APPENDIX A
Aucilla River - Hydrodynamic Model Results

HYDRODYNAMIC MODEL DEVELOPMENT, CALIBRATION, AND MFL FLOW REDUCTION AND SEA LEVEL RISE SIMULATION FOR THE TIDAL PORTION OF THE AUCILLA RIVER

AUCILLA RIVER, FLORIDA

SUWANNEE RIVER WATER MANAGEMENT DISTRICT
9225 CR 49
LIVE OAK FLORIDA 32060

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ATM
APPLIED TECHNOLOGY & MANAGEMENT

APPLIED TECHNOLOGY AND MANAGEMENT, INC.
2201 NW 40 TERRACE.
GAINESVILLE, FLORIDA 32605
386-256-1477

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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 Aucilla 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 Aucilla. A key element of the analyses is the change in salinity within the estuarine portions of the river under varying flow conditions and potential sea level rise. As such, SRWMD contracted for the development, calibration and application of a hydrodynamic model for the tidal portions of the Aucilla River. The model is used to evaluate the response of isohalines to reductions in freshwater discharge and sea level rise.

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 Aucilla, the model included up to Nutall Rise. Figure 1-1a presents a project location map showing the location of the tidal portions of the Aucilla River. Figure 1-1b presents a similar map but with a broader view to include the location of the most-downstream active flow monitoring station presently maintained by U.S. Geological Survey (USGS 02326500 at Lamont, FL). The overall project for the Aucilla River included the following components:

1. A comprehensive field data collection program within the tidal portions of the Aucilla River
2. Development and calibration of a hydrodynamic model
3. Application of the calibrated hydrodynamic model under varying freshwater inflow and sea level rise

The methodologies and results from the field data collection are presented within a separate report entitled *Hydrodynamic Monitoring of the Tidal Portions of the Aucilla River* [Applied Technology and Management, Inc. (ATM), 2015]. The data presented in the report supported the development and calibration of the hydrodynamic model presented herein.

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 Aucilla River model outlined in this report. The GCSM model provided boundary conditions (water level and salinity) for the Aucilla 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 1-1a.   Project Location of the Aucilla River and the Extent of the Study Area.

Figure 1-1b.   Project Location of the Aucilla River Including USGS Gage 02326500 at Lamont, FL.

2.0   HYDRODYNAMIC MODEL DEVELOPMENT

This section provides a detailed description of the development of the hydrodynamic model for the tidal portions of the Aucilla River. As discussed in Section 1, the model extents include the offshore area (approximately 2 miles out from the mouth, and 1.5 miles in either direction along the coast), the main stem of the Aucilla River up to Nutall Rise, and necessary tidal tributaries and adjacent marsh storage areas connected to the tributaries.

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 http://www.epa.gov/athens/wwqtsc/html/efdc.html. 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. John's River (SJRWMD), Florida Bay [South Florida Water Management District (SFWMD)], tidal Caloosahatchee River (FDEP), Pensacola and Escambia Bay (FDEP), and the tidal Suwannee River (USGS for the 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 Aucilla 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 Aucilla 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 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 Nutall Rise, including all of the main stem and the split in the system around Ward Island and Little Ward Island.

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 Aucilla model for the simulations. The bathymetry came from a detailed survey of the main stem of the river extending upstream to Nutall Rise. All bathymetric conditions were referenced to NAVD88. The bottom elevations for the Aucilla River grid were interpolated using a combination of the digital elevation model (DEM) provided by SRWMD and the bathymetry points collected during the river survey. 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. For the offshore bathymetric conditions in the final model grid, adjustments were made for the model to allow progression of the tidal wave to the mouth and facilitate boundary matching at the mouth. This is discussed in more detail in the model inputs section (Section 2.3).
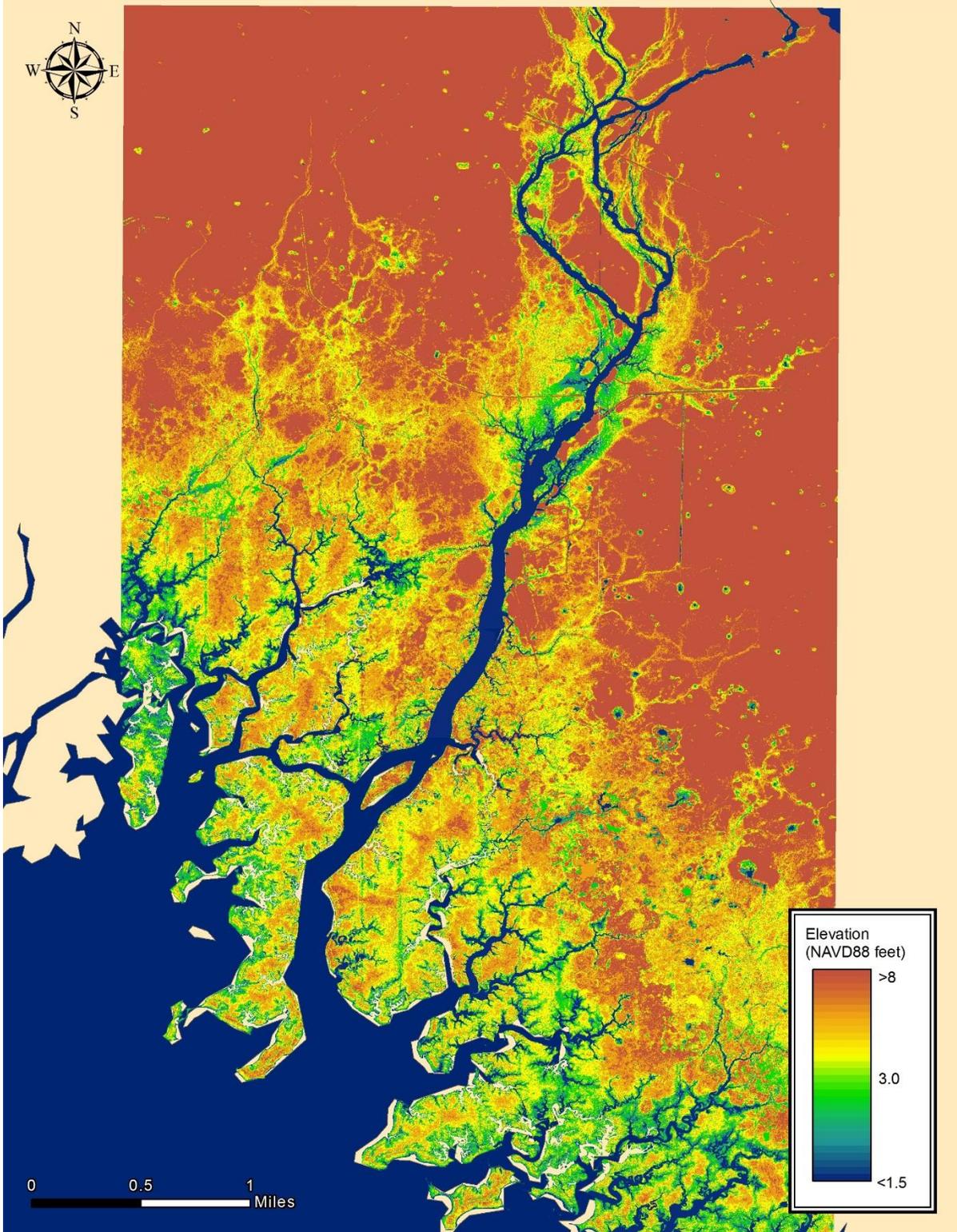
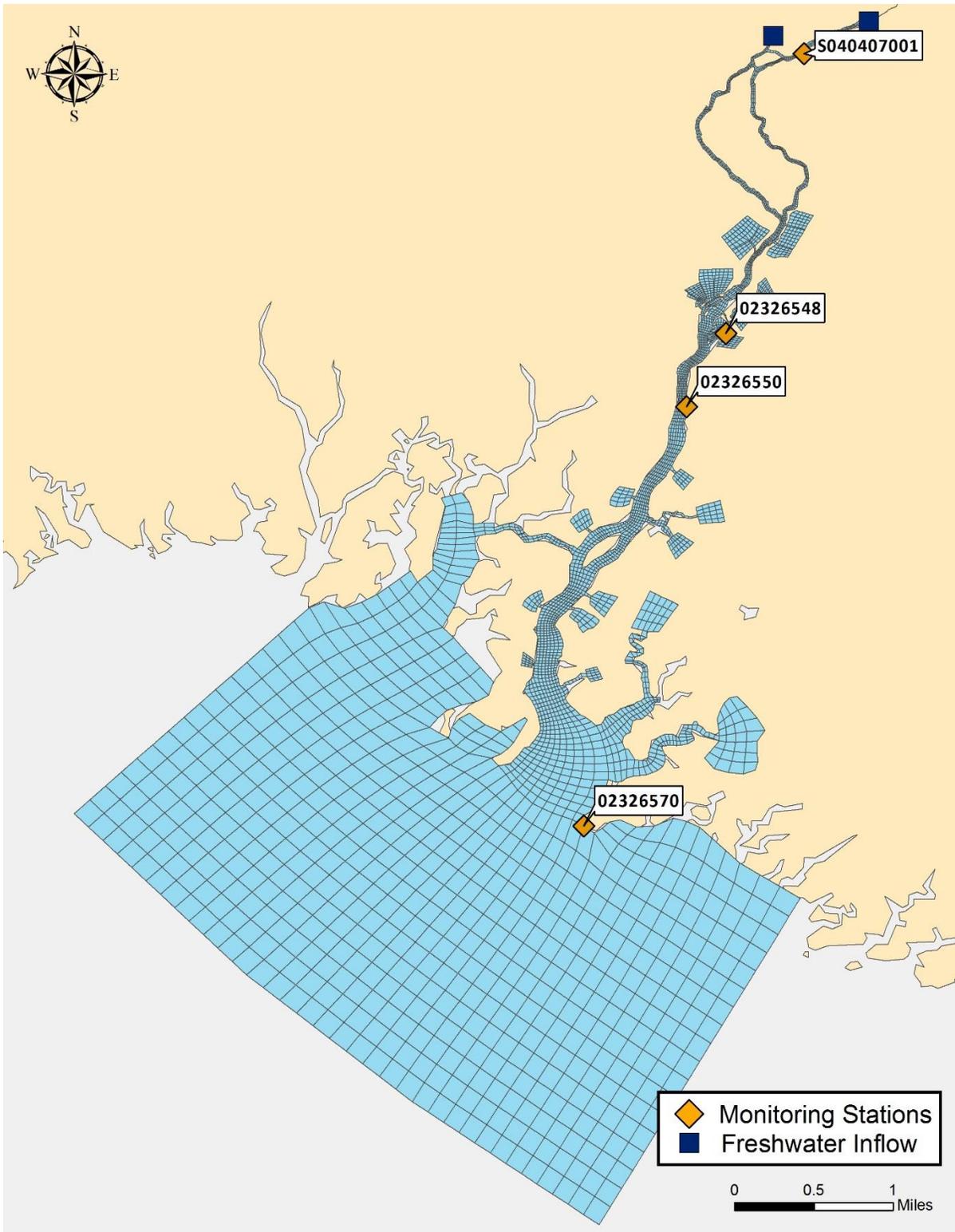*Figure 2-1.   Upland Topographic Conditions from LIDAR Data.*

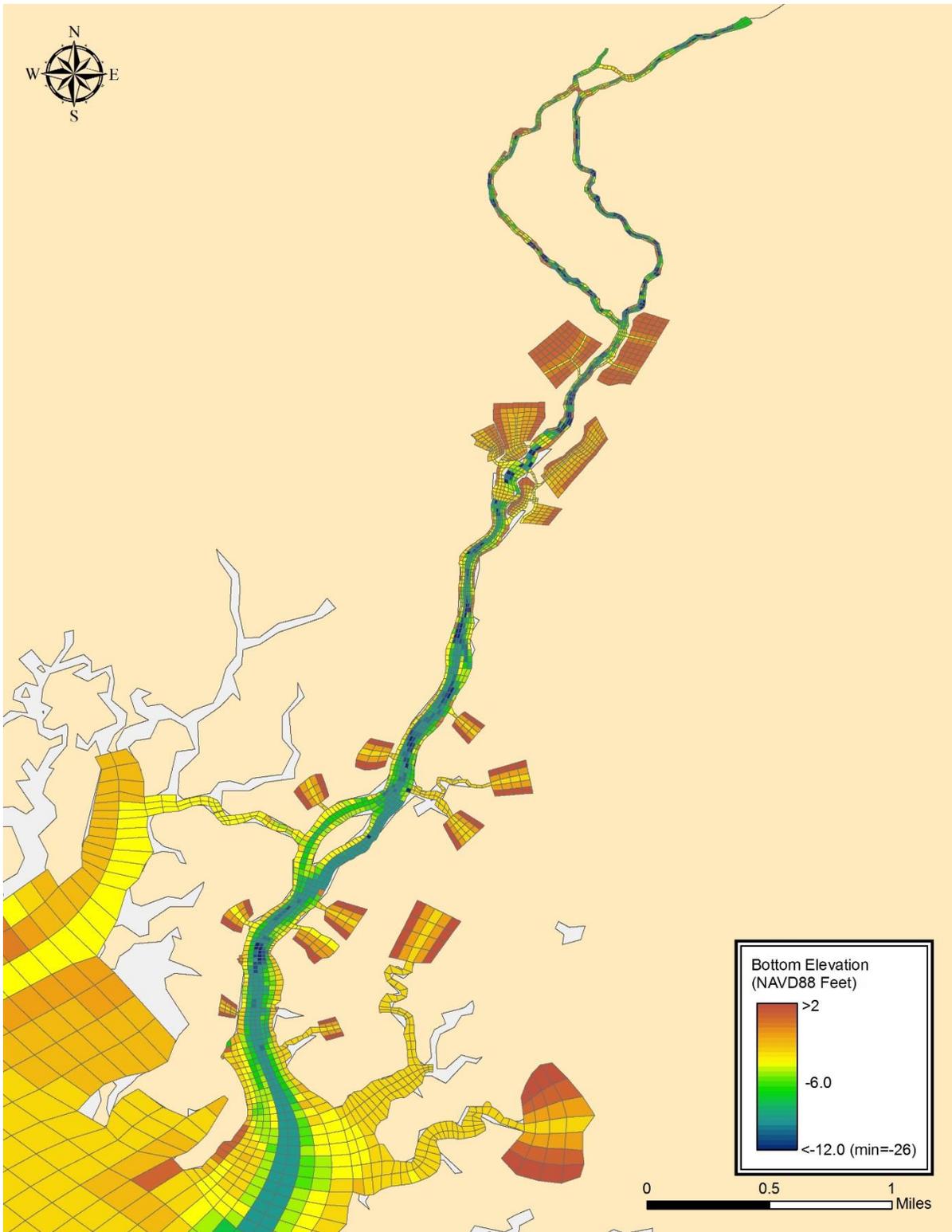*Figure 2-2.   Aucilla River Model Grid.*

Figure 2-3.   Aucilla River Model Grid Bathymetry.

2.3 MODEL BOUNDARY FORCINGS AND SIMULATION PERIOD

A number of model inputs were developed for the Aucilla 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 Aucilla model is from March 1, 2015 through June 1, 2015, with a period of simulation within February to allow the model conditions to reach an equilibrium (spin-up period). The graphs presented reflect the time-period following the model spin-up.

The model inputs were derived from the field data collected from February through June 2015. These data are presented in detail within the data collection report (ATM, 2015). The data included water levels, salinity and flow.

2.3.1 OFFSHORE WATER LEVEL

The water levels used to drive the offshore boundary shown in Figure 2-2 were derived from the measured water levels at the mouth of the Aucilla River (Station SRWMD 02326570 in Figure 2-2). The offshore water levels were derived using a process known as boundary matching. The boundary matching process went as follows:

- First, the measured tides at the mouth (SRMWD 02326570) were utilized directly as measured for the offshore forcing function.
- Second, the simulated and measured water levels at the station at the mouth (SRWMD 02326570) were analyzed for phase and amplitude errors.
- Finally, phase and amplitude adjustments were made to the offshore to minimize, as much as possible, the errors at the mouth.

