APPENDIX B

HYDRODYNAMIC MODEL DEVELOPMENT, CALIBRATION, AND MFL FLOW REDUCTION FOR THE TIDAL PORTION OF THE STEINHATCHEE RIVER

STEINHATCHEE RIVER, FLORIDA

SUWANNEE RIVER WATER MANAGEMENT DISTRICT
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1.0 INTRODUCTION

1.1 PROJECT BACKGROUND AND OBJECTIVES

The Suwannee River Water Management District (SRWMD) is performing a minimum flow and level (MFL) analysis for the Steinhatchee River. A component of the MFL analyses is the evaluation of the impacts to estuarine resources associated with potential reductions in freshwater flow in the Steinhatchee. A key element of the analyses is the change in salinity within the estuarine portions of the river under varying flow conditions. As such, SRWMD contracted for the development, calibration and application of a hydrodynamic model for the tidal portions of the Steinhatchee River. The model is used to evaluate the response of isohalines to reductions in freshwater discharge.

The extents of the hydrodynamic model are from offshore in the Gulf of Mexico up to a point above the limit of salinity intrusion under low flow conditions, including a sufficient distance upstream (area of coverage) to account for the apex of the tidal prism passing into the system. The tidal prism represents the total volume of flow that passes a point in the river through the ebb and flood cycle of the tides. For the Steinhatchee, the model included up to Steinhatchee Falls. Figure 1-1 presents a project location map showing the location of the tidal portions of the Steinhatchee River up to Steinhatchee Falls, along with the location of the flow monitoring station currently maintained by U.S. Geological Survey (USGS 02324000, Steinhatchee near Cross City, FL). The overall project for the Steinhatchee River included the following components:

1. A comprehensive field data collection program within the tidal portions of the Steinhatchee River,
2. Development and calibration of a hydrodynamic model, and
3. Application of the calibrated hydrodynamic model under varying freshwater inflows.

Janicki Environmental, Inc. (2007) developed a hydrodynamic model (the Gulf Coast Shelf Model, GCSM) under contract with the Southwest Florida Water Management District (SWFWMD). SRWMD contributed funding to support that effort. One purpose of the model was to inform the future development of coastal boundary conditions (water surface elevations and salinity) for more detailed models, such as the Steinhatchee River model outlined in this report. The GCSM model provided boundary conditions (water level and salinity) for the Steinhatchee River model during the simulations under varying freshwater inflow.

1.2 REPORT OUTLINE

Following this introduction, the report is broken down into four sections. Section 2 presents the development of the model, including a general description of the Environmental Fluid Dynamics Code (EFDC) hydrodynamic model utilized for this project, the model inputs, the data sources for the model inputs, and the period of the calibration simulation. Section 3 provides the model calibration, including the data used in the model calibration, along with graphical and statistical comparisons of the model versus measured data. Section 4 presents a discussion of the scenarios run using the calibrated model for MFL development. Section 5 summarizes the results of the model development and calibration.

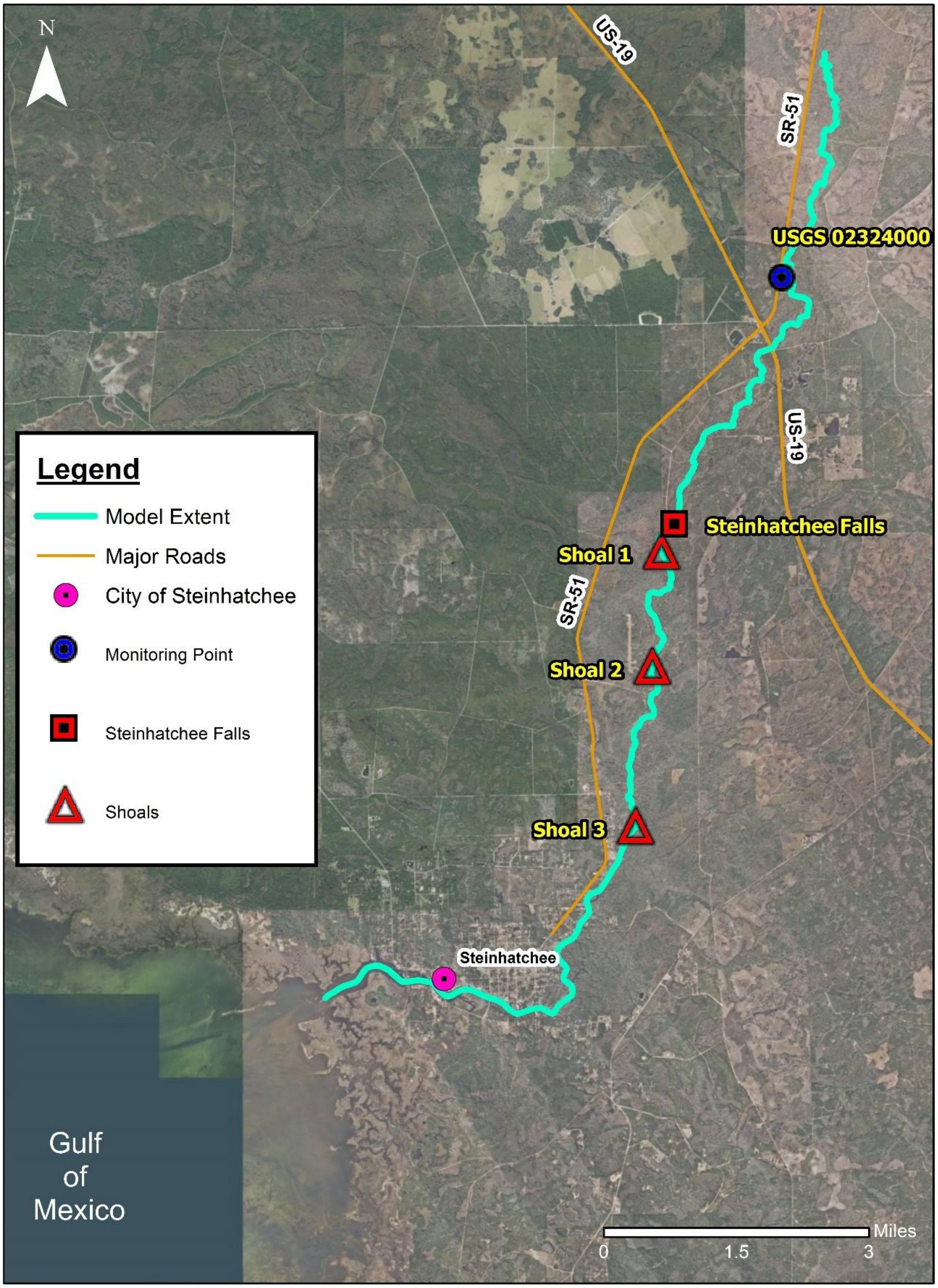

Figure 1-1. *Project location of the Steinhatchee River and the extent of the study area.*

2.0 HYDRODYNAMIC MODEL DEVELOPMENT

This section provides a detailed description of the development of the hydrodynamic model for the tidal portions of the Steinhatchee River. As discussed in Section 1, the model extents include the offshore area (approximately 2.5 miles out from the mouth, and 1.5 miles in either direction along the coast), up the main stem of the Steinhatchee River to Steinhatchee Falls, approximately 10 miles up from the mouth.

2.1 MODEL DESCRIPTION

The EFDC model used in this project is a general purpose modeling package for simulating two- and three-dimensional flow, transport and biogeochemical processes in surface water systems, including rivers, lakes, estuaries, reservoirs, wetlands and nearshore to shelf-scale coastal regions. The EFDC model was developed by Dr. John Hamrick at the Virginia Institute of Marine Science and is considered public domain software. EFDC is currently supported by the U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD), EPA Region 4, and EPA Headquarters. A link to the EPA website for the EFDC model is https://www.epa.gov/exposure-assessment-models/efdc. Additionally, the Florida Department of Environmental Protection (FDEP) and the Water Management Districts (WMDs) throughout the state have used this model extensively. Specific examples of FDEP and WMD applications of EFDC include Indian River Lagoon [St. Johns River Water Management District (SJRWMD)], tidal portions of the St. Johns River (SJRWMD), Florida Bay [South Florida Water Management District (SFWMD)], tidal Caloosahatchee River (FDEP), Pensacola and Escambia Bay (FDEP), the tidal Suwannee River (USGS for the SRWMD), the tidal Aucilla River (SRWMD), and the tidal Econfina River (SRWMD).

The physics of the EFDC model, and many aspects of the computational scheme, are equivalent to the widely-used Blumberg-Mellor model. The EFDC model solves the three-dimensional, vertically hydrostatic, free surface, turbulent-averaged equations of motions for a variable density fluid. Dynamically coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity and temperature are also solved. The two turbulence parameter transport equations implement the Mellor-Yamada level 2.5 turbulence closure scheme. The EFDC model uses a stretched or sigma vertical coordinate and curvilinear orthogonal horizontal coordinates.

The numerical scheme employed in EFDC to solve the equations of motion uses second-order accurate spatial finite differencing on a staggered or C grid. The model's time integration employs a second-order accurate three-time level, finite difference scheme with an internal-external mode splitting procedure to separate the internal shear or baroclinic mode from the external free surface gravity wave or barotropic mode. The external mode solution is semi-implicit and simultaneously computes the two-dimensional surface elevation field by a preconditioned conjugate gradient procedure. The external solution is completed by the calculation of the depth-average barotropic velocities using the new surface elevation field. The model's semi-implicit external solution allows large time steps that are constrained only by the stability criteria of the explicit central difference or higher order upwind advection scheme used for the nonlinear accelerations. Horizontal boundary conditions for the external mode solution include options for simultaneously specifying the surface elevation only, the characteristic of an incoming wave, free radiation of an outgoing wave or the normal volumetric flux on arbitrary portions of the boundary.

2.2 MODEL GRID AND BATHYMETRY

The first aspect of the hydrodynamic model development is the definition of the model extents or coverage. This is achieved through the development of the model grid. For the Steinhatchee River model grid mesh, the representation of the shoreline used was the light detection and ranging (LiDAR) data that outline elevations from 0.15 foot referenced to the North American Vertical Datum of 1988 (NAVD88) and up. These data, in essence, represent the landforms and the elevations that correspond to the edge of the open water areas for the flow. Figure 2-1 presents a contour plot of these data. For the Steinhatchee model grid, shown in Figure 2-2, the main stem and portions of tributary boundaries from these data were utilized to define the grid extents. The offshore boundary was extended a distance of approximately 2.5 miles out from the mouth. Additionally, the grid was extended approximately 1.5 miles in either direction laterally from the mouth. The purpose of the grid extension offshore was to provide sufficient area for mixing of the freshwater flowing into the Gulf of Mexico. The grid was extended upstream to Steinhatchee Falls, which was the limit of tidal fluctuations in the system (based upon measured data discussed in Section 2.3). The grid was built with some of the upper portions connected to the lower portions by definition in a MAPGNS file which links two grid cells which do not line up in computational space. These areas can be seen on the grid in Figure 2-2. This is not an error, but how the model grid was developed.

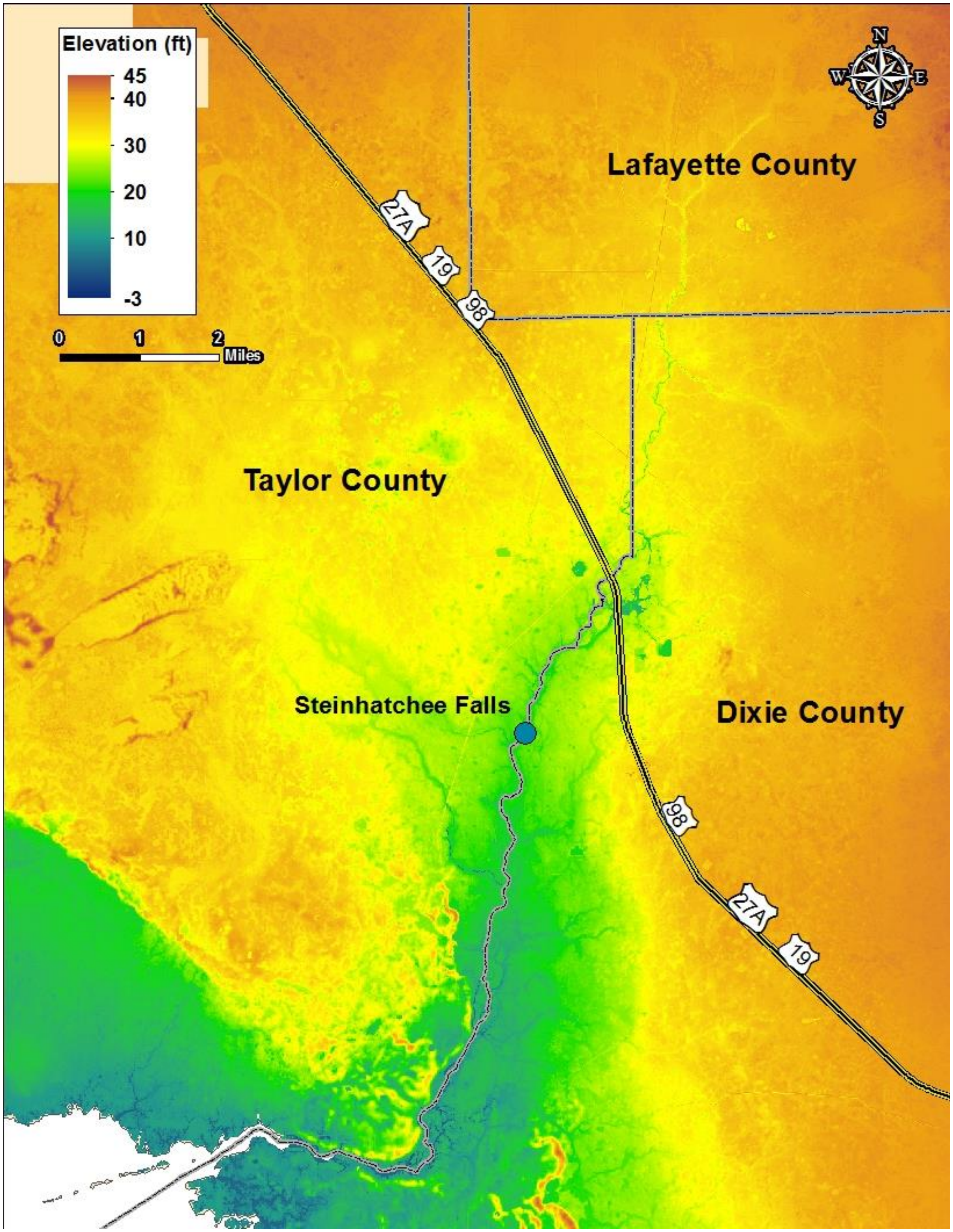

Figure 2-1. Upland topographic conditions from LIDAR data.

