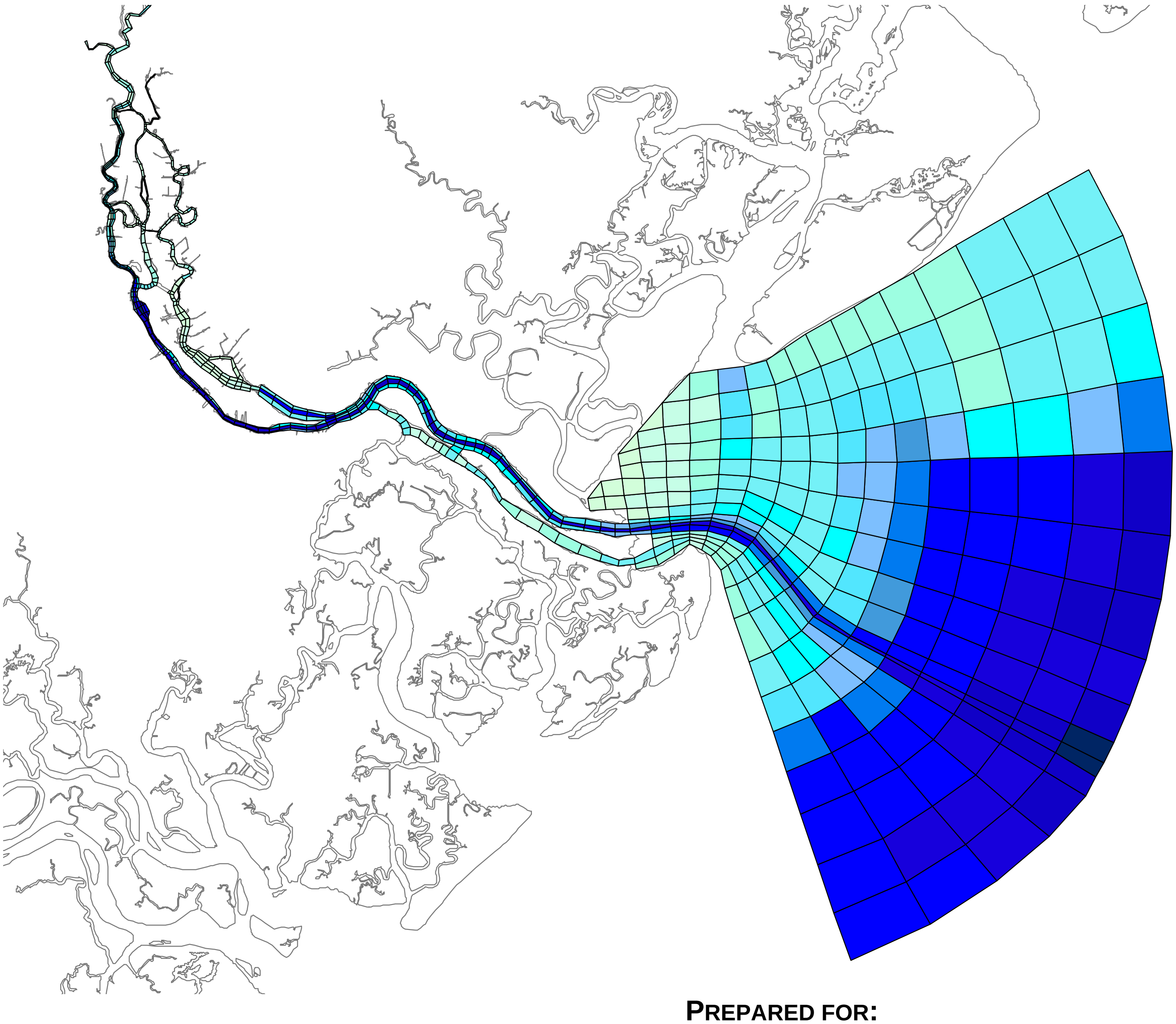
Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project



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There was a significant amount of review and comments on the first draft of the modeling report. The first draft of the model was distributed in August 2004 as part of the TMDL development for the harbor. The enhanced model for the Savannah Harbor Expansion (SHE) project was delivered on the following dates: February 7, 2005 (Draft), March 31, 2005 (Draft-Final), May 20, 2005 (Final), and this final version on January 30, 2006 (Final-Final). A special thank you is owed to the SHE Model Review Team for their patience and diligence during the peer review of these reports and of the EFDC and WASP models. The members are as follows:

- Paul Conrads, USGS-WRI-SC
- Jim Greenfield, US Environmental Protection Agency, Region 4
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- Bob Scanlon, City of Savannah Environmental Affairs
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Table of Contents

List of Figures

List of Tables

1.0 INTRODUCTION

Tetra Tech, Inc. (Tetra Tech) was contracted by the USACE Savannah District to enhance the existing three-dimensional hydrodynamic model (Environmental Fluid Dynamics Computer Code – EFDC) and the water quality model (Water Quality Analysis Simulation Program – WASP) application for the Savannah River and Harbor. Tetra Tech developed the EFDC hydrodynamic model and supported the United States Environmental Protection Agency (USEPA) Region 4 on the WASP model for developing the Total Maximum Daily Load (TMDL) for dissolved oxygen in the harbor.

The enhanced hydrodynamic and water quality models will be used to assess the environmental impacts of the Savannah Harbor Expansion (SHE) Project being led by the USACE Savannah District and the Georgia Ports Authority (GPA). The models are developed in consideration of the following efforts: (1) USACE Savannah Harbor Ecosystem Restoration Project, (2) finalization of the USEPA Region 4 Dissolved Oxygen TMDL, and (3) the states of Georgia and South Carolina issuing National Pollutant Discharge Elimination System (NPDES) permits. Therefore, federal and state agency review of model development and performance are critical to the success of using one model in Savannah Harbor. USEPA Region 4 is a Cooperating Agency for the SHE Project and has stated that these models will be adequate to evaluate water quality issues for the SHE Project.

USEPA Region 4 issued the draft dissolved oxygen TMDL on August 30, 2004 and the public notice/comment period ended on January 31, 2005. The TMDL models were run on a coarse grid in which the EFDC hydrodynamic and the WASP water quality models were applied. The coarse grid, now referred to as the TMDL grid, was documented in a report (Tetra Tech, 2004) and met the following objectives defined by USEPA:

- To represent accurately the key hydrodynamic processes of transport in the estuary,
- To utilize a model that is public domain and has been peer reviewed,
- To deliver the model to the federal agencies involved in the TMDL process,
- To run the model for multiple hydrologic periods and evaluate point and nonpoint sources, and
- To complete the effort in a timely manner in order to meet the project schedule.

The effort to develop an enhanced grid was initiated on September 29, 2004 to improve the representation of the estuary system and navigation channel from the TMDL grid. The enhanced grid is designed to allow evaluation of various scenarios such as deepening of the navigation channel and physical modifications to certain cuts and channels in the river and estuary. The major enhancements included developing a finer model grid, updating the bathymetric data used by the model, and an alternate approach for the model calculation of the river-marsh interactions. The same models, EFDC and WASP, were used on the TMDL grid and the enhanced grid.

This report includes both the hydrodynamic and water quality modeling results along with calibration and confirmation periods. The calibration of the models was performed to the summer of 1999 data, the period with the most comprehensive dataset. The confirmation of the model was performed to the summer of 1997 data and the USGS long-term data from January 1, 1997 through December 31, 2003.

The model applications described herein have been designed to meet the expectations of the model review team consisting of federal and state agencies. The model code, modeling results, in both time series and statistical formats, and a database, which contains all comparison data were also made available for peer review. Ultimately, the goals of the hydrodynamic and water quality models were to produce defensible, accurate, and logistical tools that the federal and state agencies could use to make management decisions for the Savannah Harbor and Savannah River Estuary.

1.1 Modeling Study Goals

The work presented in this report had two primary goals: (Task A) to modify and recalibrate the EFDC model and (Task B) to re-evaluate the calibration of the WASP water quality model, if needed, because of revisions to the EFDC hydrodynamic model. The objectives of Task A were to modify the EFDC model to improve the grid resolution, tidal-marsh interaction, and boundary conditions in response to issues raised during the SHE Project federal and state technical review of the initial calibration report on the EFDC portion of the TMDL grid. The objective of Task B was to re-evaluate the calibration of the WASP model for use in predicting dissolved oxygen in the harbor and use in future SHE Project alternatives. The USACE Savannah District along with the federal agencies believed that modifications to the TMDL grid of the EFDC and WASP models might enhance the TMDL Models' capabilities.

1.2 Coordination with the Water Quality Model Calibration

Selection of the hydrodynamic model was determined with the intent of linking the hydrodynamics (EFDC) to the water quality model (WASP). The parameters that the EFDC transfers to the WASP simulation are volume, depth, dispersion, salinity, temperature, and vertical mixing parameters. 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. For the new version of WASP (Version 7), the hydrodynamic linkage file has been further compressed in binary form so that file management of longer runs can be more efficient.

1.3 Report Contents

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

- Modeling report in PDF format,
- EFDC model code,
- EFDC model input files,
- EFDC model output for calibration period (1999 summer),
- WASP setup with MOVEM post-processor,
- WASP project file,
- WASP model output for calibration period (1999 summer),
- Database files of calibration data, and
- GIS shape files.

The MOVEM post-processor allows technical reviewers to view the model results anywhere in the model domain and compare with measured data. MOVEM also has the capability to calculate statistics, including percentiles, and animate results in the model grid. For calculating statistics, MOVEM can focus on defined time periods to generate results. The datasets included on the compacts discs are for the summers of 1997 and 1999 as well as the United States Geological Survey (USGS) data for January 1, 1997 through December 31, 2003.

1.4 Project Location

The model application described in this report is located near Savannah, Georgia and is on the border between Georgia and South Carolina as shown in Figure 1-1. The enhanced model grid 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 17 miles offshore from Oysterbed Island to cover the navigational channel of Savannah Harbor. This results in the model covering 78 miles or river, estuary, and ocean.

The modeling study area includes 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.

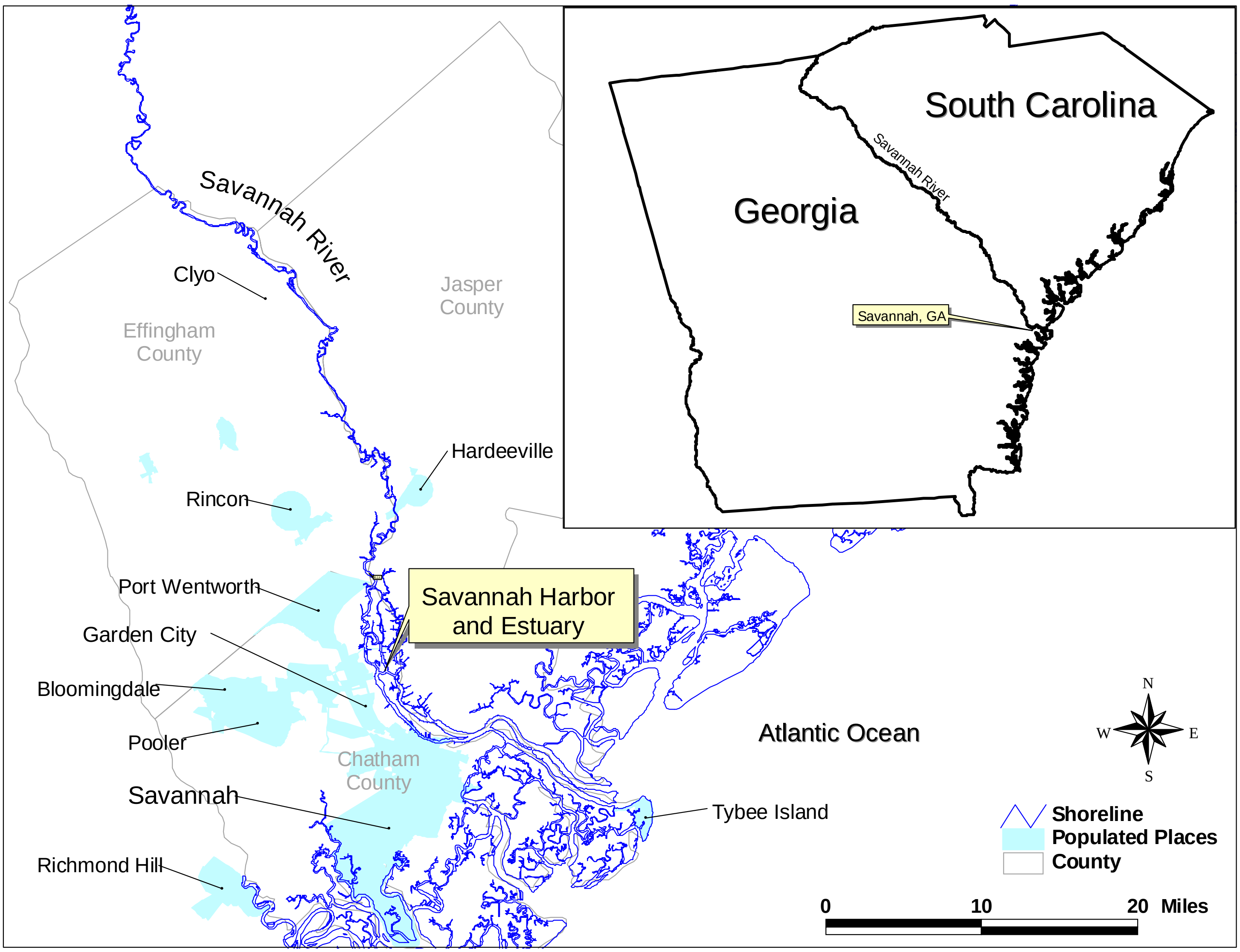


Figure 1-1 Project Location Map of the Savannah Harbor and Estuary

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. for GPA (ATM, 2000). MACTEC also has collected analyzed data in the harbor, specifically the longterm BOD (LTBOD) data, for the City of Savannah, Harbor Committee, and the USACE Savannah District. MACTEC performed the Wastewater Characterization Study in 1999 and also collected offshore samples in September 2003. These data will be discussed later in the Water Quality sections.

2.1 Location of Stations

The main stations used in the calibration and confirmation are from the GPA studies conducted 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	Description	River Mile	Parameters	1997 Location[1]	1999 Location[1]	Lat	Long
GPA							
FR-26	Front River at Fort Pulaski	0.8	S, T, WL, DO		S & B	32.0363	-80.9001
FR-02	Front River in the Entrance Channel	4.5	S, T, WL, DO	S & B	S & B	32.0665	-80.9526
SC-03	South Channel	5.5	S, T, WL, DO	Bottom	Bottom	32.0622	-80.9662
FR-04	Front River near Fort Jackson	10.4	S, T, WL, C, DO	S & B	S & B	32.0890	-81.0268
FR-21	Front River at USACE Depot	13.9	S, T, WL, DO		S & B	32.0794	-81.0782
BR-05	Back River at Hwy 17	14.5	S, T, WL, DO	Bottom	Bottom	32.1000	-81.0898
FR-06	Front River upstream of Talmadge Br	16.6	S, T, WL, C, DO	S & B	S & B	32.0964	-81.1074
FR-22	Front River at K.I. Turning Basin	18.7	S, T, WL, DO		S & B	32.1286	-81.1366
BR-07	Back River	18.9	S, T, WL, DO	Bottom	Surface	32.1464	-81.1182
FR-08	Front River	20.5	S, T, WL, C, DO	S & B	S & B	32.1500	-81.1443
LBR-15	Little Back River at Houlihan Bridge	20.9	S, T, DO	Mid-Depth	Surface	32.1654	-81.1296
FR-09	Front River at Houlihan Bridge	21.5	S, T, WL, DO	Bottom	S & B	32.1653	-81.1553
MR-10	Middle River at Houlihan Bridge	21.8	S, T, DO	Bottom	Surface	32.1653	-81.1384
FR-11	Front River	24.7	S, T, WL, DO	Bottom		32.2008	-81.1517
FR-11R	Front River, Revised 1999	23.4	S, T, WL, DO		Bottom	32.1866	-81.1525
MR-12	Middle River	24.4	S, T, WL, DO	Bottom		32.2012	-81.1412
MR-12R	Middle River, Revised 1999	23.7	S, T, DO		Surface	32.1946	-81.1384
LBR-13	Little Back River	26.6	S, T, WL, DO	Bottom		32.2048	-81.1262
SR-14	Savannah River	27.7	S, T, WL, DO	Bottom	Bottom	32.2347	-81.1500
USGS Stations							
02198980	Front River at Fort Pulaski	0.8	WL	Mid-Depth[2]	Mid-Depth[2]	32.0341	-80.9032
02198977	Front River at Broad Street	14.6	WL	Mid-Depth[2]	Mid-Depth[2]	32.0839	-81.0958
02198920	Front River at Houlihan Bridge	21.5	S, WL	Mid-Depth[2]	Mid-Depth[2]	32.1660	-81.1512
021989791	Little Back River at USF&W Dock	22.1	S	Mid-Depth[2]	Mid-Depth[2]	32.1708	-81.1182
02198979	Little Back River at Limehouse Cr	24.1	WL	Mid-Depth[2]	Mid-Depth[2]	32.1849	-81.1171
021989784	Little Back River at Lucknow Canal	24.2	S	Mid-Depth[2]	Mid-Depth[2]	32.1858	-81.1179
02198840	Savannah River at I-95 Bridge	27.7	S, WL	Mid-Depth[2]	Mid-Depth[2]	32.2358	-81.1512
02198500	Savannah River near Clyo, GA	61.0	Q	Mid-Depth[2]	Mid-Depth[2]	32.5281	-81.2689

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

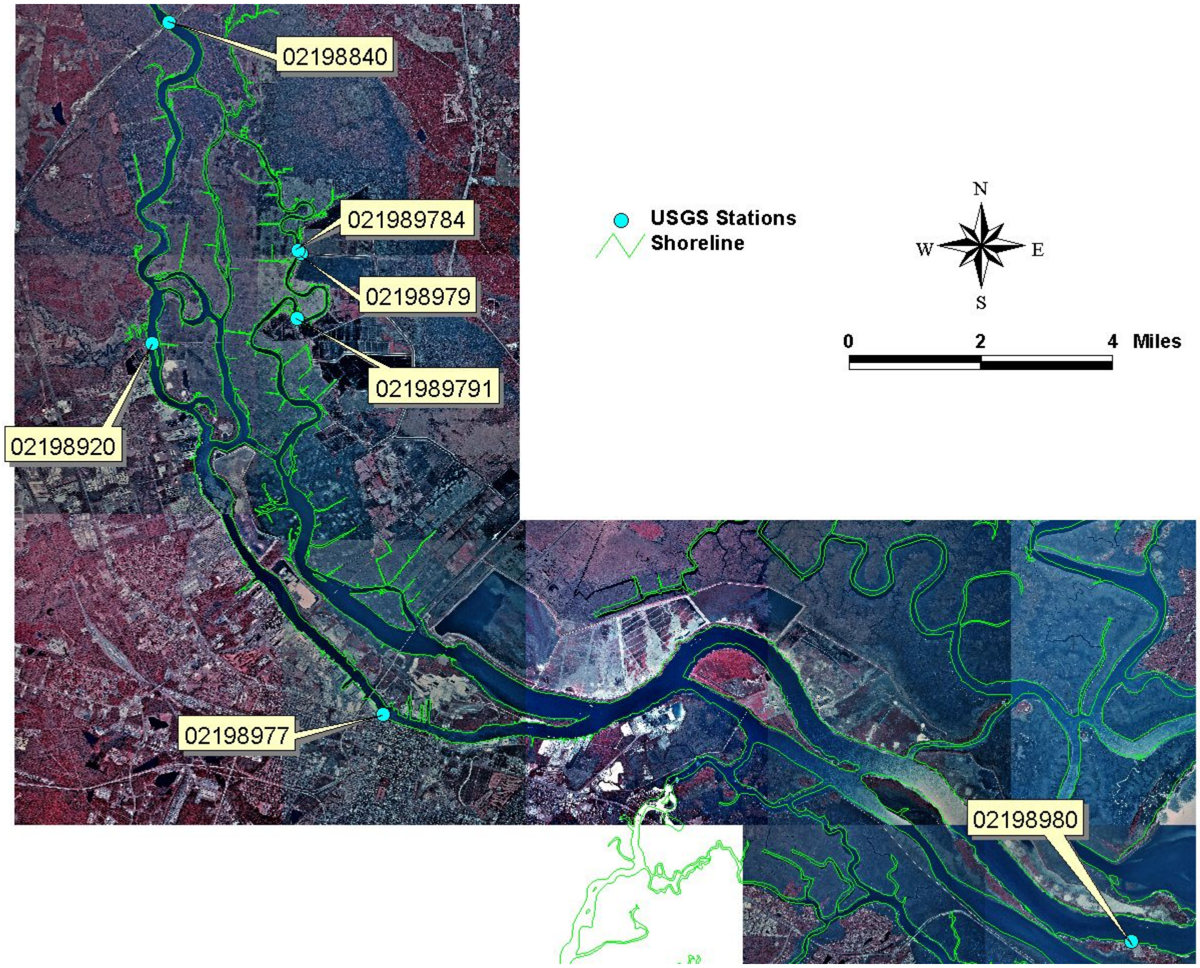


Figure 2-1 Location Map of USGS Stations in the Savannah Harbor Estuary

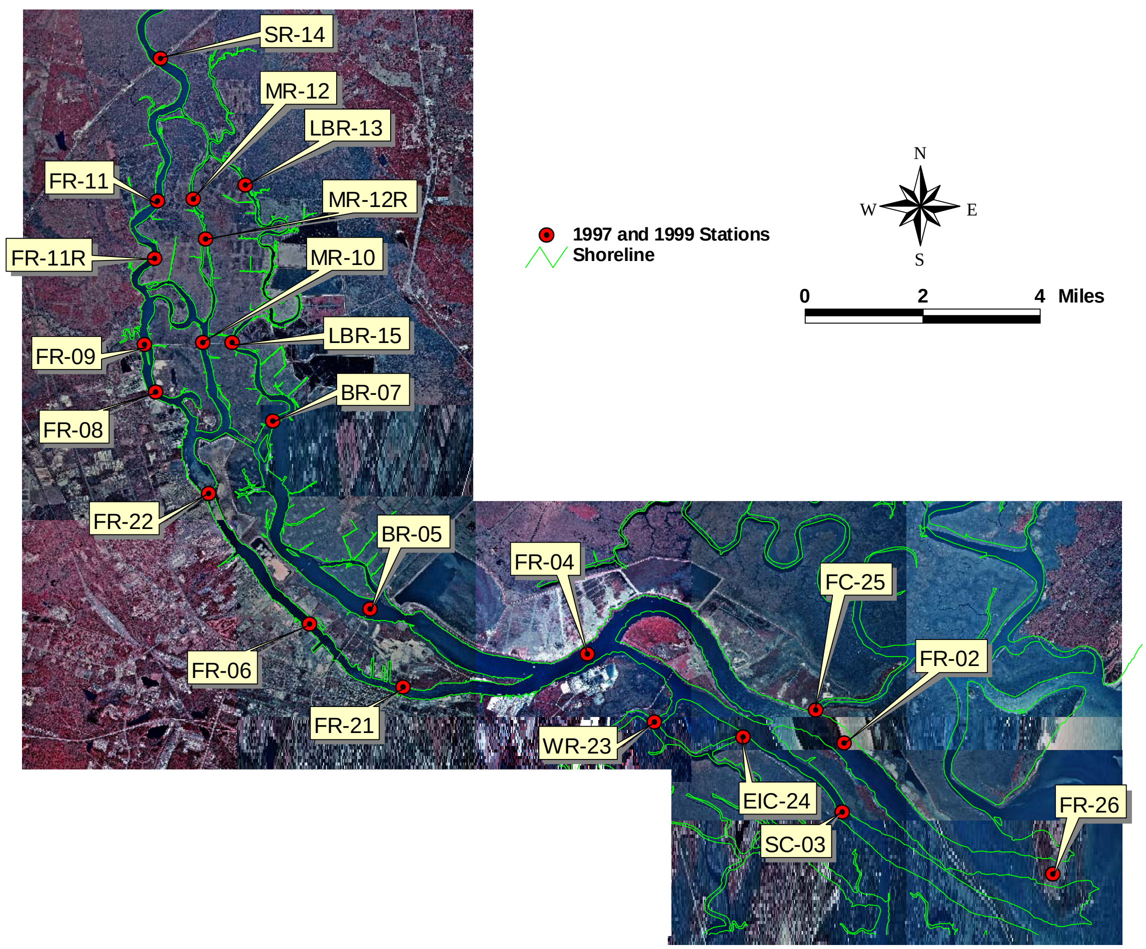


Figure 2-2 Location Map of 1997 & 1999 Stations in the Savannah Harbor Estuary

2.2 Database

The Water Resources Database (WRDB) was used to archive, analyze, and export water quality data for the hydrodynamic and water quality models. 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 (ATM, 2000). 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. A new WRDB database was developed to coincide with the final models. Additionally, the USGS data from 1997 through 2003 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).

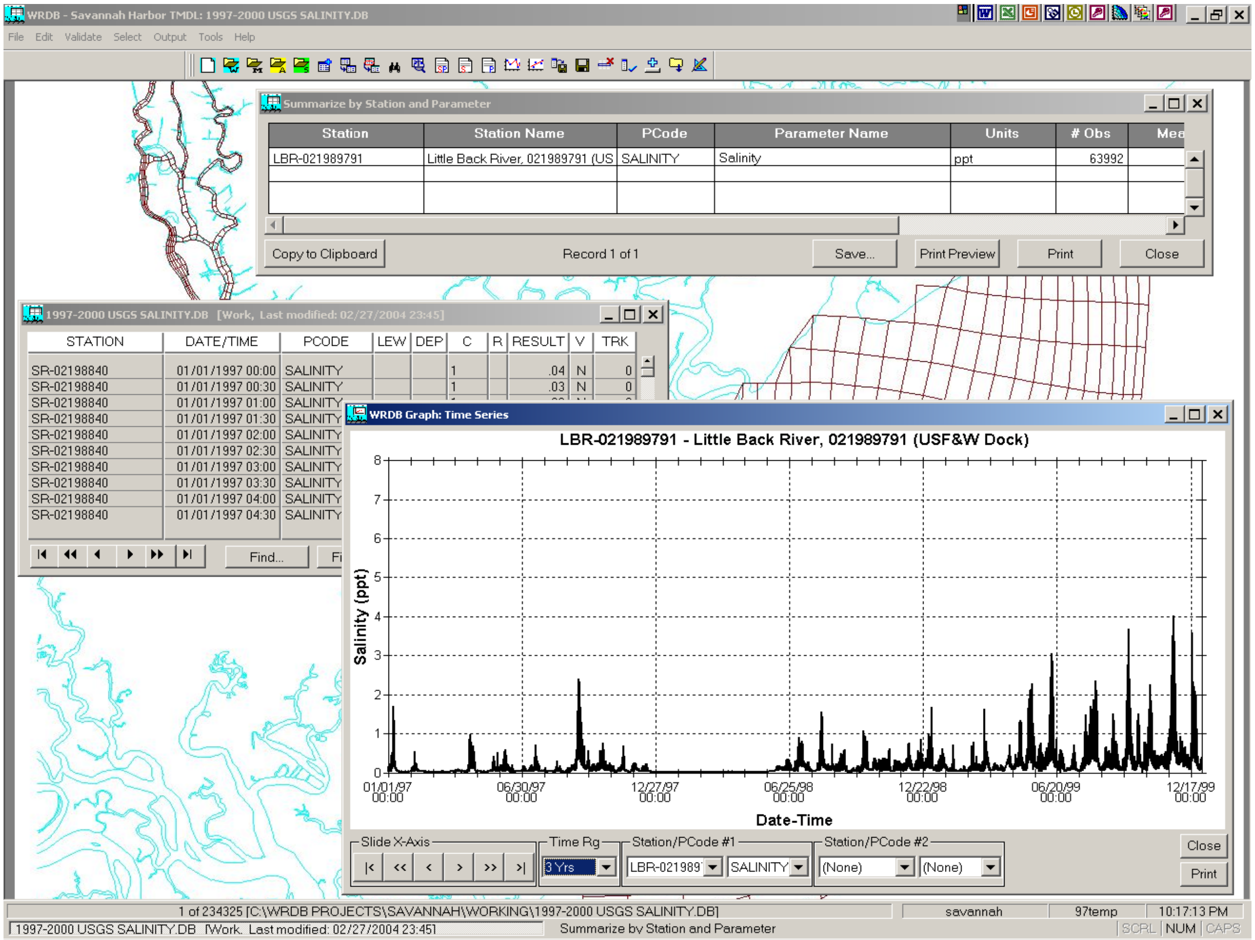


Figure 2-3 WRDB Developed for Savannah Harbor

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 primarily regulated by Thurmond Dam (river mile 237.7) (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. As shown in Figure 2-4, flow input data includes both high and low flow periods, covering flow ranging from roughly 5,000 to 50,000 cfs as measured at Clyo.

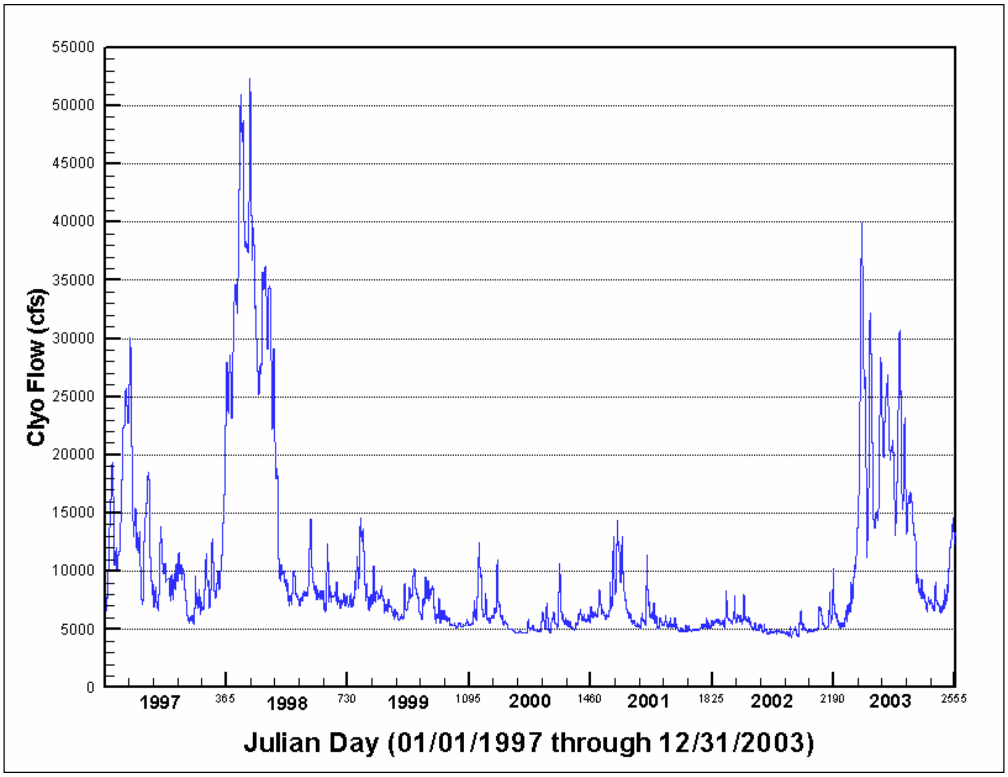


Figure 2-4 Clyo Flow Data for Model Development Period

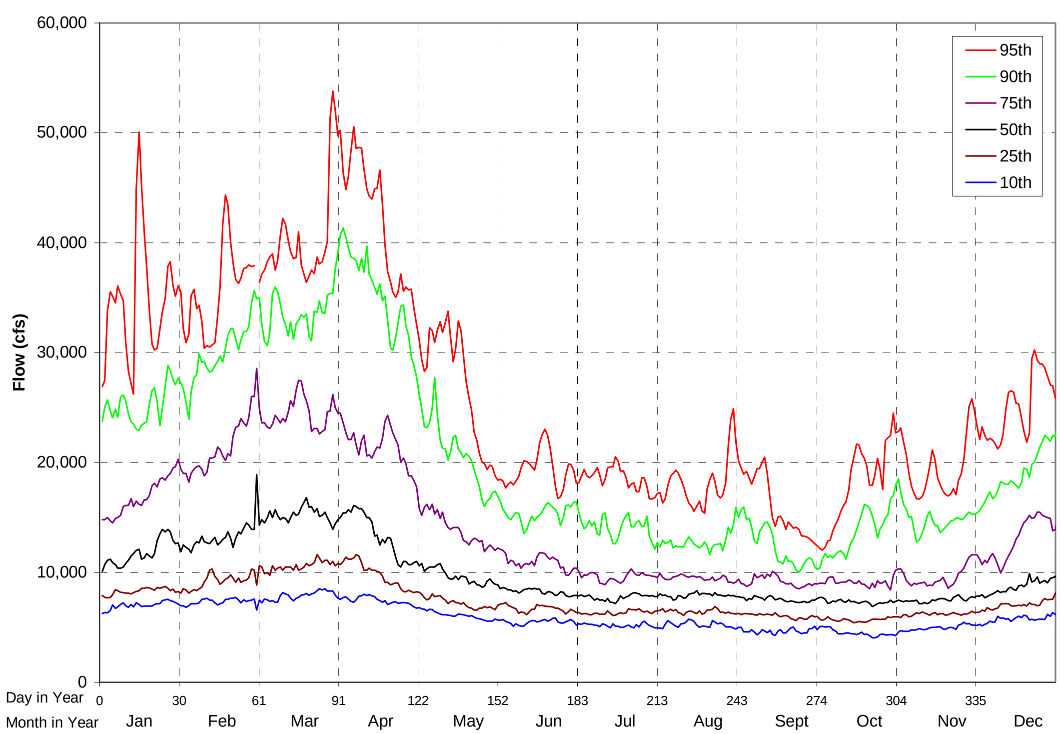


Figure 2-5 Clyo Flow Percentiles for the Period of Record (1929 to present)

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 River Estuary. In the EFDC TMDL model report (Tetra Tech, 2004), the model results were compared to observed data evaluating whether the M2 component of the tide's observed data and model show standing wave characteristics (velocity and water surface elevation 90 degrees out of phase) or progressive wave characteristics (velocity and water surface elevation in phase). As a result of the complexity of marshes and multiple channels in the Savannah River Estuary, the tidal wave on the Front River can neither be classified as a pure progressive wave nor a pure standing wave. The system's resultant wave is a combination of multiple components of reflected and standing waves, and in some cases exhibiting resonance characterized by multiple velocity peaks in the same flood or ebb tide. Observed flood tide peak velocities lead peak water surface elevation in a range from 40 to 90 degrees in the deeper, downstream site FR-04; and 20 to 90 degrees in the shallower, upstream site FR-08. This difference in phase called "phase lag" is generally smaller during neap tides (more influence of bottom friction, and exhibiting more of the progressive wave characteristic), and generally greater during spring tides (less influence of bottom friction, exhibiting more of the standing wave characteristic). The Savannah EFDC model exhibits the same characteristics and trends in phase lag as the observed data.

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 squares procedure. Prior to the harmonic analysis, the data were filtered to remove non-astronomical (air pressure induced, wind setup, resonant oscillation, and storm surge) components. Raw ADCP velocity data in two-dimensions were projected to the channel for 1.5 m and highest layers, corresponding to bottom and surface velocities. Because of fluctuations in the raw data, a Chebyshev Type II filter was applied to the data using MATLAB to remove short-term oscillations. The filter period was set at 3 hours, which removes short-period variations while maintaining wave components longer than 3 hours.

To be consistent, measured velocity and water surface elevation data and model results were all filtered using the Chebyshev Type II filter. The times of the optima corresponding to flood and ebb tide peak velocities and water surface elevations were evaluated. "Phase lag" is defined as the difference in time between the flood velocity peak and the highest water surface elevation. Figure 2-6 shows an example of measuring phase lag as well as the smoothing effect of the Chebyshev Type II filter.

Flood tide phase lags were measured for observed data and model results for the period July 13-27, 1997 (Julian days 194-208), and also for the shorter periods July 14-16 representing a neap period and July 20-22, representing a spring period. Results are shown in Table 2-2 in both hours and degrees (360 degrees is equal to one full tidal cycle or 12.42 hours). Average phase lags range from 52 to 71 degrees (1.8-2.4 hours) in observed data, and 56-72 degrees (1.9-2.5 hours) in model results for these periods at FR-04 and FR-08.

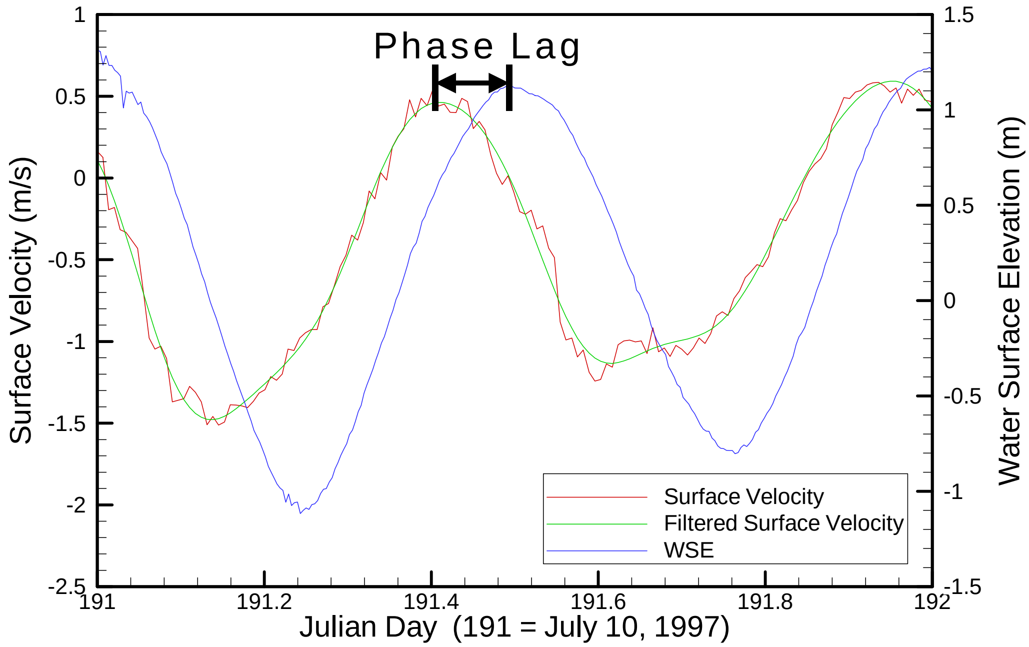


Figure 2-6 Example of Phase Lag Between Observed Surface Velocity and Observed Water Surface Elevation, Station FR-08, July 10, 1997

Table 2-2 Phase Lag of Observed Data and Model Results at FR-04 and FR-06 for Entire Tidal Cycle, Neap Period, and Spring Period in July 1997

		FR-04 Observed	FR-04 Model	FR-08 Observed	FR-08 Model
Tidal Cycle	Degrees	70	59	67	64
(Day 194-208)	Hours	2.4	2.0	2.3	2.2
Spring	Degrees	69	59	71	72
(Day 200-203)	Hours	2.4	2.0	2.4	2.5
Neap	Degrees	52	56	59	60
(Day 195-197)	Hours	1.8	1.9	2.0	2.1

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 water column. 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 2-6 demonstrates 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. These 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. Progressing from a neap tide to a spring tide, there is a subsequent increase in tidal velocity that overcomes the energy in the stratified environment which then mixes the water column vertically.

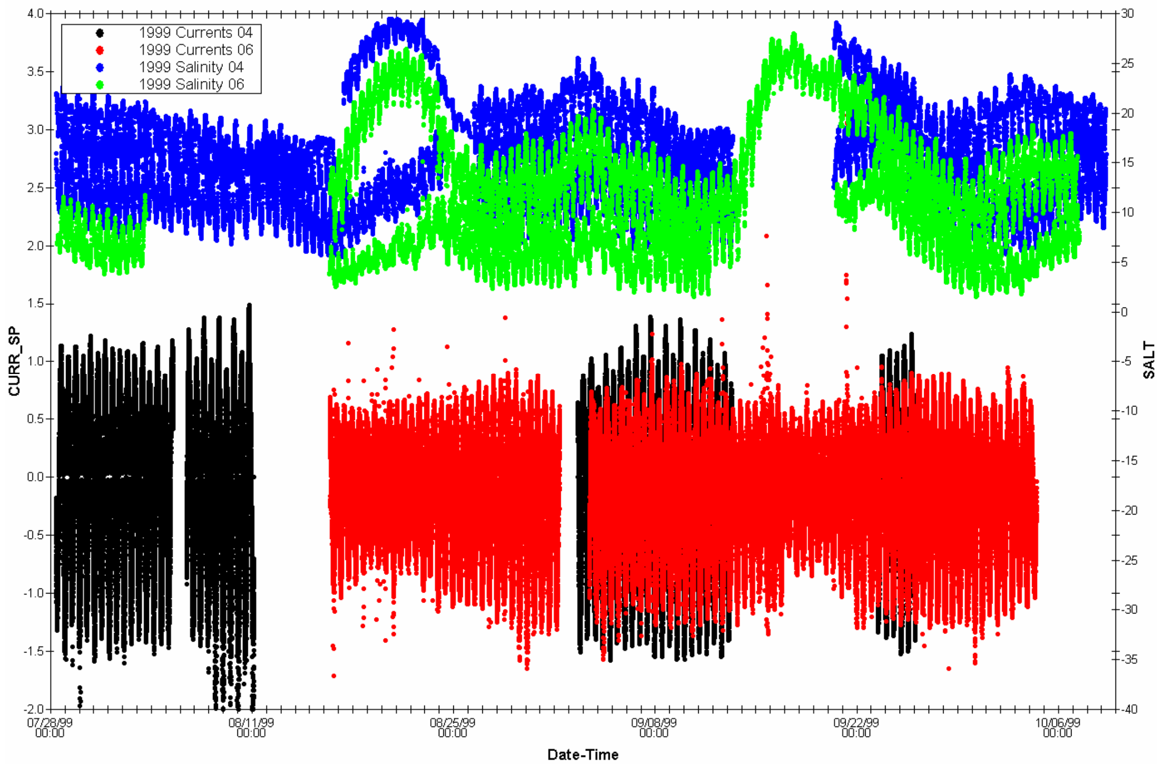


Figure 2-7 Salinity Stratification and Destratification Due to Neap and Spring Tidal Events at FR-04 and -06

2.6 Summer 1999 Continuous Data QA/QC

USGS performed additional quality assurance/quality control (QA/QC) on the summer 1999 continuous dataset by working with the raw data files of water level, specific conductance, temperature, and dissolved oxygen. The data were collected by ATM, Inc. for the GPA in 1999 and reported in 2000 (ATM, 2000). In September 2005, the EPA Region 4 requested that the USGS process the raw data and document the corrections based on the servicing profiles collected at each instrument. Data processing consisted of: (1) assigning a unique USGS station number (consisting of latitude and longitude) and name, then creating a station header files in the National Water Information System (NWIS) database, (2) writing DECODES for the raw time-series data and populating NWIS, (3) evaluate the ATM site-visit files, the vertical-profile files, and initial deployment data, in order to determine shifts corrections, (4) applying shift corrections and deleting erroneous unit data, and (5) generating primary computations, unit data plots, and station analysis for the QA package. The final QA/QC data were delivered to Tetra Tech on January 15, 2006.

3.0 EFDC HYDRODYNAMIC MODEL

3.1 Selection of Model

In developing a hydrodynamic model for the Savannah Harbor Estuary, it is critical that the model must meet the expectations discussed in the introduction section of this document. The Environmental Fluid Dynamics Code (EFDC) was selected by EPA 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 permit modeling projects on 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 systems similar to that of Savannah Harbor and is currently being applied by Tetra Tech to the Charleston Harbor, South Carolina for the SC DHEC.

The EFDC model is a part of the USEPA TMDL Modeling Toolbox due to its application in many TMDL-type projects. As such, the code has been peer reviewed and tested and has been freely distributed for public use. EFDC was developed by Dr. John Hamrick and is currently supported by Tetra Tech for USEPA Office of Research and Development (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 various applications of 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 WASP7 model. This model linkage, from EFDC hydrodynamics to WASP7 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 the Corps of Engineers Engineering Research and Development Center's CE-QUAL-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. There were no code modifications required for the Savannah Harbor application.

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 EFDC APPLICATION TO THE SAVANNAH RIVER ESTUARY

The Savannah River Estuary is a highly complex estuarine system characterized by a branching channel network and extensive intra-tidal marsh areas. The combination of an energetic tidal environment and significant river basin drainage area result in a highly variable salinity regime that is 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 affect impacts on 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 with the ability to run the model for seven years. The input files start on January 1, 1997, and were extended through December 31, 2003. When the 2004 data become available from the USGS, they can be extended through 2004. The model can be run for any time period during those dates with an appropriate spin-up period of 30 days.

4.2 Model Grid and Bathymetry

The model grid was enhanced to include more cells in the navigation channel. There are now 931 horizontal cells that extend upstream to Clyo, Georgia (~ 61 miles from Fort Pulaski) and downstream to the Atlantic Ocean (~17 miles offshore from Fort Pulaski). If the marsh cells are included, there are 947 total cells. The man-made connections were included such as McCoys Cut, Rifle Cut, Drakies Cut, New Cut as closed, and the sill of the Tide Gate. The as-builts for the tide gate show a structure 645 feet in width with a 9-foot sill below, Mean Low Water (MLW). The structure has 14 openings each measuring 22 feet high by 40 feet wide, with the bottom sill at elevation –9 feet. The shipping channel is better defined compared to the TMDL grid and was matched with the USACE channel configuration. Most of the navigation channel is represented as one cell wide from toe to toe and then another grid cell on either side to represent the sides of the channel. Additional grid cells were added at the Kings Island Turning basin and the Elba Island Bight areas. Figure 4-1 shows the enhanced grid with a closer view in Figure 4-2 of the upper estuary.

The bathymetry data were obtained from several sources. There is not one particular year in which the bathymetry data were measured throughout the system; therefore, sections of bathymetry files were constructed to form a bathymetry dataset for the river and harbor. The bathymetry sources are as follows:

- USACE Annual Surveys (1999 and 2002);
- USGS SNWR (2004) for the Back, Middle, and Little Back Rivers;
- USACE Upstream of I-95 (1999); and

- NOAA Surveys (1980s) for the offshore non-channel and south channel areas.

The annual surveys were compared and it was determined that 1999 and 2002 do have some differences in the navigation channel. The differences depend on the line of the survey because they usually do not follow the exact same ship tracking line. Also, it depends on when the survey occurred (just after dredging or an extended time after dredging).

Model bottom elevation was determined based on the 2002 survey data in the harbor and based on river cross-sections in the upper extents of the grid. The invert of the model at Clyo is at +0.5 meters NGVD with the invert of the harbor near -15 to –16 meters. The slope change from Clyo to the I-95 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.

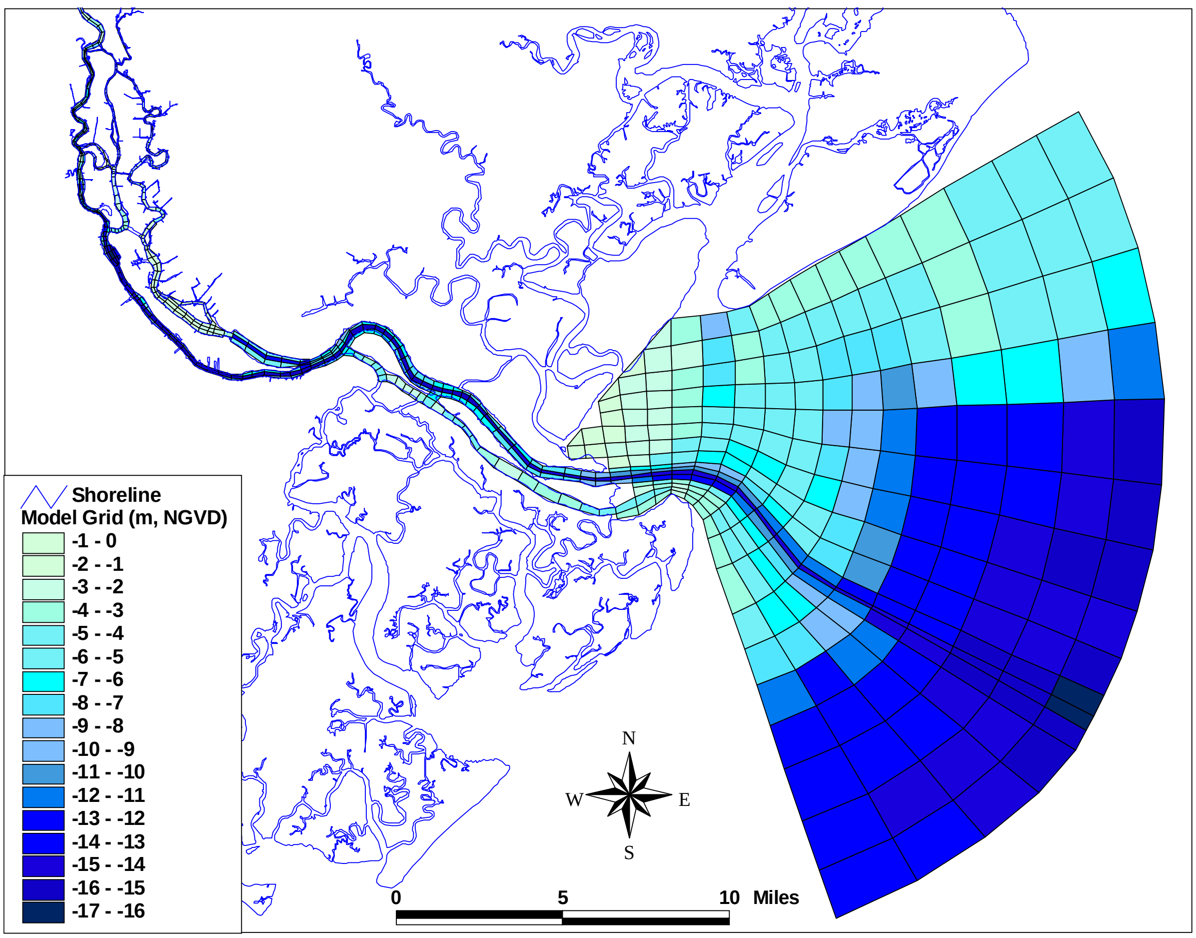


Figure 4-1 Model Grid and Bathymetry

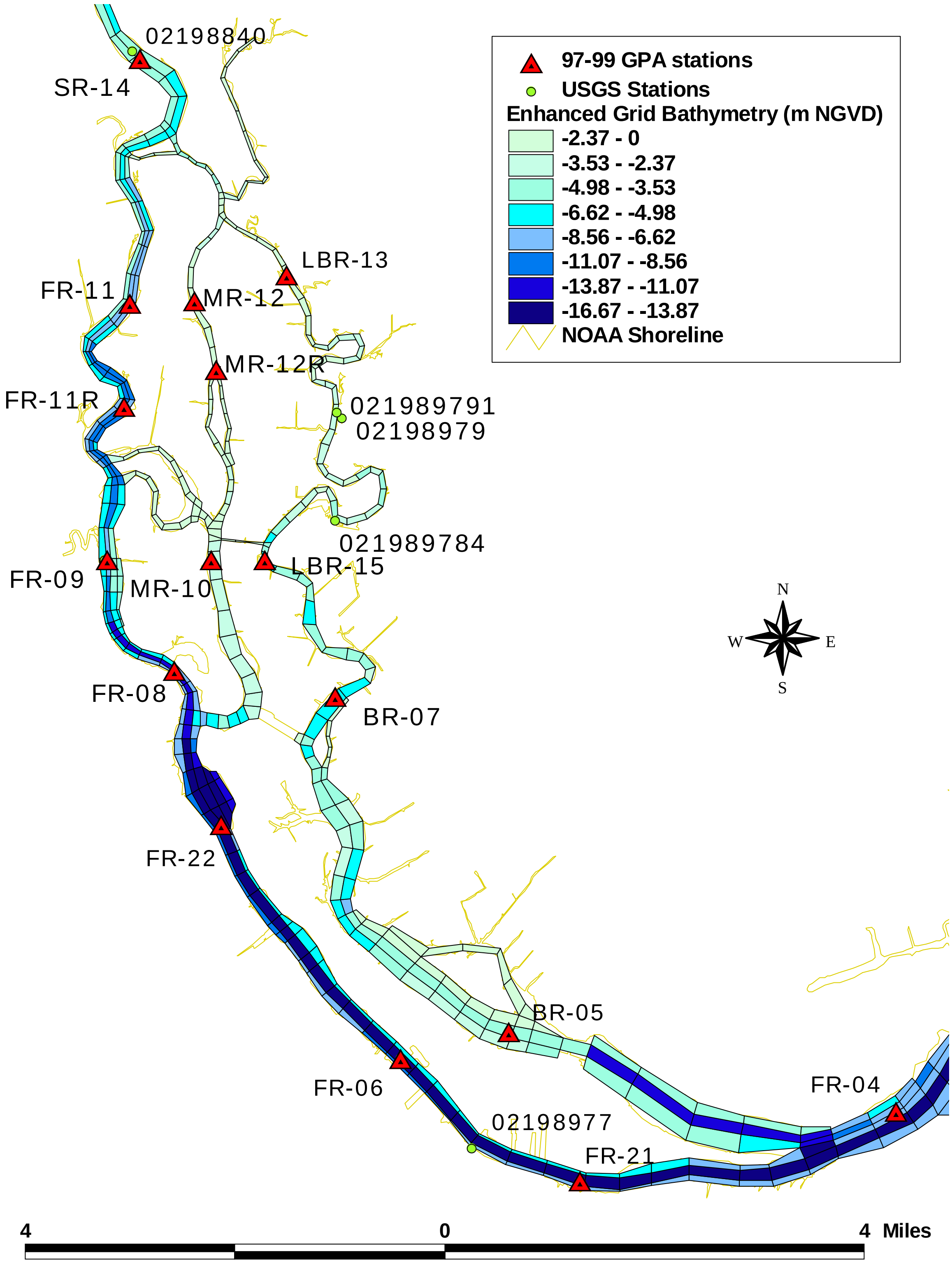


Figure 4-2 Model Grid and Bathymetry in the Upper Estuary

The 2004 USGS survey is shown in Figure 4-3. These data points were essential for enhancing the representation of the bathymetry in the Back, Little Back, and Middle River areas.

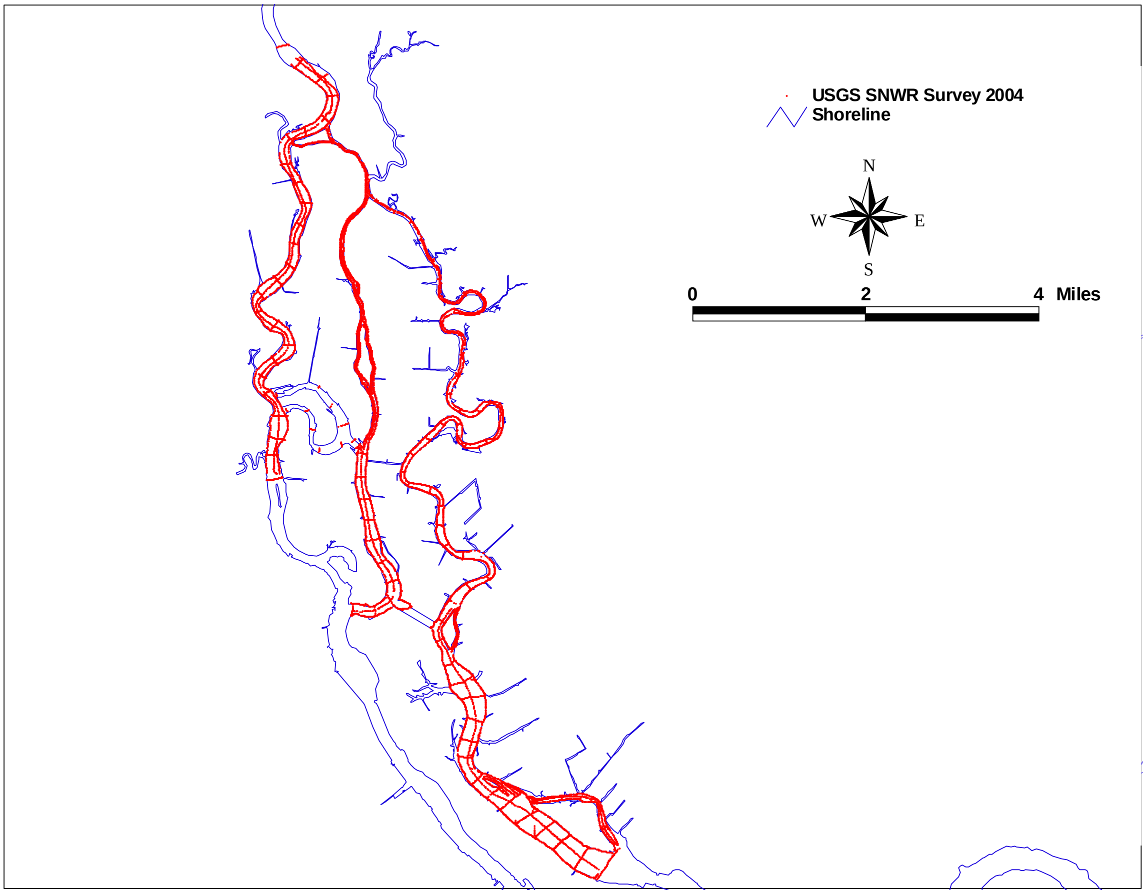


Figure 4-3 USGS 2004 Survey Points in the Savannah National Wildlife Refuge (SNWR)

After receiving the electronic GIS files of the 2002 annual survey from the USACE Savannah District, the channel and side-channel areas were re-examined to not only examine the cross-sectional area of the channel, but also examine the longitudinal aspect of the bathymetry. Figure 4-4 shows that the bottom of the navigation channel is not smooth and can vary by 0.5 meters from station to station. The USACE stationing is in 1,000-foot increments. For the enhanced model grid, five cross-section inverts were averaged to develop the channel depths used in the model. The green line in Figure 4-4 was used to represent the channel in the enhanced model grid. According to the measured bathymetry soundings along the Front River (USGS, 2004), the channel thalweg alternates from bank to bank and the channel is deepest on the outside of channel bends. In order to properly represent this for optimal model results, the thalweg was considered to be the center cell in the model grid. This is shown in Figure 4-5 with I = 14 being the center cell (thalweg) and I = 13 and 15 the side cells.

The 2002 and 1999 datasets were compared by analyzing cross-sections between the two surveys at many locations. Although there were some differences in alignment of the cross-sections, there was not a difference between the two surveys. Also, the survey data are grouped and averaged according to the model grid cell, and there was not a difference between 1999 and 2002 once this averaging occurred. Since dredging is a continuous operation in the navigation channel from year to year, the goal was to have a bathymetry that represents the current channel configuration, or depth, since the last deepening in 1994.

It was determined that the 1999 and 2002 annual surveys are interchangeable in the model grid and best represent the existing (calibration) conditions.

Tetra Tech also compared the variations across the width of the cross-section. The navigational channel is not a typical trapezoidal channel due to the bends in the navigational channel and associated deposition and scouring. Figures 4-6 and 4-7 show a comparison of the cross-sectional variation between the 1999 and 2002 USACE surveys. The 2002 survey was selected for use in the grid bathymetry because we were able to obtain the entire dataset electronically whereas the 1999 we only had the partial channel. Also, the 2002 survey appeared to be consistent with the 2004 USGS survey for the Back, Little Back, Middle, and Front Rivers. The depth selected for each cell represents the average depth condition for the entire cell.

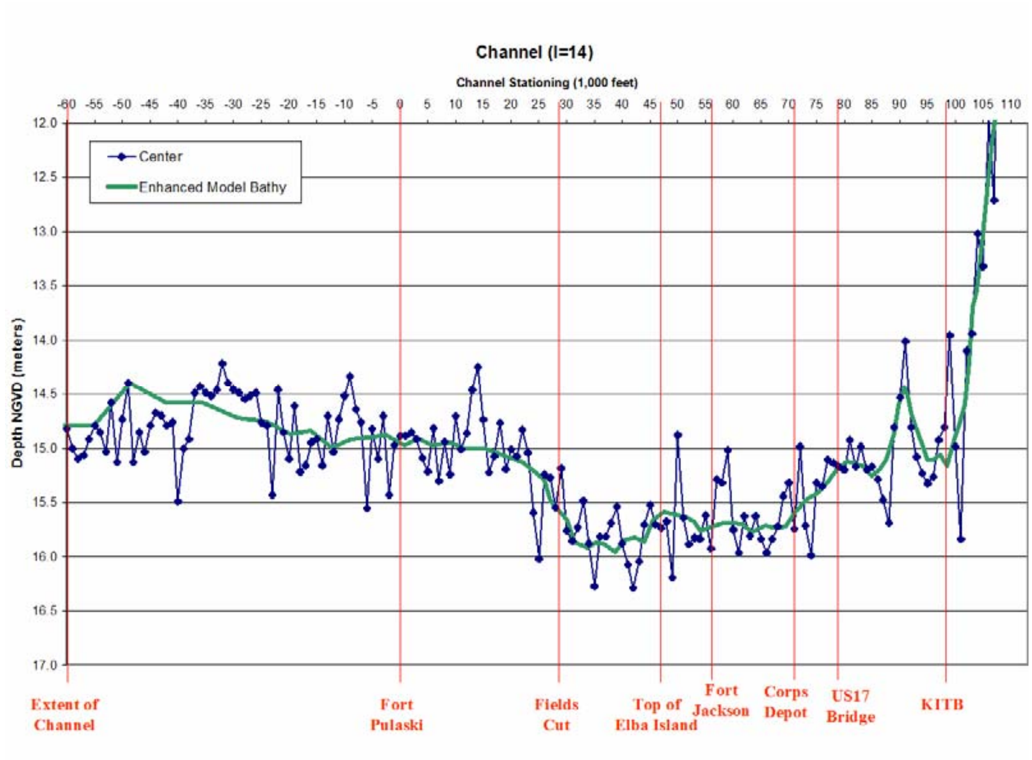


Figure 4-4 Longitudinal Plot of the Navigation Channel

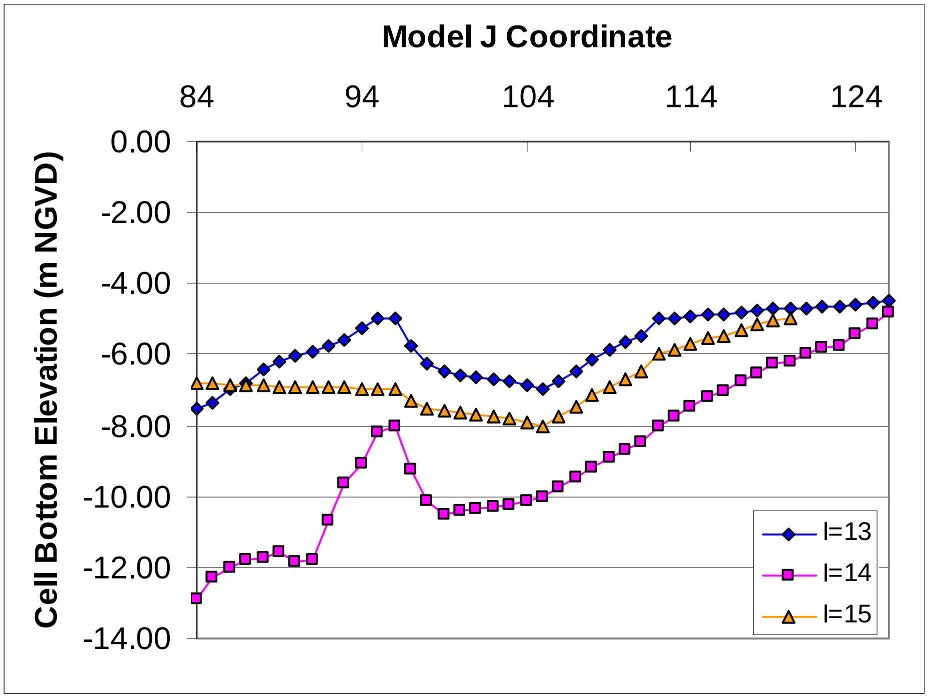


Figure 4-5 Longitudinal Bottom Elevations from Houlihan Bridge to I-95 Bridge (I = 14 is the center cell and I = 13 and 15 are the side cells)

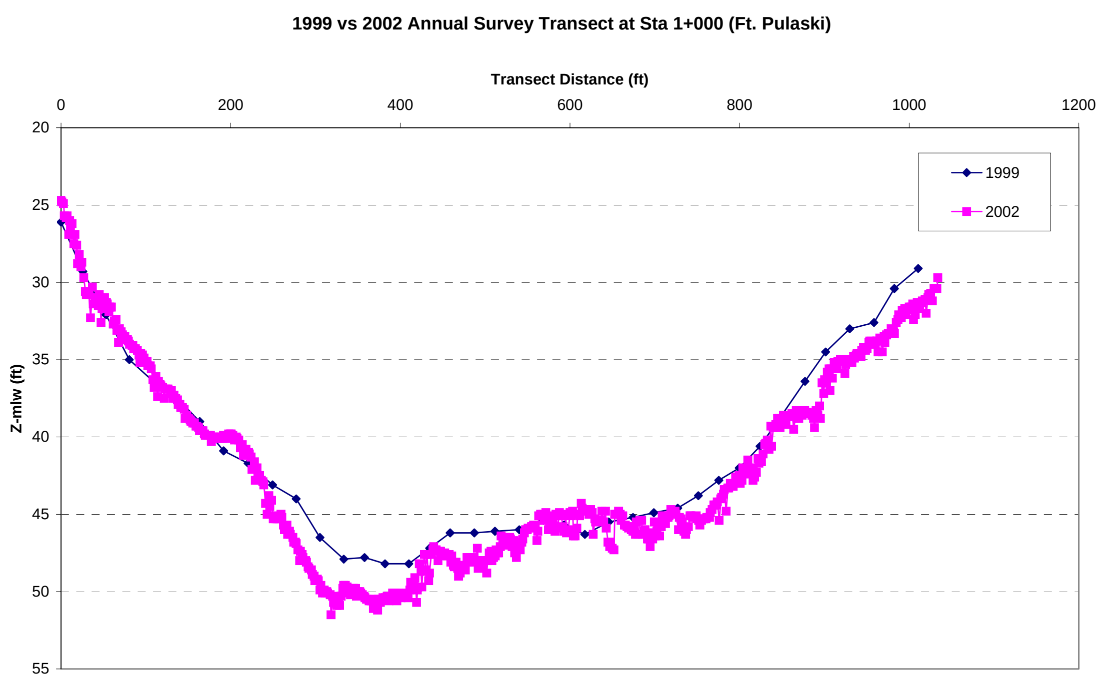


Figure 4-6 Cross-Sectional Comparison near Fort Pulaski of the 1999 and 2002 Annual Surveys by the USACE

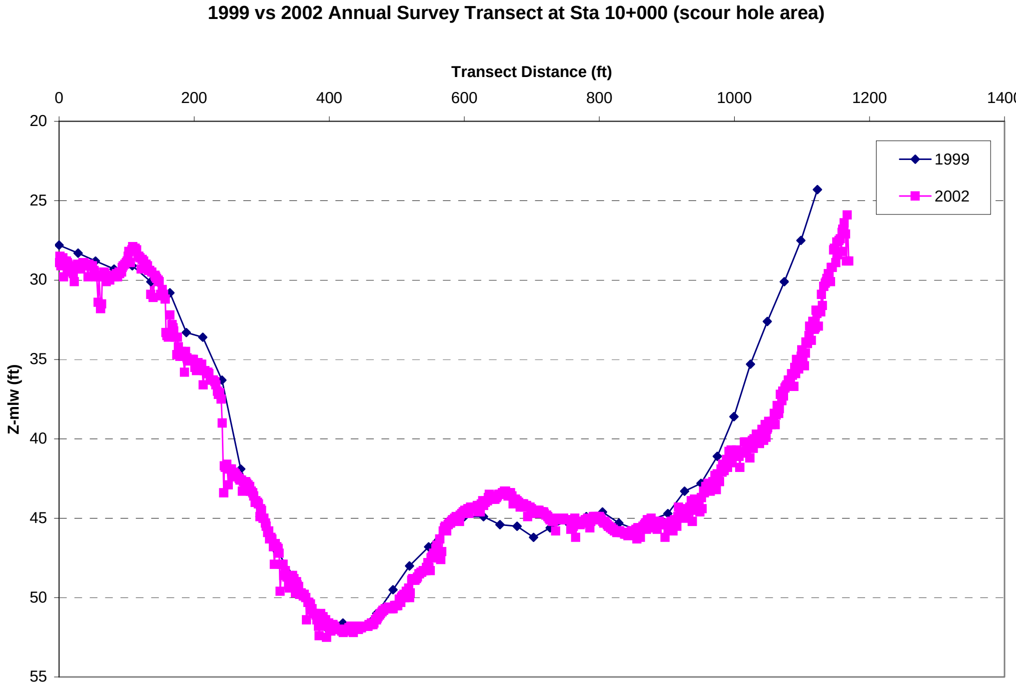


Figure 4-7 Cross-Sectional Comparison near New Channel Bend of the 1999 and 2002 Annual Surveys by the USACE

4.2.1 Grid Convergence Test

The federal agencies believe that a grid convergence test should be completed to ensure that the model is defensible and convergence testing of the model must be performed on the application to the Savannah Harbor.

A model grid convergence test was performed to determine the appropriate level of grid resolution for numerical solution, where a finer grid would not produce substantially different model predictions. The model grid convergence test results are shown in Appendix A. A simple approach was taken to develop the grid convergence test. The TMDL model had been developed on a coarse model grid (655 horizontal cells) and calibrated to the same datasets. The enhanced grid has more cells (931) and represents a finer grid. The TMDL model grid and the enhanced model grid were run with two depth scenarios, 7 and 10 meters. The entire model domain was run with both of these depth scenarios and compared. The 7-meter TMDL grid was compared to the 7-meter enhanced grid to determine if there are differences based on the grid resolution. The same analysis was done with the 10-meter model runs.

Appendix A shows that there are some areas where the TMDL and enhanced grids show differences. The closer to the ocean boundary obviously, the better the comparison. Also, when the 7- and 10-meter depths are put in the grid for the entire model domain, it allows more salinity to intrude into the system. Both grids represent the intrusion equally as well with differences in the upper part of the system. The approach shows that the two grids represent the processes occurring in the system with differences attributed to the widths and lengths of the grids being slightly different.

4.3 Model Coefficients

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

4.3.1 Bottom Roughness

The bottom roughness of the EFDC Savannah Harbor model was applied as a constant of 0.02 m in the estuary. In the upper riverine sections, the bottom roughness was higher near 0.14 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 τ_b:

$$\tau_b = \rho u_*^2 = c_b \rho U^2$$

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:

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

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 grain 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.

The value of 0.02 m roughness is reasonable in Savannah Harbor. The 0.02 m was used for all EFDC applications in the James River where the model did very well in predicting salinity, current meter transects at James River Bridge, and frontal structure at Newport News Point. Conversely, the James model used an approximately 400 m grid and much of the z_o may be sub-grid scale topography. For the Savannah model, the attribution to lateral effects may have some bearing since the lateral resolution may not capture resistance of very shallow areas. As to the sensitivity, there would not be much change between 0.015, 0.02, and 0.025 and typical estuary applications for z_o range from 0.0005 to 0.02 (Hamrick, 2005). The rationale for the larger values is that, in addition to representing the actual bed grain scale roughness, the z_o accounts for larger scale effects which could include bed form drag, drag due to obstacles in flow, and drag implied by sub-grid scale topographic variability. The z_o is basically calibrated to achieve correct amplitude attenuation and phase propagate for the tide. With this in mind, other features such as unaccounted marsh storage, etc. could influence the choice of z_o globally to achieve the calibration to the tide. Of course, in an estuary where there is little apparent propagation and the tide has more of a standing wave characteristic, the tidal calibration can be relatively insensitive to z_o. In this case, larger values of z_o would tend to be used to increase vertical mixing if necessary to calibrate to stratification and length of salinity intrusion. In a strongly stratified estuary, such as Savannah, the turbulence model can tend to over stratify since phenomena such as internal wave breaking, which would enhance mixing, are not represented.

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 and modified by Galperin *et al* (1988). 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 turbulence intensity based Richardson Number. The turbulence closure model uses nine 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 nine parameters are located in Card 13 of the “efdc.inp” file. The turbulent kinetic energy equation is shown below.

$$\partial_t\left(m_x m_y H q^2\right)+\partial_x\left(m_y H u q^2\right)+\partial_y\left(m_x H v q^2\right)+\partial_z\left(m_x m_y w q^2\right)$$
$$=\partial_z\left(m_x m_y \frac{A_q}{H}\partial_z q^2\right)-2m_x m_y \frac{Hq^3}{B_1 l}$$
$$+2m_x m_y\left(\frac{A_v}{H}\left(\left(\partial_z u\right)^2+\left(\partial_z v\right)^2\right)+\eta_p c_p D_p\left(u^2+v^2\right)^{3/2}+gK_v\partial_z b\right)+Q_q$$
$$q^2 = 2 \text{ x turbulent kinetic energy}$$

The turbulent length scale equation is shown below. Three of the nine parameters discussed above can be seen as E1, E2, and E3 below. The other parameters do not appear if 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).

$$\partial_t\left(m_x m_y H q^2 l\right)+\partial_x\left(m_y H u q^2 l\right)+\partial_y\left(m_x H v q^2 l\right)+\partial_z\left(m_x m_y w q^2 l\right)$$
$$=\partial_z\left(m_x m_y \frac{A_q}{H}\partial_z\left(q^2 l\right)\right)-m_x m_y \frac{Hq^3}{B_1}\left(1+E_2\left(\frac{l}{\kappa Hz}\right)^2+E_3\left(\frac{l}{\kappa H\left(1-z\right)}\right)^2\right)$$
$$+m_x m_y E_1 l\left(\frac{A_v}{H}\left(\left(\partial_z u\right)^2+\left(\partial_z v\right)^2\right)+gK_v\partial_z b+\eta_p c_p D_p\left(u^2+v^2\right)^{3/2}\right)+Q_l$$

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.

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

The water surface elevation data collected by the National Ocean Survey at Fort Pulaski were used as the initial approximation of the offshore boundary conditions for the hydrodynamic model. These data were obtained in feet of MLLW. The available USGS data upstream of Savannah River have units of feet NGVD. The conversion of units and adjustment of water surface elevation boundary conditions were made to fit the Fort Pulaski water surface elevation dynamics in magnitude and phase.

4.4.1 Offshore Boundary

The offshore boundary of the grid is approximately 17 miles from river mile 0.0 as shown in the previous Figure 4-1. River mile 0.0 is at the mouth of the river and entrance channel near Oysterbed Island.

The offshore boundary for water surface elevation consisted of examining the data collected by the USGS at Fort Pulaski (02198980). These data were obtained in feet of MLLW and used as the initial approximation of the offshore boundary conditions for the hydrodynamic model. The conversion of units into NGVD and adjustment of water surface elevation values were made to reach an acceptable agreement of the model versus data at Fort Pulaski.

The offshore salinity boundary was determined by examining three data sources: (1) data collected by the Skidaway Institute of Oceanography from a partnered field research study called the South Atlantic Bight Synoptic Offshore Observational Network (SABSOON); (2) the Carolinas Coastal Ocean Observing and Prediction System (Caro-COOPS) based upon an instrumented array of coastal and offshore moorings; and (3) offshore data collected by MACTEC during the offshore LTBOD samples on September 24, 2003.

The SABSOON is a real-time observational network that has been developed on the U.S. Southeastern continental shelf and the sites are shown in Figure 4-8. 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. The historical measurements at R2 range from 33 to 36 ppt.

MACTEC collected a sample offshore at a site called "Southern Ocean Sample" and the salinity was 34.6 ppt on September 24, 2003.

The Caro-COOPS site that is closest to the Savannah Harbor model grid is FRP2 Fripp Nearshore. The location of the stations can be found at http://nautilus.baruch.sc.edu/carocoops_website/index.php. The data from August 2003 to March 2005 ranged from 30 to 35 ppt.

Ultimately, the model performance was used to derive the appropriate boundary condition. Data collected at FR-26 near Fort Pulaski during 1999 were not appropriate because of fresh water mixing and stratification occurring at this location. There were often times that a variable salinity boundary would have performed better for the salinity statistics in 1999 or 1997, 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. The SABSOON and Caro-COOPS data networks were not operating during 1997 and 1999. The data at R2 in the SABSOON network had near surface and near bottom (~23 meters) instruments that did show a difference of 3-5 ppt between the surface and bottom at times. Therefore, the EFDC calibrated hydrodynamics used a 32.5 ppt at the surface and 35 ppt at the bottom with 0.5 ppt increments in layers two through six.

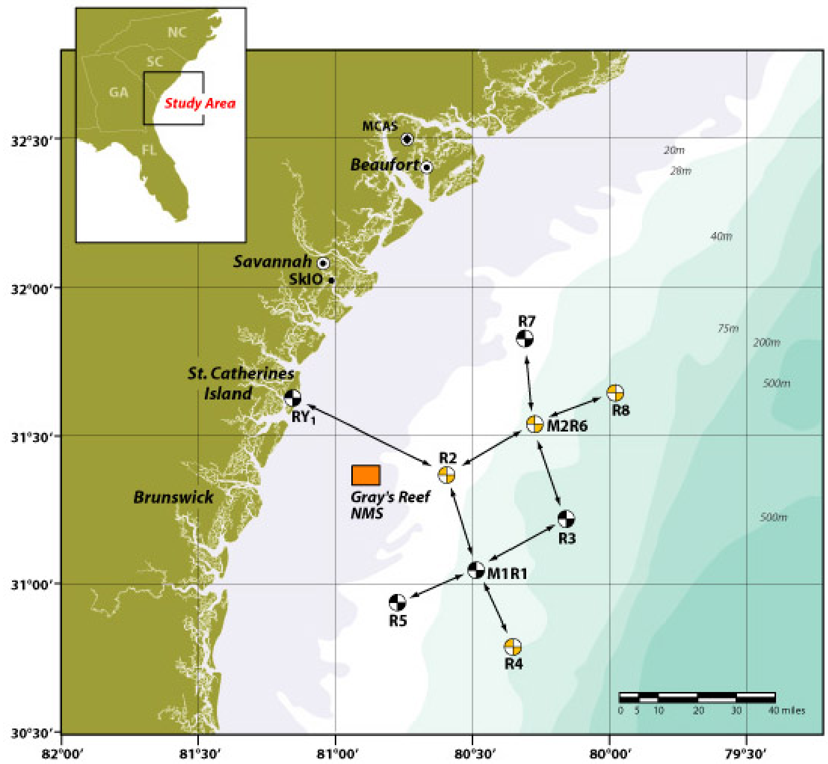


Figure 4-8 SABSOON Stations in the Atlantic Ocean

4.4.2 Upstream Boundary

The upstream boundary of the grid at Clyo, Georgia is approximately 61 miles from river mile 0.0. 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 and are plotted in Figure 4-9.

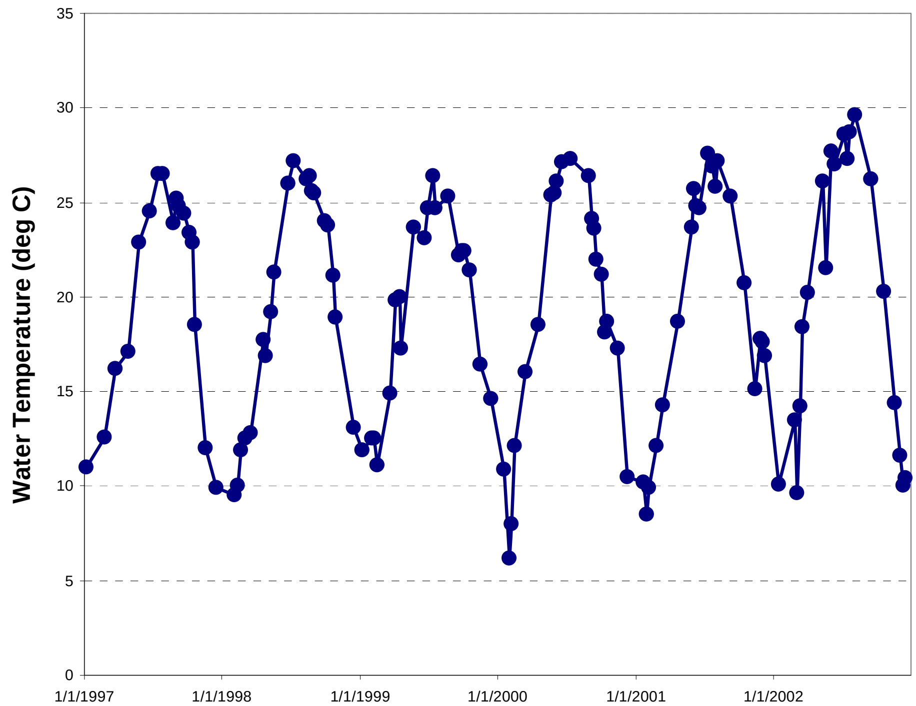


Figure 4-9 Water Temperature at Clyo for 1997 through 2002

4.4.3 Marsh Boundaries

The initial model runs of the enhanced grid were performed without the marsh areas. Overall, the salinity calibration on the Front River was very good without including these areas. After careful examination of the salinity influences on the Middle and Little Back Rivers, it was determined that the marsh areas were critical to capturing the salinity trends in the upper part of the estuary. Also, the marsh areas would be more critical for the water quality model. Since the EFDC model calibration was mostly successful without the marsh areas, a simple but comprehensive solution was developed.

Tetra Tech pulled the existing marsh area coverages from the ATM "Tidal Marsh Studies Data Report" Volumes 1 and 3 (2003). The surface areas of the river, marsh, and feeder channels were determined for 10 separate marsh zones called Q zones. These 10 zones were delineated based on vegetation zones measured by ATM's field studies. In Volume 1 of the ATM marsh data report, the flooding frequency, duration, and average depth by Q zone were reported and are summarized in Table 4-1. In Volume 3 of the ATM marsh report, the total acreages were calculated for secondary canals, river channels, and marshes for each vegetation cell, or Q zone. Total volumes were then calculated based on areas and depths and are presented in Table 4-2.

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 4-2 Marsh Area and Volume Calculations used in the EFDC Model

Q zone	Waterbody	Area (acres)	Area (m^2)	Depth (m)	Volume (m^3)
Q1	CHANNEL	15	59,870	1.2	72,994
	MARSH	490	1,981,290	0.12	235,520
Q2	CHANNEL	187	755,863	1.2	921,549
	MARSH	2,190	8,861,825	0.25	2,187,878
Q3	CHANNEL	89	360,733	1.2	439,806
	MARSH	1,363	5,516,392	0.18	1,008,838
Q4	CHANNEL	12	46,544	1.2	56,746
	MARSH	336	1,359,504	0.21	285,920
Q5	CHANNEL	8	33,334	1.2	40,641
	MARSH	210	851,168	0.20	168,633
Q6	CHANNEL	8	33,080	1.2	40,331
	MARSH	489	1,977,169	0.16	307,347
Q7	CHANNEL	9	35,485	1.2	43,264
	MARSH	247	1,000,219	0.29	289,623
Q8	CHANNEL	29	117,309	1.2	143,023
	MARSH	682	2,760,700	0.14	387,072
Q9	CHANNEL	5	18,996	1.2	23,160
	MARSH	457	1,849,307	0.21	394,568
Q10	CHANNEL	13	53,515	1.2	65,245
	MARSH	409	1,656,197	0.22	363,462

The inclusion of the marsh areas is critical to enhancing the model's performance. The EFDC model was having difficulties simulating flows on the Little Back and Middle Rivers and we confirmed that it was due to the marsh approach. Our first marsh approach was to calculate a tidal prism based on the simulated water surface elevations in the river compared to the bottom elevation of the marsh. We developed modifications to the EFDC codes for equations used for flow, salinity, and temperature and we intended to implement these modifications after we proved they were working. Preliminary results indicate that flows on the Little Back and Middle Rivers appeared to reflect with one another and produce flows that were out of phase with the data. We tested different sized marsh areas, but did not see improved results. Therefore, we decided to abandon our marsh approach (code modifications) and use a function that was already in the EFDC code. The revised marsh approach entails having a marsh cell connected to the model grid through a hydraulic structure. There were 17 marsh areas added to the enhanced grid and they are listed in Table 4-3 and shown in Figure 4-10. The structure requires an invert elevation and a flow table. The structure was needed to retain a water depth in the marsh cells so they did not go dry and better define the flow exchange between the marsh and the channel. The marsh cell is similar to any other model cell and requires a bottom roughness and elevation. The hydraulic structure simply allows the water to move between the river and the marsh based on the water surface elevation difference. The hydraulic structures were calibrated by modifying the marsh areas and invert elevations of the structure. Table 4-3 below shows the marsh cell connections, dimensions, bottom elevations, and structure inverts. The Q-zones reported by ATM's "Tidal Marsh Studies Data Report" Volumes 1 and 3 (2003) were still used to determine the marsh areas. Since the marsh areas do not flood on every tidal cycle, the areas were adjusted down as shown in Table 4-3. Additional marsh cells were included to represent Union Creek, Upper Little Back River, and Augustine Creek, which were not included in the Q-zones. Union Creek was put in as a storage cell without a structure.

Table 4-3 Marsh Grid Cell Parameters used in the EFDC Model

River Cell		Marsh Cell		Marsh Dimensions		Bottom Elevations		Q-zone
I	J	I	J	Calculated Size (m x m)	Adjusted Size (m x m)	Marsh (m, NGVD)	Structure Invert (m, NGVD)	
23	133	23	134	1000	1000	-0.7	no structure	Union Creek
28	123	28	125	1000	1000	-0.6	-0.5	Upper LBR
33	123	33	125	1000	800	-0.6	-0.5	Upper LBR
39	122	41	122	1000	300	-0.6	-0.5	Q8
39	113	41	113	1300	300	-0.6	-0.5	Q8
30	92	32	92	1183	400	-0.6	-0.5	Q4
30	87	32	87	1354	400	-0.6	-0.5	Q3
36	68	38	68	1354	400	-0.6	-0.5	Q3
31	76	33	76	1354	600	-0.6	-0.5	Q3
26	95	28	95	922	600	-0.6	-0.5	Q5
22	108	24	108	1110	600	0.2	0.3	Q6
26	110	28	110	1110	400	0.2	0.3	Q6
26	116	28	116	1110	400	0.2	0.3	Q9
36	66	38	66	2846	400	-0.6	-0.5	Q2
13	104	11	104	1378	600	-0.6	-0.5	Q1
15	86	17	86	1000	600	-0.6	-0.5	Q7
13	96	11	96	2000	600	-0.6	-0.5	Augustine

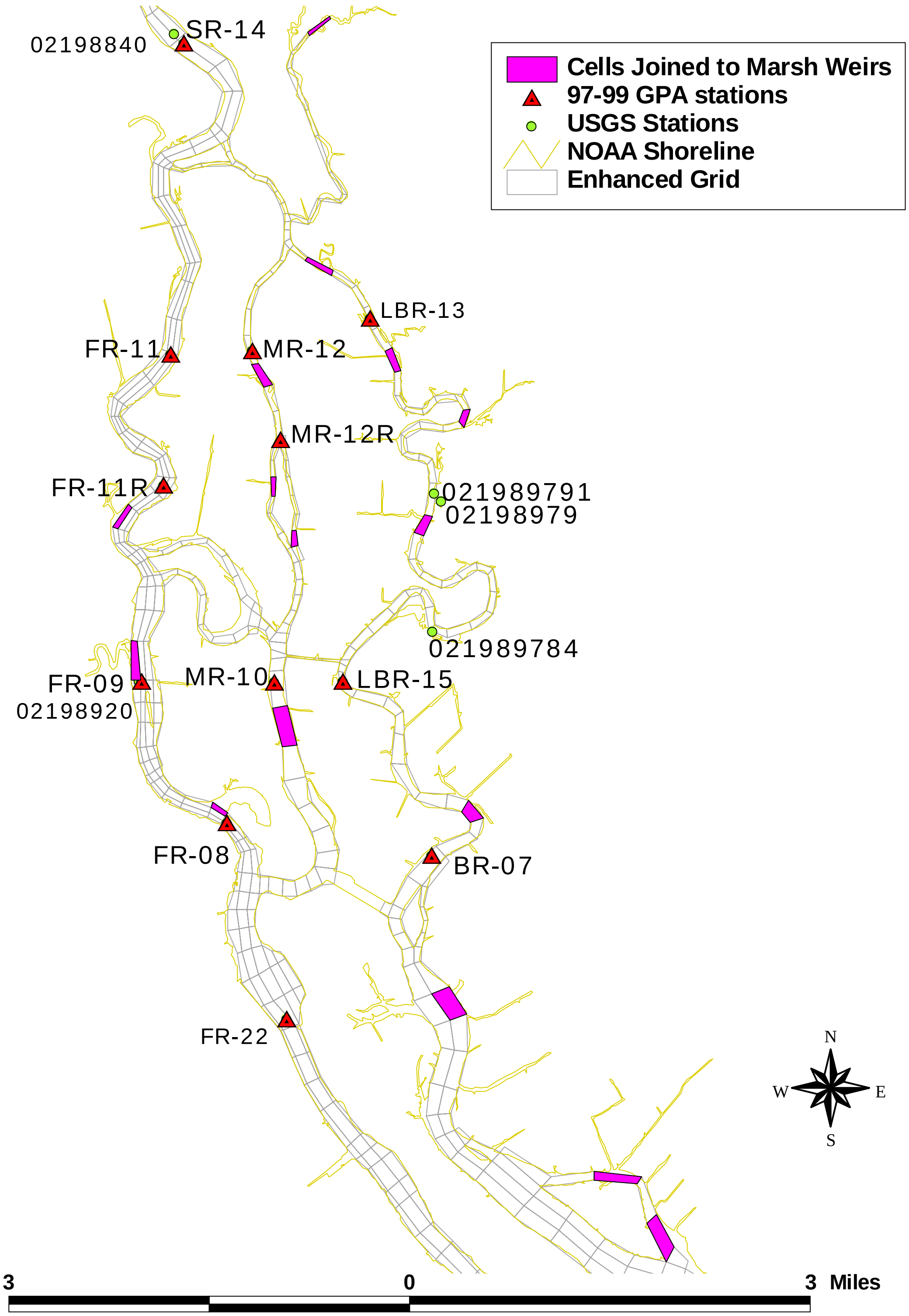


Figure 4-10 Marsh Locations in the Enhanced Model Grid (Lower Back River marsh not shown on this map)

There were several advantages to the revised marsh approach. First, our flow calibration was much improved and the simulated flows were smoother similar to the rising and falling tides. Second, there were no changes to the EFDC code necessary, since the hydraulic structures have always been in the EFDC code. Third, the salinity calibration was much improved in the Little Back and Middle Rivers, as we now see the elevated levels of salinity at those stations. Fourth, we did not have to use the wetting and drying options in EFDC that would significantly lower our model time step and increase the model run times.

The flow through the structure was calculated based on the Manning equation described below:

$$Q = \frac{1}{n} A R^{2/3} F^{1/2}$$

$$R = A / P$$

where ***n*** is a Manning roughness; ***R*** is a hydraulic radius; ***P*** is a wetted perimeter; ***F*** is the energy slope.

F can be approximated by a water surface elevation slope:

$$F = \frac{\Delta H}{L_x}$$

where ΔH is a water surface elevation difference between the marsh cell and the channel cell. The EFDC weir formulation uses a look-up table of ΔH versus flow (Q). The look-up tables were computed based on the information in Table 4-3.

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. The airport is located roughly 4 miles from the estuary and represents the best source of meteorological data for the estuary. 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 seven years so a consistent record was created. The "aser.inp" file was developed on an hourly basis. Figure 4-11 shows the air temperature and rainfall for the period.

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

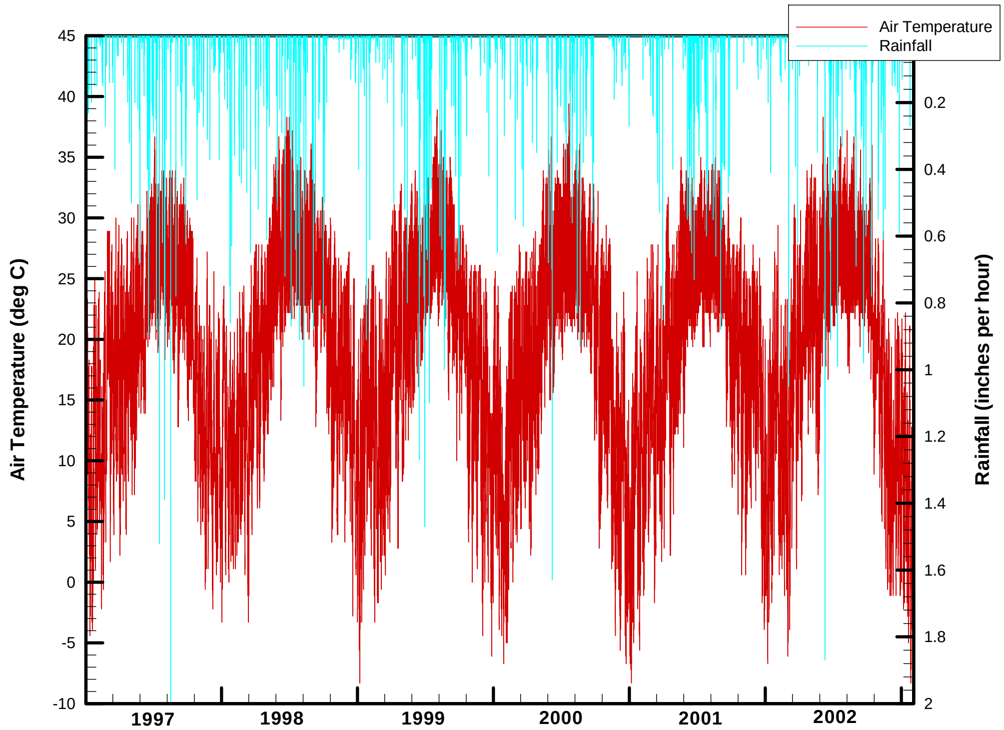


Figure 4-11 Air Temperature and Rainfall in Meteorological Forcing

4.4.5 Point Sources Flow and Heat Loads

The Savannah Hydrodynamic Model includes major point sources/sinks discharges and withdrawals. The corresponding information was presented to Tetra Tech Inc. by partnering federal, state and local agencies. Some of these discharges/withdrawals were presented as annual averages, and for some of them the time series measurements were available. The averaged discharges/withdrawals are presented in Table 4-4; time series discharges/withdrawals are referred in Table 4-5.

Table 4-4 Annually Averaged Point Sources Discharges/Withdrawals for Savannah River Model

Point Source Discharge/Withdrawal	Location Cell (I, J)	Flow (m^3/s)
Smurfit discharge	I=13, J=95	0.113906
Garden City discharge	I=13, J=77	0.049943
Whilshire discharge	I=13, J=74	0.135811
Travis Field discharge	I=13, J=74	0.033296
President Street discharge	I=13, J=54	0.823628
Englehard discharge	I=13, J=52	0.042496
Kerr McGee #1 discharge	I=13, J=48	0.56953
Kerr McGee #2 discharge	I=13, J=48	0.122668
Savannah Electric Plant Macintosh discharge	I=14, J=172	5.7
Savannah Electric Port Wentworth discharge	I=13, J=85	11.3
Savannah Electric Plant Macintosh withdrawal	I=14, J=173	-5.7
Savannah Electric Port Wentworth withdrawal	I=13, J=84	-11.3
Riverside Power Plant discharge	I=13, J=57	2.13
Riverside Power Plant withdrawal	I=13, J=58	-2.13

Table 4-5 Time Series Discharges/Withdrawals for Savannah River Model

Point Source Discharge/Withdrawal	Location Cell (I, J)	Flow (m^3/s)
Hardeeville discharge	I=14, J=148	Time Series
Fort James discharge	I=14, J=171	Time Series
Savannah Industrial & Domestic Water Supply withdrawal	I=8, J=130	Time Series
Beaufort-Jasper Water Authority withdrawal	I=14, J=163	Time Series
International Paper discharge	I=15, J=70	Time Series

Estimates of potential freshwater flow from watersheds (based on values of their areas) surrounding the Savannah River from Clyo down to Savannah Harbor support increasing the upstream boundary freshwater river flow by 10% and including two additional sources of freshwater flow at: Union Creek (I=21,J=59) – 5m^3/s, and Front River (I=5,J=52) – 10m^3/s.

Heat loads from three power plants: Savannah Electric Plant Macintosh, Savannah Electric Port Wentworth and Riverside Power Plant were calculated based on estimates of their discharges by pump capacities for river water withdrawal, and capacities of power generation.

The "heat rate" for coal-fired steam-electric power plants is about 10,000 BTU heat input per Kw-hr of electricity generated (about 34% efficient). One Kw-hr is equivalent to 3413 BTU. Therefore, generating one Kw-hr of electricity results in a heat load of 6587 BTU (10,000 – 3413) that must be rejected to the environment. Assuming 95% of this heat is rejected to the river (with the other 5% going directly to the local atmosphere), one Kw-hr of generated electricity results in a heat load of about 6300 BTU to the river. One BTU raises the temperature of one pound of water one degree Fahrenheit.

Based on these assumptions and available data we can calculate increasing of temperature in discharged power plants' waters by following formula:

$$\Delta^0 C = \mathrm{P} * 6300 * a * Q^{-1} * b$$

where $\Delta^0 C$ is a increasing of temperature of discharged waters (degree of Celsius); P is a power generation (Kw-hr); a=0.55 is a conversion coefficient of temperature change from Fahrenheit to Celsius; Q is a power plant discharge (m^3/hr); b=0.0004536 is a conversion coefficient from a pound to a metric ton. We did not have detailed information about power generation of the Riverside Power Plant. The temperature increase was assumed to equal the increase of the Savannah Electric Port Wentworth plant.

Table 4-6 Heat Loads for Savannah River Model

Power Plant	Power Generation (Kw-Hr)	Water Discharge (m^3/s)	Heat Load (BTU)
Savannah Electric Plant Macintosh	800,000	5.70	$5.040*10^9$
Savannah Electric Port Wentworth	160,000	11.27	$1.008*10^9$
Riverside Power Plant	30,240	2.13	$1.906*10^8$

The temperature of discharged waters of power plants was assumed to be the sum of Clyo water temperature time series plus . These new calculated time series were placed into TSER.INP file and use to determine the heat load of the Savannah power plants and results are shown in Table 4-6.

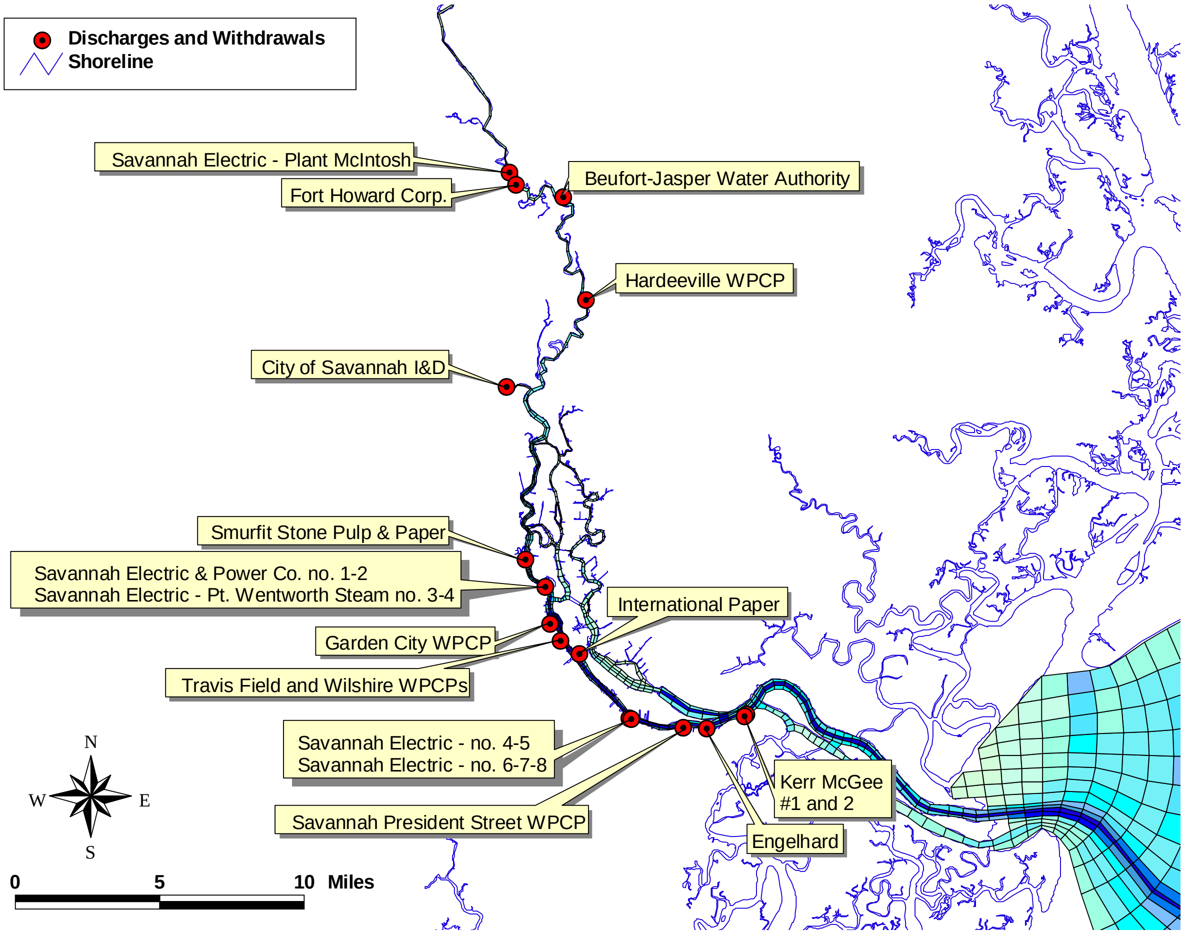


Figure 4-12 Point Source Discharges and Withdrawals in the Savannah River Estuary

5.0 EFDC CALIBRATION

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,
- Currents,
- Flow,
- 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 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 “EFDC_OUT.BMD” is included for the 1999 calibration period and contains every cell in the grid domain. The “fixed_grid8” shape files are 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.

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 calculations. For the statistical evaluations, the following calculations were generated along with the percentiles.

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

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

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

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

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

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

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

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

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

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

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

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

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, comparisons of selected percentiles are to be used to evaluate model performance. The statistical analyses are to be performed on both the 1997 and 1999 data sets. For the 1997 validation data set, analyses 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, analyses 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 and Water Quality 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
DO (mg/L)		-	+/- 0.2	+/- 0.2	-	-	+/- 30
DO Deficit (mg/L)		-	+/- 0.2	+/- 0.2	-	-	+/- 30
Temperature (^{o}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

The model calibration results are presented in this section and in several appendices to this report. As stated previously, the model calibration was performed from the qualitative comparisons, quantitative comparisons, and the federal agency expectations comparisons. The calibration period was the summer of 1999 and the confirmation period was the summer of 1997. The longterm USGS data will also be used for confirmation. The two summer periods were both low-flow conditions with several spring/neap tide events occurring throughout the period.