For the Aucilla model, a phase lag of 10 minutes was applied to the measured tides for use in the offshore boundary. No tidal amplitude adjustments were made to the measured data. Figure 2-4 presents a plot of the offshore tides used for the boundary forcing.
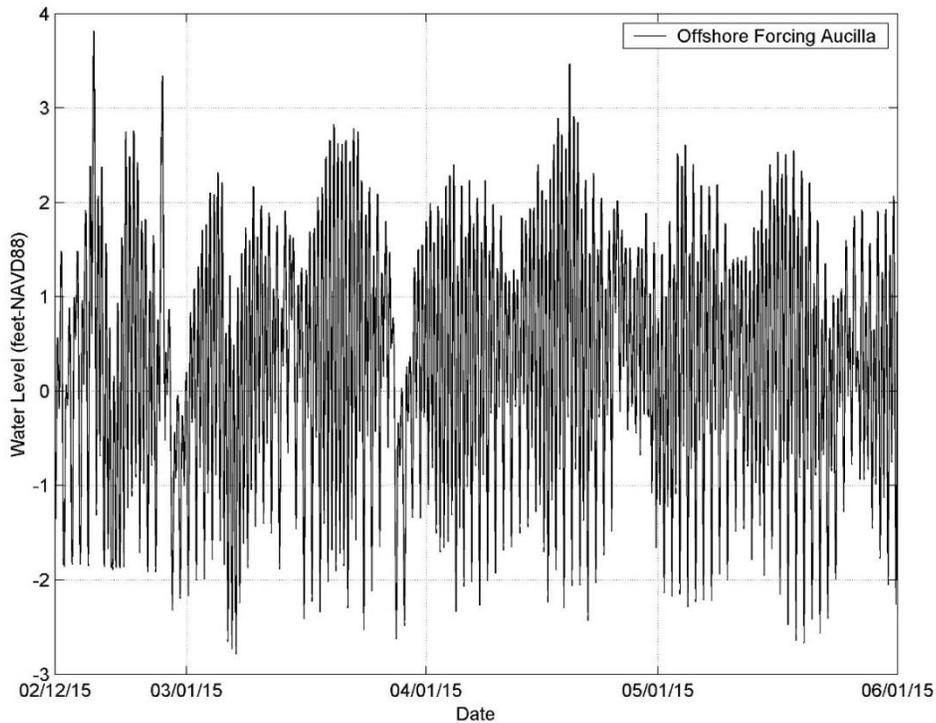
Figure 2-4.   Derived Offshore Water Level Boundary Condition.

2.3.2   OFFSHORE SALINITY

The offshore salinity conditions for the Aucilla model were derived using a similar approach to that used for the tides, with one difference. For the salinity, the daily maximums measured at the mouth were utilized as the base condition to start the boundary matching process. The reason for using the daily maximums measured at the mouth is that in any one day the station at the mouth measures the salinity through the ebb and flood cycle (inflow and outflow). At the end of a flood tide cycle (inflowing) water from offshore has moved from the offshore to the mouth to the maximum extent, therefore, the measurements at the end of the flood cycle (when the salinities are at their highest) would best reflect the conditions offshore. The following describes the boundary matching process used to establish the offshore salinity.

- First, the daily maximum measured salinities at the mouth (SRWMD 02326570) were derived from the data and used as a time series in the offshore.

- Second, the errors in the measured versus simulated salinity at the mouth were evaluated.
- Finally, adjustments were made to the baseline offshore salinity (using the daily maximums) to minimize the salinity error at the mouth (SRWMD 02326570).

Using the daily maximums as the base, the comparisons at the station at the mouth were sufficiently representative so that no manipulation of the offshore conditions was needed to achieve boundary matching. Figure 2-5 presents the time series of the boundary forcing derived for the Aucilla model.

At the offshore boundary, the system was assumed to be well mixed, so that salinity at the surface and bottom are the same. The boundary matching at the mouth supported this assumption. The offshore areas were included in the model to provide an appropriate boundary for the GCSM inputs under the MFL reduction and sea-level rise scenarios, and to provide some level of mixing of the freshwater discharges with the offshore. For the model calibration, due to the use of the boundary matching approach, the important areas for model simulation extend from the mouth upstream to Nutall Rise.
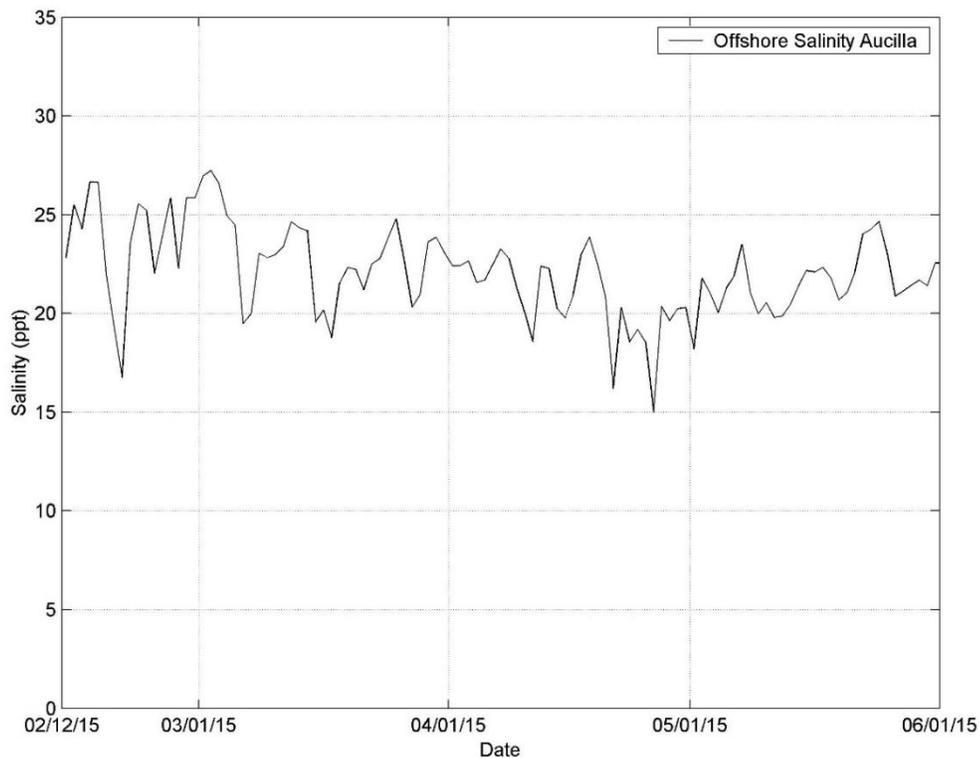

Figure 2-5.   Derived Offshore Salinity Boundary Condition.

2.3.3 FRESHWATER INFLOW

The time series of freshwater inflow used in the hydrodynamic model was derived from the flow measured at SRWMD Station 02326550[1] (Figure 2-2). At this station, an Acoustic Doppler Current Meter and a water level sensor were deployed for the period of the model calibration (February 2015 through May of 2015). 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 details of the deployment, and the analyses performed on these data to calculate the flow are presented in detail in the hydrodynamic data collection report (ATM, 2015). The time series of tidal flow were then filtered using a low-band pass filter to remove the tidal components leaving the net freshwater outflow. The filtered flow data were averaged over a daily time step to provide the flow input to the model. The filtered and averaged flow represents the total freshwater inflow from the watershed above station SRWMD 02326550.

For the Aucilla model, the total freshwater inflow was divided into two inflow points. One of the points is at the upper end of the grid, above Nutall Rise. The second is at a dead-end point near Nutall Rise. For the first point, 75 percent of the flow was entered, while 25 percent was entered into the second. This was based roughly on overall contribution area for the inflow points, but as these two flows ultimately merge together downstream prior to reaching the estuarine portions of the model, the split is not significant. Figure 2-2 shows the locations of the freshwater inflow points. Figure 2-6 presents the daily average total freshwater inflow input to the model.

2.3.4 WIND SPEED AND DIRECTION

The meteorological inputs to the model include the wind speed and direction acting on the water surface. The National Data Buoy Center (NDBC) Keaton Beach site was used for winds. Figure 2-7 presents the wind inputs, including the wind speed and direction.

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[1]The SRWMD Station 02326550 was previously a USGS station with the same number. Historically, this station monitored flow, but currently only gage height is measured.
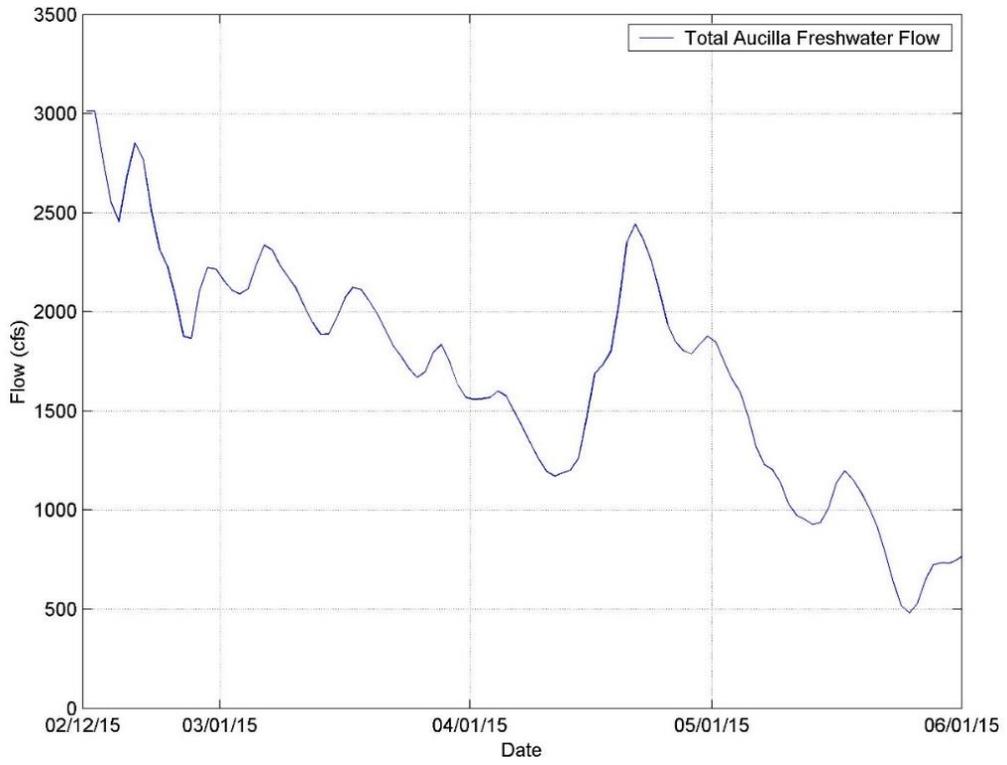
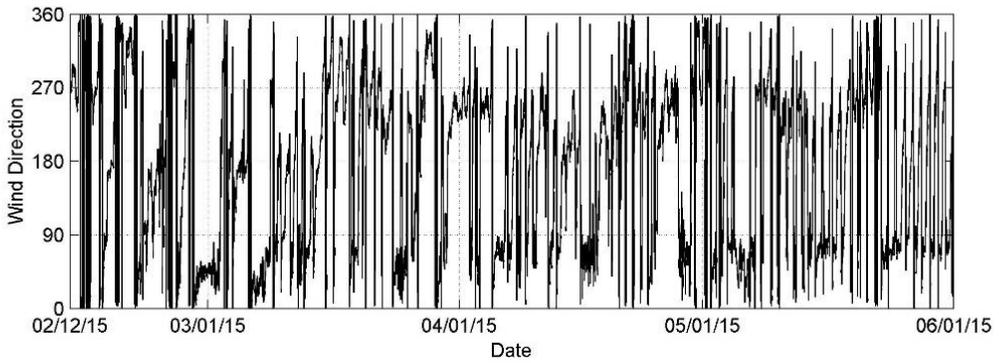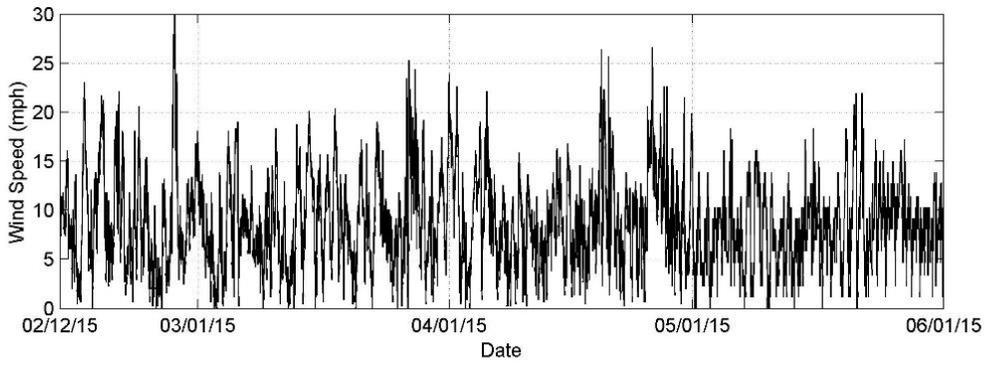*Figure 2-6.   Total Freshwater Inflow.*

Figure 2-7.   Wind Speed and Direction Model Inputs.

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

A companion hydrodynamic monitoring report (ATM, 2015) provides a detailed discussion of the data collected for this project. For the purposes of model calibration, the data used included the water levels at all three stations, the measured salinity at all three stations, and the time series of flow. Figure 3-1 presents the locations of the continuous monitoring stations along the main stem of the river. At the downstream station (SRWMD 02326570) and upstream station (SRWMD 02326548), water level and bottom salinity data were collected. At the mid-station (SRWMD 02326550), water level, flow, and bottom and surface salinity were collected. Data from March 1, 2015 through June 1, 2015 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 then calculated from the 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 under-prediction or over-prediction, 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 under-predicting 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 coefficient of determination (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.
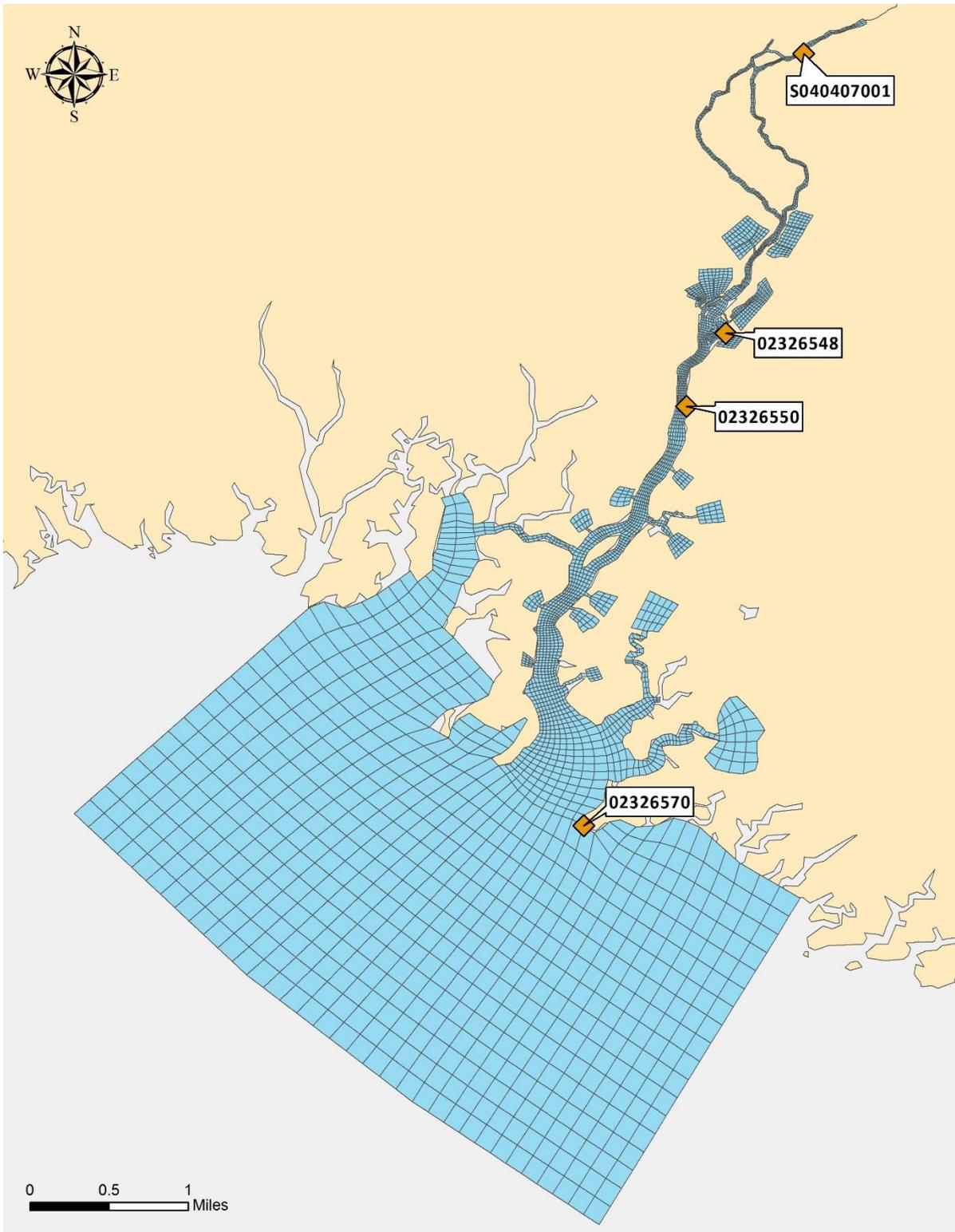
Figure 3-1.   Locations of Continuous Monitoring Stations.

3.2   SIMULATED VERSUS MEASURED WATER LEVELS

Figures 3-2a through 3-2c present comparisons of the measured versus simulated water level at the three stations along the main stem of the Aucilla. The comparisons are presented by month from March through May. In addition to the three stations along the main stem, data were available from a groundwater monitoring station along the edge of the river near Nutall Rise (S040407001). The station location is show in Figure 3-1. It is important to note that the degree of damping of the tidal signal within the groundwater monitoring well in comparison to the actual water level fluctuations in the river is unknown, therefore, the model-to-data comparisons should be evaluated with this in mind.