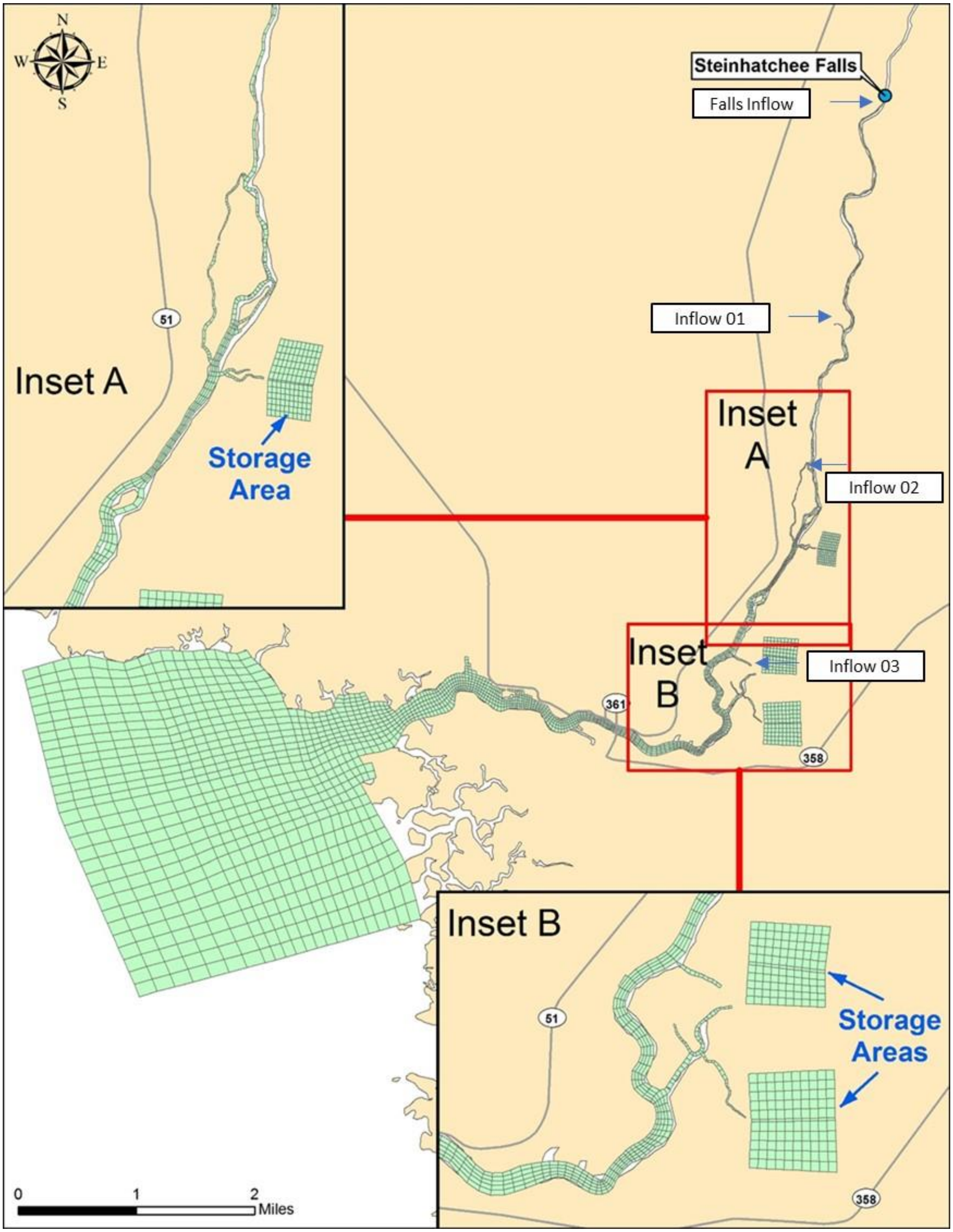

Figure 2-2. Steinhatchee River model grid.

A key aspect of the model calibration was the need to include representative storage areas along the main stem. As Figure 2-1 demonstrates, extensive areas inundate under different water level conditions (high tides can be up around 2.0 feet NAVD88 at times). As such, to accurately simulate the tidal prism moving through the system, representative storage areas were added (Figure 2-2) that fill through tributary spurs off the main stem model grid. These were roughly based upon the area of inundation shown in Figure 2-1, but were more driven by the simulation of the flow measured at one of the field data collection stations. These aspects are discussed further in the model calibration section (Section 3).

Figure 2-3 presents the bathymetric conditions in the Steinhatchee model for the simulations. The bathymetry came from a detailed survey of the main stem of the river extending upstream to the point where the river begins to braid, around 6 miles upstream from the mouth. Above the upstream extent of the survey to Steinhatchee Falls, the bathymetric conditions came from cross-sections from an existing Hydrologic Engineering Centers River Analysis System (HEC-RAS) model. All bathymetric conditions were referenced to NAVD88. The bottom elevations for the Steinhatchee River grid were interpolated using a combination of the digital elevation model (DEM) provided by SRWMD, the bathymetry points collected during the river survey, and the cross-section from the HEC-RAS model. The DEM was first converted from a raster coverage to a point coverage of 10-foot horizontal resolution. This coverage was modified to remove any DEM point within the river or near a bathymetry data point. The DEM point coverage was combined with the bathymetric point coverage into a single coverage to represent both the land elevations and the bathymetric data. An inverse distance-weighted raster interpolation was performed to create a single raster coverage of the rivers and the surrounding watershed referenced to NAVD88. This coverage was used to find the mean elevation value of each model grid cell, with the mean values of rasters within a cell representing the cell bottom elevation.

USGS created the offshore bathymetry interpolated onto the model grid for the Florida Shelf Habitat (FLaSH) map study in 2007. This was a multi-agency effort that created a compilation dataset of available bathymetry from the Florida coast to the edge of the Florida shelf. This coverage is a bathymetry point file that was used to create the elevations for the model grid cells offshore in the Gulf of Mexico. Bottom elevations were converted from the vertical datum of the coverage [mean lower low water (MLLW)] to NAVD88.

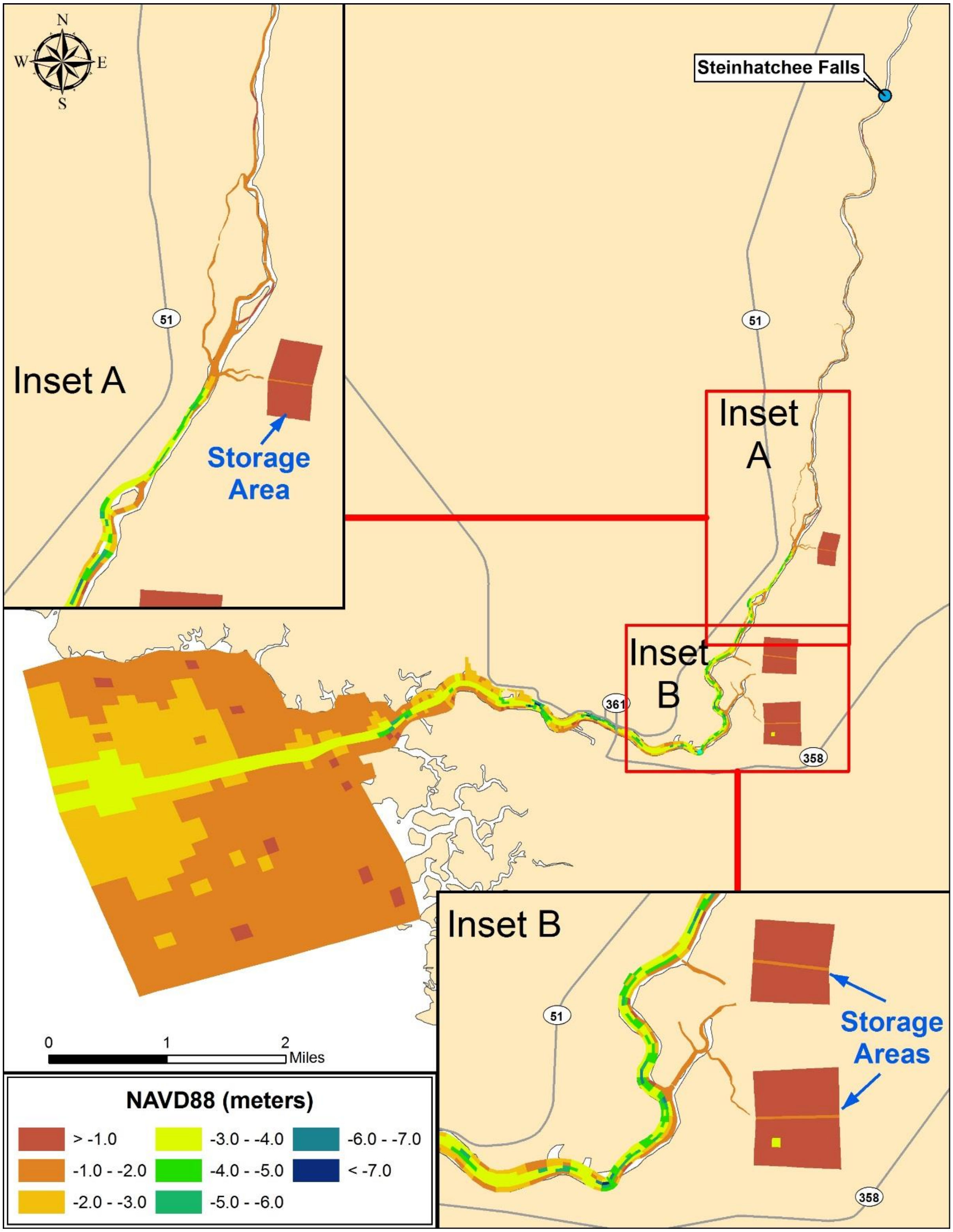

Figure 2-3. Steinhatchee River model bathymetry.

2.3 DATA COLLECTION

In support of the model development, SRWMD contracted for the collection of continuous in-situ hydrodynamic data within the tidal portions of the Steinhatchee River. The following specific parameters were measured:

- Water level
- Salinity
- Tidal flow

Three primary stations were established within the tidal portions of the Steinhatchee River. The locations included the following:

- A station approximately 2.5 miles offshore of the mouth of the river (collecting water level and bottom salinity data)
- A mid-station between the mouth and the upstream station (collecting water level, surface/middle/bottom salinity, and velocity data across the cross-section)
- An upstream station near the upper end of salinity intrusion during lower flow conditions (collecting water level and bottom salinity data)

Figure 2-4 presents the locations of the continuous data collection stations (SRWMD 02324160, SRWMD 02324170, SRWMD 02324190). The instrument installation for the Steinhatchee River began on September 25, 2015, and ended on May 15, 2016. During the first few months of the data collection, it was determined that the middle station bottom meter was not measuring the salinities at the deepest location within the cross-section. In January, an additional instrument was installed closer to the deepest bottom conditions to provide a more accurate measurement of bottom salinities at this location. This instrument was maintained through the end of the deployment.

Survey benchmarks were established at each of the continuous data collection stations. The benchmarks were utilized to relate the measured water level fluctuations at each location to the NGVD88 datum. The bathymetric survey was related to this datum.

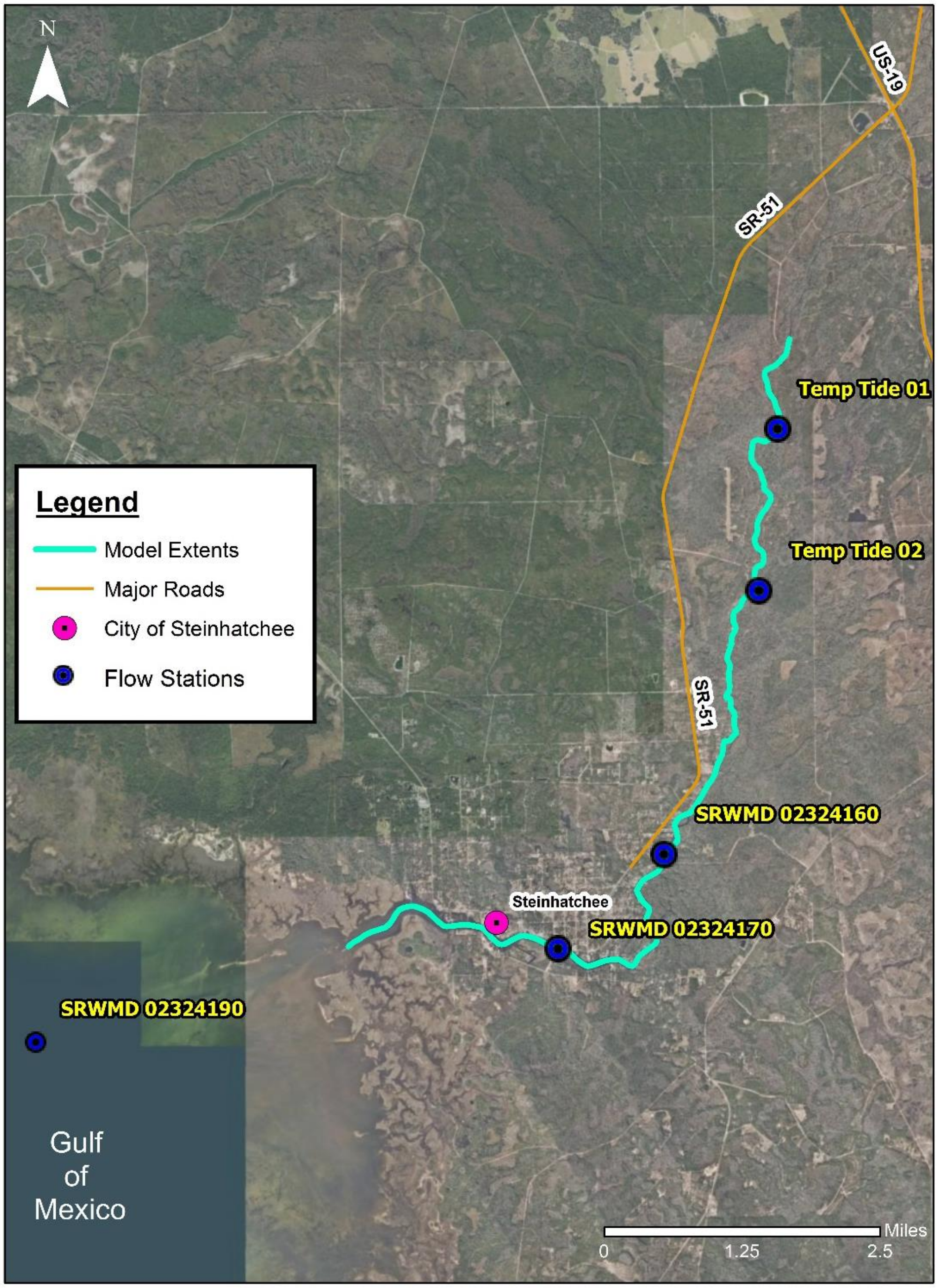

Figure 2-4. Locations of continuous monitoring stations along the tidal portions of the Steinhatchee River

During the data collection, it was identified that shoals, located upstream of the uppermost station, were truncating the tidal propagation in the upstream areas up to Steinhatchee Falls during low water conditions. To establish the degree of the tidal truncation, temporary tide stations were established and measurements taken at each station over a short period. Figure 2-4 shows the locations of the temporary stations.

The middle station collected velocity data across the cross-section using an acoustic Doppler velocity meter (ADVM). From these data, the time series of flow was calculated using the USGS methodology detailed in *Computing Discharge Using the Index Velocity Method* (USGS, 2012). This method consists of developing two interdependent relationships. The first is the stage/area relationship, which establishes a specified cross-sectional area based on the water level elevation. This relationship was established by evaluation of the surveyed cross-section at the location of the ADVM. The second step is to establish a relationship between the velocities measured across the cross-section by the ADVM, the water level (and, therefore, area) and measured discrete flows.

