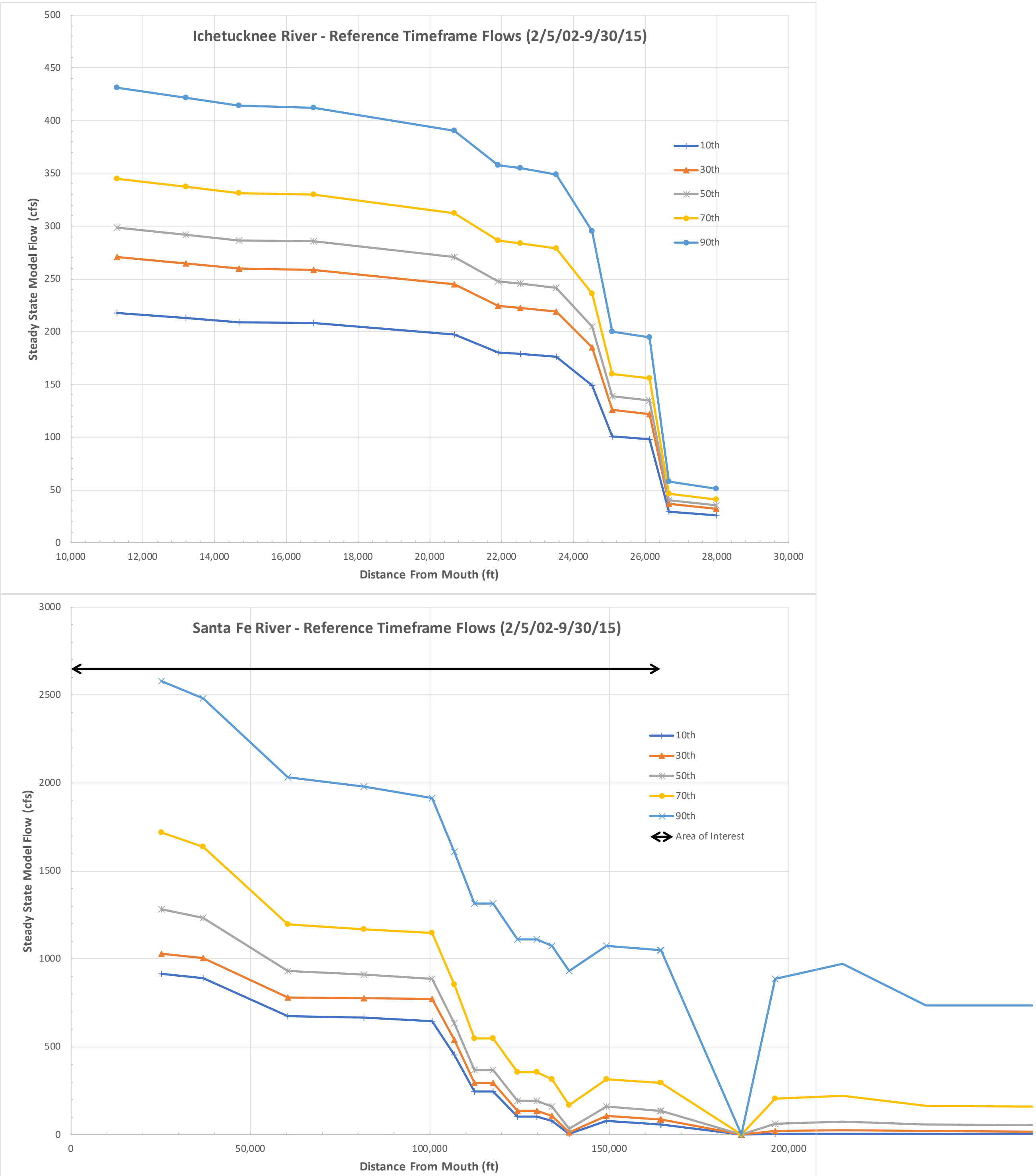


Figure 57. MFLs Re-evaluation Model Steady State Input Flow Profiles for Select Non-exceedance Frequencies: Santa Fe River (top) and Ichetucknee River (bottom)

4.2 Downstream Boundary Condition

For the initial MFLs assessment steady state modeling, a fixed water-surface elevation equal to that for the 20th percentile non-exceedance flow in the Suwanee River at the confluence with the Santa Fe River was prescribed as the downstream boundary condition for all of the simulated flow regimes. The justification for that prescription (SRWMD, 2013, p. 4-22) was:

> "The selection of the 20th percentile Suwanee Stage was deemed most appropriate, since it minimized the influence of the Suwanee River backwater effects to the Santa Fe and Ichetucknee rivers. Using a low backwater effect best simulates what flows are needed to protect the Ichetucknee and Santa Fe River communities."

A "Normal Depth" boundary condition (Hydrologic Engineering Center 2010) minimally affected by backwater from the Suwannee River is prescribed for the MFLs update steady state model. The boundary condition is implemented in the steady state model as a slope at the most downstream SFR cross section.

To apply a normal depth downstream boundary condition, the flow energy slope must be specified at the downstream boundary. A common approach is to use the bed slope. However, the bed slope between the two most downstream cross sections in the Santa Fe River is adverse (i.e. the downstream channel thalweg is higher than the upstream channel thalweg).