The EFDC locations where data comparisons were made is shown in Table 5-2. The I and J locations are used to plot the time series comparisons in MOVEM and calculate statistics.

Table 5-2 EFDC I and J Locations of Data Stations

Station ID	Description	River Mile	I	J
GPA Stations				
FR-26	Front River at Fort Pulaski	0.8	14	23
FR-02	Front River in the Entrance Channel	4.5	14	30
SC-03	South Channel	5.5	10	28
FR-04	Front River near Fort Jackson	10.4	14	48
FR-21	Front River at USACE Depot	13.9	14	57
BR-05	Back River at Hwy 17	14.5	31	66
FR-06	Front River upstream of Houlihan Bridge	16.6	14	63
FR-22	Front River at Kings Island Turning Basin	18.7	14	76
BR-07	Back River	18.9	30	84
FR-08	Front River	20.5	14	85
LBR-15	Little Back River at Houlihan Bridge	20.9	30	96
FR-09	Front River at Houlihan Bridge	21.5	14	95
MR-10	Middle River at Houlihan Bridge	21.8	26	96
FR-11	Front River	24.7	14	113
FR-11R	Front River, Revised 1999	23.4	14	106
MR-12	Middle River	24.4	26	117
MR-12R	Middle River, Revised 1999	23.7	26	113
LBR-13	Little Back River	26.6	31	123
SR-14	Savannah River at I-95 Bridge	27.7	14	126
SR-16	Savannah River near Hardeeville		14	137
SR-17	Savannah River near Ebenezer Creek		14	173
USGS Stations				
02198980	Front River at Fort Pulaski	0.8	13	23
02198977	Front River at Broad Street	14.6	13	59
02198920	Front River at Houlihan Bridge	21.5	14	95
021989791	Little Back River at USF&W Dock	22.1	30	106
02198979	Little Back River at Limehouse Cr	24.1	39	114
021989784	Little Back River at Lucknow Canal	24.2	39	114
02198840	Savannah River at I-95 Bridge	27.7	14	127
02198500	Savannah River near Clyo, GA	61	14	213

5.4 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. Bottom roughness is the key parameter in addition to bathymetry to calibrate water surface elevation. Currently, the EFDC model uses 0.03 as a global bottom roughness with no adjustments spatially. This value can be found in the "efdc.inp" file and the spatial adjustments in the "dxdy.inp" file.

The summary statistics and time series plots of the draft calibration for water surface elevation are shown in Appendix B. The Federal Expectations require reporting of the 10^{th}, 50^{th}, and 90^{th} percentiles of the model compared with the data. Table B-1 shows the percentiles for the entire 1999 summer period and Table B-2 shows the summary statistics. The five spring/neap events are plotted and summarized in Tables B-3 through B-12.

The 1999 water surface elevation was also compared using a harmonic analysis. The harmonic analysis calculates the main tidal components (M2, S2, N2, K1, O1) from the time series of measurements and simulated results. The results are presented in Table 5-3.

5.5 Currents Calibration

The summary statistics and time series plots of the draft calibration for currents are shown in Appendix D. The Federal Expectations require reporting of the 5^{th}, 50^{th}, and 95^{th} percentiles of the model compared with the data. The EFDC model performs very well on the currents in magnitude and phasing at FR-04 and –06 for 1999 for the surface stations. The Federal Expectations are met for the surface data.

The stations upstream of I-95 Bridge where the AquaDopp Current meters were deployed could not be compared to a "Surface Current" as pointed out in the Federal Expectations document. Therefore, these stations were not considered in the statistical comparisons with the model.

5.6 Flow Calibration

The flow calibration was performed on the ADCP transect data collected in 1999. The transect locations are not shown in a figure but the transect times are located in Appendix F in Table F-1 and results are shown for F-2. There were 15 transects in 1997 and 42 transects in 1999.

The summary statistics and time series plots of the draft calibration for flows are shown in Appendix F. The Federal Expectations require reporting of the peak ebb and the peak flood of the model compared with the data. The EFDC model performs very well on the flows overall but under predicts the ebb flows in the Front and Back Rivers.

5.7 Temperature Calibration

Temperature was the hydrodynamic parameter with the least calibration. The temperature data were used at Clyo and then a seasonal temperature function was used for the downstream boundary. The summary statistics and time series plots of the draft calibration for temperature are shown in Appendix H with the summary of results in Tables H-1 and H-2. The Federal Expectations require reporting of the 50^{th} percentiles of the model compared with the data. The EFDC model performs very well on the temperature and meets all of the Federal Expectations for the Absolute Mean Error at every site.

Table 5-3 Comparison of Observed and Model Predicted Tidal Harmonic Constituents

Station	Harm	AmpObs (m)	AmpMod (m)	Amp Error (m)	Amp Relative Error (%)	PhsObs (hr)	PhsMod (hr)	Phs Error (hr)	Phs Error (degrees)
FR-26	M2	1.034	1.026	0.008	0.8	6.14	6.25	-0.11	-3.19
	S2	0.158	0.147	0.011	7.0	8.81	8.89	-0.08	-2.40
	N2	0.169	0.176	-0.007	4.1	6.79	6.80	-0.01	-0.28
	K1	0.094	0.094	0.000	0.0	9.32	9.48	-0.16	-2.41
	O1	0.071	0.075	-0.004	5.6	4.88	5.49	-0.61	-8.51
FR-04	M2	1.134	1.149	-0.015	1.3	6.50	6.59	-0.09	-2.61
	S2	0.176	0.168	0.008	4.5	9.20	9.43	-0.23	-6.90
	N2	0.198	0.195	0.003	1.5	7.25	7.26	-0.01	-0.28
	K1	0.098	0.100	-0.002	2.0	9.95	9.74	0.21	3.16
	O1	0.083	0.073	0.010	12.0	5.41	5.69	-0.28	-3.90
FR-06	M2	1.178	1.219	-0.041	3.5	6.70	6.72	-0.02	-0.58
	S2	0.153	0.160	-0.007	4.6	9.31	9.44	-0.13	-3.90
	N2	0.178	0.177	0.001	0.6	7.68	7.65	0.03	0.85
	K1	0.088	0.090	-0.002	2.3	10.13	9.95	0.18	2.71
	O1	0.090	0.078	0.012	13.3	5.12	5.67	-0.55	-7.67
FR-08	M2	1.198	1.255	-0.057	4.8	6.82	6.78	0.04	1.16
	S2	0.167	0.178	-0.011	6.6	9.62	9.68	-0.06	-1.80
	N2	0.199	0.204	-0.005	2.5	7.56	7.48	0.08	2.28
	K1	0.100	0.103	-0.003	3.0	10.17	9.93	0.24	3.61
	O1	0.083	0.072	0.011	13.3	5.70	5.95	-0.25	-3.49
FR-09	M2	1.195	1.243	-0.048	4.0	6.85	6.87	-0.02	-0.58
	S2	0.168	0.173	-0.005	3.0	9.65	9.81	-0.16	-4.80
	N2	0.203	0.202	0.001	0.5	7.62	7.61	0.01	0.28
	K1	0.102	0.102	0.000	0.0	10.20	10.08	0.12	1.80
	O1	0.083	0.073	0.010	12.0	5.95	6.04	-0.09	-1.25
SR-14	M2	0.975	1.174	-0.199	20.4	7.67	7.23	0.44	12.75
	S2	0.089	0.137	-0.048	53.9	10.15	10.25	-0.10	-3.00
	N2	0.096	0.163	-0.067	69.8	9.70	8.32	1.38	39.25
	K1	0.098	0.090	0.008	8.2	12.54	10.43	2.11	31.74
	O1	0.097	0.076	0.021	21.6	7.40	6.18	1.22	17.01
02198979	M2	1.079	1.022	0.057	5.3	7.51	7.47	0.04	1.16
	S2	0.128	0.133	-0.005	3.9	11.01	10.66	0.35	10.50
	N2	0.179	0.163	0.016	8.9	8.74	8.26	0.48	13.65
	K1	0.127	0.096	0.031	24.4	11.66	10.56	1.10	16.55
	O1	0.109	0.070	0.039	35.8	7.91	6.55	1.36	18.96

5.8 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 from the system, including surface and bottom instruments in the navigation channel. Therefore, it was important to perform a rigorous calibration meanwhile keeping in mind that the model could be used over longer time periods. Also, that the model will be used in a predictive mode to simulate a management scenario for the harbor.

The summary statistics and time series plots of the draft calibration for salinity are shown in Appendix J. The Federal Expectations require reporting of the 10^{th}, 50^{th}, and 90^{th} percentiles of the model compared with the data. The EFDC model performs very well in the navigation channel and demonstrates the stratifying and de-stratifying process at stations FR-04, -21, -06, -22, -08, and –09 (main Front River stations).

The criteria were established for the stations: GPA 5, 6, 7, 8, 9, 10, 11R, 12R, 15, and 22 and five USGS stations. The July 31-October 13 (Appendix J) calibration results show that the model met the criteria for USGS stations 80% (4/5) and for GPA stations 21% (3/14) for 10th percentile and 29% (4/14) for 90th percentile. Correlation of simulations and observations was meaningful (>0.6) for 80% of USGS stations and 79% (11/14) of GPA stations. The difference in meeting criteria for USGS and GPA sites can be explained partly by quality and duration of compared data. The average duration of data for USGS stations is 100% of the simulated period of time, and only 50-70% for GPA stations due to data gaps. This explains some problematic aspects of comparing percentiles of simulation results with incomplete data.

The EFDC calibration for 1999 has been enhanced over the TMDL version of the model. Once again, we went back through the bathymetry data to confirm the deepest point of the cross-section to verify the model depths for the channel. Also, the revised marsh approach increased the tidal prism, or amount of water moving into and out of the harbor on a tidal cycle, which has improved the mixing in the channel. The more tidal prism (spring tides), the more mixing. Table 5-4 and Figure 5-1 characterize the amount of stratification and de-stratification represented by the model. The analysis below was performed at FR-06 for a stratified and de-stratified (mixed) period in August 1999.

Table 5-4 Characterization of Stratified and Mixed Salinity Conditions

Stratified Conditions: 8/20/99 0:00 - 8/23/99 0:00		
	Mean Observed	**Mean Predicted**
Bottom:	23.9	21.1
Surface:	6.5	5.2
Delta:	**17.4**	**15.8**
Mixed Conditions: 8/28/99 0:00 - 8/31/99 0:00		
	Mean Observed	**Mean Predicted**
Bottom:	12.0	11.8
Surface:	5.5	3.5
Delta:	**6.5**	**8.3**

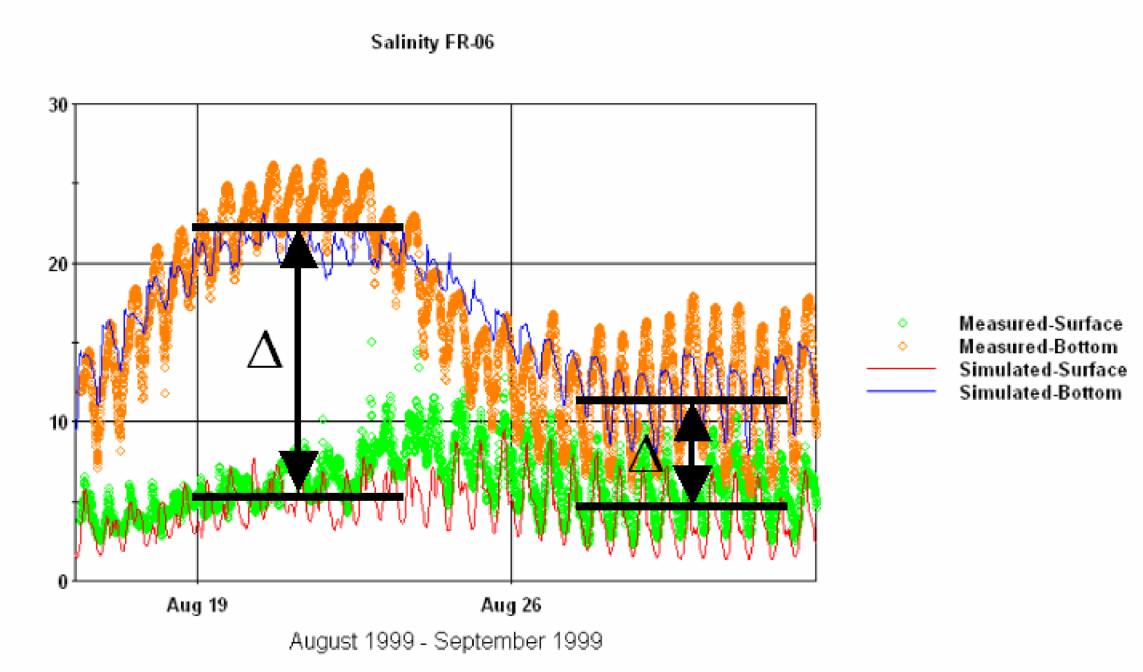


Figure 5-1 Salinity Stratification at FR-06 on the Front River

Figures 5-2 through 5-5 show the model's performance on stratifying and de-stratifying at stations FR-04, -06, -08, and –09, respectively. The EFDC model is capturing the dynamics of the salinity stratification for the navigation channel. The model still under predicts the range in salinity but this is much improved from the TMDL model.

Figures 5-6 and 5-7 show the salinity at station FR-11R, which is 2 miles upstream of the Houlihan Bridge on the Front River. This station captures the edge of the salinity wedge as it moves out of the navigation channel downstream of the Houlihan Bridge and pushes up the river. This is a critical station to compare to the model and important for demonstrating the model's abilities to identify changes expected from future deepening scenarios. Figure 5-6 shows the entire 1999 calibration period and Figure 5-7 shows a 7-day neap event in August. The salinity pumping is evident in Figure 5-7 by the steepness of the salinity signal and the salinity concentrations go from 0 to 10 back to 0 ppt in a very short period of time.

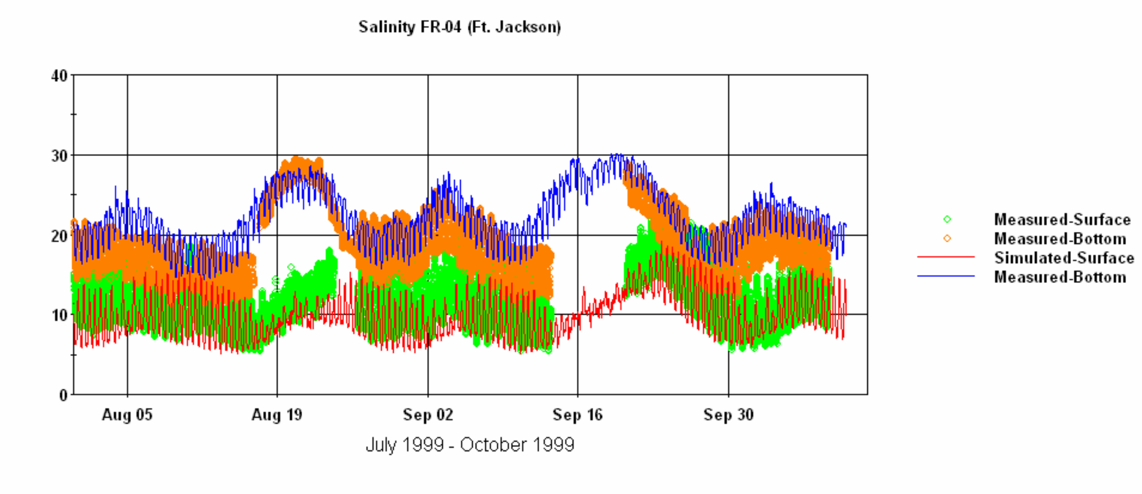


Figure 5-2 1999 Salinity on the Front River at Fort Jackson (FR-04)

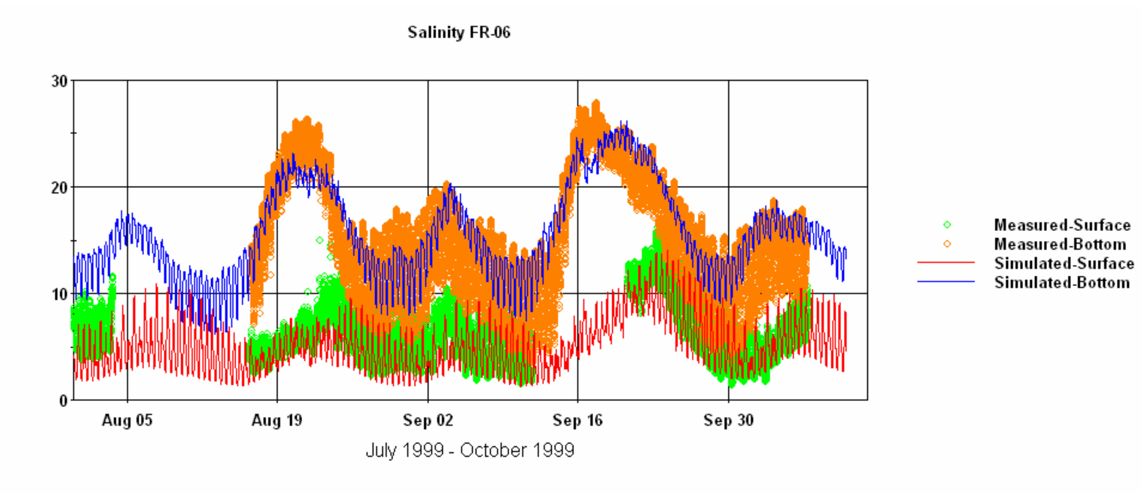


Figure 5-3 1999 Salinity on the Front River Upstream of Talmadge Bridge (FR-06)

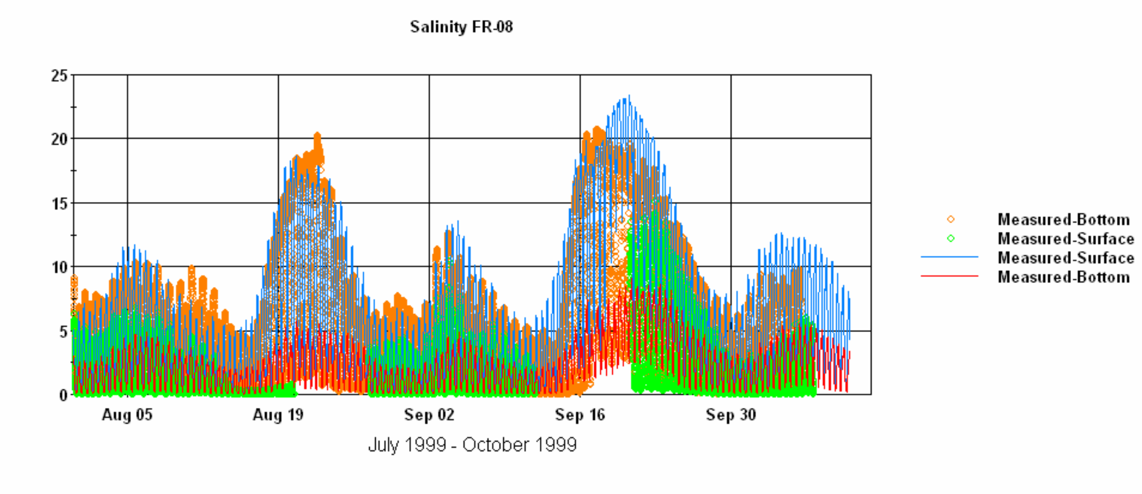


Figure 5-4 1999 Salinity on the Front River near Middle River Confluence (FR-08)

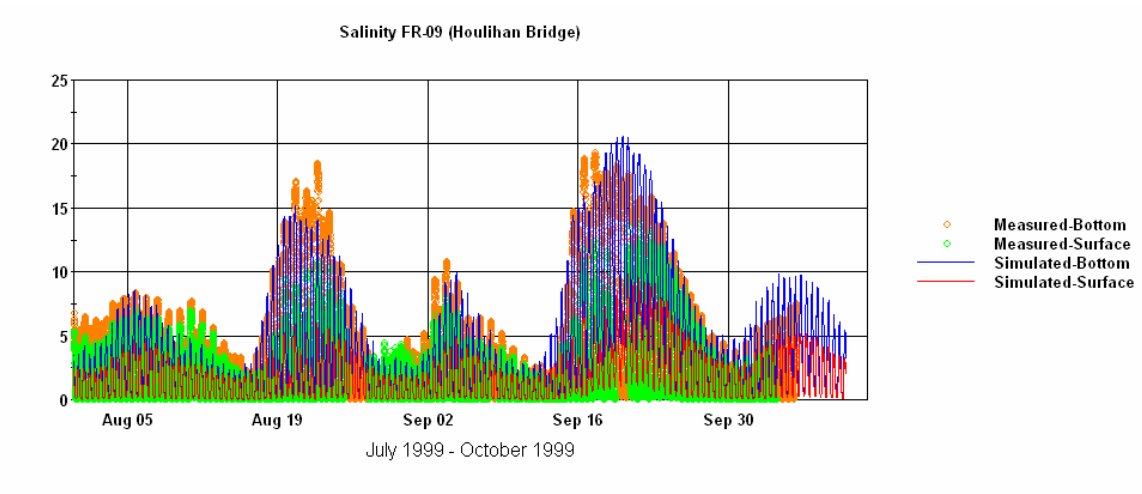


Figure 5-5 1999 Salinity on the Front River at Houlihan Bridge (FR-09)

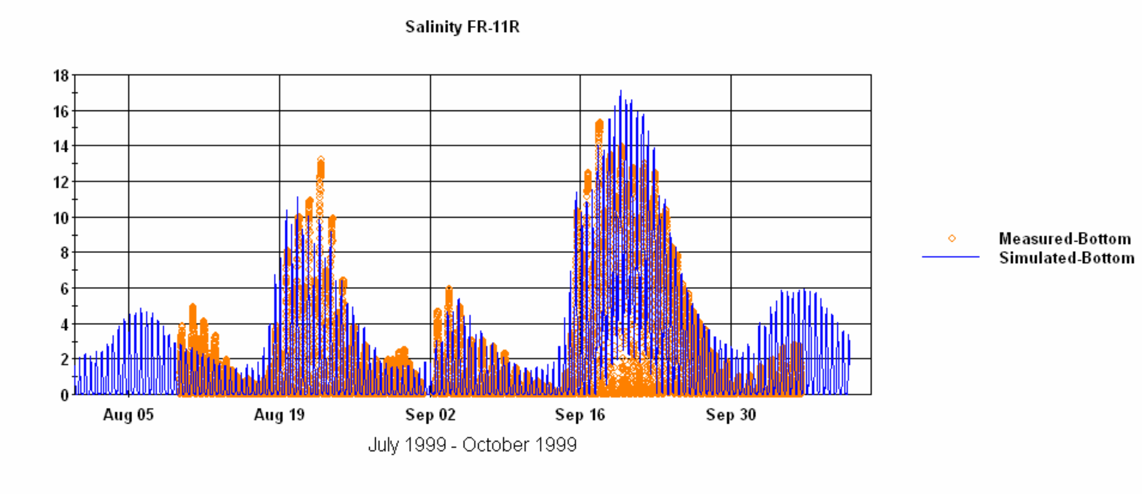


Figure 5-6 1999 Salinity on the Front River Upstream of Houlihan Bridge (FR-11R)

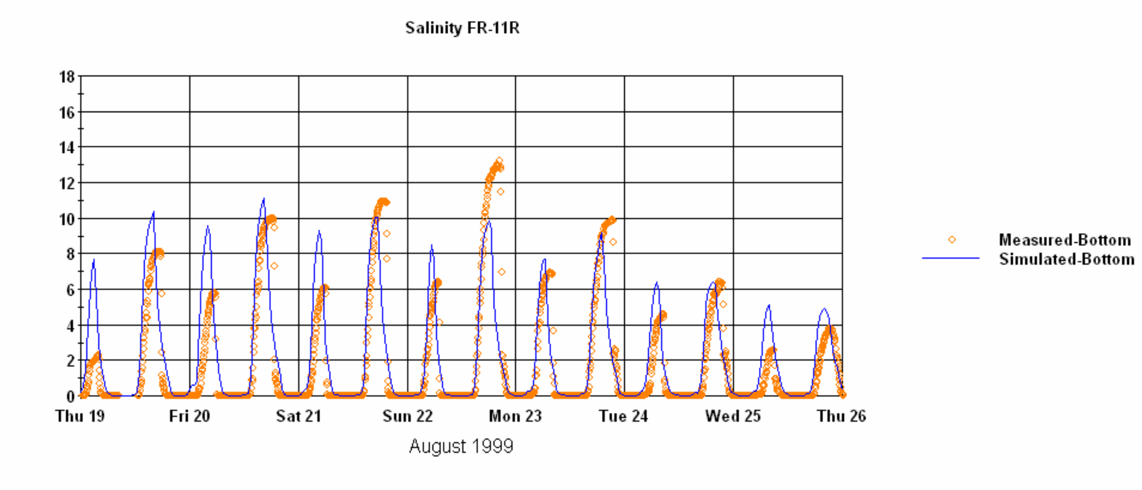


Figure 5-7 August 1999 Salinity on the Front River Upstream of Houlihan Bridge (FR-11R)

Another way to visualize the model's performance is to examine the statistics on a longitudinal plot. Figures 5-8 and 5-9 show the Front River and navigational channel stations for 1999. Figure 5-8 shows the surface comparisons and Figure 5-9 shows the bottom comparisons. The comparisons show that the EFDC model is capturing the major trends in the navigation channel. Figure 5-8 also shows that the model more accurately represents measured surface salinities in the upper harbor (where salinity is more of a concern) than in the lower harbor.

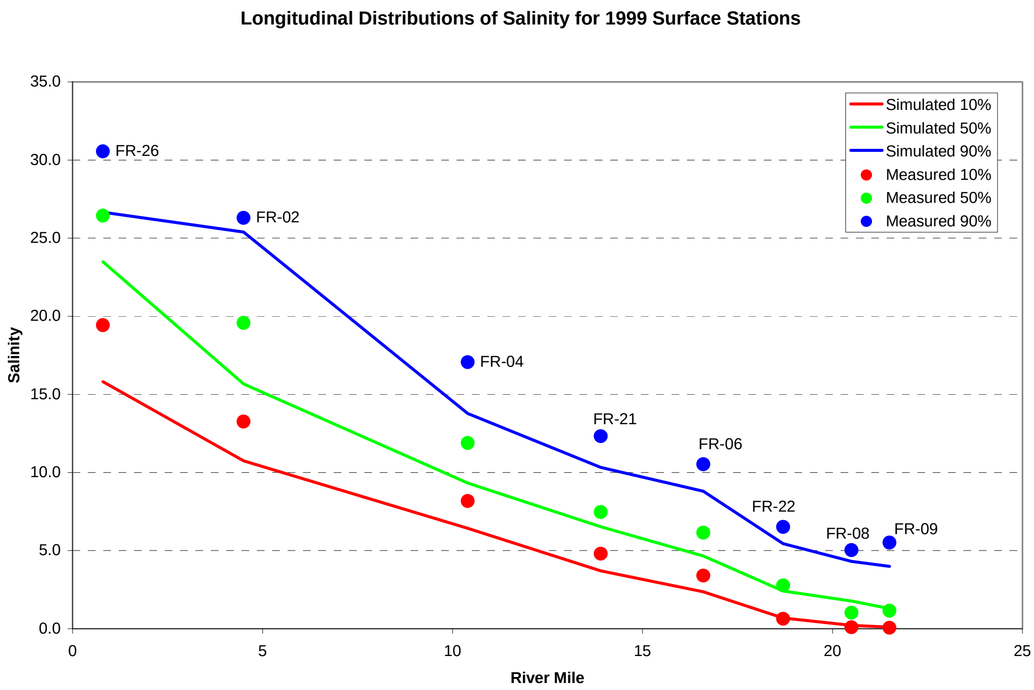


Figure 5-8 1999 Measured versus Simulated Longitudinal Surface Salinity

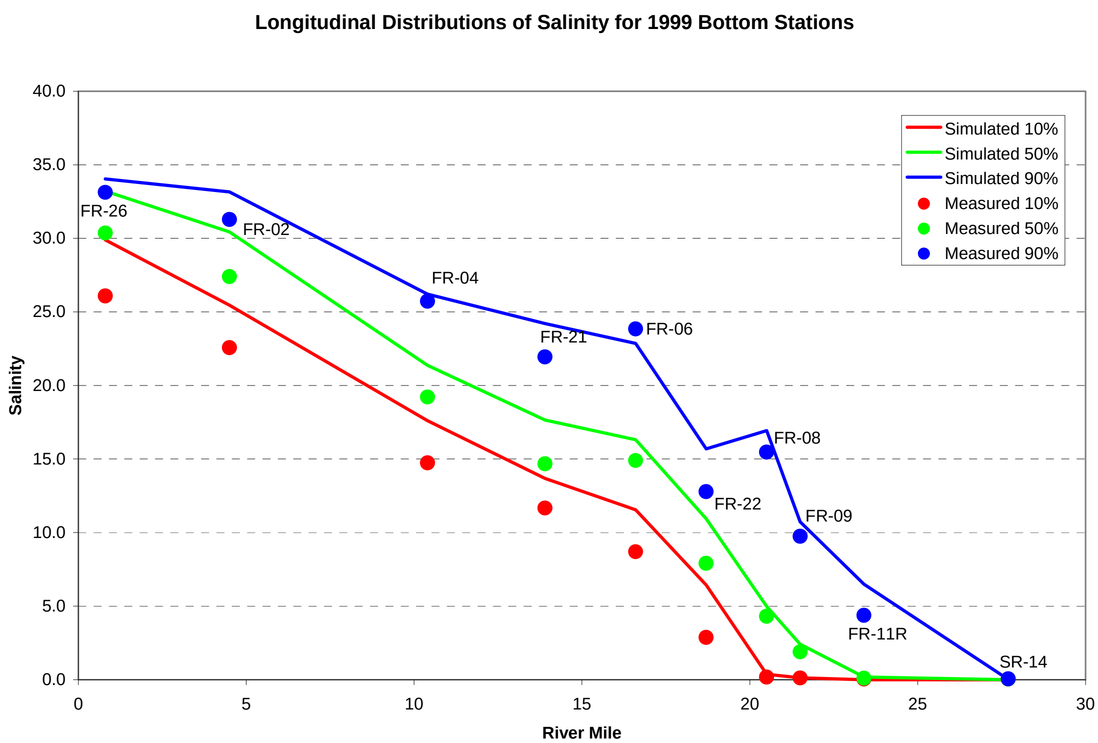


Figure 5-9 1999 Measured versus Simulated Longitudinal Bottom Salinity

6.0 EFDC MODEL CONFIRMATION

After the model was calibrated, the reliability of the model's predictions was 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 obtained for the periods of January 1, 1997 through December 31, 2003 to confirm the EFDC model. These data were not used to calibrate the model, but rather confirm the model's performance over the seven years. The data were imported into WRDB so that they could be available through MOVEM and statistics generated. The following sections summarize the confirmation results.

The time period for the EFDC model confirmation is the summer of 1997 from July 5, 1997 through October 13, 1997. The 1997 confirmation was performed with no changes to the boundary conditions or inputs. Figures 6-1 and 6-2 show the results of the longitudinal distributions of salinity in the navigational channel.

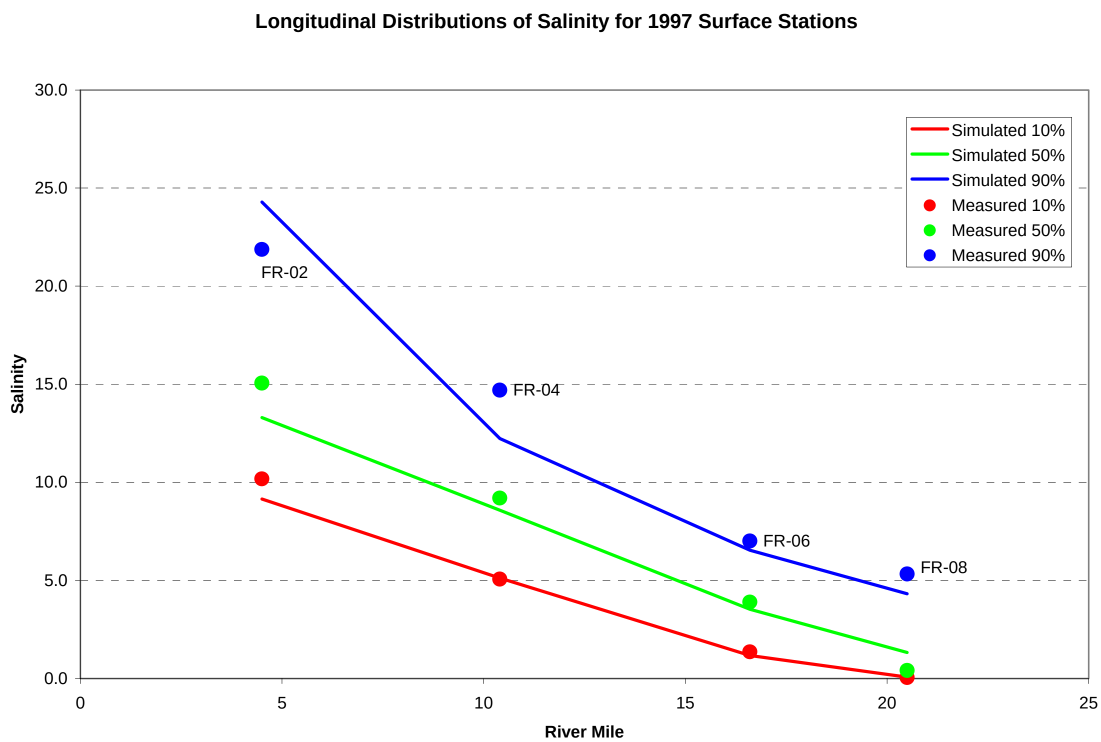


Figure 6-1 1997 Measured versus Simulated Longitudinal Surface Salinity

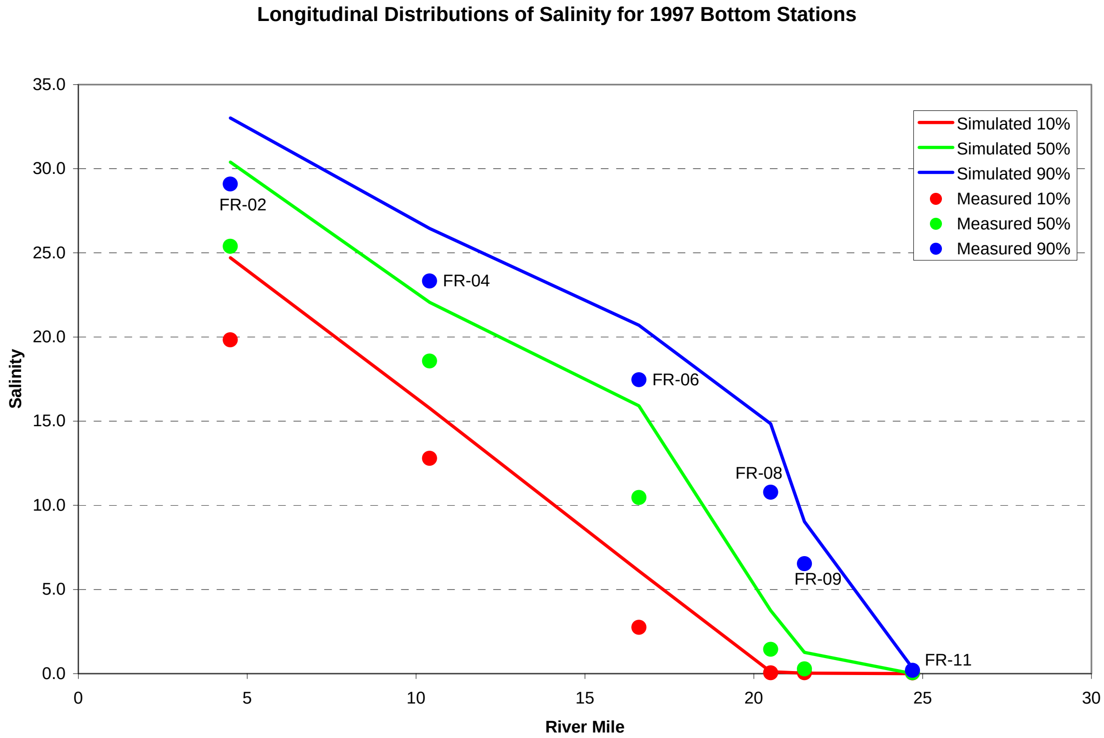


Figure 6-2 1997 Measured versus Simulated Longitudinal Bottom Salinity

Appendix C shows the water surface elevation, Appendix E shows the currents, Appendix G shows the flows, Appendix I shows the temperature, and Appendix K shows the salinity of the 1997 confirmation model run.

Appendix L shows the 1997 through 2003 water surface elevation confirmation comparisons and Appendix M shows the salinity comparisons for all seven years.

7.0 WASP WATER QUALITY MODEL

The Water Quality Analysis Simulation Program Version 7.0 (WASP7) was used for the water quality model development described in this report. WASP7 was released by USEPA on April 27, 2005 on the Modeling Toolbox website (http://www.epa.gov/athens/wwqtsc/html/wasp.html). This model calibration report contains a copy of the model so that reviewers can immediately assess this application for the Savannah River Estuary. WASP7 is the new version of WASP with many upgrades to the user's interface and the model's capabilities. The major upgrades to WASP have been the addition of multiple BOD components, addition of sediment diagenesis routines, and addition of periphyton routines. The TMDL model used WASP6 and the enhanced grid calibration was performed with WASP7, referred to from this point forward as just WASP. Figure 7-1 shows a diagram for the water quality model used in this application.

WASP is an enhanced Windows version of the USEPA Water Quality Analysis Simulation Program (WASP). The Windows version WASP has been developed to aid modelers in the implementation of WASP. With the new WASP, model execution can be performed up to ten times faster than the previous USEPA DOS version of WASP. Nonetheless, WASP uses the same algorithms to solve water quality problems as those used in the DOS version of WASP. WASP contains 1) a user-friendly Windows-based interface, 2) a pre-processor to assist modelers in the processing of data into a format that can be used in WASP, 3) high-speed WASP eutrophication and organic chemical model processors, and 4) a graphical postprocessor (MOVEM) for the viewing of WASP results and comparison to observed field data.

The new release of USEPA WASP was an enhancement of the original WASP (Di Toro et al., 1983; Connolly and Winfield, 1984; Ambrose, R.B. et al., 1988). WASP is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. The time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in the basic program. Water quality processes are represented in special kinetic subroutines that are either chosen from a library or written by the user. WASP is structured to permit easy substitution of kinetic subroutines into the overall package to form problem-specific models. WASP comes with two such models -- TOXI for toxicants and EUTRO for conventional water quality. Earlier versions of WASP have been used to examine eutrophication of Tampa Bay; phosphorus loading to Lake Okeechobee; eutrophication of the Neuse River and estuary; eutrophication and PCB pollution of the Great Lakes (Thomann, 1975; Thomann et al., 1976; Thomann et al, 1979; Di Toro and Connolly, 1980), eutrophication of the Potomac Estuary (Thomann and Fitzpatrick, 1982), kepone pollution of the James River Estuary (O'Connor et al., 1983), volatile organic pollution of the Delaware Estuary (Ambrose, 1987), and heavy metal pollution of the Deep River, North Carolina (JRB, 1984). In addition to these, numerous applications are listed in Di Toro et al., 1983.

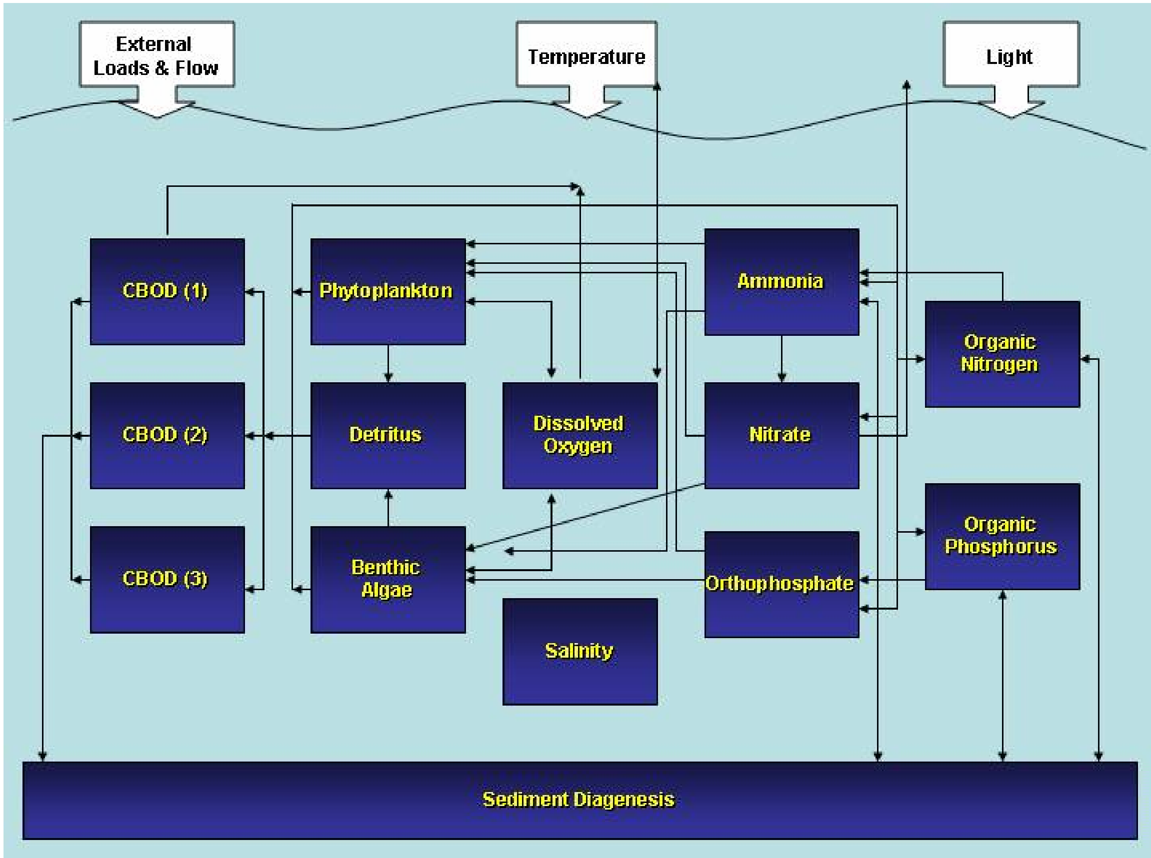


Figure 7-1 Water Quality Diagram for WASP

8.0 WASP APPLICATION TO THE SAVANNAH RIVER ESTUARY

Normal water quality modeling procedures were used to calibrate the Savannah Harbor model. Since there is limited algal activity or primary production in the harbor, nutrients were determined not to be a significant issue by EPA Region 4 and were not included in the water quality modeling scenarios. The water quality model incorporated normal oxygen dynamics, including reaeration, sediment oxygen demand (SOD), carbonaceous Biochemical Oxygen Demand (CBOD) and uptake, Nitrogenous Biochemical Oxygen Demand (NBOD) and uptake. The modeling approach was a five step process:

1. Incorporation of the hydrodynamic modeling results.
2. Determination of upstream and ocean boundary conditions.
3. Development of the point discharge loadings, marsh loadings and tributary loadings.
4. Determination of the instream modeling parameters and kinetic rates.
5. Calibration to measured water quality data

8.1 Incorporation of the Hydrodynamic Modeling Results

The EFDC was used to perform the hydrodynamic simulations for the Savannah Harbor Estuary. The model and the application to Savannah Harbor is documented in the previous sections of this report. The model was run from 1997 through 2003.

Savannah Harbor EFDC hydrodynamic model provides to WASP:

- Ocean flow and tidal dynamics,
- Upstream flow,
- Three dimensional model cell structure and volumes,
- Cell volumes and transport,
- Salinity and Temperature

The hydrodynamic modeling information is incorporated into the WASP model through the hydrodynamic linkage file.

8.2 Determination of Upstream and Ocean Boundaries

8.2.1 Headwater Boundary at USGS Clyo Gage #02198500

The headwater or upstream boundary of the Savannah Harbor Model was at the USGS Clyo Gage 02198500, 61 miles upstream from harbor mouth, the same as used in the EFDC Model. The headwater flows were based on USGS gaging record and incorporated through the EFDC model linkage. CBOD, NBOD and dissolved oxygen headwater boundary conditions were developed from field measurements and results of an upstream water quality model used by USEPA Region 4. USEPA adapted the EPD-RIV1 hydrodynamic and water quality model to the Savannah River for 1997 through 2001. (USEPA, 2004) The original model was developed by GAEPD based on data collected by USEPA, Georgia and South Carolina during summers of 1990 and 1991. Updated point source discharges' CBOD, NBOD and dissolved oxygen loadings along with measured discharged flows were incorporated in the model. The Savannah River EPD-RIV1 model was run under three scenarios:

- Background condition with no point source loadings.
- Existing conditions with DMR reported discharge flows and BOD5 and ammonia loads. F-ratios from 1990 and 1991 long-term data were used to develop the appropriate CBODu loadings. NBOD loads are equal to ammonia loads time a 4.57 conversion factor.
- Permit conditions using NPDES permitted flow and BOD5 and ammonia loads, along with the appropriate f-ratios

For the 1999 WASP model, the existing conditions run was used for CBODu, ammonia, nitrate-nitrite, and dissolved oxygen concentrations at Clyo were used for the headwater boundary conditions. Figures 8-1, 8-2, and 8-3 illustrate the boundary concentrations calculated by the Savannah River EPD-RIV1 at Clyo.

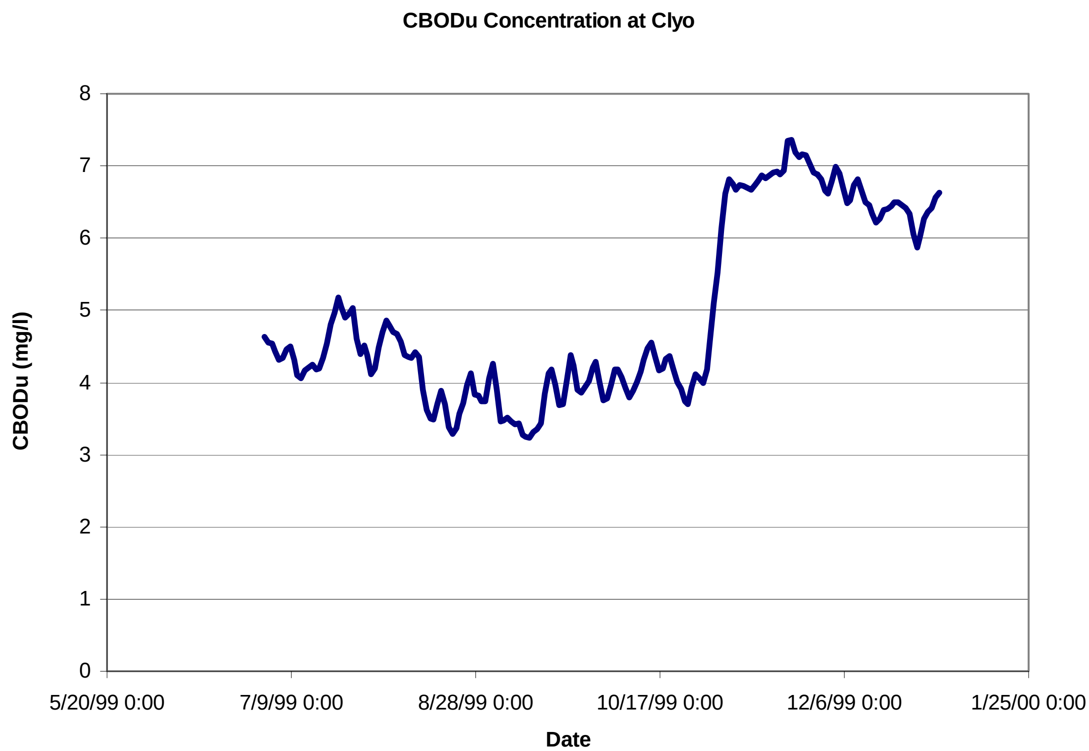


Figure 8-1 Headwater CBOD Concentrations at Clyo

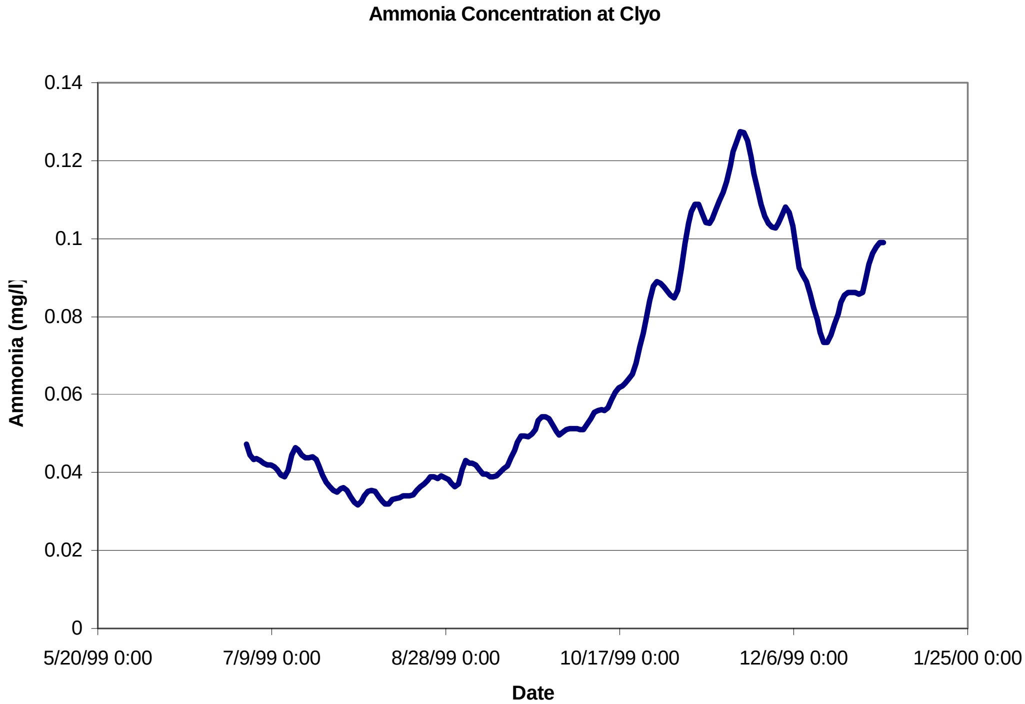


Figure 8-2 Headwater Ammonia Concentrations at Clyo

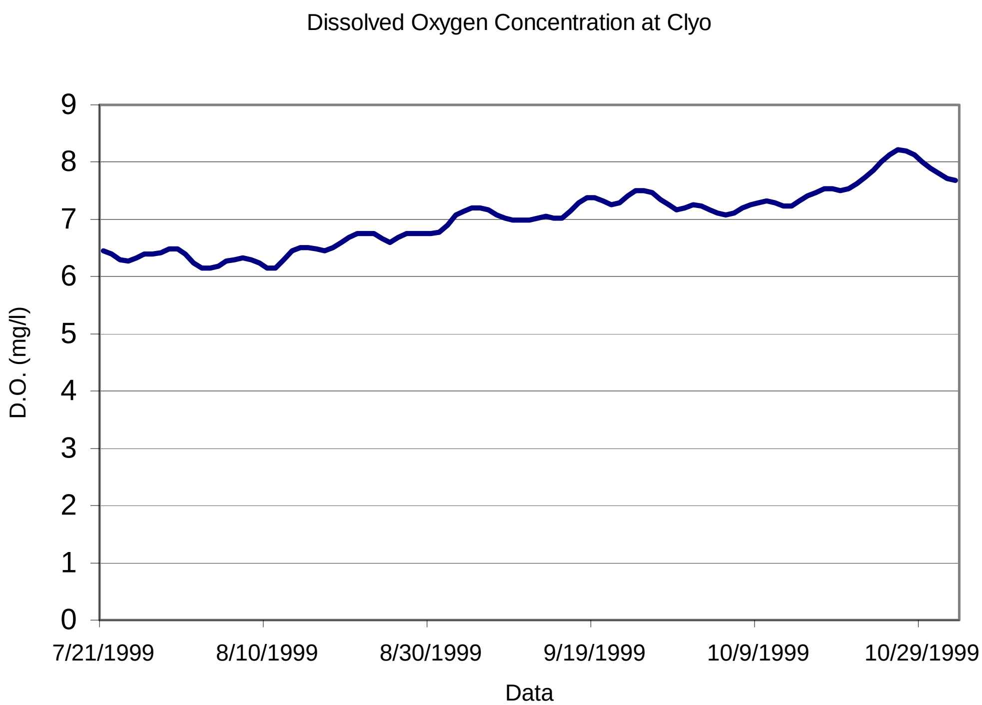


Figure 8-3 Headwater Dissolved Oxygen Concentrations at Clyo

8.2.2 Ocean Boundary Conditions

Limited data were available to establish the ocean boundary DO, CBOD and ammonia concentrations. Ocean boundary dissolved oxygen levels (Figure 8-4) were set at 90% of dissolved oxygen saturation calculated from EFDC hydrodynamic model temperature and salinity results.

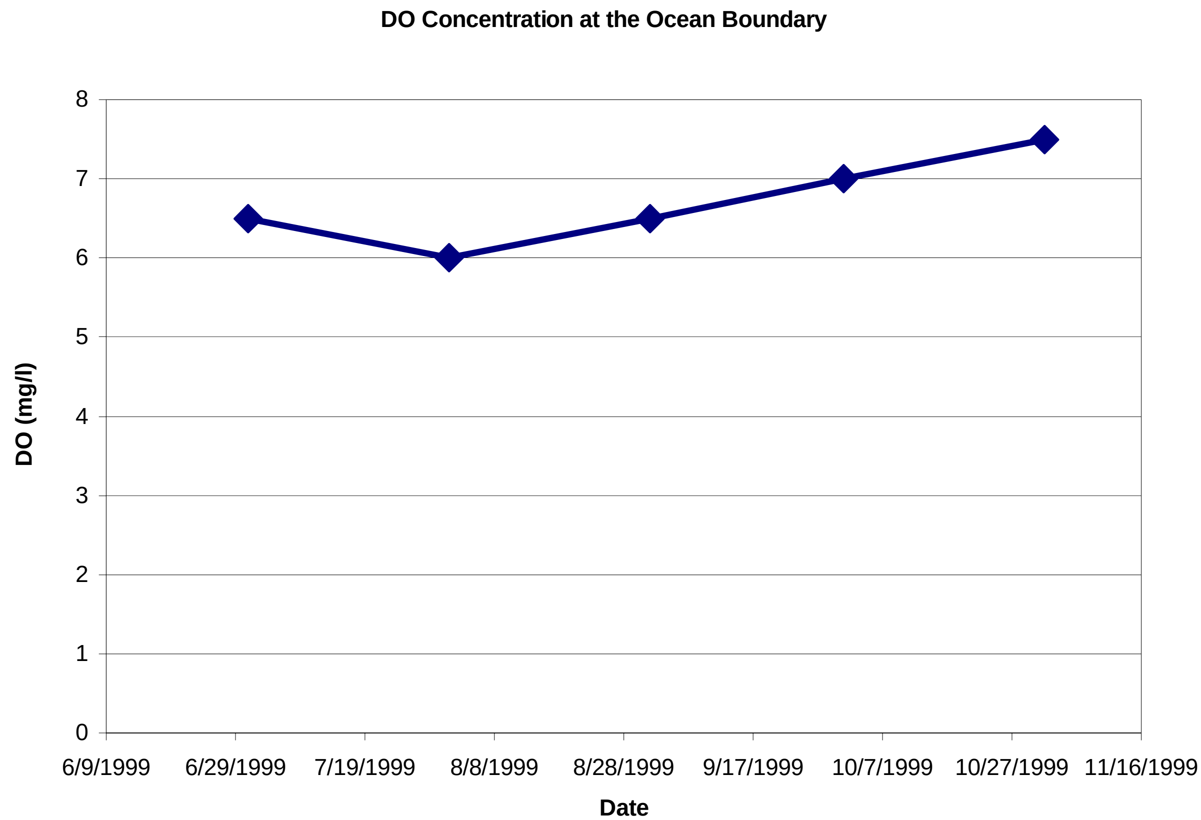


Figure 8-4 Dissolved Oxygen Concentration at the Ocean Boundary

CBODu and ammonia values were determined from long-term BOD sampling conducted on September 2003. MACTEC (2004) reported the results of nine long-term ocean BOD samples collected by the Savannah Harbor Committee on September 24, 2003. These samples were collected during high wave conditions and may not be representative of long-term average BOD conditions. Table 8-1 shows the data collected by MACTEC at the ocean boundary. Based on the data in Table 8-1, the ocean boundary CBODu was set at a constant 5 mg/L and ammonia set at 0.07 mg/L.

Table 8-1 Ocean Boundary Long-Term BOD

Station	BODu (mg/L)	CBODu (mg/L)	K1 (1/day)	NBODu (mg/L)	Kn (1/day)
SWS-01 South Ocean Boundary	5.67	5.25	0.03	0.42	0.02
SWS-02 Middle Ocean Boundary	4.07	3.74	0.04	0.34	0.01
SWS-03 Northern Ocean Boundary	9.13	8.82	0.03	0.3	0.01
SWS-04 11.5 Miles Offshore	6.18	5.67	0.03	0.51	0.01

Available USEPA data were used to establish 1997 Clyo boundary conditions for dissolved oxygen and ammonia. Because of the lack of necessary dynamic data, the 1997 CBODu boundary conditions for Clyo and ocean boundary were set to 5.0 mg/L. The dynamic dissolved oxygen ocean boundary conditions have been set similar to 1999 scenario. All other state variables remained the same as the 1999 WASP model run.

8.3 Development of Point Source, Marsh, and Tributary Loadings

8.3.1 Point Source Loads

Detailed point source CBOD and ammonia measurements were made during the 1999 Savannah Harbor Wastewater Characterization Study (Law Engineering, 1999). For the remaining time periods, the facility's Discharge Monitoring Reports (DMR) data were used to develop the appropriate loads.

A summary of the summer 1999 loads are included in Table 8-2. Detailed time series loads were incorporated into the model when daily values were available (index TS in Table 8-2), otherwise an average loads were used. So tabulated in cells with (TS) numbers display only estimated average values but are not used in the model set-up. The following calculations and nomenclature were used:

- CBODu (Ultimate CBOD) = BOD5 times f-ratio,
- NBODu (Ultimate NBOD) = Ammonia times 4.57, and
- TBODu (Ultimate Total BOD) = CBODu plus NBODu.

Table 8-2 Point Source Loads for Summer 1999

Facility name	NPDES	Flow (mgd)	CBODu (kg/day)	NH3 (kg/day)
Hardeeville	SC0034584	0.5 (TS)	11 (TS)	0.2
Fort James	GA0046973	19.3 (TS)	1830 (TS)	22
Smurfit Stone	GA0002798	2.6	280	1.1
Garden City	GA0031038	1.1	64 (TS)	0.4
Whilshire	GA0020443	3.1	292 (TS)	117 (TS)
Travis Field	GA0020447	0.8	56 (TS)	0.3 (TS)
President Street	GA0025348	19.0 (TS)	2,129 (TS)	93 (TS)
International Paper	GA0001998	30.0 (TS)	25,010 (TS)	125
Englehard	GA0048330	1.0	14	66
Kerr McGee*	GA0003646	13.0	299	NA

*NOTES: Kerr McGee has an immediate oxygen demand load of 11,519 lbs/day (5,225 kg/day)

Table 8-3 Point Source Loads for Summer 1997

Facility name	NPDES	Flow (mgd)	CBODu (kg/day)	NH3 (kg/day)
Hardeeville	SC0034584	0.5 (TS)	11.0	0
Fort James	GA0046973	19.3 (TS)	1,410 (TS)	10
Smurfit Stone	GA0002798	2.6	2,573 (TS)	1.1
Garden City	GA0031038	1.1	32 (TS)	0.1
Whilshire	GA0020443	3.1	165 (TS)	53.2 (TS)
Travis Field	GA0020447	0.8	55 (TS)	0.2 (TS)
President Street	GA0025348	18.8	2,138 (TS)	30 (TS)
International Paper	GA0001998	30 (TS)	34,645 (TS)	56.8
Englehard	GA0048330	1	NA	30
Kerr McGee*	GA0003646	13	NA	NA

*NOTES: Kerr McGee has an immediate oxygen demand load of 11,519 lbs/day

Table 8-4 NPDES Discharge Concentrations for Summers 1997 and 1999

Facility name	NPDES	Flow (mgd)	DO (mg/L)	NH3 (mg/L)	NO3-NO2 (mg/L)	CBODu (mg/L)
Hardeeville	SC0034584	0.5	6	NA	0.3	NA
Fort James	GA0046973	19.3	6	NA	0.3	NA
Smurfit Stone	GA0002798	2.6	6	NA	0.3	NA
Garden City	GA0031038	1.1	6	NA	0.3	NA
Wilshire	GA0020443	3.1	6	NA	0.3	NA
Travis Field	GA0020447	0.8	6	NA	0.3	NA
President Street	GA0025348	18.8	6	NA	0.3	NA
International Paper	GA0001998	30	6	NA	0.3	NA
Englehard	GA0048330	1	6	NA	0.3	NA
Kerr McGee	GA0003646	13	6	NA	0.3	NA
Savannah Electric Plant Macintosh*		130	6	See note	See note	See note
Savannah Electric Port Wentworth*		258	6	See note	See note	See note
Riverside Power Plant*		49	6	See note	See note	See note

*NOTE: For the Savannah Electric Plant Macintosh, Savannah Electric Port Wentworth, and the Riverside Power Plant, the return flows have consistent concentrations as the intake concentrations. For the heat loads of the power plants, see Table 4-6 in Section 4.4.5.

Figures 8-5 through 8-11 illustrate the variability of the various major harbor discharges.

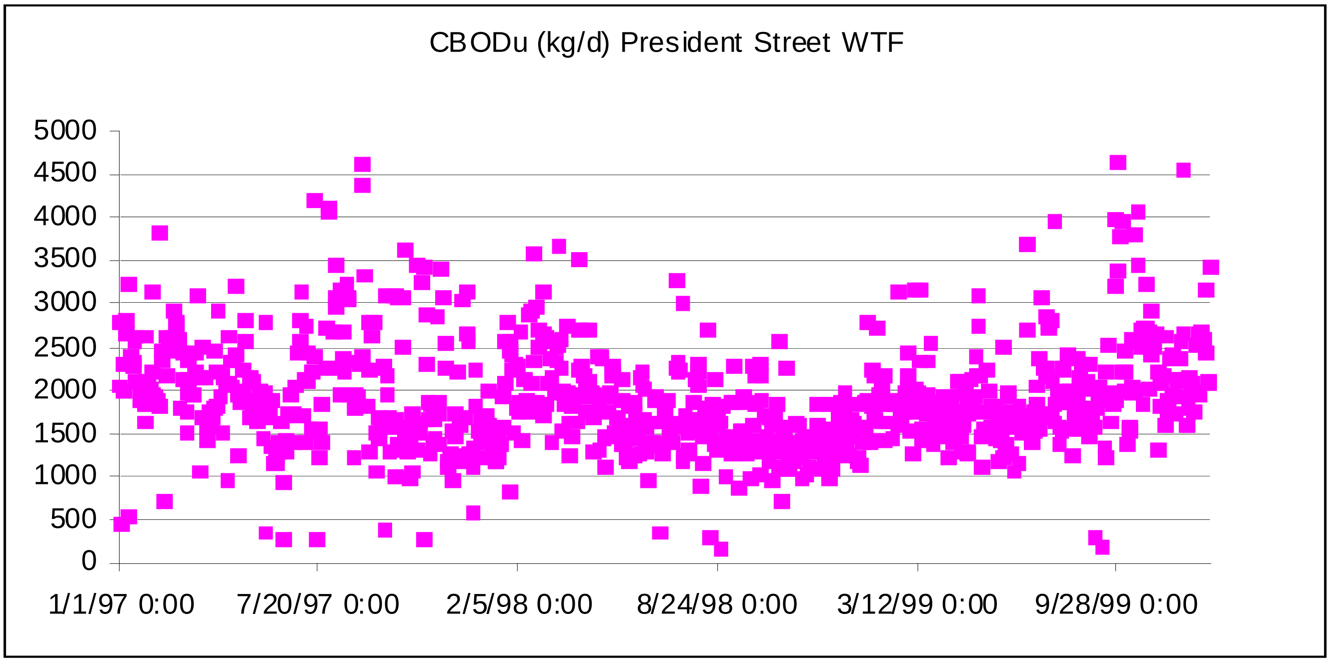


Figure 8-5 President Street CBODu Load

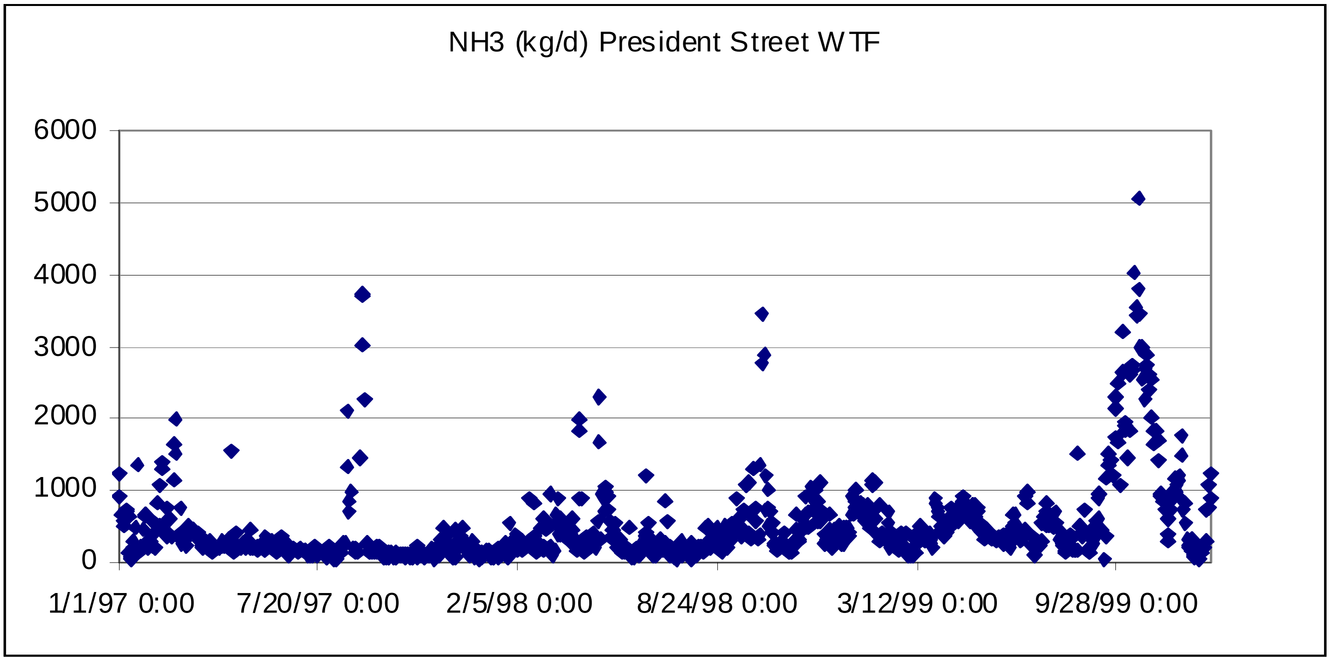


Figure 8-6 President Street Ammonia Load

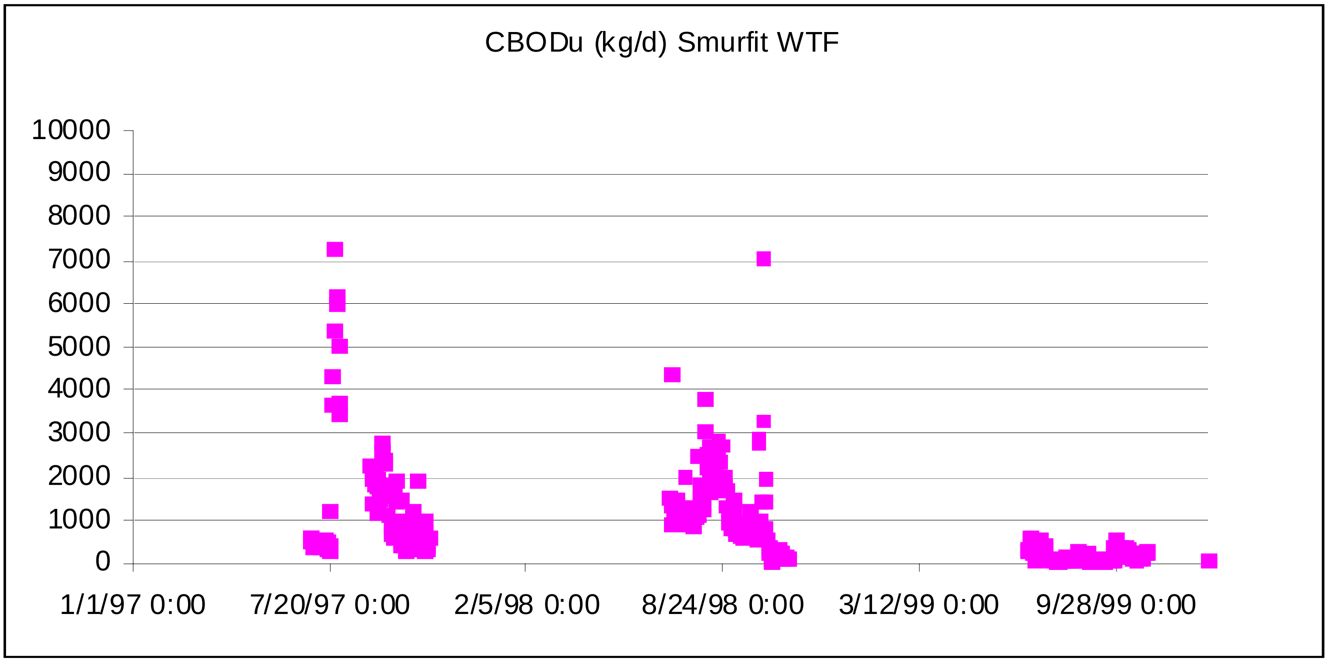


Figure 8-7 Smurfit Stone CBODu Load

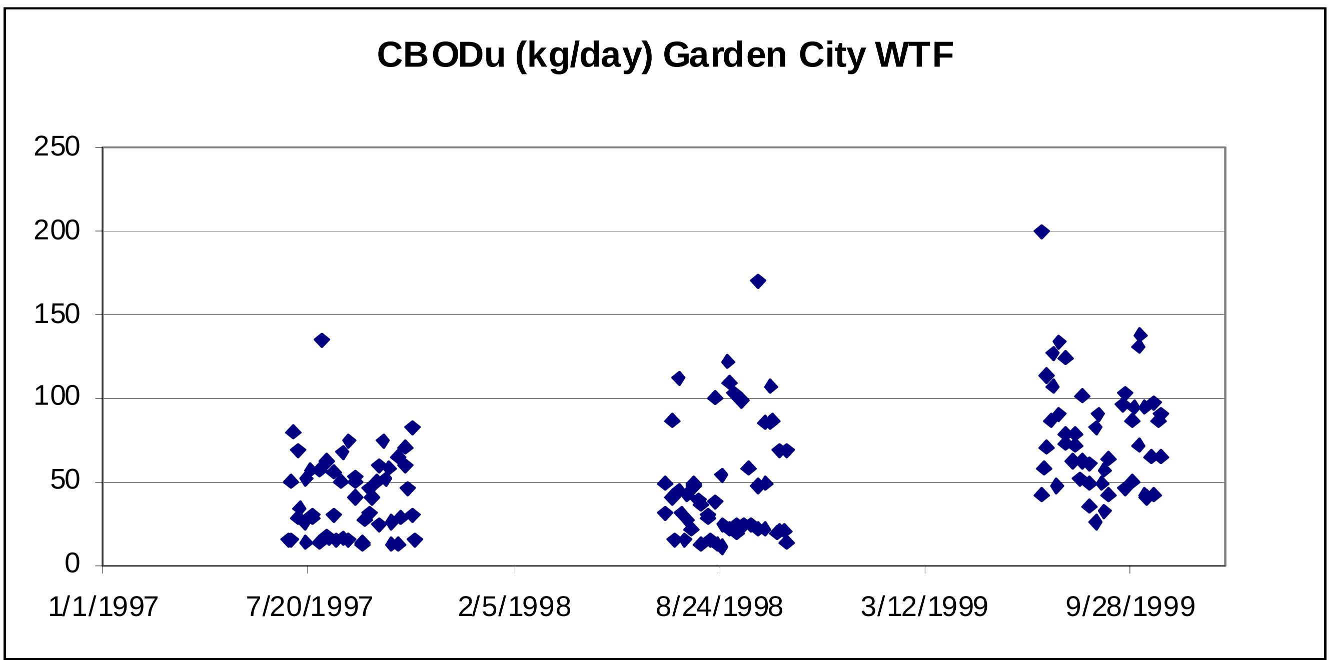


Figure 8-8 Garden City CBODu Load

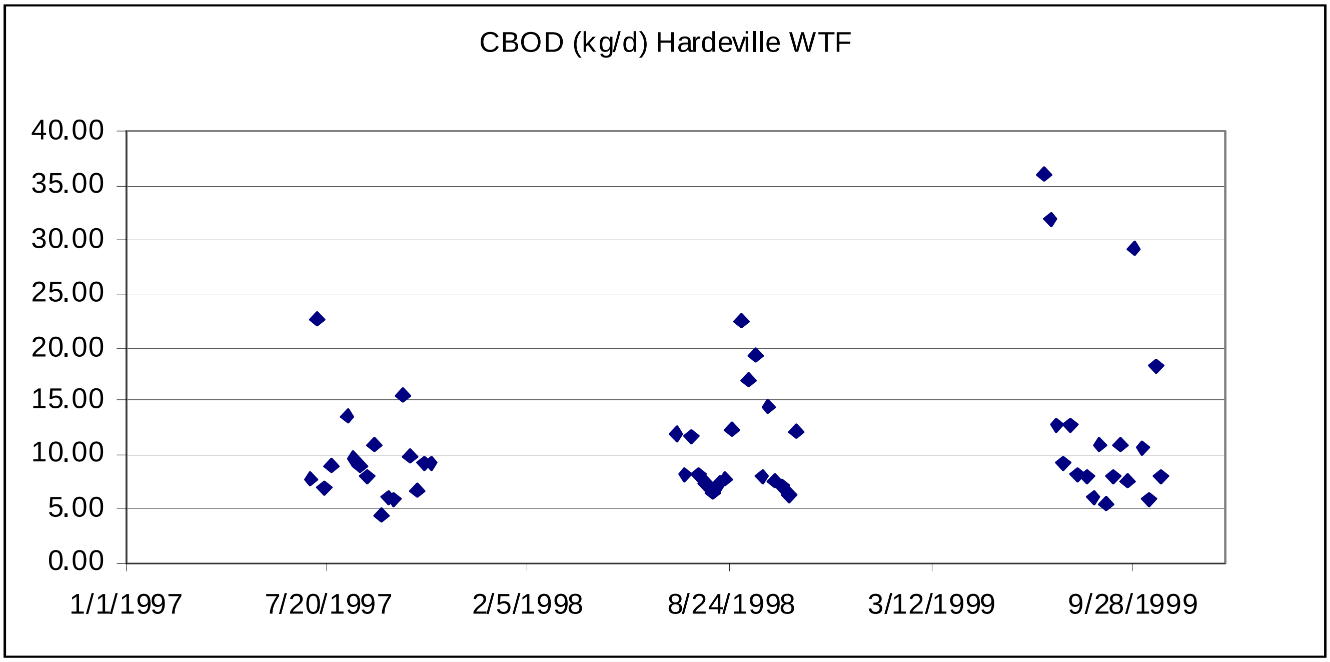


Figure 8-9 Hardeeville CBODu Load

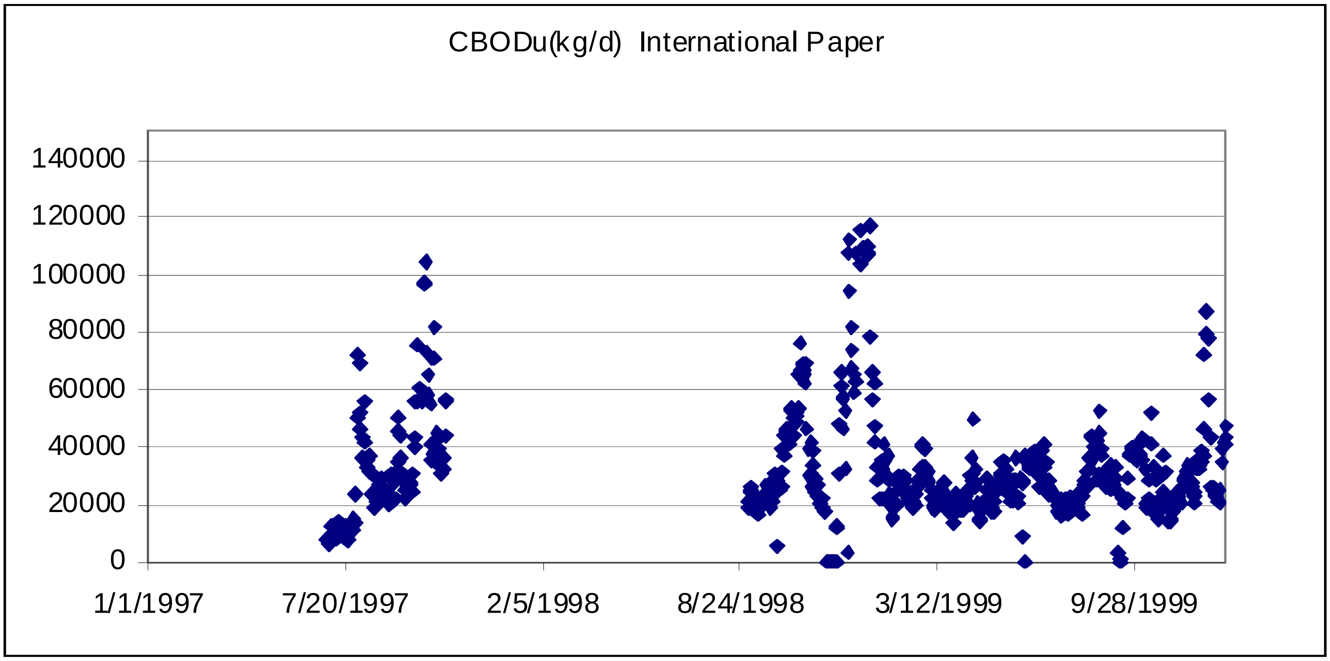


Figure 8-10 International Paper CBODu Load

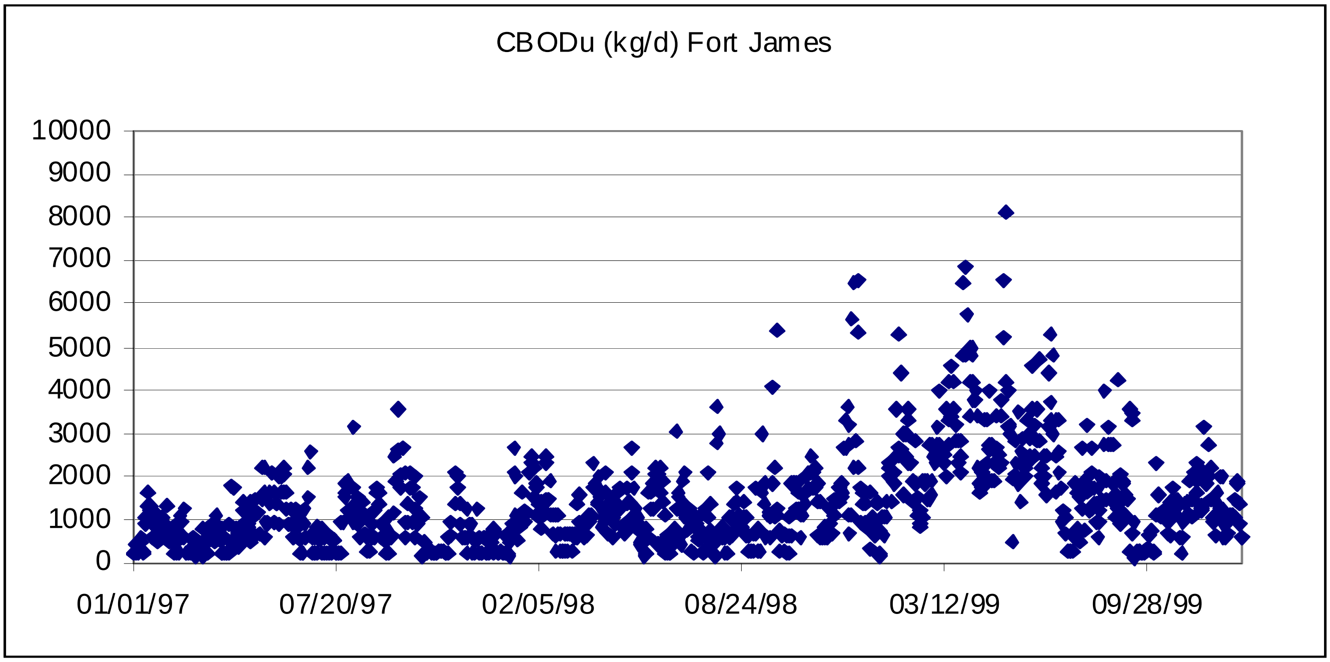


Figure 8-11 Fort James Paper CBODu Load

8.3.2 Marsh Loadings

The adjacent marsh areas in the Lower Savannah River and Estuary (Harbor) effect significantly the dissolved oxygen concentrations in the Front River. The marsh areas are important for the hydrodynamics in the way they affect the salinity transport on the Middle and Little Back Rivers. Therefore, it was determined that the inclusion of the marsh areas into the model was necessary for capturing the salinity trends in the upper part of the estuary. The modeled marsh areas would also provide a mechanism to simulate CBODu loadings from the marsh areas into Savannah Harbor. As described in detail in Section 4.4.3, a simple, but comprehensive solution was developed to handle the marsh areas in the EFDC hydrodynamic and WASP water quality models. The enhanced EFDC model includes 17 separate marsh areas to represent the 10 Q zones of the estuarine marshes from the Tidegate to I-95. Only 15 of the marshes were used as water quality loads. The Union Creek and Augustine Creek sites were used as storage only.

To quantify the exchange of organic material between marshes and the open water of the Savannah Harbor, previous studies were reviewed to develop appropriate loading rates. The following studies were reviewed and used to quantify the marsh loadings.

- GPA field data during Summer of 1999 – marsh data (ATM, 2000).
- Maybank Project: A Study of the Intertidal Marshes and Streams. USEPA Environmental Services Division, Athens, Georgia, May 1984 (USEPA, 1984).
- Burke III, Roy 1984. Proposed Protocol for: Incorporating the Effects of a Spartine Salt Marsh into a Simplified Water Quality Model of Adjacent Tidal Waters in Georgia. US USEPA, Region 4 (Burke, 1984).
- Nutrient Dynamics and Water Quality Interactions in the Goose Creek Sub-Basin of the Charleston Harbor Estuary. Department of Environmental Health Science University of South Carolina, Columbia, SC, October 1996 (McKellar, 1996).

- Nixon, Scott W. and Virginia Lee. Wetlands and Water Quality. Technical Report Y-86-2, October 1986 (Nixon, 1986).

Results of all long-term BOD (LTBOD) sampling at Marsh Exchange Transect sites in the lower Savannah River (ATM, 2000) demonstrate that all BOD samples collected during mid-ebbing tides exceed the values of BOD collected during corresponding mid-flooding tides. This indicates that marshes in Savannah Harbor export organic matter to open waters of the harbor.

The initial CBODu loading from the marsh were based on maximum literature export coefficient, the long-term data collect by ATM in 1999 (ATM, 2000), and data analyses completed by MACTEC. The marsh CBODu loadings were calculated based on the long-term BOD data as a maximum loading value. The 50% reduction of the calculated maximum loads is a reasonable assumptions considering the complete marsh area is not flooded over every tidal cycle, thus not all of the marsh area will export a CBOD load. The results are shown in Tables 8-5 and 8-6. The marsh loads were distributed in the top three layers of the model in WASP.

Table 8-5 Marsh CBOD Loading Calculations

Channel CBOD Model Predicted (mg/L) based on Maximum Loads	Measured CBOD (mg/L)	Calculated Ratio of Model output to measured CBODu	Measured Ammonia (mg/L)	Marsh Data Collection Station
8	3.5	0.44	0.3	4
25	10	0.40	0.3	
20	10	0.50	0.3	5
9	4.5	0.50	0.3	
12	4.5	0.38	0.3	4
7	3.5	0.50	0.3	1 & 3
7	4.5	0.64	0.3	
9	3.5	0.39	0.3	2
16	10	0.63	0.3	
		Average = 0.49		

Table 8-6 Marsh CBODu Loads by Q-Zone

QZONE	Marsh Type	CBOD Load (kg/d)
1	Fresh	900
2	Salt	38,100
3	Salt	18,000
4	Mixed	11,110
5	Fresh	1,848
6	Fresh	2,550
7	Mixed	750
8	Fresh	1,518
9	Fresh	2,550
10	Mixed	630

8.4 Model Kinetics

Model kinetics and parameters determine the decay of the pollutants and the oxygen uptake amount in the system. These kinetic rates and parameters are determined based on the measured data and standard water quality modeling assumptions. The parameters are shown in Table 8-7.

The main rates and parameters are:

- Decay rate K1 (1/day) for Carbonaceous BOD,
- Decay rate K1 (1/day) for Ammonia and Rest of Nitrogen Series,
- Sediment Oxygen Demand (gram/meter^2/day), and
- Reaeration (1/day).

Table 8-7 Rates and Constants in WASP Model

Rate	Value
Nitrification rate at 20 ^oC	0.035
Nitrification Temperature Coefficient	1.08
Half Saturation: Nitrification Oxygen Limitation	1
Denitrification rate at 20 ^oC	0.1
Denitrification Temperature Coefficient	1.08
Half Saturation: Denitrification Oxygen Limitation	0
Reaeration Option	O'Connor (Wind + Hydraulic)
Reaeration Temperature Correction	1.024
Oxygen:Carbon Stoychiometric Ratio	2.66
Offshore Correction Factor for BOD Decay Rate	0.5
BOD Decay Rate Temperature Correction	1.047
BOD Half Saturation Oxygen Limit	0.5
Fraction of BOD Carbon Source for Denitrification	2.66
Sediment Oxygen Demand	0.5 to 1.2
Sediment Oxygen Demand Temperature Correction	1.065
Offshore Wind Correction Factor	6

8.4.1 Decay Rate K1 (1/day) for Carbonaceous BOD

The CBOD represents the oxygen demanding equivalent of the complex organic carbonaceous material in water. The ultimate CBOD (CBODu) and the initial CBOD decay rates were determined from the long-term BOD results summarized in the Savannah Harbor Expansion Project TMDL 1999 River and Marsh Long-term Biochemical Oxygen Demand Results (Federal Agencies, 2004). This report, lead by Dr. Roy Burke at GAEPD, provided backup documentation for the 39 long-term BOD samples collected during the 1999 intensive summer survey.

The distinction between "bottle" BOD rates and the loss rate (or decay rate) of BOD in surface water depends on the type and size of the receiving water body. For shallow streams, one would expect the in-stream decay rate to be higher than the bottle rate due to the influence of the benthic community located on the sides and bottom of the stream bed. For larger streams and estuaries, where the volume of water is large compared to the area of the sides and bottom, the river or estuary decay rate will be equivalent to the measured bottle rate and the measured bottle rates are good indicators of the actual stream CBOD decay rates. A temperature correction factor 1.047 was used to adjust the CBOD decay rate for the changes in temperature. The measurements from 1999 are shown in Table 8-8.

Table 8-8 Measured Long-term BOD rates and F-ratios

Survey No.	Slack Tide	Ultimate Carbonaceous BOD			Ultimate Nitrogenous BOD	
		mg/L	K1 Rate per day	f-ratio	mg/L	Kn Rate per day
Station 1. Ft. Pulaski. River Mile 0.8						
1	High	2.99	0.062	3.75	1.77	0.029
2	High	4.25	0.105	2.45	1.88	0.027
3	High	2.62	0.081	3.02	2.26	0.018
1	Low	2.81	0.076	3.17	1.60	0.032
2	Low	3.09	0.047	4.75	1.27	0.051
3	Low	3.52	0.084	2.90	1.68	0.034
Average =		**3.21**	**0.076**	**3.34**	**1.74**	**0.032**
Station 2. Ft. Jackson. River Mile 10.6						
1	High	3.03	0.055	4.15	2.08	0.030
2	High	3.24	0.062	3.77	1.49	0.062
3	High	2.46	0.082	3.00	1.77	0.040
1	Low	2.88	0.057	4.02	1.73	0.032
2	Low	2.96	0.061	3.83	1.54	0.059
3	Low	2.54	0.072	3.30	1.72	0.027
Average =		**2.85**	**0.065**	**3.68**	**1.72**	**0.042**
Station 3. Corps Dock. River Mile 16.6						
2	High	2.38	0.034	6.48	0.80	0.055
3	High	2.58	0.070	3.37	1.62	0.032
1	Low	2.64	0.054	4.20	1.31	0.018
2	Low	2.38	0.034	6.48	0.80	0.055
3	Low	2.33	0.064	3.67	1.59	0.023
Average =		**2.46**	**0.051**	**4.84**	**1.22**	**0.037**
Station 4. I-95 Bridge. River Mile 27.7						
3	High	1.69	0.065	3.59	0.91	0.018
1	Low	2.29	0.066	3.68	0.79	0.018
2	Low	2.19	0.028	7.78	0.64	0.037
3	Low	1.87	0.067	3.49	1.24	0.018
Average =		**2.01**	**0.057**	**4.64**	**0.90**	**0.023**
Clyo, Georgia. River Mile 61.0						
1	---	3.10	0.078	3.09	0.92	0.027
2	---	3.65	0.071	3.34	2.04	0.038
3	---	1.68	0.068	3.49	0.38	L
Average =		**2.81**	**0.072**	**3.31**	**1.11**	**0.033**

The Savannah Harbor is a complex system which receives wastewater with various types of long-term BOD characteristics. For example, pulp mill wastewater that has a low bottle decay rate, CBODu concentration and high f-ratio. There have been multiple discussions on how to assign an appropriate decay rate that accurately accounts for the impact of these low BOD decay rate wastewaters. One method would be to assume each wastewater discharge acts independently in the receiving water and assign a unique CBOD decay rate to each wastewater discharge that is equivalent to their respective bottle rate. The other method is to assume the wastewater and receiving waters' concentration of organic material combine and the oxidation of the organic carbon in a body of water is a single rate that decays the combine CBODu. The second approach was most supported by USEPA and GAEPD, so it is the method used in the Savannah Harbor modeling described herein.

Based on the long-term BOD data and analyses, spatial varying K1 rates, as reported in Table 8-9, were assigned to the various portions of the harbor model.

Table 8-9 Spatial Distribution of CBODu Decay Rates (1/day)

Harbor Segment	K1 Scale Factor
Savannah River (from Clyo to K.I. Turning Basin)	0.92-1.08
Front River	0.83-1.08
Middle River	0.83-0.92
Back and Little Back Rivers	0.5
Offshore	0.5-0.67
F.R. Sediment Basin	0.5-0.67
Sediment Basin	0.92-1.08
Turning Basin	0.92-1.08
South Channel	0.92-1.08
Union Creek	1.08
Marshes	0.83-0.92

For the point source dischargers, the LTBOD demonstrated various types of long-term BOD characteristics. For example, pulp mill wastewater that has a low bottle decay rate, CBODu concentration and high f-ratio. There have been multiple discussions on how to assign an appropriate decay rate that accurately accounts for the impact of these different BOD decay rate wastewaters. Dr. Roy Burke III of Georgia EPD has re-evaluated the Savannah Harbor long-term data using the updated GAEPD LTBOD program. These results are located in Table 8-10 and described below. Based on extensive data analyses and taking into account existing limitations of the WASP code the following LTBOD approach is proposed.

The Enhanced Savannah Harbor water quality model will use three carbonaceous decay rates. These three rates are selected based on Dr. Burke's initial LTBOD analyses. Using these three rates, each discharge and boundaries conditions' ultimate CBOD and resultant f-ratio, were determined using a one or two component CBOD LTBOD analysis.

- Fast acting K1 rate of 0.12/day with an f-ratio of 2.3
- Middle K1 rate of 0.06/day with an f-ratio of 5
- Slow acting K1 rate of 0.02/day with an f-ratio of 10.5

The long-term BOD analysis (LTBOD program) was conducted using the following steps:

- NBOD curve determined using a lag first order curve fit:
  - The curve subtracted from long-term time series to yield CBOD time series.
  - NBODult determined.
- Fast or initial acting CBOD component using first order curve fit:
  - This resultant curve was also subtracted to yield the residue CBOD.
  - CBODult1 and f-ratio determined.
- Slow acting CBOD component using a lagged first order curve fit with 0.02/day rate:

  - The normal in bottle lag time was 20 to 40 days.
  - CBODult2 and f-ratio determined.
- For the dual rate component WTF discharges:
  - Total CBODult and the percentage of fast acting and slow acting CBODult where determined.
  - CBOD5 was determined from the initial CBOD curve fit.
  - This total CBODult (CBOD1 plus CBOD2) was divided by this CBOD5 to determine the combined f-ratio.
  - Using the combined f-ratio the total CBODult can be determined from the WTF's CBOD5 time series and then divided in to the appropriate loading category.

Based on the described analyses, the following CBOD decay rates in Table 8-10 were assigned.

Table 8-10 CBODu Decay Rates (1/day)

Source/Water	% of total discharge	K1 (1/day)	F-ratio
Hardeeville (fast)	50	0.12	2.3
Hardeeville (slow)	50	0.02	10.5
Fort James (fast)	50	0.12	2.3
Fort James (slow)	50	0.02	10.5
Smurfit Stone (fast)	65	0.12	2.3
Smurfit Stone (slow)	35	0.02	10.5
Garden City	100	0.02	10.5
Wilshire	100	0.02	10.5
Travis Field	100	0.02	10.5
President Street	100	0.02	10.5
International Paper	100	0.02	10.5
Englehard	100	0.06	5.0
Marshes	100	0.06	5.0
Clyo boundary (fast)	70	0.12	2.3
Clyo boundary (slow)	30	0.02	10.5
Ocean Boundary (fast)	50	0.12	2.3
Ocean Boundary (slow)	50	0.02	10.5

8.4.2 Ammonia Reaction Rates

A uniform ammonia Kn rate of 0.035/day was based on measured rates from long-term BOD analyses. See CBODu rates discussion. A temperature correction factor 1.08 was used to adjust the Kn rate for the changes in temperature.

8.4.3 Sediment Oxygen Demand

The sediment oxygen demand (SOD) in rivers and estuaries may result from the discharge of settleable organic solids, urban runoff and upstream nonpoint sources of organic materials. The SOD in the Savannah Harbor system were last measured in 1999 and are reported in the 1999 USEPA Region 4 study "Dissolved Oxygen Diffusion Study and Sediment Oxygen Demand Study, Savannah River, Savannah, Georgia, August 2 – 14, 1999". The average SOD measurements in the main portion of the Front River were 1.1 grams/meter^2/day at 30 degrees Celsius with a SOD range of 0.86 to 1.3. This value was used as a starting SOD value for the model. Higher SOD rates of 2.58 grams/ meter^2/day at 30 degrees Celsius were measured in the Kings Island Turning Basin. The 1.2 grams/ meter^2/day SOD at 20 degrees Celsius was used as a starting value for the Turning Basin and the downstream Sediment Basin and 0.7 to 0.9 for the Front and Savannah Rivers and 0.65 for rest of system. A temperature correction factor 1.065 was used to adjust the SOD rate for the changes in temperature. Figure 8-12 is output from the WASP model and shows how SOD varies over time in the sediment and turning basins in comparison to the rest of the harbor.

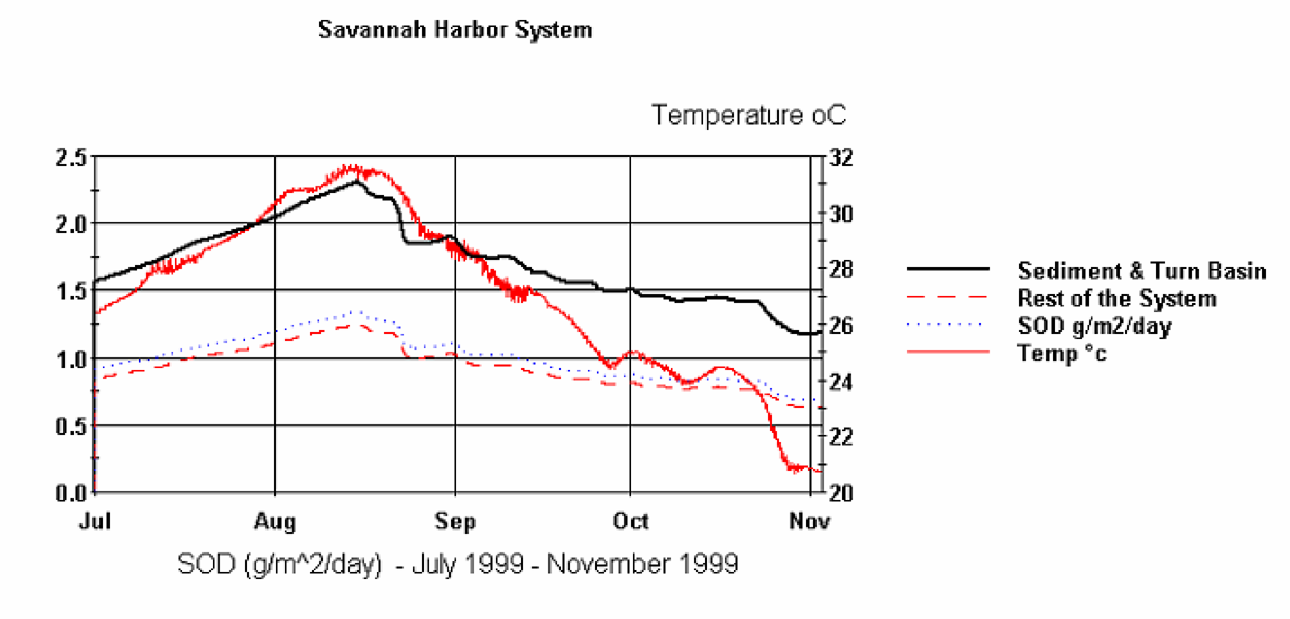


Figure 8-12 SOD (g/m^2/day) for Savannah Harbor System

8.4.4 Reaeration

Oxygen transfer in natural waterbodies depends on internal mixing and turbulence due to velocity gradients and fluctuations, temperature, wind mixing, waterfalls, dams and rapids and surface films. (Thomann and Mueller, 1987) For the Savannah Harbor system, a time varying tidal reaeration using the O'Connor Dobbins formulation, incorporating the model's surface layer predicted depths and velocities, was used to calculate this oxygen transfer. For the open ocean portion of the model and the harbor mouth area, the wind-induced reaeration option was used to calculate the oxygen transfer. O'Connor-Dobbins reaeration formulation was developed to be applied to estuaries using average tidal velocity and depth. To adjust the WASP-calculated reaeration value, a factor of 0.2 was applied. This factor was determined through the dissolved oxygen calibration process. A temperature correction factor of 1.024 was used to adjust the reaeration rate for the changes in temperature.

Diffusion in the Savannah Harbor system was measured in 1999 and are reported in the 1999 USEPA Region 4 study as reported in "Dissolved Oxygen Diffusion Study and Sediment Oxygen Demand Study, Savannah River, Savannah, Georgia, August 2 – 14, 1999". The diffusion measurements were compared to the model predicted reaeration results and it indicated that the calculated reaeration values are in line with the measured reaeration values using the diffusion dome method. Figure 8-13 is output from the WASP model and shows how reaeration varies over time in the Front River, Savannah River, and open ocean.

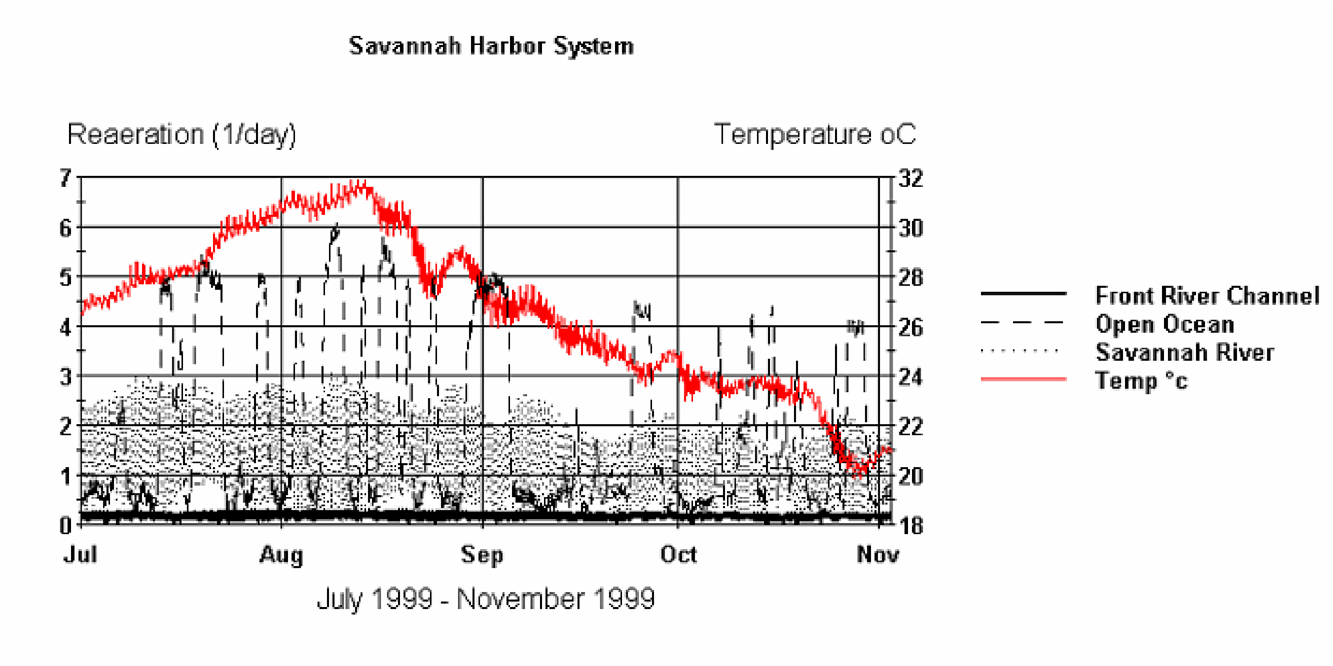


Figure 8-13 Reaeration (1/day) for Savannah Harbor System

9.0 WASP MODEL CALIBRATION

9.1 Model Calibration Process

The calibration was performed using the summer 1999 dataset. The EFDC Savannah Harbor Hydrodynamic model was used to provide the model grids, depths, volumes, velocities, and diffusion parameters along with the predicted temperatures and salinities. The hydrodynamic model was run from June 1, 1999 through October 30, 1999, with a one-month or 30-day spin up time. The WASP model was run from July 21, 1999 to October 13, 1999 with a 10-day spin up time. The WASP output is from August 1, 1999 to October 13, 1999 with 2.4-hour intervals.