The measured flows used for the calibration came from direct flow measurements taken by a towed acoustic Doppler current profiler (ADCP) over full ebb and flood tide cycles on 2 separate days. Discrete measurements of the flow were taken in the Steinhatchee River at Station SRWMD 02324170 on February 10, 2016 and April 6, 2016. A continuous flow record was calculated using the relationship established from the ADVM velocities, the water levels, and the discrete flows.

2.4 MODEL BOUNDARY FORCINGS AND SIMULATION PERIOD

A number of model inputs were developed for the Steinhatchee River hydrodynamic model. Based on the grid provided in Section 2.2, the specific inputs include:

- Offshore water levels relative to NAVD88
- Offshore salinity
- Upstream freshwater inflow
- Meteorological inputs (wind speed and direction)

This section provides an overview of the inputs utilized in the model and how they were developed. The simulation period for the Steinhatchee model calibration is from October 1, 2015 through May 1, 2016, with a period of simulation within October to allow the model conditions to reach an equilibrium (spin-up period). The graphs presented in the model calibration section (Section 3.0) reflect the time-period following the model spin-up.

2.4.1 OFFSHORE WATER LEVEL

The water levels used to drive the offshore boundary shown in Figure 2-2 came from the measured water levels at the offshore station (Station SRWMD 02324190 in Figure 2-4). The station was located right at the offshore boundary, therefore, no phase shifting or amplitude adjustment was necessary on the data. Figures 2-5a and 2-5b present plots of the water level offshore boundary forcing. Prior to use for the offshore boundary forcing, the data were filtered to remove high-frequency noise in the signal.

2.4.2 OFFSHORE SALINITY

The offshore salinity conditions for the Steinhatchee model were also taken directly from the bottom salinity measurements at the offshore station. During the field data collection effort, measurements at the site showed little to no stratification in the system at this offshore location. Based upon these measurements, the bottom salinity was determined to represent a good offshore forcing signal for the full water column. Figures 2-6a and 2-6b present the time series of the boundary forcing derived for the Steinhatchee model.

2.4.3 FRESHWATER INFLOW

The time series of freshwater inflow used in the hydrodynamic model was derived from the flow measured at SRWMD Station 02324170 (Figure 2-2) and the flow measured at the USGS station (02324000). As discussed previously, at Station 02324170, an ADCP and a water level sensor were deployed for the period of the model calibration (October 1, 2015 through May 12, 2016). At this site, the continuous measured velocities (6-minute interval across the river section) and continuous measured water levels (6-minute interval) were used to derive a continuous time series of tidally driven flow. The time series of tidal flow were then filtered using a low-band pass filter to remove the tidal components. The filtered flow data were averaged over a daily time step for the period of record and compared to the USGS measured flow at USGS 02324000 (Figure 1-1). The filtered flow compared to the measured flow at USGS 02324000 showed some long-term fluctuations related to offshore mean water level variations that were not filtered out. The long-term fluctuations most likely represent mean water level changes in the Gulf that bring flow into the system which is not related to freshwater inflows. Corrections were applied to the filtered data to remove the long-term fluctuations, and the difference calculation (between the corrected filtered flow and the measured flow at USGS) provided the net flow coming into the system below the USGS gage.

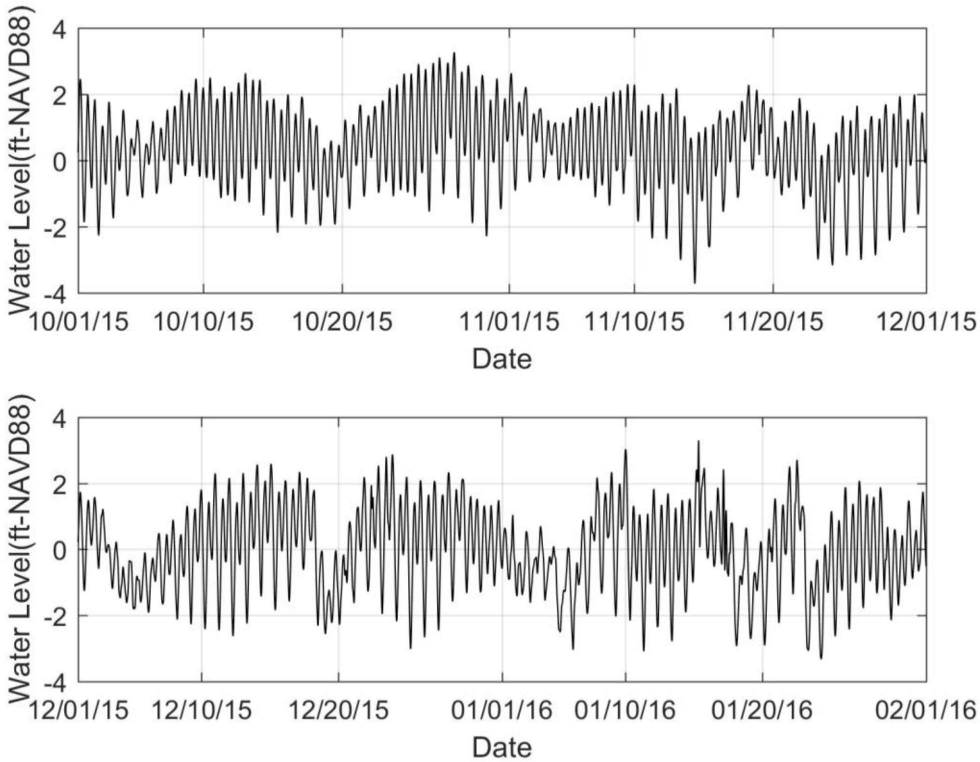

Figure 2-5a. *Offshore water level boundary condition (SRWMD 02324190) (October 1, 2015 to February 1, 2016).*

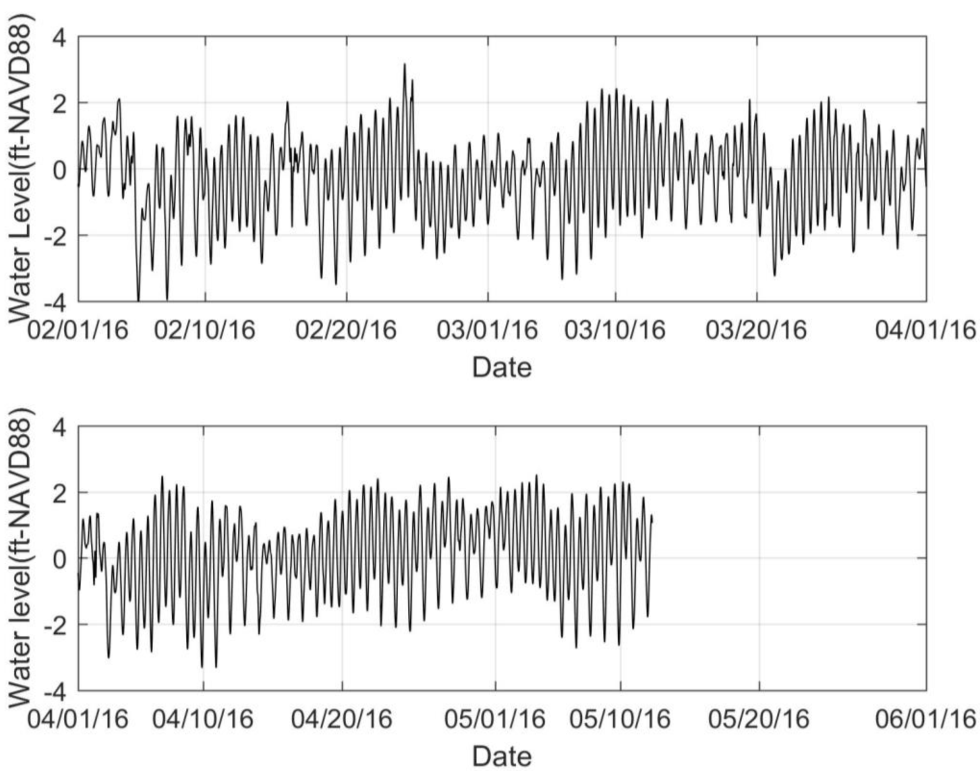

Figure 2-5b. *Offshore water level boundary condition (SRWMD 02324190) (February 1, 2016 to June 1, 2016).*

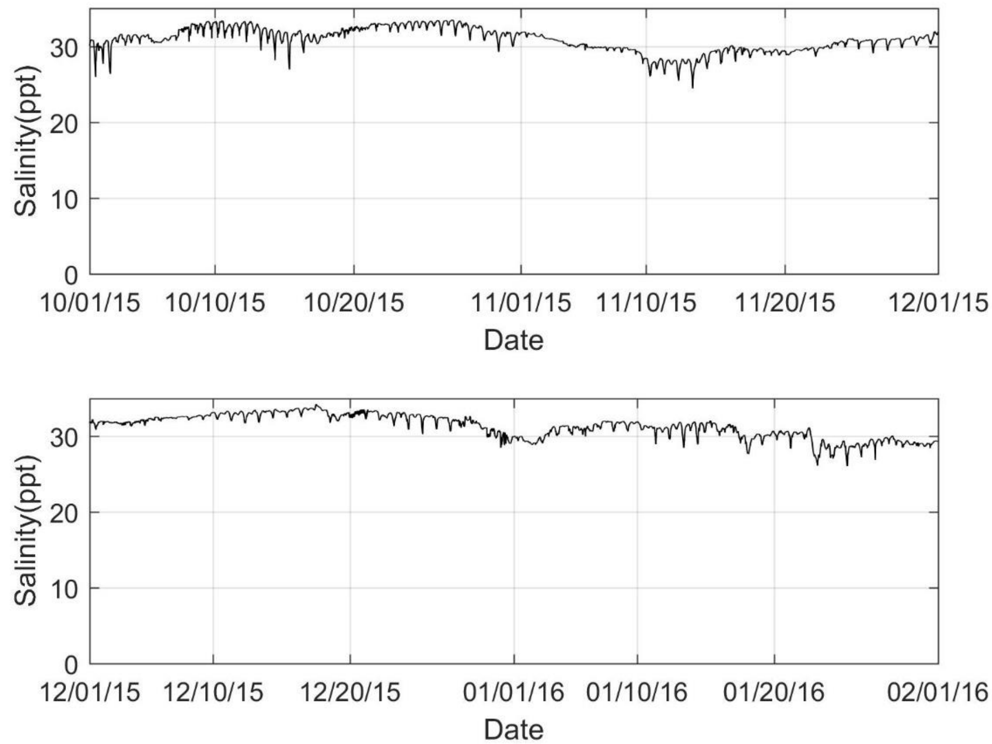

Figure 2-6a. *Offshore salinity boundary condition (SRWMD 02324190) (October 1, 2015 to February 1, 2016).*

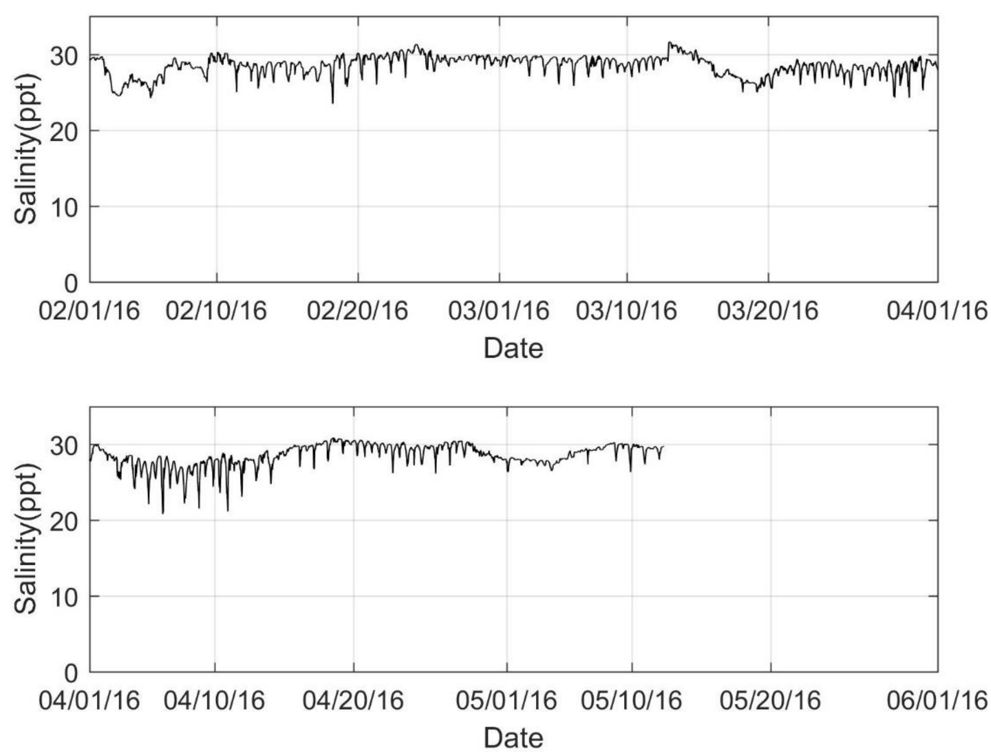

Figure 2-6b. *Offshore salinity boundary condition (SRWMD 02324190) (February 1, 2016 to June 1, 2016).*

Figure 2-7 presents a plot of the USGS flow plotted against the total flow input to the model. Based upon basin delineations, the total freshwater inflow was divided into four inflow points representing the following:

- Flow over Steinhatchee Falls
- Inflow 01 – below falls first tributary
- Inflow 02 – below falls second tributary
- Inflow 03 – below falls third tributary

The flow over Steinhatchee Falls represents the measured USGS flow multiplied by 1.3 to account for the difference in the watershed area above the falls and above the USGS gage. Approximately 30 percent of the watershed area above the falls is not included in the measurements at the USGS gage. The remaining three tributaries represent the remaining flow below Steinhatchee Falls calculated as the difference between the net flow measured at SRWMD 02324170 and the flow over the falls. The three inflows were proportionalized by the basin areas below the Falls. The locations of the inflows are presented on Figure 2-2.

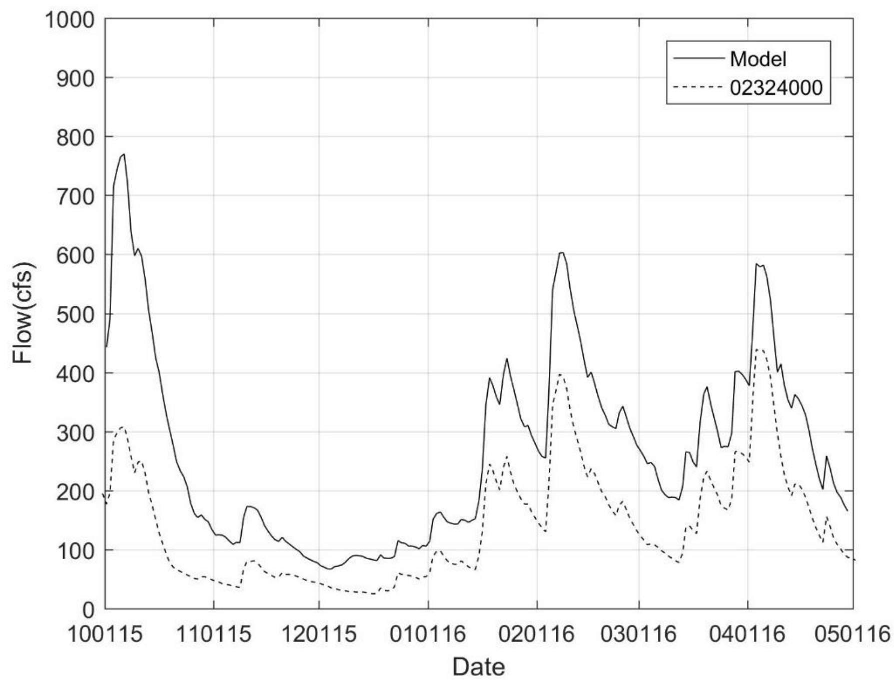

Figure 2-7. Total freshwater inflow to EFDC model versus USGS measured flow at 02324000.