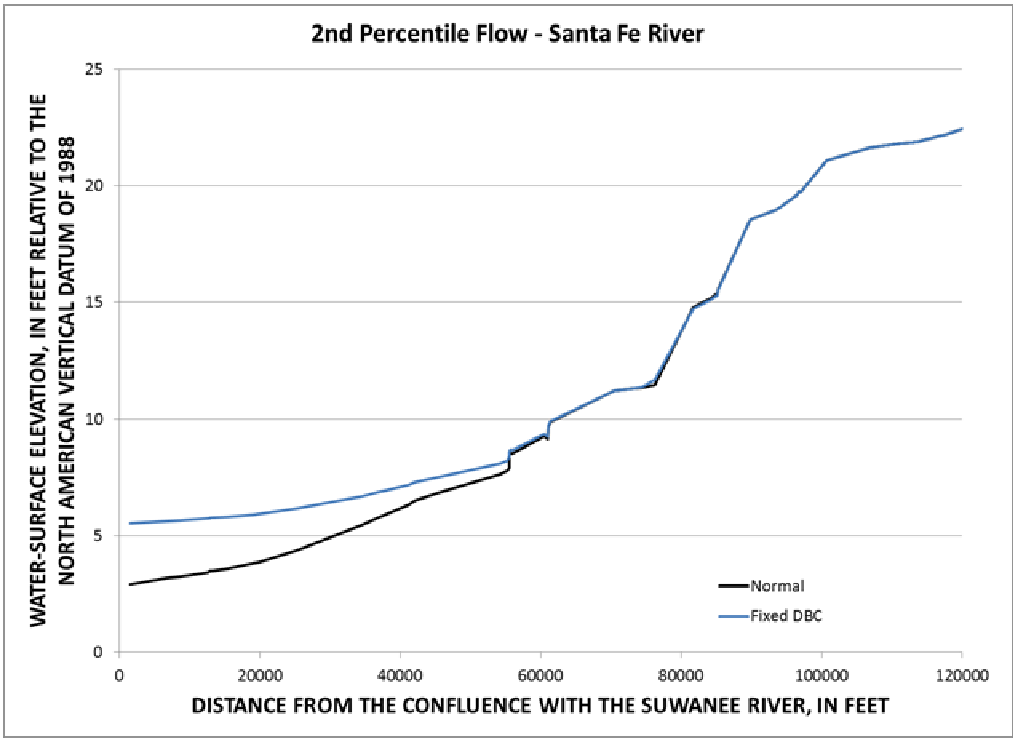
The water-surface slope also can be used to approximate the energy slope, and in a flat river system, such as the lower Santa Fe River below the Ichetucknee River, the water-surface slope is a better approximation of the energy slope than the bed slope. The water-surface slope near the confluence is determined from the difference in the water-surface elevations between the confluence of the Suwanee River and the Santa Fe River (computed from measured water-surface elevations at Branford and Bell on the Suwanee River) and the Hildreth gage.

As described in Section 2.5.2, the slope varies inversely with SFR flow becoming steeper as flow diminishes. The equation used to calculate the slope (ft/ft) as a function of the flow at the SFR Hildreth gage (in cfs) is: Slope = 0.000835 $(Q_{Hildreth})^{-0.425}$. Using the 10th and 90th percentile non-exceedance flows (Table 24) for Station 25348.59 as an example, the slope prescribed for the downstream boundary condition would equal 0.000046 ft/ft (0.24 ft/mi) for a low-flow condition of 915 cfs and 0.000030 ft/ft (0.16 ft/mi) for a high-flow condition of 2580 cfs.

The sensitivity of the calculated water-surface profiles to the boundary conditions assumed in the initial and updated MFLs assessment is illustrated in a series of profile plots (Figure 58) for flow conditions at the SFR near Hildreth gage ranging from very high flow (98th percentile non-exceedance frequency) to very low flow (2nd percentile non-exceedance frequency). Water-surface profiles for the Santa Fe and Ichetucknee rivers were calculated for all the percentile flows for both the normal depth and fixed (20th percentile Suwanee River stage adjusted to NAVD88) downstream boundary conditions. The first set of plots in Figure 58 is for a very-low (2nd percentile non-exceedance) flow condition, and the last set is for a very-high flow (98th percentile non-exceedance) condition.

At about the median (50th percentile) flow, the SFR water-surface profiles obtained for the two different downstream boundary conditions are similar. For higher flows, the normal depth downstream boundary condition results in much higher downstream stages on both rivers than does the fixed downstream boundary condition, implying easier drainage from the lower Santa Fe and Ichetucknee rivers during high flows for the fixed downstream boundary condition. Conversely, for lower flows the fixed downstream boundary condition results in higher stages than does the normal depth downstream boundary condition, implying a larger backwater influence from the Suwanee River during low flows.

Both of the foregoing implications of using a fixed downstream boundary condition seem unreasonable and inconsistent with data collated for the transient modeling period (see Section 2.5.2 and Figure 16). The normal depth boundary condition results in water-surface profiles that are consistent with intuition and the data.



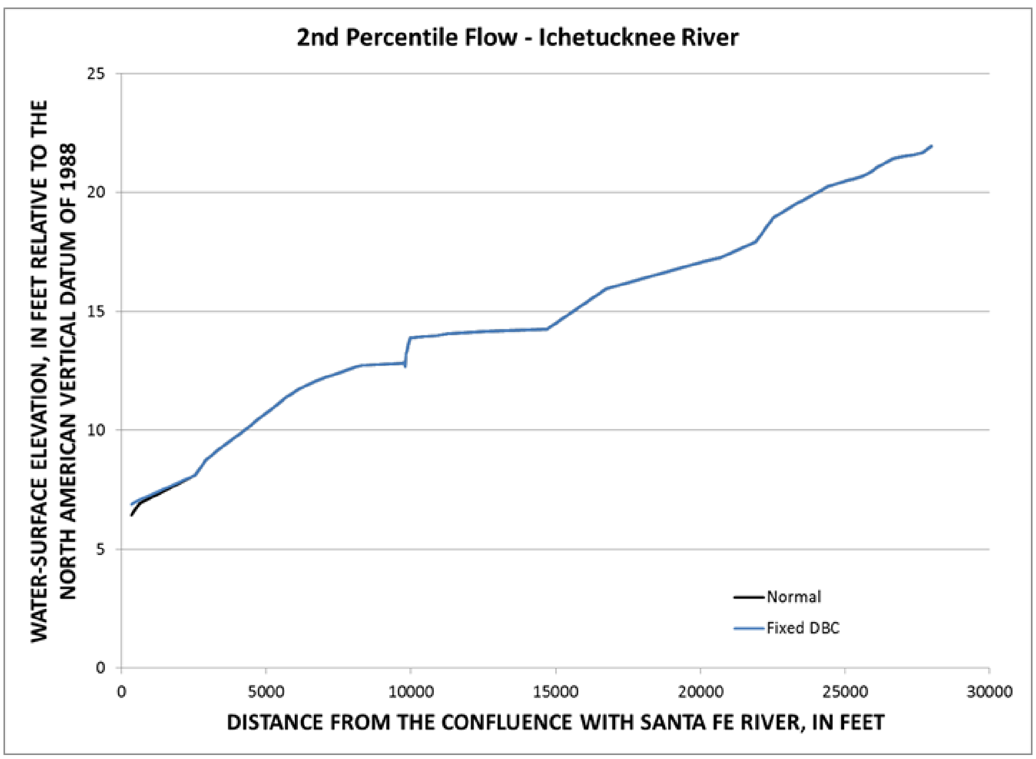
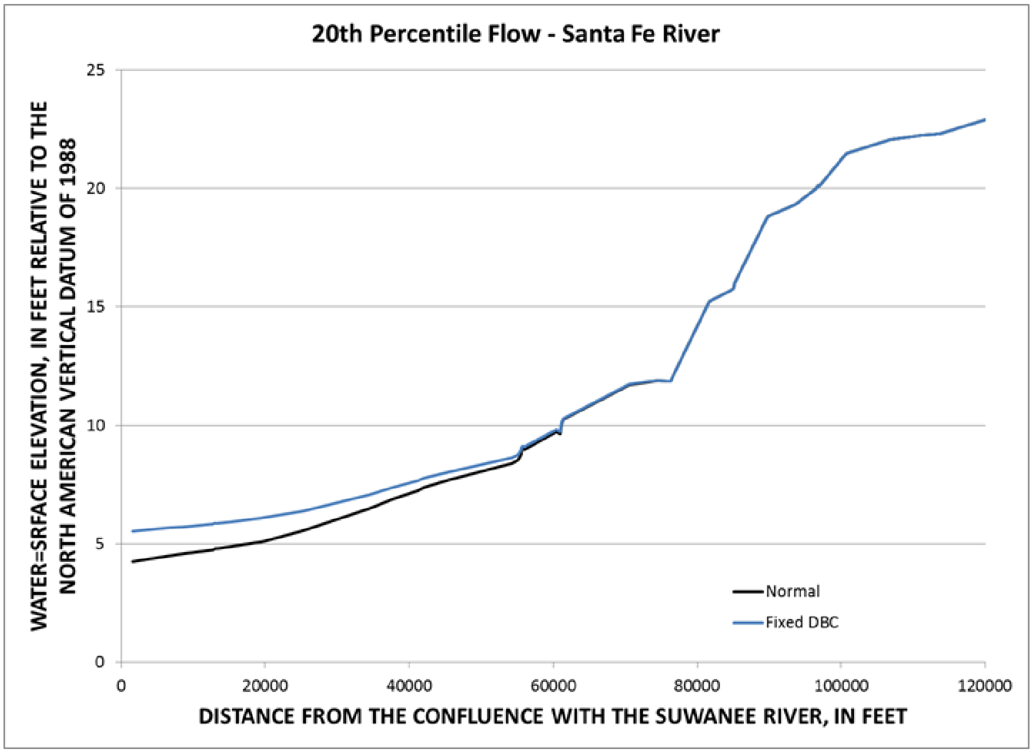


