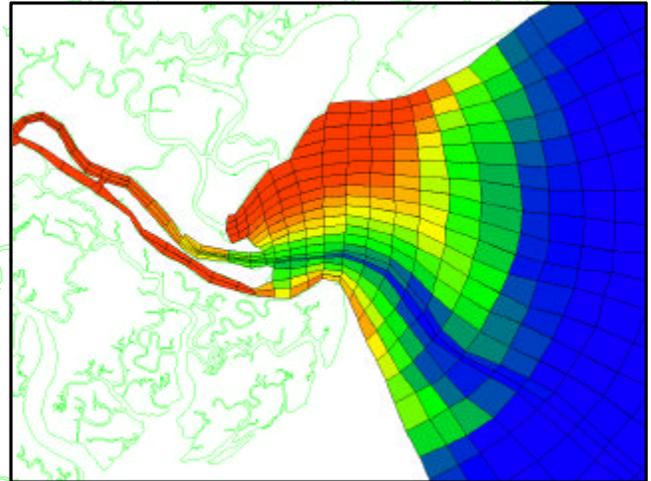


Development of the EFDC Hydrodynamic Model for the Savannah Harbor



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1.0 INTRODUCTION

Tetra Tech, Inc. (Tetra Tech) was contracted by the United States Environmental Protection Agency (USEPA) Region 4 to support the development of a Total Maximum Daily Load (TMDL) for dissolved oxygen in the Savannah Harbor Estuary. To support the development of the TMDL, Tetra Tech was tasked to setup a hydrodynamic model that met the following criteria:

- Able to capture the key hydrodynamic processes of transport in the estuary,
- Use a model that is public domain and the code has been peer reviewed on other TMDLs,
- Link the hydrodynamic model to a water quality model,
- Deliver the model to the federal agencies involved in the TMDL process,
- Run the model for multiple hydrologic periods to examine point and nonpoint sources, and
- Complete the effort in a timely manner to meet the consent decree schedule.

Tetra Tech has been supporting this effort since August 2003 and will continue to support the USEPA until the TMDL is completed in August 2004. In January 2004, the United States Corps of Engineers (USACE), Savannah District contracted with Tetra Tech to provide a hydrodynamic modeling report that fulfills the obligation of the “Evaluation of Savannah Harbor Estuary Models by Federal Agencies” (December 2003) and deliver the report in March 2004.

The hydrodynamic modeling described herein has been a major effort in a very short duration to meet the expectations of the USEPA and USACE. The model code, modeling results, in both time series and statistical formats, and a database, which contains model comparison data are all readily available for peer review and are delivered with this report.

1.1 *Hydrodynamic Modeling Study Goals*

Ultimately, the modeling goals of the hydrodynamic model are to develop a defensible, accurate, and logistical tool for the Federal and State Agencies to make management decisions for the Savannah Harbor. In providing this management tool, several modeling aspects are important such as the selection of the model, model application, and technology transfer to the appropriate groups.

The calibration period was selected to be the 1997 and 1999 datasets collected by the Georgia Ports Authority (GPA). Since the hydrodynamic modeling parameters were not modified year to year or month to month, the 1997 and 1999 datasets were treated equally with respect to calibrating the hydrodynamics. USGS stations located in the lower Savannah River and Estuary were used to confirm the model’s ability to predict water surface elevation and salinity for longer periods of time. For this report, the 1997 through 2000 time period was used as the model confirmation. Once the 2001, 2002, and 2003 data are obtained for the harbor stations, the model can be run to confirm the model’s response as the Savannah basin responded to increased rainfalls in late 2002 and early 2003. Georgia experienced a 5-year drought from 1998 through 2002 (Barber and Stamey, 2000-2002).

1.2 *Coordination with the Water Quality Model Calibration*

The selection of the hydrodynamic model was done so with the intent of linking the hydrodynamics to a water quality model. The parameters that the hydrodynamic model passes to the water quality model are volume, depth, dispersion, salinity, temperature, and vertical mixing parameters to a water quality model. The linkage is critical for passing the information to a water quality model because the transport processes in the system determine the fate and transport of water quality constituents.

1.3 Report Contents

In addition to the report, there are two compact discs included in the back of the report. The compact discs include the following:

- Modeling report in PDF format,
- EFDC model code,
- EFDC model input files,
- Savannah Harbor model output for 1997 and 1999,
- Savannah Harbor model output for 1997 through 2000,
- Database files of calibration data,
- GIS shape files, and
- MOVEM post-processor.

The MOVEM post-processor will allow the Federal Agencies and technical reviewers to view the EFDC model results anywhere in the model domain and compare with measured data. MOVEM also has the functionality to calculate statistics, including percentiles, and animate parameters with the model grid. For calculating statistics, MOVEM can window in on a defined time period to generate the results. The datasets included on the compact discs are for the summers of 1997 and 1999 in addition to the USGS data for 1997 through 2000.

1.4 Project Location

The model development described in this report is located near Savannah, Georgia and is on the border between Georgia and South Carolina. The hydrodynamic model extends upstream on the Savannah River to river mile 61.0 near Clyo, Georgia at USGS station 02198500. The downstream end of the model extends approximately 19 miles offshore from Oyster Island to cover the navigational channel of Savannah Harbor. Figure 1-1 shows the model extents and overall location map of the study area.

The modeling study covers the Savannah River, the Front River, the Middle River, the Little Back River, the Back River, the South Channel, and the offshore portions in the Atlantic Ocean.

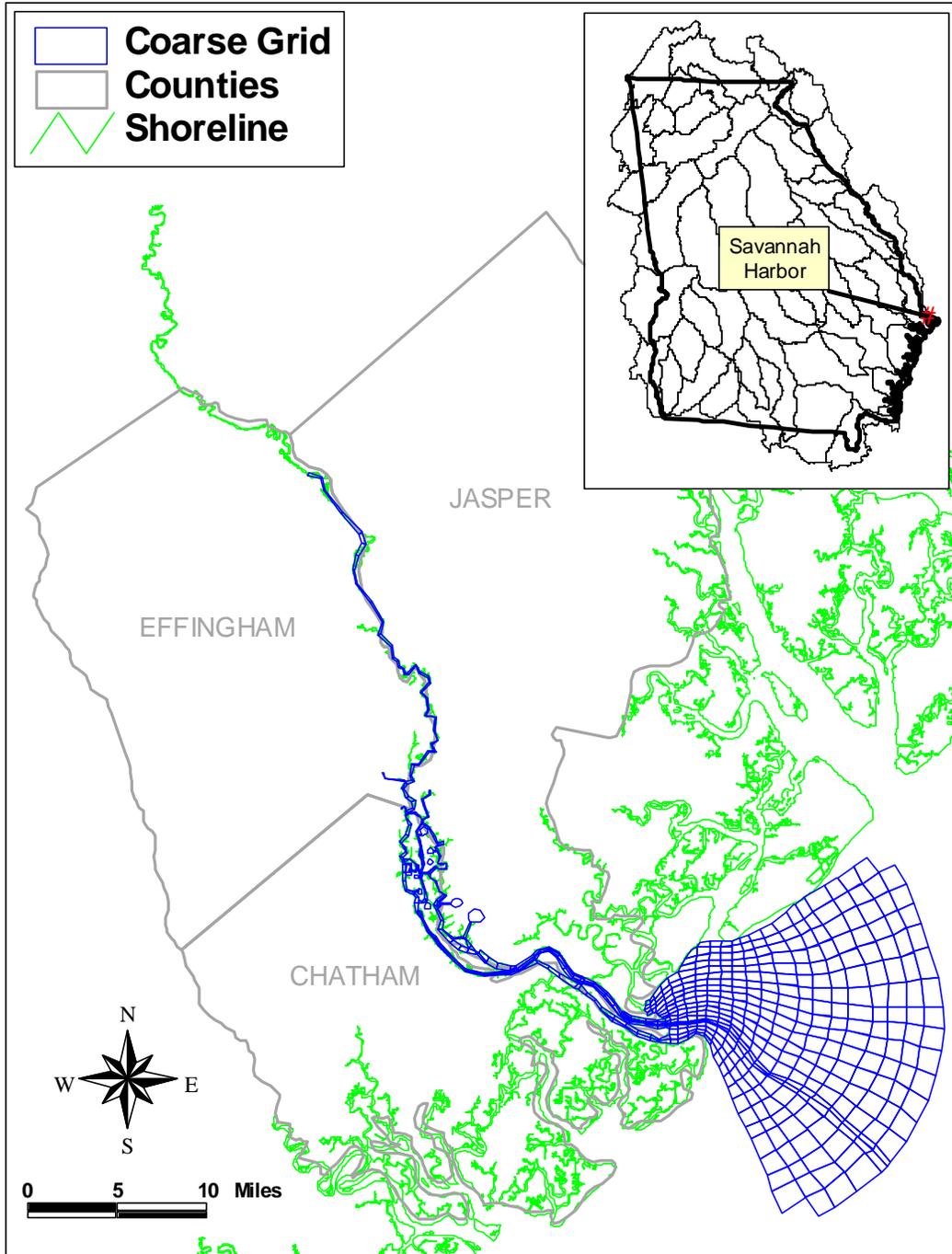


Figure 1-1 Project Location Map of the Savannah Harbor Estuary

2.0 DATA ANALYSIS

The data used in the calibration and confirmation of the model were collected by the Georgia Ports Authority (GPA), the USGS, the Georgia Environmental Protection Division (GAEPD), the USACE, and the USEPA. An extensive amount of work has been completed to date on the data reporting and analysis by Applied Technology and Management, Inc. (ATM, 2000).

2.1 Location of Stations

The main stations used in the calibration were from the GPA studies in 1997 and 1999. Figure 2-1 shows the locations of the USGS stations and Figure 2-2 shows the locations of the 1997 and 1999 stations. Table 2-1 gives an overall list of the locations of these stations and the vertical placement in the water column which will be critical for the salinity calibration in the subsequent sections. The Clyo flow gage is not shown in Figure 2-1.

Table 2-1 Description of USGS/GPA Stations in the Savannah River Estuary

| Station ID | Station Description | River Mile | Agency | Parameters | 1997 Location ¹ | 1999 Location ¹ |
|------------|------------------------------------|------------|--------|-------------|----------------------------|----------------------------|
| BR-05 | Back River at Hwy 17 | 14.5 | GPA | S, T, WL | Bottom | Bottom |
| FR-02 | Front River | 4.5 | GPA | S, T, WL | Surface & Bottom | Surface & Bottom |
| FR-04 | Front River | 10.4 | GPA | S, T, WL, C | Surface & Bottom | Surface & Bottom |
| FR-06 | Front River | 16.6 | GPA | S, T, WL, C | Surface & Bottom | Surface & Bottom |
| FR-08 | Front River | 20.5 | GPA | S, T, WL, C | Surface & Bottom | Surface & Bottom |
| FR-09 | Front River | 21.5 | GPA | S, T, WL | Bottom | Surface & Bottom |
| FR-11 | Front River | 24.7 | GPA | S, T, WL | Bottom | |
| FR-11R | Front River, Revised 1999 | 23.4 | GPA | S, T, WL | | Bottom |
| FR-21 | Front River | 13.9 | GPA | S, T, WL | | Surface & Bottom |
| FR-22 | Front River | 18.7 | GPA | S, T, WL | | Surface & Bottom |
| FR-26 | Front River | 0.8 | GPA | S, T, WL | | Surface & Bottom |
| BR-07 | Back River | 18.9 | GPA | S, T, WL | Bottom | Surface |
| LBR-13 | Little Back River | 26.6 | GPA | S, T, WL | Bottom | |
| LBR-15 | Little Back River | 20.9 | GPA | S, T, WL | Mid-Depth | Surface |
| MR-10 | Middle River | 21.8 | GPA | S, T, WL | Bottom | Surface |
| MR-12 | Middle River | 24.4 | GPA | S, T, WL | Bottom | |
| MR-12R | Middle River, Revised 1999 | 23.7 | GPA | S, T, WL | | Surface |
| SC-03 | South Channel | 5.5 | GPA | S, T, WL | Bottom | Bottom |
| SR-14 | Savannah River | 27.7 | GPA | S, T, WL | Bottom | Bottom |
| 02198920 | Front River at Houlihan Bridge | 21.5 | USGS | S, WL | Mid-Depth ² | Mid-Depth ² |
| 02198977 | Front River at Broad Street | 14.6 | USGS | WL | Mid-Depth ² | Mid-Depth ² |
| 02198980 | Front River at Fort Pulaski) | 0.8 | USGS | WL | Mid-Depth ² | Mid-Depth ² |
| 021989784 | Little Back River at Lucknow Canal | 24.2 | USGS | S | Mid-Depth ² | Mid-Depth ² |
| 02198979 | Little Back River at Limehouse Cr | 24.1 | USGS | WL | Mid-Depth ² | Mid-Depth ² |
| 021989791 | Little Back River at USF&W Dock | 22.1 | USGS | S | Mid-Depth ² | Mid-Depth ² |
| 02198500 | Savannah River near Clyo, GA | 61.0 | USGS | Q | Mid-Depth ² | Mid-Depth ² |
| 02198840 | Savannah River at I-95 Bridge | 27.7 | USGS | S, WL | Mid-Depth ² | Mid-Depth ² |

NOTES: Parameters - S=Salinity, T=Temperature, WL=Water Level, C=Currents, Q=Flow
 1. Location is describing vertical water column location.
 2. Mid-Depth = 2.7 feet below Mean Low Water (MLW).

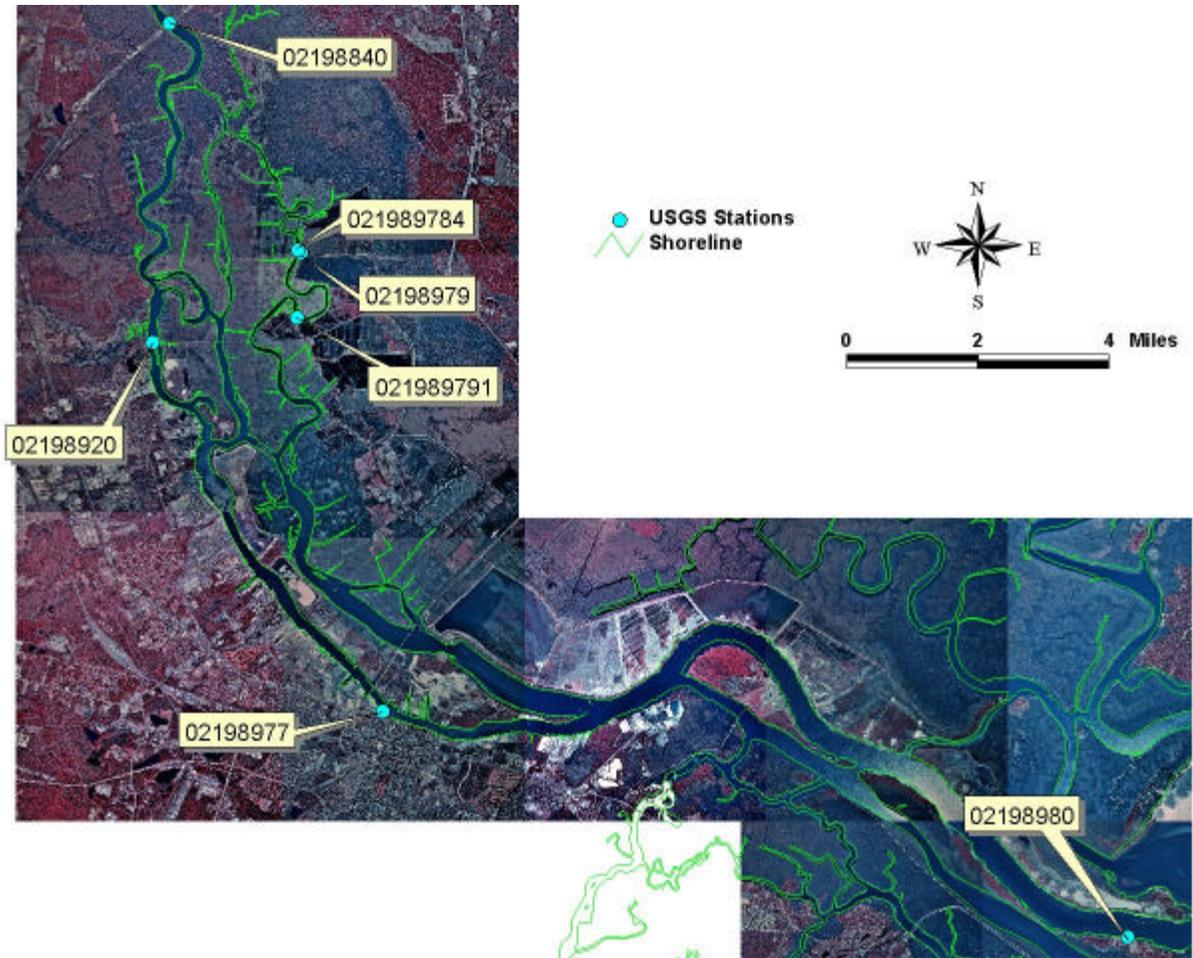


Figure 2-1 Location Map of USGS Stations in the Savannah Harbor Estuary

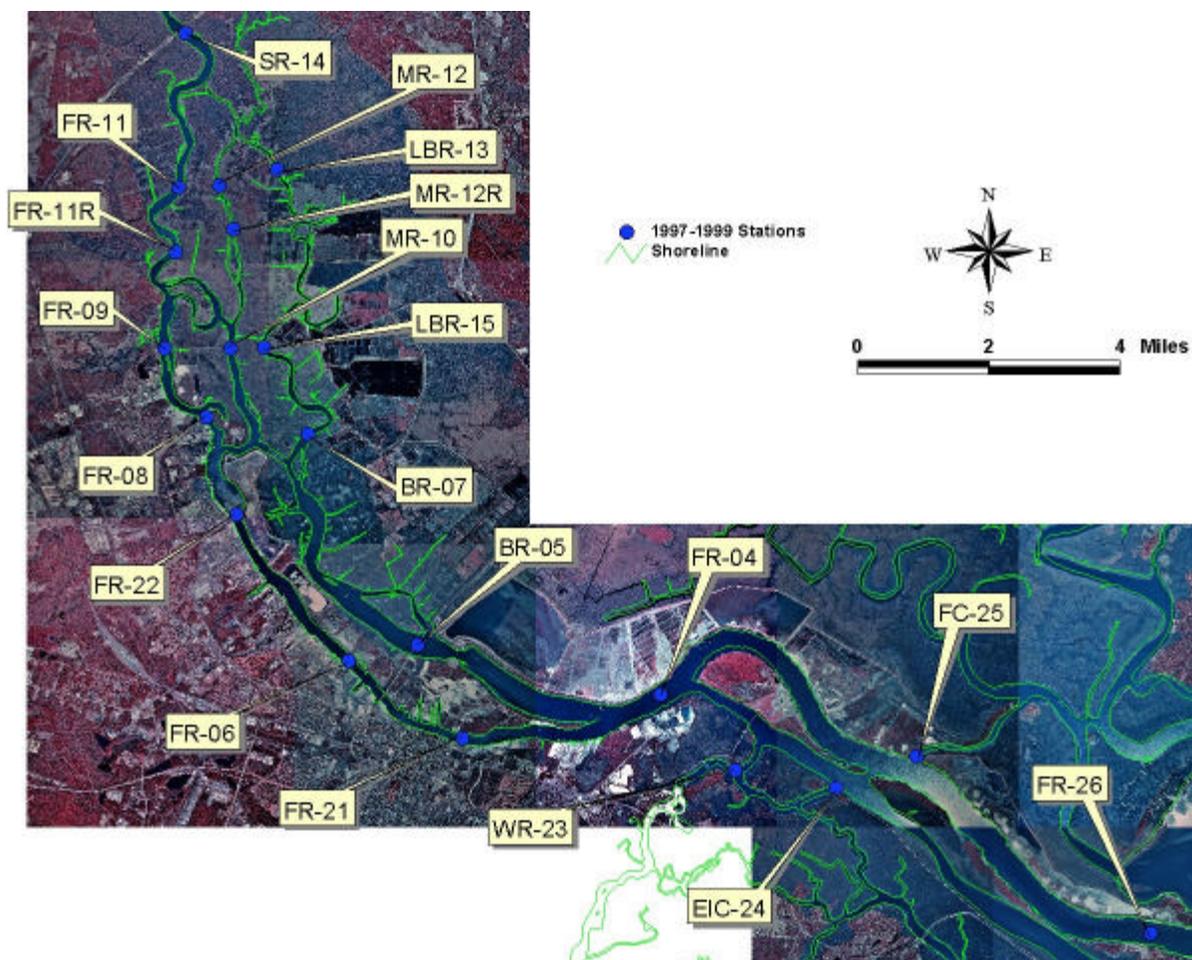


Figure 2-2 Location Map of 1997 & 1999 Stations in the Savannah Harbor Estuary

2.2 Database

The Water Resources Database (WRDB) was used to archive, analyze, and pull data into the model post-processor. WRDB is a comprehensive data storage system capable of handling a vast amount of data, accommodating a wide variety of data types and diverse information, and presenting data conveniently and efficiently. WRDB was originally developed by the Georgia Environmental Protection Division (GAEPD) in association with USEPA Region 4 to address the imposing data management challenges presented by the Chattahoochee River Modeling Project. Since its inception, WRDB has been enhanced a number of times and applied to numerous projects in Region 4. A main goal of the system has been to provide data management and analysis tools to users possessing an assortment of professional specialties and a variety of software skill levels. Figure 2-3 is an example of a screen shot of the Savannah WRDB and is delivered on the compact discs included with this report.

WRDB was originally delivered to the Federal Agencies as part of ATM's data report. Since that time, USEPA Region 4 and Tetra Tech have not only made extensive updates to the program itself, but also to the datasets within the Savannah WRDB. There were several issues with the existing database, such as noon times were input as midnight, currents were considered to be positive with ebb and flood flows, and invalid salinity time series records. Additionally, the USGS data from 1997 through 2000 were input into the Savannah WRDB for salinity and water surface elevation. The water surface elevation data were corrected to the National Geodetic Vertical Datum (or Mean Sea Level of 1929) based on USGS report adjustments (Stokes, 2002).

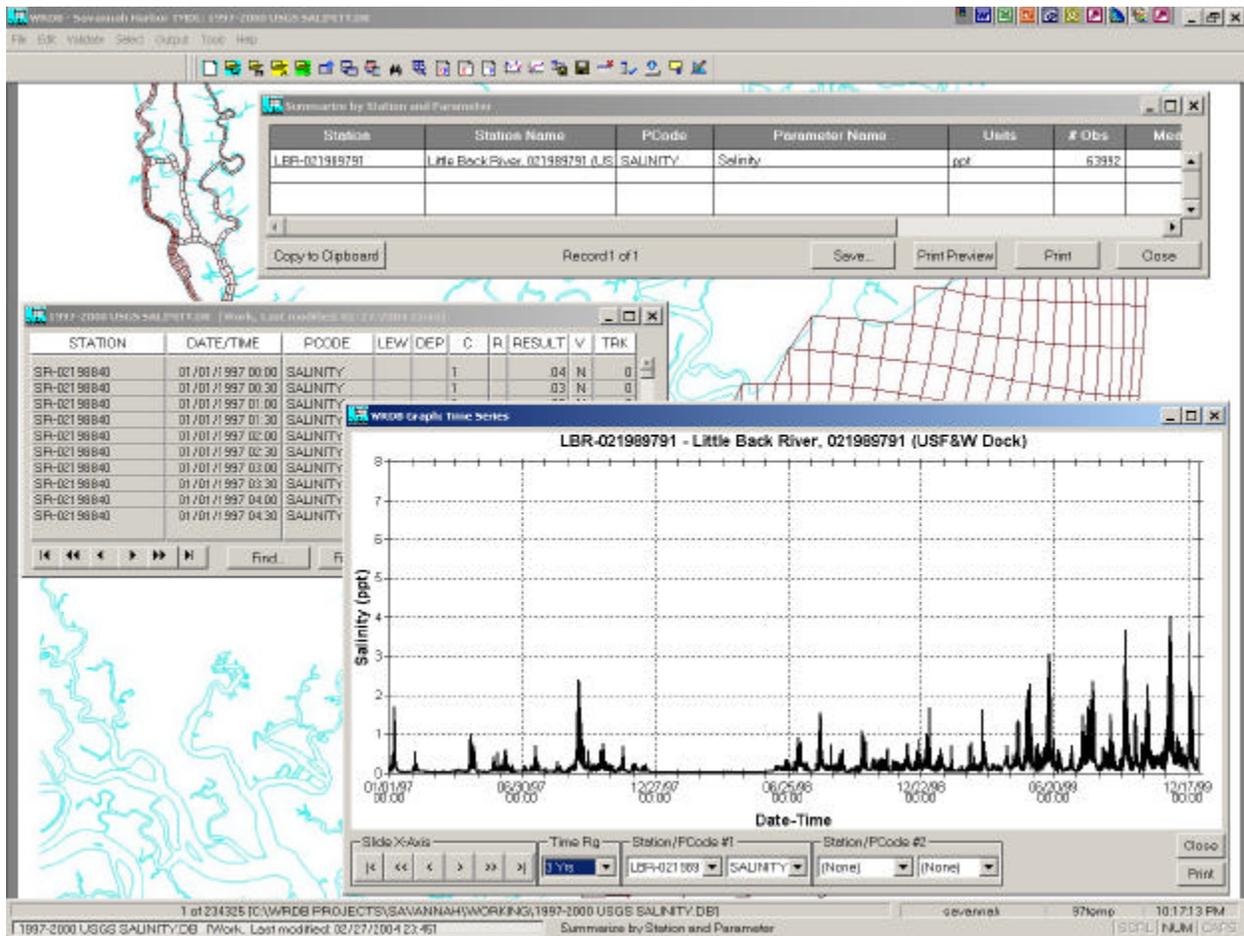


Figure 2-3 WRDB Developed for Savannah Harbor

2.3 Hydrology

The Clyo flow gage (USGS 02198500 – Savannah River near Clyo, GA) was used to evaluate the fresh water sources of water into the lower riverine and estuarine sections of the Savannah River. Tetra Tech gathered all of the available flow data from the USGS gage at Clyo. The flows at this location are regulated by Thurmond Lake (see station 02194500), and by other power plants above the station. The Clyo station is the closest flow gage to the upper end of the estuary and was used as the upstream boundary.

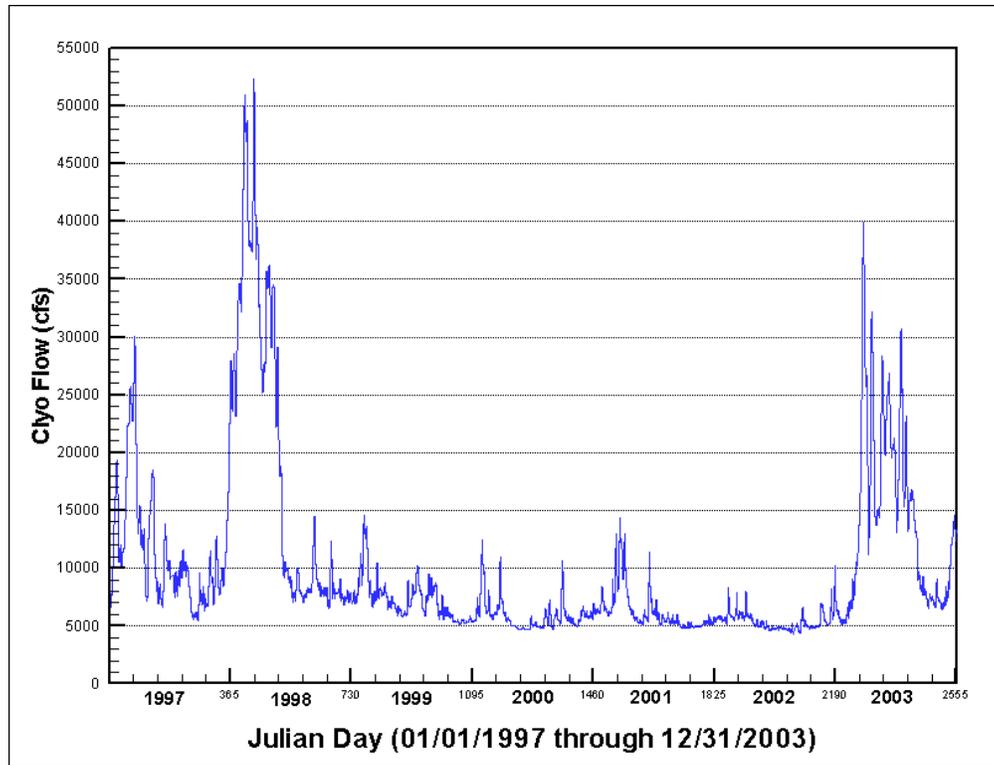


Figure 2-4 Clio Flow Data for Model Development Period

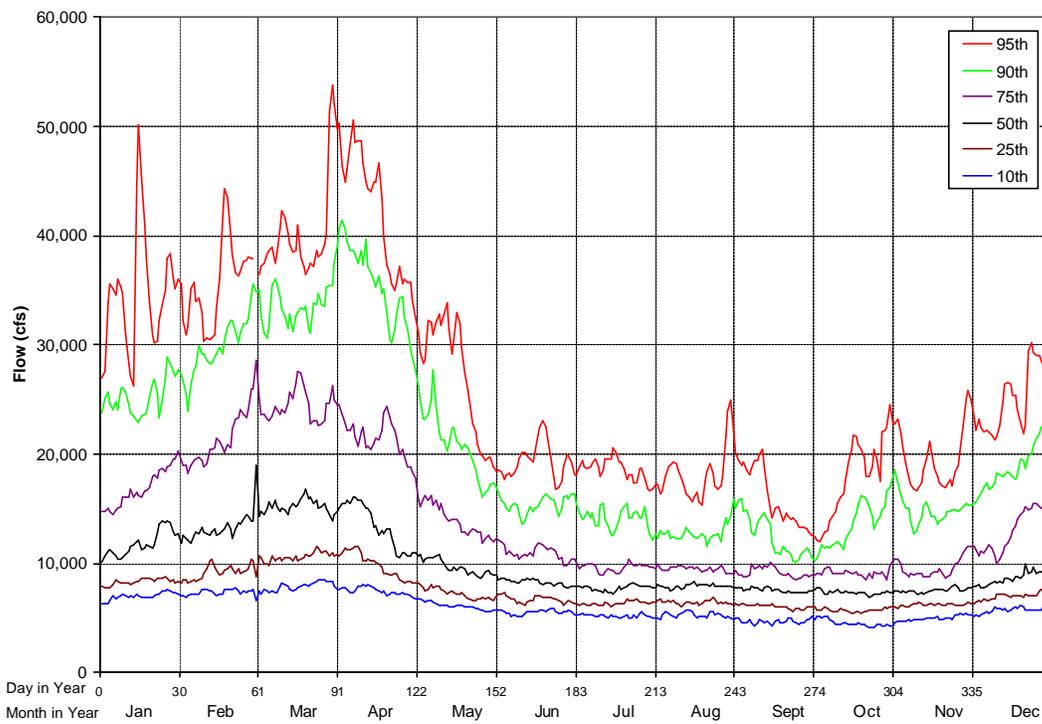


Figure 2-5 Clio Flow Percentiles for the Period of Record (1929 to present)

2.4 Currents

The phasing between water surface elevation and velocity was analyzed in order to determine the degree of reflection of the tidal wave entering the Savannah estuary. Both the measured data and the model results were analyzed at stations that have simultaneous measurements of water surface elevation and currents. The stations were FR-04 and -08 during the summer of 1997 and stations FR-04 and -06 during the summer of 1999. The analysis was done considering only the M2 component of the tide. The amplitude and phase of the M2 component of the time series of water surface elevation and velocity were obtained by harmonic analysis using the least square procedure. Before the harmonic analysis the data was filtered to remove non-astronomical low frequency (air pressure induced, wind setup, resonant oscillation, and storm surge) components.

Figure 2-6 shows the comparison between the M2 component of water surface elevation and velocity at FR-04. The amplitude shown in Figure 2-6 is the normalized amplitude $a/|a|$ in order to show just the phasing. Appendix A shows a comparison of model versus data at FR-04 and -08 for 1997 and FR-04 and -06 for 1999.

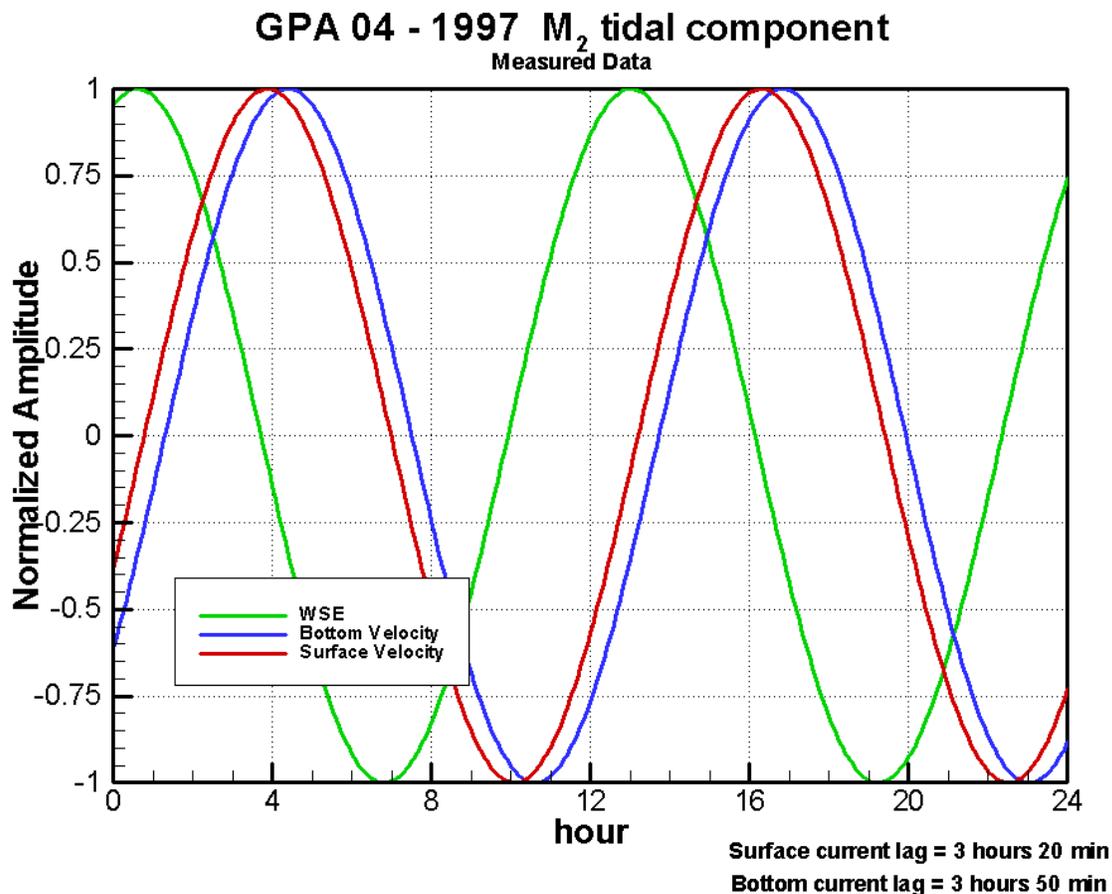


Figure 2-6 Tidal Harmonic Analysis at FR-04 for 1997

2.5 Salinity Intrusion

By examination of the 1997 and 1999 salinity data where surface and bottom data are available, it is evident that vertical stratification occurs. Stratification occurs when there are more saline waters (more

dense) on the bottom and fresh waters (less dense) overlying, therefore, causing a “salt wedge” in the vertical. Vertical mixing is decreased when this occurs. For turbulent mixing to begin, the tidal energy in the system must be raised to increase the potential energy of the water column (Fischer, 1979). Figure 2-7 proves the effect of less tidal energy with the display of water velocity (currents) on the left-hand axis and salinity for surface and bottom measurements on the right-hand axis. The comparisons were made to compare FR-04 and -06 during 1999 because this is the best data signal of combined currents and salinity for 1997 and 1999. It is obvious from Figure 2-7 that the stratification events occur sharply on August 16, 1999 and September 14, 1999. Then as the neap tide decreases and the spring tide increases, there is a subsequent increase in tidal velocity that overcomes the energy in the stratified environment which then mixes the vertical water column.

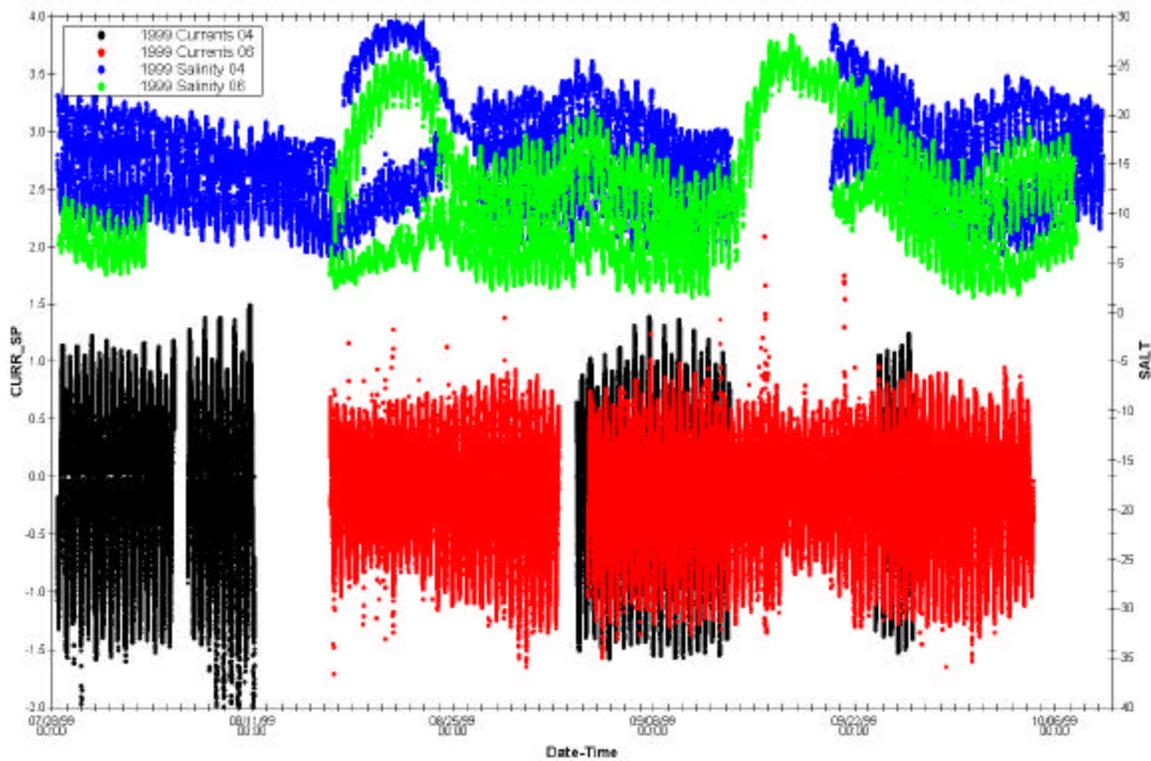


Figure 2-7 Salinity Stratification and Destratification Due to Neap and Spring Tidal Events at FR-04 and -06

3.0 EFDC HYDRODYNAMIC MODEL

3.1 Selection of Model

For the hydrodynamic model development for the Savannah Harbor Estuary, it was critical to both clients (USACE and USEPA) that the model must meet the expectations discussed in the introduction section of this document. The Environmental Fluid Dynamics Code (EFDC) was selected to perform the hydrodynamic simulations because it was able to fulfill all of the requirements presented in the goals of the study. EFDC has been applied on many waterbodies within USEPA Region 4 for TMDL and permitting modeling projects including complex systems such as Mobile Bay AL, Neuse River and Estuary NC, Brunswick Harbor GA, Fenholloway River and Estuary FL, Loxahatchee River and Estuary FL, Indian River Lagoon FL, Lake Worth Lagoon FL, Florida Bay, Lake Okeechobee FL, Cape Fear River NC, and St. Johns River FL. EFDC has proven to capture the complex hydrodynamics in similar systems such as Savannah Harbor and is currently being applied by Tetra Tech in the Charleston Harbor SC.

The EFDC model is included in the USEPA TMDL Modeling Toolbox as a result of many TMDL-type projects. Therefore, the code has been peer reviewed and tested and has been freely distributed and supported by Tetra Tech. EFDC was developed by Dr. John Hamrick and is currently supported by Tetra Tech for USEPA ORD, USEPA Region 4, and USEPA Headquarters. The EFDC model is nonproprietary and publicly available through USEPA Region 4 and USEPA ORD from the Watershed and Water Quality Modeling Technical Support Center (<http://www.epa.gov/athens/wwqtsc/index.html>). The models, tools, and databases in the TMDL Modeling Toolbox are continually updated and upgraded through TMDL development in Region 4. Tetra Tech is currently supporting the development of the toolbox with a grid generator and EFDC pre-processor (EFDCview).

With many of the EFDC applications in Region 4 being tied to the regulatory TMDL process, Tetra Tech has delivered the model to state and federal personnel to run the model for regulatory management decisions.

Although a number of models provide some of the features necessary for modeling hydrodynamics, water quality, and sediment transport in the Savannah River Estuary, the EFDC hydrodynamic and sediment transport model linked with the WASP water quality model provides the most appropriate combination of features necessary for this study.

3.2 History of Model

The EFDC model comprises an advanced three-dimensional surface water modeling system for hydrodynamic and reactive transport simulations of rivers, lakes, reservoirs, wetland systems, estuaries and the coastal ocean. The modeling system was originally developed at the Virginia Institute of Marine Science as part of a long-term research program to develop operational models for resource management applications in Virginia's estuarine and coastal waters (Hamrick, 1992). Since the EFDC model is public domain, with current users including universities, governmental agencies and engineering consultants. The following sub-sections describe the model's capabilities and previous applications and its theoretical and computational formulations.

The EFDC model's hydrodynamic model component is based on the three-dimensional shallow water equations and includes dynamically coupled salinity and temperature transport. The basic physical process simulation capabilities of the EFDC hydrodynamic component are similar to those of the Blumberg-Mellor or POM model (Blumberg & Mellor, 1987), the U.S. Army Corps of Engineers' (USACOE) CH3D-WES model (Johnson, et al., 1993), and the TRIM model. Notable extensions to the EFDC hydrodynamic model include representation of hydraulic structures for controlled flow systems,

vegetation resistance for wetland systems (Hamrick and Moustafa, 1996), and high frequency surface wave radiation stress forcing for nearshore coastal simulations.

EFDC is a multifunctional, surface-water modeling system, which includes hydrodynamic, sediment-contaminant, and eutrophication components. The EFDC model is capable of 1, 2, and 3D spatial resolution. The model employs a curvilinear-orthogonal horizontal grid and a sigma or terrain following vertical grid. The EFDC model's hydrodynamic component employs a semi-implicit, conservative finite volume-finite difference solution scheme for the hydrostatic primitive equations with either two or three-level time stepping. (Hamrick, 1992). The semi-implicit scheme is based on external mode splitting with the external mode being implicit with respect to the water surface elevation and the internal mode being implicit with respect to vertical turbulent momentum diffusion. Advective and Coriolis-curvature accelerations in both the external and internal modes are represented by explicit conservative formulations. Salinity and temperature transport are simultaneously solved with the hydrodynamics and dynamically coupled through an equation of state. The hydrodynamic component includes two additional scalar transported variables, a reactive variable which can be used to represent dye or pathogenic organisms, and a shell fish larvae variable which includes a number vertical swimming behavior options. Scalar transport options include a number of high accuracy advection schemes including flux corrected MPDATA and flux limited COSMIC. Additional hydrodynamic component features include, the Mellor-Yamada turbulence closure formulation, simulation of drying and wetting, representation of hydraulic control structures, vegetation resistance, wave-current boundary layers and wave induced currents, and dynamic time stepping. An embedded single and multi-port buoyant jet module is included for coupled near and far field mixing analysis.

The EFDC hydrodynamic model can run independently of a water quality model. The EFDC model simulates the hydrodynamic and constituent transport and then writes a hydrodynamic linkage file for a water quality model such as the WASP6 model. This model linkage, from EFDC hydrodynamics to WASP6 water quality, has been applied on many USEPA Region 4 projects in support of TMDLs and has been well tested (Wool, 2003). EFDC is also directly linked to Waterways Experiment Station CEQUAL-ICM.

3.3 Peer Review

All components of the EFDC model have been extensively validated over the course of the model's 15-year existence with more than 80 applications. The model has been extensively peer reviewed as evidenced by 12 peer reviewed journal articles and 17 peer reviewed conference proceedings articles.

3.4 Technology Transfer

The technology transfer will occur with the distribution of this report. There are two compact discs (CDs) included in the back of the report. The Savannah Harbor WRDB database is on CD1 that includes most of the model comparison data files. On CD2, the EFDC model input files, model code, model output files, model executables, and GIS files are included. The EFDC model output and database files can be viewed in a post-processor called the Model Visualization Enhancement Module (MOVEM). There was a significant amount of effort by USEPA Region 4, USPEA ORD, and Alex Comer (software developer) to include the modeling statistics and percentiles in the MOVEM post-processor so that the Federal Expectations criteria can be examined directly by the technical reviewers.

4.0 APPLICATION TO THE SAVANNAH RIVER

The Savannah River Estuary is a highly complex estuarine system characterized by a branching channel network and extensive intra-tidal marsh areas. The combinations of a moderately energetic tidal environment and significant river basin drainage area result in a highly variable salinity regime that is a characteristic of stratified estuaries. Vertical density stratification significantly influences dissolved oxygen dynamics while both stratification, the landward intrusion of salinity, and the associated sub-tidal residual circulation strongly influence sedimentation dynamics. The complexities of the branching channel system dynamically coupled with the intra-tidal marshes result in complex current amplitude and phase distributions, which further complicate the transport dynamics of the system. Increasing the depth of the navigational channel can impact local vertical mixing, increase landward salinity intrusion, and alter existing patterns of sediment deposition and resuspension.

Predicting the transport of salinity, sediment, and water quality constituents in the Lower Savannah River necessitates the use of a three-dimensional modeling system, which includes hydrodynamic, sediment transport, and water quality components. The branching channel system and the presence of intra-tidal marshes further require a modeling system capable of representing complex open water regions dynamically coupled with marshes which dry and wet during the tidal cycles.

4.1 Simulation Period

The EFDC modeling files were developed to be able to run the model for six years. The input files start on January 1, 1997 and were extended through December 31, 2002. The model can be run for any time period during those dates with an appropriate spin-up period of 45 days.

4.2 Model Grid and Bathymetry

The bathymetry data were obtained from the USACE and the USEPA based on the agreed upon configuration that were measured in 1999. The data were given to Tetra Tech already corrected to NGVD in meters. The bathymetry data were then extrapolated into the grid to represent a vertical depth for every horizontal grid cell in the model.

Two grids were developed for the Savannah Harbor application, a coarse and fine grid. The coarse grid was developed to capture the key hydrodynamic transport processes such as vertical mixing, influence of fresh water flows, and flow distribution and connections. The coarse grid has 655 horizontal grid cells with six vertical layers for a total of 3,930 grid cells in the coarse EFDC model. The fine grid has 1,368 horizontal grid cells with eight vertical layers for a total of 10,944 in the fine EFDC model. The coarse grid is shown in Figure 4-1 and the fine grid in Figure 4-2. Due to the goals defined in the Introduction, it was determined that the coarse grid was performing well enough to capture the stratification and destratification process; could be run for longer hydrological periods; and could have reasonable run times for management scenarios once it was delivered to the various agencies. The fine grid model has not been calibrated to the extent of the coarse grid model calibration, which included bathymetric and friction adjustments and the addition of marsh areas. The results of the fine grid EFDC model are presented in Appendix L and should be viewed only as preliminary. From this point forward, the coarse grid calibration and confirmation are presented as the model that will be reviewed and linked to the WASP water quality model.

Bottom elevation was put in the model based on the 1999 survey data in the harbor and based on river cross-sections in the upper extents of the grid. The invert of the model at Clio is at +0.5 meters NGVD with the invert of the harbor near -15 meters. The slope change from Clio to the I95 Bridge is

approximately six meters with an additional nine meters to the Front River and Back River confluence near Fort Jackson. The bottom elevation can be reviewed in the “dxdy.inp” file.

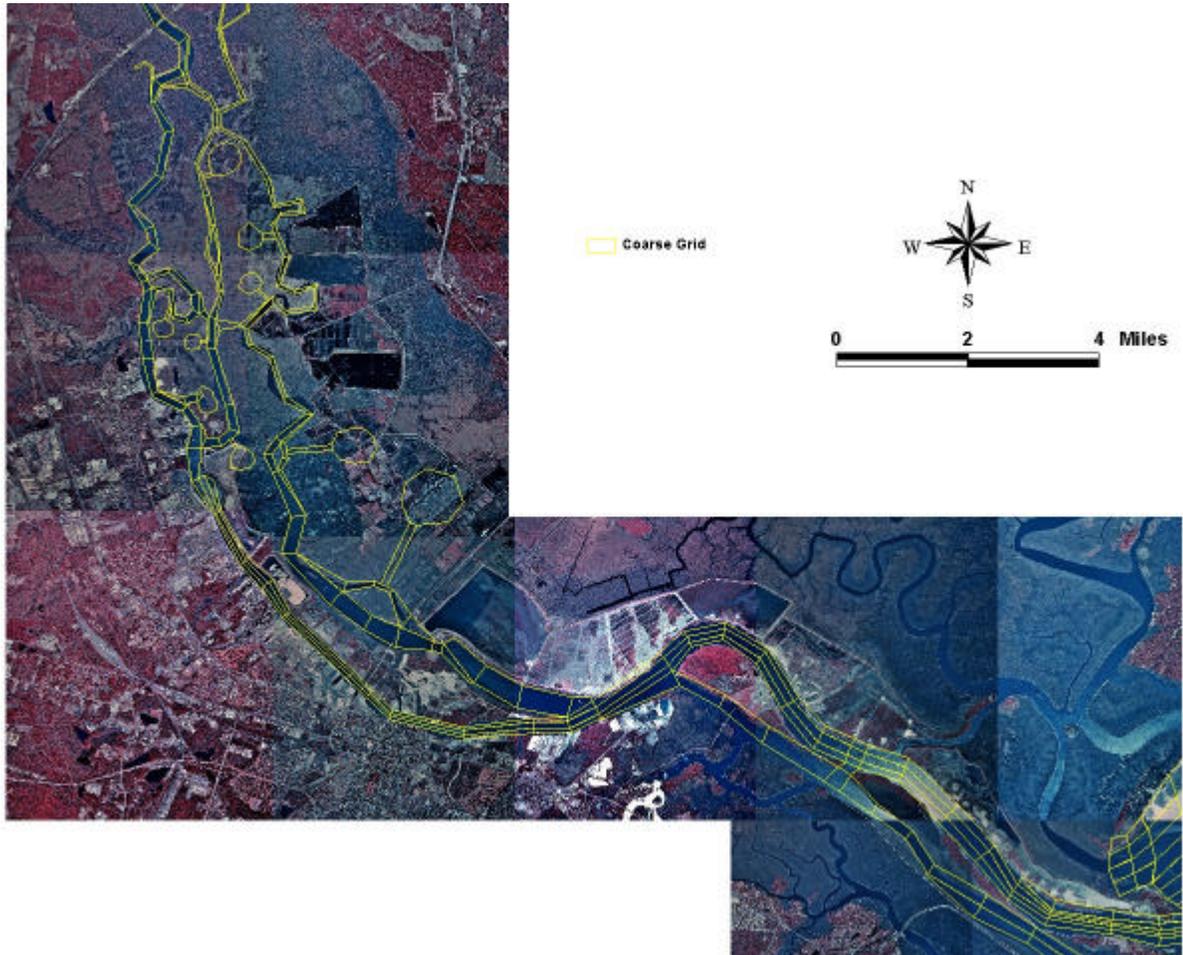


Figure 4-1 Coarse EFDC Grid

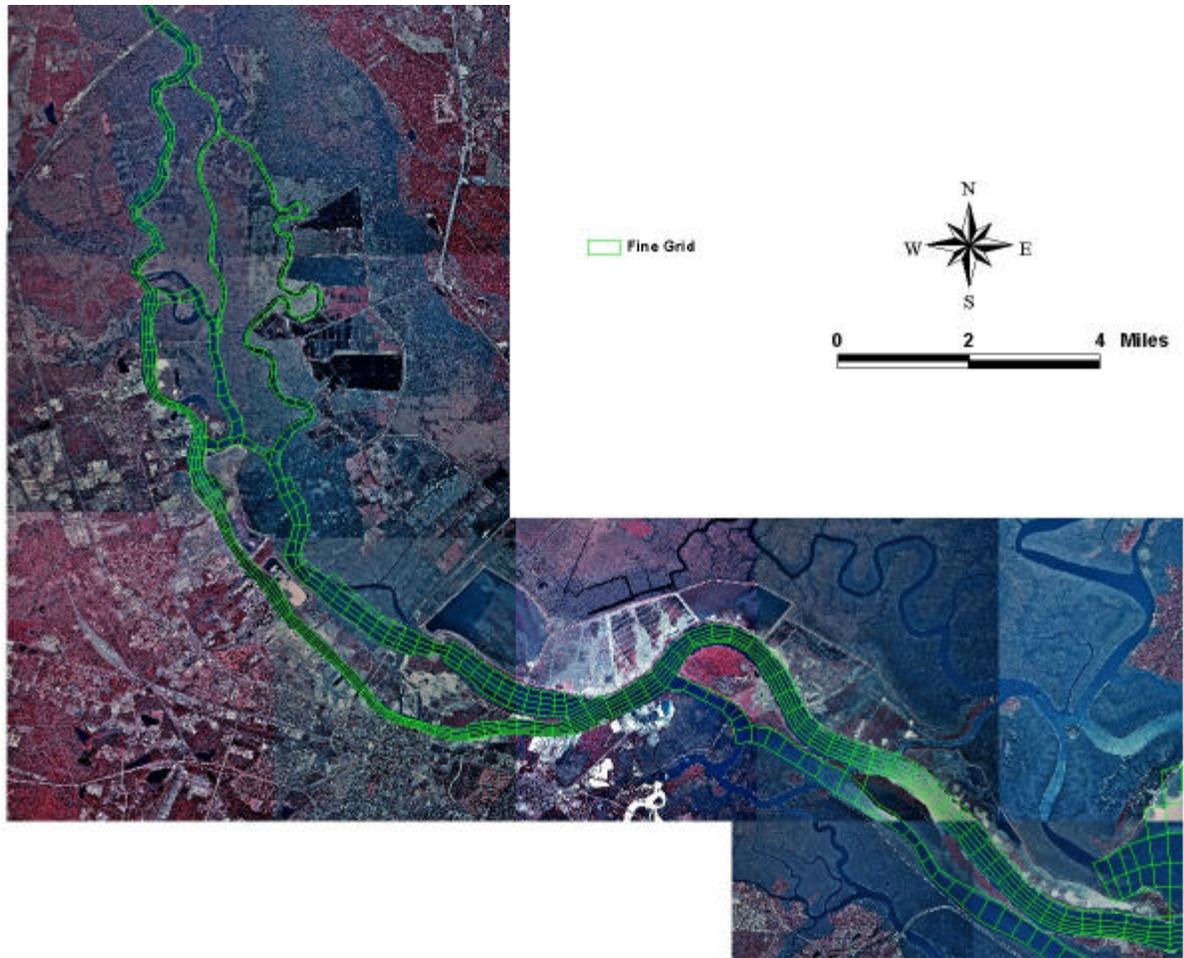


Figure 4-2 Fine EFDC Grid

4.3 Model Coefficients

The main EFDC modeling coefficients are bottom friction, bathymetry, and vertical mixing.

4.3.1 Bottom Roughness

The bottom roughness of the EFDC Savannah Harbor model was applied spatially in the grid domain with values ranging from 0.01 to 0.28 m. Bottom roughness is different from a friction coefficient because it is the logarithmic boundary layer roughness height in meters. The solution of the momentum equations requires the specification of the bottom stress \mathbf{t}_b :

$$\mathbf{t}_b = \mathbf{r} u_*^2 = c_b \mathbf{r} U^2$$

where u_* is the friction or shear velocity, c_b is the bottom stress coefficient (friction coefficient) and U is the flow velocity at the bottom layer. Assuming a logarithmic velocity profile between the solid bottom and the middle of the bottom cell layer gives the bottom stress coefficient:

$$c_b = \mathbf{k}^2 \left[\ln \left(\frac{H}{2z_0^*} \right) \right]^{-2}$$

where z_0^* is the dimensional bottom roughness height, κ is von Karman constant and H is the height of the bottom layer.

The bottom roughness forms a hierarchy from smallest-to-largest that include typical:

- Nikuradse roughness – sediment grains roughness
- Biogenic roughness – mounds and burrows that were created by benthic organisms and vegetation
- Saltation roughness – often dominates on sandy coastal areas
- Bedform roughness- characterized by the height, wavelength and roughness of sand ripples.

Such important factors of Savannah Estuary hydrodynamic regime formation like river meandering and bathymetric irregularities inside the cells of computational grid, as well as factors of wall friction in the riverine part of the estuary were also taking into account by assigning the bottom roughness values. Other than bathymetry and grid cell volume, the bottom roughness z_0 was the basic calibration parameter for EFDC hydrodynamic model application to Savannah River Estuary.

4.3.2 Vertical Mixing

EFDC calculates vertical eddy diffusivity and vertical kinematic viscosity based on the Mellor-Yamada (M-Y) turbulence closure scheme developed at Princeton University in the 1970s by Dr. George Mellor and T. Yamada. The EFDC implementation exactly follows that maintained by Dr. Mellor in the Princeton Ocean Model (POM). The M-Y Turbulence Model is the most widely used prediction scheme for turbulent transport in estuary and ocean models. No equations are needed externally to force vertical mixing in EFDC so the model can be used in a predictive mode to simulate the physics of mixing.

The M-Y turbulence closure scheme solves the two 3-dimensional transport equations for turbulent kinetic energy and the turbulent length scale. The vertical turbulent viscosity and diffusivity are analytically derived functions of the turbulent kinetic energy, length scale, and a turbulence intensity based Richardson Number. The turbulence closure model uses 9 parameters, which were determined by M-Y using extensive data from laboratory studies of turbulent shear flow (A1, A2, B1, B2, C1, C2, E1, E2, and E3). These 9 parameters are located in Card 13 of the “efdc.inp” file. Adjustment of these 9 parameters for specific sites is not usually necessary but for the Savannah Harbor application, E3 was modified from an empirical value of 0.53 developed by Galperin in 1988 to a value of 0.6 for this EFDC application. The turbulent kinetic energy equation is shown below.

$$\begin{aligned}
& \int_t (m_x m_y H q^2) + \int_x (m_y H u q^2) + \int_y (m_x H v q^2) + \int_z (m_x m_y w q^2) \\
& = \int_z \left(m_x m_y \frac{A_q}{H} \int_z q^2 \right) - 2 m_x m_y \frac{H q^3}{B_1 l} \\
& + 2 m_x m_y \left(\frac{A_v}{H} \left((\int_z u)^2 + (\int_z v)^2 \right) + \mathbf{h}_p c_p D_p (u^2 + v^2)^{3/2} + g K_v \int_z b \right) + Q_q \\
& \quad q^2 = 2 \times \text{turbulent kinetic energy}
\end{aligned}$$

The turbulent length scale equation is shown below. Three of the 9 parameters discussed above can be seen as E1, E2, and E3 below. The other parameters do not appear in the equations above or below because they are used in the turbulent viscosity (A_v), turbulent diffusivity (K_v), and turbulent intensity Richardson Number (R_q).

$$\begin{aligned}
& \int_t (m_x m_y H q^2 l) + \int_x (m_y H u q^2 l) + \int_y (m_x H v q^2 l) + \int_z (m_x m_y w q^2 l) \\
& = \int_z \left(m_x m_y \frac{A_q}{H} \int_z (q^2 l) \right) - m_x m_y \frac{H q^3}{B_1} \left(1 + E_2 \left(\frac{l}{k H z} \right)^2 + E_3 \left(\frac{l}{k H (1-z)} \right)^2 \right) \\
& + m_x m_y E_1 l \left(\frac{A_v}{H} \left((\int_z u)^2 + (\int_z v)^2 \right) + g K_v \int_z b + \mathbf{h}_p c_p D_p (u^2 + v^2)^{3/2} \right) + Q_l
\end{aligned}$$

Results from the EFDC model runs are plotted and compared with 1997 and 1999 vertical eddy diffusivity values on a log scale in Figure 4-3. The maximum value for the 1997 calibration is 0.18 m²/s and the minimum is 1.18E-8 m²/s. For 1999, the maximum value is 0.19 m²/s and the minimum is 1.18E-8 m²/s. The figure shows that the 1997 and 1999 time periods exhibit relatively the same vertical eddy diffusivity simulated by the EFDC model. This is consistent considering the flows were similar between the two years in the range of 5,500 cfs to 11,000 cfs as shown in Figure 2-4 (Clyo flows). The tide range was also examined and determined to be consistent as well. What is evident in Figure 4-3 is that the spring/neap periods are consistent when comparing the two periods, but offset because of different lunar periods. The vertical eddy diffusivities compared in Figure 4-3 were from the middle layer in the coarse grid model at FR-04 for 1997 and 1999.

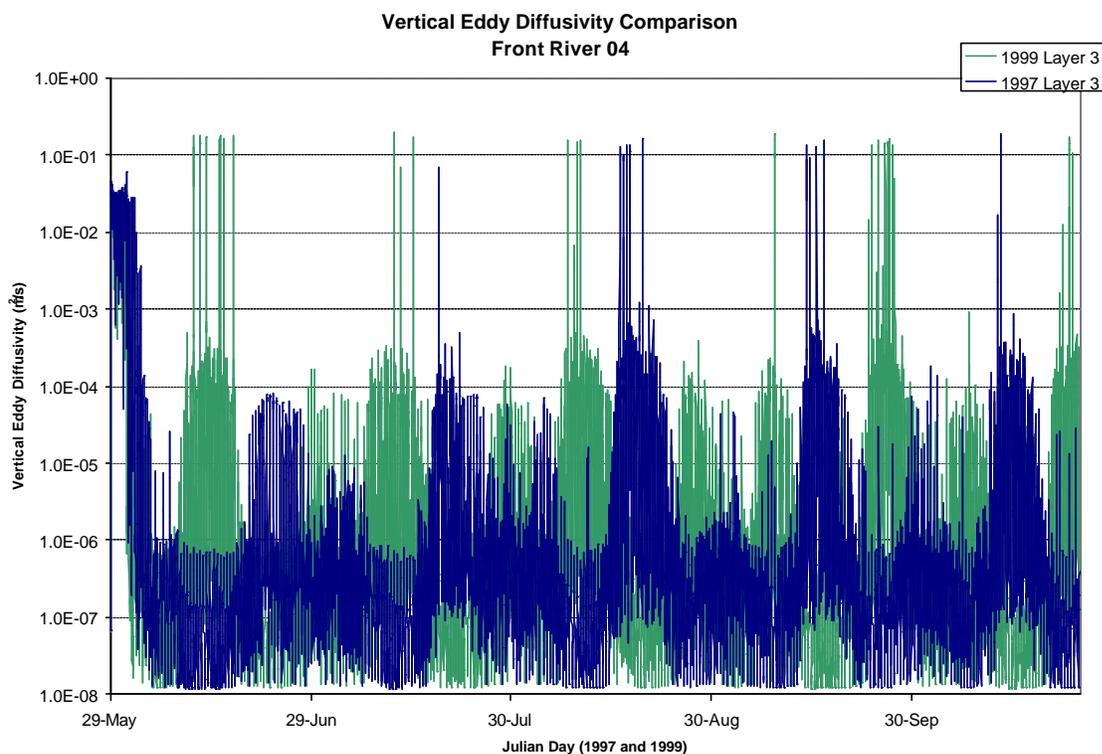


Figure 4-3 Vertical Eddy Diffusivity Comparison at FR-04

To check the accuracy of the EFDC model's ability to represent vertical mixing in Savannah Harbor, the peaks were challenged by estimating an extreme spring tidal velocity and calculating the eddy diffusivity with the following equation:

$$\epsilon_v = 0.067 d u^* \text{ (Equation 5.3 Fischer, 1979)}$$

where ϵ_v = eddy diffusivity (m²/s), d = total depth (m), and u^* = shear velocity

The shear velocity can often times be approximated by one-tenth of the mean velocity in a logarithmic velocity profile. Therefore, if the spring tidal velocity is 1.1 m/s, total depth at FR-04 is 15 meters, the vertical eddy diffusivity would calculate to be 0.11 m²/s. The rough calculation is consistent to Figure 4-3 and the results EFDC is producing.

4.4 Model Boundary Conditions

The model boundary conditions for the EFDC model consisted of the following components:

- offshore salinity, temperature, and water surface elevation;
- upstream flow and temperature;
- adjacent marsh boundary areas; and
- meteorological forcing conditions.

The boundaries were rather straightforward and developed in a way that was consistent with the continuous records available from the USGS. Ideally, the EFDC model can be run for any time period by gathering the Clio flows and temperature for the upstream boundary and water surface elevation and temperature at the downstream boundary.

4.4.1 Offshore Boundary

The offshore boundary of the grid is approximately 19 miles from river mile 0.0. River mile 0.0 is at the mouth of the river and entrance channel near Oyster Island.

The offshore boundary for water surface elevation consisted of examining the data collected by the USGS at Fort Pulaski (02198980) and moving the phase forward in time by two hours and by elevating the signal by 0.15 feet (0.046 meters) to reach an acceptable agreement of the model versus data at Fort Pulaski.

The offshore salinity boundary was determined to be a constant of 33.5 ppt. There were often times that a variable salinity boundary would have performed better for the salinity statistics, but it was deemed more defensible to have a constant boundary especially for multiple year runs or for model predictions outside the limits of the data. It was determined that the salinity data at Fort Pulaski and FR-26 had influences of fresh water mixing and stratification. Therefore, the data in the channel at the mouth would not be an appropriate downstream salinity boundary.

In December 2003, Tetra Tech requested offshore salinity data from the Skidaway Institute of Oceanography from a partnered field research study called the South Atlantic Bight Synoptic Offshore Observational Network (SABSOON). The SABSOON is a real-time observational network that has been developed on the U.S. Southeastern continental shelf. There are eight large offshore platforms currently operated by the U.S. Navy for flight training and are being instrumented to provide a range of oceanographic and meteorological observations on a continuous real-time basis.

Flows from the eastern coastline in South Carolina, Georgia, and Florida appear to have a 2 to 4 ppt influence on salinity levels 55 miles offshore. The winter and spring flows (February through April) show a response in salinity with the base near 36 ppt. For Figures 4-5 and 4-6, the Clyo flows were plotted as an easy way to look at freshwater flows in eastern coast basins.

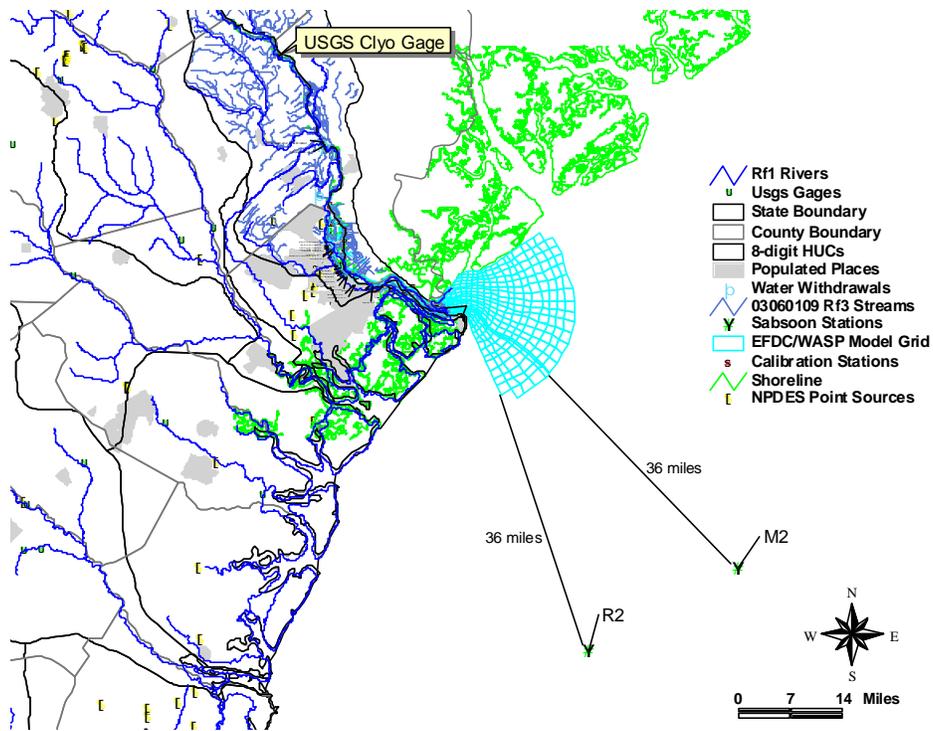


Figure 4-4 Location of SABSOON Stations

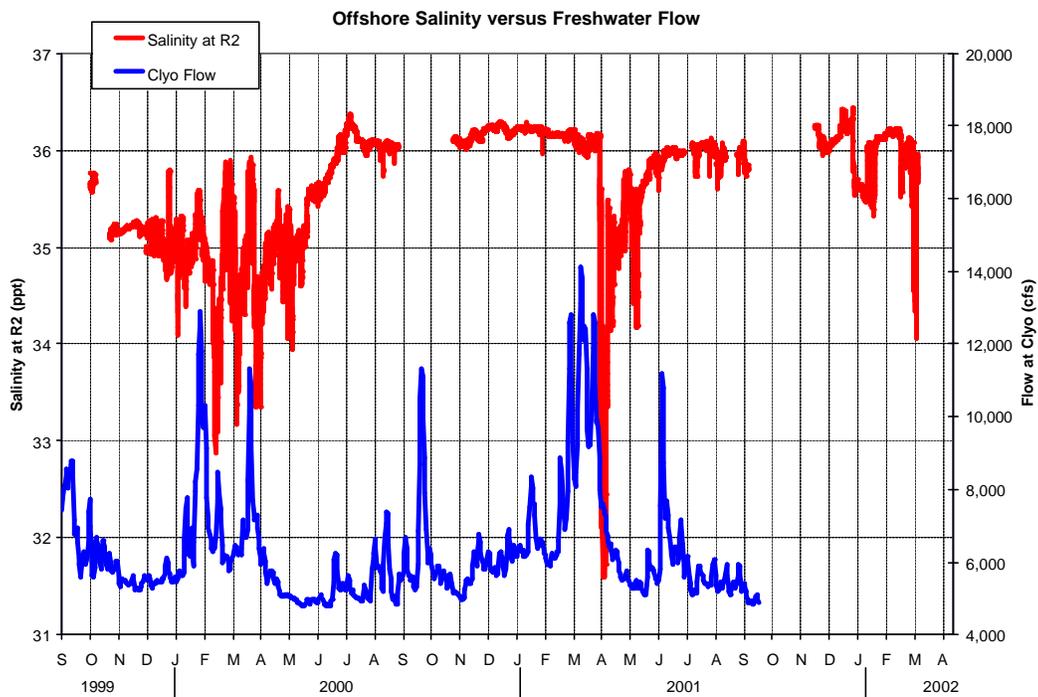


Figure 4-5 SABSOON Salinity Data from R2 Located 55 miles Offshore

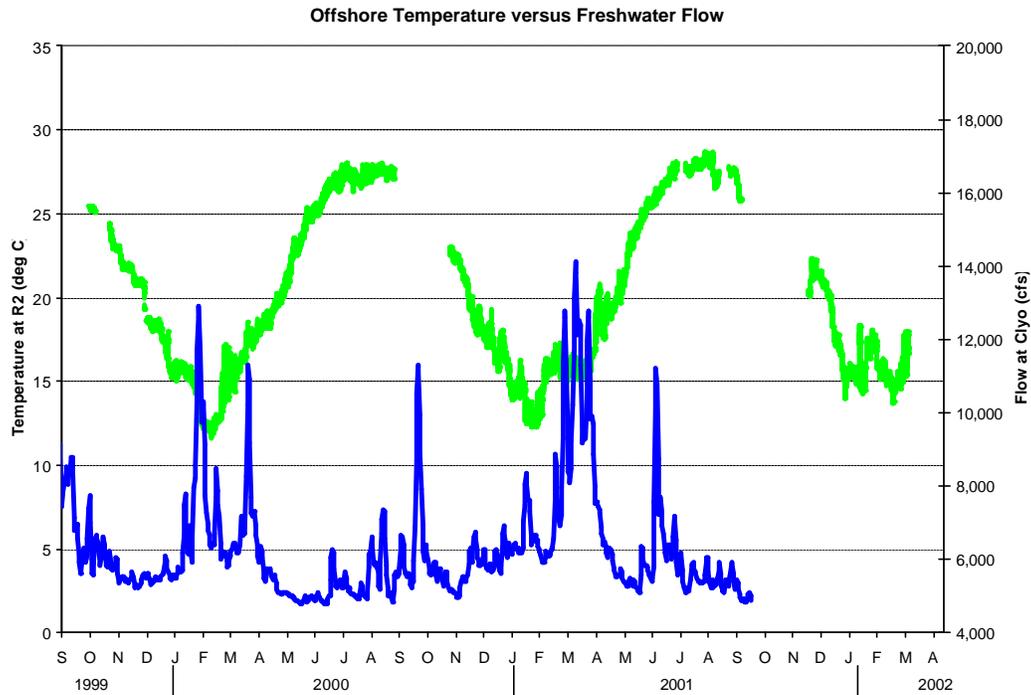


Figure 4-6 SABSOON Temperature Data from R2 Located 55 miles Offshore

4.4.2 Upstream Boundary

The upstream boundary of the grid is approximately 61 miles from river mile 0.0 near Oyster Island. The USGS flow data shown in Figure 2-4 were used as the upstream boundary forcing. The flow data were 30-minute and 1-hour intervals depending on the time period and data retrieved from USGS. The upstream temperature data were retrieved from USGS and measured as part of GAEPD's trend monitoring network.

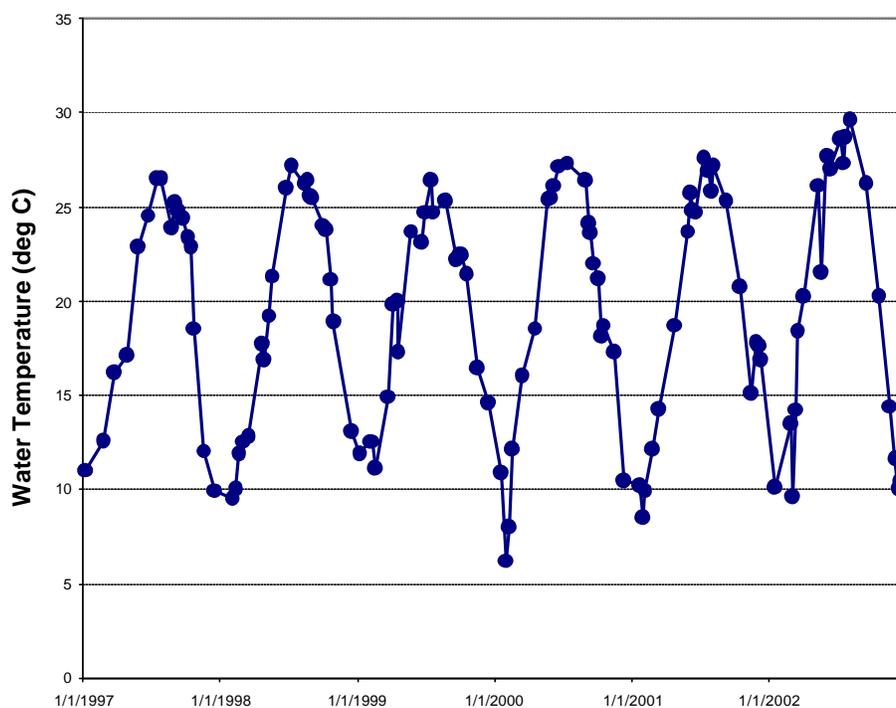


Table 4-1 Flooding Frequency, Duration, and Average Depth by Q Zone

| River | Q zone | Flooding % Freq | Flooding % Duration | Avg Depth (ft) | Avg Depth (m) | Elev (ft) NGVD |
|-------|--------|-----------------|---------------------|----------------|---------------|----------------|
| FR | Q1 | 30.9 | 5.6 | 0.39 | 0.12 | 5.05 |
| BR | Q2 | 91.2 | 22.6 | 0.81 | 0.25 | 3.69 |
| BR | Q3 | 63.2 | 14.7 | 0.60 | 0.18 | 4.29 |
| BR | Q4 | 75.0 | 19.2 | 0.69 | 0.21 | 4.20 |
| MR | Q5 | 62.9 | 16.3 | 0.65 | 0.20 | 4.47 |
| MR | Q6 | 56.5 | 12.9 | 0.51 | 0.16 | 4.64 |
| FR | Q7 | 91.8 | 26.8 | 0.95 | 0.29 | 3.83 |
| BR | Q8 | 60.5 | 13.8 | 0.46 | 0.14 | 4.68 |
| MR | Q9 | 79.6 | 21.5 | 0.70 | 0.21 | 4.18 |
| MR | Q10 | 75.2 | 19.7 | 0.72 | 0.22 | 4.31 |

Table 4 in Volume 3, Part 1 had the total acreages calculated for secondary canals, river channels, and marshes for each vegetation cell, or Q zone. Total volume was then calculated based on actual areas and actual depths reported in Table 4-1. For the feeder channels, an estimated (based on field experience) depth of 1.2 meters was used. Since the model stability was necessary to have a good management tool for the harbor, the model depths were then exaggerated to be larger than reality but meanwhile, holding the total actual volume of the marsh and feeder channel to be consistent. Then, the model areas were re-calculated based on new depths. After calculations, all feeder channels were 3.0 meters and marsh areas were 1.4 meters deep. Table 4-2 shows the marsh area calculations. The EFDC model was then extended with 1 marsh cell and 1 feeder cell that were represented with the exact surface areas in Table 4-2. These areas can be reviewed in the “dxdy.inp” input file for EFDC.