The comparisons presented within the figures show that the model is doing very well simulating the magnitudes of the water level fluctuations and, specifically, the distribution of the damping of the tidal wave as it moves upstream. 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 5 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, all above 0.96, 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 Aucilla model represent a good calibration.
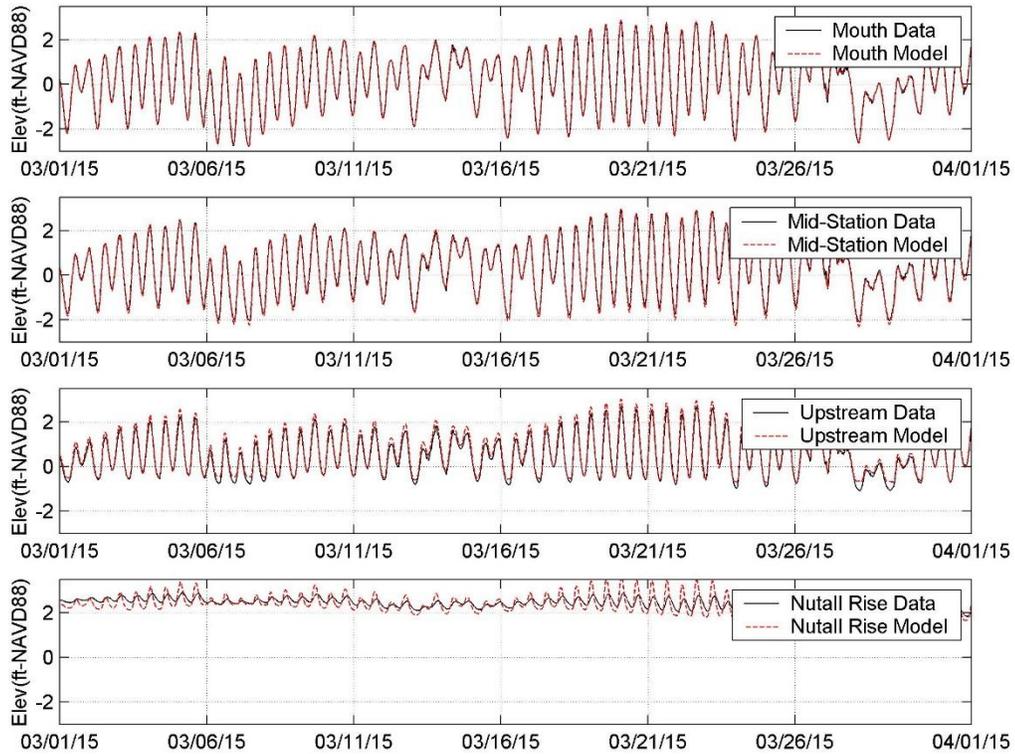
Figure 3-2a.   Simulated versus Measured Water Levels at SRWMD stations 02326570, 02326550, 02326548, and S040407001 in March 2015.
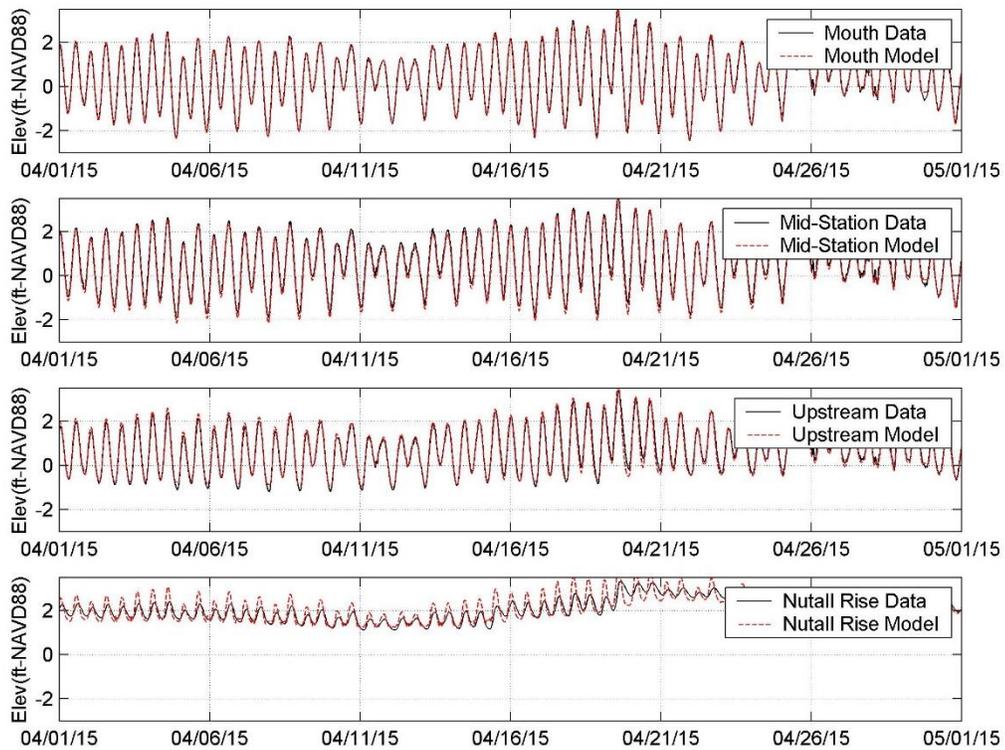

Figure 3-2b.   Simulated versus Measured Water Levels at SRWMD stations 02326570, 02326550, 02326548, and S040407001 in April 2015.
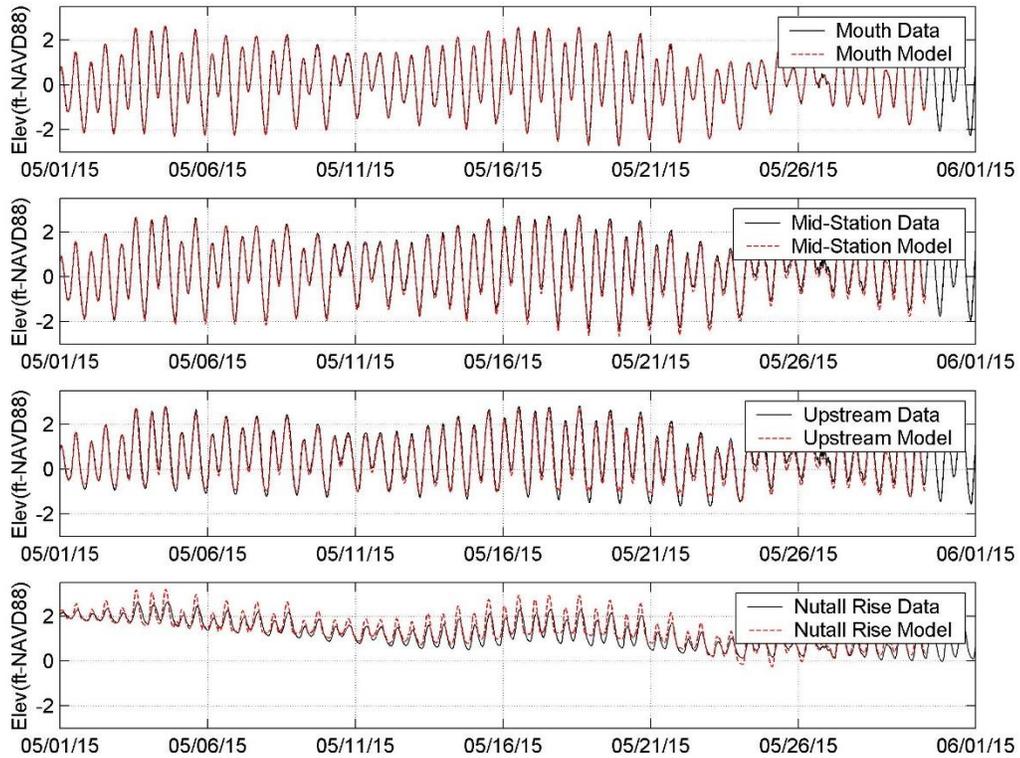
Figure 3-2c.   Simulated versus Measured Water Levels at SRWMD Stations 02326570, 02326550, 02326548, and S040407001 in May 2015.

Table 3-1.   Model Calibration Statistics.

Station Number	Station Name	Parameter	Units	RMS Error	RMS %	Mean Error	R2
02326570	Aucilla - Mouth	Water Level	ft	0.06	2%	0.01	1.00
02326550	Aucilla - Middle	Water Level	ft	0.16	4%	-0.01	0.99
02326548	Aucilla - Upstream	Water Level	ft	0.19	5%	-0.01	0.96
02326550	Aucilla - Middle	Flow	cfs	471.6	16%	-0.1	0.77

3.3   SIMULATED VERSUS MEASURED FLOW

Figures 3-3a through 3-3f present comparisons of the measured versus simulated flow at Station SRWMD 02326550. The plots show the comparison of the simulated flows against the calculated flows as well as the discrete direct flow measurements taken to establish the flow time series. The plots present the monthly comparisons as well as zoomed-in views of the comparisons at the time of the discrete measurements. 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. 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 3-1 presents the model statistics for the flow measurements. The results show that the RMS error is around 470 cfs, which is reflective of a 15 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 0.77, which is a reasonable correlation between the measured and modeled flow.

Figure 3-3a.   Simulated versus Measured Flow at SRWMD 02326550 in March 2015.

Figure 3-3b. Simulated versus Measured Flow at SRWMD 02326550 (March 17 to March 20, 2015).

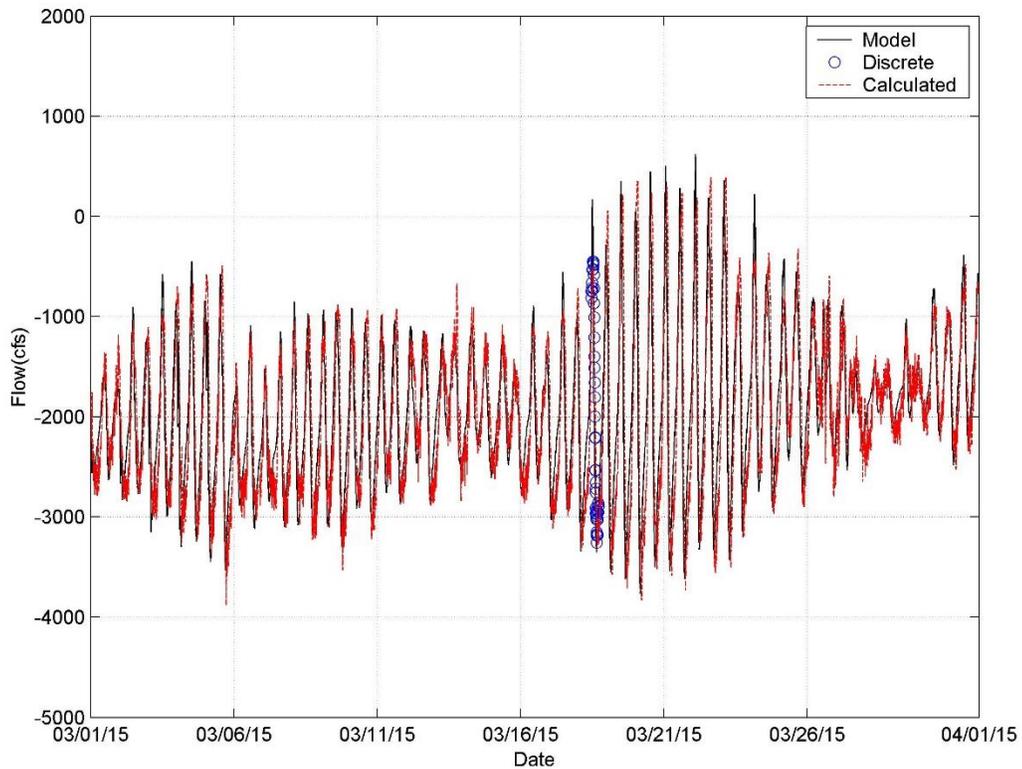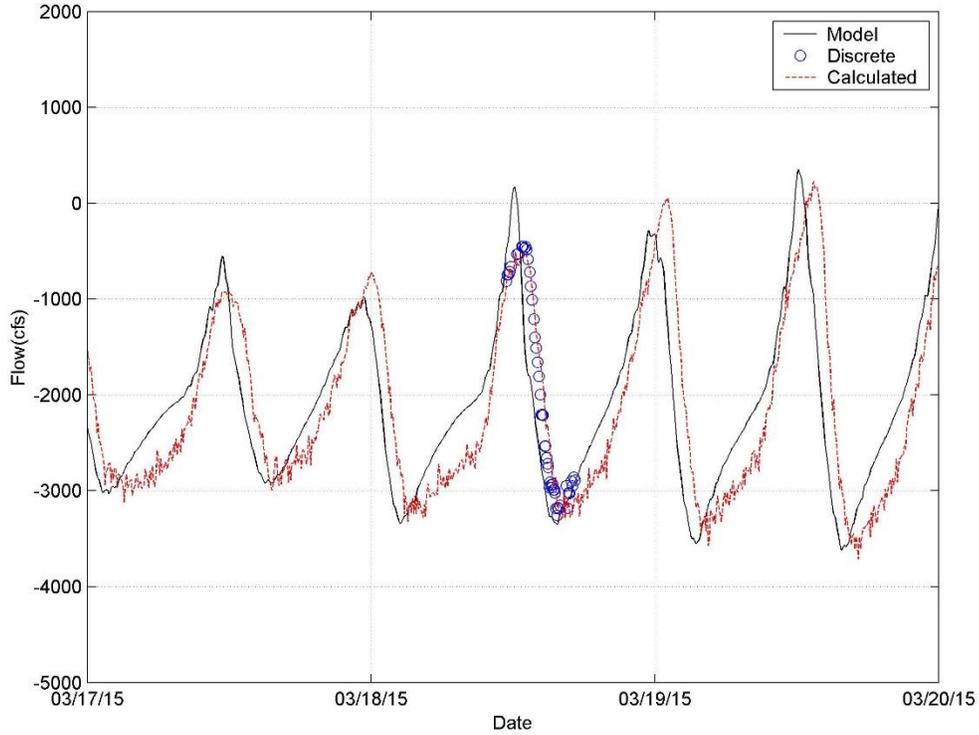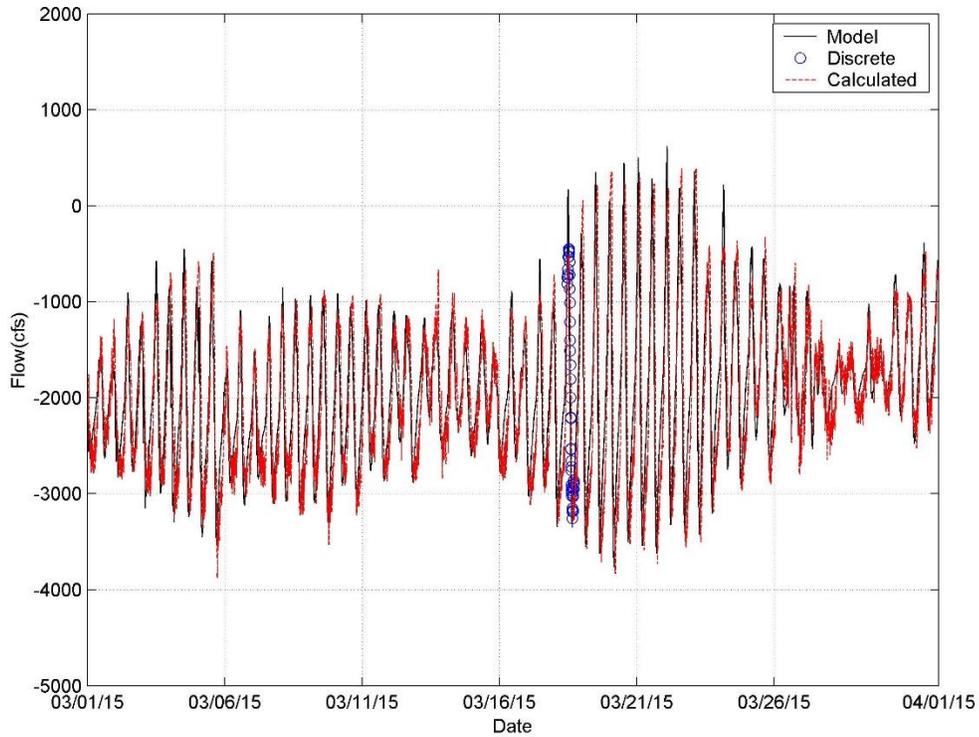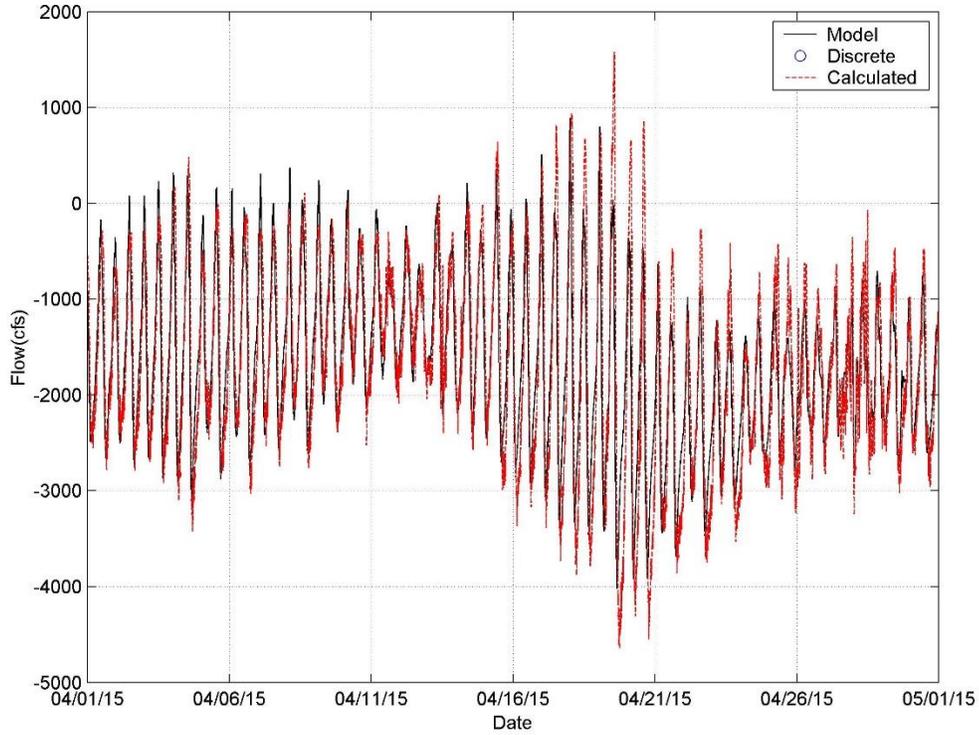*Figure 3-3c. Simulated versus Measured Flow at SRWMD 02326550 in April 2015.*