Figure 58. Comparison of computed water-surface profiles on the Santa Fe and Ichetucknee Rivers for normal depth and fixed downstream boundary conditions for selected percentile flows.



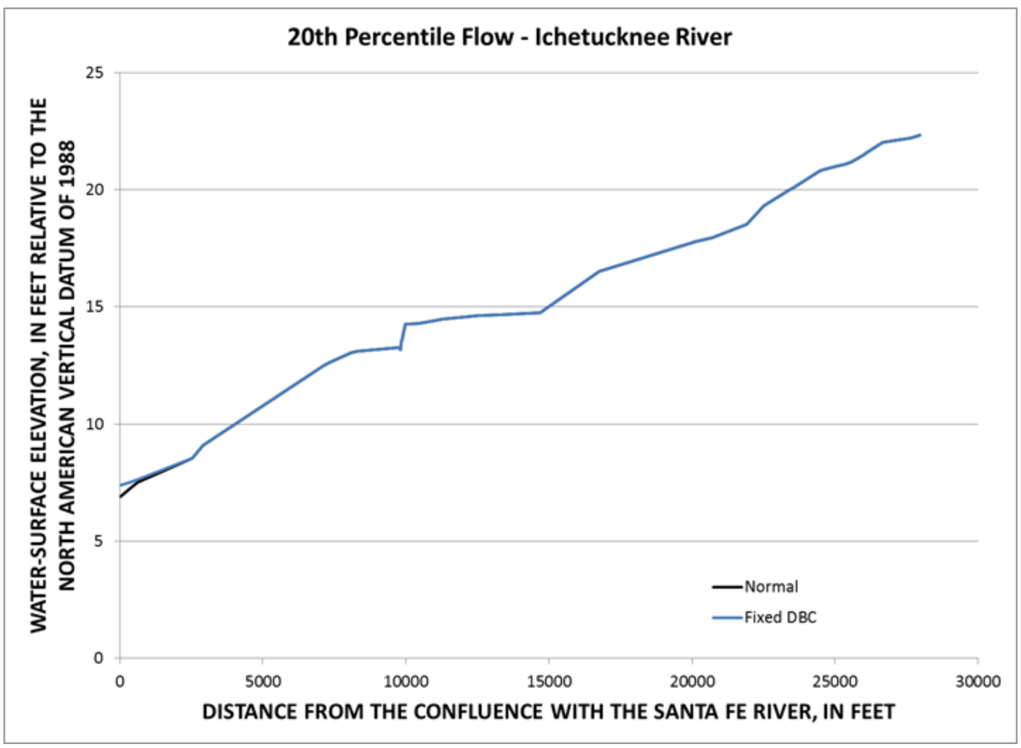
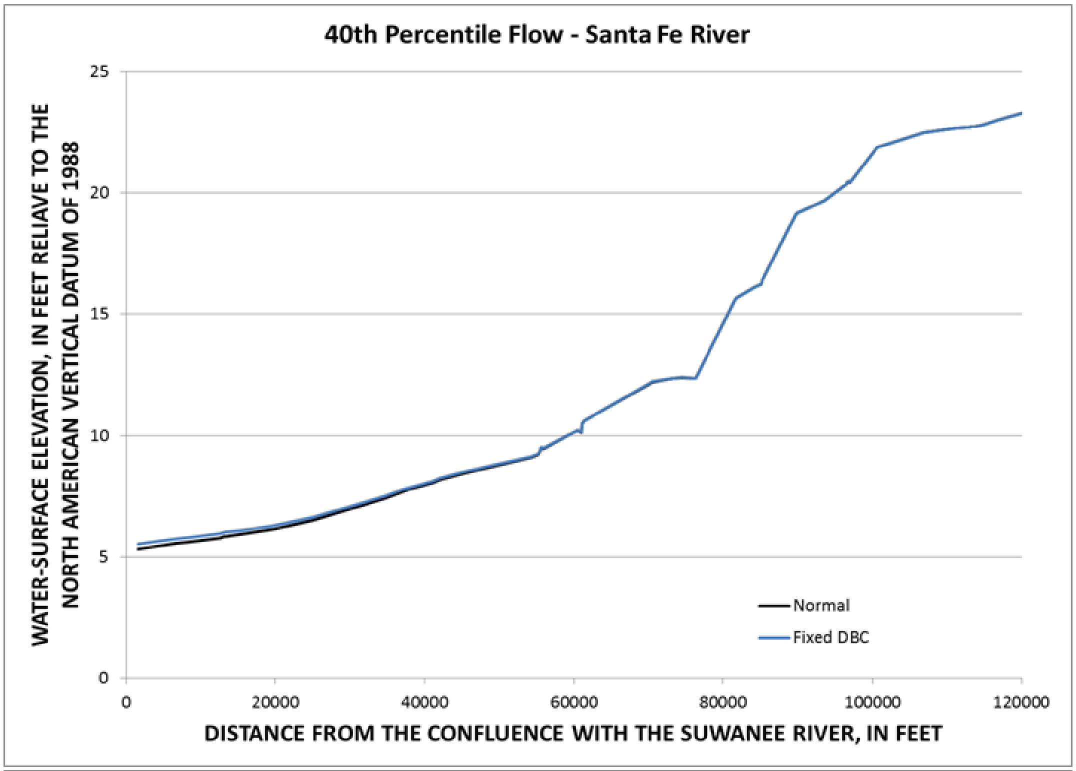