As illustrated in the previous sections, the majority of the model kinetic parameters have been defined by the measured data. Preliminary values used for the kinetic rates were discussed with the SHE Modeling Review Team. The model loading and boundary conditions were also measured and input directly into the model. The main calibration parameters were minor adjustments to SOD and the reaeration scaling factor.

9.1.1 Available Data Evaluation

The measured values from the data collected during the 1999 summer survey were used for calibration the WASP water quality model. The data consisted of dissolved oxygen, BOD, ammonia, other nutrients, and chlorophyll-a concentrations. Specifically, for the WASP model calibration, dissolved oxygen, BOD, and ammonia were used.

The quality of dissolved oxygen measurements differed for different stations. Raw data collected at stations FR-02, -04, -21, -10, -06 surface, and -22 bottom during significant parts of observation period show unrealistically low (sometimes negative) or unrealistically high values and were removed the final datasets by ATM. Unfortunately, Tetra Tech does not have information about exact approaches and the methods of dissolved oxygen data cleaning. Visual comparisons of raw and cleaned data create some doubts about effectiveness of applied cleaning procedures. The existence of possible wrong data can be the one of explanations of the difficulty in achieving the Federal Expectations criteria.

Measured BOD and ammonia data demonstrate the range of values from 3 to 10 mg/L for BOD and from 0.2 to 0.15 mg/L for ammonia. The higher values of these water quality components were observed during the first week of August 1999. Unfortunately, the observed BOD and ammonia dynamics during this first week of sampling cannot be explained by existing DMR data from point sources or any kind of meteorological event.

9.2 CBODu Comparison

The simulated CBODu output was compared to the measured values from the long-term data collected during the 1999 summer survey. Appendix O demonstrates that the calibrated model is yielding reasonable CBODu values. The statistics were not calculated for CBODu, only time series plots were produced.

The data measured during the week of August 5, 1999 (week 1 of the water chemistry sampling) was higher than any other period in the 1999 data collection. The abnormally high CBODu concentrations were noticeable at stations FR-26, FR-02, and FR-21 and could be attributed to a point source in the vicinity of these stations. When compared to nearby stations, the CBODu values are lower. The loads for the NPDES facilities did not exhibit the higher values in their discharge during this time period. The second period with abnormally high CBODu concentrations (up to 30 mg/L) in vicinity of station FR-21 was October 8-9 of 1999. Unfortunately, the point sources used for the 1999 WASP model set-up does not contain the corresponding loads for these events. Accordingly the water quality model cannot reproduce the high CBODu values without the correction of available point source information.

9.3 Ammonia Comparison

The predicted model ammonia output was compared to the measured values from the 1999 survey. Appendix N demonstrates that the calibrated model is yielding reasonable ammonia values. The statistics were not calculated because of the lack of time series data (only grab samples were collected).

A similar occurrence in ammonia was recognized in the data as discussed in the previous discussion about the CBODu. The abnormally high ammonia concentrations were observed at stations FR-21 and FR-06 during the week of August 5, 1999. Because of timing and location coincidence it is assuming logically that the CBODu and ammonia abnormally high discharges were occurred from the same source. Unfortunately, the data for the point sources does not contain information about the discharges that can be associated with the observed high ammonia (and CBODu) concentrations.

9.4 Dissolved Oxygen Comparison

To provide goals, or a measuring stick, for how well the model is performing the Federal Agencies previously developed a draft expectations document entitled "Draft Savannah Harbor Data Analysis and Modeling Expectations of the Federal Agencies". The evaluation criteria are very stringent and not intend to be used individually (by station and parameter) for pass/fail evaluation of the model calibration, but are viewed as performance goals to which model predictions will be compared and by which an understanding of their uncertainties may be developed.

The predicted model DO output was compared to the measured values from the long-term data collected during the 1999 summer survey for each station that was mentioned as an important station in Federal Expectations (GPA 2, 4, 6, 8, 9, 10, 11R, 14, 21, and 22). The following sections illustrate that the calibrated model is yielding reasonable DO values and is representing the long-term DO trends of the system. DO calibration results are shown in Appendix P.

Table 9-1 WASP Segments for Data Comparisons

Station ID	Description	River Mile	Segment Location index
FR-26	Front River at Fort Pulaski	0.8	I=14, J=23
FR-02	Front River in the Entrance Channel	4.5	I=14, J=30
FR-04	Front River near Fort Jackson	10.4	I=14, J=48
FR-21	Front River at USACE Depot	13.9	I=14, J=57
FR-06	Front River upstream of Houlihan Bridge	16.6	I=14, J=63
FR-22	Front River at Kings Island Turning Basin	18.7	I=14, J=76
FR-08	Front River	20.5	I=14, J=85
FR-09	Front River at Houlihan Bridge	21.5	I=14, J=95
MR-10	Middle River at Houlihan Bridge	21.8	I=26, J=96
FR-11	Front River	24.7	I=14, J=113
FR-11R	Front River, Revised 1999	23.4	I=14, J=106
SR-14	Savannah River	27.7	I=14, J=126
SR-16	Savannah River	30.2	I=14, J=137

Table P-1 provides the 10th, 50th, and 90th percentile comparisons of model simulated dissolved oxygen to measured values for the period of July 31, 1999 to October 13, 1999. Table P-2 provides values of mean error, absolute mean error, root mean square error, number of pairs of measured and simulated values, along with means and standard deviations for both measured and simulated results. Tables P-3 through P-12 provide the same information for the 5 spring/neap tidal cycles between July 31, 1999 to October 13, 1999.

Table P-1 for the simulation period of July 31, 1999 to October 13 shows that Federal Expectations requirements were satisfied 19 times from the total 36, or 53%. 7 times from 17 unsatisfied comparisons the Federal Expectations requirements were violated by 0.1 mg/L. We evaluate these results as an acceptably strong performance particularly referring to often not enough high quality of available D.O. data. The tidal cycles statistical tables generally show some weaker performance probably because of shorter sets of available clean data.

Another way to visualize the model's performance is to examine the statistics on a longitudinal plot. Figures 9-1 and 9-2 show the Front River and navigational channel stations for 1999. Figure 9-1 shows the surface comparisons and Figure 9-2 shows the bottom comparisons. The comparisons show that the WASP model is capturing the longitudinal distribution of dissolved oxygen in the Front River. The simulated and measured comparisons in Figure 9-2 show the critical low dissolved oxygen area is between FR-04 and FR-08 (river mile 10.4 to 20.5).

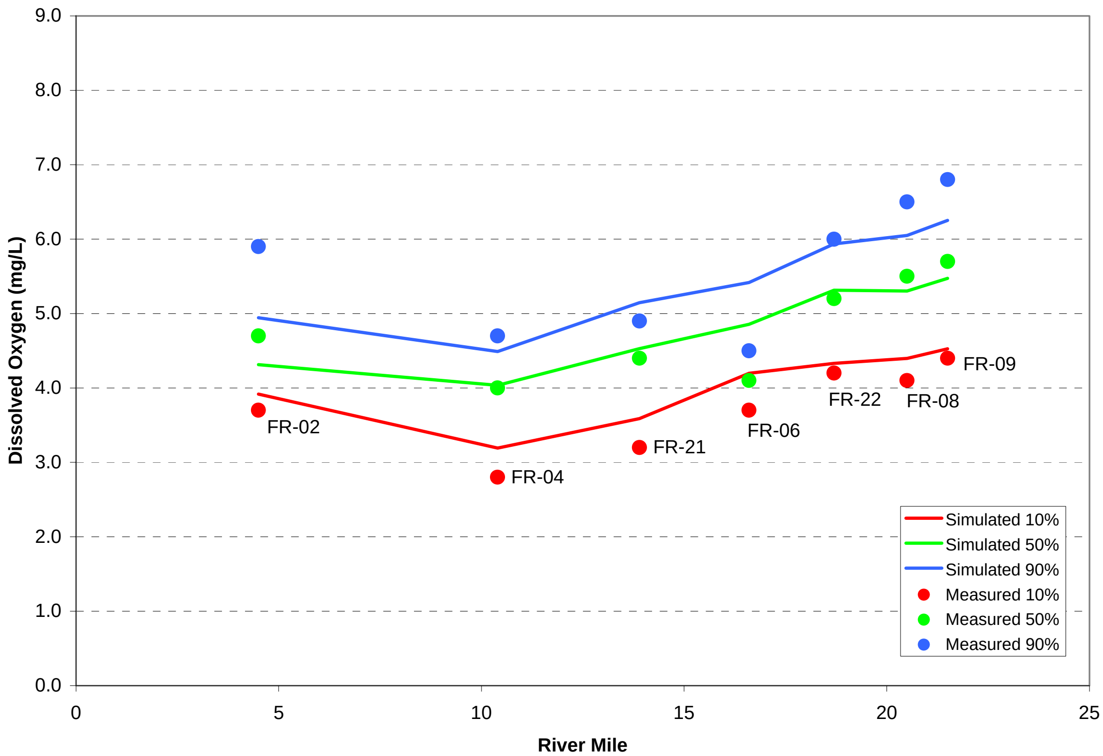


Figure 9-1 1999 Measured versus Simulated Longitudinal Surface Dissolved Oxygen

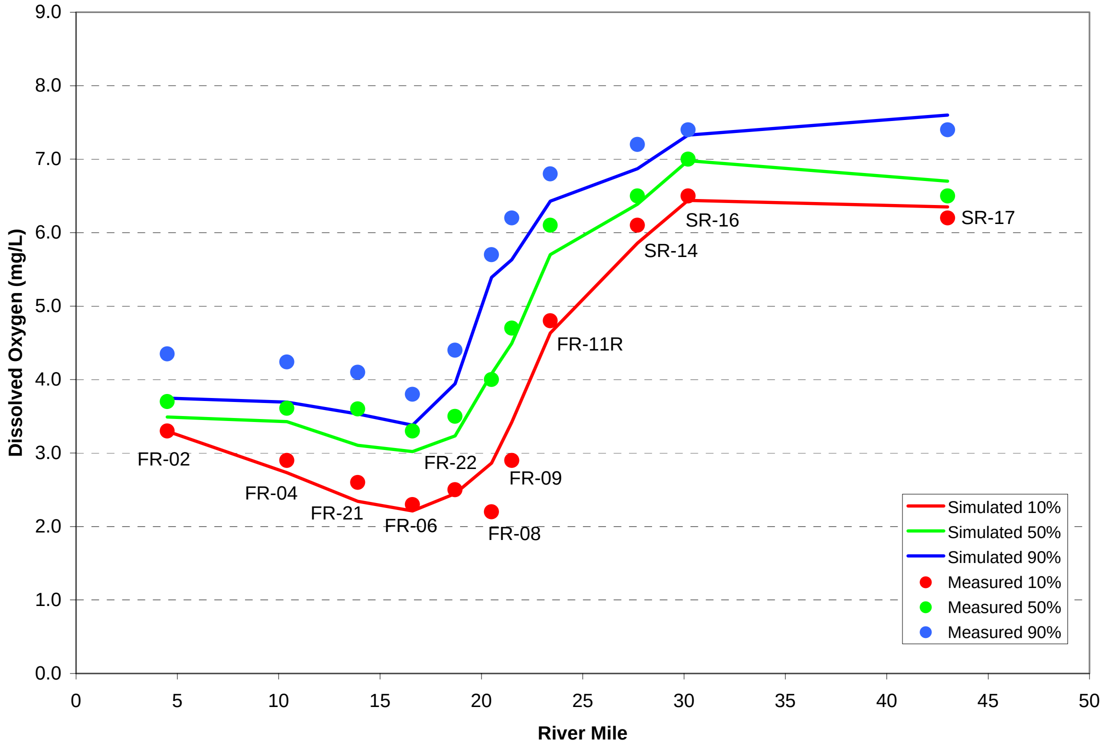


Figure 9-2 1999 Measured versus Simulated Longitudinal Bottom Dissolved Oxygen

9.5 Dissolved Oxygen Deficit Comparison

Appendix R illustrates the comparisons of one-day moving averages of dissolved oxygen deficit of both measured and simulated results. Results show reasonable correspondence of measurements and simulated results for the majority of Front River stations. This proves that the complexity of salinity, temperature, loads, reaeration, and SOD in the model are representing the existing processes.

10.0 WASP MODEL CONFIRMATION

10.1 Model Confirmation Period

The time period for the WASP model confirmation is the summer of 1997 from July 5, 1997 through October 13, 1997. In addition to the 1999 summer data collection, the 1997 summer data collection represents the most recent dissolved oxygen and water chemistry data for the system.

Table Q-1 provides the 10^{th}, 50^{th}, and 90^{th} percentile comparisons of model simulated dissolved oxygen to measured values for the period of July 5, 1997 through October 13, 1997. Table Q-2 provides values of mean error, absolute mean error, root mean square error, number of pairs of measured and simulated values, along with means and standard deviations for both measured and simulated results. Tables Q-3 through Q-12 provide the same information for the 6 spring/neap tidal cycles between July 5, 1997 through October 13, 1997.

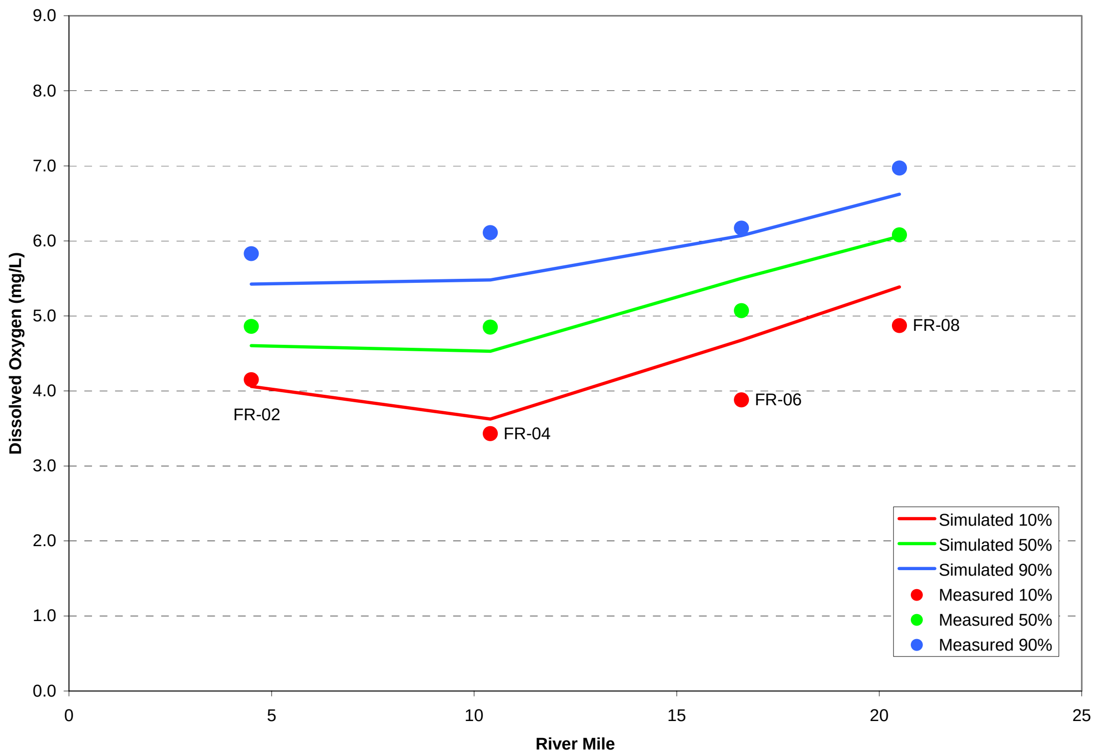


Figure 10-1 1997 Measured versus Simulated Longitudinal Surface Dissolved Oxygen

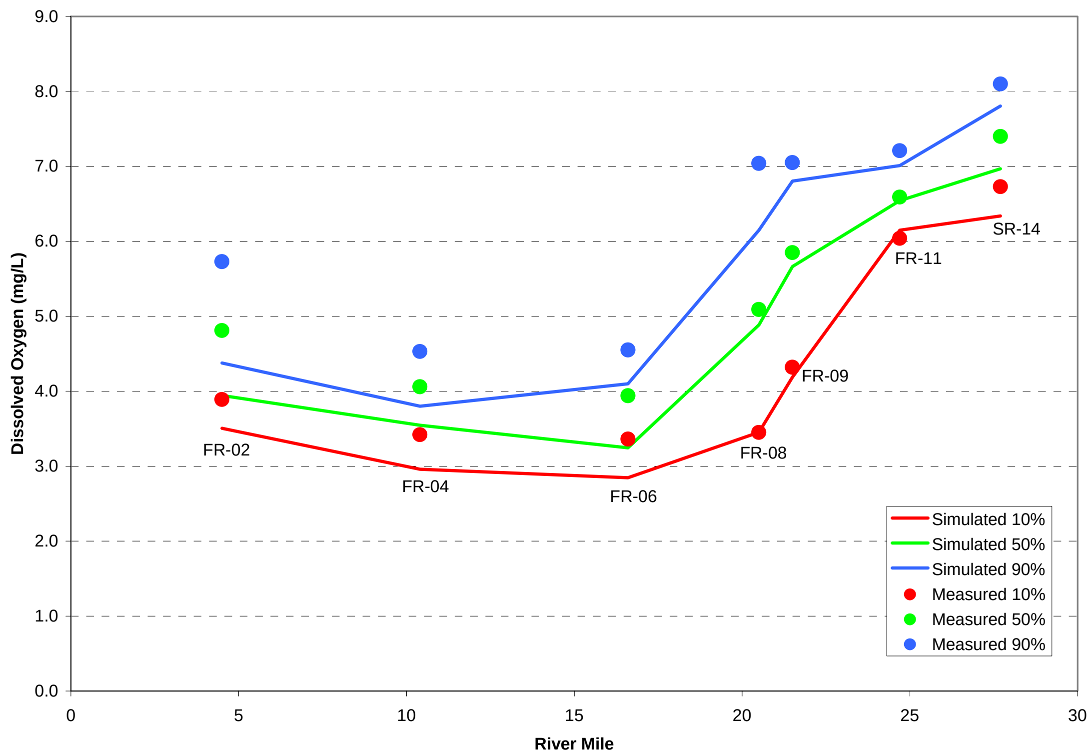


Figure 10-2 1997 Measured versus Simulated Longitudinal Bottom Dissolved Oxygen

The 1997 confirmation was performed with the water quality constituents of the upstream boundaries setting in accordance with 1997 measurements by USGS and the USEPA output from the EPDRiv1 model. The open ocean boundaries were selected to be similar to the summer of 1999. The plots and statistics shown in Appendix Q along with the longitudinal distributions shown in Figures 10-1 and 10-2 displays that the WASP model is acceptable for simulating dissolved oxygen in the Savannah Harbor. The upper part of the Savannah Harbor water quality model is sensitive to the dissolved oxygen boundary at Clyo. This is evident in examining dissolved oxygen simulated versus measured upstream of I-95 Bridge.

11.0 UNCERTAINTY ANALYSIS

Kinetic Analysis Corporation (KAC) performed the uncertainty analysis on the TMDL grid and the enhanced grid. For the TMDL grid, KAC reached the following conclusions:

1. Available data is adequate, but precautions must be taken to avoid over calibration to 1997/1999 conditions.
2. TMDL model demonstrates good qualitative skill – variables change in the directions expected, tracks flow, tide cycle, etc.
3. TMDL model does not demonstrate good quantitative skill – in other words, values are significantly over or underestimated for specific predictions.
4. Variations in the model from observed often exceed the differences noted before and after the 1994 project. Therefore, while the model is useful for predicting trends in variables, it is recommended that the TMDL model not be used in cases where the exact values or magnitude of forecast changes of variables are critical.

KAC recommended the following on the enhanced grid during the calibration based on the results above from the TMDL grid:

1. Enhanced grid model calibration should take care to avoid over calibration to 1997/1999 conditions. Long-term data should be partitioned to include both calibration and blind test (verification) runs.
2. Use of bottom roughness for calibration should be carefully examined to ensure additional uncertainty is not being introduced in the calibration process.
3. Bathymetry should be for average conditions – not just immediately after maintenance or dredging. This could be a data problem having only data before and after maintenance rather than for average conditions.

Tetra Tech incorporated KAC's recommendations by paying close attention to the bathymetry incorporation and interpolation into the model grid and the bottom roughness (friction) coefficients in the EFDC model. See Section 4.2 on the model grid bathymetry and Section 4.3.1 on the bottom roughness coefficient. A constant (global) bottom roughness was used in the enhanced grid to calibrate the hydrodynamics. Also, the bathymetry was not averaged or smoothed in the navigational channel to allow for the perturbations in the longitudinal direction to be accounted for and not compensated through the bottom roughness term.

Overall, the uncertainty analysis (UA) report was very thorough and helpful in the enhanced grid calibration process. Tetra Tech learned through KAC's techniques how to look at the model's performance under varying conditions, particularly by stratifying ranges of flows and ebb and flood tides. Through working with KAC, many issues were brought up and addressed successfully such as potential issues in the EFDC model with different computer platforms (Windows versus Linux), different Fortan compilers (Intel, Absoft, and Lahey), and different model time steps (10- versus 5-second time steps). Through many weeks and months of working with each one of these issues, all of them were successfully resolved.

Tetra Tech agrees with the conclusions of the UA report that the enhanced grid is a significant improvement over the TMDL grid. However, even through the KAC report met expectations and was helpful in the calibration process, Tetra Tech does not agree with the conclusion that the model could be unstable. Tetra Tech was not able to the run the model for the full 7-year confirmation period due to one set of conditions measured by the Fort Pulaski tide station. On December 31, 2000, the Fort Pulaski tide data was lower than any other period in the 7 years and the high tide and low tide appeared to be shifted down causing a much lower high tide than normal and, more importantly, a much lower low tide. However, we were able to run the model through this period by smoothing the tide data for that one day and the EFDC model at a 5-second time step. Overall, it appeared that the summer low-flow conditions were stable at a 10-second time step, but the longer, more dynamic flow, runs needed a 5-second time step. The calibration and confirmation periods of the summer of 1999 and 1997 used a 10-second time step.

Typically, complex estuarine models are not calibrated, validated, or confirmed to longer datasets than 1-3 years. Most of the time, it is less than 1 year and focused on a summer critical conditions. Therefore, for ease of confirmation runs, the EFDC model was run in two parts: 1997-1999 and 2001-2003, both are three-year periods. Seven years of validation in Savannah is unusual for complex models such as this one so we believe the emphasis on both summer periods and validation to 3 and 4-yr periods is appropriate. Appendices L and M were shown for the full seven year period. The resultant figures were created with two model runs. One ended at the end of December 2000 and the other started in early December 2000. Tetra Tech does not agree that 7 years is a requirement for confirmation and that by not having 7 years prevents the model from being used to evaluate scenarios for the harbor.

Tetra Tech ran the EFDC model for the 5-second and 10-second time steps and achieved the same answer. Tetra Tech also ran the 5-second and 10-second for worst case deepening (August 1999 and 46-foot depth) and there were some differences in salinity results but very small (1-2% at Houlihan Bridge). Even though the 5-second is a smaller time step, it is not necessarily more accurate than the 10-second. It depends on the numerical dispersion, grid sizes, velocity, etc. There is nothing to show that the model is unstable other than it crashes when running it from day one and running through Dec 31, 2000.

Tetra Tech also believes that there is uncertainty in the data being used to develop the model and the data used for calibration. For example, the uncertainty of the bathymetry data (best professional judgment of ±0.5 ft), the measured water level at Fort Pulaski on December 31, 2000 (inaccurate shift in the data), salinity of instrument is ±1% of reading or 0.1 ppt whichever is greater, and dissolved oxygen is ±2% of reading or 0.2 mg/L whichever is greater.

The final UA report by KAC is shown in Appendix S of this report.

12.0 SENSITIVITY ANALYSIS

This section of the report describes the sensitivity analysis of the EFDC and WASP models. A sensitivity analysis is the process of varying model input parameters over a reasonable range (range of uncertainty in values of model parameters) and observing the relative change in model response. The purpose of the sensitivity analysis is to demonstrate the sensitivity of the model simulations to uncertainty in values of model input data or calibration parameters. The sensitivity of one model parameter relative to other parameters is also demonstrated. Sensitivity analysis was performed on the following model parameters and boundary inputs:

- Turbulence scheme coefficients,
- Offshore salinity concentration,
- Freshwater inflow rate and timing,
- Bottom friction,
- Horizontal eddy viscosity,
- Selected water-quality rate kinetics,
- Dissolved oxygen boundary conditions, and
- BOD loads from point sources and marshes.

The EFDC and WASP models were run for a 30-day spin-up period during July 1999 and comparisons were made from July 30 through August 7, 1999, a seven-day period. This time period is appropriate because the last week of July and first week of August represents a transition from a spring tide into a neap tide.

12.1 EFDC Hydrodynamic Model

Through our work on the calibration of the TMDL grid and then to the enhanced grid, it was apparent which parameters were sensitive in the EFDC model. Obviously, bathymetry is one of the most critical pieces of information for the model and a significant amount of time and effort were placed on capturing the bathymetry in the model with limited smoothing and averaging. As far as other model inputs and calibration parameters, the Clyo upstream flow (and other watershed flows downstream of Clyo), downstream/ocean salinity boundary, and bottom roughness rank as the most sensitive parameters for the EFDC model. The horizontal eddy viscosity was also run for comparisons. These parameters were changed in the EFDC model while holding the bathymetry constant. The next sections, tables, and figures present the sensitivity analysis of the EFDC model.

12.1.1 Clyo Upstream Flow

The upstream flow at Clyo was increased by 10% and decreased by 10% and compared against the baseline conditions run. The baseline conditions run is the calibration run during the first week of August. Tables 12-1 and 12-2 show the results of the EFDC sensitivity runs by comparing the baseline (calibration) run for 7 days for the 10th, 50th, and 90th percentiles. The baseline, or base case, is then compared and the differences (ppt) are shown in Table 12-1 and the percent differences (%) are shown in Table 12-2. The tables show the largest impacts are in the Front River region between FR-11R (upstream of Houlihan Bridge) and FR-21 (Corps Dept Dock). Figures 12-1, 12-2, and 12-3 show the results for the 7 days at the beginning of August for the Front River (FR-11R and FR-09) and the Little Back River (USF&W Dock) locations. The model is very sensitive to the upstream flow as this dictates how much mixing and intrusion occurs in the harbor region, especially at the edge of the salinity front between Houlihan Bridge and I-95 Bridge. Figures 12-1 and 12-2 shows that salinity can vary by 1-2 ppt at the Houlihan Bridge and the same upstream at station FR-11R. Figure 12-3 shows that salinity can vary by 0.2 ppt on the Little Back River at the USF&W Dock.

12.1.2 Salinity Boundary

The downstream/ocean salinity boundary was increase 1 ppt and decreased 1 ppt. The EFDC hydrodynamic model was calibrated using a 32.5 ppt at the surface and 35 ppt at the bottom with 0.5 ppt increments in layers two through six. The sensitivity increased and decreased the boundary by 1 ppt but held the values constant over time and kept the vertical stratification constant as well. Therefore, the two runs were 31.5 to 34 ppt and 33.5 to 36 ppt. The results are shown in Table 12-1 as the differences (ppt) and Table 12-2 as the percent differences (%). The results show that the boundary can alter the salinity by up to 30% in the Front, Middle, and Little Back River sites at the edge of the salinity front. Figures 12-1 and 12-2 show differences at Houlihan Bridge and Front River (FR-11R) can be in the 1-2 ppt range for the differences. The USF&W Dock shows much smaller differences in the 0.1 ppt range.

12.1.3 Bottom Roughness

The EFDC model uses bottom roughness to account for the energy loss due to friction exerted from the sides and bottom of the channel and any other forms of energy loss, i.e. meandering channels. Based on the uncertainty analysis described in the previous section and in Appendix S, the bottom roughness was constant throughout most of the model domain. As learned in the TMDL grid, the bottom roughness was higher and therefore could have dampened some of the small scale phenomena that occur in the system. The sensitivity was performed by altering the global bottom roughness from 0.015 to 0.025 as compared to the calibration roughness of 0.02. Tables 12-1 and 12-2 show the results for the runs and show that the model is sensitive to the bottom roughness with differences as high as 30-40%. Figure 12-1 shows a difference of approximately 1 ppt at the 0.015 and 0.025 roughness coefficients, but a larger difference at the Front River FR-11R, at the edge of the salt front, of 4 ppt when the bottom roughness is lowered to 0.015. This is shown in Figure 12-2. The Little Back River shows small differences in the 0.1 ppt range as shown in Figure 12-3.

12.1.4 Horizontal Eddy Viscosity

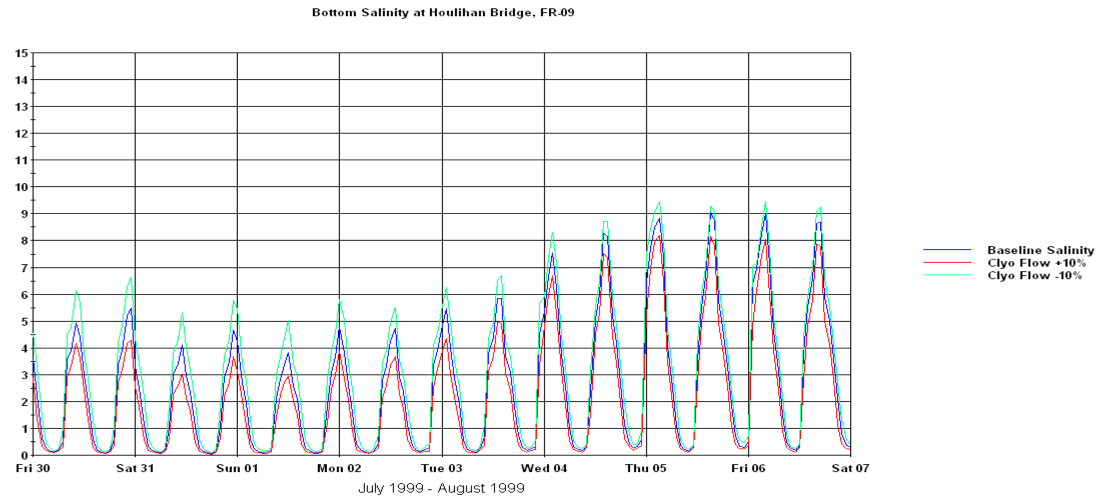
The EFDC model was not sensitive to the horizontal eddy viscosity. The calibration run was made with the horizontal eddy viscosity at 50 m^2/s. This term was varied to 25 and 75 m^2/s and no change was detected in the results as shown in Tables 12-1 and 12-2 with 0% differences at all of the comparison stations. Since there was no change in the sensitivity runs, the time series were not included in Figure 12-1, 12-2, ad 12-3.

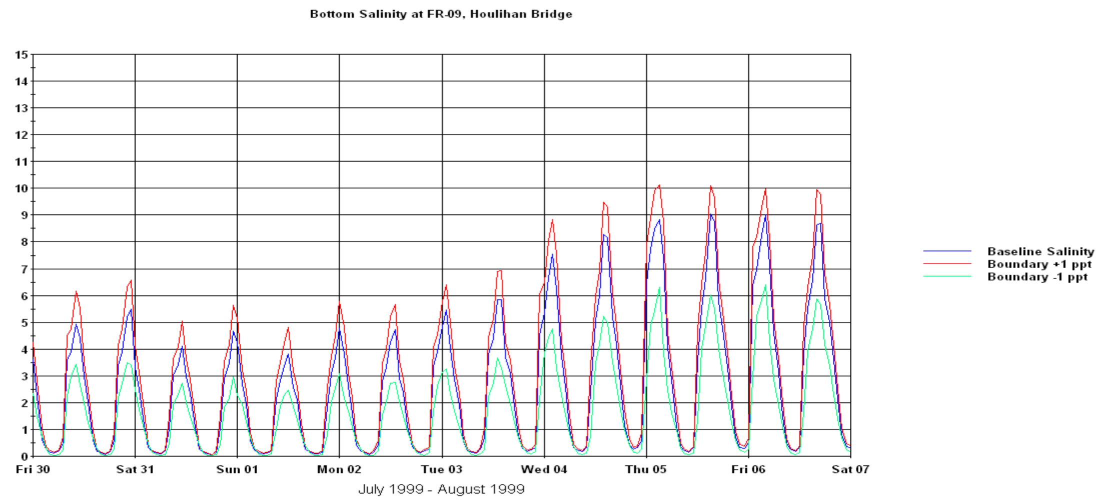
Table 12-1 Model Salinity Percentiles for Base Case and Sensitivity Scenarios (Difference from Base Case in ppt)

Station	Layer	Percentile	Baseline (ppt)	AHO25	AHO75	Salt+1ppt	Salt-1ppt	Clyo-10%	Clyo+10%	zbr015	zbr025
BR-05	Bottom	10%	6.0	0.0	0.0	0.4	-0.7	0.3	-0.5	0.1	-0.5
		50%	10.0	0.0	0.0	0.7	-0.8	0.5	-0.5	0.5	-0.4
		90%	11.7	0.0	0.0	0.7	-1.0	0.3	-0.5	0.7	-0.7
	Surface	10%	6.0	0.0	0.0	0.4	-0.7	0.3	-0.6	0.1	-0.4
		50%	9.5	0.0	0.0	0.5	-0.7	0.4	-0.5	0.2	-0.4
		90%	11.1	0.0	0.0	0.7	-0.8	0.4	-0.4	0.5	-0.5
FR-06	Bottom	10%	11.7	0.0	0.0	1.1	-1.4	0.4	-0.5	0.6	-0.8
		50%	14.5	0.0	0.0	1.0	-1.2	0.2	-0.4	0.8	-0.9
		90%	17.0	0.0	0.0	1.0	-1.3	0.0	-0.4	0.7	-0.9
	Surface	10%	2.8	0.0	0.0	0.3	-0.4	0.5	-0.4	0.4	-0.3
		50%	4.8	0.0	0.0	0.4	-0.6	0.5	-0.5	0.4	-0.4
		90%	8.1	0.0	0.0	0.5	-0.6	0.7	-0.6	0.5	-0.5
BR-07	Bottom	10%	0.8	0.0	0.0	0.2	-0.2	0.3	-0.2	0.2	-0.1
		50%	3.0	0.0	0.0	0.7	-0.7	0.6	-0.5	0.5	-0.5
		90%	4.9	0.0	0.0	0.6	-0.6	0.4	-0.3	0.6	-0.5
	Surface	10%	0.8	0.0	0.0	0.2	-0.1	0.2	-0.2	0.2	-0.1
		50%	1.6	0.0	0.0	0.3	-0.3	0.3	-0.3	0.2	-0.2
		90%	4.0	0.0	0.0	0.5	-0.4	0.4	-0.4	0.4	-0.4
FR-08	Bottom	10%	0.5	0.0	0.0	0.1	-0.1	0.2	-0.2	0.1	-0.1
		50%	4.9	0.0	0.0	1.0	-1.0	1.0	-1.0	0.9	-0.9
		90%	10.4	0.0	0.0	1.1	-1.5	0.5	-0.9	1.1	-1.3
	Surface	10%	0.3	0.0	0.0	0.1	-0.1	0.2	-0.1	0.1	-0.1
		50%	2.0	0.0	0.0	0.3	-0.3	0.5	-0.4	0.3	-0.3
		90%	3.9	0.0	0.0	0.4	-0.5	0.5	-0.4	0.4	-0.4
FR-09	Bottom	10%	0.2	0.0	0.0	0.0	0.0	0.1	-0.1	0.0	0.0
		50%	2.6	0.0	0.0	0.6	-0.7	0.8	-0.7	0.7	-0.6
		90%	6.7	0.0	0.0	1.3	-1.2	0.7	-0.8	1.3	-1.0
	Surface	10%	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
		50%	1.5	0.0	0.0	0.2	-0.3	0.4	-0.4	0.3	-0.3
		90%	3.9	0.0	0.0	0.4	-0.5	0.5	-0.5	0.4	-0.4
MR-10	Bottom	10%	0.5	0.0	0.0	0.1	-0.1	0.1	-0.1	0.1	-0.1
		50%	1.1	0.0	0.0	0.2	-0.2	0.3	-0.2	0.2	-0.2
		90%	2.5	0.0	0.0	0.4	-0.4	0.5	-0.4	0.5	-0.4
	Surface	10%	0.5	0.0	0.0	0.1	-0.1	0.1	-0.1	0.1	-0.1
		50%	1.0	0.0	0.0	0.2	-0.2	0.3	-0.2	0.2	-0.2
		90%	2.3	0.0	0.0	0.3	-0.3	0.4	-0.4	0.4	-0.3
FR-11R	Bottom	10%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		50%	0.1	0.0	0.0	0.0	0.0	0.1	-0.1	0.1	0.0
		90%	3.5	0.0	0.0	0.8	-0.7	0.8	-0.7	0.9	-0.6
	Surface	10%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		50%	0.1	0.0	0.0	0.0	0.0	0.1	-0.1	0.0	0.0
		90%	2.2	0.0	0.0	0.4	-0.4	0.6	-0.6	0.6	-0.4
MR-12R	Bottom	10%	0.2	0.0	0.0	0.0	0.0	0.1	-0.1	0.0	0.0
		50%	0.5	0.0	0.0	0.1	-0.1	0.2	-0.1	0.1	-0.1
		90%	1.3	0.0	0.0	0.2	-0.2	0.2	-0.2	0.2	-0.2
	Surface	10%	0.2	0.0	0.0	0.0	0.0	0.1	-0.1	0.0	0.0
		50%	0.5	0.0	0.0	0.1	-0.1	0.1	-0.1	0.1	-0.1
		90%	1.3	0.0	0.0	0.2	-0.2	0.2	-0.2	0.2	-0.2
LBR-15	Bottom	10%	0.2	0.0	0.0	0.0	0.0	0.1	-0.1	0.1	0.0
		50%	0.5	0.0	0.0	0.1	-0.1	0.2	-0.1	0.1	-0.1
		90%	1.3	0.0	0.0	0.4	-0.3	0.4	-0.3	0.4	-0.2
	Surface	10%	0.2	0.0	0.0	0.0	0.0	0.1	-0.1	0.1	0.0
		50%	0.5	0.0	0.0	0.1	-0.1	0.2	-0.1	0.1	-0.1
		90%	1.0	0.0	0.0	0.2	-0.2	0.3	-0.2	0.2	-0.2
FR-22	Bottom	10%	7.9	0.0	0.0	1.1	-1.3	0.8	-0.8	1.2	-0.9
		50%	11.3	0.0	0.0	1.1	-1.4	0.5	-0.6	1.0	-1.2
		90%	14.2	0.0	0.0	1.1	-1.3	0.2	-0.5	1.0	-1.0
	Surface	10%	0.9	0.0	0.0	0.2	-0.2	0.4	-0.3	0.2	-0.2
		50%	2.4	0.0	0.0	0.3	-0.4	0.4	-0.4	0.3	-0.3
		90%	4.2	0.0	0.0	0.4	-0.4	0.5	-0.5	0.3	-0.4
USGS F&W Dock	Mid-depth	10%	0.2	0.0	0.0	0.0	0.0	0.1	-0.1	0.1	0.0
		50%	0.4	0.0	0.0	0.0	-0.1	0.1	-0.1	0.1	-0.1
		90%	0.7	0.0	0.0	0.1	-0.1	0.2	-0.1	0.1	-0.1
USGS Lucknow Canal	Mid-depth	10%	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0
		50%	0.2	0.0	0.0	0.0	0.0	0.1	-0.1	0.1	-0.1
		90%	0.3	0.0	0.0	0.0	-0.1	0.1	-0.1	0.1	-0.1

Table 12-2 Model Salinity Percentiles for Base Case and Sensitivity Scenarios (Percent Difference from Base Case)

Station	Layer	Percentile	Baseline (ppt)	AHO25	AHO75	Salt+1ppt	Salt-1ppt	Clyo-10%	Clyo+10%	zbr015	zbr025
BR-05	Bottom	10%	6.04	0	0	6	-11	5	-9	2	-8
		50%	9.98	0	0	7	-8	5	-5	5	-4
		90%	11.71	0	0	6	-8	2	-4	6	-6
	Surface	10%	6.01	0	0	6	-11	5	-10	1	-7
		50%	9.48	0	0	5	-7	4	-5	3	-4
		90%	11.07	0	0	6	-7	3	-4	4	-4
FR-06	Bottom	10%	11.66	0	0	9	-12	4	-4	5	-7
		50%	14.53	0	0	7	-8	2	-3	5	-6
		90%	17.01	0	0	6	-8	0	-2	4	-5
	Surface	10%	2.78	0	0	12	-15	19	-15	14	-11
		50%	4.77	0	0	9	-12	11	-11	9	-9
		90%	8.15	0	0	6	-8	9	-8	6	-6
BR-07	Bottom	10%	0.83	0	0	23	-23	33	-29	18	-15
		50%	3.00	0	0	23	-25	20	-17	16	-15
		90%	4.90	0	0	13	-12	9	-6	12	-11
	Surface	10%	0.79	0	0	20	-18	31	-25	20	-14
		50%	1.63	0	0	17	-16	18	-17	13	-13
		90%	3.96	0	0	12	-11	11	-9	11	-9
FR-08	Bottom	10%	0.46	0	0	25	-27	50	-37	22	-24
		50%	4.90	0	0	21	-21	20	-20	19	-18
		90%	10.40	0	0	11	-14	4	-9	11	-12
	Surface	10%	0.31	0	0	24	-21	51	-33	22	-19
		50%	2.03	0	0	15	-17	23	-21	14	-15
		90%	3.89	0	0	10	-12	12	-10	11	-10
FR-09	Bottom	10%	0.17	0	0	22	-25	48	-31	27	-20
		50%	2.63	0	0	23	-25	29	-25	25	-22
		90%	6.69	0	0	19	-18	10	-11	20	-15
	Surface	10%	0.15	0	0	18	-20	36	-28	17	-19
		50%	1.52	0	0	15	-19	29	-26	20	-19
		90%	3.92	0	0	11	-13	13	-12	10	-11
MR-10	Bottom	10%	0.47	0	0	16	-17	31	-25	14	-13
		50%	1.08	0	0	15	-17	24	-21	21	-18
		90%	2.48	0	0	15	-16	19	-17	19	-15
	Surface	10%	0.47	0	0	16	-17	31	-25	13	-13
		50%	1.03	0	0	17	-17	25	-20	21	-15
		90%	2.32	0	0	14	-15	18	-16	19	-15
FR-11R	Bottom	10%	0.00	0	0	17	-17	109	-51	40	-29
		50%	0.14	0	0	25	-24	74	-41	39	-29
		90%	3.53	0	0	21	-20	23	-20	25	-18
	Surface	10%	0.00	0	0	18	-19	101	-52	42	-27
		50%	0.14	0	0	20	-24	51	-46	33	-26
		90%	2.23	0	0	19	-20	29	-25	27	-20
MR-12R	Bottom	10%	0.16	0	0	16	-13	51	-32	30	-18
		50%	0.47	0	0	12	-15	34	-25	16	-19
		90%	1.34	0	0	12	-14	17	-14	14	-15
	Surface	10%	0.16	0	0	16	-13	51	-32	30	-18
		50%	0.46	0	0	12	-17	31	-25	16	-20
		90%	1.31	0	0	12	-15	19	-13	15	-15
LBR-15	Bottom	10%	0.21	0	0	15	-13	49	-31	25	-17
		50%	0.48	0	0	15	-16	33	-23	20	-15
		90%	1.32	0	0	29	-23	33	-26	28	-17
	Surface	10%	0.21	0	0	15	-14	48	-32	27	-17
		50%	0.48	0	0	15	-17	33	-24	18	-16
		90%	1.02	0	0	16	-16	25	-20	16	-15
FR-22	Bottom	10%	7.89	0	0	14	-17	10	-10	15	-11
		50%	11.29	0	0	10	-13	4	-6	9	-10
		90%	14.17	0	0	8	-9	1	-3	7	-7
	Surface	10%	0.95	0	0	20	-23	38	-31	22	-19
		50%	2.38	0	0	12	-15	17	-18	13	-13
		90%	4.24	0	0	8	-10	11	-11	8	-8
USGS F&W Dock	Mid-depth	10%	0.16	0	0	15	-13	54	-34	36	-22
		50%	0.36	0	0	14	-16	35	-26	24	-21
		90%	0.67	0	0	15	-16	28	-21	19	-15
USGS Lucknow Canal	Mid-depth	10%	0.14	0	0	15	-11	58	-35	38	-23
		50%	0.22	0	0	15	-15	47	-31	35	-24
		90%	0.35	0	0	13	-15	38	-28	31	-24





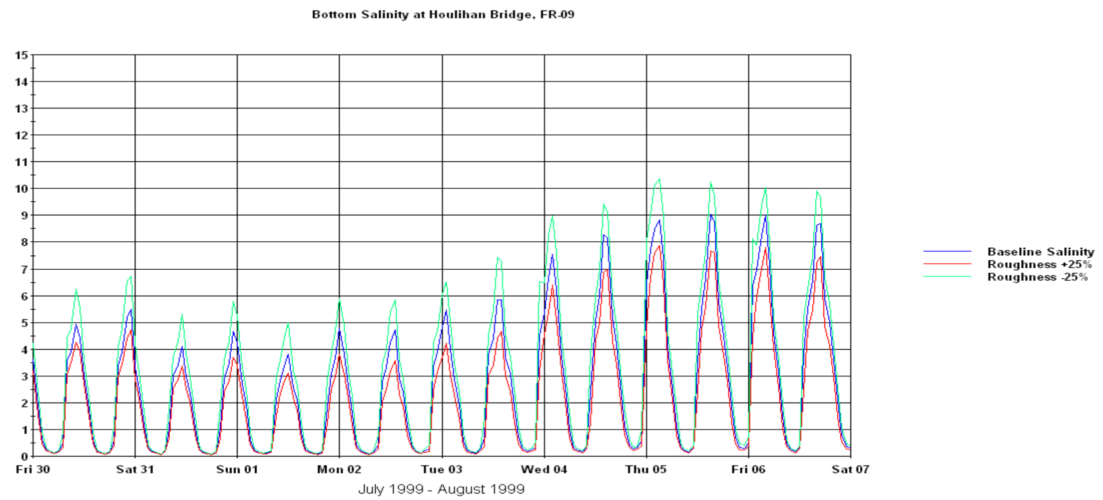


Figure 12-1 Houlihan Bridge (FR-09) Sensitivity with Clyo Flow, Boundary, and Roughness

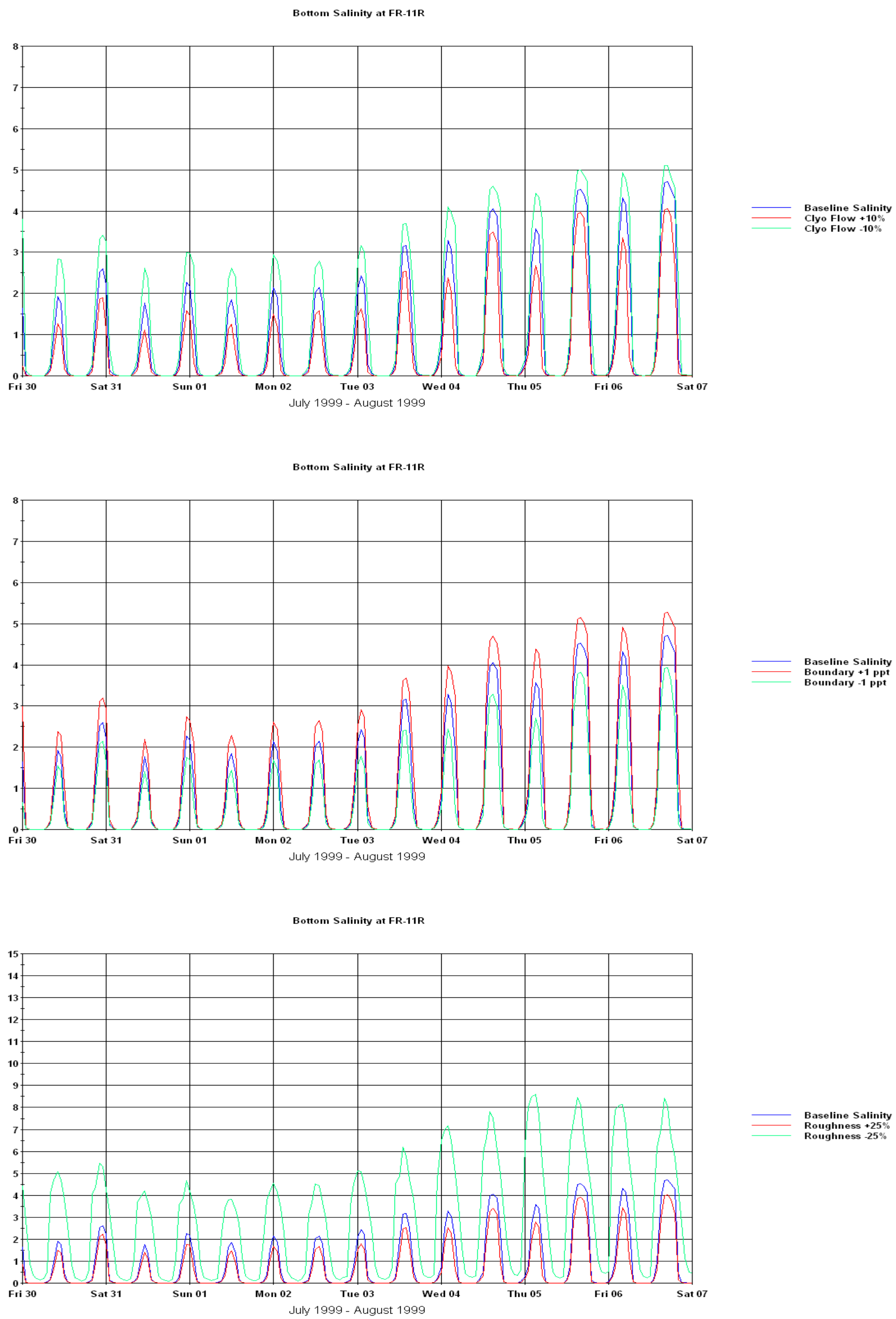


Figure 12-2 Savannah River (FR-11R) Sensitivity with Clyo Flow, Boundary, and Roughness

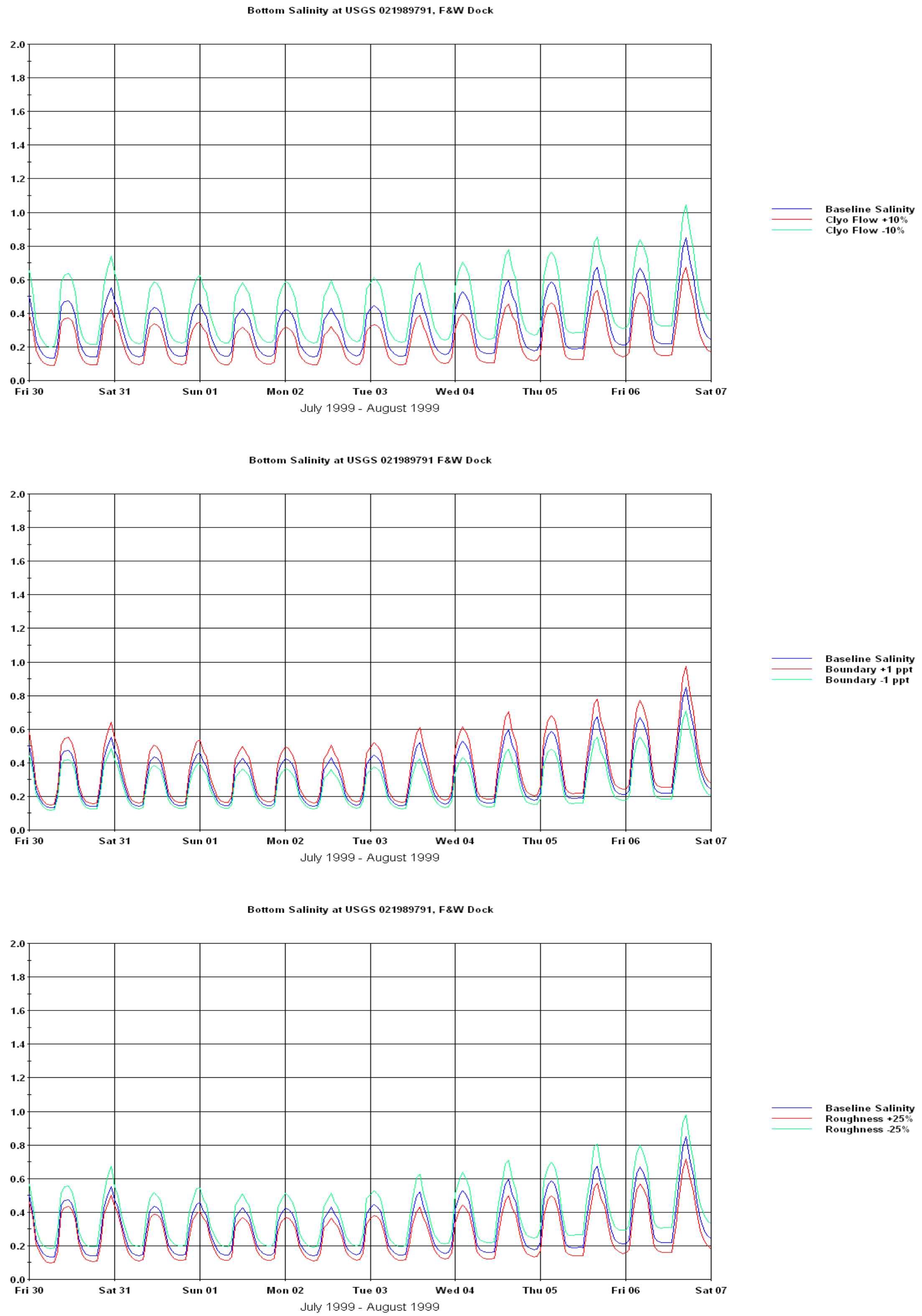


Figure 12-3 Little Back River Sensitivity with Clyo Flow, Boundary, and Roughness

12.2 WASP Water Quality Model

The WASP water quality model was tested in a similar way as the EFDC model. The testing of the water quality model behavior in reaction to changes in the assumedly independent factors: inputs and parameters, was performed to estimate the model sensitivity. The list of factors mostly was based upon input from the SMART group (years 2002-2004). The parameters tested included:

- Upstream boundary D. O. concentrations
- Offshore boundary D. O. concentrations
- BOD decay rates
- Nitrification rates
- Marsh CBOD loadings
- Point source CBOD loading
- Sediment oxygen demand (SOD)
- Reaeration rates

Sensitivity tests were run on a baseline model simulation for August of 1999. The sensitivity of the 10th and 50th percentile dissolved oxygen to the parameters changes were estimate by comparing with the baseline model scenario. Tables 12-3, 12-4, 12-5, and 12-6 present the sensitivity analysis results (mg/L and % changes in bottom and surface layers dissolved oxygen concentrations based upon the parameters varied). The D.O. upstream and offshore boundary concentrations were varied +/- 15%. The BOD decay and nitrification rates, as well as marshes, point sources loads and SOD were varied +/- 33%. Reaeration rates were varied +/- 50%. The following sections discuss the results of the parameters tested.

12.2.1 Upstream D.O. Boundary Concentrations

The water quality model demonstrates high sensitivity to the upstream D.O conditions change for the area beginning from Clyo and up to Station FR-08 (12-17% at 15% upstream boundary D.O. concentrations variations). The upstream area can be characterized by absence of CBOD loads from major point sources and marshes. The relatively little significance of SOD and reaeration processes makes Clyo boundary D.O. concentrations being the dominating factor of D.O regime formation in the upstream area of Savannah river. Beginning from FR-22 the dominating factors for D.O. regime formation become to be point sources, partly marshes and increased influence of offshore boundaries. The sensitivity to upstream D.O. boundaries is not high (1-8%) in the area between FR-06 and offshore open boundary. Bottom layers of the model demonstrate higher sensitivity to upstream D.O. boundary concentrations than surface layers.

12.2.2 Offshore D.O. Boundary Concentrations

The influence of the offshore D.O. boundary variations is most significant for downstream stations FR-02 (+/- 12-14%) and FR-04 (+/- 9-10%). The boundary effect decreases rapidly upstream of Savannah estuary and becomes insignificant after FR-22. Because of influence of high concentration of point sources and increased SOD in the area between FR-04 and FR-22 the spatial area of significant sensitivity to offshore D.O. variations is smaller than in case of Clyo D.O. variations. Bottom layers of the model demonstrate higher sensitivity to offshore D.O. boundary concentrations than surface layers.

12.2.3 CBOD Decay Rate

The basic CBOD decay rate for the baseline run was 0.06 1/day. The variations of the parameter were 0.08 and 0.04 1/day. The area of high sensitivity to the parameter variation is the area between stations FR-04, FR-06, FR-21, FR-22, FR-08 and FR-09. This is the same area where most of the significant CBOD point source discharges occur in the harbor. The 33% decay rate variations lead to 15-25 % variations in D.O concentrations in the area. The model's sensitivity to the parameter steeply decreases in upstream area (3-7%) where major CBOD sources are not located. Bottom layers of the model demonstrate higher sensitivity to CBOD decay rate variations than surface layers.

12.2.4 Nitrification rate

The 33% nitrification rate variations do not create any significant (more than 1-2%) variations in D.O. within the system. The D.O regime in Savannah estuary is not sensitive to this parameter variation.

12.2.5 CBOD Point Source Load

The simulation runs did not show significant sensitivity of the water quality model to 33% variation of the factor. The area of highest sensitivity (2-3%) is located in neighborhood of International Paper discharge (Stations FR-06 and FR –22).

12.2.6 CBOD Marsh Load

The marsh baseline loads were varied +/- 33%. The area of highest sensitivity to the marsh variation is located between stations FR-21 and FR-22 on Front River. The sensitivity is not significantly high (6-7% for bottom layer) in relation to the level of the loads variations. The more sensitive to marsh loads variation is Little Back River where the majority of marshes are located. The downstream stations FR-02 and FR-04 are affected by the marshes BOD loads and demonstrate relatively significant sensitivity (4-5% for surface layer D.O. concentrations) to the loads' variations.

12.2.7 Sediment Oxygen Demand (SOD)

The defined for the model SOD was varied spatially for the Front River between 0.65 and 1.2 gm/m^2/day (at 20^{o}C) with the highest values from Fort Jackson to the Turning Basin (1-1.2 gm/ m^2/day). The highest absolute SOD variations were occurred for stations that are located in this part of Savannah River (FR-21, FR-06, and FR-22). The results demonstrate up to 20% variation of bottom layer D.O. concentrations at 33% SOD variations. Bottom layers of the model are much more sensitive to CBOD decay rate variations than surface layers.

12.2.8 Reaeration rates

Reaeration rates were varied +/- 25%. The area of higher sensitivity to the reaeration is located between offshore boundary and station FR-02 for surface layer (7-9 % of D.O. concentrations response changes). For the bottom layer the highest sensitivity area (8-11%) is located between stations FR-21 and FR-22, where the D.O. concentrations are very low due to channel depths, salinity stratification, and point sources discharges.

Table 12-3 Water quality model results to changes in parameters (Bottom layer D.O. mg/L)

Station	Percentile	Base Case	Upstream D.O. Boundary		BOD Decay Rate		BOD Point Source Load		Marsh BOD Load		Nitrification Rate		Offshore Boundary D.O.		Sediment Oxygen Demand		Global Reaeration Rate	
			15%	-15%	-30%	30%	33%	-33%	33%	-33%	33%	-33%	15%	-15%	33%	-33%	25%	-25%
FR-02	10%	3.08	-0.04	0.05	-0.40	0.32	0.02	-0.02	0.05	-0.04	0.02	-0.02	-0.40	0.40	0.41	-0.42	-0.11	0.14
FR-02	50%	3.33	-0.01	0.03	-0.36	0.30	0.01	-0.01	0.02	-0.02	0.02	-0.03	-0.42	0.45	0.38	-0.39	-0.08	0.11
FR-04	10%	2.62	-0.14	0.12	-0.49	0.36	0.04	-0.04	0.11	-0.13	0.02	-0.02	-0.23	0.25	0.44	-0.45	-0.18	0.21
FR-04	50%	2.88	-0.10	0.12	-0.45	0.36	0.04	-0.03	0.10	-0.10	0.02	-0.02	-0.23	0.25	0.41	-0.42	-0.16	0.20
FR-06	10%	2.15	-0.19	0.18	-0.55	0.42	0.07	-0.07	0.18	-0.18	0.02	-0.02	-0.17	0.17	0.51	-0.53	-0.18	0.22
FR-06	50%	2.45	-0.20	0.21	-0.53	0.41	0.06	-0.06	0.16	-0.17	0.02	-0.02	-0.15	0.15	0.46	-0.48	-0.18	0.21
FR-08	10%	2.92	-0.36	0.35	-0.54	0.42	0.08	-0.08	0.15	-0.15	0.02	-0.02	-0.08	0.08	0.40	-0.42	-0.14	0.17
FR-08	50%	4.02	-0.48	0.48	-0.44	0.37	0.06	-0.06	0.10	-0.10	0.01	-0.02	-0.02	0.02	0.30	-0.32	-0.10	0.11
FR-09	10%	3.57	-0.44	0.44	-0.47	0.38	0.06	-0.06	0.11	-0.11	0.01	0.01	-0.05	0.05	0.34	-0.36	-0.12	0.14
FR-09	50%	4.67	-0.57	0.57	-0.35	0.30	0.04	-0.03	0.06	-0.05	0.01	0.01	-0.01	0.01	0.23	-0.25	-0.08	0.09
FR-11r	10%	4.65	-0.56	0.56	-0.35	0.30	0.03	-0.03	0.05	-0.06	0.01	-0.01	-0.02	0.01	0.22	-0.24	-0.09	0.10
FR-11r	50%	5.67	-0.70	0.71	-0.23	0.21	0.01	0.00	0.01	0.00	0.01	-0.01	0.00	0.00	0.12	-0.12	-0.04	0.05
FR-14	10%	5.43	-0.87	0.92	-0.24	0.23	0.00	0.00	0.00	0.00	0.01	-0.01	0.00	0.00	0.10	-0.12	-0.01	0.01
FR-14	50%	5.85	-0.95	0.94	-0.19	0.19	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.07	-0.05	-0.01	0.01
SR-16	10%	5.69	-1.00	0.99	-0.21	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	-0.08	0.00	0.00
SR-16	50%	5.84	-1.02	1.01	-0.19	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	-0.07	0.00	0.00
FR-21	10%	2.31	-0.17	0.17	-0.53	0.40	0.05	-0.05	0.16	-0.17	0.02	-0.02	-0.20	0.18	0.49	-0.51	-0.19	0.22
FR-21	50%	2.57	-0.20	0.18	-0.53	0.40	0.05	-0.05	0.16	-0.17	0.02	-0.02	-0.14	0.13	0.43	-0.46	-0.19	0.22
FR-22	10%	2.46	-0.22	0.24	-0.55	0.42	0.07	-0.07	0.17	-0.17	0.02	-0.02	-0.14	0.15	0.44	-0.47	-0.18	0.21
FR-22	50%	2.88	-0.32	0.31	-0.56	0.43	0.07	-0.07	0.17	-0.19	0.02	-0.02	-0.08	0.07	0.39	-0.42	-0.16	0.18

Table 12-4 Water quality model results to changes in parameters (Bottom layer D.O. %)

Station	Percentile	Base Case	Upstream D.O. Boundary		BOD Decay Rate		BOD Point Source Load		Marsh BOD Load		Nitrification Rate		Offshore D.0. Boundary		Sediment Oxygen Demand		Global Reaeration Rate	
			15%	-15%	-33%	33%	33%	-33%	33%	-33%	33%	-33%	15%	-15%	33%	-33%	25%	-25%
FR-02	10%	3.08	1	-2	13	-10	-1	1	-1	1	-1	1	13	-13	-13	14	3	-5
FR-02	50%	3.33	0	-1	11	-9	0	0	-1	0	-1	1	13	-14	-11	12	2	-3
FR-04	10%	2.62	5	-5	19	-14	-2	2	-4	5	-1	1	9	-10	-17	17	6	-9
FR-04	50%	2.88	4	-4	16	-12	-1	1	-3	3	-1	1	8	-9	-14	15	5	-7
FR-06	10%	2.15	9	-9	26	-19	-3	3	-8	8	-1	1	8	-8	-23	25	8	-11
FR-06	50%	2.45	8	-8	22	-17	-2	2	-7	7	-1	1	6	-6	-19	20	7	-9
FR-08	10%	2.92	12	-12	18	-14	-3	3	-5	5	-1	1	3	-3	-14	14	4	-6
FR-08	50%	4.02	12	-12	11	-9	-1	1	-2	2	0	0	0	0	-7	8	2	-3
FR-09	10%	3.57	12	-12	13	-11	-2	2	-3	3	0	0	1	-1	-9	10	3	-4
FR-09	50%	4.67	12	-12	7	-6	-1	1	-1	1	0	0	0	0	-5	5	1	-2
FR-11r	10%	4.65	12	-12	8	-6	-1	1	-1	1	0	0	0	0	-5	5	2	-2
FR-11r	50%	5.67	12	-13	4	-4	0	0	0	0	0	0	0	0	-2	2	1	-1
FR-14	10%	5.43	16	-17	4	-4	0	0	0	0	0	0	0	0	-2	2	0	0
FR-14	50%	5.85	16	-16	3	-3	0	0	0	0	0	0	0	0	-1	1	0	0
SR-16	10%	5.69	18	-17	4	-4	0	0	0	0	0	0	0	0	-1	1	0	0
SR-16	50%	5.84	17	-17	3	-3	0	0	0	0	0	0	0	0	-1	1	0	0
FR-21	10%	2.31	7	-7	23	-17	-2	2	-7	7	-1	1	8	-8	-21	22	8	-10
FR-21	50%	2.57	8	-7	21	-16	-2	2	-6	7	-1	1	5	-5	-17	18	7	-9
FR-22	10%	2.46	9	-10	22	-17	-3	3	-7	7	-1	1	6	-6	-18	19	7	-9
FR-22	50%	2.88	11	-11	19	-15	-3	3	-6	7	-1	1	3	-2	-14	15	5	-7

Table 12-5 Water quality model results to changes in parameters (Surface layer D.O. mg/L)

Station	Percentile	Base Case	Upstream D.O. Boundary		BOD Decay Rate		BOD Point Source Load		Marsh BOD Load		Nitrification Rate		Offshore Boundary D.0.		Sediment Oxygen Demand		Global Reaeration Rate	
			15%	-15%	-30%	30%	33%	-33%	33%	-33%	33%	-33%	15%	-15%	33%	-33%	25%	-25%
FR-02	10%	3.08	0.23	-0.24	0.47	-0.36	-0.06	0.06	-0.15	0.16	-0.01	0.02	0.11	-0.10	-0.28	0.30	0.26	-0.30
FR-02	50%	3.33	0.16	-0.15	0.43	-0.33	-0.04	0.05	-0.11	0.13	-0.02	0.02	0.19	-0.14	-0.26	0.28	0.23	-0.25
FR-04	10%	2.62	0.27	-0.26	0.48	-0.37	-0.06	0.06	-0.15	0.16	-0.01	0.02	0.07	-0.07	-0.26	0.30	0.23	-0.29
FR-04	50%	2.88	0.32	-0.33	0.45	-0.35	-0.06	0.06	-0.14	0.15	-0.01	0.02	0.06	-0.05	-0.26	0.27	0.21	-0.26
FR-06	10%	2.15	0.37	-0.38	0.46	-0.37	-0.06	0.06	-0.13	0.13	-0.01	0.02	0.05	-0.05	-0.27	0.29	0.17	-0.19
FR-06	50%	2.45	0.50	-0.48	0.39	-0.31	-0.04	0.05	-0.07	0.08	-0.01	0.01	0.02	-0.02	-0.22	0.25	0.11	-0.13
FR-08	10%	2.92	0.48	-0.47	0.33	-0.28	-0.03	0.03	-0.05	0.05	-0.01	0.01	0.02	-0.02	-0.19	0.20	0.09	-0.11
FR-08	50%	4.02	0.54	-0.58	0.27	-0.23	-0.02	0.02	-0.04	0.03	-0.01	0.01	0.01	-0.01	-0.15	0.16	0.07	-0.08
FR-09	10%	3.57	0.48	-0.48	0.35	-0.29	-0.04	0.03	-0.06	0.05	-0.01	0.01	0.02	-0.03	-0.21	0.22	0.10	-0.12
FR-09	50%	4.67	0.65	-0.57	0.27	-0.24	-0.01	0.01	-0.02	0.02	-0.01	0.01	0.00	0.00	-0.14	0.16	0.06	-0.07
FR-10	10%	4.65	0.53	-0.56	0.33	-0.29	-0.01	0.01	-0.08	0.08	-0.01	0.01	0.00	0.00	-0.14	0.13	0.08	-0.10
FR-10	50%	5.67	0.58	-0.57	0.30	-0.28	-0.01	0.01	-0.06	0.06	-0.01	0.01	0.00	0.00	-0.14	0.15	0.07	-0.09
FR-21	10%	5.43	0.36	-0.36	0.44	-0.36	-0.06	0.06	-0.13	0.13	-0.01	0.02	0.02	-0.03	-0.25	0.26	0.17	-0.20
FR-21	50%	5.85	0.45	-0.44	0.42	-0.34	-0.05	0.05	-0.09	0.10	-0.01	0.01	0.04	-0.04	-0.25	0.27	0.13	-0.15
FR-22	10%	5.69	0.47	-0.45	0.37	-0.30	-0.04	0.04	-0.07	0.07	-0.01	0.01	0.02	-0.02	-0.21	0.23	0.11	-0.13
FR-22	50%	5.84	0.58	-0.58	0.30	-0.26	-0.02	0.02	-0.03	0.03	-0.01	0.01	0.01	-0.01	-0.16	0.17	0.08	-0.10

Table 12-6 Water quality model results to changes in parameters (Surface layer D.O. %)

Station	Percentile	Base Case	Upstream D.O. Boundary		BOD Decay Rate		BOD Point Source Load		Marsh BOD Load		Nitrification Rate		Offshore D.0. Boundary		Sediment Oxygen Demand		Global Reaeration Rate	
			15%	-15%	-33%	33%	33%	-33%	33%	-33%	33%	-33%	15%	-15%	33%	-33%	25%	-25%
FR-02	10%	3.08	7	-7	13	-10	-2	2	-4	5	0	1	3	-3	-8	9	8	-9
FR-02	50%	3.33	4	-4	11	-9	-1	1	-3	3	0	0	5	-4	-7	7	6	-7
FR-04	10%	2.62	8	-8	14	-11	-2	2	-4	5	0	1	2	-2	-8	9	7	-8
FR-04	50%	2.88	8	-8	12	-9	-2	2	-4	4	0	0	1	-1	-7	7	5	-7
FR-06	10%	2.15	9	-9	11	-9	-2	2	-3	3	0	0	1	-1	-7	7	4	-5
FR-06	50%	2.45	10	-10	8	-6	-1	1	-1	2	0	0	0	0	-4	5	2	-3
FR-08	10%	2.92	9	-9	6	-5	-1	1	-1	1	0	0	0	0	-4	4	2	-2
FR-08	50%	4.02	9	-10	5	-4	0	0	-1	1	0	0	0	0	-3	3	1	-1
FR-09	10%	3.57	10	-9	7	-6	-1	1	-1	1	0	0	0	-1	-4	4	2	-2
FR-09	50%	4.67	11	-9	4	-4	0	0	0	0	0	0	0	0	-2	3	1	-1
FR-10	10%	4.65	10	-11	6	-6	0	0	-2	1	0	0	0	0	-3	2	1	-2
FR-10	50%	5.67	11	-11	6	-5	0	0	-1	1	0	0	0	0	-3	3	1	-2
FR-21	10%	5.43	10	-10	12	-10	-2	2	-3	4	0	0	1	-1	-7	7	5	-6
FR-21	50%	5.85	10	-9	9	-7	-1	1	-2	2	0	0	1	-1	-6	6	3	-3
FR-22	10%	5.69	9	-9	7	-6	-1	1	-1	1	0	0	0	0	-4	5	2	-3
FR-22	50%	5.84	10	-10	5	-5	0	0	-1	1	0	0	0	0	-3	3	1	-2

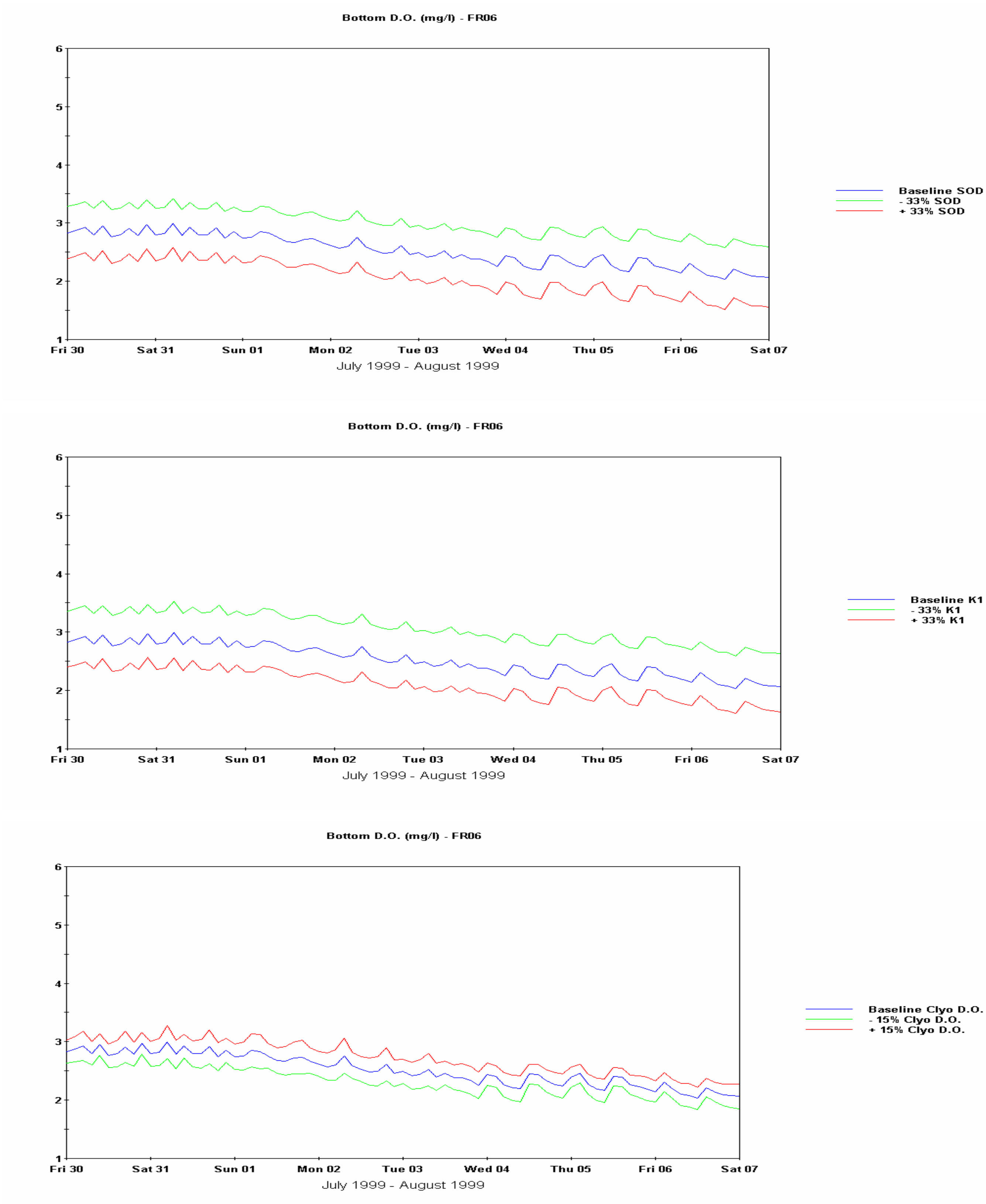


Figure 12-4 Front River (FR-06) Sensitivity with SOD, K-rate, and Upstream DO Boundary

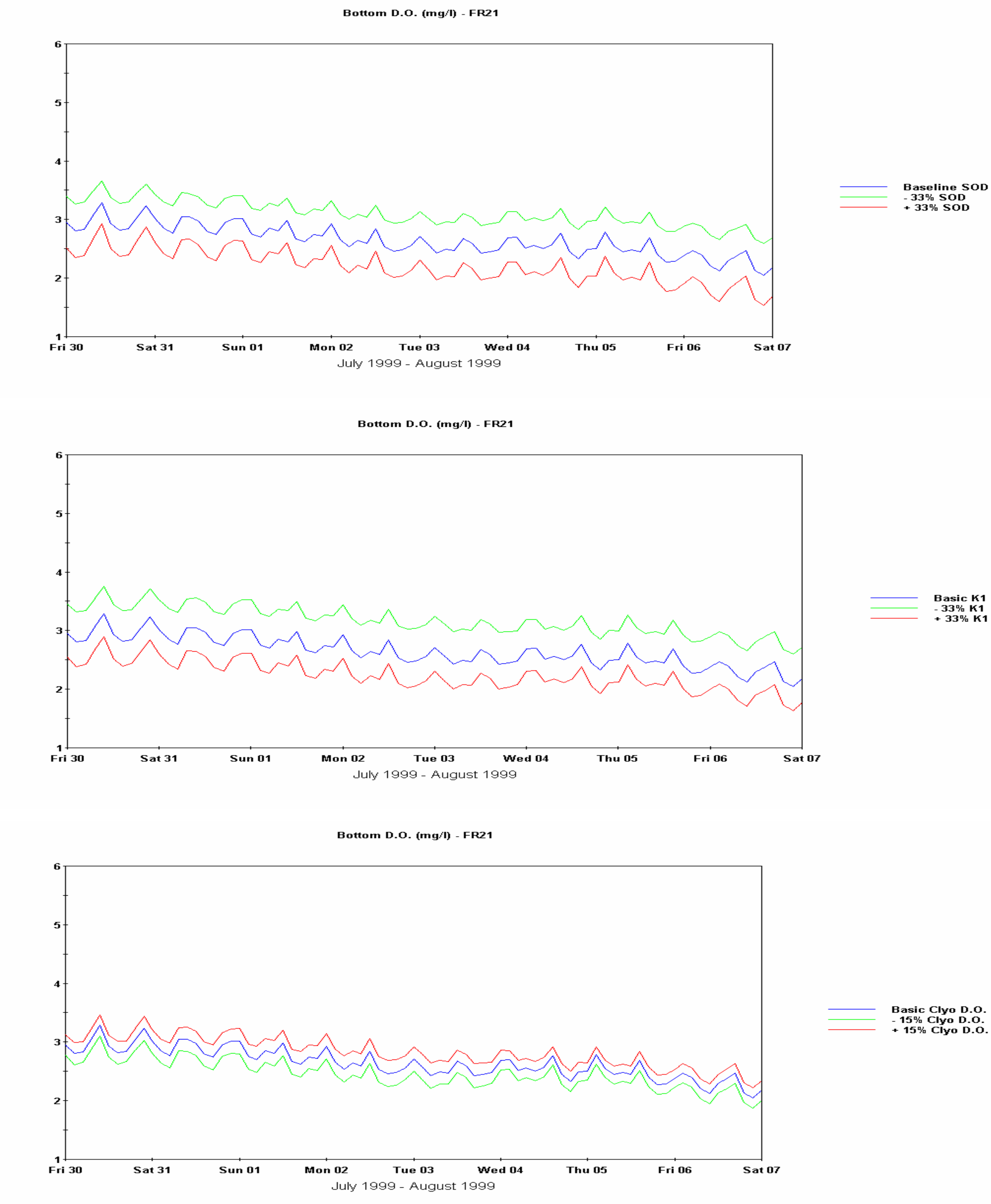


Figure 12-5 Front River (FR-21) Sensitivity with SOD, K-rate, and Upstream DO Boundary

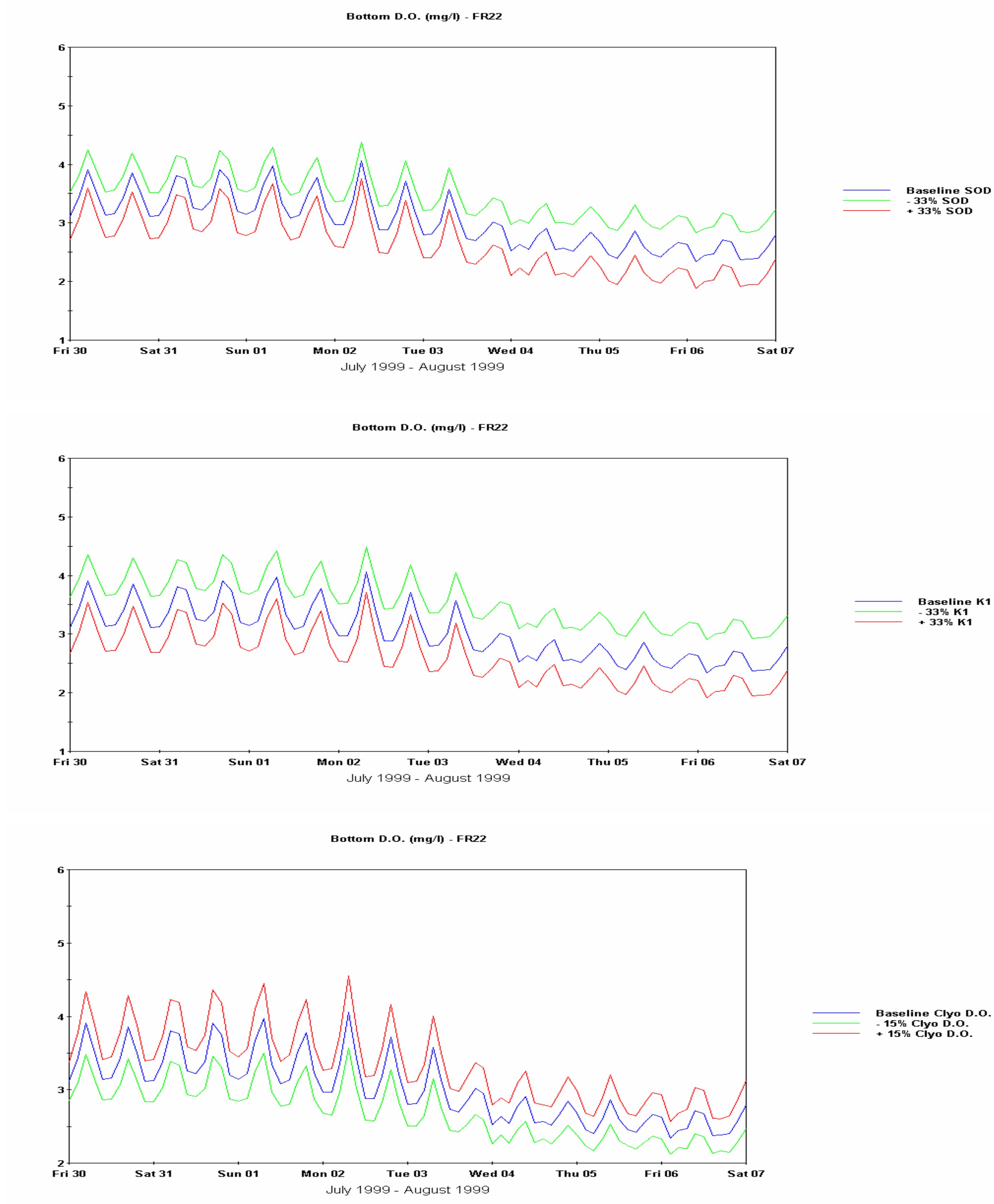


Figure 12-6 Front River (FR-22) Sensitivity with SOD, K-rate, and Upstream DO Boundary

13.0 CONCLUSIONS

This report is a culmination of an extensive amount of work. The TMDL model grid demonstrated that the EFDC and WASP models are appropriate for a complex system such as Savannah Harbor. With further refinement on the bathymetry, grid, and marsh interactions described in this report, the enhanced model grid improved its ability to simulate summer conditions in 1997 and 1999. As demonstrated in Appendix L and M, with the seven-year water surface elevation and salinity comparisons, the model can perform equally well in high flows and summer-time low-flow conditions. Unfortunately for the water quality, there is not a robust dataset over the seven years to challenge the WASP dissolved oxygen predictions, but the critical conditions in 1997 and 1999 are captured well with the WASP model. A combination of the three time periods (summer 1999, summer 1997, and 1997 through 2003) proves the model's usefulness to evaluate physical changes expected from proposed deepening, mitigation alternatives, and ecosystem restoration.

The tools developed under this work effort include the WRDB database, the EFDC hydrodynamic model, and the WASP water quality model. A combination of these tools allow for easy data assimilation and model comparisons. The MOVEM post-processor allows the end users to view the EFDC and WASP model results along with the WRDB data files. These tools are non-proprietary, or public domain, and are available on the EPA Modeling Toolbox website (http://www.epa.gov/athens/wwqtsc/).

The development of the enhanced grid EFDC model involved a complete redesign of grid bathymetry/geometry based on new GIS data and desired flexibility for project scenario alternatives. Model bathymetry was derived from a wealth of newly-available bathymetric data, including an essential USGS survey on the Front River between Houlihan Bridge and I-95 Bridge, and including the Middle, Back, and Little Back Rivers. Evaluation and analysis of the raw bathymetric data was performed via several methods, including weighted interpolation of points, and also by hand using the modeler's best judgment in consideration of model results. Bathymetry in the Front River main channel was rigorously interpreted from 2002 USACE Annual Survey results.

Another important aspect of the EFDC model enhancements was to incorporate marsh interactions to accurately represent salinity retention, increase of tidal flows, and attenuation of tidal flows in the Middle and Little Back Rivers. The marsh approach was developed using weir structures already in the EFDC code. The resultant salinity retention in the Little Back River is evident from the comparisons at the USGS site near the F&W Docks. Marsh areas and locations control the degree of salinity retention, and the best way to evaluate results is by examining salinity time series in the Middle and Little Back Rivers.

The salinity criteria were established for the stations: GPA 5, 6, 7, 8, 9, 10, 11R, 12R, 15, and 22 and five USGS stations. The July 31-October 13 (Appendix J) calibration results in Table J-1 show that the model met the criteria for USGS stations 80% (4/5). The criteria were +/- 0.5 ppt at the 50th and 90th percentiles. The one station that did not meet was at Houlihan Bridge (02198920) and it had differences on 0.8 and 1.9 ppt for the 50th and 90th percentiles, respectively. At the GPA stations, the model met 15% (2/13) for 10th percentile and 54% (7/13) for 90th percentile for the stations > 5 ppt 50% of the time. For the stations < 5 ppt 50% of the time, the model met 60% (6/10) for 50th percentile and 10% (1/10) for 90th percentile. The difference in meeting criteria for USGS and GPA sites can be explained partly by quality and duration of compared data. The average duration of data for USGS stations is 100% of the simulated period of time, and only 50-70% for GPA stations due to data gaps. This explains some problematic aspects of comparing percentiles of simulation results with incomplete data.

The WASP water quality simulations of dissolved oxygen were critical to the success of the modeling approach. To improve the model performance, the CBODu loads were separated between three different types of CBODu. Based on GAEPD and EPA Region 4's re-evaluation of the 1999 LTBOD data, three categories of CBODu were determined as fast, middle, and slow decay rates. The summer 1999 dissolved oxygen raw data were QA/QC'd (corrected) by USGS methods to increase the reliability of data used for the model comparisons.

For the 1999 dissolved oxygen calibration, the visual and statistical comparisons of simulated versus measured show that the calibrated model is yielding reasonable dissolved oxygen values and is capturing the existing dissolved oxygen dynamics, tidal variability, and spatial distribution in the Savannah Harbor system. The stringent requirements of the Federal Expectations document entitled "Draft Savannah Harbor Data Analysis and Modeling Expectations of the Federal Agencies" were satisfied for approximately 50% of the stations for July 10 – October 6, 1997 validation period, and 35% for half of the stations for July 31 - October 13, 1999 calibration period. The comparison of statistics of the model outputs that use USGS corrected data and ATM cleaned data shows improvement of results after using the USGS data: 7/31/99-10/13/99 – 12 versus 11 times of Federal Expectations meeting. For two-weeks periods: 7/31/99-8/15/99 – 11 versus 13 times (-); 8/16/99-8/30/99 – 11 versus 6 times (+); 8/31/99-9/13/99 – 7 versus 7 (=); 9/14/99-9/28/99 – 12 versus 11 (+); 9/29/99-10/13/99 – 22 versus 10 (+).

The new CBODu load separation also improved the model performance. The comparisons of statistics for new model and old (May report) outputs for 1997 run shows the following results: 7/10/97-10/6/97 – 13 versus 11 (+); 7/10/97-7/23/97 – 10 versus 2 (+); 7/24/97-8/7/97 – 6 versus 11 (-); 8/8/97-8/22/97 – 4 versus 2 (+); 8/23/97-9/6/97 – 9 versus 3 (+); 9/7/97-9/20/97 – 5 versus 6 (-); 9/21/97-10/6/97 – 13 versus 6 (+).

For the 1997 dissolved oxygen confirmation, the visual and statistical comparisons of simulated versus measured show acceptable model performance. The model clearly displays sensitivity to the upstream Savannah River dissolved oxygen boundary conditions (Clyo) especially for Savannah River stations upstream of the I-95 Bridge. The validation results show that the constant dissolved oxygen concentration applied for the Clyo boundary is not good enough. The results can be easily improved by using the output of EPD-Riv1 model as the boundary condition (as it was used for 1999 calibration run). Both 1999 and 1997 runs show that the developed WASP water quality model is capturing the longitudinal distribution of dissolved oxygen in the Front River. The simulated and measured comparisons show the critical low dissolved oxygen area is between FR-04 and FR-08 (river mile 10.4 to 20.5).

Overall, the federal expectations criteria are met approximately 50% of the time and the comparisons vary by parameter. The criteria are stringent but do provide a goal to judge the model's performance. The model's performance can be assessed against the criteria but also needs to factor in the ability of the model to predict the physics in the estuary for seven years in the most difficult and contentious areas such as the Little Back River and the upper extent of the salt wedge (between the Houlihan Bridge and the I-95 Bridge) on the Front River. The seven-year confirmation was successful for water surface elevation and salinity, as those were the only parameters included in the 7-year dataset. The WASP water quality model shows a sensitivity to four main processes: (1) salinity intrusion and stratification, (2) marsh loadings, (3) point source loads in the Front River between Fort Jackson and Houlihan Bridge, and (4) SOD especially for bottom waters during neap tide stratification events. Since the EFDC and WASP models performed well for the 1999 and 1997 periods based on these four key processes, we would expect the WASP model to perform just as well for a seven-year period if the data were available.

The next step in the use of the models will be to predict salinity, temperature, velocity, water surface elevation, and dissolved oxygen for various scenarios including changes in point sources, TMDL runs, deepening alternatives, and mitigation levels. EPA Region 4 will be revising the August 30, 2004 TMDL with the enhanced models while the USACE Savannah District and Georgia Ports Authority will be using the enhanced models to predict impacts to the SHE project along with mitigation alternatives.

14.0 REFERENCES

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15.0 APPENDICES

APPENDIX A GRID CONVERGENCE TEST RESULTS

A.1 APPROACH

In order to address the issue of grid resolution and potential impact on hydrodynamic and salinity results, an extra fine EFDC grid ("Convergence Grid") was developed based on the Enhanced Grid. Ideally, the Enhanced Grid would be of adequate horizontal resolution such that finer resolution (greater number of horizontal cells) would have no effect on model results. Since increasing the number of cells also increases model complexity and run time, and furthermore requires a smaller time step, it is desirable to minimize the number of cells in the grid.

The Convergence Grid was developed with 2,249 horizontal cells, where each Enhanced Grid cell was split into four cells, for the offshore area and main channel up to Steamboat River (1,250 m upstream of Houlihan Bridge). For simplicity, it was determined to keep the existing grid resolution for the Middle River, Back River, and the upper Savannah River. Comparison of the Enhanced Grid (black) and Convergence Grid (red) is shown in Figure A-1.

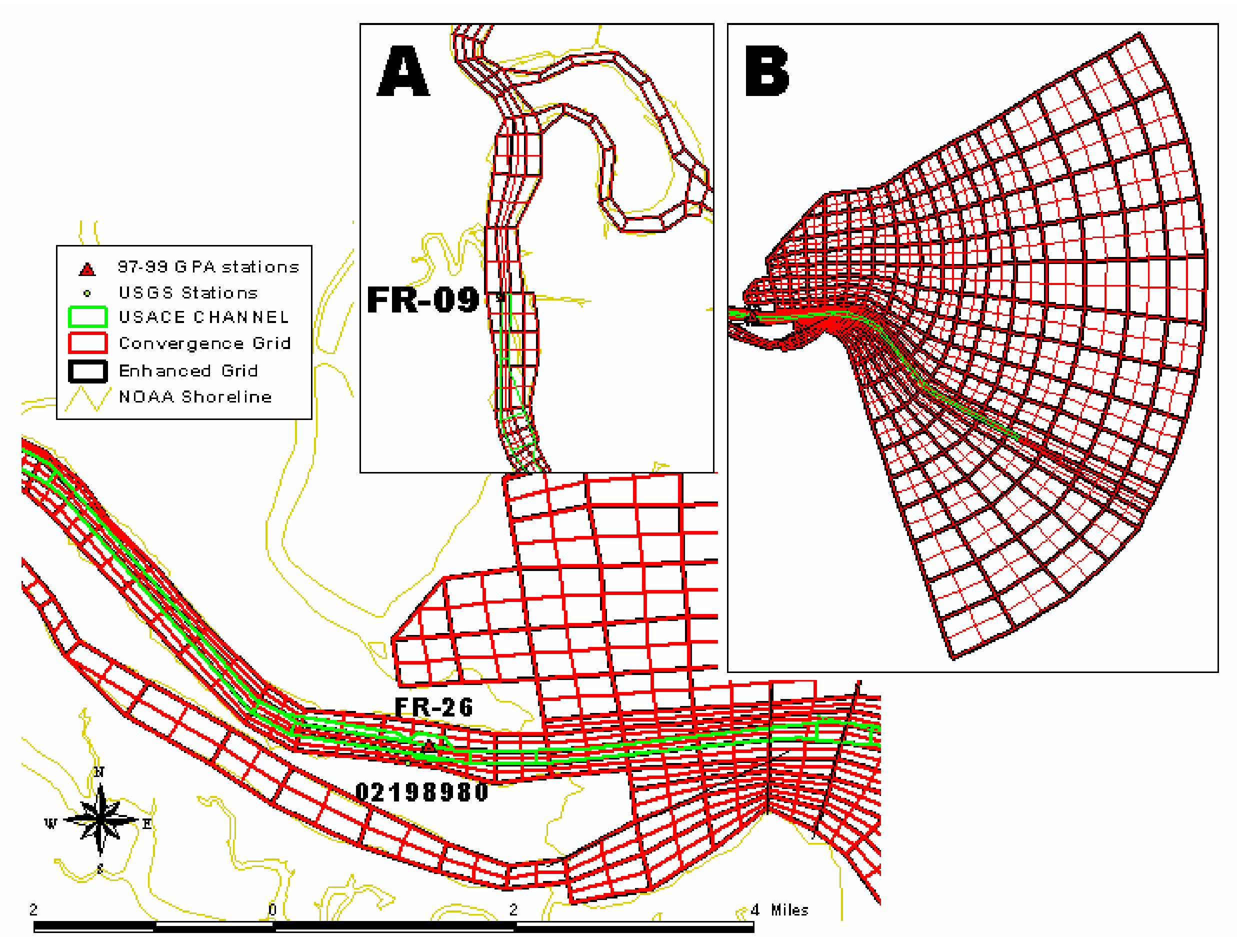


Figure A-1 Enhanced Grid (black) and Convergence Grid (red) developed for convergence test, at the mouth of the Savannah River, at Houlihan Bridge (inset A) and offshore (inset B).

A.2 Enhanced Grid and Convergence Grid Bathymetry

Bathymetry in the Convergence Grid was set for all downstream cells at –14 m and compared to an idealized Enhanced Grid bathymetry, also at –14 m. Upstream of Abercorn Creek, both grids were assigned an identical smooth slope from –14 m to represent the slope up to Clyo at +0.4 m. The reason for constant and equal depth is that using actual depths for both grids would require interpolation between cell centers and result in a non-identical bathymetry (and cross section) for the Convergence Grid even with identical overall cell geometry to the Enhanced Grid. By setting a constant depth the bathymetry is more comparable between the two grids, and therefore any difference in model results can be attributed to grid resolution rather than differences in bathymetry. The sloped section upstream to Clyo is necessary to investigate the effects of grid resolution on salinity intrusion results.

Initial salinity conditions were set to zero for both grids, and both grids were assigned identical forcing files for offshore boundary salinity and temperature conditions, wind, and flows, including the freshwater inflow at the uppermost cell at Clyo. Both grids were run without marsh cells. Model time step was set at 1 second for both grids and the models were run for 62 days.

A.3 Comparison of Results: Enhanced Grid and Convergence Grid

Model results are consistent between the Enhanced Grid and the Convergence Grid. Water surface elevation results are virtually identical and will not be shown. Salinity results were similar as well. Slight variations in salinity are seen between the grids, generally <1 ppt, as shown at Houlihan Bridge (FR-09) in Figure A-2.

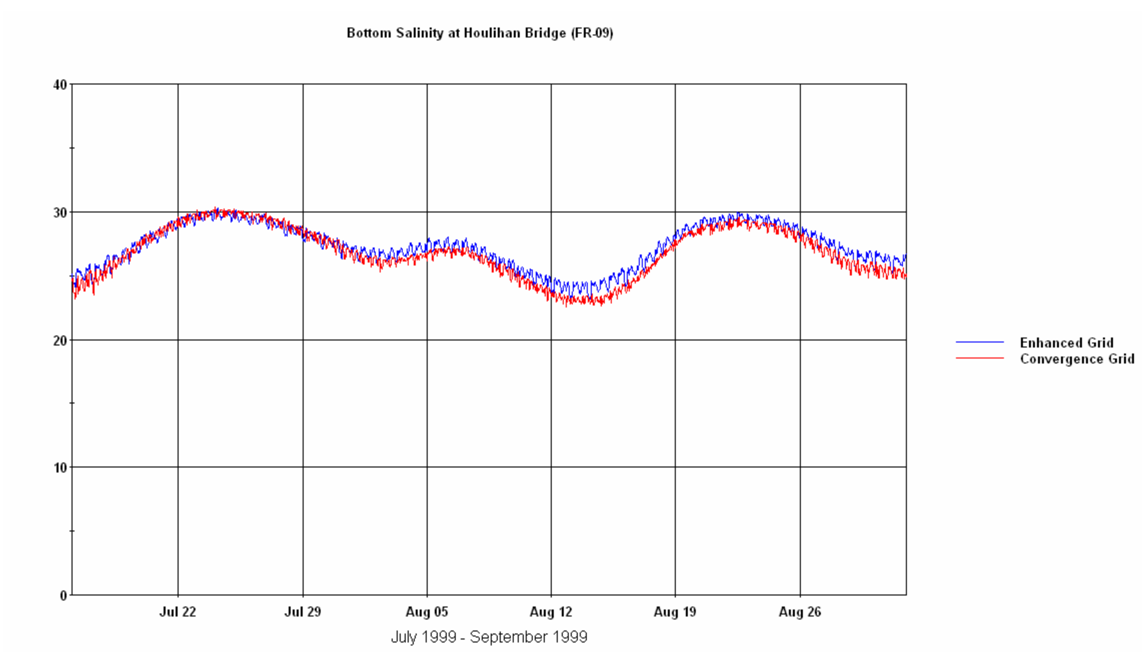


Figure A-2 Bottom Salinity at Houlihan Bridge (FR-09) for Enhanced Grid (idealized bathymetry) and Convergence Grid.

Since initial conditions at Houlihan Bridge were 0 ppt salinity, the initial salt wedge front can be seen approximately 3 days from the beginning of the run. Since most of the grid is –14 m depth, bottom salinity values are generally high, balanced by flows such as freshwater input at Clyo.

Surface salinity values at Houlihan Bridge are also similar, again within 1 or 2 ppt. The Convergence Grid exhibits slightly less salinity than the Enhanced Grid, and the difference is more apparent at surface, as shown in Figure A-3.

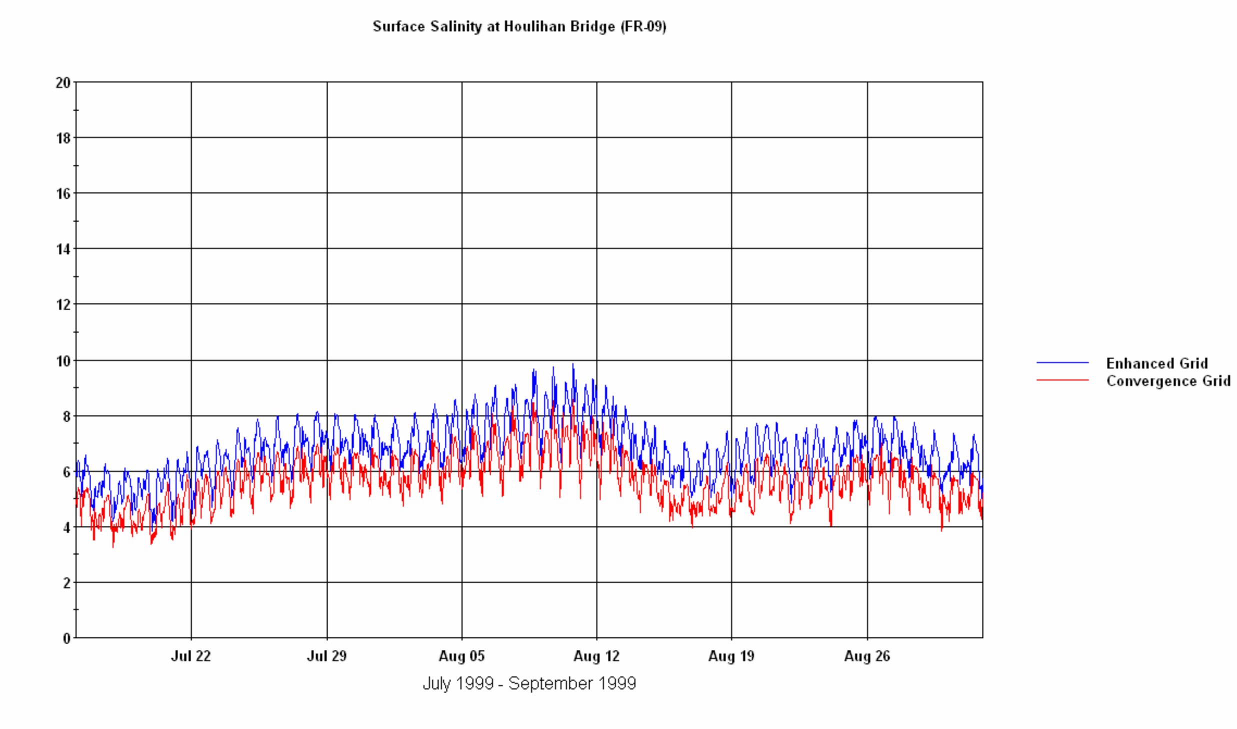


Figure A-3 Surface Salinity at Houlihan Bridge (FR-09) for Enhanced Grid (idealized bathymetry) and Convergence Grid.