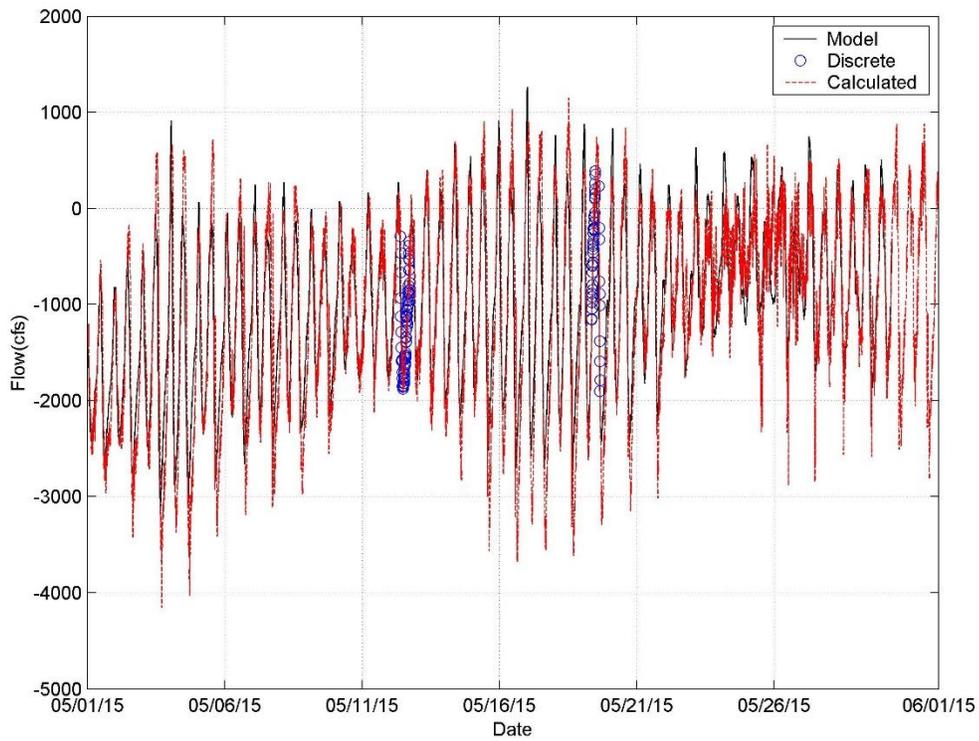*Figure 3-3d.   Simulated versus Measured Flow at SRWMD 02326550 in May 2015.*

Figure 3-3e.   Simulated versus Measured Flow at SRWMD 02326550 (May 11 to May 14, 2015).
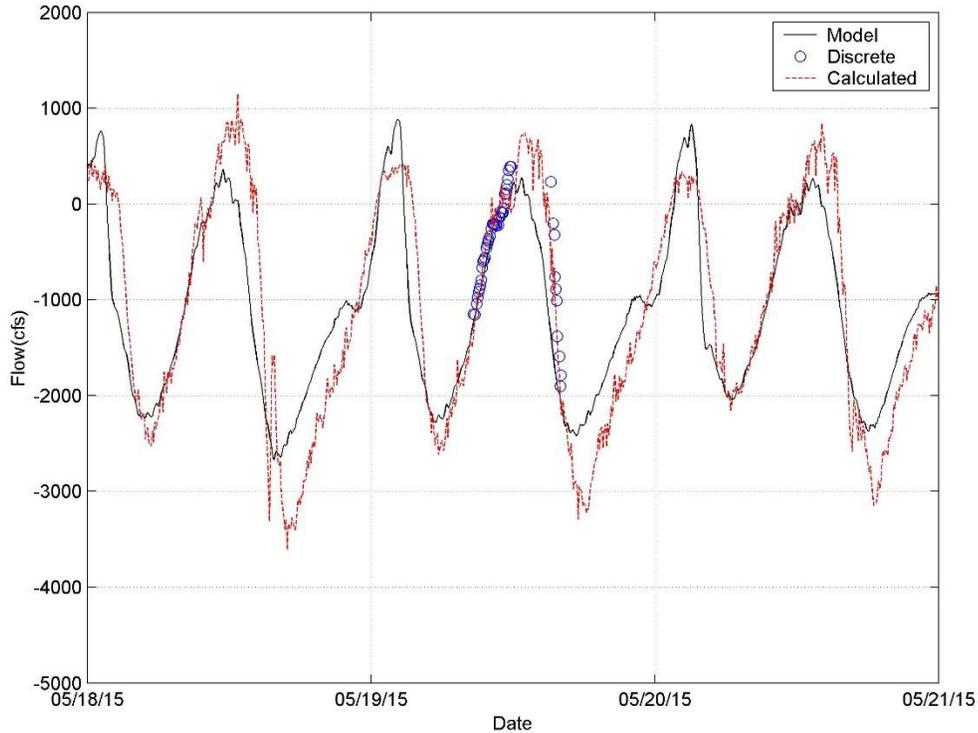
Figure 3-3f.   Simulated versus Measured Flow at SRWMD 02326550 (May 17 to May 20, 2015).

3.4   SIMULATED VERSUS MEASURED SALINITY

Figures 3-4a through 3-4c present comparisons of the measured versus simulated salinity at the downstream, mid-stream, and upstream stations. For the mid-stream station, the surface and bottom results are compared. Due to the nature of the salinity data and model simulations, with intermittent time frames where the salinity intrusion reaches the mid-stream and upstream stations, the error statistics presented for the water level and the flow do not apply. Additionally, the nature of the salinity intrusion is such that a very sharp salinity front moves up into the system, with the greatest level of intrusion occurring during neap tide conditions, when the energy is low and the level or sharpness of the stratification is highest. Due to the sharpness of the salinity front, a small error in the horizontal distance of the intrusion can result in a significant error in the salinity as the front moves up the system. For example, if the level of the salinity front intrusion in the model is 100 feet short of the location of the station where salinity measurements are taken, the data could show that salinities reach on the order of 10 to 15 parts per thousand (ppt) on the bottom, but the model simulations show zero, even though the intrusion level was only a short distance below the gage location in the model. Additionally, models, by their nature, tend to smear sharp gradients, based on the level of model vertical or horizontal resolution. For the Aucilla

model, the balance between having feasible run times for model scenarios and vertical resolution (needed to represent the sharp nature of the stratification in the system) led to running the model with eight layers. While providing relatively good resolution in comparison with the depths, this level of vertical resolution still created some vertical smearing of the salinity profile. Based upon these issues, the graphical comparisons show that the model is doing well simulating the extent of the salinity intrusion and the overall magnitude response at the surface and bottom. A key aspect is that in late May, during the low flow period, the model shows that the level and timing of intrusion measured at the upstream station were very good. This comparison (where two stations longitudinally showed good response in terms of magnitude and timing) further supports the model's capability to simulate the variations in salinity intrusion under varying freshwater inflow and tidal forcing conditions.

Figure 3-4a. Simulated versus Measured Salinity at 02326570 (bottom), 02326550 (surface and bottom), and 02326548 (bottom) in March 2015. Note: where salinity levels are shown at zero, the flows were such that salinity was pushed downstream of the station.

Figure 3-4b.   Simulated versus Measured Salinity at 02326570 (bottom), 02326550 (surface and bottom), and 02326548 (bottom) in April 2015. Note: where salinity levels are shown at zero, the flows were such that salinity was pushed downstream of the station.
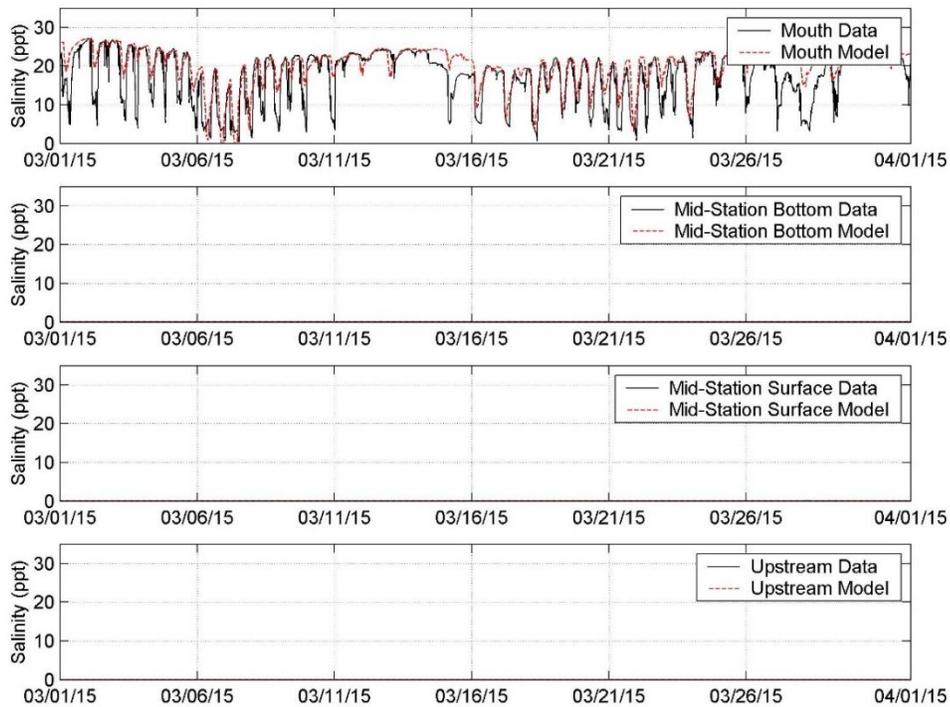

Figure 3-4c.   Simulated versus Measured Salinity at 02326570 (bottom), 02326550 (surface and bottom), and 02326548 (bottom) in May 2015. Note: where salinity levels are shown at zero, the flows were such that salinity was pushed downstream of the station.
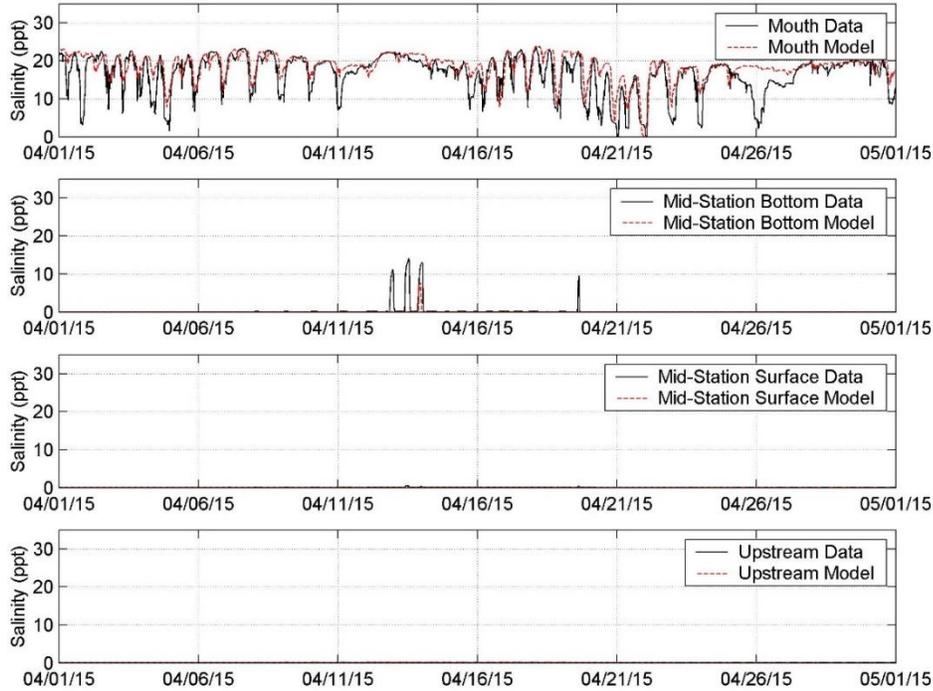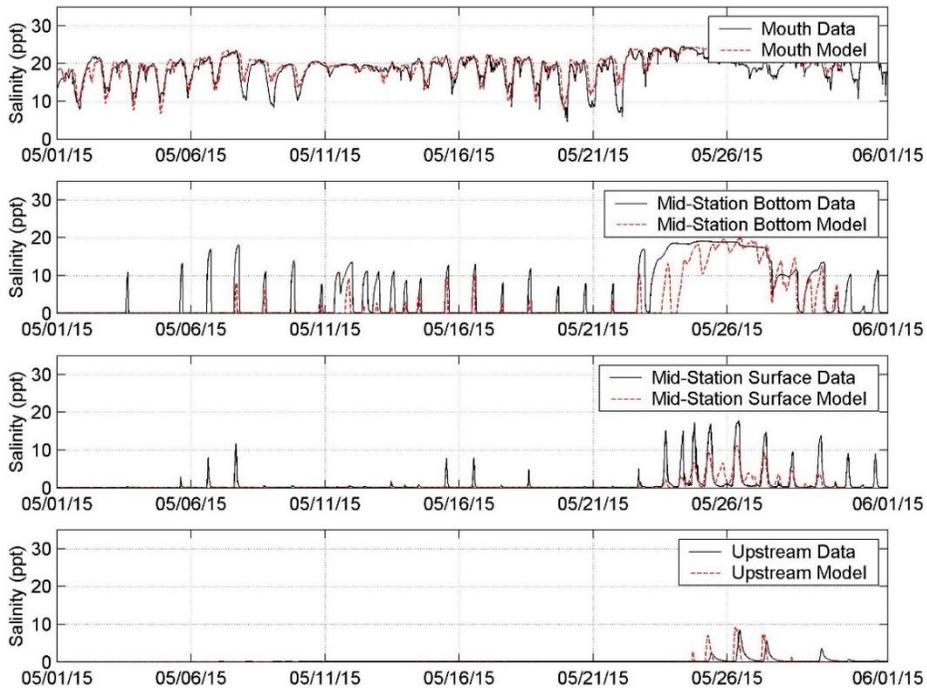
4.0   MFL SCENARIOS

Utilizing the calibrated hydrodynamic model, various scenarios were run to assess the impacts of flow reduction and sea level rise 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
- 15 percent flow reduction
- 30 percent flow reduction
- Sea level rise (5.1 inches)

For all the scenarios, a 2-year period was defined as representative of the full range of hydrologic (freshwater inflow) conditions seen for the river. The MFL document provides a detailed discussion of how this 2-year period was selected. For the Aucilla River, the 2-year period was from October 1, 1994, through September 30, 1996.

For the Aucilla model baseline time period of October 1, 1994 through September 30, 1996, the offshore boundary conditions for elevation and salinity were taken from the GCSM output at grid cells near the Aucilla model boundary. The GCSM output spanned the period 1995-2002. Based on this time period, data were needed for the offshore conditions from September 15, 1994 through December 31, 1994. For this period, the GCSM output from September 15, 1996 through December 31, 1996 was used. Prior to its use, the data from this time period was checked for consistency with conditions in 1994. Additionally, wind speed and direction data were obtained from the same local gage as that utilized for the model calibration for the full 2-year period. The scenario models were run for a 15-day period from September 15, 1994, to October 1, 1994 to bring the models into equilibrium prior to start of the scenario runs.