Figure 58 (Cont.) Comparison of computed water-surface profiles on the Santa Fe and Ichetucknee rivers for normal depth and fixed downstream boundary conditions for selected percentile flows.



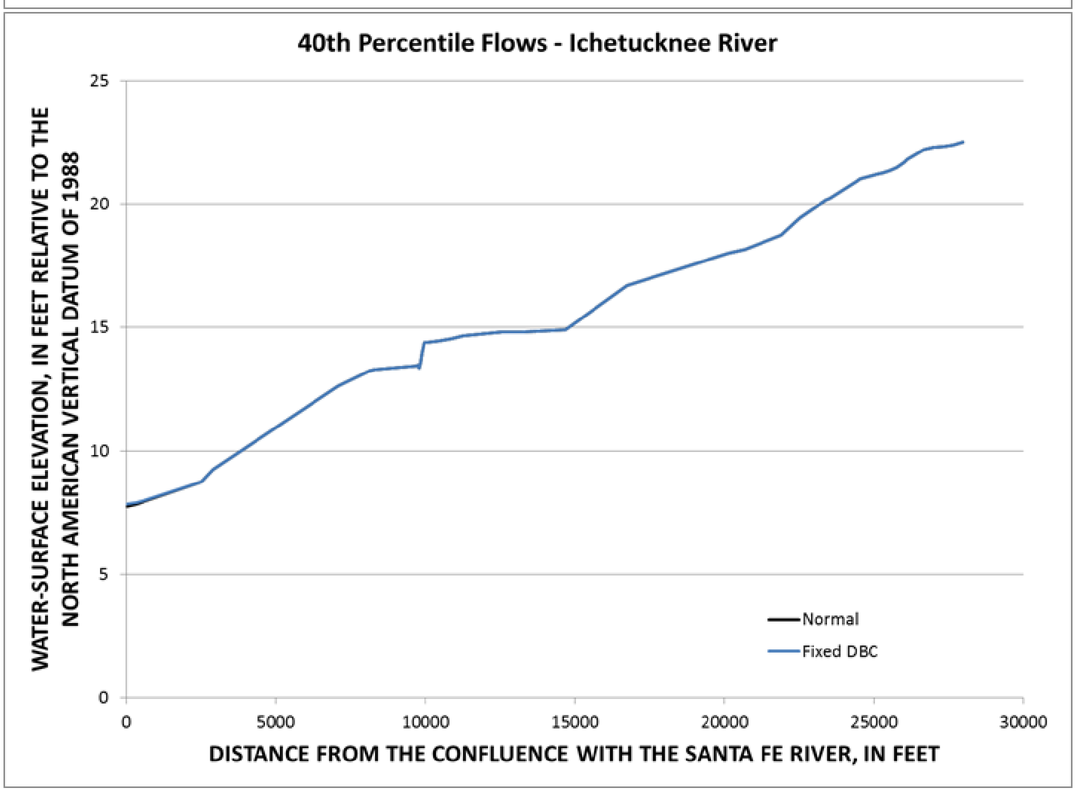


Figure 58 (Cont.) Comparison of computed water-surface profiles on the Santa Fe and Ichetucknee rivers for normal depth and fixed downstream boundary conditions for selected percentile flows.