Table 4-2 Marsh Area Calculations used in the EFDC Model

| Q zone | Waterbody | Actual Area (acres) | Actual Area (m ²) | Actual Depth (m) | Actual Volume (m ³) | Model Depth (m) | Model Area (m ²) | Model Volume (m ³) |
|--------|-----------|---------------------|-------------------------------|------------------|---------------------------------|-----------------|------------------------------|--------------------------------|
| Q1 | CHANNEL | 15 | 59,870 | 1.2 | 72,994 | 3.0 | 24,331 | 72,994 |
| | MARSH | 490 | 1,981,290 | 0.12 | 235,520 | 1.4 | 168,228 | 235,520 |
| Q2 | CHANNEL | 187 | 755,863 | 1.2 | 921,549 | 3.0 | 307,183 | 921,549 |
| | MARSH | 2,190 | 8,861,825 | 0.25 | 2,187,878 | 1.4 | 1,562,770 | 2,187,878 |
| Q3 | CHANNEL | 89 | 360,733 | 1.2 | 439,806 | 3.0 | 146,602 | 439,806 |
| | MARSH | 1,363 | 5,516,392 | 0.18 | 1,008,838 | 1.4 | 720,598 | 1,008,838 |
| Q4 | CHANNEL | 12 | 46,544 | 1.2 | 56,746 | 3.0 | 18,915 | 56,746 |
| | MARSH | 336 | 1,359,504 | 0.21 | 285,920 | 1.4 | 204,229 | 285,920 |
| Q5 | CHANNEL | 8 | 33,334 | 1.2 | 40,641 | 3.0 | 13,547 | 40,641 |
| | MARSH | 210 | 851,168 | 0.20 | 168,633 | 1.4 | 120,452 | 168,633 |
| Q6 | CHANNEL | 8 | 33,080 | 1.2 | 40,331 | 3.0 | 13,444 | 40,331 |
| | MARSH | 489 | 1,977,169 | 0.16 | 307,347 | 1.4 | 219,534 | 307,347 |
| Q7 | CHANNEL | 9 | 35,485 | 1.2 | 43,264 | 3.0 | 14,421 | 43,264 |
| | MARSH | 247 | 1,000,219 | 0.29 | 289,623 | 1.4 | 206,874 | 289,623 |
| Q8 | CHANNEL | 29 | 117,309 | 1.2 | 143,023 | 3.0 | 47,674 | 143,023 |
| | MARSH | 682 | 2,760,700 | 0.14 | 387,072 | 1.4 | 276,480 | 387,072 |
| Q9 | CHANNEL | 5 | 18,996 | 1.2 | 23,160 | 3.0 | 7,720 | 23,160 |
| | MARSH | 457 | 1,849,307 | 0.21 | 394,568 | 1.4 | 281,834 | 394,568 |
| Q10 | CHANNEL | 13 | 53,515 | 1.2 | 65,245 | 3.0 | 21,748 | 65,245 |
| | MARSH | 409 | 1,656,197 | 0.22 | 363,462 | 1.4 | 259,616 | 363,462 |

Figure 4-8 displays the coarse grid with the additions of the ten marsh areas. Q6 was added to Q9 and placed on the Middle River. When Q6 was placed on the Front River where it was delineated by ATM based on the vegetation, the marsh area played a large role in the mixing of salinity on the Front River near Houlihan Bridge. Therefore, the surface area and volume were added to Q9 on the Middle River and the totals were consistent with the reported marsh data reports.

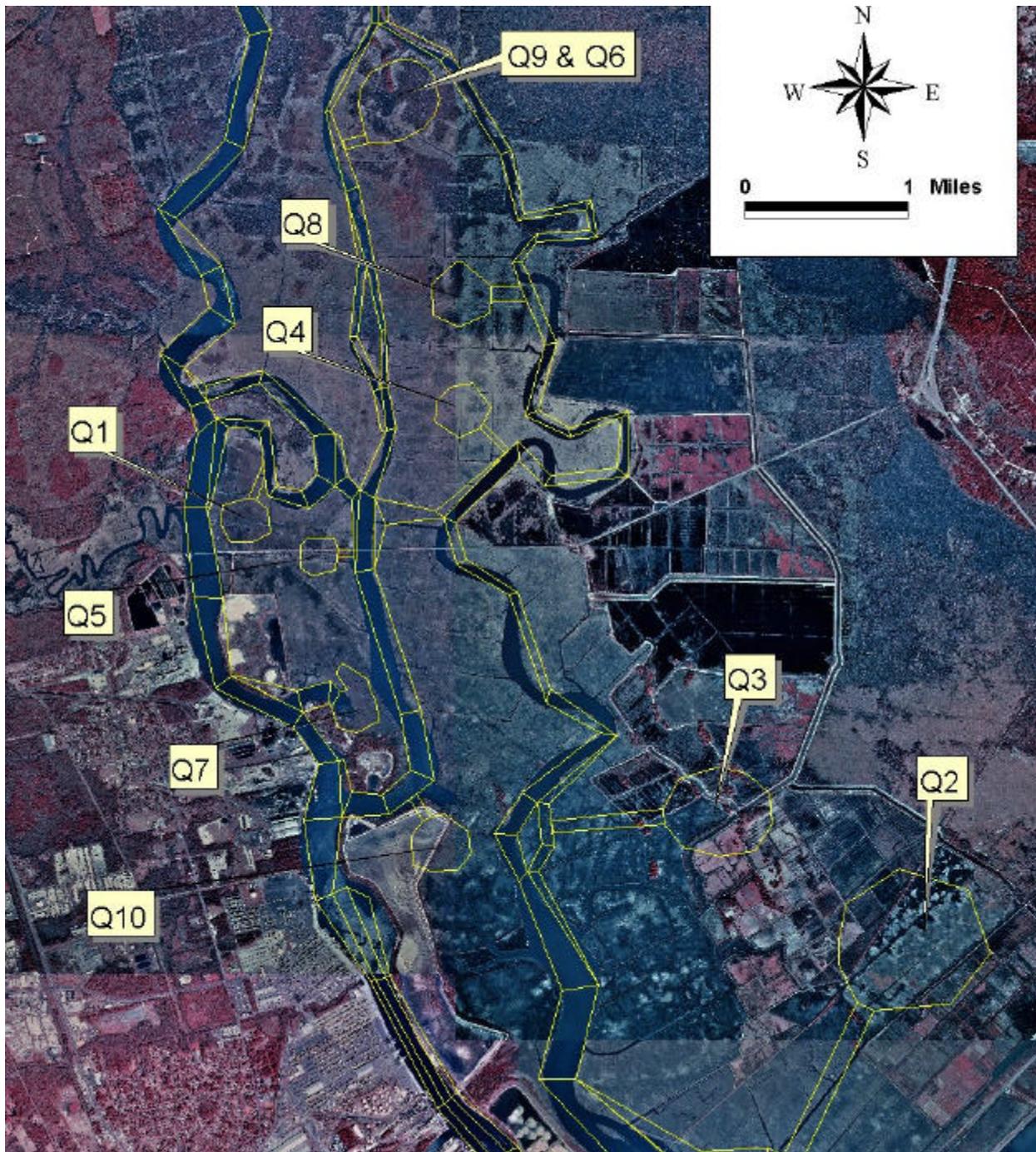


Figure 4-8 EFDC Marsh Areas

4.4.4 Meteorological

The meteorological forcing conditions are input into the EFDC model through the “aser.inp” file. This file contains the following:

- Barometric pressure,
- Dry bulb temperature,

- Relative humidity,
- Rainfall,
- Evaporation,
- Solar Radiation, and
- Cloud Cover.

Most of the parameters came from the Savannah Airport historical data record. Barometric pressure, temperature, relative humidity, rainfall, and cloud cover were all measured at the airport. Evaporation and solar radiation were calculated and put into the model. Although meteorological data were collected during 1997 and 1999, the EFDC model was setup for six years so a consistent record was created. The “aser.inp” file was developed on an hourly basis.

The wind data in the “wser.inp” file were also developed on an hourly basis and also collected at the Savannah Airport.

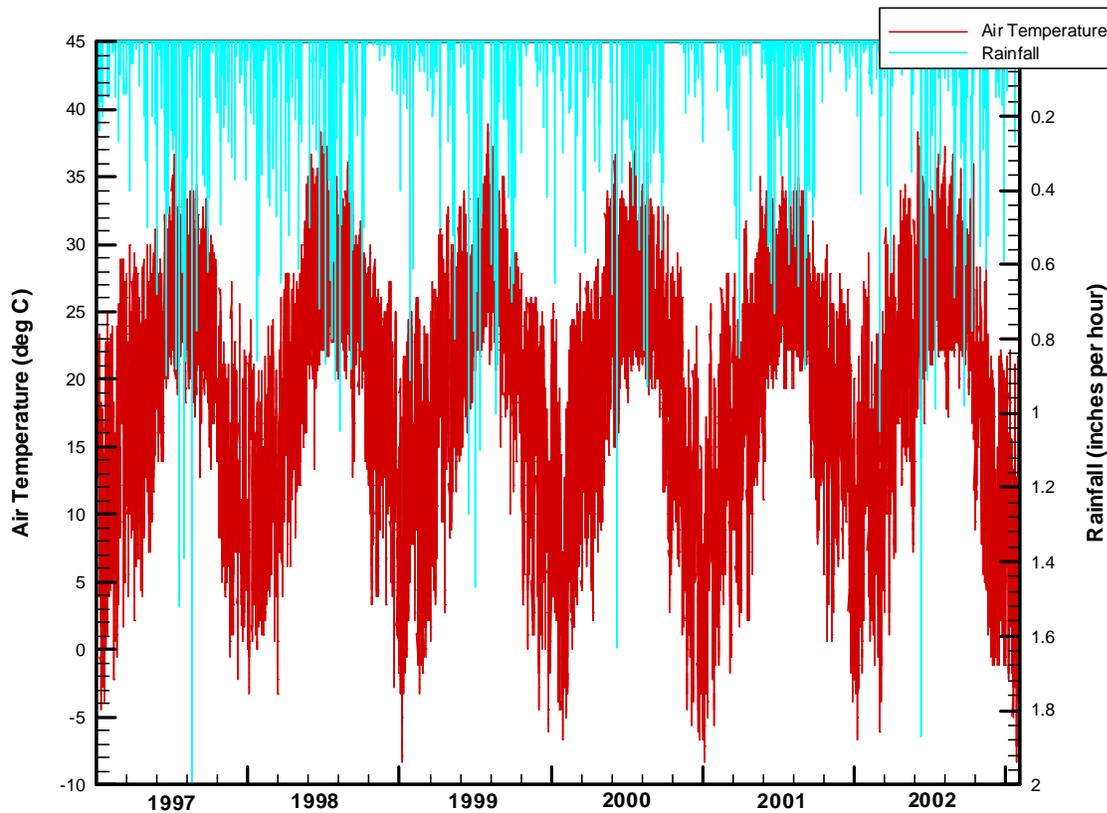


Figure 4-9 Air Temperature and Rainfall in Meteorological Forcing

5.0 CALIBRATION METHODOLOGY

The calibration methodology for the Savannah Harbor EFDC model included graphical time series comparisons (qualitative) and statistical calculations (quantitative). The statistical calculations included a variety of statistical calculations including percentiles for every 5th percentile interval. The calibration methodology was also parameter specific starting with the following order:

- Water Surface Elevation,
- Flow,
- Currents,
- Temperature, and
- Salinity.

Each one of these parameters has its importance in the determination of success for the model calibration and confirmation. The order in which the hydrodynamic model is calibrated is performed to address issues such as bathymetry, friction, tidal volume, cross-sectional area, and heat budget before salinity is calibrated. Salinity is the predominant signal in the model to ensure that mass is being moved horizontally and vertically with the appropriate timing and direction.

The calibration objectives for the hydrodynamic model were to appropriately represent the transport processes by propagating momentum and energy through the system based upon freshwater inflow from the Savannah River and tidal energy from the Atlantic Ocean. Since vertical stratification plays a major role in the water quality of the lower harbor area, it was imperative to capture the effect of tides and fresh water flows on salinity and temperature over the appropriate spatial and temporal scales. The primary objective was to simulate the salinity and temperature stratification events, and to demonstrate that the duration and magnitude of the events were appropriately represented in the model. The next three sections will describe the qualitative and quantitative calibration techniques along with reporting requirements of the Federal Agencies.

5.1 Qualitative Comparisons

Time series graphical comparisons were performed to visualize key trends in the data compared to that of the model. Seasonal fluctuations of temperature, salinity stratification, ebb current magnitudes versus flood, and spring/neap tidal fluctuations were all compared to the physical data to determine if the model is simulating appropriately.

MOVEM was used to open the EFDC model output files (*.BMD) and the WRDB data files (*.DB) for the graphical comparisons. Other than the ADCP flow transects compared in Tecplot files, all other time series graphics in this report were generated by MOVEM. MOVEM allows the user to window in on various time periods so that a closer examination of the model versus data can be performed.

MOVEM was also used to animate the model results. There are three main files included on the discs that will allow the user to visualize the EFDC model results. The “97.BMD” is included for the 1997 calibration period and contains every cell in the grid domain. The “coarse grid.shp” is also included which allows the model to be viewed in a plan view in MOVEM and links each of the grid cells to the model output. Also, the “shoreline.shp” file can be brought in as a shoreline boundary for a frame of reference.

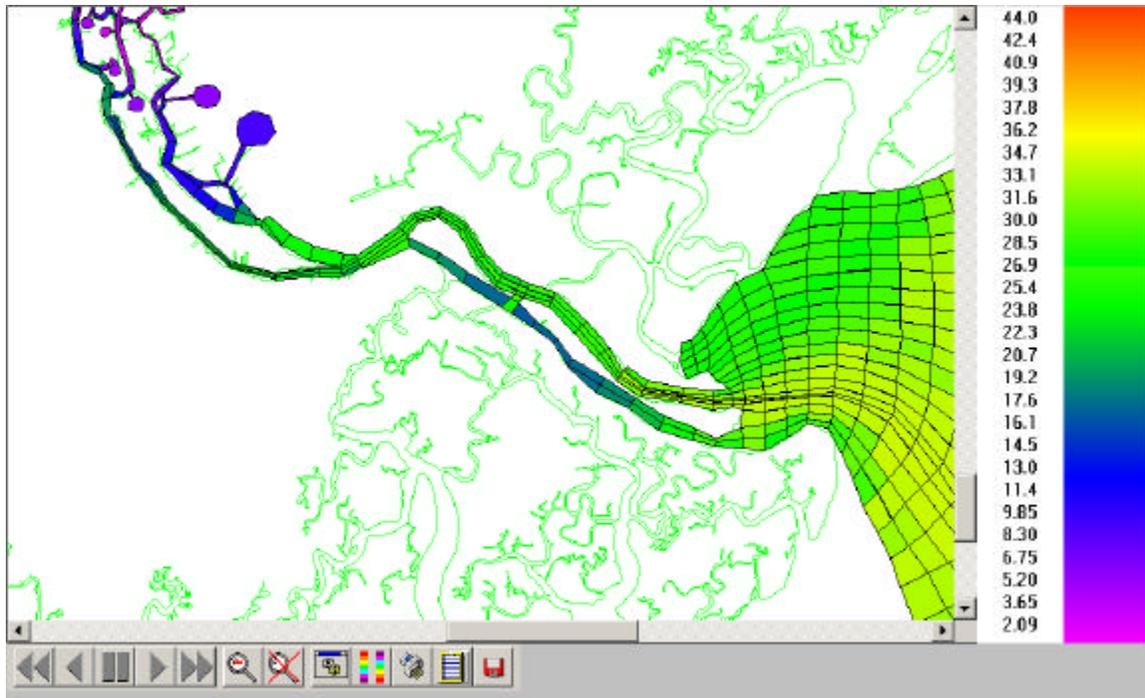


Figure 5-1 MOVEM Animation Display

5.2 Quantitative Comparisons

A variety of model fit statistics are available for evaluating model performance (Reckhow et al., 1990). Since MOVEM was used to perform the qualitative component of the calibration, MOVEM was also updated to perform the quantitative part. For the statistical evaluations, the following calculations were generated along with the percentiles.

$$\text{Mean Error: } ME = \bar{P} - \bar{O}$$

$$\text{Mean Error Absolute: } MEA = \frac{\sum_{i=1}^n |P_i - O_i|}{n}$$

$$\text{Mean Error Percent: } MEP = \frac{MEA}{\bar{O}} \times 100$$

$$\text{RMS Error: } RMSEA = \sqrt{\frac{\sum_{i=1}^n (P_i - O_i)^2}{n}}$$

$$\text{RMS Error Percent: } RMSEP = \frac{RMSEA}{\bar{O}} \times 100$$

$$\text{Mean Predicted: } \bar{P} = \frac{\sum_{i=1}^n P_i}{n}$$

$$\text{Standard Deviation Predicted: } SDP = \sqrt{\frac{\left(n \sum_{i=1}^n P_i^2 \right) - \left(\sum_{i=1}^n P_i \right)^2}{n^2}}$$

$$\text{Mean Observed: } \bar{O} = \frac{\sum_{i=1}^n O_i}{n}$$

$$\text{Standard Deviation Observed: } SDO = \sqrt{\frac{\left(n \sum_{i=1}^n O_i^2 \right) - \left(\sum_{i=1}^n O_i \right)^2}{n^2}}$$

$$\text{R squared: } R^2 = \frac{\left(n \sum_{i=1}^n (P_i \times O_i) \right) - \left(\sum_{i=1}^n O_i \times \sum_{i=1}^n P_i \right)}{\sqrt{\left(\left(n \sum_{i=1}^n P_i^2 \right) - \left(\sum_{i=1}^n P_i \right)^2 \right)} \times \sqrt{\left(\left(n \sum_{i=1}^n O_i^2 \right) - \left(\sum_{i=1}^n O_i \right)^2 \right)}}$$

$$\text{Coefficient of efficiency, E: } E = 1.0 - \frac{\sum_{i=1}^n |P_i - O_i|}{\sum_{i=1}^n |O_i - \bar{O}|}$$

$$\text{Index of agreement, d: } d = 1.0 - \frac{\sum_{i=1}^n |P_i - O_i|}{\sum_{i=1}^n (|P_i - \bar{O}| + |O_i - \bar{O}|)}$$

The correlation coefficient, R^2 , measures the tendency of the predicted and observed values to vary together linearly. It can range from -1 to 1 , with negative values indicating that the observed and predicted values tend to vary inversely. It should be recognized that even if the correlation is close to 1 , the predicted and observed values might not match each other; they only tend to vary similarly (Stow, 2003).

The root mean squared error, average error, and average absolute error are all measures of the size of the discrepancies between predicted and observed values. Values near zero indicate a close match. The average error is a measure of aggregate model bias, though values near zero can be misleading because negative and positive discrepancies can cancel each other. The average absolute error and the root mean squared error both accommodate the shortcoming of the average error by considering the magnitude rather than the direction of each discrepancy. Together these three statistics provide an indication of model prediction accuracy (Stow, 2003).

The coefficient of efficiency, E, ranges from minus infinity to 1.0, with higher values indicating better agreements. The modeling efficiency measures how well a model predicts relative to the average of the observations. A value near one indicates a close match between observations and model predictions. A value of zero indicates that the model predicts individual observations no better than the average of the observations.

5.3 Federal Expectations

In 2001, the Federal agencies prepared a Draft Expectations Document that described (1) the resources of primary concern in the estuary, (2) the locations and conditions under which project impacts should be evaluated for those resources, (3) the modeling approach to be taken, (4) the statistical analyses to be performed to document the model's performance, and (5) and the evaluation criteria (Federal Agencies, 2003).

The Expectations Document stated that its listed criteria were to be viewed as performance goals to which model predictions would be compared and evaluated for strengths and weaknesses and by which an understanding of their uncertainties may be developed. The stated criteria would not be used individually (by station and parameter) for a "pass/fail" evaluation of the model calibration and/or any post-processing routine.

The Document also stated that statistical analysis were to include calculation of the mean error, root mean square error, absolute mean error and relative error. Additionally, comparison of selected percentiles are to be used to evaluate model performance. The statistical analysis are to be performed on both the 1997 and 1999 data sets. For the 1997 validation data set, analysis are to be performed on each of the six spring/neap tidal cycles between July 9, 1997 and Oct 5, 1997. The Julian dates for those six periods are: 191-204,205-219,220-234,235-249,250-263,264-279. For the 1999 calibration data set, analysis are to be performed on each of the five spring/neap tidal cycles between July 31 and October 13, 1999. The Julian dates for the five periods are: 213-226, 227-241, 242-255, 256-270, and 271-285.

Table 5-1 Federal Expectations for Hydrodynamic Model Calibration/Confirmation

| Parameter | | Percentiles | | | | | Timing of Maxima (Min) |
|---------------------------|-------------|-------------|---------|---------|---------|---------|------------------------|
| | | 5 % | 10 % | 50 % | 90 % | 95 % | |
| Elevation (cm) | | +/- 2 | - | +/- 2 | - | +/- 2 | +/- 30 |
| Salinity (ppt) | 50% > 5 ppt | - | +/- 10% | - | +/- 10% | - | +/- 30 |
| | 50% < 5 ppt | - | - | +/- 0.5 | +/- 0.5 | - | +/- 30 |
| Temperature (°C) * | | - | - | +/- 1 | - | - | - |
| Surface Currents (m/s) ** | | +/- 25% | - | - | - | +/- 25% | +/- 30 |
| Volume Flows (m/s) ** | | +/- 25% | - | - | - | +/- 25% | - |

* 50% represent Absolute Mean Error for temperature

** 5% and 95% represent the max. ebb and flood conditions for current and flow

6.0 MODEL CALIBRATION

The model calibration results are presented in this section and in several appendices in the back of the report. As stated in Section 5, the model calibration was performed from the qualitative comparisons, quantitative comparisons, and the Federal Agency expectations comparisons. The calibration periods were summer-fall periods of 1997 and 1999. These were both low-flow conditions with several spring/neap tide events occurring throughout the period. The calibration is presented as one time period even though there are two datasets that can be compared. Ultimately, it was considered as one calibration period because bottom roughness and bathymetry were modified in the EFDC model setup and therefore consistent any period from 1997 through 2002.

6.1 Water Surface Elevation Calibration

The water surface calibration was performed by modifying the downstream elevation boundary until the model closely fit the data at Fort Pulaski. Then for the internal gages in the harbor, the bottom roughness was modified to reach an appropriate phase shift of the elevation signal at each one of the stations. Figure 6-1 and Table 6-1 show an example of three-day period in August 1999 where the qualitative (time series) and the quantitative (statistics) results are displayed.

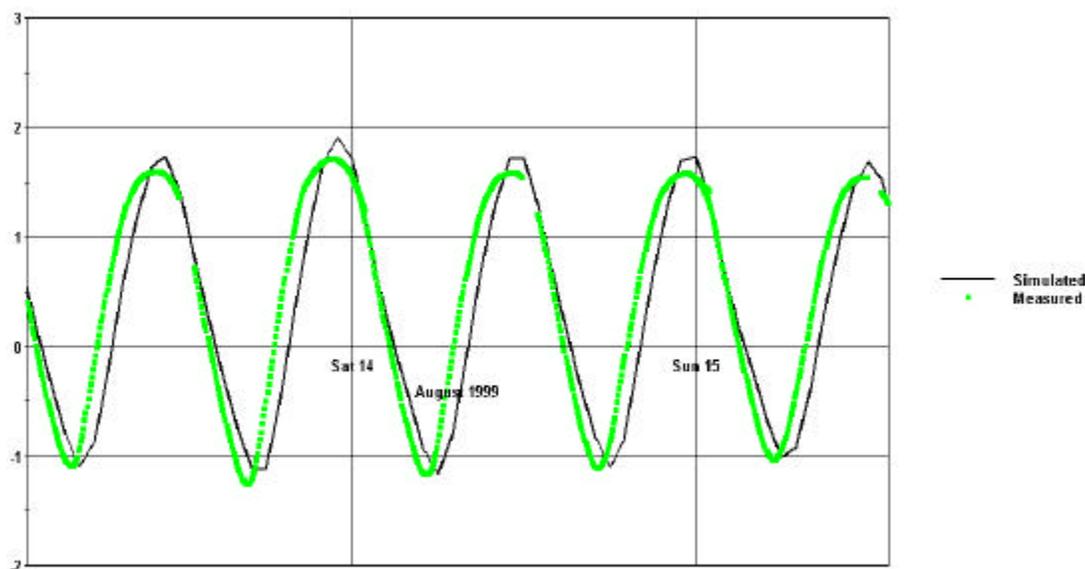


Figure 6-1 Water Surface Elevation Calibration at FR-09 for August 1999

Table 6-1 Water Surface Elevation Calibration at FR-09 for August 1999

| Percentiles | 5% | 10% | 25% | 50% | 75% | 90% | 95% | | | | | |
|-------------------------------|------------|---------------------|------------------------|-----------|-----------------------|----------------|-------------------------|---------------|------------------------|------|-----------------------------|----------------------|
| Simulated | -1.04 | -0.96 | -0.59 | 0.26 | 1.28 | 1.66 | 1.72 | | | | | |
| Observed | -1.09 | -0.99 | -0.50 | 0.51 | 1.43 | 1.57 | 1.59 | | | | | |
| Comparison Summary Statistics | | | | | | | | | | | | |
| Points | Mean Error | Mean Error Absolute | Mean Error Percent (%) | RMS Error | RMS Error Percent (%) | Mean Simulated | STD Deviation Simulated | Mean Measured | STD Deviation Measured | R2 | Coefficient of Efficiency E | Index of Agreement d |
| 710 | -0.11 | 0.30 | 71.29 | 0.38 | 89.47 | 0.32 | 0.96 | 0.42 | 0.97 | 0.86 | 0.83 | 0.92 |

An example of the results for the Federal Expectations for this period can be summarized as a 5-cm, 25-cm, and 13-cm difference for the 5th, 50th, and 95th percentiles, respectively. Therefore, not meeting the expectations criteria of +/- 2 cm. This expectation is very stringent and although the time series in the Figure 6-1 appears to be reasonable, the shape of the elevation curve can also be detrimental to the statistics. Also, there is a 30-minute phase where the model lags the data and causes the statistical results to be less favorable than the time series.

Overall, the EFDC model has a reasonable fit to the data in most cases. Appendix B shows the results for 1997 and Appendix C shows the results for 1999. The comparisons at the I95 Bridge and in the upper riverine areas are elevated higher than the data on the flood tide, but do very well on the ebb tide.

The overall elevation statistics are shown in Tables B-1 and C-1 for 1997 and 1999 with the graphical time series plots followed by the spring/neap statistic tables outlined in the federal expectations document. 1997 has six 14-day periods and 1999 has five 14-day periods with an overall summary table for both. The time series plots are not shown for the 14-day periods, only the overall period at each location.

6.2 Flow Calibration

The flow calibration was performed on the ADCP transect data collected in 1997 and 1999. The transect locations are not shown in a figure but the transect times are located in Appendix D in Table D-1 for 1997 and in Appendix E in Table E-1 for 1999. There were 15 transects in 1997 and 42 transects in 1999.

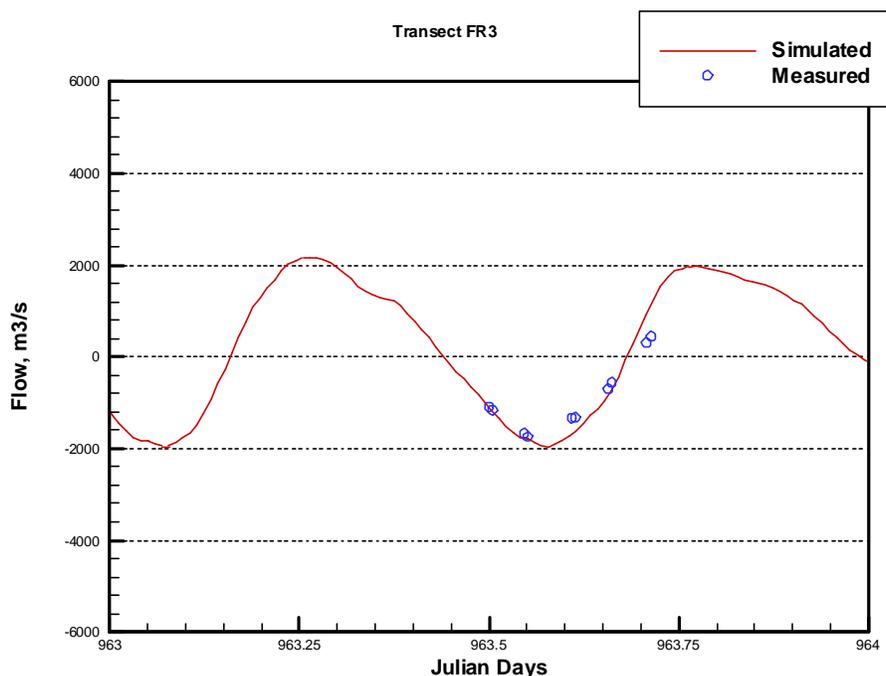


Figure 6-2 Flow Transect Calibration at FR3 (Front River) on August 21, 1999

The flow calibration in Figure 6-2 is approximately a 3% difference in peak ebb flows of the model compared to the data. The peak flow data was estimated by visual interpretation of the flow curve. The 3% difference meets the expectations of the federal criteria.

Appendix D and E give the results of the flow calibration for 1997 and 1999, respectively. Tables D-2 and E-2 present the statistical results of the calibration. 60% of the transects in 1997 and 52% of the transects in 1999 pass the federal criteria of +/- 25%.

6.3 Currents Calibration

The currents calibration was very difficult based on the data provided in the original WRDB. Most of the data had speed (m/s) with no direction so it was assumed to be along the channel. When comparing to the EFDC current results the alignment of the currents is critical for comparisons. For some of the currents data collected in 1999, such as FR-06, there were shifts of 1-2 hours in the data at certain places. For example, during the beginning of the FR-06 calibration, the model performs well, but near the middle when there has been a significant gap in the data, the data lags the model by 2 hours. This is not realistic based on the model predictions at FR-04 during the same time period.

Figure 6-3 and Table 6-3 give a representative time period in August 1999 to demonstrate the qualitative comparison of the time series and the quantitative comparison in the statistical summary in Table 6-3.

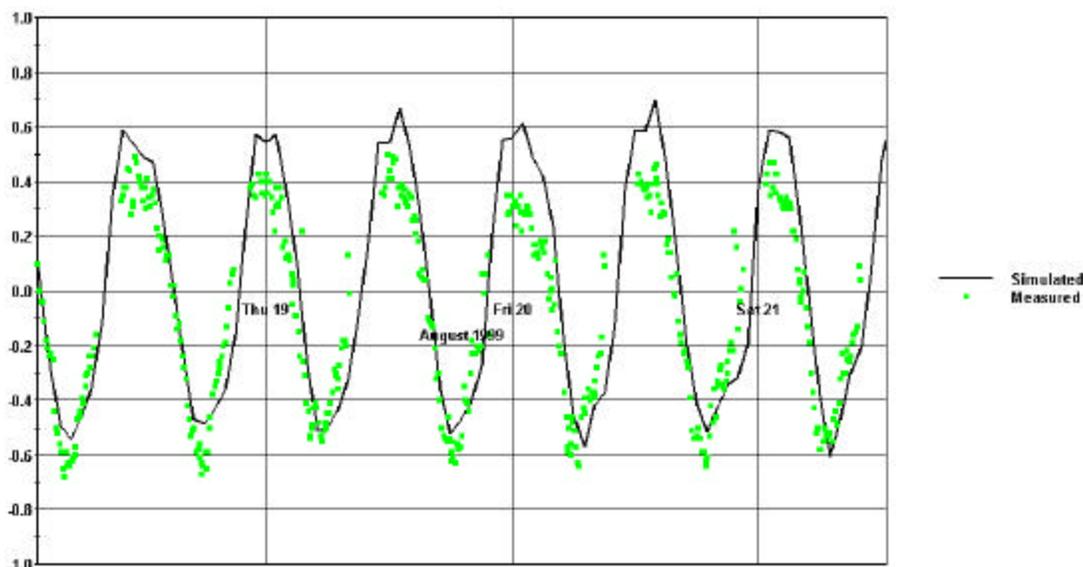


Figure 6-3 Currents Calibration for FR-06 Bottom during August 1999

Table 6-2 Currents Calibration at FR-06 Bottom for August 1999

| Percentiles | 5% | 10% | 25% | 50% | 75% | 90% | 95% | | | | | |
|-------------------------------|------------|---------------------|------------------------|-----------|-----------------------|----------------|-------------------------|---------------|------------------------|------|------------------------------|--------------------------|
| Simulated | -0.51 | -0.50 | -0.42 | -0.19 | 0.49 | 0.58 | 0.60 | | | | | |
| Observed | -0.59 | -0.55 | -0.41 | -0.15 | 0.28 | 0.38 | 0.41 | | | | | |
| Comparison Summary Statistics | | | | | | | | | | | | |
| Points | Mean Error | Mean Error Absolute | Mean Error Percent (%) | RMS Error | RMS Error Percent (%) | Mean Simulated | STD Deviation Simulated | Mean Measured | STD Deviation Measured | R2 | Coefficient of Efficiency, E | Index of Agreement, t, d |
| 462 | 0.08 | 0.15 | -164.84 | 0.18 | -192.23 | -0.01 | 0.44 | -0.09 | 0.35 | 0.88 | 0.73 | 0.85 |

For the expectations comparison, the 5th and 95th differences are 13% and 46%, respectively. Therefore, meeting on the 5th percentile and not on the 95th.

The calibration results for 1997 and 1999 are shown in Appendices F and G, respectively.

6.4 Temperature Calibration

Temperature was the hydrodynamic parameter of least concern. The temperature data were used at Clyo and then a seasonal temperature function was used for the downstream boundary. Very little to no calibration was required for temperature. The results are presented in Appendix H for 1997 and Appendix I for 1999. Except for BR-05 at 5% and BR-07 at 3% difference, all of the other stations in 1997 were -1 to 2% in difference with the data. The 1999 results were slightly larger with percent differences from 0 to 5%. Overall, the seasonal summer trends are represented in the EFDC model calibration. Further calibration of the downstream boundary can be made for a better fit of the internal gages, but at this time, the temperature calibration was sufficient.

6.5 Salinity Calibration

Salinity is the key parameter of concern because it can dictate how well the model is transporting mass in the system. For the summer-fall periods of 1997 and 1999, there is an extensive amount of salinity data and often times surface and bottom in the deepened channel. Therefore, it was important to perform a rigorous calibration meanwhile keeping in mind that the model will most likely be used over longer time periods. Also, that the model will be used in a predictive model to simulate a management scenario for the harbor. For these reasons, the overall 1997 and 1999 periods were examined together to make sure that a “goodness of fit” was achieved throughout the model domain.

The SABSOON data discussed in Section 4.4.1 was examined to adjust the downstream boundary for salinity. Figure 4-5 shows that for the 1997 and 1999 calibration periods, the salinity is constant offshore. It is during the winter and spring flows when the salinity decreases due to mixed waters discharging out of the estuaries and rivers along the east coast. Therefore, since the EFDC model boundary is for when water is moving into the model, and allows water to move out of the open boundary, it was determined that a constant boundary of 33.5 ppt was the most defensible approach for calibration. It also aids in the predictive mode when other time periods outside of 1997 through 2002 will need to be run.

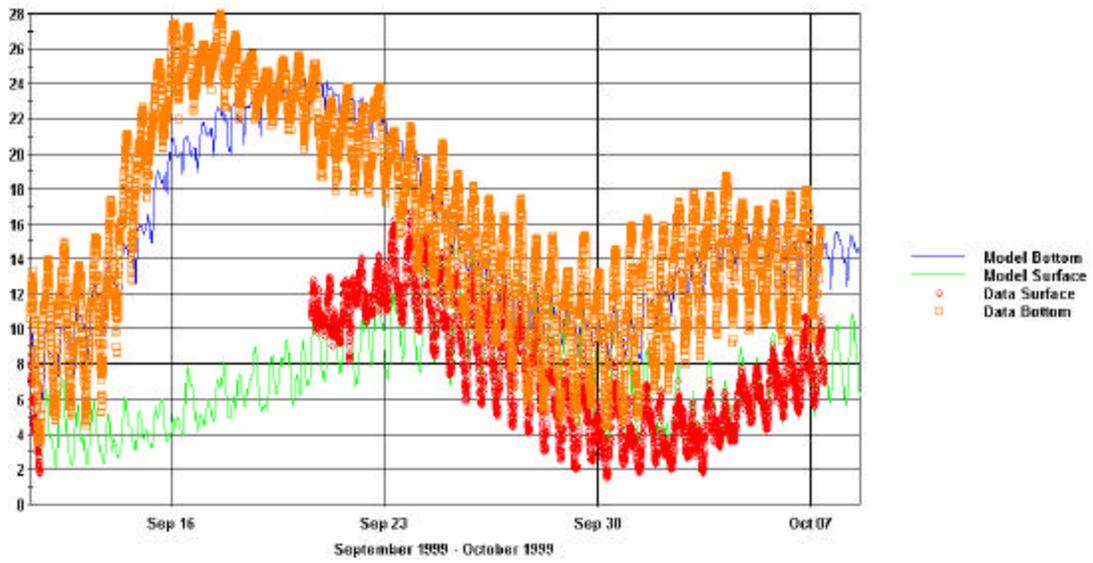


Figure 6-4 Salinity Calibration at FR-06 Surface and Bottom for 1999

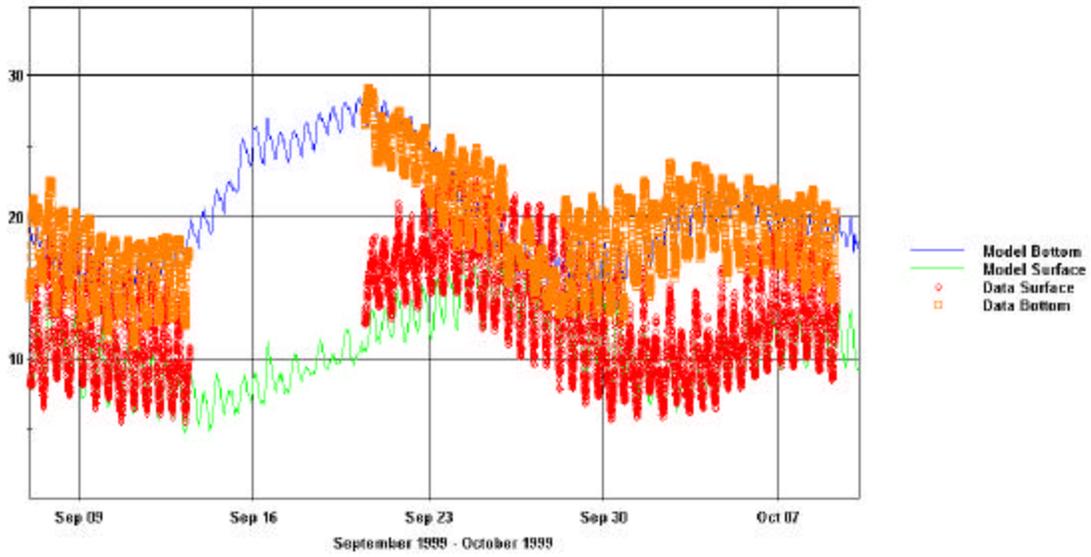


Figure 6-5 Salinity Calibration at FR-04 Surface and Bottom for 1999

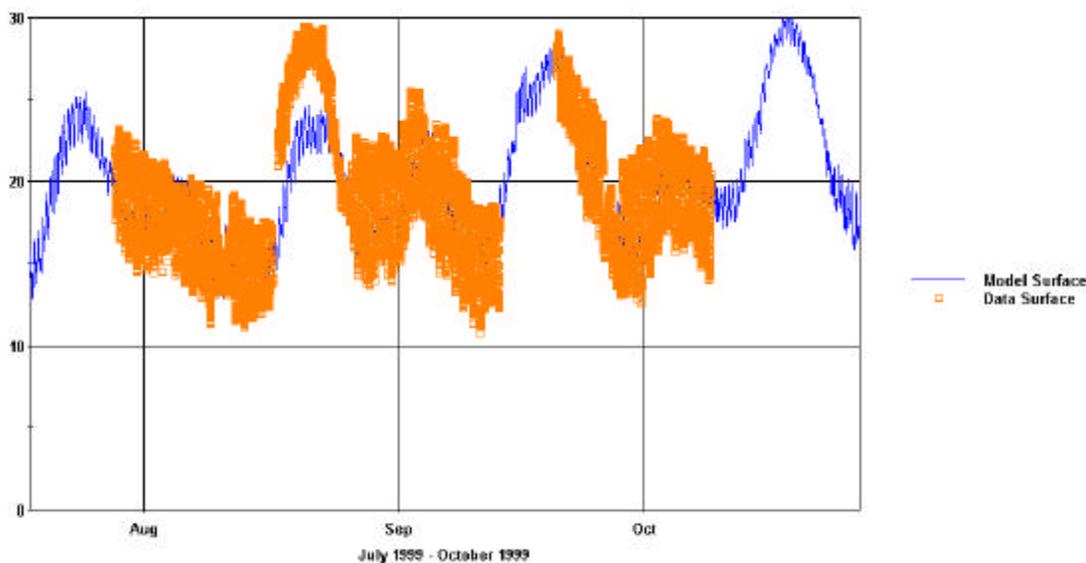


Figure 6-6 Salinity Calibration at FR-06 Bottom for 1999

Table 6-3 Salinity Calibration at FR-06 Bottom for 1999

| Percentiles | 5% | 10% | 25% | 50% | 75% | 90% | 95% | | | | | | |
|-------------------------------|------------|---------------------|------------------------|-----------|-----------------------|----------------|-------------------------|---------------|------------------------|------|------------------------------|--------------------------|--|
| Simulated | 14.13 | 15.26 | 16.63 | 18.31 | 20.62 | 22.88 | 24.18 | | | | | | |
| Observed | 13.67 | 14.82 | 16.84 | 19.27 | 21.71 | 25.61 | 27.43 | | | | | | |
| Comparison Summary Statistics | | | | | | | | | | | | | |
| Points | Mean Error | Mean Error Absolute | Mean Error Percent (%) | RMS Error | RMS Error Percent (%) | Mean Simulated | STD Deviation Simulated | Mean Measured | STD Deviation Measured | R2 | Coefficient of Efficiency, E | Index of Agreement, t, d | |
| 18,774 | -0.84 | 2.04 | 10.42 | 2.57 | 13.10 | 18.76 | 3.05 | 19.60 | 3.93 | 0.62 | 0.62 | 0.83 | |

The federal expectations require that the 10th and 90th percentile must be +/-10% for salinity with the 50th percentile of the measured values greater than 5 ppt. In Figure 6-6 and statistics shown in Table 6-4, the 10th and 90th percent differences are 3% and 10%, therefore, meeting the expectations.

Appendix J shows the 1997 results with overall period results shown in Table J-1. Tables J-2 through J-7 give the results of the spring/neap periods outlined in the expectations document. Figures J-1 through J-14 show the time series comparisons that correspond to the 14-day periods. Appendix K gives the same results for 1999 with the overall statistics, the time series comparisons, and the 14-day statistics.

The most difficult salinity calibration was on the Back River for 05 and 07. There appears to some additional source of fresh water in the adjacent marsh areas or even along the US 17 Bridge that crosses over the river between Georgia and South Carolina. The EFDC model did not perform well in this area even with modifying the bathymetry, modifying the cross-sectional area, and modifying the bottom roughness.

7.0 MODEL CONFIRMATION

After the model was calibrated, the reliability of the model's predictions must be tested with a new dataset. It is important that the model testing be performed with the exact same parameters used in the calibration process. The only real validation of a model is confirmation by independent observations (Anscombe, 1967). The testing of scientific models is considered an inductive process, which means that, even with true premises we can at best assign high probability to the correctness of the model. The fact that models can never be absolutely verified has significant policy implications. By admitting that models are approximations, it negates stall tactics based on the premise that remedial action be indefinitely postponed because models can never be demonstrated to be absolutely true (Chapra, 2003).

The USGS data were requested from Paul Conrads for the time periods of 1997 through 2000 to confirm the EFDC model. The data were imported into WRDB so that they could be available through MOVEM and statistics generated. The following two sections summarize the confirmation results.

7.1 USGS Water Surface Elevation

The water surface elevation confirmation results are shown in Tables 7-1 through 7-3 and the time series comparisons are shown in Figures 7-1 through 7-5.

Table 7-1 Water Surface Elevation Confirmation Percentiles for 1997 through 2000

| USGS Station | Measured Percentiles | | | | | | Simulated Percentiles | | | | |
|-----------------|----------------------|-------|-------|------|------|------|-----------------------|-------|------|------|------|
| | Points | 5% | 10% | 50% | 90% | 95% | 5% | 10% | 50% | 90% | 95% |
| Broad Street | 48,563 | -1.10 | -0.91 | 0.42 | 1.46 | 1.59 | -1.08 | -0.92 | 0.24 | 1.43 | 1.58 |
| Fort Pulaski | 56,463 | -0.98 | -0.81 | 0.30 | 1.26 | 1.41 | -0.99 | -0.83 | 0.21 | 1.19 | 1.33 |
| Houlihan Bridge | 36,030 | -1.05 | -0.87 | 0.49 | 1.55 | 1.66 | -1.09 | -0.93 | 0.28 | 1.55 | 1.71 |
| I-95 Bridge | 52,013 | -0.67 | -0.51 | 0.79 | 1.56 | 1.66 | -0.68 | -0.55 | 0.61 | 1.70 | 1.88 |
| Limehouse Creek | 53,979 | -0.81 | -0.63 | 0.71 | 1.60 | 1.70 | -0.99 | -0.85 | 0.29 | 1.57 | 1.74 |

Table 7-2 Water Surface Elevation Confirmation Statistics for 1997 through 2000

| USGS Station | Points | Simulated versus Measured Statistics | | | | | | | | | | | |
|-----------------|--------|--------------------------------------|---------------------|------------------------|-----------|-----------------------|----------------|-------------------------|---------------|------------------------|------|------------------------------|-----------------------|
| | | Mean Error | Mean Error Absolute | Mean Error Percent (%) | RMS Error | RMS Error Percent (%) | Mean Simulated | STD Deviation Simulated | Mean Measured | STD Deviation Measured | R2 | Coefficient of Efficiency, E | Index of Agreement, d |
| Broad Street | 48,563 | -0.09 | 0.22 | 63.68 | 0.29 | 84.87 | 0.25 | NC | 0.34 | NC | 0.91 | 0.88 | 0.94 |
| Fort Pulaski | 56,463 | -0.06 | 0.19 | 74.46 | 0.24 | 93.40 | 0.19 | NC | 0.25 | NC | 0.92 | 0.91 | 0.96 |
| Houlihan Bridge | 36,030 | -0.11 | 0.23 | 56.58 | 0.31 | 75.51 | 0.30 | 0.94 | 0.41 | 0.93 | 0.91 | 0.85 | 0.93 |
| I-95 Bridge | 52,013 | -0.05 | 0.23 | 35.16 | 0.29 | 44.31 | 0.60 | NC | 0.65 | NC | 0.89 | 0.83 | 0.91 |
| Limehouse Creek | 53,979 | -0.26 | 0.30 | 51.48 | 0.40 | 67.97 | 0.34 | NC | 0.59 | NC | 0.88 | 0.67 | 0.83 |

NC = not calculated because of low of negative values

Table 7-3 Water Surface Elevation Confirmation Comparison to Federal Expectations

| USGS Station | Elevation (cm) | | |
|-----------------|--------------------|---------------------|---------------------|
| | 5% Difference (cm) | 50% Difference (cm) | 95% Difference (cm) |
| Broad Street | 3 | -18 | 0 |
| Fort Pulaski | -1 | -9 | -7 |
| Houlihan Bridge | -3 | -22 | 5 |
| I-95 Bridge | -1 | -18 | 23 |
| Limehouse Creek | -18 | -42 | 4 |

0 = indicates a pass of the federal expectations

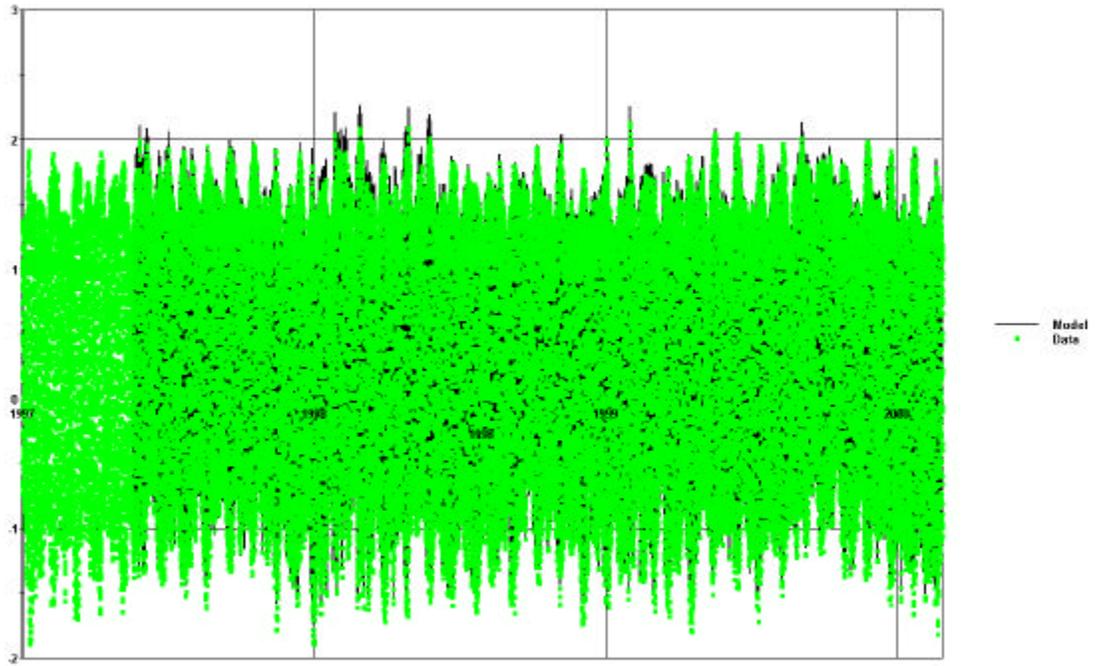


Figure 7-1 1997 – 2000 Confirmation of Water Surface Elevation at USGS 02198977 – Broad Street

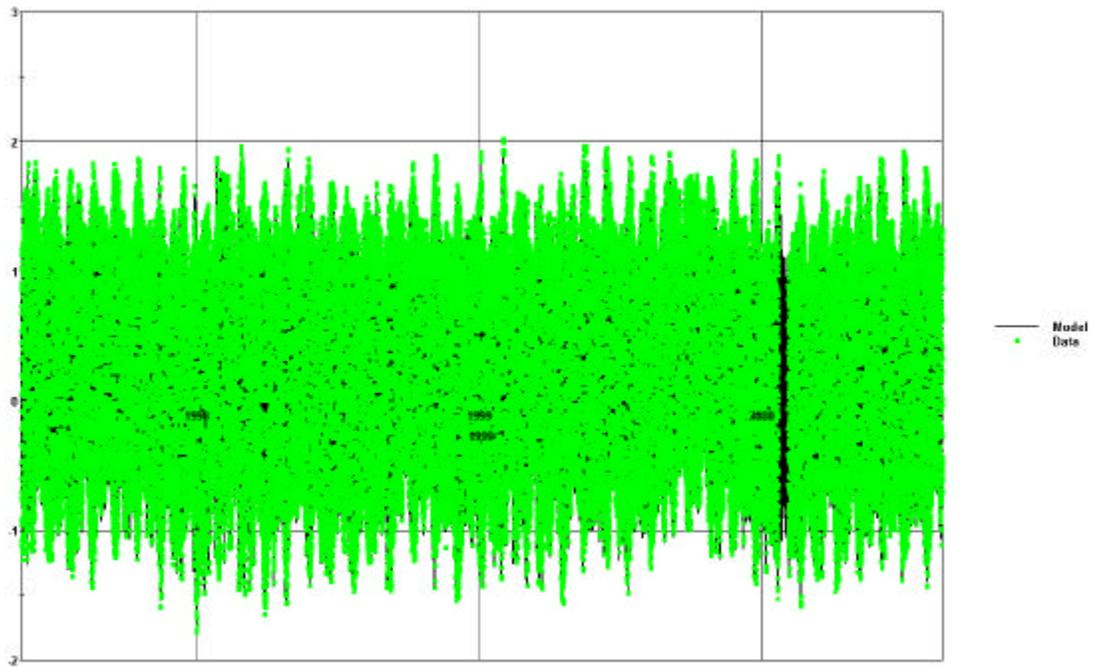


Figure 7-2 1997 – 2000 Confirmation of Water Surface Elevation at USGS 02198980 – Fort Pulaski

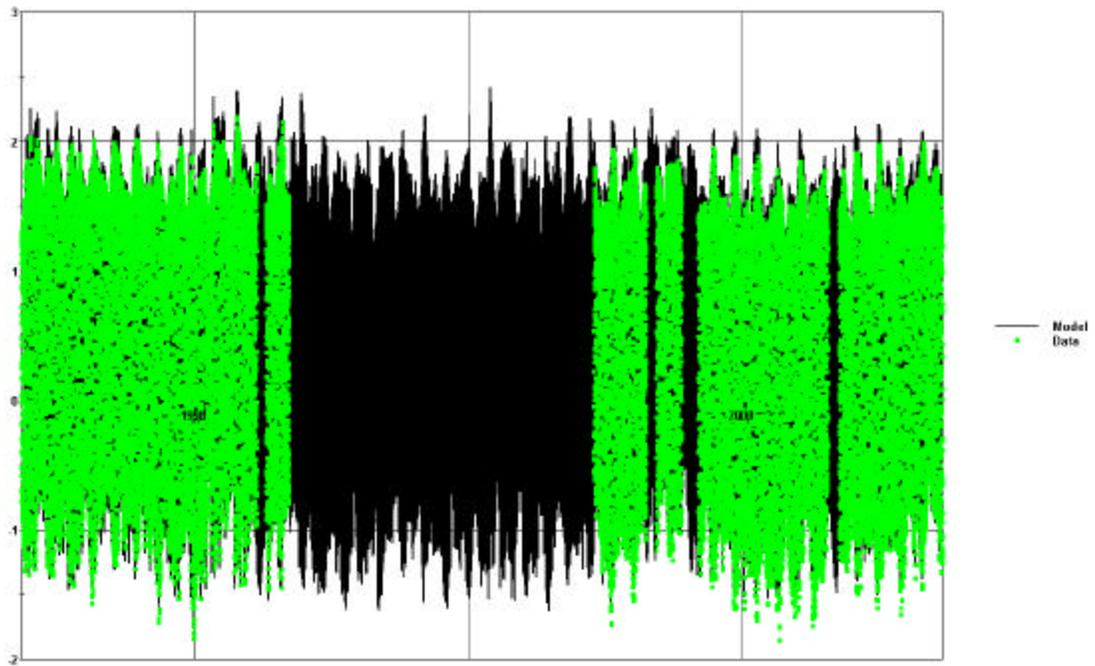


Figure 7-3 1997 – 2000 Confirmation of Water Surface Elevation at USGS 02198920 – Houlihan Bridge

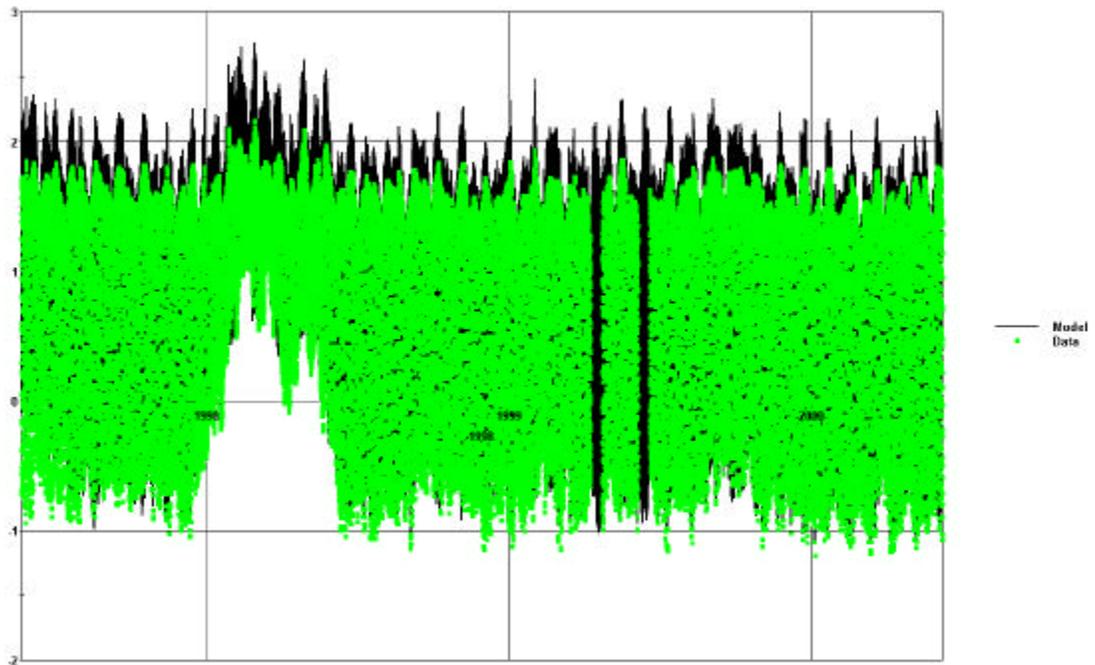


Figure 7-4 1997 – 2000 Confirmation of Water Surface Elevation at USGS 02198840 – I-95 Bridge

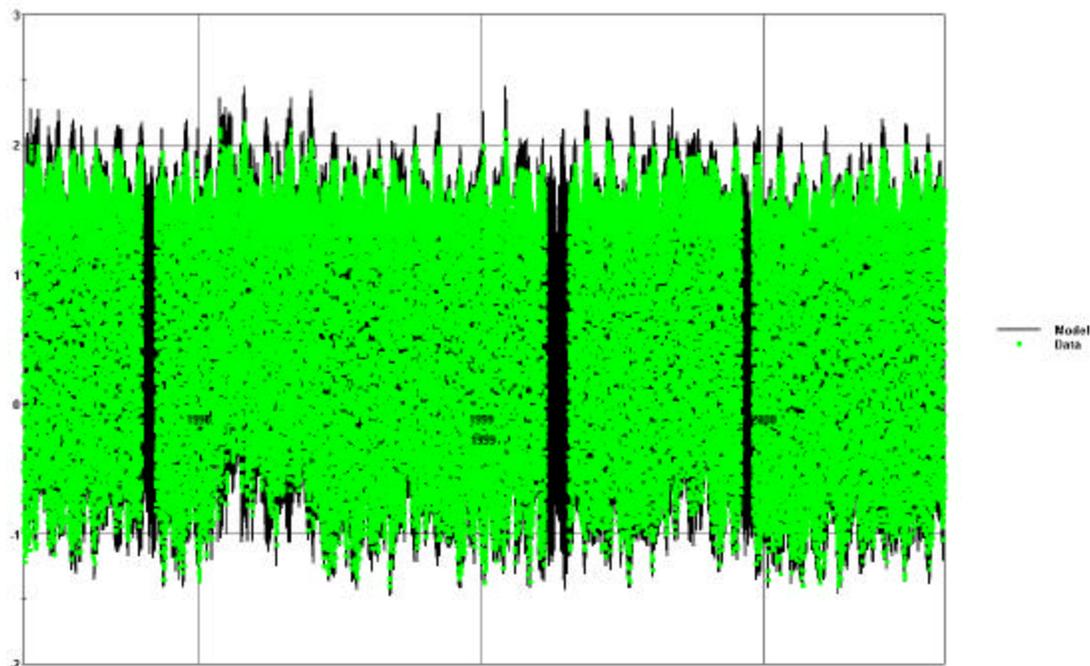


Figure 7-5 1997 – 2000 Confirmation of Water Surface Elevation at USGS 02198979 – Limehouse Creek

7.2 USGS Salinity

The salinity confirmation results are shown in Tables 7-4 through 7-6 and the time series comparisons are shown in Figures 7-6 through 7-9.

Table 7-4 Salinity Confirmation Percentiles for 1997 through 2000

| USGS Station | Measured Percentiles | | | | | | Simulated Percentiles | | | | |
|-----------------|----------------------|------|------|------|------|------|-----------------------|------|------|------|-------|
| | Points | 5% | 10% | 50% | 90% | 95% | 5% | 10% | 50% | 90% | 95% |
| US F&W Dock | 56,531 | 0.02 | 0.03 | 0.13 | 0.48 | 0.07 | 0.00 | 0.00 | 0.19 | 1.08 | 1.48 |
| Lucknow Canal | 55,951 | 0.02 | 0.03 | 0.12 | 0.38 | 0.49 | 0.00 | 0.00 | 0.09 | 0.57 | 0.71 |
| Houlihan Bridge | 27,303 | 0.02 | 0.02 | 0.15 | 5.15 | 6.90 | 0.00 | 0.00 | 1.03 | 8.80 | 10.72 |
| I-95 Bridge | 55,695 | 0.02 | 0.03 | 0.04 | 0.06 | 0.06 | 0.00 | 0.00 | 0.00 | 0.03 | 0.09 |

Table 7-5 Salinity Confirmation Statistics for 1997 through 2000

| USGS Station | Simulated versus Measured Statistics | | | | | | | | | | | | |
|-----------------|--------------------------------------|------------|---------------------|------------------------|-----------|-----------------------|----------------|-------------------------|---------------|------------------------|------|------------------------------|-----------------------|
| | Points | Mean Error | Mean Error Absolute | Mean Error Percent (%) | RMS Error | RMS Error Percent (%) | Mean Simulated | STD Deviation Simulated | Mean Measured | STD Deviation Measured | R2 | Coefficient of Efficiency, E | Index of Agreement, d |
| US F&W Dock | 56,531 | 0.18 | 0.24 | 109.15 | 0.42 | 193.51 | 0.40 | NC | 0.22 | NC | 0.52 | 0.43 | 0.62 |
| Lucknow Canal | 55,951 | 0.02 | 0.10 | 59.52 | 0.16 | 91.00 | 0.20 | NC | 0.17 | NC | 0.64 | 0.65 | 0.79 |
| Houlihan Bridge | 27,303 | 1.26 | 1.52 | 100.53 | 2.54 | 168.32 | 2.77 | 3.71 | 1.51 | 2.50 | 0.67 | 0.51 | 0.71 |
| I-95 Bridge | 55,695 | -0.03 | 0.05 | 105.34 | 0.07 | 164.76 | 0.02 | NC | 0.04 | NC | 0.18 | 0.09 | 0.24 |

NC = not calculated because of low of negative values

Table 7-6 Salinity Confirmation Comparison to Federal Expectations

| USGS Station | Salinity (ppt) | | | |
|-----------------|-------------------------|----------------------|----------------------|----------------------|
| | 50% Greater than 5 ppt? | 10% Difference (ppt) | 50% Difference (ppt) | 90% Difference (ppt) |
| US F&W Dock | N | NA | 0.07 | 0.59 |
| Lucknow Canal | N | NA | -0.03 | 0.18 |
| Houlihan Bridge | N | NA | 0.88 | 3.66 |
| I-95 Bridge | N | NA | -0.04 | -0.03 |

NA = not applicable criteria of federal expectations
 = indicates a pass of the federal expectations

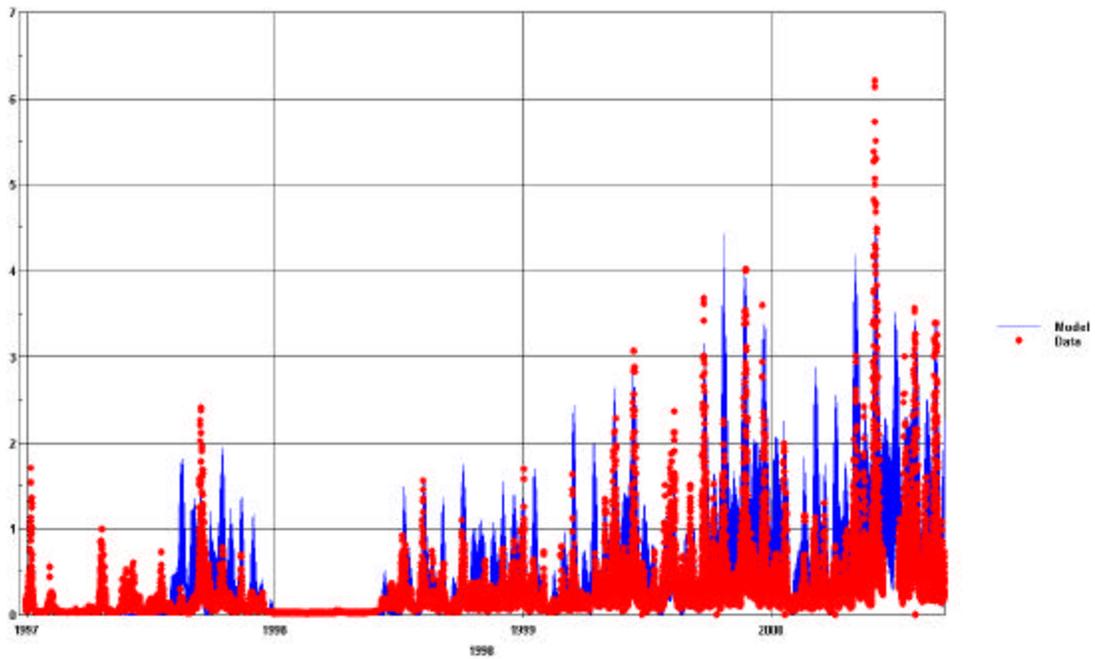


Figure 7-6 1997 – 2000 Confirmation of Salinity at USGS 021989791 – US F&W Dock

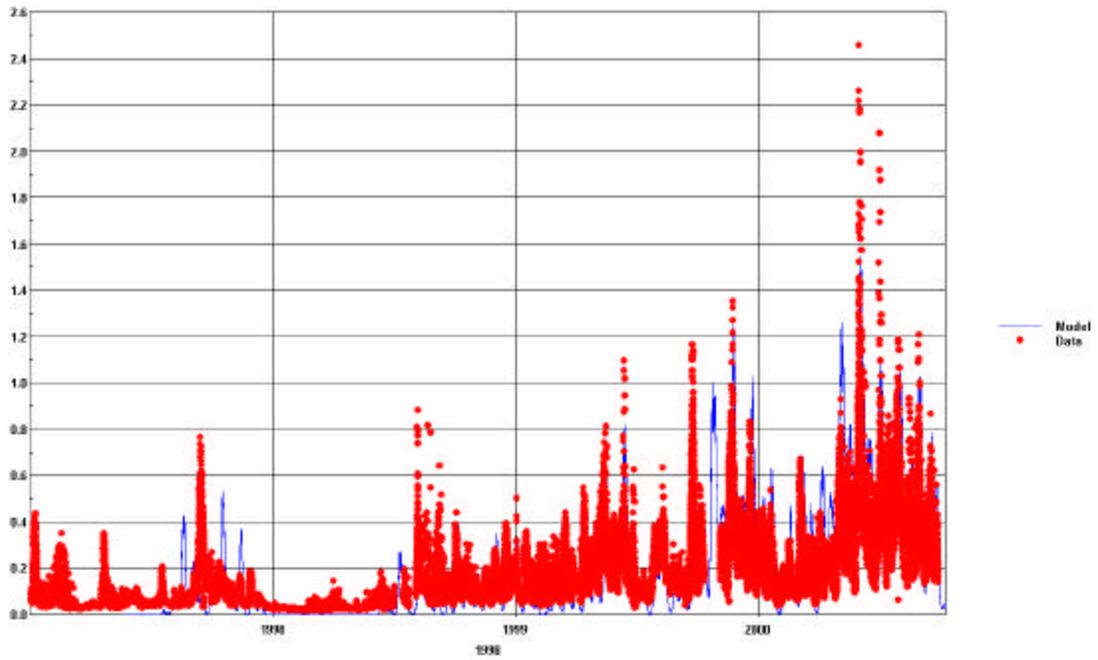


Figure 7-7 1997 – 2000 Confirmation of Salinity at USGS 021989784 – Lucknow Canal

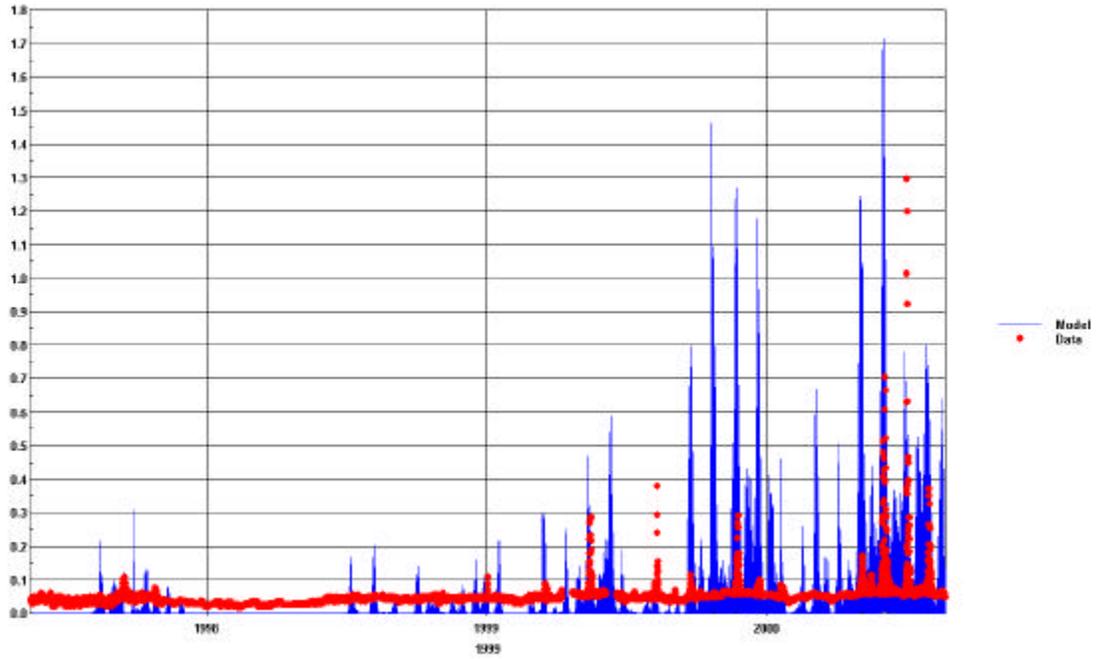


Figure 7-8 1997 – 2000 Confirmation of Salinity at USGS 02198840 – I-95 Bridge

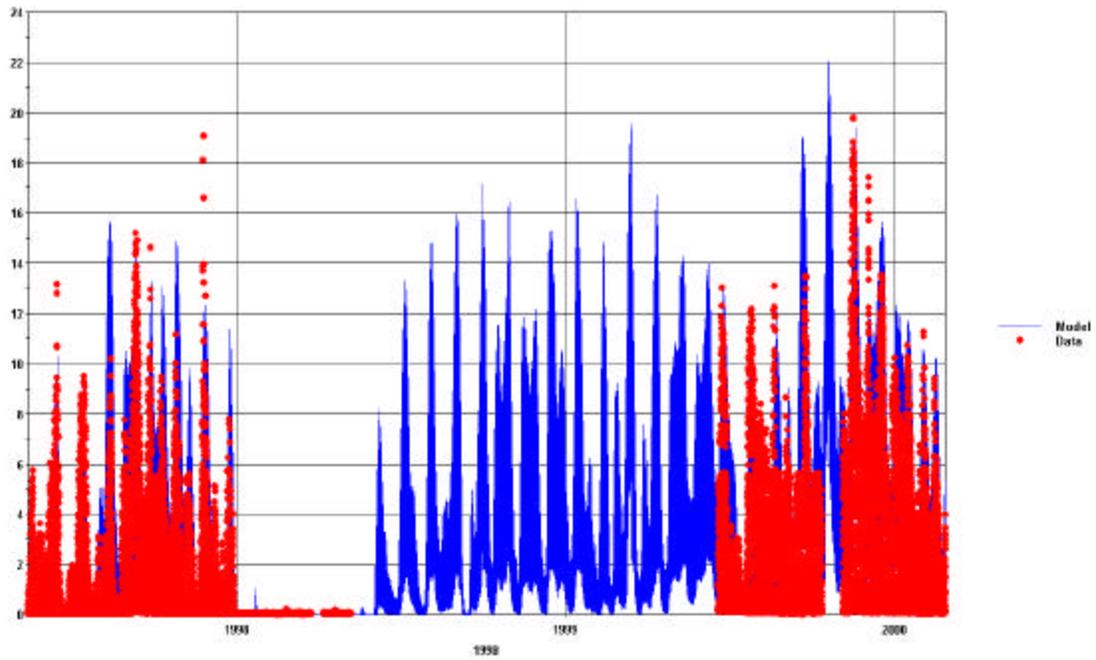


Figure 7-9 1997 – 2000 Confirmation of Salinity at USGS 02198920 – Houlihan Bridge

8.0 SUMMARY AND CONCLUSIONS

The work described herein represents an intensive seven-month period of developing an EFDC model calibration suitable for delivering an accurate series of hydrodynamic information to a water quality model for TMDL develop. At its current state, the coarse grid model calibration has performed well in representing the elevation, flow, currents, temperature, and salinity for the entire Savannah Harbor Estuary. It has responded very well to the extreme stratification and destratification that occurs on the Front River while capturing the salinity intrusion in the upper parts of the estuary on the Little Back River, Middle River, and the I95 Bridge. This was an extensive test to see if EFDC could represent the vertical mixing in the harbor with the turbulence closure model that has been successfully applied to many other complex waterbodies. EFDC also proved that a coarse grid can indeed represent the hydrodynamics well enough while still maintaining a representative number of vertical layers and horizontal segmentation for reasonable model run times.

Of course all models can be continually tweaked and refined, but this calibration of the EFDC model seems appropriate for moving forward with the calibration of the water quality model for the harbor. The coarse grid can capture the hydrodynamics for linking to the water quality model. If sediment transport or extensive modification of the harbor “plumbing network” is required for simulation, the fine grid may need to be involved. Also, the coarse grid may be used as more of a screening tool to channel and harbor modifications with the final run ultimately with the fine grid. The model run times with the coarse grid take approximately 2.7 hours to run one full year, and therefore, 4 years takes approximately 11 hours to run. This is a very good run time for the complex nature of the system and taking into account how well the coarse grid was able to perform for 1997, 1999, and 1997-2000.

The model confirmation was the key to a successful calibration and confirmation. To have four years of record to examine salinity intrusion in the upper estuary will be important in modeling scenarios for the dissolved oxygen TMDL.