The upstream inflow conditions were calculated based upon a relationship established between the upstream gage at Lamont (USGS 02326500) (see Figure 1-1b) and the measured flow at the mid-station (SRWMD 02326550) for the period of the field data collection (February 2015 to May 2015). The details of the relationship are presented within the MFL document, along with the flow conditions for the scenarios. For the flow reduction scenarios, the time series of flow 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 2-year period.

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 Aucilla River. This included the following:

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

The model extended offshore within the Gulf of Mexico and up the main stem of the Aucilla River to Nutall Rise and 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 mid-February 2015 to the end of May 2015.

The model had one open boundary condition approximately 2 miles offshore of the mouth of the Aucilla River. The offshore water level boundary conditions were developed from measured water levels at the mouth using boundary matching techniques. The offshore salinity boundary conditions were derived from the daily maxima of the continuous salinity measured at the mouth.

Graphical and/or statistical comparisons of the simulated versus measured water levels were presented at four locations along the system. These included data at the mouth, at a mid-station and upstream station, and at Nutall Rise. 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 data at the mouth, bottom and surface data at the mid-station, and bottom data at the upstream stations. The comparisons showed that the model captured the timing and magnitude of the responses to the freshwater inflow on salinity intrusion and the distribution of the salinity between the stations.

6.0   REFERENCES

Applied Technology and Management, Inc. (ATM). 2015. Hydrodynamic Monitoring of the Tidal Portions of the Aucilla River. Prepared for Suwannee River Water Management District (SRWMD), Live Oak, FL.

Janicki Environmental, Inc. 2007. Cross Florida Greenway: Watershed Evaluation Hydrodynamic Models. Prepared for: Southwest Florida Water Management District, Brooksville, FL.

Janicki Environmental, Inc. 2014. Old Tampa Bay Integrated Model Development Project: Task 4, Development of Calibrated Models for the Old Tampa Bay Integrated Model System (Appendix B2). Prepared for: Tampa Bay Estuary Program and Southwest Florida Water Management District, Brooksville, FL.

APPENDIX B

Aucilla River - SEFA Results

Use of the System for Environmental Flow Analysis (SEFA) Software in a Minimum Flows and Levels (MFL) Study of the Aucilla River.

Introduction

The Suwannee River Water Management District is tasked with developing minimum flows and levels (MFL) on both lentic and lotic water bodies within its boundary. Each year, the District produces a document called the MFL Priority List, on which listed water bodies will be given an MFL within a specific time frame. The purpose of an MFL is to protect a specified water body from what is known as "significant harm." In order to address this, the District has adopted a threshold of no more than a 15% reduction for in-channel habitat before "significant harm" is reached.

SEFA is a Windows-based program that was developed as a tool for use in studies that utilize the Instream Flow Incremental Methodology (IFIM). It contains hydraulic, instream habitat, and time series models and can be used in the development of flow recommendations. The program allows for the alteration of flows to demonstrate the effects on the availability of habitat (shown as area weighted suitability) for species of interest in the body of water (Jowett et.al 2014).

Methods

Study Area

The Aucilla River is a dark-water river system located on the border of Taylor, Madison, and Jefferson Counties in Florida and is slated to have an established MFL in 2015. The river flows relatively southward from Georgia until it eventually empties into a series of sinks north of the Florida coastline. Nutall Rise, located between river miles 5 and 6, serves as the major resurgence of the river, flowing from this point downstream towards the Gulf of Mexico. A major tributary, the Wacissa River, is a spring-dominated river that empties into the Aucilla River at multiple locations due to its braided nature.

The study area encompasses an approximately 0.2-mile reach located about 11 miles downstream of US highway 27 near Lamont, FL (Figure 1). Project staff collected data at 7 transects at the site during 3 different flow/stage conditions. The team collected the necessary survey, velocity, discharge, depth, and substrate values on June 8-9, 13, and 18, 2015. All recorded data were utilized in the hydraulic, instream habitat, and time series models of the river.
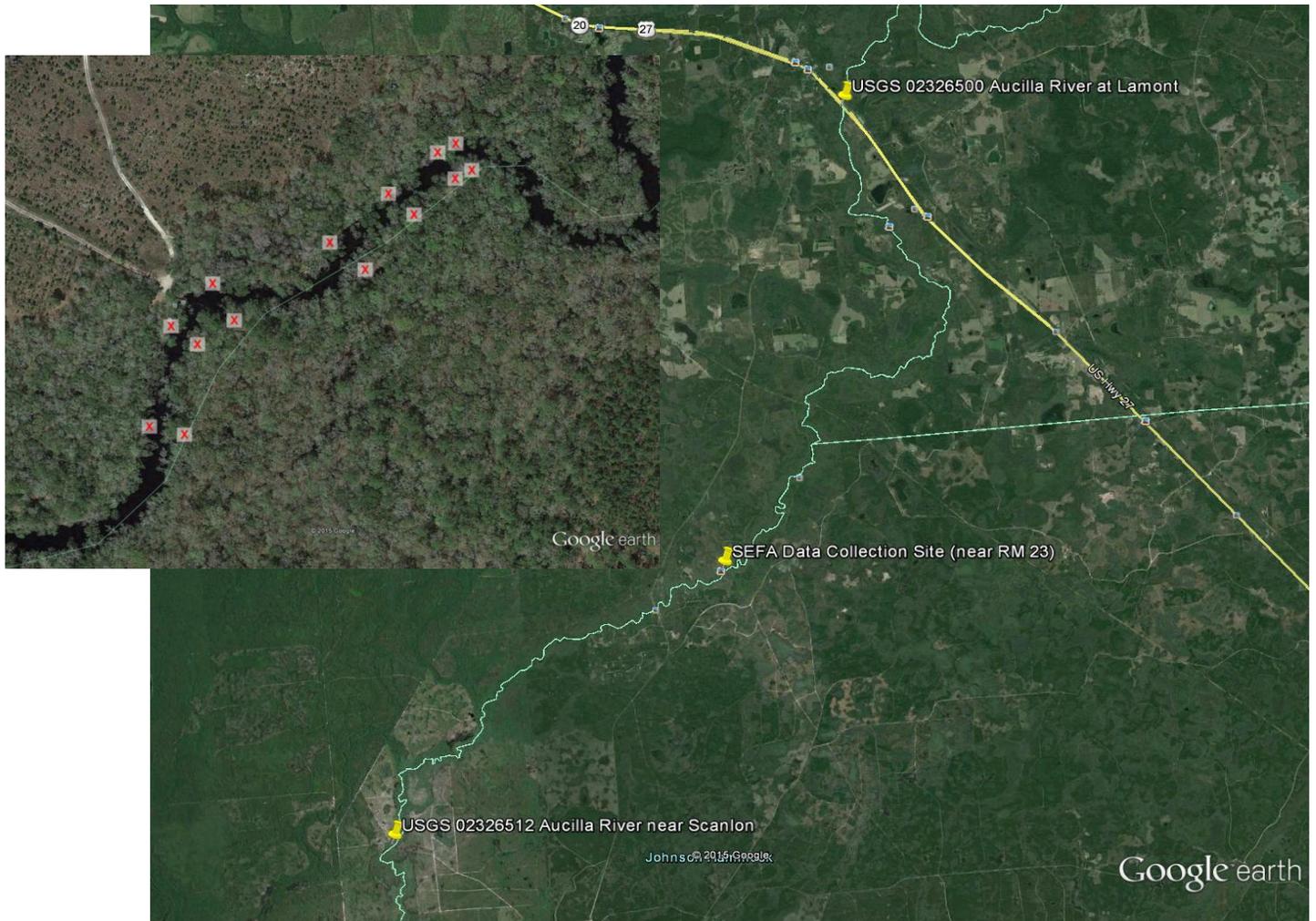
Figure 1. Map of the Aucilla River study area with transect locations.

Instream Habitat Model Calibration

The three measured stage/discharge values were used to establish log-log rating relationships for each transect in the SEFA program. The rating curves were each calculated with IFG4 emulation, the same method applied by the Physical Habitat Simulation model (PHABSIM) (Jowett et.al 2014; Milhous and Waddle 2001).

Habitat Suitability Curves

Forty habitat suitability curves of various species and life stages were incorporated into both the above and below tram instream habitat models (Table 1). Most or all of these curves have been applied in previous MFL analyses depending on the specific water body. For this analysis, the velocity, depth, and habitat preference criteria for each species and life stage were utilized in the calculation of the area weighted suitability.

Table 1. Habitat Suitability Curves used in the MFL analysis.

Species or Group	Life Stage
Suwannee Bass	Adult, Juvenile
Redbreast Sunfish	Adult, Juvenile, Spawning, Fry
Habitat Guilds	Shallow/Slow, Shallow/Fast, Deep/Slow, Deep/Fast
Channel Catfish	Adult, Juvenile (spring, summer, fall, warmwater), Spawning, Fry
Darters	Generic, Blackbanded
Macroinvertebrates	Ephemoptera, Plecoptera, Tricoptera, EPT Total, *Pseudocloeon ephippiatum*, Hydropsychidae - Total, *Tvetenia vitracies*
Largemouth Bass	Adult, Juvenile, Spawning, Fry
Bluegill	Adult, Juvenile, Spawning, Fry
Spotted Sunfish	Adult, Juvenile, Spawning, Fry
Cyprinidae	Adult

Time Series Flow

Discharge data from a USGS gage (02326500, Aucilla River at Lamont) was used in the time series analysis portion of the SEFA program. Statistics for this flow record are presented in Table 2.

Table 2. Period of record flow statistics for the USGS gage 02326500 – Aucilla River at Lamont.

Statistic	Value
Sample size	13879
Minimum	0
Maximum	11500
Mean	339.77
Median	81
Standard deviation (denom. = n-1)	690.9

Flow Reduction Approach

This approach involved a straight percent reduction of each discharge measurement value in the historic period of record. Ten and 20 percent flow reductions were chosen as the starting points for all species and life stage curves. Appendix Figure A1 contains the flow duration curve along with the associated percent reductions to the flow record. Those species and life stages that showed significant decrease in mean area weighted suitability from the initial flow reductions were deemed critical species. These were then reduced by ascending percent reductions in the flow record until the percent difference between the reduced and historic discharge recorded just less than a 15% reduction in mean area weighted suitability.

Results and Discussion

Three species and life stages in this method were deemed as critical during the initial use of the 10% and 20% flow reductions. Channel catfish adult, the shallow/fast habitat guild, and total EPT were all listed as critical and were analyzed further. Each was reduced incrementally by 5% from 25-50% flow reduction in the period of record. Table 3 contains the percent flow reductions along with the corresponding percent habitat reductions for each of the critical species that were identified by this method. Duration curves containing the area weighted suitability and percent reductions across the historic flow record are shown in Appendix figures A2-A4.

Table 3. Percent flow reduction across the historical period of record and associated percent change in certain species and life stages. Red denotes a violation in the percent habitat reduction.

| Species/Life Stage			Reductions			
		25%	30%	35%	40%	45%	50%
Channel catfish adult		6.15	7.57	9.27	10.97	12.96	15.14
Habitat guild - shallow/fast		9.52	9.52	14.29	19.05	23.81	23.81
EPT - Total		6.39	8.03	10.04	12.04	14.42	16.97

Of the three critical species and life stages, the shallow/fast habitat guild was the most restrictive in terms of percent reduction to the flow record. Any flow reduction greater than 35% would cause a greater than 15% reduction in the species' habitat. The low mean area weighted suitability of the shallow/fast habitat guild (0.21 ft^2/ft) causes increased sensitivity to habitat reduction when compared with the other two critical species.

It should be advised, however, that this data only represents a minor section of the Aucilla River (about 0.2 mi), and caution should be utilized whenever applying these results to the whole waterbody. Larger scale and unconstrained data collection methods should be practiced in order to interpret proper results for the entirety of the river.

References

Aquatic Habitat Analysts, Inc. 2012. SEFA: System for Environmental Flow Analysis (Version 1.2 build 23). Available from http://sefa.co.nz/.

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Milhous, R.T. and T.J. Waddle. 2001. PHABSIM for Windows User's Manual and Exercises. Open File Report 01-340. Fort Collins, CO: Midcontinent Ecological Science Center. 288p.