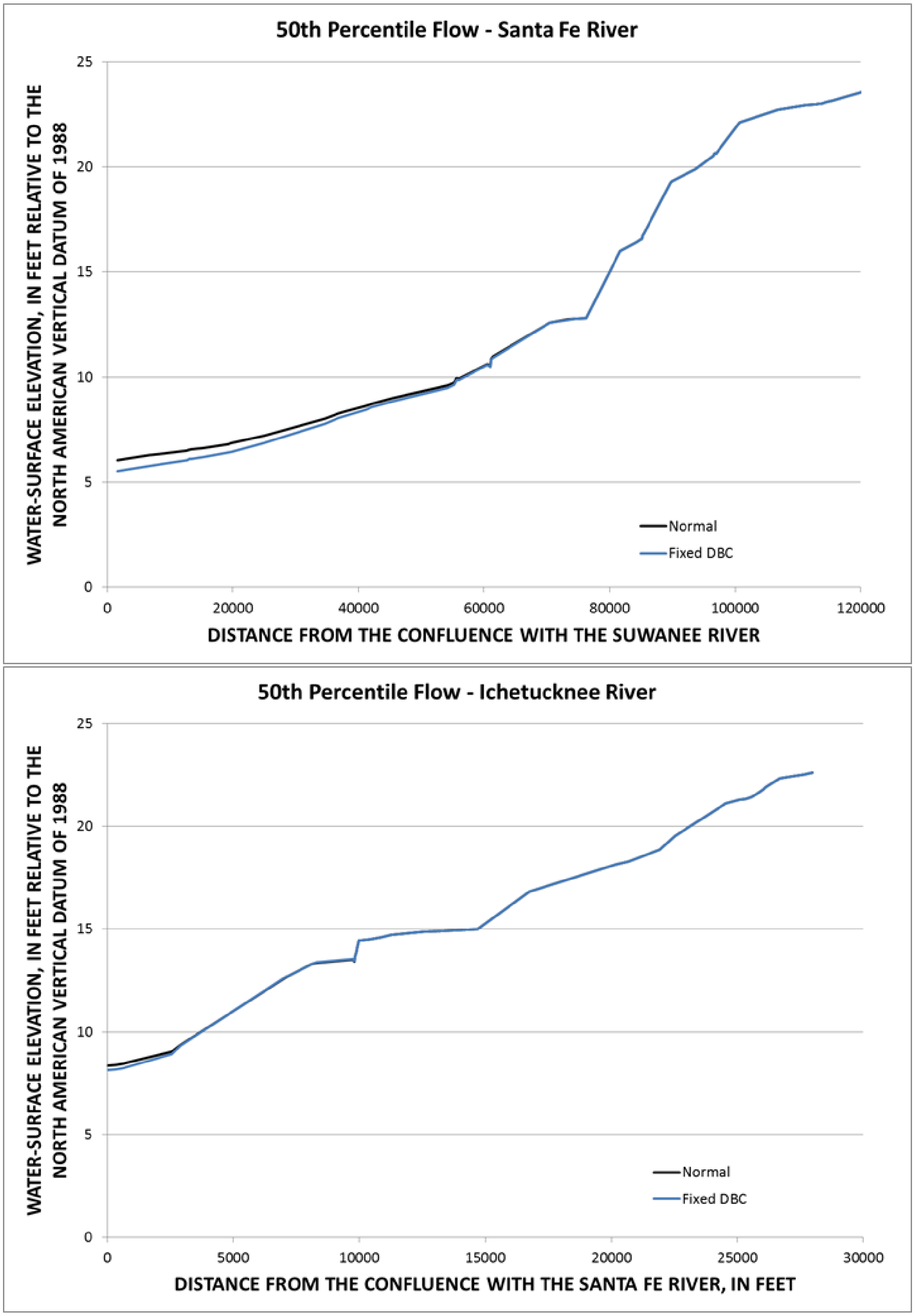
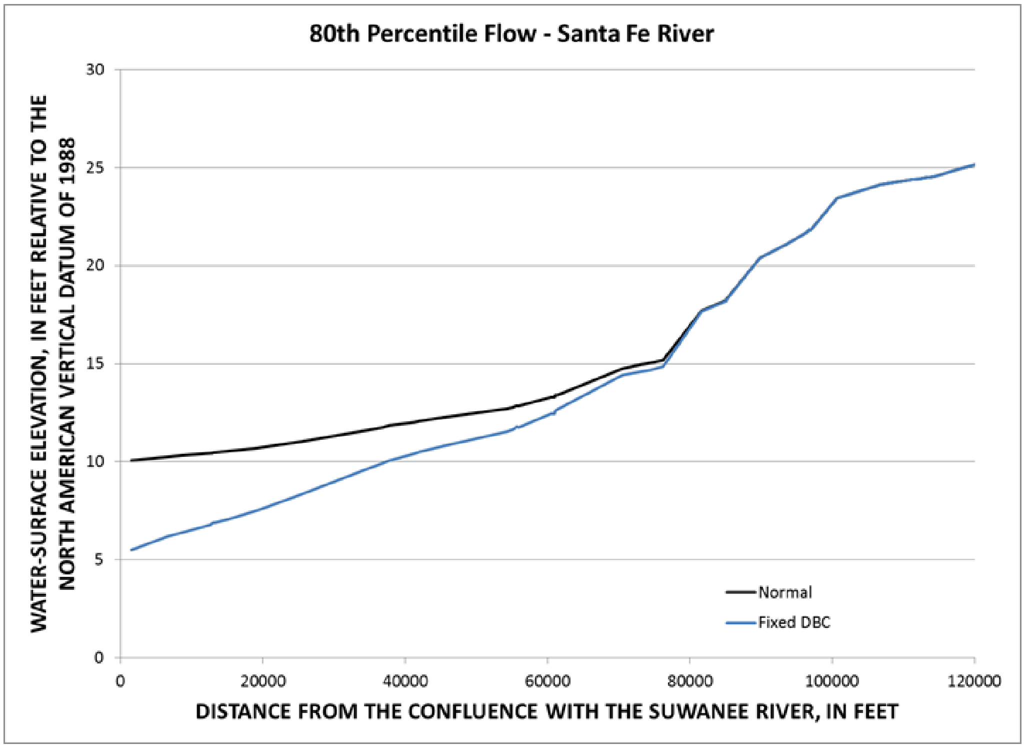


Figure 58 (Cont.) Comparison of computed water-surface profiles on the Santa Fe and Ichetucknee rivers for normal depth and fixed downstream boundary conditions for selected percentile flows.