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APPENDICIES

APPENDIX A TIDAL CURRENT ANALYSIS

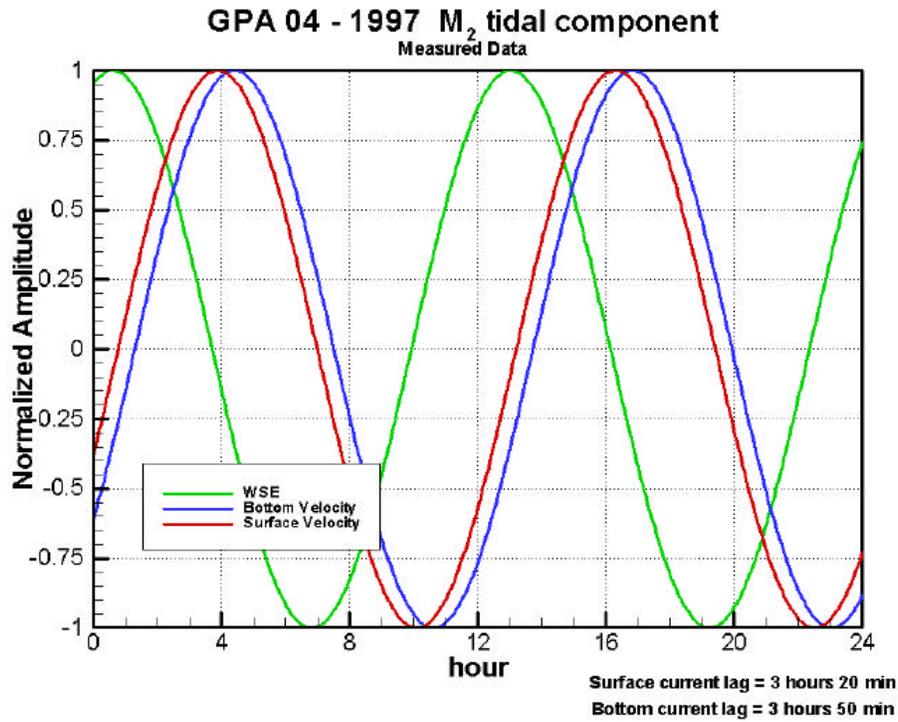


Figure A-1 1997 Measured Tidal Current Comparison at FR-04

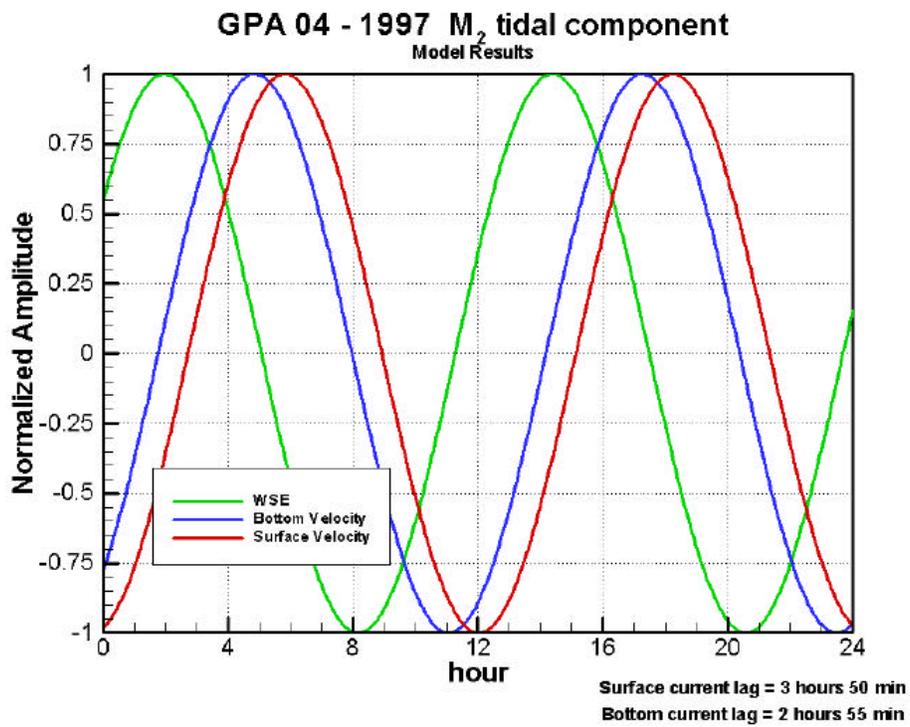


Figure A-2 1997 Simulated Tidal Current Comparison at FR-04

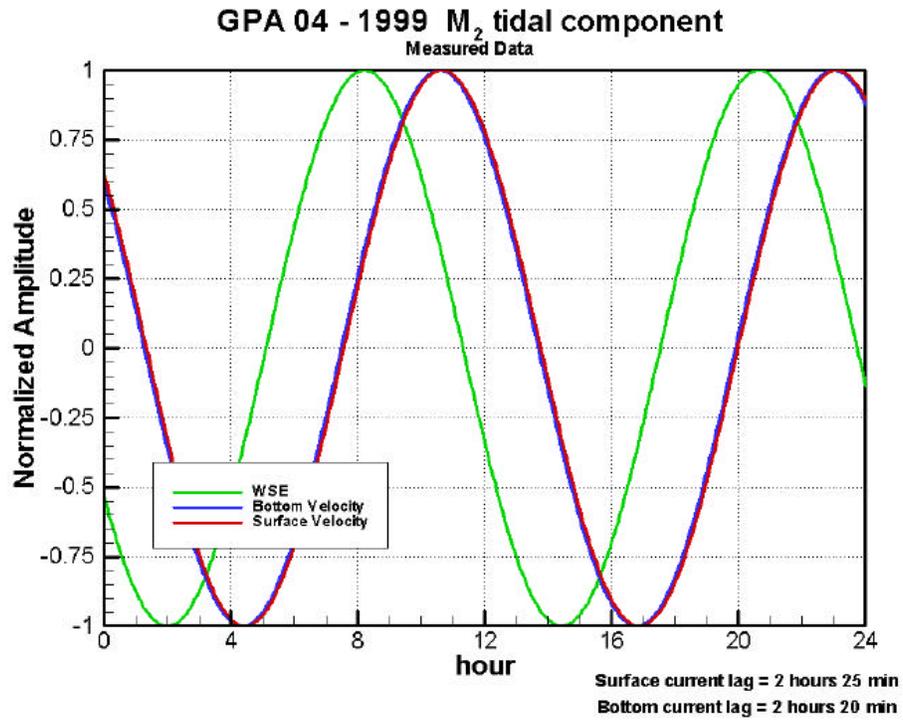


Figure A-3 1999 Measured Tidal Current Comparison at FR-04

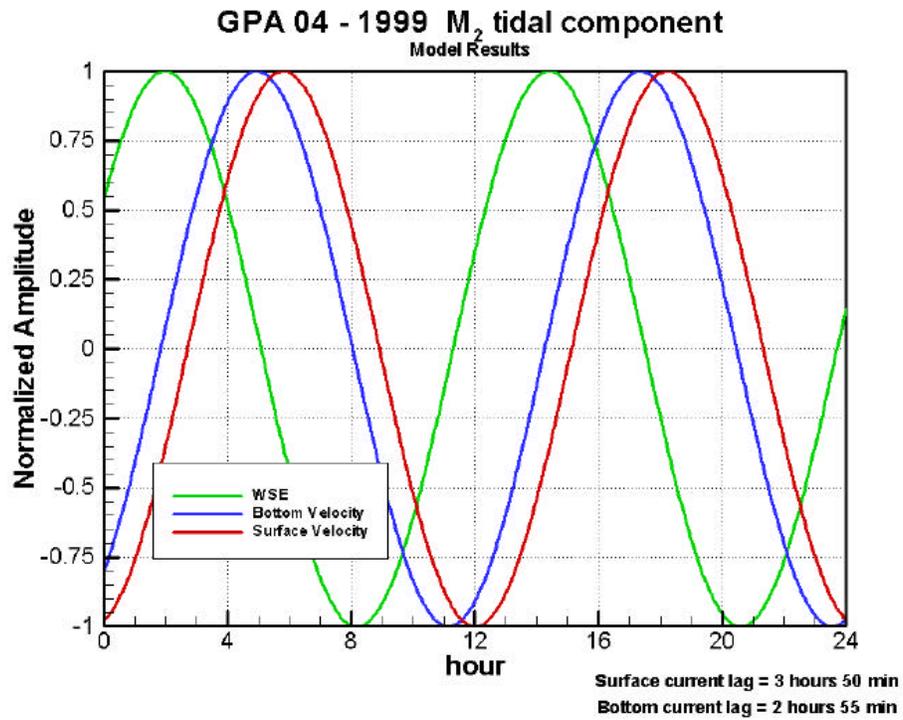


Figure A-4 1999 Simulated Tidal Current Comparison at FR-04

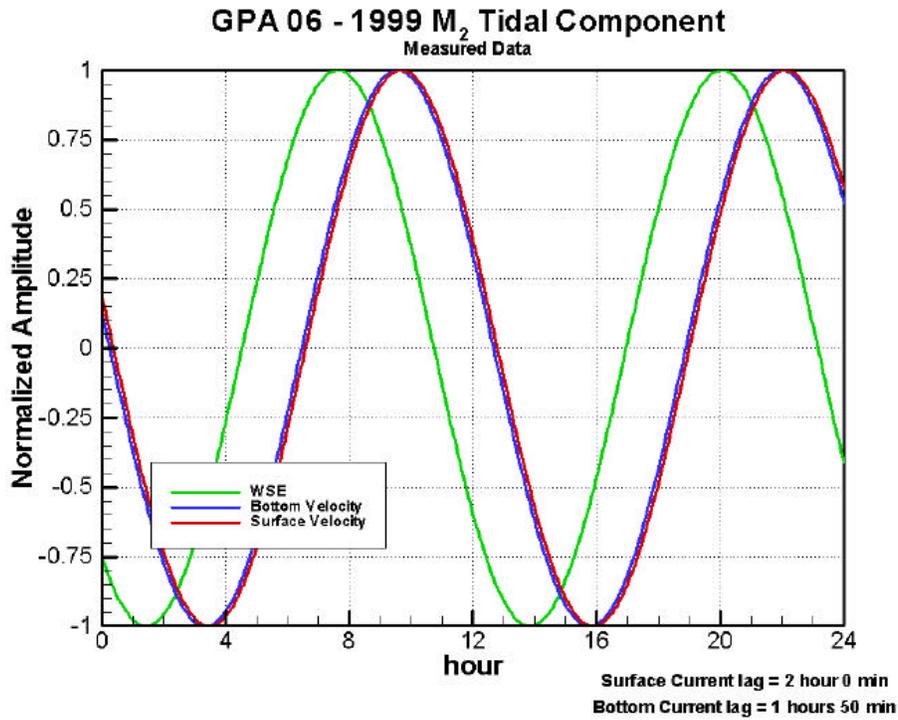


Figure A-5 1999 Measured Tidal Current Comparison at FR-06

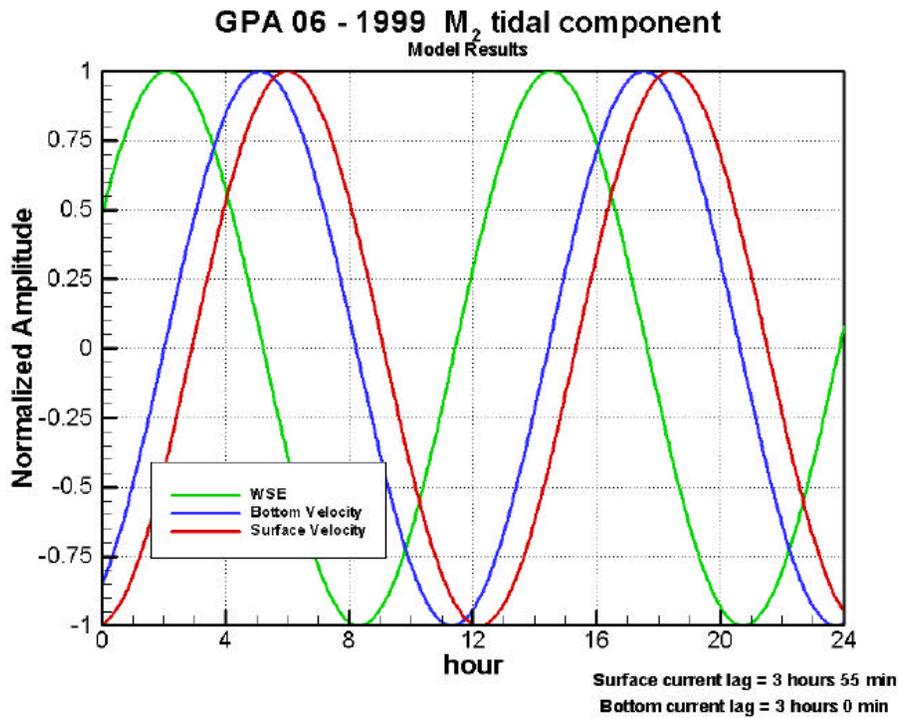


Figure A-6 1999 Simulated Tidal Current Comparison at FR-06

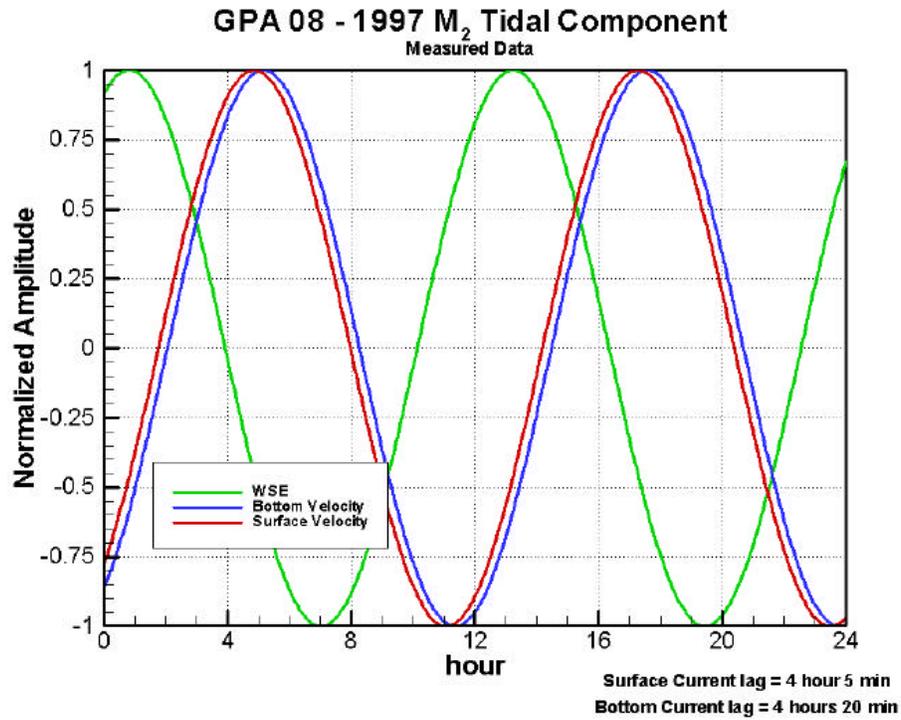


Figure A-7 1997 Measured Tidal Current Comparison at FR-08

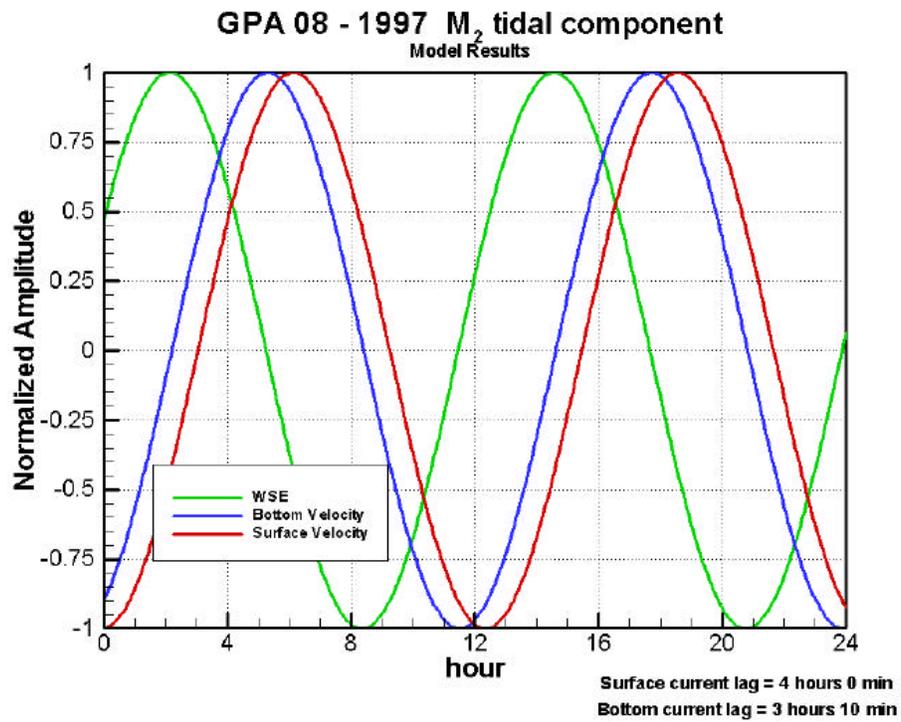


Figure A-8 1997 Simulated Tidal Current Comparison at FR-08

APPENDIX B 1997 WATER SURFACE ELEVATION COMPARISONS

Table B-1 Summary Statistics for Elevation (meters) for July 9, 1997 through October 5, 1997

| July 9 - October 5, 1997 [Julian Days 190-278] | | | | | | | | | |
|---|----------|-----|-----|-----------|-----|-----|------------|------|------|
| Stations | Measured | | | Simulated | | | Difference | | |
| | 5% | 50% | 95% | 5% | 50% | 95% | 5% | 50% | 95% |
| BR-05 | -1.0 | 0.5 | 1.6 | -1.0 | 0.3 | 1.6 | 0.0 | -0.2 | 0.0 |
| FR-06 | -1.0 | 0.5 | 1.6 | -0.9 | 0.4 | 1.7 | 0.1 | -0.1 | 0.0 |
| BR-07 | -0.9 | 0.4 | 1.7 | -0.9 | 0.6 | 1.7 | 0.1 | 0.3 | 0.0 |
| FR-08 | -1.0 | 0.6 | 1.8 | -1.0 | 0.4 | 1.8 | 0.0 | -0.2 | 0.0 |
| FR-09 | -0.9 | 0.6 | 1.7 | -1.0 | 0.4 | 1.8 | -0.1 | -0.2 | 0.1 |
| MR-10 | -1.0 | 0.6 | 1.7 | -0.9 | 0.4 | 1.8 | 0.0 | -0.2 | 0.0 |
| FR-11R | -0.9 | 0.7 | 1.7 | -1.0 | 0.4 | 1.9 | -0.1 | -0.3 | 0.2 |
| MR-12R | -0.8 | 0.7 | 1.7 | -0.8 | 0.4 | 1.8 | -0.1 | -0.3 | 0.1 |
| USGS02198840 (I-95) | -0.6 | 0.8 | 1.7 | 1.7 | 0.5 | 1.9 | 2.2 | -0.2 | 0.2 |
| USGS02198920 (Houlihan Bridge) | -1.0 | 0.6 | 1.7 | -0.9 | 0.4 | 1.8 | 0.0 | -0.2 | 0.1 |
| USGS02198979 (Limehouse Creek) | -0.7 | 0.8 | 1.7 | -0.9 | 0.4 | 1.8 | -0.1 | -0.4 | 0.1 |
| USGS02198977 (Broad St) | -1.0 | 0.5 | 1.6 | -0.9 | 0.4 | 1.7 | 0.1 | -0.1 | 0.1 |
| USGS02198980 (Ft Pulaski) | -0.9 | 0.4 | 1.5 | -0.8 | 0.4 | 1.4 | 0.1 | 0.0 | -0.1 |

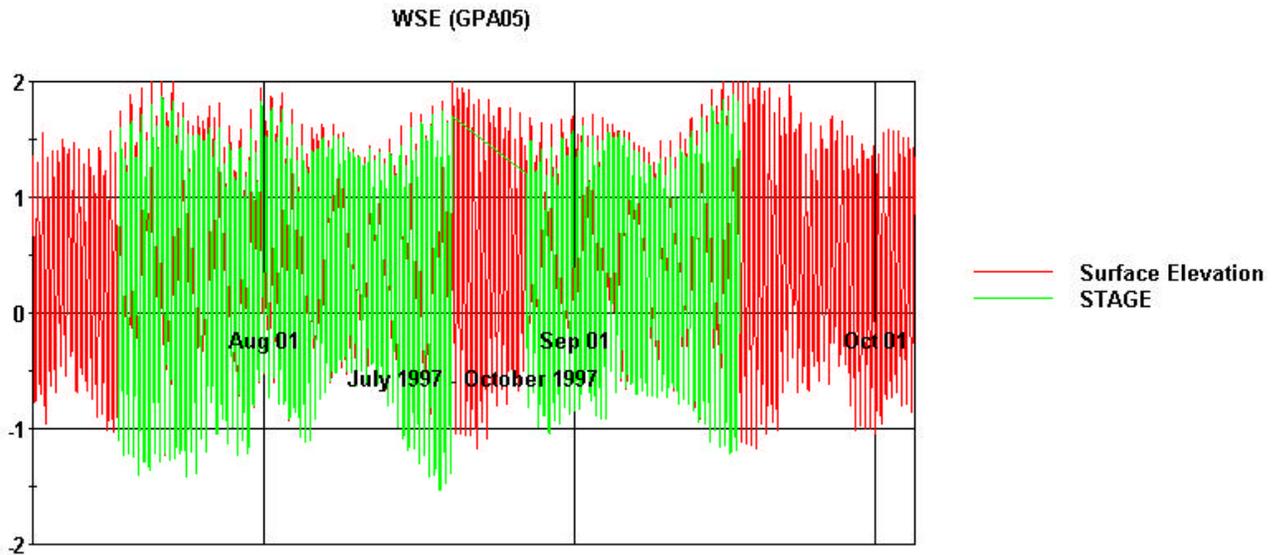


Figure B-1 Elevation (meters) Calibration at BR-05 for July 9, 1997 through October 5, 1997

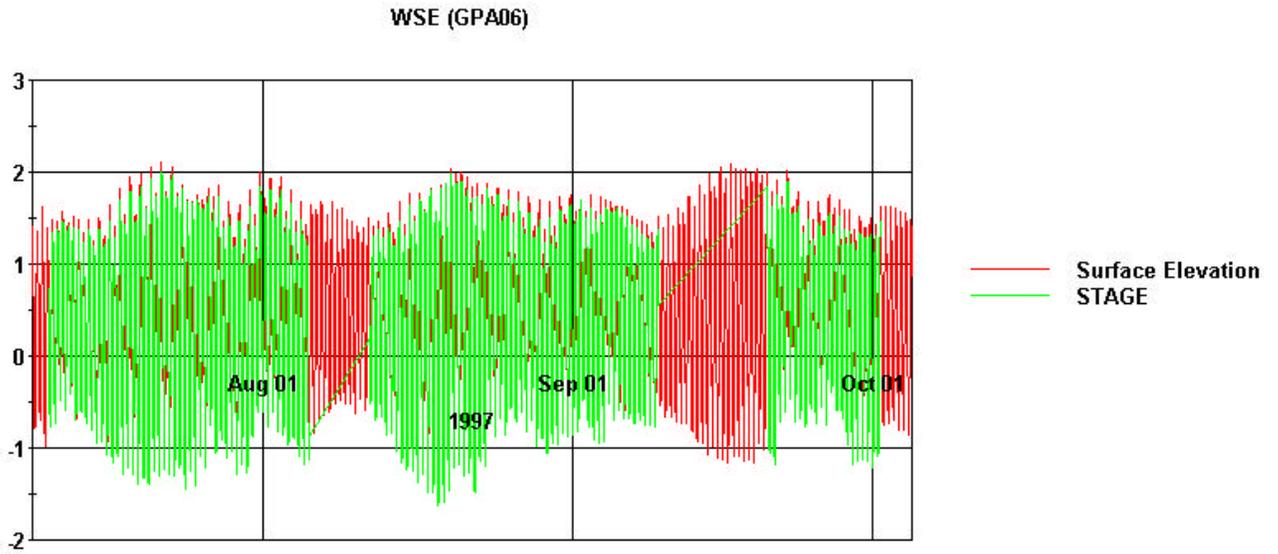


Figure B-2 Elevation (meters) Calibration at FR-06 for July 9, 1997 through October 5, 1997

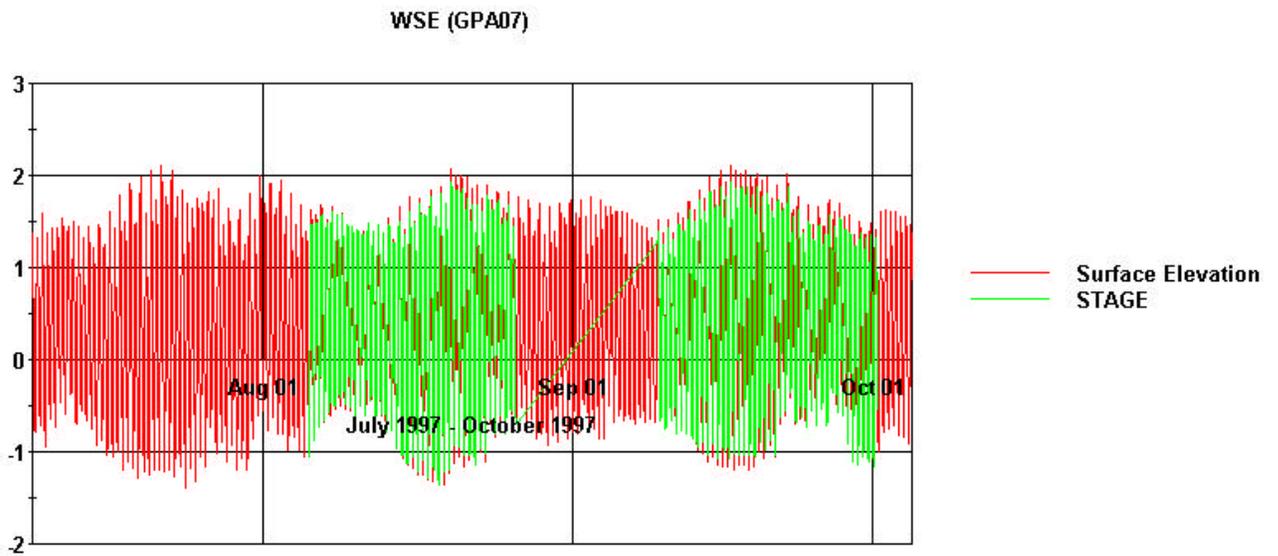


Figure B-3 Elevation (meters) Calibration at BR-07 for July 9, 1997 through October 5, 1997

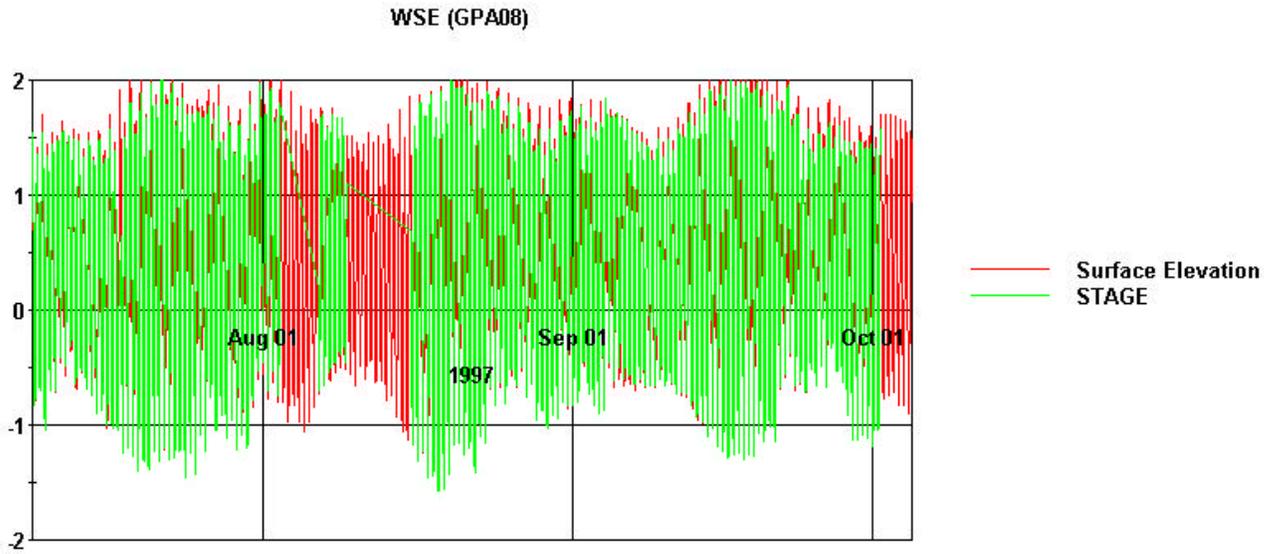


Figure B-4 Elevation (meters) Calibration at FR-08 for July 9, 1997 through October 5, 1997

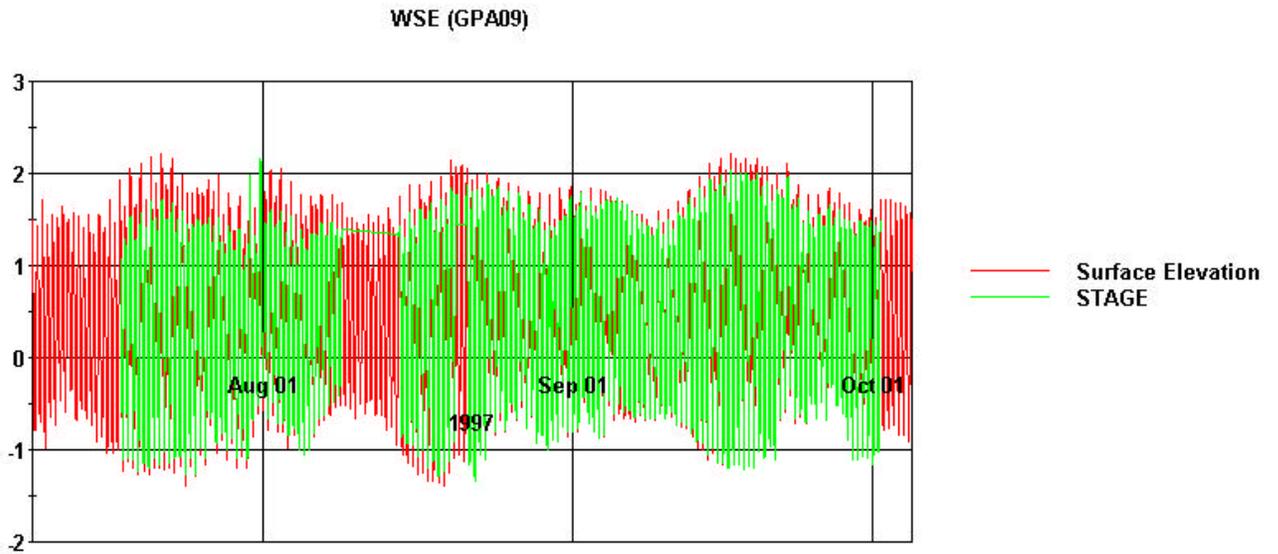


Figure B-5 Elevation (meters) Calibration at FR-09 for July 9, 1997 through October 5, 1997

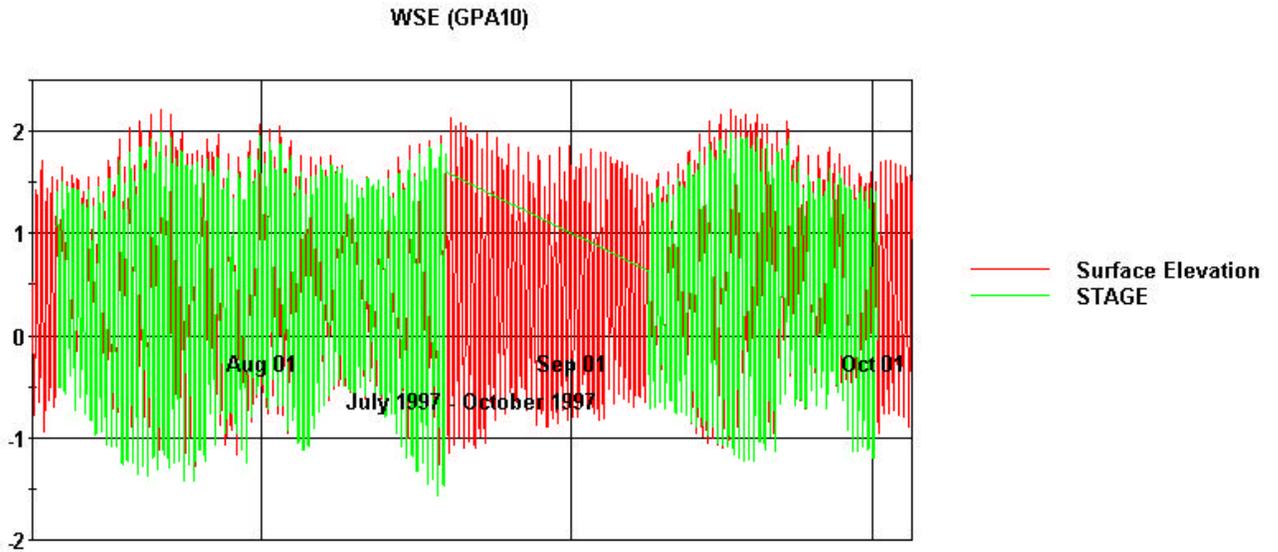


Figure B-6 Elevation (meters) Calibration at MR-10 for July 9, 1997 through October 5, 1997

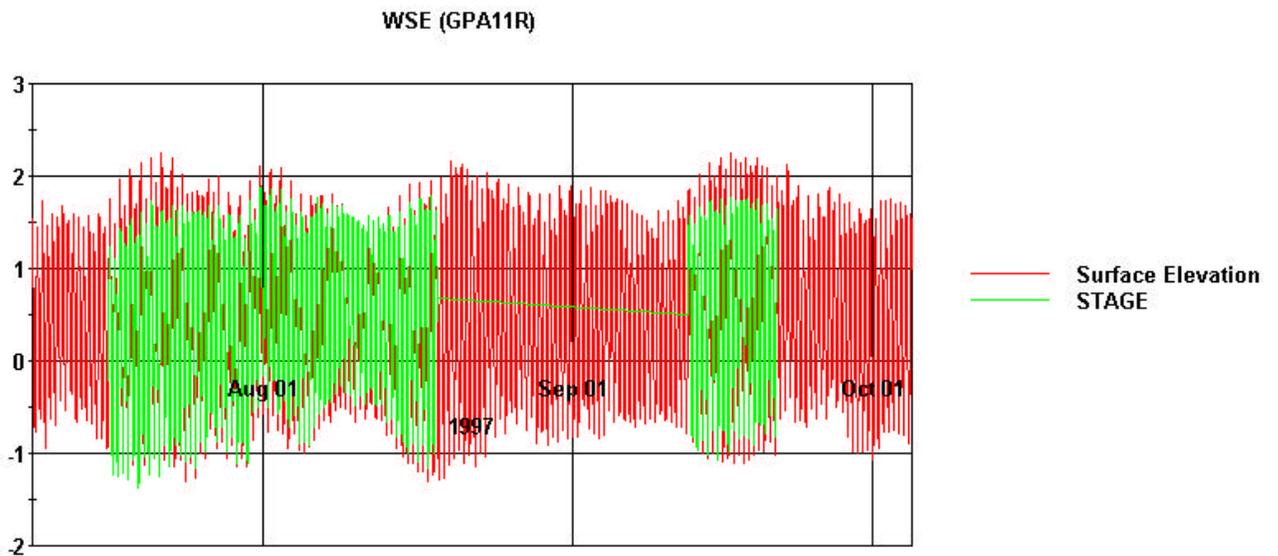


Figure B-7 Elevation (meters) Calibration at FR-11R for July 9, 1997 through October 5, 1997

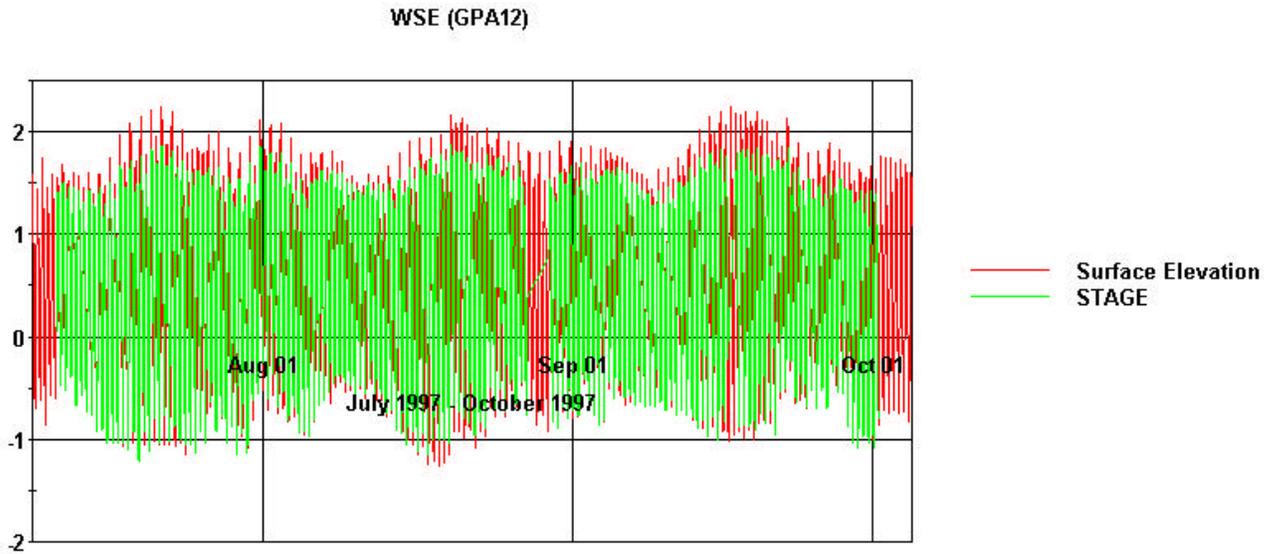


Figure B-8 Elevation (meters) Calibration at MR-12R for July 9, 1997 through October 5, 1997

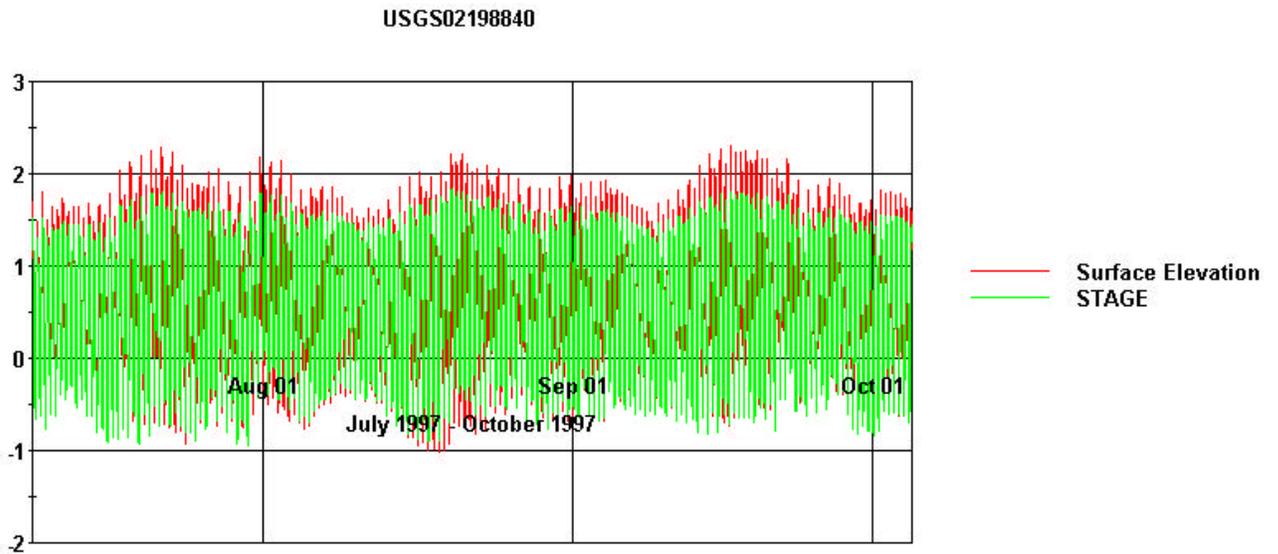


Figure B-9 Elevation (meters) Calibration at I-95 Bridge for July 9, 1997 through October 5, 1997

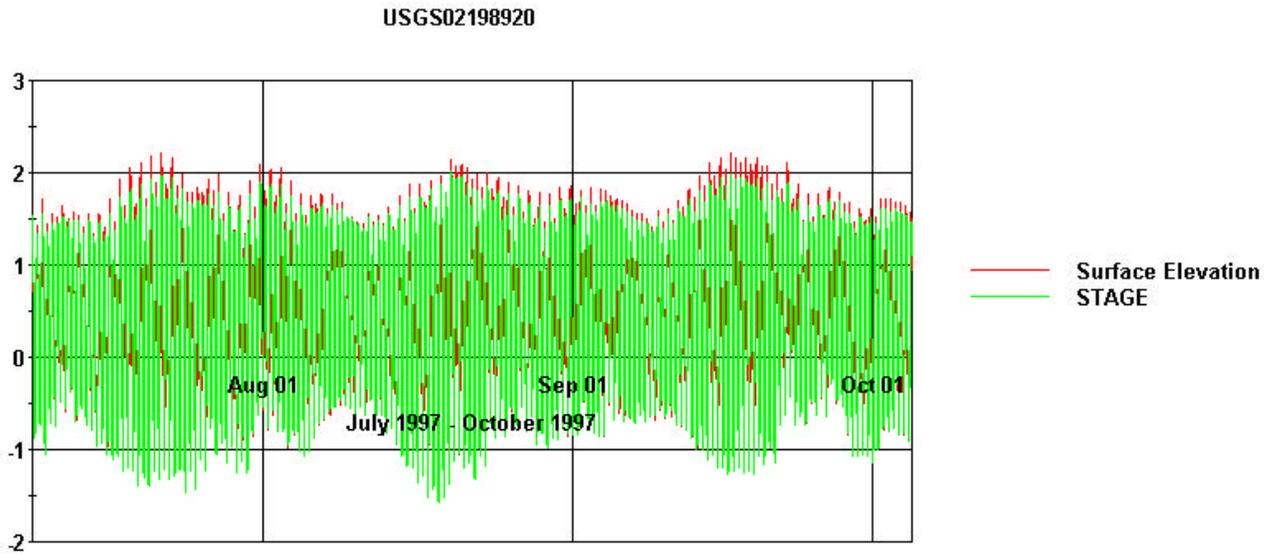


Figure B-10 Elevation (meters) Calibration at Houlihan Bridge for July 9, 1997 through October 5, 1997

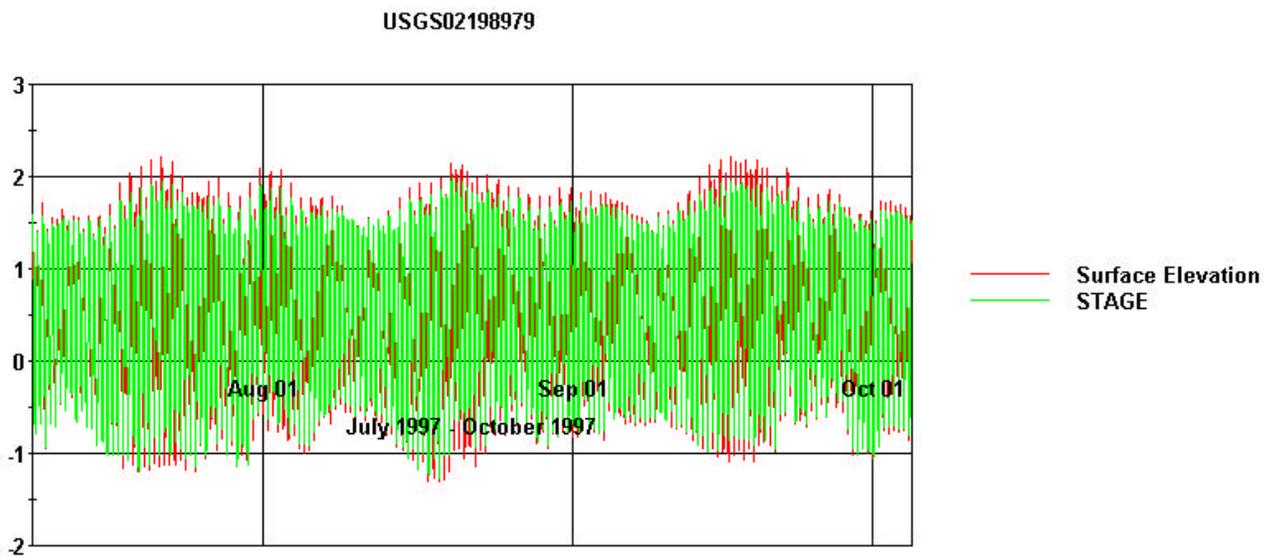


Figure B-11 Elevation (meters) Calibration at Limehouse Creek for July 9, 1997 through October 5, 1997

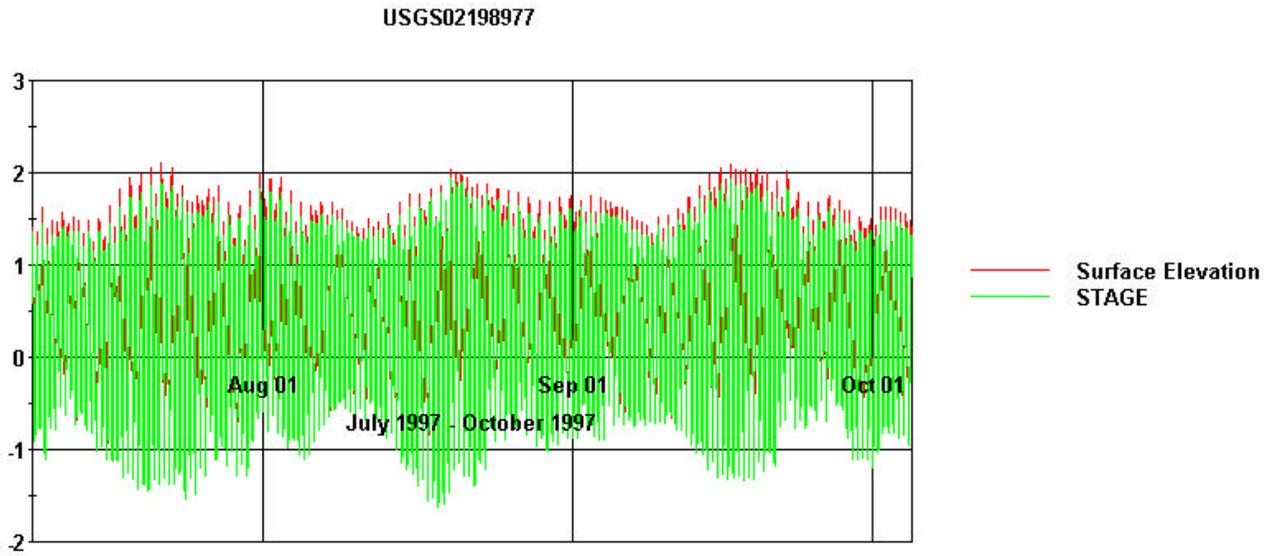


Figure B-12 Elevation (meters) Calibration at Broad St. for July 9, 1997 through October 5, 1997

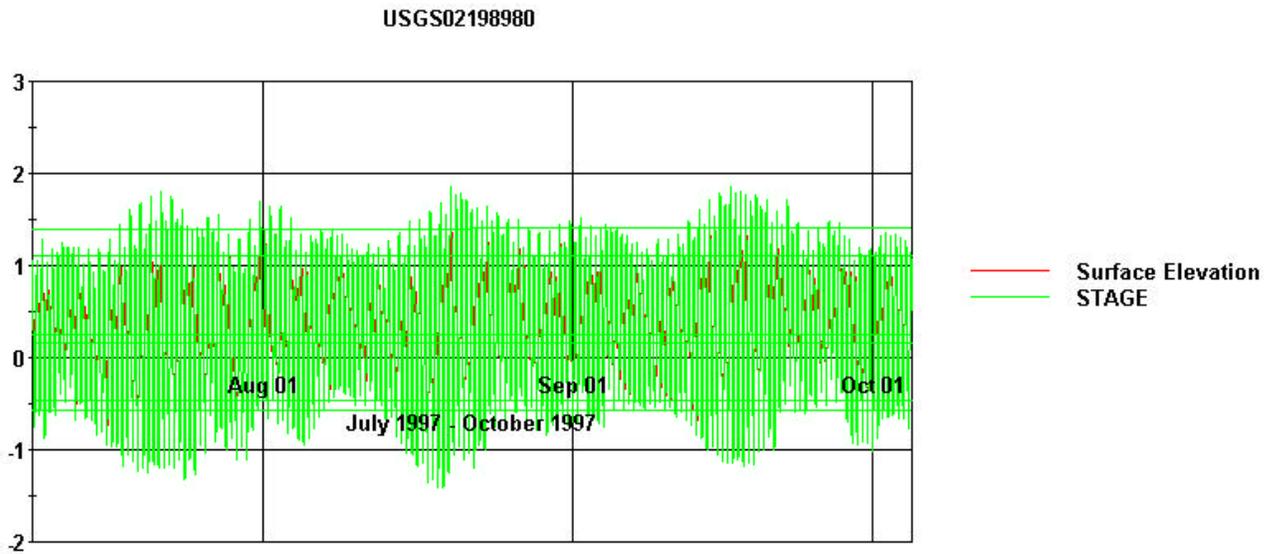


Figure B-13 Elevation (meters) Calibration at Ft. Pulaski for July 9, 1997 through October 5, 1997

Table B-2 Summary Statistics for Elevation (meters) for July 9, 1997 through July 23, 1997

| July 9 - 23, 1997 [Julian Days 190-204] | | | | | | | | | |
|--|----------|------|-----|-----------|------|-----|------------|------|------|
| Stations | Measured | | | Simulated | | | Difference | | |
| | 5% | 50% | 95% | 5% | 50% | 95% | 5% | 50% | 95% |
| BR-05 | -1.2 | 0.5 | 1.7 | -1.1 | 0.3 | 1.8 | 0.1 | -0.2 | 0.1 |
| FR-06 | -1.1 | 0.4 | 1.7 | -1.0 | 0.3 | 1.7 | 0.1 | -0.1 | 0.0 |
| FR-08 | -1.0 | 0.5 | 1.7 | -1.0 | 0.3 | 1.7 | 0.0 | -0.2 | 0.0 |
| FR-09 | -1.1 | 0.5 | 1.6 | -1.2 | 0.3 | 2.0 | -0.1 | -0.2 | 0.4 |
| MR-10 | -1.1 | 0.5 | 1.7 | -1.0 | 0.3 | 1.8 | 0.0 | -0.2 | 0.1 |
| FR-11R | -1.1 | 0.5 | 1.6 | -1.1 | 0.4 | 2.0 | 0.1 | -0.1 | 0.4 |
| MR-12R | -0.9 | 0.6 | 1.7 | -0.9 | 0.4 | 1.8 | 0.0 | -0.2 | 0.2 |
| USGS02198840 (I-95) | -0.7 | -0.7 | 1.6 | -0.5 | -0.5 | 1.8 | 0.1 | 0.1 | 0.2 |
| USGS02198920 (Houlihan Bridge) | -1.1 | 0.5 | 1.7 | -1.0 | 0.3 | 1.8 | 0.0 | -0.2 | 0.1 |
| USGS02198979 (Limehouse Creek) | -0.8 | 0.7 | 1.7 | 1.7 | 0.3 | 1.7 | 2.5 | -0.3 | 0.0 |
| USGS02198977 (Broad St) | -1.1 | 0.4 | 1.6 | -1.0 | 0.3 | 1.7 | 0.1 | -0.1 | 0.1 |
| USGS02198980 (Ft Pulaski) | -1.0 | 0.3 | 1.4 | -0.9 | 0.3 | 1.4 | 0.1 | 0.0 | -0.1 |

Table B-3 Summary Statistics for Elevation (meters) for July 24, 1997 through August 7, 1997

| July 24 - August 7, 1997 [Julian Days 205-219] | | | | | | | | | |
|---|----------|-----|-----|-----------|-----|-----|------------|------|------|
| Stations | Measured | | | Simulated | | | Difference | | |
| | 5% | 50% | 95% | 5% | 50% | 95% | 5% | 50% | 95% |
| BR-05 | -1.0 | 0.5 | 1.6 | -1.0 | 0.3 | 1.6 | 0.1 | -0.2 | 0.1 |
| FR-06 | -1.1 | 0.5 | 1.6 | -1.0 | 0.3 | 1.7 | 0.1 | -0.2 | 0.0 |
| BR-07 | -0.8 | 0.7 | 1.5 | -0.8 | 0.4 | 1.6 | 0.0 | -0.3 | 0.1 |
| FR-08 | -1.1 | 0.6 | 1.7 | -1.0 | 0.3 | 1.8 | 0.0 | -0.3 | 0.0 |
| FR-09 | -0.9 | 0.5 | 1.5 | -1.0 | 0.3 | 1.8 | 0.0 | -0.1 | 0.3 |
| MR-10 | -1.0 | 0.6 | 1.7 | -0.9 | 0.4 | 1.8 | 0.0 | -0.3 | 0.1 |
| FR-11R | -0.8 | 0.7 | 1.7 | -0.9 | 0.4 | 1.8 | -0.1 | -0.4 | 0.1 |
| MR-12R | -0.8 | 0.7 | 1.6 | -0.9 | 0.4 | 1.8 | 0.0 | -0.3 | 0.2 |
| USGS02198840 (I-95) | -0.6 | 0.8 | 1.7 | -0.7 | 0.5 | 1.9 | -0.1 | -0.3 | 0.2 |
| USGS02198920 (Houlihan Bridge) | -1.0 | 0.6 | 1.7 | -1.0 | 0.4 | 1.8 | 0.0 | -0.2 | 0.1 |
| USGS02198979 (Limehouse Creek) | -0.8 | 0.8 | 1.7 | -0.9 | 0.4 | 1.8 | -0.1 | -0.4 | 0.1 |
| USGS02198977 (Broad St) | -1.1 | 0.5 | 1.6 | -1.0 | 0.3 | 1.7 | 0.1 | -0.2 | 0.1 |
| USGS02198980 (Ft Pulaski) | -0.9 | 0.4 | 1.4 | -0.8 | 0.3 | 1.3 | 0.1 | 0.0 | -0.1 |

Table B-4 Summary Statistics for Elevation (meters) for August 8, 1997 through August 22, 1997

| August 8 - 22, 1997 [Julian Days 220-234] | | | | | | | | | |
|--|----------|-----|-----|-----------|-----|-----|------------|------|------|
| Stations | Measured | | | Simulated | | | Difference | | |
| | 5% | 50% | 95% | 5% | 50% | 95% | 5% | 50% | 95% |
| BR-05 | -1.1 | 0.5 | 1.5 | -1.0 | 0.3 | 1.5 | 0.1 | -0.2 | 0.0 |
| FR-06 | -1.2 | 0.4 | 1.7 | -1.1 | 0.3 | 1.7 | 0.2 | -0.2 | 0.0 |
| BR-07 | -0.9 | 0.6 | 1.7 | -1.0 | 0.3 | 1.6 | -0.1 | -0.3 | 0.0 |
| FR-08 | 1.9 | 0.6 | 1.9 | -1.1 | 0.3 | 1.9 | -3.0 | -0.3 | 0.0 |
| FR-09 | -1.0 | 0.6 | 1.7 | -1.2 | 0.4 | 1.9 | -0.1 | -0.3 | 0.2 |
| MR-10 | -1.1 | 0.6 | 1.6 | -1.0 | 0.3 | 1.6 | 0.1 | -0.2 | 0.0 |
| FR-11R | -0.8 | 0.7 | 1.6 | -0.9 | 0.4 | 1.6 | -0.2 | -0.3 | 0.0 |
| MR-12R | -0.8 | 0.7 | 1.7 | -0.9 | 0.4 | 1.8 | -0.2 | -0.3 | 0.1 |
| USGS02198840 (I-95) | -0.6 | 0.8 | 1.7 | -0.7 | 0.5 | 1.8 | -0.1 | -0.3 | 0.2 |
| USGS02198920 (Houlihan Bridge) | -1.1 | 0.6 | 1.8 | -1.1 | 0.4 | 1.8 | 0.1 | -0.2 | 0.0 |
| USGS02198979 (Limehouse Creek) | -0.8 | 0.8 | 1.8 | -1.0 | 0.4 | 1.8 | -0.2 | -0.4 | 0.0 |
| USGS02198977 (Broad St) | -1.2 | 0.5 | 1.7 | -1.0 | 0.3 | 1.7 | 0.2 | -0.1 | 0.0 |
| USGS02198980 (Ft Pulaski) | -1.0 | 0.4 | 1.5 | -0.9 | 0.3 | 1.4 | 0.1 | 0.0 | -0.1 |

Table B-5 Summary Statistics for Elevation (meters) for August 23, 1997 through September 6, 1997

| August 23 - September 6, 1997 [Julian Days 235-249] | | | | | | | | | |
|--|----------|-----|-----|-----------|-----|-----|------------|------|------|
| Stations | Measured | | | Simulated | | | Difference | | |
| | 5% | 50% | 95% | 5% | 50% | 95% | 5% | 50% | 95% |
| BR-05 | -0.8 | 0.6 | 1.5 | -0.7 | 0.4 | 1.6 | 0.1 | -0.2 | 0.1 |
| FR-06 | -0.8 | 0.6 | 1.6 | -0.7 | 0.4 | 1.7 | 0.1 | -0.2 | 0.1 |
| BR-07 | -0.7 | 0.7 | 1.7 | -0.8 | 0.4 | 1.7 | -0.1 | -0.3 | 0.1 |
| FR-08 | 1.7 | 0.7 | 1.7 | -0.8 | 0.4 | 1.7 | -2.5 | -0.2 | 0.0 |
| FR-09 | -0.8 | 0.6 | 1.7 | -0.8 | 0.4 | 1.8 | 0.0 | -0.2 | 0.0 |
| MR-12R | -0.7 | 0.8 | 1.6 | -0.7 | 0.5 | 1.8 | 0.0 | -0.3 | 0.1 |
| USGS02198840 (I-95) | -0.5 | 0.8 | 1.6 | -0.6 | 0.6 | 1.8 | 0.0 | -0.3 | 0.2 |
| USGS02198920 (Houlihan Bridge) | -0.8 | 0.7 | 1.7 | -0.8 | 0.4 | 1.8 | 0.0 | -0.3 | 0.1 |
| USGS02198979 (Limehouse Creek) | -0.7 | 0.9 | 1.7 | -0.7 | 0.5 | 1.8 | -0.1 | -0.4 | 0.1 |
| USGS02198977 (Broad St) | -0.8 | 0.6 | 1.6 | -0.7 | 0.4 | 1.7 | 0.1 | -0.1 | 0.1 |
| USGS02198980 (Ft Pulaski) | -0.7 | 0.5 | 1.4 | -0.6 | 0.4 | 1.4 | 0.1 | 0.0 | -0.1 |

Table B-6 Summary Statistics for Elevation (meters) for September 7, 1997 through September 20, 1997

| September 7 - 20, 1997 [Julian Days 250-263] | | | | | | | | | |
|---|----------|-----|-----|-----------|------|-----|------------|------|------|
| Stations | Measured | | | Simulated | | | Difference | | |
| | 5% | 50% | 95% | 5% | 50% | 95% | 5% | 50% | 95% |
| BR-05 | -0.8 | 0.5 | 1.7 | -0.9 | 0.4 | 1.7 | 0.0 | -0.2 | 0.0 |
| FR-06 | -0.7 | 0.5 | 1.3 | -0.6 | 0.4 | 1.4 | 0.1 | -0.1 | 0.1 |
| BR-07 | -0.9 | 0.7 | 1.8 | -1.0 | 0.4 | 1.9 | -0.1 | -0.3 | 0.1 |
| FR-08 | -1.0 | 0.6 | 1.9 | -0.9 | 0.4 | 1.9 | 0.0 | -0.2 | 0.1 |
| FR-09 | -0.9 | 0.7 | 1.9 | -1.0 | 0.4 | 1.9 | 0.0 | -0.3 | 0.1 |
| MR-10 | -0.9 | 0.6 | 1.8 | -0.9 | 0.4 | 2.0 | 0.0 | -0.3 | 0.1 |
| FR-11R | -0.8 | 0.9 | 1.7 | -1.0 | 0.5 | 2.1 | -0.2 | -0.4 | 0.3 |
| MR-12R | -0.7 | 0.7 | 1.7 | -0.8 | 0.5 | 1.9 | -0.1 | -0.3 | 0.2 |
| USGS02198840 (I-95) | -0.6 | 0.8 | 1.7 | -0.6 | 0.6 | 2.0 | 0.0 | -0.2 | 0.3 |
| USGS02198920 (Houlihan Bridge) | -1.0 | 0.7 | 1.8 | -0.9 | 0.4 | 2.0 | 0.0 | -0.2 | 0.1 |
| USGS02198979 (Limehouse Creek) | -0.7 | 0.8 | 1.8 | -0.9 | -0.9 | 2.0 | -0.2 | -1.7 | 0.1 |
| USGS02198977 (Broad St) | -1.1 | 0.6 | 1.7 | -0.9 | 0.4 | 1.8 | 0.1 | -0.2 | 0.1 |
| USGS02198980 (Ft Pulaski) | -0.9 | 0.4 | 1.6 | -0.8 | 0.4 | 1.5 | 0.1 | 0.0 | -0.1 |

Table B-7 Summary Statistics for Elevation (meters) for September 21, 1997 through October 5, 1997

| September 21 - October 5, 1997 [Julian Days 264-278] | | | | | | | | | |
|---|----------|-----|-----|-----------|-----|-----|------------|------|------|
| Stations | Measured | | | Simulated | | | Difference | | |
| | 5% | 50% | 95% | 5% | 50% | 95% | 5% | 50% | 95% |
| FR-06 | -1.0 | 0.5 | 1.5 | -0.8 | 0.4 | 1.6 | 0.1 | -0.1 | 0.1 |
| BR-07 | -0.8 | 0.6 | 1.6 | -0.8 | 0.4 | 1.6 | 0.0 | -0.2 | 0.1 |
| FR-08 | -0.9 | 0.6 | 1.6 | -0.8 | 0.4 | 1.7 | 0.1 | -0.2 | 0.1 |
| FR-09 | -0.9 | 0.6 | 1.7 | -0.8 | 0.4 | 1.7 | 0.0 | -0.2 | 0.1 |
| MR-10 | -0.9 | 0.6 | 1.6 | -0.8 | 0.4 | 1.7 | 0.1 | -0.2 | 0.1 |
| FR-11R | -0.8 | 0.9 | 1.6 | -0.9 | 0.6 | 2.0 | -0.2 | -0.3 | 0.3 |
| MR-12R | -0.8 | 0.7 | 1.6 | 1.6 | 0.5 | 1.7 | 2.4 | -0.2 | 0.1 |
| USGS02198840 (I-95) | -0.6 | 0.8 | 1.6 | -0.6 | 0.6 | 1.8 | 0.0 | -0.2 | 0.2 |
| USGS02198920 (Houlihan Bridge) | -0.8 | 0.7 | 1.6 | 1.6 | 0.4 | 1.7 | 2.5 | -0.2 | 0.1 |
| USGS02198979 (Limehouse Creek) | -0.7 | 0.8 | 1.7 | -0.8 | 0.4 | 1.7 | -0.1 | -0.4 | 0.0 |
| USGS02198977 (Broad St) | -0.9 | 0.5 | 1.5 | -0.8 | 0.4 | 1.6 | 0.1 | -0.1 | 0.1 |
| USGS02198980 (Ft Pulaski) | -0.7 | 0.4 | 1.4 | -0.6 | 0.4 | 1.3 | 0.1 | 0.0 | -0.1 |

APPENDIX C 1999 WATER SURFACE ELEVATION COMPARISONS

Table C-1 Summary Statistics for Elevation (meters) for July 31, 1999 through October 13, 1999

| July 31 - October 13, 1999 [Julian Days 212-286] | | | | | | | | | |
|---|----------|-----|-----|-----------|-----|-----|------------|------|------|
| Stations | Measured | | | Simulated | | | Difference | | |
| | 5% | 50% | 95% | 5% | 50% | 95% | 5% | 50% | 95% |
| BR-05 | -0.9 | 0.6 | 1.7 | -0.8 | 0.4 | 1.8 | 0.0 | -0.2 | 0.1 |
| FR-06 | -0.9 | 0.6 | 1.7 | -0.8 | 0.5 | 1.8 | 0.1 | -0.1 | 0.1 |
| FR-08 | -0.9 | 0.6 | 1.7 | -0.9 | 0.5 | 1.9 | 0.1 | -0.2 | 0.1 |
| FR-09 | -1.0 | 0.6 | 1.7 | -0.9 | 0.5 | 1.9 | 0.1 | -0.2 | 0.2 |
| FR-11R | -0.8 | 0.7 | 1.7 | -0.8 | 0.5 | 1.9 | 0.0 | -0.2 | 0.2 |
| FR-22 | -1.1 | 0.6 | 1.7 | -0.9 | 0.5 | 1.9 | 0.1 | -0.2 | 0.1 |
| USGS02198840 (I-95) | -0.5 | 0.9 | 1.7 | -0.6 | 0.6 | 2.0 | -0.1 | -0.3 | 0.3 |
| USGS02198920 (Houlihan Bridge) | -1.0 | 0.6 | 1.7 | -0.9 | 0.5 | 1.9 | 0.1 | -0.1 | 0.2 |
| USGS02198979 (Limehouse Creek) | -0.6 | 0.9 | 1.8 | -0.8 | 0.5 | 1.9 | -0.2 | -0.5 | 0.1 |
| USGS02198977 (Broad St) | -0.9 | 0.6 | 1.7 | -0.8 | 0.5 | 1.8 | 0.1 | -0.1 | 0.1 |
| USGS02198980 (Ft Pulaski) | -0.8 | 0.5 | 1.6 | -0.7 | 0.5 | 1.5 | 0.1 | 0.0 | -0.1 |

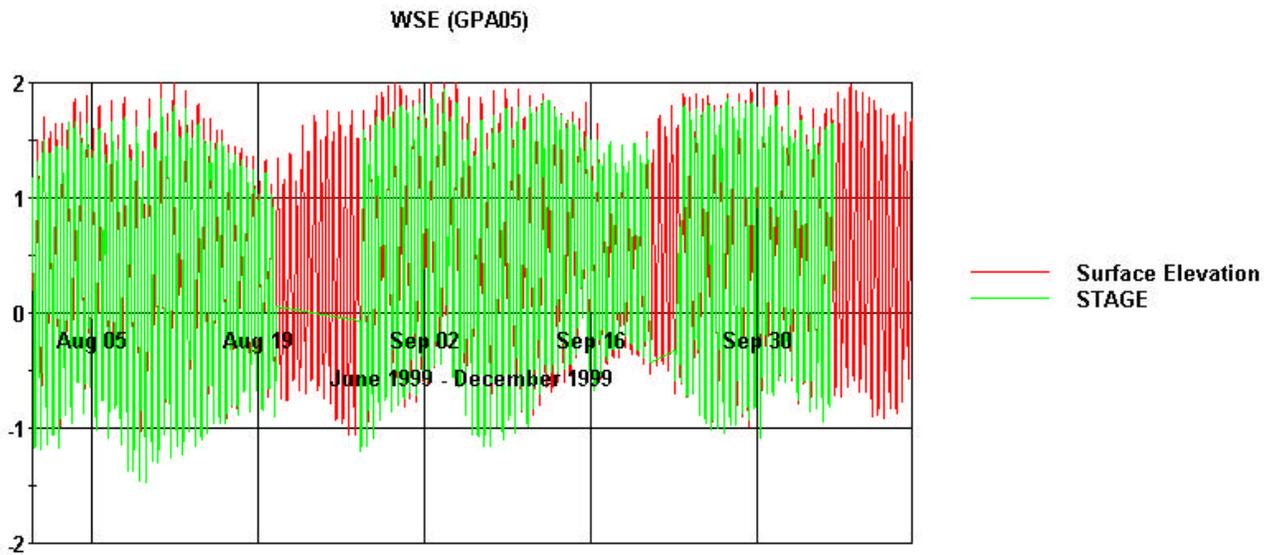


Figure C-1 Elevation (meters) Calibration at BR-05 for July 31, 1999 through October 13, 1999

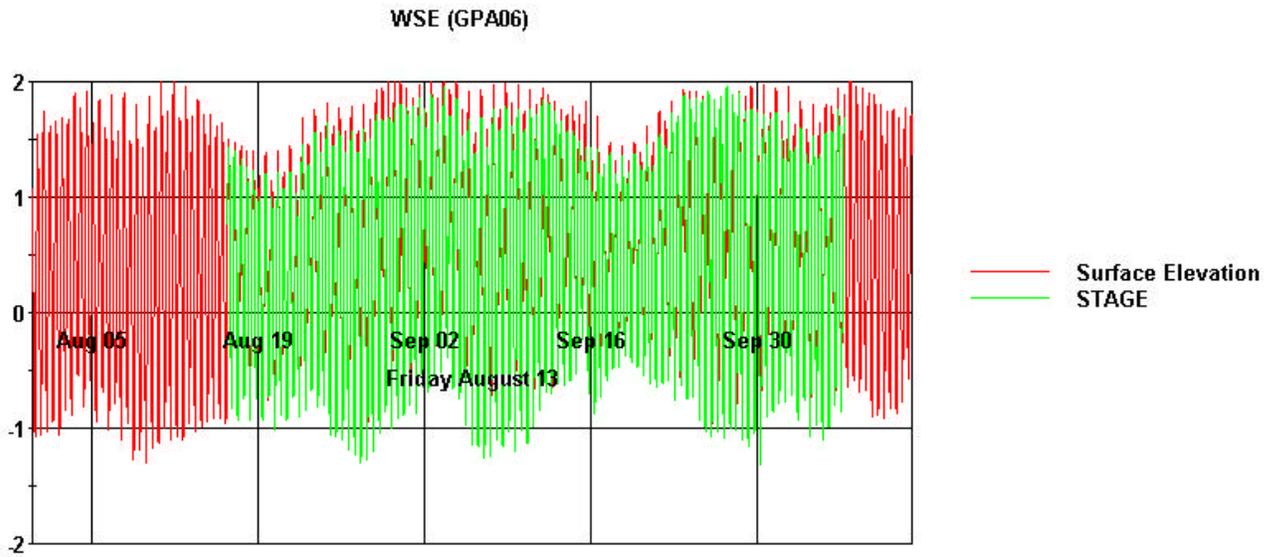


Figure C-2 Elevation (meters) Calibration at FR-06 for July 31, 1999 through October 13, 1999

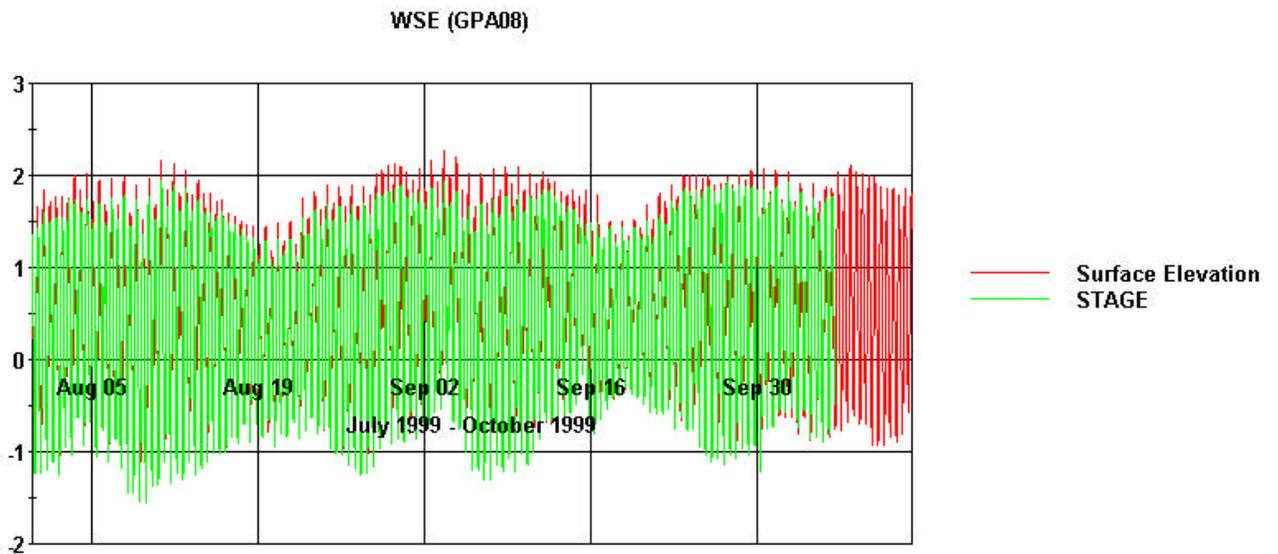


Figure C-3 Elevation (meters) Calibration at FR-08 for July 31, 1999 through October 13, 1999

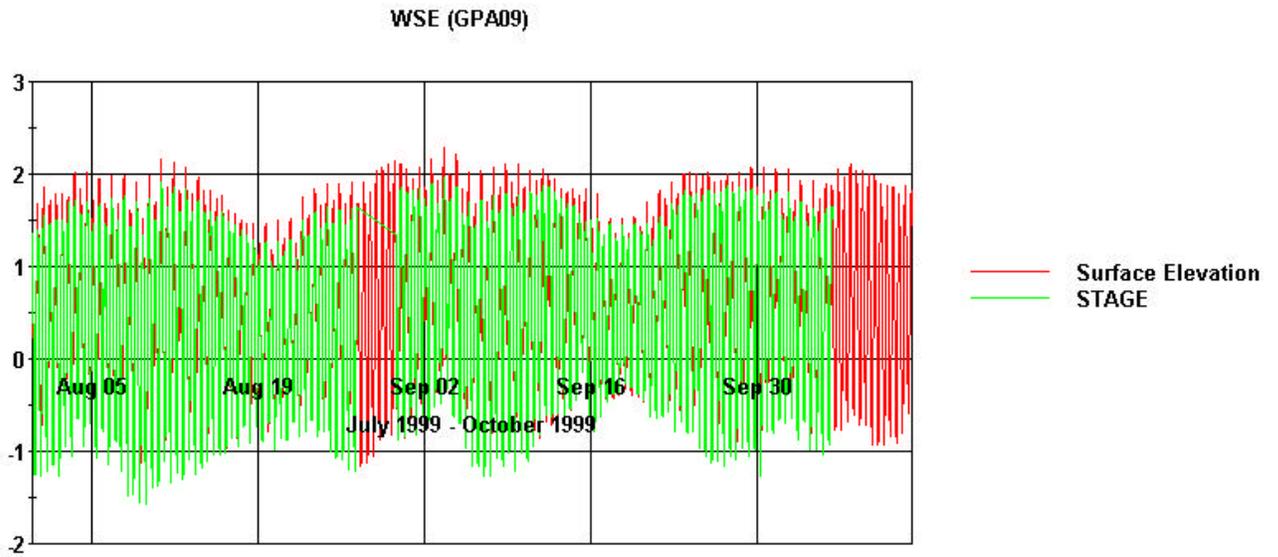


Figure C-4 Elevation (meters) Calibration at FR-09 for July 31, 1999 through October 13, 1999

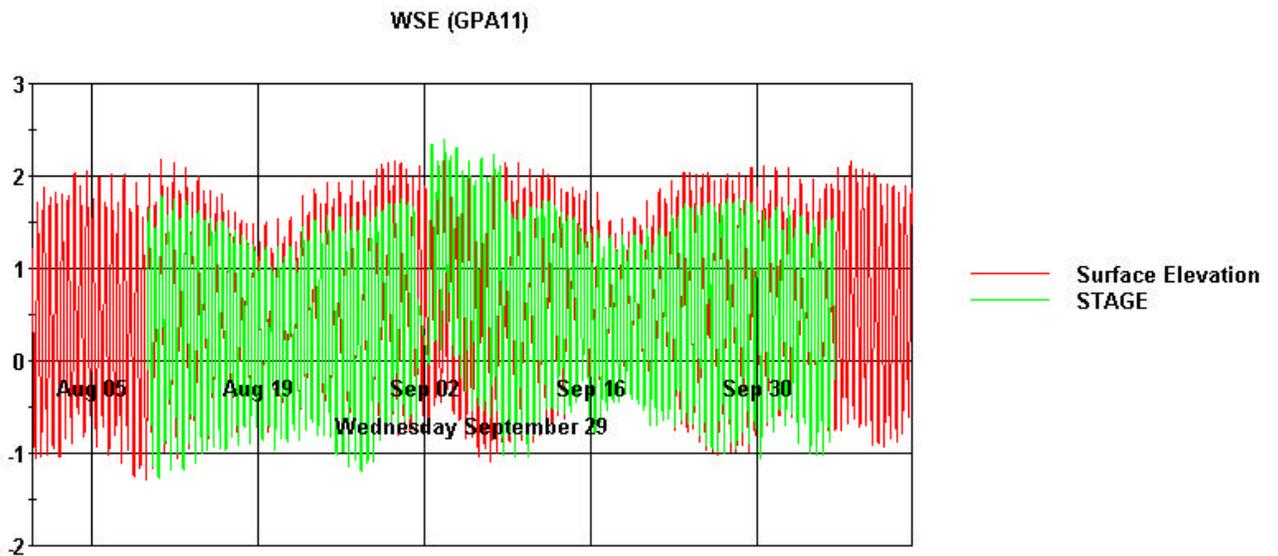


Figure C-5 Elevation (meters) Calibration at FR-11R for July 31, 1999 through October 13, 1999

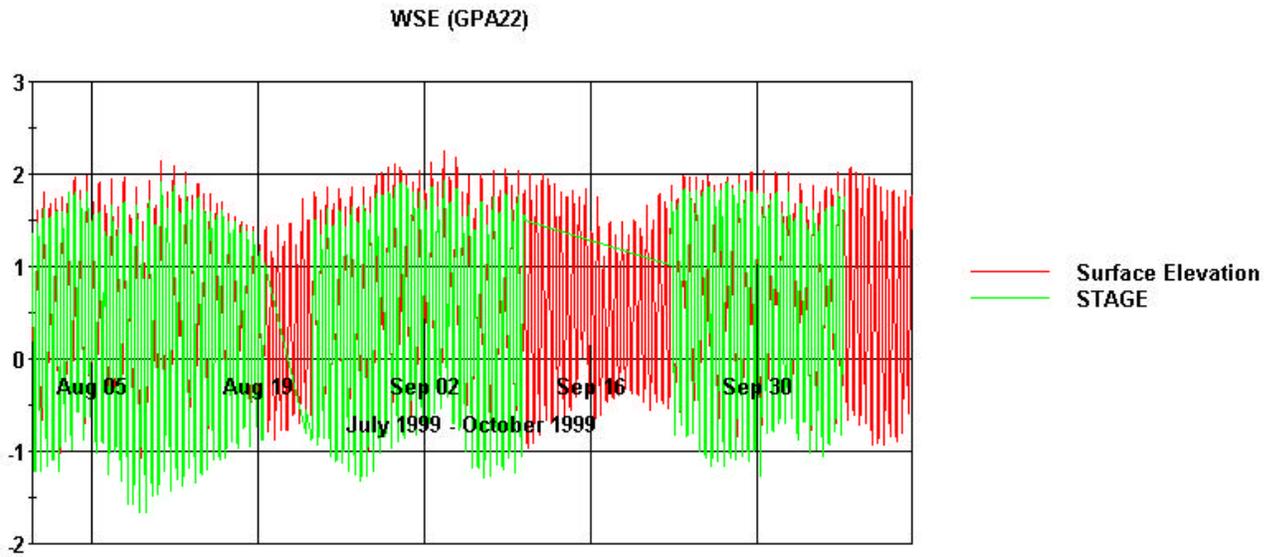


Figure C-6 Elevation (meters) Calibration at FR-22 for July 31, 1999 through October 13, 1999