APPENDIX
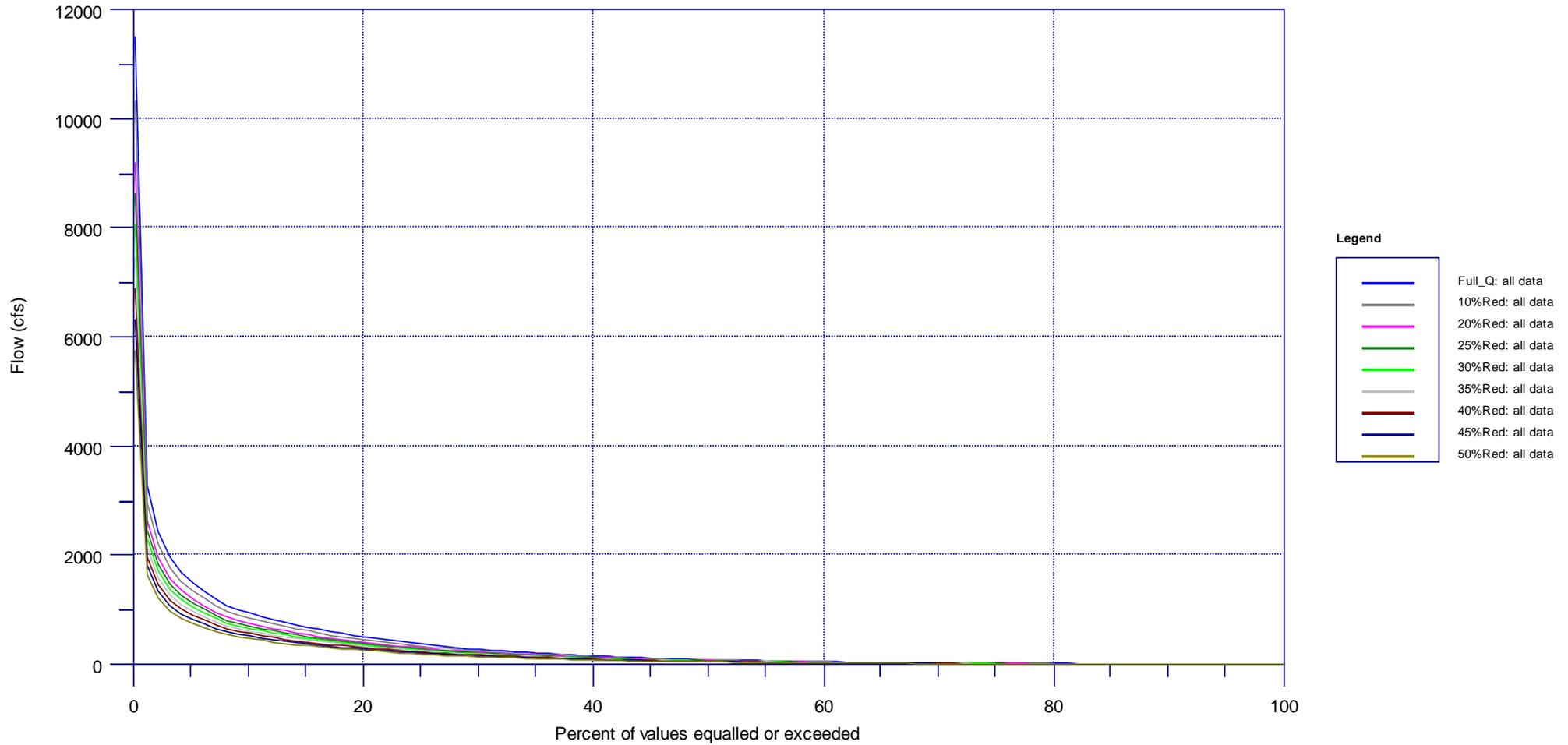
Figure A1. Flow duration curve comparing the historic and percent reduced flow records. The historic flow data (labeled Full_Q) is included for reference.
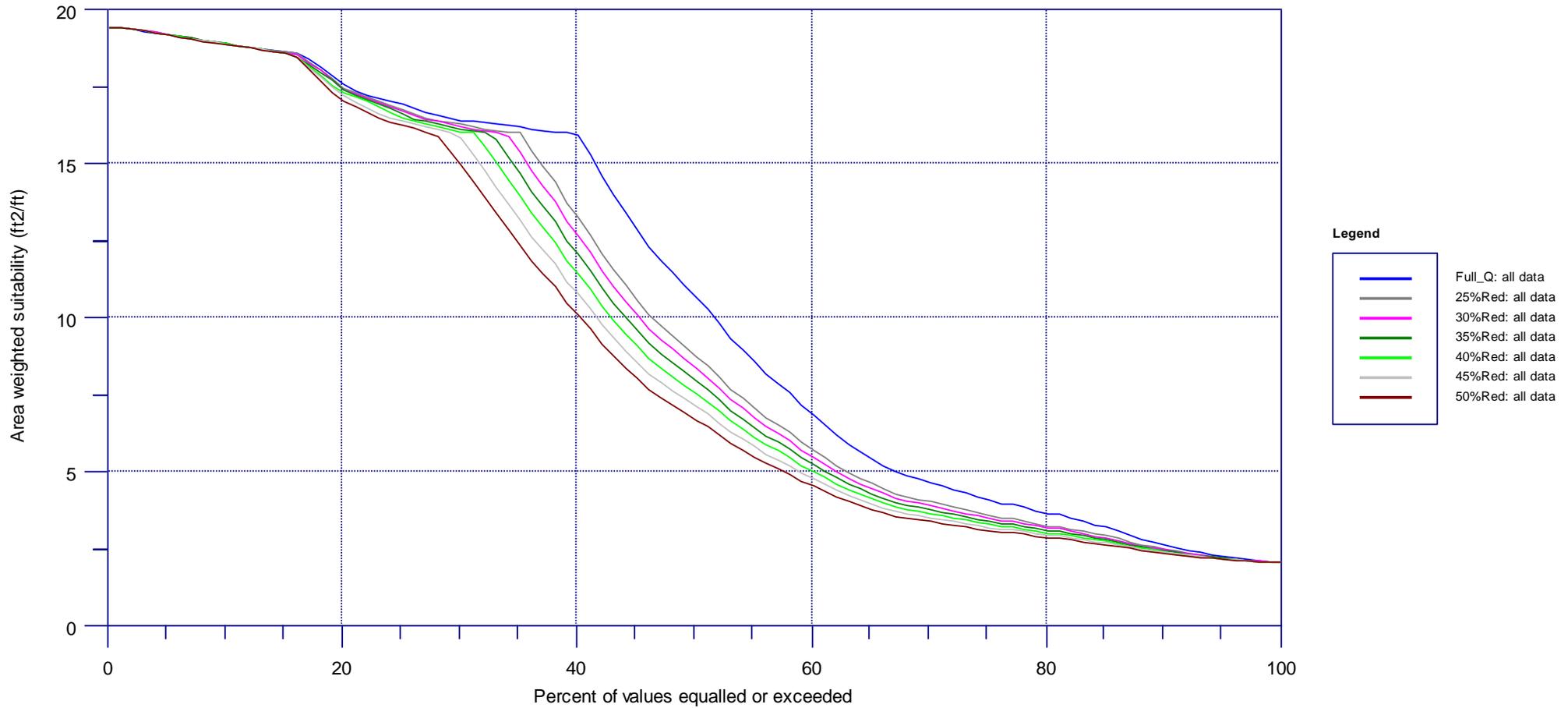
Figure A2. Area weighted suitability duration curves with historic discharge (Full_Q) including the various percent reductions for channel catfish adult.
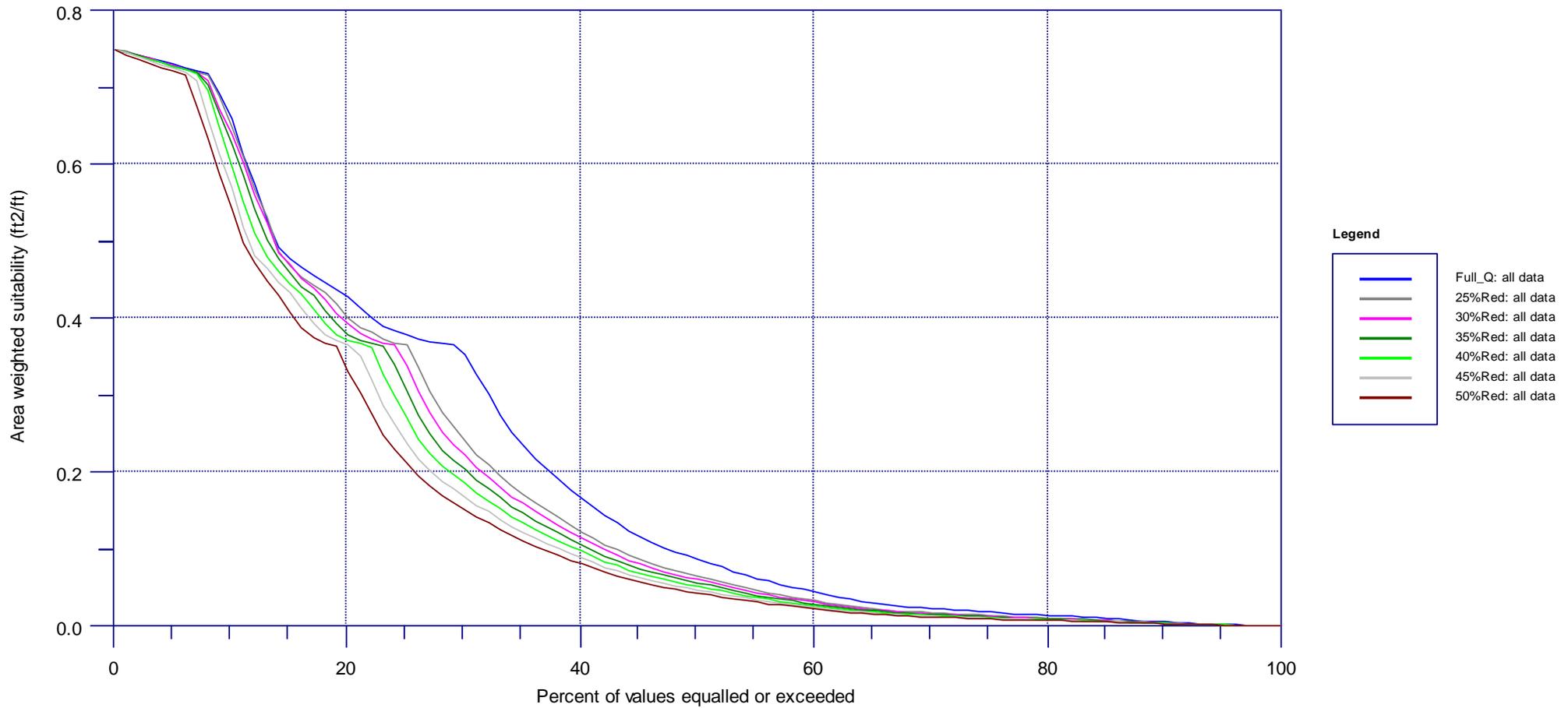
Figure A3. Area weighted suitability duration curves with historic discharge (Full_Q) including the various percent reductions for the shallow/fast habitat guilds.

Figure A4. Area weighted suitability duration curves with historic discharge (Full_Q) including the various percent reductions for the EPT total.
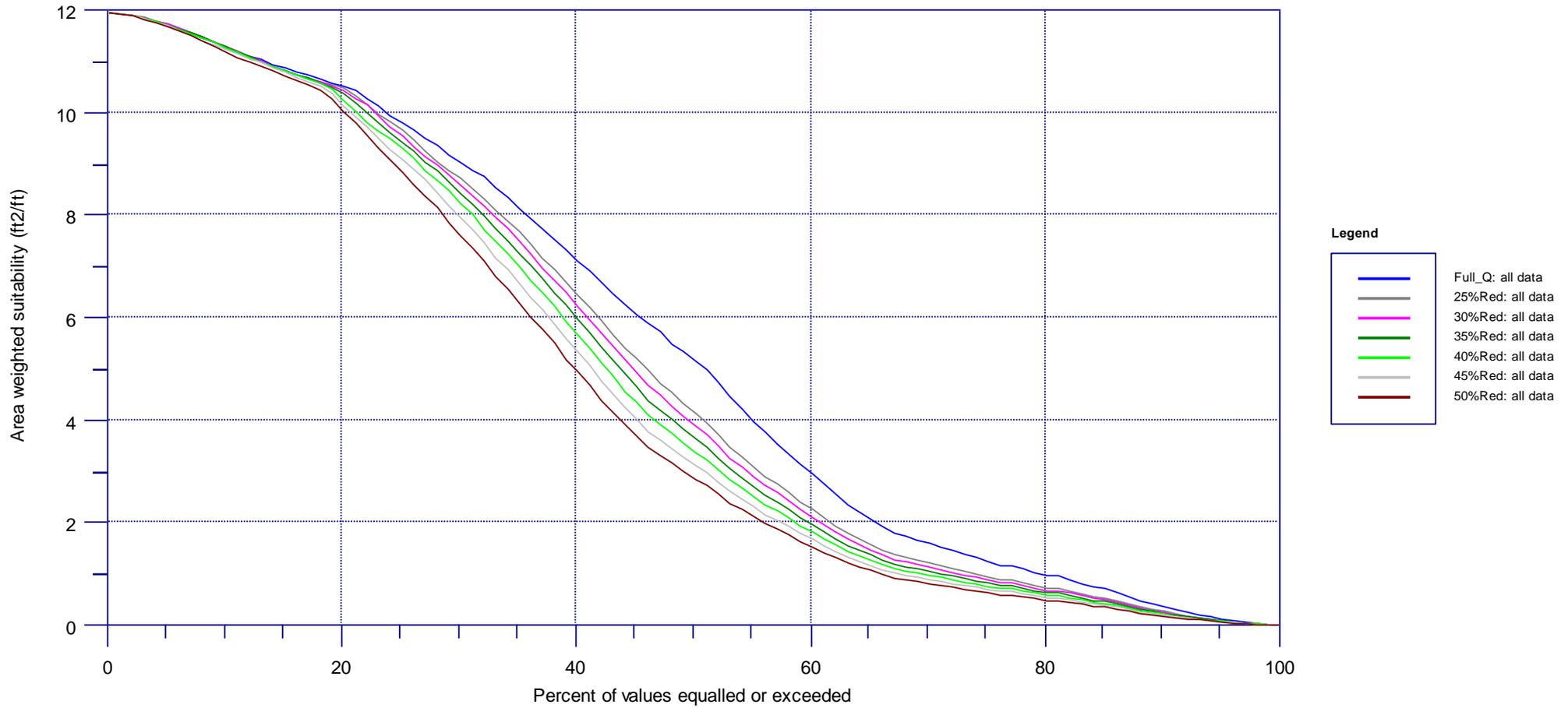
APPENDIX C

Wacissa River - SEFA Results

Use of the System for Environmental Flow Analysis (SEFA) Software in a Minimum Flows and Levels (MFL) Study of the Wacissa River.

Introduction

The Suwannee River Water Management District is tasked with developing minimum flows and levels (MFL) on both lentic and lotic water bodies within its boundary. Each year, the District produces a document called the MFL Priority List, on which listed water bodies will be given an MFL within a specific time frame. The purpose of an MFL is to protect a specified water body from what is known as "significant harm." In order to address this, the District has adopted a threshold of no more than a 15% reduction for in-channel habitat before "significant harm" is reached.

SEFA is a Windows-based program that was developed as a tool for use in studies that utilize the Instream Flow Incremental Methodology (IFIM). It contains hydraulic, instream habitat, and time series models and can be used in the development of flow recommendations. The program allows for the alteration of flows to demonstrate the effects on the availability of habitat (shown as area weighted suitability) for species of interest in the body of water (Jowett et.al 2014).

Methods

Study Area

The Wacissa River is a spring-fed river located in Jefferson County, Florida, and is slated to have an established MFL in 2015. The river flows relatively southward from the headspring for about 12 miles until it branches off into a large number of braided channels. The remnants of old tram pilings cross the river approximately 3 miles downstream of the headspring. These pilings can be easily crossed under normal flow but may require portage at low flows. The Wacissa eventually flows into the Aucilla River, a dark-water system that empties into the Gulf of Mexico.

The study area encompasses an approximately 10-mile area from the headspring downstream to Goose Pasture. The magnitude of the river braiding below this area is too difficult to properly model. A total of 32 cross sections, established in previous studies, were used as part of the instream habitat modeling portion of the SEFA software (Figure 1). The tram pilings were considered a natural boundary condition for the river, with 13 transects above the tram and 19

transects below used in the development of two separate instream habitat models (i.e., "above" and "below" tram models).
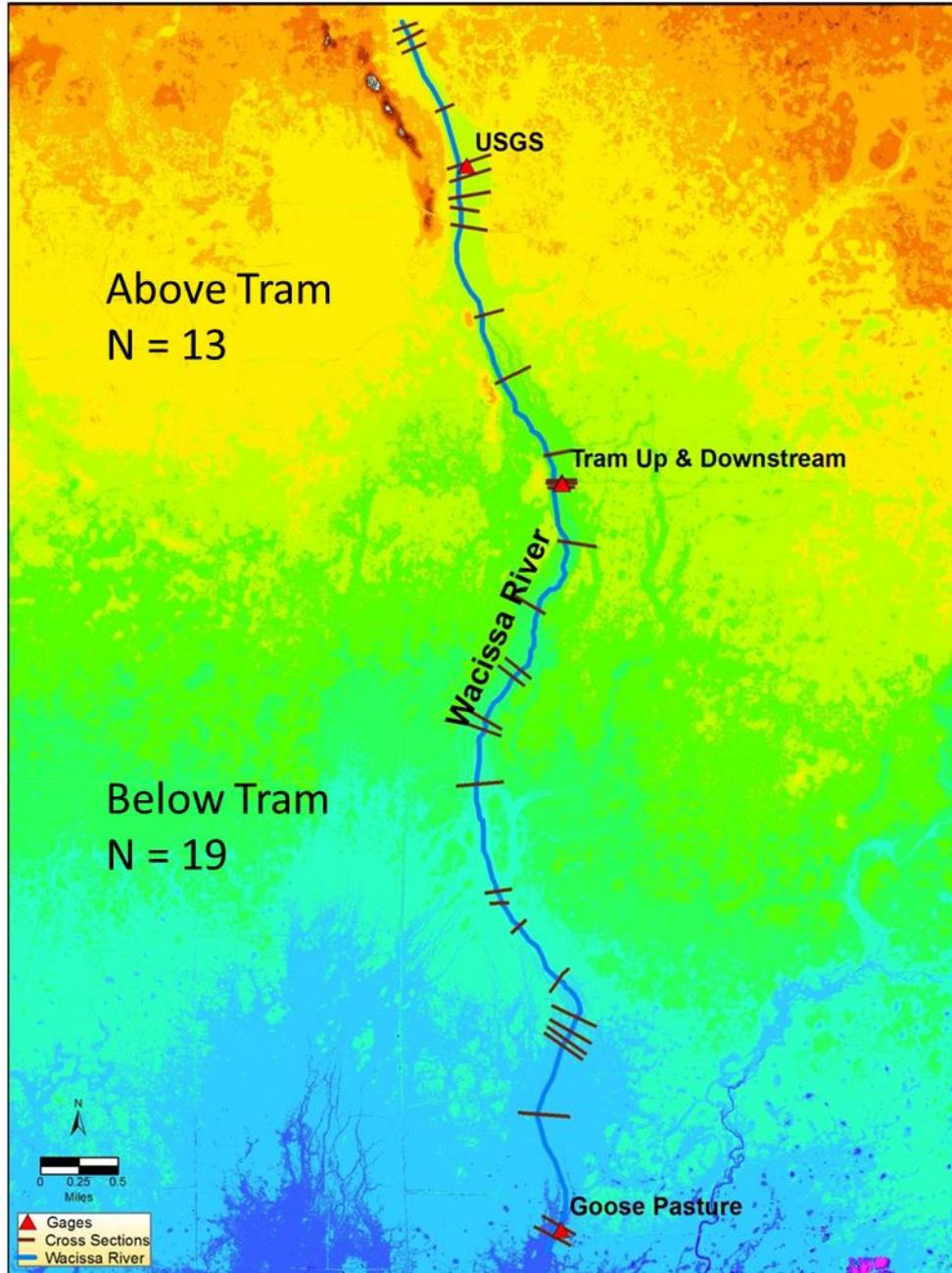
Figure 1. Map of the Wacissa River study area with transect locations.

Instream Habitat Model Calibration

Due to both time constraints and the degree of difficulty in measuring the necessary parameters in the Wacissa River, a HEC-RAS model was developed to simulate the necessary stage/discharge relationships over six different flow scenarios along with the velocities at specific points across each transect under the highest flow regime. These model calibration values were then used to establish log-log rating relationships for each transect in the SEFA program. The rating curves were each calculated with IFG4 emulation, the same method applied by the Physical Habitat Simulation model (PHABSIM) (Jowett et.al 2014; Milhous and Waddle 2001). Since no *in situ* data were collected, the substrate index codes were absent in the final calculation of the area weighted suitability for each species and life stage.

Habitat Suitability Curves

Forty habitat suitability curves of various species and life stages were incorporated into both the above and below tram instream habitat models (Table 1). Most or all of these curves have been applied in previous MFL analyses depending on the specific water body. Note that only the velocity and depth criteria for each species and life stage were taken into account in the calculation of preference habitat.

Table 1. Habitat Suitability Curves used in the MFL analysis.