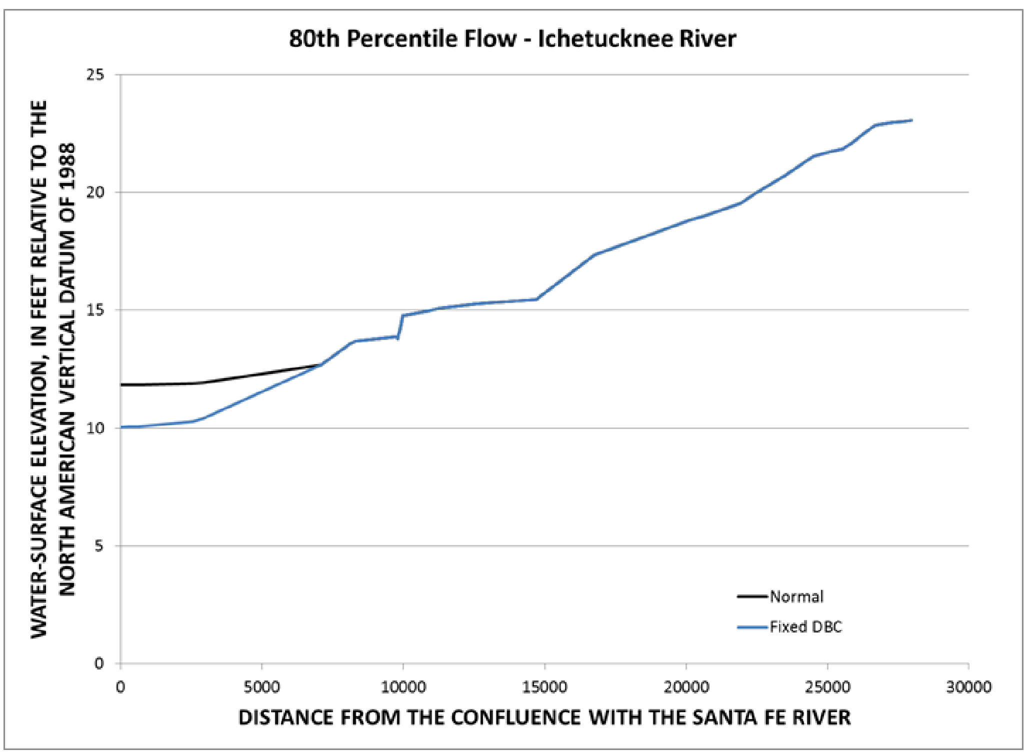
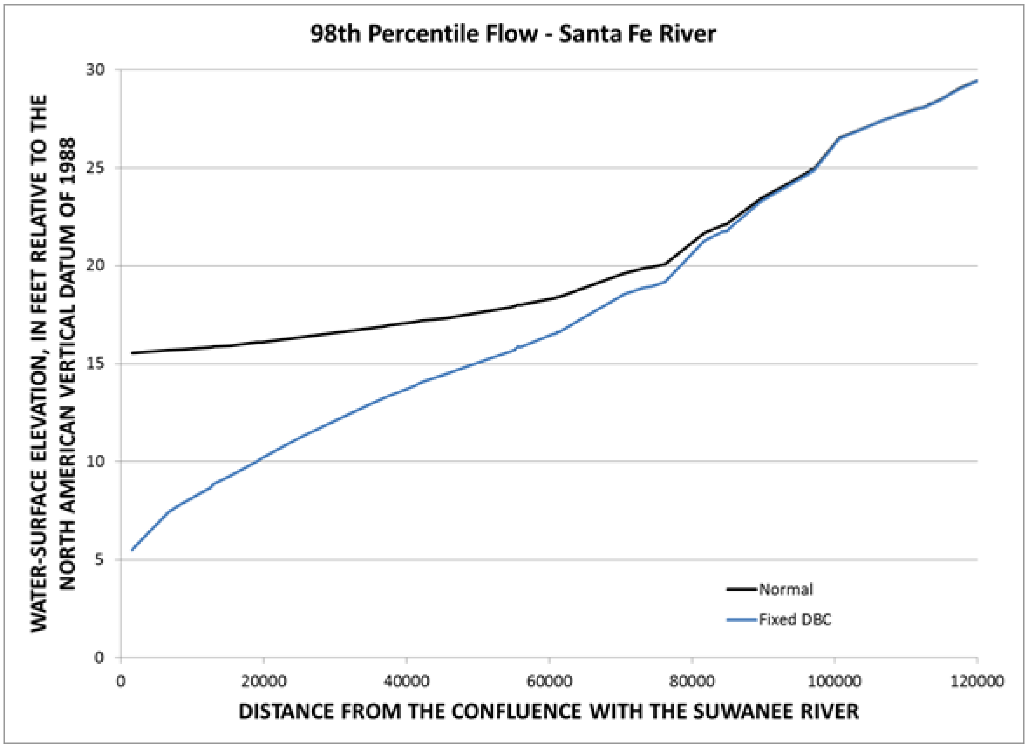


Figure 58 (Cont.) Comparison of computed water-surface profiles on the Santa Fe and Ichetucknee rivers for normal depth and fixed downstream boundary conditions for selected percentile flows.



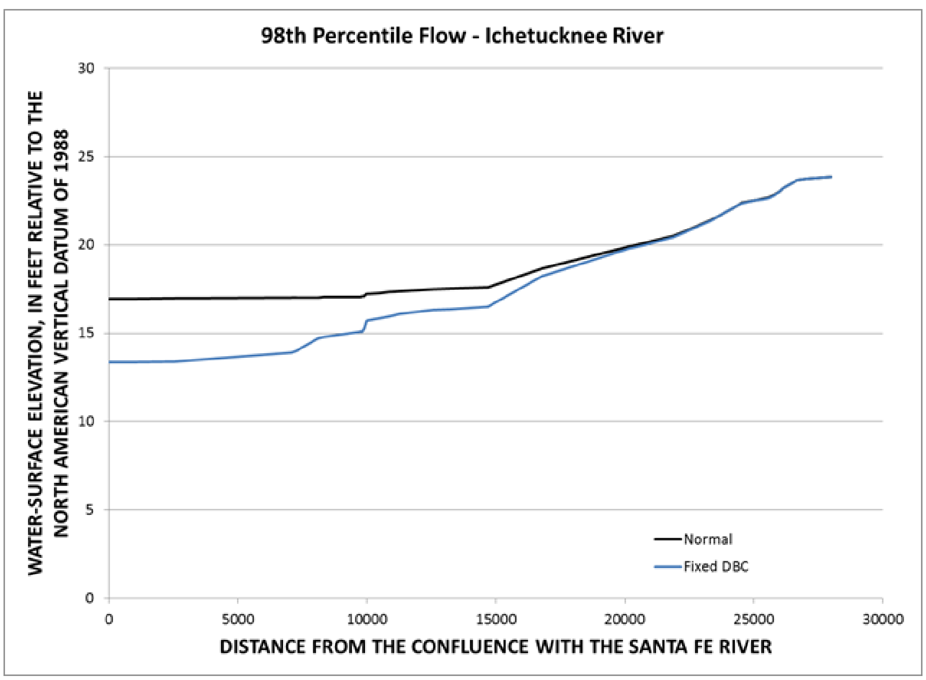


Figure 58 (Cont.) Comparison of computed water-surface profiles on the Santa Fe and Ichetucknee rivers for normal depth and fixed downstream boundary conditions for selected percentile flows.

4.3 Application

Predictive steady-state simulations were made for the same suite of flow-exceedance frequencies considered for the initial MFLs assessment but assuming a normal depth downstream boundary condition. The spatially varying flows were apportioned to the various model reaches as discussed in Section 4.1 (Table 24, Table 25, Figure 57).

Detailed output from HEC-RAS was exported to an ASCII file for use in the ecological modeling of the Lower Santa Fe and Ichetucknee River Systems. The detailed output defines the velocities, depths, wetted perimeter, and other hydraulic properties for each cross section. These data were generated for every 2nd percentile of the reference timeframe flow data.