Farther upstream, where there are shallower cells on the slope up to Clyo, salinity is reduced to zero due to flushing during ebb tides, and at times of low inflow at Clyo (drought periods) salinity peaks up to about 0.35 ppt are seen on incoming flood tides. These peaks are shown in Figure A-4. Convergence Grid and Enhanced Grid results are virtually identical for many salinity peaks, although there are some where the finer Convergence Grid shows greater (0.1 ppt) salinity intrusion.

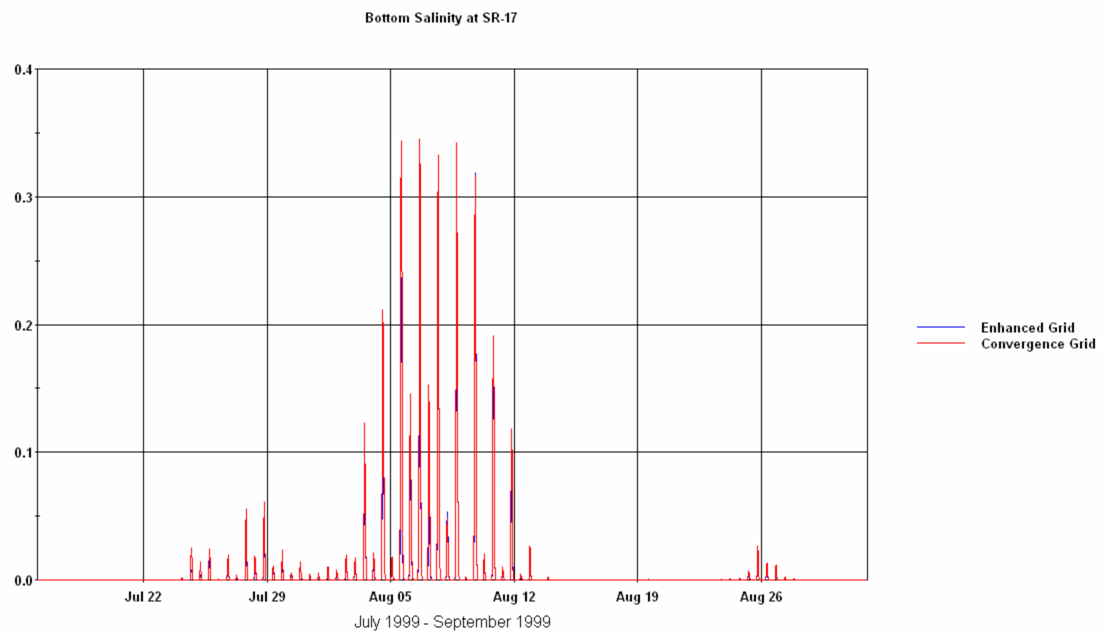


Figure A-4 Bottom Salinity at 26 kilometers downstream of Clyo (SR-17) for Enhanced Grid (idealized bathymetry) and Convergence Grid.

Quantification of the convergence grid test results has been performed and is presented in the following table (Table A-1). Model spin up (15 days) has been excluded from these statistics.

Table A-1 Quantification of the Convergence Grid Test Results

Site	Layer	Enhanced Grid Average Salinity (ppt)	Convergence Grid Average Salinity (ppt)	Average Difference (ppt)	Average Percent Difference
FR-09	Bottom	27.27	26.83	-0.43	-1.6%
FR-09	Surface	6.78	5.69	-1.09	-16.2%
SR-17	Bottom	0.005	0.006	0.001	21.9%

A plot of the daily average salinity difference and percent difference at FR-09 Bottom shows no consistent trend of difference (no divergence with time), shown in Figure A-5 and the minor difference in system response for each grid may depend more on hydrologic or tidal conditions.

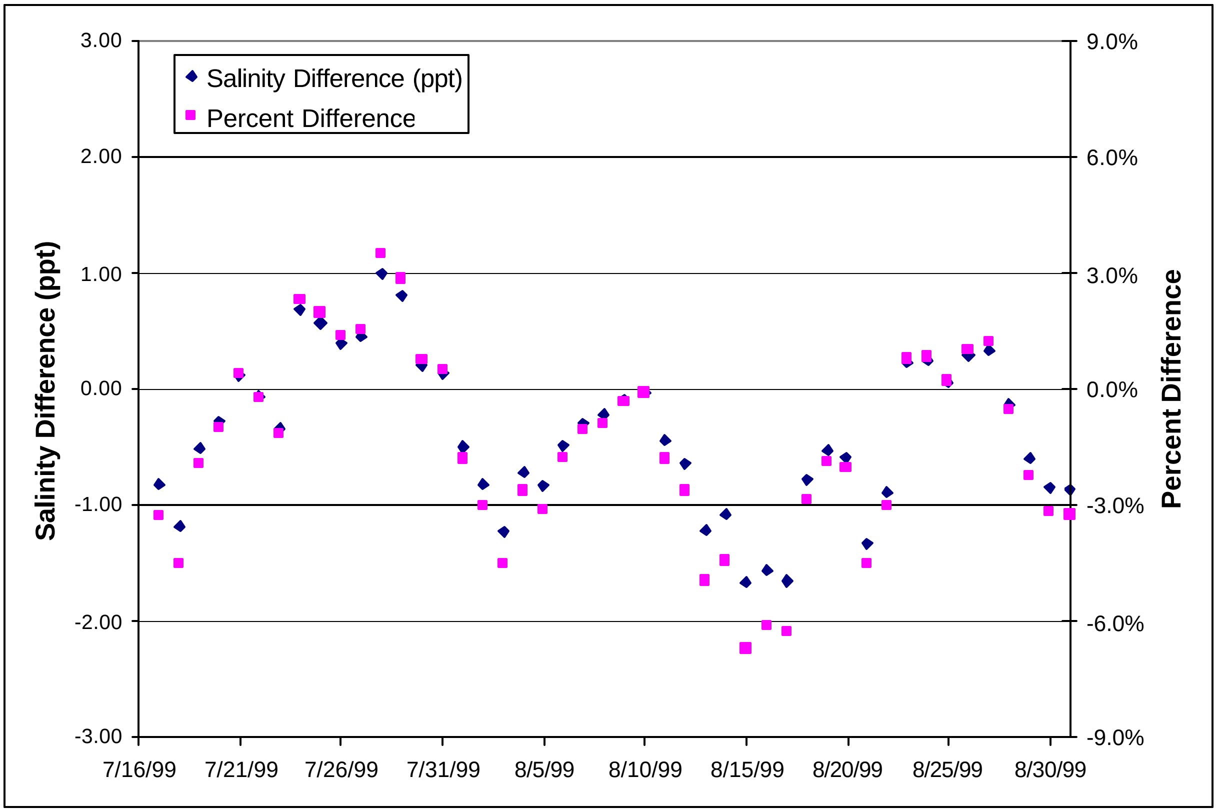


Figure A-5 Salinity and Percent Difference of Grid Convergence Results

The TMDL grid with equal bathymetry should not be compared because the surface area of the grid does not exactly match the enhanced or the convergence grid. The convergence grid is useful because the grid cells can be collapsed back to regenerate the enhanced grid. This could not be done with the TMDL grid.

A.4 Grid Convergence Test: Conclusion

The Convergence Grid was designed to quadruple the resolution of the Enhanced Grid for the offshore area and main channel, while maintaining the simplicity of the Enhanced Grid for Middle and Back Rivers and upstream of Houlihan Bridge. Bathymetry was idealized to –14 m with a slope up to +0.4 m at Clyo from upstream of Abercorn Creek. Water surface elevation results were virtually identical but slight variations were seen in salinity results between grids.

This grid convergence test was performed to assess the appropriateness of the Enhanced Grid horizontal resolution by investigating whether a finer grid produced different results. Trends and results were similar between the Enhanced Grid and the finer Convergence Grid. It should be noted that the Convergence Grid required a 1 second time step to ensure numerical stability due to the small cell size, therefore it required much more computer time (10x) to run the model than the 10 second time step used for Enhanced Grid calibration.

APPENDIX B 1999 WATER SURFACE ELEVATION COMPARISONS

Table B-1 Summary Percentiles for Elevation (meters) for July 31 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%**
FR-26	-0.82	0.46	1.58	-0.81	0.41	1.56	0.00	0.05	0.02
FR-02	-0.92	0.40	1.53	-0.90	0.32	1.52	-0.03	0.07	0.01
SC-03	-0.89	0.49	1.63	-0.85	0.43	1.63	-0.04	0.06	0.00
FR-04	-0.95	0.54	1.69	-0.89	0.45	1.76	-0.06	0.09	-0.08
FR-21	-0.94	0.56	1.69	-0.89	0.46	1.81	-0.05	0.10	-0.12
BR-05	-0.89	0.64	1.69	-0.80	0.45	1.81	-0.09	0.19	-0.12
FR-06	-0.89	0.59	1.70	-0.84	0.49	1.85	-0.05	0.09	-0.15
FR-22	-1.05	0.63	1.74	-0.99	0.49	1.95	-0.06	0.14	-0.21
FR-08	-0.95	0.63	1.74	-0.94	0.48	1.92	-0.01	0.15	-0.19
FR-09	-0.95	0.63	1.72	-0.92	0.50	1.93	-0.04	0.13	-0.22
FR-11R	-0.79	0.71	1.72	-0.86	0.55	1.98	0.07	0.16	-0.26
SR-14	-0.56	0.86	1.67	-0.75	0.62	2.05	0.19	0.24	-0.38
SR-16	-0.66	1.03	2.12	-0.65	0.65	2.03	-0.01	0.38	0.09
SR-17	1.90	2.51	3.00	1.90	2.56	3.09	0.00	-0.05	-0.09
USGS02198980 (Ft Pulaski)	-0.79	0.47	1.56	-0.80	0.43	1.55	0.01	0.04	0.01
USGS02198977 (Broad St)	-0.94	0.59	1.69	-0.90	0.47	1.83	-0.04	0.13	-0.14
USGS02198920 (Houlihan Bridge)	-0.96	0.61	1.69	-0.92	0.50	1.94	-0.04	0.11	-0.25
USGS02198979 (Limehouse Creek)	-0.65	0.93	1.78	-0.57	0.48	1.85	-0.08	0.45	-0.07
USGS02198840 (I-95)	-0.55	0.86	1.69	-0.78	0.61	2.04	0.23	0.25	-0.35

Table B-2 Summary Statistics for Elevation (meters) for July 31 through October 13, 1999

July 31 - October 13, 1999 [Julian Days 212-285]									
Station	**N**	**ME**	**AME**	**RMS**	**Mean Obs**	**StDev Obs**	**Mean Pred**	**StDev Pred**	**R^2**
FR-26	16577	-0.02	0.06	0.08	0.42	0.80	0.39	0.79	0.99
FR-02	6721	-0.04	0.09	0.11	0.35	0.82	0.31	0.80	0.98
SC-03	15516	-0.01	0.09	0.11	0.43	0.84	0.42	0.83	0.98
FR-04	18022	-0.01	0.10	0.12	0.46	0.88	0.45	0.89	0.98
FR-21	15387	-0.02	0.11	0.14	0.48	0.88	0.46	0.89	0.98
BR-05	16665	-0.05	0.15	0.18	0.53	0.86	0.48	0.86	0.96
FR-06	14947	0.00	0.12	0.15	0.49	0.87	0.50	0.89	0.97
FR-22	14993	0.00	0.14	0.17	0.50	0.96	0.50	0.98	0.97
FR-08	19437	-0.03	0.14	0.18	0.53	0.91	0.49	0.95	0.97
FR-09	18431	0.00	0.15	0.18	0.52	0.90	0.51	0.94	0.96
FR-11R	16309	-0.04	0.21	0.29	0.60	0.85	0.56	0.93	0.91
SR-14	11326	-0.08	0.30	0.35	0.72	0.76	0.63	0.93	0.88
SR-16	14912	-0.22	0.38	0.49	0.89	0.93	0.67	0.88	0.79
SR-17	15774	0.04	0.17	0.22	2.50	0.35	2.54	0.36	0.67
USGS02198980 (Ft Pulaski)	3601	-0.02	0.05	0.06	0.43	0.78	0.41	0.78	0.99
USGS02198977 (Broad St)	3601	-0.02	0.10	0.12	0.50	0.89	0.48	0.91	0.98
USGS02198920 (Houlihan Bridge)	2858	0.01	0.13	0.17	0.50	0.91	0.51	0.94	0.97
USGS02198979 (Limehouse Creek)	3601	-0.19	0.27	0.32	0.75	0.83	0.56	0.79	0.90
USGS02198840 (I-95)	3601	-0.10	0.29	0.35	0.73	0.76	0.63	0.93	0.88

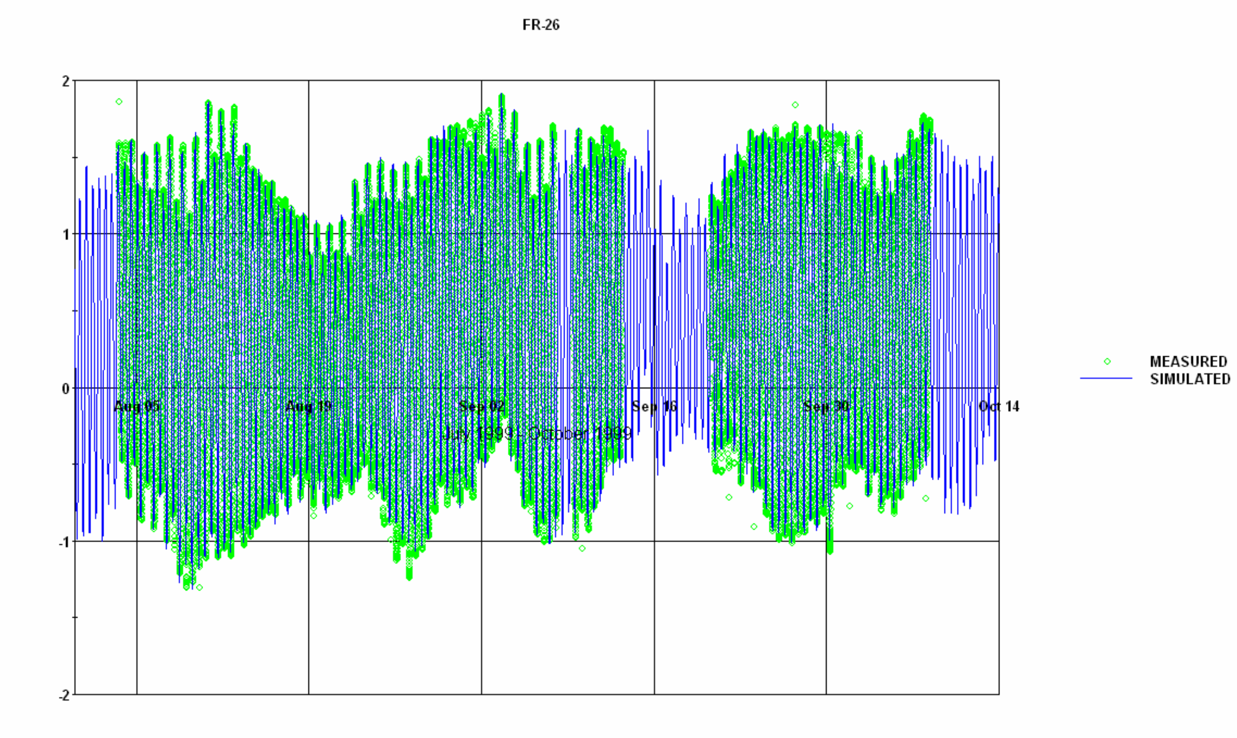


Figure B-1 Elevation (meters) Calibration at FR-26 for July 31 through October 13, 1999

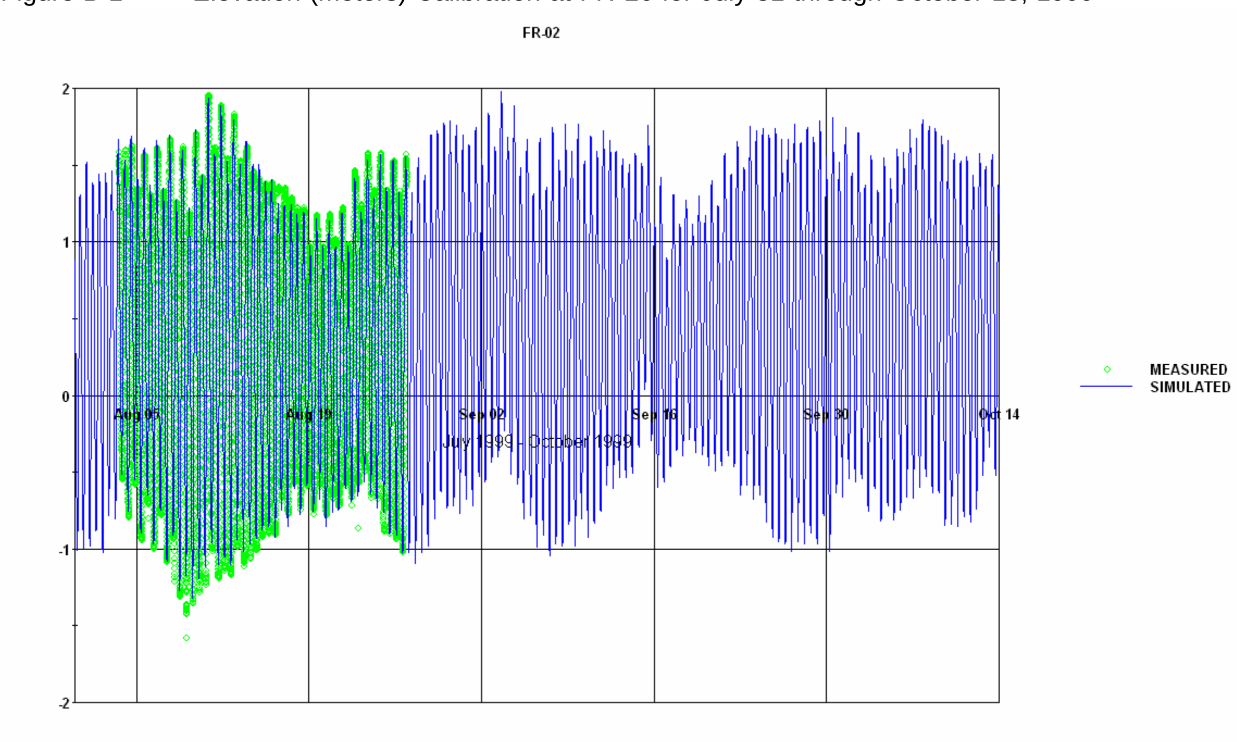


Figure B-2 Elevation (meters) Calibration at FR-02 for July 31 through October 13, 1999

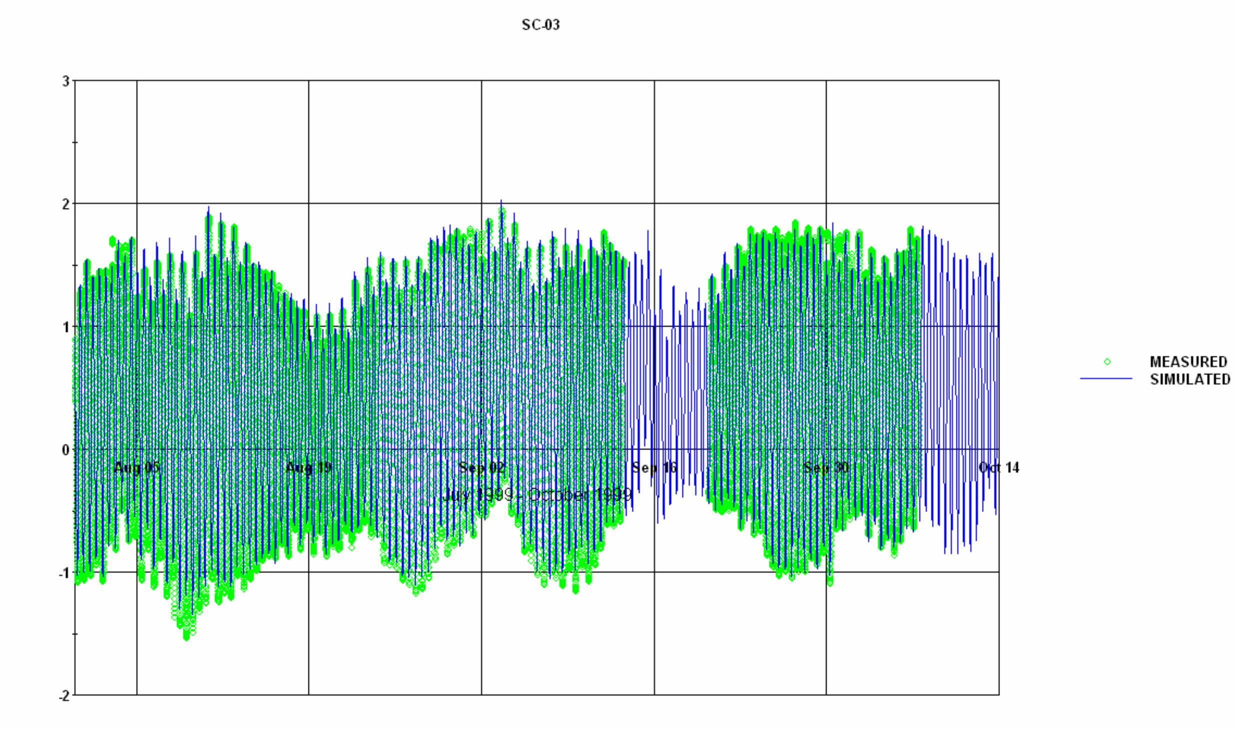


Figure B-3 Elevation (meters) Calibration at SC-03 for July 31 through October 13, 1999

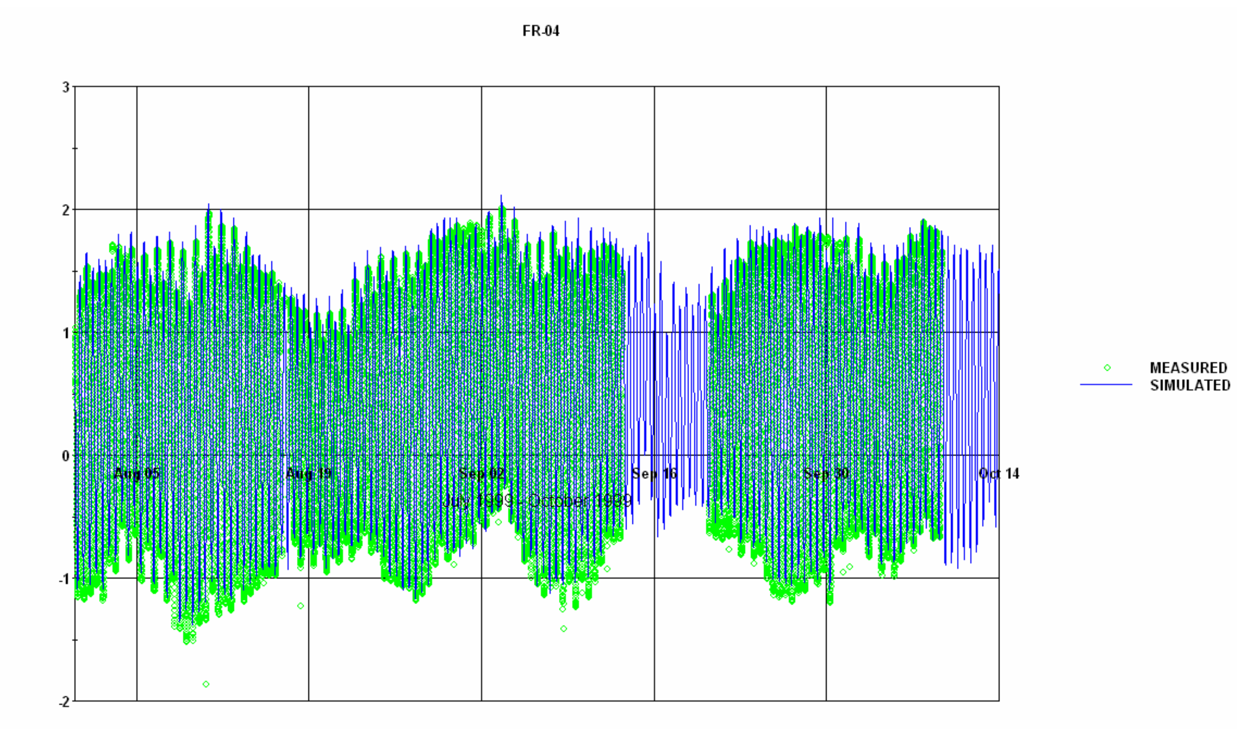


Figure B-4 Elevation (meters) Calibration at FR-04 for July 31 through October 13, 1999

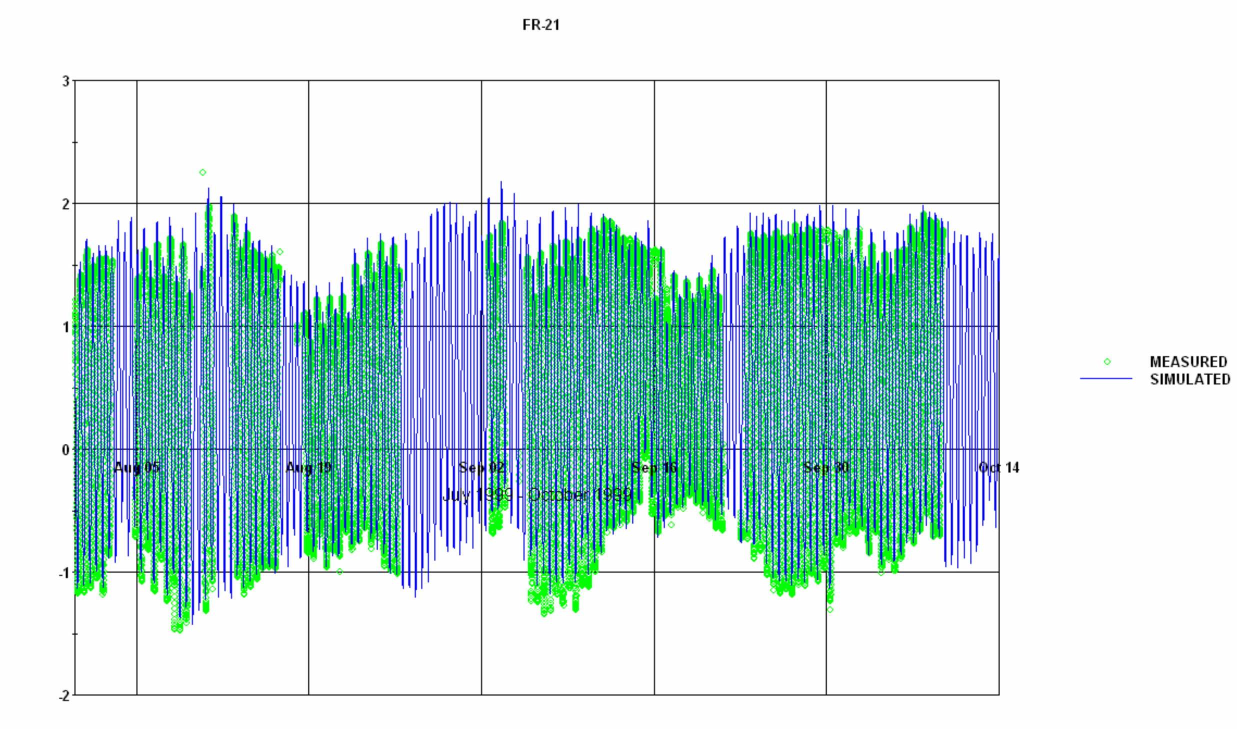


Figure B-5 Elevation (meters) Calibration at FR-21 for July 31 through October 13, 1999

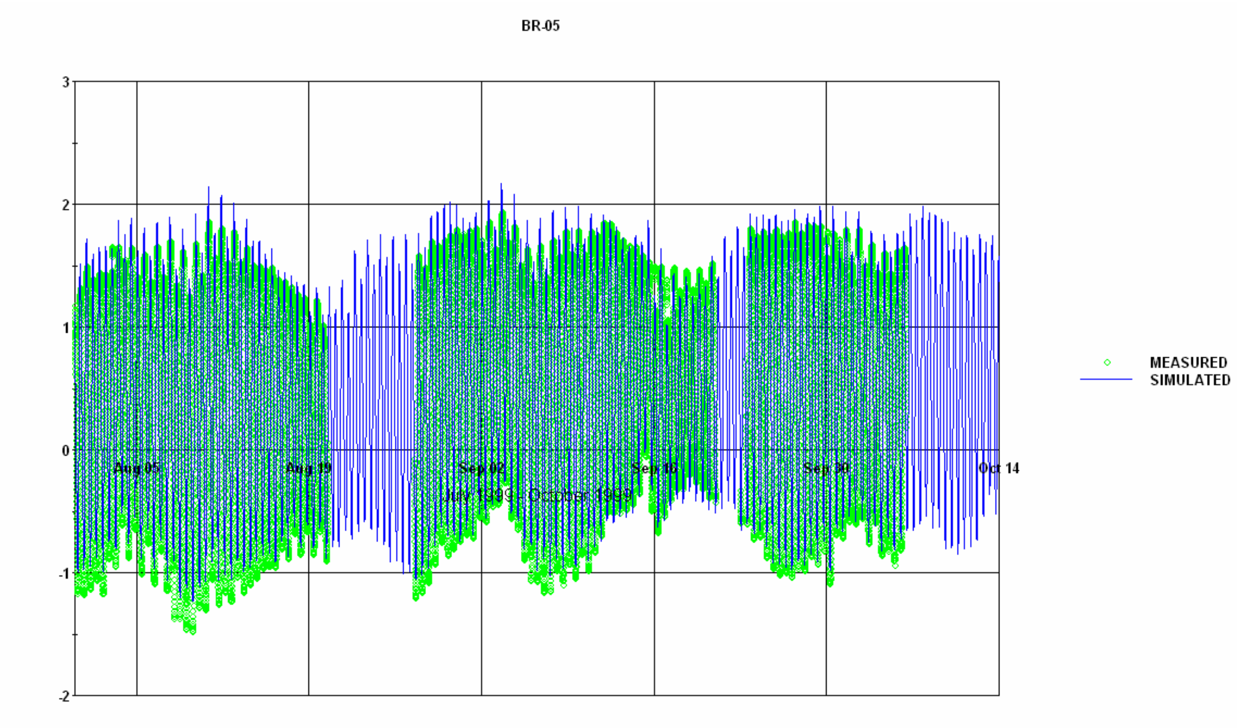


Figure B-6 Elevation (meters) Calibration at BR-05 for July 31 through October 13, 1999

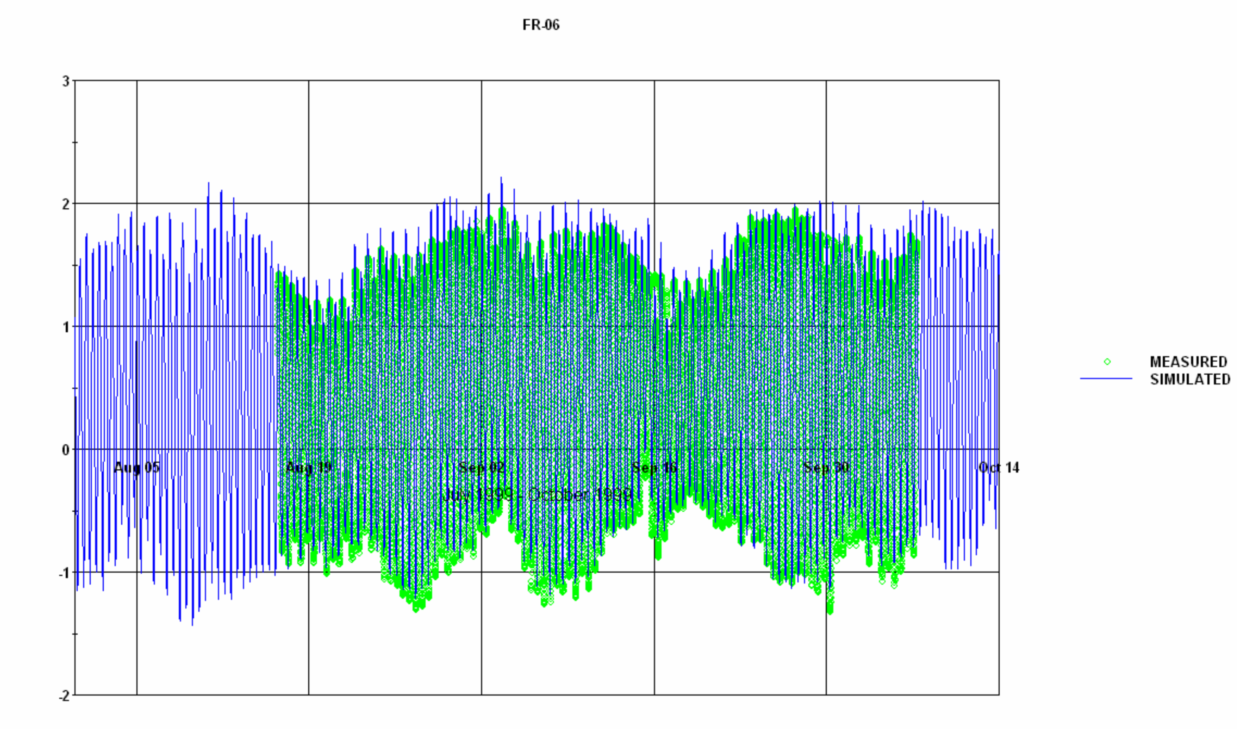


Figure B-7 Elevation (meters) Calibration at FR-06 for July 31 through October 13, 1999

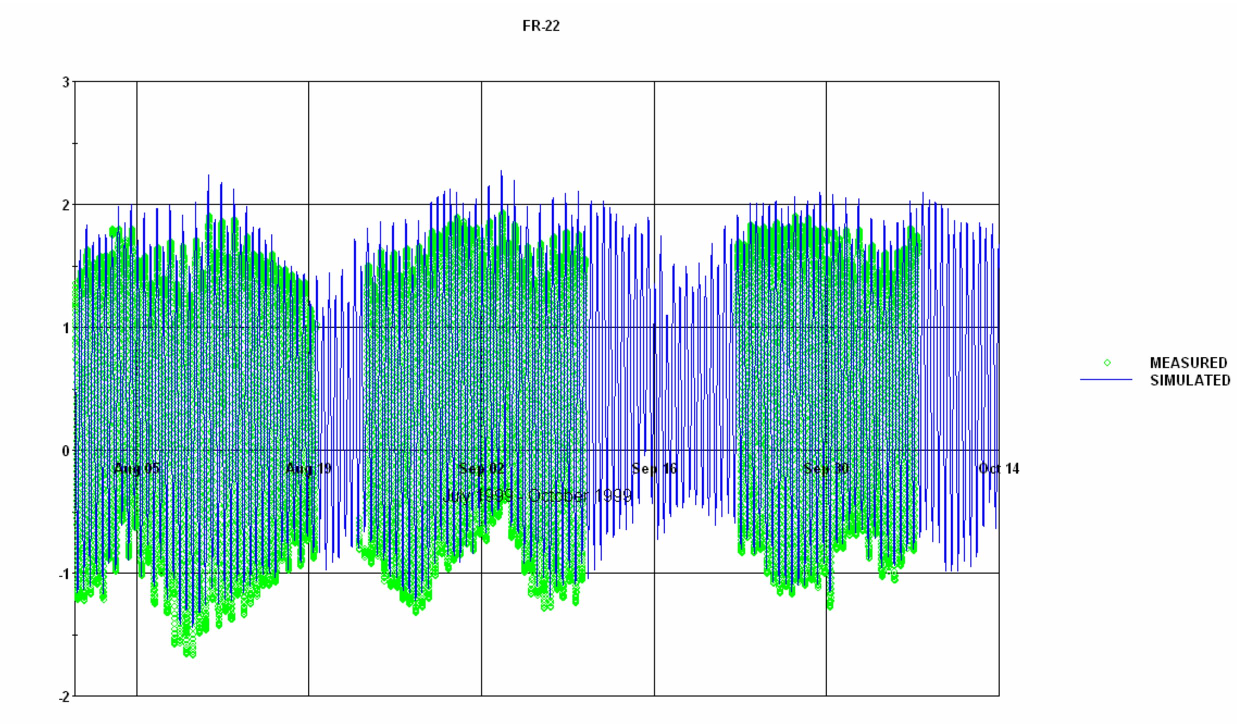


Figure B-8 Elevation (meters) Calibration at FR-22 for July 31 through October 13, 1999

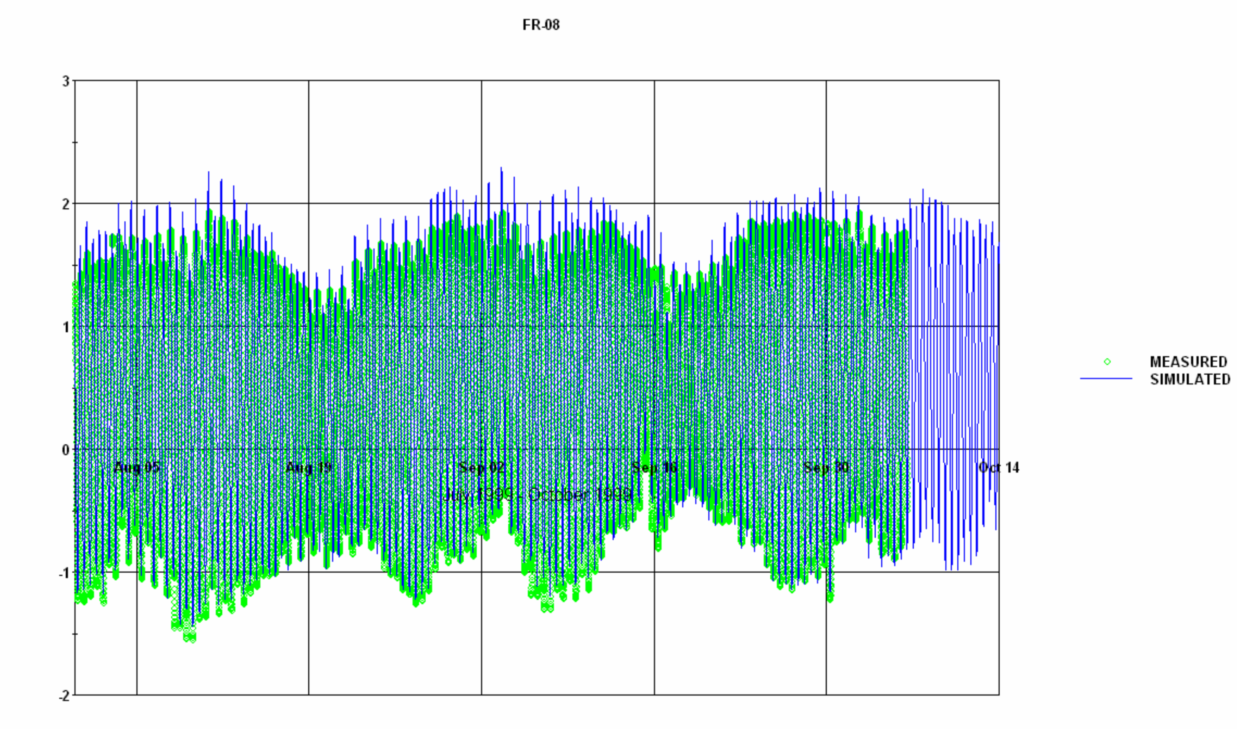


Figure B-9 Elevation (meters) Calibration at FR-08 for July 31 through October 13, 1999

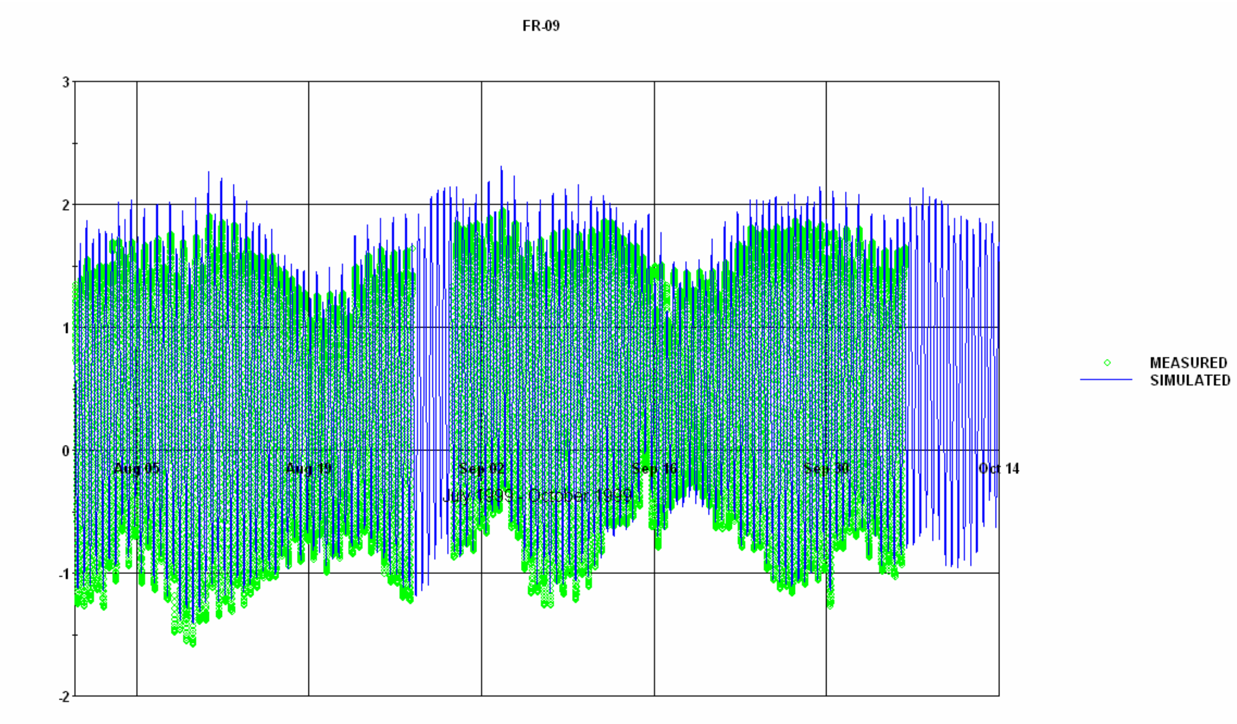


Figure B-10 Elevation (meters) Calibration at FR-09 for July 31 through October 13, 1999

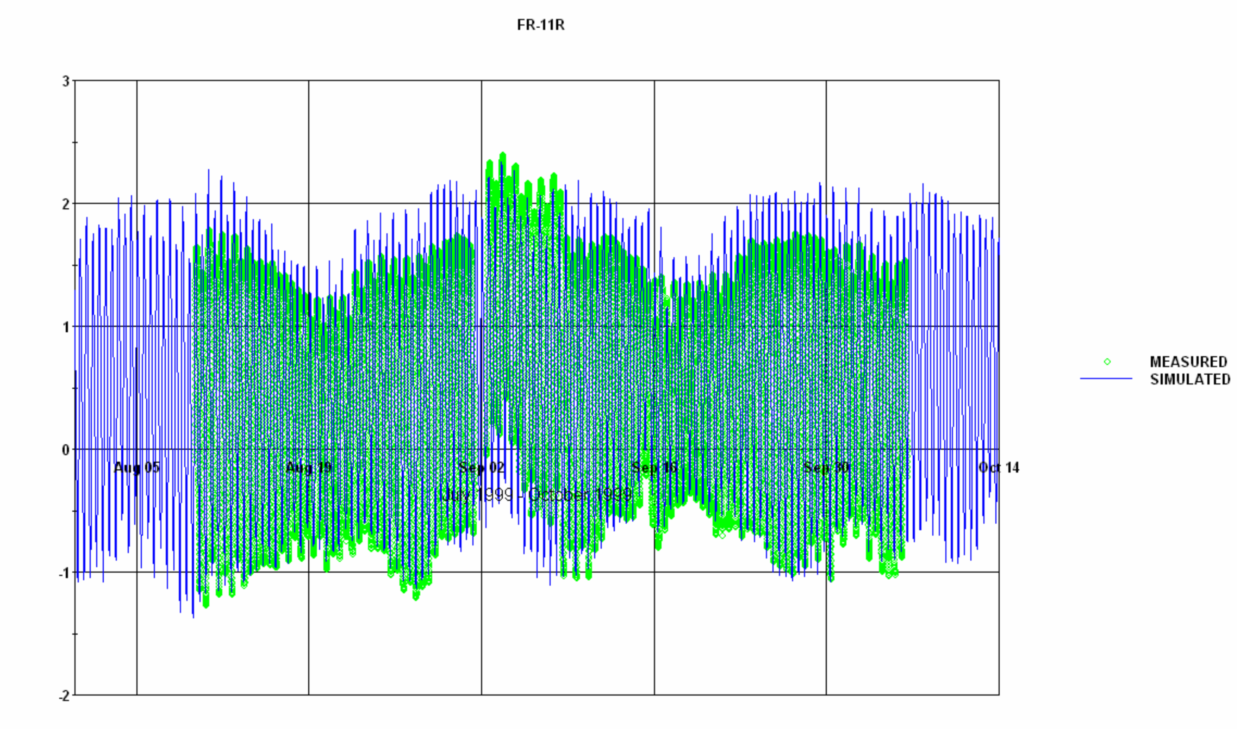


Figure B-11 Elevation (meters) Calibration at FR-11R for July 31 through October 13, 1999

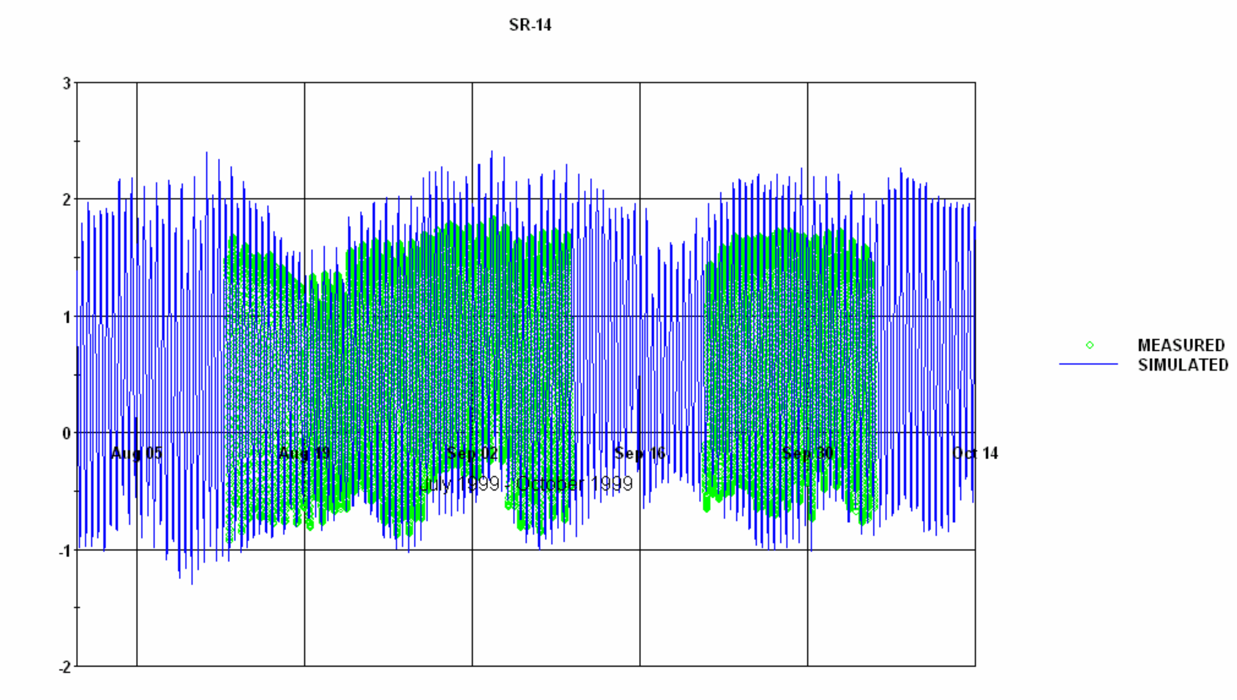


Figure B-12 Elevation (meters) Calibration at SR-14 for July 31 through October 13, 1999

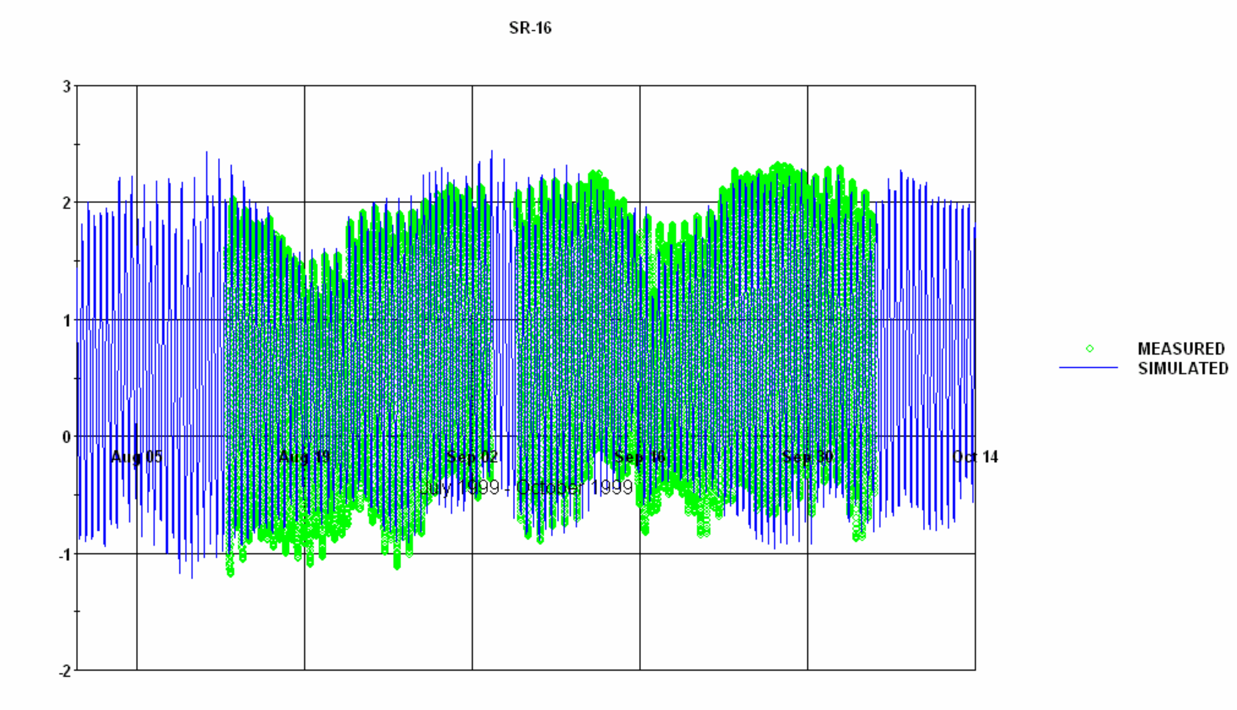


Figure B-13 Elevation (meters) Calibration at SR-16 for July 31 through October 13, 1999

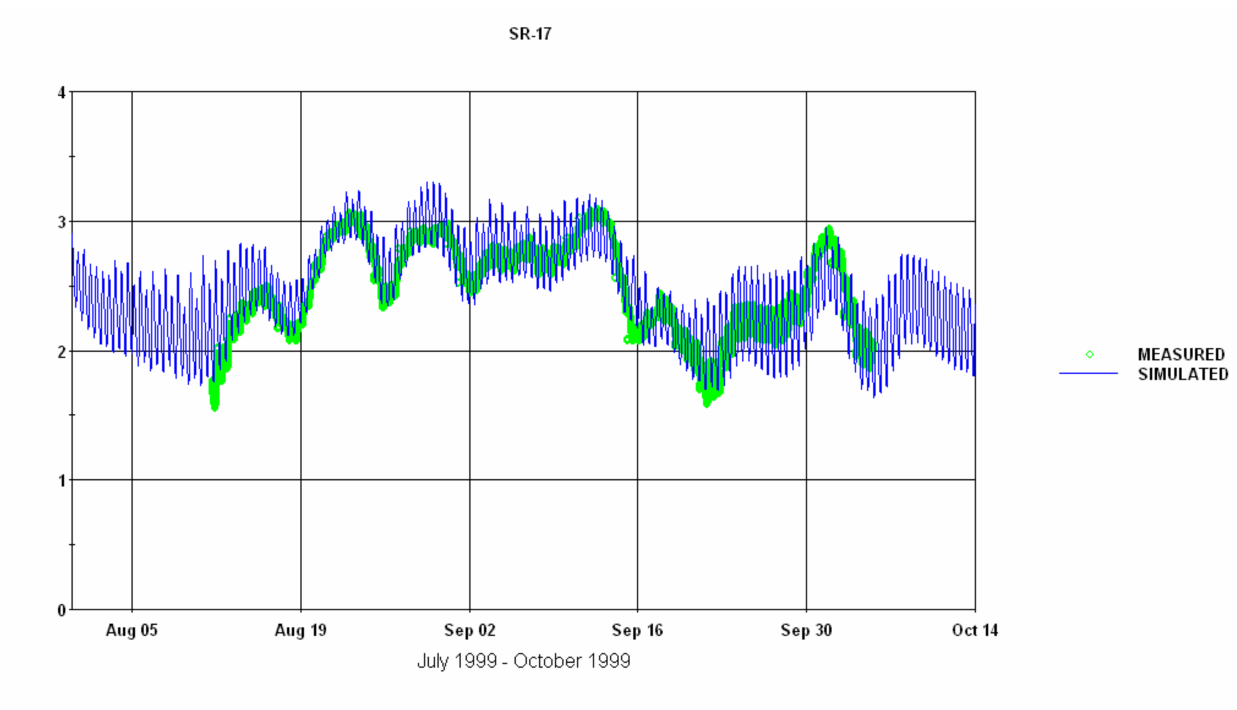


Figure B-14 Elevation (meters) Calibration at SR-17 for July 31 through October 13, 1999

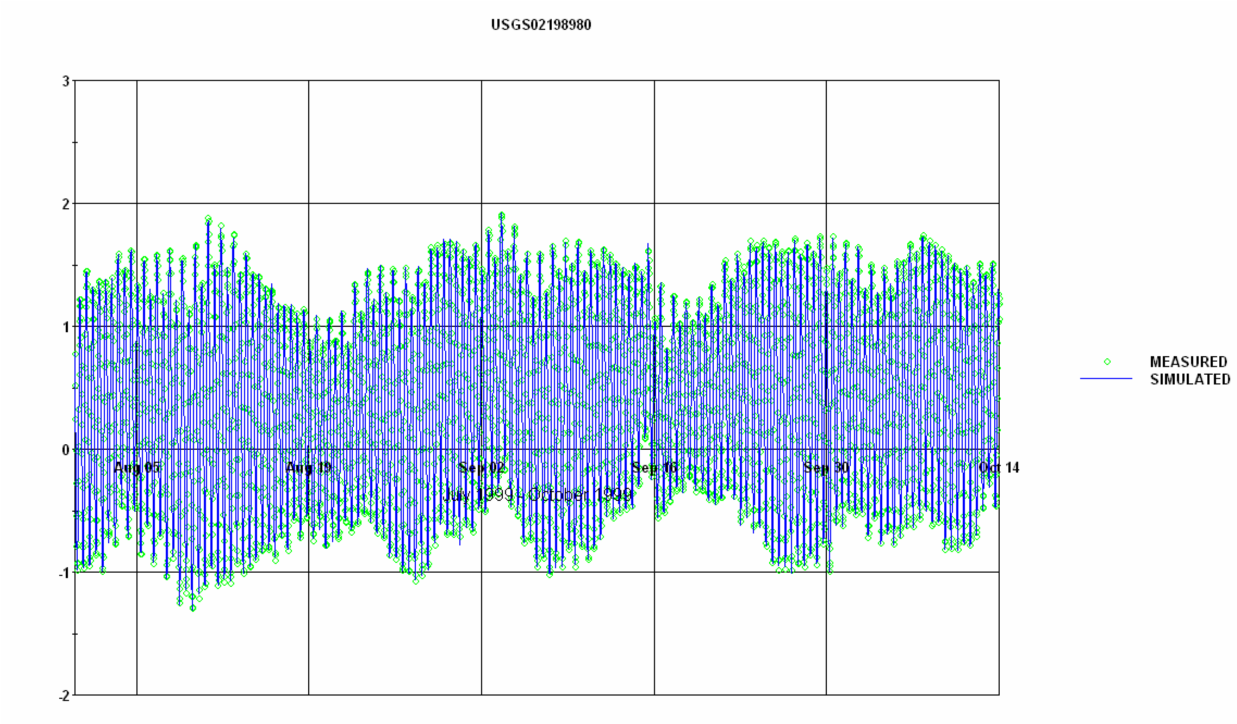


Figure B-15 Elevation (meters) Calibration at Ft. Pulaski for July 31 through October 13, 1999

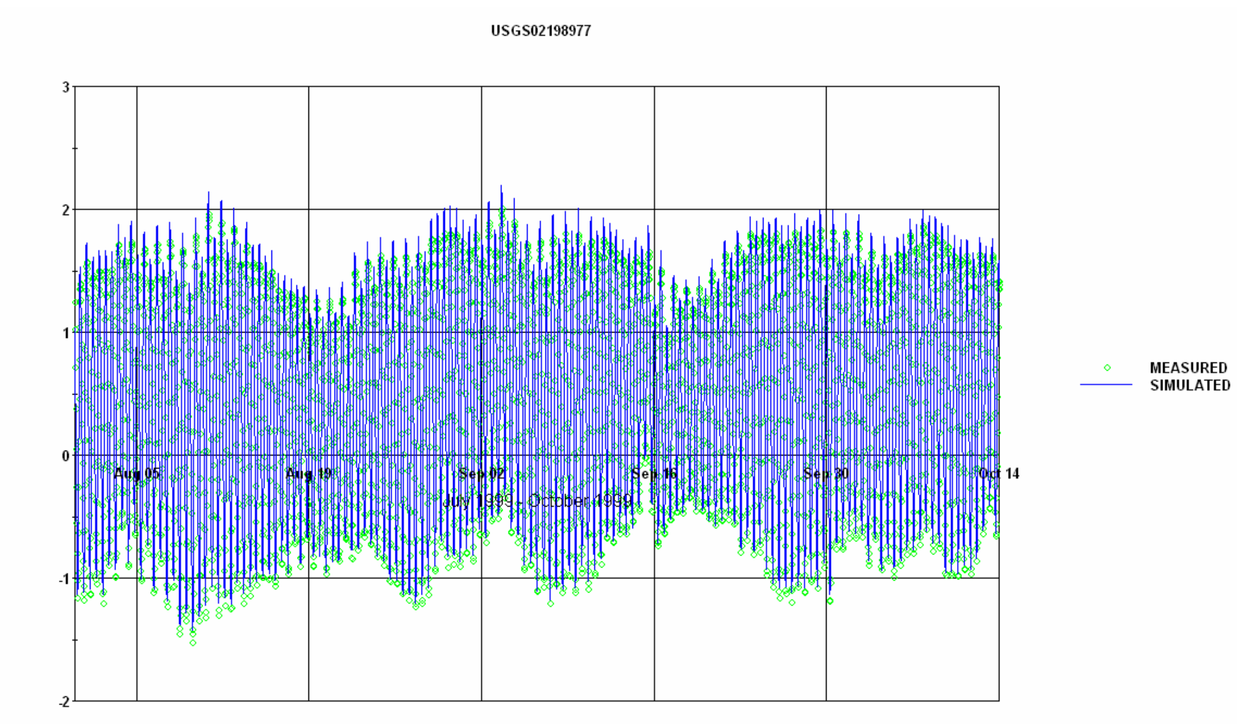


Figure B-16 Elevation (meters) Calibration at Broad St. for July 31 through October 13, 1999

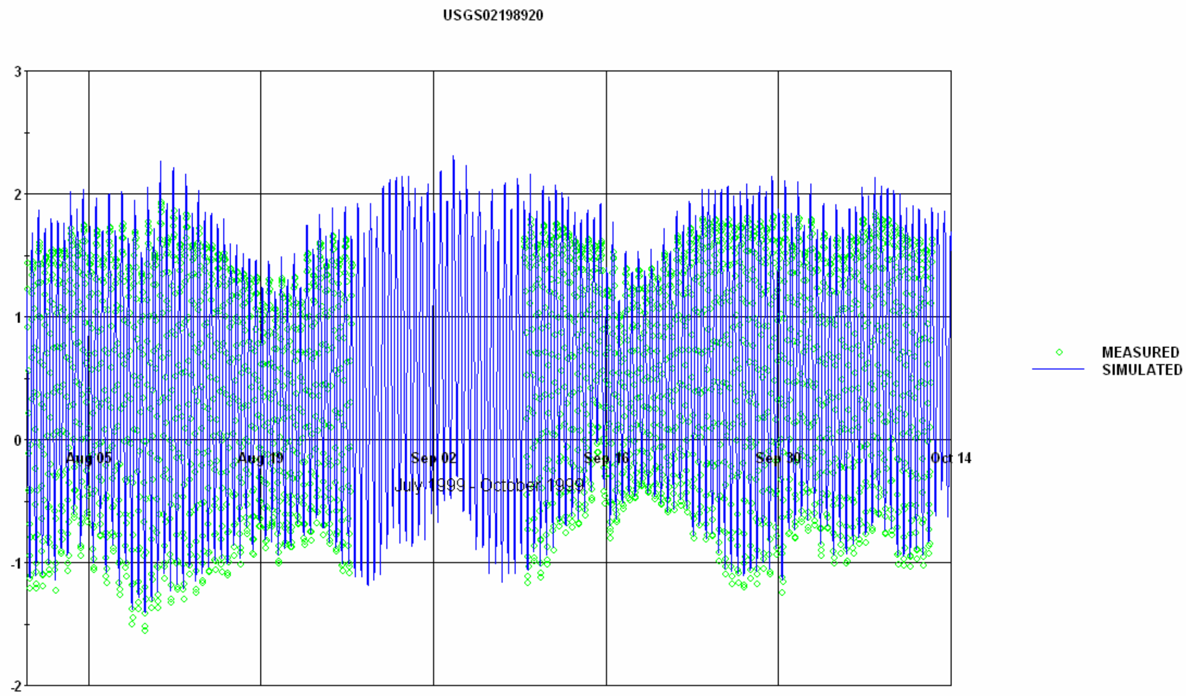


Figure B-17 Elevation (meters) Calibration at Houlihan Bridge for July 31 through October 13, 1999

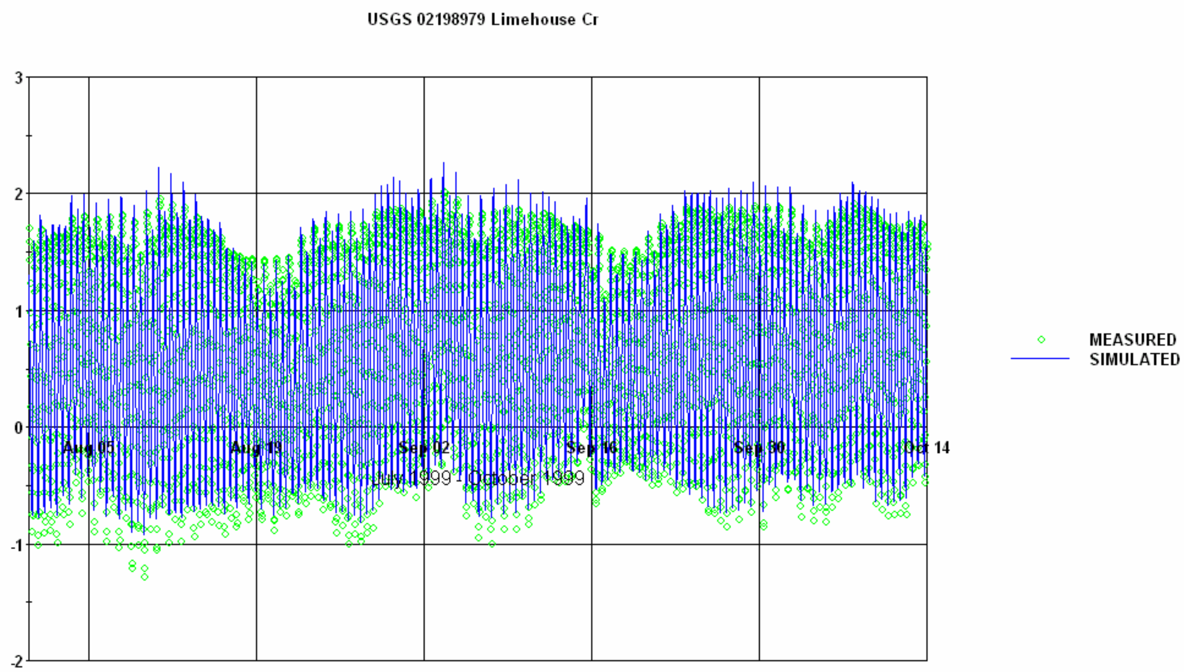


Figure B-18 Elevation (meters) Calibration at Limehouse Creek for July 31 through October 13, 1999

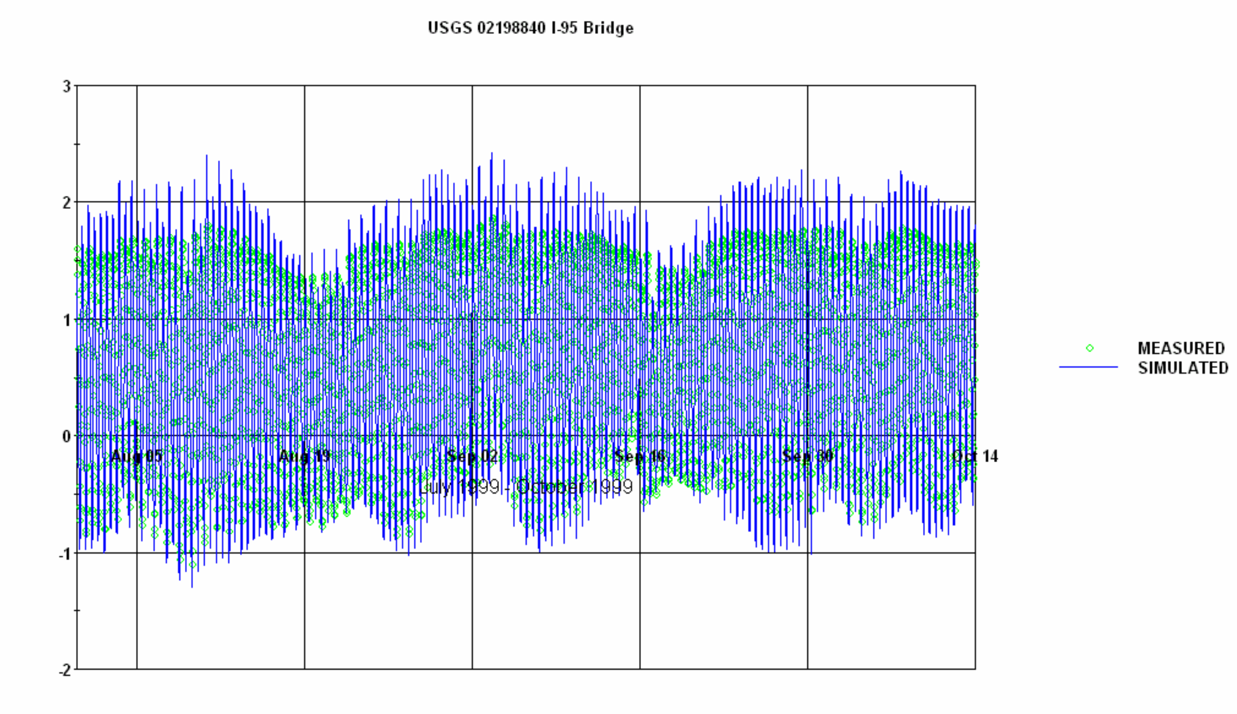


Figure B-19 Elevation (meters) Calibration at I-95 Bridge for July 31 through October 13, 1999

APPENDIX C 1997 WATER SURFACE ELEVATION COMPARISONS

Table C-1 Summary Percentiles for Elevation (meters) for July 10, 1997 through October 5, 1997

July 9 - October 6, 1997 [Julian Days 190-279]									
Stations	Measured			Simulated			Difference		
	5%	50%	95%	5%	50%	95%	5%	50%	95%
FR-02	-0.93	0.51	1.64	-0.95	0.36	1.53	0.02	0.15	0.11
SC-03	-1.00	0.41	1.55	-0.99	0.36	1.58	-0.01	0.05	-0.03
FR-04	-1.03	0.45	1.63	-1.02	0.36	1.66	-0.01	0.09	-0.02
BR-05	-1.00	0.52	1.57	-0.91	0.35	1.66	-0.08	0.17	-0.09
FR-06	-1.04	0.50	1.65	-1.04	0.36	1.73	0.00	0.13	-0.09
FR-08	-1.00	0.60	1.77	-1.07	0.37	1.84	0.07	0.22	-0.08
FR-09	-0.92	0.60	1.71	-1.06	0.43	1.88	0.13	0.18	-0.16
MR-10	-0.98	0.62	1.73	-1.03	0.41	1.83	0.05	0.21	-0.11
FR-11	-0.87	0.73	1.66	-1.06	0.47	1.95	0.19	0.26	-0.29
MR-12	-0.76	0.70	1.66	-0.63	0.57	1.79	-0.13	0.13	-0.13
LBR-13	-0.74	0.81	1.71	-0.14	0.55	1.65	-0.60	0.26	0.06
USGS02198980 (Ft Pulaski)	-0.93	0.37	1.43	-0.93	0.32	1.43	0.00	0.04	0.00
USGS02198977 (Broad St)	-1.03	0.51	1.60	-1.01	0.37	1.71	-0.01	0.13	-0.11
USGS02198920 (Houlihan Bridge)	-0.98	0.61	1.72	-1.03	0.42	1.85	0.05	0.19	-0.13
USGS02198979 (Limehouse Creek)	-0.73	0.80	1.72	-0.65	0.38	1.71	-0.08	0.42	0.01
USGS02198840 (I-95)	-0.59	0.78	1.65	-0.83	0.54	1.92	0.24	0.24	-0.28

Table C-2 Summary Statistics for Elevation (meters) for July 10, 1997 through October 5, 1997

July 9 - October 6, 1997 [Julian Days 190-279]									
Station	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	17704	-0.11	0.13	0.16	0.34	0.82	0.45	0.84	0.98
SC-03	16879	-0.01	0.10	0.16	0.34	0.85	0.34	0.84	0.97
FR-04	14958	-0.03	0.09	0.12	0.35	0.88	0.38	0.88	0.98
BR-05	15727	-0.04	0.14	0.17	0.37	0.86	0.42	0.87	0.96
FR-06	19083	-0.04	0.11	0.13	0.37	0.92	0.41	0.90	0.98
FR-08	21273	-0.11	0.15	0.19	0.40	0.96	0.51	0.93	0.97
FR-09	19929	-0.07	0.18	0.24	0.44	0.97	0.51	0.89	0.95
MR-10	17766	-0.09	0.22	0.29	0.42	0.93	0.51	0.91	0.91
FR-11	12058	-0.11	0.25	0.30	0.47	0.98	0.59	0.86	0.93
MR-12	22750	-0.02	0.28	0.37	0.57	0.79	0.59	0.83	0.81
LBR-13	16082	-0.02	0.35	0.42	0.64	0.59	0.66	0.84	0.79
USGS02198980 (Ft Pulaski)	4273	-0.02	0.05	0.06	0.30	0.78	0.32	0.78	0.99
USGS02198977 (Broad St)	4273	-0.03	0.10	0.13	0.38	0.91	0.41	0.89	0.98
USGS02198920 (Houlihan Bridge)	4273	-0.08	0.14	0.18	0.43	0.95	0.51	0.92	0.97
USGS02198979 (Limehouse Creek)	4273	-0.19	0.26	0.31	0.46	0.78	0.65	0.84	0.91
USGS02198840 (I-95)	4273	-0.11	0.25	0.31	0.55	0.91	0.66	0.77	0.91

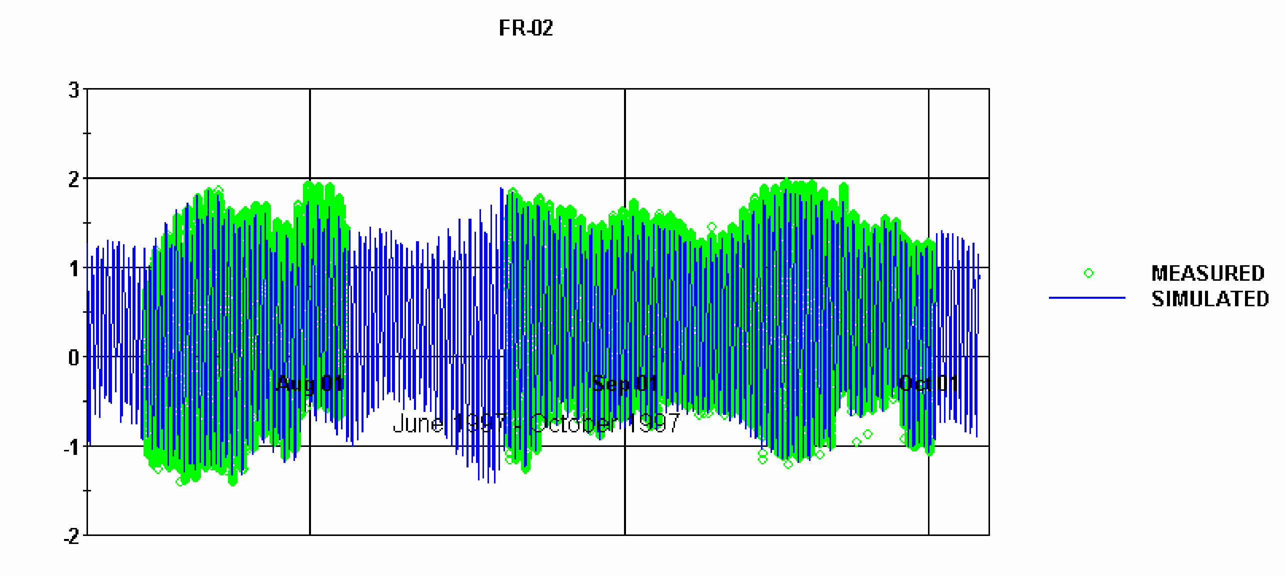


Figure C-2 Elevation (meters) Comparison at FR-02 for July 10, 1997 through October 5, 1997

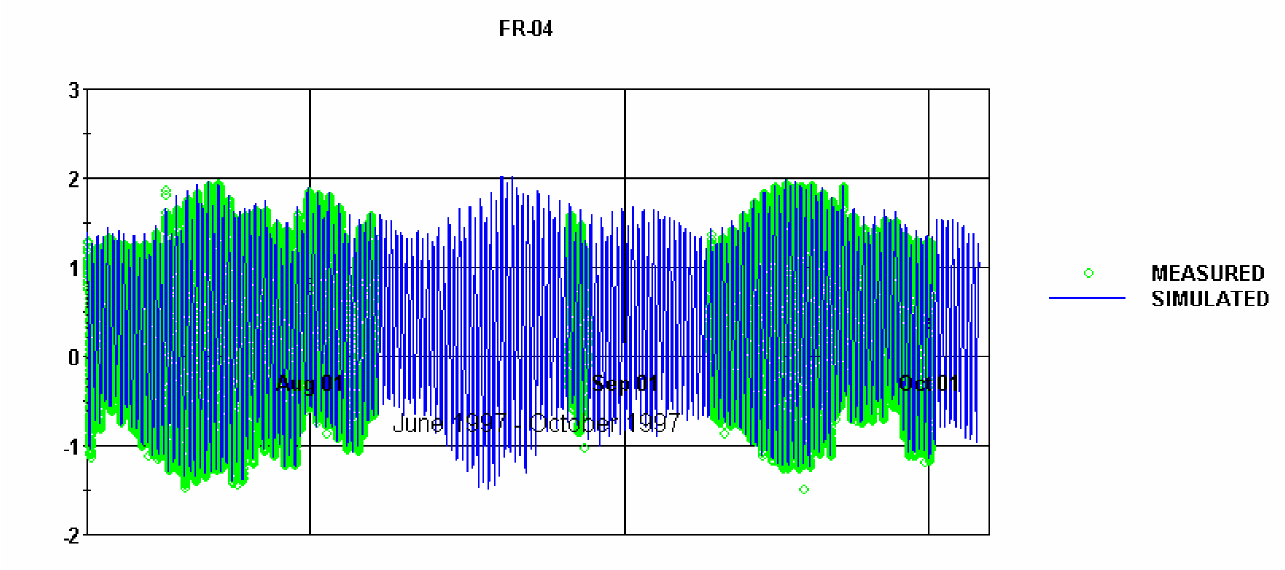


Figure C-4 Elevation (meters) Comparison at FR-04 for July 10, 1997 through October 5, 1997

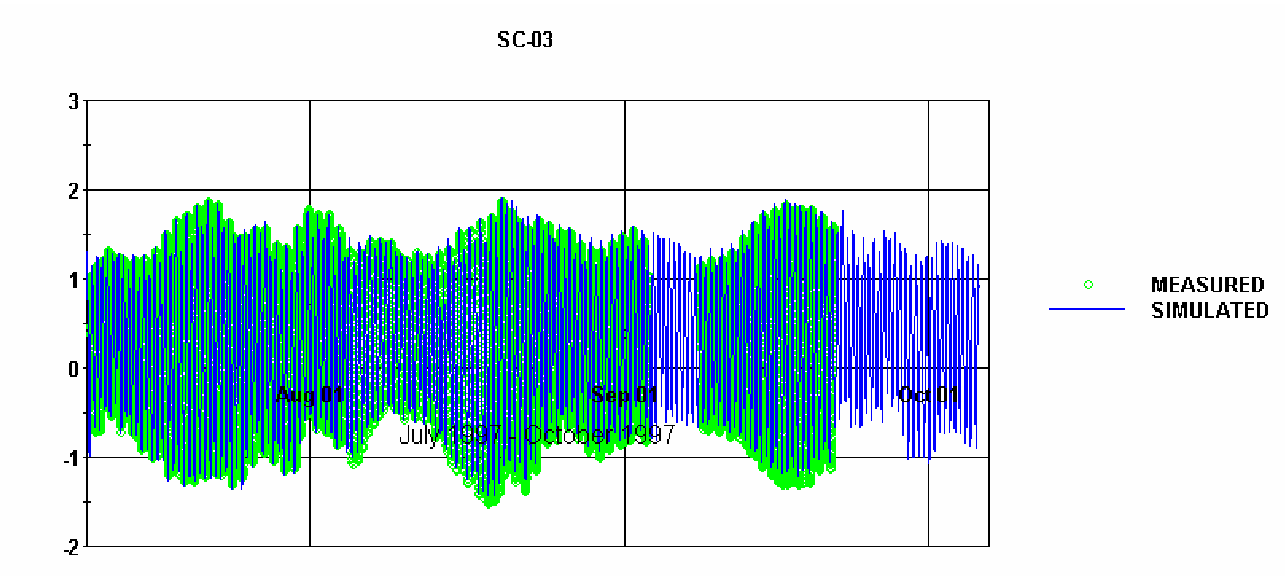


Figure C-5 Elevation (meters) Comparison at SC-03 for July 10, 1997 through October 5, 1997

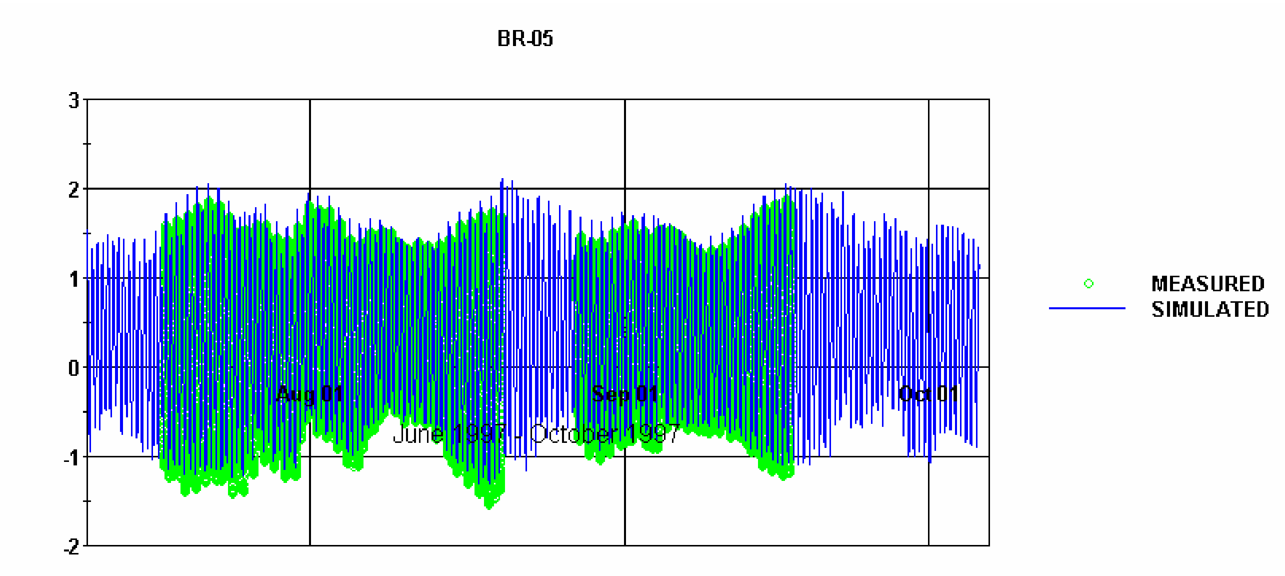


Figure C-6 Elevation (meters) Comparison at BR-05 for July 10, 1997 through October 5, 1997

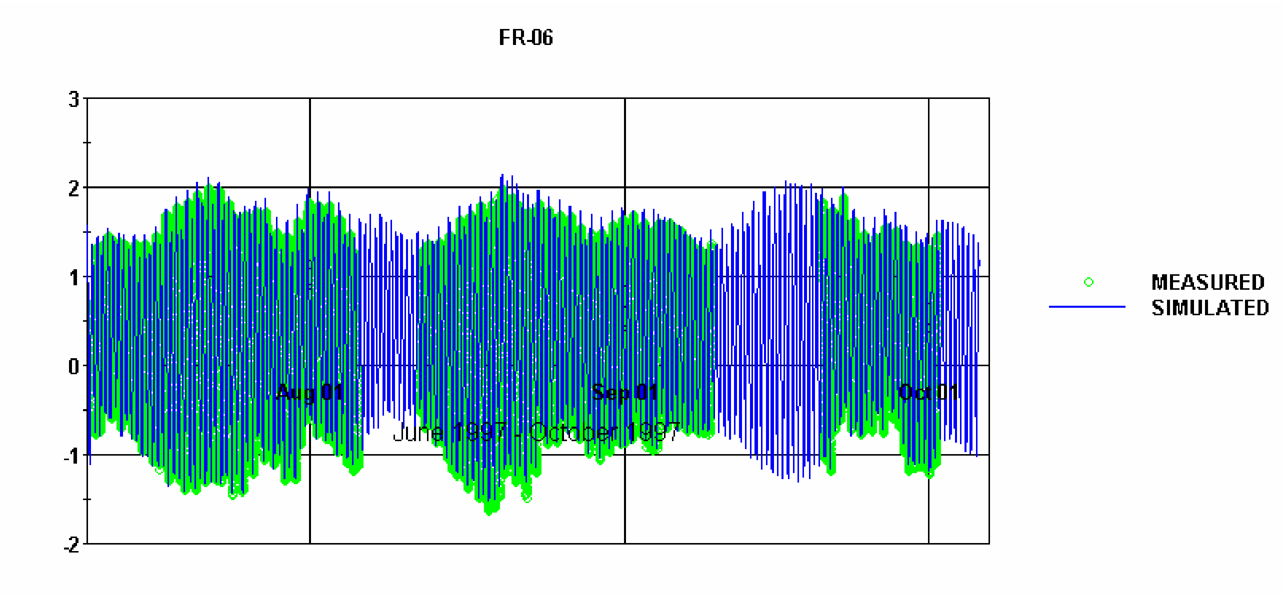


Figure C-7 Elevation (meters) Comparison at FR-06 for July 10, 1997 through October 5, 1997

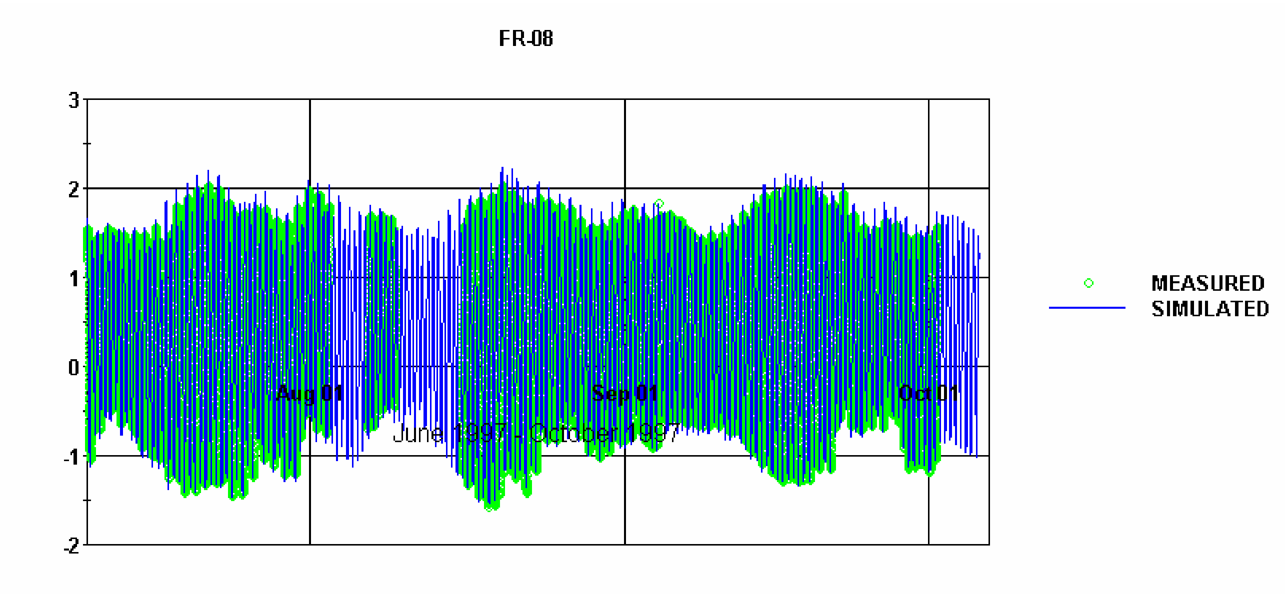


Figure C-9 Elevation (meters) Comparison at FR-08 for July 10, 1997 through October 5, 1997

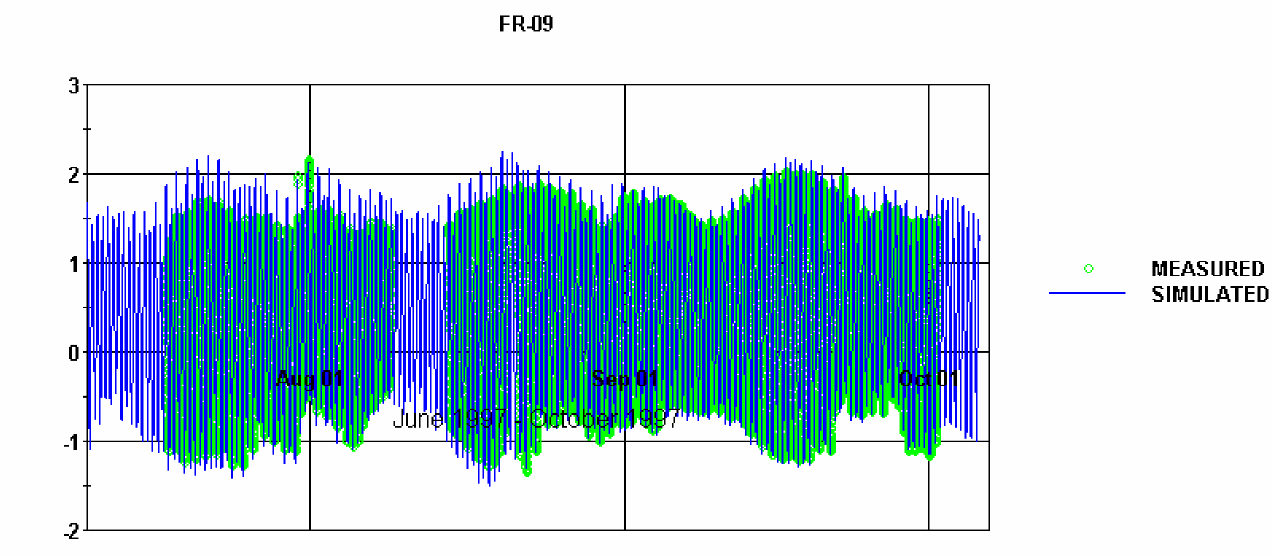


Figure C-10 Elevation (meters) Comparison at FR-09 for July 10, 1997 through October 5, 1997

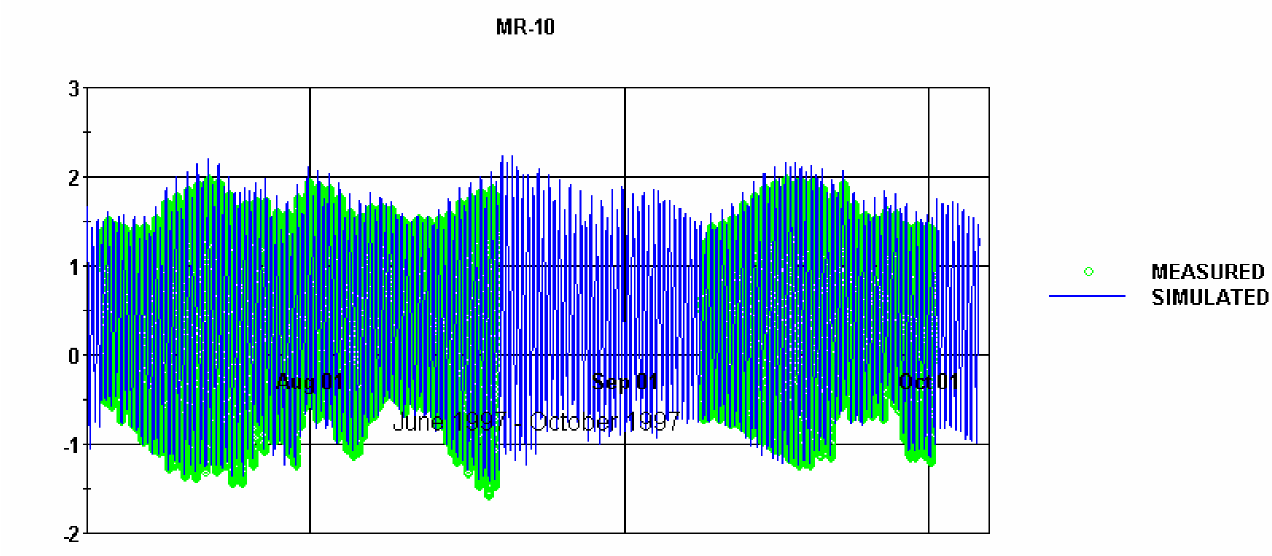


Figure C-11 Elevation (meters) Comparison at MR-10 for July 10, 1997 through October 5, 1997

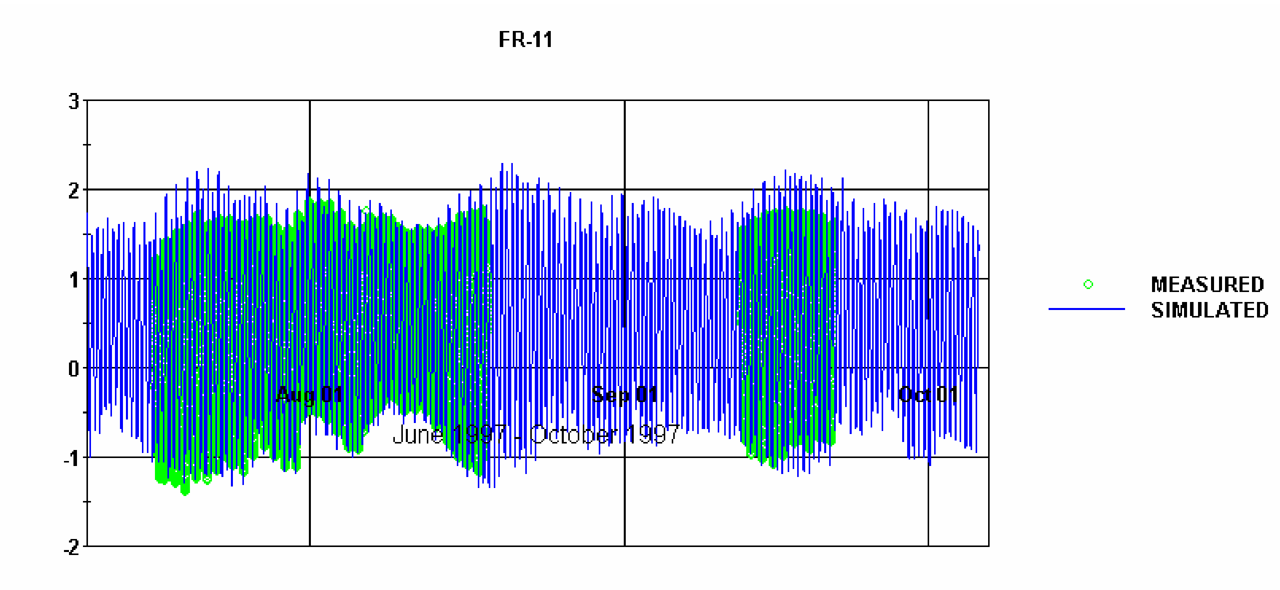


Figure C-12 Elevation (meters) Comparison at FR-11 for July 10, 1997 through October 5, 1997

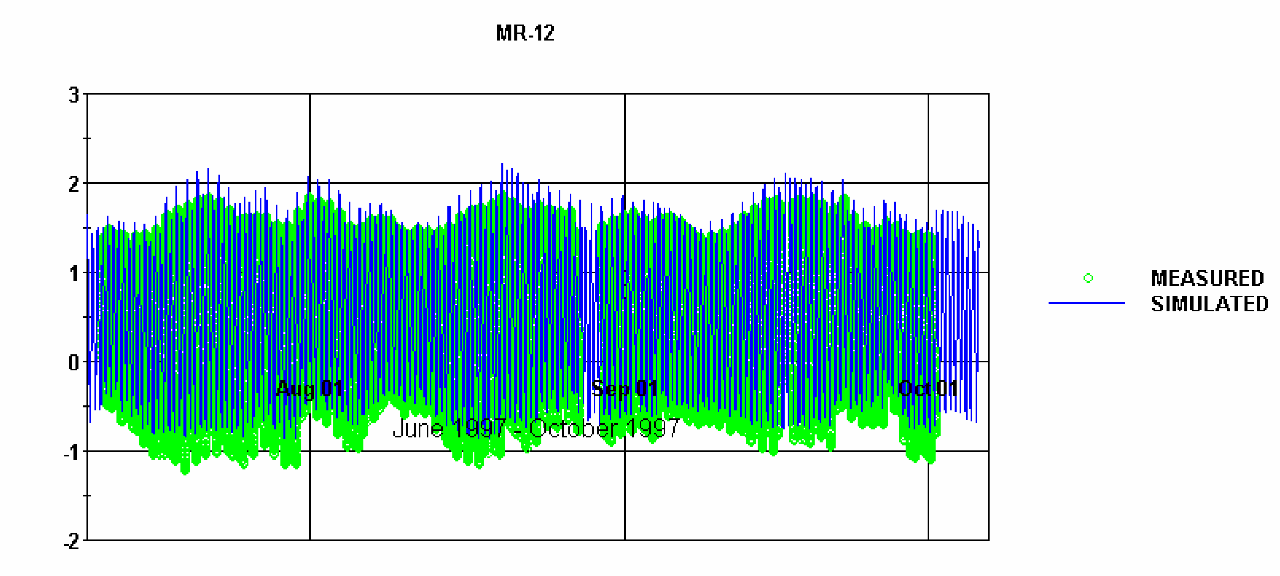


Figure C-13 Elevation (meters) Comparison at MR-12 for July 10, 1997 through October 5, 1997

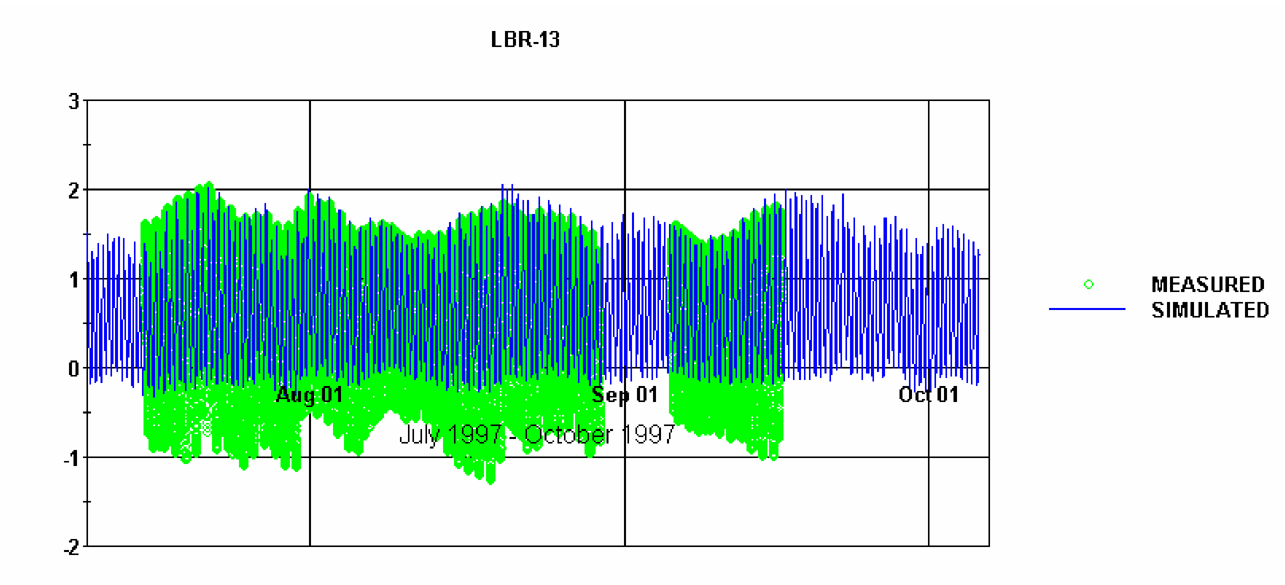


Figure C-14 Elevation (meters) Comparison at LBR-13 for July 10, 1997 through October 5, 1997

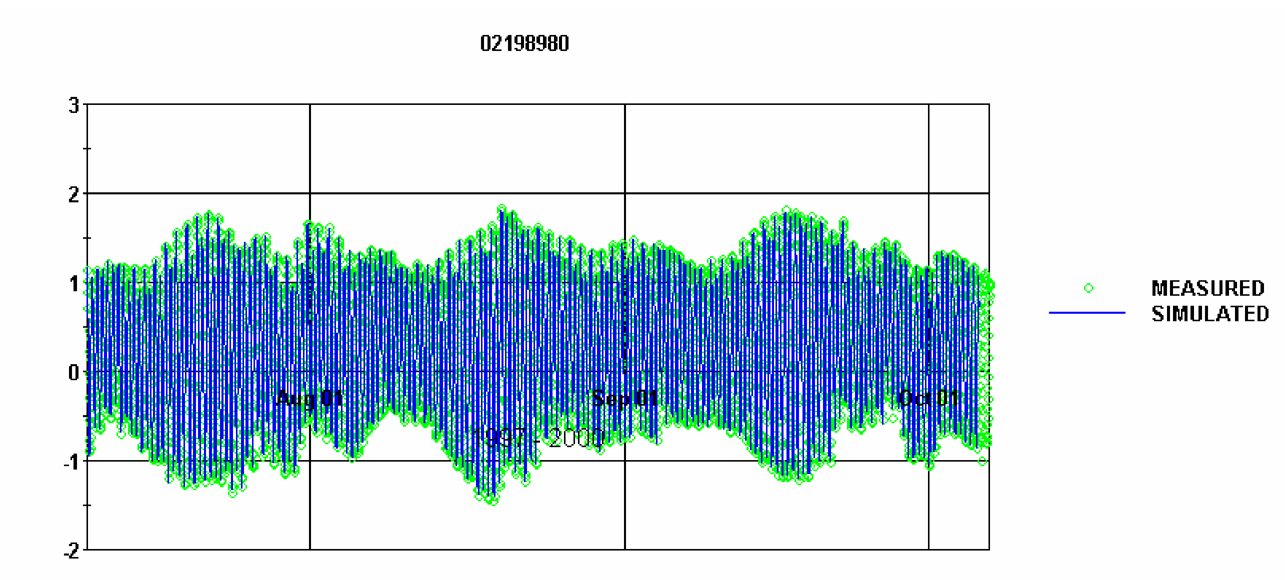


Figure C-15 Elevation (meters) Comparison at Ft. Pulaski for July 10, 1997 through October 5, 1997