Species or Group	Life Stage
Suwannee Bass	Adult, Juvenile
Redbreast Sunfish	Adult, Juvenile, Spawning, Fry
Habitat Guilds	Shallow/Slow, Shallow/Fast, Deep/Slow, Deep/Fast
Channel Catfish	Adult, Juvenile (spring, summer, fall, warmwater), Spawning, Fry
Darters	Generic, Blackbanded
Macroinvertebrates	Ephemoptera, Plecoptera, Tricoptera, EPT Total, *Pseudocloeon ephippiatum*, Hydropsychidae - Total, *Tvetenia vitracies*
Largemouth Bass	Adult, Juvenile, Spawning, Fry
Bluegill	Adult, Juvenile, Spawning, Fry
Spotted Sunfish	Adult, Juvenile, Spawning, Fry
Cyprinidae	Adult

Time Series Flow

Discharge data from the USGS gage 02326526 (Wacissa River near Wacissa) were utilized in the time series analysis portion of the SEFA program. Daily values from 2001-2014 were added to sporadic measurements from 1971-1976, 1999-2000, and 2007 to form the complete period of record. Statistics for this flow record are presented in Table 2.

Table 2. Period of record flow statistics for the USGS gage 02326526 – Wacissa River near Wacissa.

Statistic	Value
Sample Size	4310
Minimum	216
Maximum	1200
Mean	376.66
Median	349
Standard Deviation (denom.=n-1)	105.71

Flow Reduction Approaches

Percent Reduction from the Median Flow Value

Two different flow reduction approaches were taken during the analysis, and the results were evaluated for similarities and usefulness in the overall establishment of the MFL. The first approach involves a constant flow reduction from the median flow value shown in Table 2 to each value in the period of record. A percent of the median value was calculated and each value in the flow record was reduced by that amount (Table 3). Beginning with a 10% of the median reduction and using a descending stepwise approach, a percent difference was calculated between the reduced and historic period of records until less than a 15% reduction in mean habitat (i.e. area weighted suitability) was shown.

Table 3. Percent discharge reductions of the median value (349 cfs) by which period of record values were reduced.

Median % Q Reduction	Value
10%	34.9
9%	31.41
8%	27.92
7%	24.43

Percent Reduction across the Flow Record

The second approach involved a straight percent reduction of each discharge measurement value in the historic period of record. Once again, ten percent was chosen as the starting point, and flows were reduced by descending stepwise percentages until the difference between the reduced and historic discharge records revealed a less than 15% reduction in mean area weighted suitability. Reductions used on the discharge record ranged from 10% down to 5%. A comparison of the two flow reduction methods is shown in Figure A1 in the Appendix.

Results and Discussion

Percent Reduction from the Median Flow Value

Initial use of the 10% constant flow reduction from the median discharge value showed only one species and life stage, largemouth bass fry, violated the 15% criterion recognized at the beginning of the study. This critical species and life stage only showed a violation in the "below tram" habitat model. A 9% reduction in the discharge record had a 14% reduction in area weighted suitability, and anything below this discharge reduction value was in the range considered to be acceptable (Table 4). A graph of area weighted suitability duration curves can be seen in Appendix Figure 2.

Table 4. Percent flow reduction from the median discharge value and associated percent change in largemouth bass fry habitat. Red denotes a violation in the percent habitat reduction.

Percent Flow Reduction	Percent Change
10%	15.92
9%	14.44
8%	12.95
7%	11.36

Percent Reduction across the Flow Record

More species and life stages in this method were deemed as critical during the initial use of the 10% flow reduction. Once again, only the "below tram" model was significant, and the largemouth bass fry along with the additions of bluegill fry and the shallow/slow habitat guilds were deemed critical. Table 5 contains the percent reductions along with the corresponding percent reductions for each of the critical species that were identified by this method. Duration curves containing the area weighted suitability and percent reductions across the historic flow record are shown Figures A3-A5.

One macroinvertebrate species, *Pseudocloeon ephippiatum*, had an extremely high percent habitat reduction of 33.3% in the "above" tram model for the initial 10% flow reduction. However, the mean of area weighted suitability prior to reducing the flow was only 0.03 ft^2/ft. It was decided that that this species should be omitted from consideration due to the extremely low mean habitat value along with the lack of residence information in the Wacissa River.

Table 5. Percent flow reduction across the historical period of record and associated percent change in certain species and life stages. Red denotes a violation in the percent habitat reduction.

Species / Life Stage	Reductions					
	5%	**6%**	**7%**	**8%**	**9%**	**10%**
Largemouth bass fry	10.51	12.53	14.44	16.35	18.26	18.74
Bluegill fry	10.09	11.95	13.73	15.45	17.13	18.74
Habitat guilds - Shallow/Slow	9.24	10.91	12.52	14.10	15.61	17.06

Each flow reduction scenario seems to have biggest impact on values below the 50th percent exceedance in each of the species and life stages of concern. This could be attributed to overbank flow conditions during the lower exceedances that result in a small increase in the availability of preferred depth and velocities. Additional flow reductions would result in a higher percent change in available habitat as opposed to the higher exceedances.

Conclusion

Depending on the chosen methodology, a 7% to 9% reduction in the historic flow record is allowable without violating more than a prescribed 15% reduction in habitat for critical species identified in this report. A summary of the maximum allowable flow reduction by species and method is presented in Table 6.

Table 6. Summary of critical species and maximum allowable reduction in flow by method. All critical species and life stages result from the "below" tram habitat model.

| Species	Max. Reduction in Q to Avoid a 15% Habitat Reduction	Method
Largemouth Bass Fry	9%	Constant Reduction from Median Q Value
Largemouth Bass Fry	7%	Percent Reduction Across POR Flow
Bluegill Fry	7%	Percent Reduction Across POR Flow
Habitat Guilds - Shallow/Slow	8%	Percent Reduction Across POR Flow

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Milhous, R.T. and T.J. Waddle. 2001. PHABSIM for Windows User's Manual and Exercises. Open File Report 01-340. Fort Collins, CO: Midcontinent Ecological Science Center. 288p.
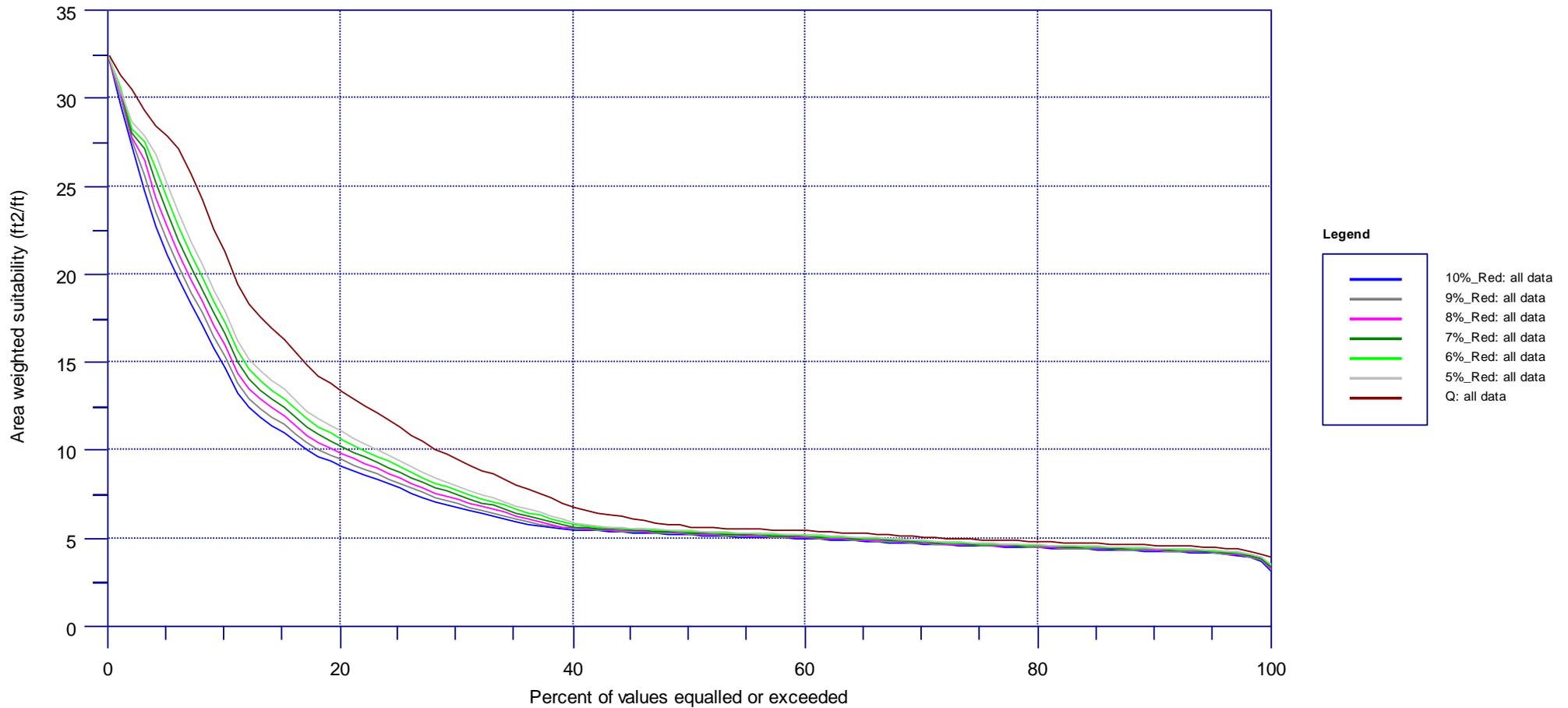
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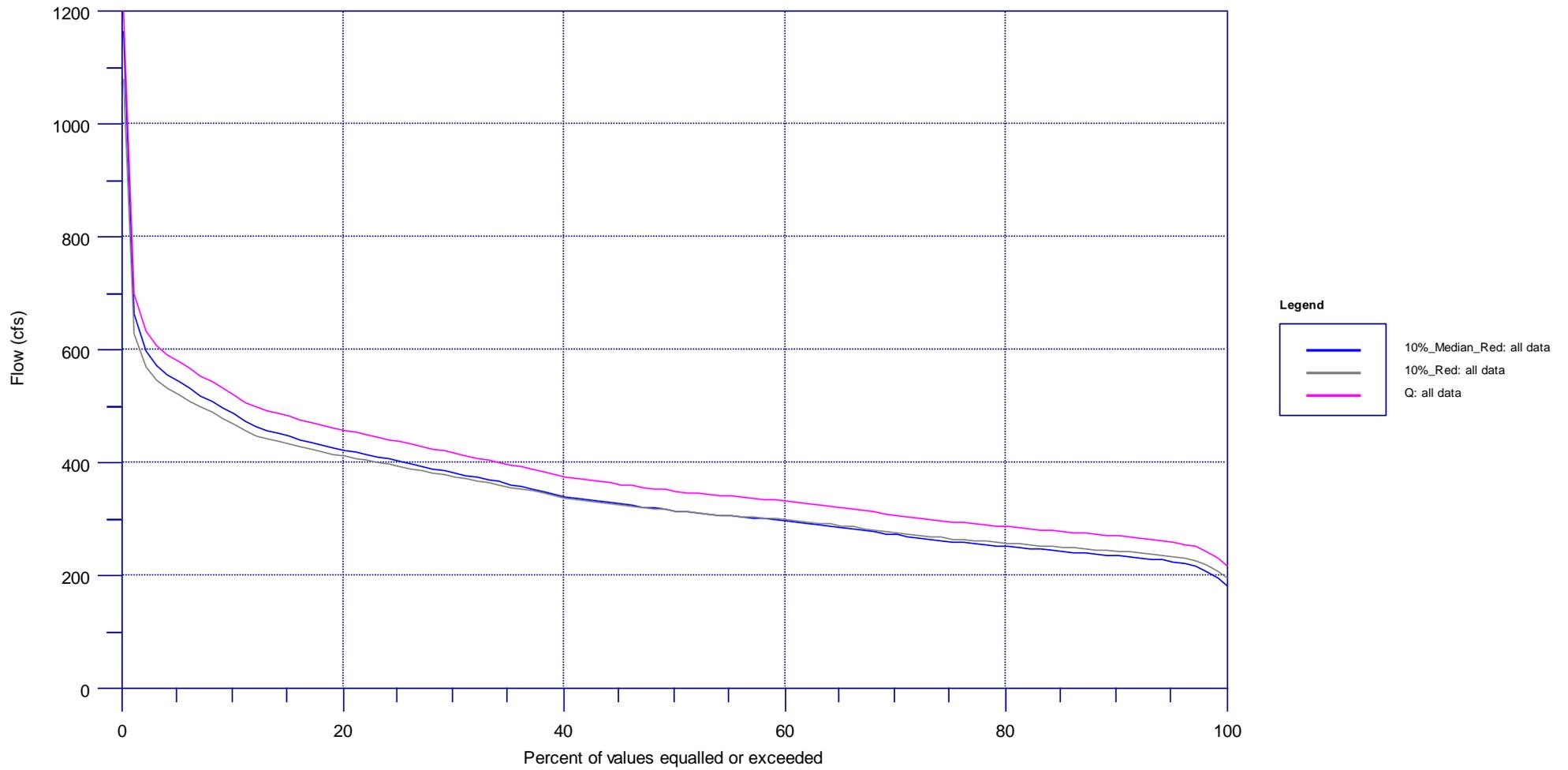
Figure A1. Flow duration curve comparing the two 10% flow reduction methods. The historic flow data (labeled Q) is included for reference.
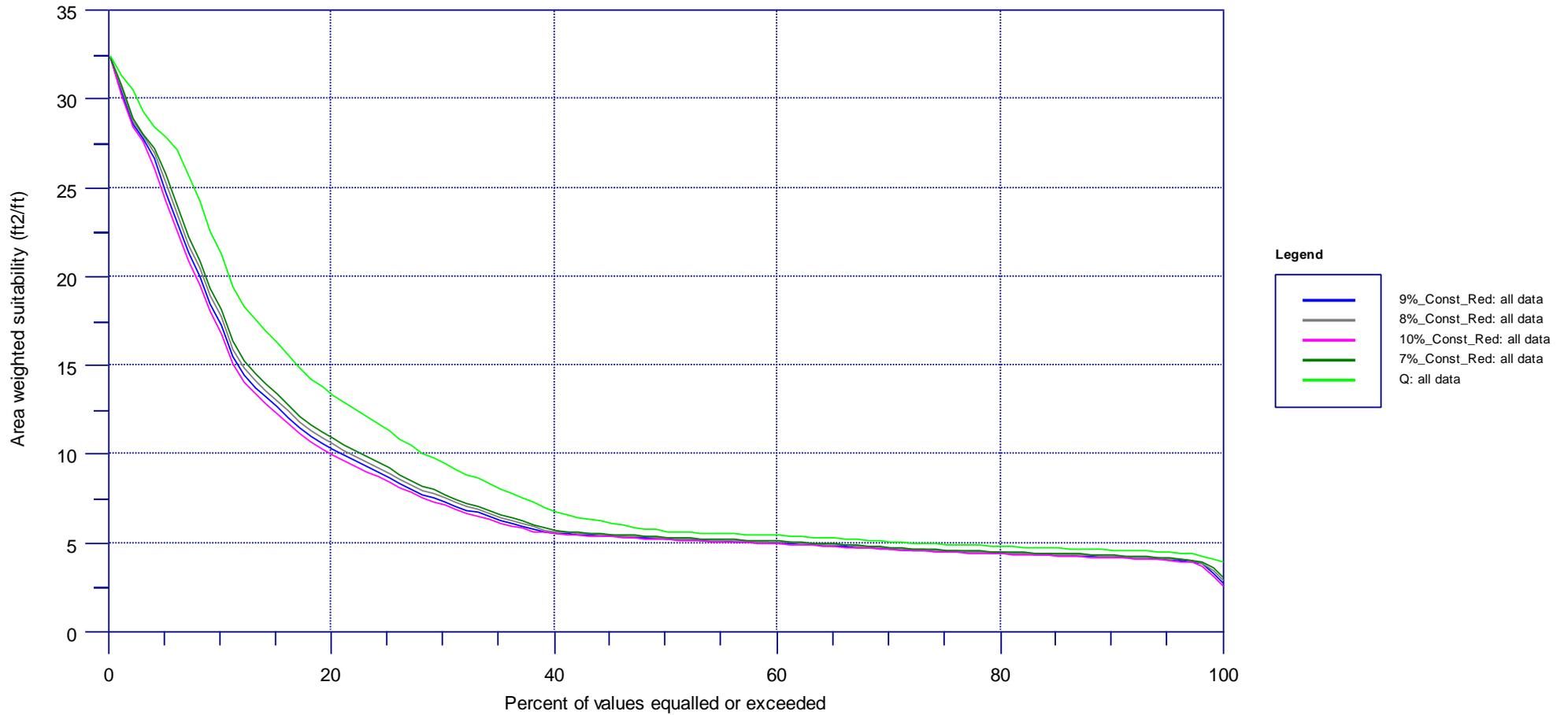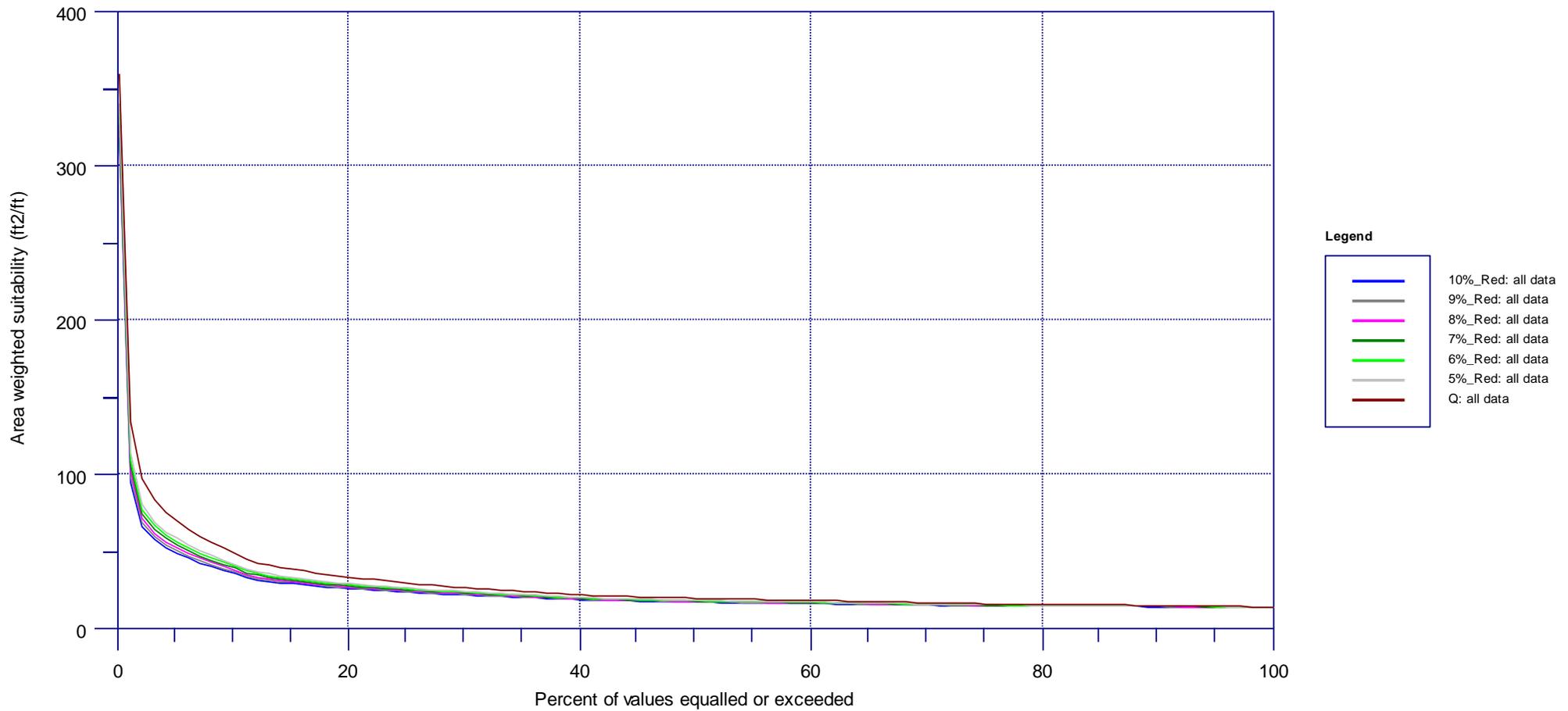
Figure A2. Area weighted suitability duration curves with historic discharge (Q) including the various percent reductions from the historic median value for largemouth bass fry below the tram.