2.4.4 WIND SPEED AND DIRECTION

The meteorological inputs to the model include the wind speed and direction acting on the water surface. The measured winds at the Perry Airport were utilized in the model. Figures 2-8a through 2-8c present plots of the wind inputs, including the wind speed and direction.

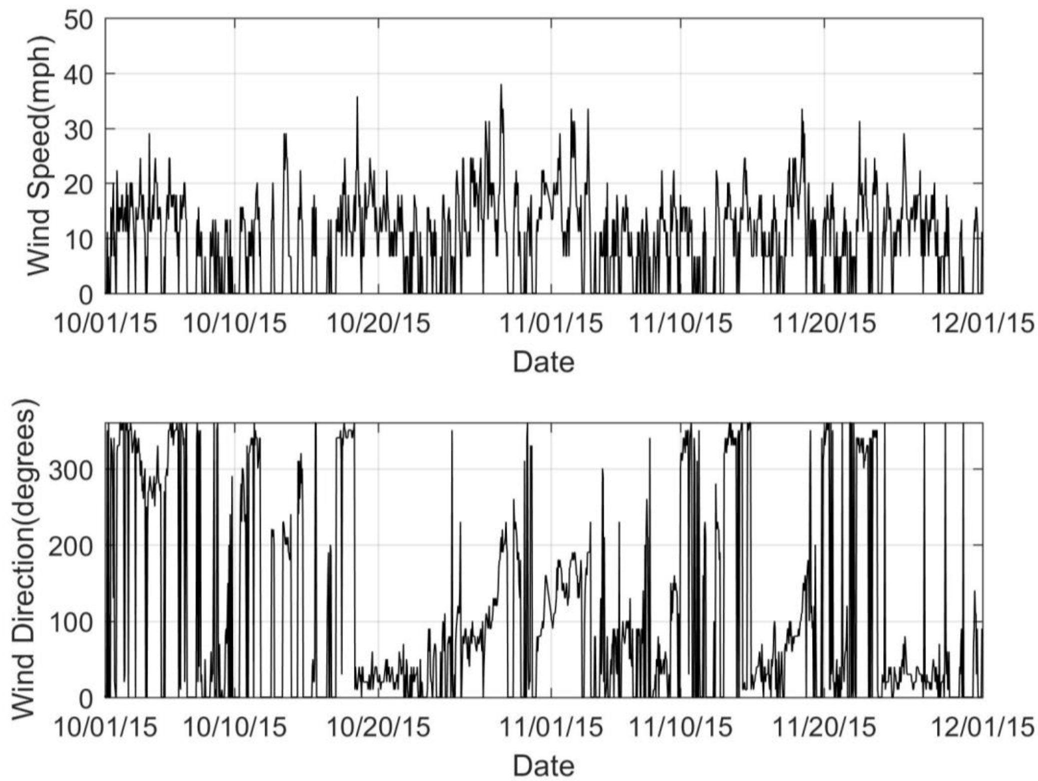

Figure 2-8a. Wind Speed and direction model inputs, November to December 2015.

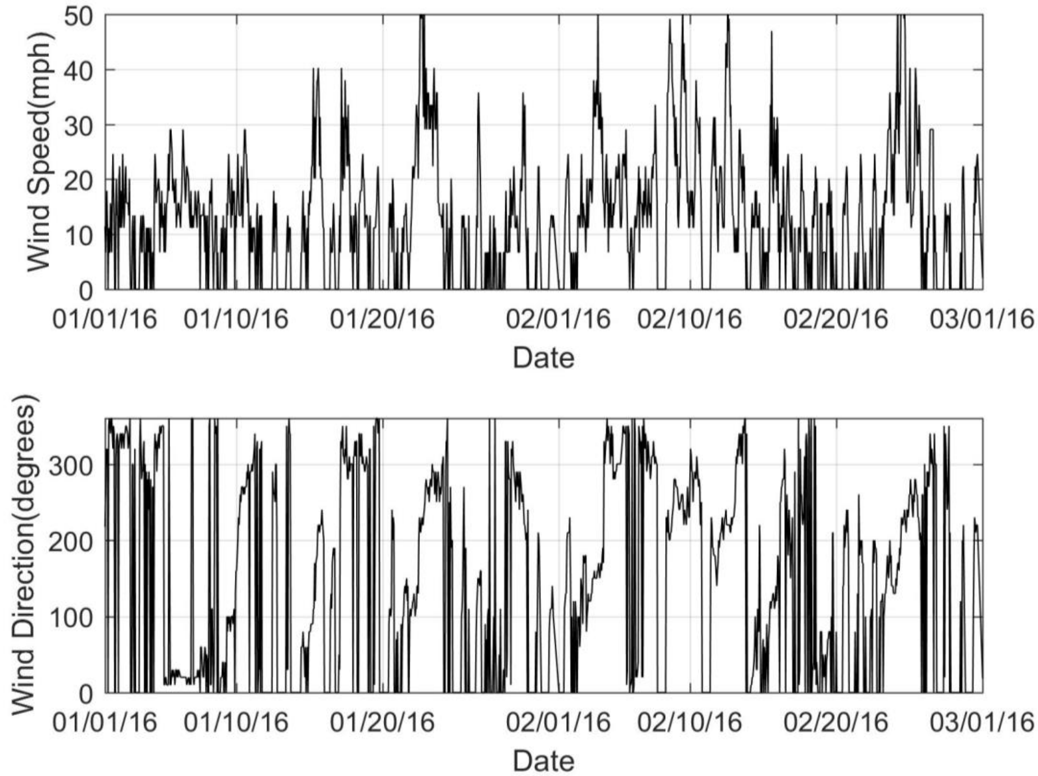

Figure 2-8b. Wind speed and direction model inputs, January to February 2016.

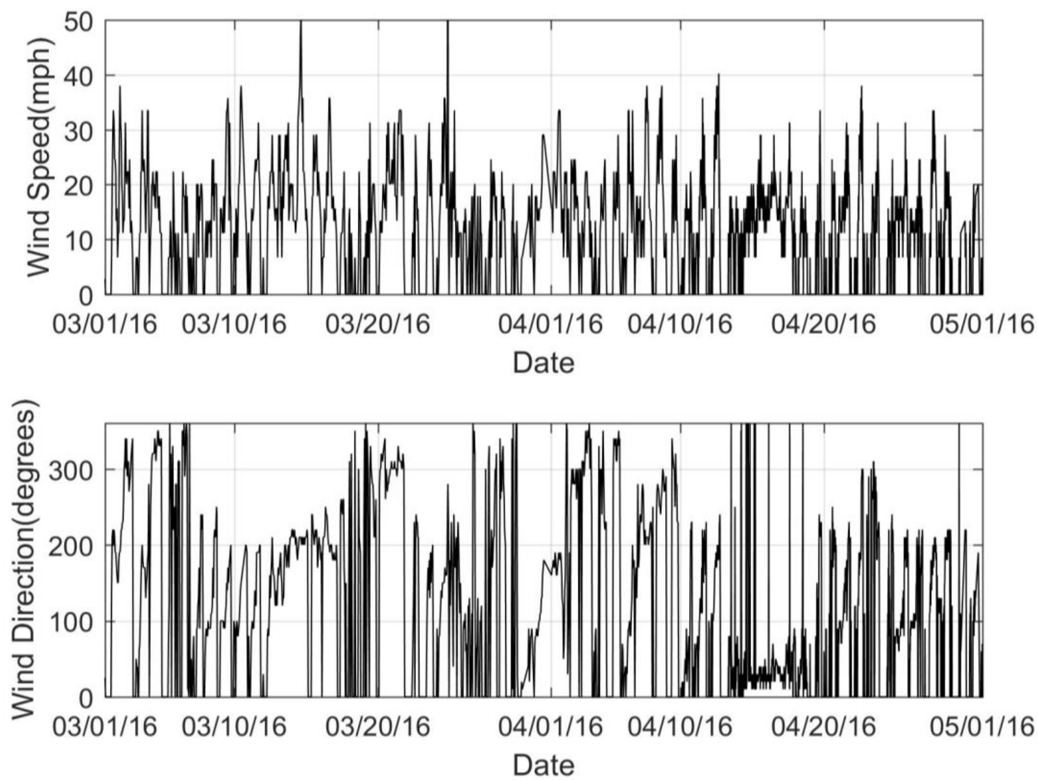

Figure 2-8c. Wind speed and direction model inputs, March to April 2016.

3.0 HYDRODYNAMIC MODEL CALIBRATION

This section provides a detailed description of the calibration of the hydrodynamic model, including the data used in the model calibration, a discussion of the calibration process used for this model, and presentation of the comparison of the model simulations to measured data for the water levels, flow, and salinity.

3.1 DATA USED IN MODEL CALIBRATION AND CALIBRATION STATISTICS

For the purposes of model calibration, the data used included the water levels and salinities at the two interior stations, and the time series of flow at Station 02324170. Figure 2-4 presents the locations of the continuous monitoring stations along the main stem of the river. At the upstream station (SRWMD 02324160), water level and bottom salinity data were collected. At the mid-station (SRWMD 02324170), water level, flow, and bottom, middle, and surface salinity were collected. Data from November 1, 2015 through May 1, 2016 were utilized for the calibration comparisons.

In addition to graphical comparisons of the simulated versus measured results, statistical comparisons were performed, where appropriate. The statistics include the root mean square error (RMS), the mean error (ME), and the coefficient of determination (R^2). The following presents how each of these error statistics are calculated.

- Root Mean Squared Error (RMS):

$$\sqrt{\frac{\sum_{i=1}^{n}(O_i - m_i)^2}{N}}$$

- Mean Error (ME):

$$\frac{\sum_{i=1}^{n}(O_i - m_i)}{N}$$

- Coefficient of determination (R^2):

$$\left(Corrcoef\ (O_i, m_i)\right)^2$$

where: O_i = observation

M_i = model output

N = number of observations

Note: Corrcoef is a MATLAB function for correlation coefficient

The data from the model were extracted to match times of available measured data for the analyses. The statistics were calculated from matched data sets for the period identified.

The RMS represents the deviation of each of the individual measured-versus-simulated matched data pairs and is the most direct measurement of model-to-simulation error or difference between the results. This measure does not have a sign (i.e., negative or positive), so it does not identify if this is an underprediction or overprediction, simply what the overall differences are. The ME represents whether or not there is a bias in the results. For example, if the ME is less than zero, it means that overall, the model is underpredicting in an absolute sense. For both the RMS and the ME, the results are presented as values in the units of measure [feet for water level and cubic feet per second (cfs) for flow] as well as a percent error. The percent error is the value divided by the average range of the data signal being compared. The R^2 is a measure of how the model and data line up or correlate. If the model and data lined up perfectly, the R^2 value would be 1.

3.2 <u>SIMULATED VERSUS MEASURED WATER LEVELS</u>

Figures 3-1a through 3-1f present comparisons of the measured versus simulated water level at the two stations along the main stem of the Steinhatchee River. The comparisons are presented by month from November through April, with October identified as a spin up month.

The comparisons presented within the figures show that the model is doing very well simulating the magnitudes of the water level fluctuations along the main stem of the system. Table 3-1 presents the model statistics for the water level measurements. The results show that the RMS errors are all less than 0.2 foot, which equates to less than or equal to a 4 to 6 percent error. The percent error is based on dividing the RMS value by the average range for the tides on a daily basis over the period of the error analyses. In addition to the RMS errors, the mean errors are low and the R^2 values are very good, both 0.99, indicating very good correlation between the measured data and the simulated results. Recent peer-reviewed work under a SWFWMD project for Tampa Bay identified an allowable error for water level for a good calibration of 0.16 foot for RMS error, ±0.16 foot for mean error, and 0.90 for R^2 (Janicki, 2014). Based on these criteria, the water level simulations for the Steinhatchee model represent a good calibration.

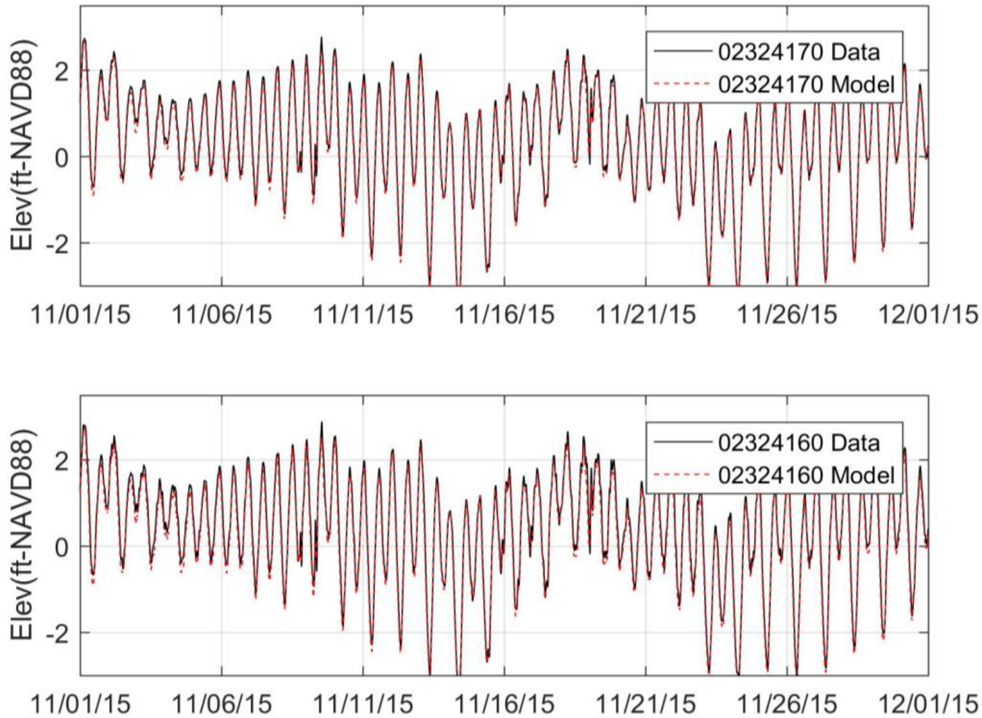

Figure 3-1a. Simulated versus measured water levels at SRWMD Stations 02324170 and 02324160 in November 2015.