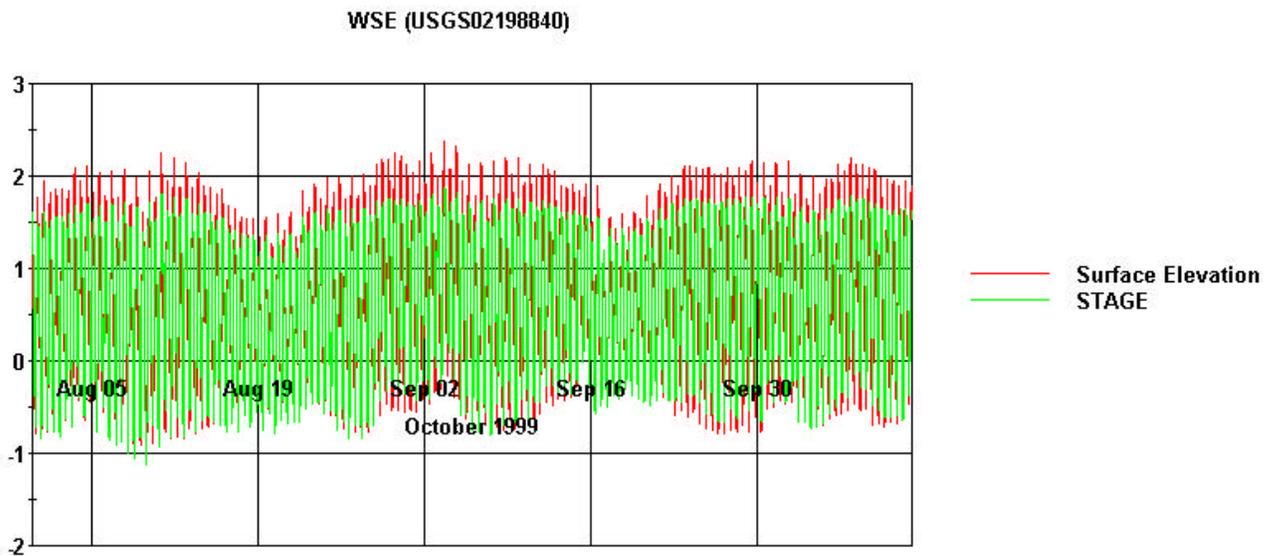


Figure C-7 Elevation (meters) Calibration at I-95 Bridge for July 31, 1999 through October 13, 1999

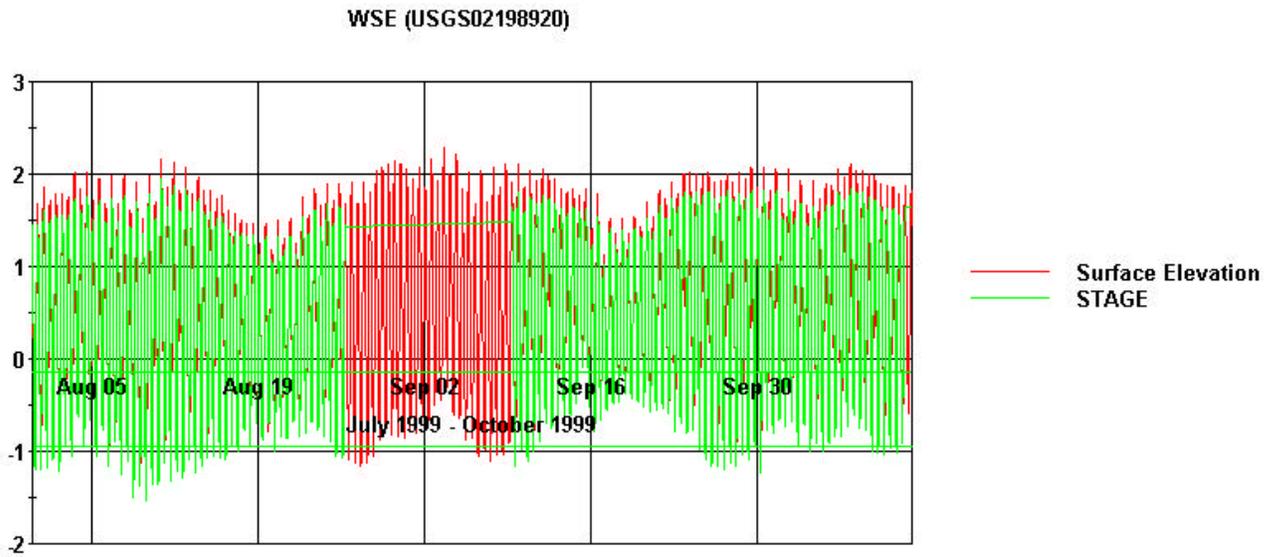


Figure C-8 Elevation (meters) Calibration at Houlihan Bridge for July 31, 1999 through October 13, 1999

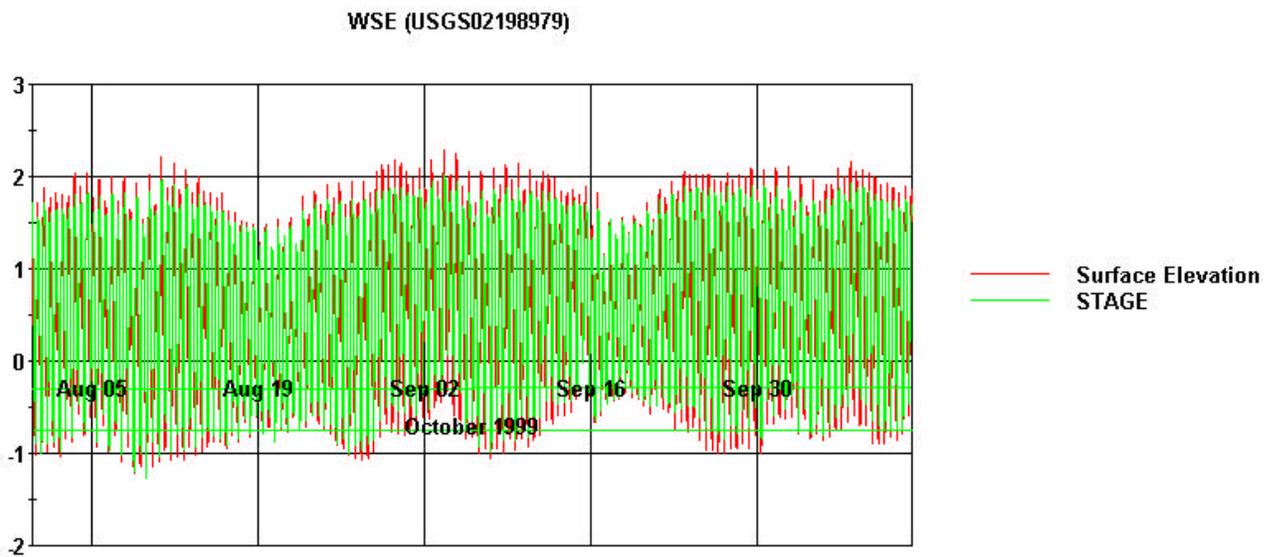


Figure C-9 Elevation (meters) Calibration at Limehouse Creek for July 31, 1999 through October 13, 1999

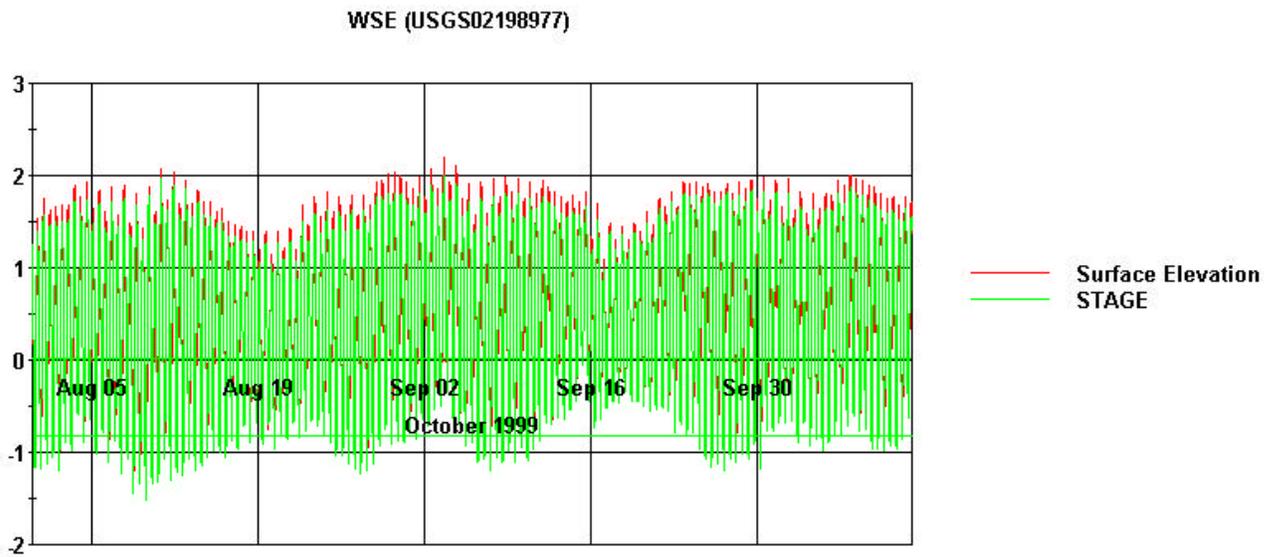


Figure C-10 Elevation (meters) Calibration at Broad St. for July 31, 1999 through October 13, 1999

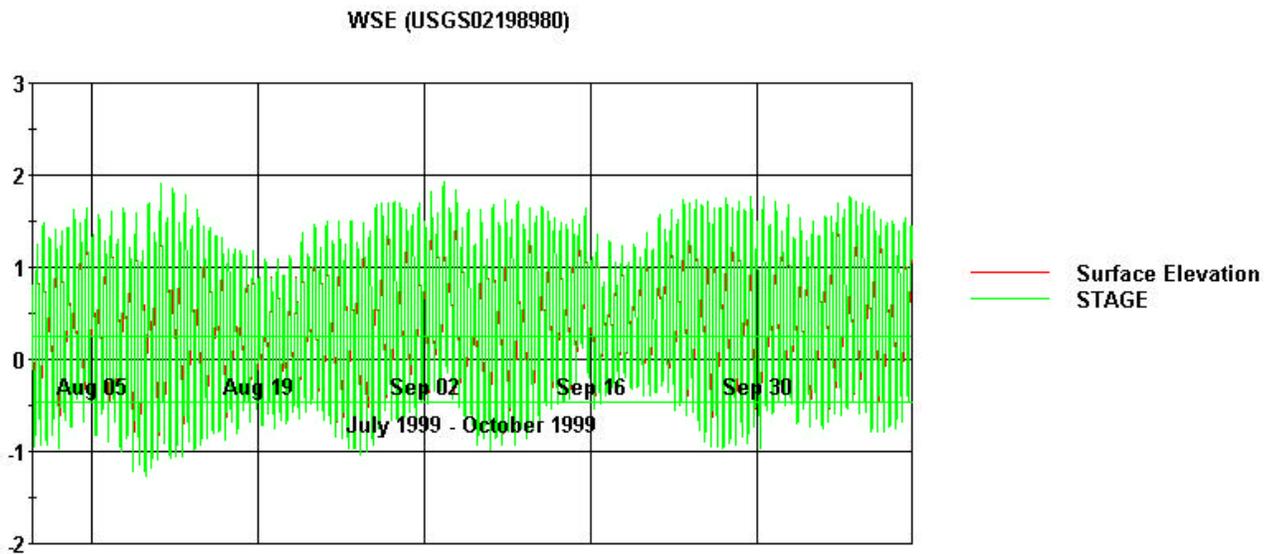


Figure C-11 Elevation (meters) Calibration at Ft. Pulaski for July 31, 1999 through October 13, 1999

Table C-2 Summary Statistics for Elevation (meters) for July 31, 1999 through August 14, 1999

| July 31 - August 14, 1999 [Julian Days 212-226] | | | | | | | | | |
|--|----------|------|-----|-----------|-----|-----|------------|------|-----|
| Stations | Measured | | | Simulated | | | Difference | | |
| | 5% | 50% | 95% | 5% | 50% | 95% | 5% | 50% | 95% |
| BR-05 | -1.1 | 0.5 | 1.6 | -1.0 | 0.4 | 1.7 | 0.1 | -0.2 | 0.1 |
| FR-08 | -1.2 | 0.6 | 1.7 | -1.0 | 0.4 | 1.8 | 0.1 | -0.2 | 0.1 |
| FR-09 | -1.2 | 0.6 | 1.7 | -1.0 | 0.4 | 1.9 | 0.2 | -0.2 | 0.2 |
| FR-11R | -1.0 | -1.0 | 1.7 | -1.0 | 0.5 | 2.0 | 0.0 | 1.5 | 0.3 |
| FR-22 | -1.2 | 0.5 | 1.7 | -1.0 | 0.4 | 1.8 | 0.2 | -0.2 | 0.1 |
| USGS02198840 (I-95) | -0.7 | 0.8 | 1.7 | -0.7 | 0.5 | 1.9 | 0.0 | -0.3 | 0.3 |
| USGS02198920 (Houlihan Bridge) | -1.2 | 0.6 | 1.7 | -1.0 | 0.4 | 1.9 | 0.1 | -0.2 | 0.2 |
| USGS02198979 (Limehouse Creek) | -0.8 | 0.9 | 1.8 | -0.9 | 0.4 | 1.9 | -0.1 | -0.5 | 0.1 |
| USGS02198977 (Broad St) | -1.1 | 0.5 | 1.7 | -1.0 | 0.4 | 1.8 | 0.1 | -0.2 | 0.1 |
| USGS02198980 (Ft Pulaski) | -0.9 | 0.4 | 1.6 | -0.9 | 0.4 | 1.6 | 0.1 | -0.1 | 0.0 |

Table C-3 Summary Statistics for Elevation (meters) for August 15, 1999 through August 29, 1999

| August 15 - 29, 1999 [Julian Days 227-241] | | | | | | | | | |
|---|----------|-----|-----|-----------|-----|-----|------------|------|-----|
| Stations | Measured | | | Simulated | | | Difference | | |
| | 5% | 50% | 95% | 5% | 50% | 95% | 5% | 50% | 95% |
| BR-05 | -0.9 | 0.3 | 1.5 | -0.9 | 0.2 | 1.5 | 0.0 | -0.1 | 0.1 |
| FR-06 | -0.9 | 0.4 | 1.5 | -0.8 | 0.3 | 1.6 | 0.1 | 0.0 | 0.1 |
| FR-08 | -0.9 | 0.4 | 1.6 | -0.9 | 0.3 | 1.7 | 0.0 | -0.1 | 0.1 |
| FR-09 | -0.9 | 0.4 | 1.5 | -0.8 | 0.3 | 1.6 | 0.1 | -0.1 | 0.1 |
| FR-11R | -0.9 | 0.5 | 1.5 | -0.8 | 0.4 | 1.7 | 0.0 | -0.1 | 0.2 |
| FR-22 | -1.0 | 0.4 | 1.6 | -0.9 | 0.3 | 1.7 | 0.1 | -0.1 | 0.1 |
| USGS02198840 (I-95) | -0.7 | 0.6 | 1.6 | -0.6 | 0.5 | 1.8 | 0.0 | -0.1 | 0.2 |
| USGS02198920 (Houlihan Bridge) | -0.9 | 0.4 | 1.5 | -0.8 | 0.3 | 1.6 | 0.1 | -0.1 | 0.1 |
| USGS02198979 (Limehouse Creek) | -0.7 | 0.7 | 1.7 | -0.8 | 0.3 | 1.7 | -0.1 | -0.3 | 0.1 |
| USGS02198977 (Broad St) | -0.9 | 0.4 | 1.5 | -0.9 | 0.3 | 1.6 | 0.1 | -0.1 | 0.1 |
| USGS02198980 (Ft Pulaski) | -0.8 | 0.3 | 1.4 | -0.7 | 0.3 | 1.3 | 0.1 | 0.0 | 0.0 |

Table C-4 Summary Statistics for Elevation (meters) for August 30, 1999 through September 12, 1999

| August 30 - September 12, 1999 [Julian Days 242-255] | | | | | | | | | |
|---|----------|-----|-----|-----------|-----|-----|------------|------|------|
| Stations | Measured | | | Simulated | | | Difference | | |
| | 5% | 50% | 95% | 5% | 50% | 95% | 5% | 50% | 95% |
| BR-05 | -0.8 | 0.8 | 1.8 | -0.8 | 0.5 | 1.9 | 0.0 | -0.3 | 0.1 |
| FR-06 | -0.9 | 0.7 | 1.8 | -0.8 | 0.6 | 1.9 | 0.1 | -0.2 | 0.2 |
| FR-08 | -1.0 | 0.8 | 1.8 | -0.8 | 0.6 | 2.0 | 0.1 | -0.2 | 0.2 |
| FR-09 | -0.9 | 0.8 | 1.8 | -0.8 | 0.6 | 2.0 | 0.1 | -0.2 | 0.2 |
| FR-11R | -0.6 | 1.1 | 2.2 | -0.8 | 0.6 | 2.1 | -0.2 | -0.5 | -0.1 |
| FR-22 | -1.0 | 0.7 | 1.8 | -0.8 | 0.6 | 2.0 | 0.1 | -0.2 | 0.2 |
| USGS02198840 (I-95) | -0.4 | 1.1 | 1.7 | -0.6 | 0.7 | 2.1 | -0.1 | -0.4 | 0.4 |
| USGS02198920 (Houlihan Bridge) | -1.0 | 0.9 | 1.8 | -0.9 | 0.6 | 2.0 | 0.1 | -0.2 | 0.3 |
| USGS02198979 (Limehouse Creek) | -0.6 | 1.1 | 1.8 | -0.8 | 0.6 | 2.0 | -0.2 | -0.6 | 0.2 |
| USGS02198977 (Broad St) | -0.9 | 0.8 | 1.8 | -0.8 | 0.6 | 1.9 | 0.1 | -0.2 | 0.2 |
| USGS02198980 (Ft Pulaski) | -0.7 | 0.6 | 1.7 | 1.7 | 0.6 | 1.6 | 2.4 | 0.0 | -0.1 |

Table C-5 Summary Statistics for Elevation (meters) for September 13, 1999 through September 27, 1999

| September 13 - 27, 1999 [Julian Days 256-270] | | | | | | | | | |
|--|----------|------|-----|-----------|-----|-----|------------|------|------|
| Stations | Measured | | | Simulated | | | Difference | | |
| | 5% | 50% | 95% | 5% | 50% | 95% | 5% | 50% | 95% |
| BR-05 | -0.6 | 0.7 | 1.7 | -0.6 | 0.5 | 1.7 | 0.0 | -0.2 | 0.0 |
| FR-06 | -0.6 | 0.6 | 1.7 | -0.6 | 0.5 | 1.7 | 0.1 | -0.1 | 0.0 |
| FR-08 | -0.6 | 0.7 | 1.7 | -0.6 | 0.6 | 1.8 | 0.0 | -0.1 | 0.1 |
| FR-09 | -0.6 | 0.7 | 1.7 | -0.6 | 0.5 | 1.8 | 0.0 | -0.1 | 0.1 |
| FR-11R | -0.6 | 0.7 | 1.6 | -0.6 | 0.6 | 1.8 | 0.0 | -0.1 | 0.3 |
| FR-22 | -0.9 | 0.9 | 1.8 | -0.8 | 0.7 | 1.9 | 0.1 | -0.3 | 0.1 |
| USGS02198840 (I-95) | -0.4 | 0.8 | 1.7 | -0.4 | 0.6 | 1.9 | 0.0 | -0.2 | 0.2 |
| USGS02198920 (Houlihan Bridge) | -0.7 | 0.7 | 1.7 | -0.6 | 0.5 | 1.8 | 0.0 | -0.1 | 0.1 |
| USGS02198979 (Limehouse Creek) | -0.4 | 0.9 | 1.8 | -0.6 | 0.6 | 1.8 | -0.1 | -0.4 | 0.1 |
| USGS02198977 (Broad St) | -0.6 | 0.6 | 1.6 | -0.6 | 0.5 | 1.7 | 0.0 | -0.1 | 0.1 |
| USGS02198980 (Ft Pulaski) | -0.5 | -0.5 | 1.6 | 1.6 | 0.5 | 1.5 | 2.0 | 1.0 | -0.1 |

Table C-6 Summary Statistics for Elevation (meters) for September 28, 1999 through October 13, 1999

| September 28 - October 13, 1999 [Julian Days 271-286] | | | | | | | | | |
|--|----------|-----|-----|-----------|-----|-----|------------|------|------|
| Stations | Measured | | | Simulated | | | Difference | | |
| | 5% | 50% | 95% | 5% | 50% | 95% | 5% | 50% | 95% |
| BR-05 | -0.8 | 0.7 | 1.7 | -0.8 | 0.5 | 1.7 | 0.0 | -0.3 | 0.0 |
| FR-06 | -0.9 | 0.6 | 1.7 | -0.8 | 0.5 | 1.8 | 0.2 | -0.1 | 0.1 |
| FR-08 | -0.8 | 0.8 | 1.8 | -0.8 | 0.5 | 1.9 | 0.0 | -0.3 | 0.1 |
| FR-09 | -0.9 | 0.7 | 1.7 | -0.8 | 0.5 | 1.9 | 0.1 | -0.2 | 0.1 |
| FR-11R | -0.8 | 0.7 | 1.6 | -0.8 | 0.5 | 1.9 | 0.0 | -0.2 | 0.3 |
| FR-22 | -0.9 | 0.7 | 1.7 | -0.8 | 0.5 | 1.9 | 0.1 | -0.2 | 0.1 |
| USGS02198840 (I-95) | -0.5 | 1.0 | 1.7 | -0.6 | 0.6 | 2.0 | -0.1 | -0.4 | 0.3 |
| USGS02198920 (Houlihan Bridge) | -0.9 | 0.7 | 1.7 | -0.8 | 0.5 | 1.9 | 0.1 | -0.2 | 0.2 |
| USGS02198979 (Limehouse Creek) | -0.6 | 1.1 | 1.8 | -0.7 | 0.5 | 2.0 | -0.2 | -0.5 | 0.2 |
| USGS02198977 (Broad St) | -0.9 | 0.7 | 1.7 | -0.8 | 0.5 | 1.8 | 0.1 | -0.2 | 0.1 |
| USGS02198980 (Ft Pulaski) | -0.7 | 0.6 | 1.6 | -0.6 | 0.5 | 1.6 | 0.1 | 0.0 | -0.1 |

APPENDIX D 1997 FLOW COMPARISONS

Table D-1 1997 Flow Transect Locations and Julian Day

| Station | I | J | 1997 Julian Day |
|------------|---------|-----|--------------------|
| FR2 | 5 | 52 | 273 |
| MR2 | 27 | 87 | 273 |
| LBR2 | 16 | 89 | 273 |
| FR3 | 5,6,7 | 39 | 253,276,280 |
| BR | 17 | 73 | 253,280 |
| FJ | 4,5,6,7 | 36 | 253,276,280 |
| FR1 | 5 | 61 | 279 |
| MR1 | 27 | 95 | 279 |
| LBR1 | 16 | 104 | 279 |
| 195 -GPA14 | 5 | 65 | 279 |

| 1997 Flow Comparisons (m ³ /s) | | | | | | | | |
|---|--------------------|--------------|------------|----------|-----------|----------|---------------------|-------------------|
| Transect Location | Julian Day 1997 | Date | Peak Flood | | Peak Ebb | | Flood Difference | Ebb Difference |
| | | | Simulated | Measured | Simulated | Measured | | |
| FJ | 253 | September 10 | 3,574 | 2,696 | -3,437 | -3,719 | 33% | -8% |
| | 276 | October 03 | 4,259 | 3,377 | -3,749 | -4,311 | 26% | -13% |
| | 280 | October 07 | 3,766 | 3,099 | | | 22% | |
| FR3 | 253 | September 10 | 1,879 | 1,660 | -1,857 | -1,859 | 13% | 0% |
| | 280 | October 07 | 2,025 | 1,552 | | | 30% | |
| BR | 253 | September 10 | 1,151 | 1,067 | -1,100 | -1,177 | 8% | -7% |
| | 280 | October 07 | 1,155 | 1,108 | | | 4% | |
| FR2 | 273 | September 30 | 968 | 862 | -853 | -1,035 | 12% | -18% |
| MR2 | 273 | September 30 | 474 | 302 | -423 | -254 | 57% | 67% |
| LBR2 | 273 | September 30 | 94 | 142 | -194 | -200 | -34% | -3% |
| FR1 | 279 | October 06 | 401 | 350 | -504 | -638 | 15% | -21% |
| MR1 | 279 | October 06 | | | -128 | -70 | | 83% |
| LBR1 | 279 | October 06 | -13 | -8 | -68 | -43 | 63% | 58% |

NOTES: = determined to be insufficient data to determine peak
 Table D-2 1997 Flow Statistical Comparisons

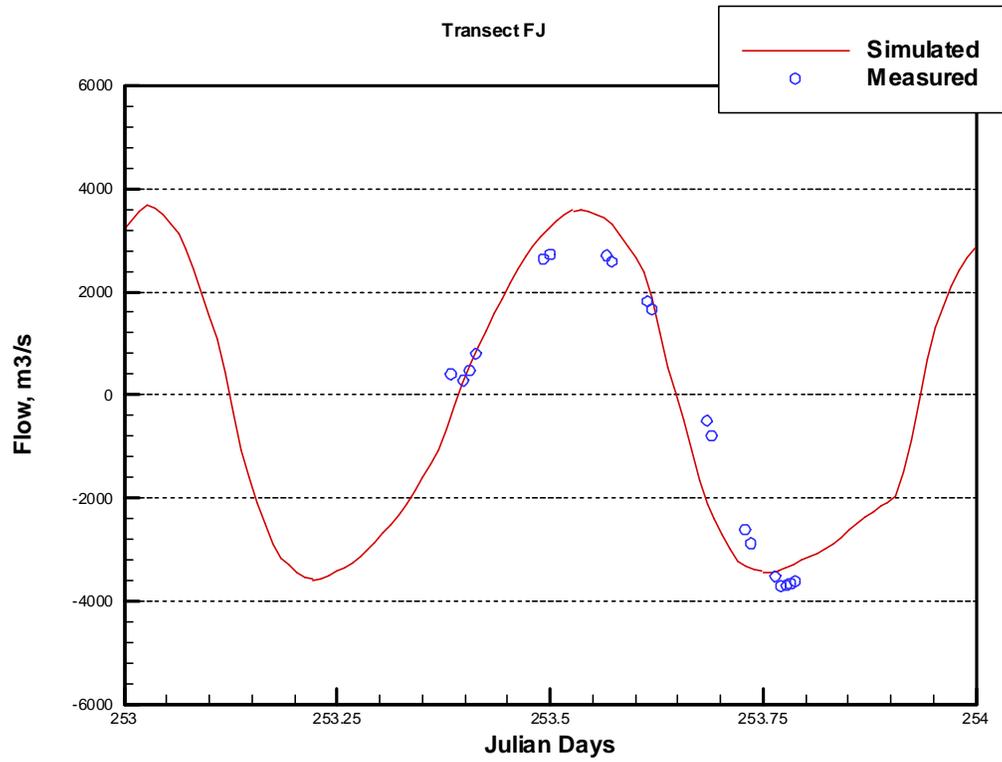


Figure D-1 Flow (m³/s) at Transect FJ on September 10, 1997

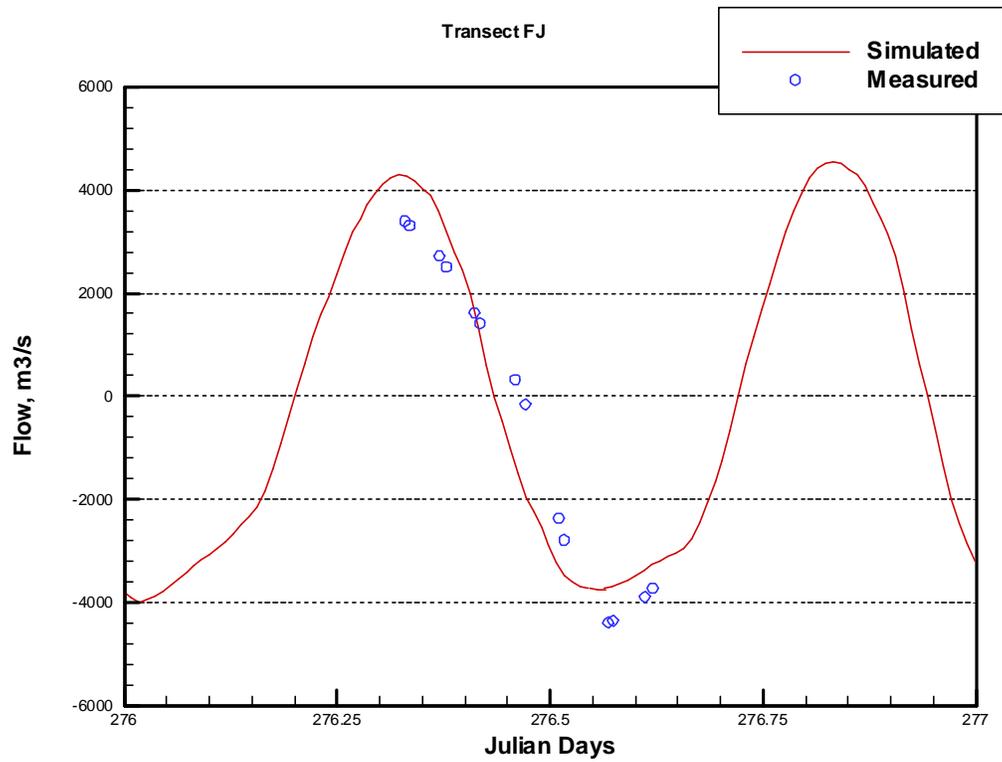


Figure D-2 Flow (m³/s) at Transect FJ on October 3, 1997

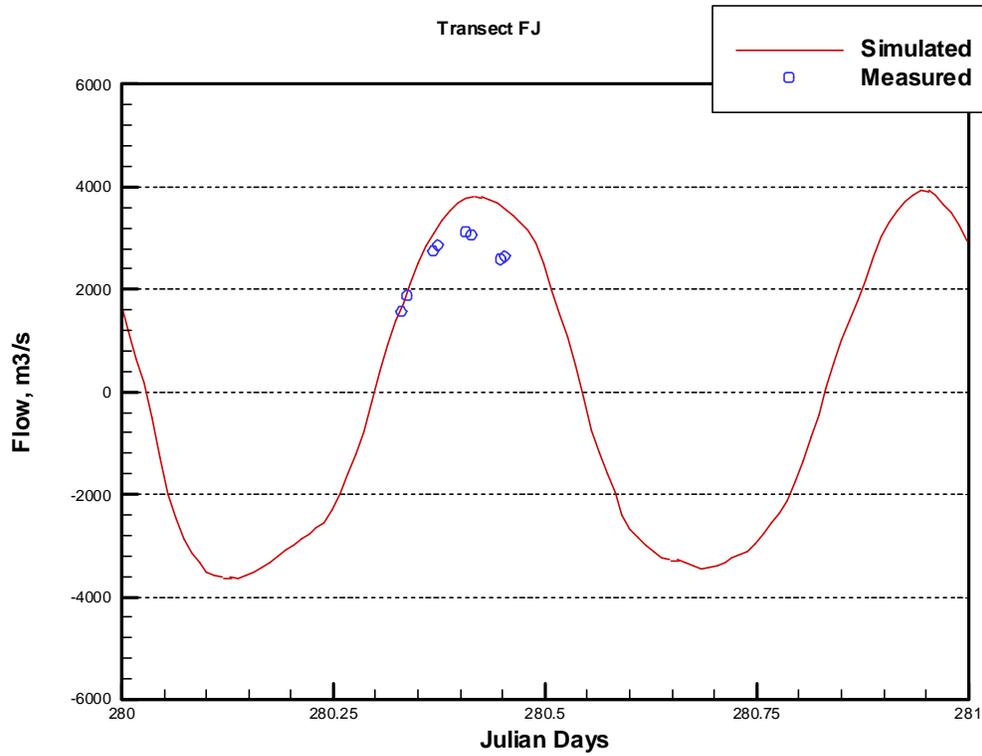


Figure D-3 Flow (m³/s) at Transect FJ on October 7, 1997

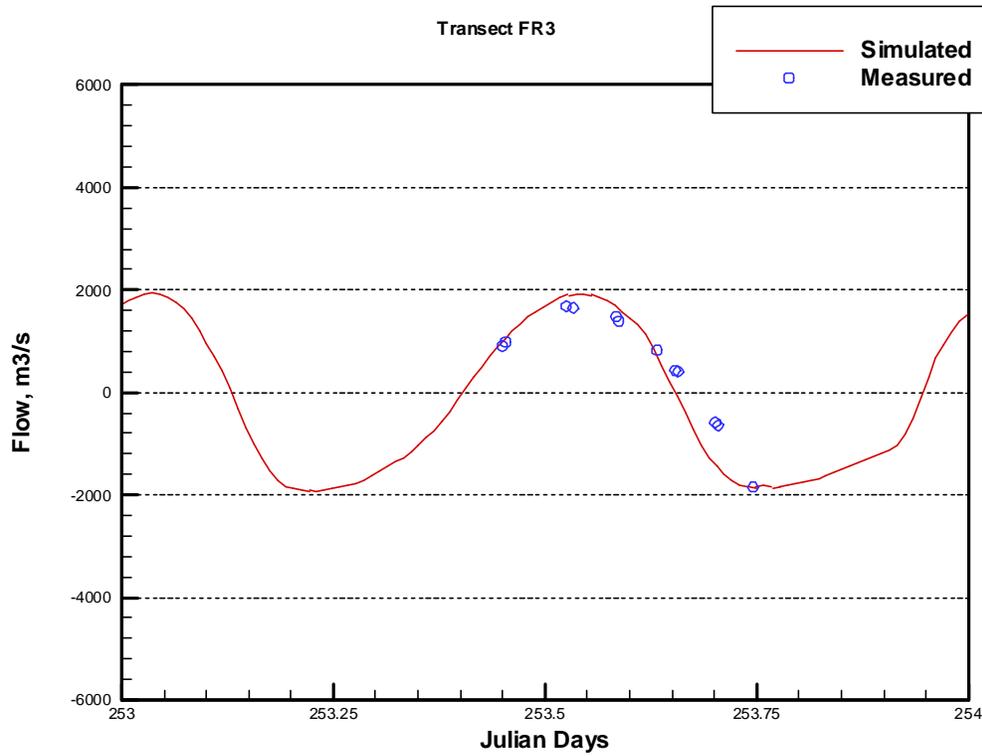


Figure D-4 Flow (m³/s) at Transect FR3 on September 10, 1997

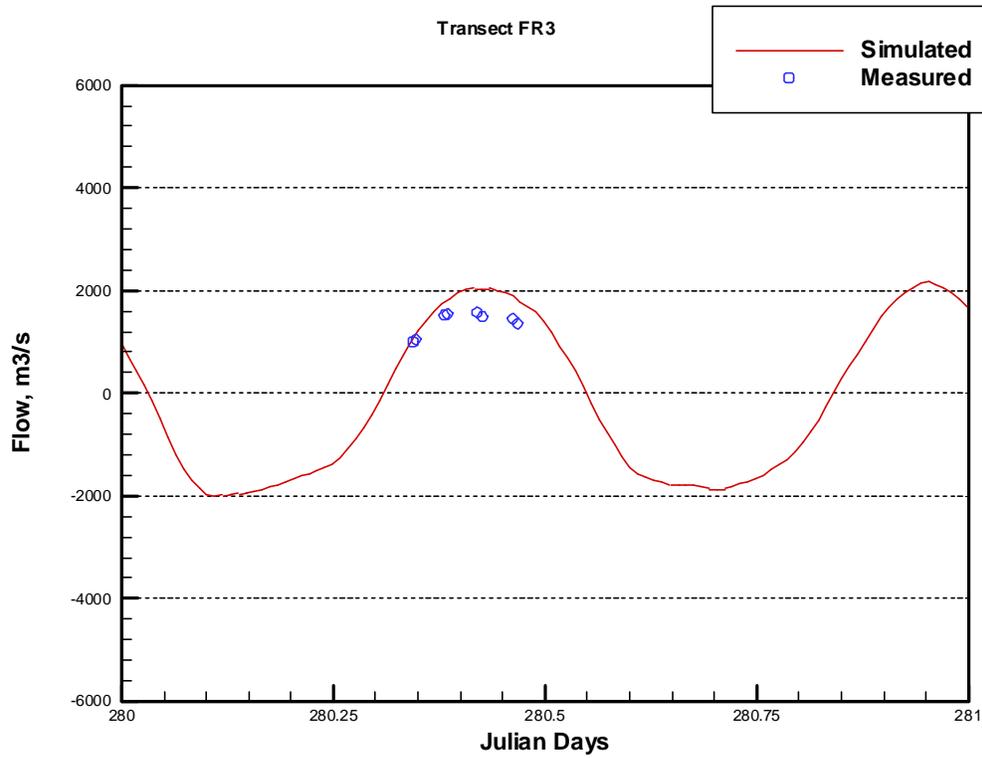


Figure D-5 Flow (m³/s) at Transect FR3 on October 7, 1997

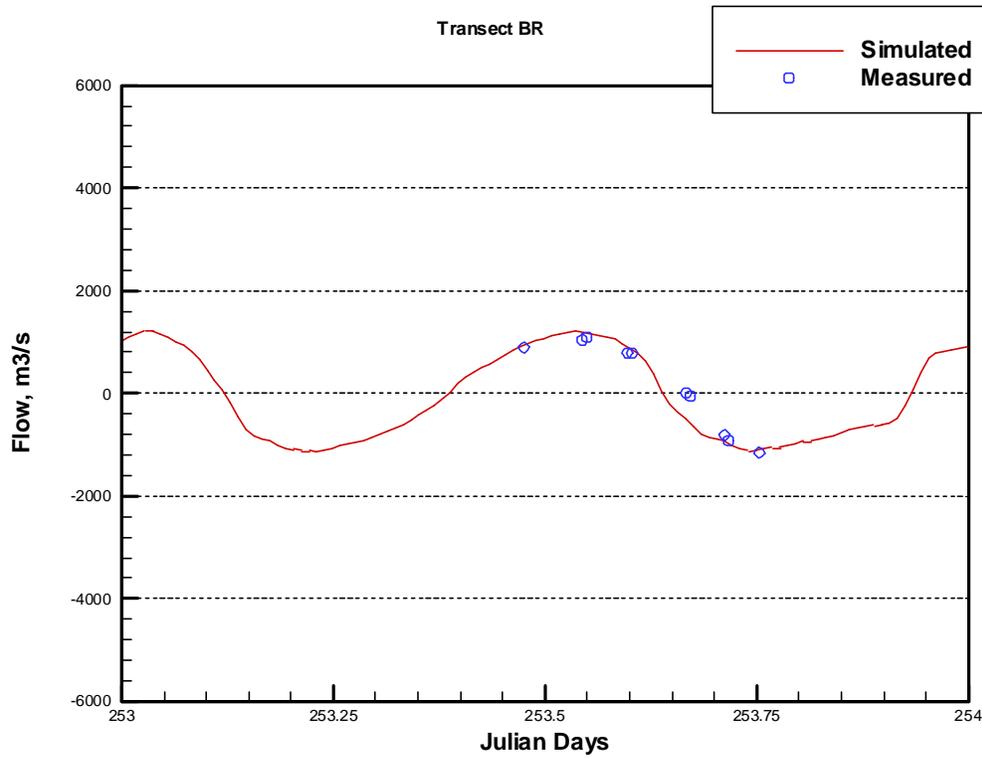


Figure D-6 Flow (m³/s) at Transect BR on September 10, 1997

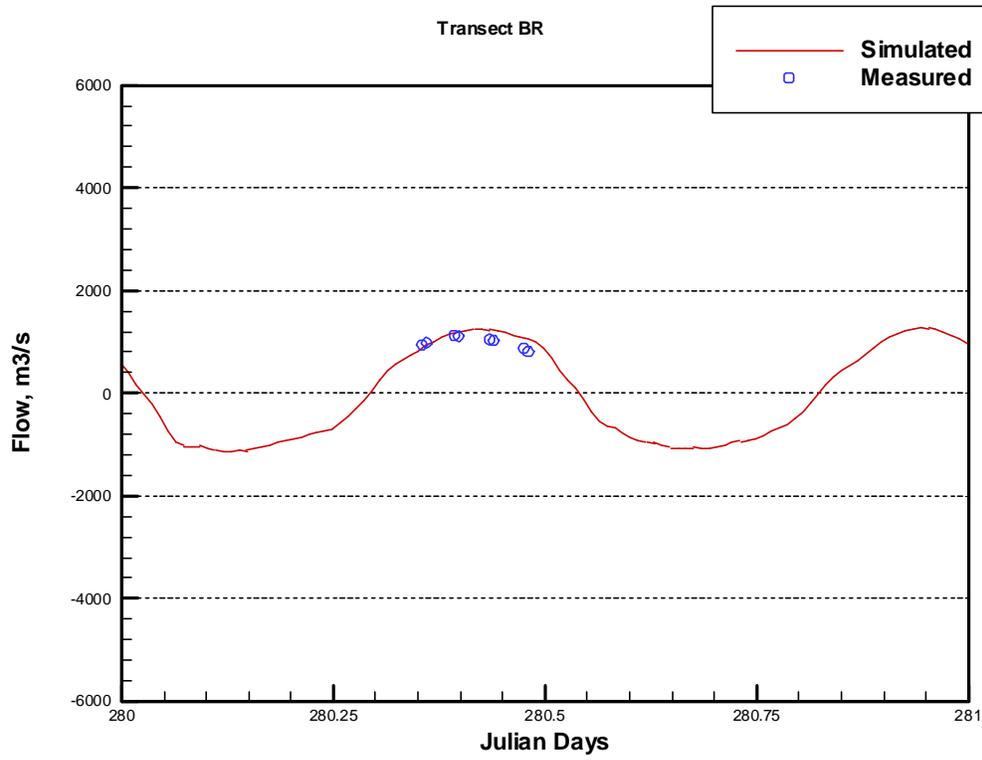


Figure D-7 Flow (m³/s) at Transect BR on October 7, 1997

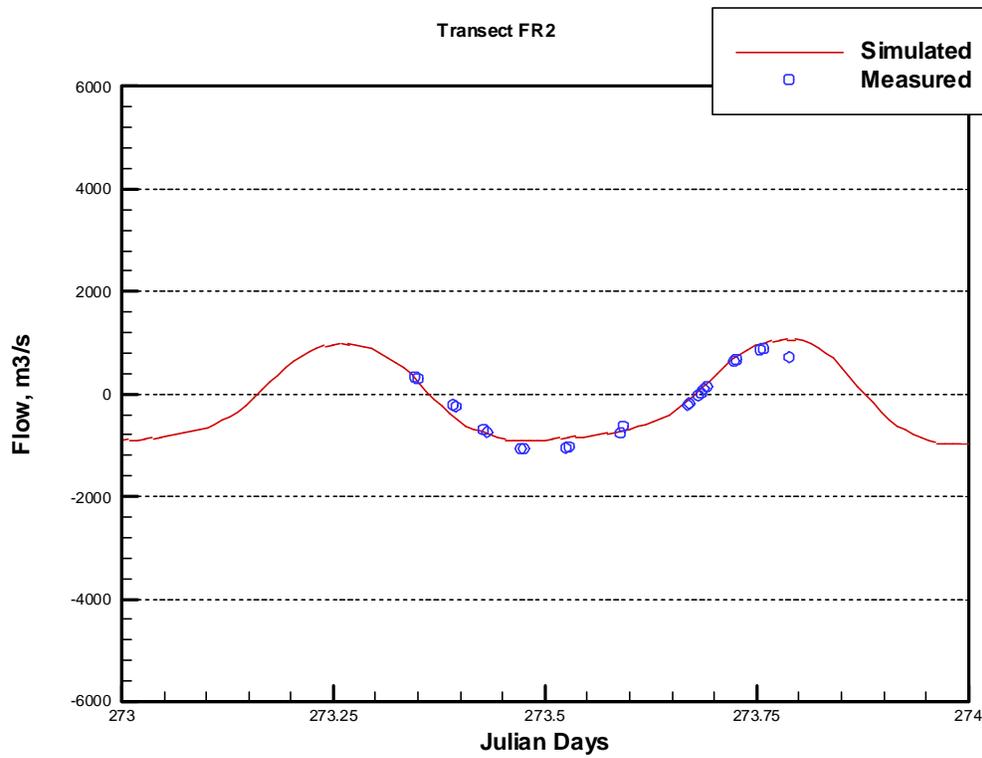


Figure D-8 Flow (m³/s) at Transect FR2 on September 30, 1997

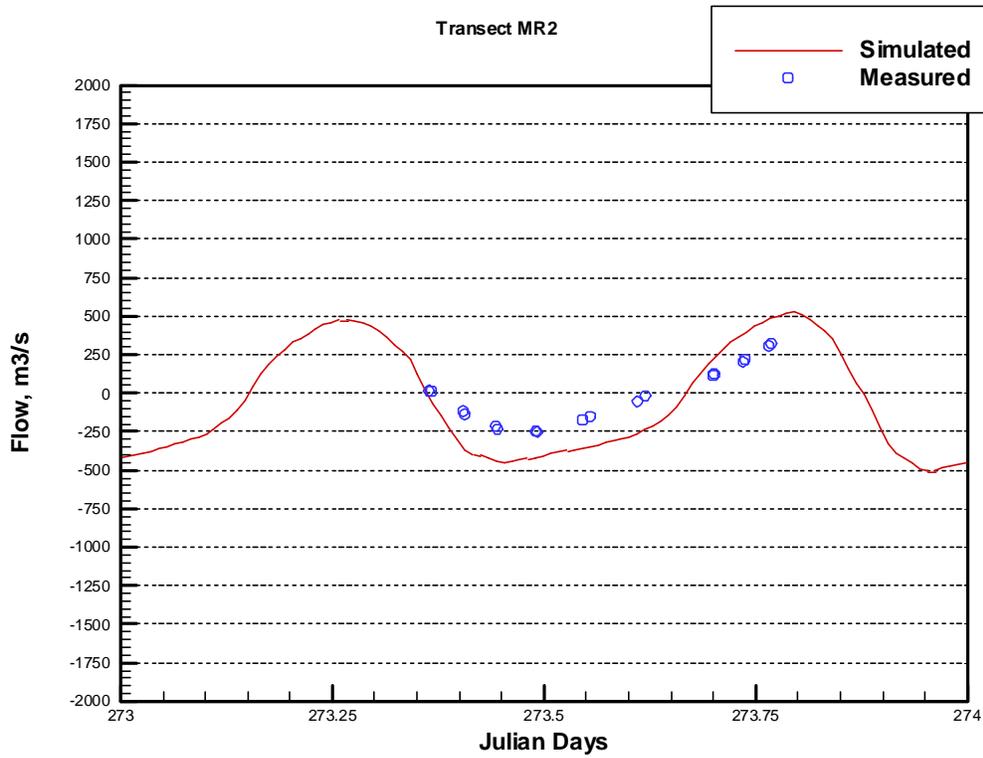


Figure D-9 Flow (m³/s) at Transect MR2 on September 30, 1997

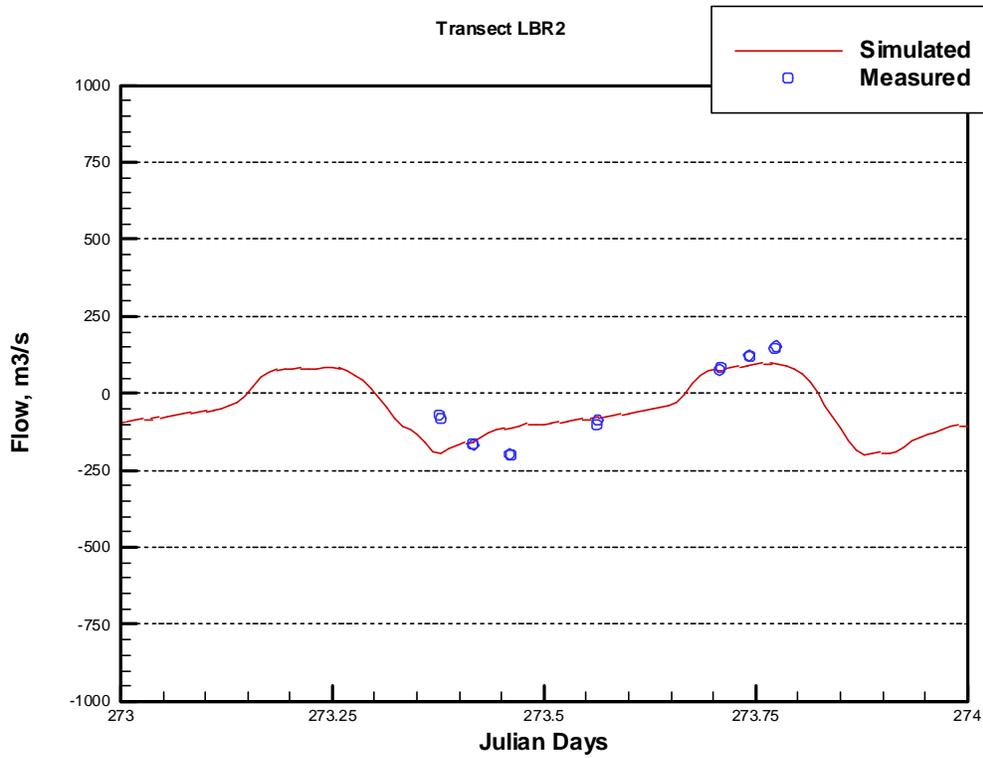


Figure D-10 Flow (m³/s) at Transect LBR2 on September 30, 1997

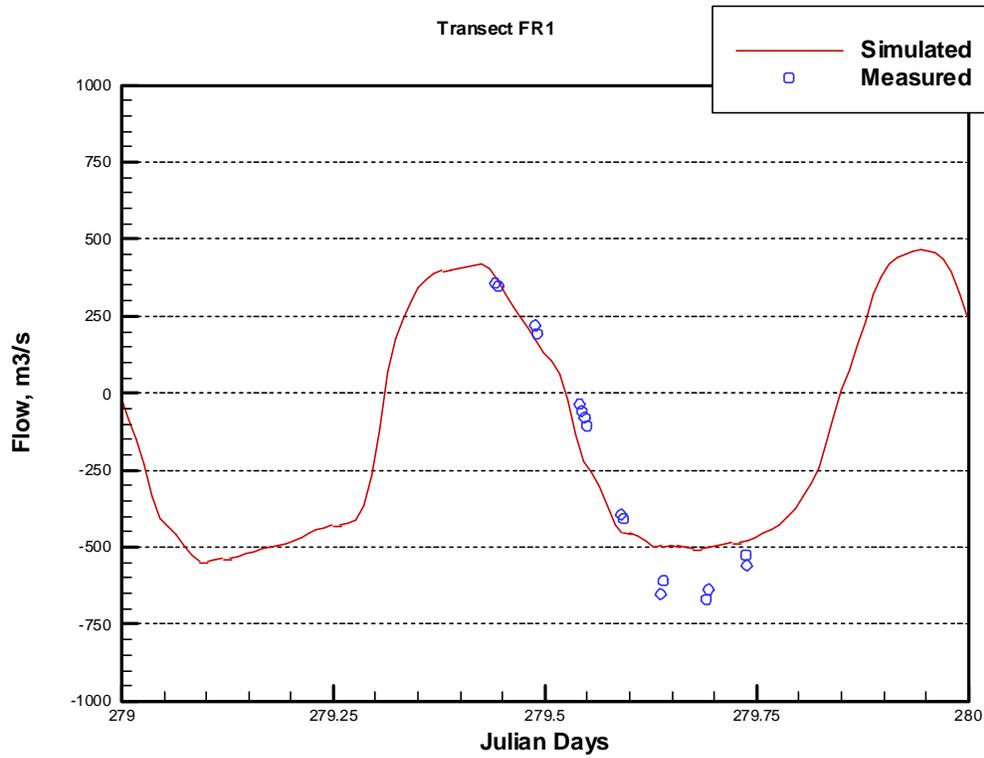


Figure D-11 Flow (m³/s) at Transect FR1 on October 6, 1997

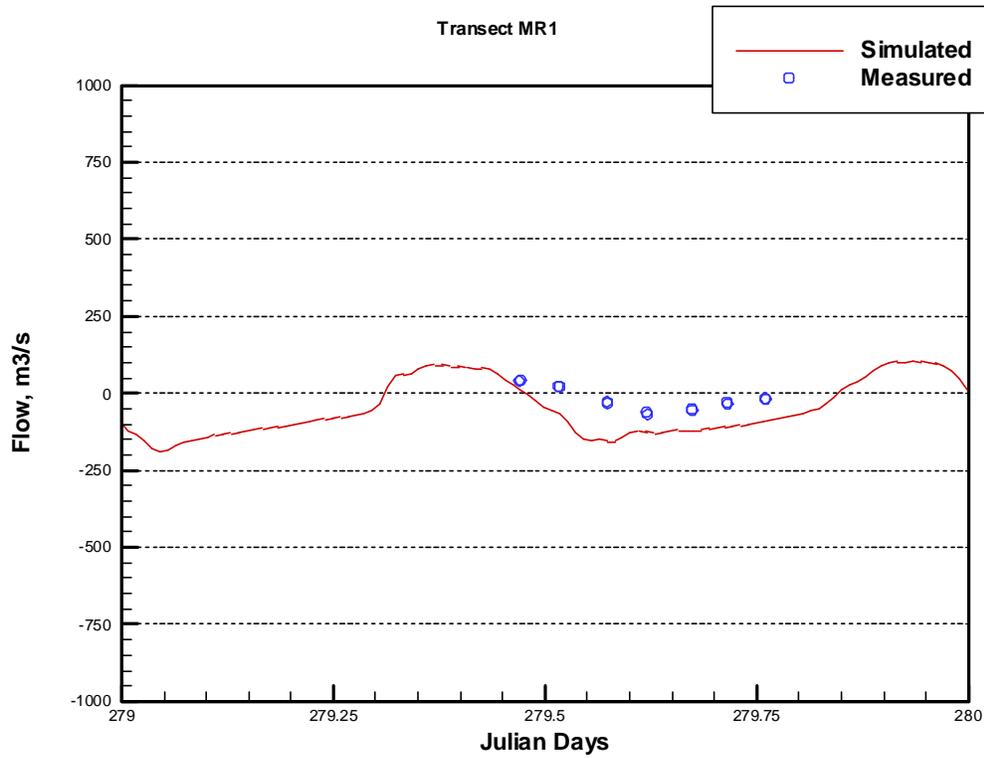


Figure D-12 Flow (m³/s) at Transect MR1 on October 6, 1997

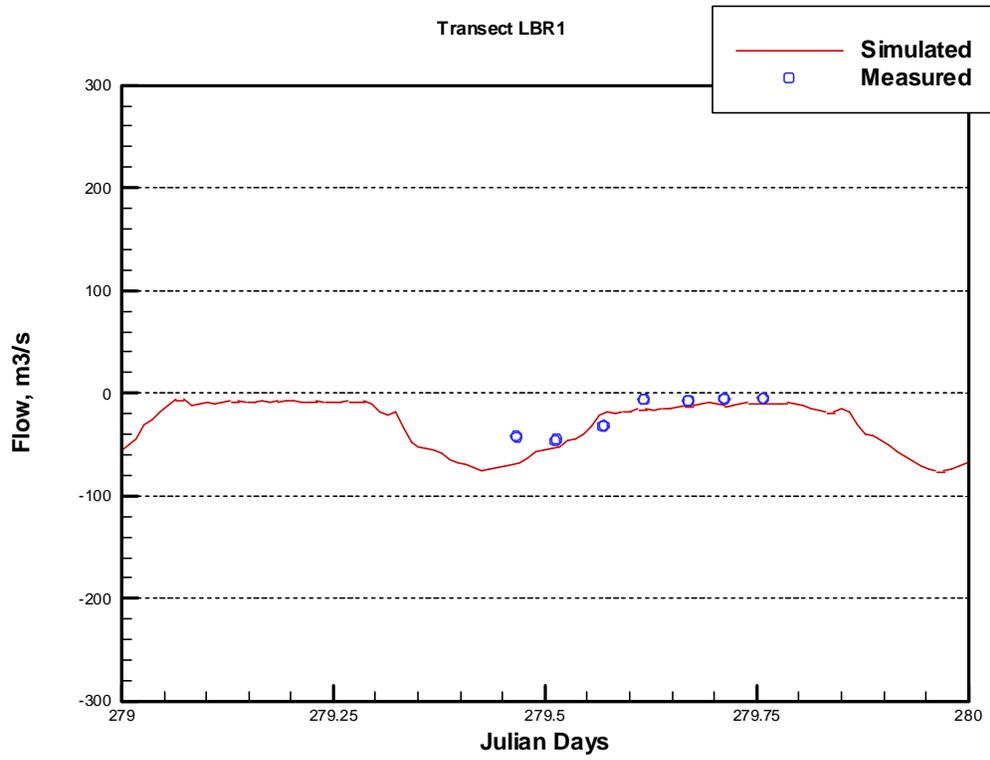


Figure D-13 Flow (m³/s) at Transect LBR1 on October 6, 1997

APPENDIX E 1999 FLOW COMPARISONS

Table E-1 1999 Flow Transect Locations and Julian Day

| Station | I | J | 1999 Julian Day |
|------------|---------|-----|--------------------|
| FR2 | 5 | 52 | 964,998,1011 |
| MR2 | 27 | 87 | 964,998,1011 |
| LBR2 | 16 | 89 | 964,998 |
| FR3 | 5,6,7 | 39 | 963,999,1010 |
| BR | 17 | 73 | 963,999,1010 |
| FJ | 4,5,6,7 | 36 | 963,999,1010 |
| FR1 | 5 | 61 | 1002,1009 |
| MR1 | 27 | 95 | 1002,1009 |
| LBR1 | 16 | 104 | 1002,1009 |
| I95 –GPA14 | 5 | 65 | 1007 |
| FW1 | 16 | 102 | 1022,1028 |
| FW2 | 16 | 97 | 1022,1028 |
| FW3 | 16 | 93 | 1022,1028 |
| FW4 | 16 | 87 | 1021,1029 |
| FW5 | 16 | 82 | 1021,1029 |
| FW6 | 16 | 81 | 1021,1029 |
| MC | 26 | 97 | 1002,1009 |
| SCU | 3 | 32 | 997 |
| GPA16 | 5 | 71 | 1007 |
| UC | 21 | 57 | 1002,1009 |

Table E-2 1999 Flow Statistical Comparisons

| 1999 Flow Comparisons (m ³ /s) | | | | | | | | |
|---|-----------------|--------------|------------|----------|-----------|----------|------------------|----------------|
| Transect Location | Julian Day 1997 | Date | Peak Flood | | Peak Ebb | | Flood Difference | Ebb Difference |
| | | | Simulated | Measured | Simulated | Measured | | |
| FJ | 963 | August 21 | | | -3,587 | -2,835 | | 27% |
| | 999 | September 26 | 4,398 | 5,080 | | | -13% | |
| | 1010 | October 07 | 4,485 | 4,678 | | | -4% | |
| FR3 | 963 | August 21 | | | -1,798 | -1,744 | | 3% |
| | 999 | September 26 | 2,345 | 3,045 | | | -23% | |
| | 1010 | October 07 | 2,311 | 2,764 | | | -16% | |
| BR | 963 | August 21 | | | -1,092 | -1,030 | | 6% |
| | 999 | September 26 | 1,375 | 1,470 | | | -6% | |
| | 1010 | October 07 | 1,282 | 1,542 | | | -17% | |
| FR2 | 964 | August 22 | 820 | 918 | -643 | -717 | -11% | -10% |
| | 998 | September 25 | 980 | 1,521 | | | -36% | |
| | 1011 | October 08 | 998 | 1,505 | | | -34% | |
| MR2 | 964 | August 22 | 335 | 177 | -266 | -163 | 89% | 63% |
| | 998 | September 25 | 588 | 467 | -239 | -327 | 26% | -27% |
| | 1011 | October 08 | 529 | 471 | | | 12% | |
| LBR2 | 964 | August 22 | 163 | 144 | -76 | -110 | 13% | -31% |
| | 998 | September 25 | 234 | 230 | | | 2% | |
| FR1 | 1002 | September 29 | 601 | 1,079 | -573 | -316 | -44% | 81% |
| | 1009 | October 06 | 537 | 944 | -612 | -651 | -43% | -6% |
| MR1 | 1002 | September 29 | 134 | 126 | | | 6% | |
| | 1009 | October 06 | 90 | 34 | -149 | -89 | 165% | 67% |
| LBR1 | 1002 | September 29 | 16 | 4 | -13 | -42 | 300% | -69% |
| | 1009 | October 06 | | | -73 | -53 | | 38% |
| I-95 | 1007 | October 04 | 390 | 482 | -403 | -362 | -19% | 11% |
| FW1 | 1022 | October 19 | 59 | 43 | 0 | -8 | 37% | -100% |
| | 1028 | October 25 | 82 | 74 | -20 | -42 | 11% | -52% |
| FW2 | 1022 | October 19 | | | -115 | -67 | | 72% |
| | 1028 | October 25 | 201 | 187 | -200 | -108 | 7% | 85% |
| FW3 | 1022 | October 19 | 131 | 158 | -99 | -100 | -17% | -1% |
| | 1028 | October 25 | 191 | 247 | -163 | -132 | -23% | 23% |
| FW4 | 1021 | October 18 | 200 | 209 | -95 | -162 | -4% | -41% |
| | 1029 | October 26 | 262 | 347 | -147 | -250 | -24% | -41% |
| FW5 | 1021 | October 18 | 382 | 347 | -300 | -387 | 10% | -22% |
| | 1029 | October 26 | 563 | 817 | -494 | -654 | -31% | -24% |
| FW6 | 1021 | October 18 | 412 | 487 | -343 | -552 | -15% | -38% |