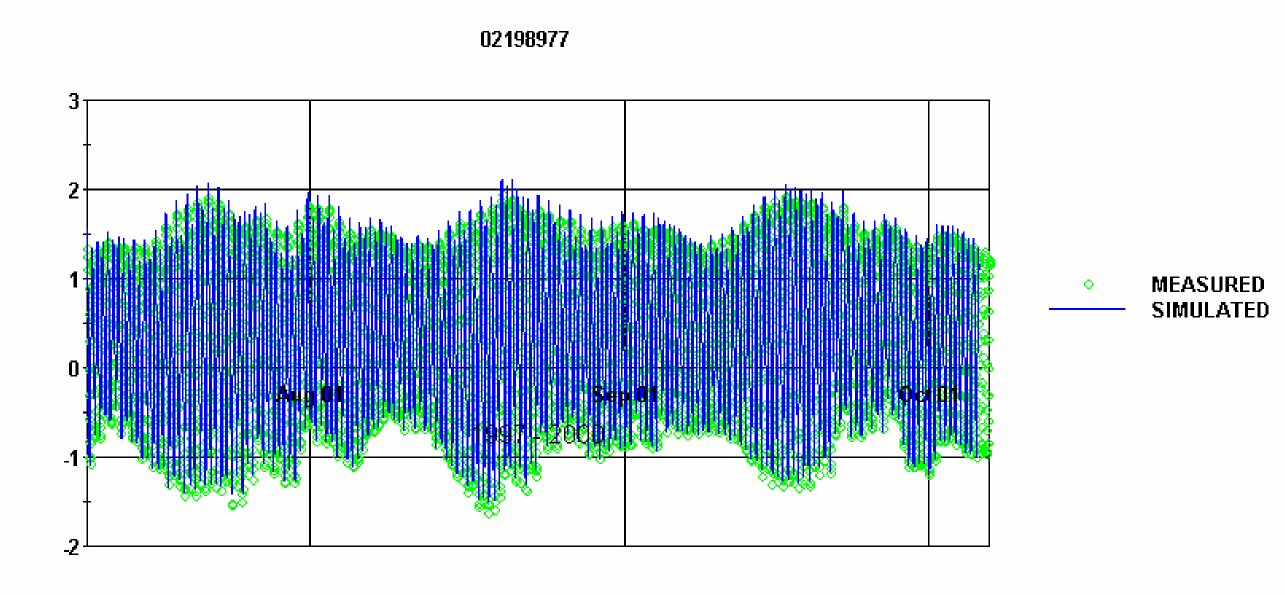


Figure C-16 Elevation (meters) Comparison at Broad St. for July 10, 1997 through October 5, 1997

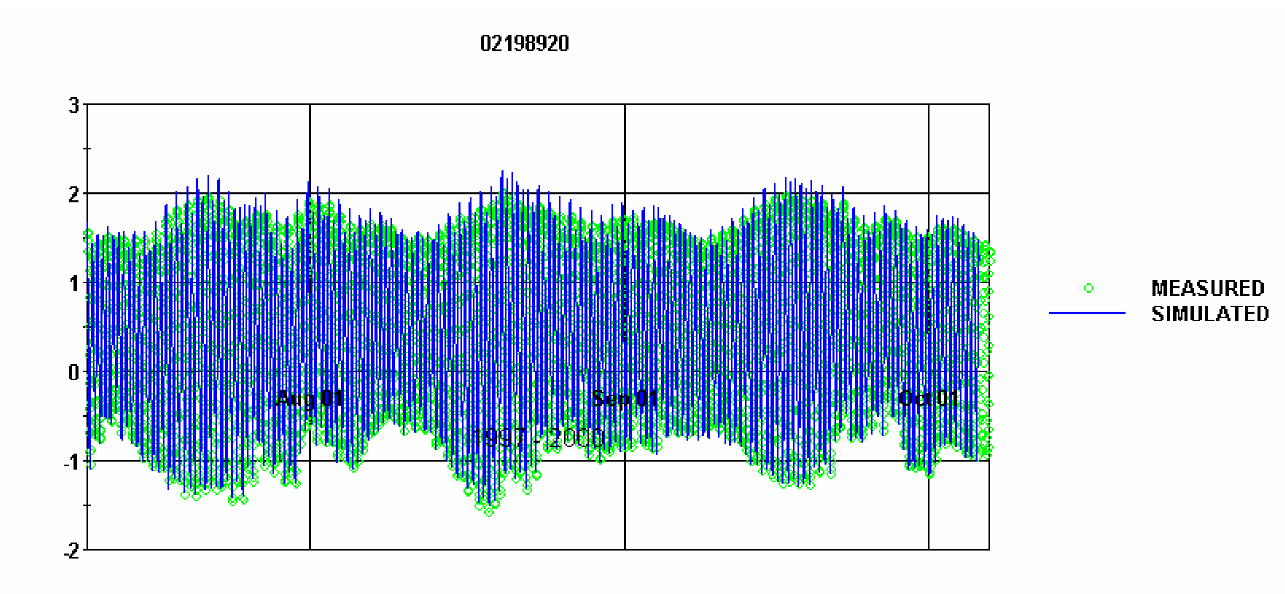


Figure C-17 Elevation (meters) Comparison at Houlihan Bridge for July 10, 1997 through October 5, 1997

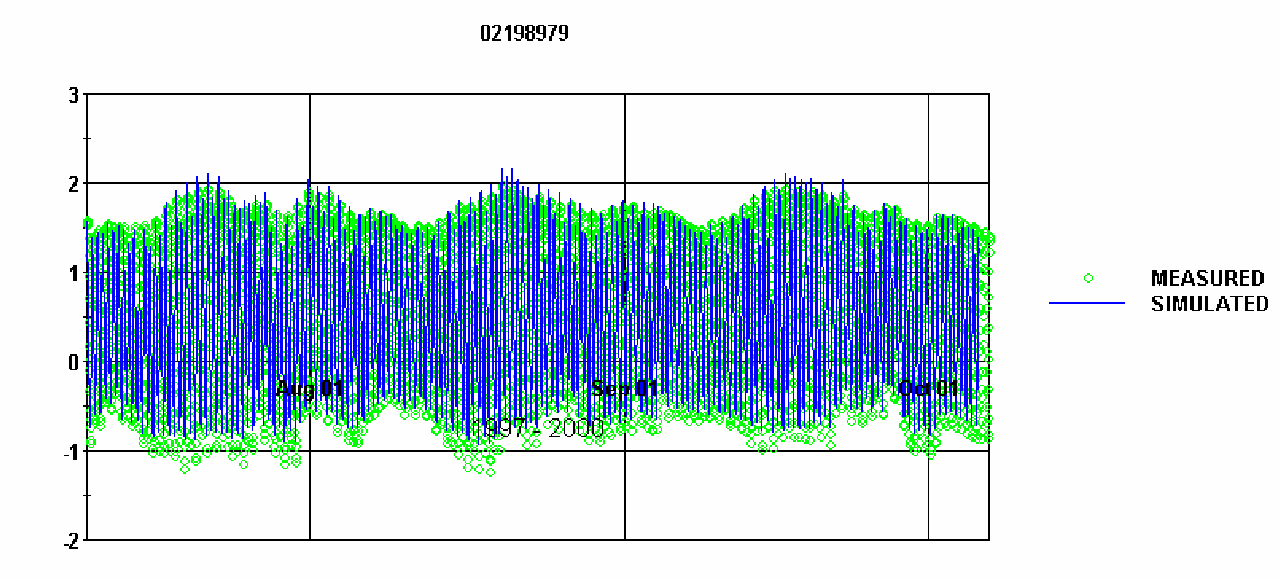


Figure C-18 Elevation (meters) Comparison at Limehouse Creek for July 10, 1997 through October 5, 1997

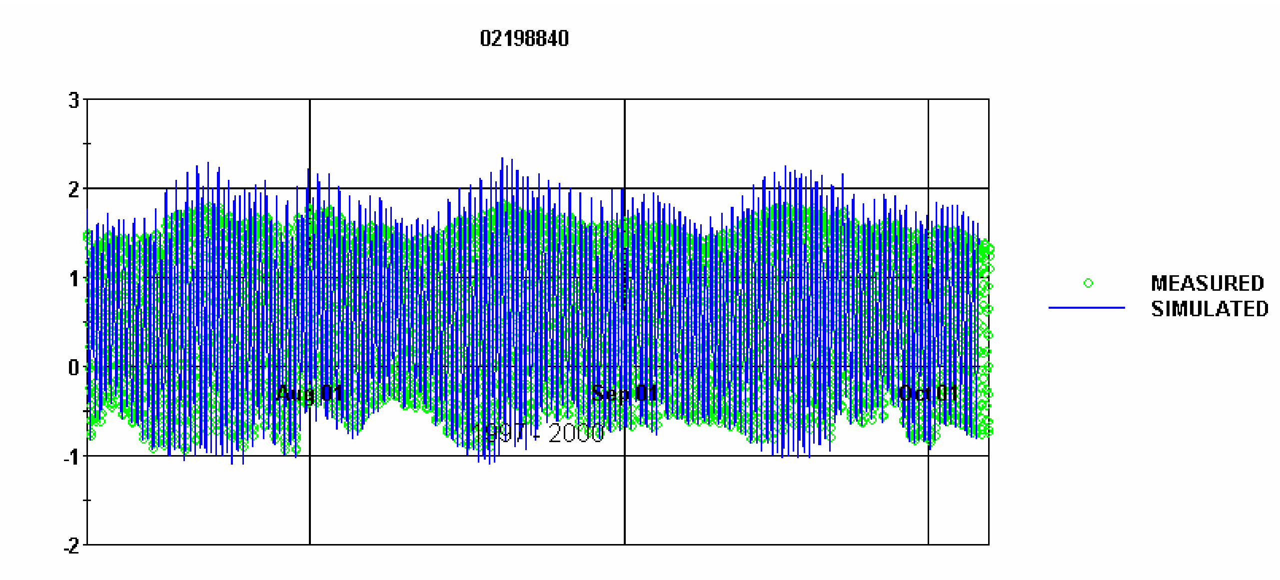


Figure C-19 Elevation (meters) Comparison at I-95 Bridge for July 10, 1997 through October 5, 1997

APPENDIX D 1999 CURRENTS COMPARISONS

Table D-1 1999 Currents (m/s) Statistical Comparisons for July 31, 1999 through October 13, 1999

July 31 - October 14, 1999 [Julian Days 212 - 287]									
Stations	Depth	Measured			Simulated			Differences	
		5%	50%	95%	5%	50%	95%	5%	95%
FR-04	S	-0.98	0.13	0.87	-1.08	-0.51	0.85	-10%	2%
FR-04	B	-0.74	0.18	0.73	-0.33	0.09	0.67	56%	8%
FR-06	S	-1.03	-0.15	0.63	-0.99	-0.53	0.74	4%	-18%
FR-06	B	-0.61	0.06	0.54	-0.59	-0.10	0.90	3%	-67%

S = Surface

B = Bottom

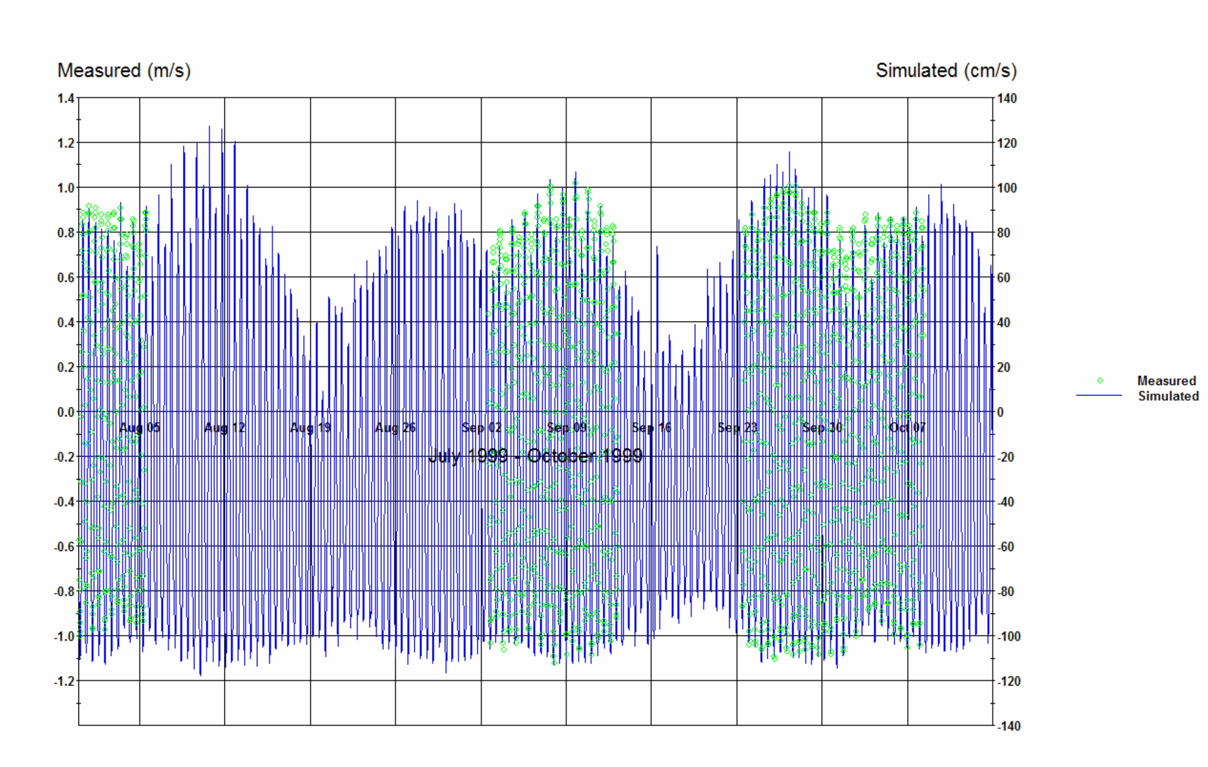


Figure D-1 Currents Comparison at FR-04 Surface for July 31, 1999 through October 14, 1999

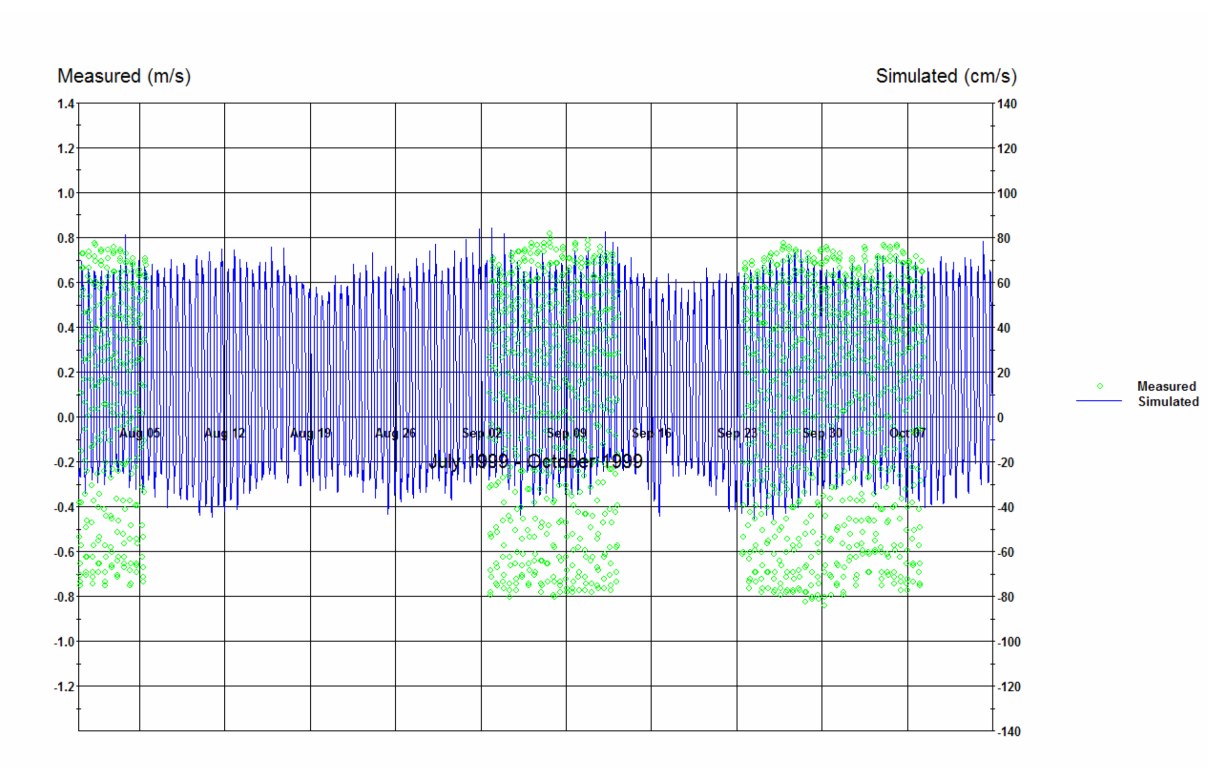


Figure D-2 Currents Comparison at FR-04 Bottom for July 31, 1999 through October 14, 1999

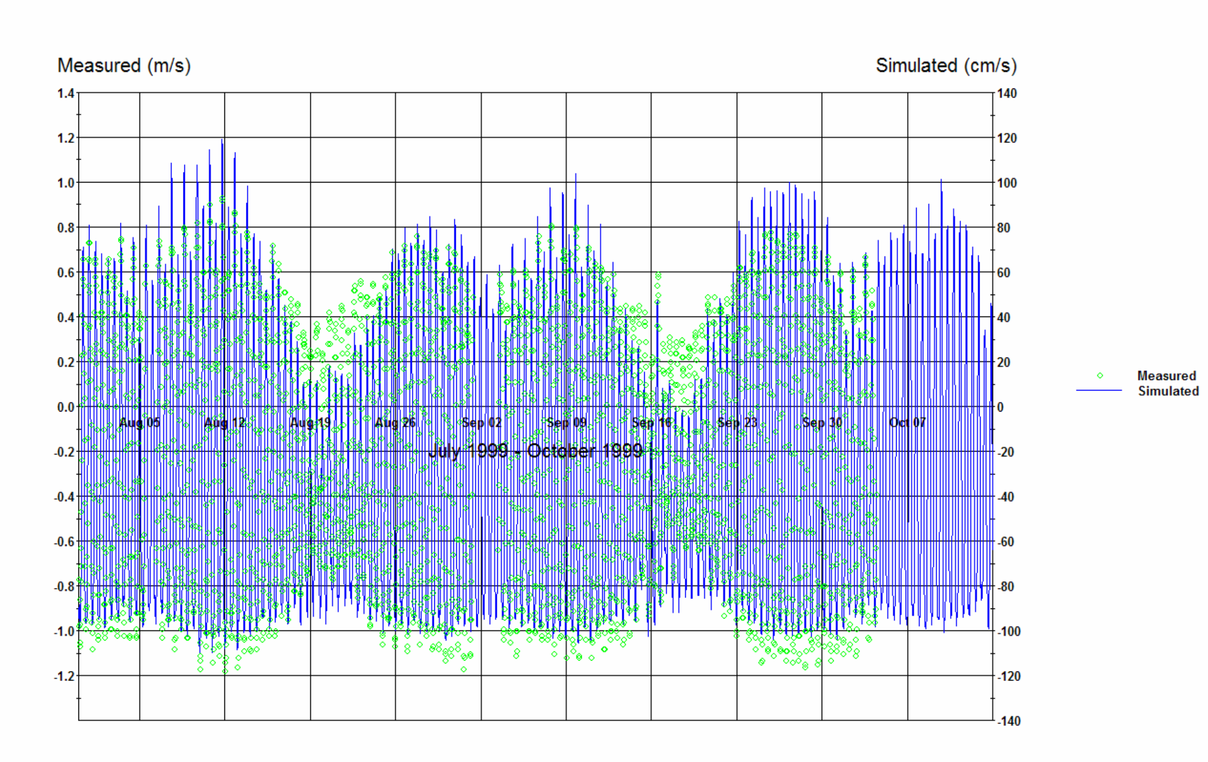


Figure D-3 Currents Comparison at FR-06 Surface for July 31, 1999 through October 14, 1999

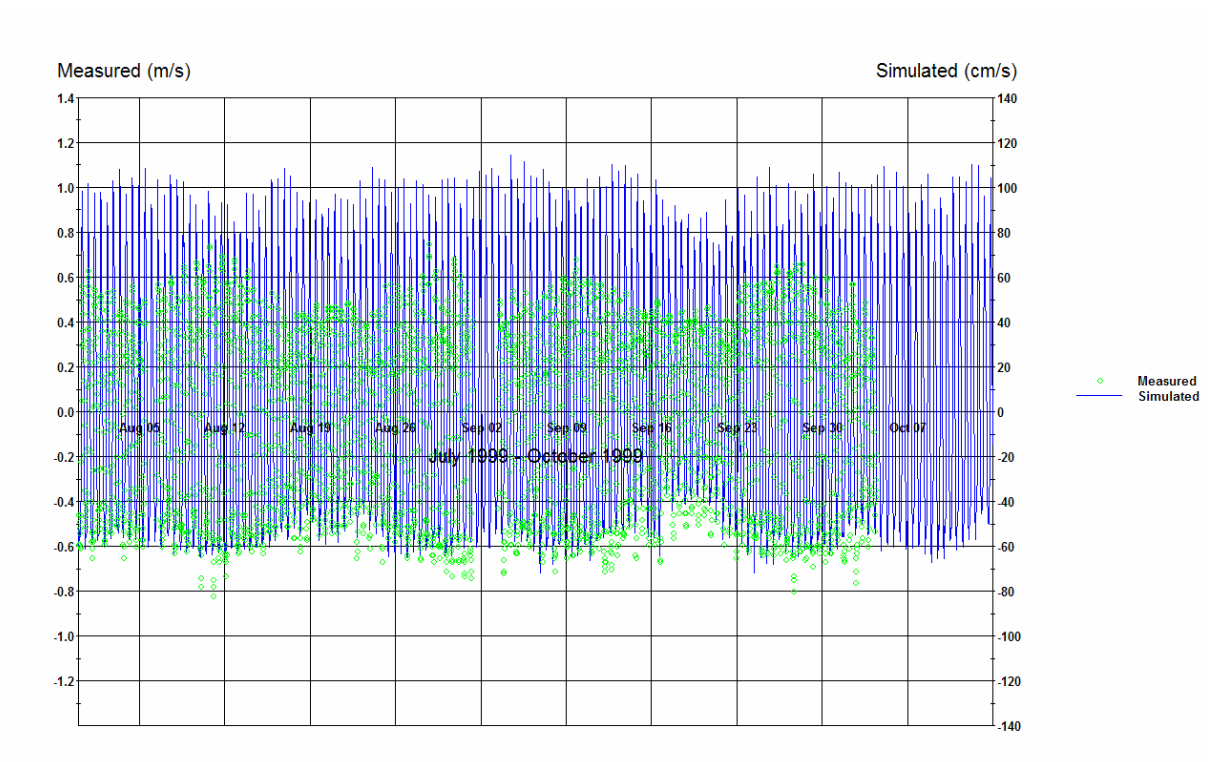


Figure D-4 Currents Comparison at FR-06 Bottom for July 31, 1999 through October 14, 1999

2-Week Currents Plots

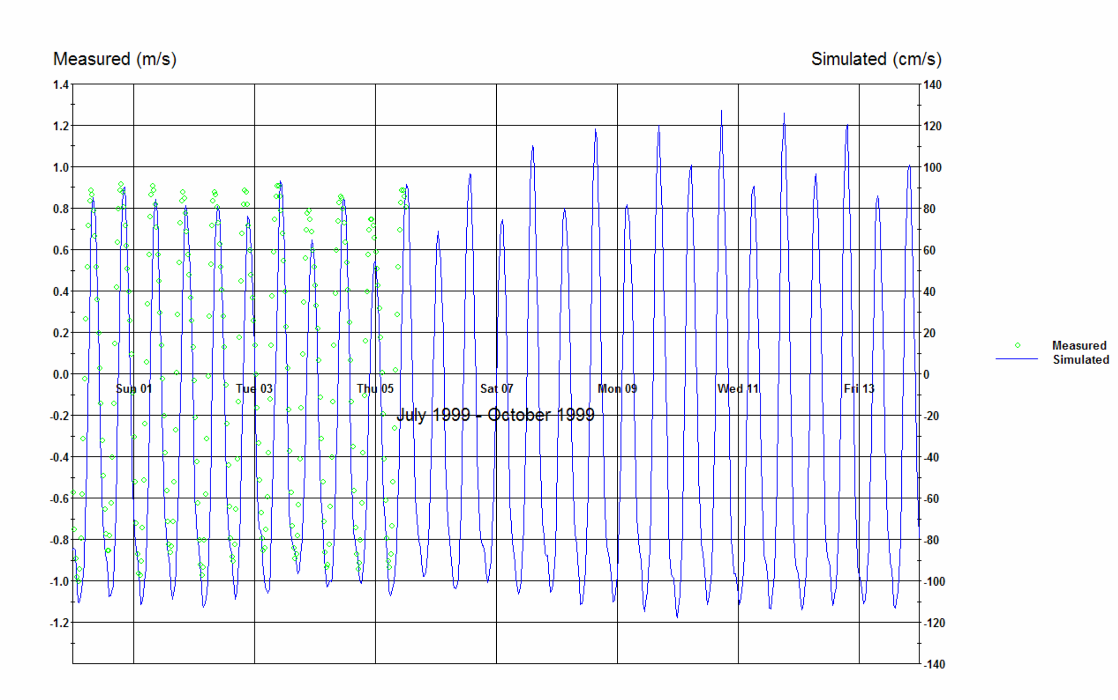


Figure D-5 Currents Comparison at FR-04 Surface for July 31, 1999 through August 14, 1999

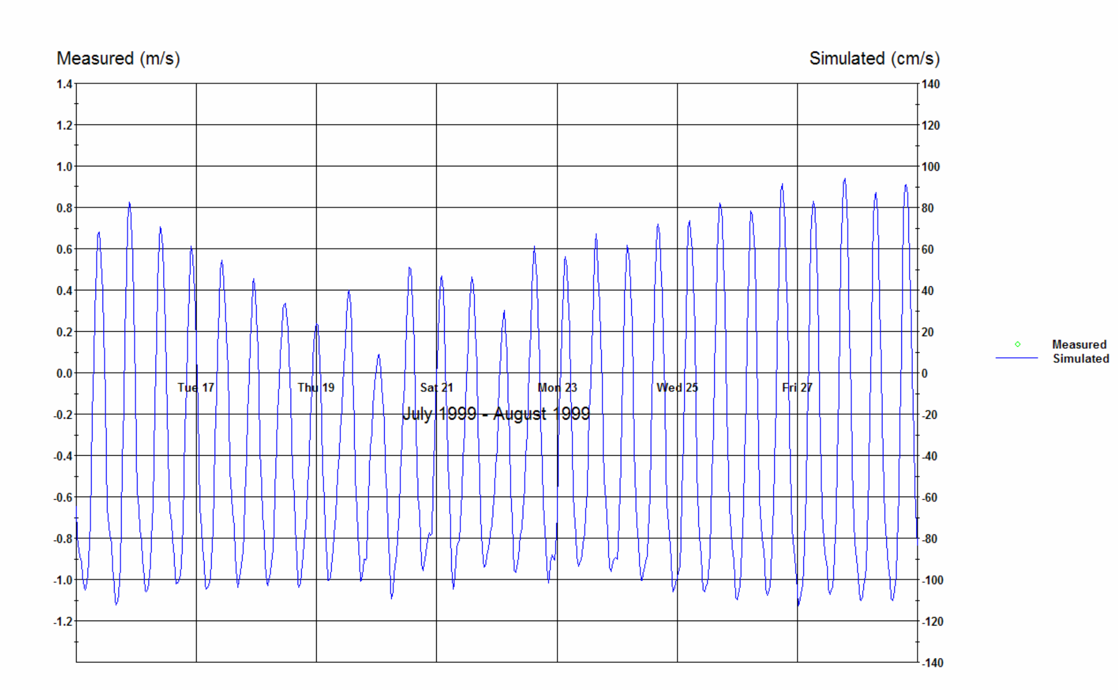


Figure D-6 Currents Comparison at FR-04 Surface for August 15, 1999 through August 29, 1999

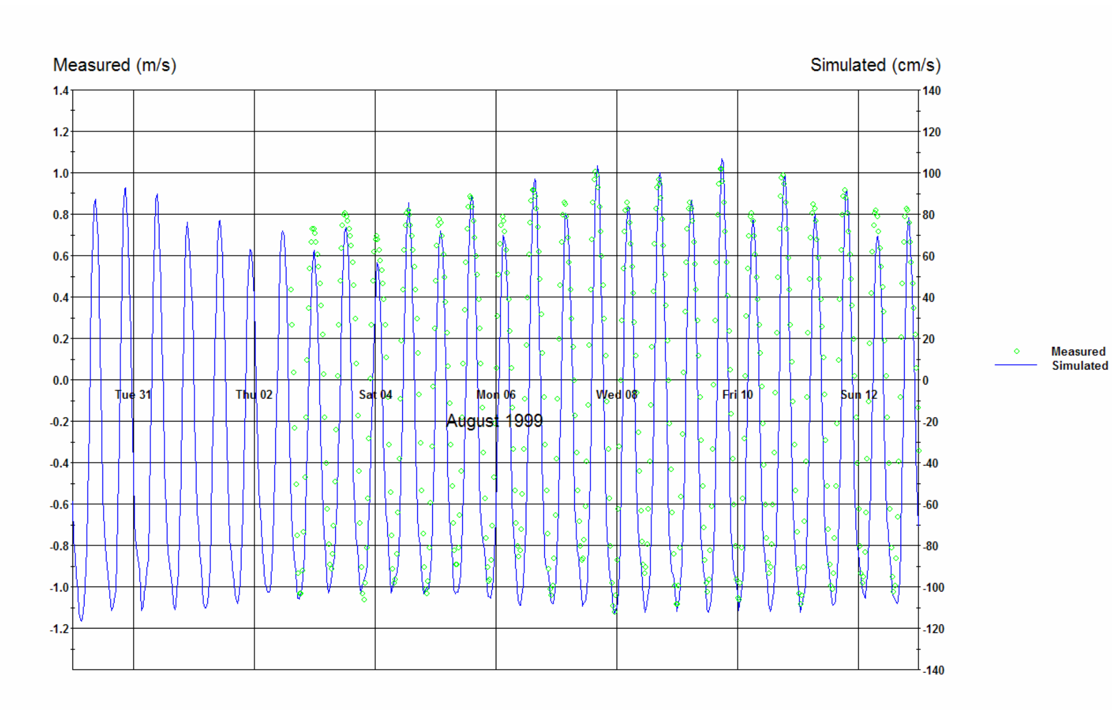


Figure D-7 Currents Comparison at FR-04 Surface for August 30, 1999 through September 13, 1999

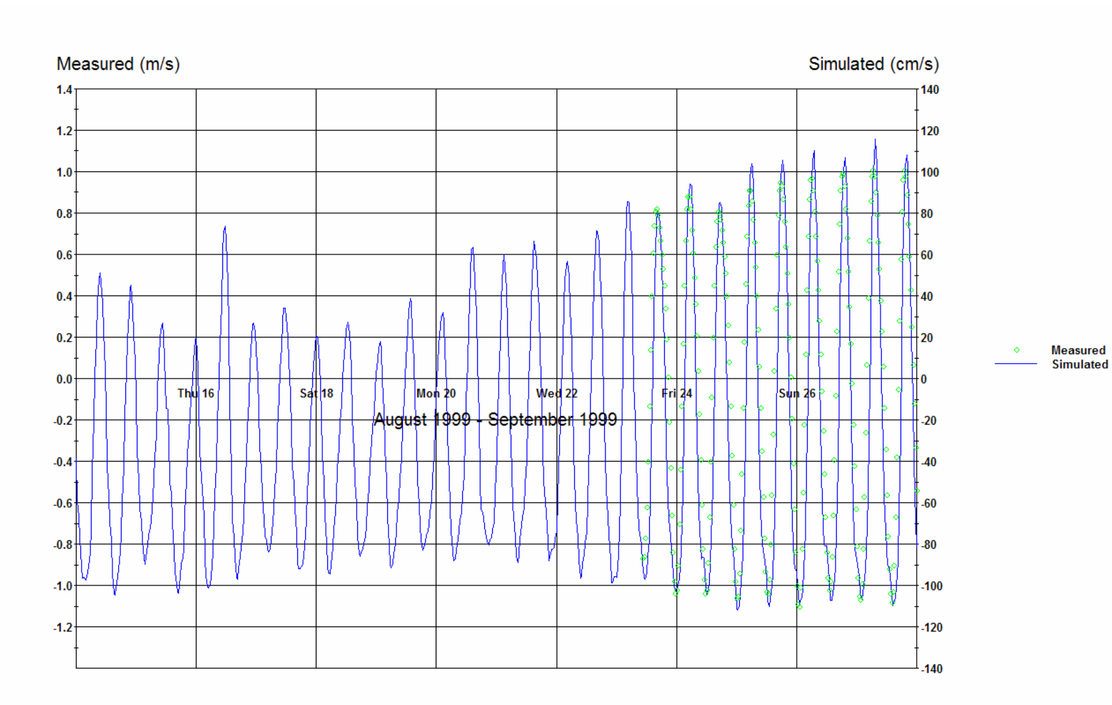


Figure D-8 Currents Comparison at FR-04 Surface for September 14, 1999 through September 28, 1999

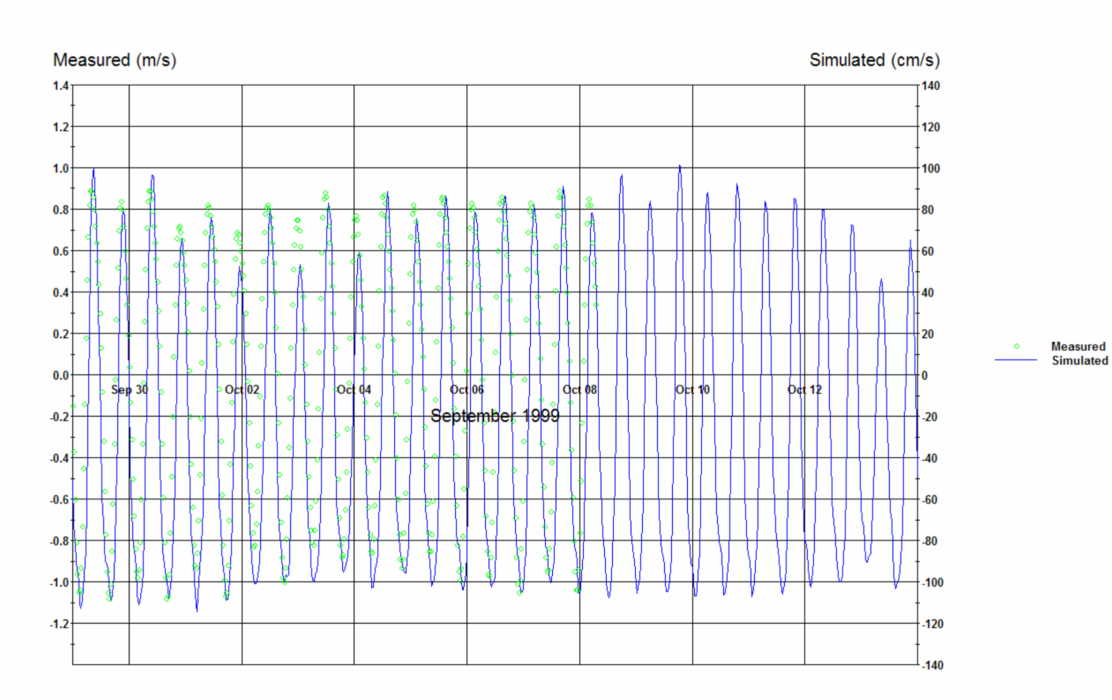


Figure D-9 Currents Comparison at FR-04 Surface for September 29, 1999 through October 14, 1999

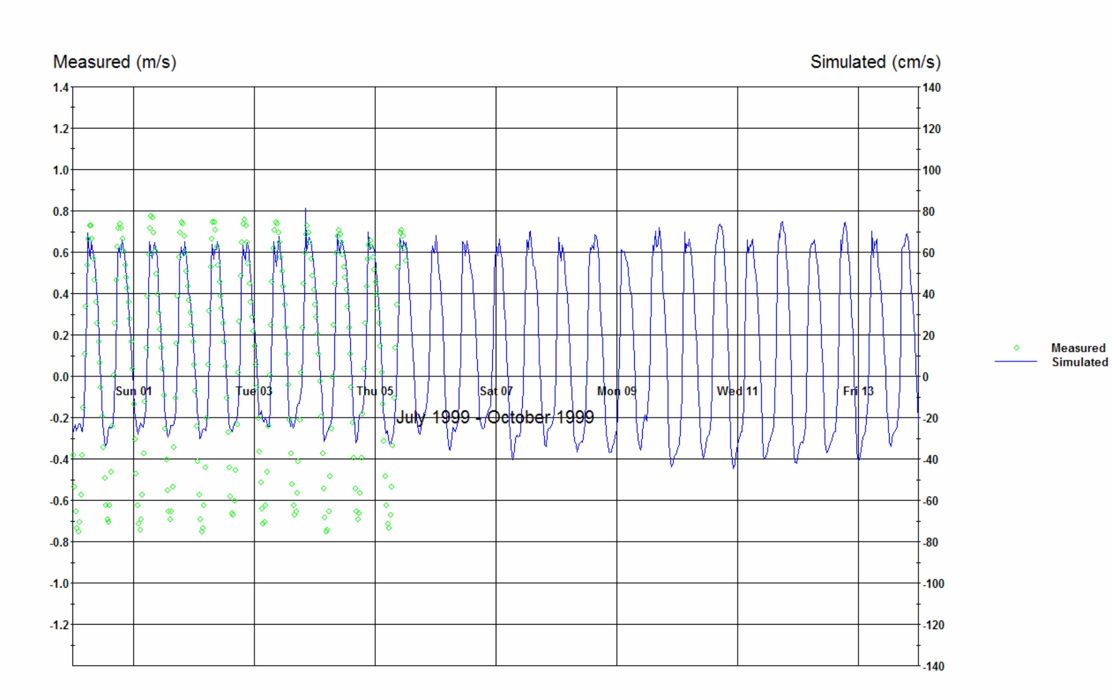


Figure D-10 Currents Comparison at FR-04 Bottom for July 31, 1999 through August 14, 1999

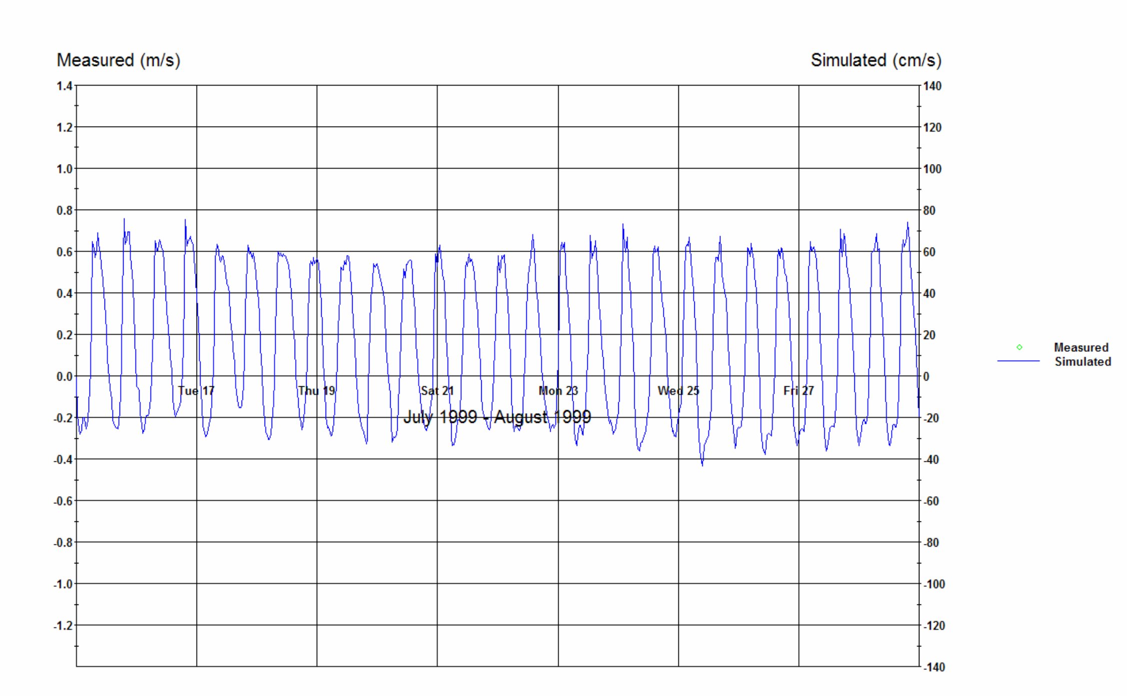


Figure D-11 Currents Comparison at FR-04 Bottom for August 15, 1999 through August 29, 1999

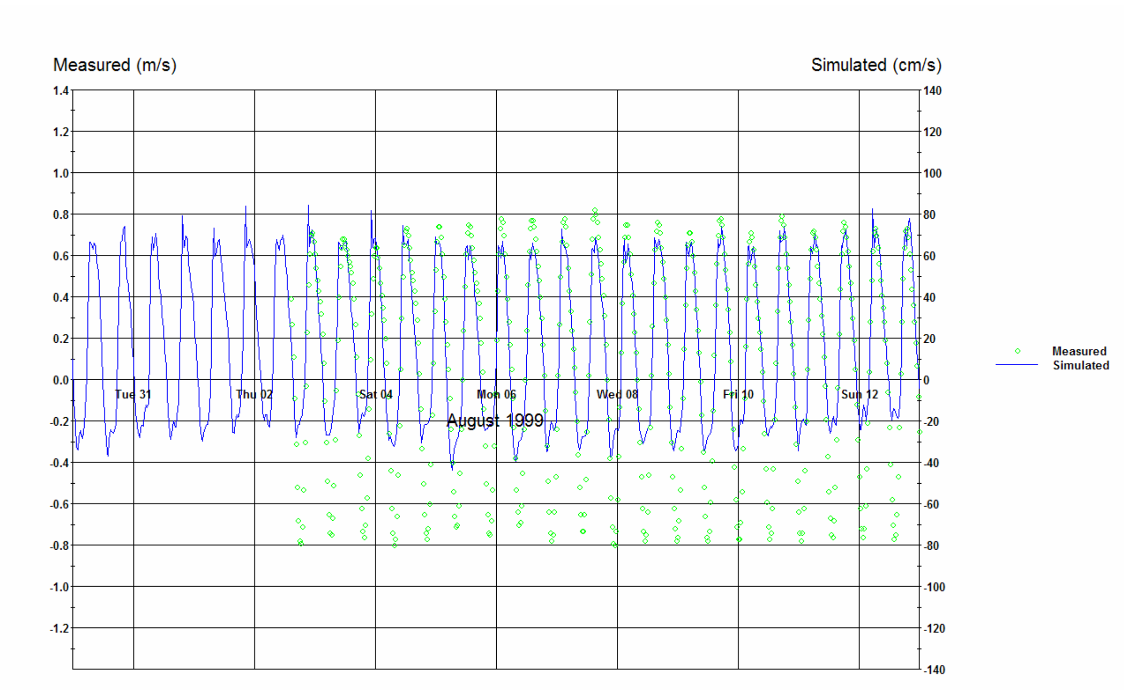


Figure D-12 Currents Comparison at FR-04 Bottom for August 30, 1999 through September 13, 1999

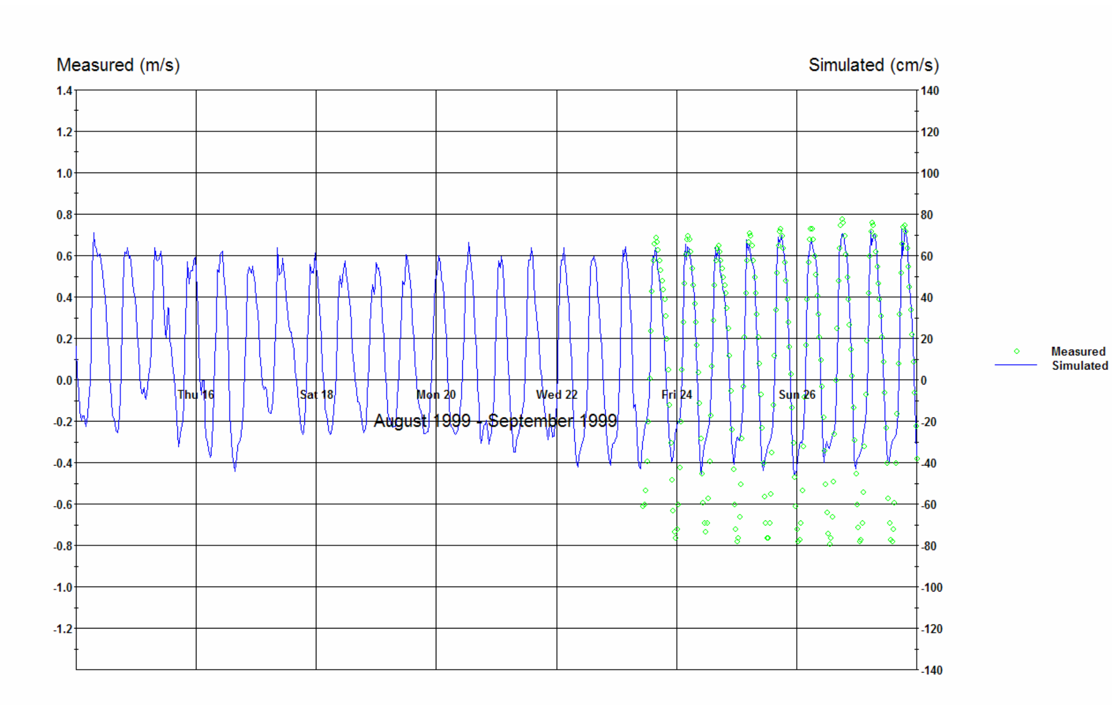


Figure D-13 Currents Comparison at FR-04 Bottom for September 14, 1999 through September 28, 1999

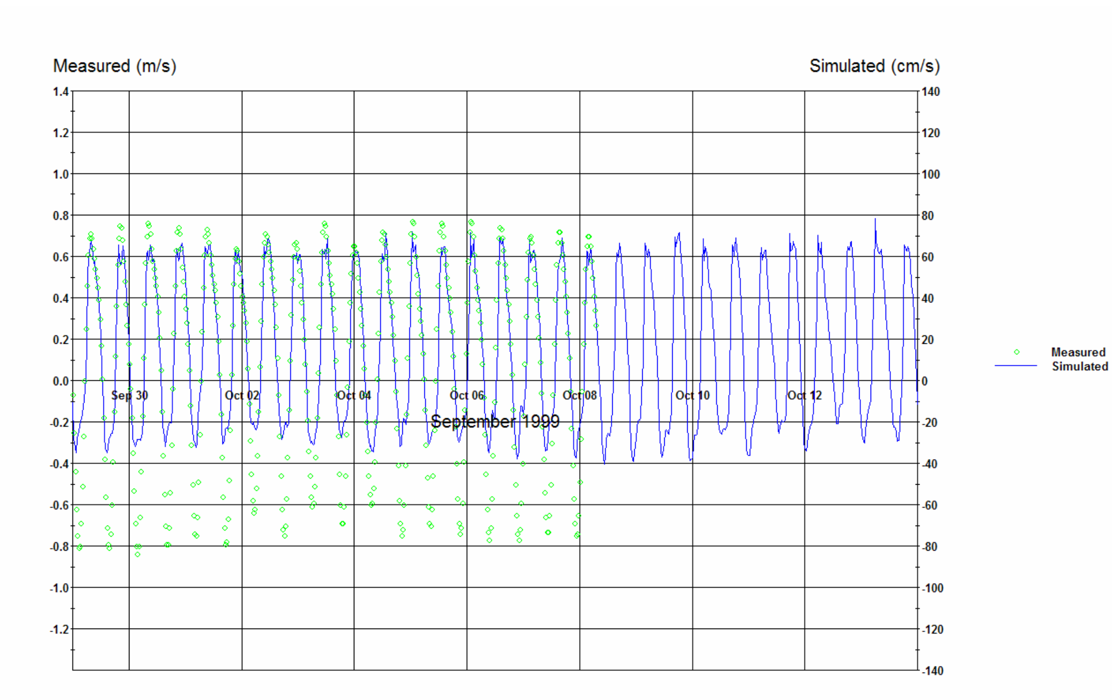


Figure D-14 Currents Comparison at FR-04 Bottom for September 29, 1999 through October 14, 1999

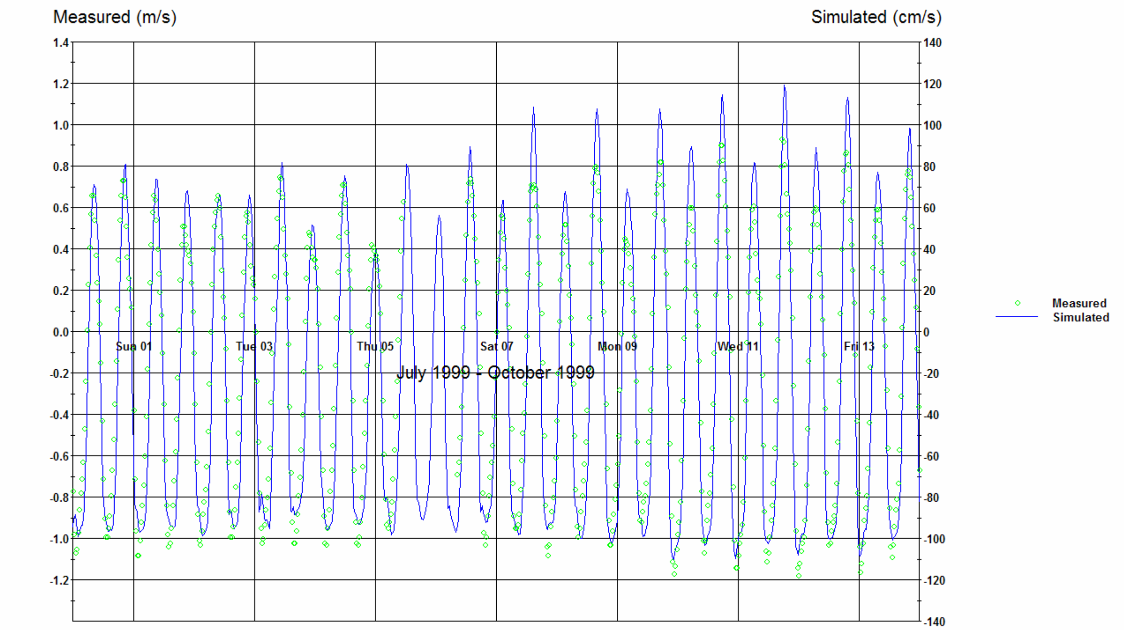


Figure D-15 Currents Comparison at FR-06 Surface for July 31, 1999 through August 14, 1999

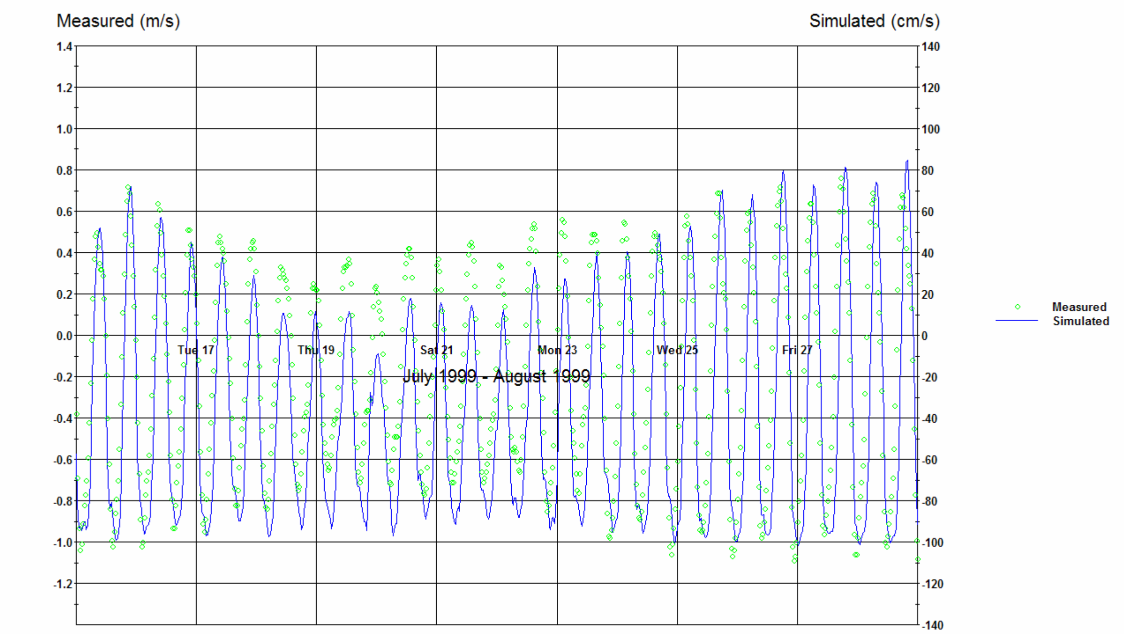


Figure D-16 Currents Comparison at FR-06 Surface for August 15, 1999 through August 29, 1999

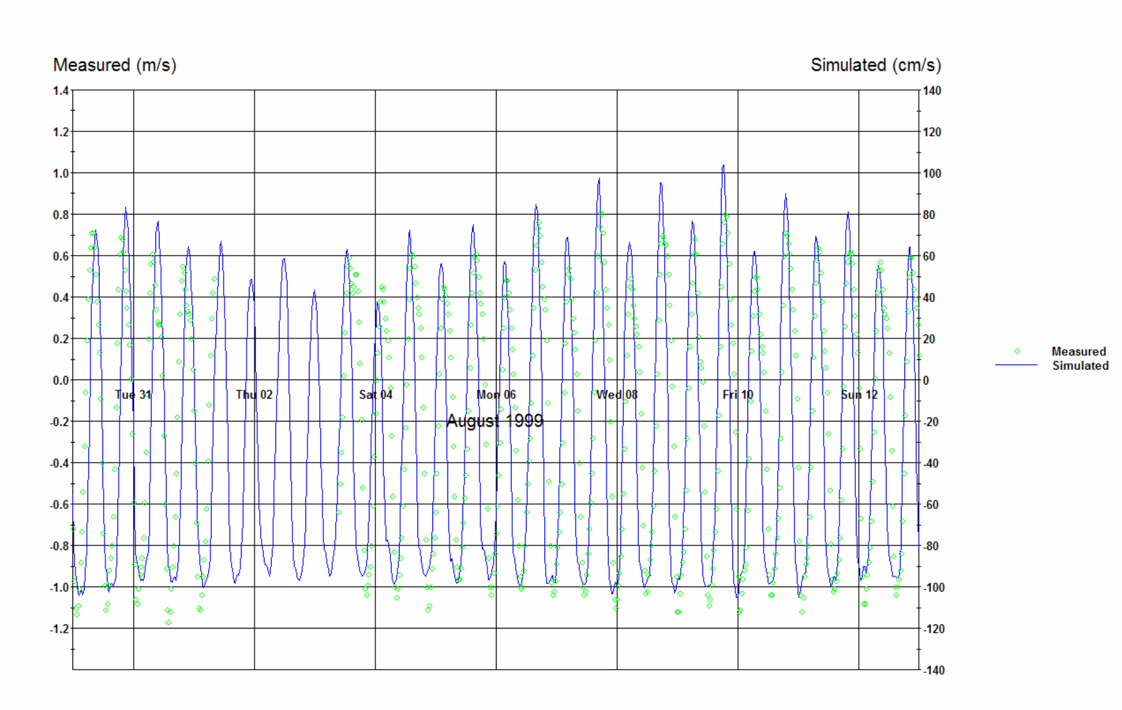


Figure D-17 Currents Comparison at FR-06 Surface for August 30, 1999 through September 13, 1999

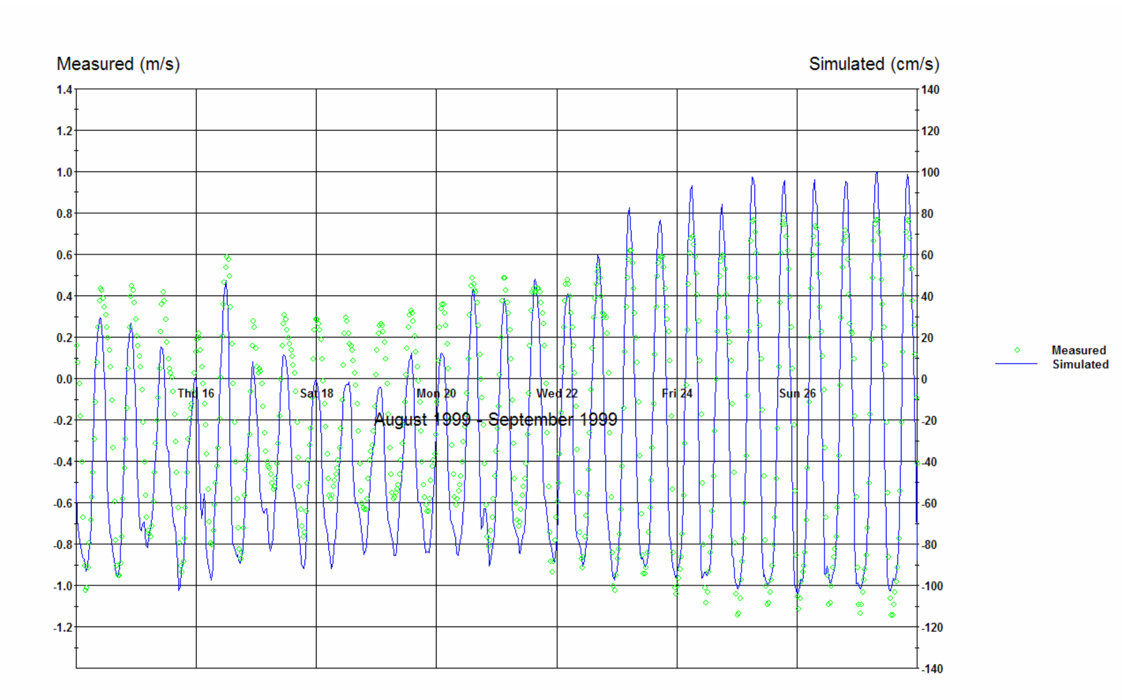


Figure D-18 Currents Comparison at FR-06 Surface for September 14, 1999 through September 28, 1999

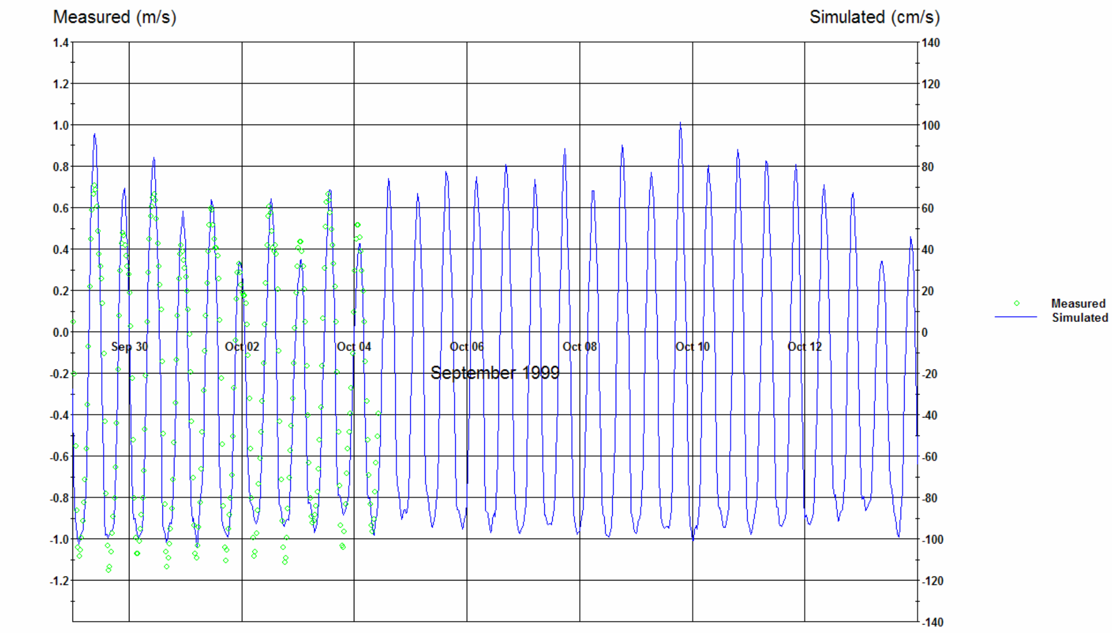


Figure D-19 Currents Comparison at FR-06 Surface for September 29, 1999 through October 14, 1999

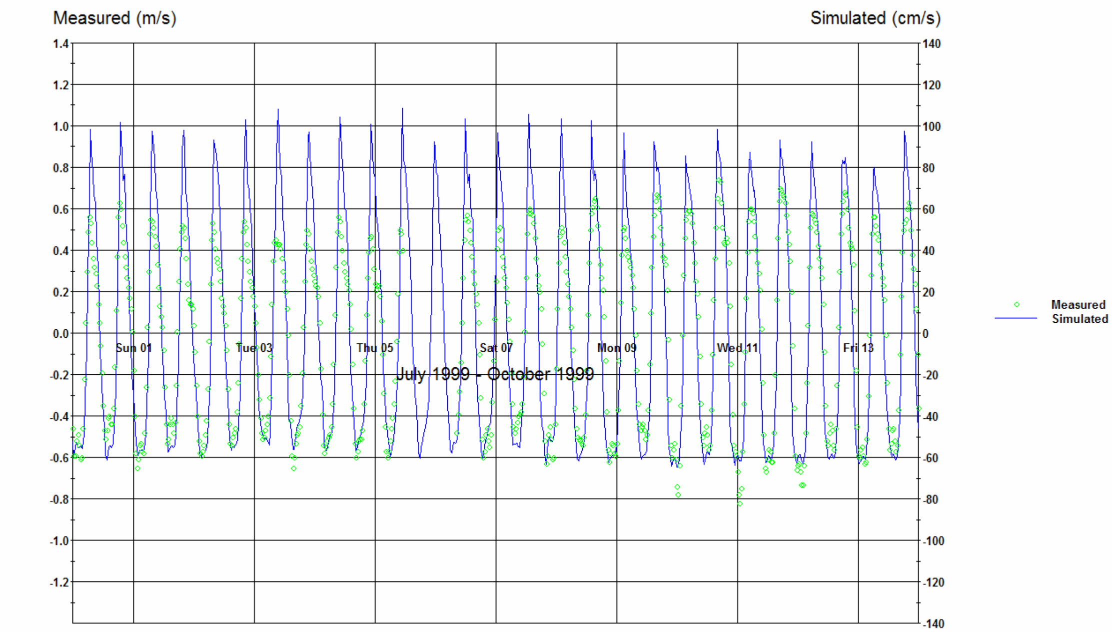


Figure D-20 Currents Comparison at FR-06 Bottom for July 31, 1999 through August 14, 1999

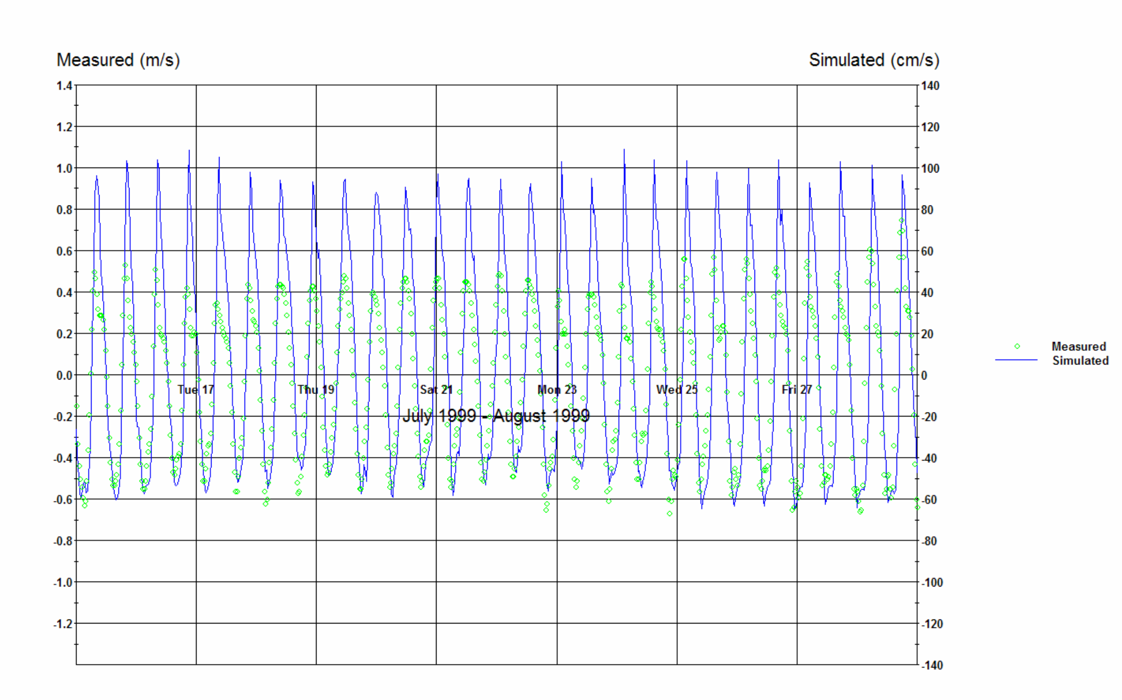


Figure D-21 Currents Comparison at FR-06 Bottom for August 15, 1999 through August 29, 1999

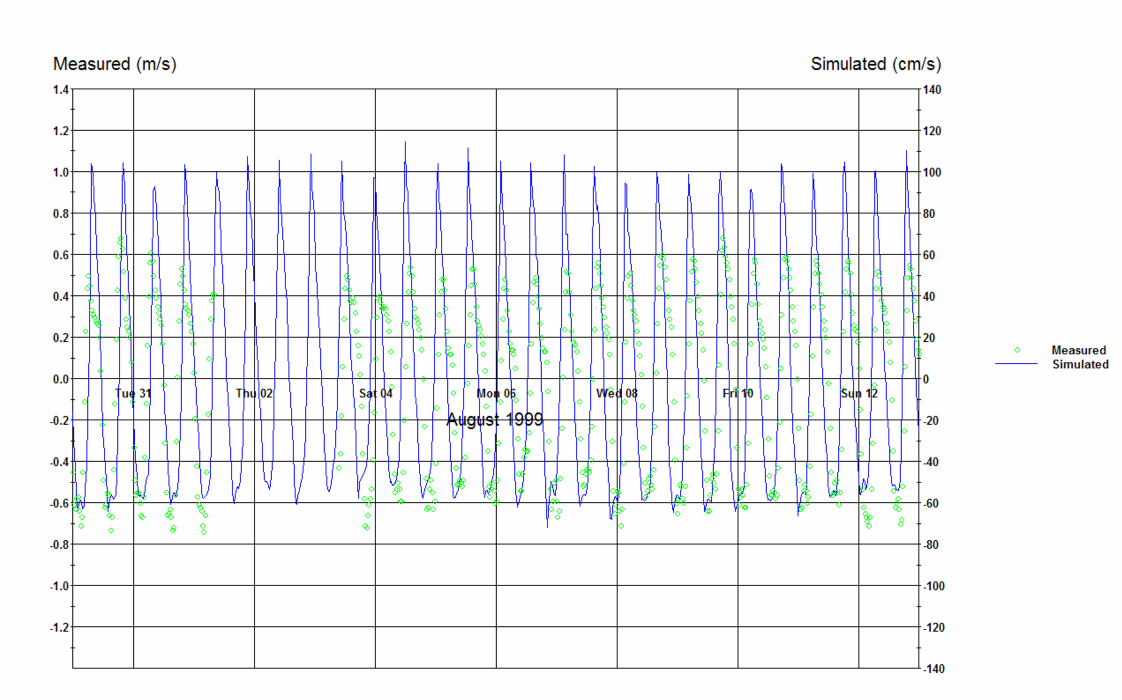


Figure D-22 Currents Comparison at FR-06 Bottom for August 30, 1999 through September 13, 1999

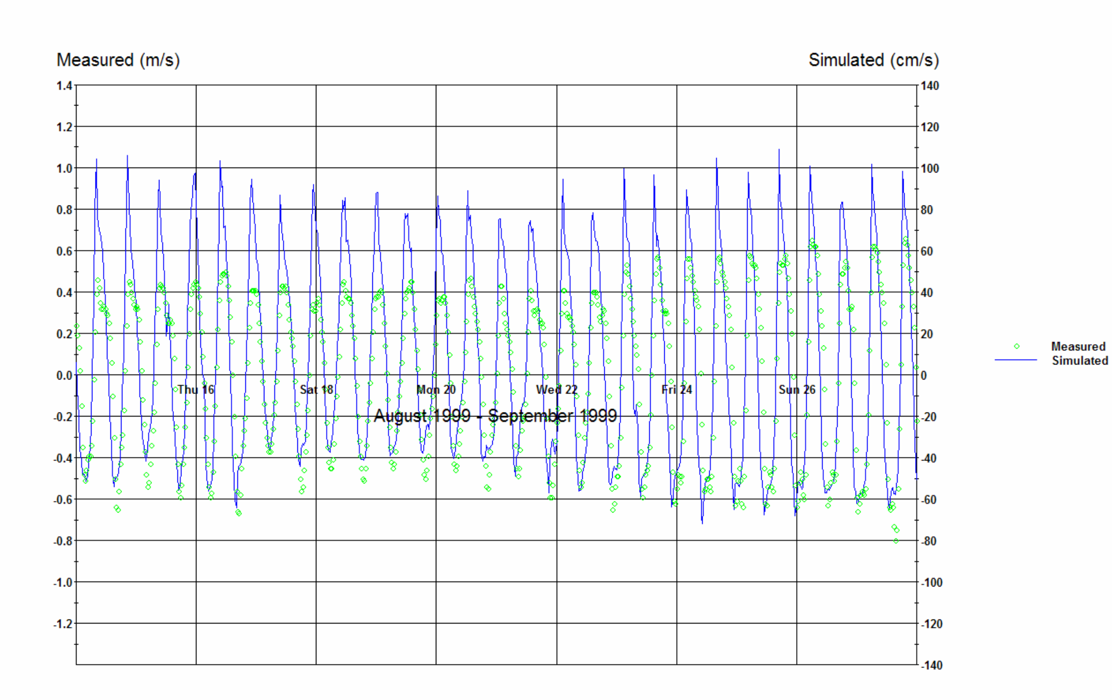


Figure D-23 Currents Comparison at FR-06 Bottom for September 14, 1999 through September 28, 1999

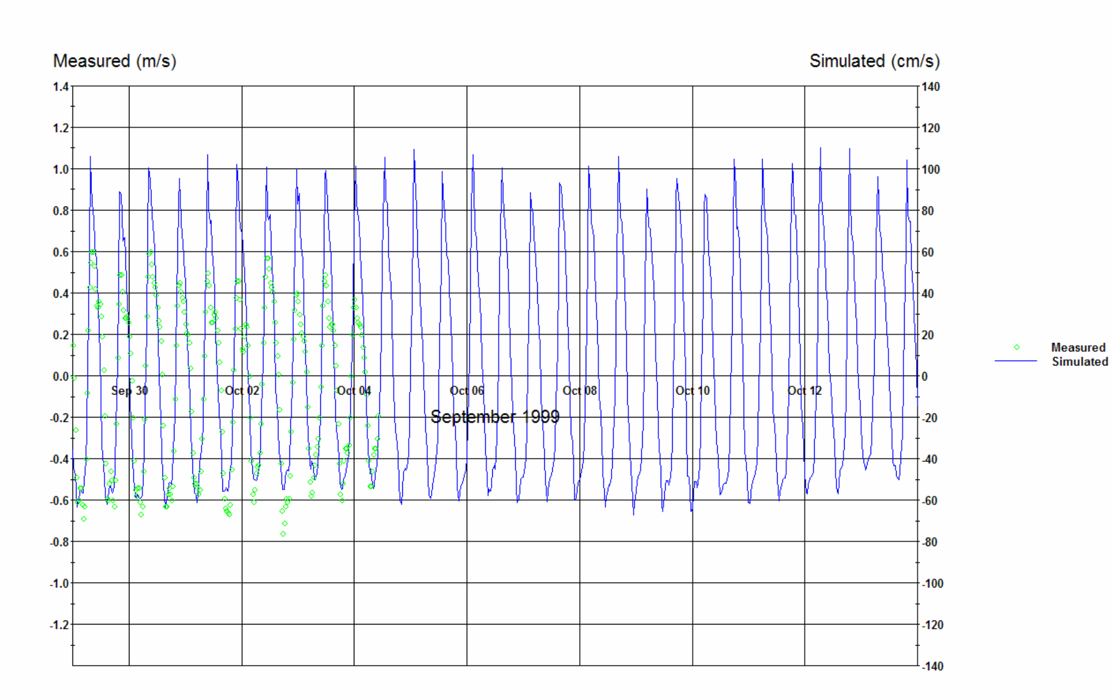


Figure D-24 Currents Comparison at FR-06 Bottom for September 29, 1999 through October 14, 1999

APPENDIX E 1997 CURRENTS COMPARISONS

Table E-1 1997 Currents (m/s) Statistical Comparisons for July 9, 1997 through October 6, 1997

July 9 - October 5, 1997 [Julian Days 191 - 279]									
Stations	**Depth**	**Measured**			**Simulated**			**Differences**	
		5%	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**95%**
FR-04	S	-0.88	0.09	0.82	-1.10	-0.49	0.76	-24%	7%
FR-04	B	-0.66	0.18	0.77	-0.34	0.13	0.67	48%	13%
FR-08	S	-0.87	-0.16	0.78	-1.05	-0.41	0.86	-20%	-10%
FR-08	B	-0.76	-0.10	0.58	-0.73	-0.25	0.63	4%	-9%

S = Surface

B = Bottom

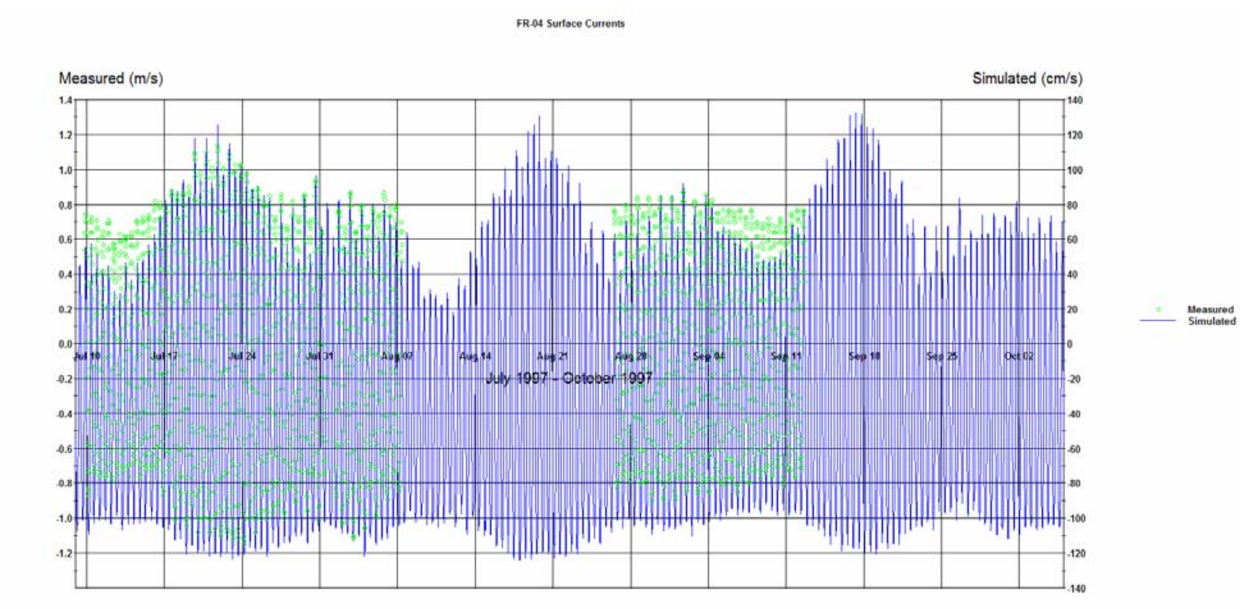


Figure E-1 Currents Comparison at FR-04 Surface for July 9, 1997 through October 6, 1997

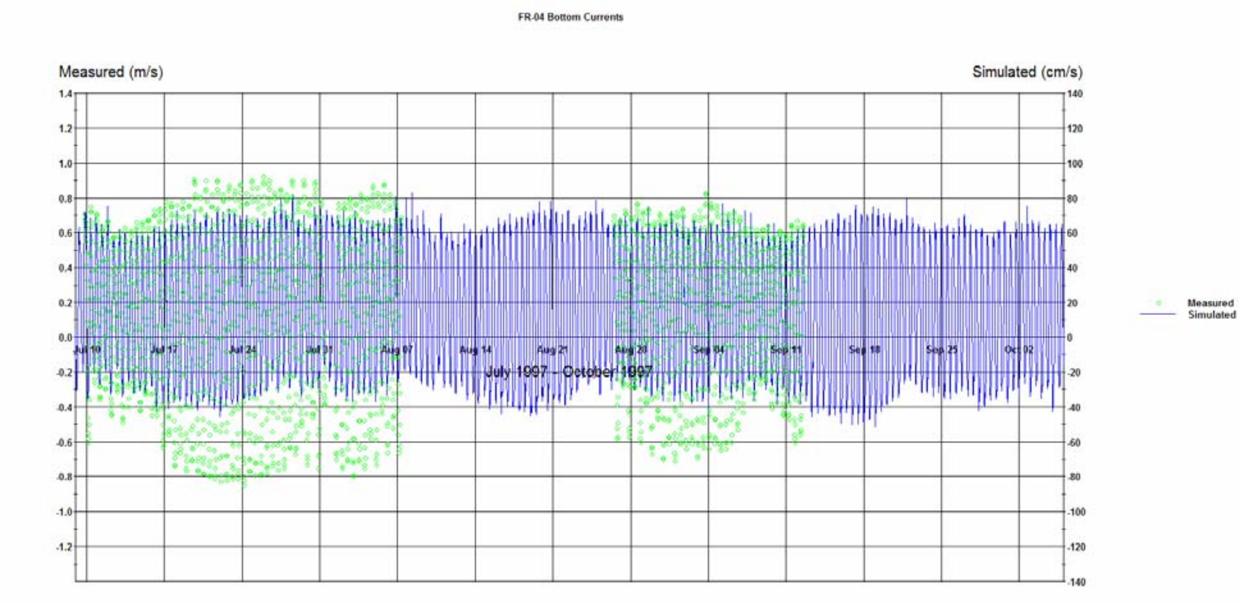


Figure E-2 Currents Comparison at FR-04 Bottom for July 9, 1997 through October 6, 1997

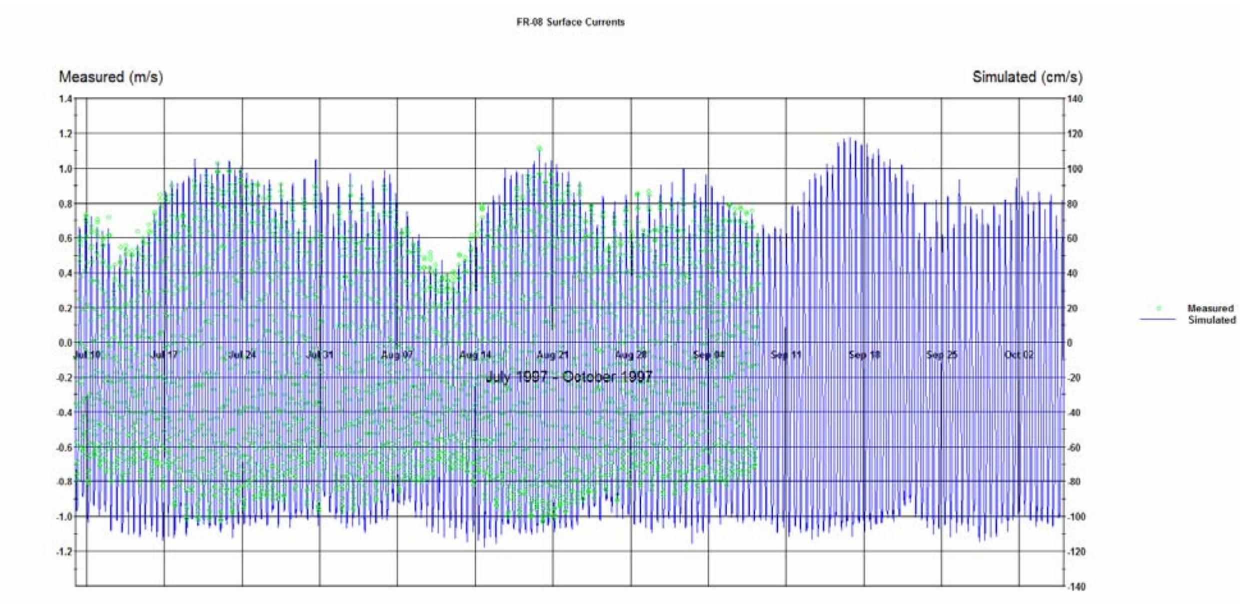


Figure E-3 Currents Comparison at FR-08 Surface for July 9, 1997 through October 6, 1997

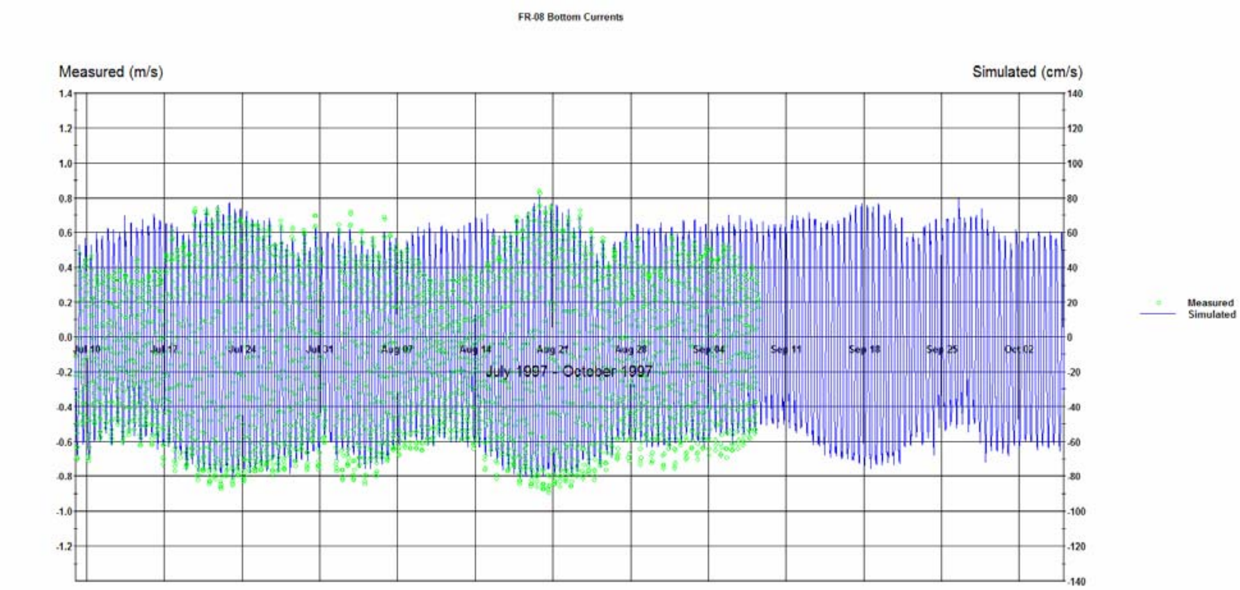


Figure E-4 Currents Comparison at FR-08 Bottom for July 9, 1997 through October 6, 1997

2-Week Currents Plots

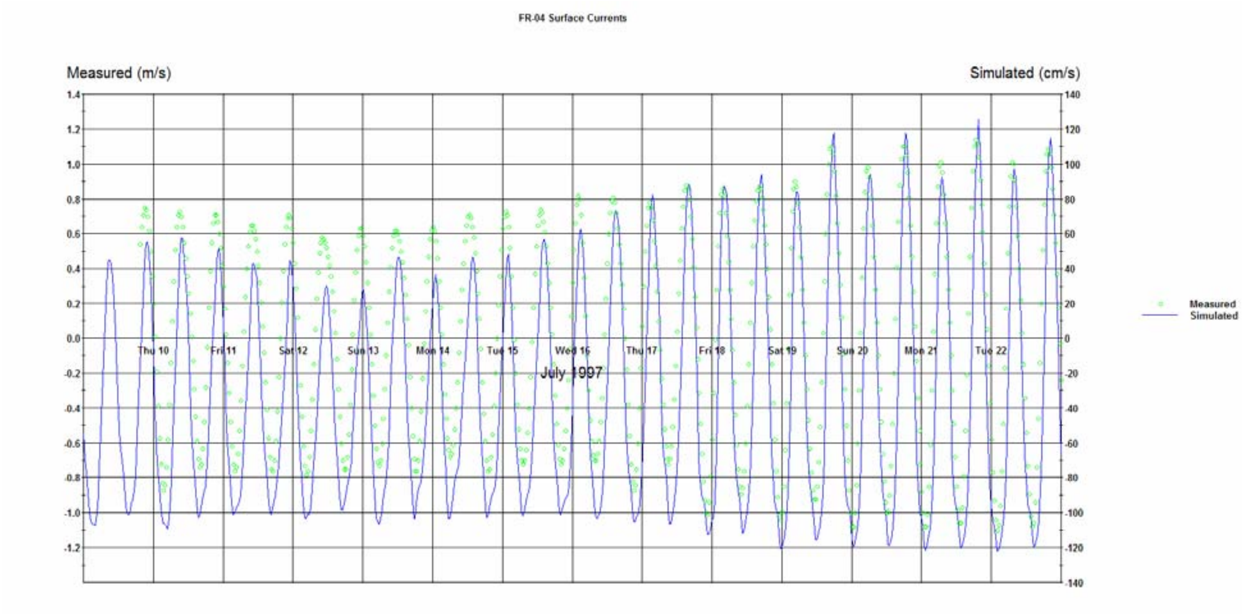


Figure E-5 Currents Comparison at FR-04 Surface for July 9, 1997 through July 23, 1997

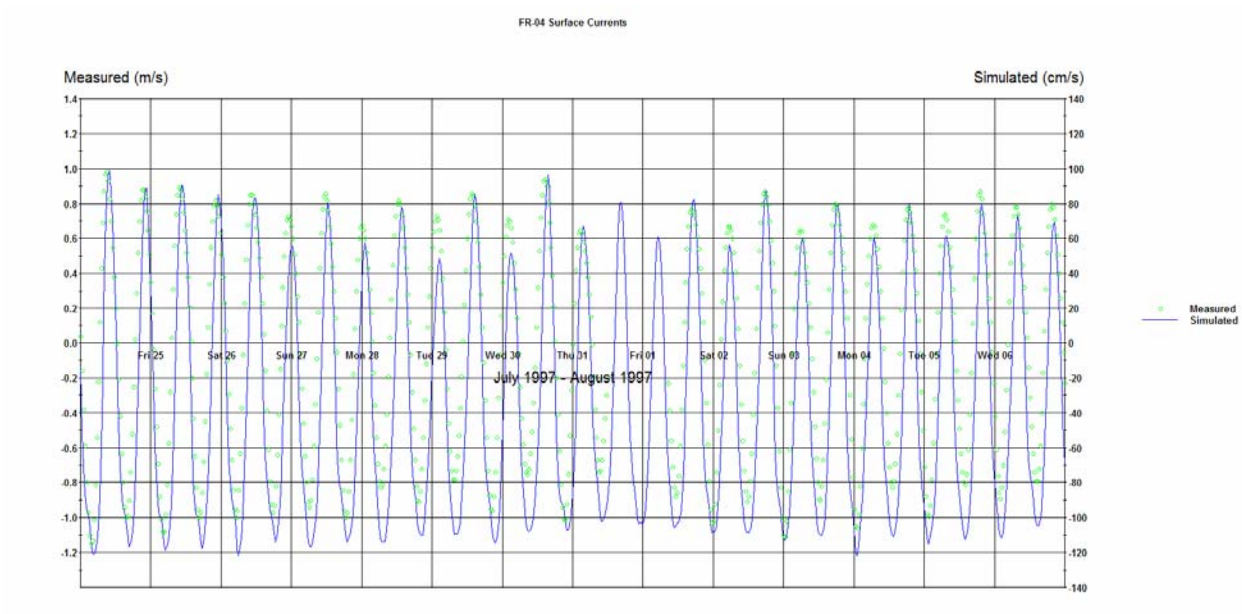


Figure E-6 Currents Comparison at FR-04 Surface for July 24, 1997 through August 7, 1997

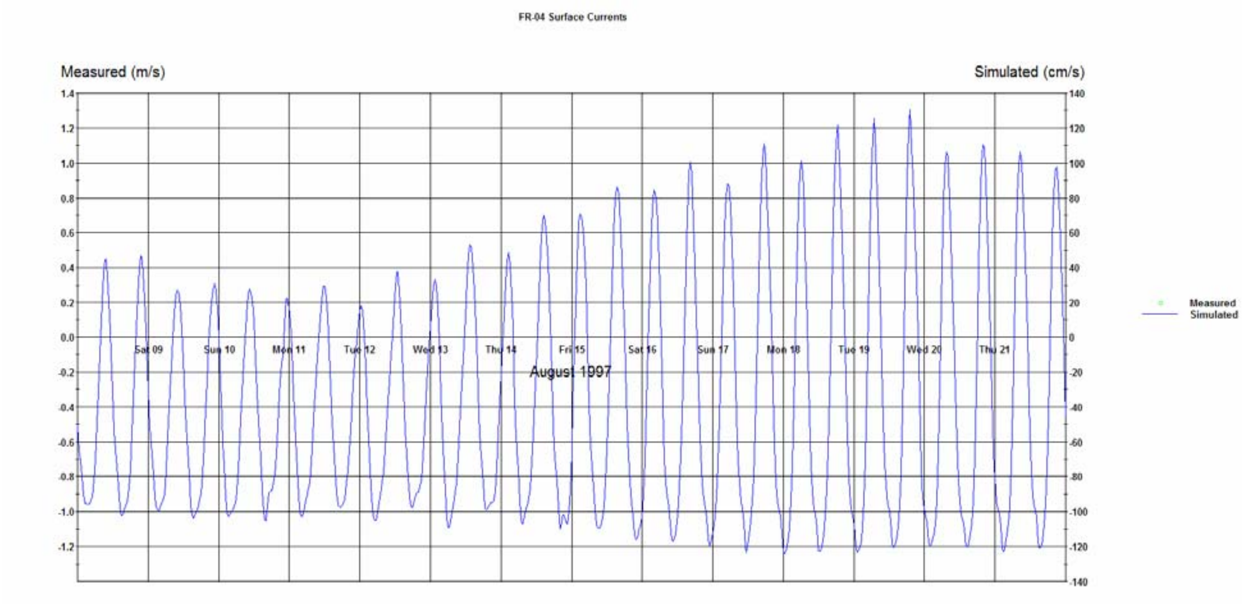


Figure E-7 Currents Comparison at FR-04 Surface for August 8, 1997 through August 22, 1997

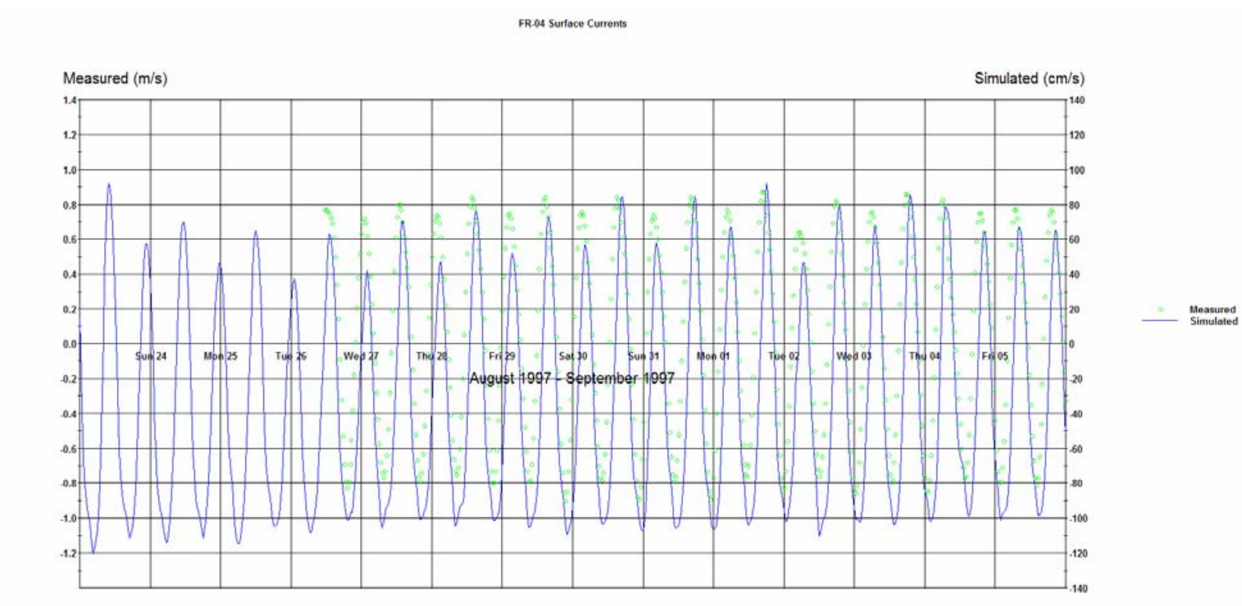


Figure E-8 Currents Comparison at FR-04 Surface for August 23, 1997 through September 6, 1997

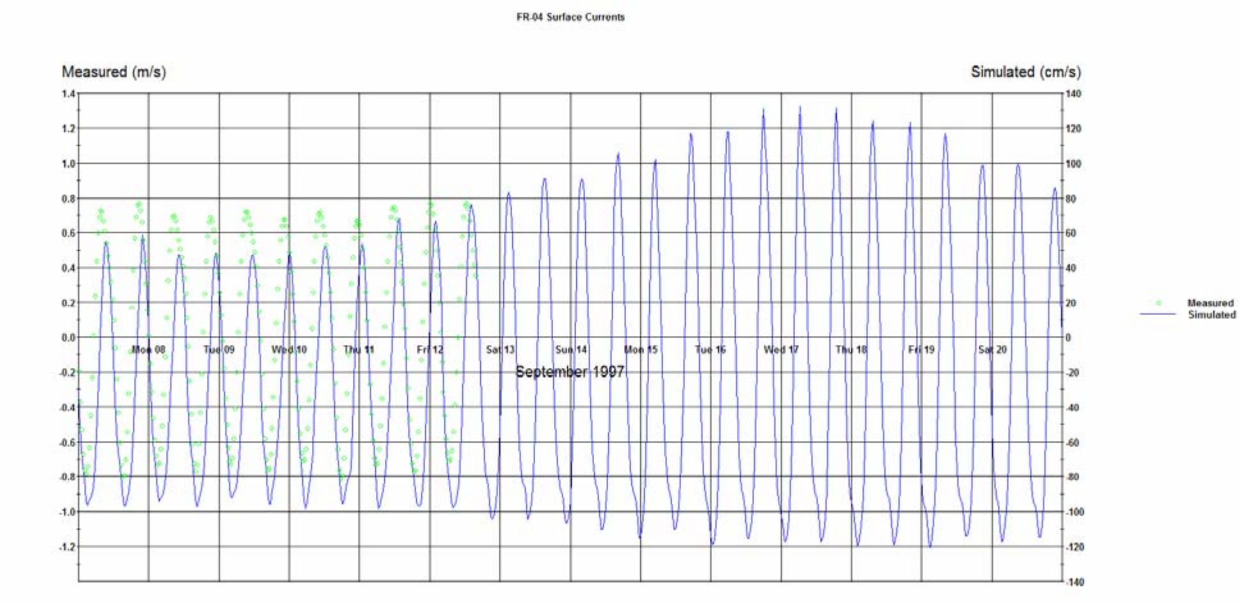


Figure E-9 Currents Comparison at FR-04 Surface for September 7, 1997 through September 21, 1997

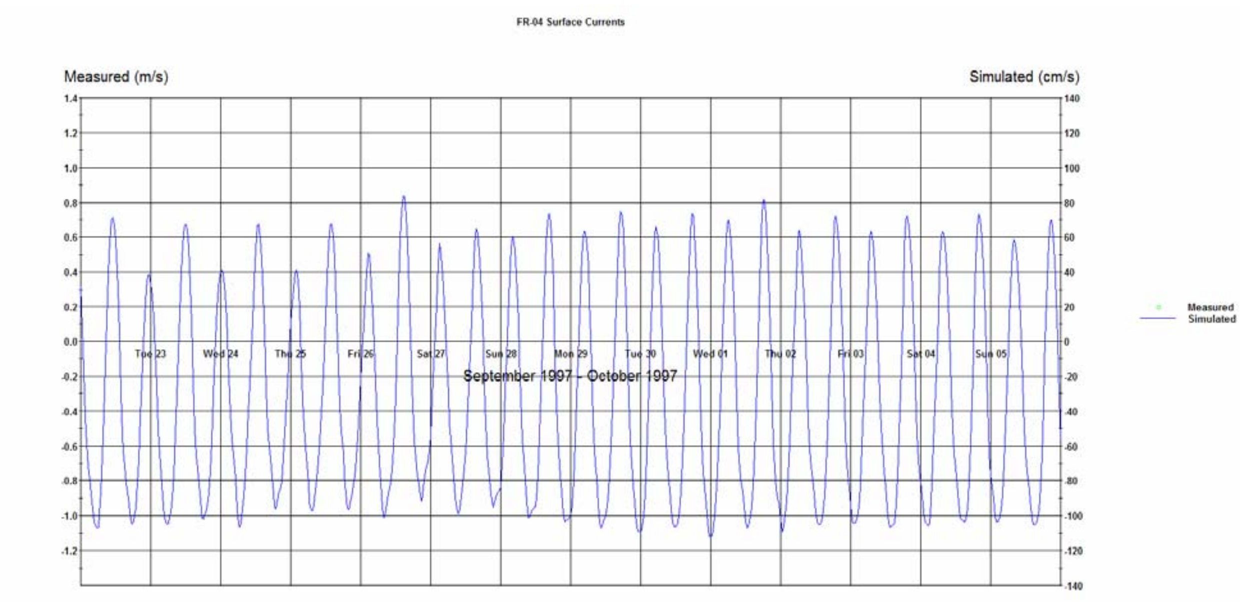


Figure E-10 Currents Comparison at FR-04 Surface for September 22, 1997 through October 6, 1997

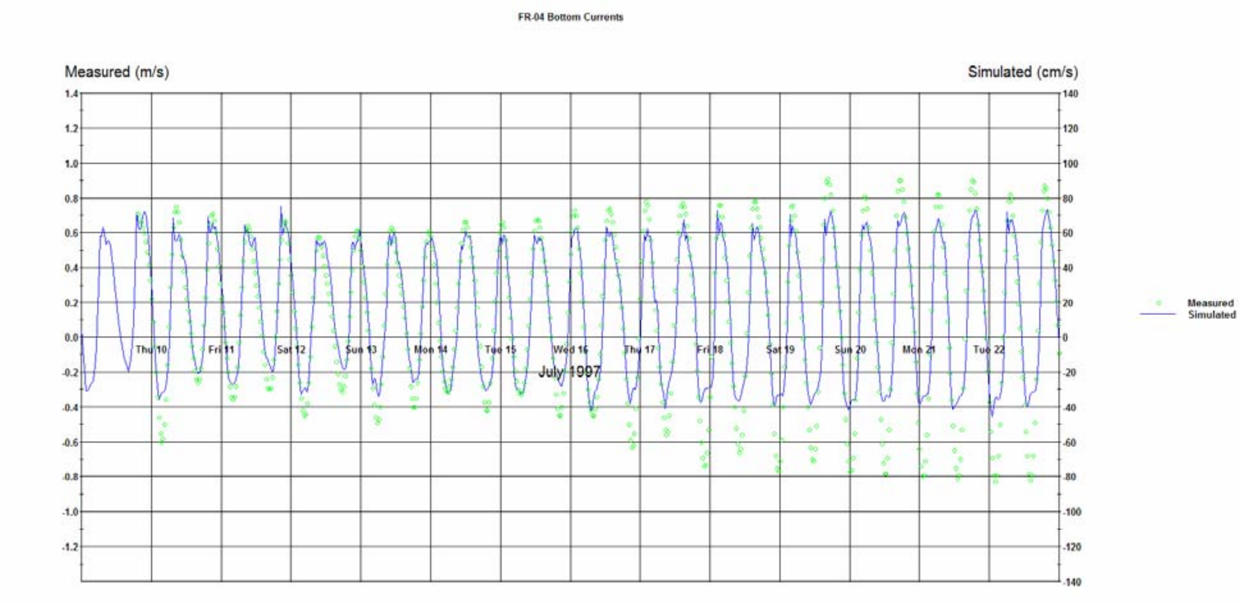


Figure E-11 Currents Comparison at FR-04 Bottom for July 9, 1997 through July 23, 1997

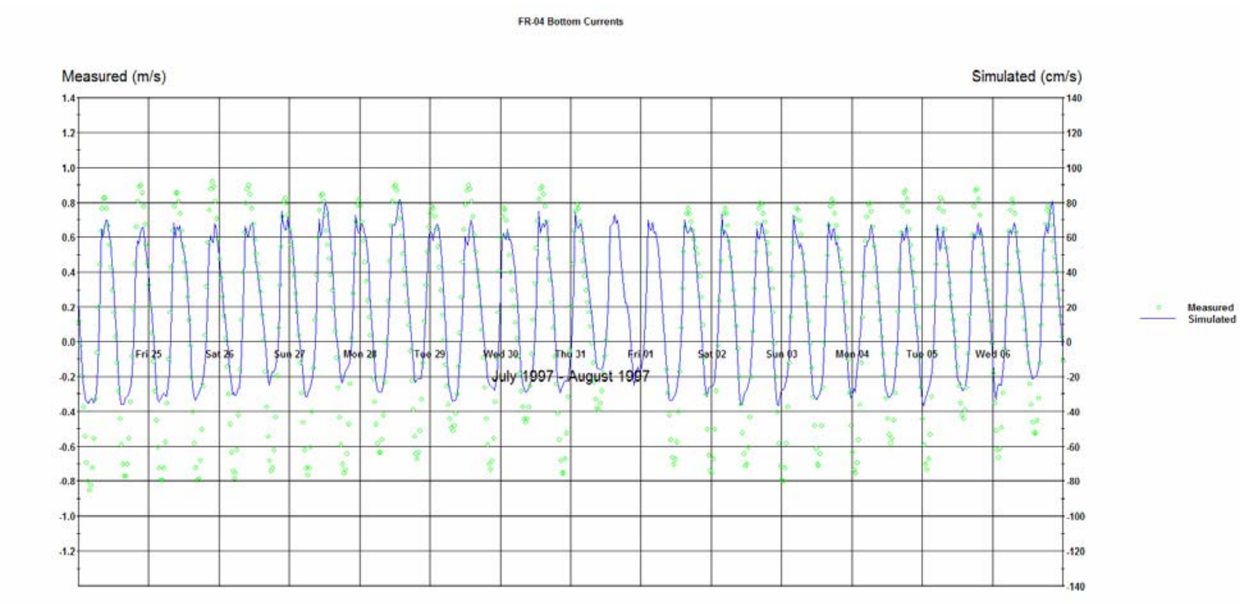


Figure E-12 Currents Comparison at FR-04 Bottom for July 24, 1997 through August 7, 1997