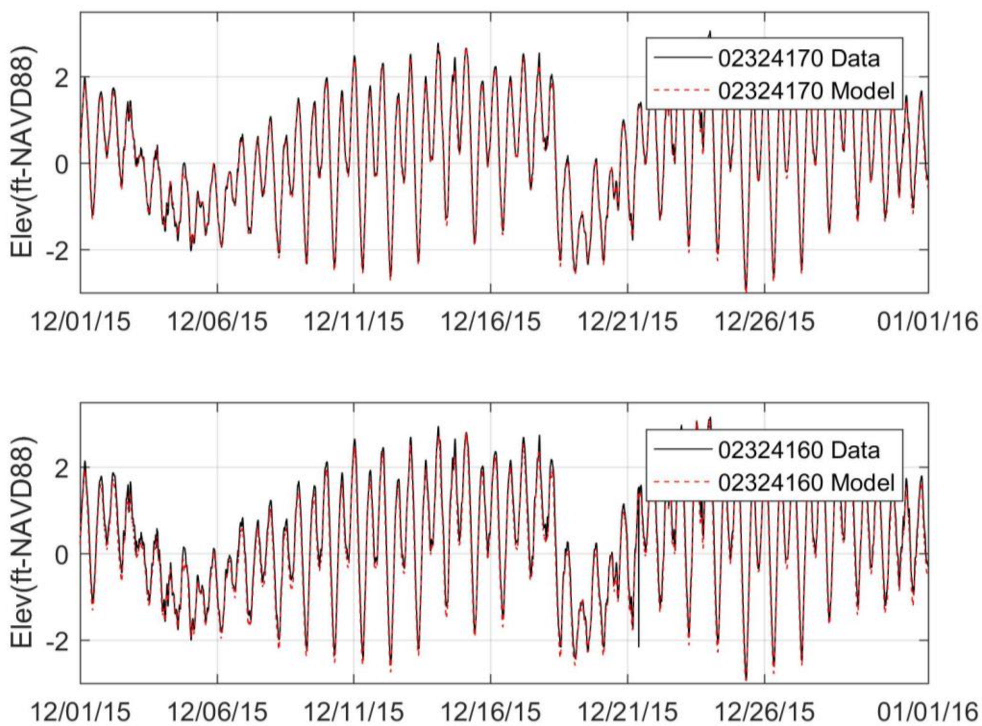

Figure 3-1b. Simulated versus measured water levels at SRWMD Stations 02324170 and 02324160 in December 2015.

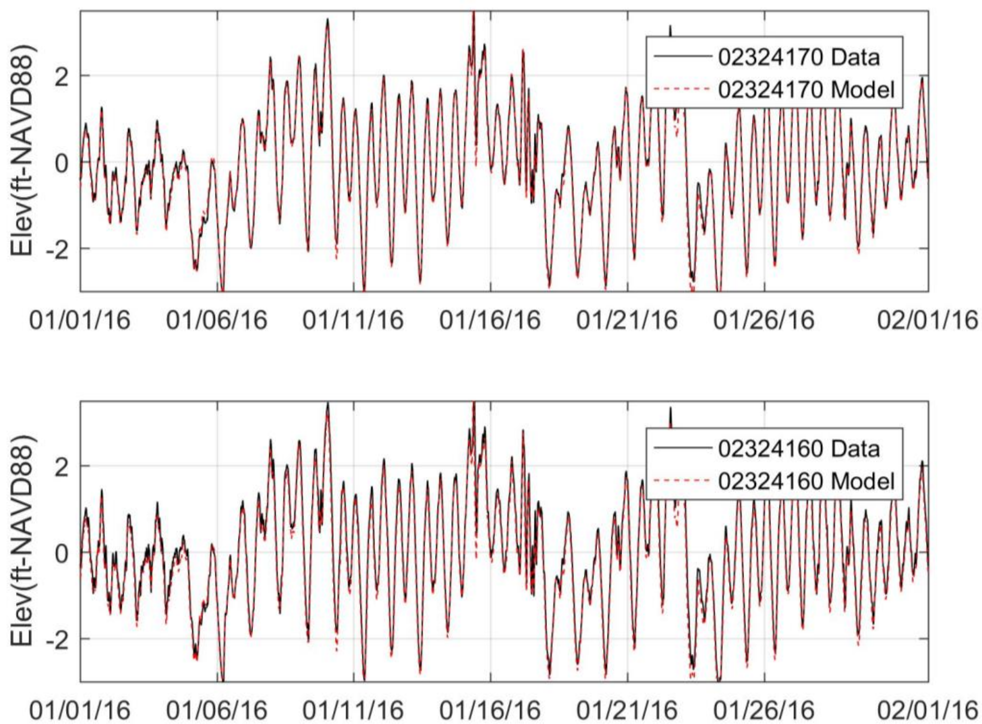

Figure 3-1c. Simulated versus measured water levels at SRWMD Stations 02324170 and 02324160 in January 2016.

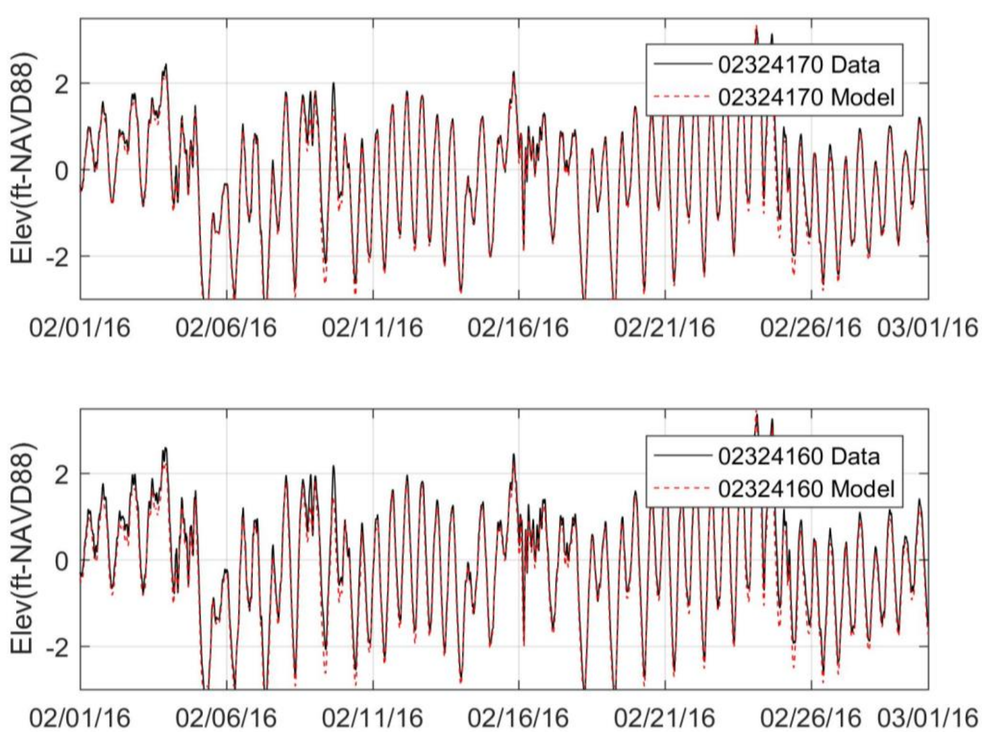

Figure 3-1d. Simulated versus measured water levels at SRWMD Stations 02324170 and 02324160 in February 2016.

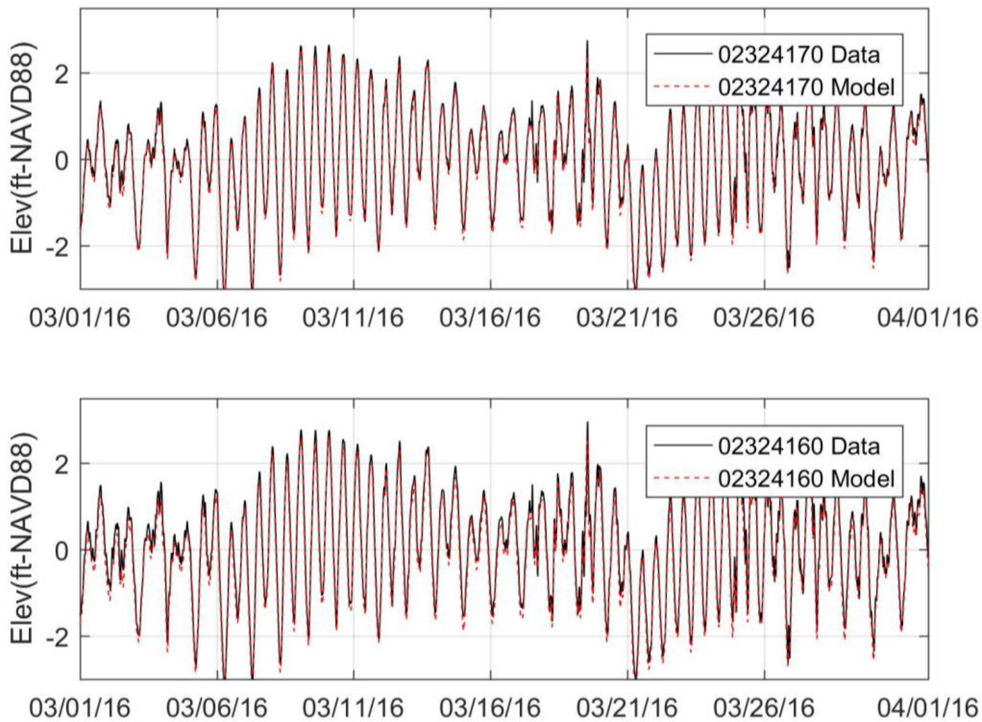

Figure 3-1e. Simulated versus measured water levels at SRWMD Stations 02324170 and 02324160 in March 2016.

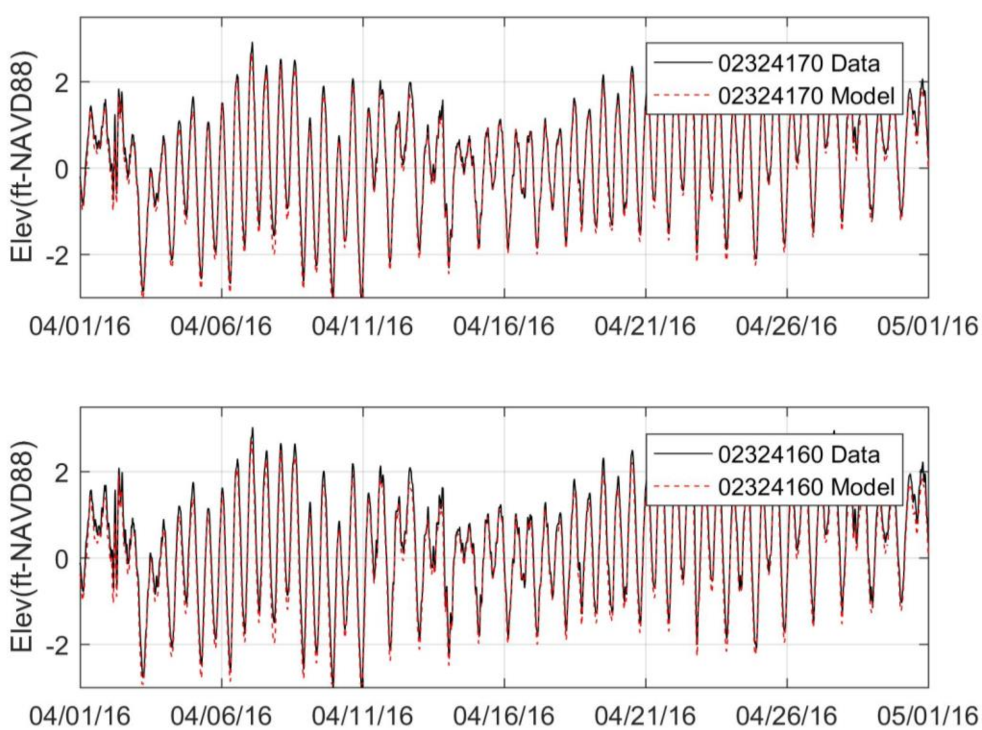

Figure 3-1f. Simulated versus measured water levels at SRWMD Stations 02324170 and 02324160 in April 2016.

Table 3-1. Model calibration statistics for water levels.

Station Number	Station Name	Parameter	Units	RMS Error	RMS %	Mean Error	R^2
02324170	Steinhatchee Middle	Water Level	ft	0.15	4%	-0.10	0.99
02324160	Steinhatchee Upper	Water Level	ft	0.23	6%	-0.18	0.99

As discussed earlier, one aspect of the tidal portion of the Steinhatchee was the existence of shoals upstream of the uppermost station. Figure 1-1 showed the locations of shoals identified during the field data collection. These shoals act as barriers, and generally their elevations are around 0 ft NAVD88 or above. The water levels downstream of the shoals can go as high as 3.0 ft NAVD88 and as low as -3.0 feet looking at the tidal levels plotted in Figures 3-1a through 3-1f. Based on this, the area of the shoals can significantly change in hydrology over the tidal cycle. When tides are higher, they progress up the system above the shoals up as far as Steinhatchee Falls. When tides are lower, the shoals act somewhat like weirs, holding back water upstream and acting like a sloped stream condition. Figure 3-2 provides a photo of one of the shoals during a low tide condition. During high tides, that same area would be fully inundated. In order to quantify the tidal fluctuations in these areas in some manner, temporary water level measurements stations were installed, and readings were taken over a short period of time. The locations of the temporary station (T1 and T2) are shown in Figure 2-4. The shoal conditions were simulated in the model grid, and Figure 3-3 presents plots comparing the short-term measurements against the model simulation. The results show that the inclusion of the shoals in the model reasonably simulated the attenuation of the tidal conditions upstream to Steinhatchee Falls.

Figure 3-2. Photo of shoals during low tide condition

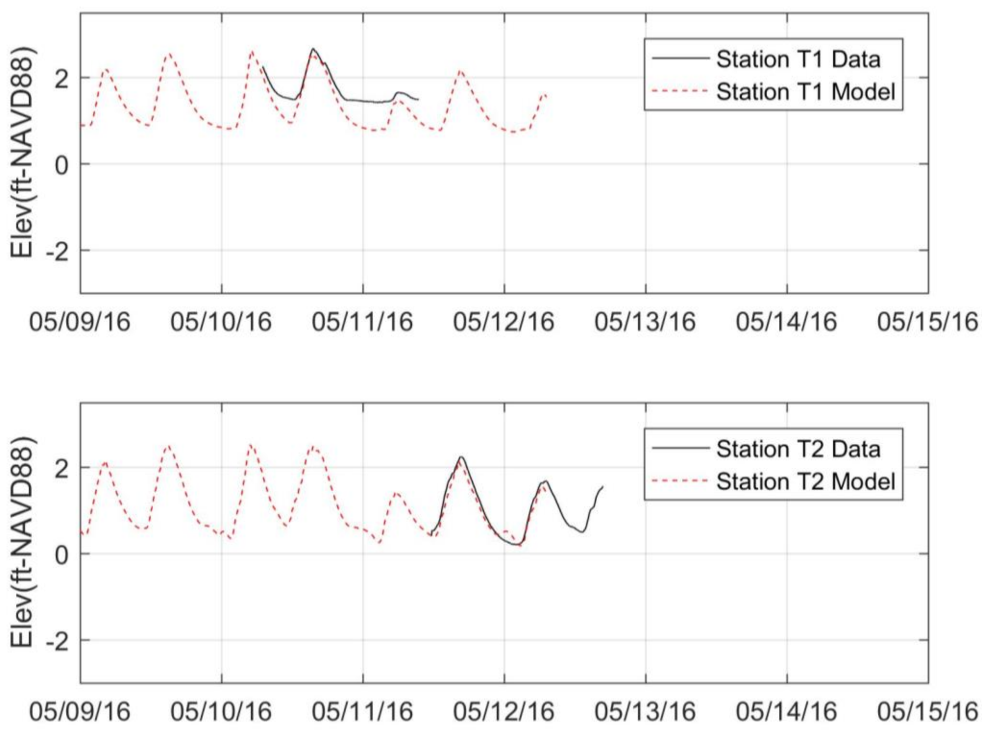

Figure 3-3. Simulated versus measured water levels at Stations T1 and T2

3.3 SIMULATED VERSUS MEASURED FLOW

As discussed earlier, discrete ADCP measurements were utilized in conjunction with cross-sectional velocity measurements to calculate a time series of flow at Station SRWMD 02324170. For the flow comparisons discussed in this section, comparisons are provided with the discrete flow measurements as well as the time series of calculated flows. Statistics for model comparison were performed on the simulated versus calculated flows.