Backwater effects become more evident in the lower 90,000 feet of the SFR at flows greater than the median flow (Figure 59). The Ichetucknee River appears to be similarly affected in the lower 7,500 feet of the river (Figure 60).

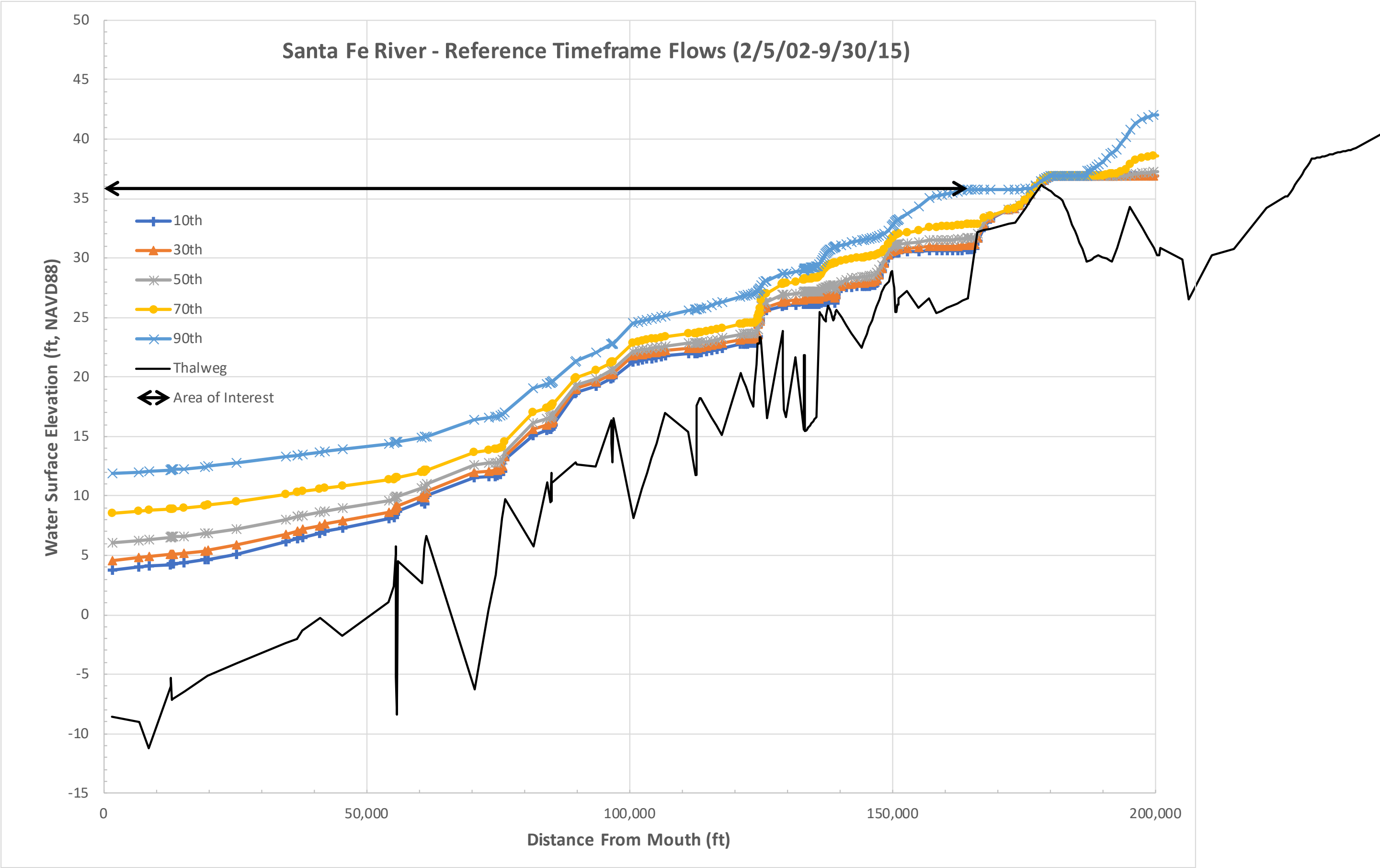


Figure 59. Steady State Water Surface Profiles Simulated For Select Flow Non-Exceedance Frequencies: Santa Fe River