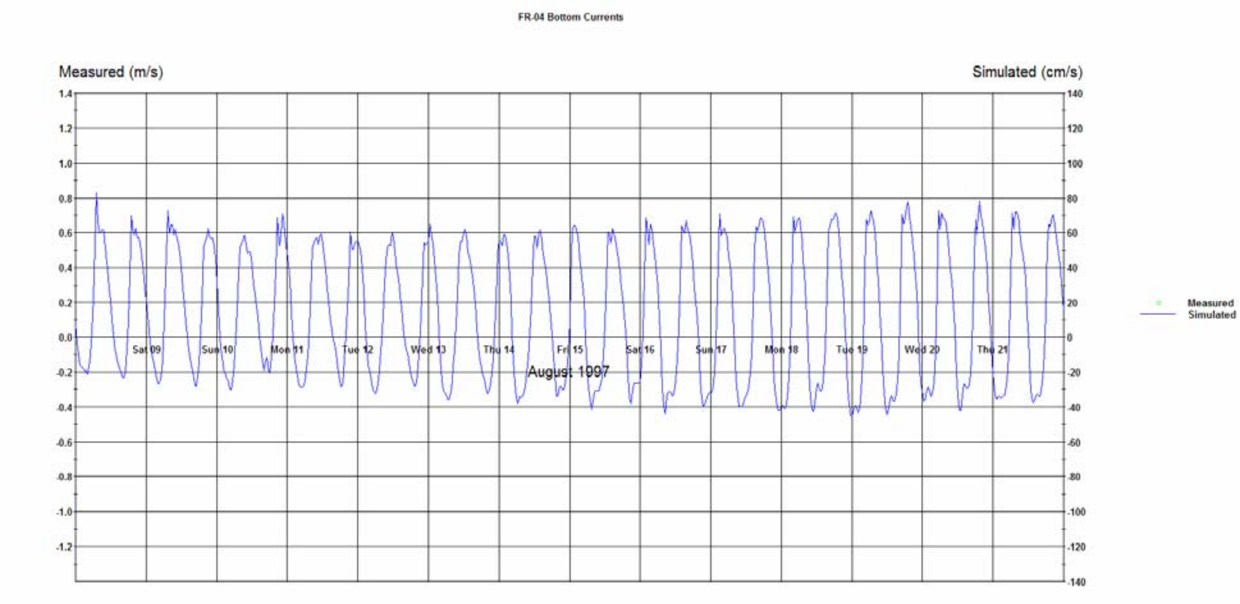


Figure E-13 Currents Comparison at FR-04 Bottom for August 8, 1997 through August 22, 1997

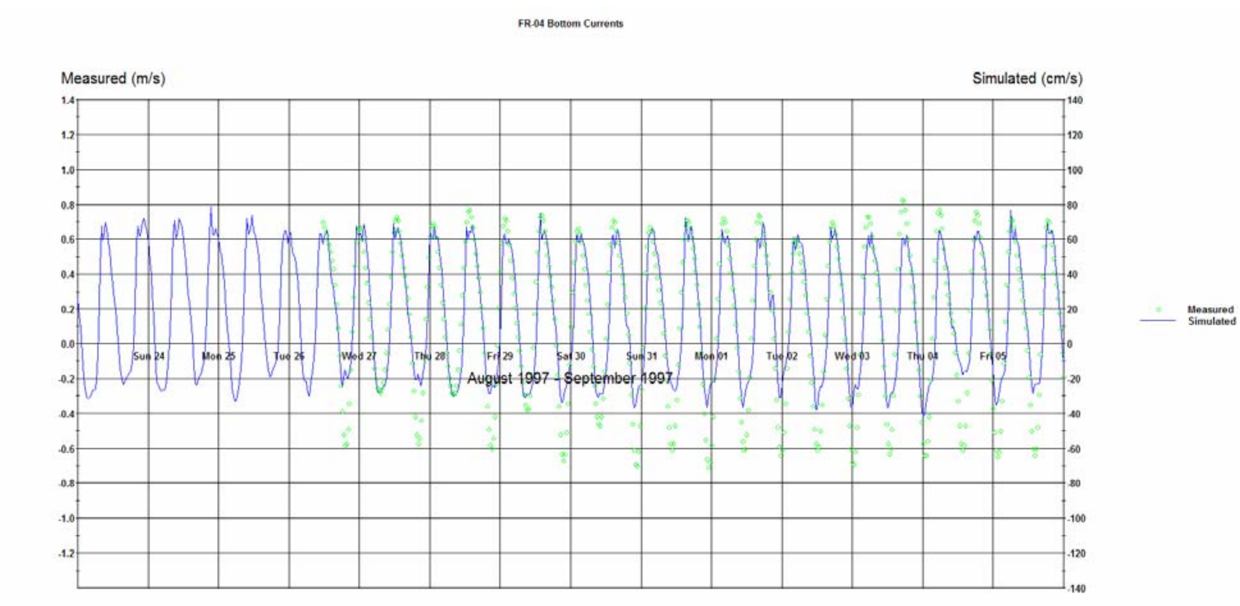


Figure E-14 Currents Comparison at FR-04 Bottom for August 23, 1997 through September 6, 1997

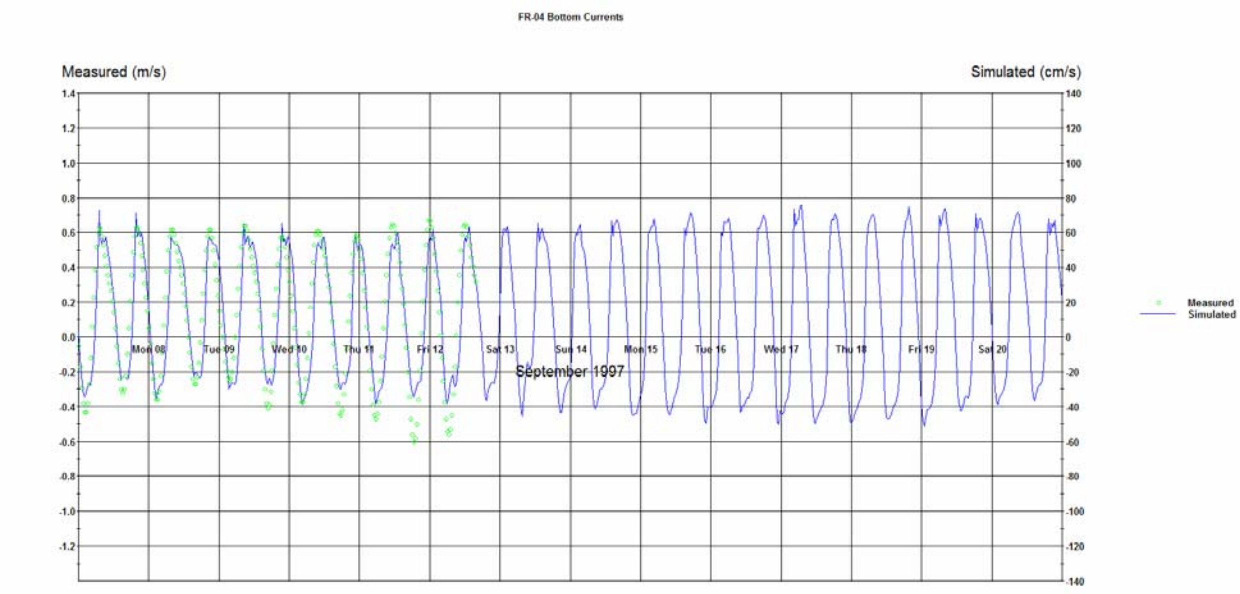


Figure E-15 Currents Comparison at FR-04 Bottom for September 7, 1997 through September 21, 1997

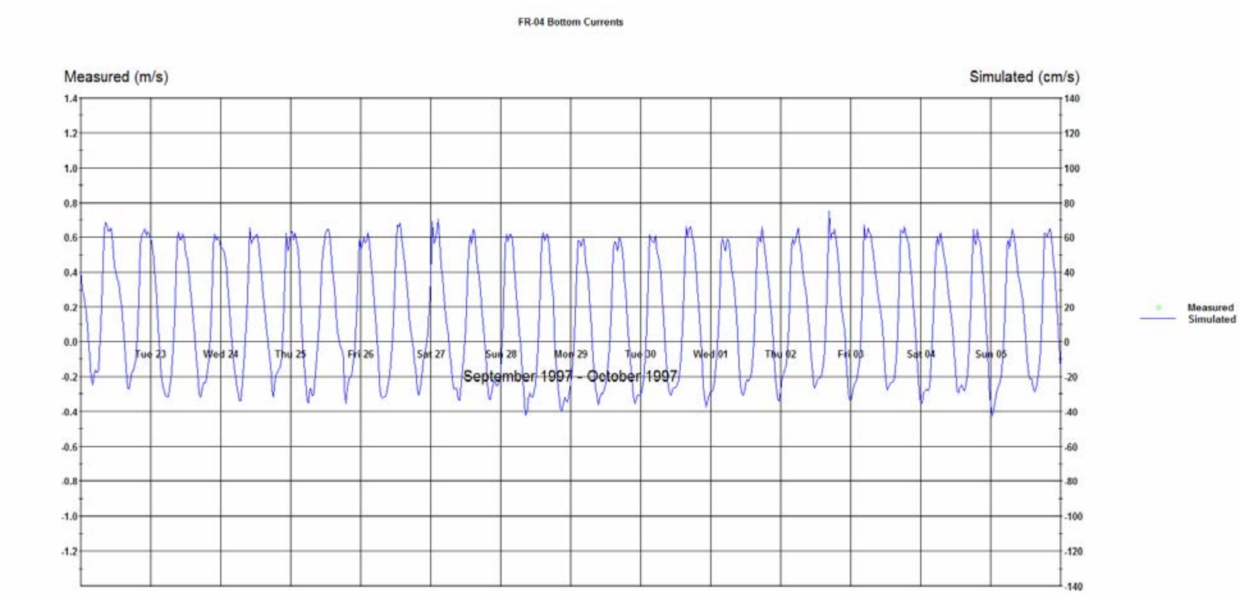


Figure E-16 Currents Comparison at FR-04 Bottom for September 22, 1997 through October 6, 1997

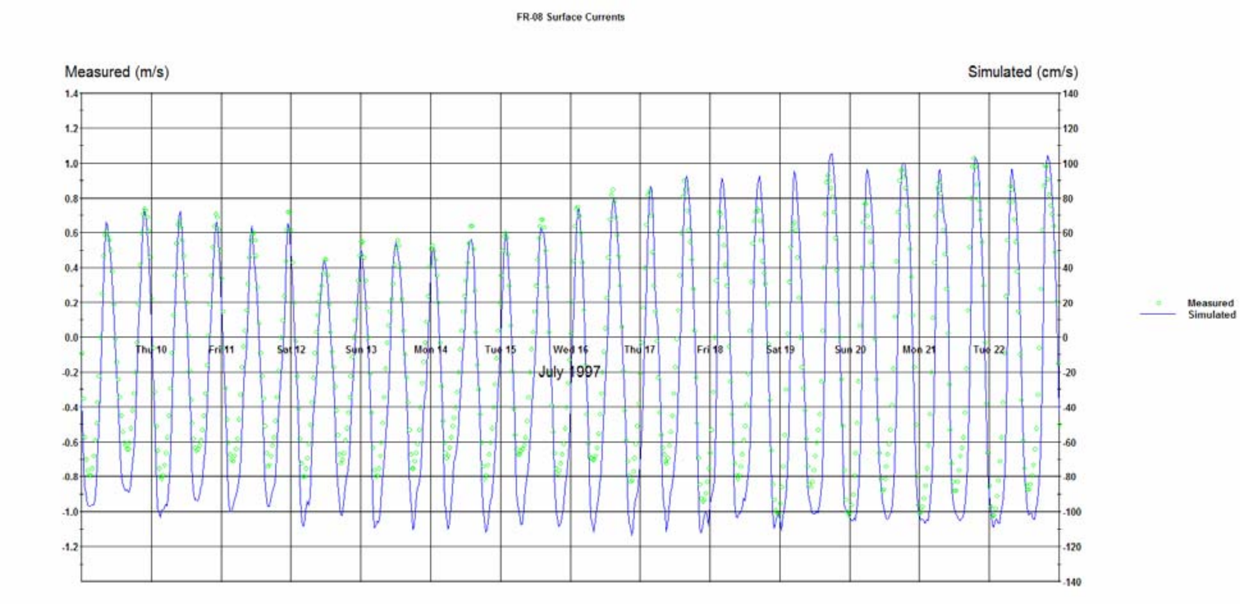


Figure E-17 Currents Comparison at FR-08 Surface for July 9, 1997 through July 23, 1997

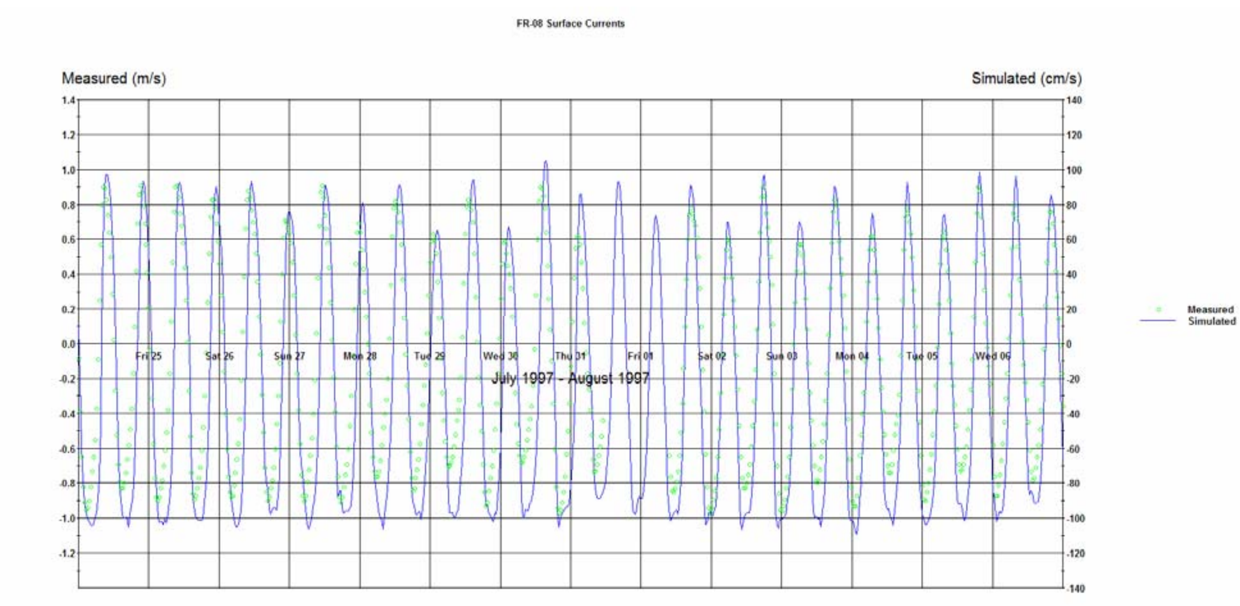


Figure E-18 Currents Comparison at FR-08 Surface for July 24, 1997 through August 7, 1997

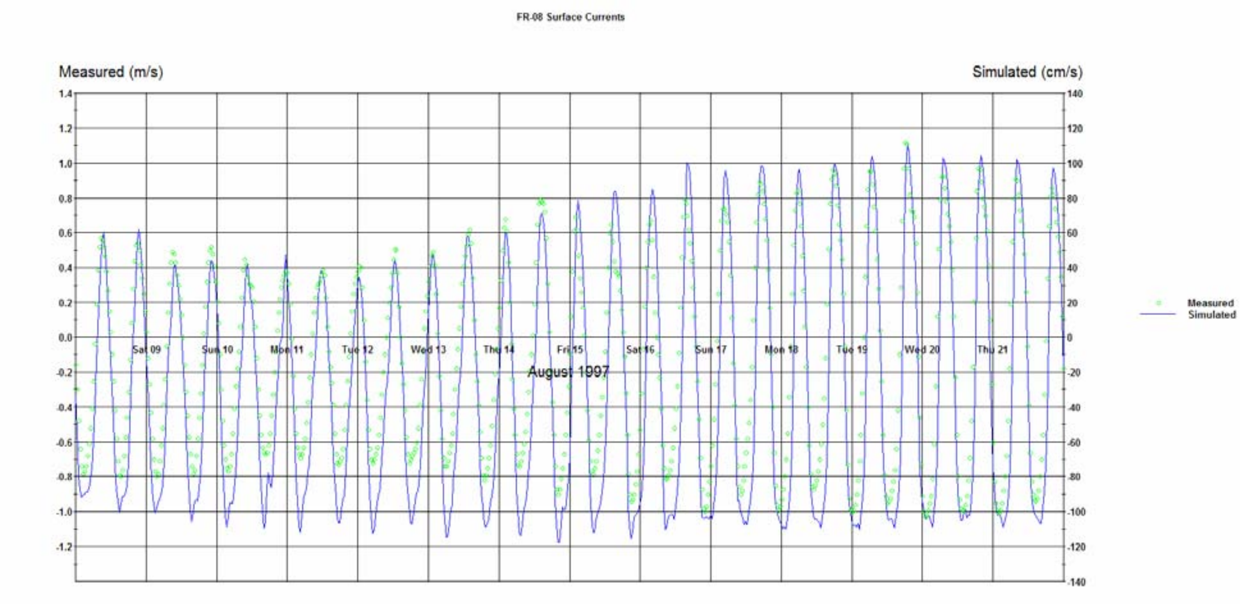


Figure E-19 Currents Comparison at FR-08 Surface for August 8, 1997 through August 22, 1997

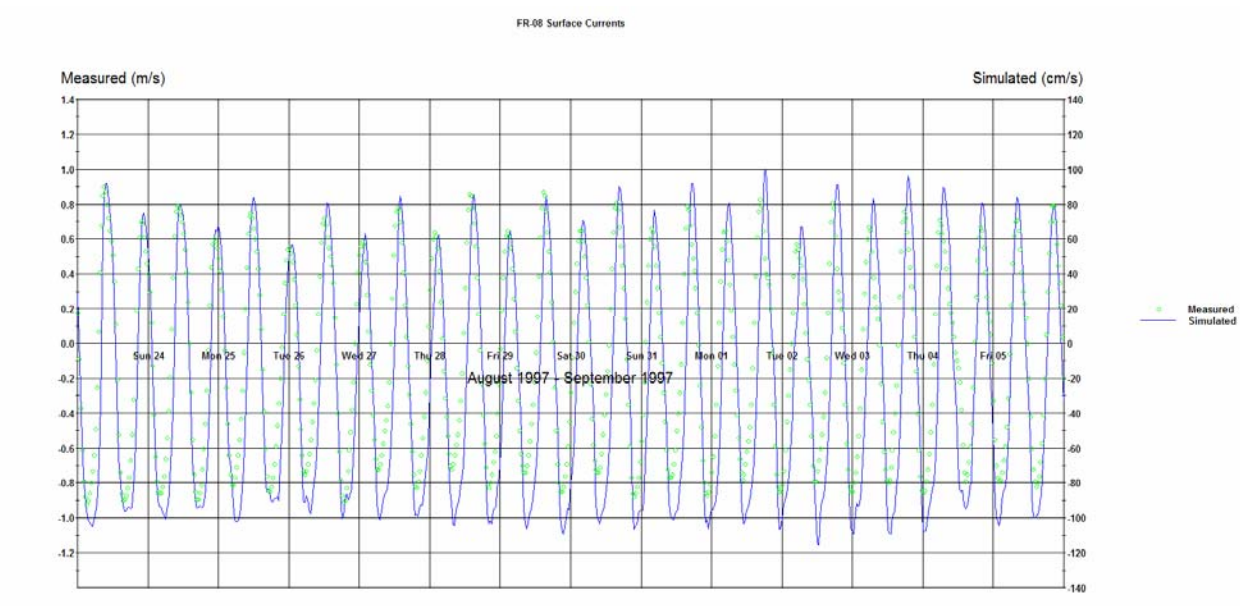


Figure E-20 Currents Comparison at FR-08 Surface for August 23, 1997 through September 6, 1997

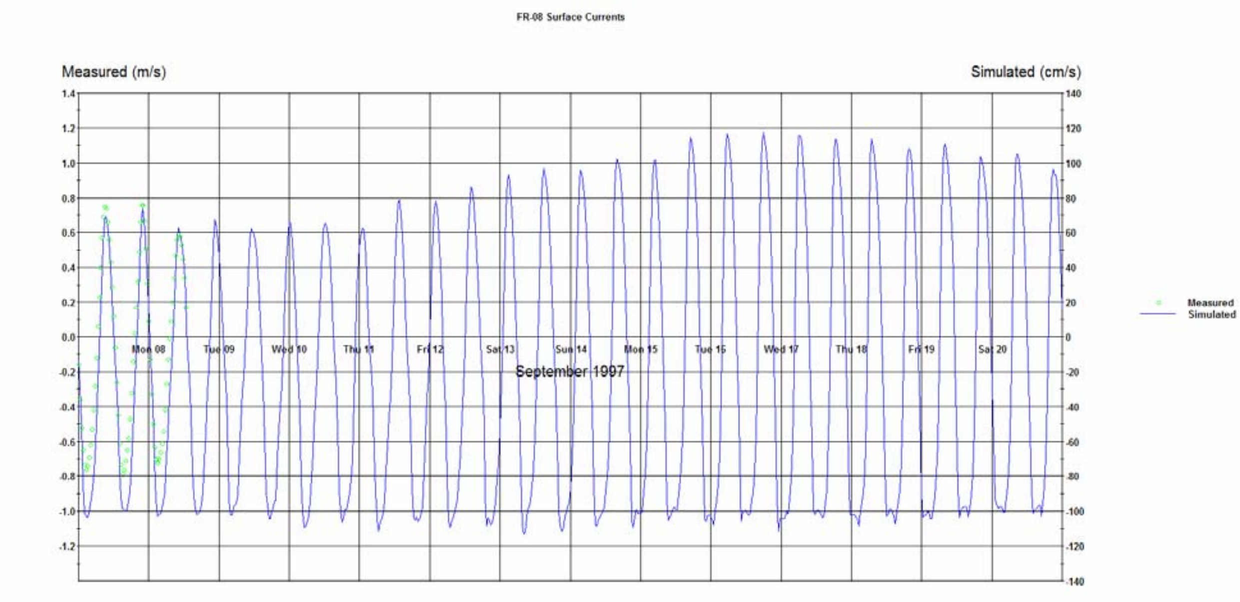


Figure E-21 Currents Comparison at FR-08 Surface for September 7, 1997 through September 21, 1997

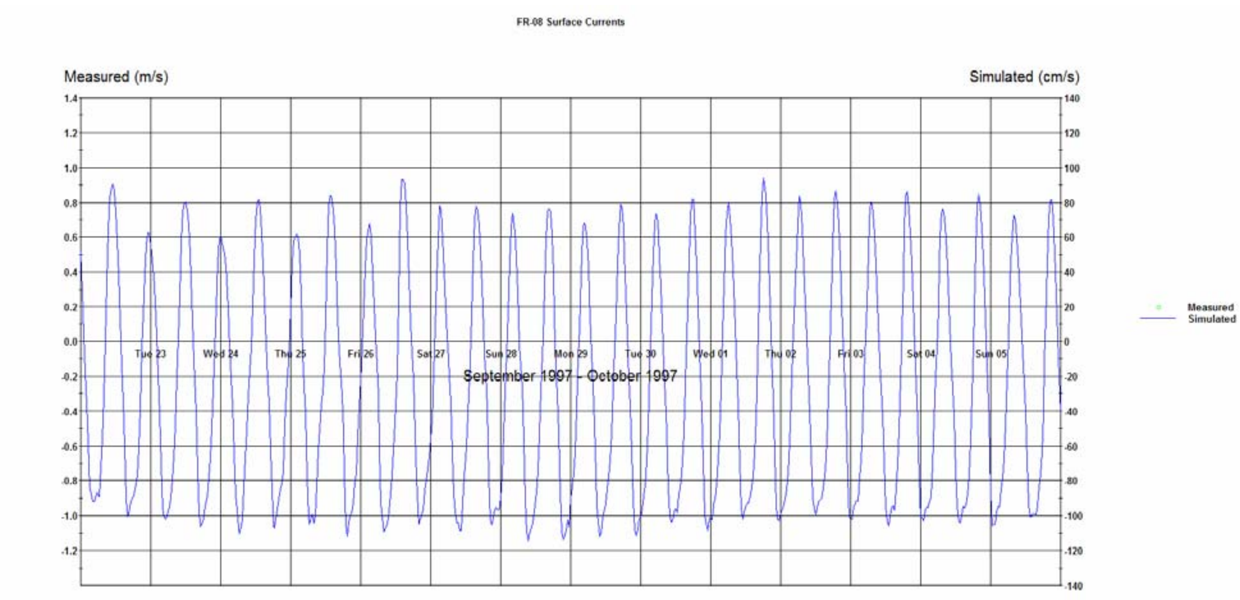


Figure E-22 Currents Comparison at FR-08 Surface for September 22, 1997 through October 6, 1997

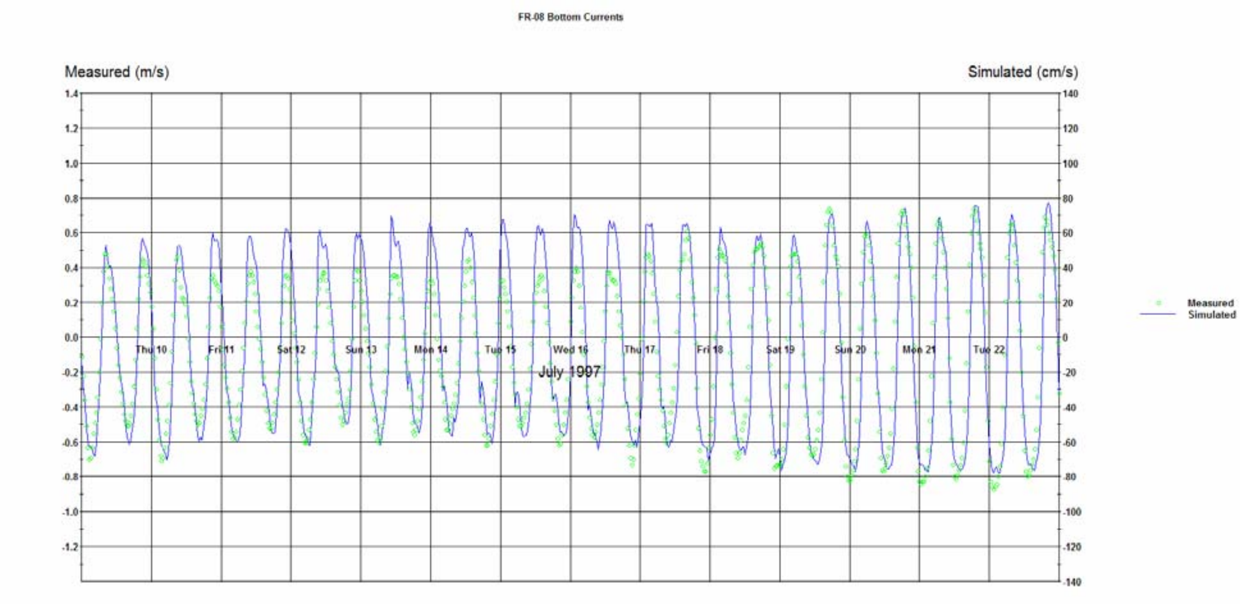


Figure E-23 Currents Comparison at FR-08 Bottom for July 9, 1997 through July 23, 1997

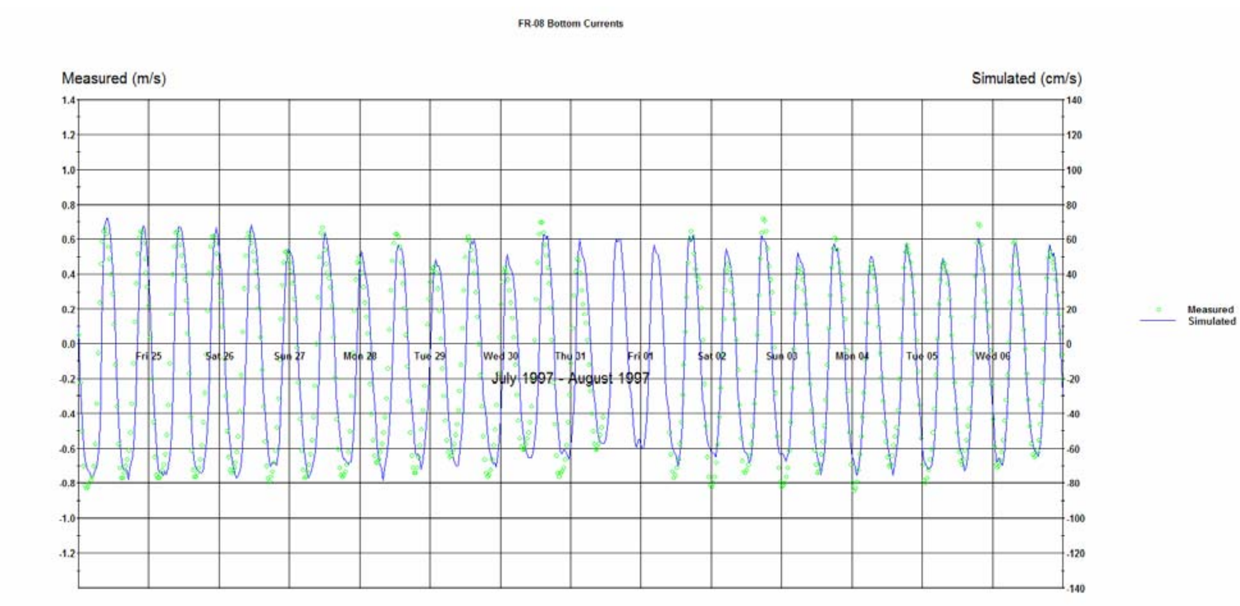


Figure E-24 Currents Comparison at FR-08 Bottom for July 24, 1997 through August 7, 1997

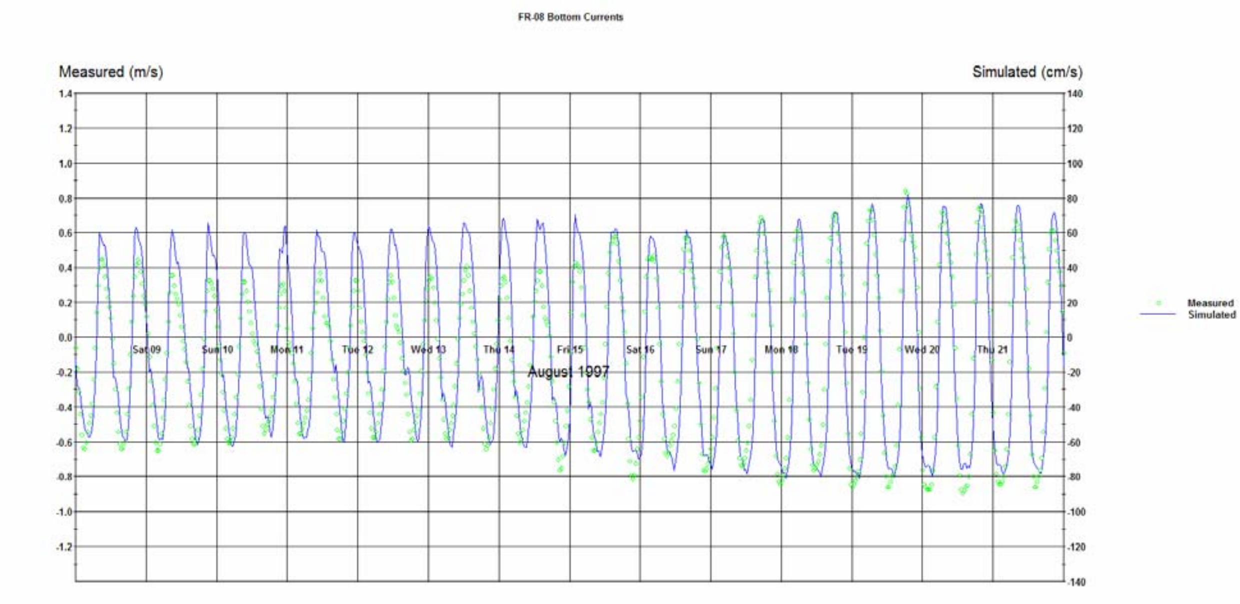


Figure E-25 Currents Comparison at FR-08 Bottom for August 8, 1997 through August 22, 1997

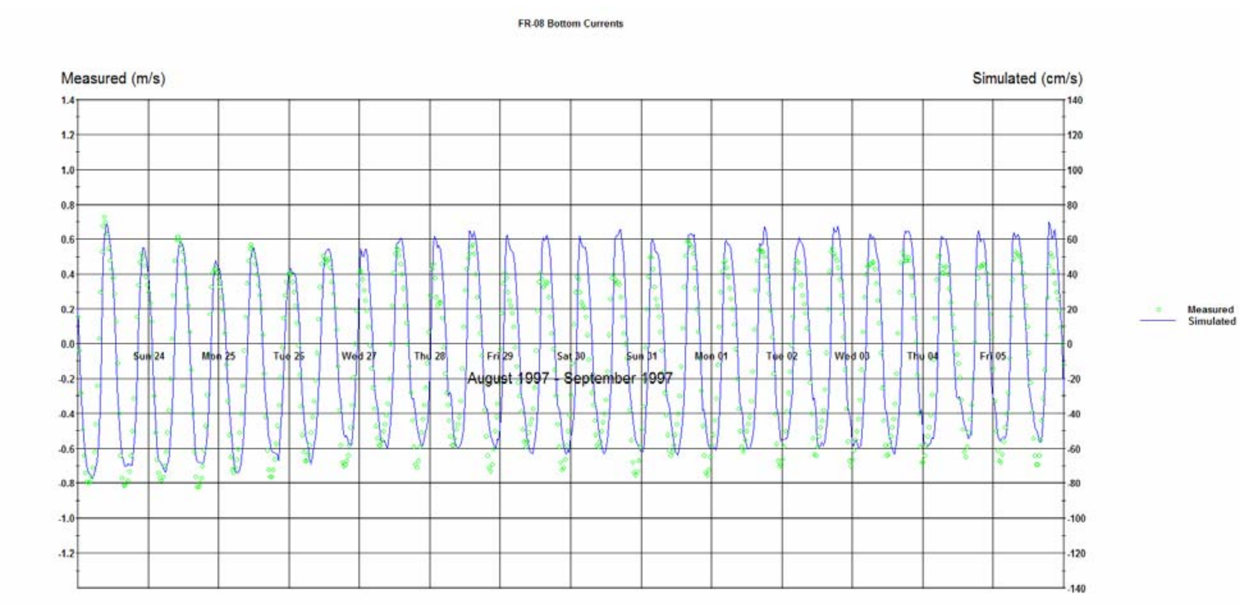


Figure E-26 Currents Comparison at FR-08 Bottom for August 23, 1997 through September 6, 1997

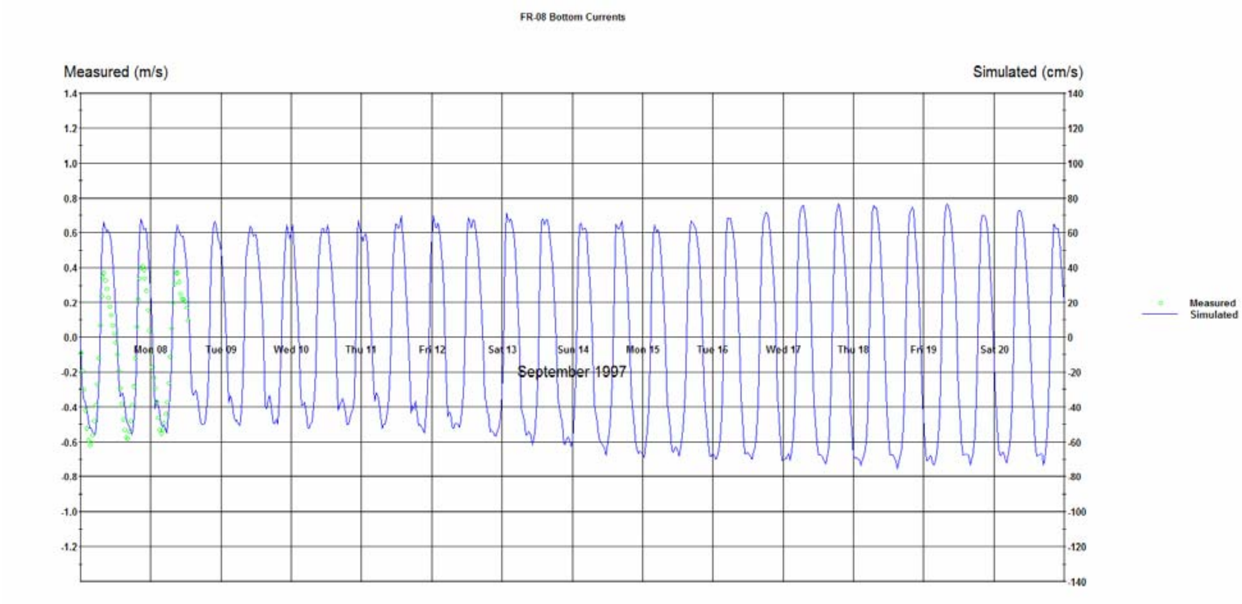


Figure E-27 Currents Comparison at FR-08 Bottom for September 7, 1997 through September 21, 1997

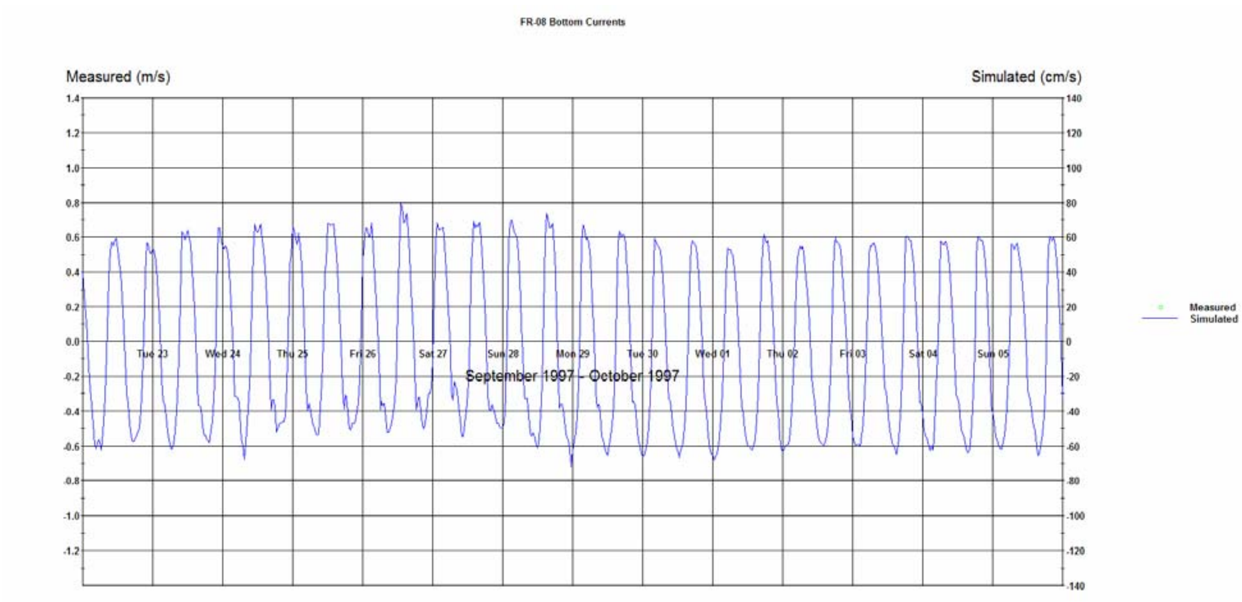


Figure E-28 Currents Comparison at FR-08 Bottom for September 22, 1997 through October 6, 1997

APPENDIX F 1999 FLOW COMPARISONS

Table F-1 1999 Flow Transect Locations and Julian Day

Station	I	J	1999 Julian Day
FR2	13-15	96	964, 998, 1011
MR2	26	96	964, 998, 1011
LBR2	30	96	964,998
FR3	13-15	53	963, 999, 1010
BR	30-32	60	963, 999, 1010
FJ	13-17	49	963, 999, 1010
FR1	13-15	118	1002, 1009
MR1	26	120	1002, 1009
LBR1	30	123	1002, 1009
I95 –GPA14	13-14	126	1007
FW1	33	123	1022, 1028
FW2	39	114	1022, 1028
FW3	30	109	1022, 1028
FW4	30	92	1021, 1029
FW5	30-31	76	1021, 1029
FW6	30-32	71	1021, 1029
MC	19	123	1002, 1009
UC	23	125	1002, 1009

Table F-2 1999 Flow Statistical Comparison

1999 Flow Comparisons (m^3/s)								
Transect Location	**Julian Day 1997**	**Date**	**Peak Flood**		**Peak Ebb**		**Ebb Difference**	**Flood Difference**
			Simulated	**Measured**	**Simulated**	**Measured**		
FJ	963	August 21	2,989	2,850				5%
	999	September 26			-3,380	-5,080	-33%	
	1010	October 07			-3,343	-4,678	-29%	
FR3	963	August 21	1,738	1,744				0%
	999	September 26			-2,402	-2,951	-19%	
	1010	October 07			-2,090	-2,755	-24%	
BR	963	August 21	1,033	1,037				0%
	999	September 26			-1,049	-1,543	-32%	
	1010	October 07			-1,219	-1,558	-22%	
FR2	964	August 22			-694	-918	-24%	
	998	September 25			-1,065	-1,460	-27%	
	1011	October 08			-1,064	-1,505	-29%	
MR2	964	August 22	208	163	-167	-181	-8%	28%
	998	September 25			-250	-467	-46%	
	1011	October 08			-241	-490	-51%	
LBR2	964	August 22	107	110	-120	-144	-17%	-3%
	998	September 25			-155	-241	-36%	
FR1	1002	September 29			-684	-873	-22%	
	1009	October 06	641	651	-625	-942	-34%	-2%
MR1	1002	September 29			-130	-126	3%	
	1009	October 06	95	94				1%
LBR1	1002	September 29	2	45				-96%
	1009	October 06			-38	-55	-31%	
I-95	1007	October 04	362	434	-448	-687	-35%	-17%
FW1	1022	October 19	0	7	-17	-43	-60%	-100%
	1028	October 25	10	42	-39	-74	-47%	-76%
FW2	1022	October 19	95	67	-60	-101	-41%	42%
	1028	October 25	130	108	-71	-188	-62%	20%
FW3	1022	October 19	162	102	-87	-158	-45%	59%
	1028	October 25	190	143	-128	-247	-48%	33%
FW4	1021	October 18	58	162	-117	-209	-44%	-64%
	1029	October 26	232	245	-174	-347	-50%	-5%
FW5	1021	October 18	388	385	-313	-347	-10%	1%
	1029	October 26	644	648	-418	-804	-48%	-1%
FW6	1021	October 18	463	552	-363	-486	-25%	-16%
MC	272	September 29	111	137				-19%
	279	6-Oct	106	106	-100	-166	-40%	0%
UC	272	September 29			-106	-175	-39%	
	279	6-Oct	156	101	-100	-173	-42%	54%