NOTES: = determined to be insufficient data to determine peak

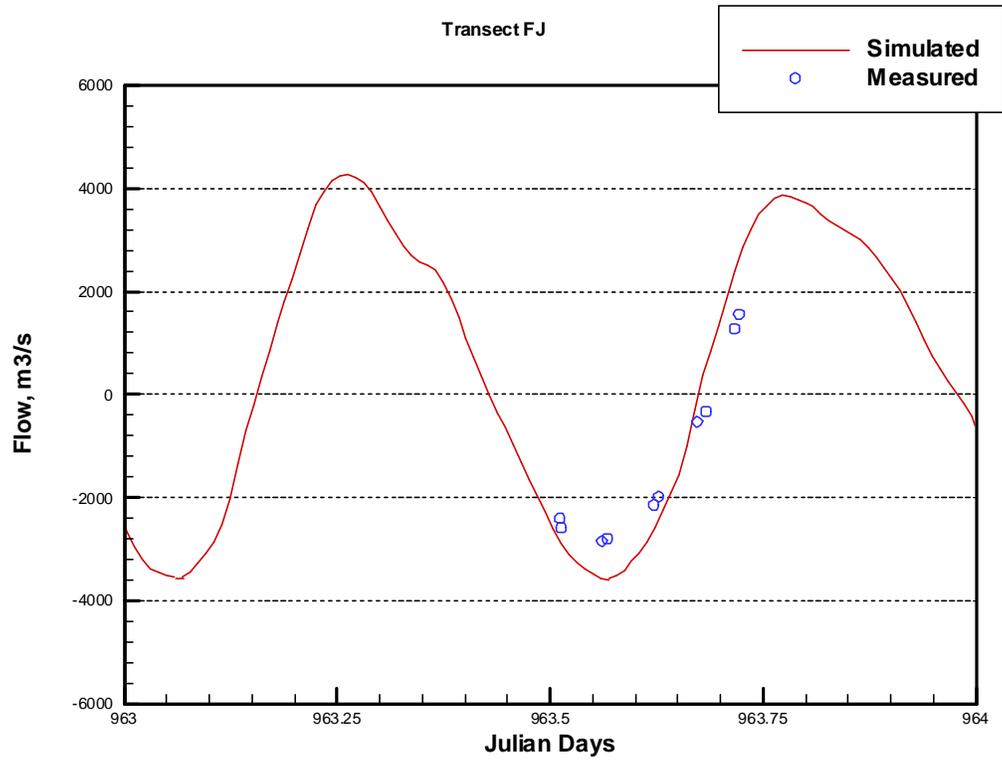


Figure E-1 Flow (m³/s) at Transect FJ on August 21, 1999

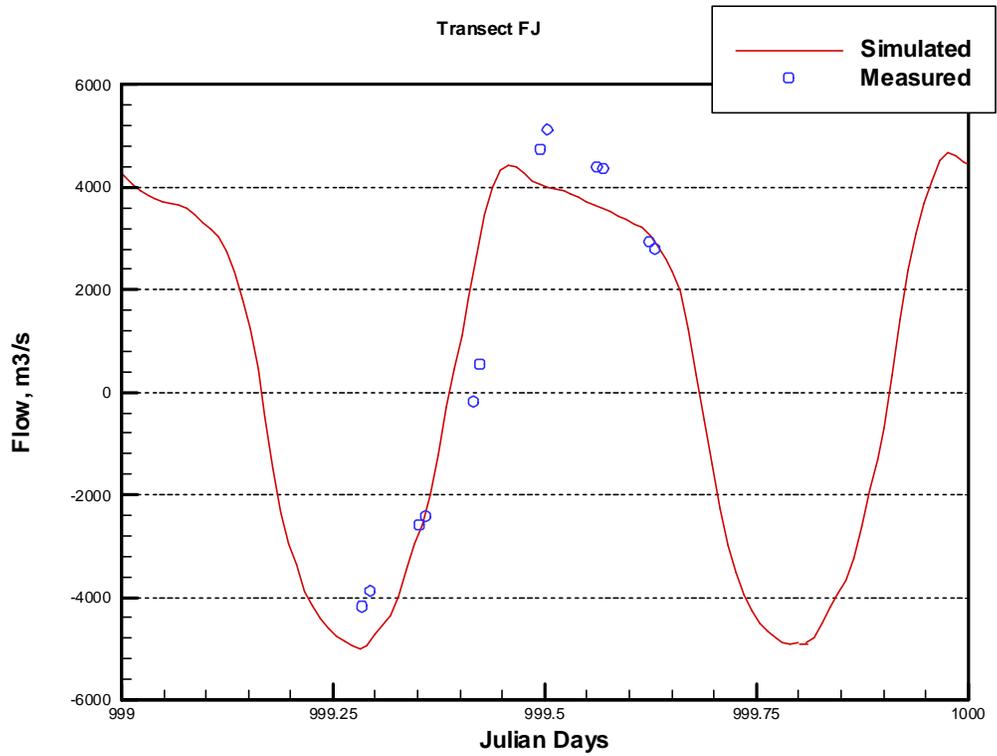


Figure E-2 Flow (m³/s) at Transect FJ on September 26, 1999

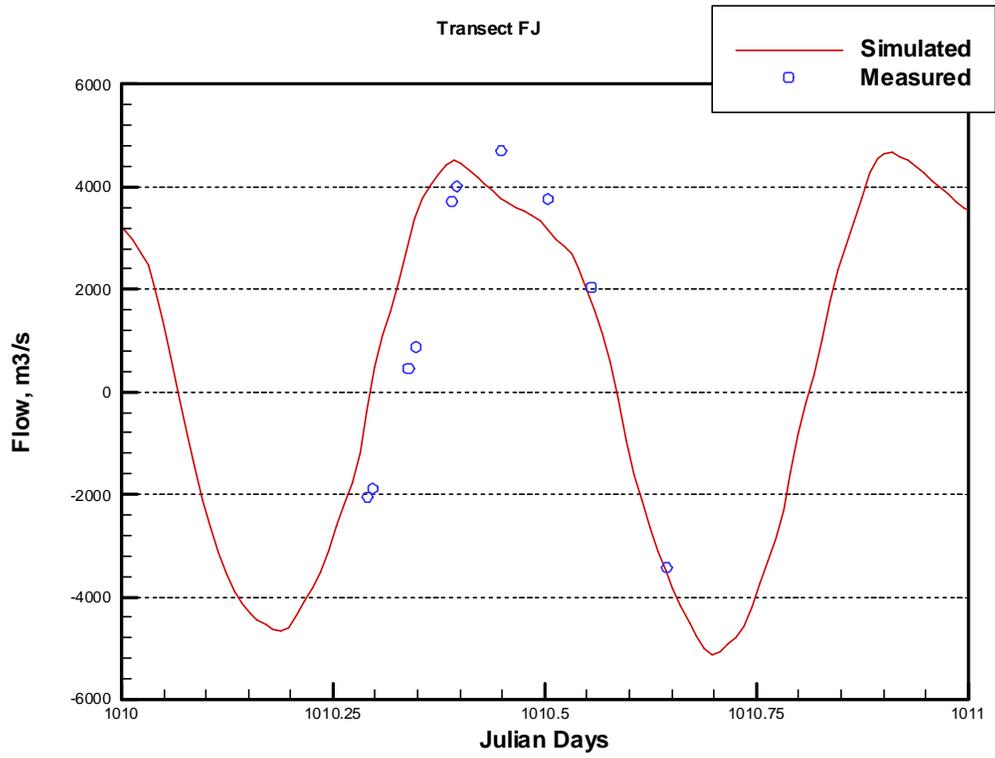


Figure E-3 Flow (m³/s) at Transect FJ on October 7, 1999

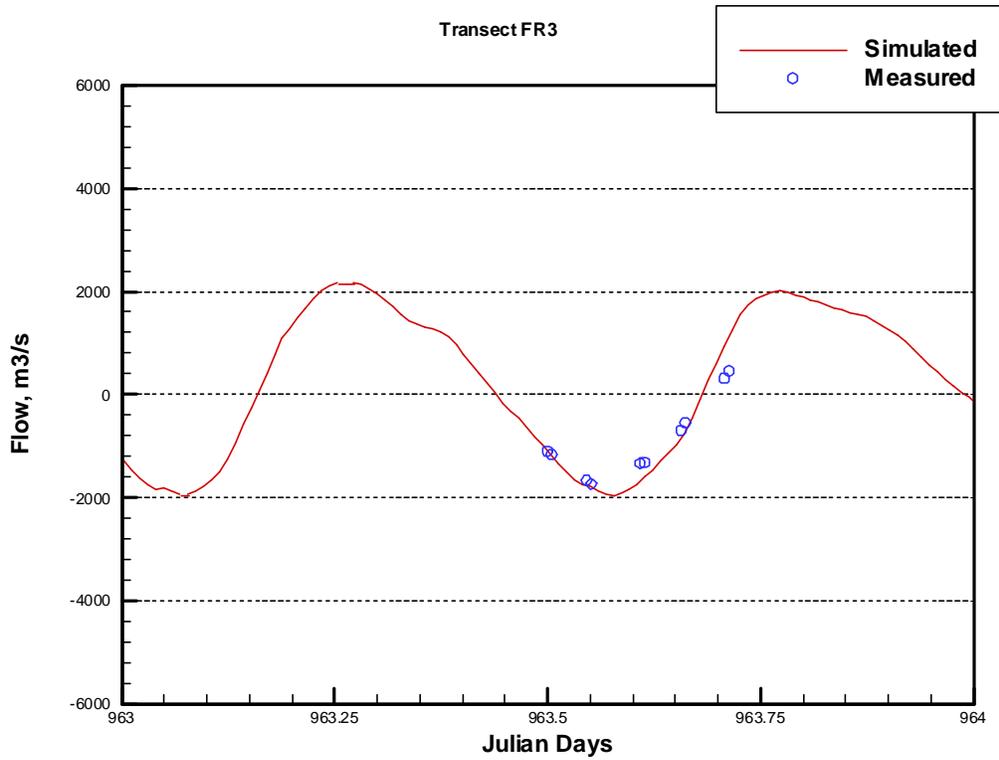


Figure E-4 Flow (m³/s) at Transect FR3 on August 21, 1999

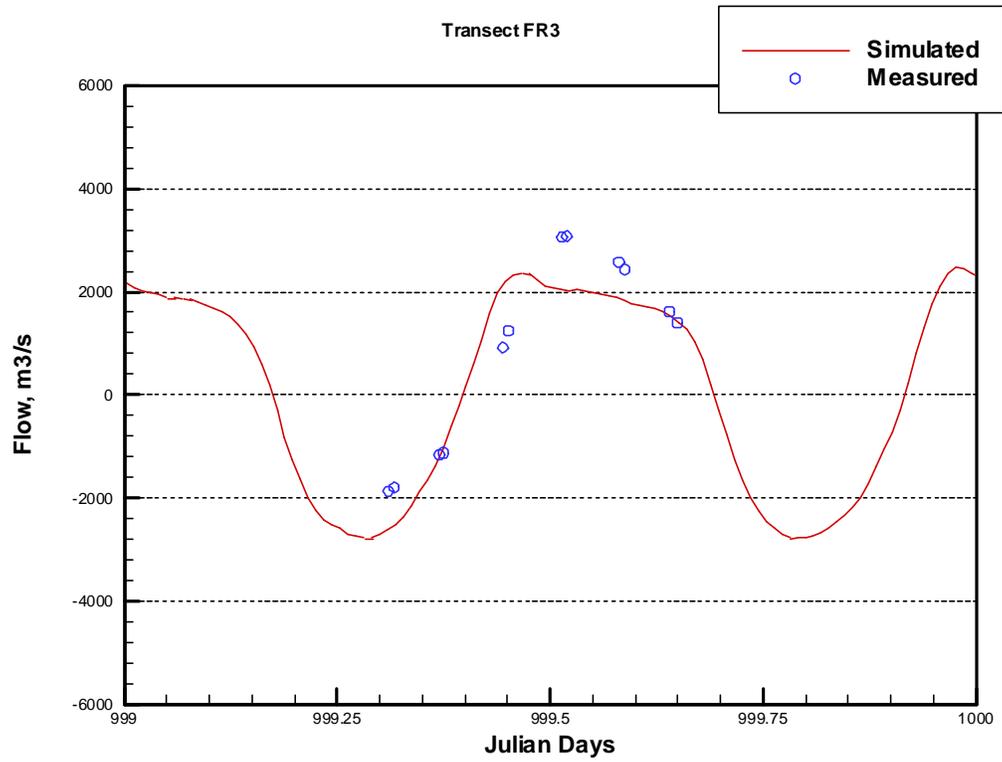


Figure E-5 Flow (m³/s) at Transect FR3 on September 26, 1999

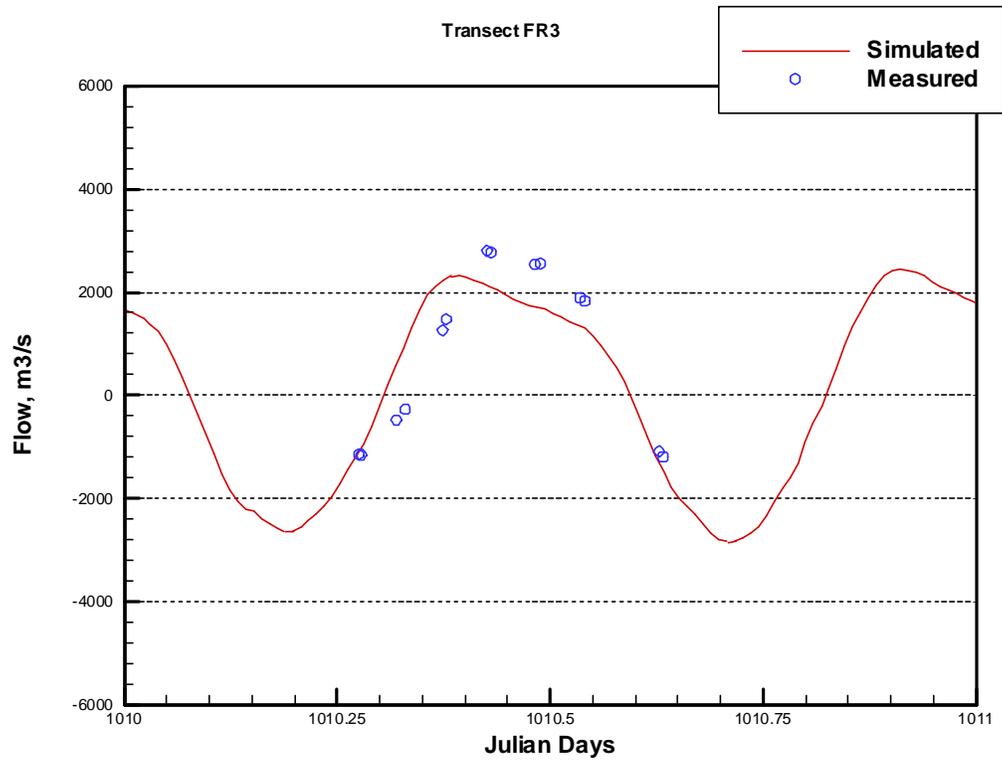


Figure E-6 Flow (m³/s) at Transect FR3 on October 7, 1999

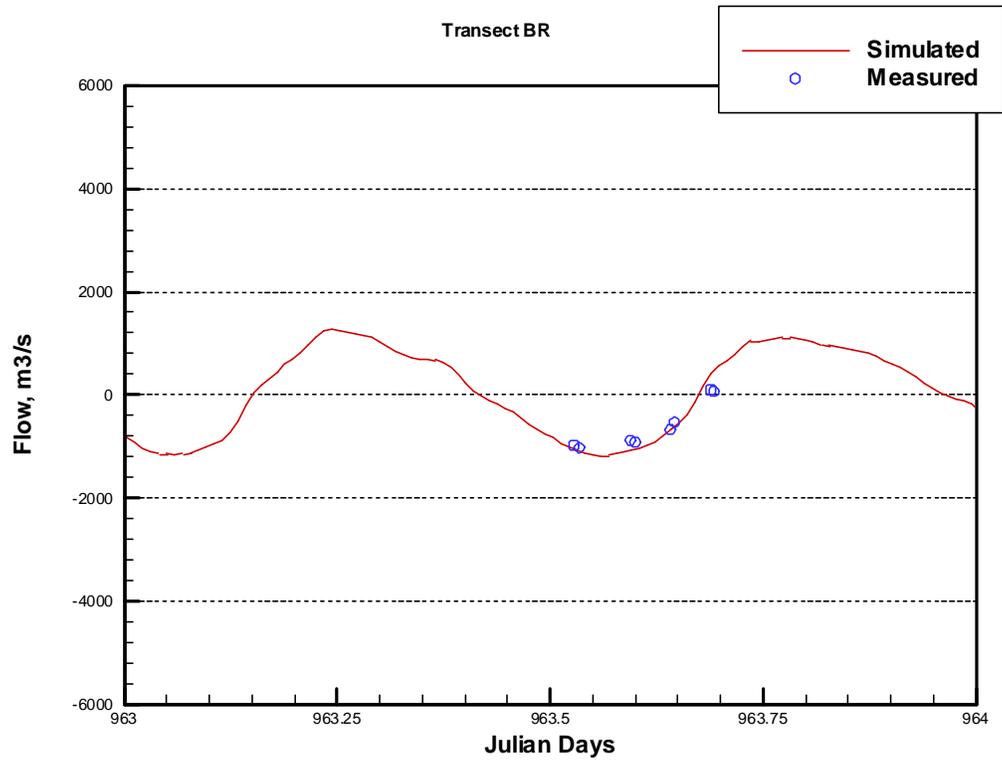


Figure E-7 Flow (m³/s) at Transect BR on August 21, 1999

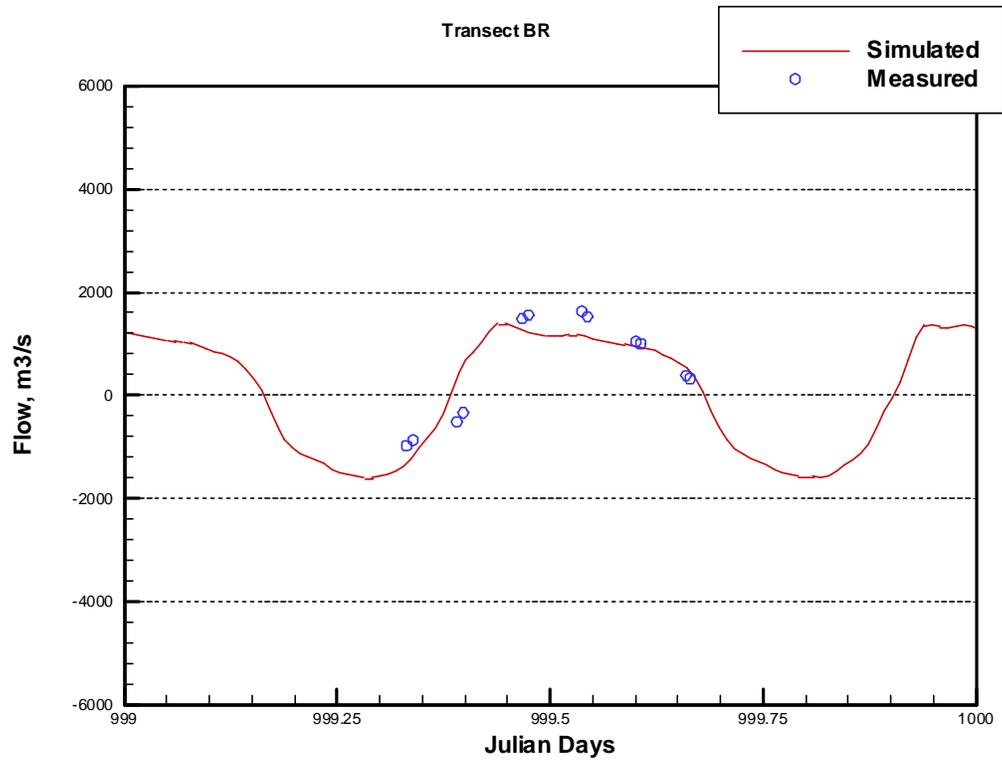


Figure E-8 Flow (m³/s) at Transect BR on September 26, 1999

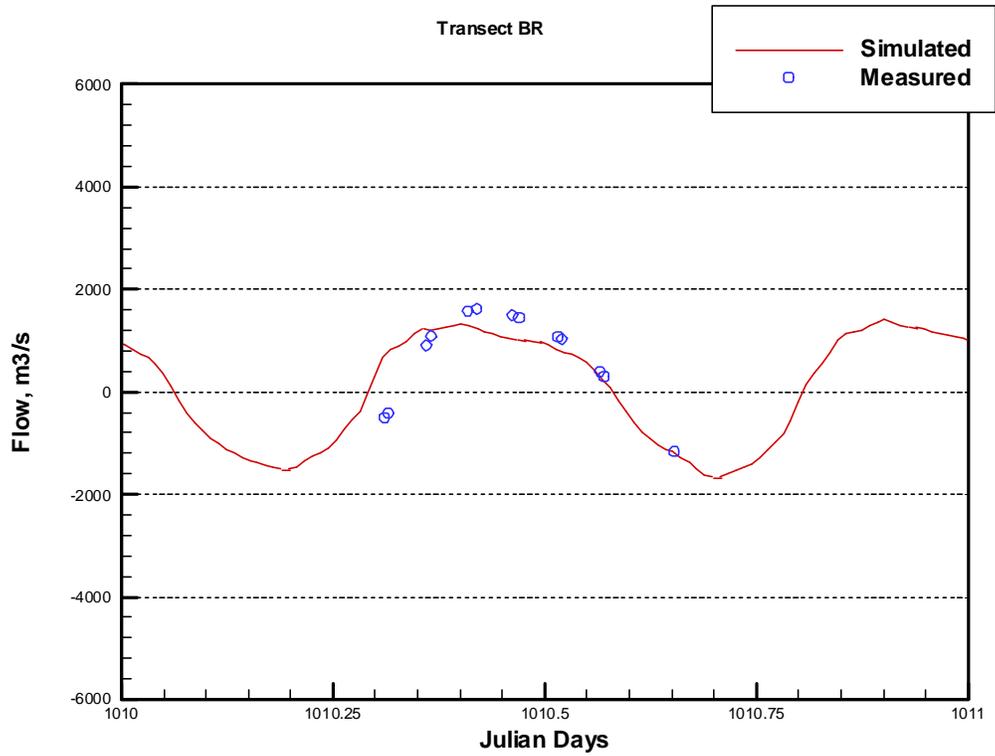


Figure E-9 Flow (m³/s) at Transect BR on October 7, 1999

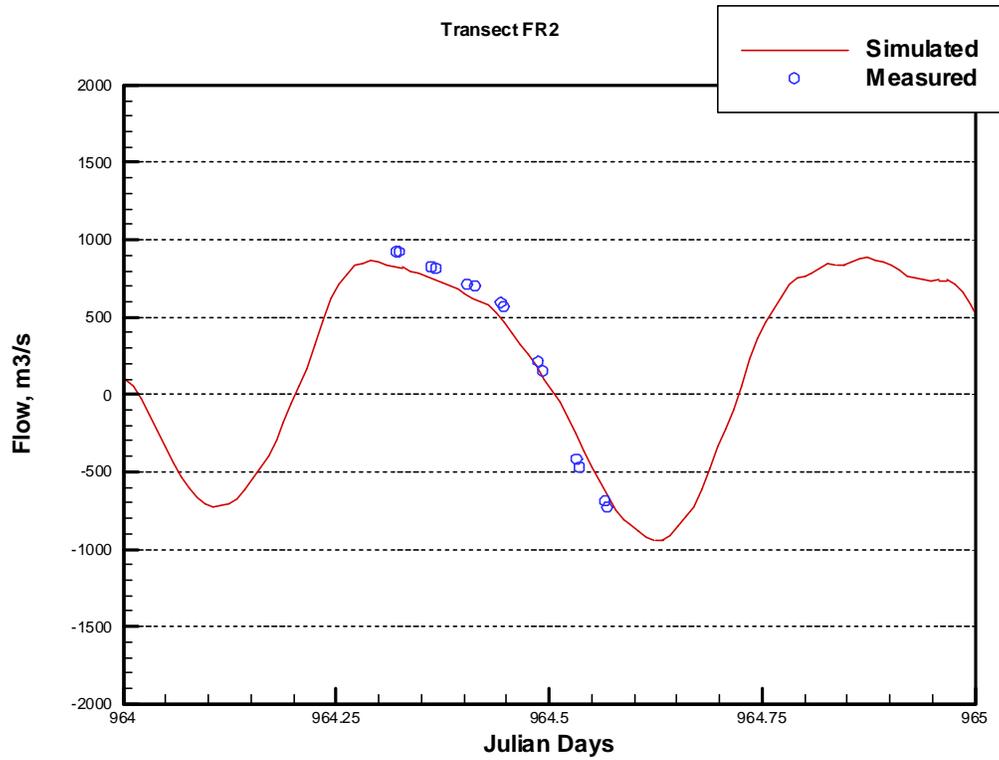


Figure E-10 Flow (m³/s) at Transect FR2 on August 22, 1999

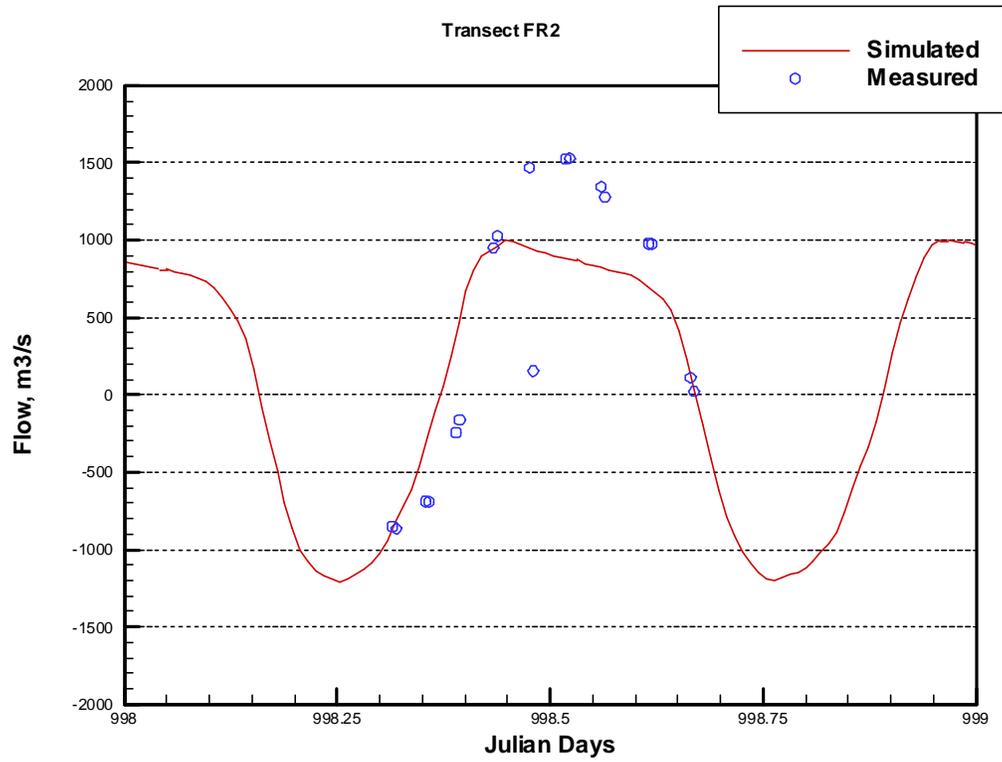


Figure E-11 Flow (m³/s) at Transect FR2 on September 25, 1999

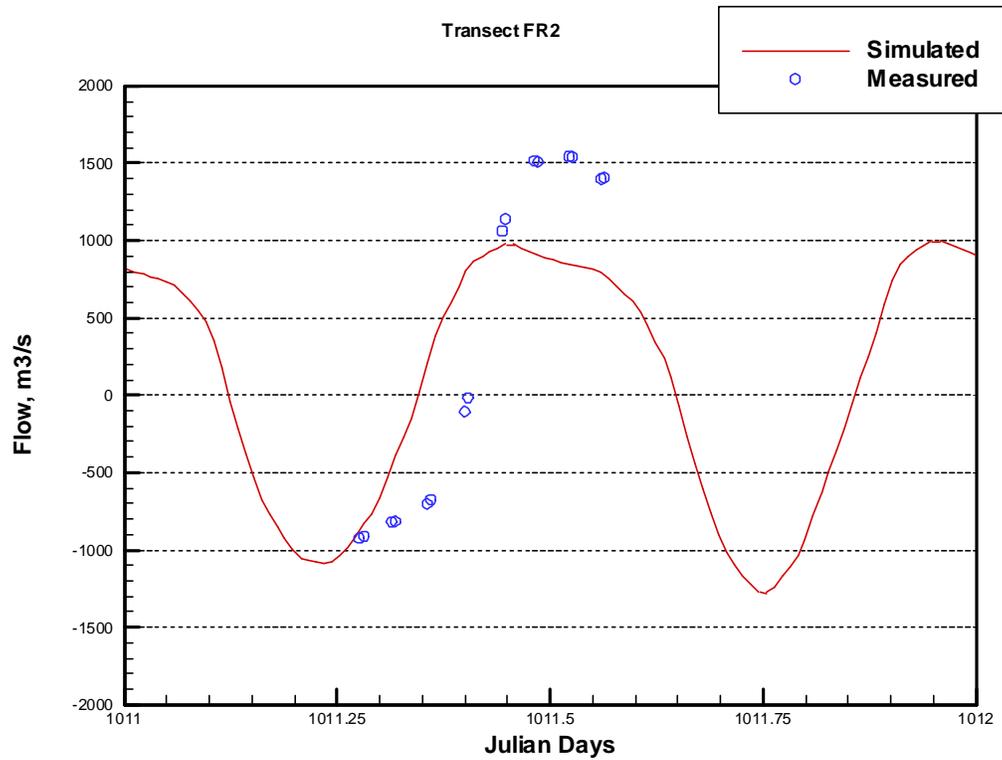


Figure E-12 Flow (m³/s) at Transect FR2 on October 8, 1999

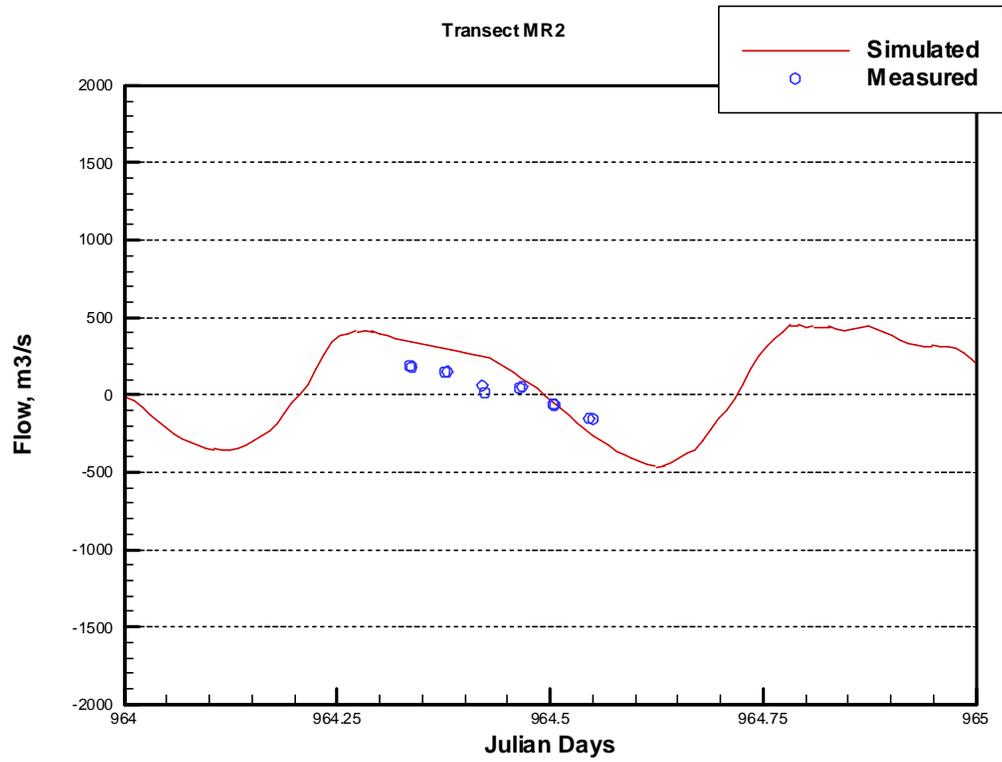


Figure E-13 Flow (m³/s) at Transect MR2 on August 22, 1999

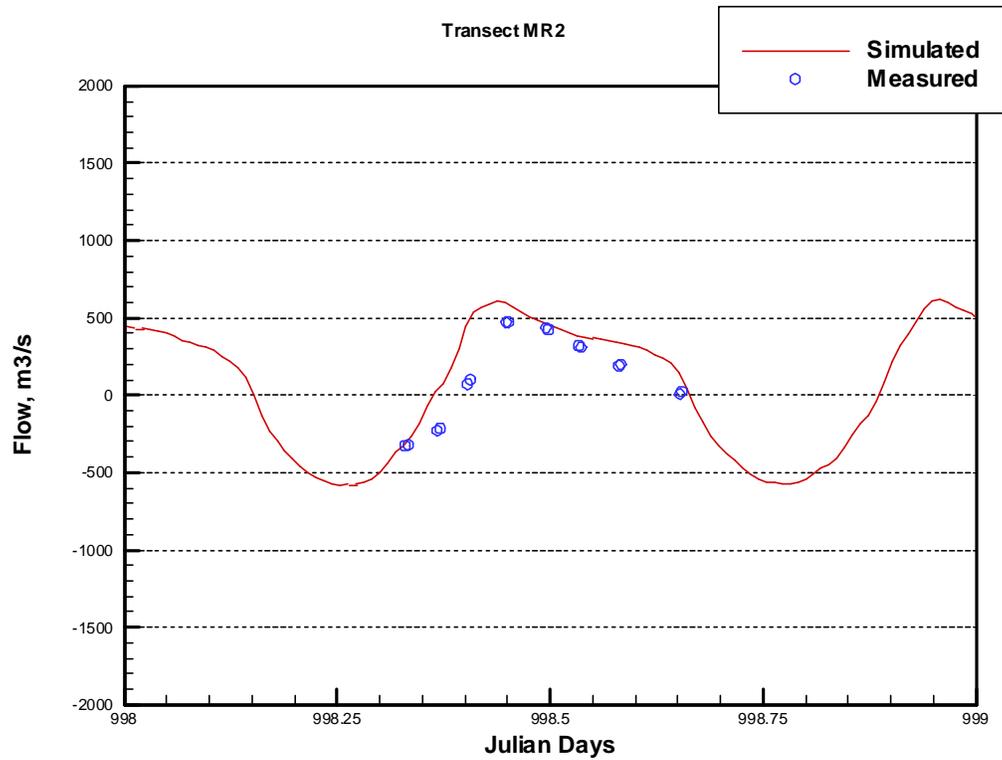


Figure E-14 Flow (m³/s) at Transect MR2 on September 25, 1999

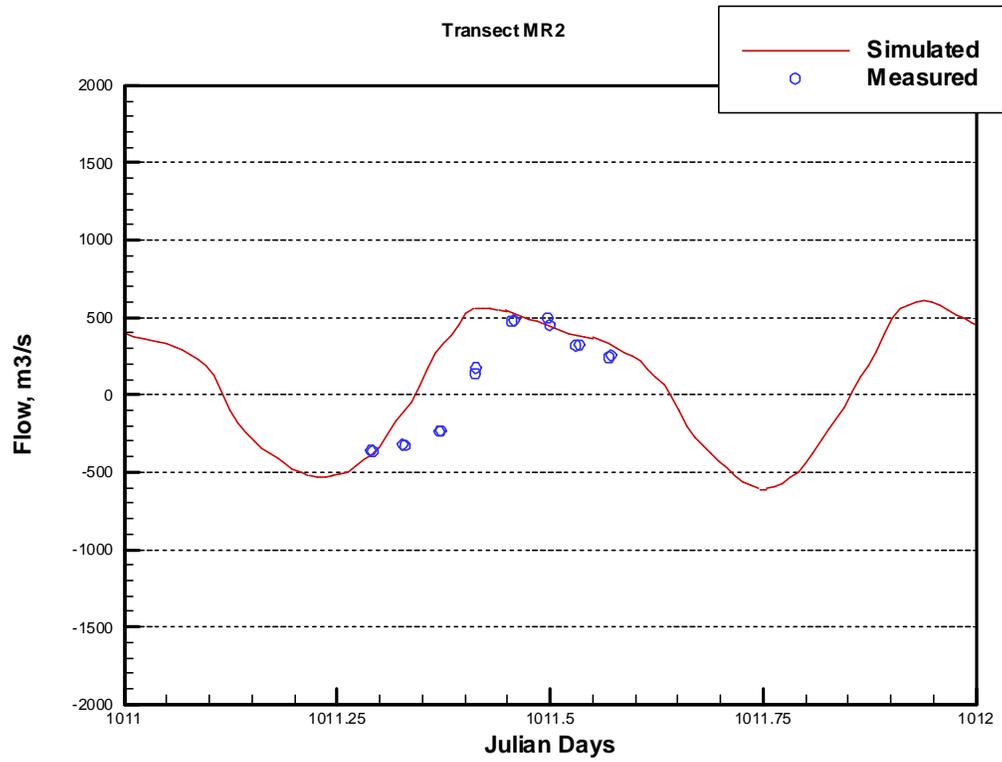


Figure E-15 Flow (m³/s) at Transect MR2 on October 8, 1999

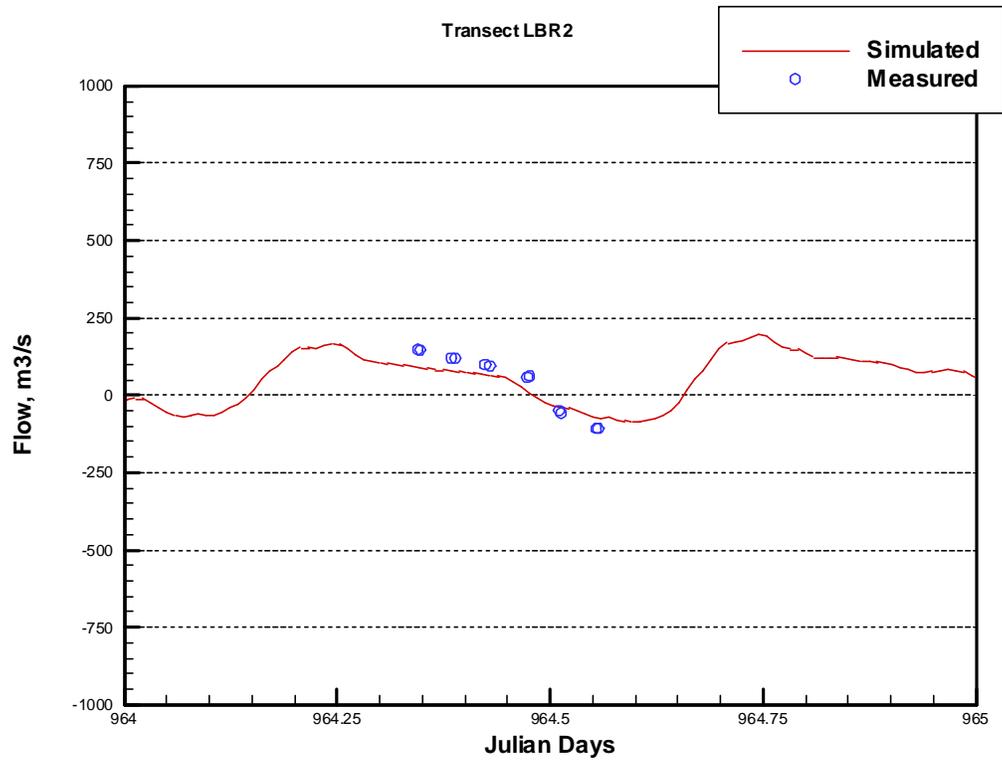


Figure E-16 Flow (m³/s) at Transect LBR2 on August 22, 1999

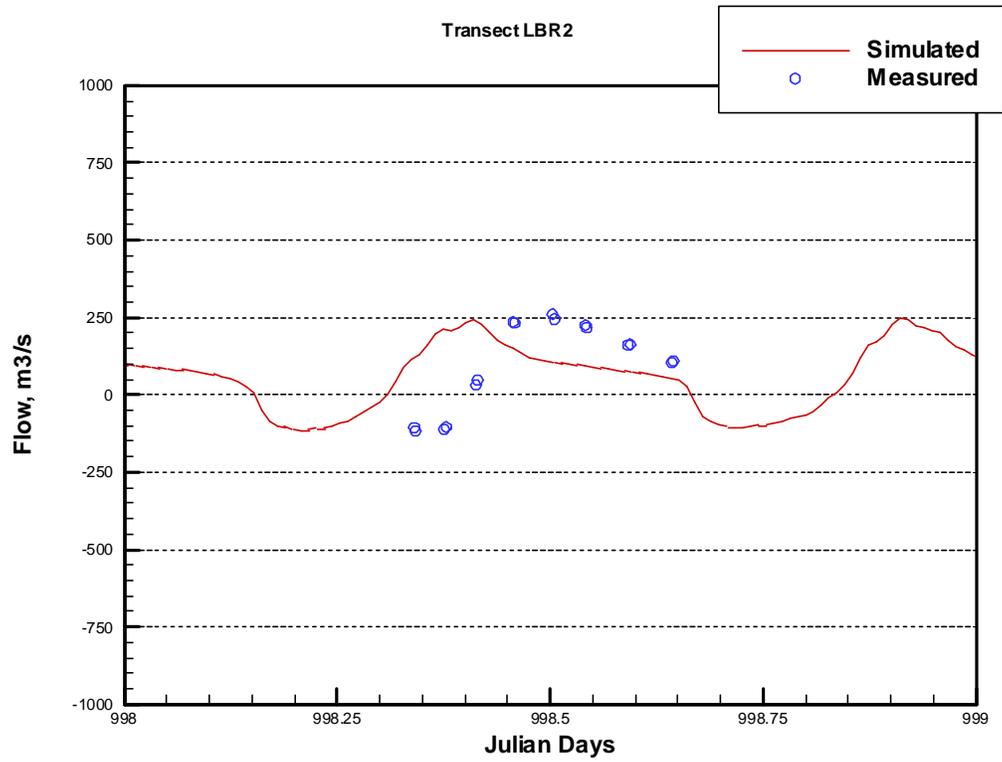


Figure E-17 Flow (m³/s) at Transect LBR2 on September 25, 1999

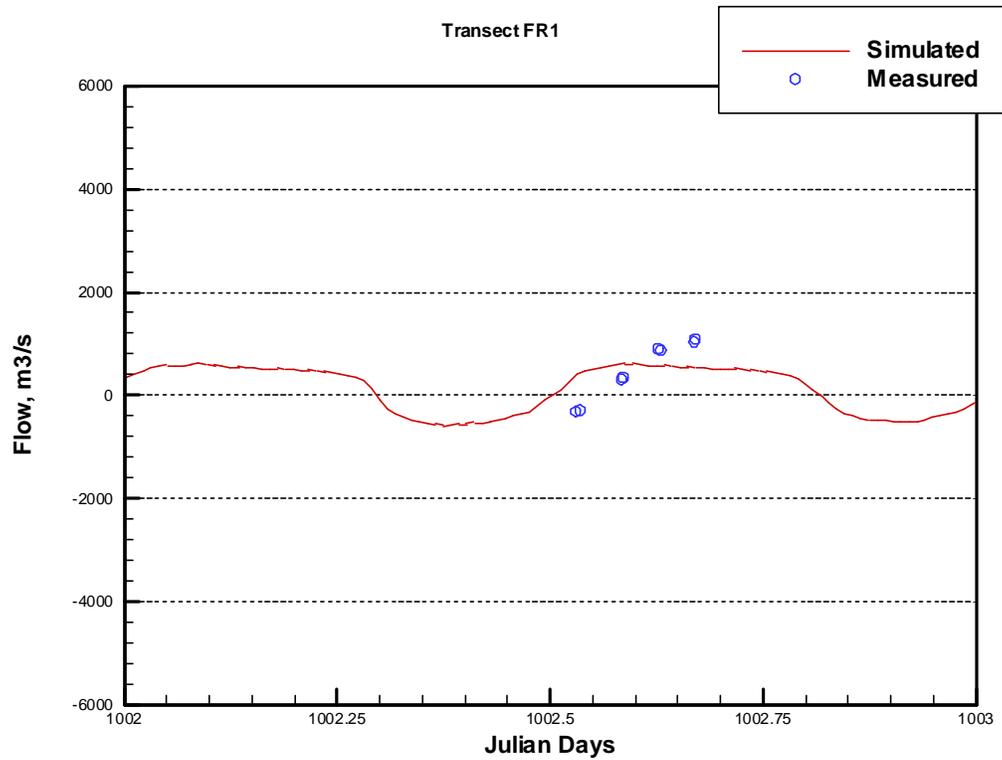


Figure E-18 Flow (m³/s) at Transect FR1 on September 29, 1999

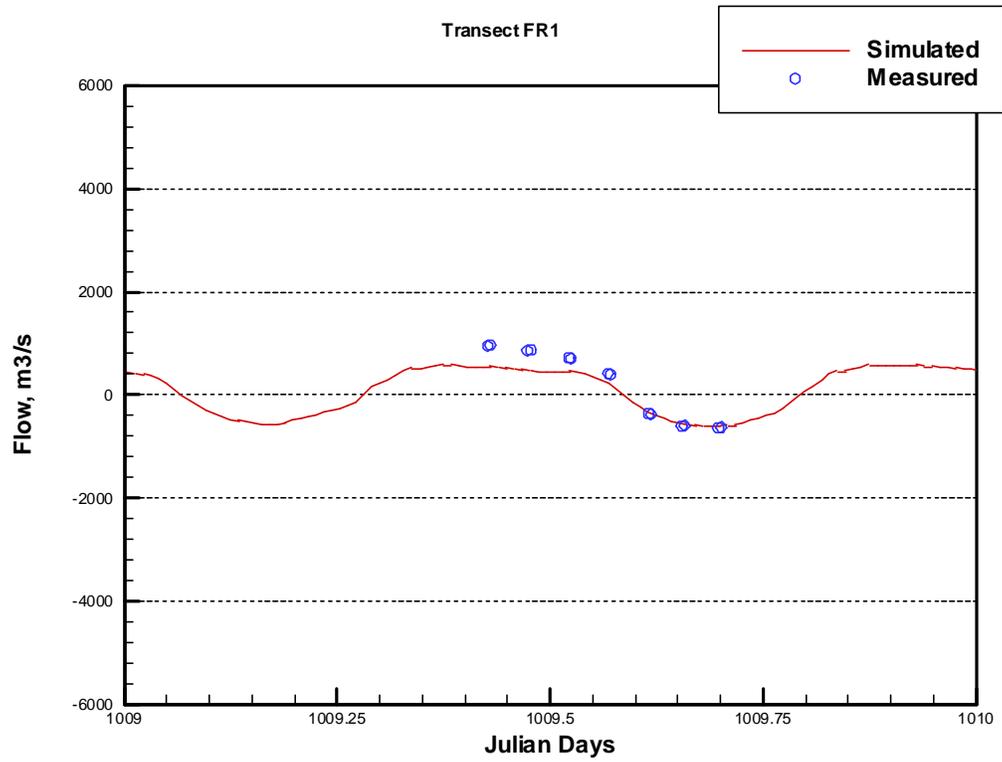


Figure E-19 Flow (m³/s) at Transect FR1 on October 6, 1999

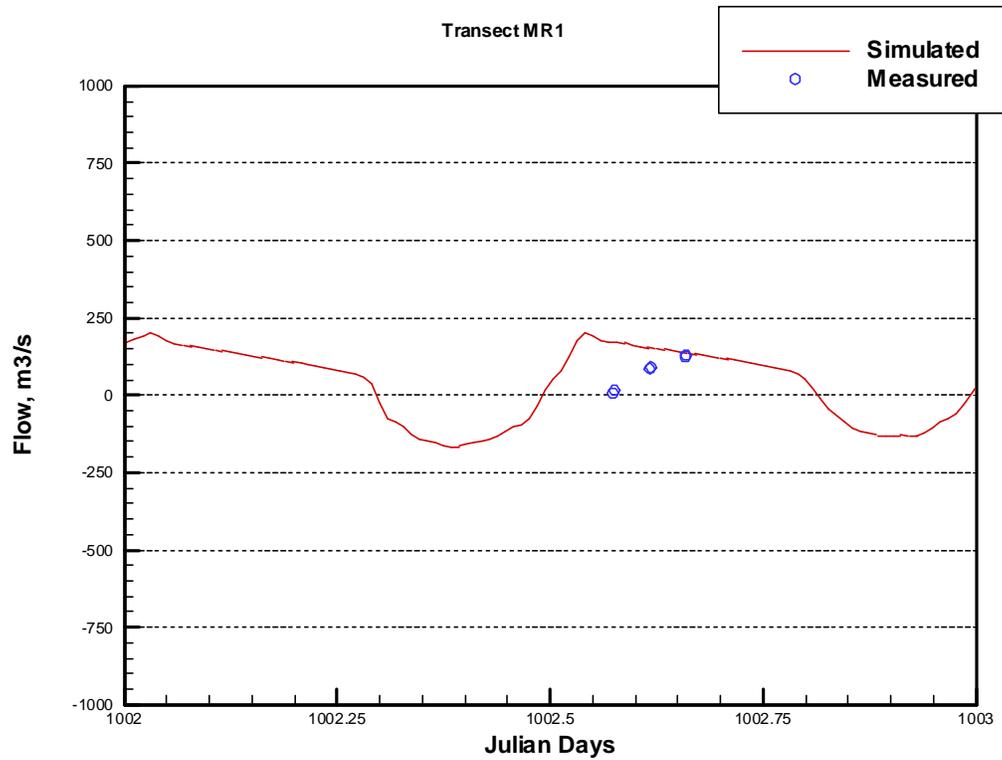


Figure E-20 Flow (m³/s) at Transect MR1 on September 29, 1999

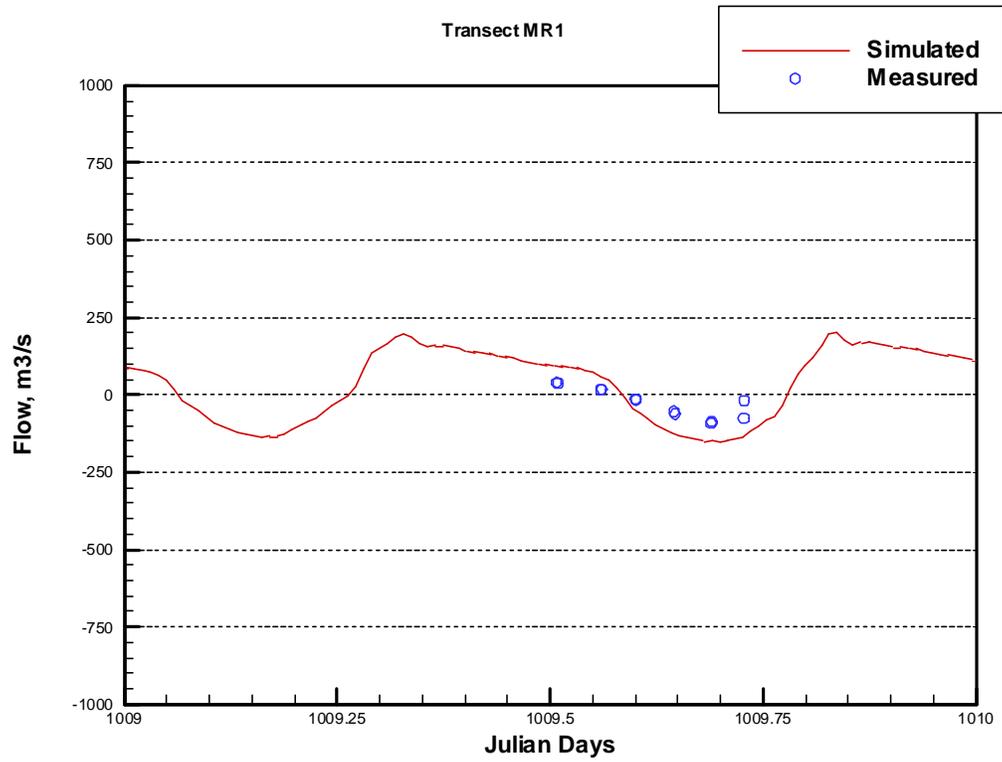


Figure E-21 Flow (m³/s) at Transect MR1 on October 6, 1999

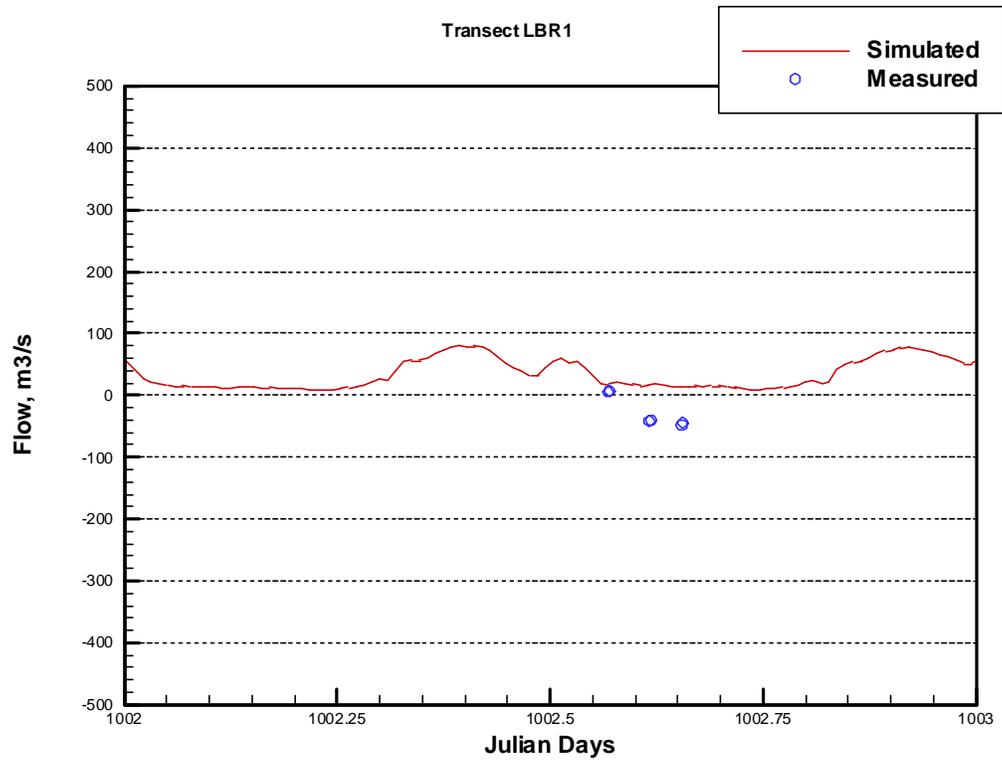


Figure E-22 Flow (m³/s) at Transect LBR1 on September 29, 1999

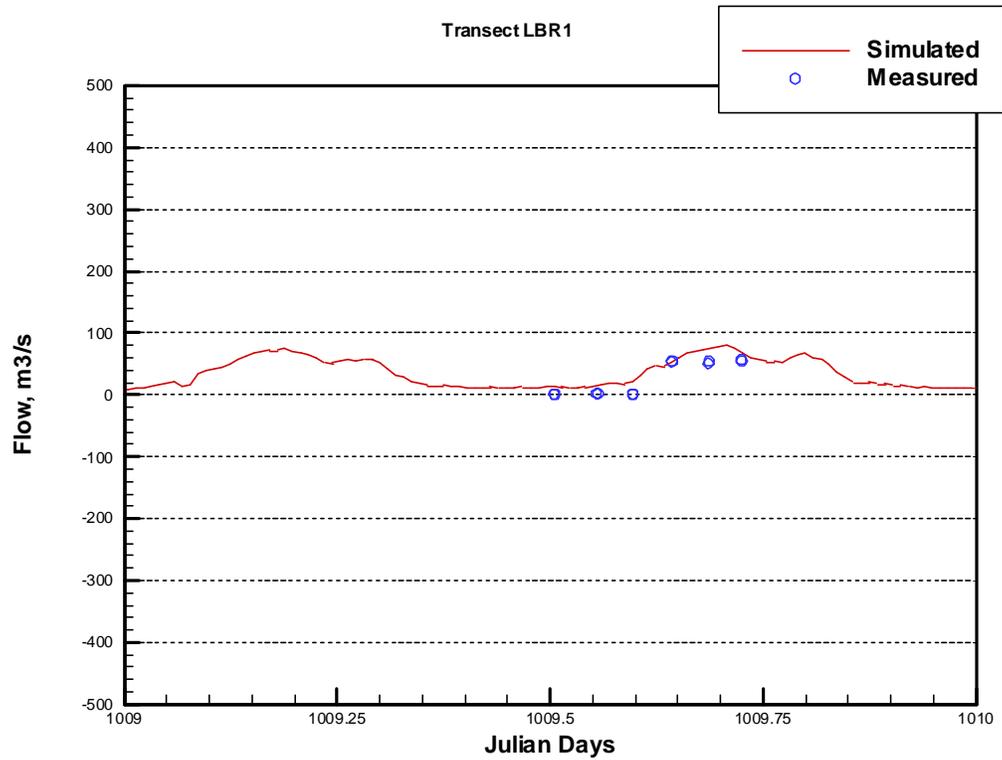


Figure E-23 Flow (m³/s) at Transect LBR1 on October 6, 1999

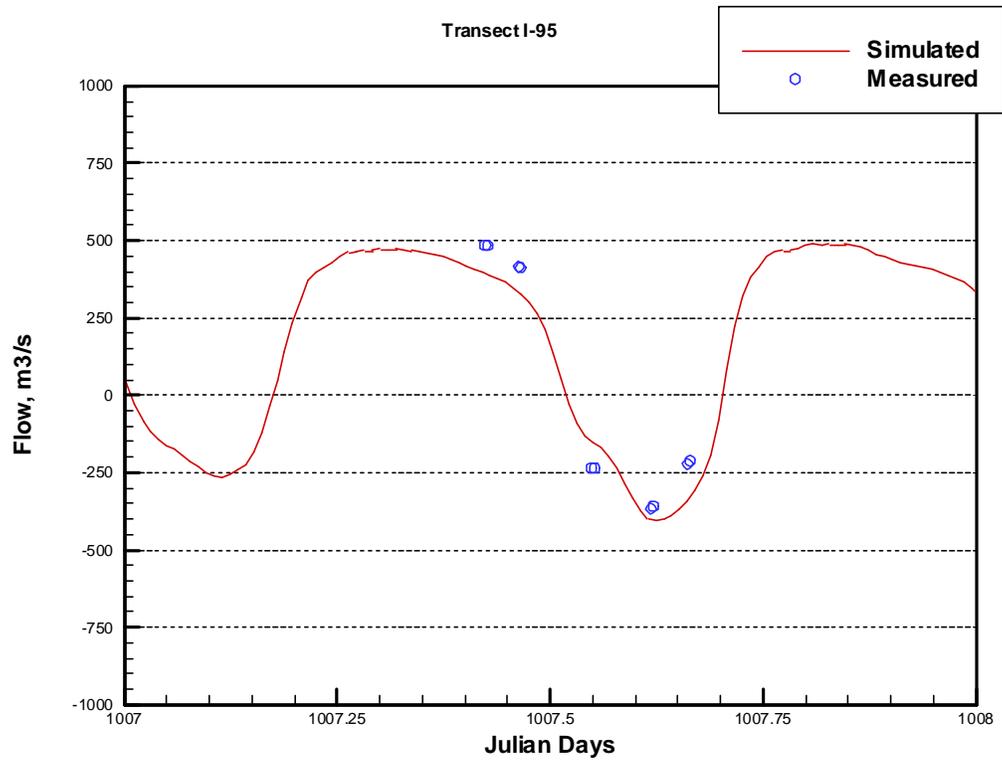


Figure E-24 Flow (m³/s) at Transect I-95 on October 4, 1999

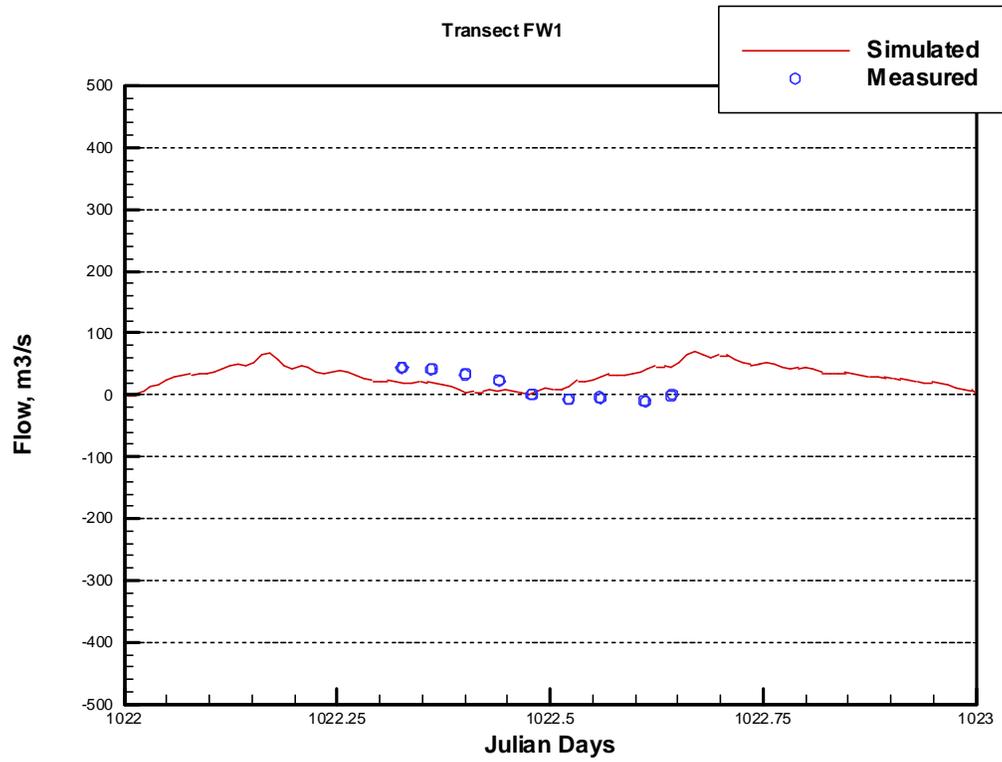


Figure E-25 Flow (m3/s) at Transect FW1 on October 19, 1999

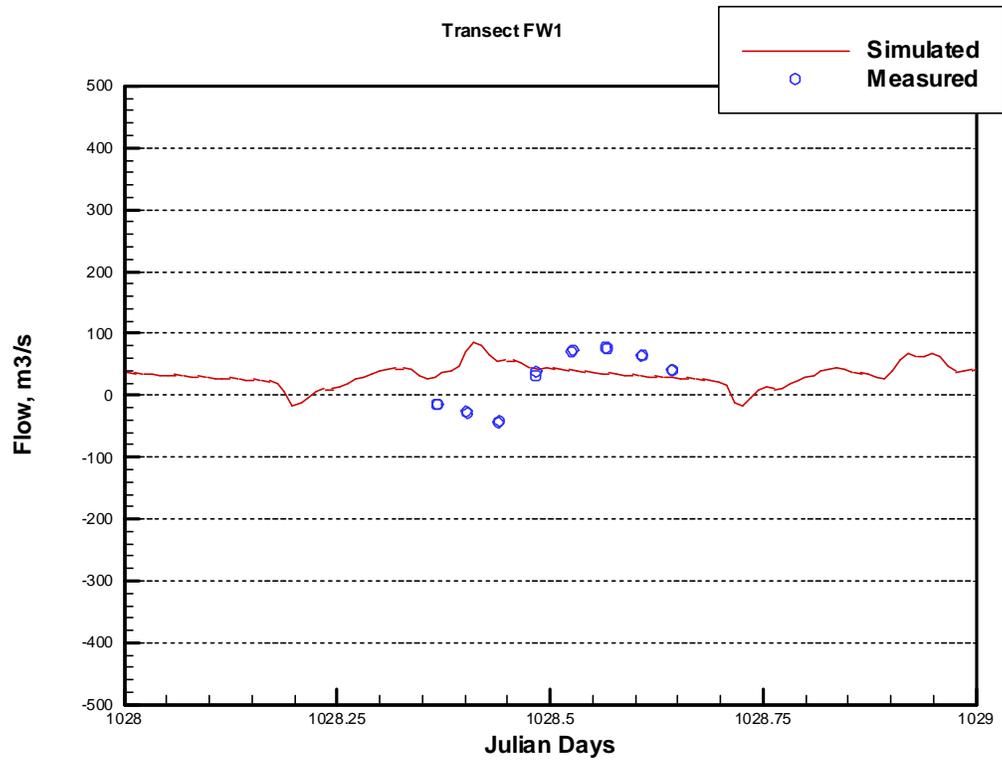


Figure E-26 Flow (m3/s) at Transect FW1 on October 25, 1999

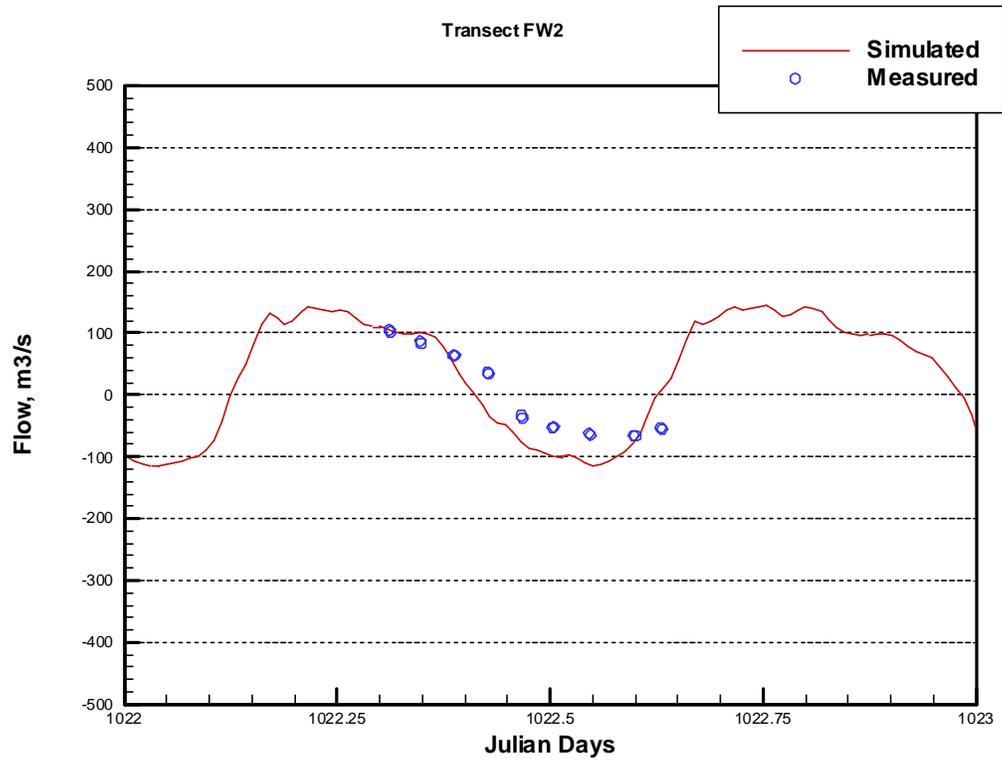


Figure E-27 Flow (m3/s) at Transect FW2 on October 19, 1999

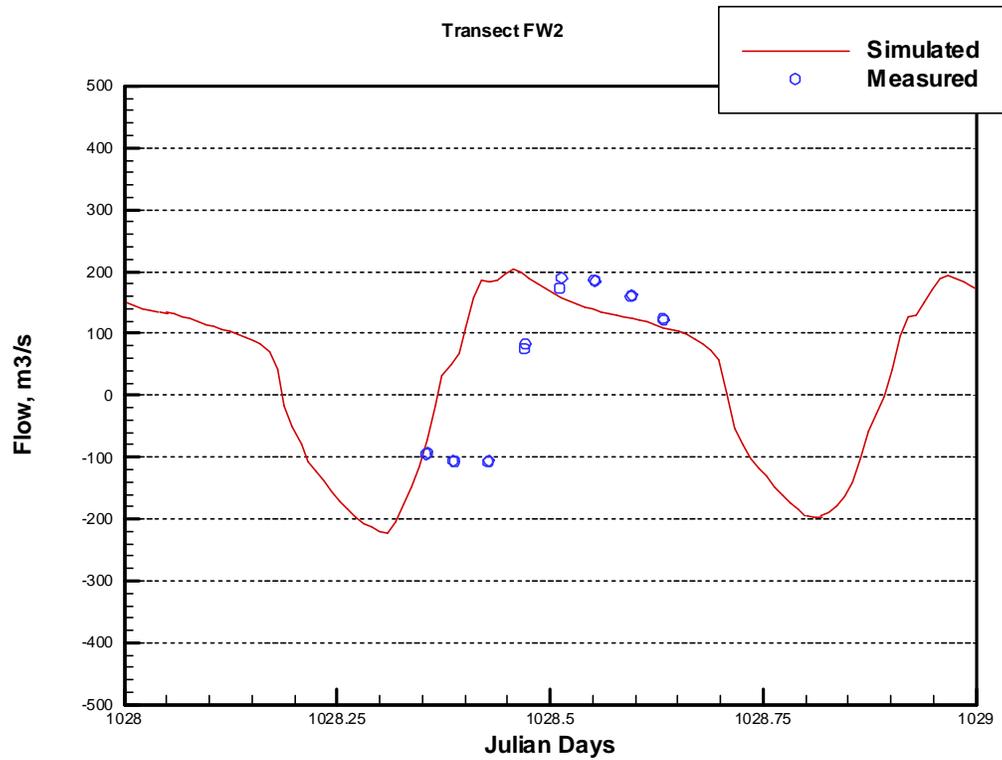


Figure E-28 Flow (m3/s) at Transect FW2 on October 25, 1999

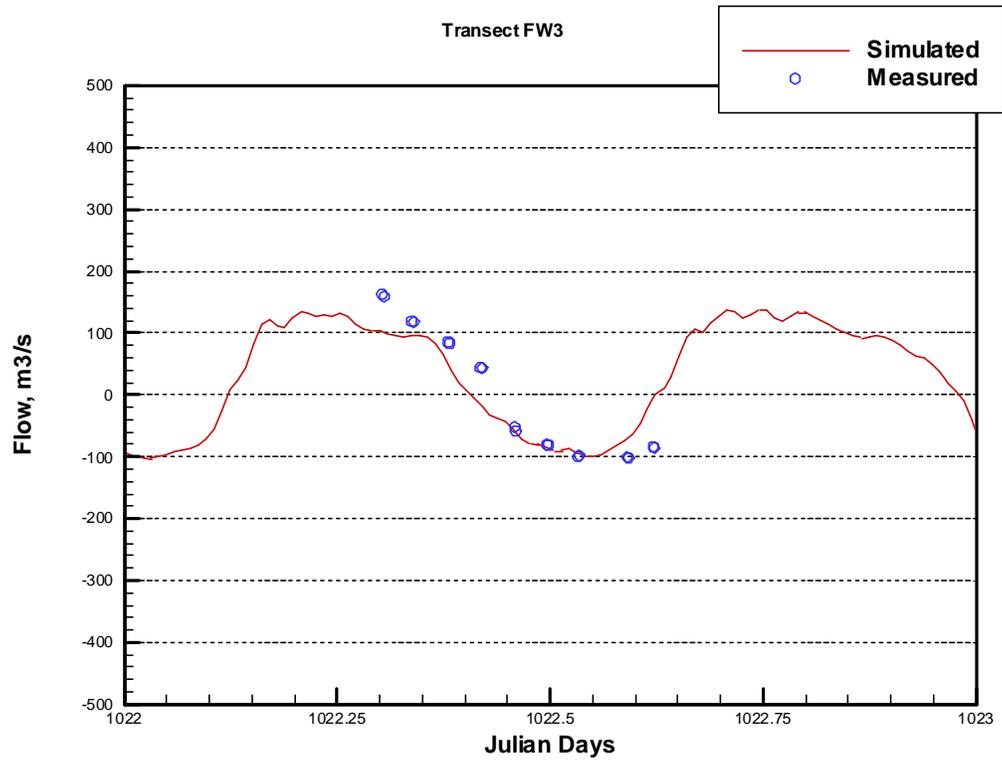


Figure E-29 Flow (m³/s) at Transect FW3 on October 19, 1999

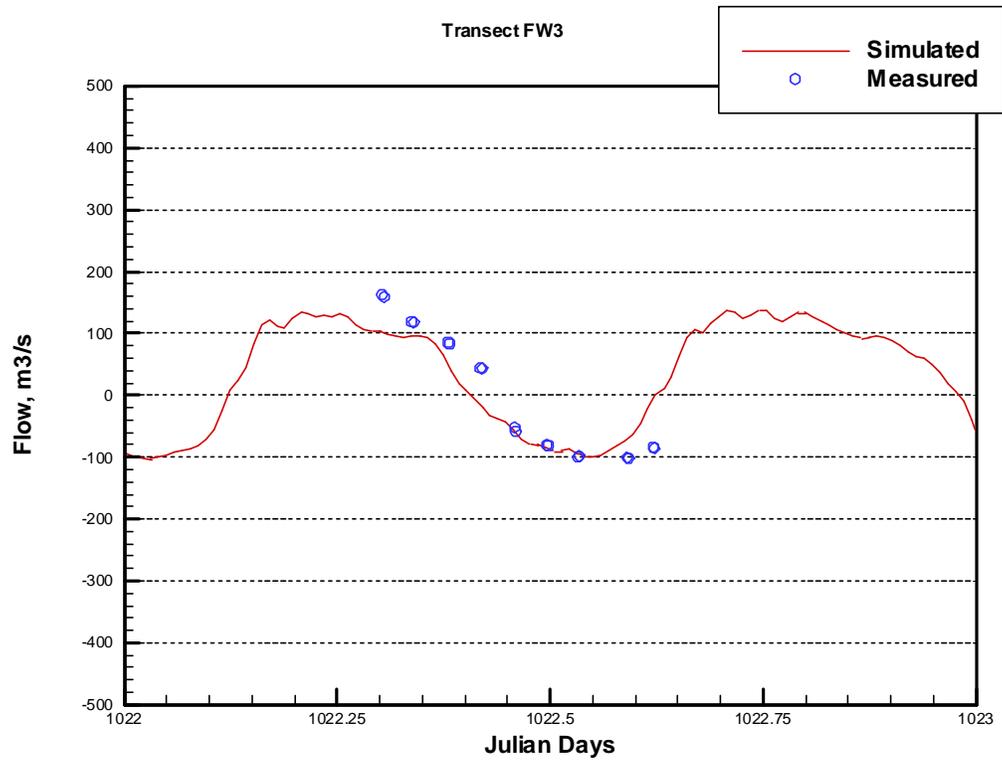


Figure E-30 Flow (m³/s) at Transect FW3 on October 25, 1999

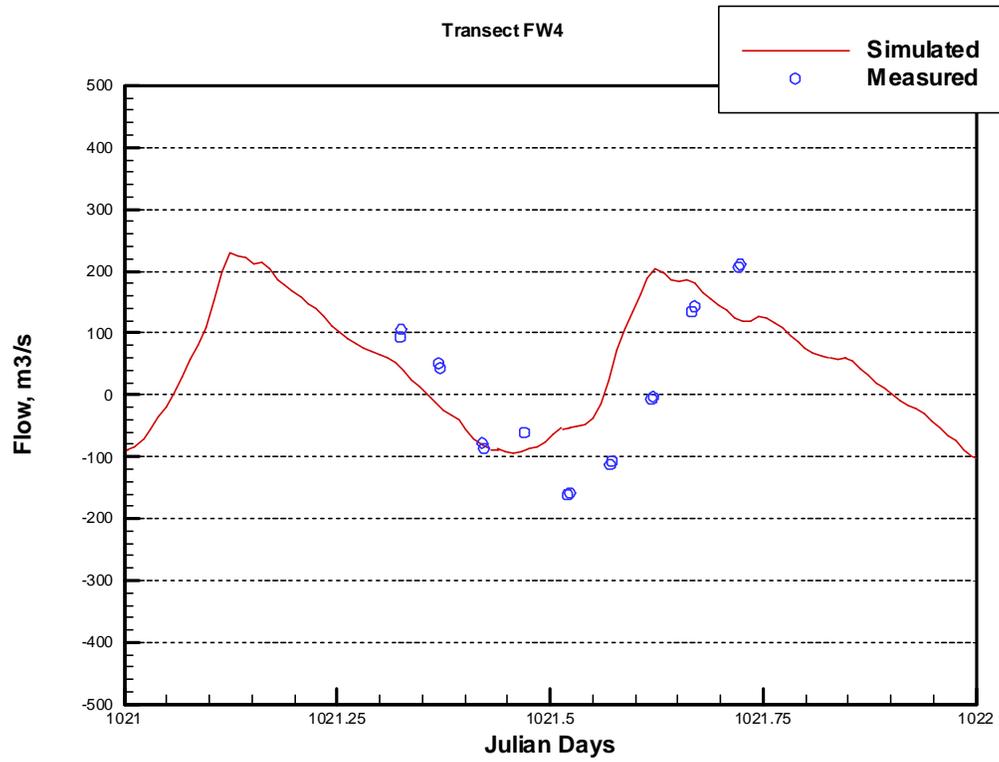


Figure E-31 Flow (m³/s) at Transect FW4 on October 18, 1999

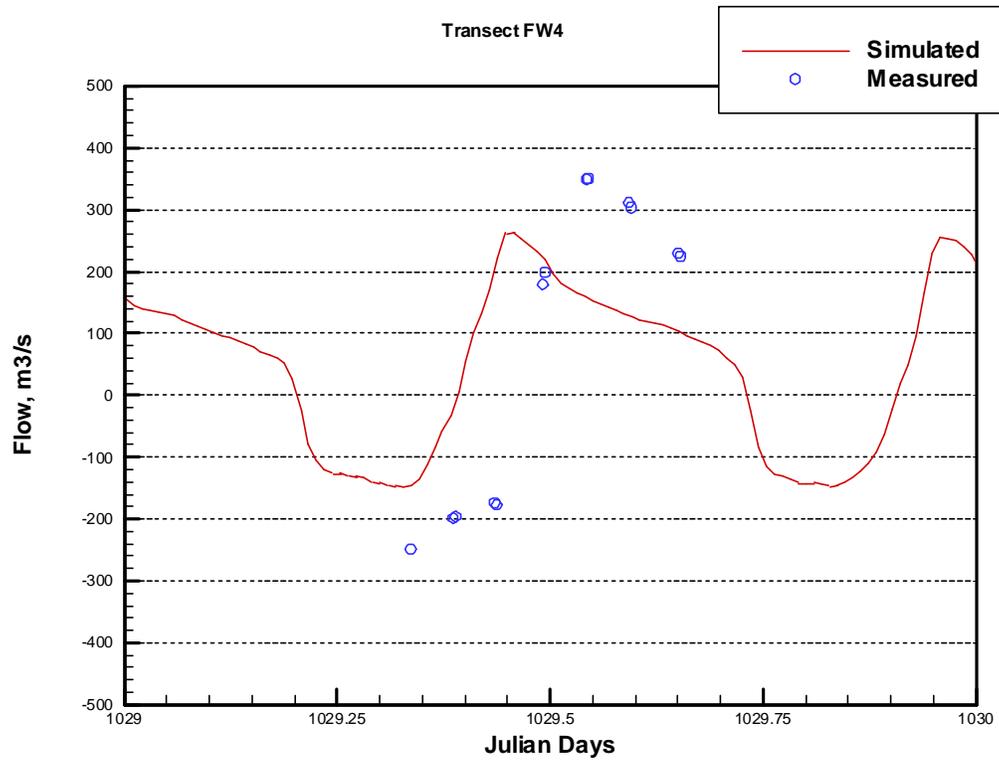


Figure E-32 Flow (m³/s) at Transect FW4 on October 26, 1999

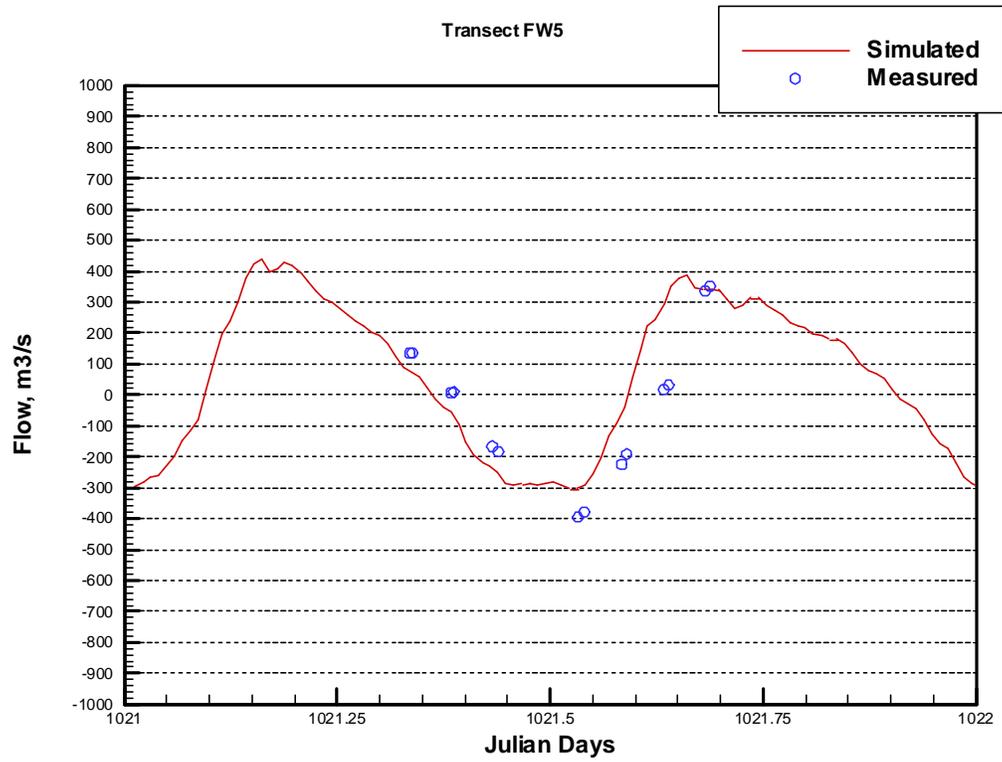


Figure E-33 Flow (m³/s) at Transect FW5 on October 18, 1999

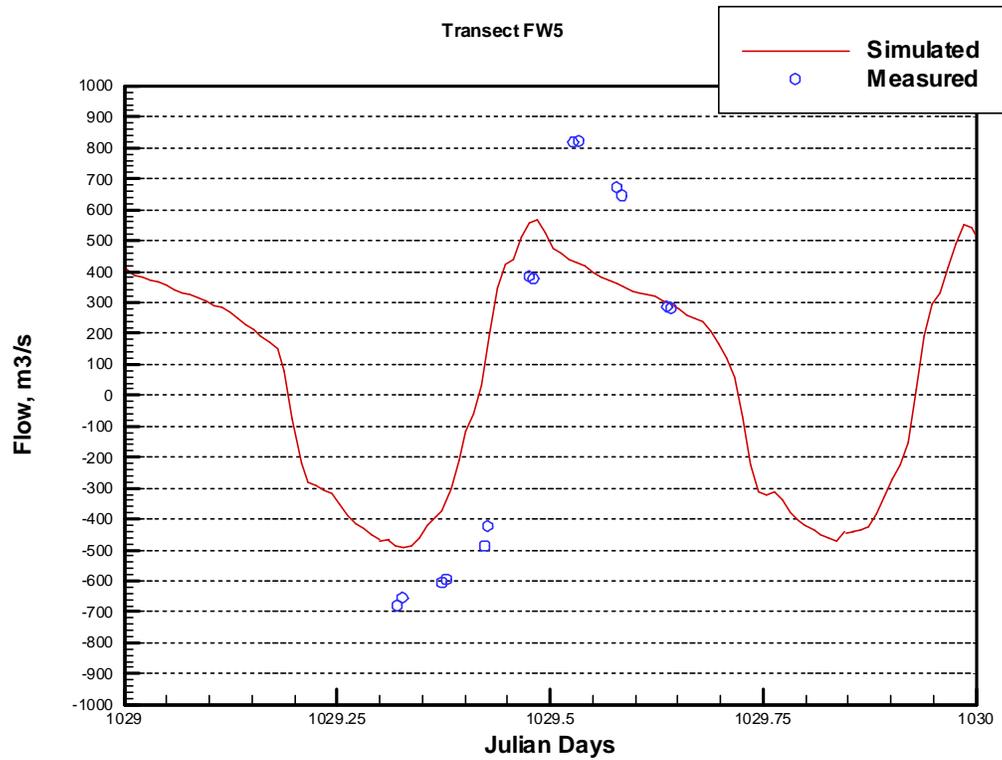


Figure E-34 Flow (m³/s) at Transect FW5 on October 26, 1999

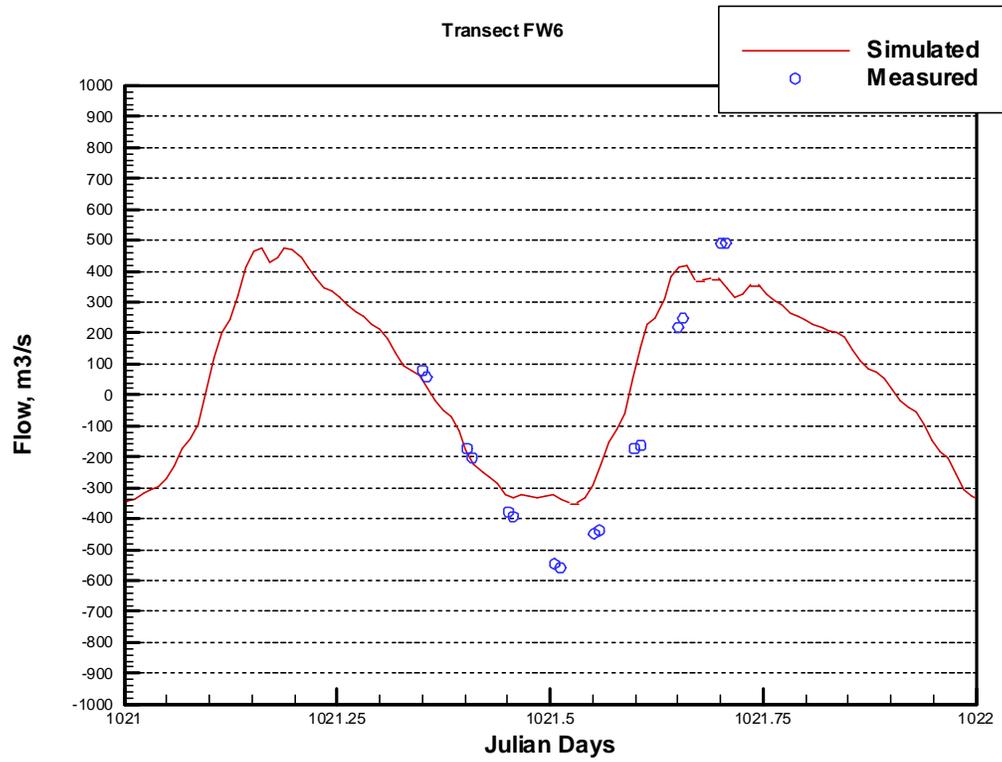


Figure E-35 Flow (m³/s) at Transect FW6 on October 18, 1999

APPENDIX F 1997 CURRENTS COMPARISONS

Table F-1 1997 Currents (m/s) Statistical Comparisons

| Stations | Date of Comparisons | Depth* | Measured | | | Simulated | | | Differences | |
|----------|------------------------|--------|----------|-------|------|-----------|-------|------|-------------|------|
| | | | 5% | 50% | 95% | 5% | 50% | 95% | 5% | 95% |
| FR-04 | July 9 - Sept 12, 1997 | S | -1.31 | -0.16 | 1.01 | -0.91 | -0.35 | 0.83 | -30% | -18% |
| FR-04 | July 9 - Sept 12, 1997 | B | -0.66 | 0.34 | 0.79 | -0.67 | 0.27 | 0.75 | 2% | -5% |
| FR-08 | July 8 - Sept 8, 1997 | S | -0.87 | -0.2 | 0.79 | -0.62 | -0.28 | 0.48 | -29% | -39% |
| FR-08 | July 8 - Sept 8, 1997 | B | -0.6 | 0.24 | 0.63 | -0.33 | 0.33 | 0.70 | -46% | 11% |

* S = Surface
 B = Bottom
 M = Mid-Depth

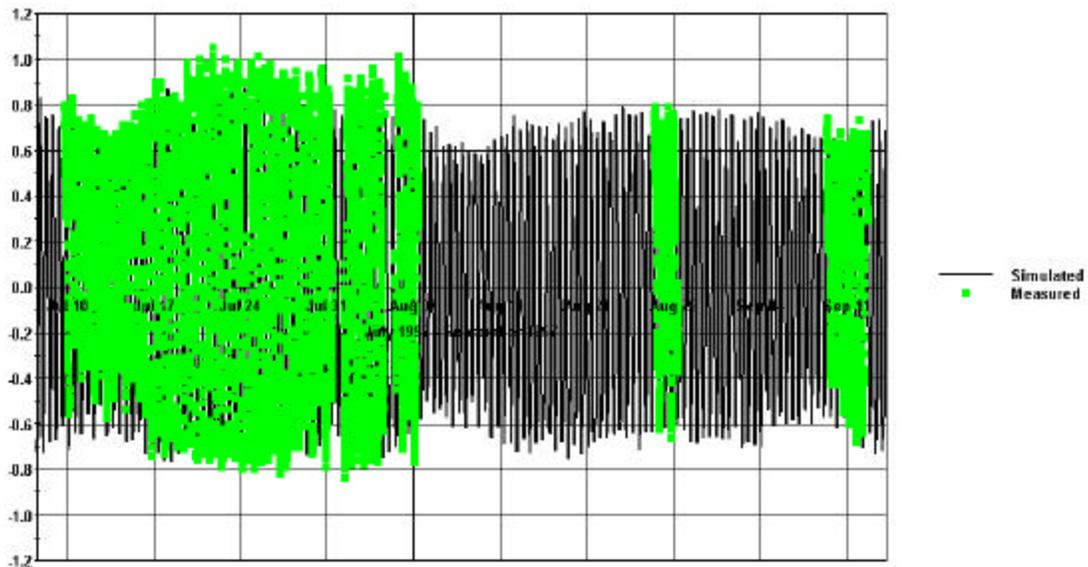


Figure F-1 Current Comparison at FR-04 Surface for July 9, 1997 through September 12, 1997

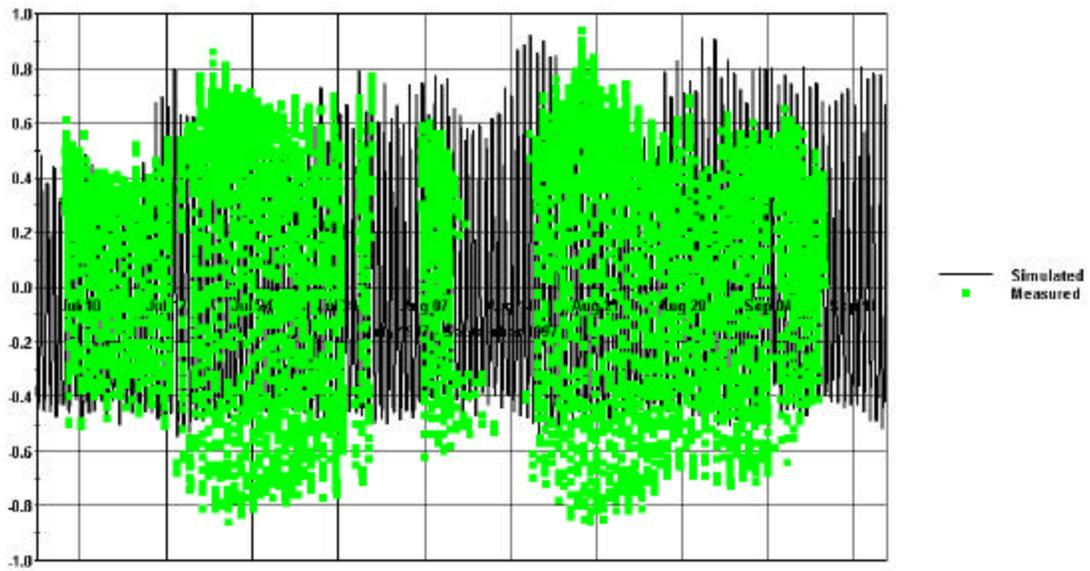


Figure F-2 Current Comparison at FR-04 Bottom for July 9 through September 12, 1997