Figure A3. Area weighted suitability duration curves with historic discharge (Q) including the various percent reductions across the entire historical period of record for largemouth bass fry below the tram.
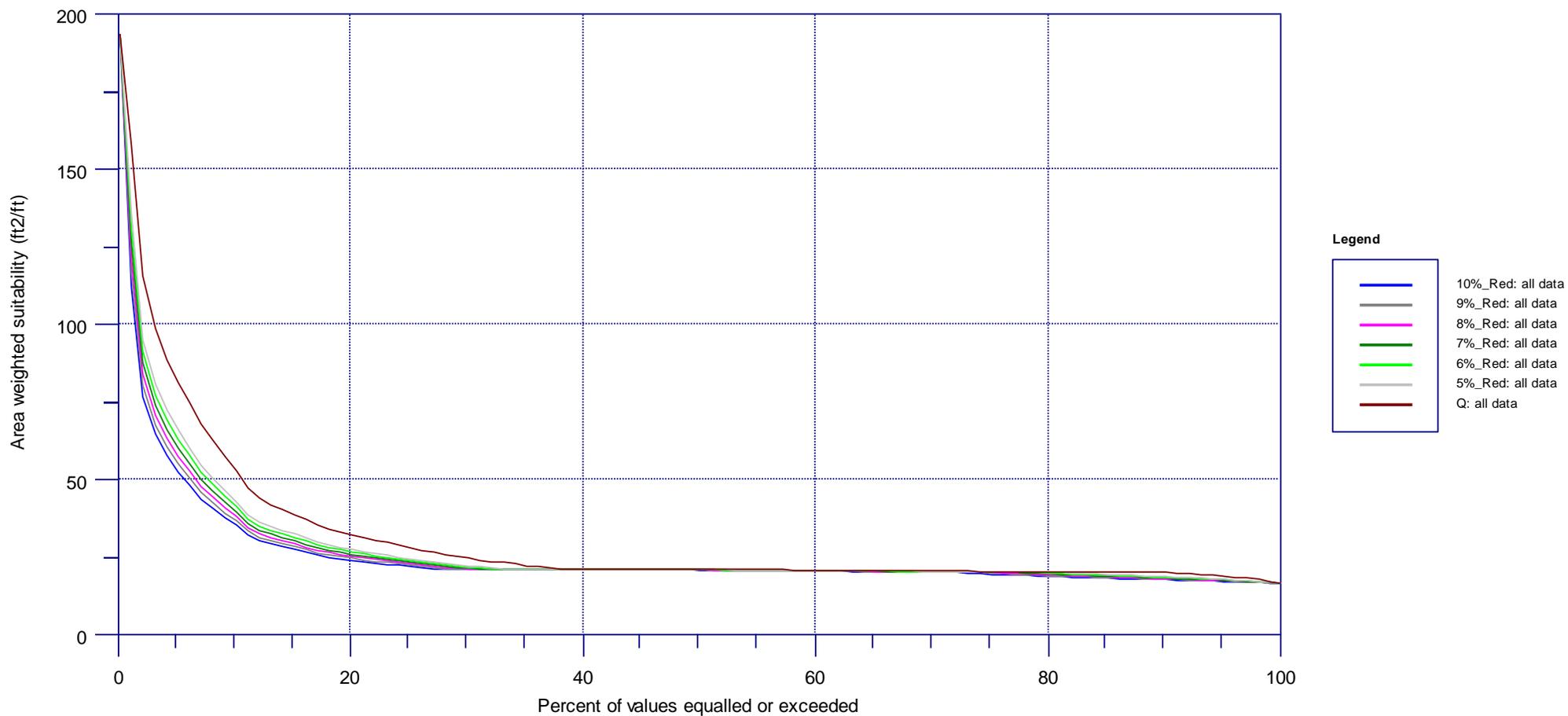
Figure A4. Area weighted suitability duration curves with historic discharge (Q) including the various percent reductions across the entire historical period of record for bluegill fry below the tram.

Figure A5. Area weighted suitability duration curves with historic discharge (Q) including the various percent reductions across the entire historical period of record for the shallow/slow habitat guilds below the tram.

APPENDIX D
MFL Translations

1.1. MFL Translations

The three Aucilla River MFLs referenced to the USGS gage at Lamont can be translated to the USGS gage location at Scanlon and the temporary Aucilla ADVM gage located downstream of Nutall Rise using regression equations developed for the common period flow records.

The respective flow reductions and thresholds at the Scanlon gage (Table 1) are:

- 6.5% up to 545 cfs to remain protective of estuarine habitat,
- 13% from 545 to 823 cfs to remain protective of riverine bank habitat, and
- 17% of flows greater than 823 cfs to remain protective or floodplain habitat.

The respective flow reductions and thresholds at the Aucilla ADVM gage (Table 1) are:

- 6.5% up to 1,075 cfs to remain protective of estuarine habitat,
- 13% from 1,075 to 1,371 cfs to remain protective of riverine bank habitat, and
- 17% of flows greater than 1,371 cfs to remain protective or floodplain habitat.

Table 1. MFLs Summary

	Threshold Habitat	Baseline Flow Range* (cfs)	Percent Time MFL is applicable	Range of Flow available (cfs)	Flow Reduction (%)
Scanlon	Estuarine	$\leq$545	72	<35	6.5
	Riverine	545-823	8	71-107	13
	Floodplain	>823	20	>140	17
Nutall Rise** (Aucilla ADVM)	Estuarine	$\leq$1,075	72	<70	6.5
	Riverine	1,075–1,371	8	140-178	13
	Floodplain	>1,371	20	>233	17

* Flow values for Scanlon were derived from Lamont using the regression equation $(Q_{Scanlon})$ = -0.000121*$(Q_{Lamont})^2$+1.48*(Q_{Lamont})+34.5. Flow range values for ADVM were derived from Lamont using the regression equation (Q_{ADVM}) = 1.4579*(Q_{Lamont}) + 557.02.

** The available water at the ADVM gage reflects the weighted average of available water at Scanlon and Wacissa so that the allowable reductions at Wacissa and Aucilla are not violated.

APPENDIX E

Sea Level Rise Results

7.0   SEA LEVEL RISE SCENARIO-HYDRODYNAMIC MODEL RESULTS

The Aucilla River hydrodynamic model was applied to simulate the effects of sea level rise on the baseline condition. The process used to determine the amount of rise followed that used by the SWFWMD for the Chassahowitzka River (SWFWMD, 2012; USACE, 2011) with the rise projected to 2035 instead of 2030. The intermediate projection of 5.1 inches was used in the model to develop the results summarized here. The rise scenario was achieved by increasing the boundary condition water surface elevation by this amount. All other model inputs were the same as used in the baseline scenario.

Volume, bottom area, and shoreline length corresponding to two selected salinity regimes (0-2 ppt and 0-5 ppt) were evaluated for a sea level rise of 5.1 inches.

- The maximum volume of 0-2 ppt salinity regime is 7% lower than the maximum volume of 0-2 ppt baseline condition.

- The average volume of the 0-2 ppt is 11.5% lower than average volume during the baseline condition (Figure 1).

- Similarly, the maximum and average volume of the 0-5 ppt salinity regime are 5.4% and 9.1% lower than during baseline condition (Figure 2).

- The 0-2 ppt salinity regime is more sensitive to sea level rise with greater reductions in volume and bottom area, while the 0-5 ppt salinity regime is more sensitive with greater reduction in shoreline length, when compared to the baseline condition (Table 2).

Table 2. Summary of Volume, Bottom Area, and Shoreline Length change due to sea level rise

	Baseline	Sea Level Rise	Baseline	Sea Level Rise	Baseline	Sea Level Rise
	Volume (cubic ft)		Bottom Area (Square ft)		Shoreline Length (ft)	
0-2 ppt	7,583,397	6,711,635	911,073	640,390	9,927	7,703
% Change from Baseline		11.5		29.7		22.4
0-5 ppt	12,202,837	10,927,095	1,415,159	1,270,914	16,200	12,221
% Change		10.4		10.2		24.5

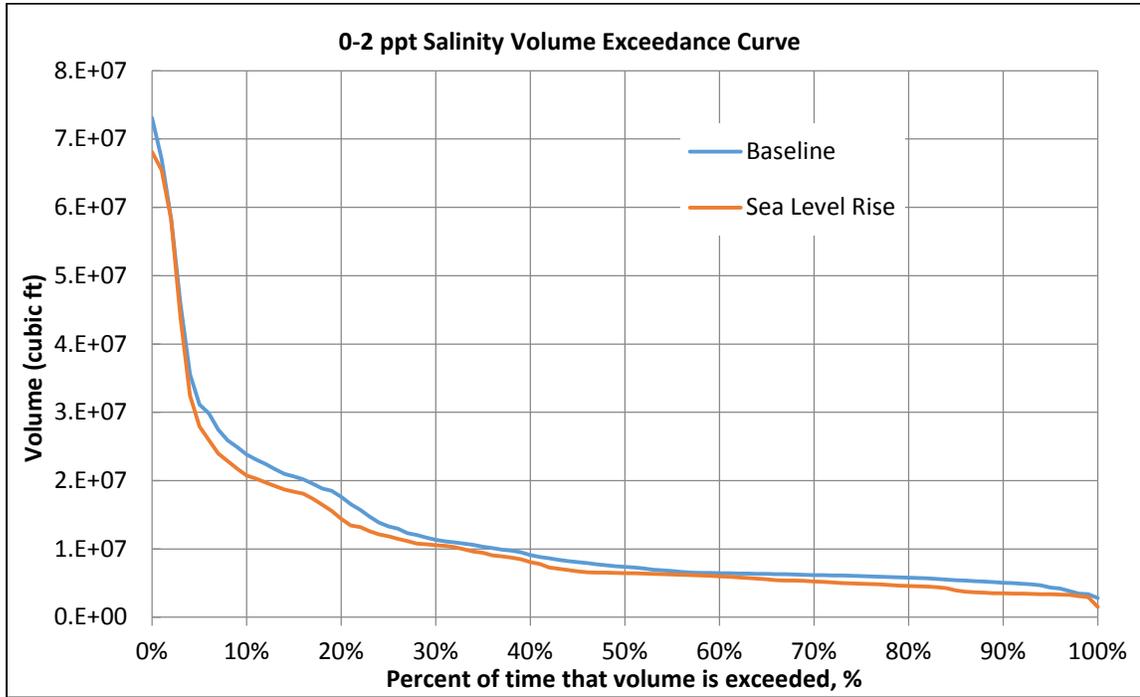| from Baseline					

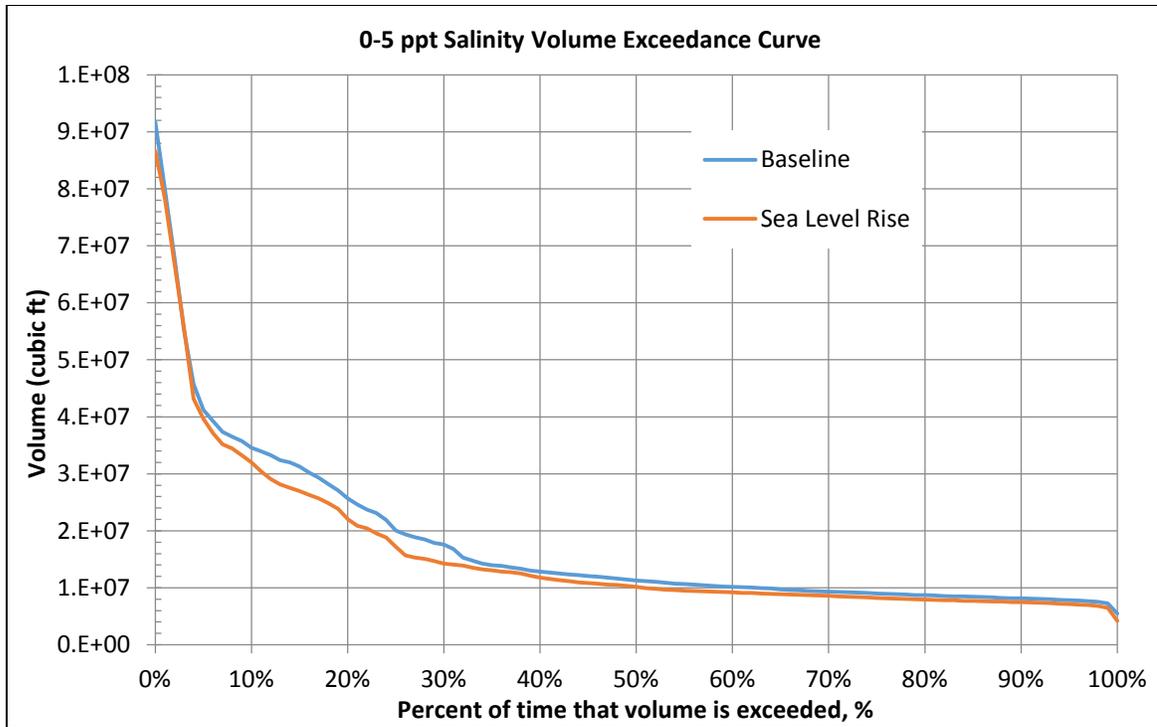Figure 1. Salinity volume exceedance curve (0-2 ppt)

Figure 2. Salinity volume exceedance curve (0-5 ppt)

USACE, 2011. Water Resource Policies and Authorities Incorporating Sea-Level Change Considerations in Civil Works Programs. Circular No. 1165-2-212
http://140.194.76.129/publications/eng-circulars/EC_1165-2-212_2011Nov/EC_1165-2-212_2011Nov.pdf

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October 30, 2012, Michael G. Heyl, Doug Leeper, Ron Basso
Southwest Florida Water Management District
Brooksville, Florida 34604-6899

and

Marty Kelly
(Formerly with Southwest Florida Water Management District)
With contributions by Balanced Environmental Management Systems, Inc.
Prime Contractor