NOTES: [grey box] = Determined to be insufficient data to determine peak

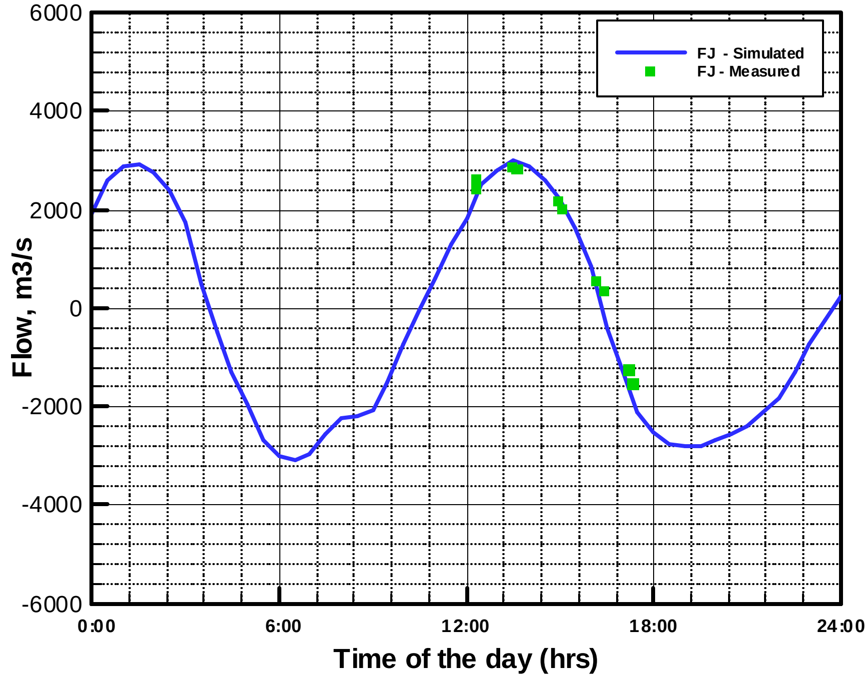


Figure F-1 Flow (m3/s) at Transect FJ on August 21, 1999

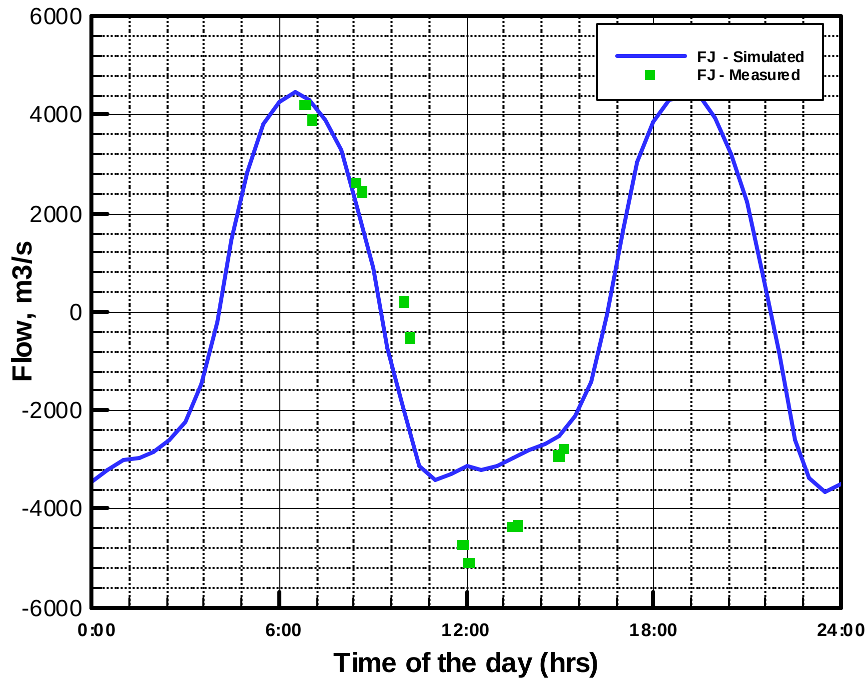


Figure F-2 Flow (m3/s) at Transect FJ on September 26, 1999

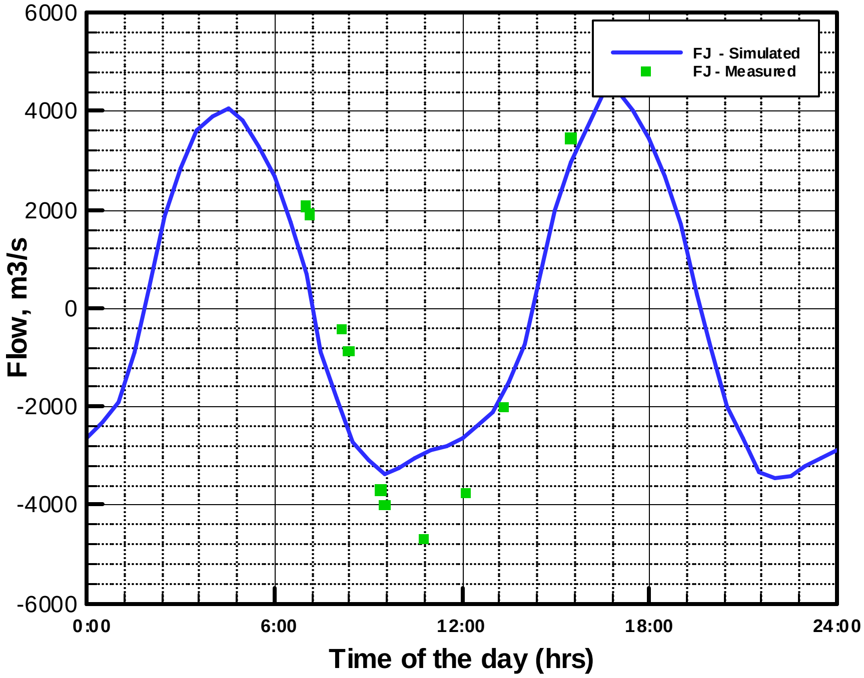


Figure F-3 Flow (m3/s) at Transect FJ on October 7, 1999

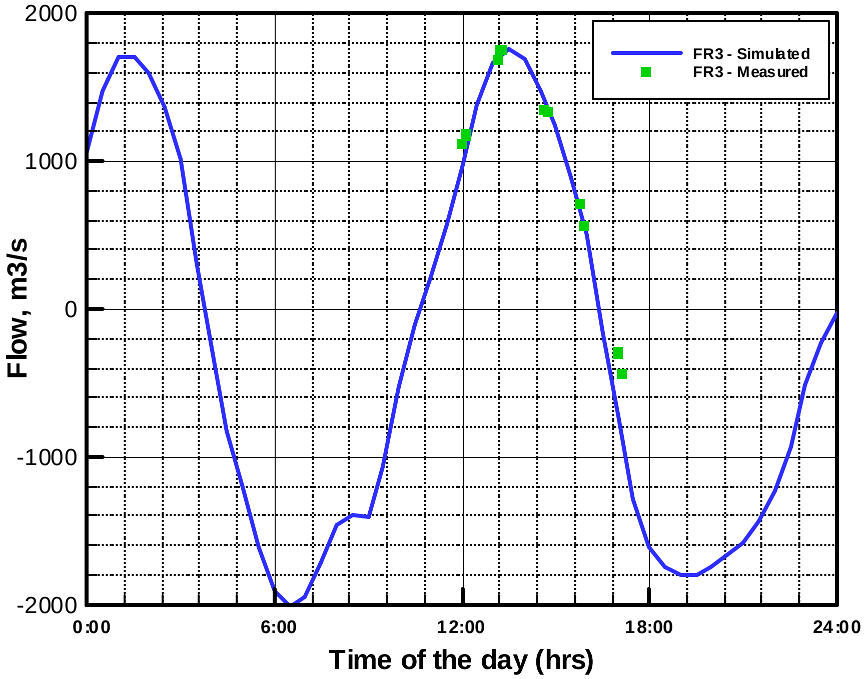


Figure F-4 Flow (m3/s) at Transect FR3 on August 21, 1999

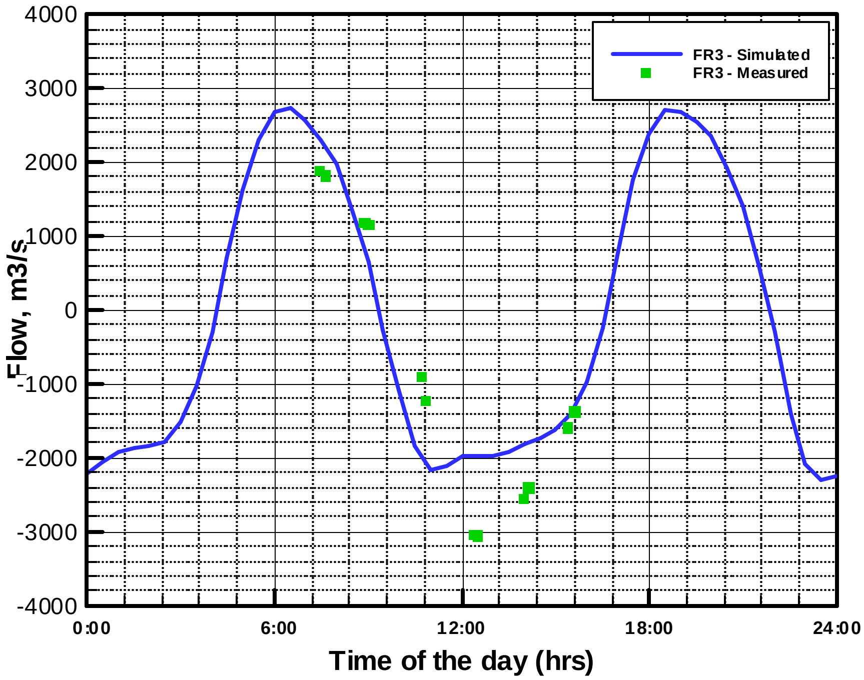


Figure F-5 Flow (m3/s) at Transect FR3 on September 26, 1999

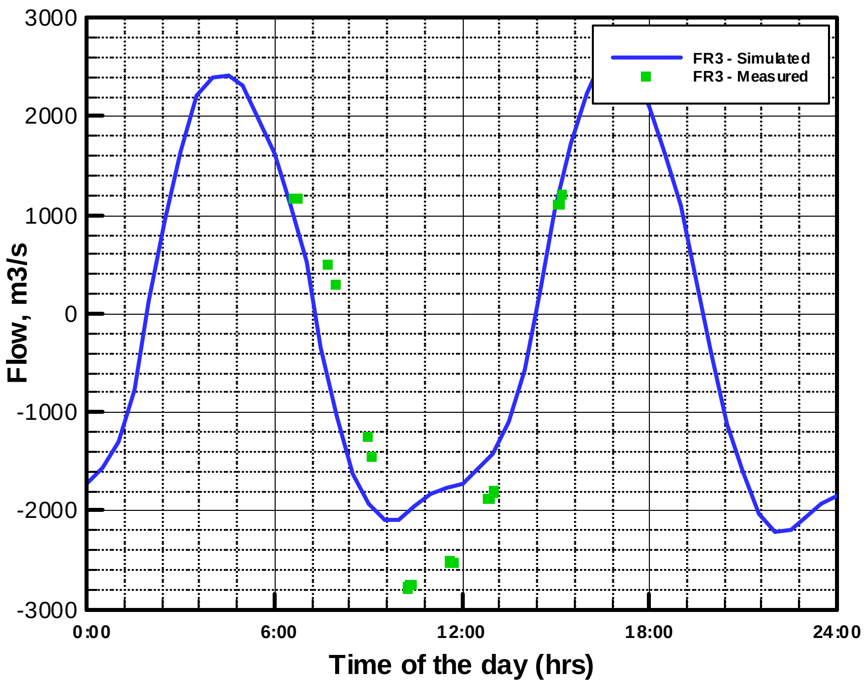


Figure F-6 Flow (m3/s) at Transect FR3 on October 7, 1999

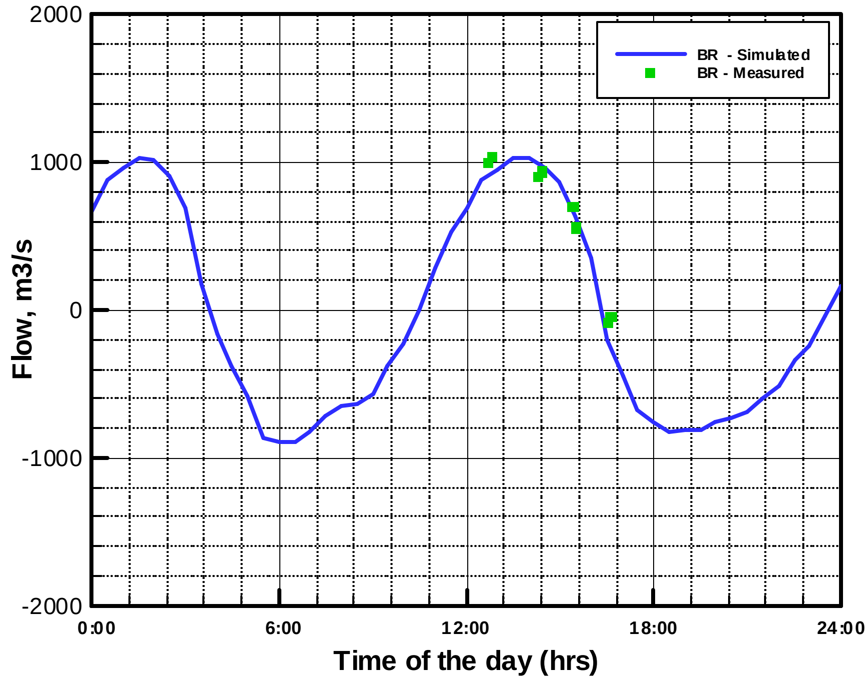


Figure F-7 Flow (m3/s) at Transect BR on August 21, 1999

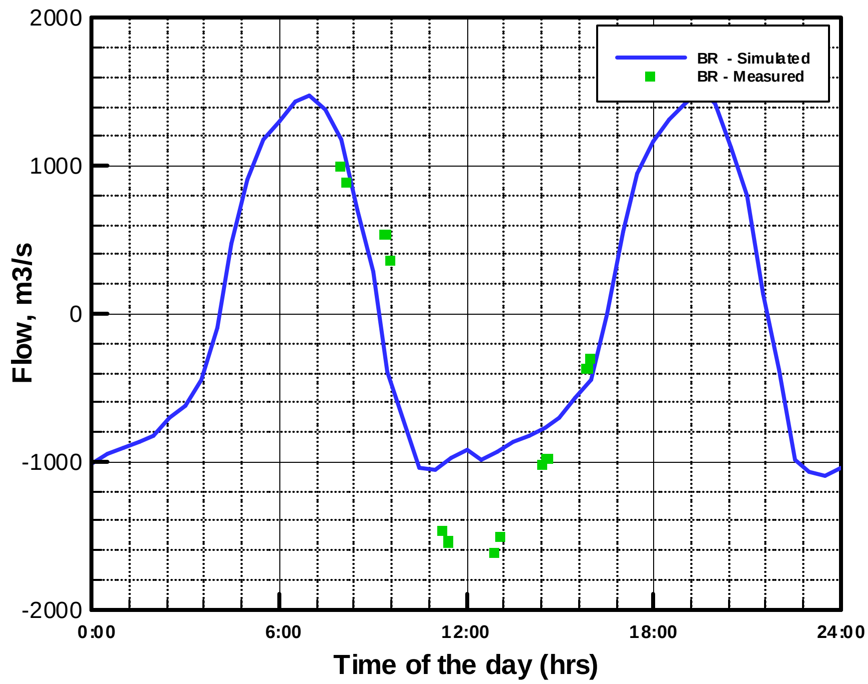


Figure F-8 Flow (m3/s) at Transect BR on September 26, 1999

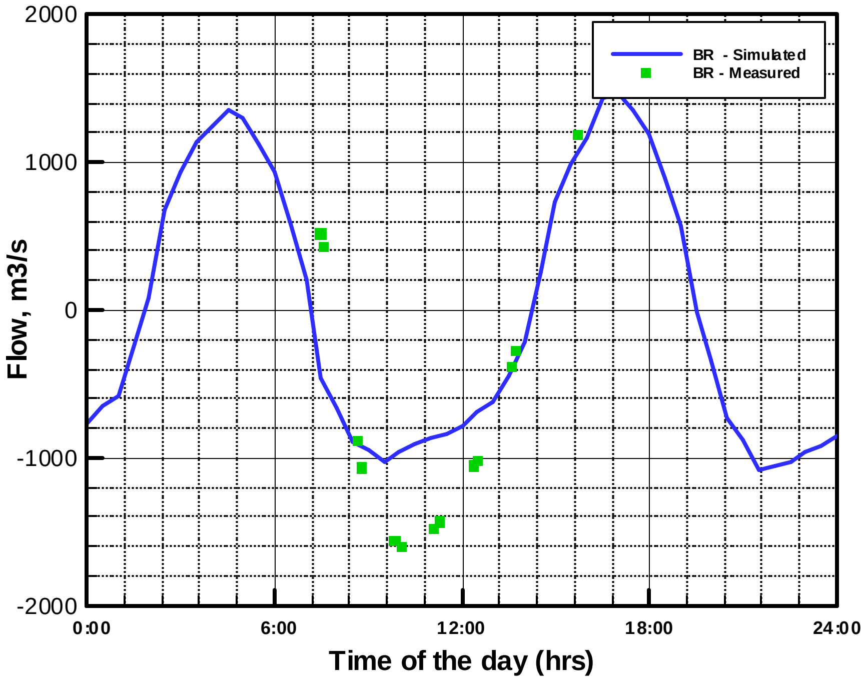


Figure F-9 Flow (m3/s) at Transect BR on October 7, 1999

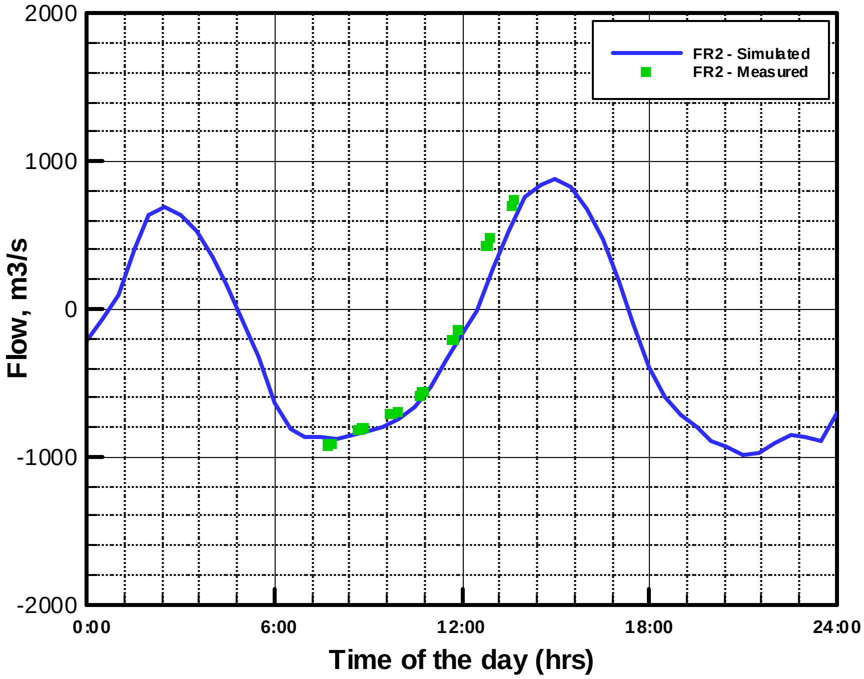


Figure F-10 Flow (m3/s) at Transect FR2 on August 22, 1999

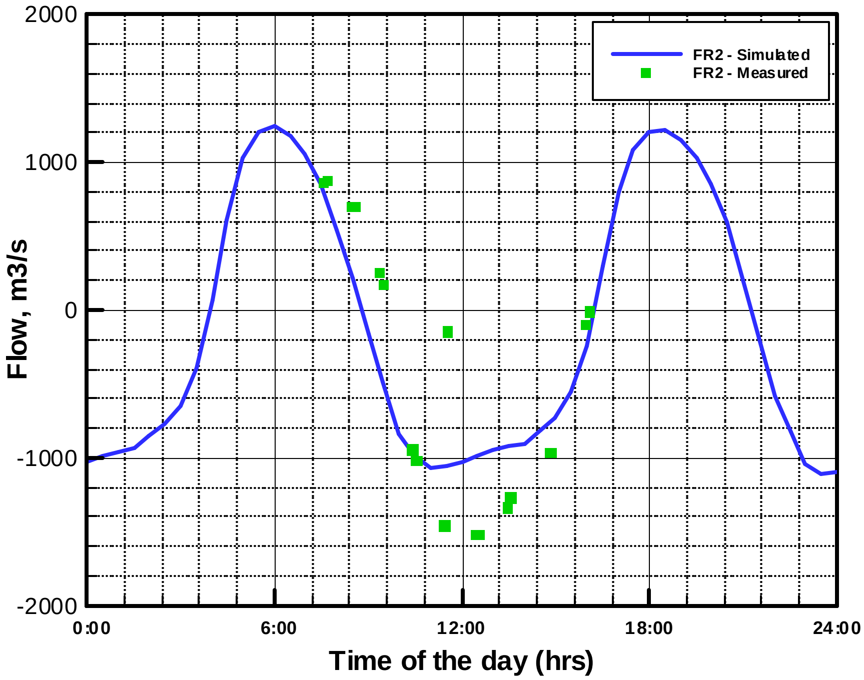


Figure F-11 Flow (m3/s) at Transect FR2 on September 25, 1999

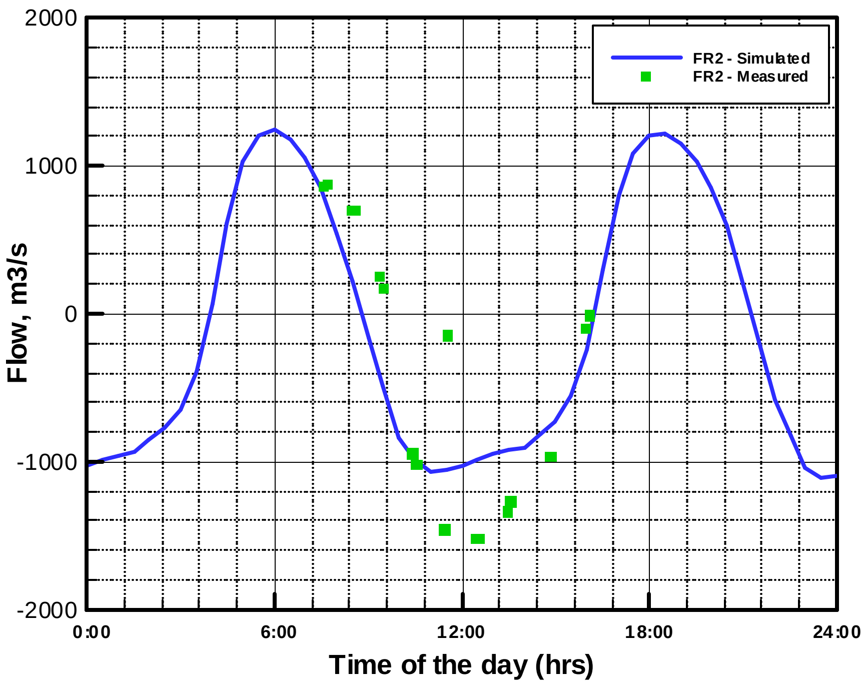


Figure F-12 Flow (m3/s) at Transect FR2 on October 8, 1999

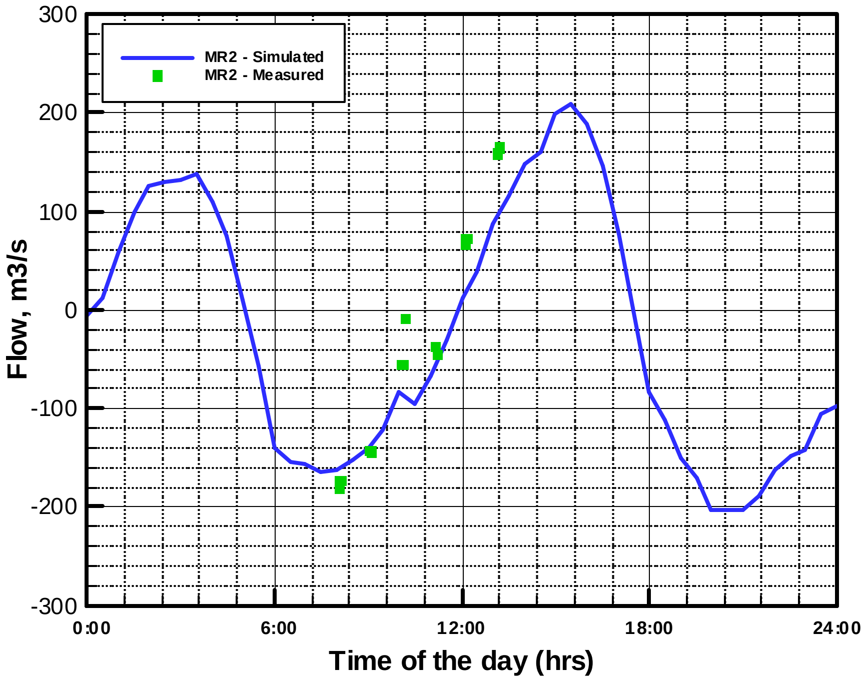


Figure F-13 Flow (m3/s) at Transect MR2 on August 22, 1999

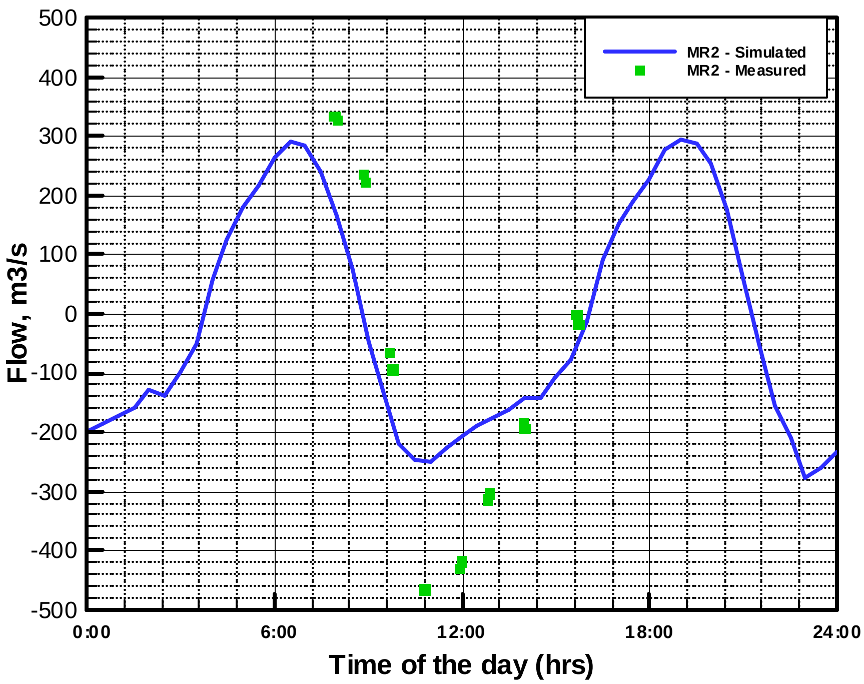


Figure F-14 Flow (m3/s) at Transect MR2 on September 25, 1999

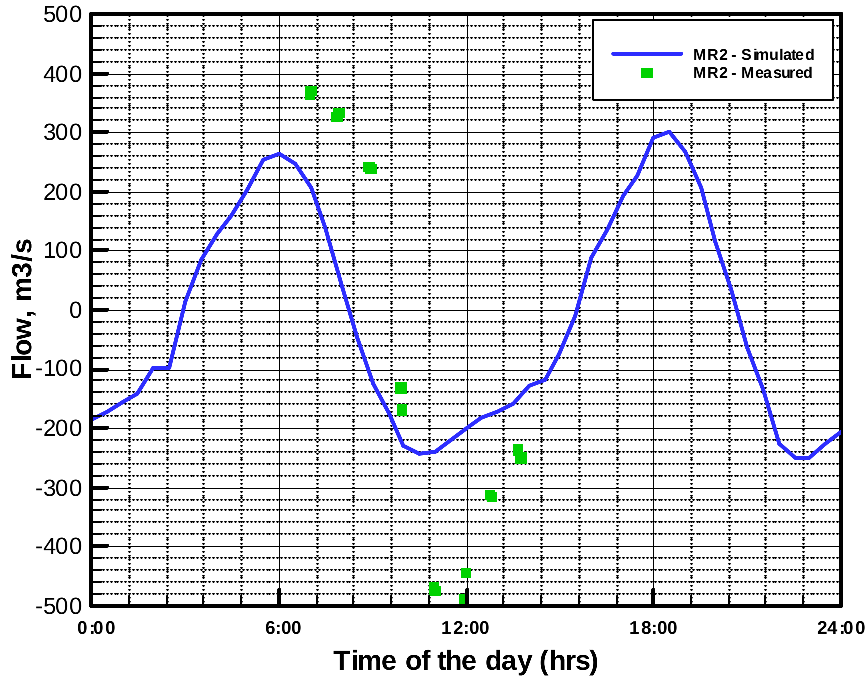


Figure F-15 Flow (m3/s) at Transect MR2 on October 8, 1999

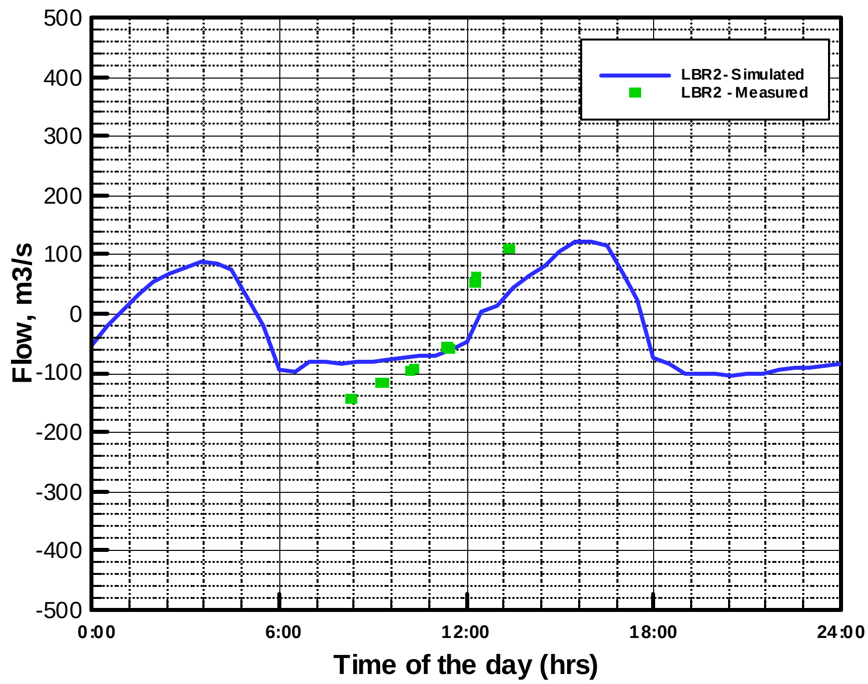


Figure F-16 Flow (m3/s) at Transect LBR2 on August 22, 1999

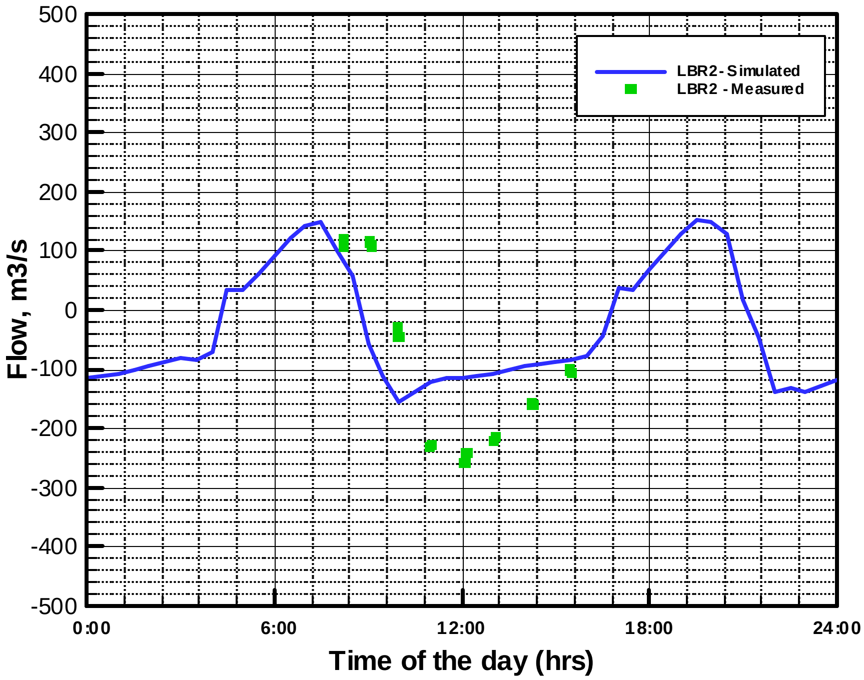


Figure F-17 Flow (m3/s) at Transect LBR2 on September 25, 1999

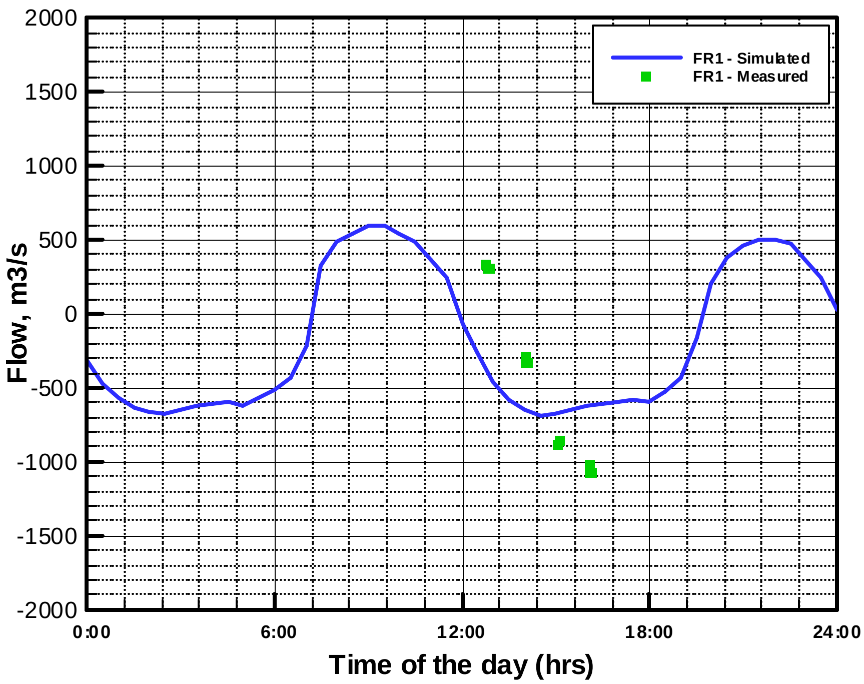


Figure F-18 Flow (m3/s) at Transect FR1 on September 29, 1999

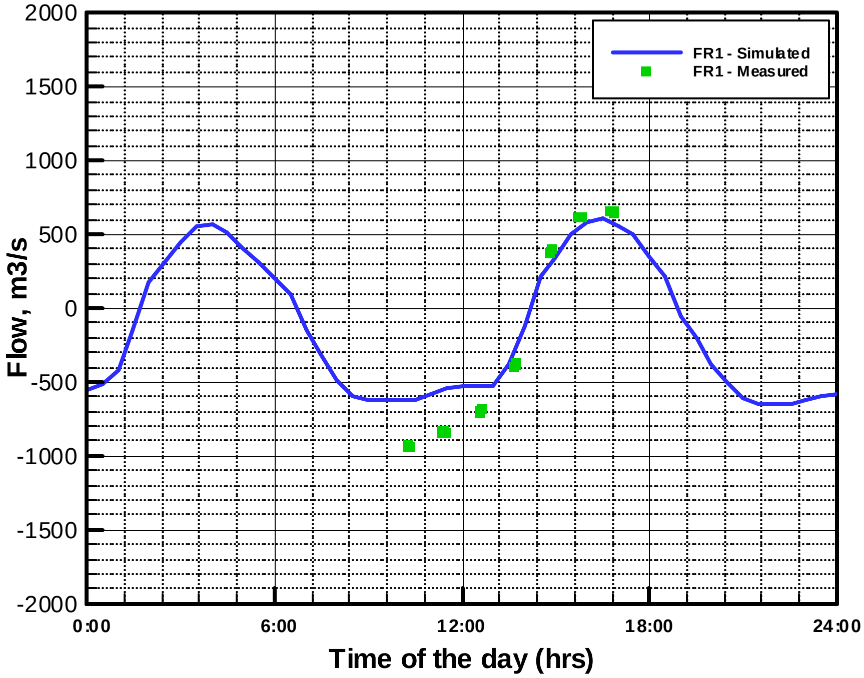


Figure F-19 Flow (m3/s) at Transect FR1 on October 6, 1999

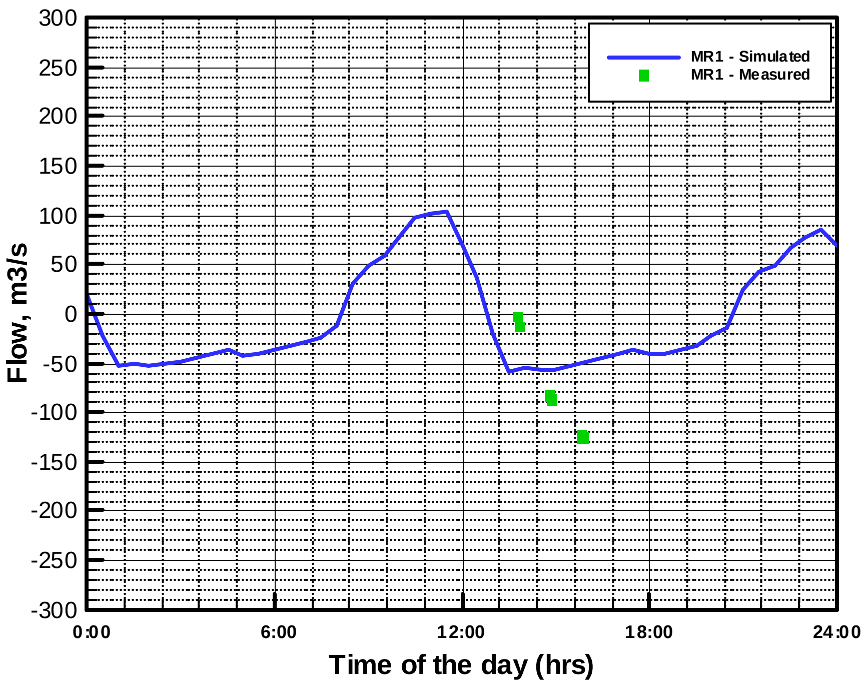


Figure F-20 Flow (m3/s) at Transect MR1 on September 29, 1999

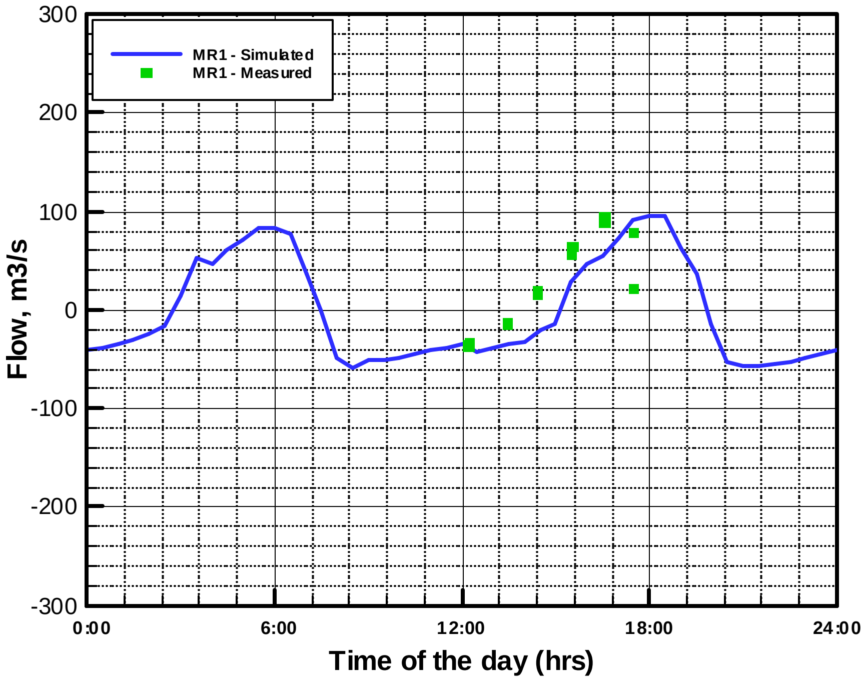


Figure F-21 Flow (m3/s) at Transect MR1 on October 6, 1999

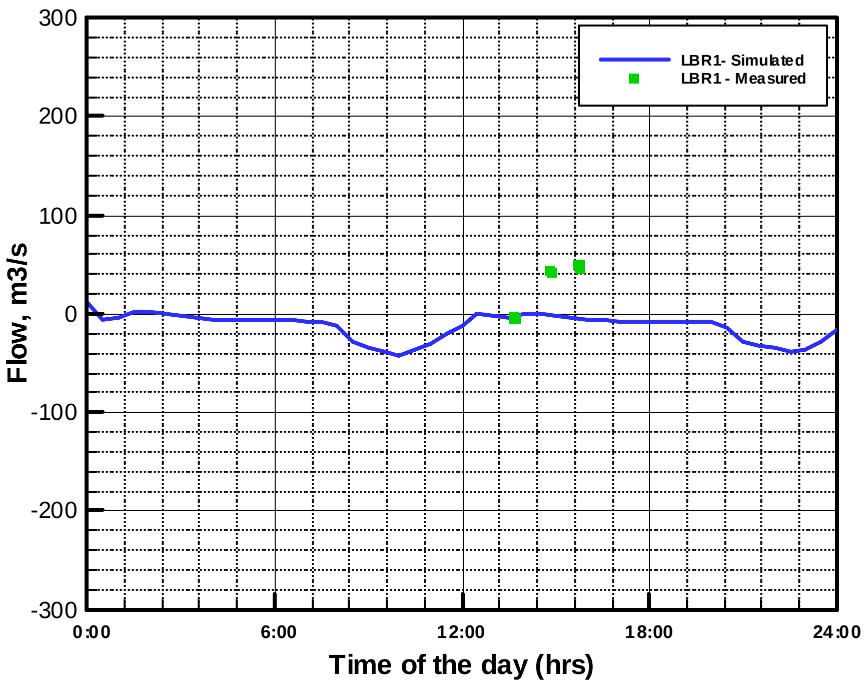


Figure F-22 Flow (m3/s) at Transect LBR1 on September 29, 1999

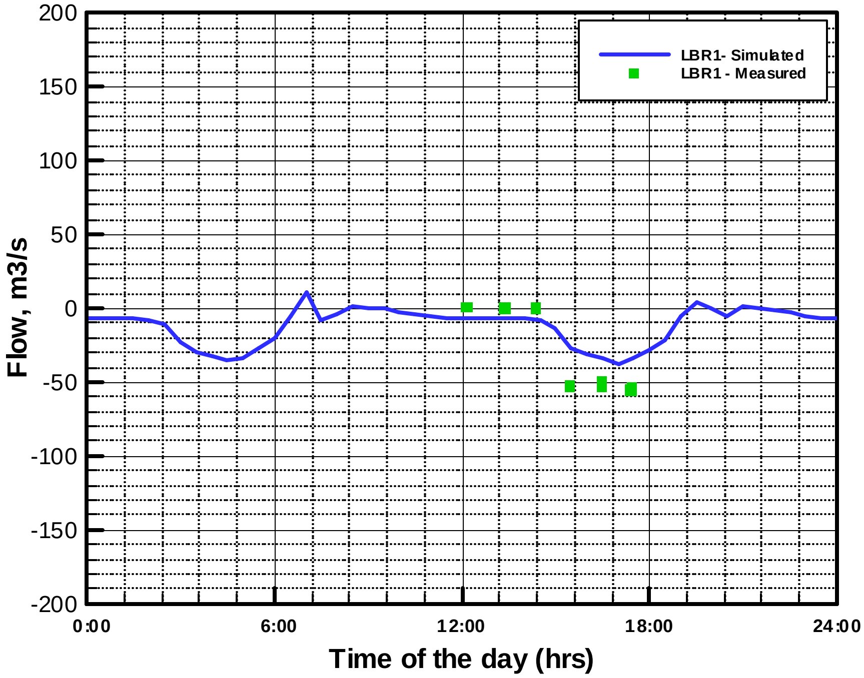


Figure F-23 Flow (m3/s) at Transect LBR1 on October 6, 1999

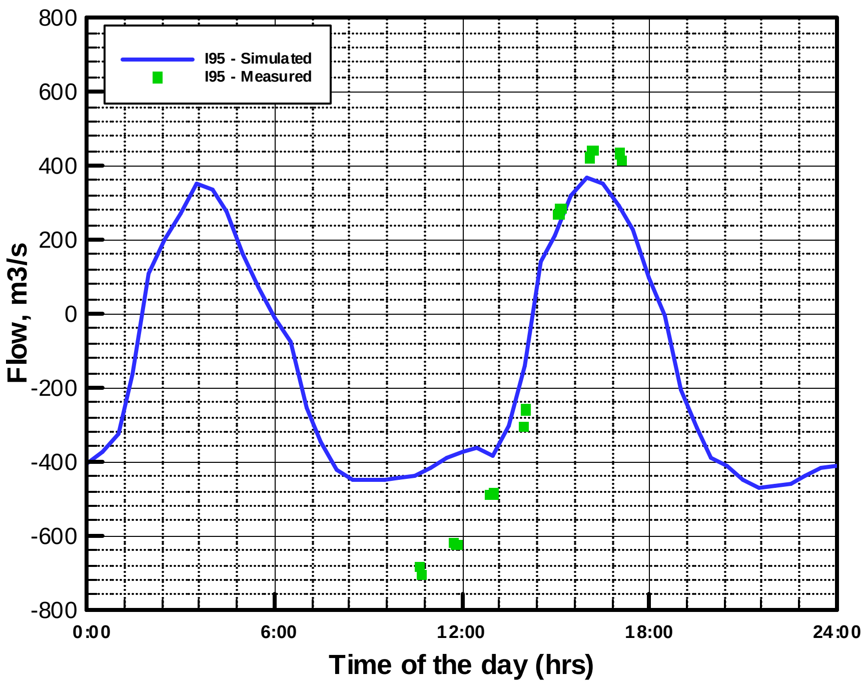


Figure F-24 Flow (m3/s) at Transect I-95 on October 4, 1999

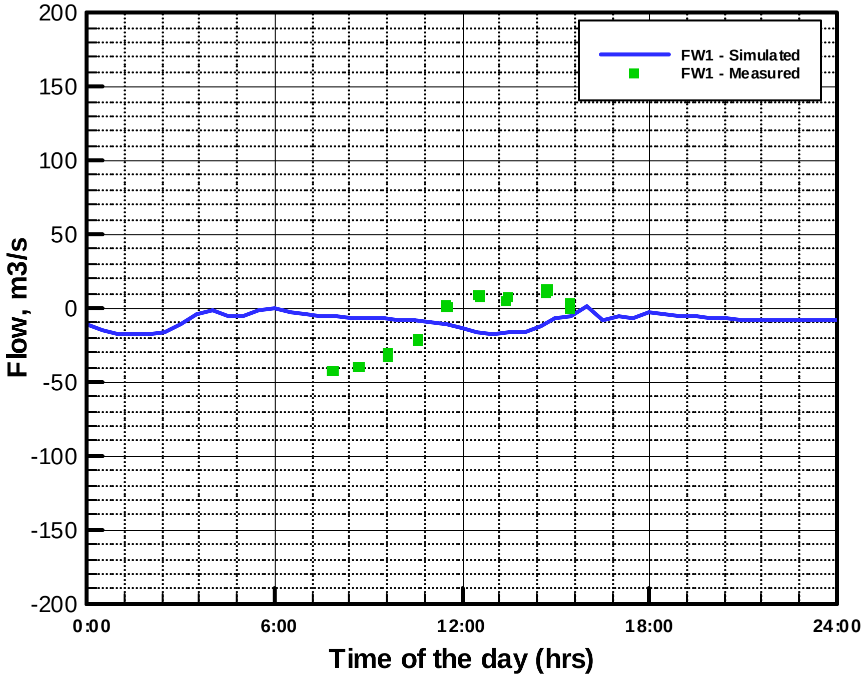


Figure F-25 Flow (m3/s) at Transect FW1 on October 19, 1999

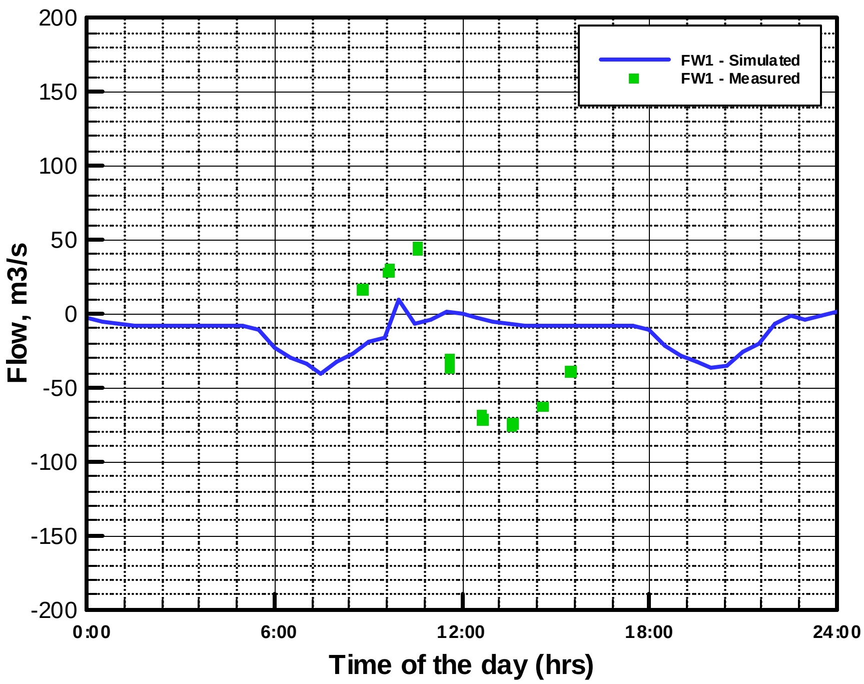


Figure F-26 Flow (m3/s) at Transect FW1 on October 25, 1999

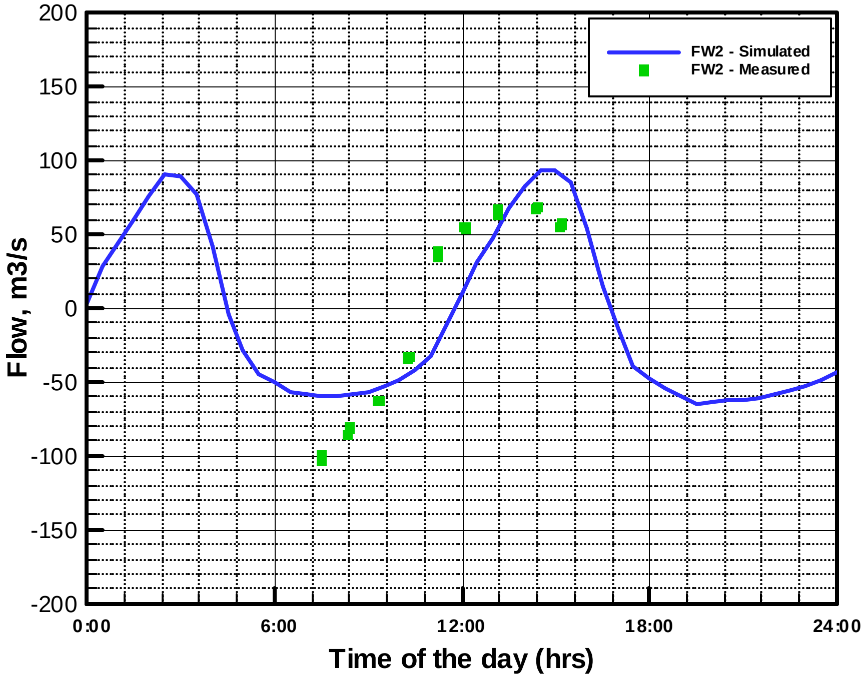


Figure F-27 Flow (m3/s) at Transect FW2 on October 19, 1999

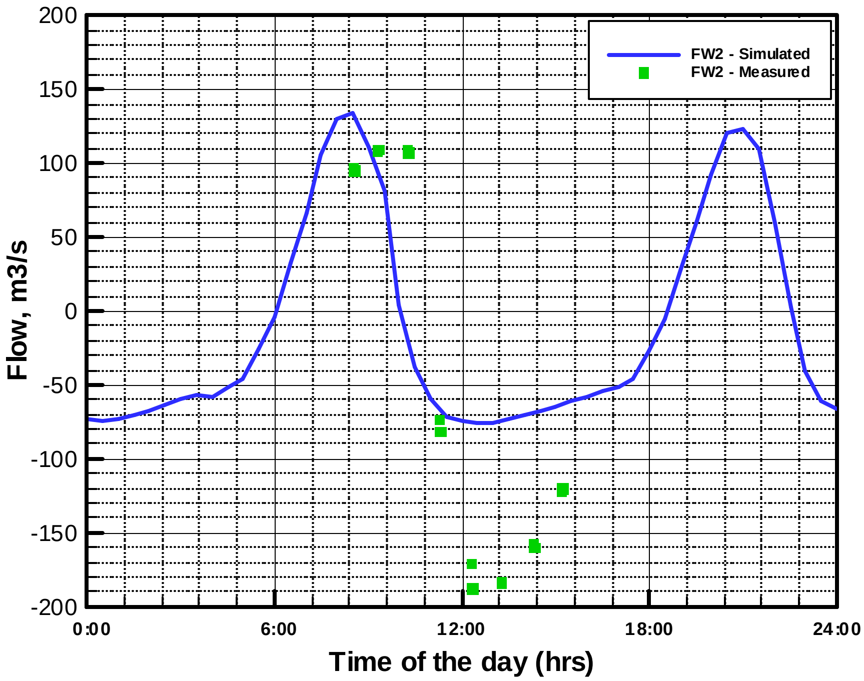


Figure F-28 Flow (m3/s) at Transect FW2 on October 25, 1999

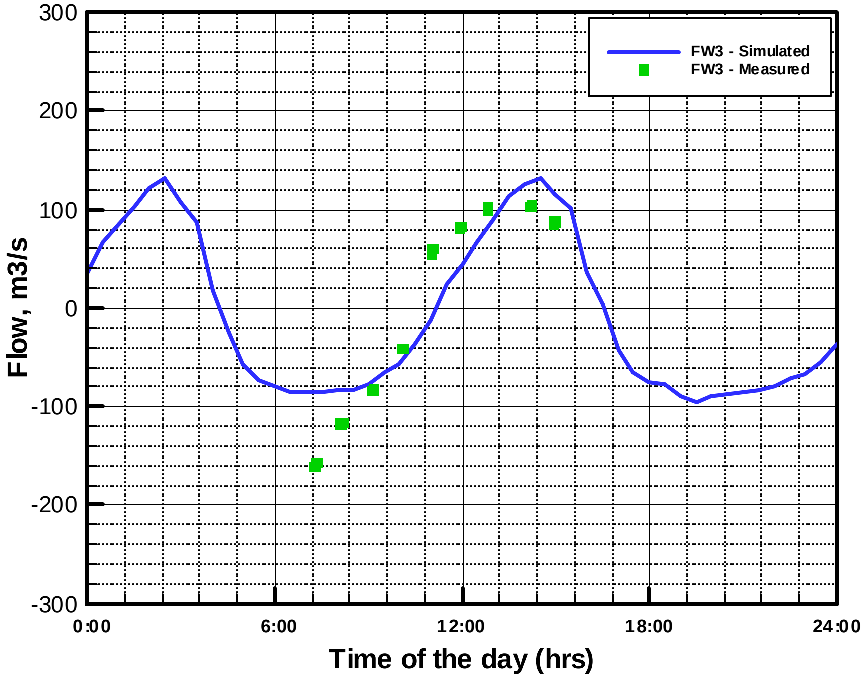


Figure F-29 Flow (m3/s) at Transect FW3 on October 19, 1999

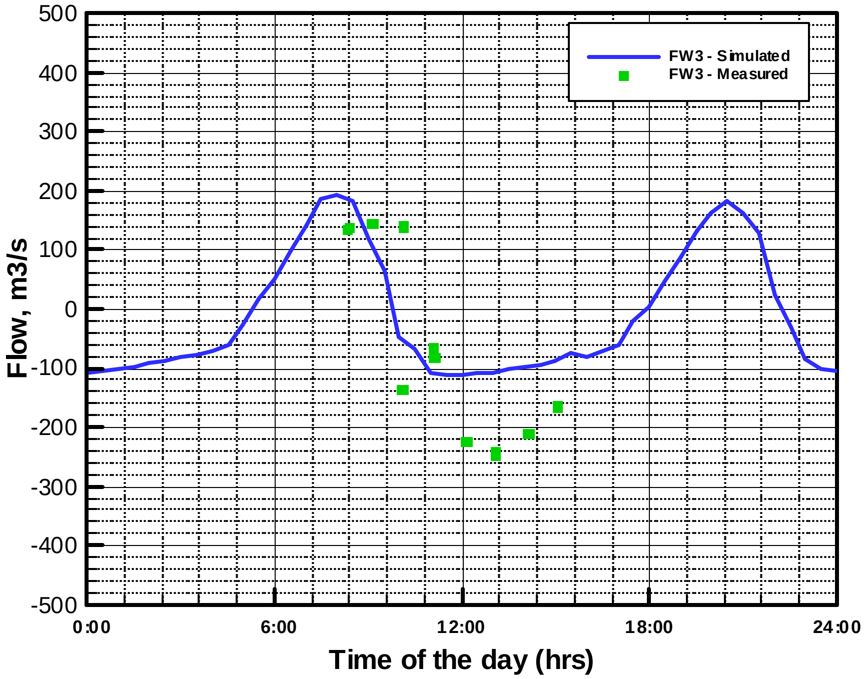


Figure F-30 Flow (m3/s) at Transect FW3 on October 25, 1999

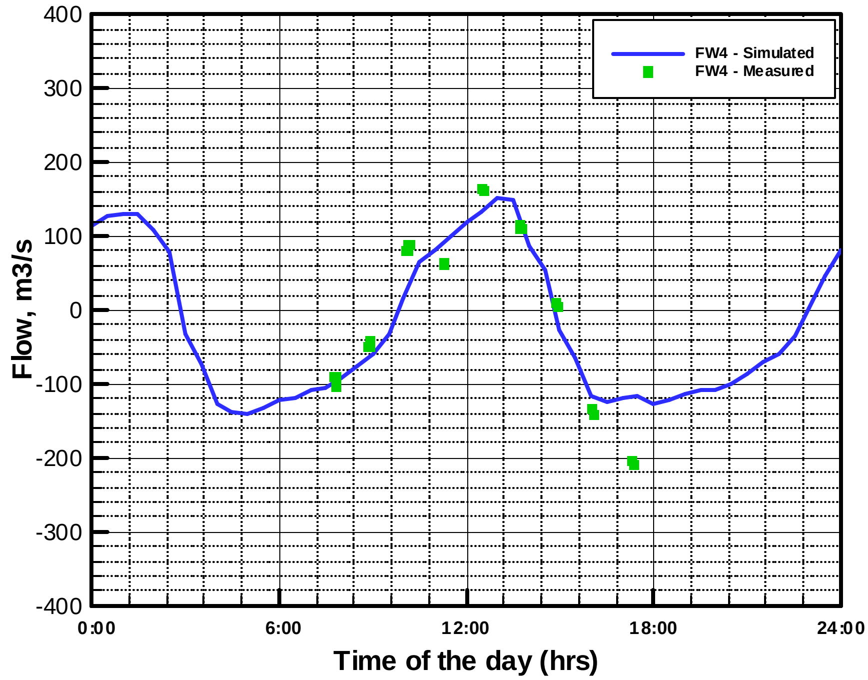


Figure F-31 Flow (m3/s) at Transect FW4 on October 18, 1999

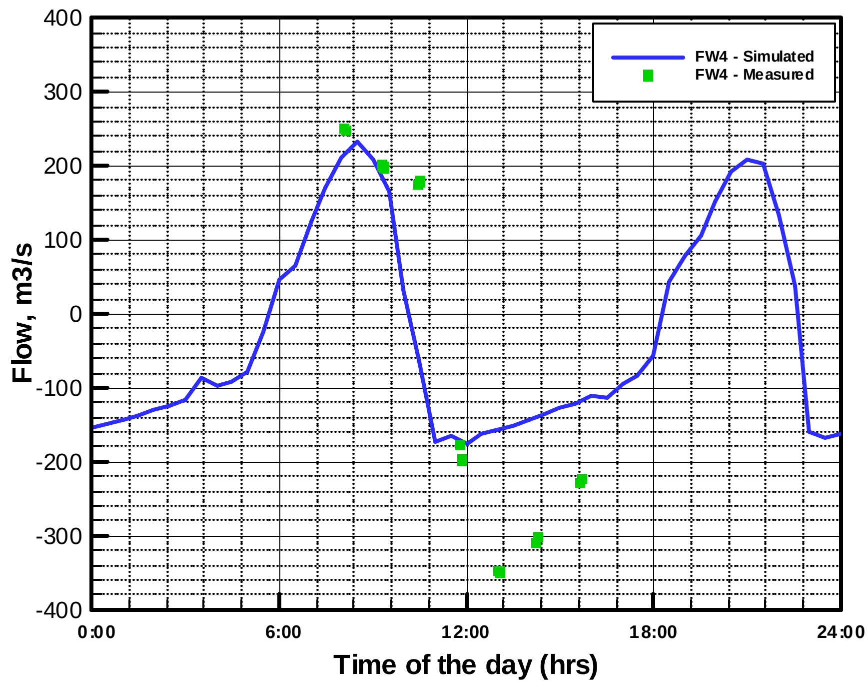


Figure F-32 Flow (m3/s) at Transect FW4 on October 26, 1999

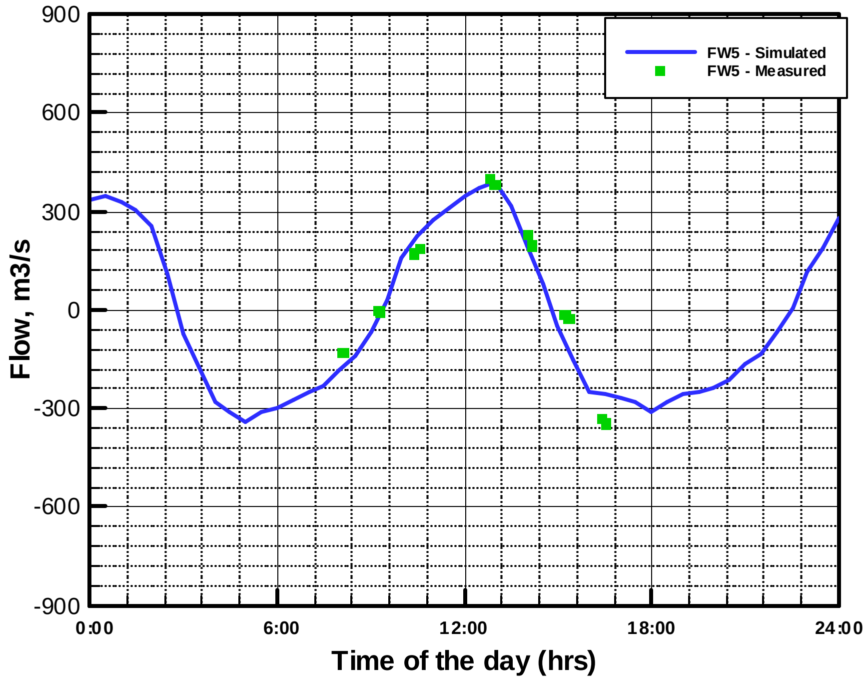


Figure F-33 Flow (m3/s) at Transect FW5 on October 18, 1999

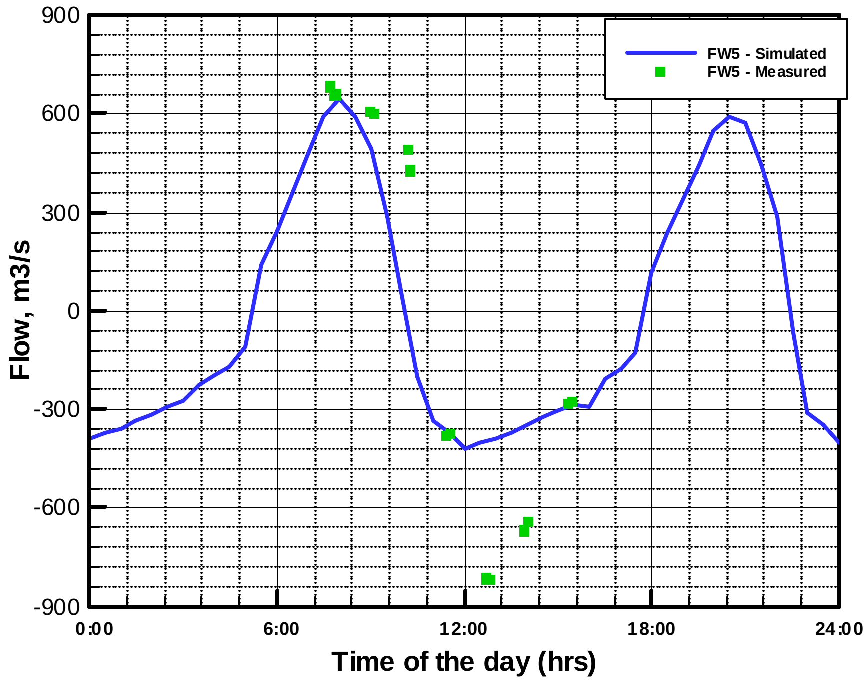


Figure F-34 Flow (m3/s) at Transect FW5 on October 26, 1999

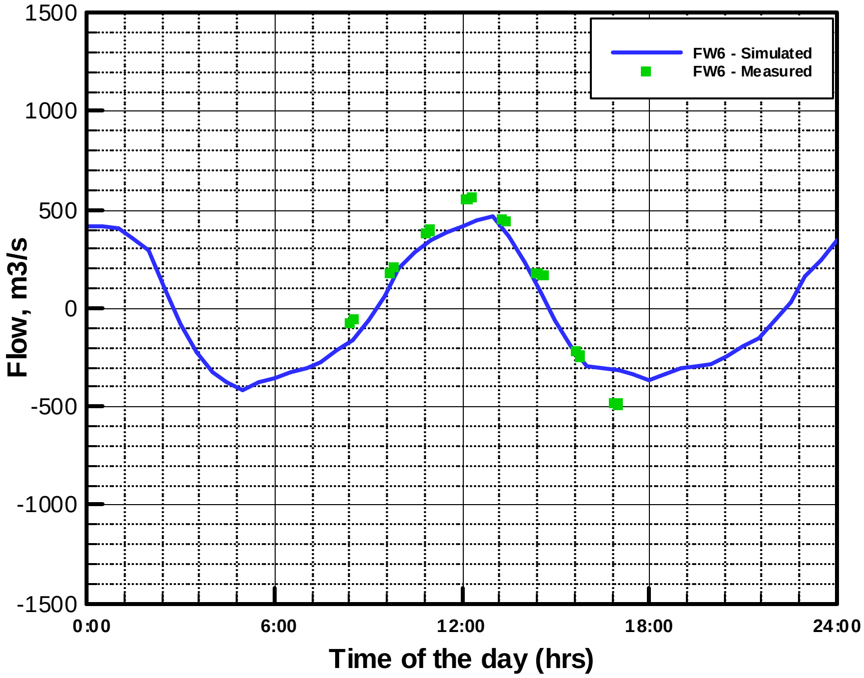


Figure F-35 Flow (m3/s) at Transect FW6 on October 18, 1999

Transect MC on September 29, 1999

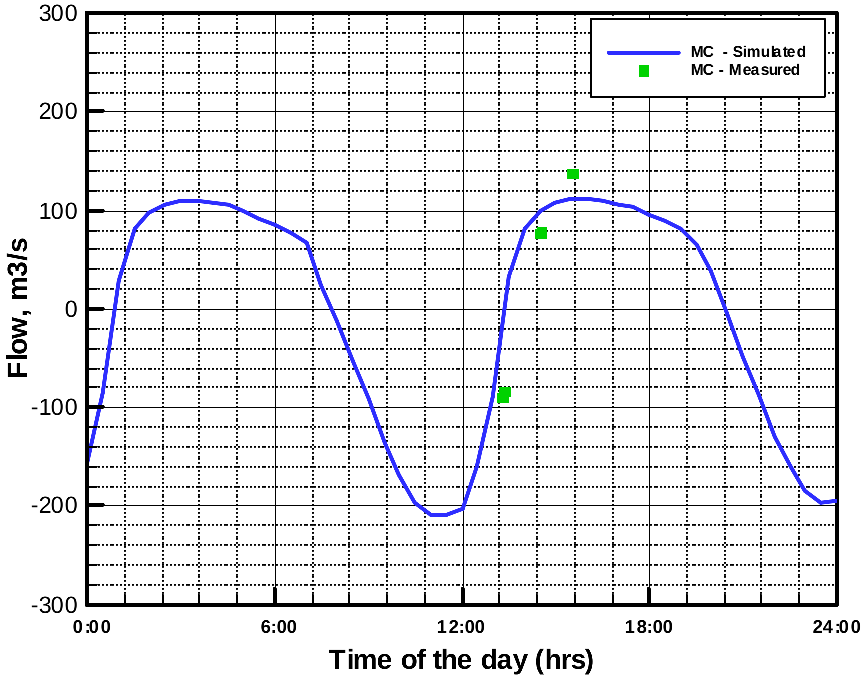


Figure F-36 Flow (m3/s) at Transect MC on September 29, 1999

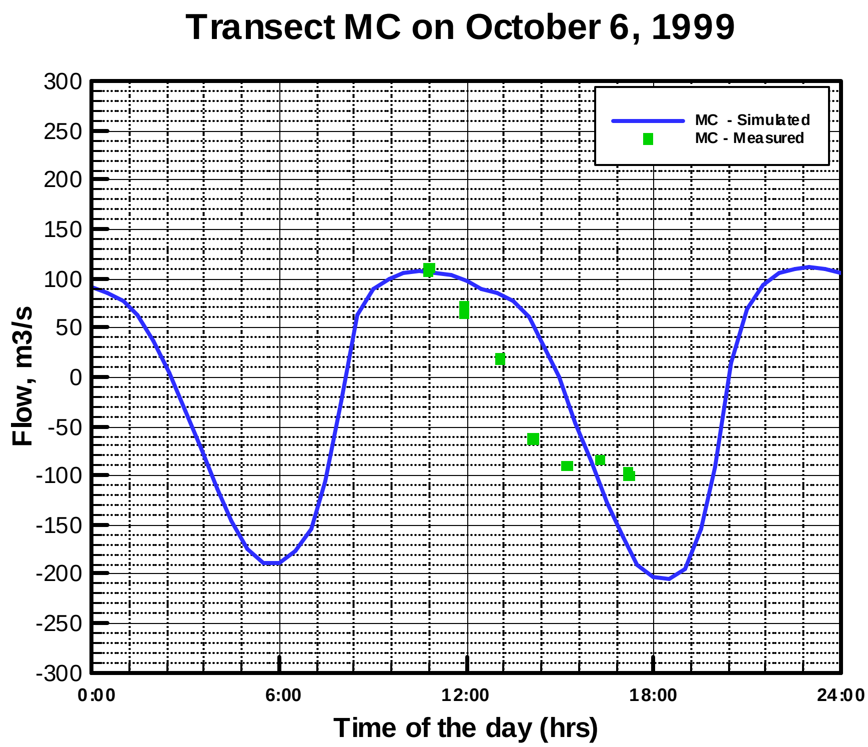


Figure F-37 Flow (m3/s) at Transect MC on October 6, 1999

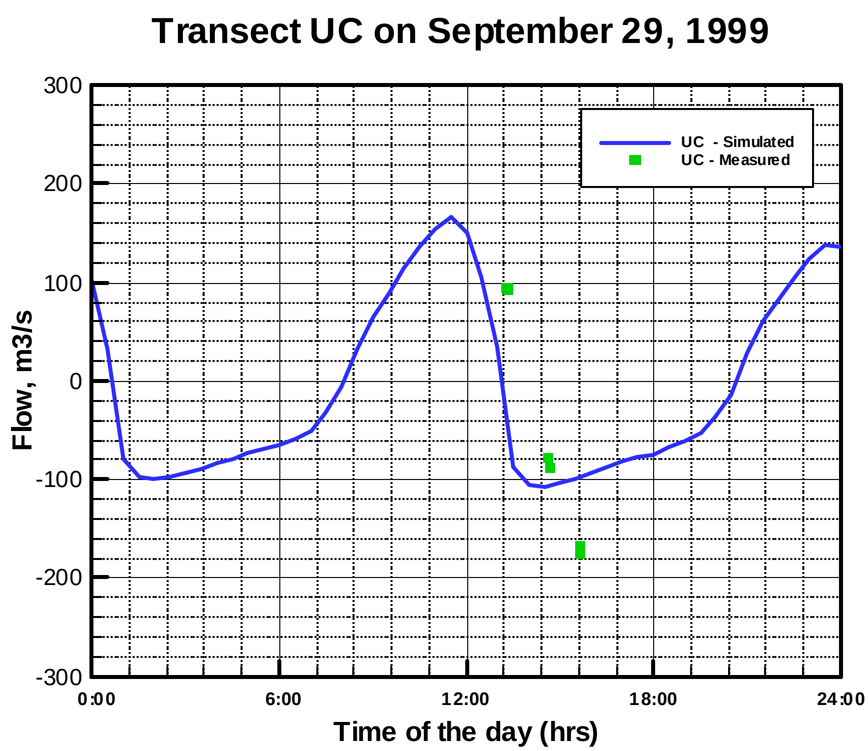


Figure F-38 Flow (m3/s) at Transect UC on September 29, 1999

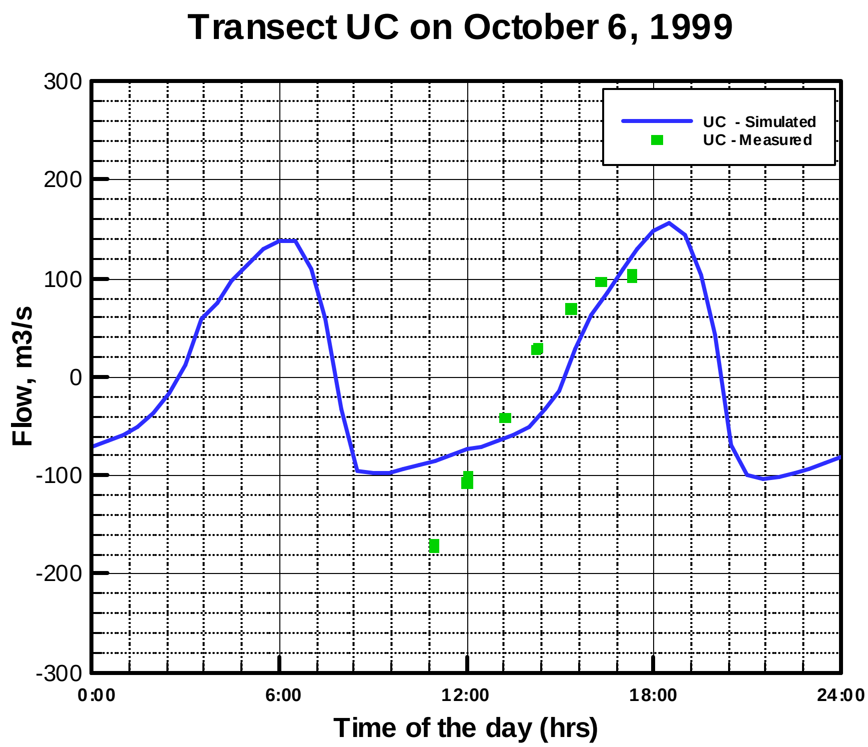


Figure F-39 Flow (m3/s) at Transect UC on October 18, 1999

APPENDIX G 1997 FLOW COMPARISONS

Table G-1 1997 Flow Transect Locations and Julian Day

Station	I	J	1997 Julian Day
FR2	13-15	96	273
MR2	26	96	273
LBR2	30	96	273
FR3	13-15	53	253, 280
BR	30-32	60	253, 280
FJ	13-17	49	253, 276, 280
FR1	13-15	118	279
MR1	26	120	279
LBR1	30	123	279
I95	13-14	126	254, 279
MC	19	123	279
UC	23	125	279

Table G-2 1997 Flow Statistical Comparisons

1997 Flow Comparisons (m^3/s)								
Transect Location	**Julian Day 1997**	**Date**	**Peak Flood**		**Peak Ebb**		**Ebb Difference**	**Flood Difference**
			Simulated	**Measured**	**Simulated**	**Measured**		
FJ	253	September 10	3,052	2,666	-2,938	-3,720	-21%	14%
	276	October 03			-3,250	-4,386	-26%	
	280	October 07	3,170	3,102				2%
FR3	253	September 10	1,841	1,650				12%
	280	October 07	1,916	1,551				24%
BR	253	September 10	1,022	1,050				-3%
	280	October 07	1,057	1,101				-4%
FR2	273	September 30	983	849	-989	-1,076	-8%	16%
MR2	273	September 30	234	300	-183	-248	-26%	-22%
LBR2	273	September 30	105	130	-100	-192	-48%	-19%
FR1	279	October 06	407	352	-660	-661	0%	16%
MR1	279	October 06	61	40	-50	-65	-23%	53%
LBR1	279	October 06	-6	-8	-30	-45	-33%	-25%
I-95	254	September 11	411	229				79%
	279	October 06	224	230	-509	-561	-9%	-3%
MC	279	October 06	25	85	-149	-88	69%	-71%
UC	279	October 06	102	60	-76	-80	-5%	70%

NOTES: [grey shaded cell] = Determined to be insufficient data to determine peak

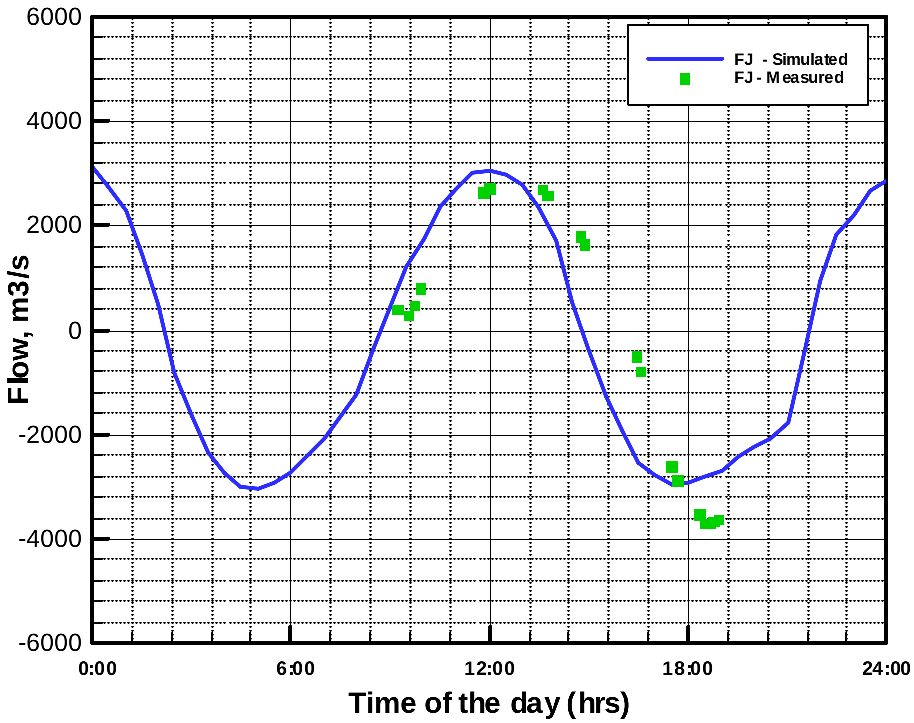


Figure G-1 Flow (m3/s) at Transect FJ on September 10, 1997

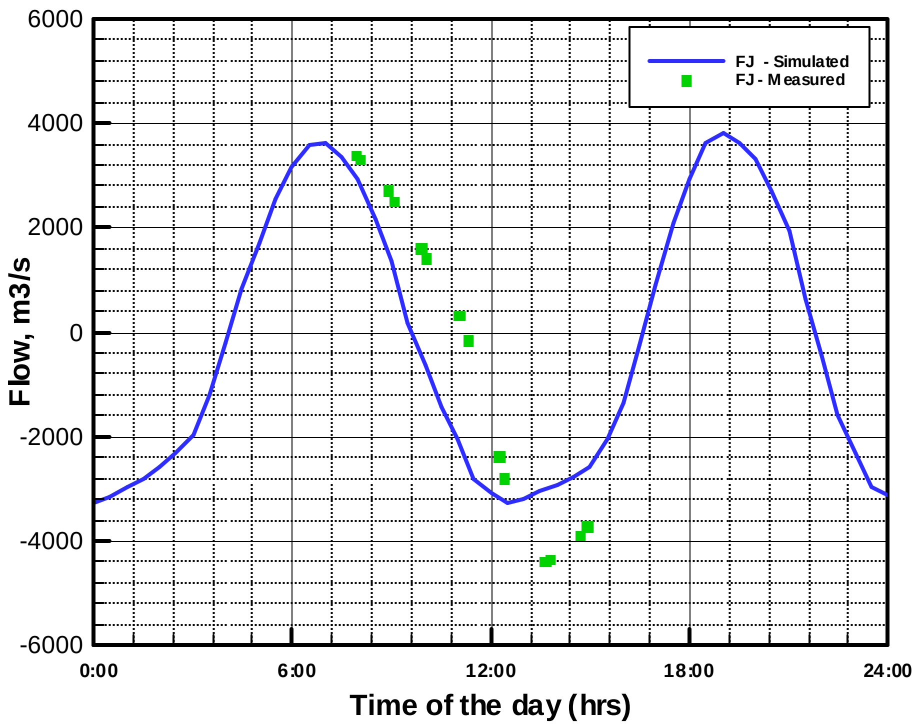


Figure G-2 Flow (m3/s) at Transect FJ on October 3, 1997

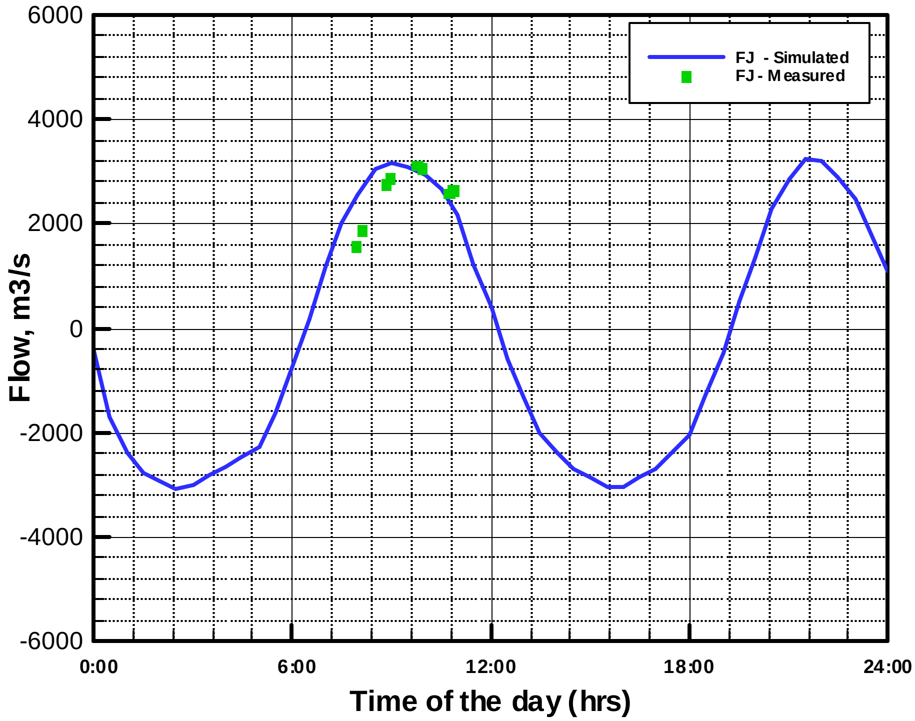


Figure G-3 Flow (m3/s) at Transect FJ on October 7, 1997

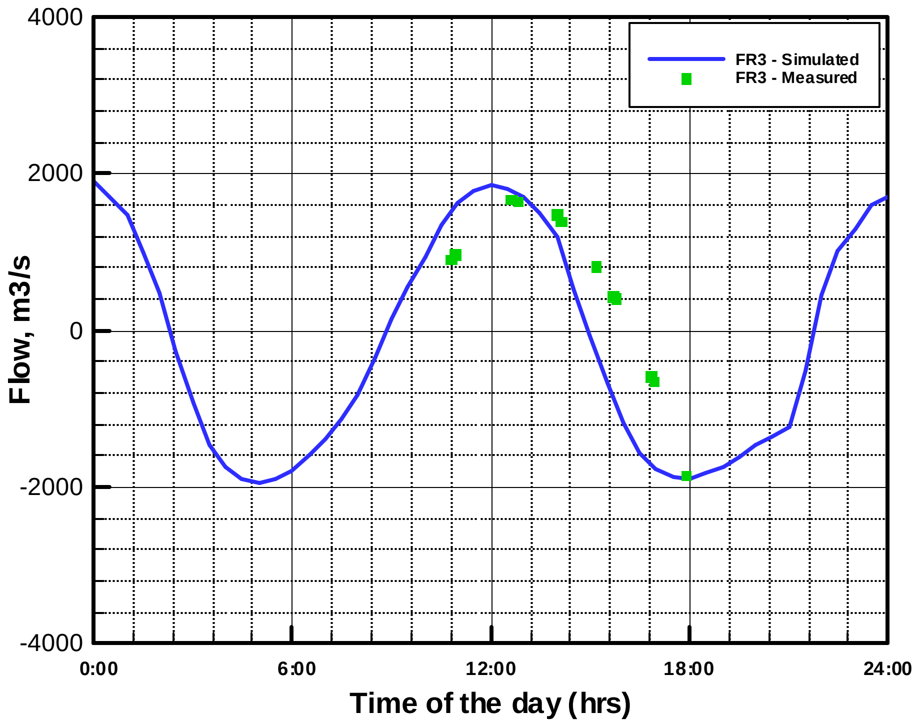


Figure G-4 Flow (m3/s) at Transect FR3 on September 10, 1997

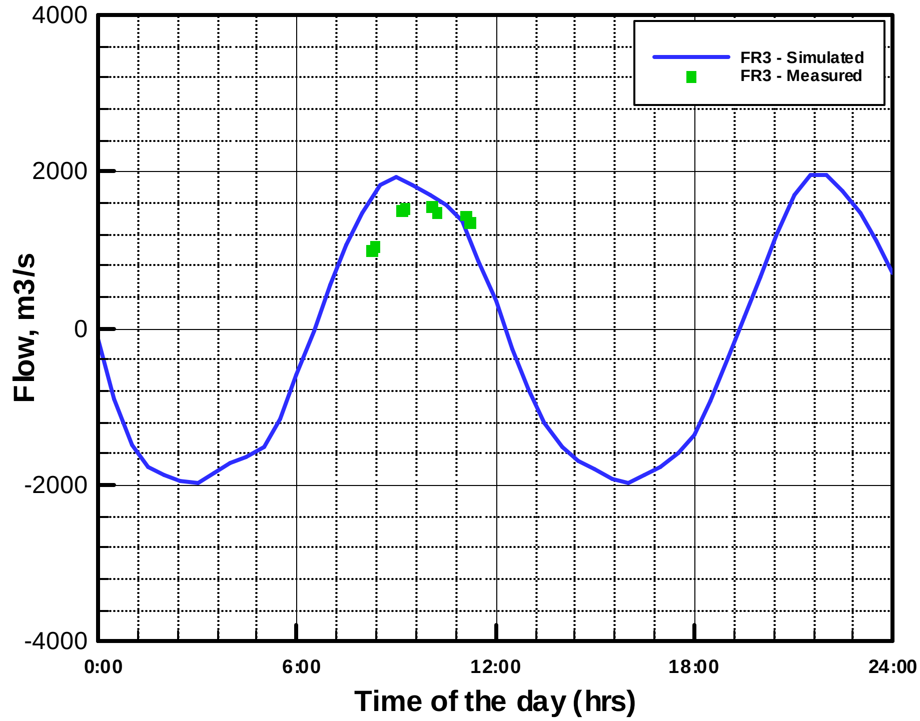


Figure G-5 Flow (m3/s) at Transect FR3 on October 7, 1997

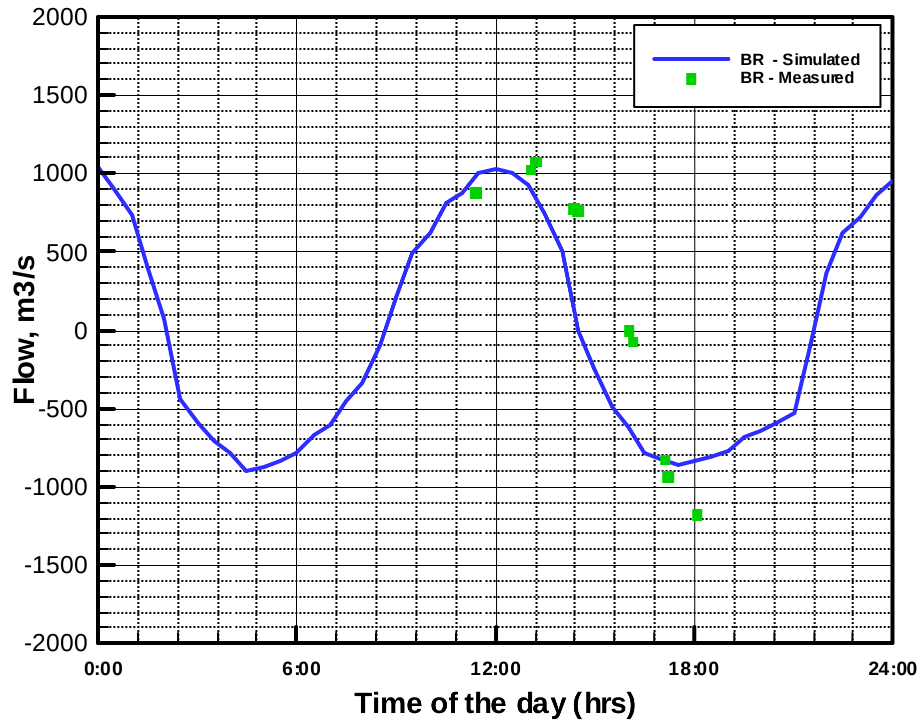


Figure G-6 Flow (m3/s) at Transect BR on September 10, 1997

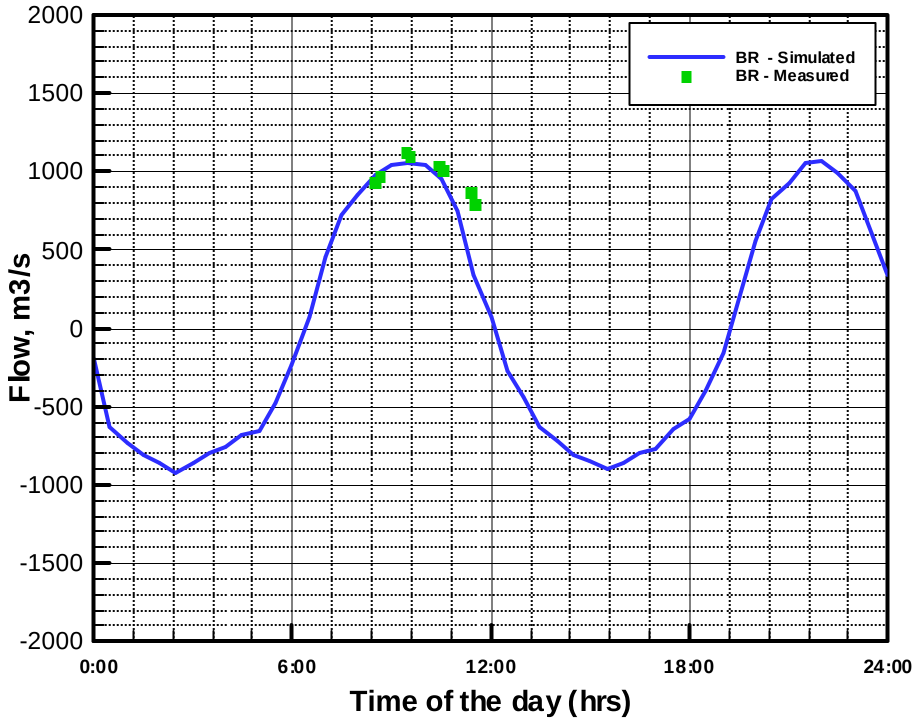


Figure G-7 Flow (m3/s) at Transect BR on October 7, 1997

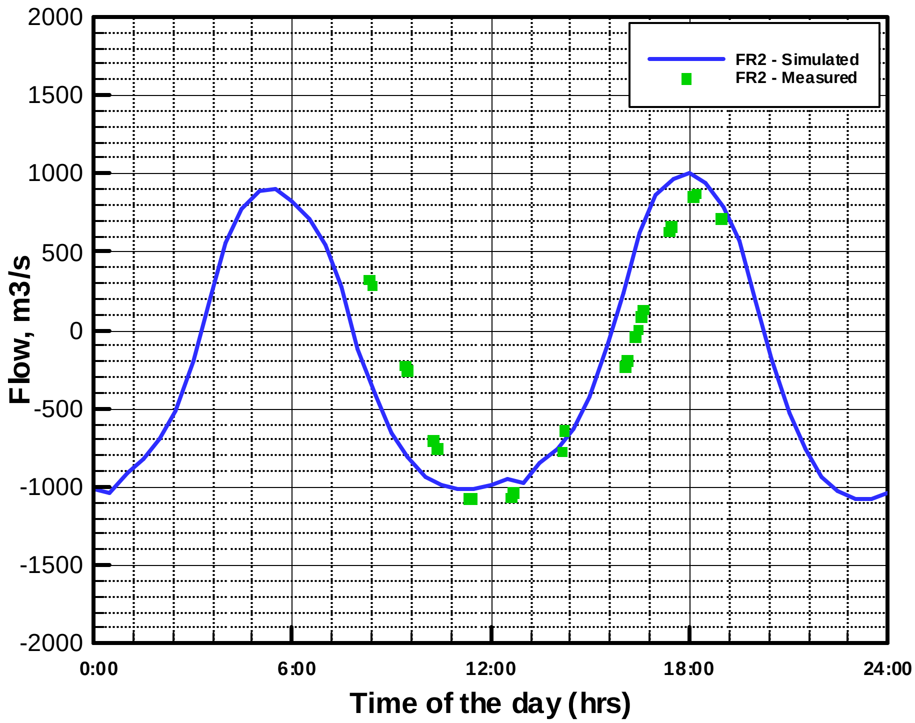


Figure G-8 Flow (m3/s) at Transect FR2 on September 30, 1997

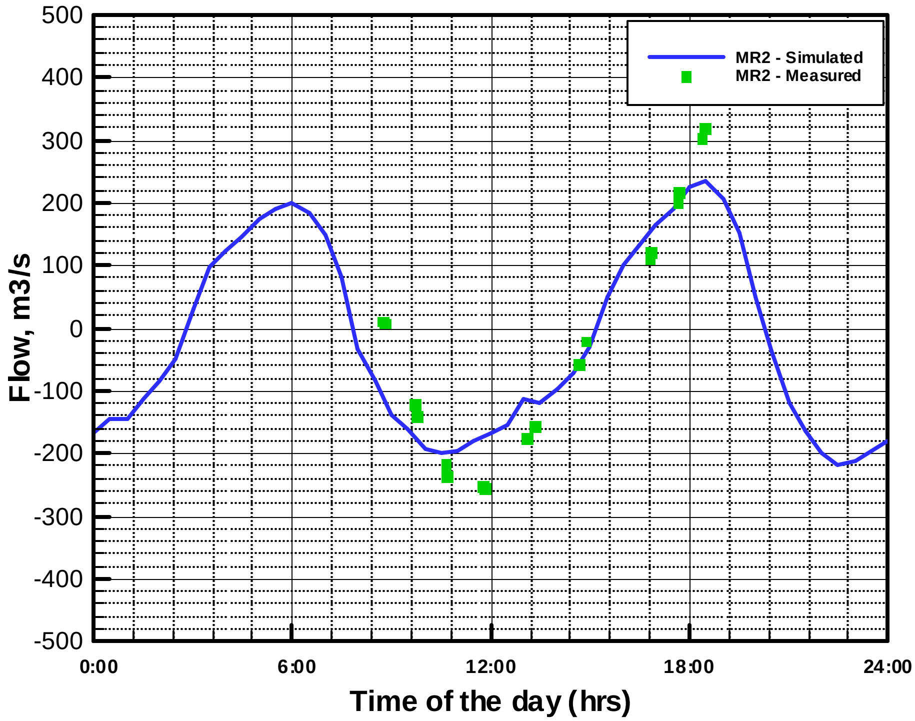


Figure G-9 Flow (m3/s) at Transect MR2 on September 30, 1997

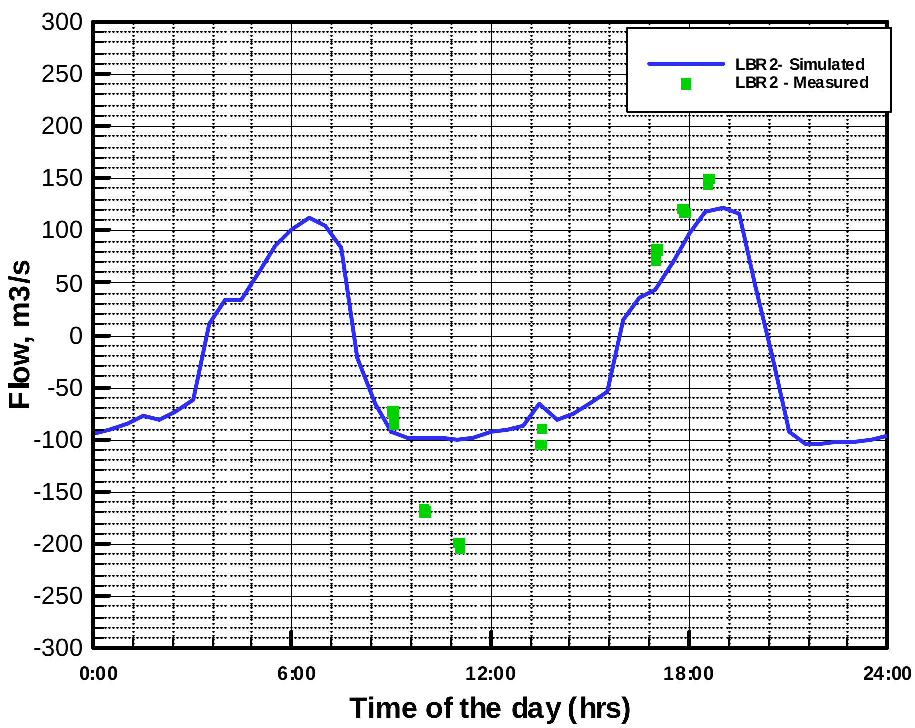


Figure G-10 Flow (m3/s) at Transect LBR2 on September 30, 1997

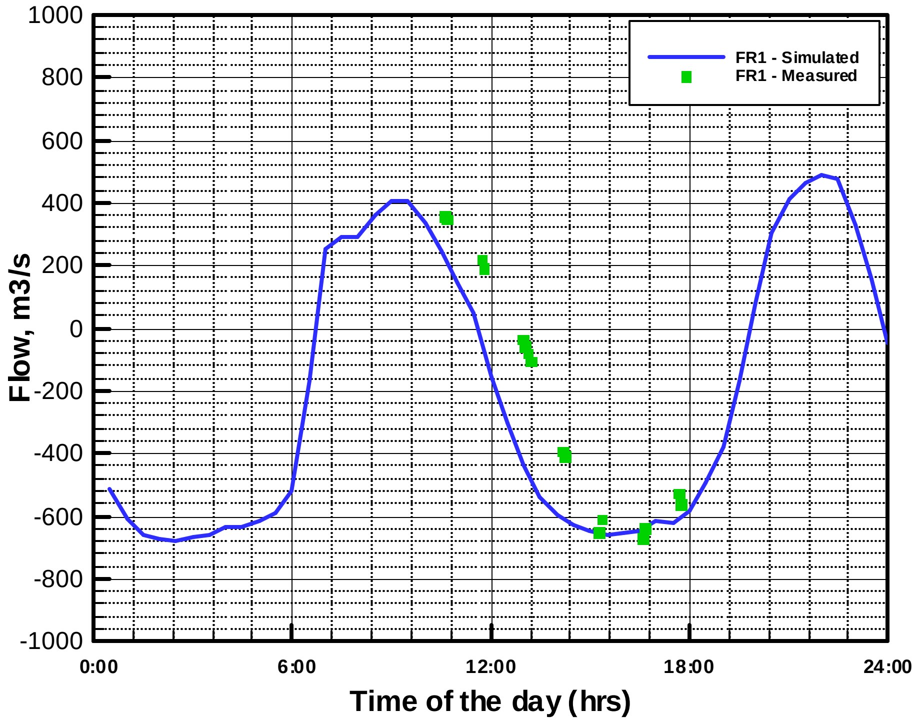


Figure G-11 Flow (m3/s) at Transect FR1 on October 6, 1997

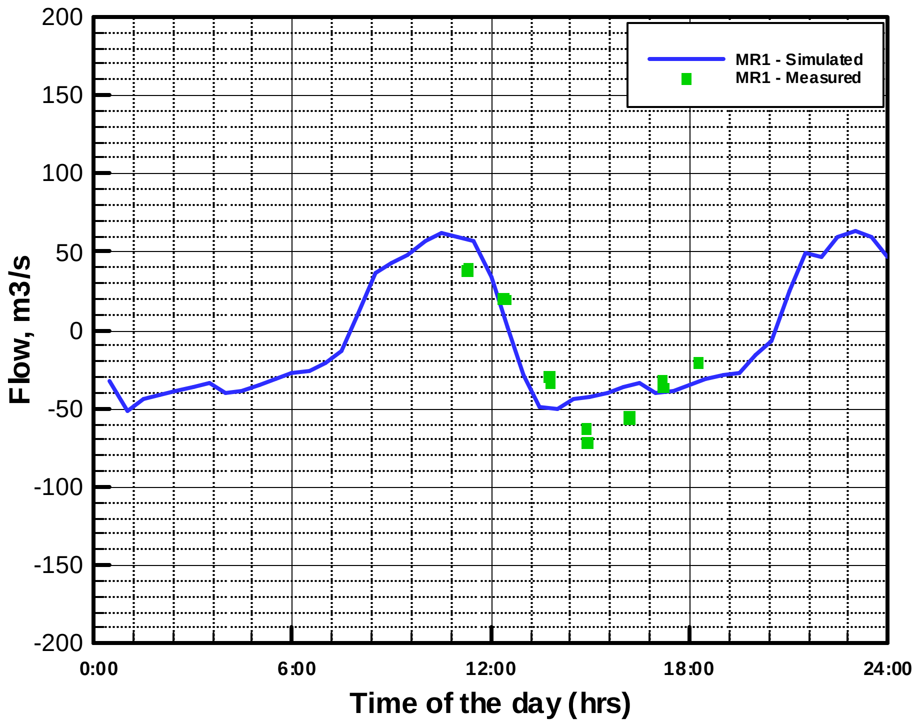


Figure G-12 Flow (m3/s) at Transect MR1 on October 6, 1997

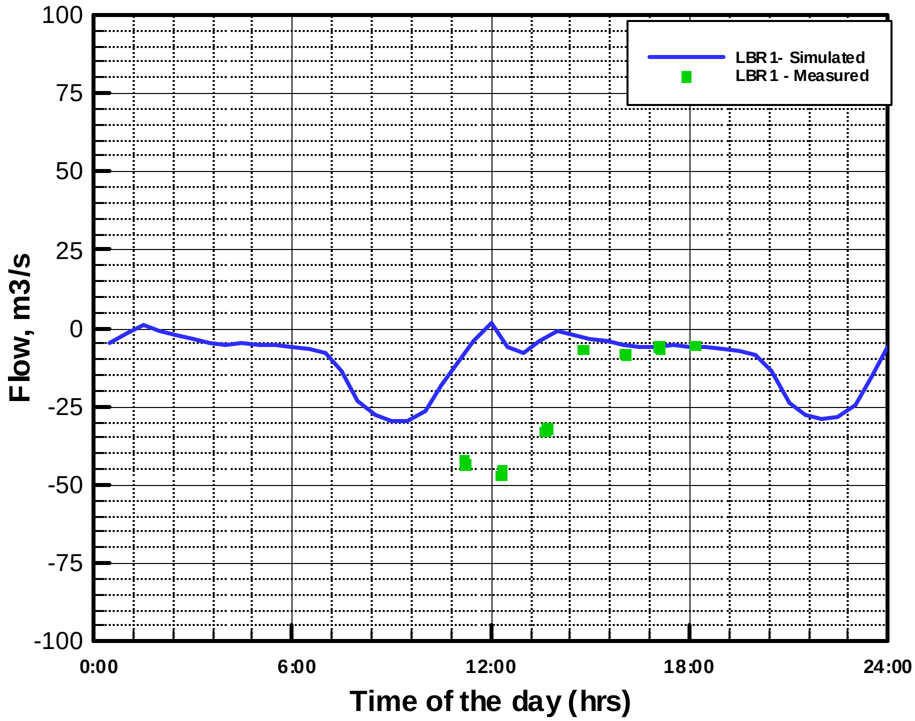


Figure G-13 Flow (m3/s) at Transect LBR1 on October 6, 1997

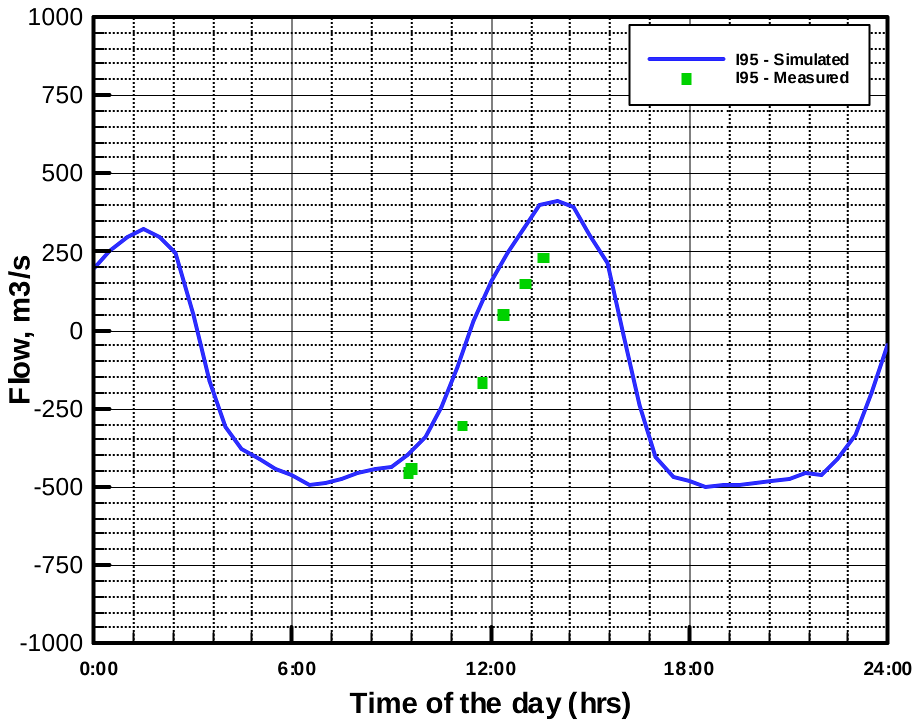


Figure G-14 Flow (m3/s) at Transect I95 on September 11, 1997

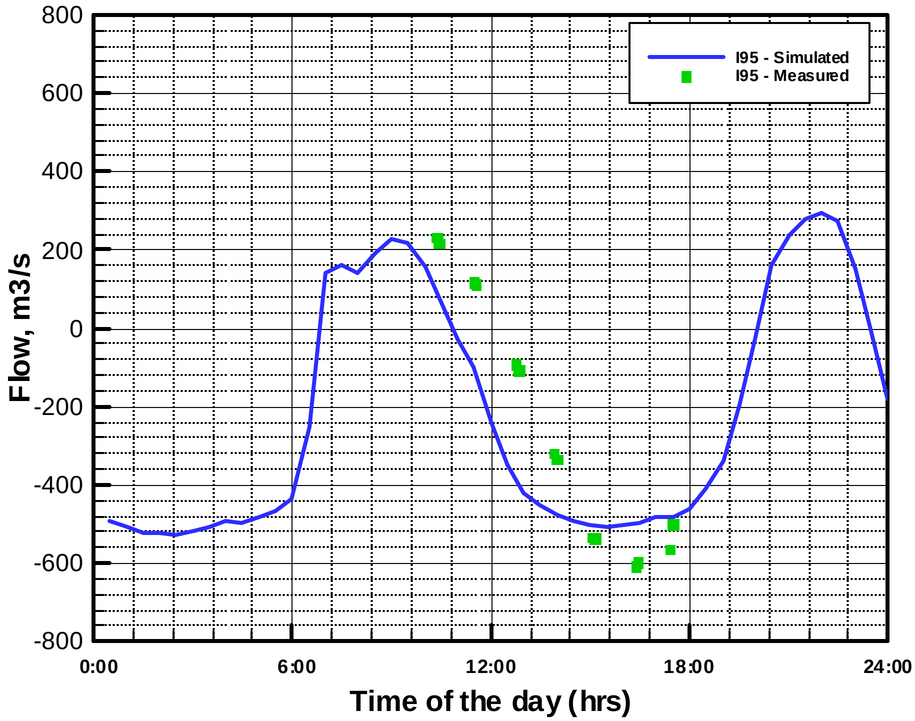


Figure G-15 Flow (m3/s) at Transect I95 on October 6, 1997

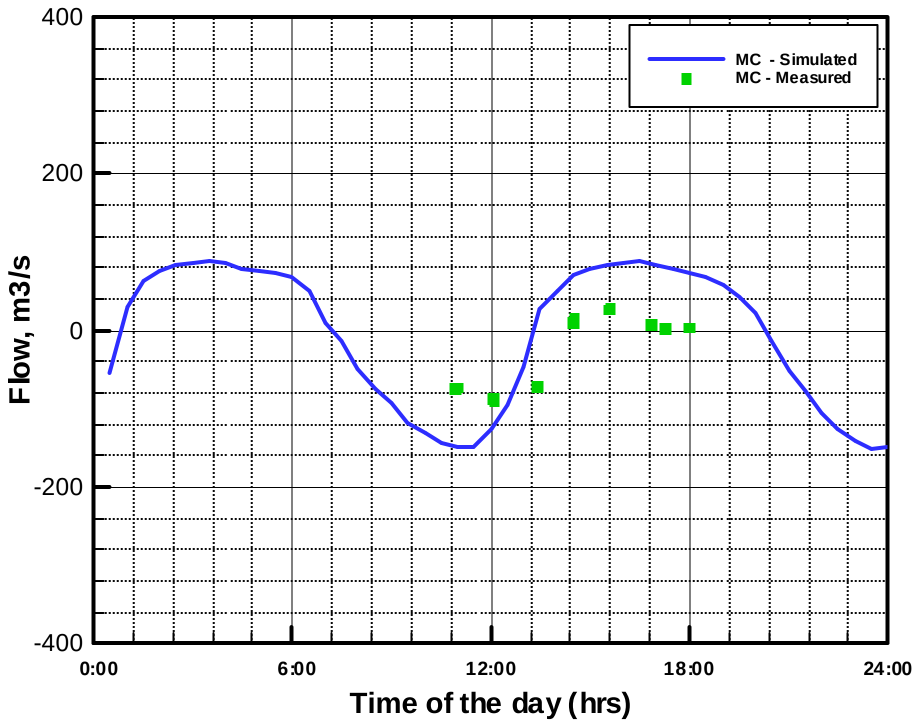


Figure G-16 Flow (m3/s) at Transect MC on October 6, 1997

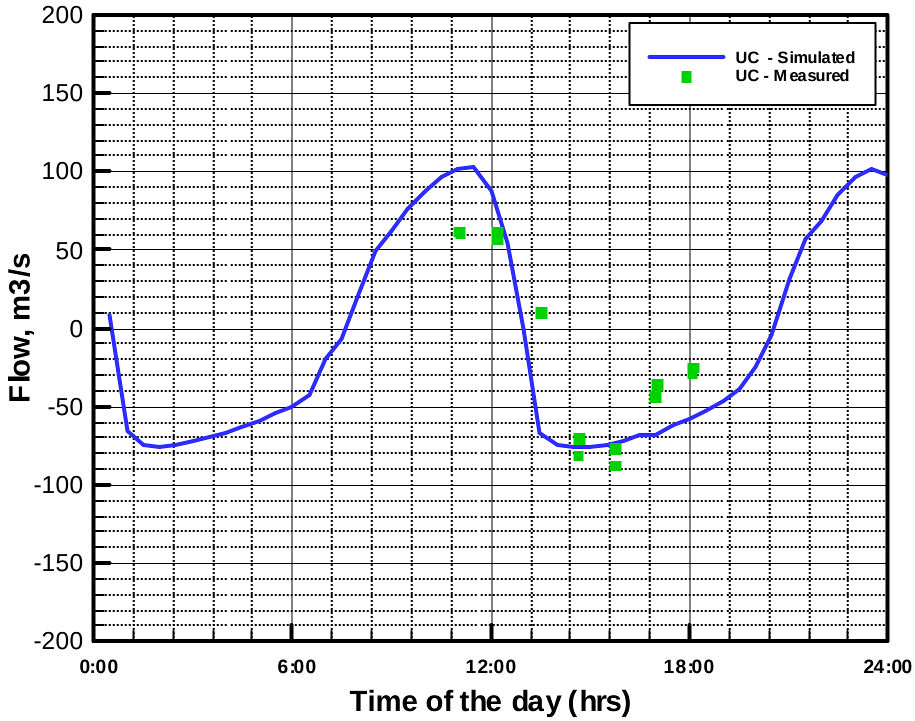


Figure G-17 Flow (m3/s) at Transect UC on October 6, 1997

APPENDIX H 1999 TEMPERATURE COMPARISONS

Table H-1 1999 Temperature Comparison Percentiles

July 31 - October 13, 1999 [Julian Days 212-285]					
Stations	**Depth***	**Measured 50%**	**Simulated 50%**	**Difference**	**Absolute Mean Error**
		(deg C)	**(deg C)**	**(deg C)**	**(deg C)**
FR-26	S	27.4	28	0.6	0.5
FR-26	B	27.9	28.5	0.6	0.7
FR-02	S	25.8	26.3	0.5	0.5
FR-02	B	28.8	30.1	1.3	1.4
FR-04	S	28.2	28.4	0.2	0.5
FR-04	B	29.1	30.3	1.2	0.6
FR-21	S	26.8	27.6	0.8	0.5
FR-21	B	27.2	28.3	1.1	0.9
BR-05	B	26.7	26.7	0.0	0.5
FR-06	S	26.4	27.1	0.7	0.5
FR-06	B	27.0	27.4	0.4	0.5
FR-22	S	26.3	26.9	0.6	0.5
FR-22	B	27.4	27.3	-0.1	0.5
FR-08	S	26.5	27.4	0.9	0.6
FR-08	B	30.3	29.9	-0.4	0.6
FR-09	S	26.3	27	0.7	0.6
FR-09	B	26.4	26.7	0.3	0.6
MR-10	S	26.1	26.4	0.3	0.5
FR-11R	B	25.7	26	0.3	0.6
SR-14	B	25.6	26.1	0.5	0.5

Table H-2 1999 Temperature Comparison Statistics

July 31 - October 13, 1999 [Julian Days 212-285]										
Station	**Depth***	**N**	**ME**	**AME**	**RMS**	**Mean Pred**	**StDev Pred**	**Mean Obs**	**StDev Obs**	**R^2**
FR-26	S	13600	-0.1	0.5	0.6	27.4	2.6	27.5	2.8	1.0
FR-26	B	16940	-0.6	0.7	1.0	27.4	2.5	28.0	2.8	0.9
FR-02	S	10346	-0.3	0.5	0.7	26.4	2.4	26.8	2.6	1.0
FR-02	B	2225	-1.4	1.4	1.4	28.8	0.3	30.2	0.3	0.3
FR-04	S	14937	-0.2	0.5	0.6	28.1	2.6	28.2	2.7	1.0
FR-04	B	12963	-0.5	0.6	0.8	28.3	2.8	28.7	3.0	1.0
FR-21	S	18694	-0.3	0.5	0.6	27.2	2.8	27.5	2.8	1.0
FR-21	B	16674	-0.8	0.9	1.2	27.5	2.8	28.3	2.7	0.9
BR-05	B	11806	0.3	0.5	0.6	26.8	2.1	26.4	2.3	0.9
FR-06	S	11862	-0.1	0.5	0.6	26.5	2.4	26.6	2.7	1.0
FR-06	B	15018	0.0	0.5	0.6	26.8	2.1	26.7	2.5	1.0
FR-22	S	18949	-0.1	0.5	0.6	26.9	2.7	27.1	2.7	1.0
FR-22	B	18570	0.3	0.5	0.6	27.6	2.6	27.3	2.8	1.0
FR-08	S	11922	0.1	0.6	0.8	27.4	3.3	27.3	3.6	1.0
FR-08	B	8385	-0.2	0.6	0.7	28.6	2.6	28.7	2.4	0.9
FR-09	S	18337	-0.1	0.6	0.8	27.0	2.7	27.1	2.9	0.9
FR-09	B	18471	0.2	0.6	0.8	27.1	2.7	26.9	3.0	0.9
MR-10	S	15570	0.1	0.5	0.6	26.6	2.6	26.5	2.7	1.0
FR-11R	B	16657	0.1	0.6	0.7	26.2	2.4	26.1	2.4	0.9
SR-14	M	12348	0.0	0.5	0.7	25.9	2.3	25.9	2.3	0.9

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

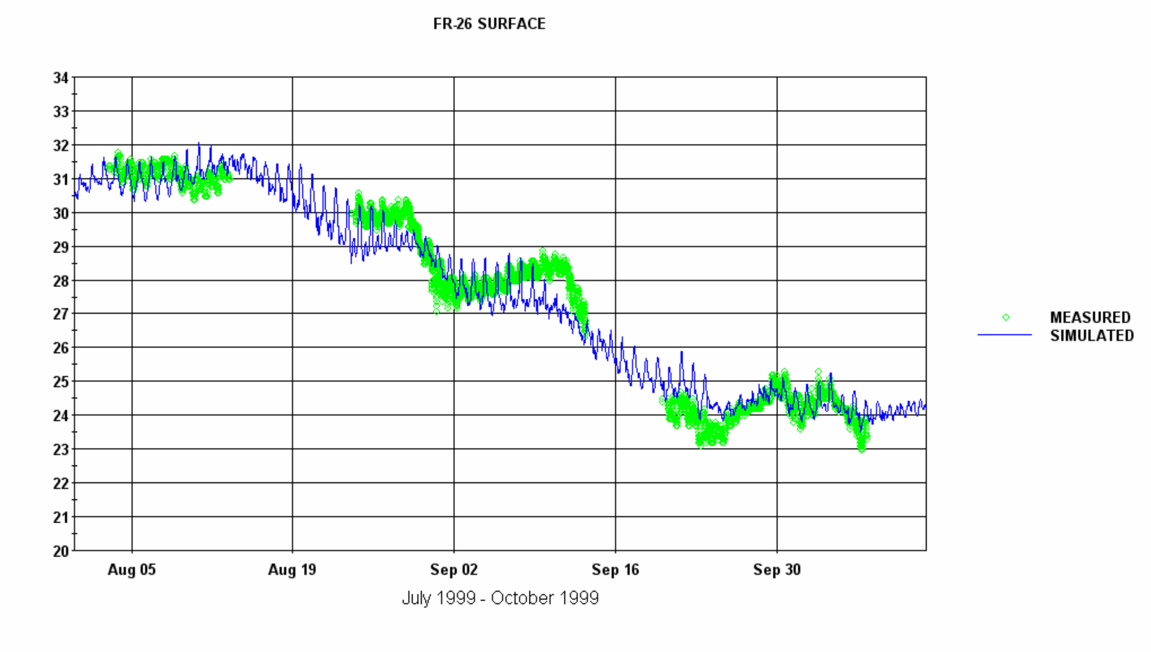


Figure H-1 Temperature (degrees C) Comparisons at FR-26 (Surface) for July 31, 1999 through October 13, 1999

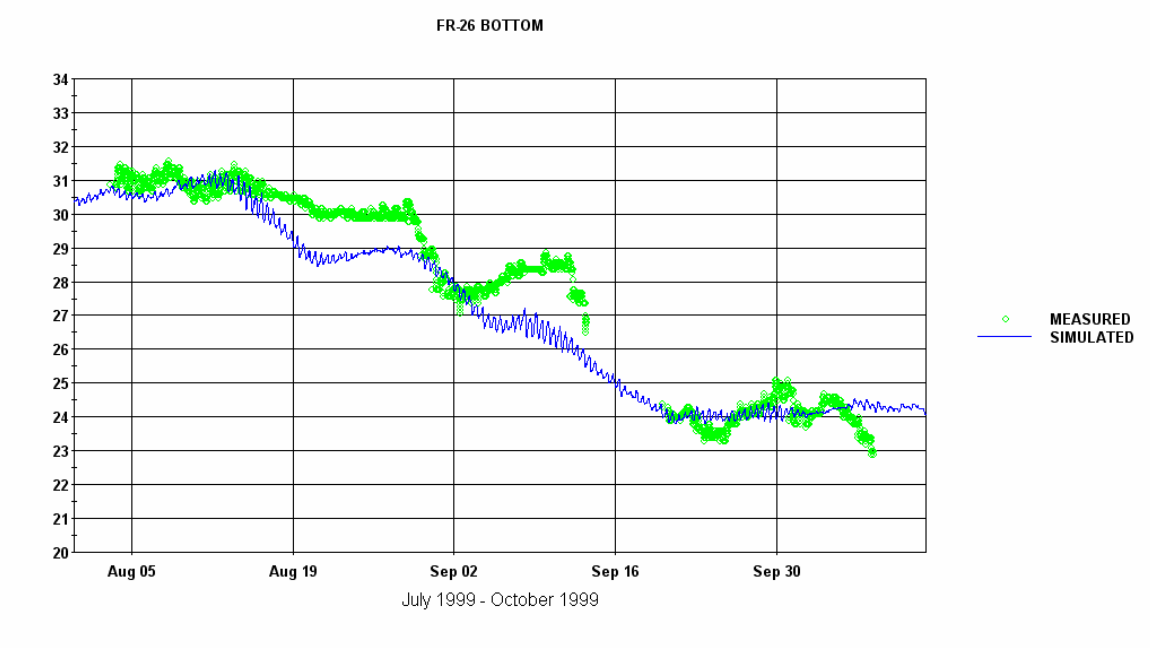


Figure H-2 Temperature (degrees C) Comparisons at FR-26 (Bottom) for July 31, 1999 through October 13, 1999

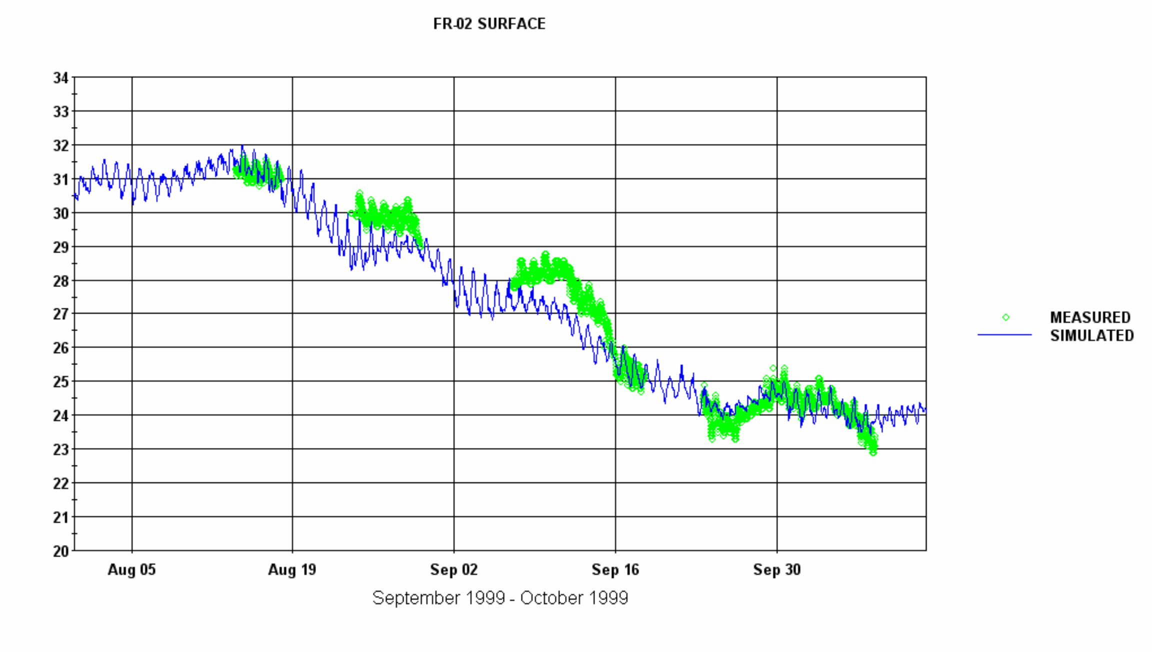


Figure H-3 Temperature (degrees C) Comparisons at FR-02 (Surface) for July 31, 1999 through October 13, 1999

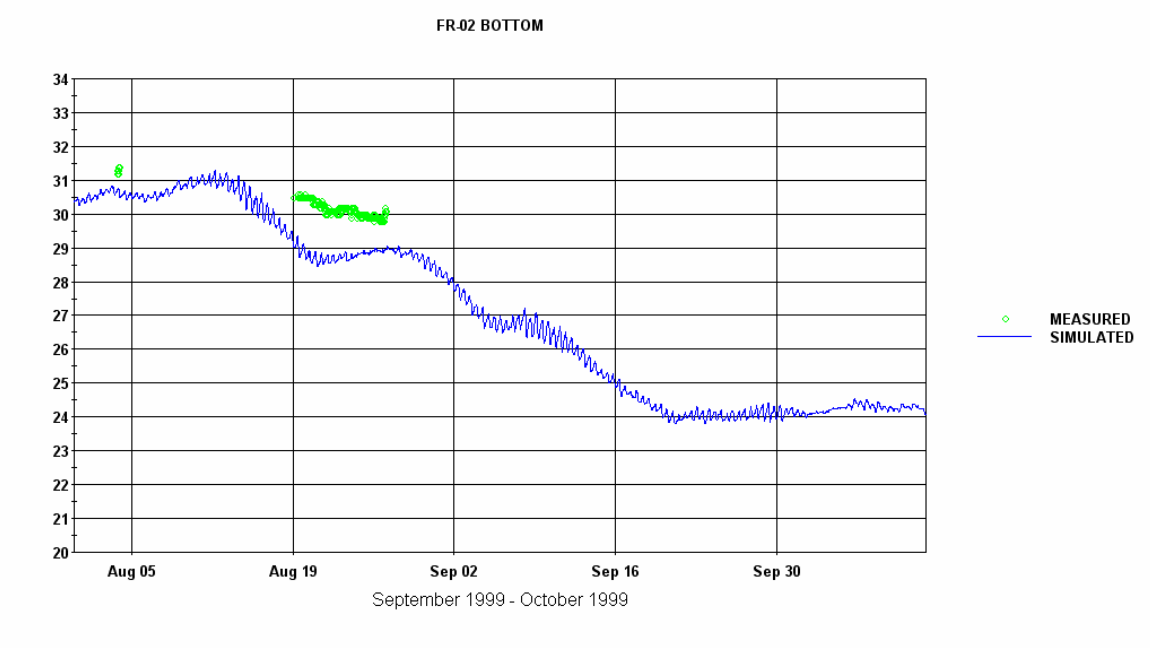


Figure H-4 Temperature (degrees C) Comparisons at FR-02 (Bottom) for July 31, 1999 through October 13, 1999

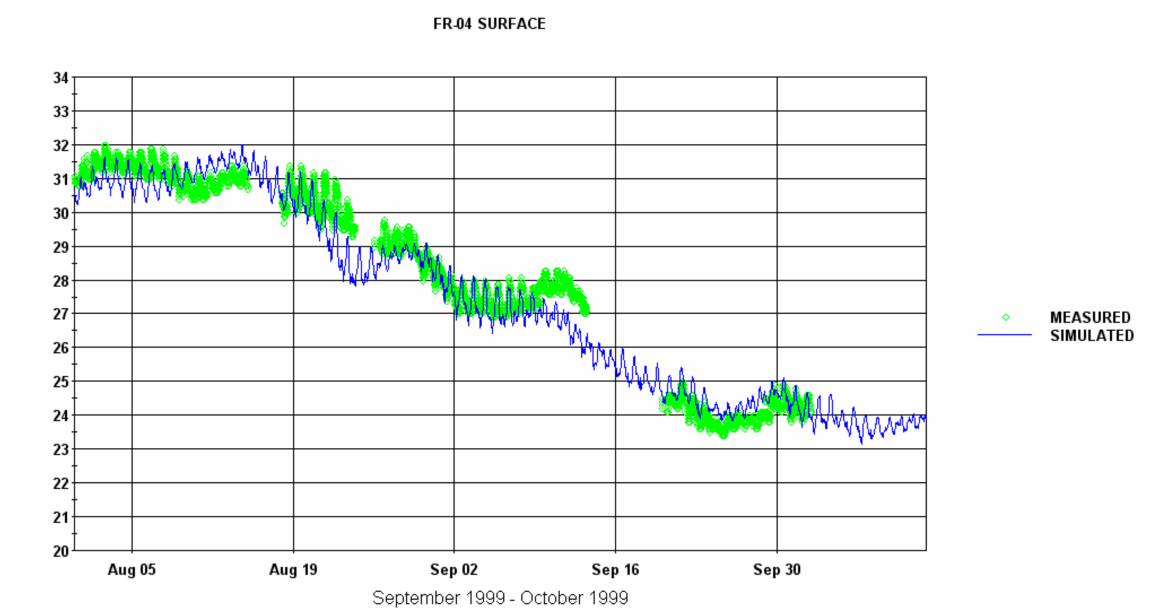


Figure H-5 Temperature (degrees C) Comparisons at FR-04 (Surface) for July 31, 1999 through October 13, 1999

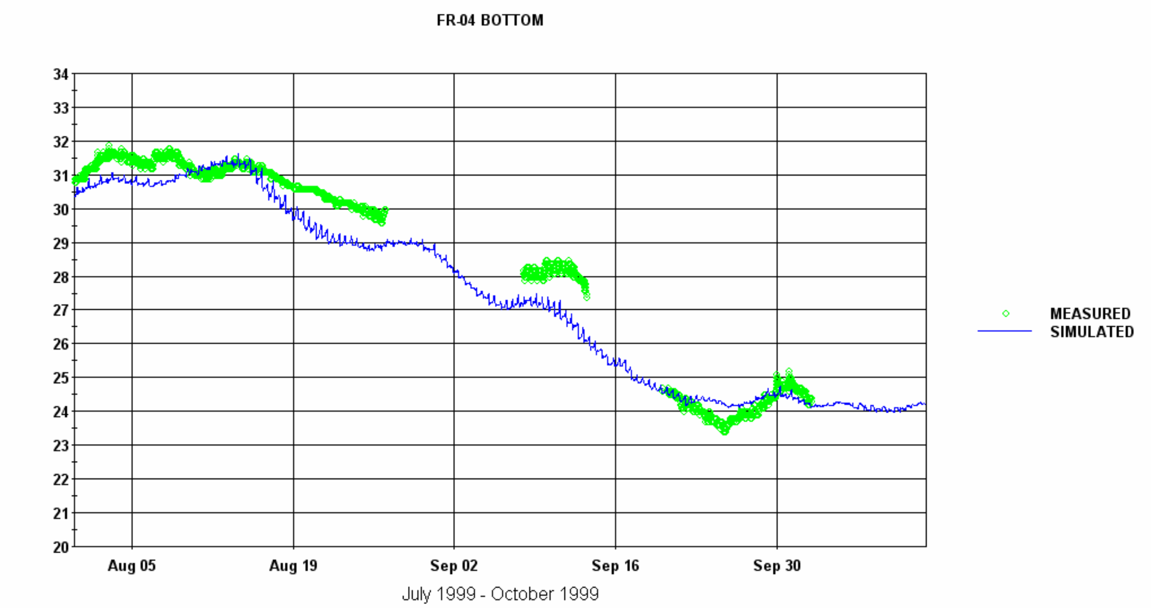


Figure H-6 Temperature (degrees C) Comparisons at FR-04 (Bottom) for July 31, 1999 through October 13, 1999

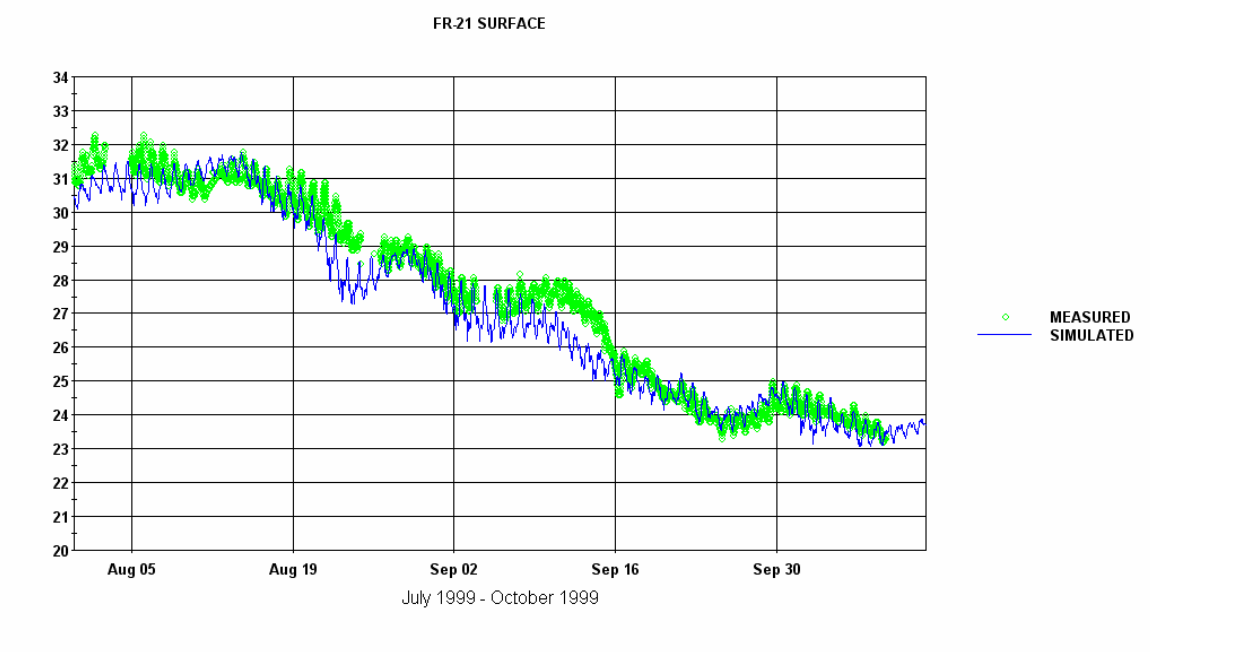


Figure H-7 Temperature (degrees C) Comparisons at FR-21 (Surface) for July 31, 1999 through October 13, 1999

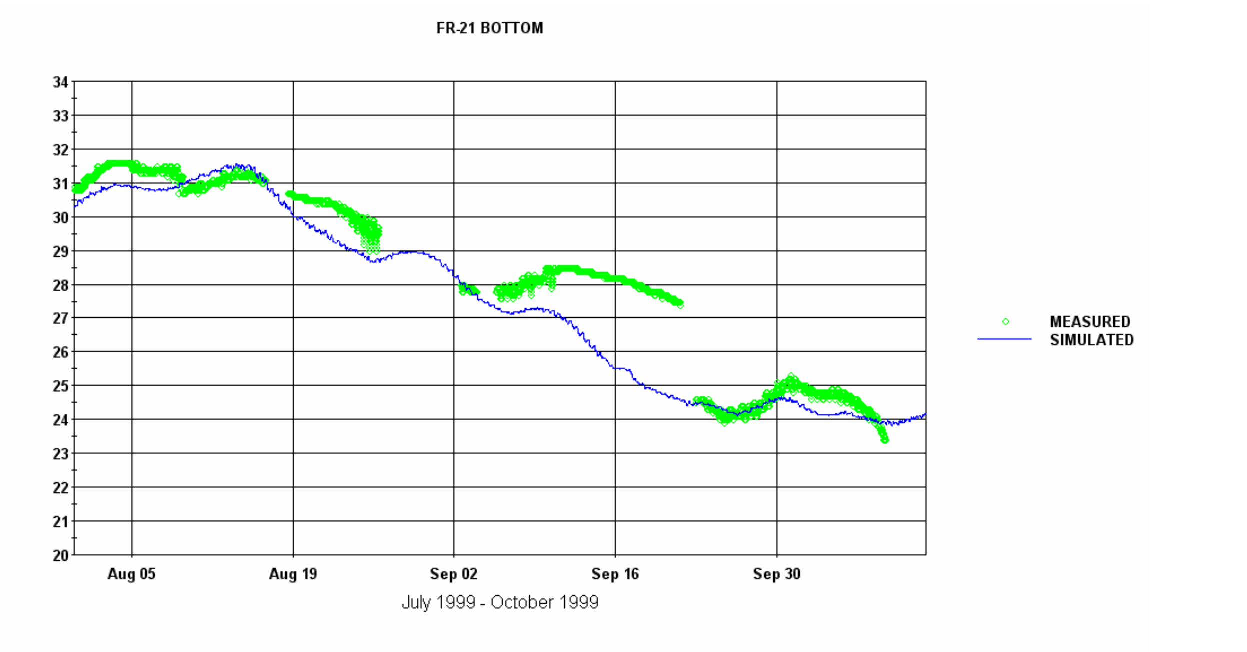


Figure H-8 Temperature (degrees C) Comparisons at FR-21 (Bottom) for July 31, 1999 through October 13, 1999

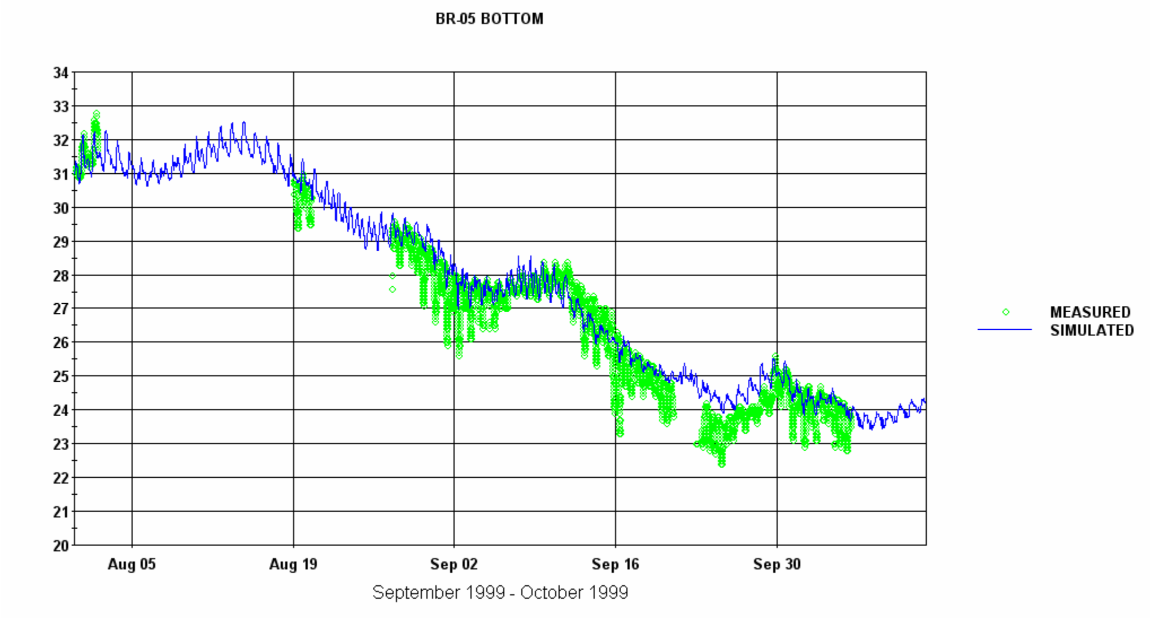


Figure H-9 Temperature (degrees C) Comparisons at BR-05 (Bottom) for July 31, 1999 through October 13, 1999

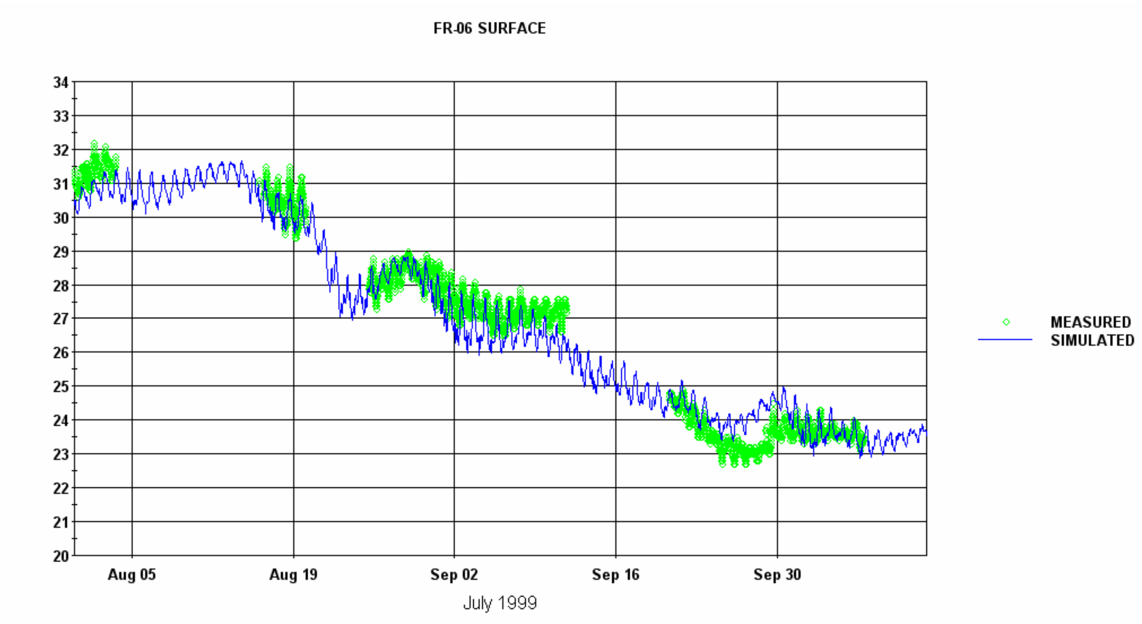


Figure H-10 Temperature (degrees C) Comparisons at FR-06 (Surface) for July 31, 1999 through October 13, 1999

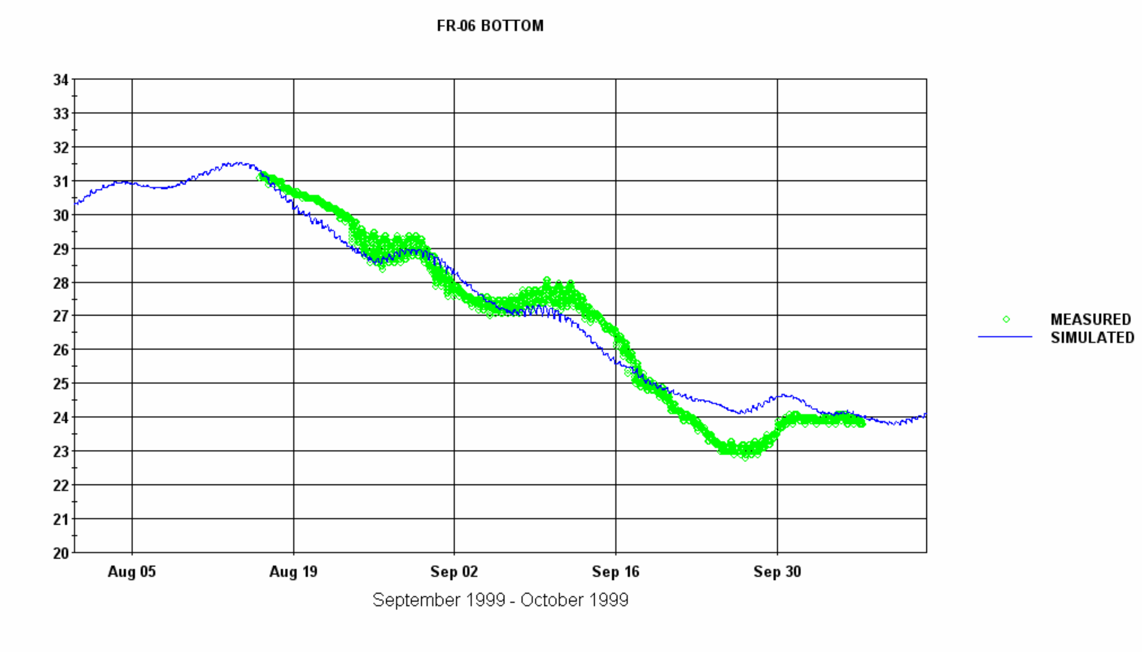


Figure H-11 Temperature (degrees C) Comparisons at FR-06 (Bottom) for July 31, 1999 through October 13, 1999

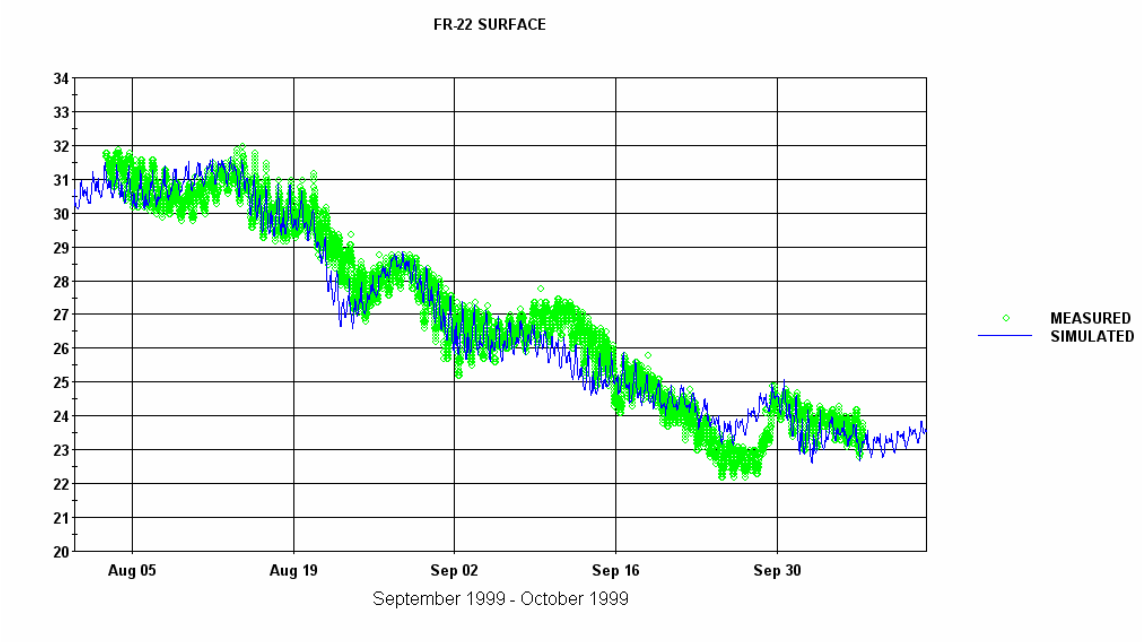


Figure H-12 Temperature (degrees C) Comparisons at FR-22 (Surface) for July 31, 1999 through October 13, 1999

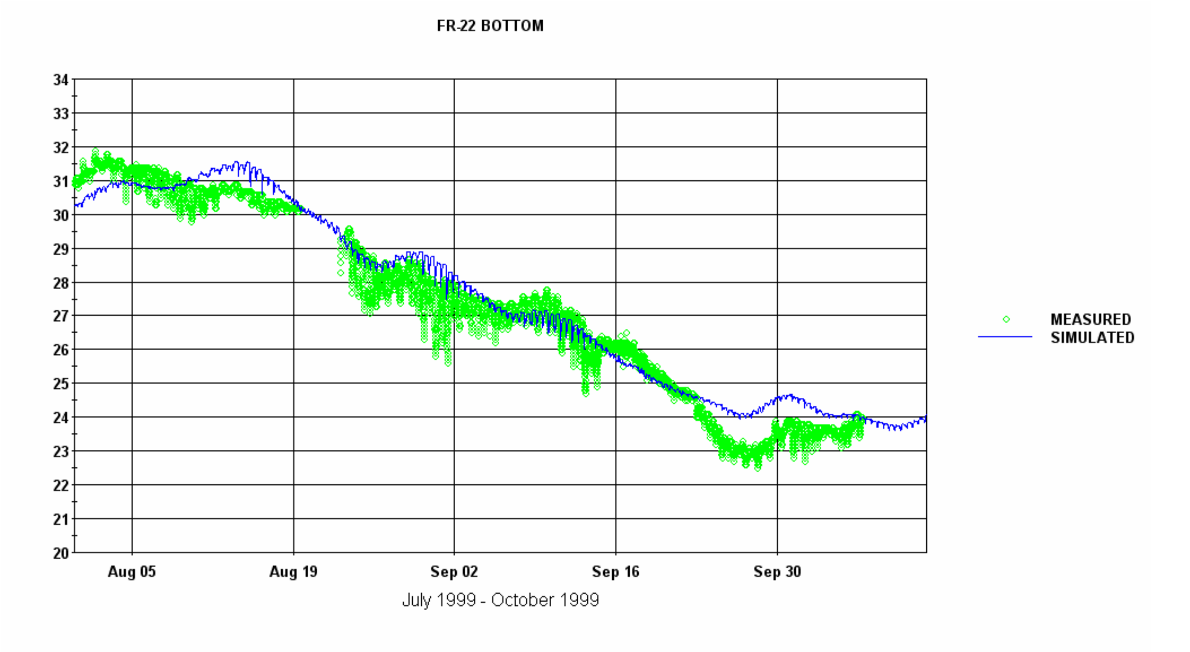


Figure H-13 Temperature (degrees C) Comparisons at FR-22 (Bottom) for July 31, 1999 through October 13, 1999

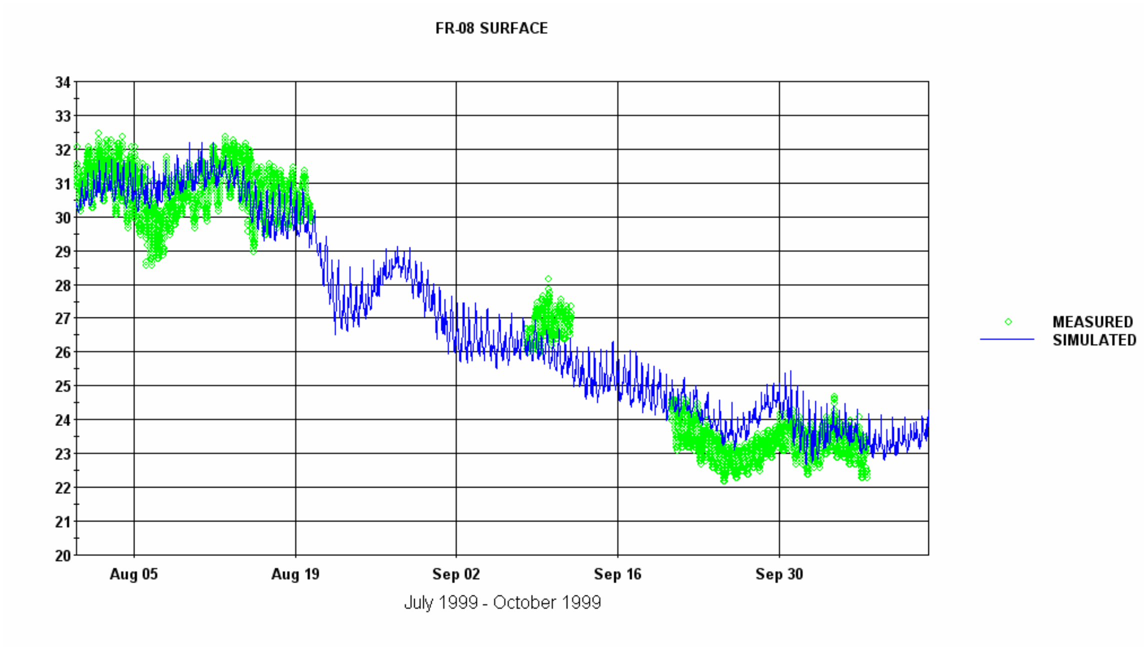


Figure H-14 Temperature (degrees C) Comparisons at FR-08 (Surface) for July 31, 1999 through October 13, 1999

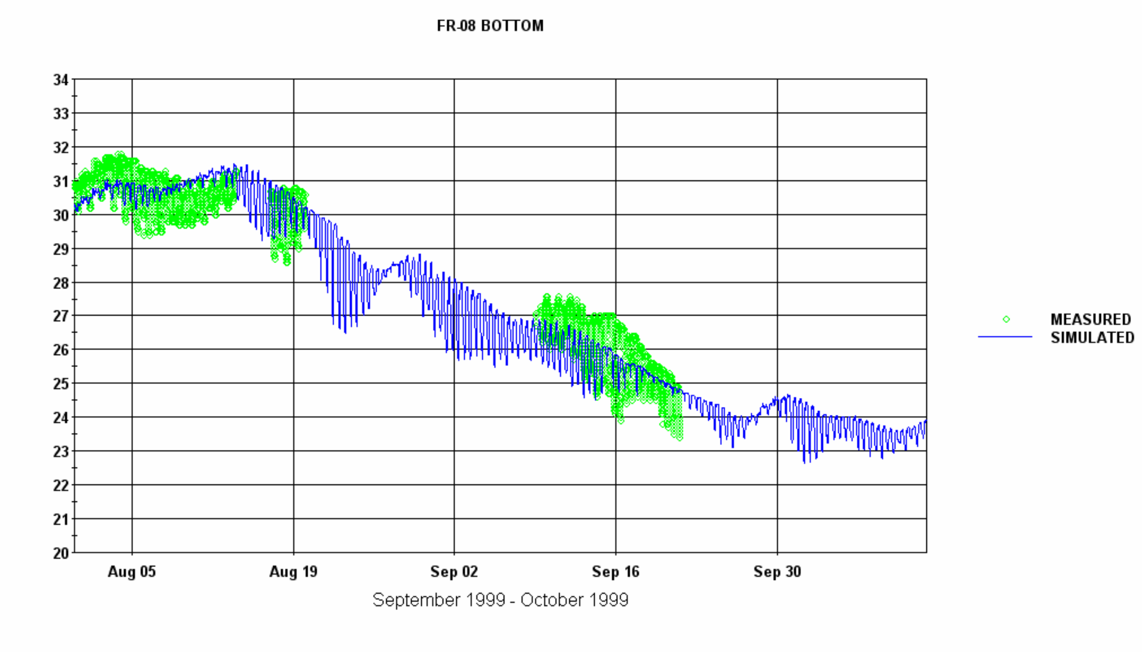


Figure H-15 Temperature (degrees C) Comparisons at FR-08 (Bottom) for July 31, 1999 through October 13, 1999

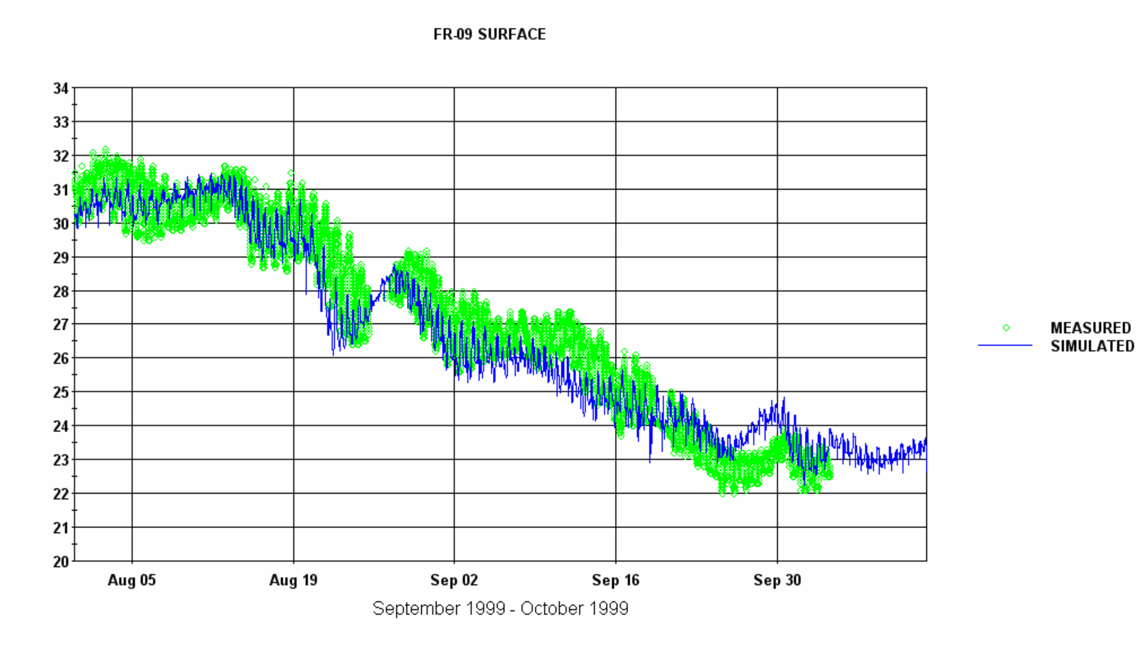


Figure H-16 Temperature (degrees C) Comparisons at FR-09 (Surface) for July 31, 1999 through October 13, 1999

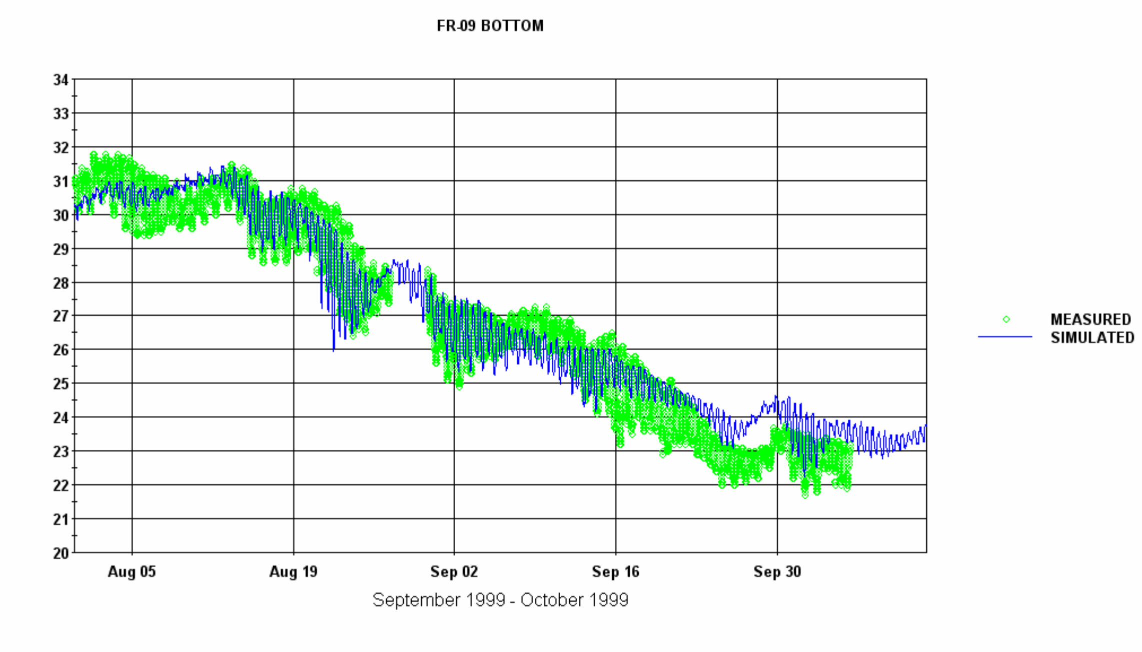


Figure H-17 Temperature (degrees C) Comparisons at FR-09 (Bottom) for July 31, 1999 through October 13, 1999

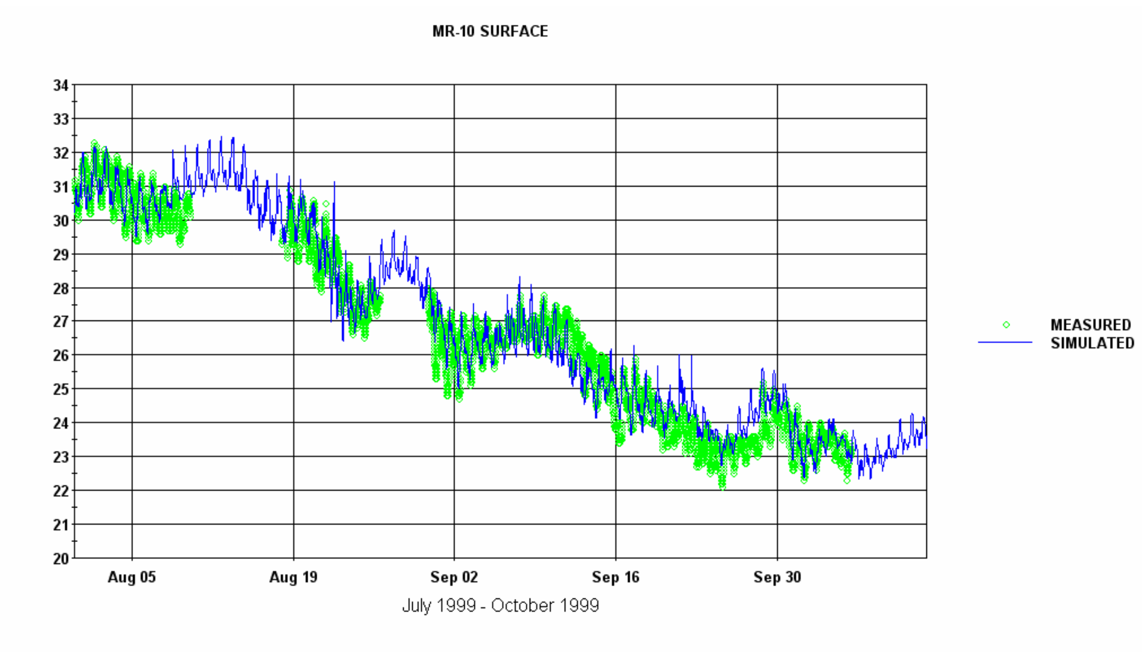


Figure H-18 Temperature (degrees C) Comparisons at MR-10 (Surface) for July 31, 1999 through October 13, 1999