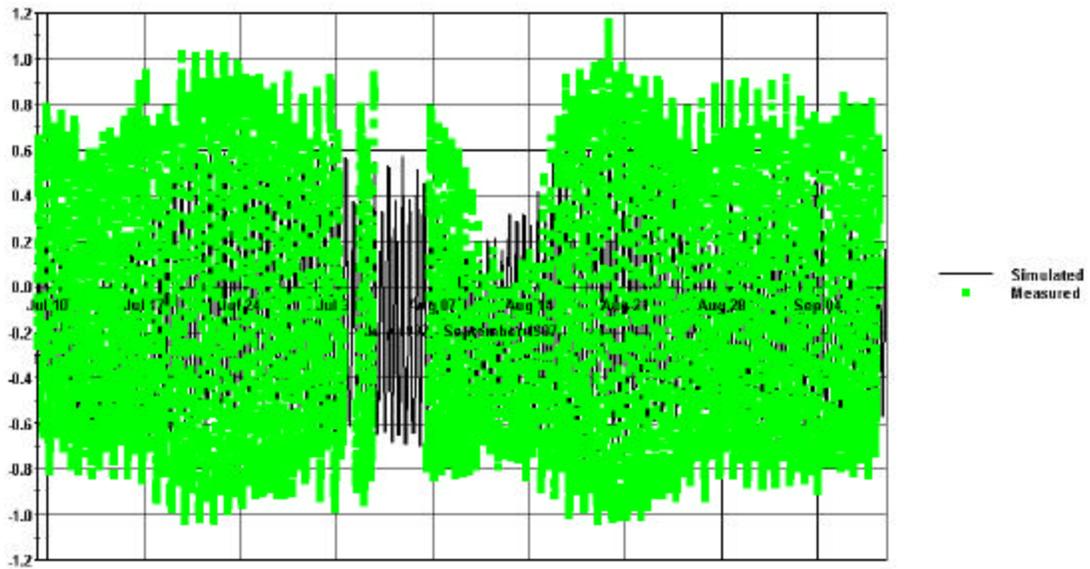


Figure F-3 Current Comparison at FR-08 Surface for July 8, 1997 through September 8, 1997

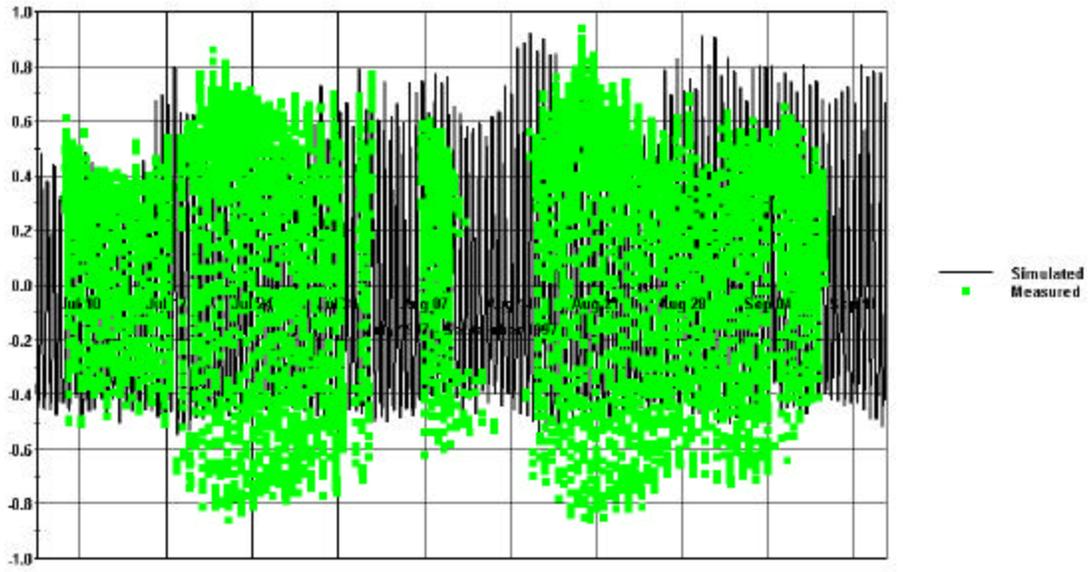


Figure F-4 Current Comparison at FR-08 Bottom for July 8, 1997 through September 8, 1997

APPENDIX G 1999 CURRENTS COMPARISONS

Table G-1 1999 Currents (m/s) Statistical Comparisons

| Stations | Date of Comparisons | Depth* | Measured | | | Simulated | | | Differences | |
|----------|-------------------------|--------|----------|-------|------|-----------|-------|------|-------------|------|
| | | | 5% | 50% | 95% | 5% | 50% | 95% | 5% | 95% |
| FR-04 | July 28 - Sept 26, 1999 | S | -1.33 | 0.05 | 1.01 | -0.91 | -0.43 | 0.83 | -32% | -17% |
| FR-04 | Sept 2 - Sept 26, 1999 | B | -0.68 | 0.25 | 0.71 | -0.67 | -0.28 | 0.67 | -2% | -5% |
| FR-06 | Aug 16 - Sept 1, 1999 | S | -0.83 | -0.16 | 0.56 | -0.86 | -0.35 | 0.89 | 4% | 58% |
| FR-06 | Aug 16 - Sept 1, 1999 | B | -0.69 | -0.12 | 0.39 | -0.52 | -0.24 | 0.63 | -25% | 62% |

* S = Surface
 B = Bottom
 M = Mid-Depth

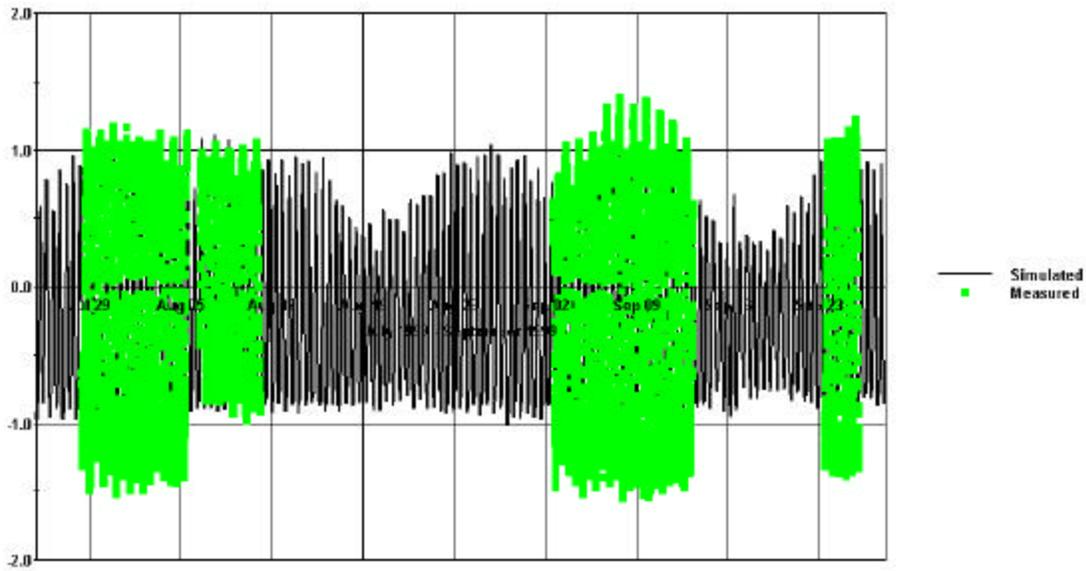


Figure G-1 Current Comparison at FR-04 Surface for July 28, 1999 through September 26, 1999

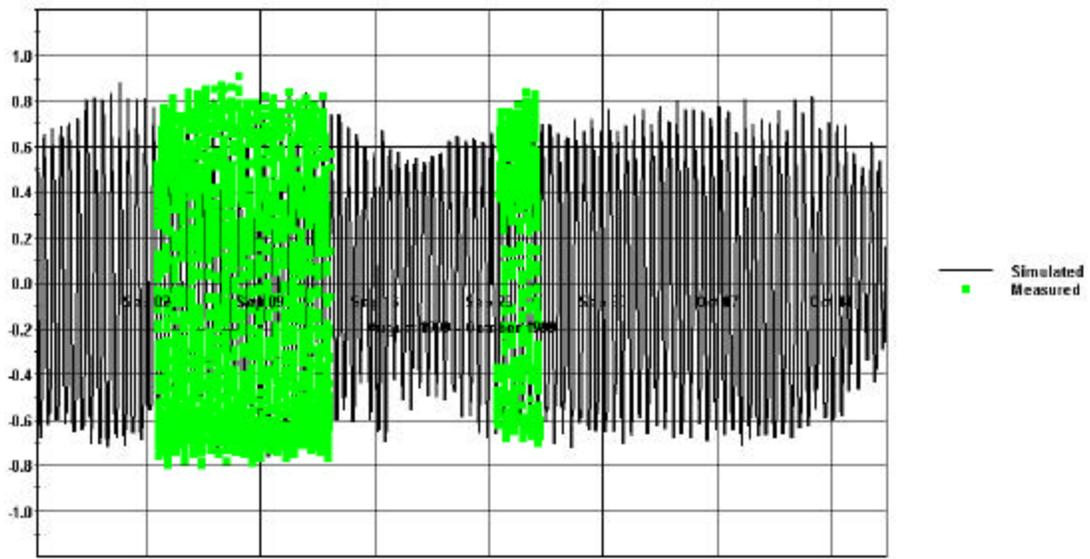


Figure G-2 Current Comparison at FR-04 Bottom for September 2, 1999 through September 26, 1999

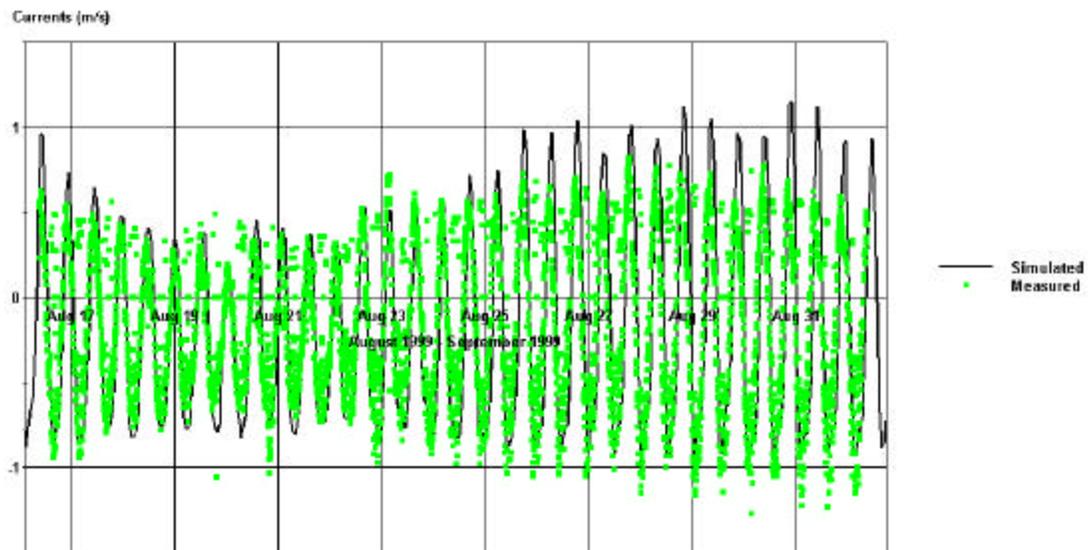


Figure G-3 Current Comparison at FR-06 Surface for August 16, 1999 through September 1, 1999

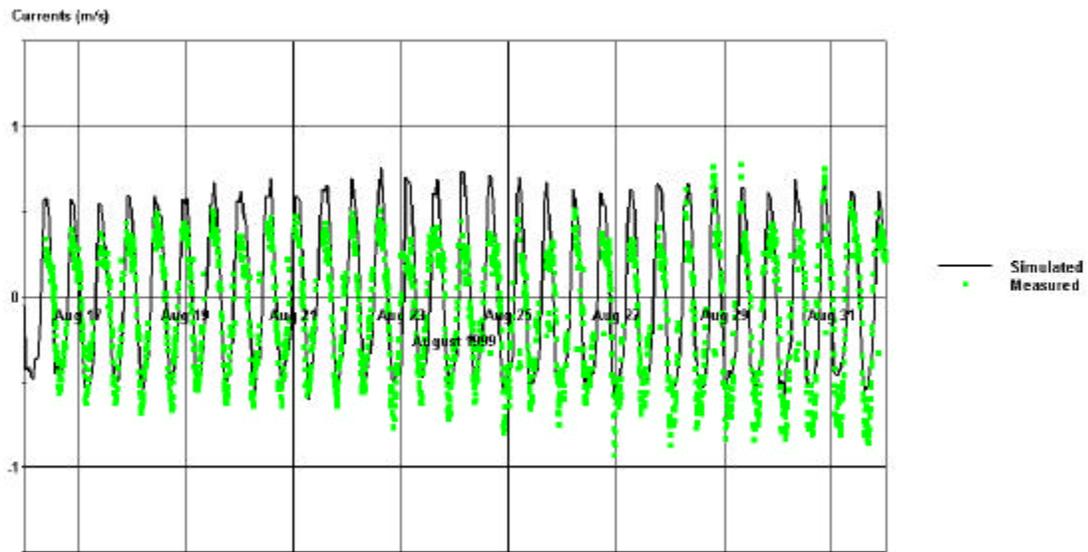


Figure G-4 Current Comparison at FR-06 Bottom for August 16, 1999 through September 1, 1999

APPENDIX H 1997 TEMPERATURE COMPARISONS

Table H-1 1997 Temperature Comparison Statistics

| July 9 - October 5, 1997 [Julian Days 190-278] | | | | |
|---|--------|----------|-----------|------------|
| Stations | Depth* | Measured | Simulated | Difference |
| | | 50% | 50% | |
| BR-05 | B | 27.5 | 28.3 | 3% |
| FR-06 | S | 27.4 | 27.6 | 1% |
| FR-06 | B | 27.8 | 27.5 | -1% |
| BR-07 | B | 26.9 | 28.3 | 5% |
| FR-08 | S | 26.9 | 27.2 | 1% |
| FR-08 | B | 27.2 | 27.4 | 1% |
| FR-09 | B | 27.0 | 27.2 | 1% |
| MR-10 | B | 26.8 | 27.2 | 1% |
| FR-11 | B | 26.6 | 26.8 | 1% |
| MR-12 | B | 26.5 | 27.0 | 2% |

* S = Surface
B = Bottom

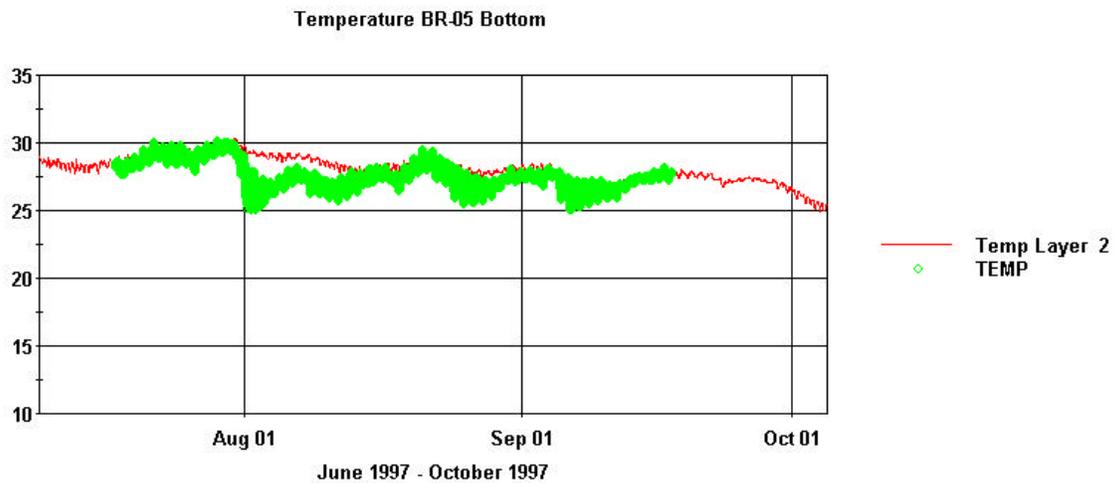


Figure H-1 Temperature (degrees C) Comparisons at BR-05 (Bottom) for July 9, 1997 through October 5, 1997

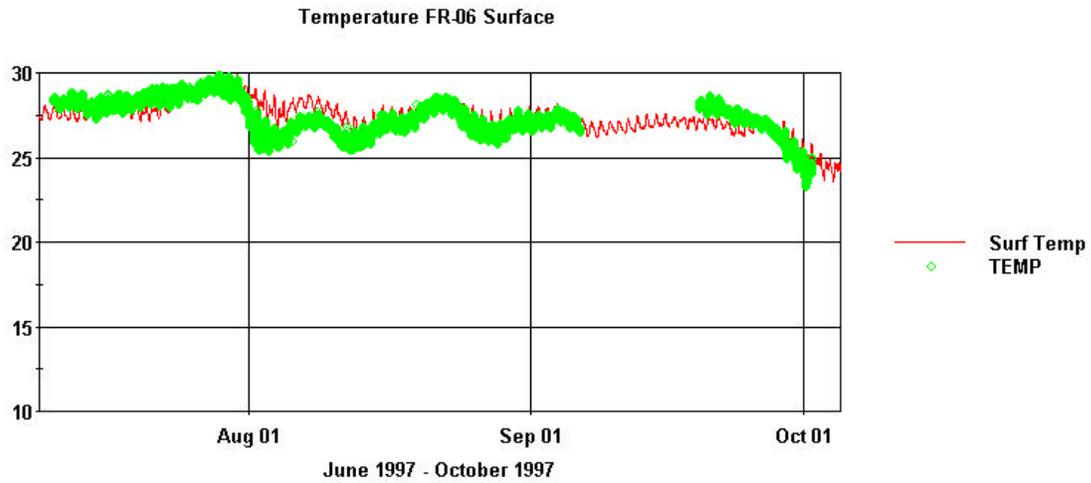


Figure H-2 Temperature (degrees C) Comparisons at FR-06 (Surface) for July 9, 1997 through October 5, 1997

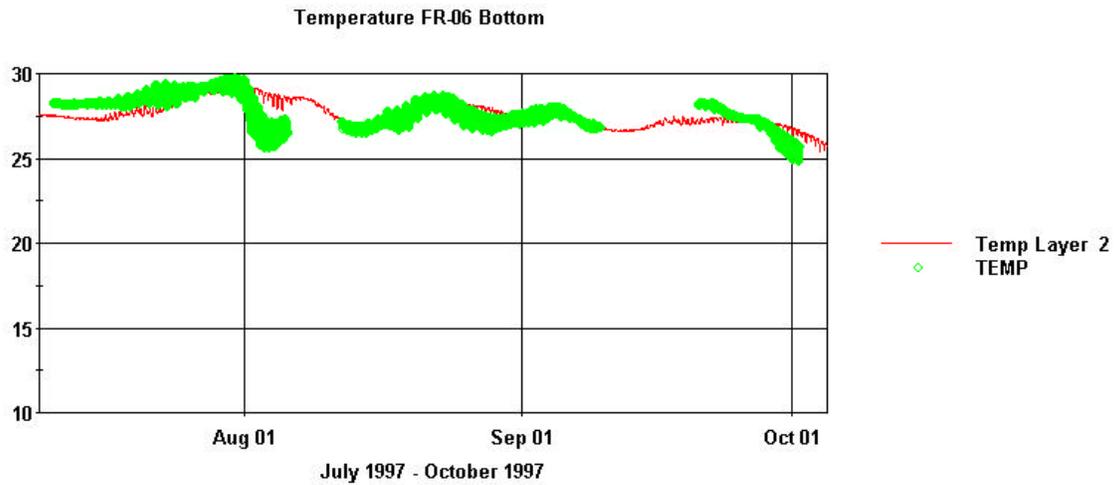


Figure H-3 Temperature (degrees C) Comparisons at FR-06 (Bottom) for July 9, 1997 through October 5, 1997

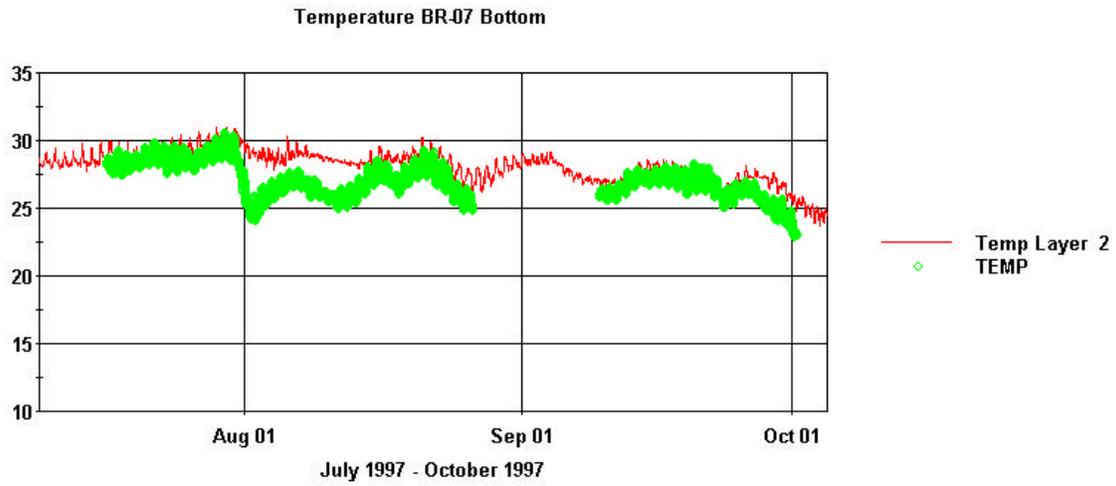


Figure H-4 Temperature (degrees C) Comparisons at BR-07 (Bottom) for July 9, 1997 through October 5, 1997

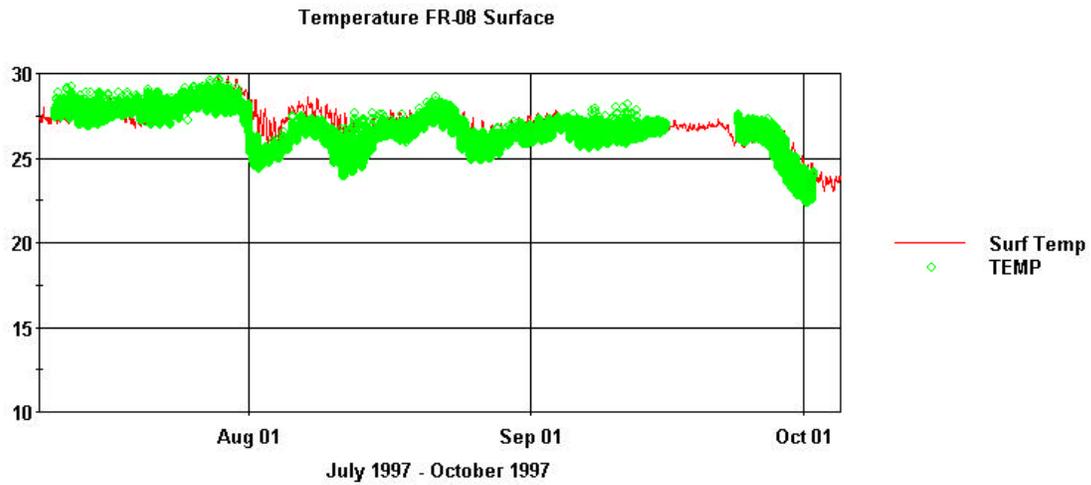


Figure H-5 Temperature (degrees C) Comparisons at FR-08 (Surface) for July 9, 1997 through October 5, 1997

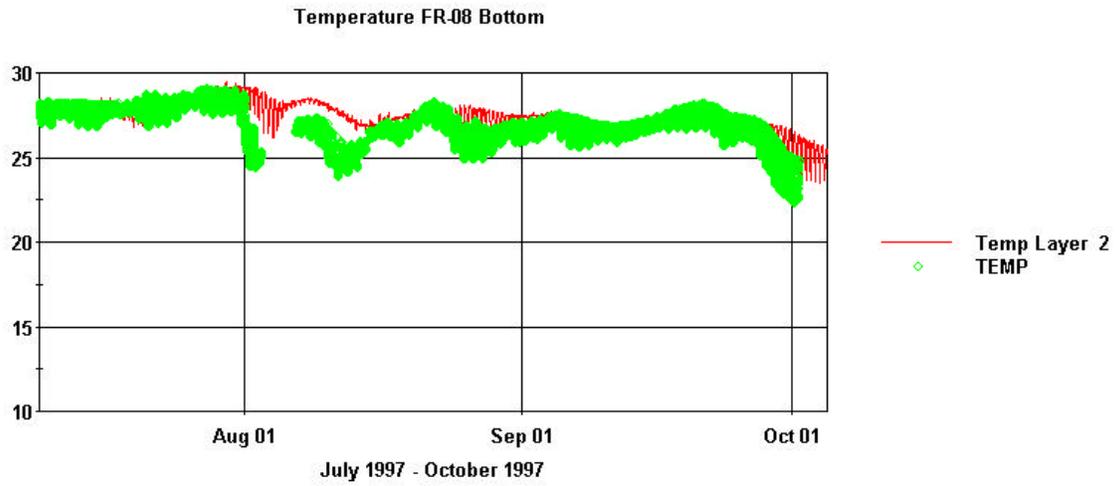


Figure H-6 Temperature (degrees C) Comparisons at FR-08 (Bottom) for July 9, 1997 through October 5, 1997

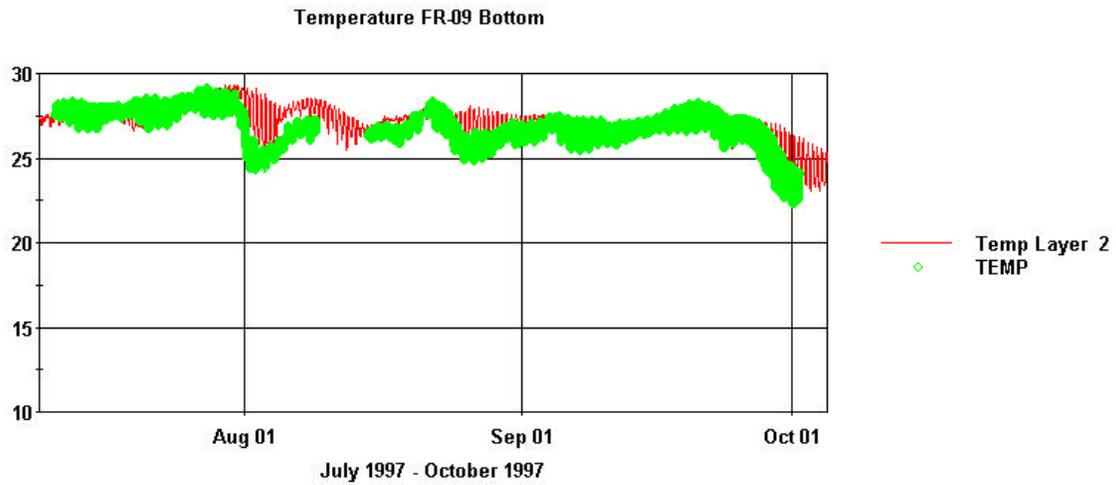


Figure H-7 Temperature (degrees C) Comparisons at FR-09 (Bottom) for July 9, 1997 through October 5, 1997

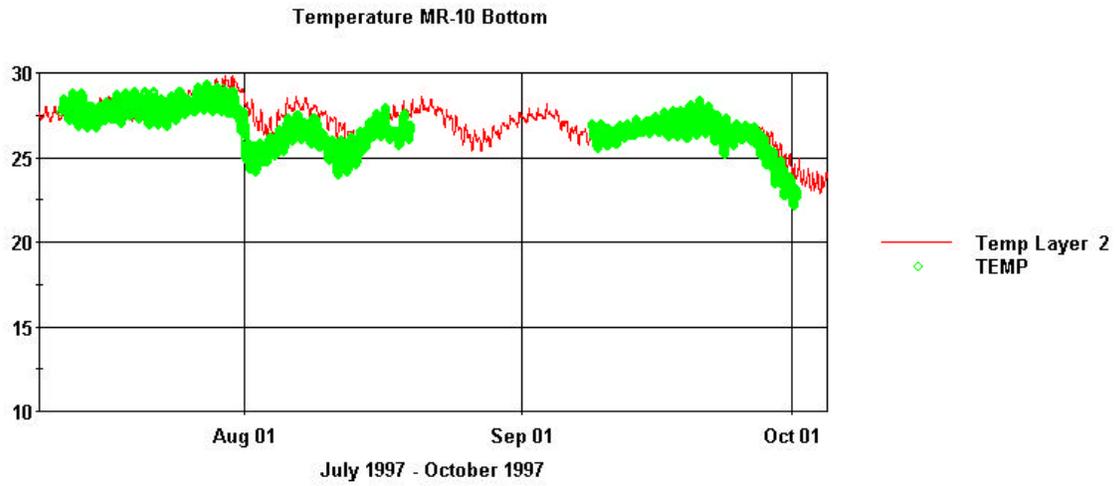


Figure H-8 Temperature (degrees C) Comparisons at MR-10 (Bottom) for July 9, 1997 through October 5, 1997

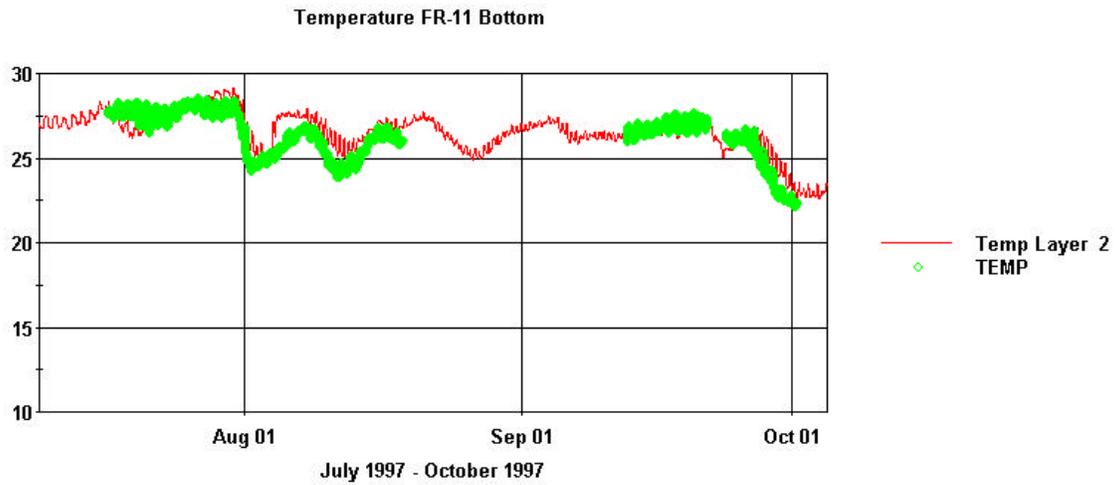


Figure H-9 Temperature (degrees C) Comparisons at FR-11 (Bottom) for July 9, 1997 through October 5, 1997

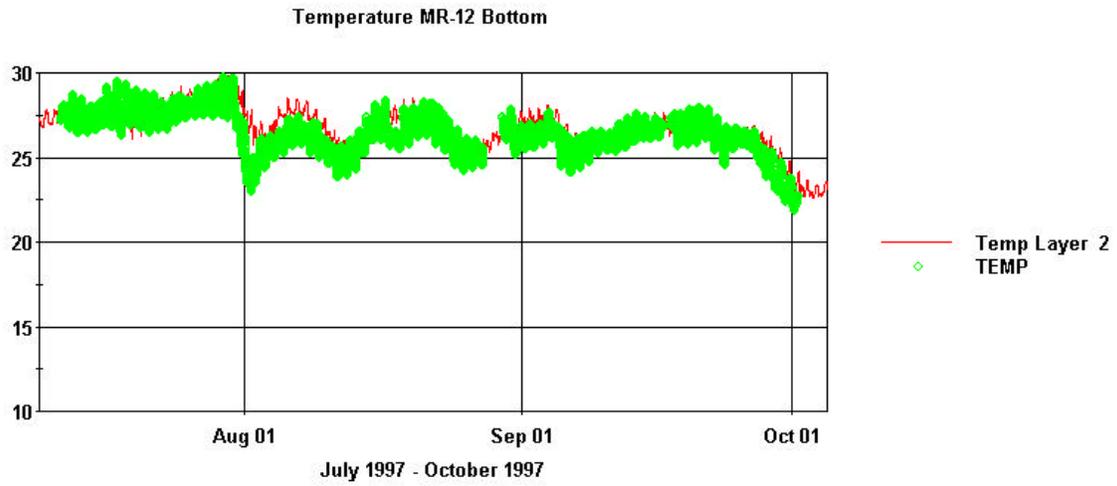


Figure H-10 Temperature (degrees C) Comparisons at MR-12 (Bottom) for July 9, 1997 through October 5, 1997

APPENDIX I 1999 TEMPERATURE COMPARISONS

Table I-1 1999 Temperature Comparison Statistics

| July 31 - October 13, 1999 [Julian Days 212-286] | | | | |
|---|--------|----------|-----------|------------|
| Stations | Depth* | Measured | Simulated | Difference |
| | | 50% | 50% | |
| BR-05 | B | 27.7 | 28.4 | 3% |
| FR-06 | S | 27.5 | 27.6 | 0% |
| FR-06 | B | 27.6 | 28.1 | 2% |
| BR-07 | S | 27.2 | 27.7 | 2% |
| FR-08 | S | 27.1 | 27.2 | 0% |
| FR-08 | B | 27.2 | 28.6 | 5% |
| FR-09 | S | 27.0 | 27.1 | 0% |
| FR-09 | B | 26.9 | 27.6 | 3% |
| MR-10 | S | 26.9 | 27.0 | 0% |
| FR-11R | B | 26.1 | 27.1 | 4% |
| MR-12R | S | 26.6 | 26.9 | 1% |
| LBR-15 | S | 27.8 | 28.0 | 1% |

* S = Surface
B = Bottom

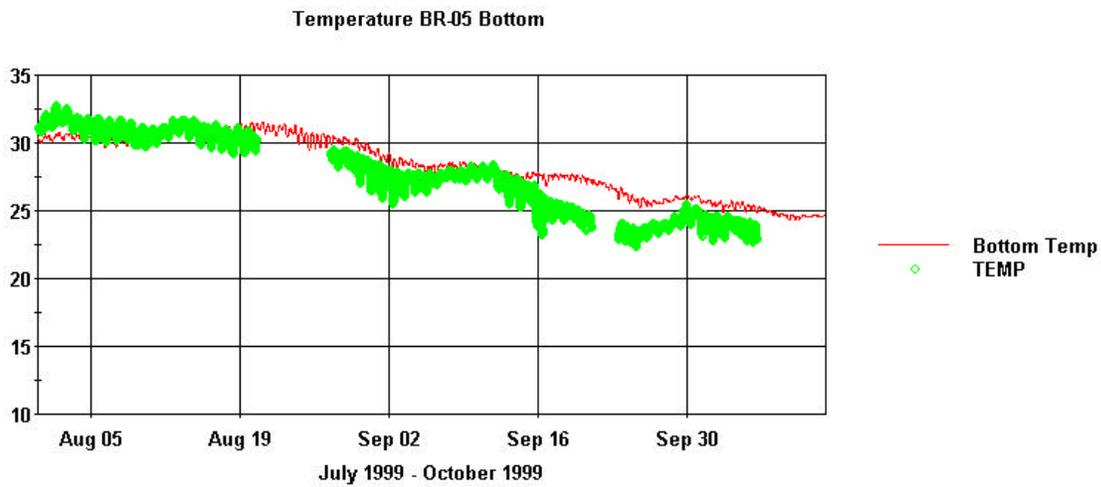


Figure I-1 Temperature (degrees C) Comparisons at BR-05 (Bottom) for July 31, 1999 through October 13, 1999

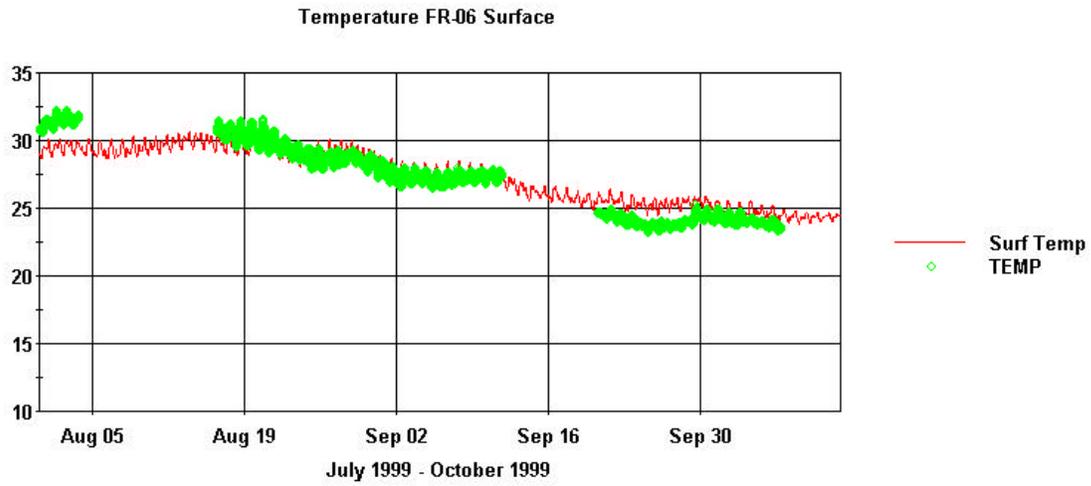


Figure I-2 Temperature (degrees C) Comparisons at FR-06 (Surface) for July 31, 1999 through October 13, 1999

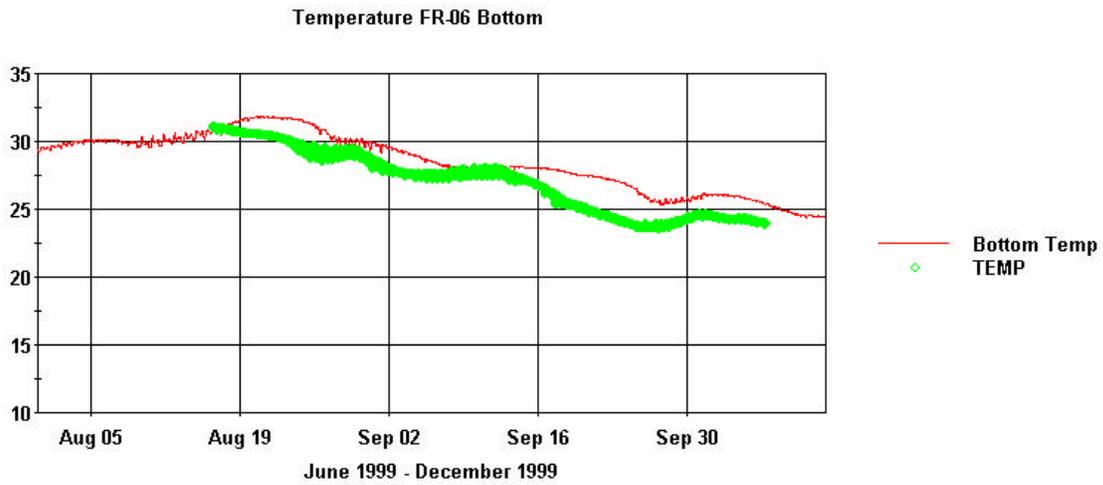


Figure I-3 Temperature (degrees C) Comparisons at FR-06 (Bottom) for July 31, 1999 through October 13, 1999

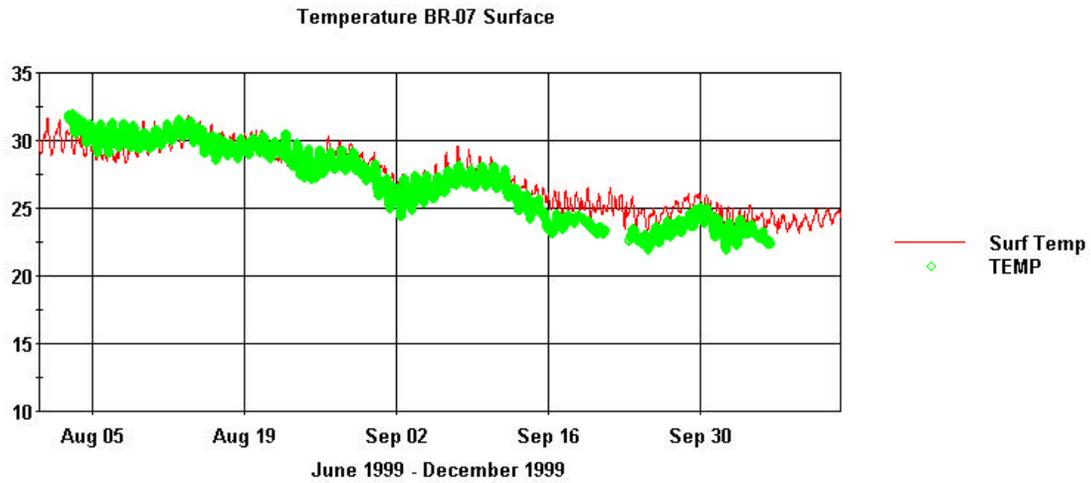


Figure I-4 Temperature (degrees C) Comparisons at BR-07 (Surface) for July 31, 1999 through October 13, 1999

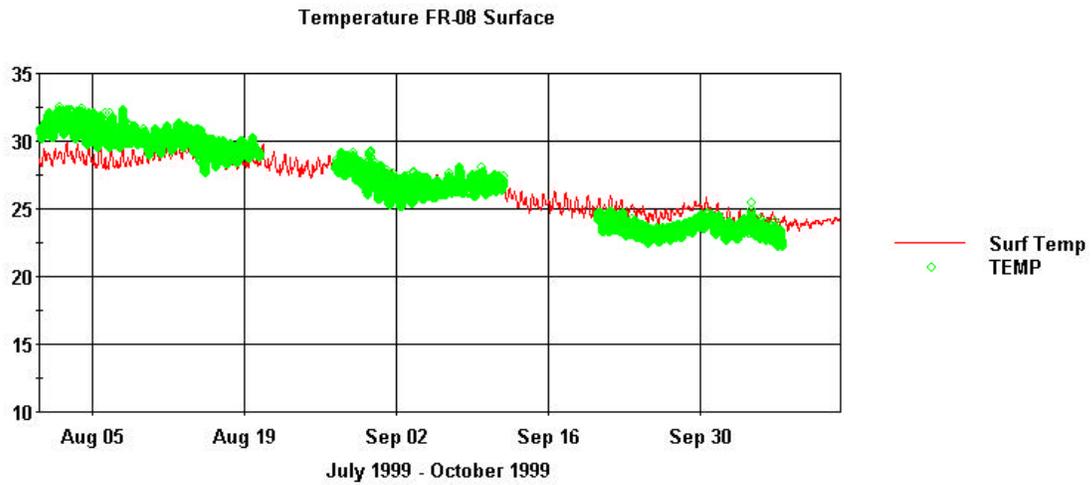


Figure I-5 Temperature (degrees C) Comparisons at FR-08 (Surface) for July 31, 1999 through October 13, 1999

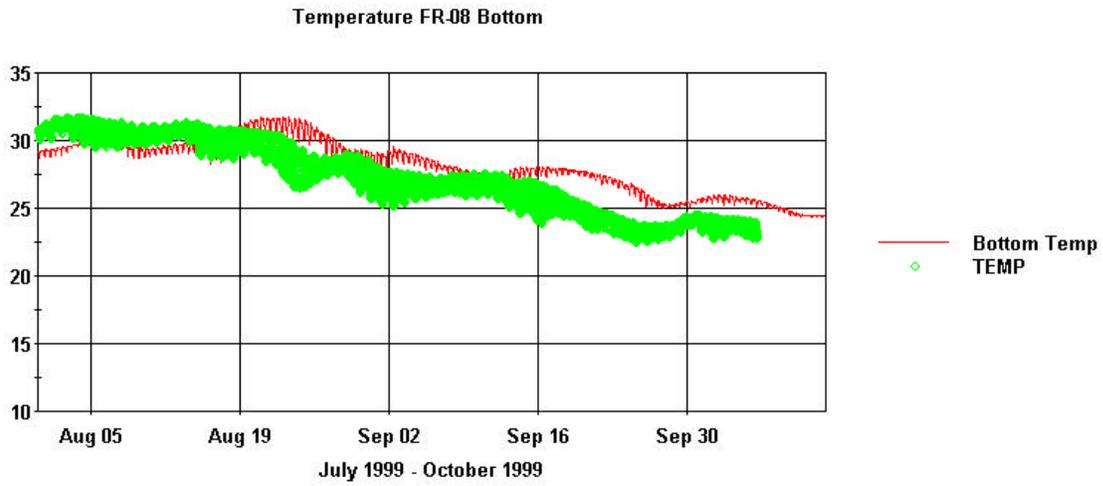


Figure I-6 Temperature (degrees C) Comparisons at FR-08 (Bottom) for July 31, 1999 through October 13, 1999

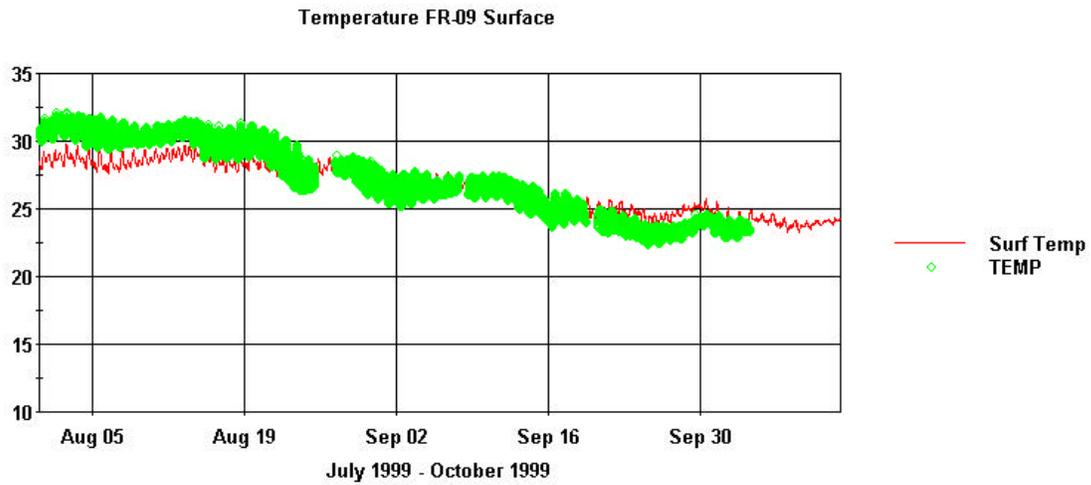


Figure I-7 Temperature (degrees C) Comparisons at FR-09 (Surface) for July 31, 1999 through October 13, 1999

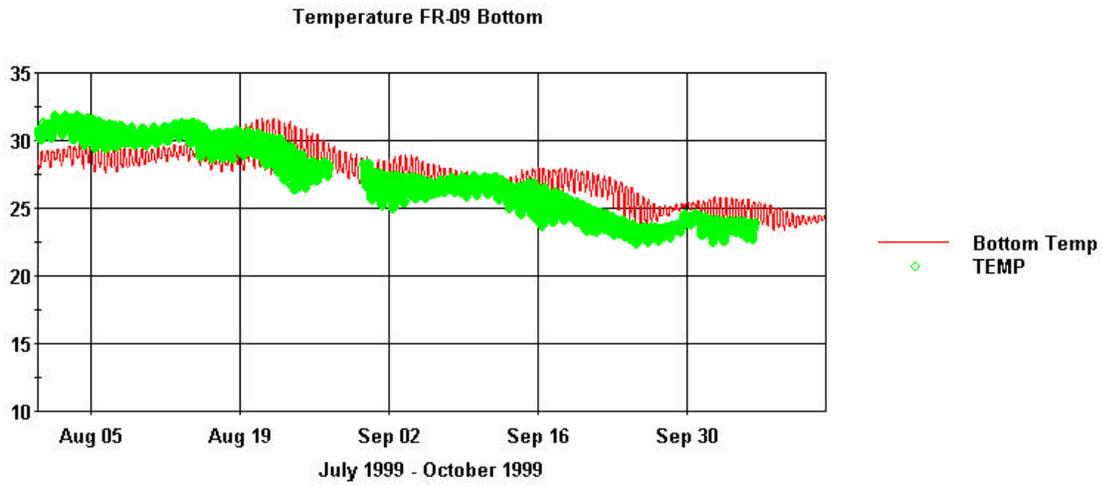


Figure I-8 Temperature (degrees C) Comparisons at FR-09 (Bottom) for July 31, 1999 through October 13, 1999

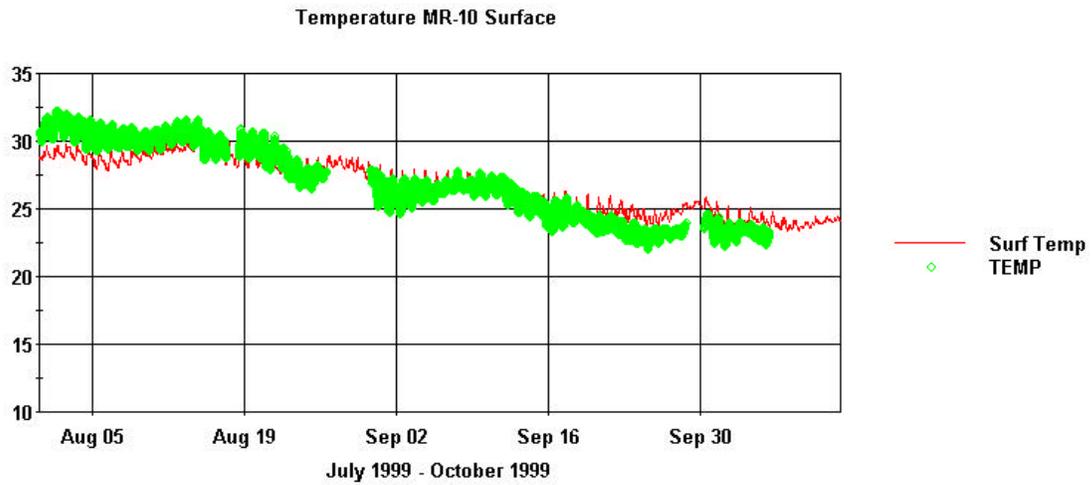


Figure I-9 Temperature (degrees C) Comparisons at MR-10 (Surface) for July 31, 1999 through October 13, 1999

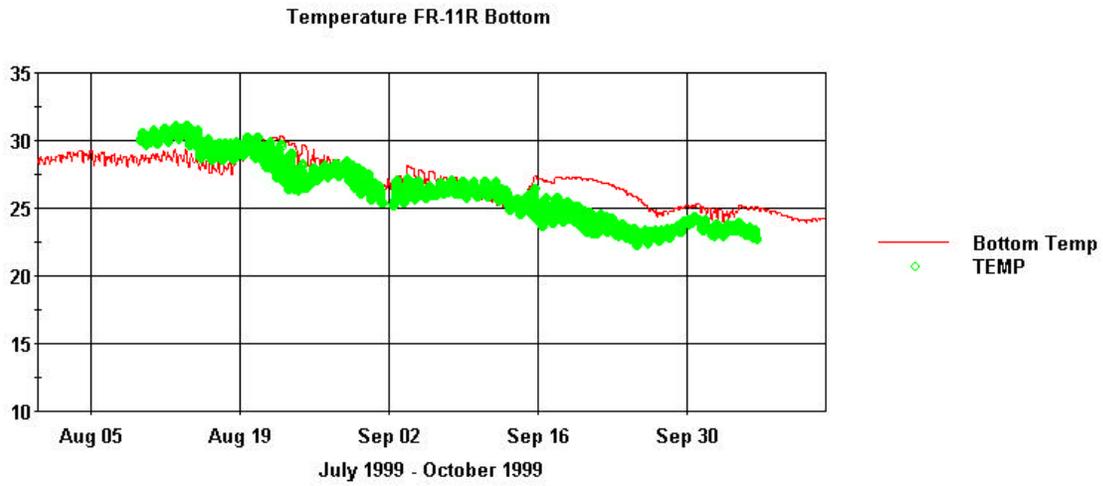


Figure I-10 Temperature (degrees C) Comparisons at FR-11R (Bottom) for July 31, 1999 through October 13, 1999

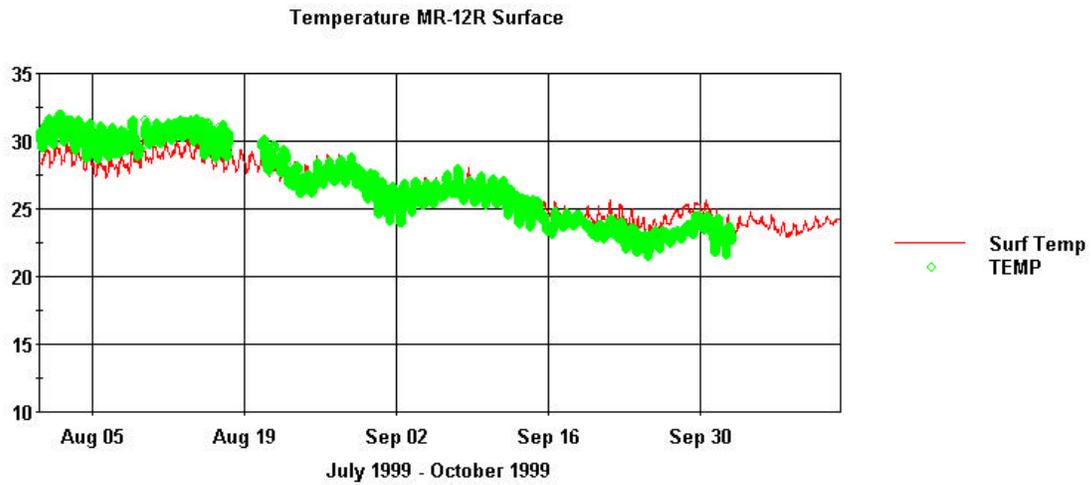


Figure I-11 Temperature (degrees C) Comparisons at MR-12R (Surface) for July 31, 1999 through October 13, 1999

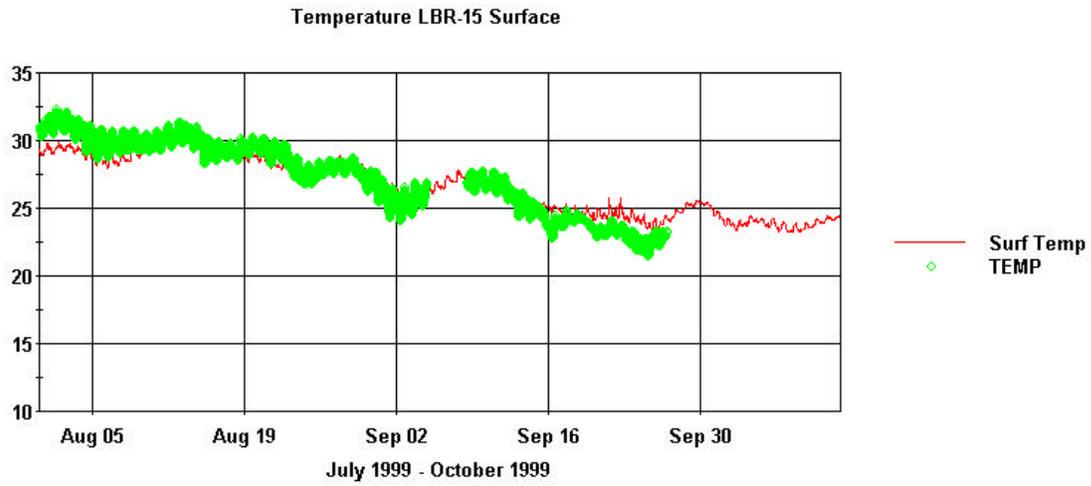


Figure I-12 Temperature (degrees C) Comparisons at LBR-15 (Surface) for July 31, 1999 through October 13, 1999

APPENDIX J 1997 SALINITY COMPARISONS

Table J-1 Summary Statistics for Salinity (ppt) for July 9, 1997 through October 5, 1997

| July 9 - October 5, 1997 [Julian Days 190-278] | | | | | | | | | | |
|---|--------|----------|------|------|-----------|------|------|------------|------|------|
| Stations | Depth* | Measured | | | Simulated | | | Difference | | |
| | | 10% | 50% | 90% | 10% | 50% | 90% | 10% | 50% | 90% |
| BR-05 | B | 3.9 | 6.7 | 10.8 | 1.0 | 5.4 | 10.3 | -2.9 | -1.3 | -0.5 |
| FR-06 | S | 2.2 | 5.3 | 8.6 | 1.4 | 3.9 | 7.0 | -0.8 | -1.4 | -1.6 |
| FR-06 | B | 5.6 | 14.3 | 19.9 | 2.8 | 10.5 | 17.4 | -2.8 | -3.8 | -2.5 |
| BR-07 | S | 0.6 | 2.2 | 4.3 | 0.1 | 0.4 | 3.3 | -0.5 | -1.8 | -1.0 |
| FR-08 | S | 0.5 | 3.0 | 6.2 | 0.1 | 0.4 | 5.3 | -0.4 | -2.6 | -0.9 |
| FR-08 | B | 0.3 | 4.5 | 11.9 | 0.1 | 1.2 | 10.0 | -0.2 | -3.3 | -1.9 |
| FR-09 | B | 0.1 | 2.5 | 9.7 | 0.1 | 0.3 | 5.3 | 0.0 | -2.2 | -4.4 |
| MR-10 | B | 0.1 | 1.0 | 5.0 | 0.1 | 0.5 | 3.0 | 0.0 | -0.5 | -2.0 |
| FR-11 | B | 0.0 | 0.0 | 1.9 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | -1.7 |
| MR-12 | B | 0.0 | 0.2 | 0.9 | 0.0 | 0.1 | 0.9 | 0.0 | -0.1 | 0.0 |
| USGS02198840 (I-95) | M | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| USGS021989784 (Lucknow Canal) | M | 0.0 | 0.1 | 0.2 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.0 |
| USGS02198920 (Houlihan Bridge) | M | 0.1 | 2.3 | 7.8 | 0.0 | 0.3 | 5.4 | -0.1 | -2.0 | -2.4 |
| USGS02198791 (US F&W Docks) | M | 0.0 | 0.1 | 0.8 | 0.0 | 0.1 | 0.3 | 0.0 | 0.0 | -0.5 |

* S = Surface
 B = Bottom
 M = Mid-Depth

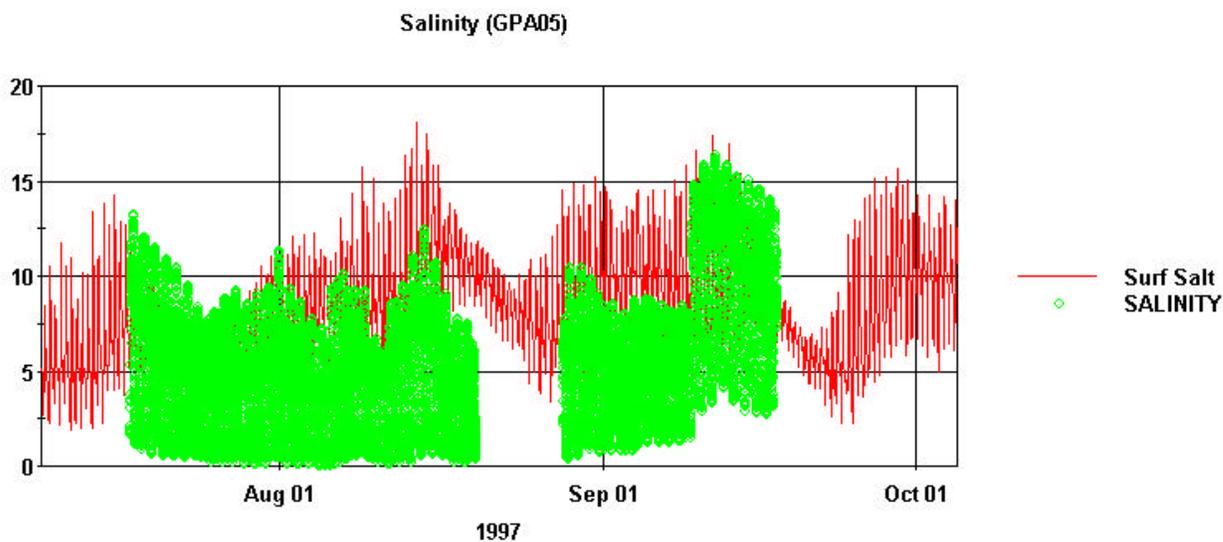


Figure J-1 Salinity (ppt) Calibration at BR-05 (Bottom) for July 9, 1997 through October 5, 1997

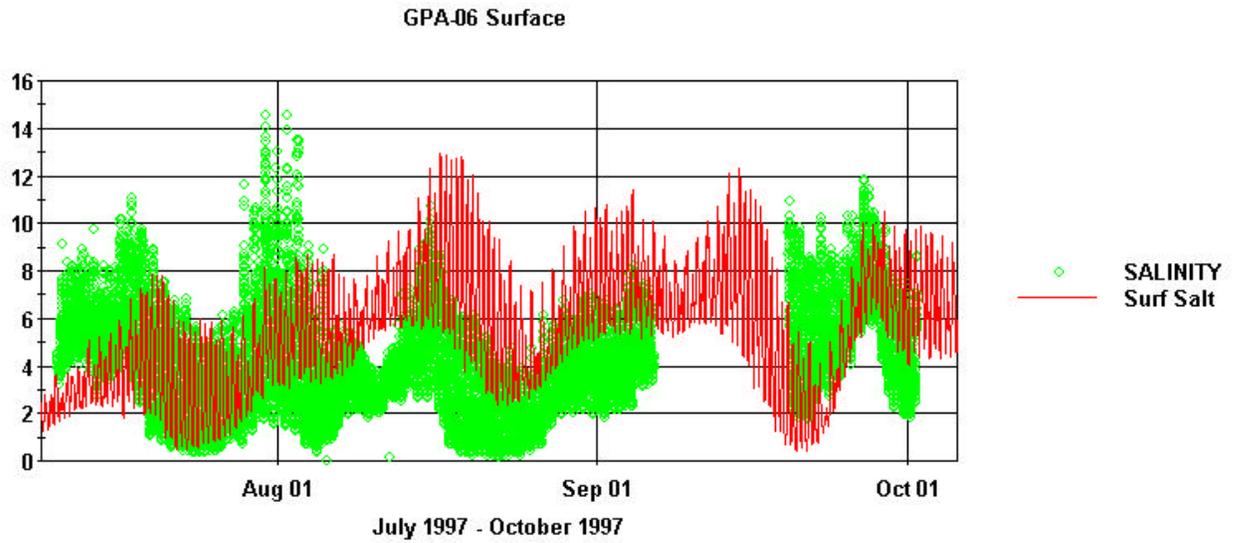


Figure J-2 Salinity (ppt) Calibration at FR-06 (Surface) for July 9, 1997 through October 5, 1997

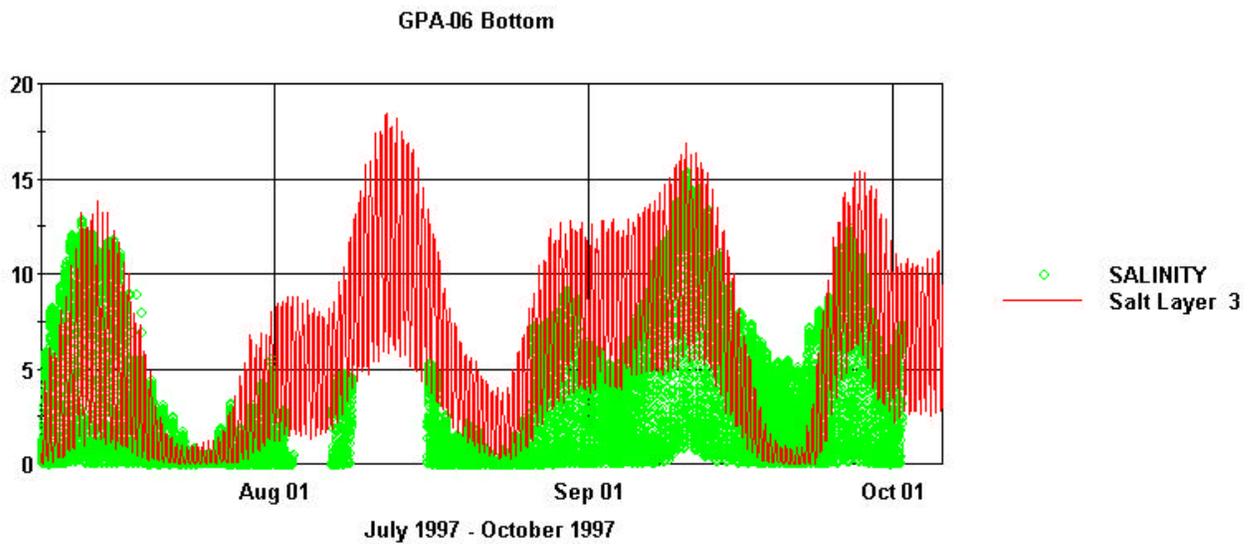


Figure J-3 Salinity (ppt) Calibration at FR-06 (Bottom) for July 9, 1997 through October 5, 1997

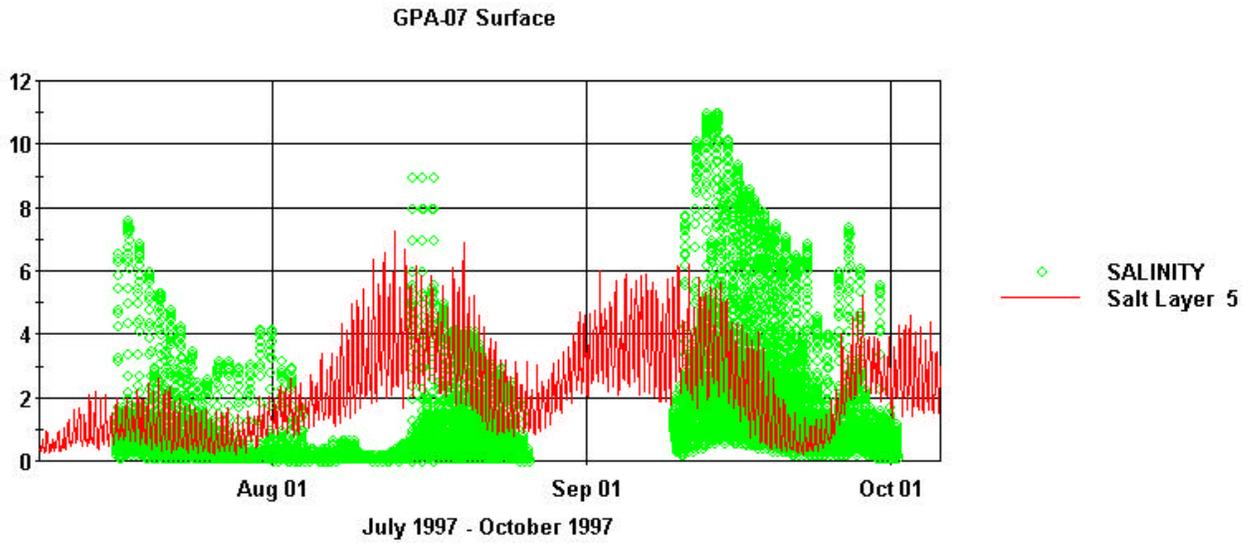


Figure J-4 Salinity (ppt) Calibration at BR-07 (Surface) for July 9, 1997 through October 5, 1997

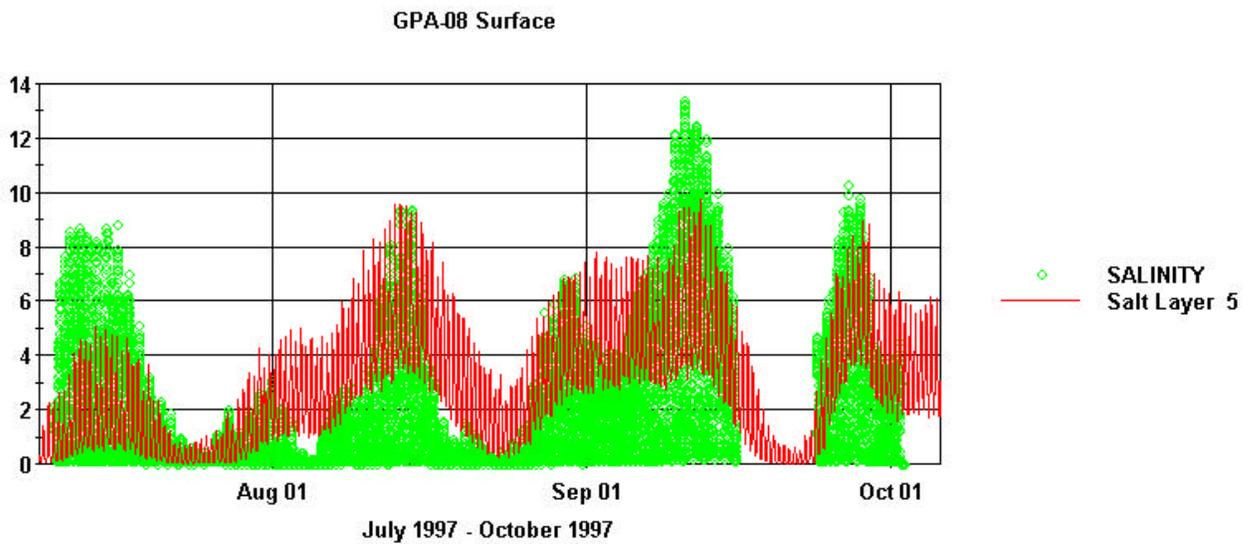


Figure J-5 Salinity (ppt) Calibration at FR-08 (Surface) for July 9, 1997 through October 5, 1997

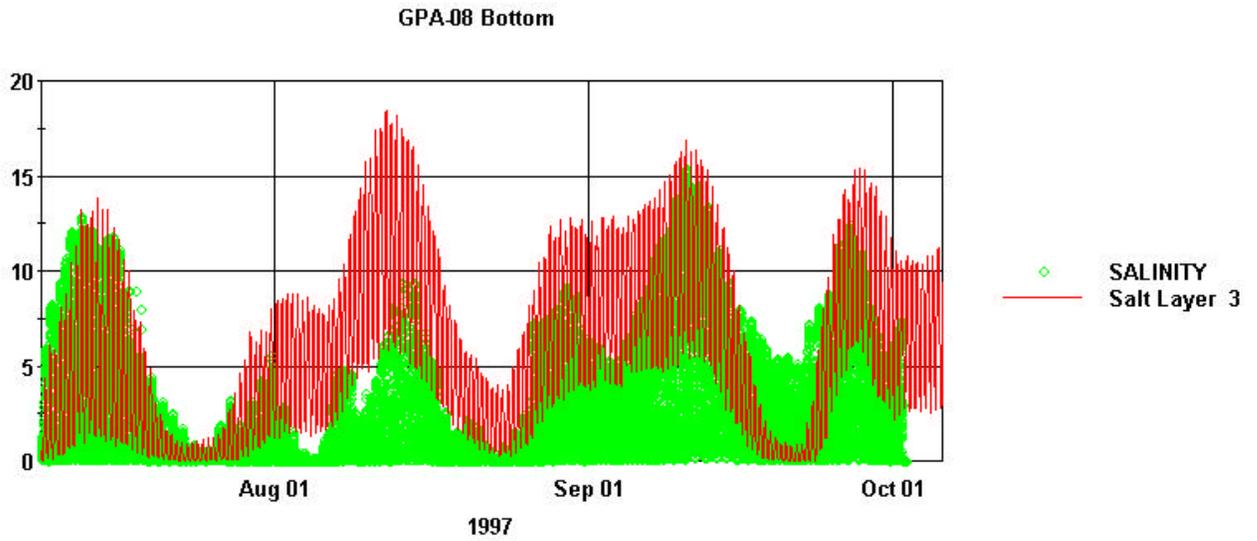


Figure J-6 Salinity (ppt) Calibration at FR-08 (Bottom) for July 9, 1997 through October 5, 1997

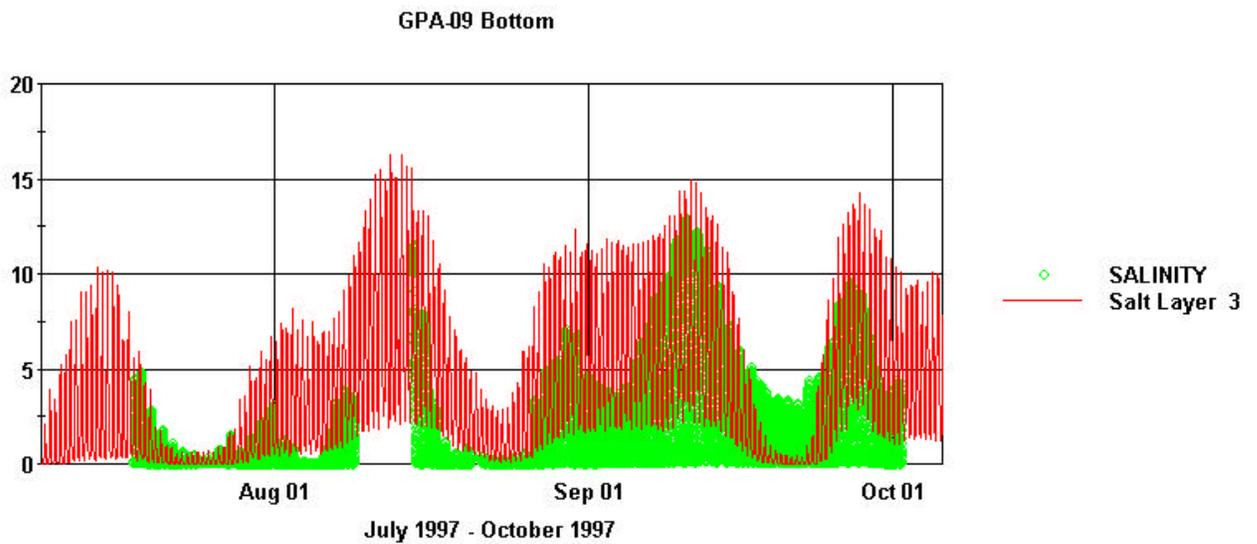


Figure J-7 Salinity (ppt) Calibration at FR-09 (Bottom) for July 9, 1997 through October 5, 1997

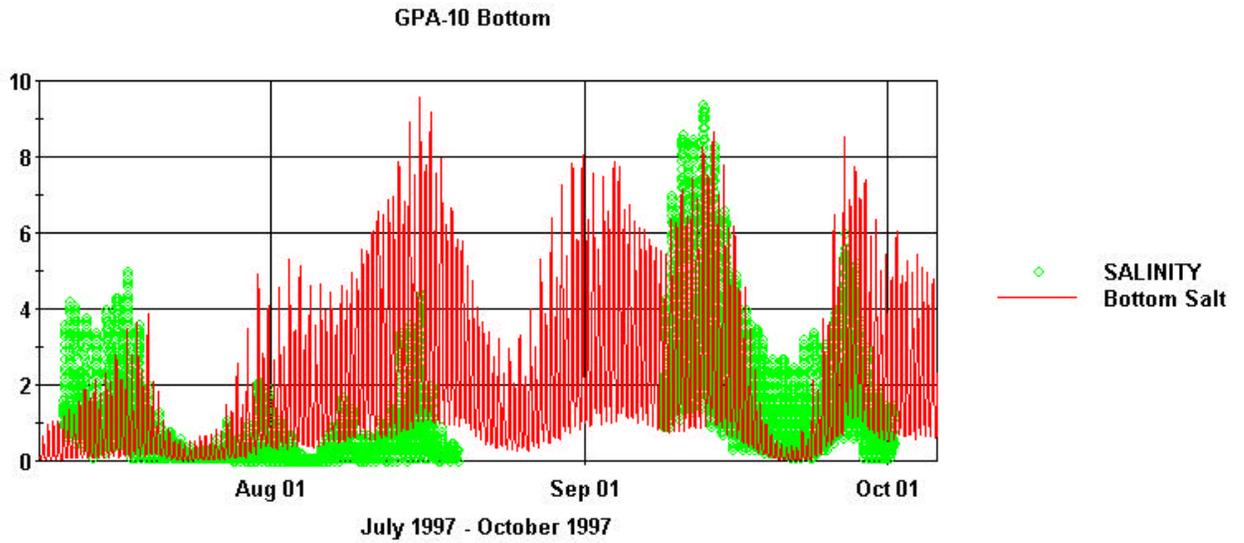


Figure J-8 Salinity (ppt) Calibration at MR-10 (Bottom) for July 9, 1997 through October 5, 1997