Figures 3-4a and 3-4b present plots of the discrete/direct measured flows against the modeled flows for those time periods. Figures 3-5a through 3-5f present comparisons of the simulated versus calculated flows for the full simulation period. For the calculated flows, during periods of significant stratification, sometimes the relationships developed did not account for the reversing flows and at times overpredicts the magnitude. These spikes can be seen in the data.

These comparisons show that the model is doing well simulating the magnitude, shape and timing of the flow signal. A key aspect of capturing the magnitude, shape and timing of the flow was the inclusion of the upstream storage areas that are fed through the tributaries (Figure 2-2). The storage areas flood and dry based upon the water level conditions, with the total area filled in the storage areas dependent upon the level reached under the high tide conditions. For higher tides (during spring tide conditions or periods with high mean water level in the Gulf), more of the storage areas fill and for a longer time.

Table 3-2 presents the model statistics for the flow measurements. The results show that the RMS error is around 456 cfs, which is reflective of a 11 percent error. As with the water levels, the percent error was calculated using the average daily range of flow for the period of the error analysis. While the literature is sparse relative to tidal flow comparisons, recent peer-reviewed work for SWFWMD identified 20 percent as an acceptable percent RMS error for the simulation of tidal flow (Janicki, 2014). The mean error is very low, 0.1 cfs, and the R^2 value is 0.86, which is a good correlation between the measured and modeled flow.

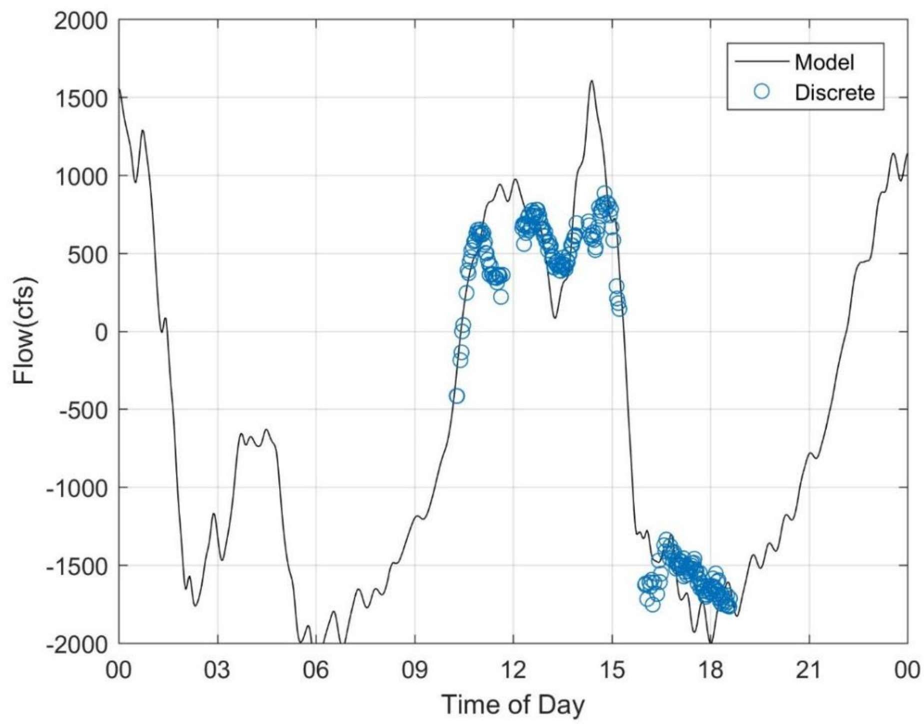

Figure 3-4a. Simulated versus measured flow at SRWMD 02324170 on February 10, 2016

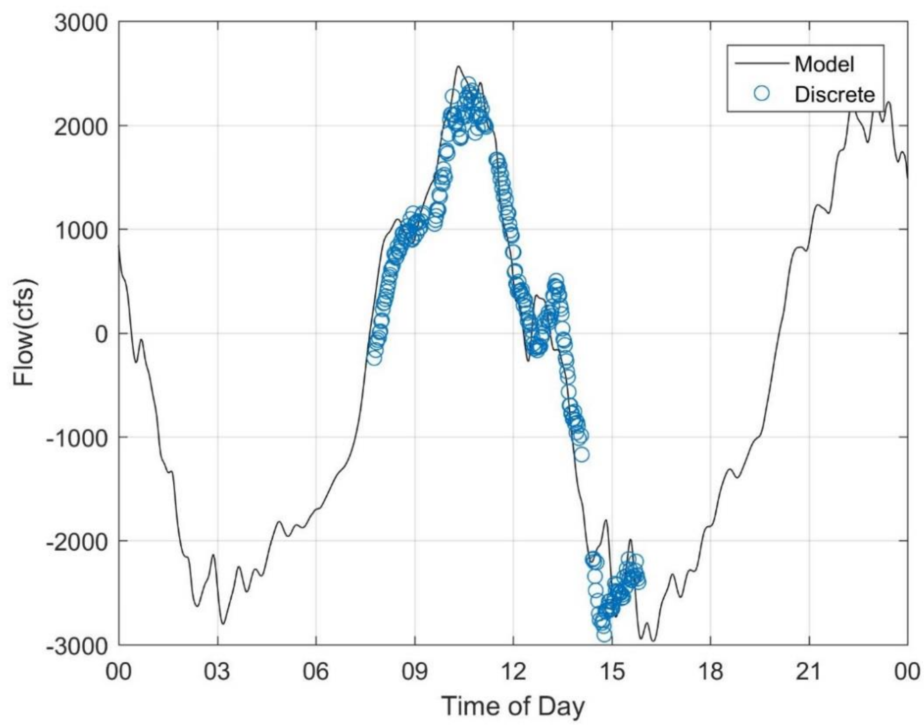

Figure 3-4b. Simulated versus measured flow at SRWMD 02324170 on April 6, 2016.

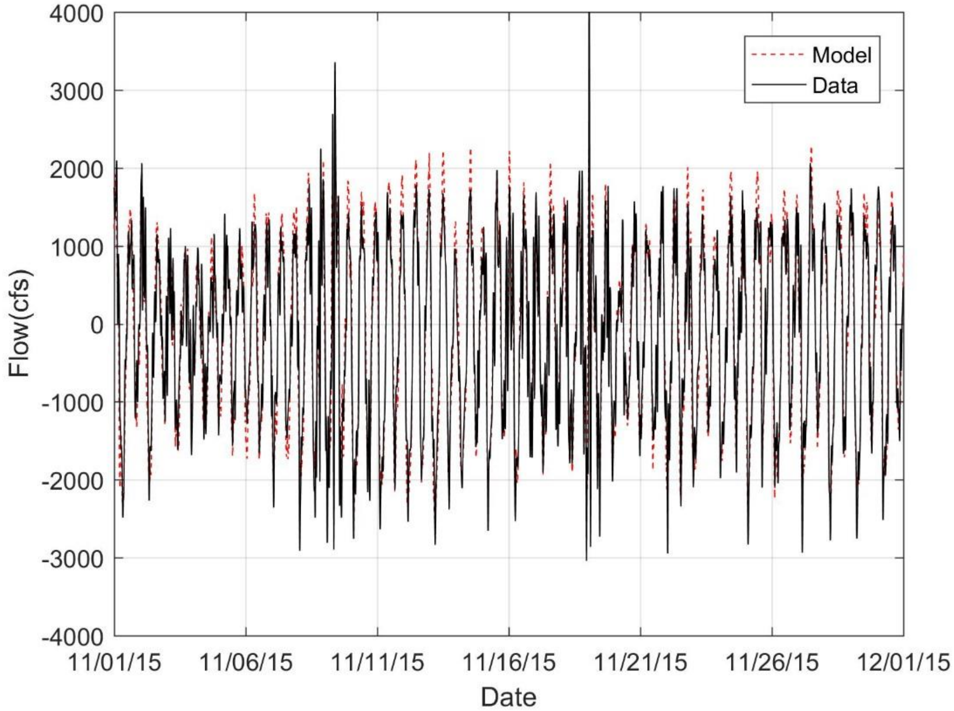

Figure 3-5a. Simulated versus measured flow at SRWMD 02324170 in November 2015.

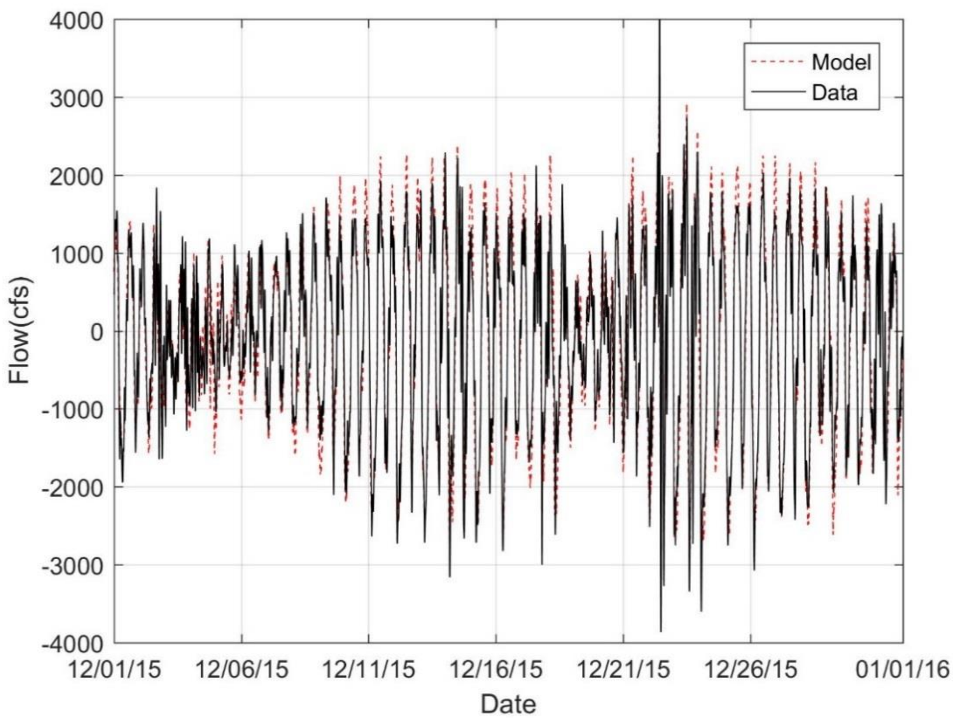

Figure 3-5b. Simulated versus measured flow at SRWMD 02324170 in December 2015.

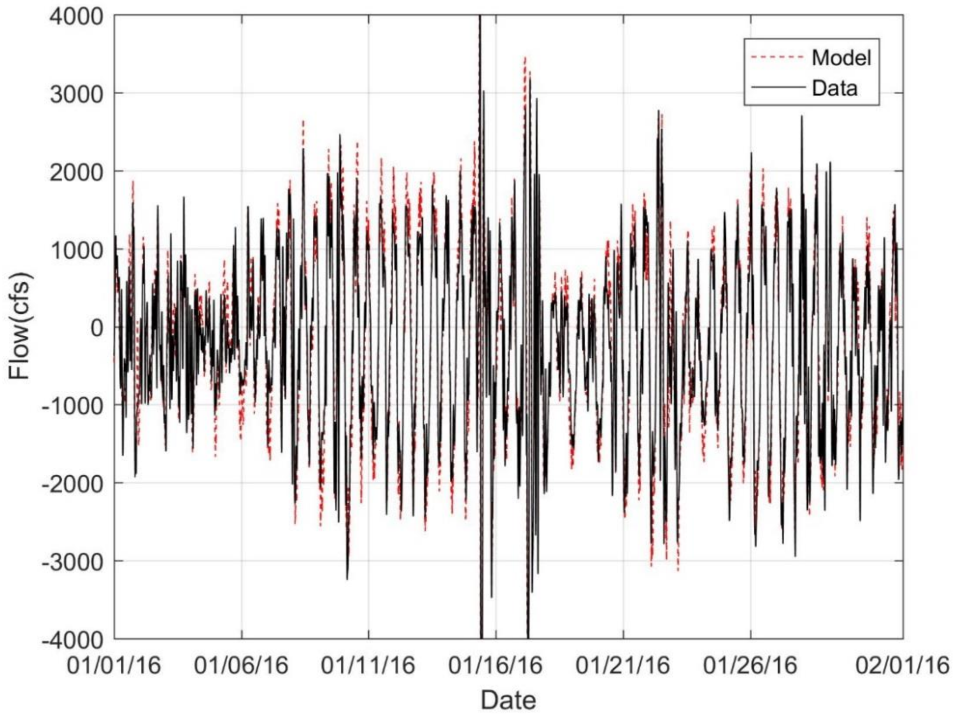

Figure 3-5c. *Simulated versus measured flow at SRWMD 02324170 in January 2016.*

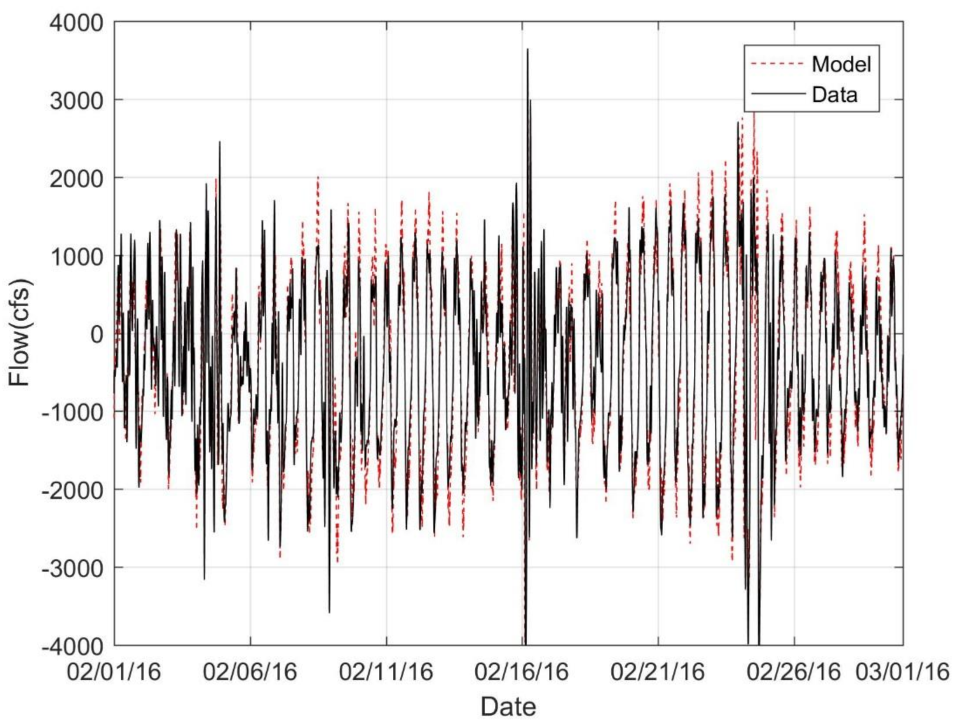

Figure 3-5d. *Simulated versus measured flow at SRWMD 02324170 in February 2016.*