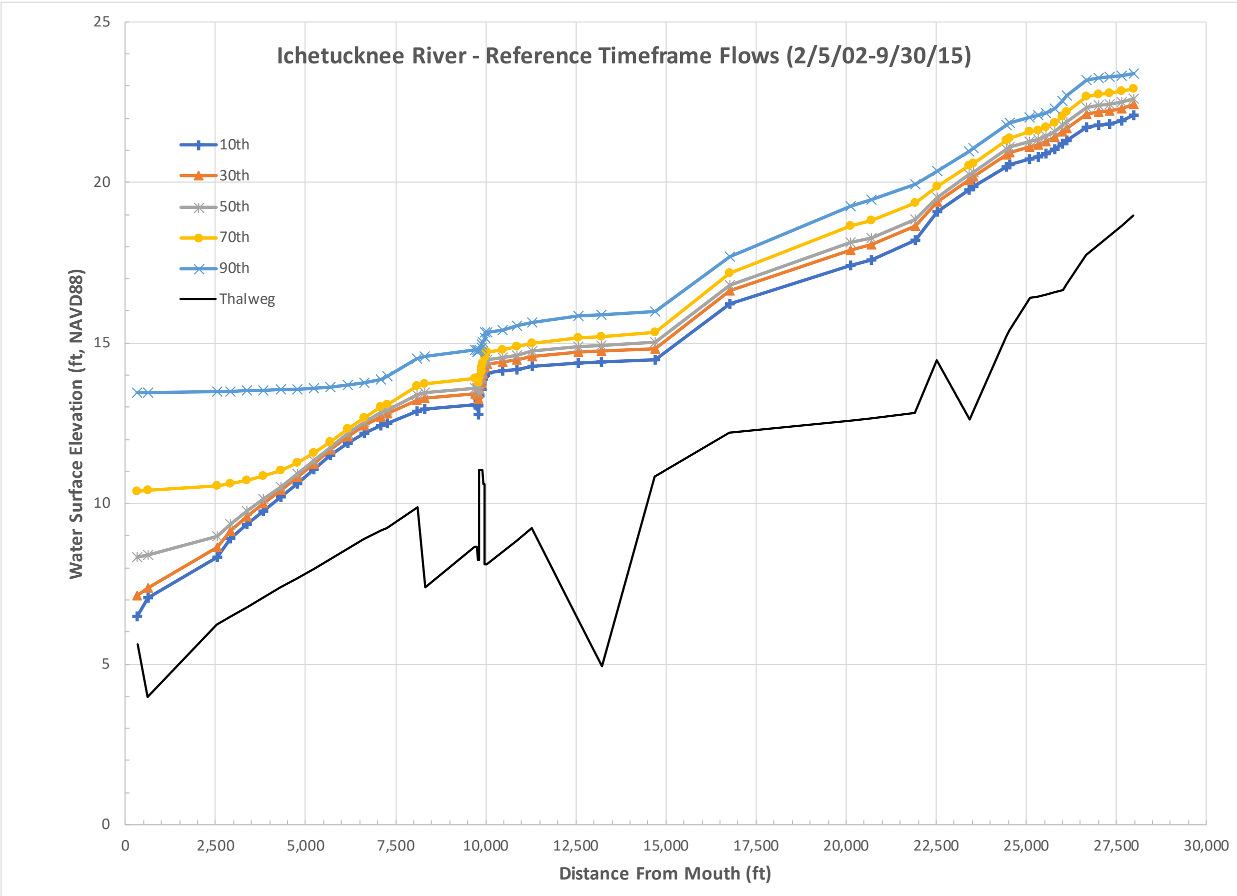


Figure 60. Steady State Water Surface Profiles Simulated For Select Flow Non-Exceedance Frequencies: Ichetucknee River

5. SUMMARY AND CONCLUSIONS

A transient model of the Santa Fe River System (including the Ichetucknee River) was developed for initial MFLs assessment using HEC-RAS version 4.1.0. USGS and District flow and stage data were utilized to characterize the hydrologic system and calibrate the model. Surveyed cross section information was provided by Delta Land Surveyors, Inc. and the District.

Transient simulations were made for a 3,516-day period from February 13, 2002 through September 29, 2011. The model was calibrated by adjusting Manning's n values and flow-dependent friction factors. The best available data at the time were utilized for model development and calibration. If multiple data sources were available, the most reliable data source was selected for use. The calibrated model performed well during both low and high flow conditions.

A technical modeling report describing the model and its calibration was prepared (INTERA 2012) and peer reviewed in support of the initial MFLs assessment (SRWMD 2013). A steady-state model was derived from the calibrated transient model, and predictive simulations were made for a wide range of flow conditions to generate velocity and depth data at gaged and ungaged locations that were further evaluated during the initial MFLs assessment.

Work performed by HSW to refine the initial MFLs assessment HEC-RAS model for use in an MFLs re-evaluation includes:

- Executing transient and steady state simulations using the current HEC-RAS version 5.0.6.
- Updating cross-section geometry data based on the latest available LiDAR data provided by the District. Control areas in the Lower Santa Fe and Ichetucknee Rivers (e.g., shoals) observed during the field investigation conducted by HSW and the District on April 19 and 20, 2018, are well depicted in the model. No additional hydrographic survey data were collected.
- Translating elevations represented in the initial MFLs assessment model from the NGVD29 vertical datum to NAVD88. The geometry and stage data input to the updated model and calculated by the model are referenced to NAVD88.
- Revising steady state model input flow data to reflect the NFSEG-adjusted Reference Timeframe flow records considered for the MFLs re-evaluation.
- Resolving numerical instability issues so that transient and steady state simulations ran successfully in HEC-RAS version 5.06.
- Evaluating transient model calibration and validation metrics for the period February 13, 2002, through September 29, 2011.
- Converting the calibrated transient model into a steady state model to represent a variety of probable flow conditions.
- Evaluating alternative steady state model downstream boundary conditions and the association between LSFR flow and stage at the junction of the Suwannee and Santa Fe Rivers to represent a condition when backwater effects are minimal.
- Simulating steady state profiles and velocity distributions for multiple Reference Timeframe flow exceedance frequencies.

The updated transient model was validated by calculating values for the coefficient of model-fit efficiency, *E*, defined by (Nash and Sutcliffe 1970) and comparing the goodness-of-fit metric to literature values for model acceptability. Coefficient values were calculated for the discharges and stages simulated and observed during the transient modeling period. Of the six locations evaluated for flow prediction accuracy, two were rated Very Good, one was Good, and three were Satisfactory. Of the seven locations evaluated for depth prediction accuracy, four were rated Very Good based on E values, one was Satisfactory, and two were Unsatisfactory. One gage rated Unsatisfactory is upstream from the area of interest (Santa Fe River Rise to mouth) and the other is at a location where there was a small variation in observed depths. Time series plots comparing simulated and observed daily discharges and depths during nearly 10-year simulation period illustrated reasonable associations that were consistent with the model-fit efficiency values.

At Dampier's Landing on the Ichetucknee River, the simulated flow is consistently lower than the measured flow. The most likely cause of an apparent loss of flow in the upstream direction from the long-term gage at Highway 27 "was from bias in the measurements at the upstream sites in areas" with vegetation in the flow-measurement areas.

Considering the statistical and graphical validation results presented in this section, it is concluded that the transient HEC-RAS model provides an acceptable simulation of flows and water depths in the Santa Fe and Ichetucknee Rivers over a wide range of flows, especially in the area of interest for the MFLs assessment. Relative to commonly applied model fit-quality criteria, the statistical results achieve at least satisfactory results throughout the study area with many of the results meeting good or very good fit quality. The parameterization of the calibrated transient HEC-RAS model is suitable for a steady-state model of the Santa Fe River system that can be used for the MFLs re-evaluation.

Predictive steady-state simulations were made for Reference Timeframe flow scenarios ranging in non-exceedance frequency from 2 to 98 percent for the period February 5, 2002, through September 30, 2015. Flows were apportioned spatially in a similar manner as done in the initial MFLs assessment modeling.

A normal depth boundary condition was implemented in the steady state model using flow-dependent slopes prescribed at the most downstream SFR cross section. The boundary condition slopes were calculated using an empirical relation developed from daily stages measured on the Suwannee River and daily discharges measured on the Santa Fe River near Hildreth.

Detailed output from HEC-RAS was exported to an ASCII file for use in the ecological modeling of the Lower Santa Fe and Ichetucknee River Systems. The detailed output defines the velocities, depths, wetted perimeter, and other hydraulic properties for each cross section.

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