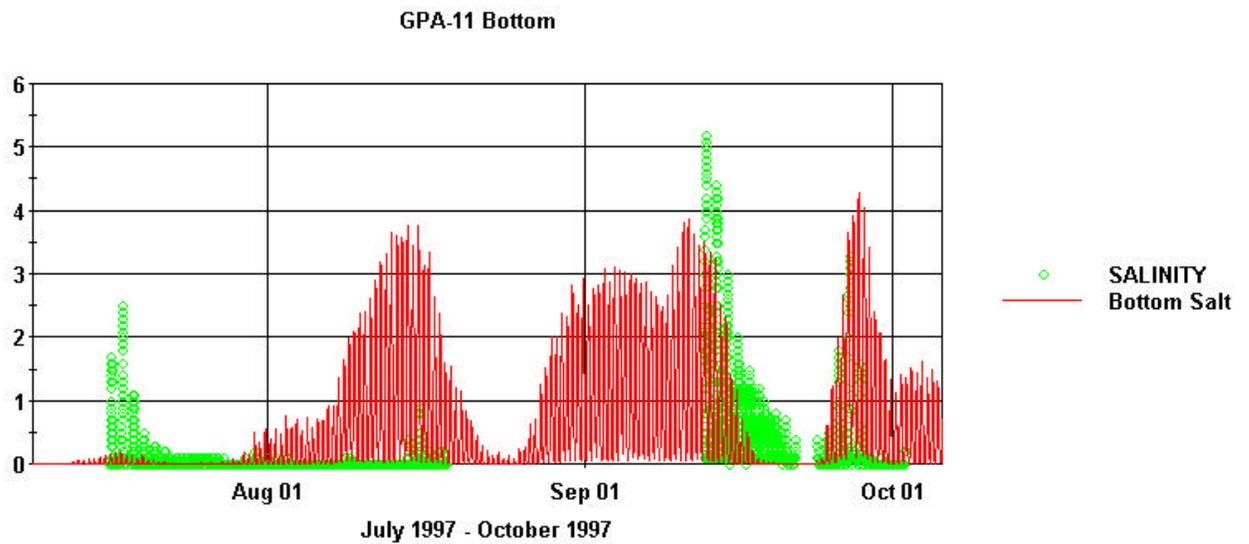


Figure J-9 Salinity (ppt) Calibration at FR-11 (Bottom) for July 9, 1997 through October 5, 1997

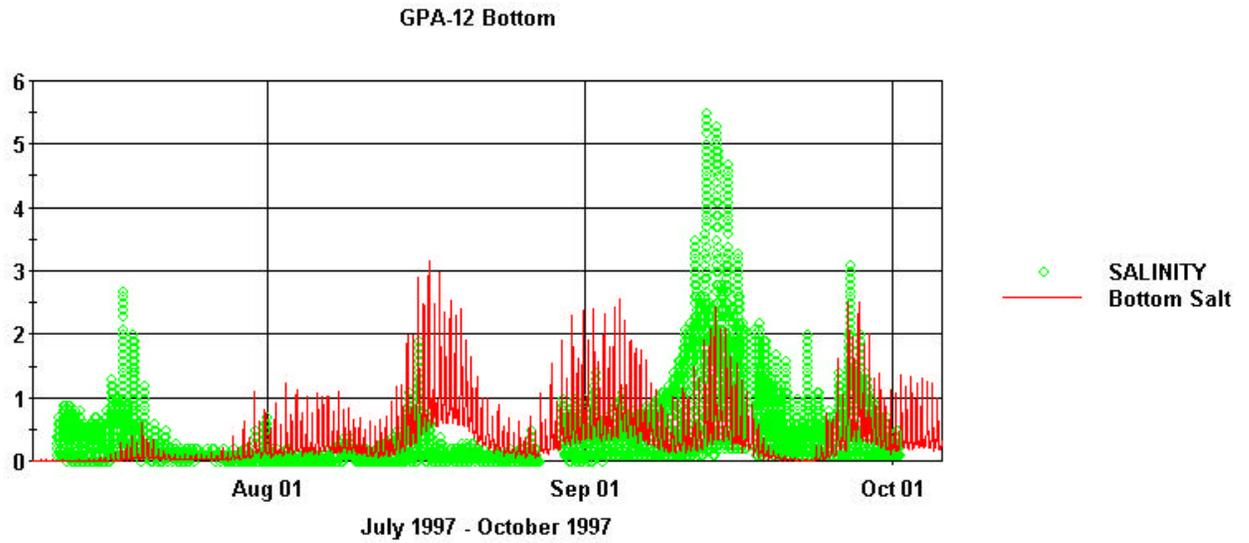


Figure J-10 Salinity (ppt) Calibration at MR-12 (Bottom) for July 9, 1997 through October 5, 1997

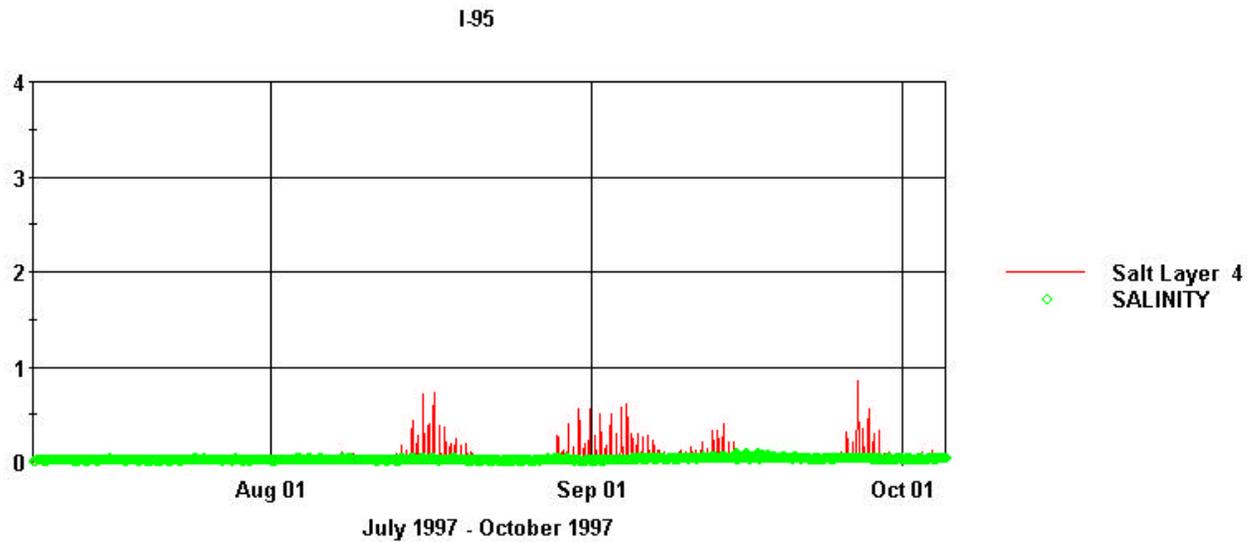


Figure J-11 Salinity (ppt) Calibration at I-95 Bridge (Mid-depth) for July 9, 1997 through October 5, 1997

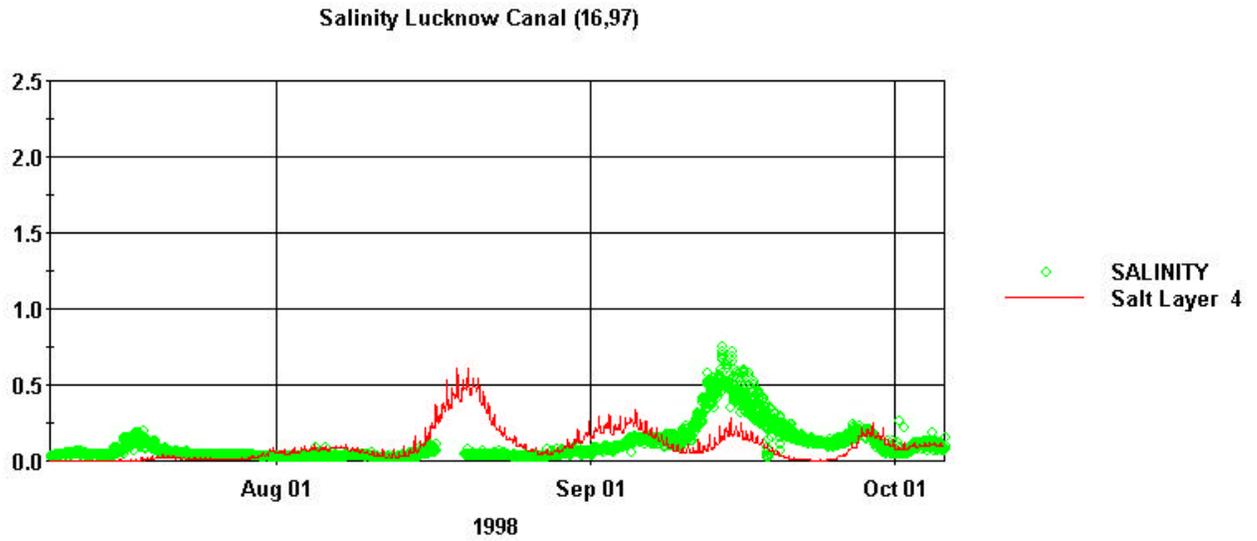


Figure J-12 Salinity (ppt) Calibration at Lucknow Canal (Mid-depth) for July 9, 1997 through October 5, 1997

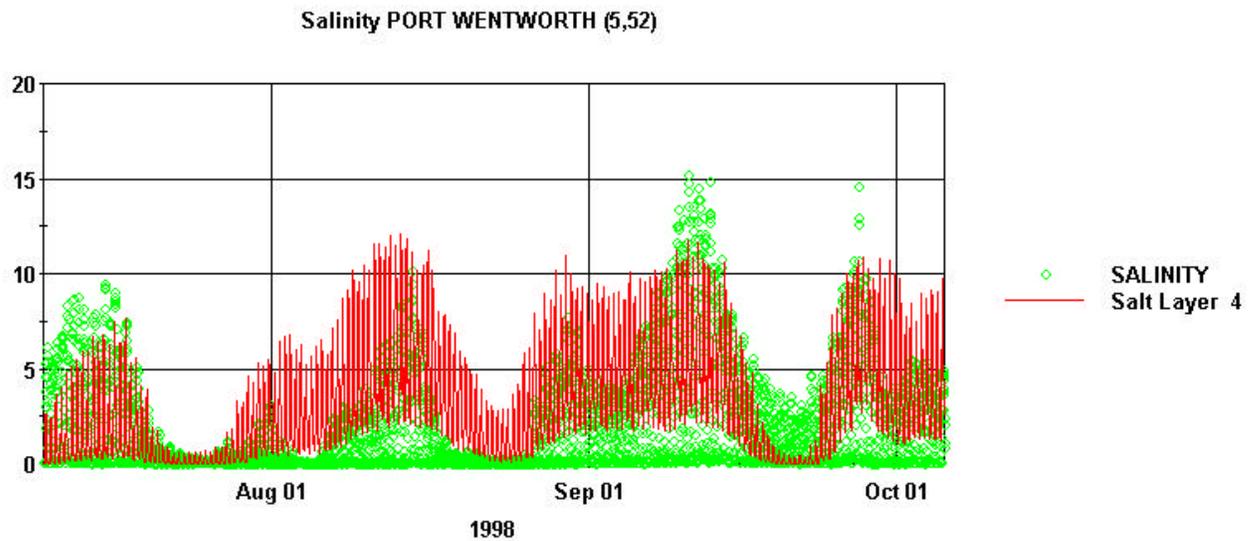


Figure J-13 Salinity (ppt) Calibration at Houlihan Bridge (Mid-depth) for July 9, 1997 through October 5, 1997

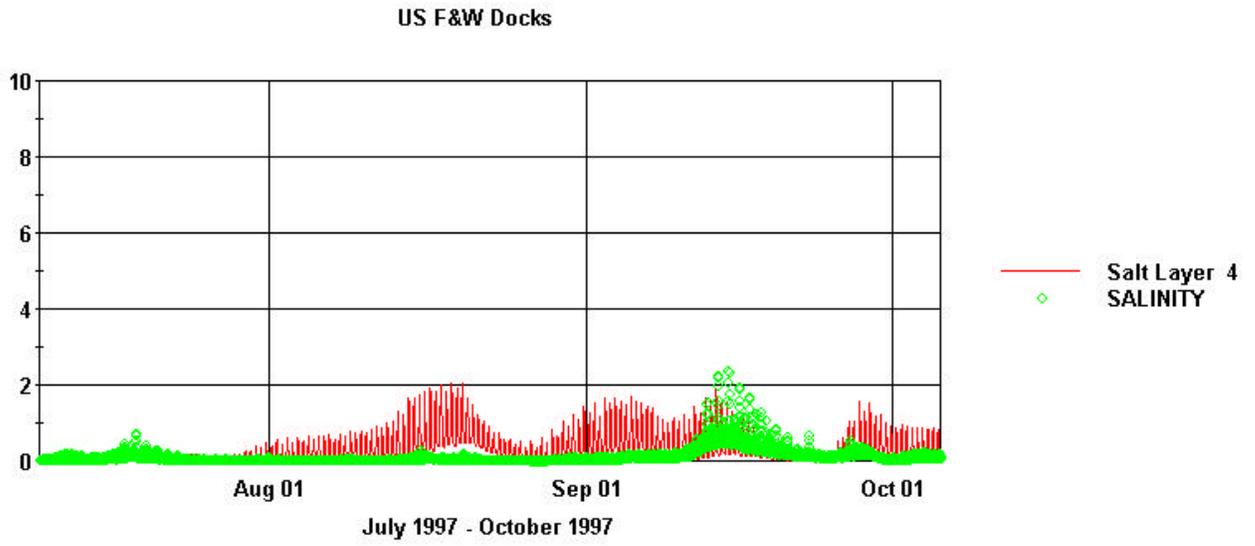


Figure J-14 Salinity (ppt) Calibration at US F&W Docks (Mid-depth) for July 9, 1997 through October 5, 1997

Table J-2 Summary Statistics for Salinity (ppt) for July 9, 1997 through July 23, 1997

| July 9 - 23, 1997 [Julian Days 190-204] | | | | | | | | | | |
|--|--------|----------|------|------|-----------|------|------|------------|------|------|
| Stations | Depth* | Measured | | | Simulated | | | Difference | | |
| | | 10% | 50% | 90% | 10% | 50% | 90% | 10% | 50% | 90% |
| BR-05 | B | 3.4 | 5.9 | 8.3 | 1.8 | 5.8 | 10.1 | -1.6 | -0.1 | 1.8 |
| FR-06 | S | 1.8 | 3.1 | 5.7 | 1.6 | 4.9 | 7.2 | -0.2 | 1.8 | 1.5 |
| FR-06 | B | 3.5 | 13.1 | 19.9 | 2.4 | 12.1 | 18.3 | -1.1 | -1.0 | -1.6 |
| BR-07 | S | 0.5 | 1.0 | 1.8 | 0.1 | 0.5 | 4.1 | -0.4 | -0.5 | 2.3 |
| FR-08 | S | 0.1 | 0.9 | 3.3 | 0.1 | 0.5 | 5.3 | 0.0 | -0.4 | 2.0 |
| FR-08 | B | 0.2 | 1.9 | 9.5 | 0.1 | 1.6 | 11.0 | -0.1 | -0.3 | 1.5 |
| FR-09 | B | 0.0 | 0.3 | 2.8 | 0.0 | 0.2 | 1.8 | 0.0 | -0.1 | -1.0 |
| MR-10 | B | 0.1 | 0.3 | 1.8 | 0.1 | 0.7 | 2.6 | 0.0 | 0.4 | 0.8 |
| FR-11 | B | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.2 |
| MR-12 | B | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.7 | 0.0 | 0.1 | 0.6 |
| USGS02198840 (I-95) | M | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| USGS021989784 (Lucknow Canal) | M | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 |
| USGS02198920 (Houlihan Bridge) | M | 0.0 | 0.5 | 4.2 | 0.0 | 0.4 | 6.1 | 0.0 | -0.1 | 1.9 |
| USGS02198791 (US F&W Docks) | M | 0.0 | 0.0 | 0.2 | 0.0 | 0.1 | 0.2 | 0.0 | 0.1 | 0.0 |

* S = Surface

B = Bottom

M = Mid-Depth

Table J-3 Summary Statistics for Salinity (ppt) for July 24, 1997 through August 7, 1997

| July 24 - August 7, 1997 [Julian Days 205-219] | | | | | | | | | | |
|---|--------|----------|------|------|-----------|-----|------|------------|------|------|
| Stations | Depth* | Measured | | | Simulated | | | Difference | | |
| | | 10% | 50% | 90% | 10% | 50% | 90% | 10% | 50% | 90% |
| BR-05 | B | 3.3 | 5.6 | 8.5 | 0.5 | 4.3 | 7.7 | -2.8 | -1.3 | -0.8 |
| FR-06 | S | 1.7 | 4.4 | 7.3 | 1.0 | 3.0 | 6.6 | -0.7 | -1.4 | -0.7 |
| FR-06 | B | 3.6 | 10.4 | 14.7 | 1.9 | 7.4 | 12.4 | -1.7 | -3.0 | -2.3 |
| BR-07 | S | 0.5 | 1.3 | 2.4 | 0.1 | 0.1 | 0.7 | -0.4 | -1.2 | -1.7 |
| FR-08 | S | 0.1 | 1.4 | 3.8 | 0.0 | 0.1 | 1.1 | -0.1 | -1.3 | -2.7 |
| FR-08 | B | 0.1 | 1.7 | 7.0 | 0.0 | 0.1 | 2.3 | -0.1 | -1.6 | -4.7 |
| FR-09 | B | 0.0 | 1.0 | 5.9 | 0.0 | 0.1 | 0.7 | 0.0 | -0.9 | -5.2 |
| MR-10 | B | 0.1 | 0.6 | 3.1 | 0.0 | 0.1 | 0.4 | -0.1 | -0.5 | -2.7 |
| FR-11 | B | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | -0.3 |
| MR-12 | B | 0.0 | 0.1 | 0.5 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | -0.4 |
| USGS02198840 (I-95) | M | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| USGS021989784 (Lucknow Canal) | M | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| USGS02198920 (Houlihan Bridge) | M | 0.0 | 0.9 | 4.6 | 0.0 | 0.1 | 0.7 | 0.0 | -0.8 | -3.9 |
| USGS02198791 (US F&W Docks) | M | 0.0 | 0.1 | 0.4 | 0.0 | 0.0 | 0.1 | 0.0 | -0.1 | -0.3 |

* S = Surface

B = Bottom

M = Mid-Depth

Table J-4 Summary Statistics for Salinity (ppt) for August 8, 1997 through August 22, 1997

| August 8 - 22, 1997 [Julian Days 220-234] | | | | | | | | | | |
|--|--------|----------|-------|------|-----------|-----|------|------------|--------|------|
| Stations | Depth* | Measured | | | Simulated | | | Difference | | |
| | | 10% | 50% | 90% | 10% | 50% | 90% | 10% | 50% | 90% |
| BR-05 | B | 4.4 | 8.0 | 11.7 | 0.7 | 4.9 | 8.2 | -3.7 | -3.1 | -3.5 |
| FR-06 | S | 4.7 | 6.7 | 10.3 | 0.8 | 3.3 | 5.9 | -3.9 | -3.4 | -4.4 |
| FR-06 | B | 7.5 | 14.4 | 22.5 | 1.0 | 8.5 | 18.9 | -6.5 | -5.9 | -3.6 |
| BR-07 | S | 1.8 | 3.2 | 5.1 | 0.1 | 0.2 | 1.9 | -1.7 | -3.0 | -3.2 |
| FR-08 | S | 1.6 | 3.7 | 7.2 | 0.1 | 0.3 | 3.3 | -1.5 | -3.4 | -3.9 |
| FR-08 | B | 1.2 | 404.0 | 10.3 | 0.0 | 0.2 | 2.2 | -1.2 | -403.8 | -8.1 |
| FR-09 | B | 0.8 | 3.1 | 9.7 | 0.0 | 0.1 | 3.1 | -0.8 | -3.0 | -6.6 |
| MR-10 | B | 0.8 | 2.4 | 6.4 | 0.1 | 0.3 | 1.3 | -0.7 | -2.1 | -5.1 |
| FR-11 | B | 0.1 | 0.7 | 2.9 | 0.0 | 0.0 | 0.1 | -0.1 | -0.7 | -2.8 |
| MR-12 | B | 0.1 | 0.5 | 1.4 | 0.0 | 0.1 | 0.3 | -0.1 | -0.4 | -1.1 |
| USGS02198840 (I-95) | M | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -0.1 |
| USGS021989784 (Lucknow Canal) | M | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| USGS02198920 (Houlihan Bridge) | M | 1.1 | 3.5 | 9.7 | 0.0 | 0.2 | 3.9 | -1.1 | -3.3 | -5.8 |
| USGS02198791 (US F&W Docks) | M | 0.1 | 0.3 | 0.7 | 0.0 | 0.0 | 0.1 | -0.1 | -0.3 | -0.6 |

* S = Surface

B = Bottom

M = Mid-Depth

Table J-5 Summary Statistics for Salinity (ppt) for August 23, 1997 through September 6, 1997

| August 23 - September 6, 1997 [Julian Days 235-249] | | | | | | | | | | |
|--|--------|----------|------|------|-----------|-----|------|------------|------|------|
| Stations | Depth* | Measured | | | Simulated | | | Difference | | |
| | | 10% | 50% | 90% | 10% | 50% | 90% | 10% | 50% | 90% |
| BR-05 | B | 4.7 | 8.0 | 10.9 | 1.4 | 5.6 | 8.1 | -3.3 | -2.4 | -2.8 |
| FR-06 | S | 3.6 | 6.2 | 9.1 | 1.3 | 3.3 | 5.6 | -2.3 | -2.9 | -3.5 |
| FR-06 | B | 9.5 | 16.1 | 18.4 | 5.1 | 9.8 | 14.3 | -4.4 | -6.3 | -4.1 |
| BR-07 | S | 1.0 | 1.6 | 2.7 | 0.1 | 0.1 | 0.9 | -0.9 | -1.5 | -1.8 |
| FR-08 | S | 1.1 | 3.4 | 6.4 | 0.1 | 0.5 | 4.7 | -1.0 | -2.9 | -1.7 |
| FR-08 | B | 2.0 | 6.4 | 12.1 | 0.1 | 1.2 | 7.2 | -1.9 | -5.2 | -4.9 |
| FR-09 | B | 0.7 | 3.8 | 10.4 | 0.0 | 0.1 | 4.3 | -0.7 | -3.7 | -6.1 |
| MR-10 | B | 0.2 | 1.3 | 5.7 | 0.4 | 2.0 | 5.9 | 0.2 | 0.7 | 0.2 |
| MR-12 | B | 0.1 | 0.4 | 1.4 | 0.0 | 0.1 | 0.6 | -0.1 | -0.3 | -0.8 |
| USGS02198840 (I-95) | M | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -0.2 |
| USGS021989784 (Lucknow Canal) | M | 0.1 | 0.1 | 0.2 | 0.0 | 0.1 | 0.1 | -0.1 | 0.0 | -0.1 |
| USGS02198920 (Houlihan Bridge) | M | 0.7 | 3.3 | 8.2 | 0.0 | 0.2 | 4.3 | -0.7 | -3.1 | -3.9 |
| USGS02198791 (US F&W Docks) | M | 0.1 | 0.3 | 1.0 | 0.0 | 0.1 | 0.1 | -0.1 | -0.2 | -0.9 |

* S = Surface

B = Bottom

M = Mid-Depth

Table J-6 Summary Statistics for Salinity (ppt) for September 7, 1997 through September 20, 1997

| September 7 - 20, 1997 [Julian Days 250-263] | | | | | | | | | | |
|---|--------|----------|------|------|-----------|------|------|------------|------|------|
| Stations | Depth* | Measured | | | Simulated | | | Difference | | |
| | | 10% | 50% | 90% | 10% | 50% | 90% | 10% | 50% | 90% |
| BR-05 | B | 5.1 | 8.2 | 11.0 | 3.2 | 8.2 | 13.9 | -1.9 | 0.0 | 2.9 |
| FR-06 | S | 0.6 | 1.9 | 5.1 | 2.4 | 5.5 | 9.2 | 1.8 | 3.6 | 4.1 |
| FR-06 | B | 5.3 | 18.9 | 20.6 | 11.3 | 16.5 | 20.2 | 6.0 | -2.4 | -0.4 |
| BR-07 | S | 0.8 | 2.7 | 4.7 | 0.4 | 1.6 | 7.4 | -0.4 | -1.1 | 2.7 |
| FR-08 | S | 2.9 | 4.3 | 7.6 | 0.2 | 4.1 | 9.6 | -2.7 | -0.2 | 2.0 |
| FR-08 | B | 0.3 | 5.9 | 14.2 | 0.2 | 4.8 | 12.9 | -0.1 | -1.1 | -1.3 |
| FR-09 | B | 0.1 | 3.1 | 11.5 | 0.1 | 2.1 | 9.8 | 0.0 | -1.0 | -1.7 |
| FR-11 | B | 0.0 | 0.0 | 2.0 | 0.1 | 0.1 | 1.3 | 0.1 | 0.1 | -0.7 |
| MR-12 | B | 0.1 | 0.3 | 1.0 | 0.1 | 0.5 | 2.0 | 0.0 | 0.2 | 1.0 |
| USGS02198840 (I-95) | M | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| USGS021989784 (Lucknow Canal) | M | 0.1 | 0.1 | 0.2 | 0.1 | 0.3 | 0.5 | 0.0 | 0.2 | 0.3 |
| USGS02198920 (Houlihan Bridge) | M | 0.1 | 2.9 | 9.2 | 0.1 | 2.3 | 10.1 | 0.0 | -0.6 | 0.9 |
| USGS02198791 (US F&W Docks) | M | 0.1 | 0.2 | 1.0 | 0.1 | 0.3 | 0.9 | 0.0 | 0.1 | -0.1 |

* S = Surface

B = Bottom

M = Mid-Depth

Table J-7 Summary Statistics for Salinity (ppt) for September 21, 1997 through October 5, 1997

| September 21 - October 5, 1997 [Julian Days 264-278] | | | | | | | | | | |
|---|--------|----------|------|------|-----------|------|------|------------|------|------|
| Stations | Depth* | Measured | | | Simulated | | | Difference | | |
| | | 10% | 50% | 90% | 10% | 50% | 90% | 10% | 50% | 90% |
| FR-06 | S | 1.6 | 5.6 | 8.8 | 3.2 | 5.7 | 8.2 | 1.6 | 0.1 | -0.6 |
| FR-06 | B | 6.5 | 16.6 | 20.2 | 8.1 | 13.5 | 17.8 | 1.6 | -3.1 | -2.4 |
| BR-07 | S | 0.4 | 1.9 | 3.5 | 0.2 | 0.6 | 2.3 | -0.2 | -1.3 | -1.2 |
| FR-08 | S | 1.8 | 3.8 | 6.6 | 0.1 | 1.6 | 6.5 | -1.7 | -2.2 | -0.1 |
| FR-08 | B | 0.2 | 6.2 | 13.2 | 0.1 | 3.5 | 9.8 | -0.1 | -2.7 | -3.4 |
| FR-09 | B | 0.0 | 3.3 | 10.7 | 0.1 | 1.0 | 6.7 | 0.1 | -2.3 | -4.0 |
| MR-10 | B | 0.1 | 1.3 | 5.3 | 0.2 | 0.9 | 3.0 | 0.1 | -0.4 | -2.3 |
| FR-11 | B | 0.0 | 0.4 | 2.7 | 0.0 | 0.0 | 0.2 | 0.0 | -0.4 | -2.5 |
| MR-12 | B | 0.0 | 0.2 | 1.0 | 0.1 | 0.2 | 1.0 | 0.1 | 0.0 | 0.0 |
| USGS02198840 (I-95) | M | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| USGS021989784 (Lucknow Canal) | M | 0.0 | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 | 0.1 | 0.0 | 0.0 |
| USGS02198920 (Houlihan Bridge) | M | 0.2 | 3.0 | 8.3 | 0.1 | 1.1 | 5.6 | -0.1 | -1.9 | -2.7 |
| USGS02198791 (US F&W Docks) | M | 0.0 | 0.1 | 0.8 | 0.1 | 0.1 | 0.2 | 0.1 | 0.0 | -0.6 |

* S = Surface

B = Bottom

M = Mid-Depth

APPENDIX K 1999 SALINITY COMPARISONS

Table K-1 Summary Statistics for Salinity (ppt) for July 31, 1999 through October 13, 1999

| July 31 - October 13, 1999 [Julian Days 212-286] | | | | | | | | | | |
|---|--------|----------|------|------|-----------|------|------|------------|------|------|
| Stations | Depth* | Measured | | | Simulated | | | Difference | | |
| | | 10% | 50% | 90% | 10% | 50% | 90% | 10% | 50% | 90% |
| BR-05 | B | 7.5 | 10.3 | 13.5 | 2.6 | 8.2 | 13.5 | -4.9 | -2.1 | 0.0 |
| FR-06 | S | 4.6 | 7.6 | 11.7 | 3.4 | 6.1 | 10.5 | -1.2 | -1.5 | -1.2 |
| FR-06 | B | 10.8 | 16.4 | 23.2 | 8.7 | 14.9 | 23.8 | -2.1 | -1.5 | 0.6 |
| BR-07 | S | 1.2 | 2.1 | 4.1 | 0.2 | 0.8 | 3.9 | -1.0 | -1.3 | -0.2 |
| FR-08 | S | 1.0 | 2.7 | 5.9 | 0.1 | 1.0 | 5.0 | -0.9 | -1.7 | -0.9 |
| FR-08 | B | 2.5 | 7.5 | 14.6 | 0.2 | 4.3 | 15.5 | -2.3 | -3.2 | 0.9 |
| FR-09 | S | 0.7 | 2.0 | 4.7 | 0.1 | 1.1 | 5.5 | -0.6 | -0.9 | 0.8 |
| FR-09 | B | 0.8 | 4.1 | 11.0 | 0.1 | 1.9 | 9.8 | -0.7 | -2.2 | -1.2 |
| MR-10 | S | 0.6 | 1.9 | 4.6 | 0.3 | 1.1 | 3.9 | -0.3 | -0.8 | -0.7 |
| FR-11R | B | 0.3 | 2.3 | 11.6 | 0.1 | 0.1 | 4.4 | -0.2 | -2.2 | -7.2 |
| MR-12R | S | 0.1 | 0.4 | 1.7 | 0.1 | 0.3 | 2.2 | 0.0 | -0.1 | 0.5 |
| LBR-15 | S | 0.1 | 0.5 | 1.5 | 0.1 | 0.3 | 1.0 | 0.0 | -0.2 | -0.5 |
| USGS02198840 (I-95) | M | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | -0.1 |
| USGS021989784 (Lucknow Canal) | M | 0.0 | 0.2 | 0.6 | 0.1 | 0.2 | 0.4 | 0.1 | 0.0 | -0.2 |
| USGS02198920 (Houlihan Bridge) | M | 0.8 | 3.1 | 8.2 | 0.1 | 1.4 | 5.3 | -0.7 | -1.7 | -2.9 |
| USGS02198791 (US F&W Docks) | M | 0.1 | 0.4 | 1.2 | 0.1 | 0.2 | 0.6 | 0.0 | -0.2 | -0.6 |

* S = Surface
 B = Bottom
 M = Mid-Depth

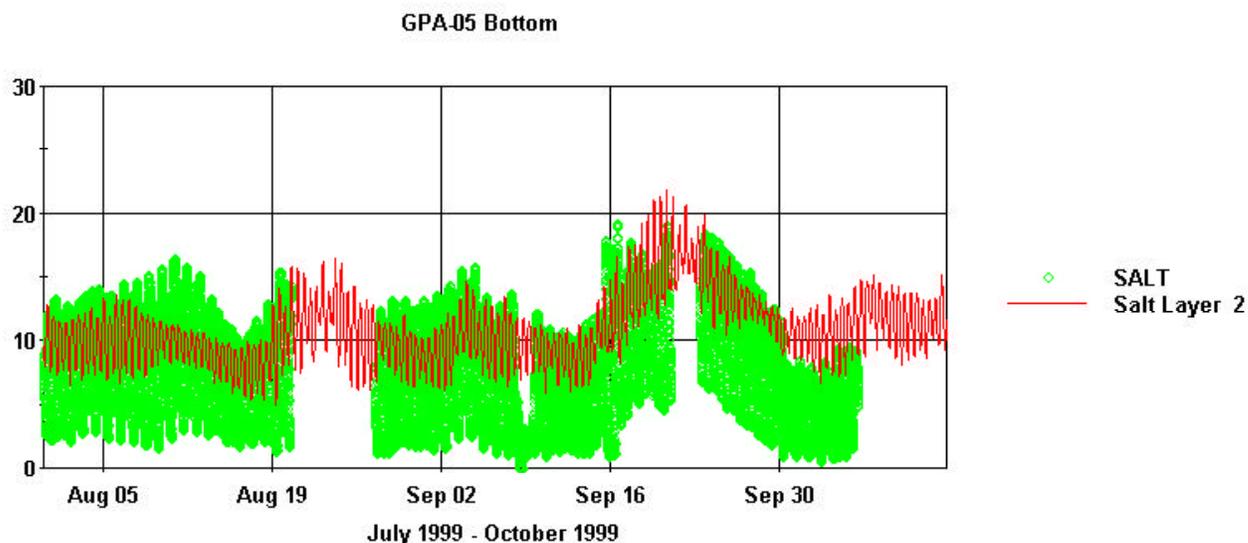


Figure K-1 Salinity (ppt) Calibration at BR-05 (Bottom) for July 31, 1999 through October 13, 1999

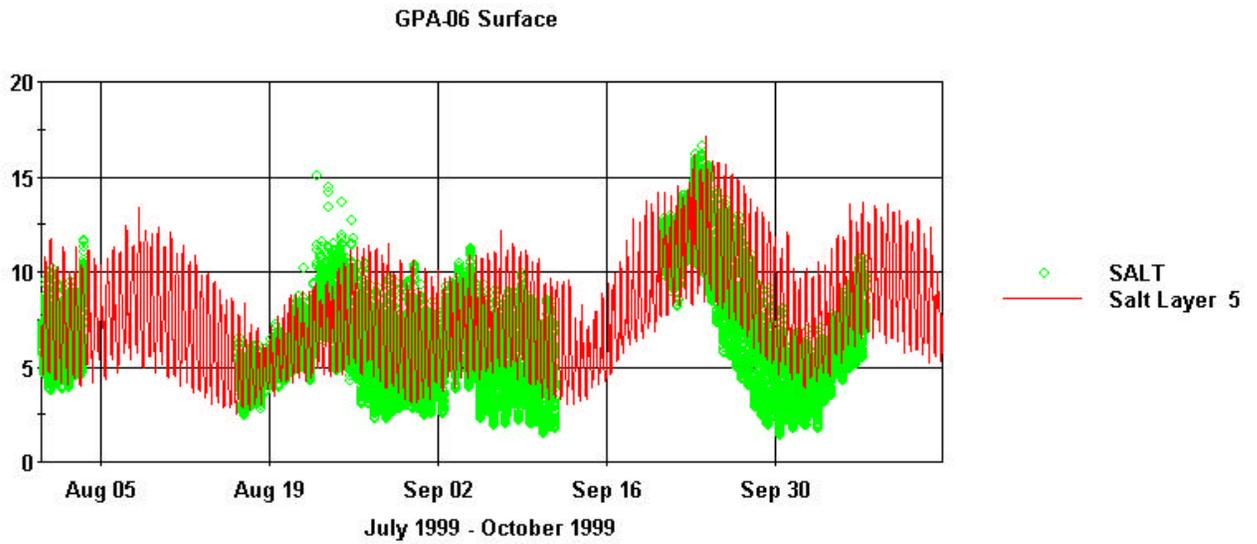


Figure K-2 Salinity (ppt) Calibration at FR-06 (Surface) for July 31, 1999 through October 13, 1999

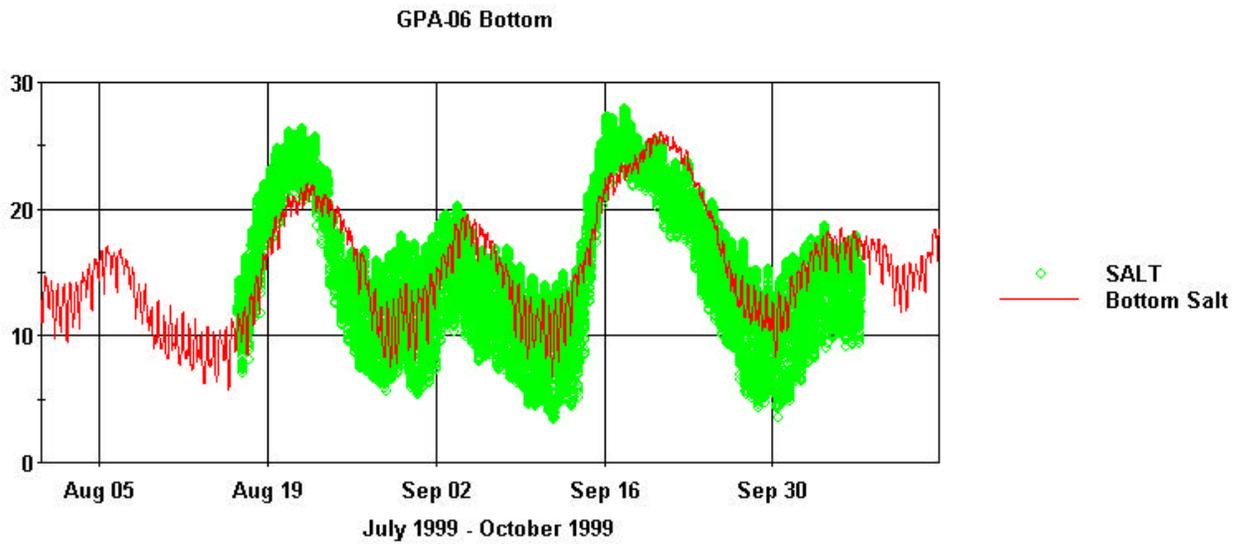


Figure K-3 Salinity (ppt) Calibration at FR-06 (Bottom) for July 31, 1999 through October 13, 1999

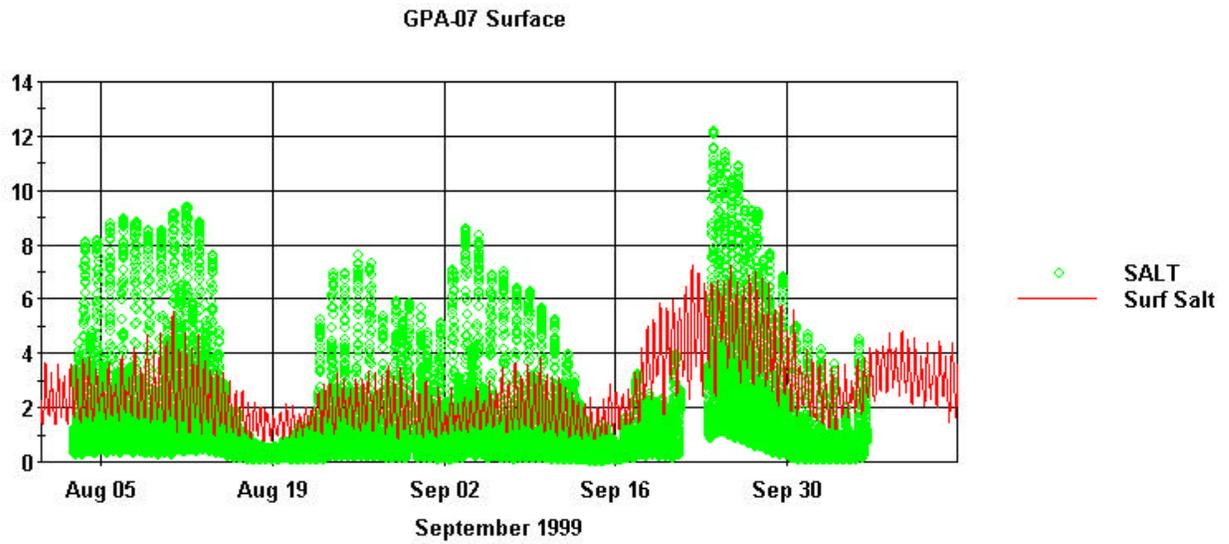


Figure K-4 Salinity (ppt) Calibration at BR-07 (Surface) for July 31, 1999 through October 13, 1999

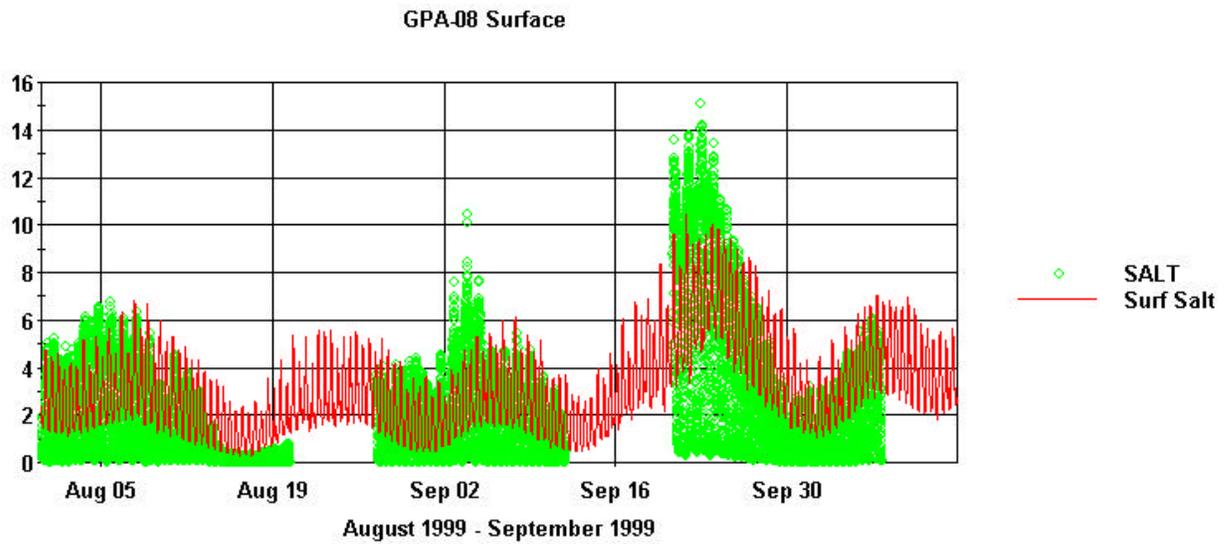


Figure K-5 Salinity (ppt) Calibration at FR-08 (Surface) for July 31, 1999 through October 13, 1999

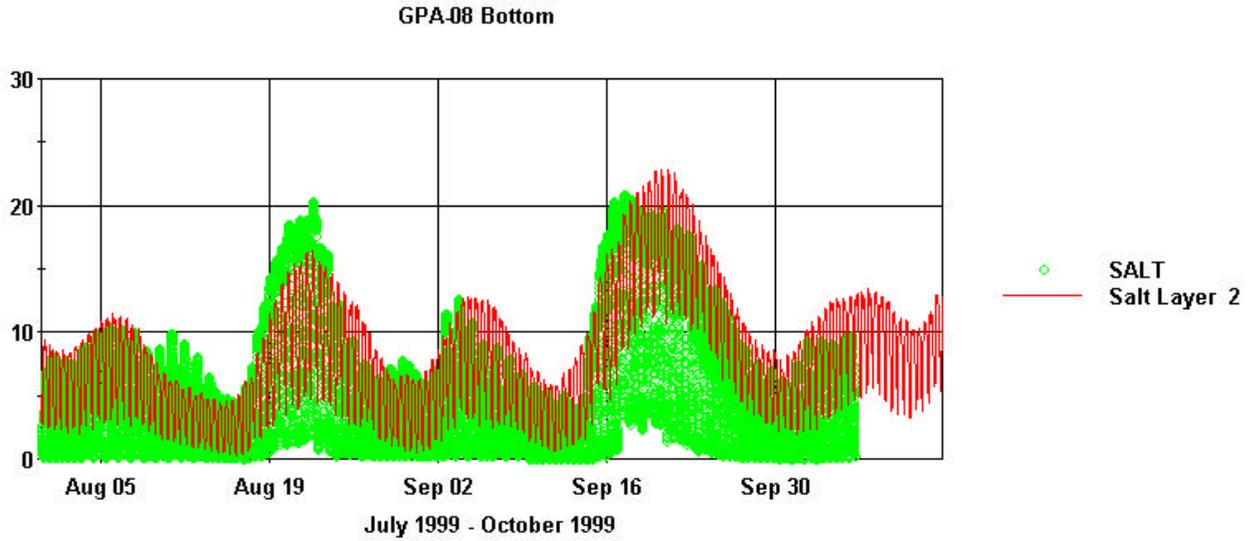


Figure K-6 Salinity (ppt) Calibration at FR-08 (Bottom) for July 31, 1999 through October 13, 1999

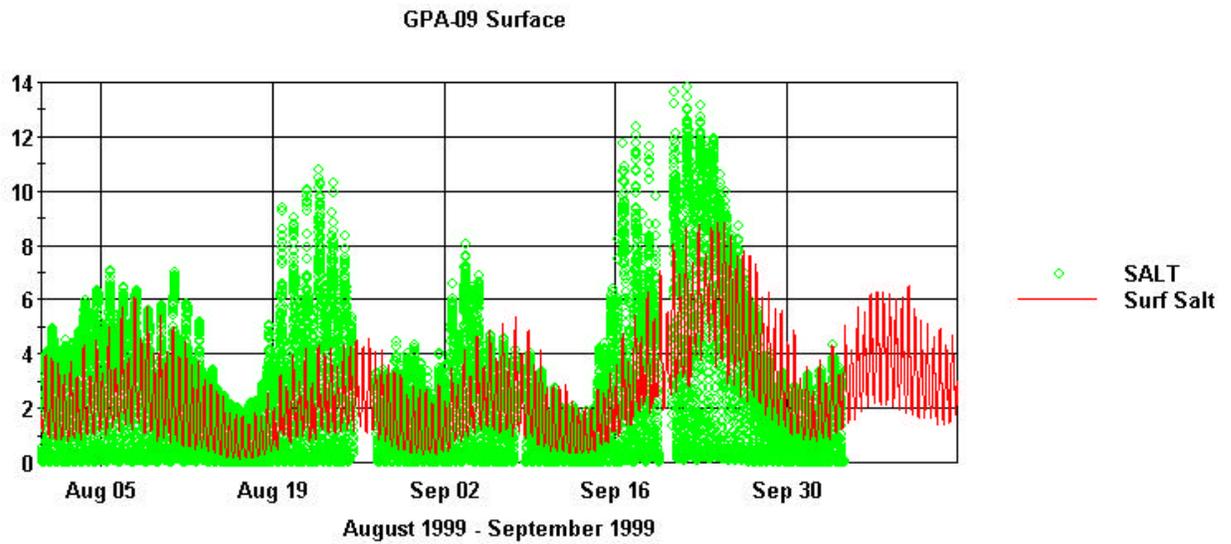


Figure K-7 Salinity (ppt) Calibration at FR-09 (Surface) for July 31, 1999 through October 13, 1999

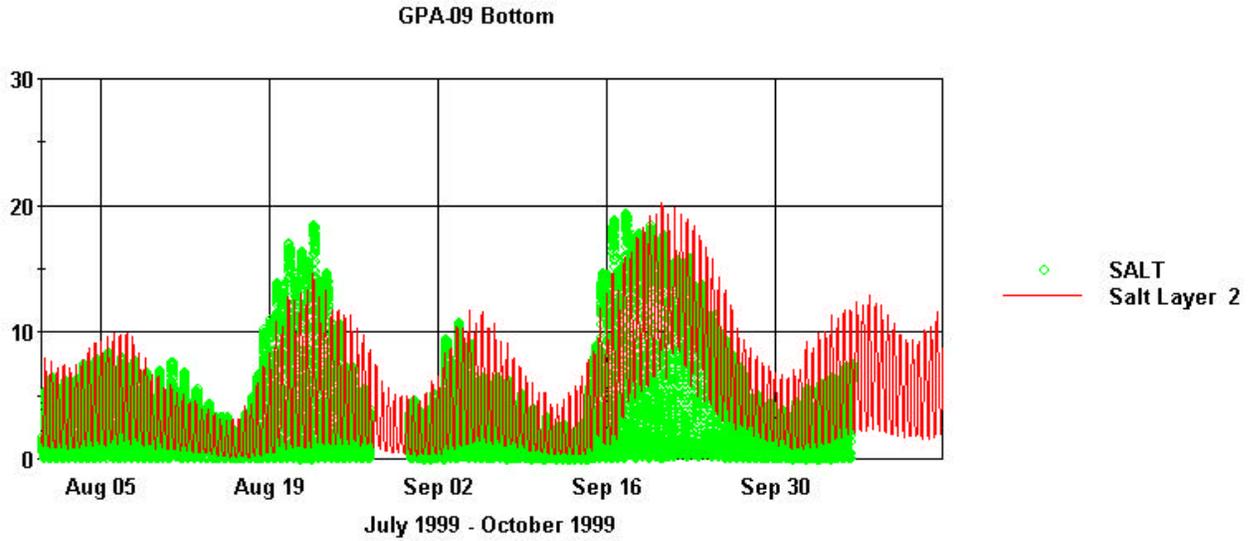


Figure K-8 Salinity (ppt) Calibration at FR-09 (Bottom) for July 31, 1999 through October 13, 1999

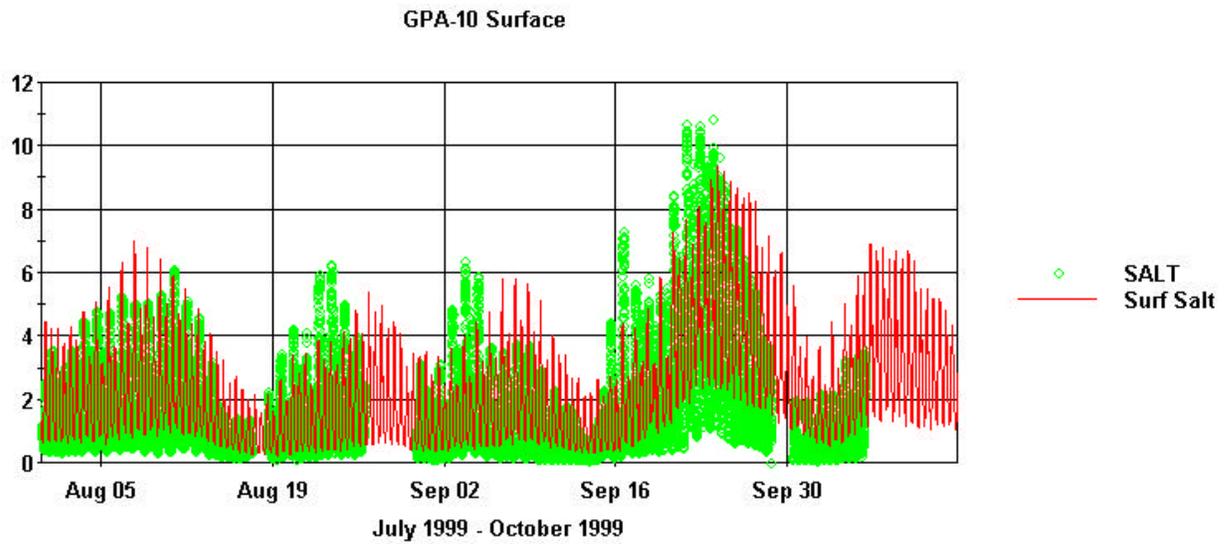


Figure K-9 Salinity (ppt) Calibration at MR-10 (Surface) for July 31, 1999 through October 13, 1999

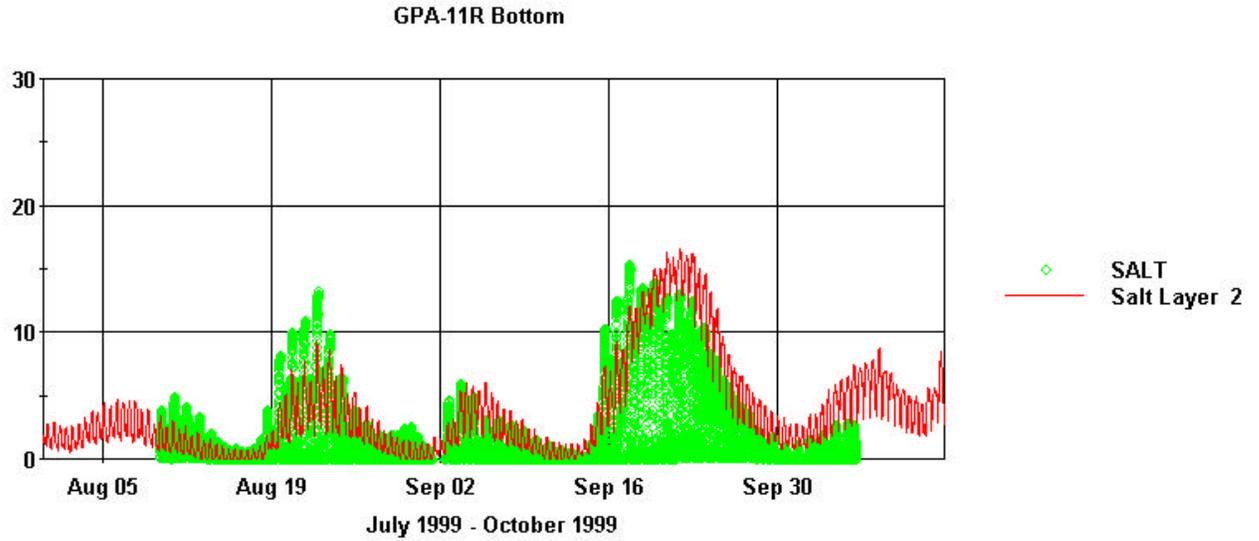


Figure K-10 Salinity (ppt) Calibration at FR-11R (Bottom) for July 31, 1999 through October 13, 1999

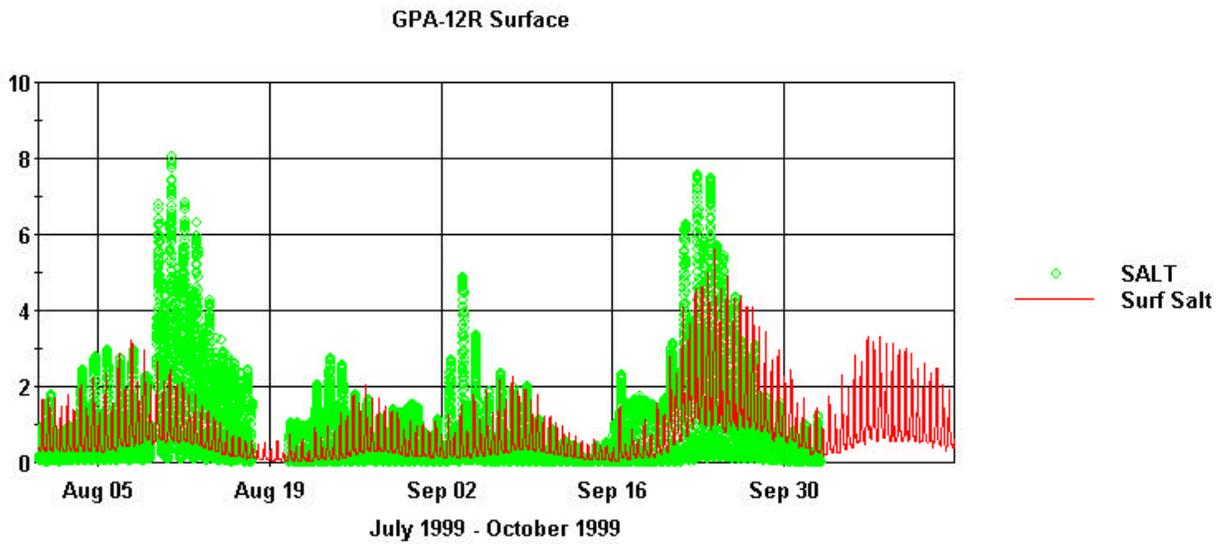


Figure K-11 Salinity (ppt) Calibration at MR-12R (Surface) for July 31, 1999 through October 13, 1999

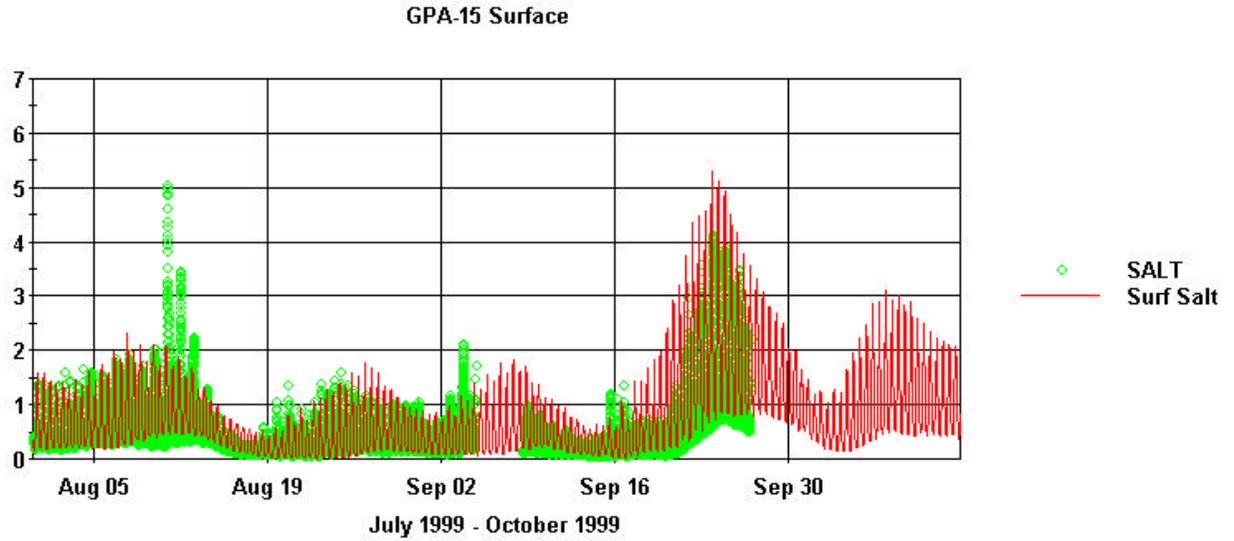


Figure K-12 Salinity (ppt) Calibration at LBR-15 (Surface) for July 31, 1999 through October 13, 1999

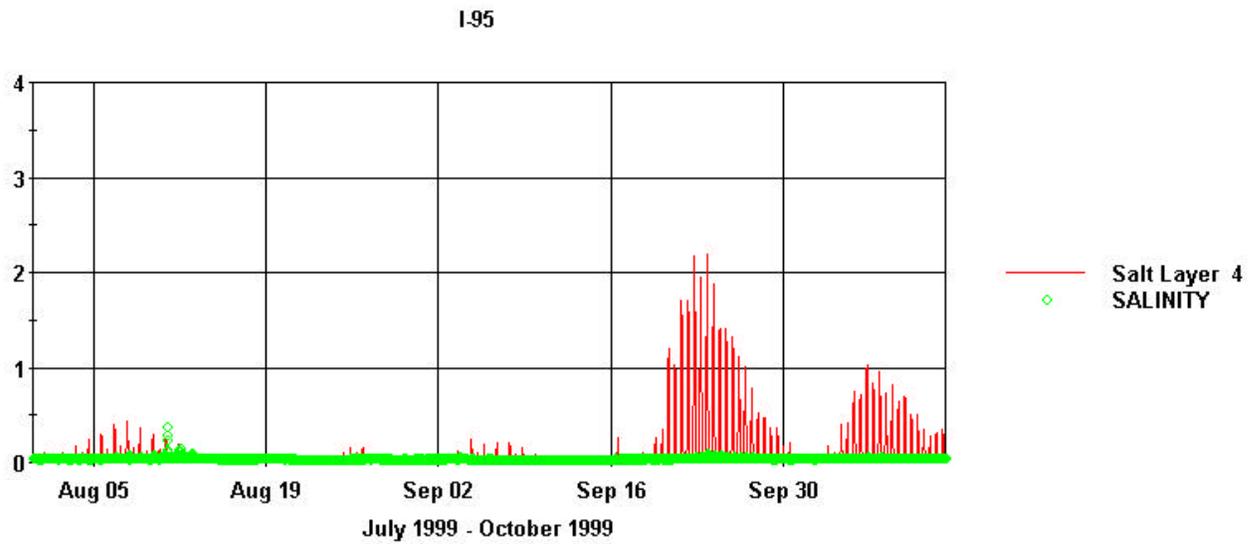


Figure K-13 Salinity (ppt) Calibration at I-95 Bridge (Mid-depth) for July 31, 1999 through October 13, 1999

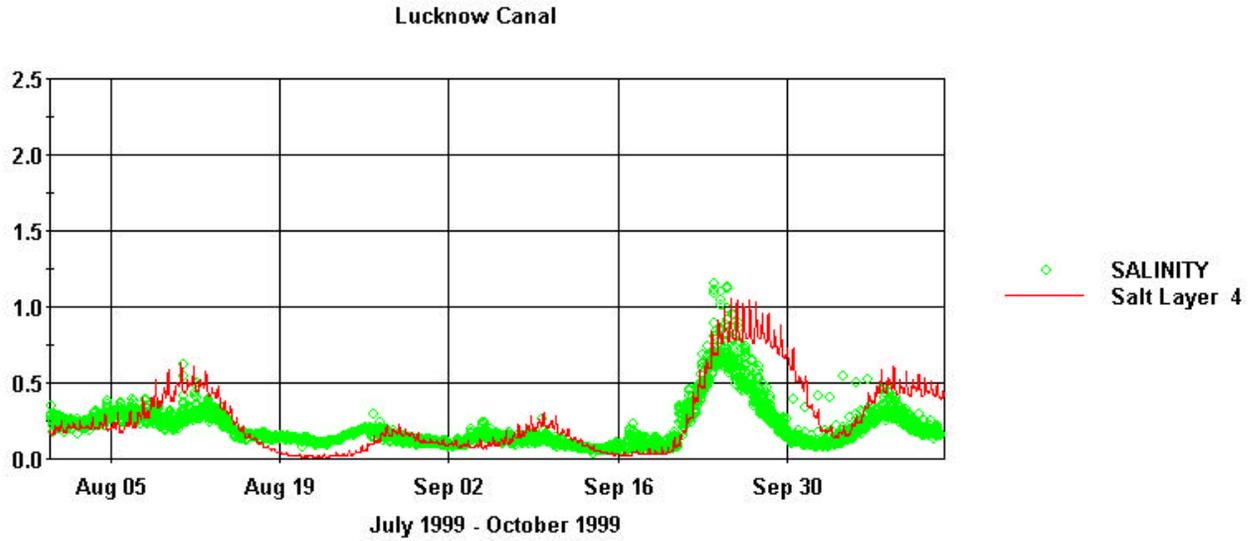


Figure K-14 Salinity (ppt) Calibration at Lucknow Canal (Mid-depth) for July 31, 1999 through October 13, 1999

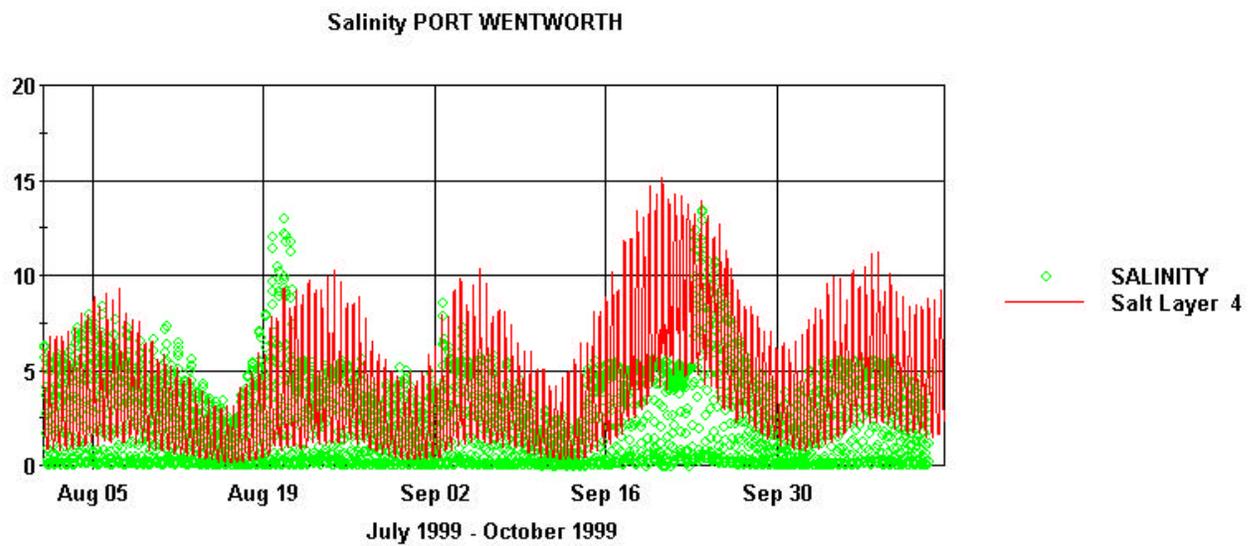


Figure K-15 Salinity (ppt) Calibration at Houlihan Bridge (Mid-depth) for July 31, 1999 through October 13, 1999

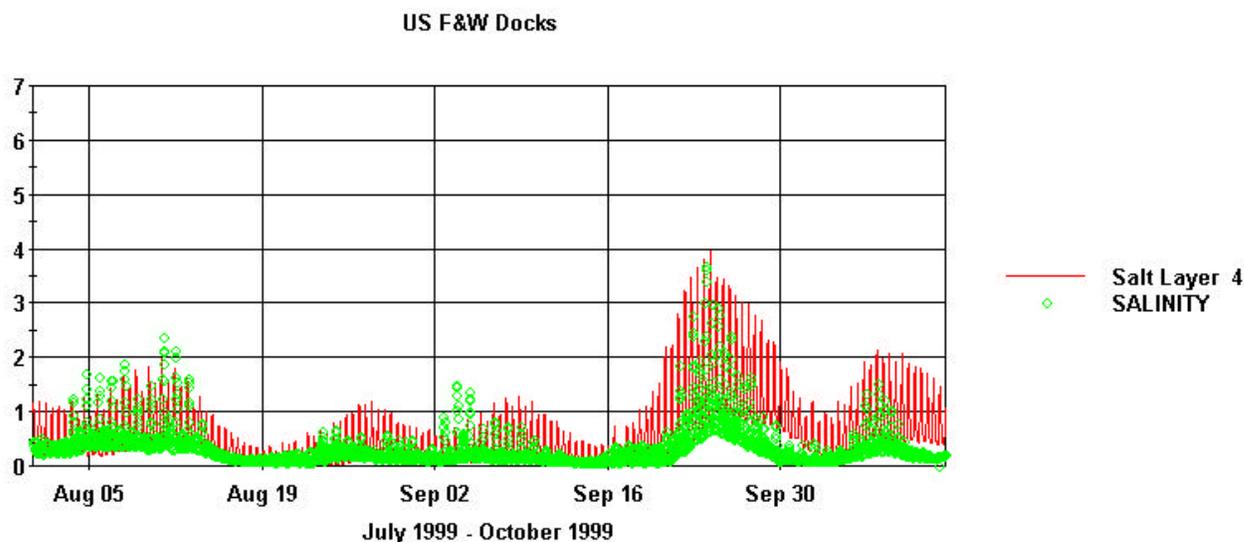


Figure K-16 Salinity (ppt) Calibration at US F&W Docks (Mid-depth) for July 31, 1999 through October 13, 1999

Table K-2 Summary Statistics for Salinity (ppt) for July 31, 1999 through August 14, 1999

| July 31 - August 14, 1999 [Julian Days 212-226] | | | | | | | | | | |
|--|--------|----------|-----|------|-----------|-----|------|------------|------|------|
| Stations | Depth* | Measured | | | Simulated | | | Difference | | |
| | | 10% | 50% | 90% | 10% | 50% | 90% | 10% | 50% | 90% |
| BR-05 | B | 7.7 | 9.9 | 11.8 | 3.8 | 9.4 | 13.2 | -3.9 | -0.5 | 1.4 |
| FR-06 | S | 4.6 | 7.3 | 10.8 | 4.7 | 6.4 | 8.5 | 0.1 | -0.9 | -2.3 |
| BR-07 | S | 1.6 | 2.4 | 3.7 | 0.4 | 1.4 | 6.0 | -1.2 | -1.0 | 2.3 |
| FR-08 | S | 1.2 | 2.5 | 4.7 | 0.1 | 1.0 | 4.5 | -1.1 | -1.5 | -0.2 |
| FR-08 | B | 2.2 | 5.6 | 10.0 | 0.2 | 4.6 | 8.2 | -2.0 | -1.0 | -1.8 |
| FR-09 | S | 0.9 | 1.9 | 3.8 | 0.1 | 1.8 | 4.8 | -0.8 | -0.1 | 1.0 |
| FR-09 | B | 0.9 | 2.5 | 7.6 | 0.2 | 2.4 | 6.3 | -0.7 | -0.1 | -1.3 |
| MR-10 | S | 0.8 | 1.8 | 4.3 | 0.5 | 1.3 | 3.5 | -0.3 | -0.5 | -0.8 |
| FR-11 | B | 0.1 | 0.8 | 2.3 | 0.1 | 0.3 | 2.8 | 0.0 | -0.5 | 0.5 |
| MR-12R | S | 0.3 | 0.6 | 1.7 | 0.1 | 0.7 | 3.4 | -0.2 | 0.1 | 1.7 |
| LBR-15 | S | 0.2 | 0.6 | 1.6 | 0.3 | 0.4 | 1.2 | 0.1 | -0.2 | -0.4 |
| USGS02198840 (I-95) | M | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | 0.1 | 0.0 |
| USGS021989784 (Lucknow Canal) | M | 0.2 | 0.3 | 0.5 | 0.2 | 0.3 | 0.3 | 0.0 | 0.0 | -0.2 |
| USGS02198920 (Houlihan Bridge) | M | 0.9 | 2.4 | 6.4 | 0.1 | 2.1 | 5.7 | -0.8 | -0.3 | -0.7 |
| USGS02198791 (US F&W Docks) | M | 0.2 | 0.5 | 1.2 | 0.3 | 0.4 | 0.8 | 0.1 | -0.1 | -0.4 |

* S = Surface
 B = Bottom
 M = Mid-Depth

Table K-3 Summary Statistics for Salinity (ppt) for August 15, 1999 through August 29, 1999

| August 15 - 29, 1999 [Julian Days 227-241] | | | | | | | | | | |
|---|--------|----------|------|------|-----------|------|------|------------|------|------|
| Stations | Depth* | Measured | | | Simulated | | | Difference | | |
| | | 10% | 50% | 90% | 10% | 50% | 90% | 10% | 50% | 90% |
| BR-05 | B | 6.3 | 9.1 | 11.1 | 2.3 | 8.1 | 12.0 | -4.0 | -1.0 | 0.9 |
| FR-06 | S | 4.3 | 6.3 | 9.7 | 3.7 | 5.9 | 9.0 | -0.6 | -0.4 | -0.7 |
| FR-06 | B | 10.6 | 17.5 | 21.0 | 10.1 | 17.1 | 24.3 | -0.5 | -0.4 | 3.3 |
| BR-07 | S | 1.1 | 1.7 | 2.6 | 0.2 | 0.5 | 2.1 | -0.9 | -1.2 | -0.5 |
| FR-08 | S | 0.5 | 1.5 | 3.5 | 0.1 | 0.2 | 2.2 | -0.4 | -1.3 | -1.3 |
| FR-08 | B | 2.2 | 6.9 | 13.8 | 0.3 | 5.3 | 16.8 | -1.9 | -1.6 | 3.0 |
| FR-09 | S | 0.4 | 1.5 | 3.3 | 0.1 | 1.1 | 5.3 | -0.3 | -0.4 | 2.0 |
| FR-09 | B | 0.5 | 3.0 | 10.5 | 0.1 | 2.2 | 12.5 | -0.4 | -0.8 | 2.0 |
| MR-10 | S | 0.4 | 1.2 | 3.1 | 0.3 | 1.0 | 2.9 | -0.1 | -0.2 | -0.2 |
| FR-11R | B | 0.1 | 1.9 | 5.6 | 0.1 | 0.1 | 4.2 | 0.0 | -1.8 | -1.4 |
| MR-12R | S | 0.1 | 0.3 | 0.9 | 0.1 | 0.3 | 1.6 | 0.0 | 0.0 | 0.7 |
| LBR-15 | S | 0.0 | 0.3 | 1.0 | 0.1 | 0.2 | 0.5 | 0.1 | -0.1 | -0.5 |
| USGS02198840 (I-95) | M | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| USGS021989784 (Lucknow Canal) | M | 0.0 | 0.1 | 0.2 | 0.1 | 0.2 | 0.2 | 0.1 | 0.1 | 0.0 |
| USGS02198920 (Houlihan Bridge) | M | 0.5 | 2.1 | 7.5 | 0.1 | 1.5 | 5.2 | -0.4 | -0.6 | -2.3 |
| USGS02198791 (US F&W Docks) | M | 0.0 | 0.2 | 0.6 | 0.1 | 0.2 | 0.4 | 0.1 | 0.0 | -0.2 |

* S = Surface
 B = Bottom
 M = Mid-Depth

Table K-4 Summary Statistics for Salinity (ppt) for August 30, 1999 through September 12, 1999

| August 30 - September 12, 1999 [Julian Days 242-255] | | | | | | | | | | |
|---|--------|----------|------|------|-----------|------|------|------------|------|------|
| Stations | Depth* | Measured | | | Simulated | | | Difference | | |
| | | 10% | 50% | 90% | 10% | 50% | 90% | 10% | 50% | 90% |
| BR-05 | B | 7.1 | 9.5 | 11.9 | 2.0 | 7.2 | 12.0 | -5.1 | -2.3 | 0.1 |
| FR-06 | S | 4.3 | 6.8 | 10.4 | 3.1 | 5.7 | 8.1 | -1.2 | -1.1 | -2.3 |
| FR-06 | B | 9.6 | 13.7 | 18.4 | 7.2 | 12.6 | 17.0 | -2.4 | -1.1 | -1.4 |
| BR-07 | S | 1.2 | 1.8 | 2.7 | 0.2 | 0.7 | 3.4 | -1.0 | -1.1 | 0.7 |
| FR-08 | S | 0.8 | 2.1 | 4.4 | 0.1 | 1.3 | 4.0 | -0.7 | -0.8 | -0.4 |
| FR-08 | B | 1.6 | 6.0 | 11.2 | 0.2 | 2.2 | 7.4 | -1.4 | -3.8 | -3.8 |
| FR-09 | S | 0.5 | 1.5 | 3.3 | 0.1 | 0.5 | 3.6 | -0.4 | -1.0 | 0.3 |
| FR-09 | B | 0.6 | 2.5 | 8.4 | 0.1 | 1.0 | 5.3 | -0.5 | -1.5 | -3.1 |
| MR-10 | S | 0.5 | 1.3 | 3.4 | 0.2 | 0.7 | 2.6 | -0.3 | -0.6 | -0.8 |
| FR-11R | B | 0.0 | 1.2 | 4.3 | 0.1 | 0.1 | 1.8 | 0.1 | -1.1 | -2.5 |
| MR-12R | S | 0.1 | 0.3 | 1.1 | 0.1 | 0.2 | 1.1 | 0.0 | -0.1 | 0.0 |
| LBR-15 | S | 0.1 | 0.3 | 0.9 | 0.1 | 0.2 | 0.7 | 0.0 | -0.1 | -0.2 |
| USGS02198840 (I-95) | M | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| USGS021989784 (Lucknow Canal) | M | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 | 0.0 | 0.0 | 0.0 |
| USGS02198920 (Houlihan Bridge) | M | 0.6 | 2.1 | 6.2 | 0.1 | 0.8 | 4.5 | -0.5 | -1.3 | -1.7 |
| USGS02198791 (US F&W Docks) | M | 0.1 | 0.2 | 0.8 | 0.1 | 0.2 | 0.4 | 0.0 | 0.0 | -0.4 |

* S = Surface
 B = Bottom
 M = Mid-Depth

Table K-5 Summary Statistics for Salinity (ppt) for September 13, 1999 through September 27, 1999

| September 13 - 27, 1999 [Julian Days 256-270] | | | | | | | | | | |
|--|--------|----------|------|------|-----------|------|------|------------|------|------|
| Stations | Depth* | Measured | | | Simulated | | | Difference | | |
| | | 10% | 50% | 90% | 10% | 50% | 90% | 10% | 50% | 90% |
| BR-05 | B | 9.4 | 13.0 | 17.1 | 4.6 | 10.9 | 15.8 | -4.8 | -2.1 | -1.3 |
| FR-06 | S | 8.7 | 11.7 | 15.0 | 10.0 | 11.6 | 14.3 | 1.3 | -0.1 | -0.7 |
| FR-06 | B | 14.7 | 22.1 | 25.3 | 12.2 | 21.1 | 25.4 | -2.5 | -1.0 | 0.1 |
| BR-07 | S | 1.4 | 3.4 | 5.9 | 0.2 | 1.1 | 5.3 | -1.2 | -2.3 | -0.6 |
| FR-08 | S | 3.8 | 6.0 | 9.1 | 0.5 | 4.8 | 10.8 | -3.3 | -1.2 | 1.7 |
| FR-08 | B | 6.6 | 13.0 | 20.6 | 0.6 | 9.7 | 18.9 | -6.0 | -3.3 | -1.7 |
| FR-09 | S | 1.2 | 3.7 | 7.1 | 0.1 | 2.7 | 9.2 | -1.1 | -1.0 | 2.1 |
| FR-09 | B | 1.5 | 8.6 | 16.6 | 0.3 | 4.9 | 15.7 | -1.2 | -3.7 | -0.9 |
| MR-10 | S | 0.7 | 2.7 | 6.9 | 0.5 | 1.9 | 6.4 | -0.2 | -0.8 | -0.5 |
| FR-11R | B | 2.0 | 9.1 | 14.9 | 0.1 | 0.3 | 10.2 | -1.9 | -8.8 | -4.7 |
| MR-12R | S | 0.1 | 0.8 | 3.0 | 0.1 | 0.3 | 3.0 | 0.0 | -0.5 | 0.0 |
| LBR-15 | S | 0.1 | 0.8 | 3.0 | 0.1 | 0.3 | 2.0 | 0.0 | -0.5 | -1.0 |
| USGS02198840 (I-95) | M | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | -0.5 |
| USGS021989784 (Lucknow Canal) | M | 0.0 | 0.1 | 0.7 | 0.1 | 0.1 | 0.6 | 0.1 | 0.0 | -0.1 |
| USGS02198920 (Houlihan Bridge) | M | 0.8 | 5.3 | 12.5 | 0.1 | 2.5 | 5.4 | -0.7 | -2.8 | -7.1 |
| USGS02198791 (US F&W Docks) | M | 0.0 | 0.3 | 1.7 | 0.1 | 0.2 | 1.0 | 0.1 | -0.1 | -0.7 |

* S = Surface
B = Bottom
M = Mid-Depth

Table K-6 Summary Statistics for Salinity (ppt) for September 28, 1999 through October 13, 1999

| September 28 - October 13, 1999 [Julian Days 271-286] | | | | | | | | | | |
|--|--------|----------|------|------|-----------|------|------|------------|------|------|
| Stations | Depth* | Measured | | | Simulated | | | Difference | | |
| | | 10% | 50% | 90% | 10% | 50% | 90% | 10% | 50% | 90% |
| BR-05 | B | 8.5 | 11.3 | 12.7 | 1.7 | 5.6 | 9.3 | -6.8 | -5.7 | -3.4 |
| FR-06 | S | 5.0 | 7.9 | 11.7 | 2.8 | 5.1 | 7.8 | -2.2 | -2.8 | -3.9 |
| FR-06 | B | 11.0 | 14.7 | 17.7 | 7.4 | 12.7 | 16.4 | -3.6 | -2.0 | -1.3 |
| BR-07 | S | 1.7 | 2.7 | 4.3 | 0.1 | 0.5 | 2.6 | -1.6 | -2.2 | -1.7 |
| FR-08 | S | 1.6 | 3.0 | 5.8 | 0.1 | 1.0 | 3.7 | -1.5 | -2.0 | -2.1 |
| FR-08 | B | 3.3 | 7.7 | 11.9 | 0.1 | 2.3 | 7.9 | -3.2 | -5.4 | -4.0 |
| FR-09 | S | 1.1 | 2.1 | 4.2 | 0.1 | 0.3 | 2.8 | -1.0 | -1.8 | -1.4 |
| FR-09 | B | 1.2 | 4.1 | 9.2 | 0.1 | 0.8 | 5.2 | -1.1 | -3.3 | -4.0 |
| MR-10 | S | 0.8 | 2.0 | 4.4 | 0.2 | 0.5 | 2.0 | -0.6 | -1.5 | -2.4 |
| FR-11R | B | 1.1 | 2.5 | 5.5 | 0.0 | 0.1 | 1.5 | -1.1 | -2.4 | -4.0 |
| MR-12R | S | 0.3 | 0.8 | 2.1 | 0.1 | 0.2 | 0.8 | -0.2 | -0.6 | -1.3 |
| USGS02198840 (I-95) | M | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | -0.4 |
| USGS021989784 (Lucknow Canal) | M | 0.2 | 0.4 | 0.7 | 0.1 | 0.2 | 0.3 | -0.1 | -0.2 | -0.4 |
| USGS02198920 (Houlihan Bridge) | M | 1.4 | 4.2 | 8.5 | 0.1 | 1.0 | 5.4 | -1.3 | -3.2 | -3.1 |
| USGS02198791 (US F&W Docks) | M | 0.2 | 0.6 | 1.6 | 0.1 | 0.2 | 0.4 | -0.1 | -0.4 | -1.2 |

* S = Surface
B = Bottom
M = Mid-Depth

APPENDIX L FINE GRID RESULTS

A fine grid model of the Savannah River was developed in addition to the coarse grid model. The fine grid has 1368 horizontal cells and currently uses eight layers in the vertical. The fine grid is shown in Figures L-1 through L-6. The fine grid model has not been calibrated to the extent of the coarse grid model calibration, which included bathymetric and friction adjustments and the addition of marsh areas. The results presented herein should be viewed as preliminary and considerable improvements in performance are anticipated as a full calibration and verification are undertaken.