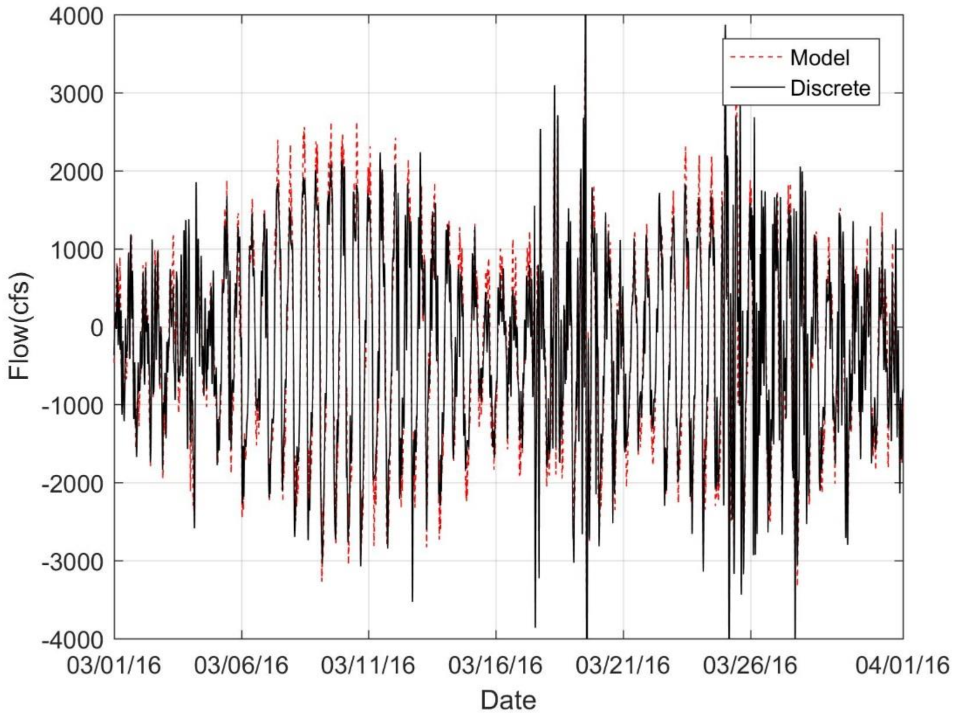

Figure 3-5e. Simulated versus measured flow at SRWMD 02324170 in March 2016.

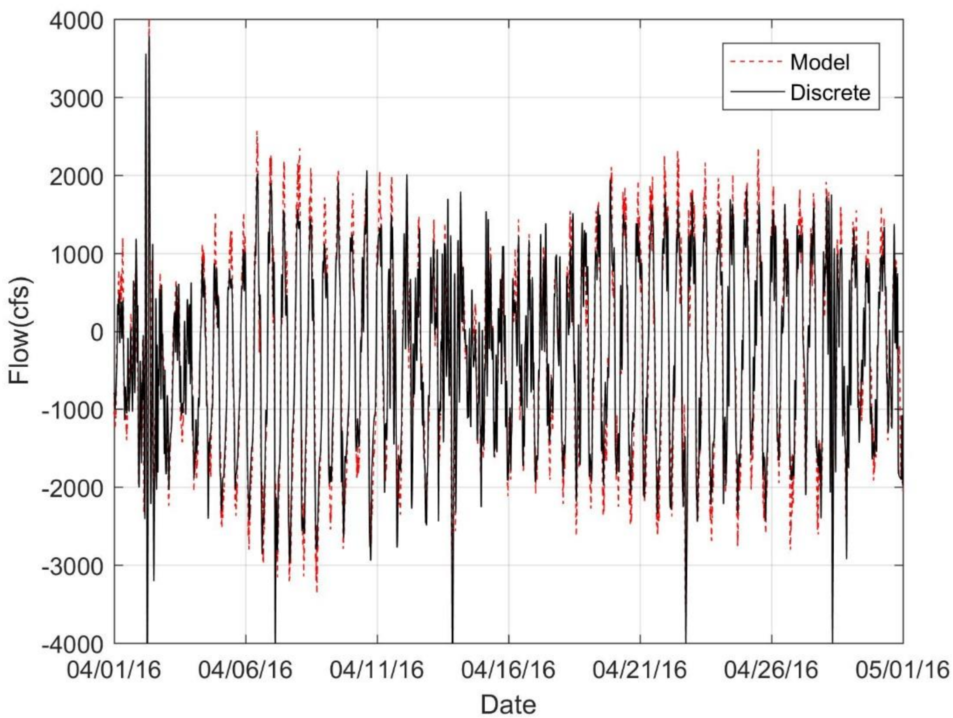

Figure 3-5f. Simulated versus measured flow at SRWMD 02324170 in April 2016.

Table 3-2. Model calibration statistics for flow.

Station Number	Station Name	Parameter	Units	RMS Error	RMS %	Mean Error	R^2
02324170	Steinhatchee Middle	Flow	cfs	456.4	11%	0.1	0.86

3.4 SIMULATED VERSUS MEASURED SALINITY

Figures 3-6a through 3-6f present comparisons of the measured versus simulated salinity at the mid-stream, and upstream stations. For the mid-stream station, the surface, middle and bottom results are compared. For the upstream station the bottom is compared. The salinity conditions in the Steinhatchee are highly variable and are strongly driven by stratification in the system. Looking at the series of plots, the model is doing a reasonable job of simulating the level of salinity intrusion along with the degree of stratification that occurs in the system. One aspect of the system that was clearly visible in the data was how the upstream salinity levels had much more reduced levels of fluctuation and varied generally over the long term, based upon the spring-neap tidal cycle with the intrusion levels, and ultimately, salinity values, highest during the neap tide conditions. The model is able to capture generally both of these characteristics, including the relative insensitivity of the magnitude of the salinity in the bottom in the upstream to flow variations.

Table 3-3 presents the model statistics for the salinity measurements. The results show that the RMS error ranges between 4 and 6 ppt. This is reflective of percent errors from 14 percent to 19 percent. These error ranges, given the dynamic nature of the system, the degree of stratification, and the comparison of time series data from the bottom, middle, and surface locations, are reasonable. The mean errors range from around 0 to -2 ppt, indicating that the model is overall underpredicting the salinity levels. The R^2 values range from 0.5 up to 0.73. As the ultimate goal is to use daily average salinity levels for the MFL analyses, statistical comparisons were also done for the daily average salinities. Table 3-3 presents those ranges. They are overall lower than the straight statistics. RMS errors for the daily average range from 3 to 4 ppt, with percent errors from 9 percent to 15 percent. R^2 values for the daily averages are also higher ranging from 0.64 to 0.86.

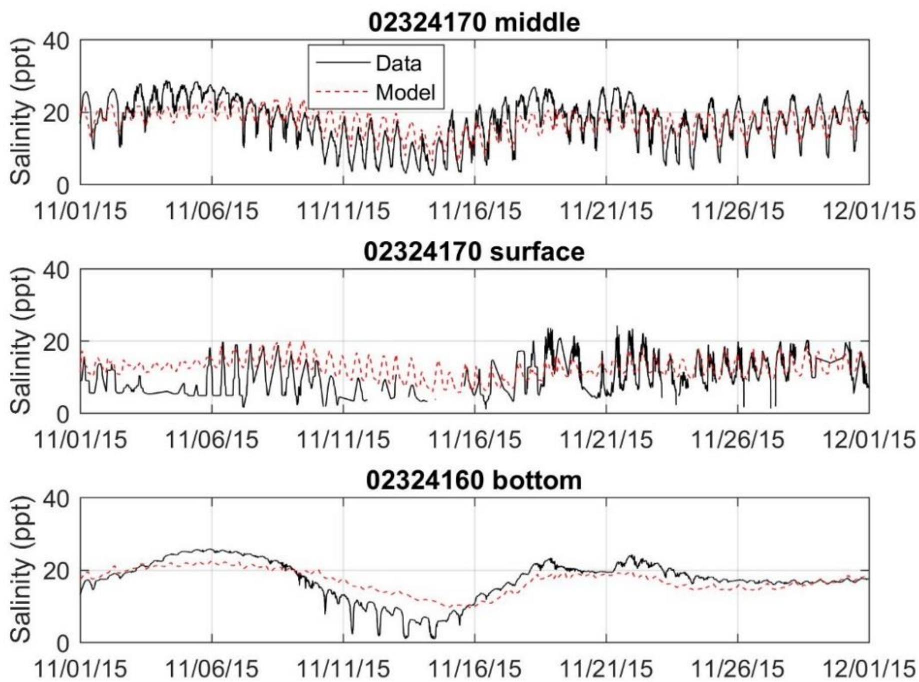

Figure 3-6a. *Simulated versus measured salinity at 02324160 (bottom) and 02324170 (middle and surface) in November 2015.*

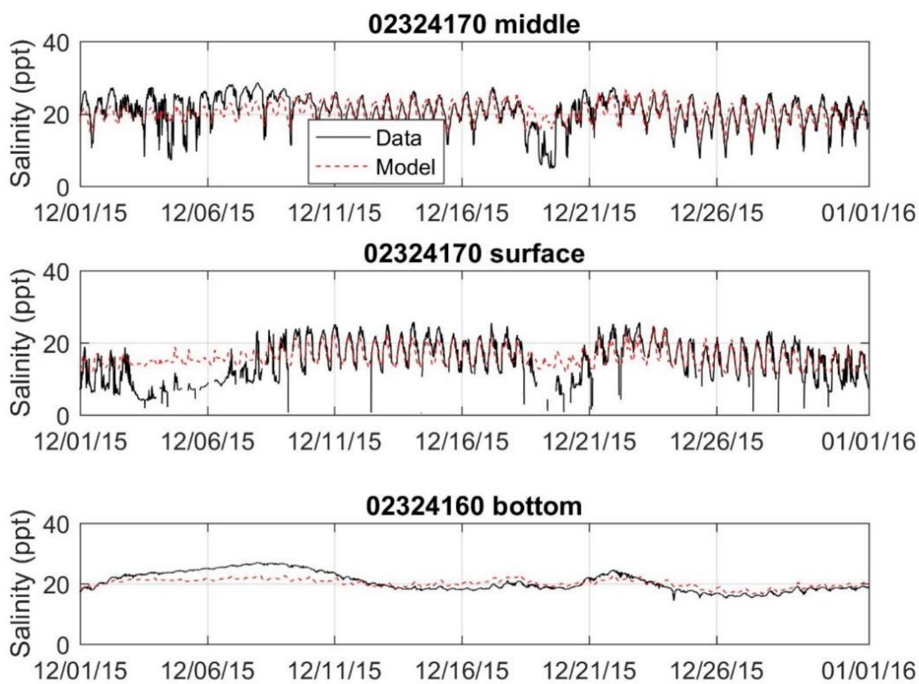

Figure 3-6b. *Simulated versus measured salinity at 02324160 (bottom) and 02324170 (middle and surface) in December 2015.*

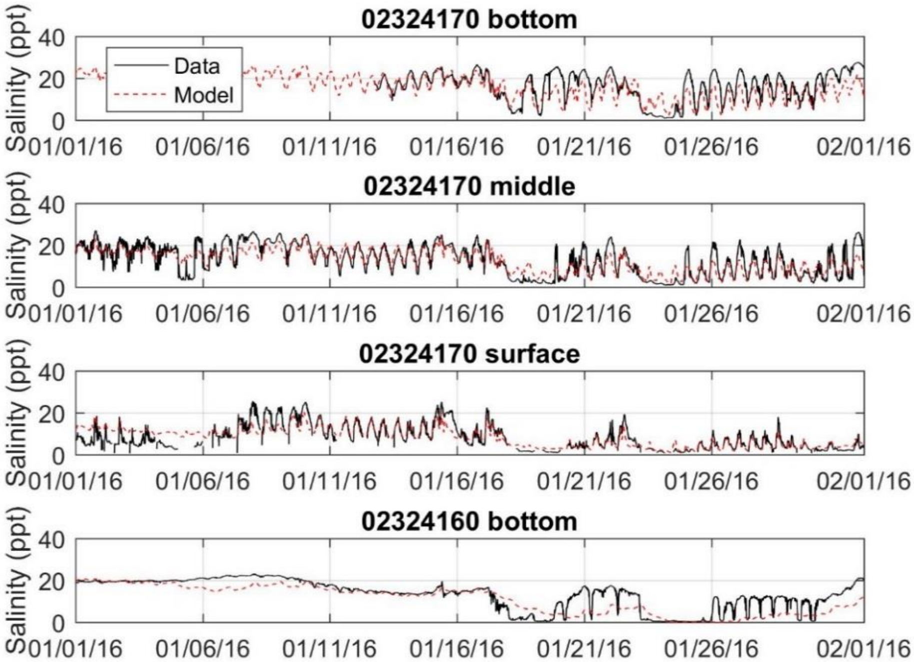

Figure 3-6c. *Simulated versus measured salinity at 02324160 (bottom) and 02324170 (surface, middle and bottom) in January 2016.*

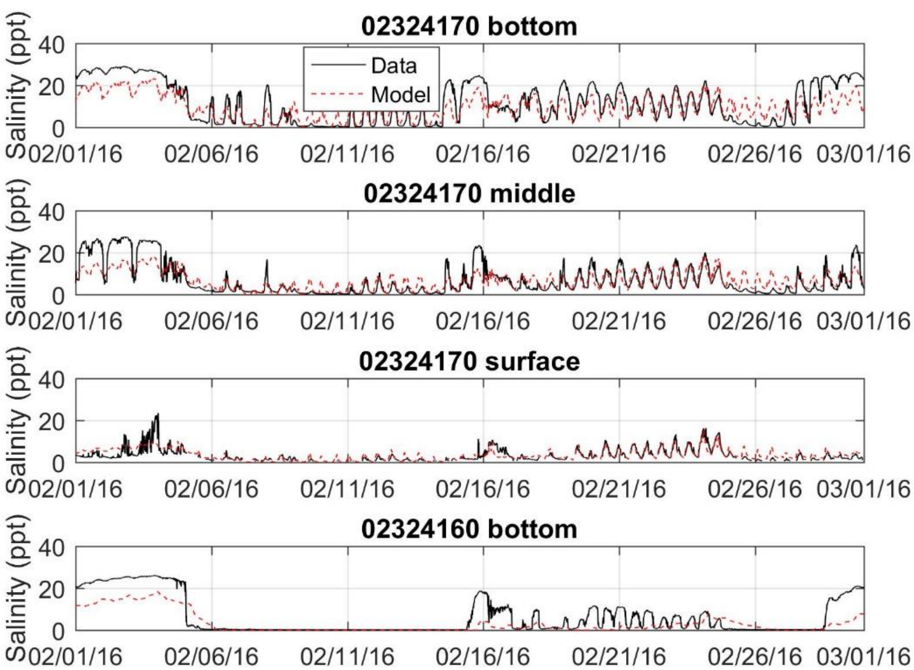

Figure 3-6d. *Simulated versus measured salinity at 02324160 (bottom) and 02324170 (surface, middle and bottom) in February 2016.*