The open boundary forcing functions for water surface elevation and salinity used for the fine grid simulation differ from those used for the coarse grid. The open boundary water surface elevation forcing function uses a radiation-separation boundary condition with separate forcings for tidal and sub-tidal time scales. The radiation-separation boundary condition specifies the characteristic of the incoming wave at the open boundary rather than the water surface elevation, and thus allow reflected outgoing waves generated in the interior of the model domain to pass out of the open boundary without spurious reflection. The tidal time scale forcing is applied by specifying the harmonic components of the incoming wave. The incoming wave harmonic components were determined such that the water surface elevation tidal harmonic components at the Ft. Pulaski tidal gauge were predicted accurately. The incoming wave forcing for sub-tidal sea level was set to the observed sub-tidal sea level record at Ft. Pulaski. This approach to specifying hydrodynamic open boundary conditions is generally superior to the simple specification of water surface elevation on the open boundary in that it eliminates spurious reflection of outgoing waves. The radiation-separate is also more appropriate when the model will be used to investigate impacts of bathymetric and shoreline changes in the interior of the model domain, since the condition automatically responds to the resulting changes in the propagation of outgoing waves across the open boundary.

The salinity open boundary condition was developed using a multiple linear regression between observed salinity at the offshore Sabsoon R2 station and the Savannah River flow at Clyo. The R2 station is approximately 36 miles south by southwest of the open boundary. Figure L-7 shows the R2 station salinity and the Clyo flow for the current period of record at R2, which begins in late September 1999. The figure clearly shows a response in salinity to the river flow with periods of lower salinity lagging behind periods of high river flow. The offshore position of the R2 station, suggest that its salinity response is also influenced by freshwater discharges along the South Carolina coast. However, for this preliminary estimation of the open boundary condition, it is assumed that discharge variations in the Savannah River at Clyo have the same general timing characteristics as rivers northward along the coast. To develop a relationship between the Clyo flow and the Sabsoon R2 station salinity, a synthesized period of record for the flow and salinity was developed by removing a period of missing data and smoothing the salinity and flow records, Figure L-8. The fine grid open boundary salinity is assumed to be given by an adjusted multiple linear regression prediction of the Sabsoon R2 salinity

$$S_{ob} = S_{rR2} - S_{adj}$$

$$S_{rR2} = \mathbf{a} + \mathbf{b}_5 Q_5 + \mathbf{b}_{10} Q_{10} + \mathbf{b}_{15} Q_{15} + \mathbf{b}_{20} Q_{20} \\ + \mathbf{b}_{25} Q_{25} + \mathbf{b}_{30} Q_{30} + \mathbf{b}_{35} Q_{35} + \mathbf{b}_{40} Q_{40}$$

where the subscript *ob* denotes the open boundary valve and the subscript *rR2* denotes the regression prediction of the Sabsoon R2 station salinity. A constant adjustment factor *S_{adj}*, determined during

salinity calibration, is removed from the Sabsoon R2 station regression prediction to define the open boundary salinity. The Sabsoon R2 station regression prediction is a multiple linear regression between observed salinity and 5-day average rivers flows over a 40-day preceding period. Figure L-8, shows the Sabsoon R2 salinity predicted by the regression equation. Figure L-9 shows a scatter plot of observed and predicted salinity. The regression prediction follows the general trend of the observations but does not exhibit as strong a response to high flows as the observations. Figures L-10 and L-11 show 1997 and 1999 boundary salinities determined by the regression and a salinity adjustment factor, S_{adj} , of 5.

The fine grid model was used to simulate a 160-day period, beginning at Julian Day 115, during 1997, and a 170-day period, beginning at Julian Day 117, during 1999. The starting date of the simulations were selected to coincide with periods of mean sea level and allow at least two months for the initial salinity distribution to come into equilibrium with the river flow and salinity boundary conditions. Figures L-12 through L-15 show comparisons of observed and model predicted salinity for the 1997 and 1999 simulations at GPA station 02, 04, 06, and 08. Figures L-16 through L-19 show comparisons of the frequency of occurrence distributions of observed and model predicted salinity for the 1997 and 1999 simulations at GPA station 02, 04, 06, and 08. The comparisons look quite reasonable at this early stage of model calibration. Overall, bottom salinities are over predicted – more so for 1997 than 1999. The over prediction of bottom salinity could be associated with a number of deficiencies in the model configuration including, not accounting for local fresh water inflows below the Clyo gauging station, using a depth invariant open boundary salinity, and over accounting for the width of the navigation channel and its associated project depth. These items are currently being investigated in the ongoing fine grid calibration effort.

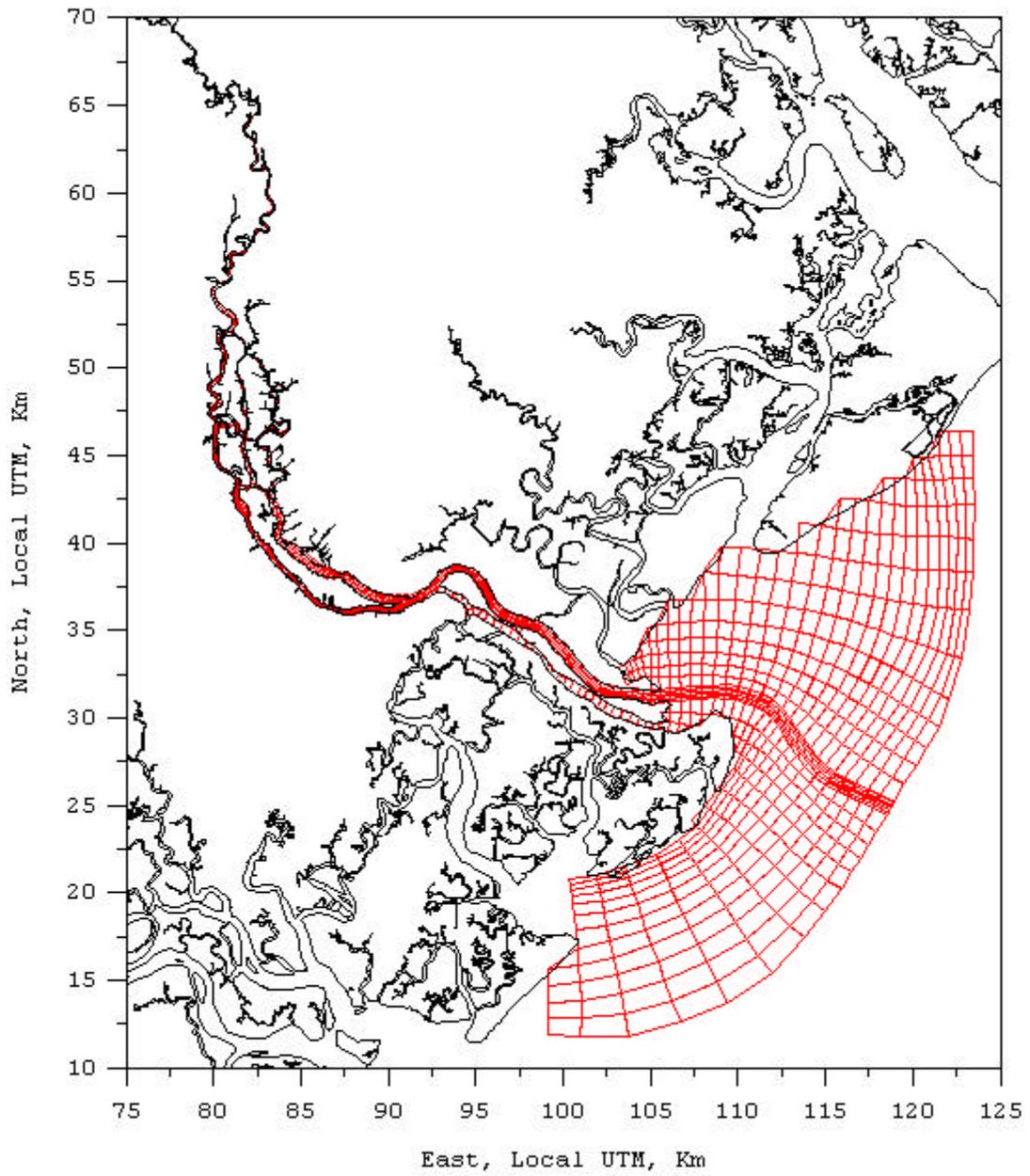


Figure L-1 Fine Grid of the Savannah River

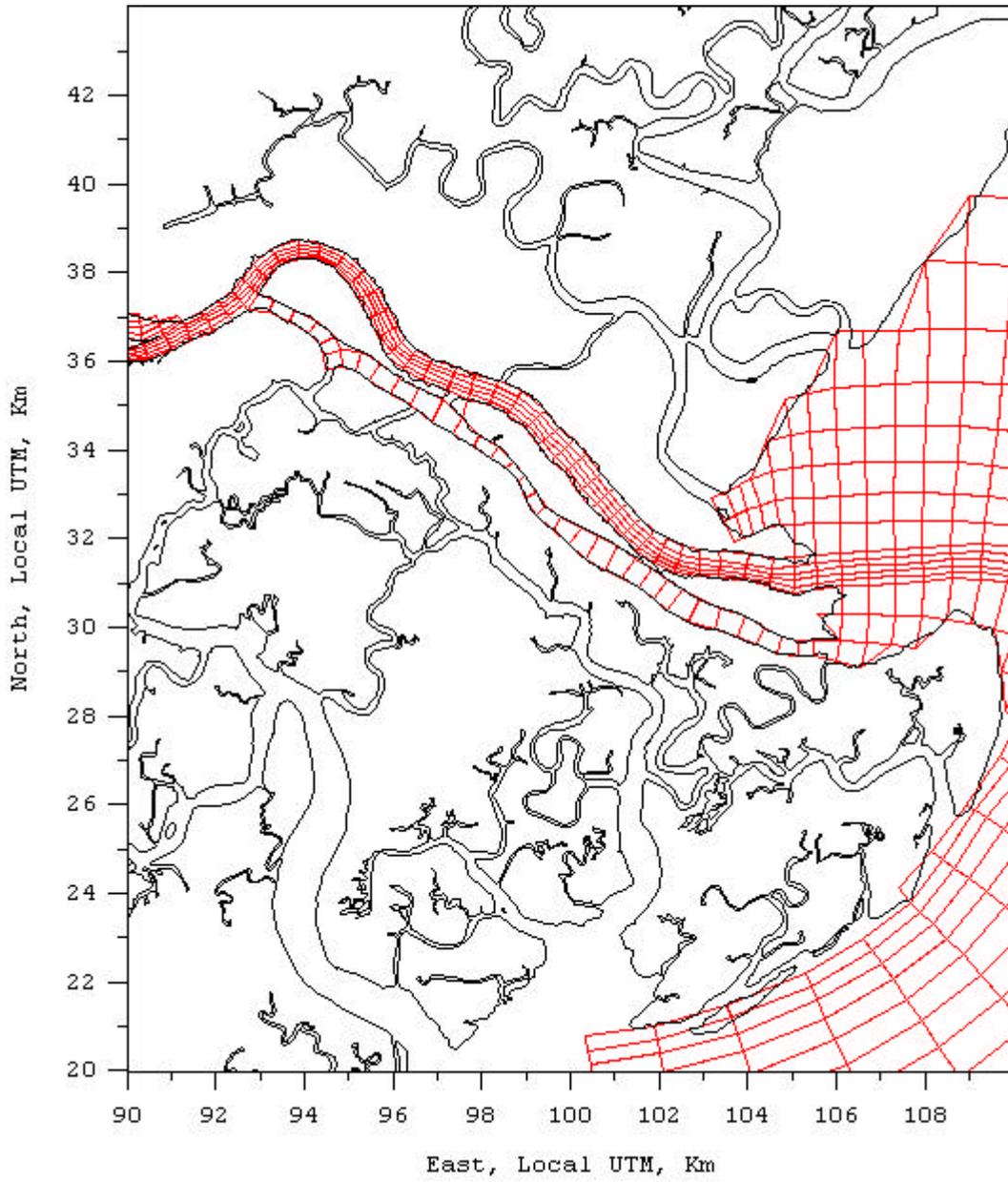


Figure L-2 Fine Grid of the Savannah River in Vicinity of the Mouth

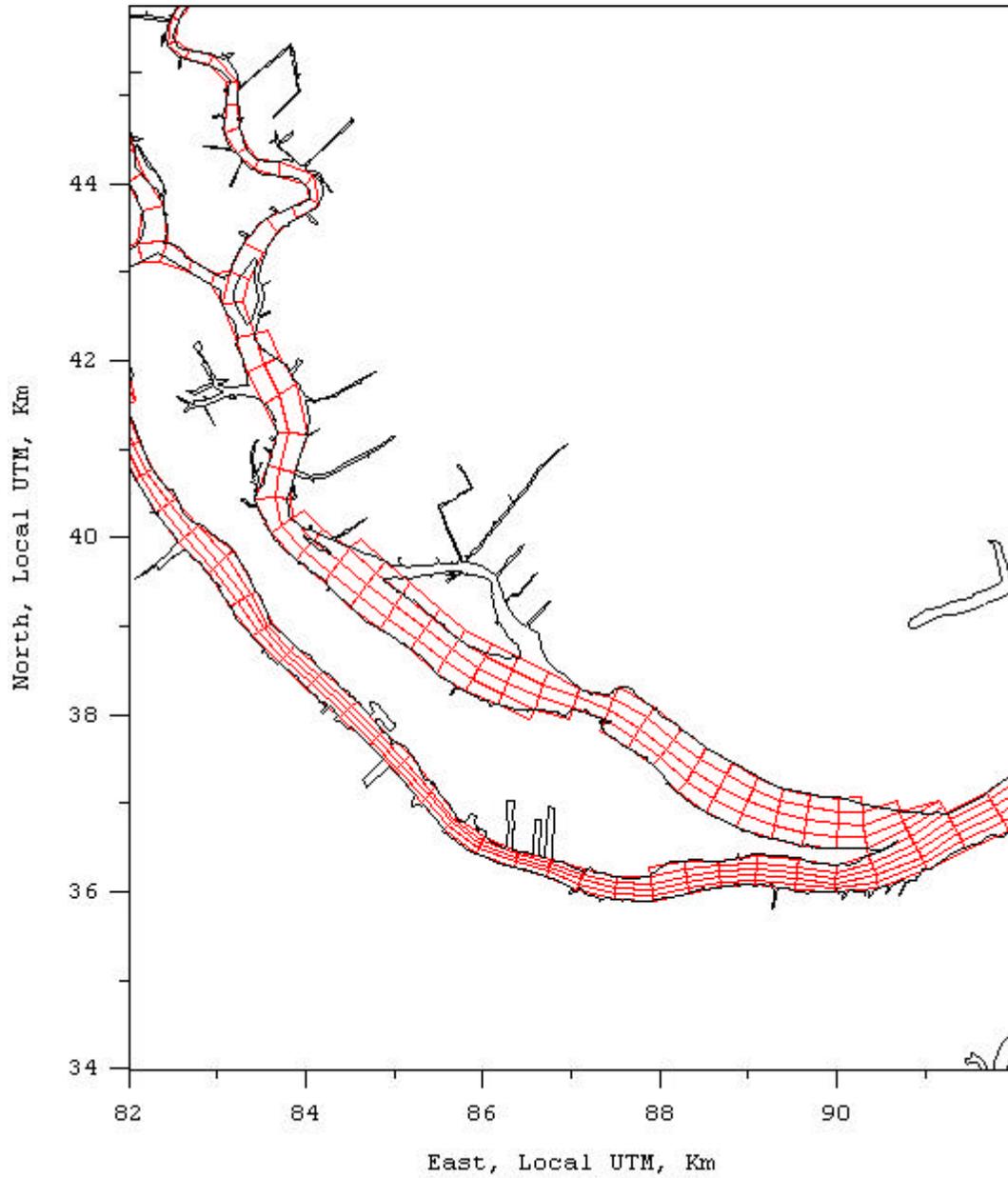


Figure L-3 Fine Grid of the Savannah River in the Vicinity of Confluence with the Back River

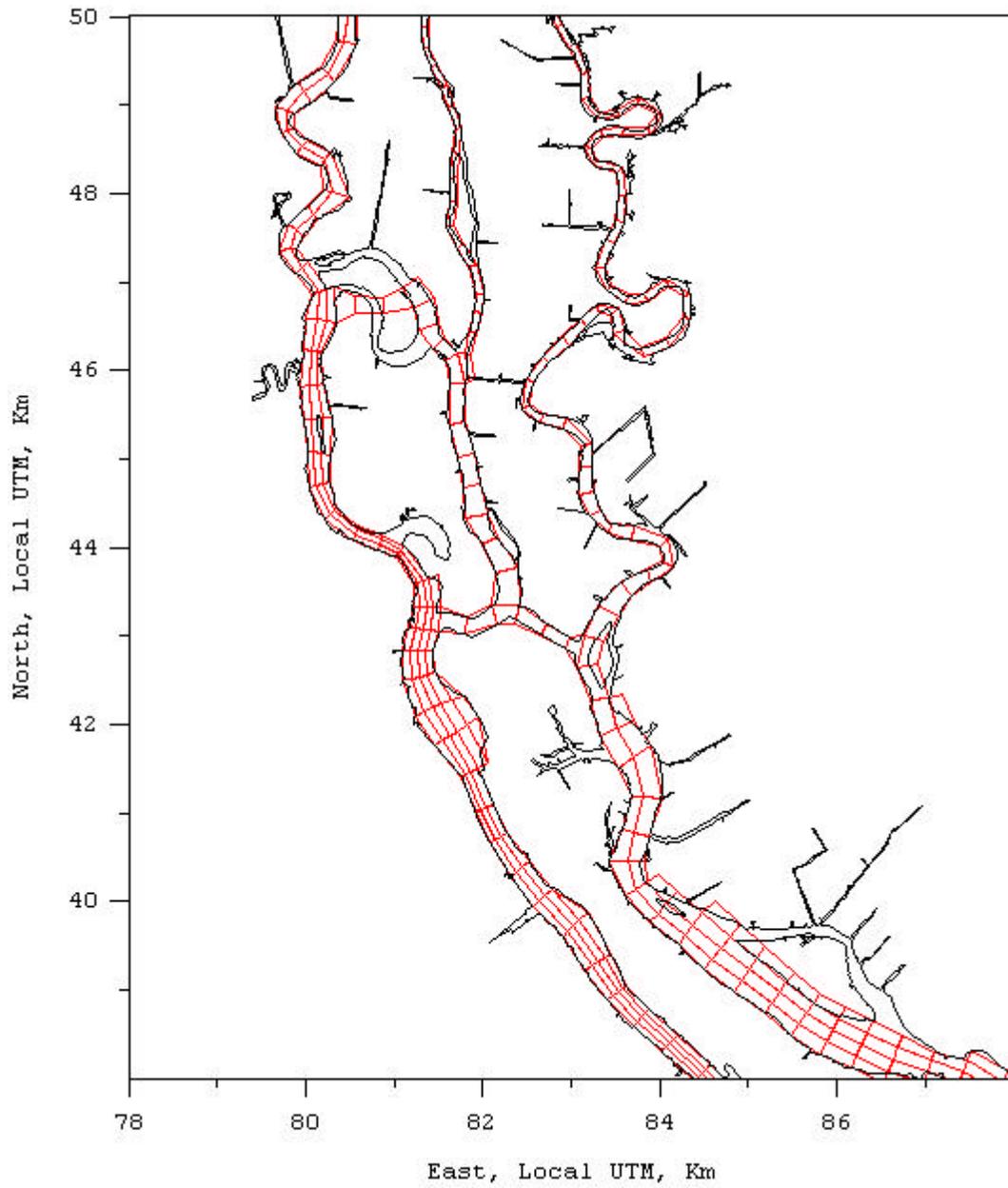


Figure L-4 Fine Grid of the Savannah River in the Vicinity of the Port

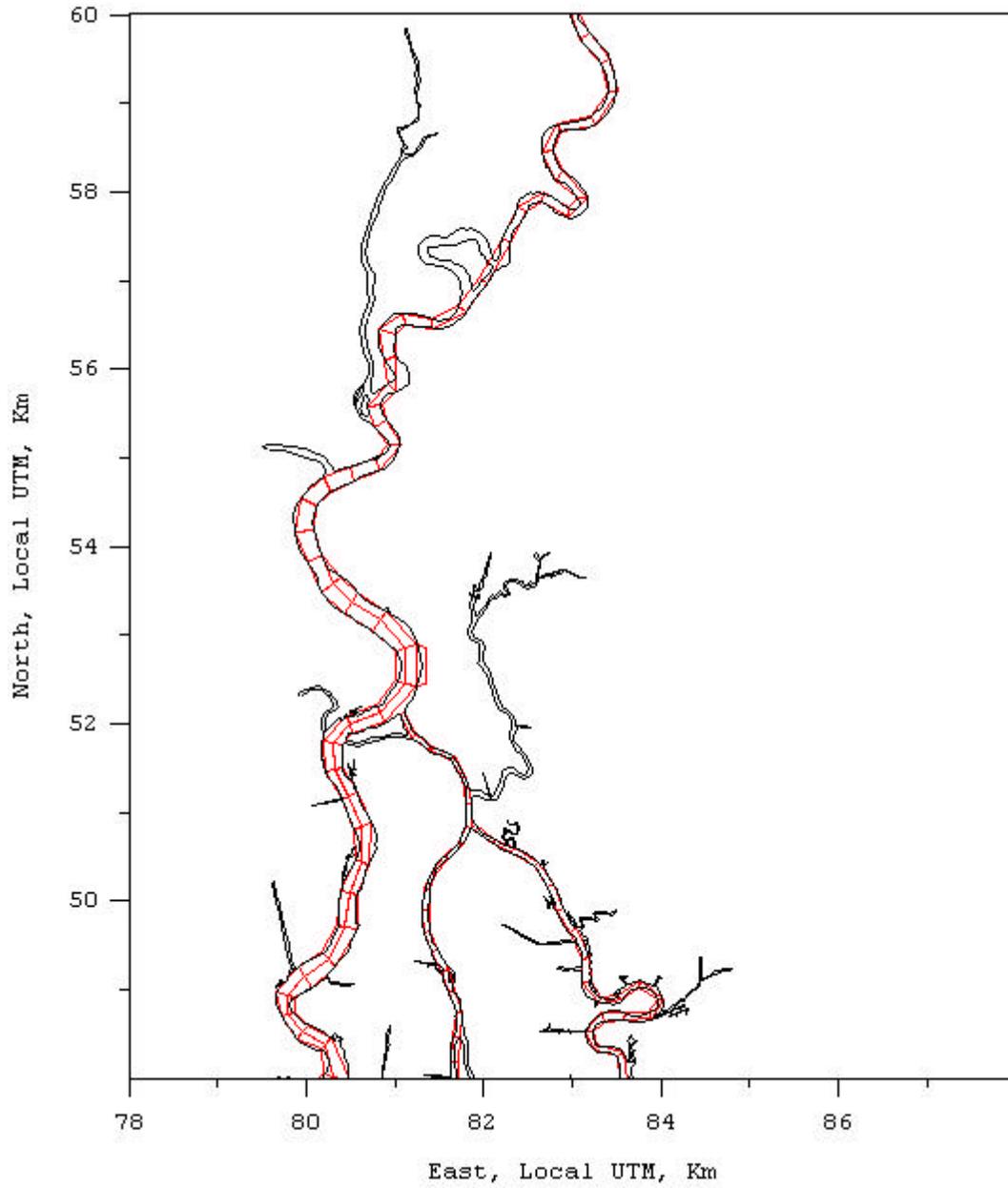


Figure L-5 Fine Grid of the Savannah River Upstream of the Port

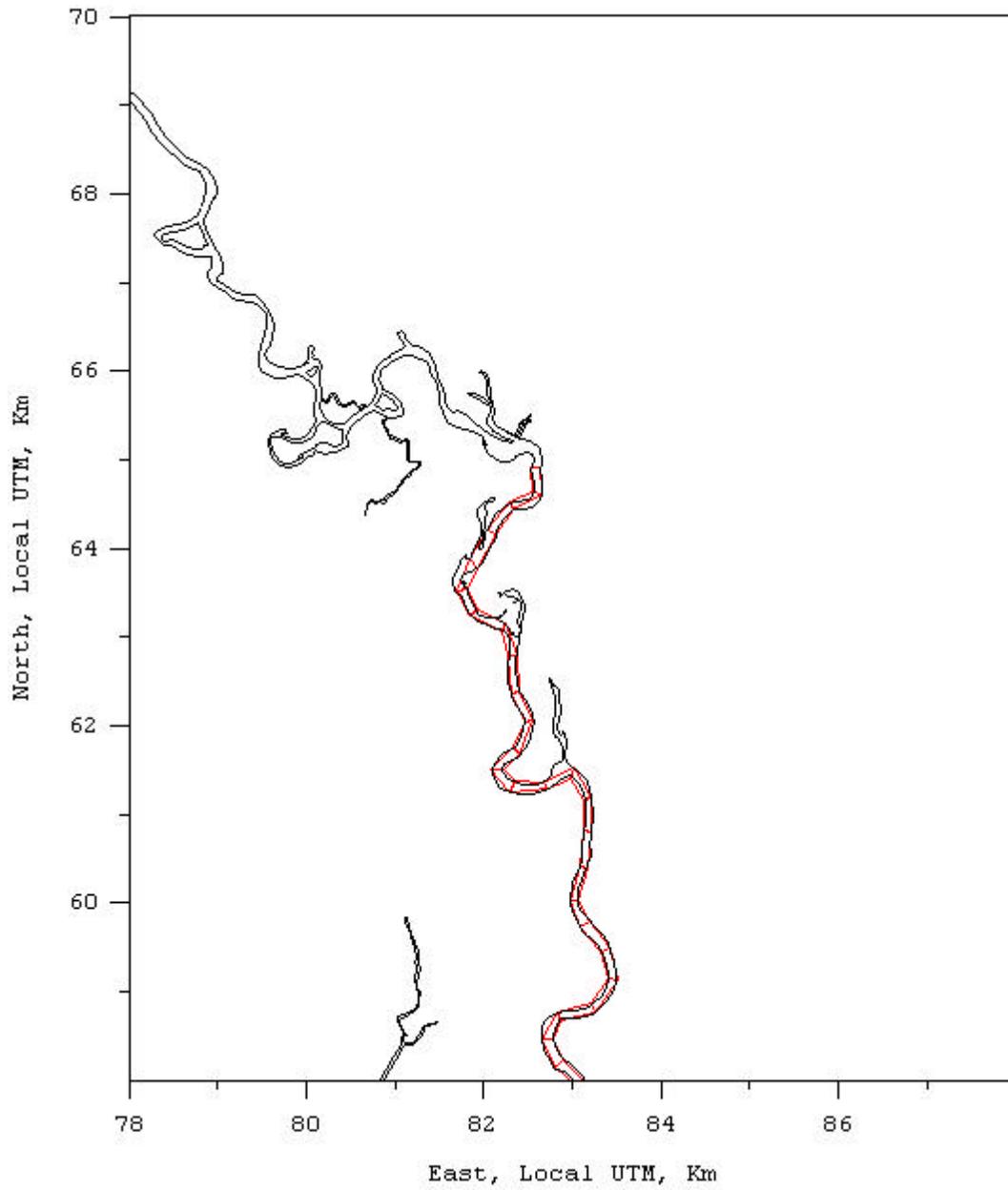


Figure L-6 Fine Grid of the Savannah River Below Clio

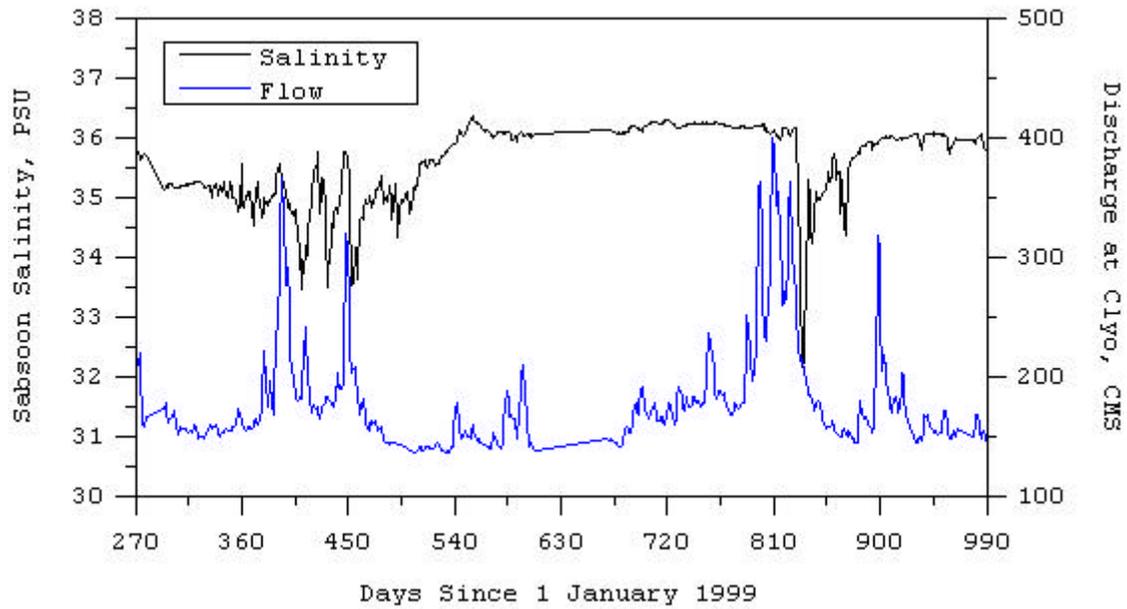


Figure L-7 Sabsoon station R2 salinity and Savannah River discharge at Clyo. Note salinity data is missing between approximately days 618 and 670.

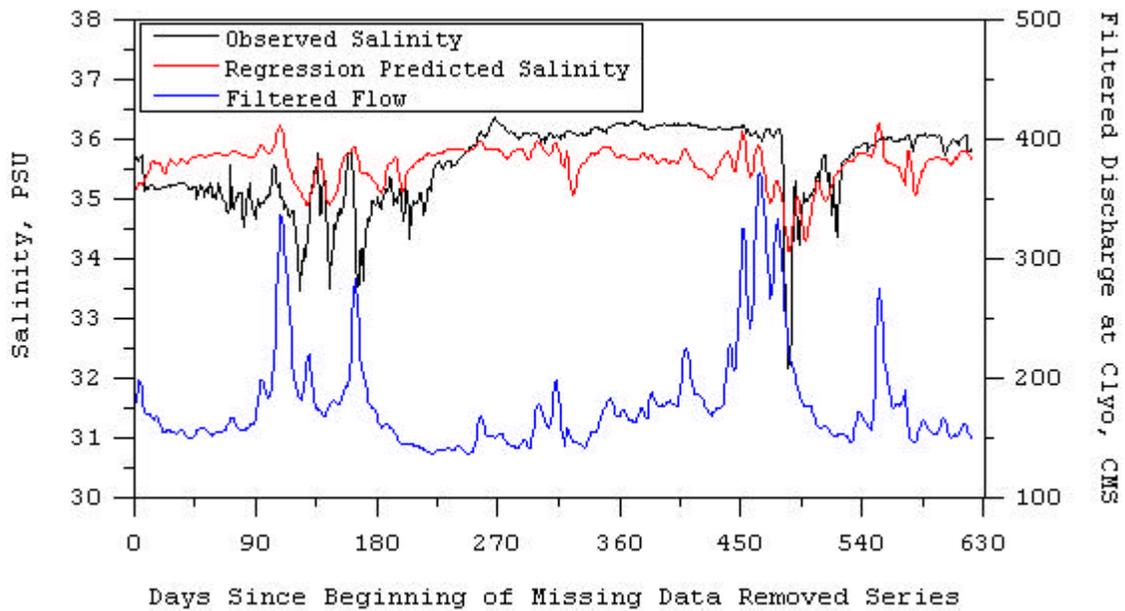


Figure L-8 Synthesized Sabsoon Station R2 Salinity and Clyo Flow with Missing Salinity Period Removed. Red line is Prediction of Sabsoon Salinity by Multiple Linear Regression.

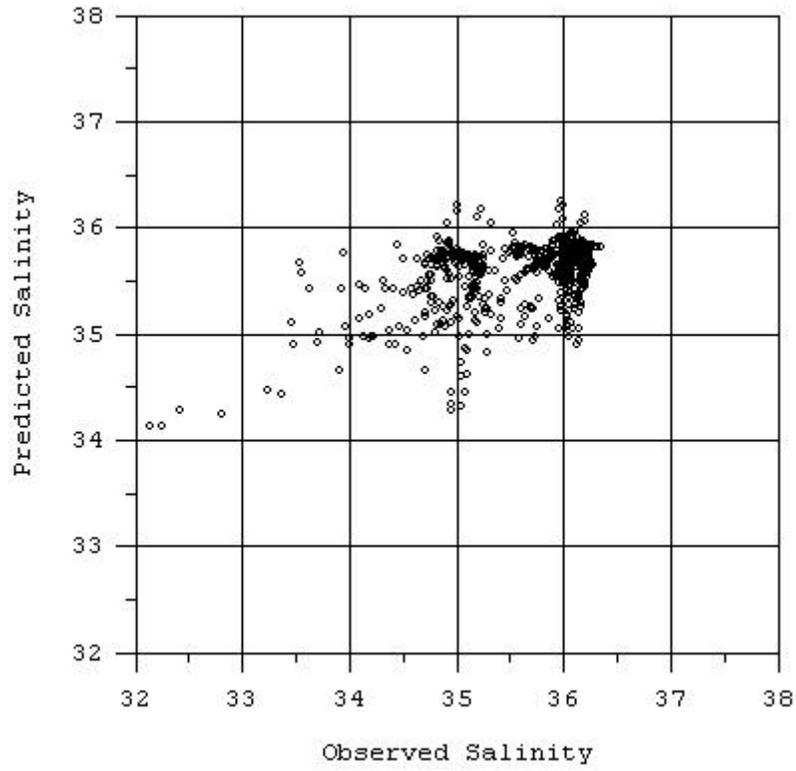


Figure L-9 Regression Predicted and Observed Sabsoon Station R2 Salinity

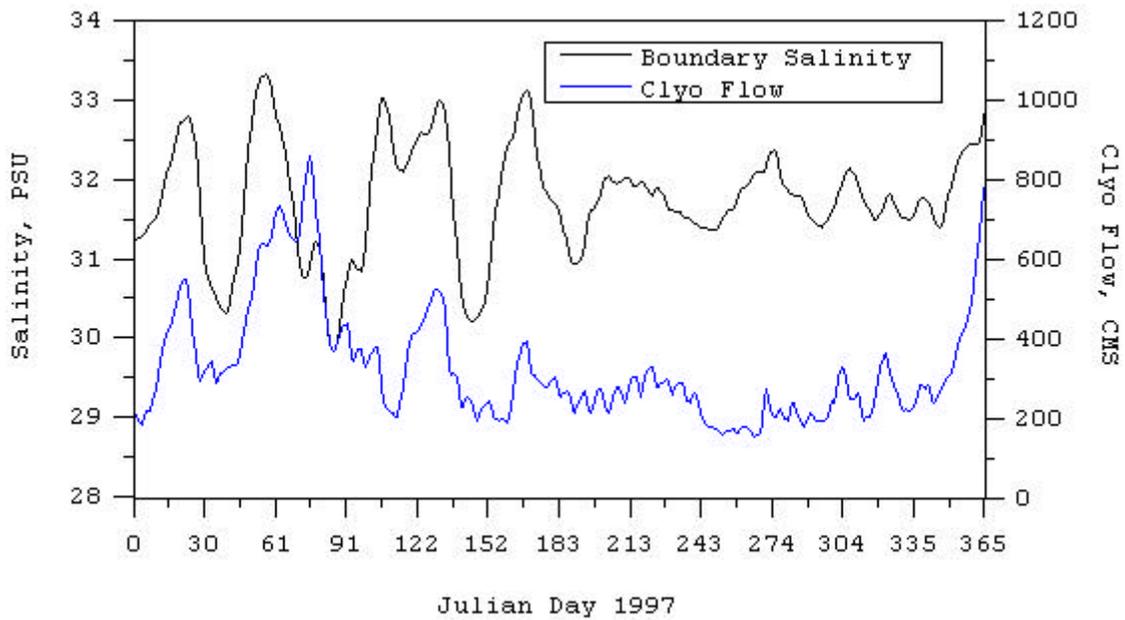


Figure L-10 Boundary Salinity used for 1997 Simulation Based on Adjusted Sabsoon Station R2 Salinity Regression

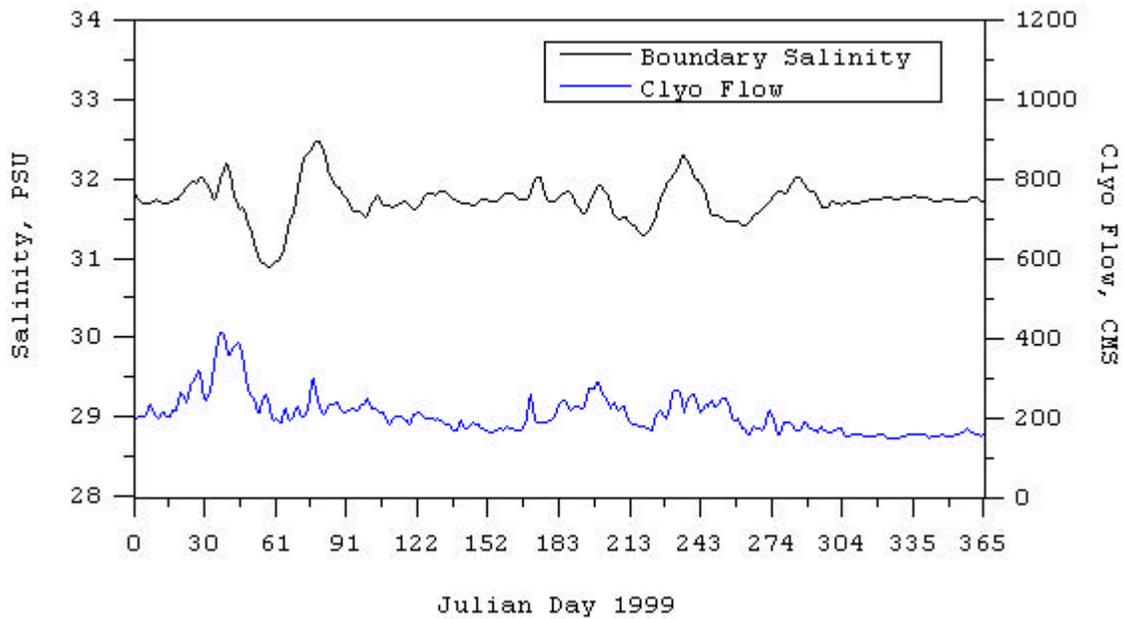


Figure L-11 Boundary Salinity used for 1999 Simulation Based on Adjusted Sabsoon Station R2 Salinity Regression

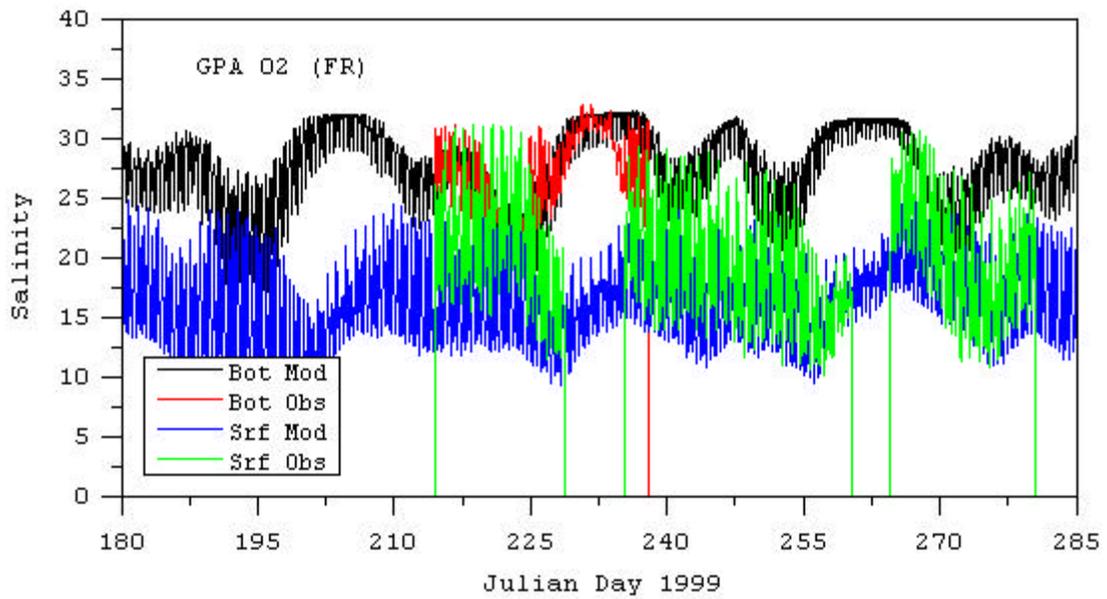
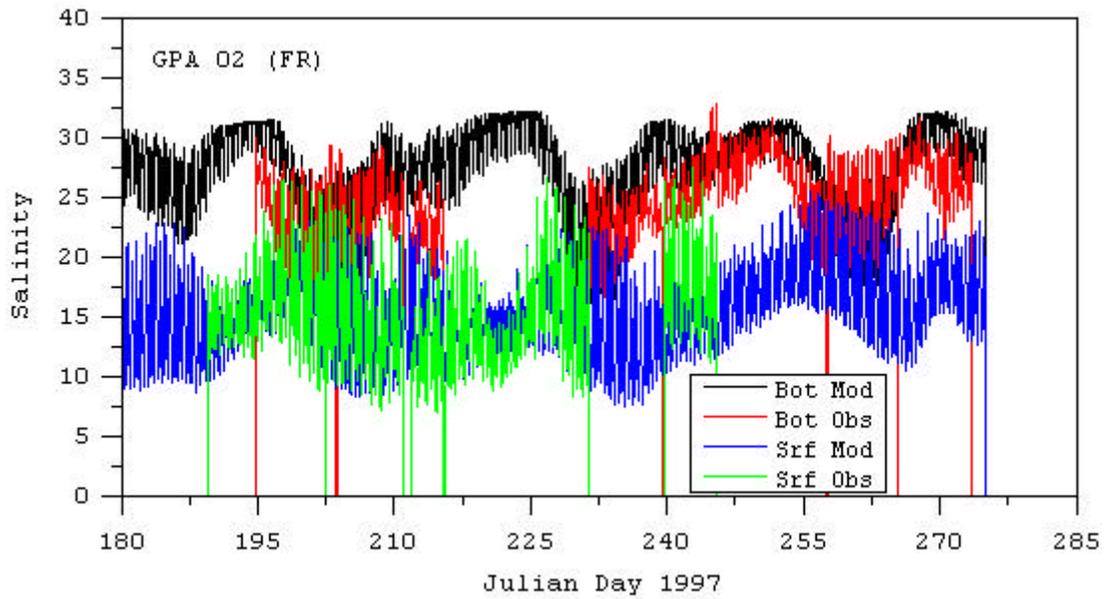


Figure L-12 Salinity at GPA 02 for 1997 and 1999

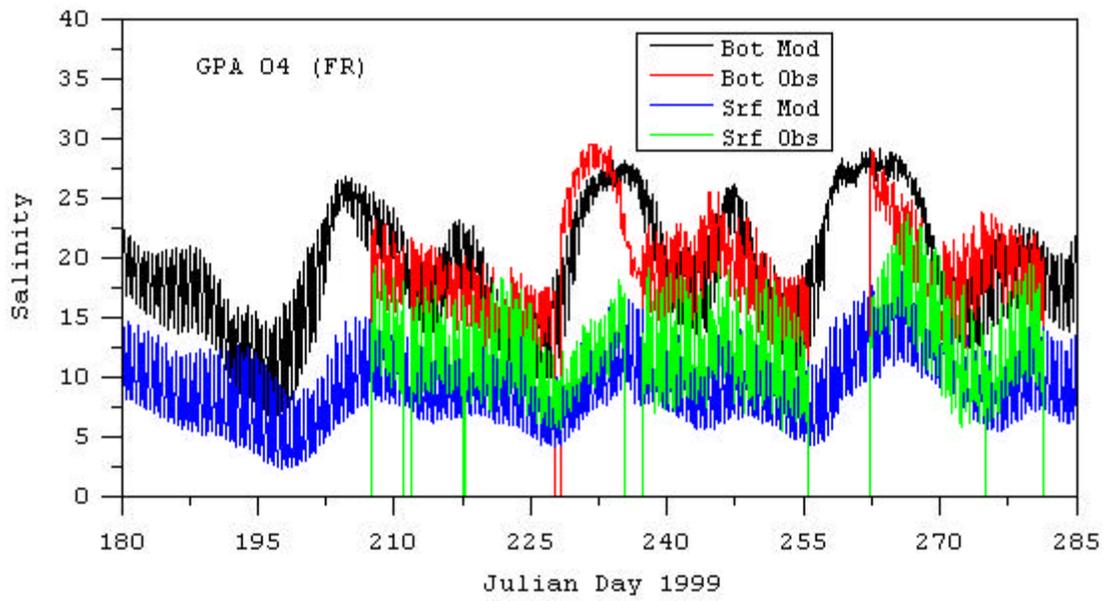
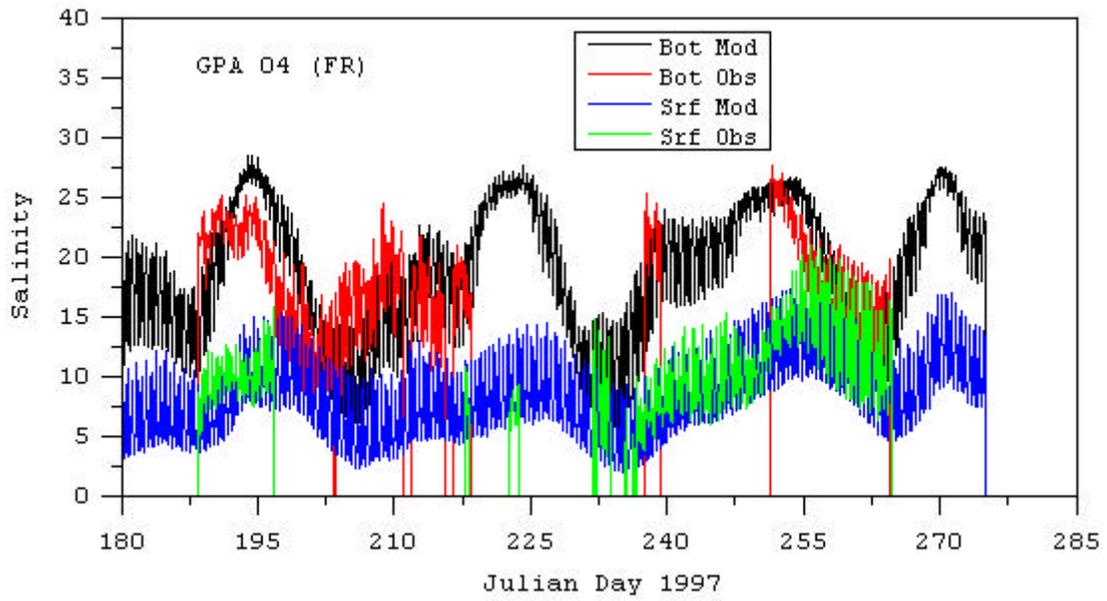


Figure L-13 Salinity at GPA 04 for 1997 and 1999

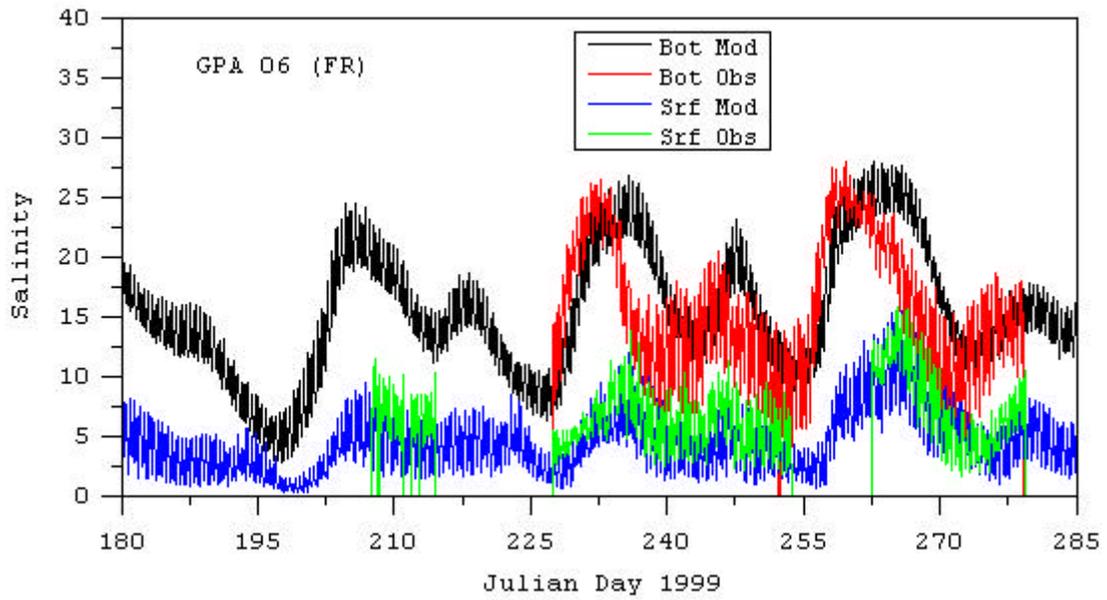
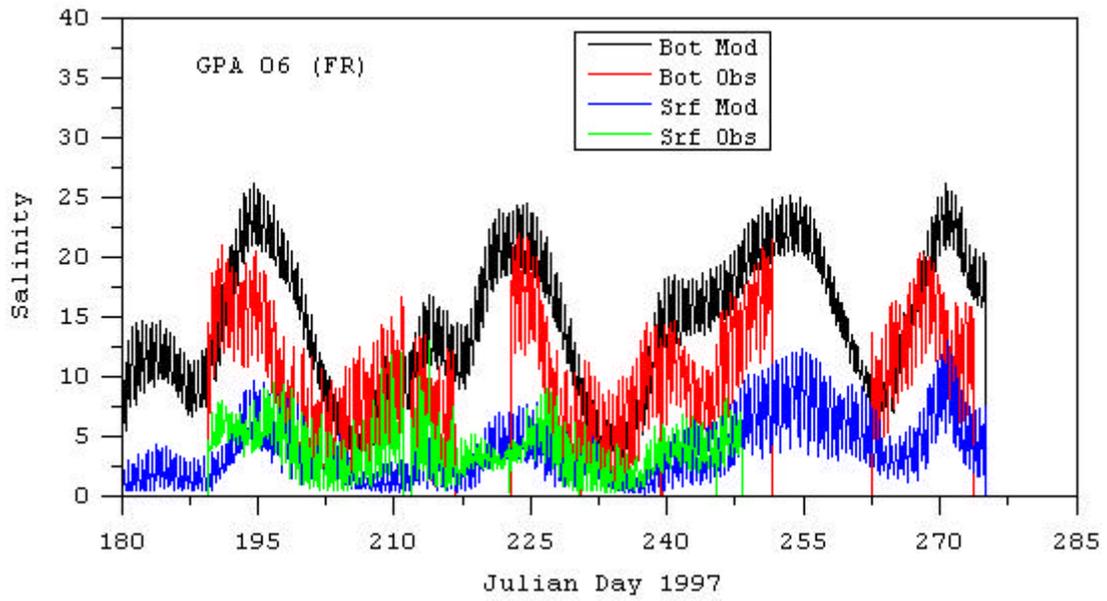


Figure L-14 Salinity at GPA 06 for 1997 and 1999

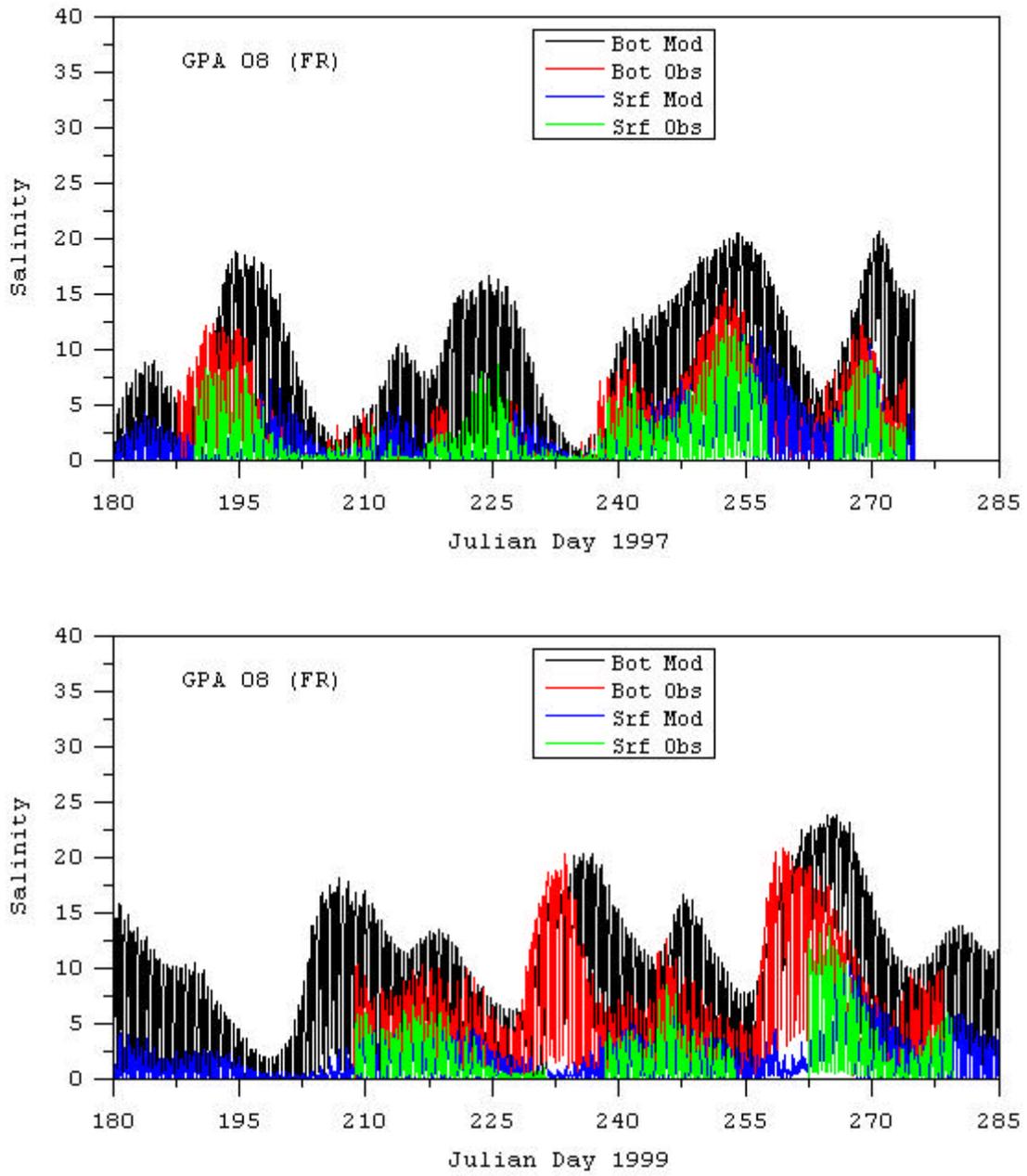


Figure L-15 Salinity at GPA 08 for 1997 and 1999

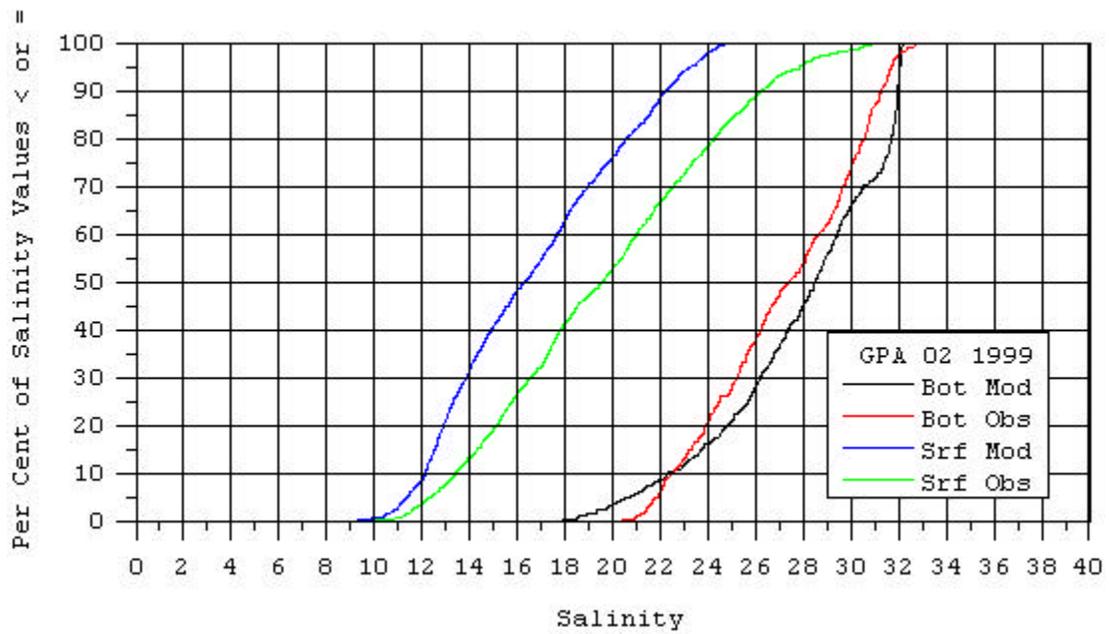
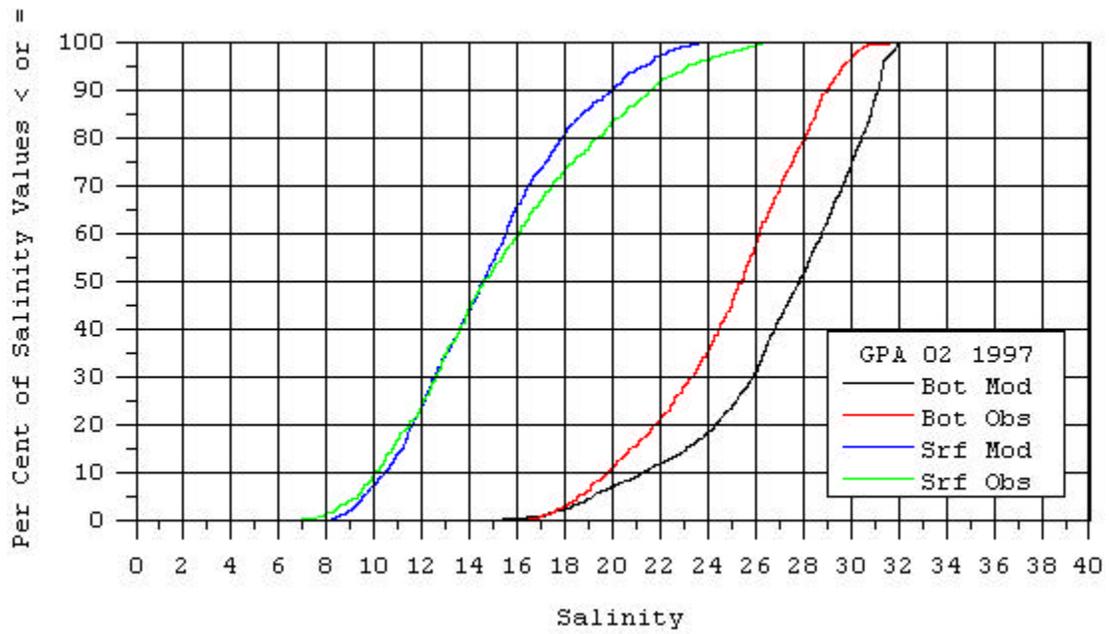


Figure L-16 Salinity Frequency Distribution at GPA 02 for 1997 and 1999

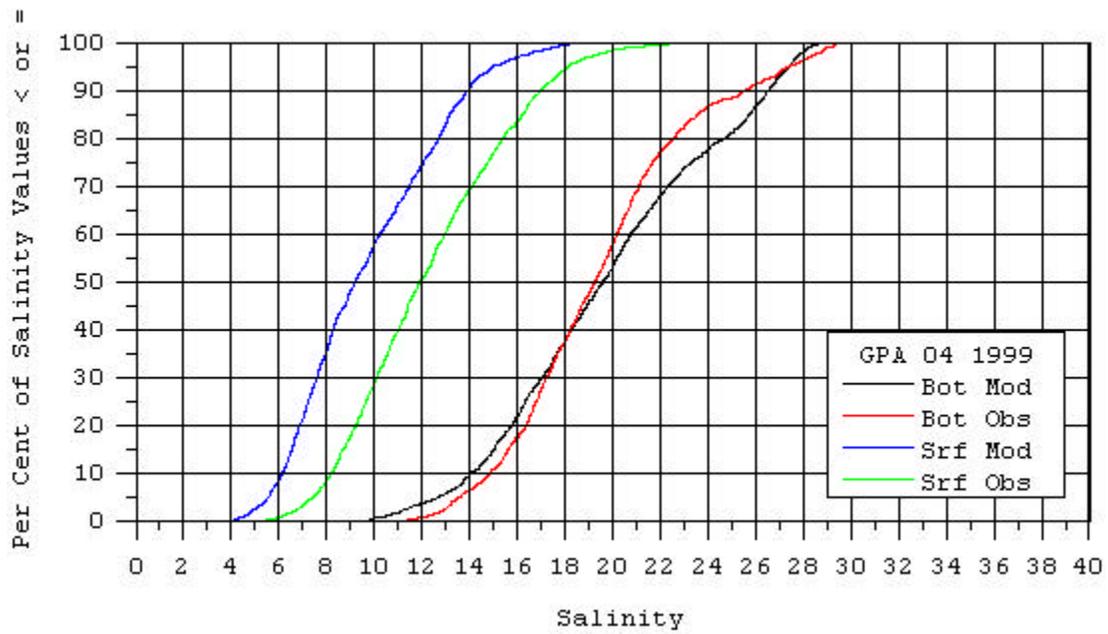
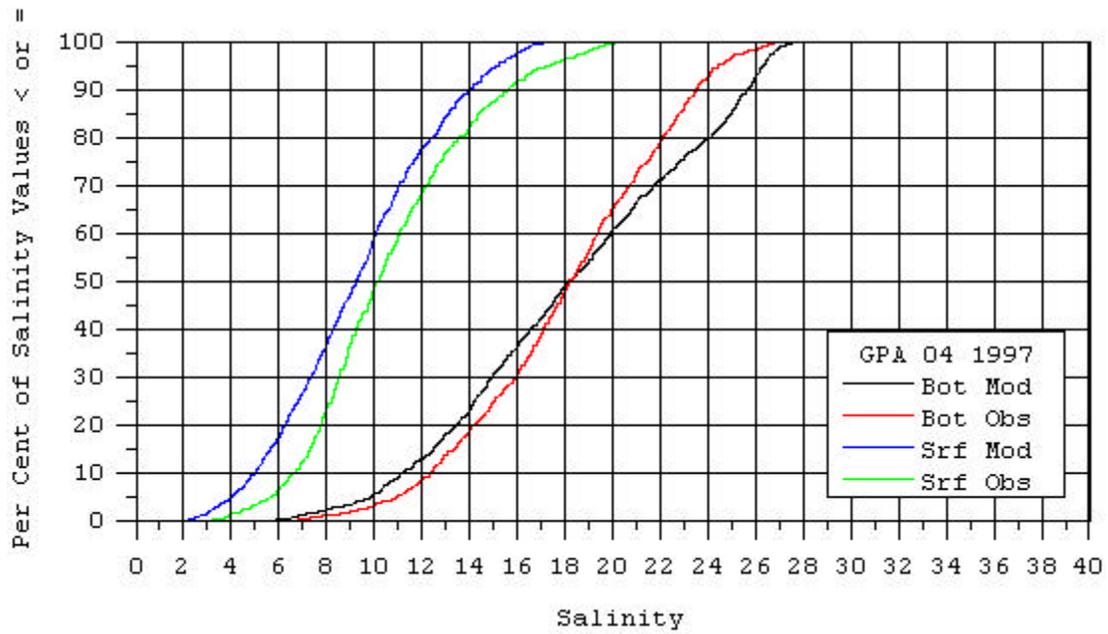


Figure L-17 Salinity Frequency Distribution at GPA 04 for 1997 and 1999

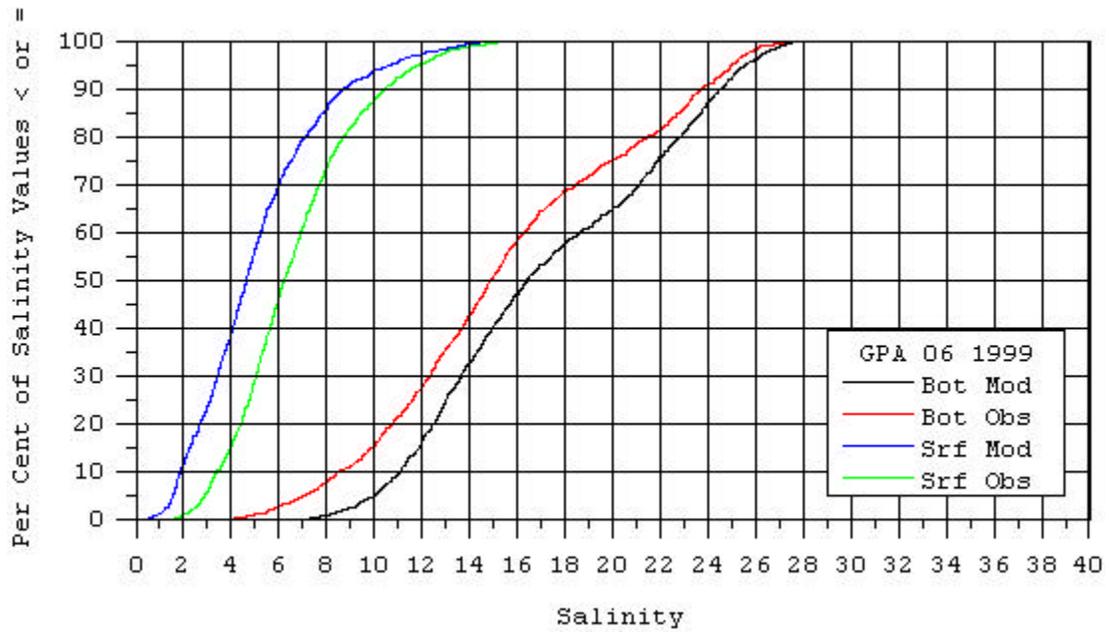
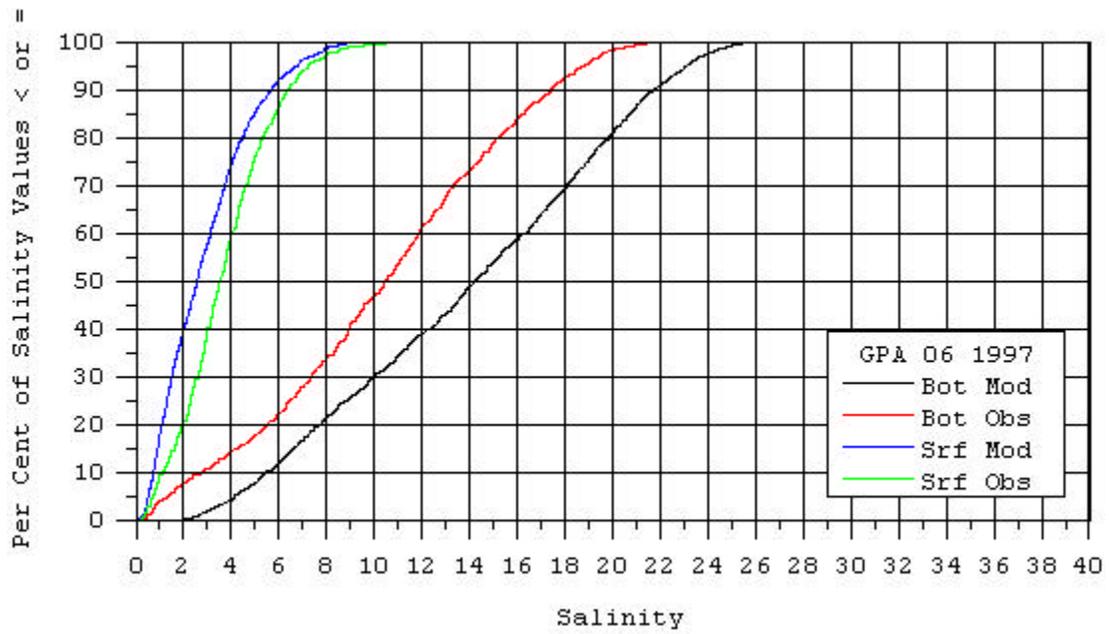


Figure L-18 Salinity Frequency Distribution at GPA 06 for 1997 and 1999

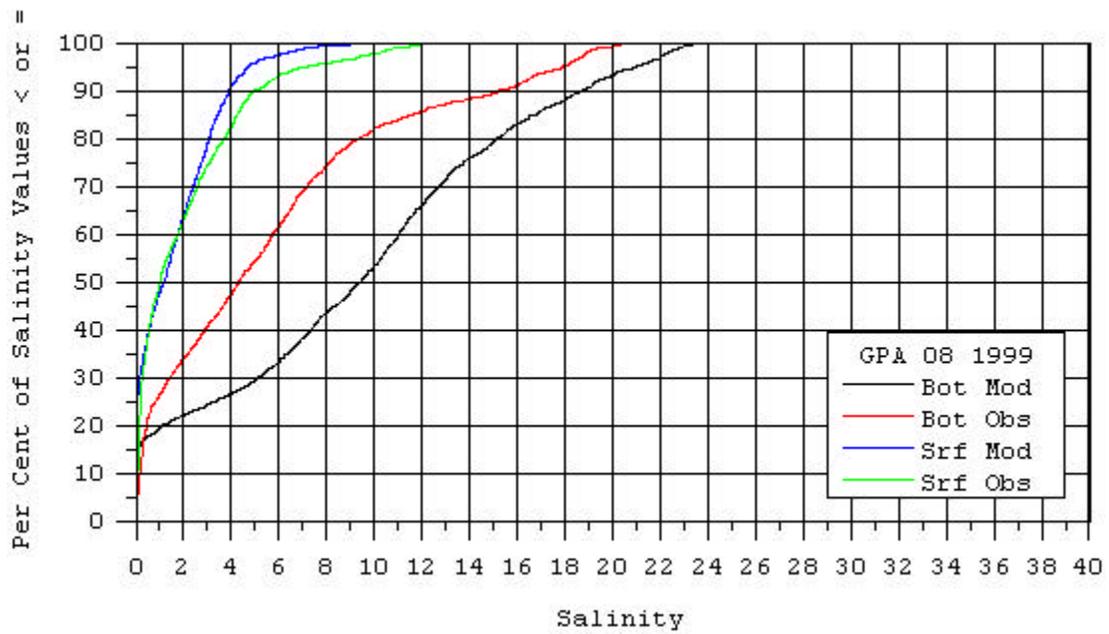
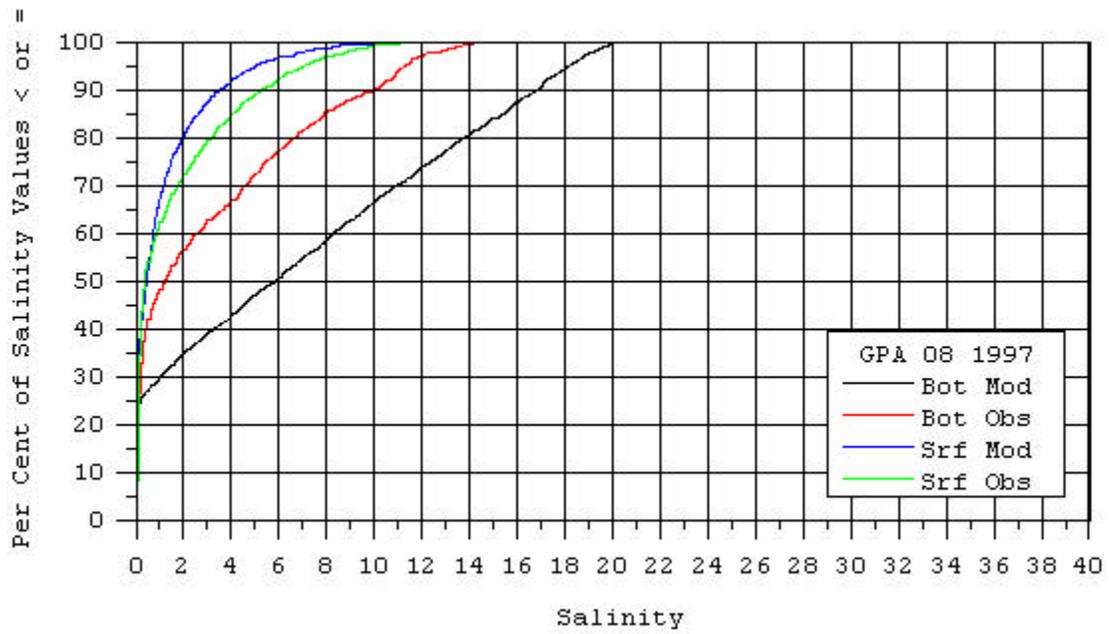


Figure L-19 Salinity Frequency Distribution at GPA 08 for 1997 and 1999