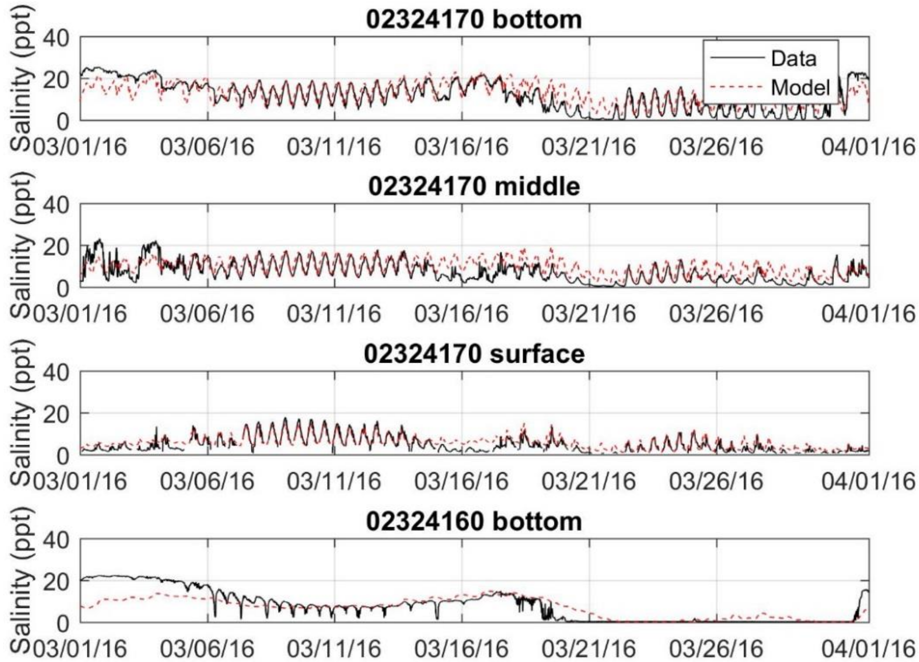

Figure 3-6e. Simulated versus measured salinity at 02324160 (bottom) and 02324170 (surface, middle and bottom) in March 2016.

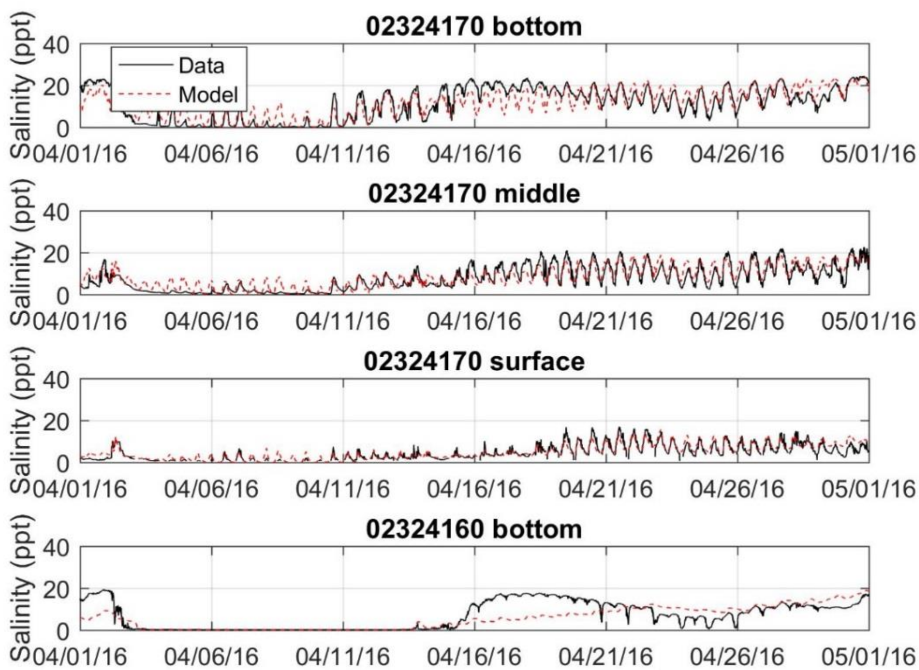

Figure 3-6f. Simulated versus measured salinity at 02324160 (bottom) and 02324170 (surface, middle and bottom) in April 2016.

Table 3-3. Model calibration statistics for salinity.

Station Number	Station Name	Parameter	Units	RMS Error	RMS %	Mean Error	R^2
02324170	Steinhatchee Middle	Bottom Salinity	ppt	5.8	19%	-1.3	0.51
02324170	Steinhatchee Middle	Middle Salinity	ppt	4.3	14%	0.1	0.73
02324170	Steinhatchee Middle	Surface Salinity	ppt	4.6	15%	-2.2	0.64
02324160	Steinhatchee Upper	Bottom Salinity	ppt	4.9	16%	-1.9	0.72
02324170	Steinhatchee Middle	Bottom Daily Average	ppt	4.2	14%	-0.4	0.64
02324170	Steinhatchee Middle	Middle Daily Average	ppt	2.8	9%	0.4	0.86
02324170	Steinhatchee Middle	Surface Daily Average	ppt	3.9	13%	-2.4	0.70
02324160	Steinhatchee Upper	Bottom Daily Average	ppt	4.4	15%	-1.6	0.77

4.0 MFL SCENARIOS

Utilizing the calibrated hydrodynamic model, various scenarios were run to assess the impacts of flow reduction on the salinity conditions in the system. The salinity results from the scenario runs are presented in detail within the MFL document. In this report, the scenario conditions and model inputs are discussed. The specific model scenarios run include the following:

- Baseline condition
- 5 percent flow reduction
- 10 percent flow reduction
- 20 percent flow reduction
- 30 percent flow reduction

For all the scenarios, a 4-year period was defined as representative of the full range of hydrologic (freshwater inflow) conditions seen for the river. The following describes how this period was determined and the derivation of the boundary conditions.

The selection of a baseline period was constrained by the length of the baseline period to be evaluated in a reasonable time (a function of model run time) and the availability of boundary condition data during the selected baseline period. Evaluation of the historical flow record against various shorter periods defined the time-period of the model scenarios. Additionally, it was necessary to choose a time-period when boundary forcing conditions were available from the previously completed GCSM runs for the period 1995-2002.

A comparison of the distribution of the period of record daily flows (WY1951-WY2015) and the distribution of flows during the period for which GCSM output existed indicated that the flow distribution for the period October 1, 1995 to October 1, 1999 (water years 1996 to 1999) was an appropriate match for the period of record distribution. Figure 4-1 provides a graphic comparison of statistics from 1995 to present and for the set of sequential 4-year (water year) periods between 1995 and 2015. Based on this evaluation, the 4-year period was selected as October 1, 1995 - September 30, 1999 (indicated on the horizontal axis by 1996). Figure 4-2 provides a graphical display of the distributions of flows for the October 1, 1995 – September 30, 1999 period and flows for the complete period-of-record. Table 4-1 provides comparison of the flow distribution statistics for the period-of-record to those for the 4-year period (October 1, 1995 - September 30, 1999).

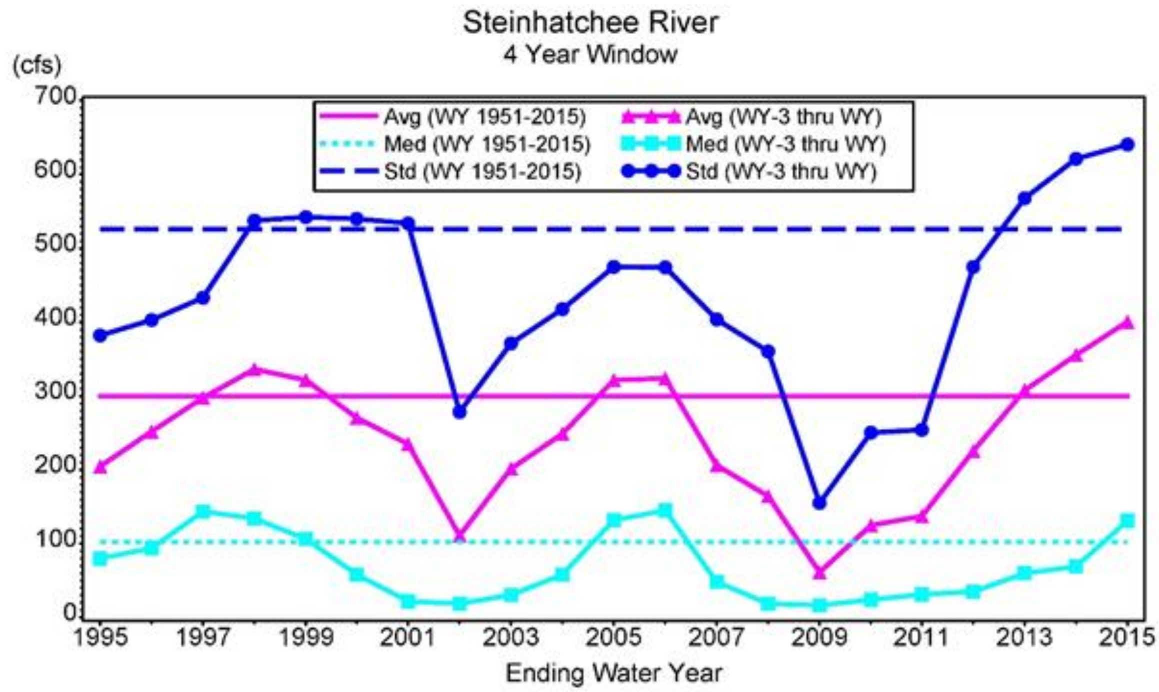

Figure 4-1. *Comparison of flow statistics (average, median, and standard deviation) for the period-of-record and potential four-year periods between 1995 and 2015.*

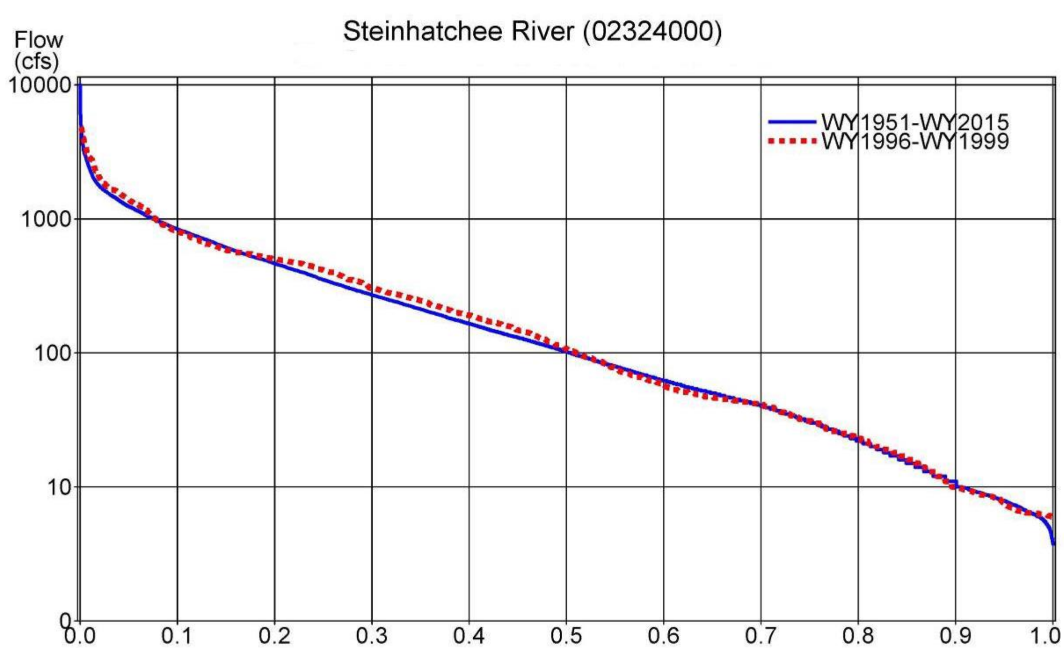

Figure 4-2. *Comparison of flow distributions for period-of-record (WY1951-2015) and the selected four-year baseline period (October 1, 1995 - September 30, 1999).*

Table 4-1. Comparison of flow distribution statistics for the period-of-record (1995-2015) and four-year baseline period (October 1, 1995 - September 30, 1999).

Flow percentile	Period-of-record Flow (cfs)	4-Year Period Flow (cfs)
5^{th}	6.2	5.3
25^{th}	31.0	31.0
50^{th} (median)	102.0	106.0
75^{th}	350.0	414.0
95^{th}	1,240.0	1,380.0
Mean	526.0	542.6

Baseline freshwater inflows to the model domain were developed based on the relationship between the measured net flow within the tidal river, collected from September 2015 through May 2016, and the flow at the USGS gage 02324000, upstream of the model domain, during the same dates (refer to Section 3). The flows into the model were parsed into the same four inflow points used in the model calibration.

For the flow reduction scenarios, the time series of flow at Steinhatchee Falls, used in the baseline run, was reduced by the amounts listed above and the model simulations were run using the identical water levels, offshore salinity, and wind conditions for the 4-year period. The flows used in the 4-year run below the Falls were not reduced under the flow reduction scenarios since the MFL is set for the USGS gage upstream of the falls.

5.0 SUMMARY AND CONCLUSIONS

This report provided a summary of the development, calibration, and application of a hydrodynamic model developed for the tidal portion of the Steinhatchee River. This included the following:

- Development of the model grid and bathymetry
- Development of the model input conditions
- Model calibration
- Graphical and statistical comparison of the simulations versus data
- Summary of the model inputs used for the MFL scenarios

The model extended offshore into the Gulf of Mexico and up the main stem of the Steinhatchee River to Steinhatchee Falls, including adjacent tributaries and tidal flats (storage areas).

The EFDC model was used to simulate the hydrodynamics, including the water levels, currents, flow, and salinity. The model simulations for the calibration extended from October 2015 to April 2016.

The model had one open boundary condition approximately 2.5 miles offshore of the mouth of the Steinhatchee River. The offshore water level and salinity boundary conditions were based upon measured data at the offshore boundary.

Graphical and/or statistical comparisons of the simulated versus measured water levels were presented for four locations along the system. These included a station located near Steinhatchee, Florida (middle station), at an upstream station, and at two temporary stations in the upstream reaches toward Steinhatchee Falls. The results showed good agreement both graphically and statistically to the measured data.

Graphical and statistical comparisons of the simulated versus measured time-dependent flow at the mid-station were presented. The results showed good agreement between the measured and simulated flow magnitudes, phasing and characteristics.

Graphical comparisons of the simulated versus measured salinity were presented. This included bottom, middle, and surface data at the mid-station, and bottom data at the upstream station. The comparisons showed that the model captured the characteristics and magnitudes of the salinity intrusion and transport along with the degree of stratification in the system. Based upon the results of the calibration presented to SRWMD staff, the EFDC model was determined appropriate for use in evaluating the relative response of flow reductions on salinity in the system.

6.0 REFERENCES

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