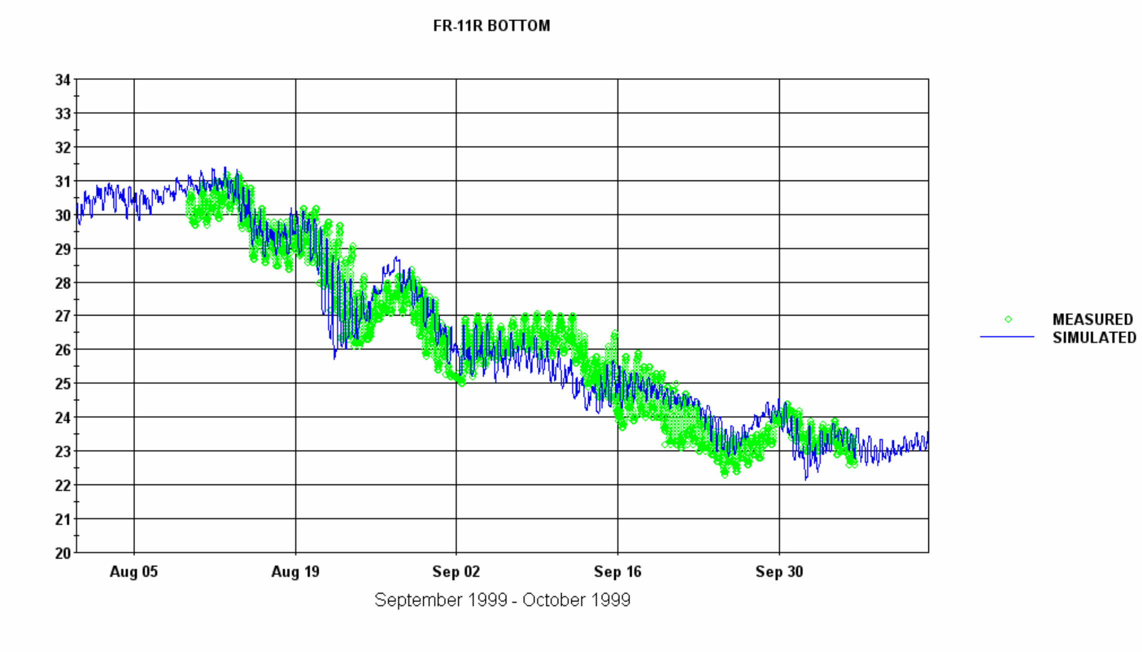


Figure H-19 Temperature (degrees C) Comparisons at FR-11R (Bottom) for July 31, 1999 through October 13, 1999

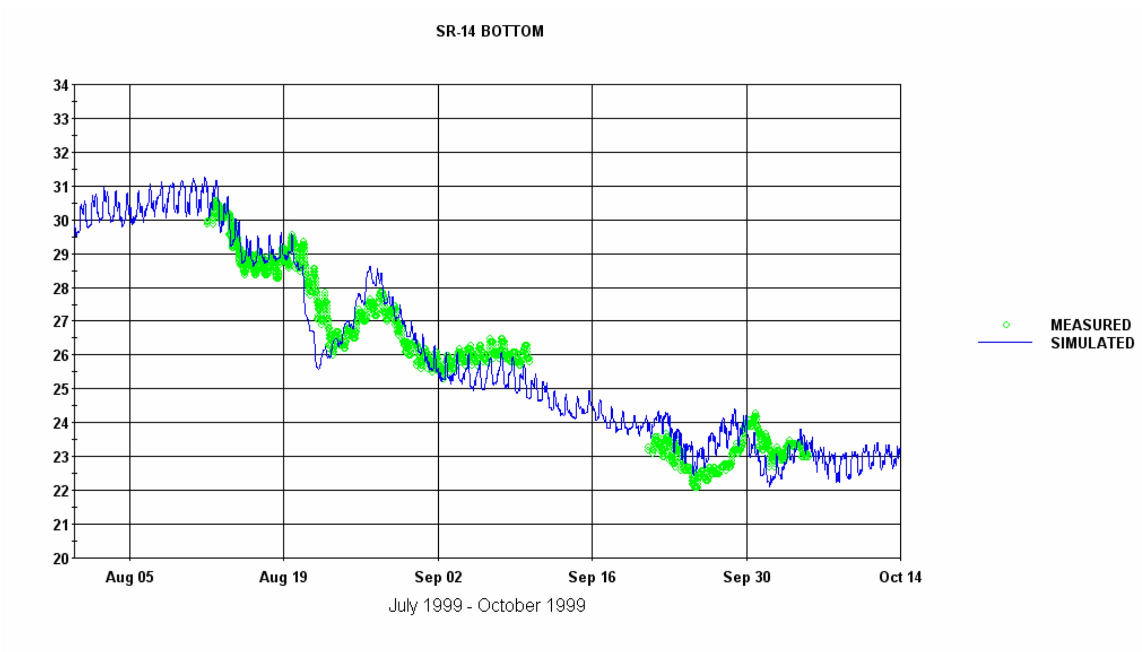


Figure H-20 Temperature (degrees C) Comparisons at SR-14 (Bottom) for July 31, 1999 through October 13, 1999

Table H-3 Temperature Comparison Percentiles, August 1 through August 15, 1999

August 1 - August 15, 1999 [Julian Days 213-226]					
Stations	Depth*	Measured 50%	Simulated 50%	Difference	Absolute Mean Error
		(deg C)	(deg C)	(deg C)	(deg C)
FR-26	S	31.2	31.1	-0.1	0.39
FR-26	B	31.0	30.5	-0.5	0.51
FR-02	S	31.3	31.2	-0.1	0.39
FR-02	B	31.2	30.7	-0.5	0.46
FR-04	S	31.3	31.2	-0.1	0.46
FR-04	B	31.4	30.9	-0.5	0.47
FR-21	S	31.3	31.0	-0.2	0.41
FR-21	B	31.4	30.8	-0.6	0.47
BR-05	B	31.2	31.5	0.3	0.59
FR-06	S	31.6	30.8	-0.7	0.66
FR-06	B	0.0	0.0	0.0	0.00
FR-22	S	30.8	30.9	0.1	0.49
FR-22	B	31.1	30.9	-0.2	0.51
FR-08	S	30.6	30.9	0.4	0.71
FR-08	B	30.9	30.9	-0.1	0.48
FR-09	S	30.7	30.8	0.1	0.50
FR-09	B	30.7	30.8	0.1	0.50
MR-10	S	30.6	31.0	0.4	0.61
FR-11R	B	30.2	30.9	0.6	0.51
SR-14	B	29.6	29.9	0.3	0.39

* S = Surface
B = Bottom

Table H-4 Temperature Comparison Statistics, August 1 through August 15, 1999

August 1 - August 15, 1999 [Julian Days 213-226]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-26	S	2874	-0.05	0.39	0.46	31.14	0.29	31.09	0.36	0.00
FR-26	B	3601	-0.47	0.51	0.59	30.97	0.24	30.50	0.30	0.04
FR-02	S	3584	-0.11	0.39	0.44	31.26	0.26	31.15	0.37	0.01
FR-02	B	3590	-0.42	0.46	0.54	31.15	0.22	30.73	0.25	0.00
FR-04	S	4299	-0.17	0.46	0.51	31.30	0.30	31.14	0.37	0.00
FR-04	B	4321	-0.39	0.47	0.56	31.36	0.20	30.97	0.27	0.25
FR-21	S	3251	-0.31	0.41	0.52	31.34	0.32	31.04	0.37	0.07
FR-21	B	3076	-0.37	0.47	0.55	31.40	0.16	31.03	0.32	0.20
BR-05	B	4303	0.33	0.59	0.72	31.14	0.55	31.47	0.46	0.05
FR-06	S	747	-0.66	0.66	0.67	31.54	0.27	30.88	0.28	0.82
FR-06	B	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FR-22	S	3848	0.24	0.49	0.58	30.82	0.47	31.07	0.27	0.00
FR-22	B	4321	-0.09	0.51	0.55	31.11	0.37	31.02	0.28	0.17
FR-08	S	4321	0.41	0.71	0.85	30.54	0.78	30.96	0.39	0.13
FR-08	B	4308	0.08	0.48	0.55	30.80	0.60	30.88	0.32	0.18
FR-09	S	4321	0.10	0.50	0.59	30.67	0.64	30.77	0.38	0.20
FR-09	B	4321	0.13	0.50	0.58	30.67	0.63	30.79	0.35	0.21
MR-10	S	4312	0.46	0.61	0.74	30.56	0.65	31.02	0.57	0.30
FR-11R	B	1829	0.49	0.51	0.59	30.21	0.55	30.70	0.55	0.67
SR-14	B	508	0.33	0.39	0.49	29.63	0.66	29.95	0.76	0.77

* S = Surface
B = Bottom

Table H-5 Temperature Comparison Percentiles, August 15 through August 30, 1999

August 15 - August 30, 1999 [Julian Days 227-241]					
Stations	Depth*	Measured 50%	Simulated 50%	Difference	Absolute Mean Error
		(deg C)	(deg C)	(deg C)	(deg C)
FR-26	S	29.9	29.0	-0.8	0.63
FR-26	B	30.1	28.7	-1.4	1.31
FR-02	S	30.2	29.4	-0.8	0.50
FR-02	B	30.3	28.9	-1.4	1.18
FR-04	S	30.2	29.5	-0.6	0.46
FR-04	B	30.2	29.1	-1.1	0.83
FR-21	S	29.9	28.9	-1.0	0.59
FR-21	B	30.5	29.6	-0.9	0.77
BR-05	B	30.1	30.9	0.8	0.75
FR-06	S	29.2	28.6	-0.6	0.60
FR-06	B	30.1	29.1	-1.0	0.55
FR-22	S	28.8	29.4	0.6	0.71
FR-22	B	29.2	28.9	-0.3	0.34
FR-08	S	28.8	29.6	0.7	0.60
FR-08	B	29.2	28.9	-0.3	0.45
FR-09	S	28.8	28.5	-0.3	0.56
FR-09	B	29.1	29.2	0.1	0.39
MR-10	S	28.9	29.3	0.4	0.62
FR-11R	B	28.2	28.3	0.1	0.49
SR-14	B	27.4	27.5	0.2	0.57

* S = Surface
B = Bottom

Table H-6 Temperature Comparison Statistics, August 15 through August 30, 1999

August 15 - August 30, 1999 [Julian Days 227-241]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-26	S	955	-0.59	0.63	0.73	29.73	0.44	29.14	0.34	0.20
FR-26	B	4606	-1.31	1.31	1.35	30.15	0.43	28.84	0.48	0.56
FR-02	S	1788	-0.35	0.50	0.65	30.36	0.76	30.01	1.16	0.85
FR-02	B	3420	-1.18	1.18	1.22	30.37	0.37	29.19	0.60	0.75
FR-04	S	3985	-0.38	0.46	0.62	30.06	0.80	29.68	1.04	0.80
FR-04	B	4393	-0.82	0.83	0.89	30.25	0.55	29.42	0.70	0.77
FR-21	S	4119	-0.58	0.59	0.77	29.92	0.87	29.34	1.08	0.79
FR-21	B	2703	-0.74	0.77	0.84	30.45	0.52	29.70	0.82	0.87
BR-05	B	2587	0.69	0.75	0.89	29.86	0.96	30.55	1.15	0.77
FR-06	S	4206	-0.59	0.60	0.79	29.43	0.85	28.84	1.02	0.73
FR-06	B	4208	-0.55	0.55	0.63	30.00	0.73	29.46	0.75	0.83
FR-22	S	4542	0.68	0.71	0.82	28.93	1.06	29.60	0.96	0.81
FR-22	B	3478	0.02	0.34	0.42	29.53	0.99	29.55	1.09	0.85
FR-08	S	2617	0.57	0.60	0.72	28.72	0.89	29.29	0.99	0.80
FR-08	B	4609	-0.10	0.45	0.58	29.19	1.25	29.09	1.14	0.79
FR-09	S	4064	-0.24	0.56	0.75	28.75	1.20	28.51	1.22	0.68
FR-09	B	3646	-0.12	0.39	0.52	29.00	1.19	28.88	1.24	0.83
MR-10	S	3070	0.31	0.62	0.77	28.79	1.09	29.10	1.32	0.71
FR-11R	B	4548	0.09	0.49	0.63	28.21	1.11	28.30	1.14	0.72
SR-14	B	3960	0.07	0.57	0.71	27.54	0.98	27.61	1.08	0.59

* S = Surface
B = Bottom

Table H-7 Temperature Comparison Percentiles, August 30 through September 13, 1999

August 30 - September 13, 1999 [Julian Days 242-255]					
Stations	Depth*	Measured 50%	Simulated 50%	Difference	Absolute Mean Error
		(deg C)	(deg C)	(deg C)	(deg C)
FR-26	S	28.1	27.4	-0.7	0.70
FR-26	B	28.1	26.6	-1.5	1.39
FR-02	S	28.1	27.3	-0.8	0.77
FR-02	B				
FR-04	S	27.8	27.1	-0.6	0.54
FR-04	B	28.1	27.3	-0.8	0.72
FR-21	S	27.7	26.8	-0.9	0.76
FR-21	B	28.1	27.2	-0.9	0.90
BR-05	B	27.6	27.7	0.1	0.47
FR-06	S	27.4	26.7	-0.8	0.61
FR-06	B	27.8	27.3	-0.5	0.47
FR-22	S	26.9	27.1	0.3	0.66
FR-22	B	27.4	27.1	-0.2	0.36
FR-08	S	26.7	26.3	-0.4	0.47
FR-08	B	26.9	26.6	-0.3	0.50
FR-09	S	26.5	25.9	-0.6	0.64
FR-09	B	26.7	26.1	-0.6	0.58
MR-10	S	26.6	26.4	-0.1	0.46
FR-11R	B	26.2	25.8	-0.4	0.52
SR-14	B	26.0	25.6	-0.4	0.46

* S = Surface
B = Bottom

Table H-8 Temperature Comparison Statistics, August 30 through September 13, 1999

August 30 - September 13, 1999 [Julian Days 242-255]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-26	S	2650	-0.54	0.70	0.82	28.04	0.47	27.51	0.69	0.23
FR-26	B	3802	-1.37	1.39	1.68	28.13	0.47	26.76	0.93	0.02
FR-02	S	2976	-0.74	0.77	0.88	28.07	0.42	27.34	0.67	0.49
FR-02	B	0								
FR-04	S	4155	-0.52	0.54	0.66	27.82	0.41	27.30	0.67	0.68
FR-04	B	4155	-0.67	0.72	0.90	28.16	0.41	27.49	0.72	0.30
FR-21	S	3816	-0.76	0.76	0.88	27.72	0.44	26.95	0.75	0.75
FR-21	B	2811	-0.86	0.90	1.04	28.02	0.23	27.16	0.43	0.31
BR-05	B	4320	0.19	0.47	0.59	27.58	0.55	27.77	0.63	0.32
FR-06	S	3656	-0.61	0.61	0.69	27.48	0.46	26.88	0.64	0.76
FR-06	B	4311	-0.37	0.47	0.58	27.89	0.43	27.52	0.70	0.62
FR-22	S	4290	0.54	0.66	0.87	26.85	0.54	27.40	0.70	0.19
FR-22	B	4284	0.10	0.36	0.47	27.29	0.70	27.39	0.70	0.61
FR-08	S	3551	-0.26	0.47	0.57	26.72	0.61	26.46	0.60	0.41
FR-08	B	4321	-0.20	0.50	0.59	26.81	0.73	26.61	0.85	0.58
FR-09	S	4115	-0.52	0.64	0.76	26.56	0.65	26.05	0.71	0.44
FR-09	B	4157	-0.44	0.58	0.69	26.61	0.62	26.17	0.73	0.48
MR-10	S	4074	-0.05	0.46	0.59	26.49	0.62	26.45	0.73	0.40
FR-11R	B	4036	-0.36	0.52	0.62	26.23	0.53	25.87	0.70	0.49
SR-14	B	3232	-0.31	0.46	0.54	25.97	0.23	25.66	0.52	0.26

* S = Surface
B = Bottom

Table H-9 Temperature Comparison Percentiles, September 13 through September 28, 1999

September 13 - September 28, 1999 [Julian Days 256-270]					
Stations	Depth*	Measured 50%	Simulated 50%	Difference	Absolute Mean Error
		(deg C)	(deg C)	(deg C)	(deg C)
FR-26	S	24.1	24.5	0.4	0.57
FR-26	B	24.0	23.8	-0.2	0.38
FR-02	S	24.4	24.8	0.4	0.44
FR-02	B				
FR-04	S	24.0	24.4	0.3	0.36
FR-04	B	24.0	24.3	0.3	0.39
FR-21	S	24.7	24.6	-0.1	0.38
FR-21	B	27.4	24.7	-2.7	1.61
BR-05	B	24.6	25.1	0.5	0.61
FR-06	S	24.0	24.2	0.2	0.20
FR-06	B	24.9	24.7	-0.2	0.53
FR-22	S	24.3	24.8	0.5	0.62
FR-22	B	24.2	24.8	0.6	0.56
FR-08	S	23.6	24.1	0.5	0.53
FR-08	B	24.7	24.7	0.1	0.51
FR-09	S	24.1	24.3	0.2	0.49
FR-09	B	24.2	24.5	0.3	0.51
MR-10	S	23.8	24.4	0.6	0.56
FR-11R	B	23.9	24.5	0.6	0.57
SR-14	B	22.7	23.7	0.9	0.84

* S = Surface
B = Bottom

Table H-10 Temperature Comparison Statistics, September 13 through September 28, 1999

September 13 - September 28, 1999 [Julian Days 256-270]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-26	S	2545	0.51	0.57	0.69	24.10	0.71	24.62	0.51	0.57
FR-26	B	2583	-0.17	0.38	0.55	24.08	0.79	23.91	0.39	0.66
FR-02	S	3431	-0.02	0.44	0.56	25.02	1.23	25.00	0.77	0.89
FR-02	B	0								
FR-04	S	2595	0.23	0.36	0.44	24.26	0.74	24.50	0.47	0.82
FR-04	B	2595	0.24	0.39	0.51	24.19	0.85	24.42	0.42	0.95
FR-21	S	4601	-0.22	0.38	0.56	24.93	1.02	24.71	0.61	0.86
FR-21	B	4094	-1.34	1.61	1.93	26.28	1.88	24.94	0.66	0.67
BR-05	B	3892	0.49	0.61	0.77	24.75	1.20	25.24	0.84	0.79
FR-06	S	2424	0.17	0.20	0.24	24.04	0.37	24.21	0.37	0.79
FR-06	B	4609	-0.25	0.53	0.66	25.20	1.27	24.94	0.68	0.97
FR-22	S	4597	0.60	0.62	0.72	24.38	0.96	24.97	0.72	0.85
FR-22	B	4609	0.54	0.56	0.68	24.43	0.85	24.98	0.72	0.78
FR-08	S	2429	0.52	0.53	0.60	23.59	0.52	24.11	0.44	0.65
FR-08	B	4609	0.05	0.51	0.60	24.73	1.23	24.78	0.73	0.89
FR-09	S	4307	0.06	0.49	0.59	24.22	0.99	24.27	0.58	0.71
FR-09	B	4609	0.16	0.51	0.60	24.42	1.14	24.59	0.67	0.86
MR-10	S	4474	0.38	0.56	0.67	24.04	0.92	24.42	0.67	0.64
FR-11R	B	4609	0.36	0.57	0.65	23.98	0.94	24.34	0.62	0.70
SR-14	B	2185	0.84	0.84	0.90	22.84	0.40	23.68	0.52	0.62

* S = Surface
B = Bottom

Table H-11 Temperature Comparison Percentiles, September 28 through October 13, 1999

September 28 - October 13, 1999 [Julian Days 271-285]					
Stations	Depth*	Measured 50%	Simulated 50%	Difference	Absolute Mean Error
		(deg C)	(deg C)	(deg C)	(deg C)
FR-26	S	24.4	24.4	0.0	0.23
FR-26	B	24.2	24.1	-0.2	0.50
FR-02	S	24.3	24.3	0.0	0.23
FR-02	B				
FR-04	S	24.2	24.0	-0.2	0.23
FR-04	B	24.4	24.2	-0.1	0.25
FR-21	S	24.1	23.7	-0.3	0.31
FR-21	B	24.3	24.2	-0.1	0.18
BR-05	B	24.2	24.5	0.3	0.45
FR-06	S	24.1	23.9	-0.2	0.36
FR-06	B	24.4	24.3	-0.1	0.18
FR-22	S	23.8	24.3	0.4	0.46
FR-22	B	24.2	24.3	0.1	0.21
FR-08	S	23.6	23.8	0.2	0.39
FR-08	B	23.9	24.1	0.2	0.33
FR-09	S	23.8	23.9	0.1	0.43
FR-09	B	23.8	23.9	0.1	0.33
MR-10	S	23.4	23.5	0.1	0.37
FR-11R	B	23.4	23.5	0.1	0.43
SR-14	B	23.3	23.4	0.1	0.60

* S = Surface
B = Bottom

Table H-12 Temperature Comparison Statistics, September 28 through October 13, 1999

September 28 - October 13, 1999 [Julian Days 271-285]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-26	S	2804	0.03	0.23	0.29	24.35	0.40	24.38	0.34	0.49
FR-26	B	2982	-0.13	0.50	0.63	24.21	0.43	24.07	0.24	0.39
FR-02	S	3015	-0.02	0.23	0.29	24.28	0.42	24.26	0.38	0.55
FR-02	B	0								
FR-04	S	3244	-0.05	0.23	0.28	24.16	0.40	24.11	0.45	0.63
FR-04	B	3257	-0.02	0.25	0.30	24.28	0.38	24.27	0.17	0.45
FR-21	S	4598	-0.22	0.31	0.35	24.08	0.32	23.86	0.45	0.66
FR-21	B	3282	0.02	0.18	0.21	24.25	0.31	24.27	0.23	0.54
BR-05	B	2428	0.38	0.45	0.55	24.17	0.53	24.55	0.46	0.48
FR-06	S	2722	-0.19	0.36	0.42	24.15	0.30	23.96	0.51	0.47
FR-06	B	2686	-0.01	0.18	0.21	24.34	0.21	24.33	0.22	0.25
FR-22	S	2716	0.44	0.46	0.56	23.85	0.42	24.29	0.23	0.36
FR-22	B	2697	0.13	0.21	0.28	24.16	0.27	24.29	0.23	0.28
FR-08	S	2757	0.29	0.39	0.49	23.56	0.46	23.85	0.56	0.50
FR-08	B	2459	0.20	0.33	0.42	23.81	0.44	24.00	0.49	0.48
FR-09	S	1889	0.04	0.43	0.51	23.70	0.43	23.74	0.65	0.38
FR-09	B	2402	0.11	0.33	0.41	23.71	0.48	23.82	0.56	0.52
MR-10	S	1916	0.20	0.37	0.47	23.42	0.48	23.62	0.58	0.47
FR-11R	B	2443	0.04	0.43	0.51	23.50	0.38	23.54	0.59	0.27
SR-14	B	2164	-0.02	0.60	0.70	23.34	0.37	23.32	0.67	0.04

* S = Surface
B = Bottom

APPENDIX I 1997 TEMPERATURE COMPARISONS

Table I-1 Temperature Comparison Percentiles, July 9, 1997 through October 6, 1997

July 9 - October 6, 1997 [Julian Days 190-279]					
Stations	Depth*	Measured 50% (deg C)	Simulated 50% (deg C)	Difference (deg C)	Absolute Mean Error (deg C)
FR-02	S	28.2	27.0	-1.1	1.0
FR-02	B	28.2	26.8	-1.4	1.5
FR-04	S	28.0	27.2	-0.7	0.8
FR-04	B	28.2	27.3	-0.8	1.0
BR-05	B	27.5	27.5	0.0	0.5
FR-06	S	27.4	26.6	-0.8	0.9
FR-06	B	27.8	26.9	-0.9	0.9
FR-08	S	26.9	26.3	-0.6	0.6
FR-08	B	27.1	26.6	-0.5	0.6
FR-09	B	27.0	26.4	-0.6	0.6
MR-10	B	26.8	26.7	-0.1	0.5
FR-11	B	26.6	25.8	-0.7	0.9
SR-14	B	26.3	25.6	-0.6	0.8

* S = Surface
B = Bottom

Table I-2 Temperature Comparison Statistics, July 9, 1997 through October 6, 1997

July 9 - October 6, 1997 [Julian Days 190-279]										
Stations	Depth*	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	9004	-0.96	0.97	1.11	28.2	0.9	27.2	1.0	0.73
FR-02	B	8858	-1.40	1.47	1.86	28.2	1.0	26.7	1.1	0.13
FR-04	S	8943	-0.76	0.76	0.85	28.0	0.8	27.2	0.9	0.81
FR-04	B	7481	-1.00	1.01	1.33	28.2	0.9	27.2	1.0	0.35
BR-05	B	8925	0.05	0.46	0.62	27.7	1.0	27.7	1.0	0.64
FR-06	S	10056	-0.91	0.91	0.99	27.4	1.1	26.5	1.2	0.91
FR-06	B	9548	-0.88	0.88	1.00	27.8	0.9	27.0	0.9	0.72
FR-08	S	10716	-0.58	0.62	0.74	26.8	1.2	26.2	1.3	0.88
FR-08	B	11053	-0.54	0.60	0.69	27.0	1.1	26.5	1.1	0.86
FR-09	B	11003	-0.62	0.64	0.74	26.9	1.1	26.2	1.2	0.88
MR-10	B	8887	-0.08	0.53	0.63	26.8	1.2	26.7	1.4	0.79
FR-11	B	7177	-0.86	0.87	1.01	26.3	1.4	25.4	1.6	0.89
SR-14	B	11851	-0.77	0.79	0.97	26.2	1.2	25.4	1.4	0.82

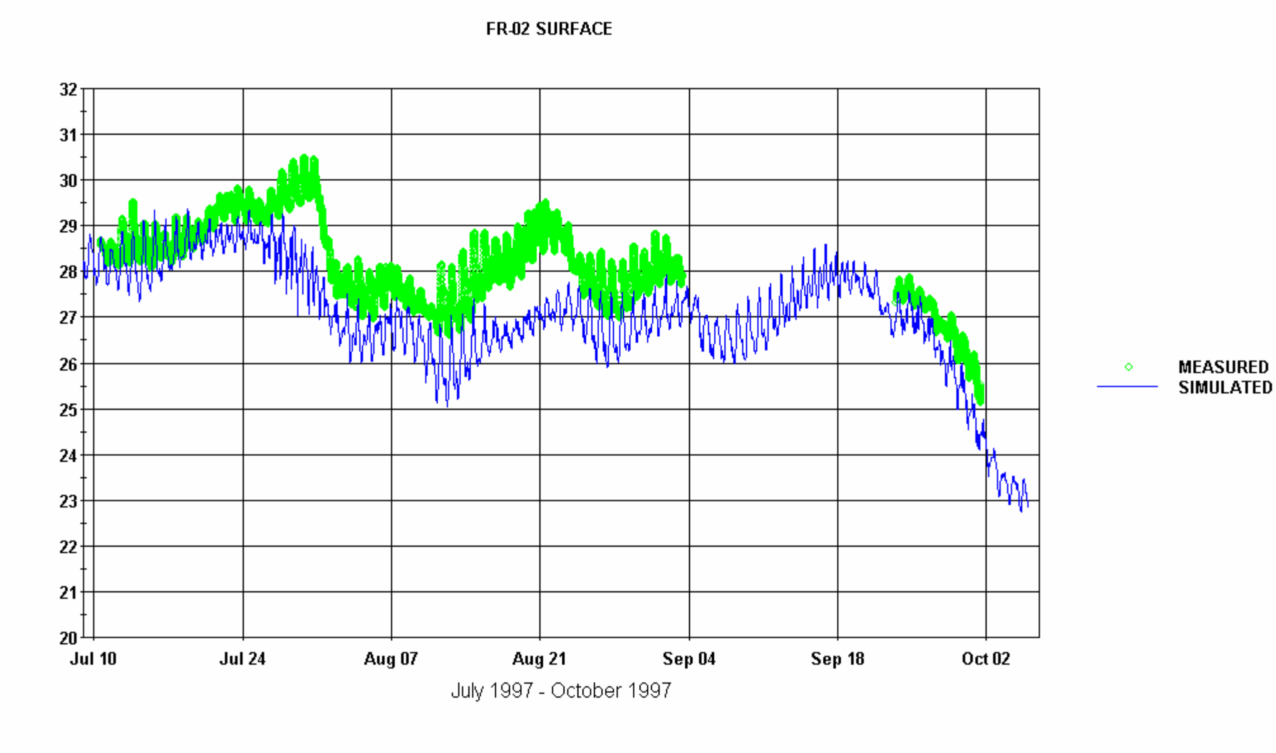


Figure I-1 Temperature (degrees C) Comparisons at FR-02 (Surface) for July 9, 1997 through October 6, 1997

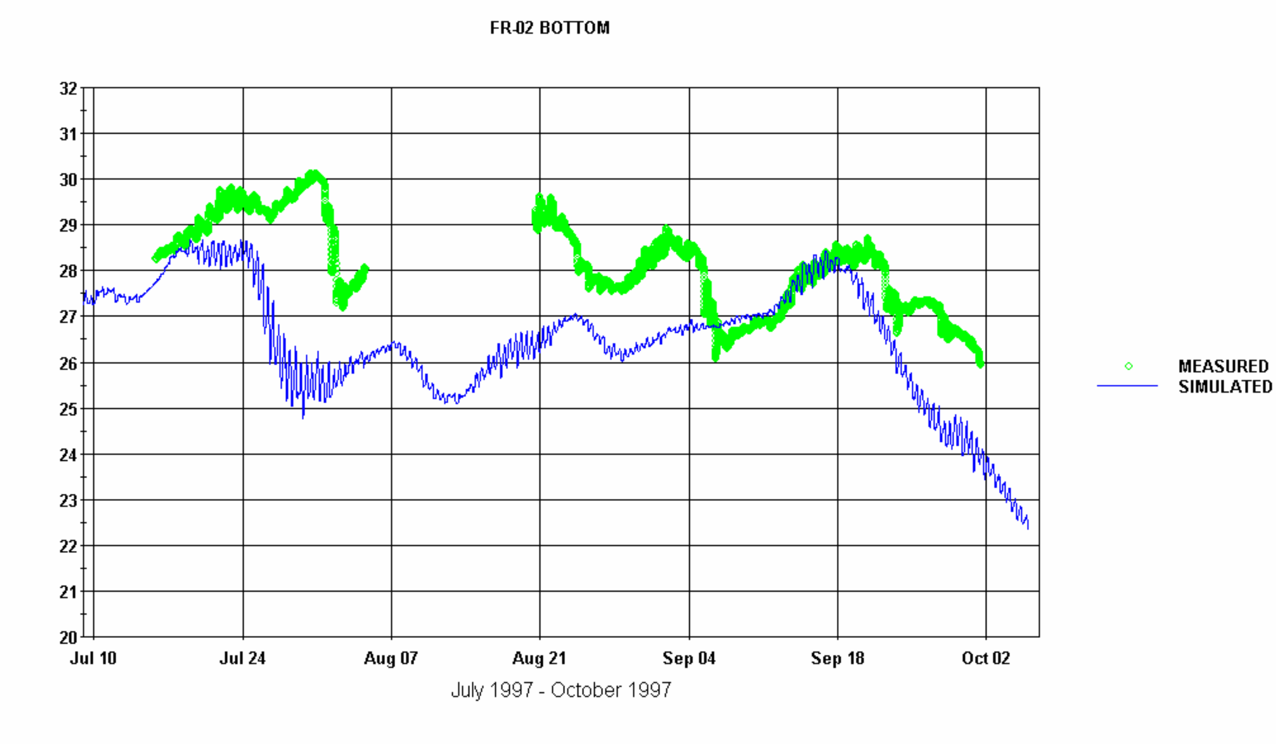


Figure I-2 Temperature (degrees C) Comparisons at FR-02 (Bottom) for July 9, 1997 through October 6, 1997

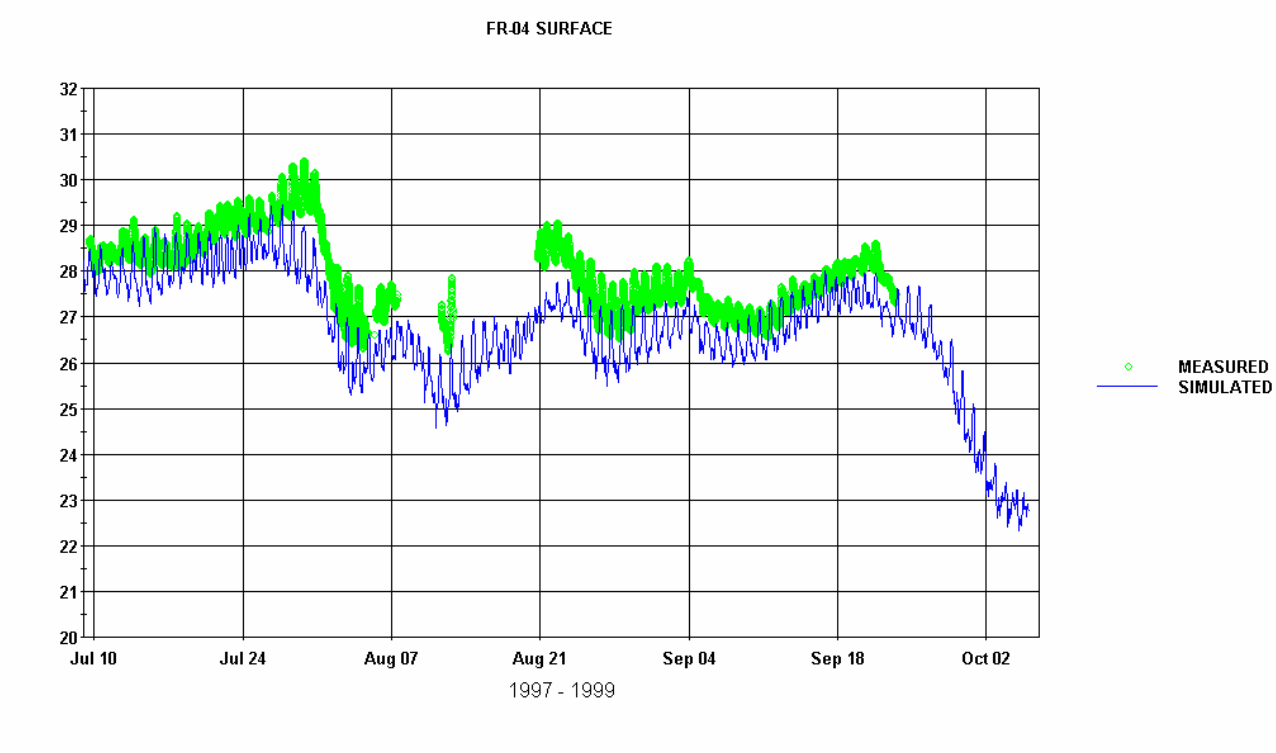


Figure I-3 Temperature (degrees C) Comparisons at FR-04 (Surface) for July 9, 1997 through October 6, 1997

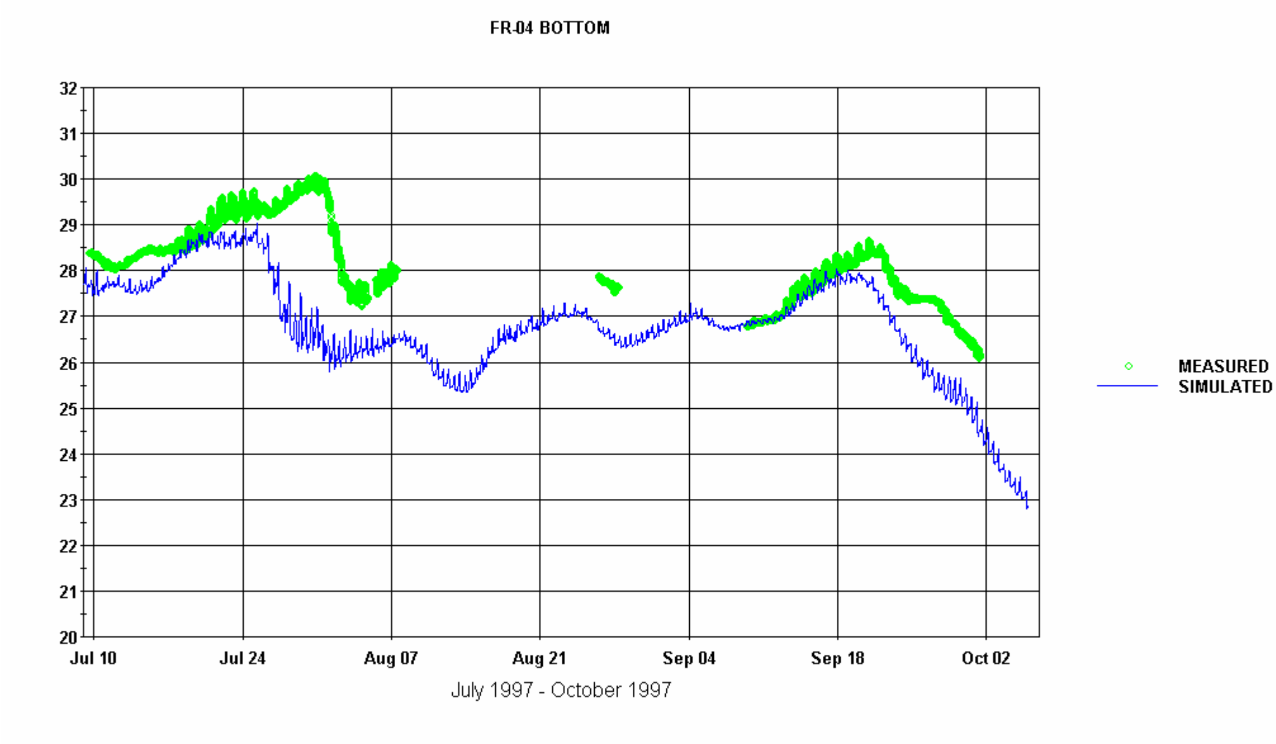


Figure I-4 Temperature (degrees C) Comparisons at FR-04 (Bottom) for July 9, 1997 through October 6, 1997

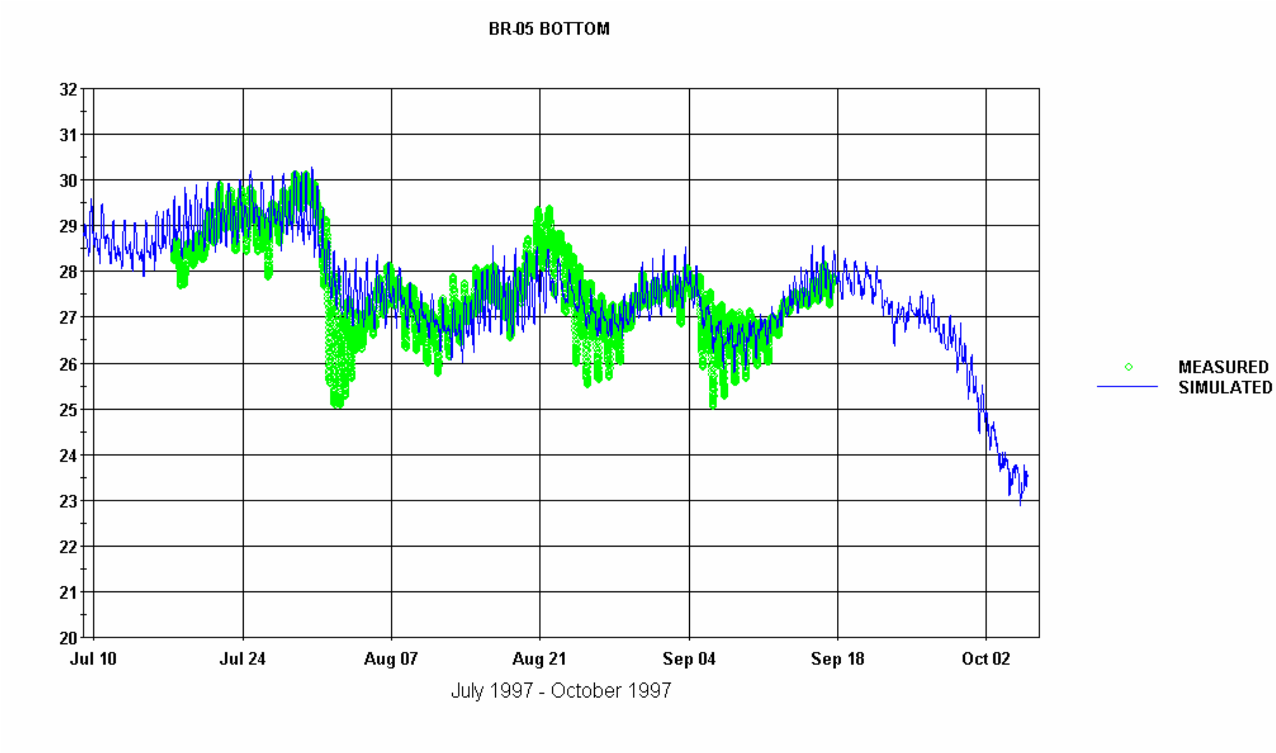


Figure I-5 Temperature (degrees C) Comparisons at BR-05 (Bottom) for July 9, 1997 through October 6, 1997

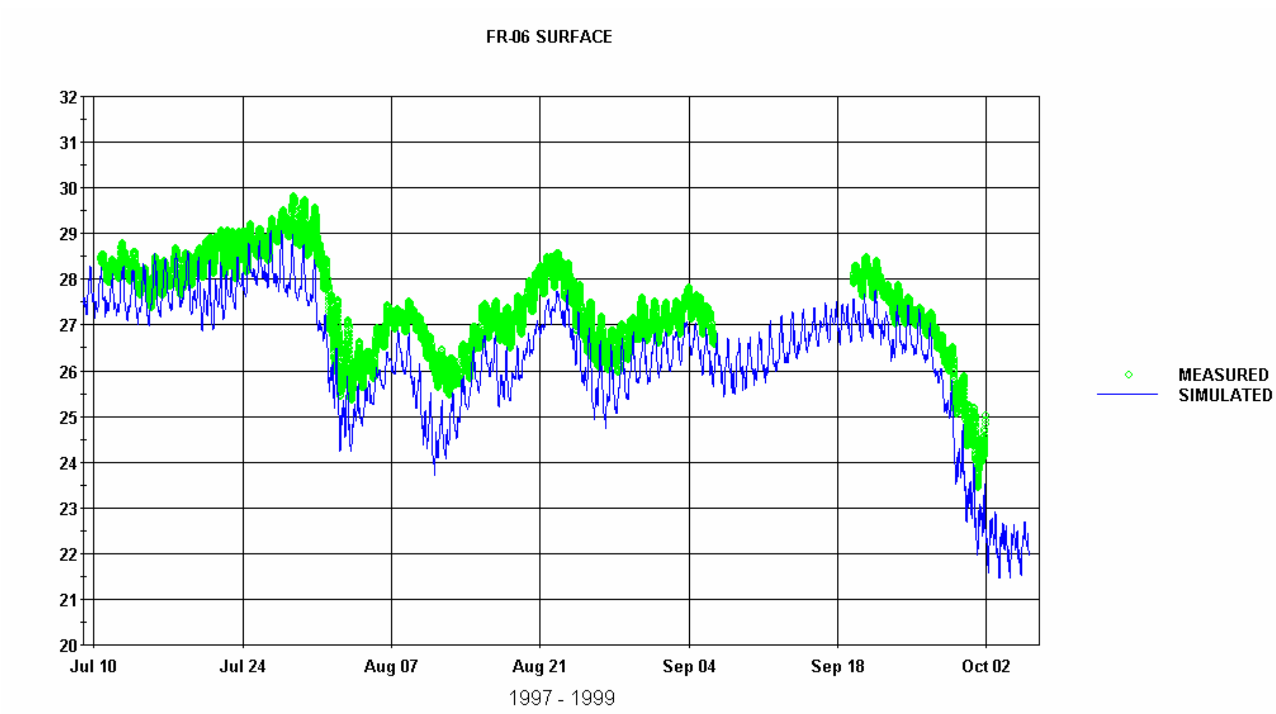


Figure I-6 Temperature (degrees C) Comparisons at FR-06 (Surface) for July 9, 1997 through October 6, 1997

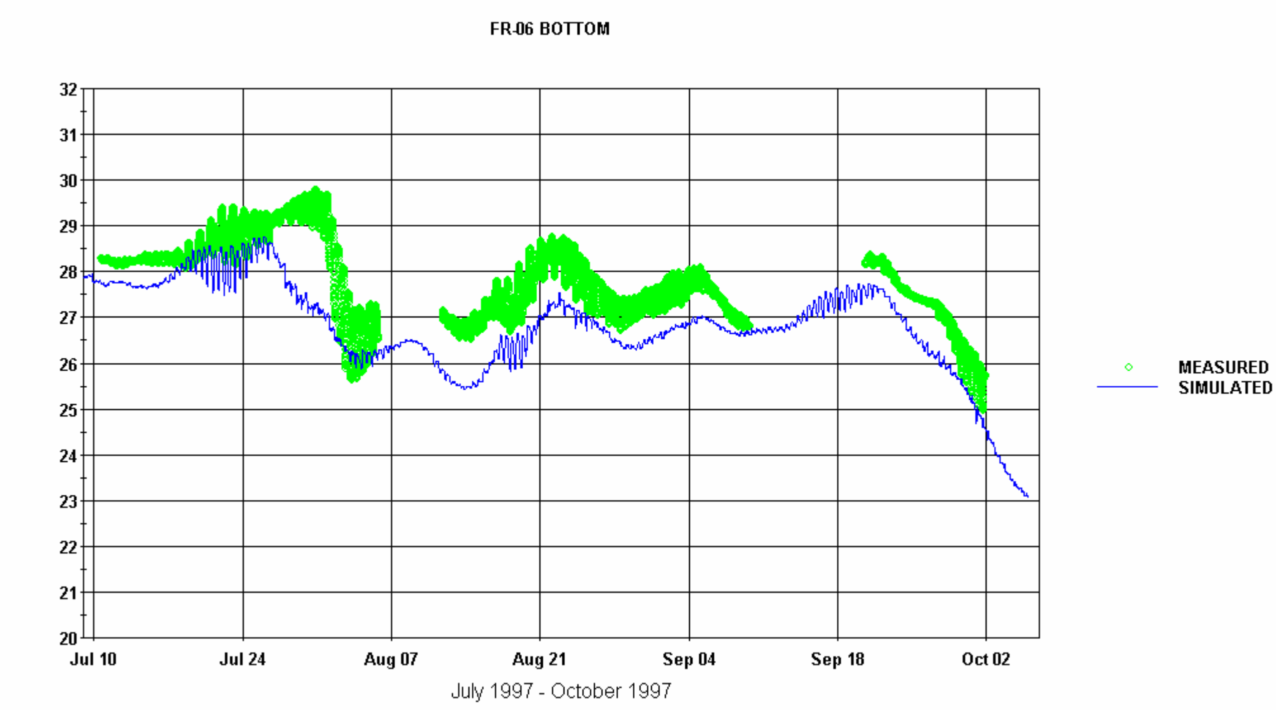


Figure I-7 Temperature (degrees C) Comparisons at FR-06 (Bottom) for July 9, 1997 through October 6, 1997

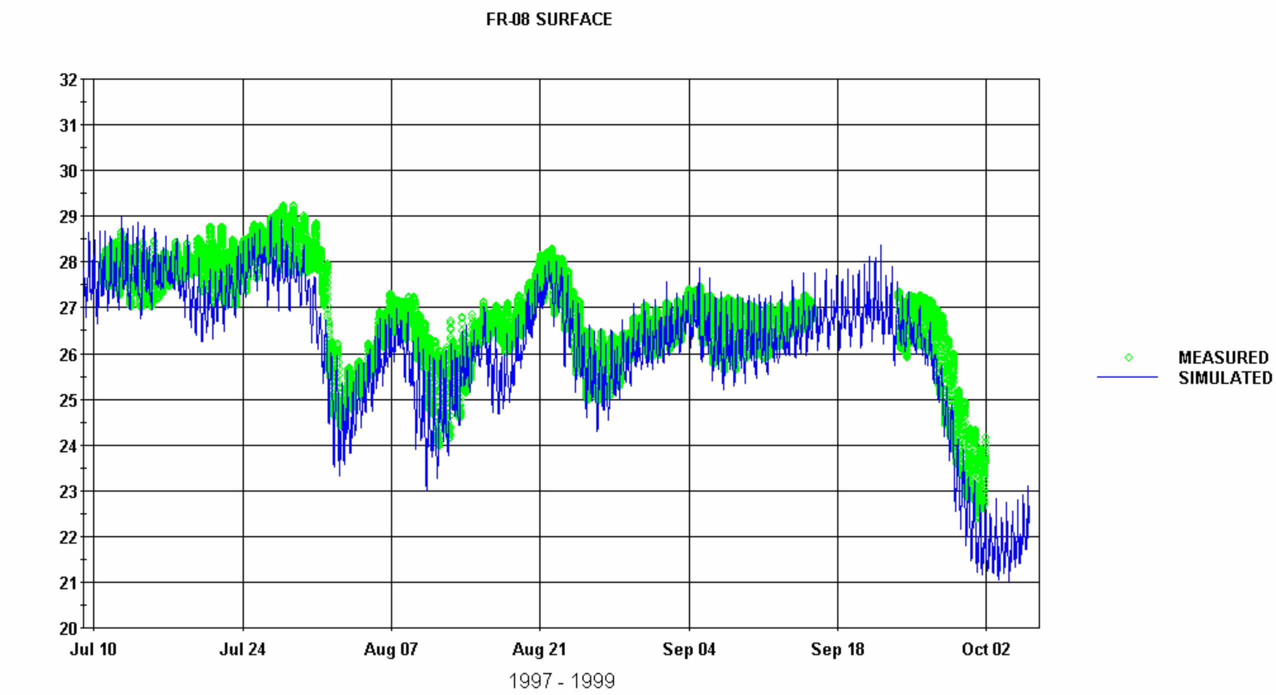


Figure I-8 Temperature (degrees C) Comparisons at FR-08 (Surface) for July 9, 1997 through October 6, 1997

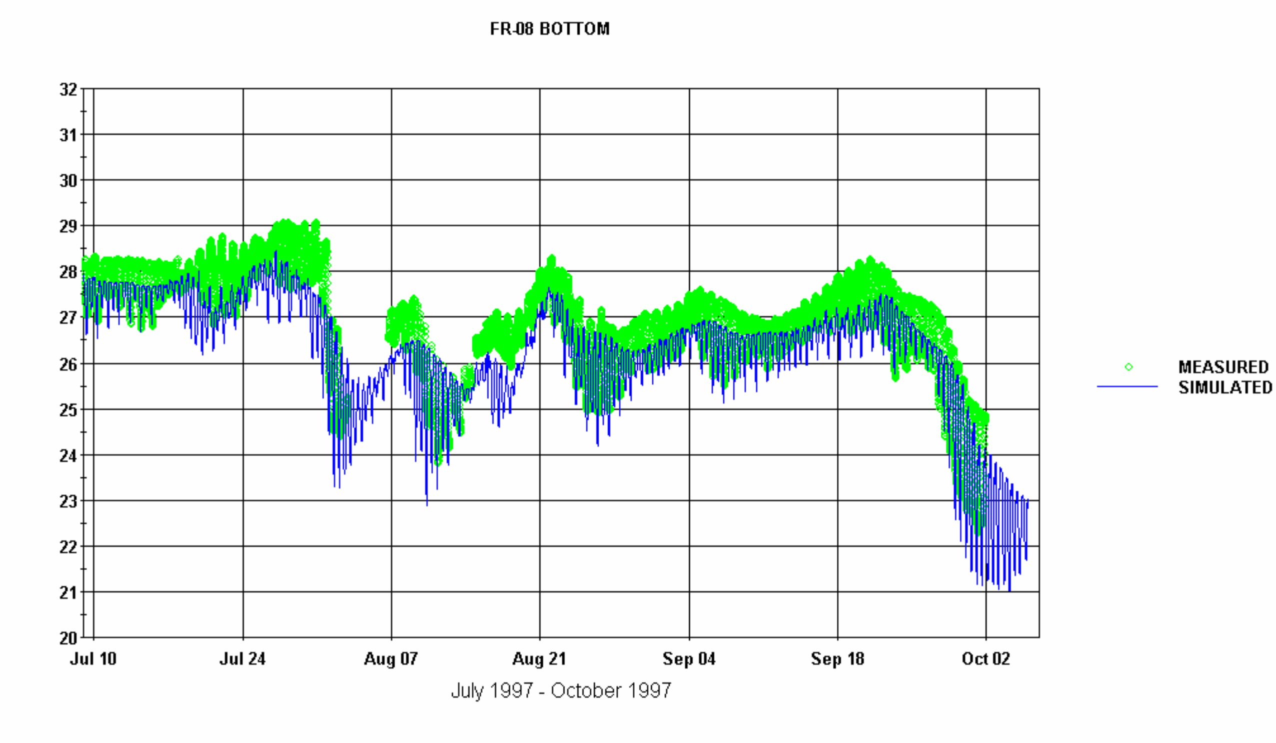


Figure I-9 Temperature (degrees C) Comparisons at FR-08 (Bottom) for July 9, 1997 through October 6, 1997

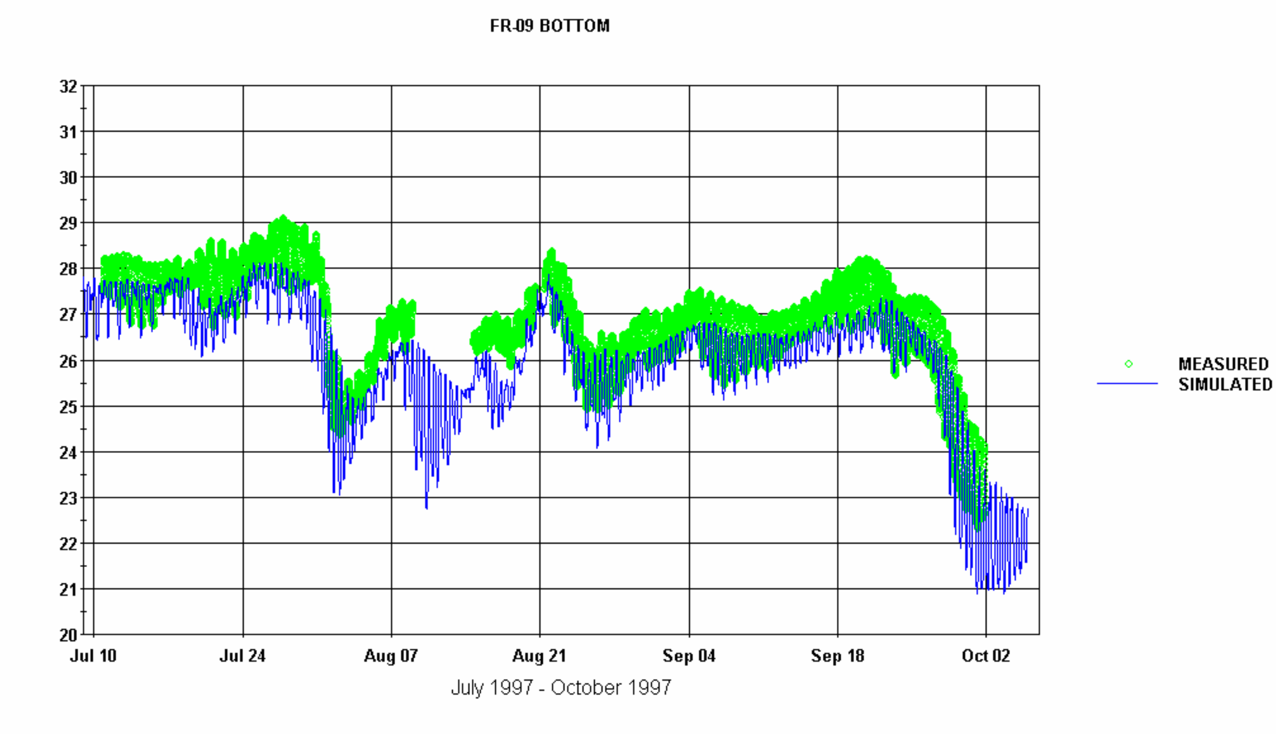


Figure I-10 Temperature (degrees C) Comparisons at FR-09 (Bottom) for July 9, 1997 through October 6, 1997

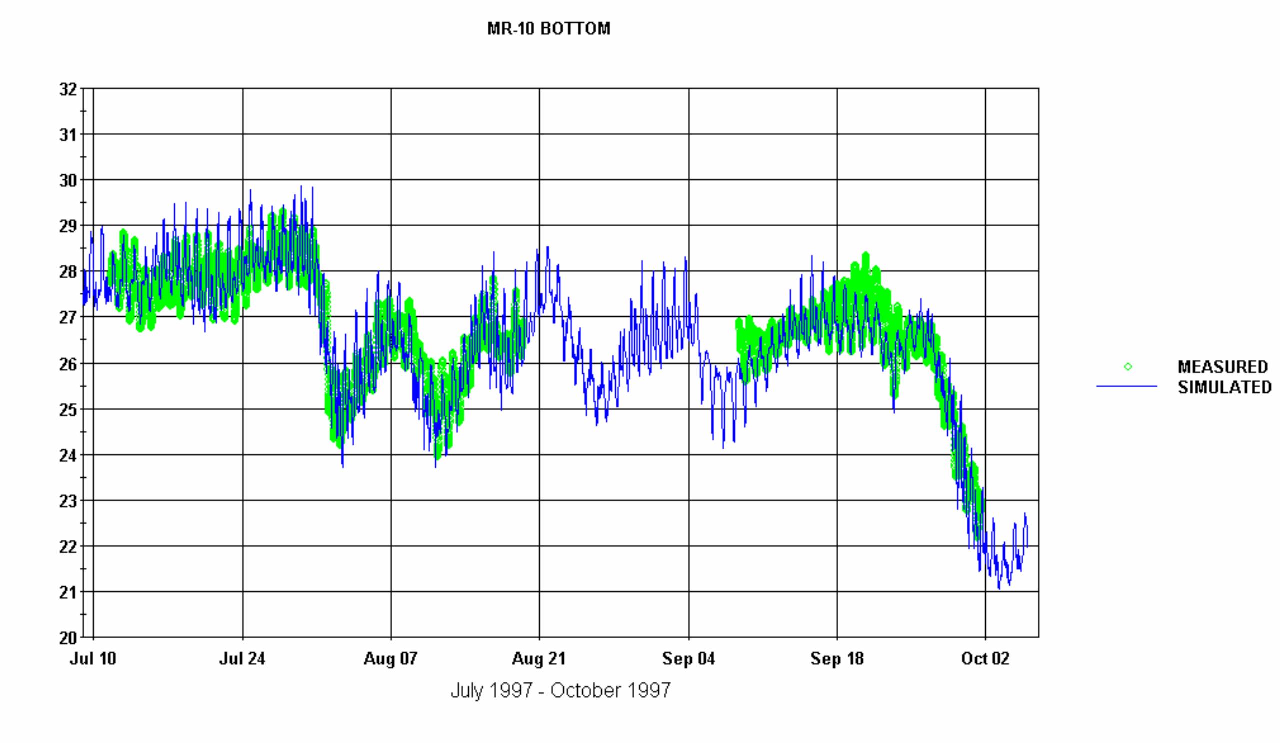


Figure I-11 Temperature (degrees C) Comparisons at MR-10 (Bottom) for July 9, 1997 through October 6, 1997

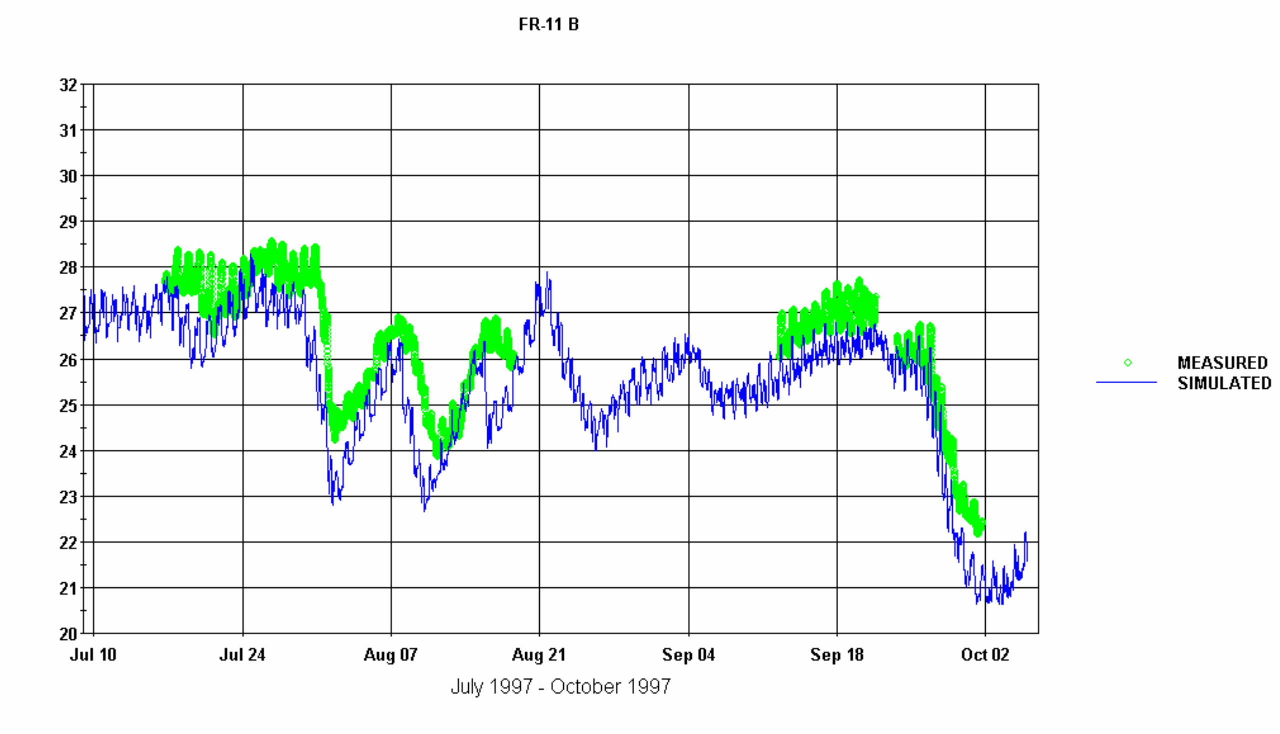


Figure I-12 Temperature (degrees C) Comparisons at FR-11 (Bottom) for July 9, 1997 through October 6, 1997

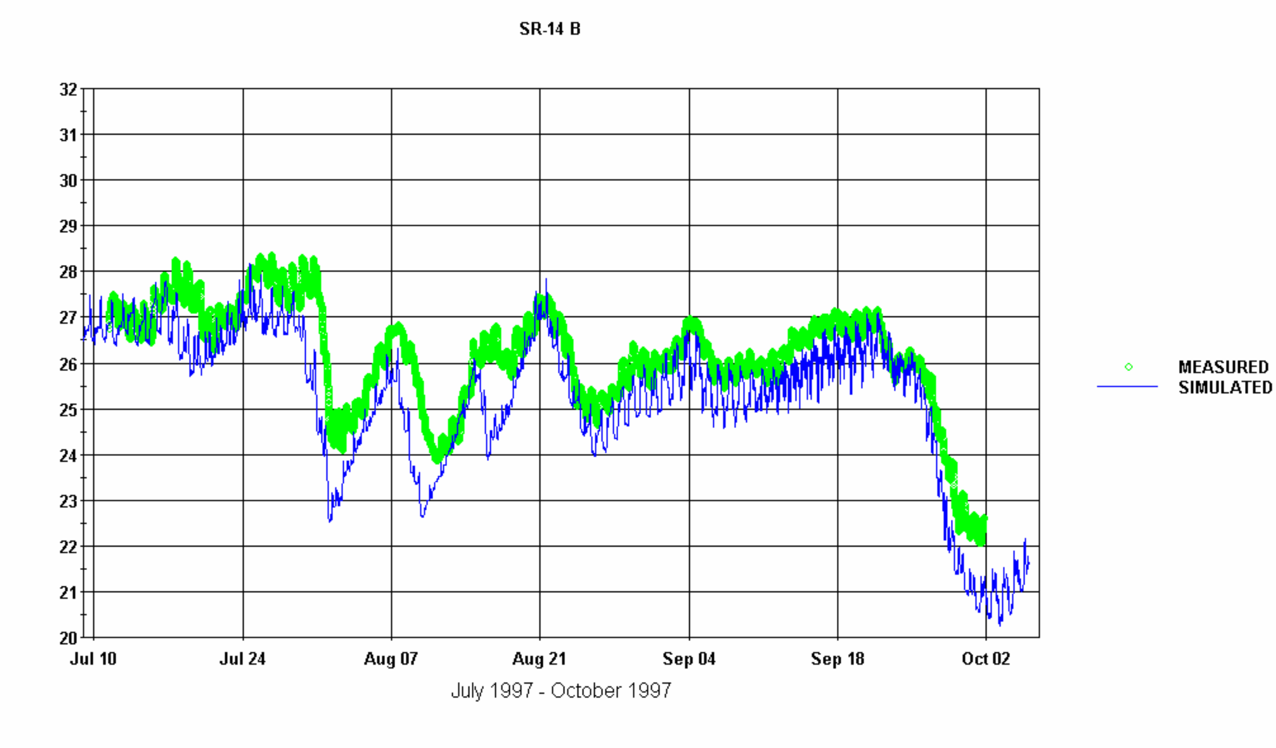


Figure I-13 Temperature (degrees C) Comparisons at SR-14 (Bottom) for July 9, 1997 through October 6, 1997

Table I-3 Temperature Comparison Percentiles, July 10, 1997 through July 23, 1997

July 10 - July 23, 1997 [Julian Days 191-204]					
Stations	**Depth***	**Measured 50% (deg C)**	**Simulated 50% (deg C)**	**Difference (deg C)**	**Absolute Mean Error (deg C)**
FR-02	S	28.7	28.5	-0.2	0.4
FR-02	B	28.9	28.4	-0.6	0.7
FR-04	S	28.5	28.0	-0.5	0.5
FR-04	B	28.5	28.0	-0.5	0.5
BR-05	B	28.8	29.1	0.3	0.5
FR-06	S	28.3	27.6	-0.7	0.6
FR-06	B	28.3	27.8	-0.5	0.5
FR-08	S	27.9	27.5	-0.4	0.5
FR-08	B	28.0	27.5	-0.5	0.5
FR-09	B	27.8	27.3	-0.5	0.6
MR-10	B	27.9	27.8	-0.1	0.5
FR-11	B	27.5	26.8	-0.7	0.7
SR-14	B	27.2	26.7	-0.5	0.6

* S = Surface
B = Bottom

Table I-4 Temperature Comparison Statistics, July 10, 1997 through July 23, 1997

July 10 - July 23, 1997 [Julian Days 191-204]										
Stations	Depth*	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	1932	-0.38	0.40	0.46	28.8	0.4	28.4	0.4	0.64
FR-02	B	1189	-0.65	0.65	0.76	29.0	0.4	28.3	0.2	0.22
FR-04	S	2078	-0.50	0.51	0.57	28.6	0.4	28.1	0.4	0.54
FR-04	B	2083	-0.52	0.52	0.58	28.6	0.4	28.1	0.5	0.73
BR-05	B	937	0.34	0.49	0.62	28.8	0.5	29.1	0.4	0.15
FR-06	S	1927	-0.62	0.64	0.73	28.3	0.3	27.7	0.4	0.21
FR-06	B	1928	-0.49	0.49	0.53	28.4	0.3	27.9	0.3	0.60
FR-08	S	1870	-0.40	0.51	0.63	27.9	0.4	27.5	0.5	0.12
FR-08	B	2109	-0.50	0.51	0.59	27.9	0.4	27.4	0.4	0.43
FR-09	B	1913	-0.53	0.56	0.66	27.8	0.4	27.2	0.4	0.32
MR-10	B	1805	0.08	0.48	0.60	27.8	0.4	27.9	0.6	0.13
FR-11	B	1068	-0.70	0.72	0.84	27.5	0.4	26.8	0.5	0.27
SR-14	B	1823	-0.52	0.59	0.73	27.2	0.4	26.7	0.5	0.07

* S = Surface
B = Bottom

Table I-5 Temperature Comparison Percentiles, July 24, 1997 through August 7, 1997

July 24 - August 7, 1997 [Julian Days 205-219]					
Stations	Depth*	Measured 50%	Simulated 50%	Difference	Absolute Mean Error
		(deg C)	(deg C)	(deg C)	(deg C)
FR-02	S	29.1	27.4	-1.7	1.1
FR-02	B	29.4	25.9	-3.5	2.9
FR-04	S	28.9	27.7	-1.2	1.0
FR-04	B	29.4	26.5	-2.8	2.0
BR-05	B	28.4	28.5	0.1	0.6
FR-06	S	28.2	26.9	-1.3	1.0
FR-06	B	29.1	27.3	-1.8	1.2
FR-08	S	27.7	26.5	-1.2	0.7
FR-08	B	28.1	27.4	-0.7	0.8
FR-09	B	27.4	26.3	-1.0	0.8
MR-10	B	27.3	27.6	0.3	0.6
FR-11	B	27.2	26.0	-1.1	1.0
SR-14	B	26.8	25.6	-1.2	1.1

* S = Surface
B = Bottom

Table I-6 Temperature Comparison Statistics, July 24, 1997 through August 7, 1997

July 24 - August 7, 1997 [Julian Days 205-219]										
Stations	Depth*	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	2137	-1.12	1.12	1.23	28.7	1.0	27.6	0.9	0.73
FR-02	B	1649	-2.87	2.87	3.13	29.1	0.9	26.2	1.0	0.01
FR-04	S	1912	-1.03	1.03	1.09	28.4	1.1	27.4	1.1	0.91
FR-04	B	1958	-1.96	1.96	2.18	28.9	0.9	27.0	0.9	0.19
BR-05	B	2157	0.23	0.62	0.87	28.2	1.3	28.4	1.0	0.58
FR-06	S	2158	-0.97	0.97	1.02	27.8	1.3	26.8	1.3	0.94
FR-06	B	1832	-1.15	1.17	1.40	28.5	1.2	27.3	0.9	0.54
FR-08	S	2149	-0.74	0.74	0.83	27.2	1.4	26.5	1.4	0.92
FR-08	B	1605	-0.67	0.80	0.88	27.7	1.2	27.0	1.1	0.79
FR-09	B	2155	-0.78	0.82	0.90	27.1	1.4	26.3	1.4	0.90
MR-10	B	2147	0.10	0.63	0.73	27.1	1.4	27.2	1.4	0.75
FR-11	B	2158	-0.96	0.96	1.08	26.8	1.3	25.8	1.4	0.88
SR-14	B	2156	-1.13	1.13	1.29	26.7	1.3	25.5	1.4	0.81

* S = Surface
B = Bottom

Table I-7 Temperature Comparison Percentiles, August 8, 1997 through August 22, 1997

August 8 - August 22, 1997 [Julian Days 220-234]					
Stations	Depth*	Measured 50% (deg C)	Simulated 50% (deg C)	Difference (deg C)	Absolute Mean Error (deg C)
FR-02	S	27.9	26.6	-1.3	1.5
FR-02	B	29.2	26.6	-2.6	2.6
FR-04	S	28.4	27.1	-1.3	1.4
FR-04	B				
BR-05	B	27.5	27.2	-0.3	0.5
FR-06	S	27.0	25.9	-1.2	1.2
FR-06	B	27.2	26.1	-1.1	1.2
FR-08	S	26.6	25.8	-0.8	0.8
FR-08	B	26.8	25.9	-0.9	0.8
FR-09	B	26.8	25.9	-0.9	0.9
MR-10	B	26.2	25.9	-0.3	0.5
FR-11	B	25.8	24.6	-1.2	1.0
SR-14	B	26.1	24.9	-1.2	0.9

* S = Surface
B = Bottom

Table I-8 Temperature Comparison Statistics, August 8, 1997 through August 22, 1997

August 8 - August 22, 1997 [Julian Days 220-234]										
Stations	Depth*	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	2154	-1.45	1.45	1.52	28.0	0.7	26.5	0.5	0.63
FR-02	B	366	-2.63	2.63	2.65	29.2	0.2	26.6	0.2	0.25
FR-04	S	481	-1.41	1.41	1.42	28.0	0.9	26.6	0.9	0.95
FR-04	B	0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.00
BR-05	B	2158	-0.28	0.53	0.63	27.5	0.7	27.3	0.5	0.37
FR-06	S	2146	-1.15	1.15	1.21	27.0	0.8	25.9	0.9	0.83
FR-06	B	1618	-1.20	1.20	1.22	27.4	0.6	26.2	0.6	0.88
FR-08	S	2128	-0.75	0.78	0.91	26.5	0.9	25.8	1.0	0.75
FR-08	B	1622	-0.78	0.81	0.91	26.7	0.9	25.9	1.0	0.78
FR-09	B	1213	-0.90	0.90	1.00	26.9	0.5	26.0	0.8	0.74
MR-10	B	1650	-0.18	0.54	0.66	26.1	0.7	25.9	0.9	0.50
FR-11	B	1514	-1.02	1.04	1.26	25.5	0.9	24.5	0.9	0.43
SR-14	B	2157	-0.90	0.92	1.18	25.9	1.0	25.0	1.3	0.63

* S = Surface
B = Bottom

Table I-9 Temperature Comparison Percentiles, August 23, 1997 through September 6, 1997

August 23 - September 6, 1997 [Julian Days 235-249]					
Stations	Depth*	Measured 50% (deg C)	Simulated 50% (deg C)	Difference (deg C)	Absolute Mean Error (deg C)
FR-02	S	27.9	26.9	-1.0	1.0
FR-02	B	28.1	26.7	-1.4	1.5
FR-04	S	27.5	26.7	-0.8	0.9
FR-04	B	27.7	26.6	-1.1	1.1
BR-05	B	27.4	27.3	-0.1	0.4
FR-06	S	27.1	26.3	-0.8	0.8
FR-06	B	27.6	26.8	-0.8	0.9
FR-08	S	26.5	26.1	-0.4	0.4
FR-08	B	26.7	26.3	-0.4	0.5
FR-09	B	26.5	26.0	-0.4	0.5
MR-10	B				
FR-11	B				
SR-14	B	25.9	25.2	-0.7	0.6

* S = Surface
B = Bottom

Table I-10 Temperature Comparison Statistics, August 23, 1997 through September 6, 1997

August 23 - September 6, 1997 [Julian Days 235-249]										
Stations	**Depth***	**N**	**ME**	**AME**	**RMS**	**Mean Obs**	**StDev Obs**	**Mean Pred**	**StDev Pred**	**R^2**
FR-02	S	1632	-1.00	1.00	1.03	27.9	0.5	26.9	0.4	0.73
FR-02	B	2149	-1.46	1.49	1.57	28.1	0.6	26.6	0.3	0.06
FR-04	S	2160	-0.86	0.86	0.90	27.5	0.4	26.6	0.5	0.69
FR-04	B	275	-1.13	1.13	1.14	27.7	0.1	26.6	0.1	0.42
BR-05	B	2158	0.05	0.39	0.48	27.2	0.6	27.3	0.4	0.37
FR-06	S	2043	-0.82	0.82	0.87	27.1	0.5	26.2	0.6	0.77
FR-06	B	2147	-0.88	0.88	0.90	27.6	0.4	26.8	0.3	0.69
FR-08	S	2136	-0.38	0.42	0.48	26.5	0.6	26.1	0.6	0.79
FR-08	B	2153	-0.42	0.47	0.52	26.6	0.7	26.2	0.6	0.79
FR-09	B	2156	-0.52	0.52	0.57	26.4	0.7	25.9	0.6	0.86
MR-10	B	0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.00
FR-11	B	0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.00
SR-14	B	2160	-0.63	0.64	0.71	25.9	0.6	25.3	0.6	0.73

* S = Surface
B = Bottom

Table I-11 Temperature Comparison Percentiles, September 7, 1997 through September 20, 1997

September 7 - September 20, 1997 [Julian Days 250-263]					
Stations	**Depth***	**Measured 50%**	**Simulated 50%**	**Difference**	**Absolute Mean Error**
		(deg C)	**(deg C)**	**(deg C)**	**(deg C)**
FR-02	S				
FR-02	B	27.7	27.5	-0.2	0.3
FR-04	S	27.4	27.0	-0.4	0.5
FR-04	B	27.7	27.5	-0.2	0.2
BR-05	B	27.0	27.0	0.0	0.2
FR-06	S	28.1	27.1	-1.0	1.0
FR-06	B	27.1	26.7	-0.4	0.4
FR-08	S	26.8	26.2	-0.6	0.5
FR-08	B	27.0	26.6	-0.4	0.5
FR-09	B	27.0	26.5	-0.5	0.6
MR-10	B	26.8	26.6	-0.2	0.5
FR-11	B	26.9	26.1	-0.8	0.7
SR-14	B	26.4	25.8	-0.6	0.7

* S = Surface
B = Bottom

Table I-12 Temperature Comparison Statistics, September 7, 1997 through September 20, 1997

September 7 - September 20, 1997 [Julian Days 250-263]										
Stations	Depth*	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	0								
FR-02	B	2012	-0.01	0.26	0.36	27.5	0.7	27.5	0.5	0.78
FR-04	S	1963	-0.50	0.50	0.55	27.4	0.5	26.9	0.6	0.81
FR-04	B	1672	-0.21	0.22	0.28	27.6	0.6	27.4	0.4	0.94
BR-05	B	1519	0.08	0.22	0.28	27.0	0.5	27.1	0.6	0.79
FR-06	S	226	-0.97	0.97	0.99	28.1	0.2	27.2	0.3	0.43
FR-06	B	466	-0.41	0.41	0.45	27.2	0.5	26.8	0.3	0.92
FR-08	S	1249	-0.45	0.49	0.55	26.7	0.4	26.2	0.4	0.49
FR-08	B	2014	-0.54	0.55	0.59	27.1	0.5	26.5	0.4	0.78
FR-09	B	2014	-0.61	0.61	0.66	27.0	0.6	26.4	0.4	0.87
MR-10	B	1770	-0.32	0.49	0.56	26.9	0.5	26.6	0.6	0.48
FR-11	B	1213	-0.74	0.74	0.77	26.9	0.4	26.1	0.3	0.72
SR-14	B	2014	-0.65	0.65	0.72	26.4	0.5	25.7	0.5	0.64

* S = Surface
B = Bottom

Table I-13 Temperature Comparison Percentiles, September 21, 1997 through October 6, 1997

September 21 - October 6, 1997 [Julian Days 264-279]					
Stations	Depth*	Measured 50%	Simulated 50%	Difference	Absolute Mean Error
		(deg C)	(deg C)	(deg C)	(deg C)
FR-02	S				
FR-02	B	27.2	25.0	-2.2	1.9
FR-04	S	27.9	27.2	-0.7	0.7
FR-04	B	27.4	25.9	-1.5	1.3
BR-05	B	0.0	0.0	0.0	0.0
FR-06	S	27.1	26.3	-0.7	0.9
FR-06	B	27.4	26.3	-1.1	0.8
FR-08	S	26.8	26.2	-0.6	0.5
FR-08	B	26.6	26.3	-0.3	0.5
FR-09	B	26.3	26.2	-0.1	0.5
MR-10	B	26.2	26.1	0.0	0.5
FR-11	B	25.2	24.7	-0.5	0.8
SR-14	B	25.7	25.0	-0.6	0.8

* S = Surface
B = Bottom

Table I-14 Temperature Comparison Statistics, September 21, 1997 through October 6, 1997

September 21 - October 6, 1997 [Julian Days 264-279]										
Stations	**Depth***	**N**	**ME**	**AME**	**RMS**	**Mean Obs**	**StDev Obs**	**Mean Pred**	**StDev Pred**	**R^2**
FR-02	S	1152	-0.69	0.69	0.75	26.9	0.6	26.2	0.9	0.97
FR-02	B	1497	-1.87	1.87	1.96	27.2	0.6	25.3	1.0	0.77
FR-04	S	353	-0.73	0.73	0.75	27.9	0.3	27.2	0.3	0.80
FR-04	B	1495	-1.29	1.29	1.34	27.3	0.6	26.0	0.9	0.91
BR-05	B	0								
FR-06	S	1560	-0.95	0.95	1.04	26.6	1.2	25.6	1.5	0.97
FR-06	B	1561	-0.84	0.84	0.87	27.2	0.8	26.4	0.9	0.93
FR-08	S	1249	-0.45	0.49	0.55	26.7	0.4	26.2	0.4	0.49
FR-08	B	1555	-0.40	0.53	0.62	26.1	1.5	25.7	1.6	0.91
FR-09	B	1557	-0.45	0.51	0.65	25.8	1.6	25.4	1.8	0.94
MR-10	B	1518	-0.13	0.49	0.59	25.7	1.4	25.5	1.5	0.85
FR-11	B	1227	-0.75	0.75	0.87	24.8	1.6	24.0	2.0	0.99
SR-14	B	1546	-0.73	0.77	0.93	24.8	1.6	24.1	2.1	0.97

* S = Surface
B = Bottom

APPENDIX J 1999 SALINITY COMPARISONS

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

July 31 - October 13, 1999 [Julian Days 212-285]														
Stations	Depth*	Simulated			Measured			Difference			Percent Difference			Evaluation Criteria
		10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	(ppt)
FR-26	S	15.0	23.5	26.6	19.5	26.5	30.8	-4.5	-3.0	-4.2	23.0	11.2	13.5	>5
FR-26	B	30.2	33.2	34.0	26.2	30.6	33.6	4.0	2.5	0.5	-15.1	-8.3	-1.4	>5
FR-02	S	10.6	15.4	25.3	12.8	18.6	25.5	-2.2	-3.3	-0.2	17.2	17.5	0.7	>5
FR-02	B	28.6	32.3	33.6	26.0	31.4	33.4	2.6	0.8	0.2	-9.9	-2.6	-0.7	>5
SC-03	B	14.4	16.6	19.2	15.2	18.2	20.7	-0.8	-1.6	-1.4	5.2	8.9	7.0	>5
FR-04	S	6.5	9.3	13.9	8.5	12.5	17.7	-2.1	-3.1	-3.8	24.3	25.2	21.5	>5
FR-04	B	17.4	21.3	27.1	13.5	18.1	26.7	3.9	3.2	0.4	-28.8	-17.8	-1.3	>5
FR-21	S	3.7	6.5	10.3	5.0	7.8	12.8	-1.3	-1.2	-2.5	26.0	16.0	19.7	>5
FR-21	B	13.5	17.2	22.4	10.7	15.8	22.7	2.8	1.4	-0.3	-26.3	-8.7	1.2	>5
BR-05	B	6.4	10.2	15.4	2.0	7.5	13.7	4.4	2.7	1.7	-216.6	-36.0	-12.1	>5
FR-06	S	2.3	4.5	9.0	3.0	5.4	10.5	-0.7	-0.9	-1.5	21.8	16.8	14.6	>5
FR-06	B	12.0	16.7	23.1	8.1	14.2	23.1	3.9	2.5	0.0	-47.7	-17.5	0.0	>5
FR-22	S	0.8	2.5	5.5	0.6	2.8	7.3	0.1	-0.4	-1.7	-22.3	13.2	24.0	<5
FR-22	B	6.9	11.1	15.9	2.7	7.6	12.8	4.2	3.5	3.1	-156.3	-46.0	-23.9	>5
BR-07	S	0.9	2.2	5.0	0.2	0.7	3.9	0.7	1.4	1.2	-393.3	-193.4	-29.9	<5
FR-08	S	0.3	1.9	4.7	0.1	0.9	5.5	0.2	1.0	-0.8	-329.7	-114.9	13.9	<5
FR-08	B	0.5	5.4	19.7	0.1	4.6	13.3	0.3	0.8	6.4	-227.2	-18.2	-48.5	<5
LBR-15	S	0.1	0.5	1.5	0.1	0.3	1.0	0.0	0.2	0.5	-8.2	-75.4	-47.9	<5
FR-09	S	0.1	1.3	3.9	0.1	0.9	5.2	0.1	0.4	-1.3	-153.2	-45.8	25.0	<5
FR-09	B	0.2	2.7	12.3	0.1	1.8	9.1	0.1	1.0	3.2	-54.7	-54.9	-34.7	<5
MR-10	S	0.4	1.1	3.2	0.2	1.1	3.9	0.1	0.0	-0.7	-46.3	3.1	17.9	<5
FR-11R	B	0.0	0.2	7.0	0.0	0.1	4.1	0.0	0.1	2.9	98.0	-144.6	-69.8	<5
MR-12R	S	0.1	0.4	1.1	0.1	0.3	2.2	0.0	0.1	-1.1	-30.1	-36.6	48.1	<5
SR-14	B	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	100.0	99.9	81.2	<5
USGS02198920 (Houlihan Bridge)	M	0.1	2.2	7.3	0.1	1.5	5.3	0.1	0.8	1.9	-99.7	-52.6	-35.8	<5
USGS02198840 (I-95)	M	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	100.0	100.0	89.8	<5
USGS021989784 (Lucknow Canal)	M	0.0	0.1	0.4	0.1	0.2	0.4	-0.1	-0.1	0.0	65.4	40.7	-4.9	<5
USGS02198791 (US F&W Docks)	M	0.1	0.3	0.9	0.1	0.2	0.6	0.0	0.1	0.3	32.9	-39.3	-53.7	<5

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

Statistic Applicable for Criteria (orange shading)
Meets Criteria (yellow shading)

Table J-2 Summary Statistics for Salinity (ppt) for July 31, 1999 through October 13, 1999

July 31 - October 13, 1999 [Julian Days 212-285]										
Station	**Depth***	**N**	**ME**	**AME**	**RMS**	**Mean Obs**	**StDev Obs**	**Mean Pred**	**StDev Pred**	**R^2**
FR-26	S	13592	-3.77	4.14	4.66	25.68	4.40	21.91	4.60	0.67
FR-26	B	16580	2.34	2.75	3.52	30.17	2.86	32.51	1.92	0.20
FR-02	S	10346	-2.02	3.71	4.37	18.90	4.72	16.89	5.46	0.52
FR-02	B	2225	1.11	2.33	3.17	30.58	2.79	31.68	1.98	0.07
SC-03	B	15516	-1.38	2.10	2.59	18.08	2.11	16.69	1.82	0.15
FR-04	S	14937	-3.00	3.10	3.74	12.85	3.48	9.85	2.83	0.59
FR-04	B	12965	2.84	3.31	4.06	18.98	4.69	21.82	3.43	0.62
FR-21	S	18693	-1.62	2.12	2.63	8.43	3.09	6.81	2.51	0.55
FR-21	B	13045	1.26	2.95	3.69	16.12	4.45	17.39	3.16	0.40
BR-05	B	11817	2.87	3.35	4.09	7.80	4.18	10.67	3.27	0.52
FR-06	S	11886	-0.89	1.44	1.80	6.03	2.77	5.15	2.56	0.69
FR-06	B	14958	2.14	2.93	3.60	14.97	5.39	17.11	4.12	0.72
FR-22	S	18949	-0.66	1.16	1.61	3.53	2.75	2.87	1.88	0.75
FR-22	B	13918	3.75	4.02	4.74	7.68	3.85	11.43	3.51	0.48
BR-07	S	18038	1.18	1.74	2.20	1.48	1.89	2.66	1.73	0.23
FR-08	S	11920	0.19	1.27	1.76	2.11	2.75	2.30	1.82	0.61
FR-08	B	8385	2.29	3.84	5.50	5.44	4.70	7.73	7.02	0.49
LBR-15	S	18893	-0.21	1.29	1.88	1.92	2.40	1.72	1.68	0.40
FR-09	S	18499	1.14	2.08	3.20	3.30	3.98	4.44	4.92	0.63
FR-09	B	15511	-0.17	0.75	1.11	1.66	1.68	1.49	1.32	0.58
MR-10	S	16641	0.75	1.29	2.32	1.30	2.71	2.05	3.43	0.59
FR-11R	B	18453	-0.25	0.46	0.94	0.77	1.16	0.53	0.60	0.41
MR-12R	S	12348	-0.04	0.04	0.04	0.05	0.01	0.00	0.01	0.13
SR-14	B	15588	0.27	0.39	0.71	0.46	0.58	0.73	0.86	0.42
USGS02198920 (Houlihan Bridge)	M	3601	-0.04	0.04	0.05	0.05	0.01	0.00	0.01	0.07
USGS02198840 (I-95)	M	3533	-0.06	0.10	0.13	0.22	0.14	0.16	0.15	0.48
USGS021989784 (Lucknow Canal)	M	3526	0.81	1.36	2.22	2.26	2.37	3.07	3.11	0.56
USGS02198791 (US F&W Docks)	M	3601	0.13	0.24	0.41	0.32	0.34	0.45	0.52	0.44

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

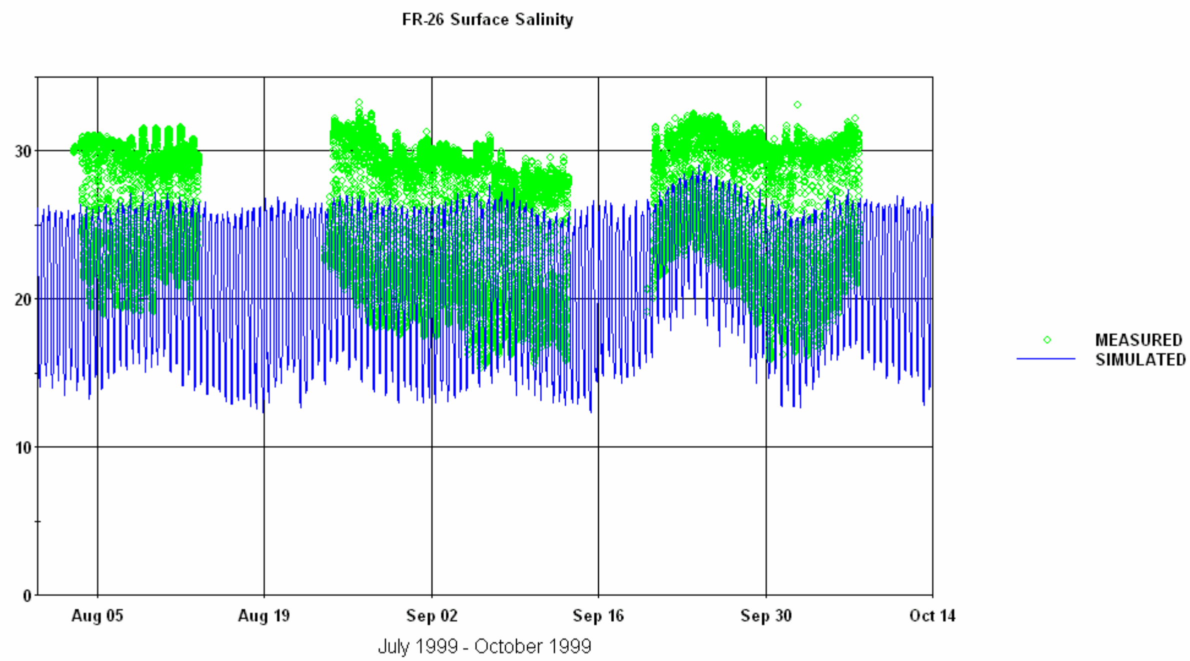


Figure J-1 Salinity (ppt) Calibration at FR-26 (Surface) for July 31, 1999 through October 13, 1999

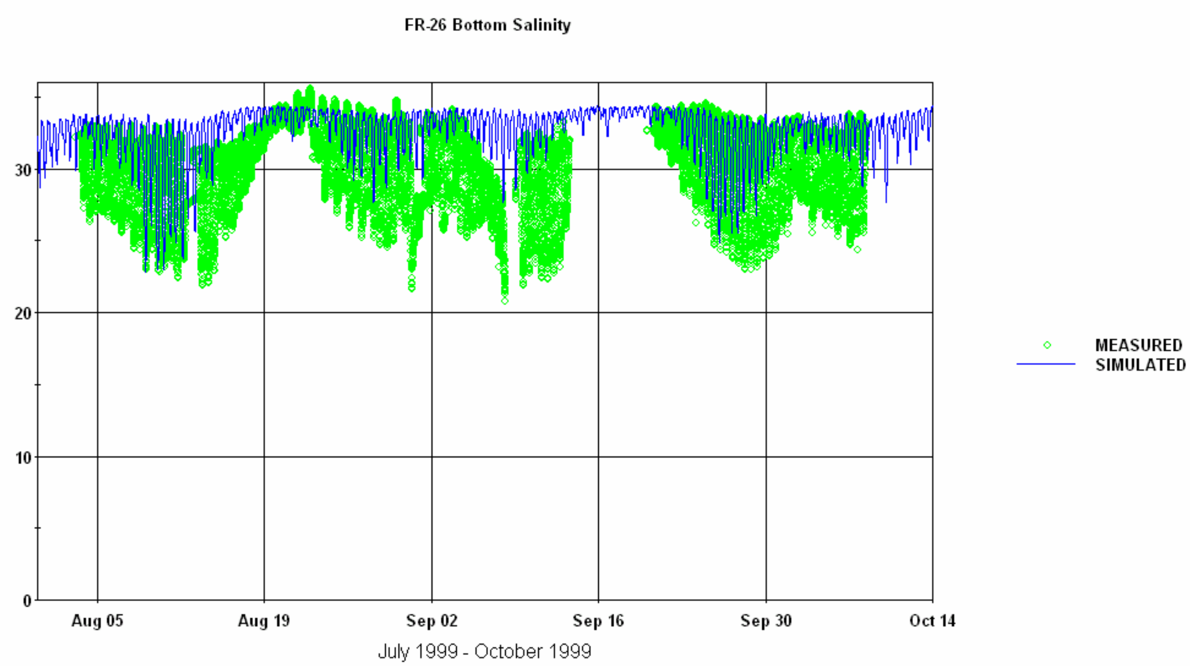


Figure J-2 Salinity (ppt) Calibration at FR-26 (Bottom) for July 31, 1999 through October 13, 1999

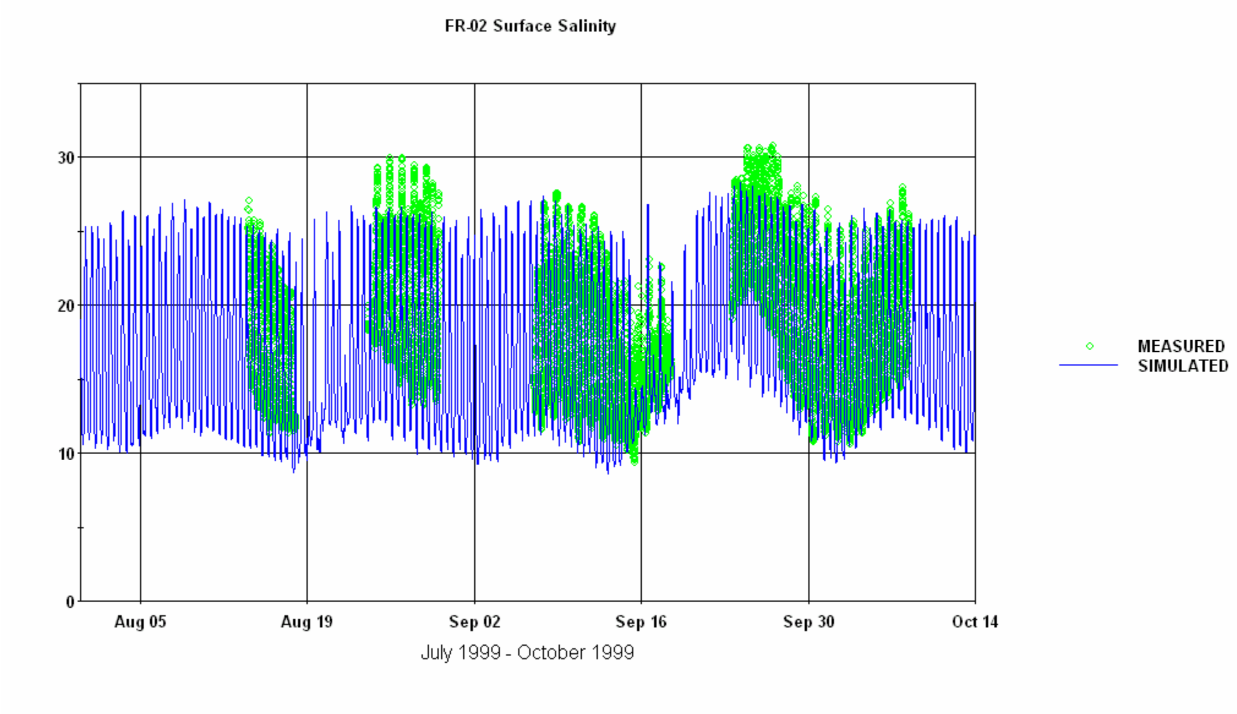


Figure J-3 Salinity (ppt) Calibration at FR-02 (Surface) for July 31, 1999 through October 13, 1999

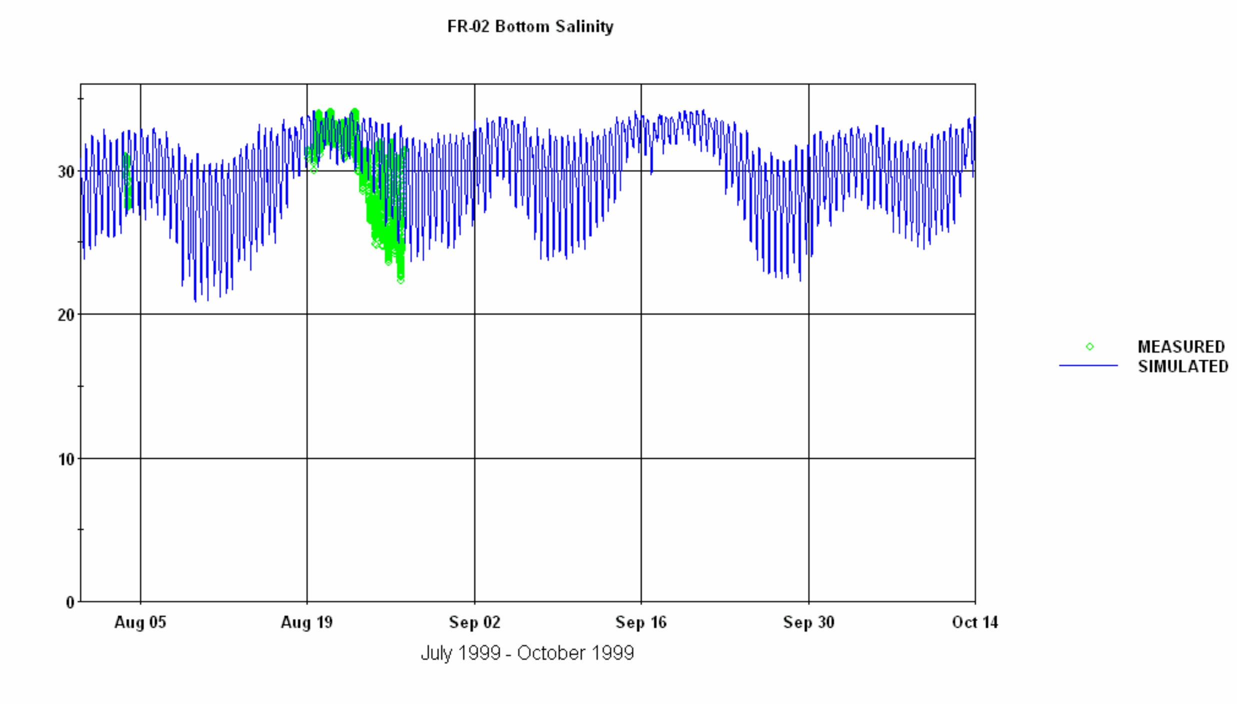


Figure J-4 Salinity (ppt) Calibration at FR-02 (Bottom) for July 31, 1999 through October 13, 1999

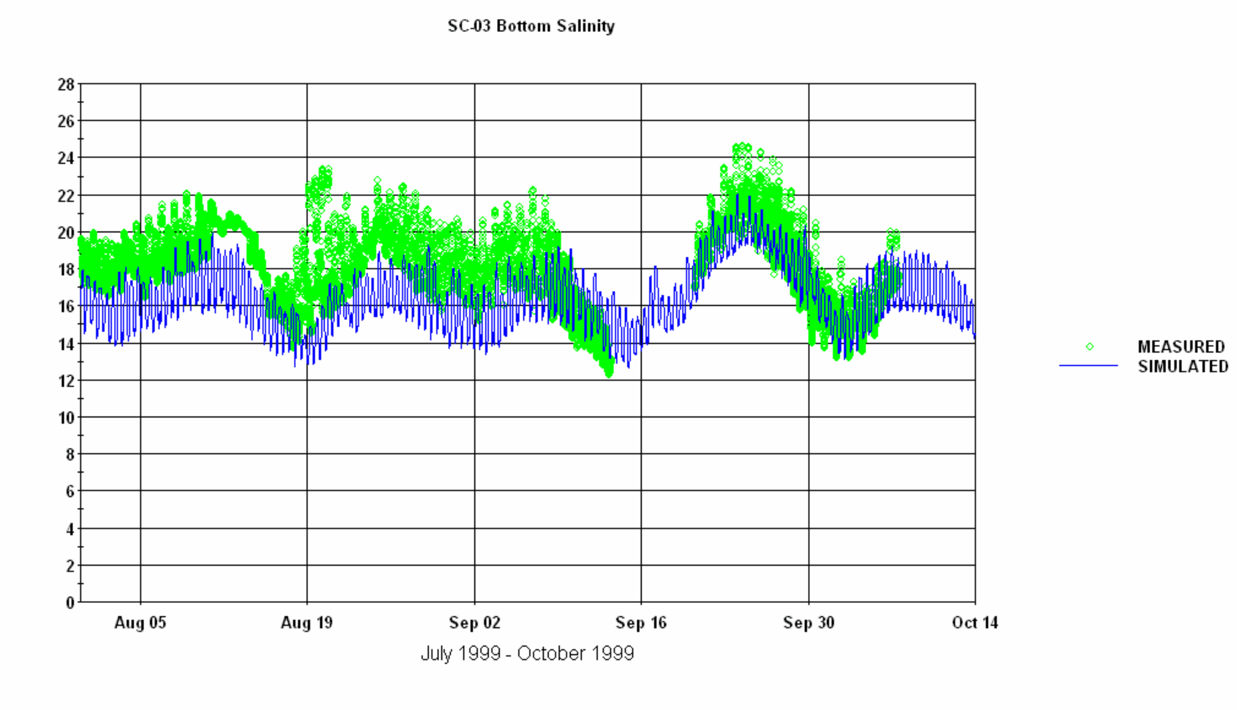


Figure J-5 Salinity (ppt) Calibration at SC-03 (Bottom) for July 31, 1999 through October 13, 1999

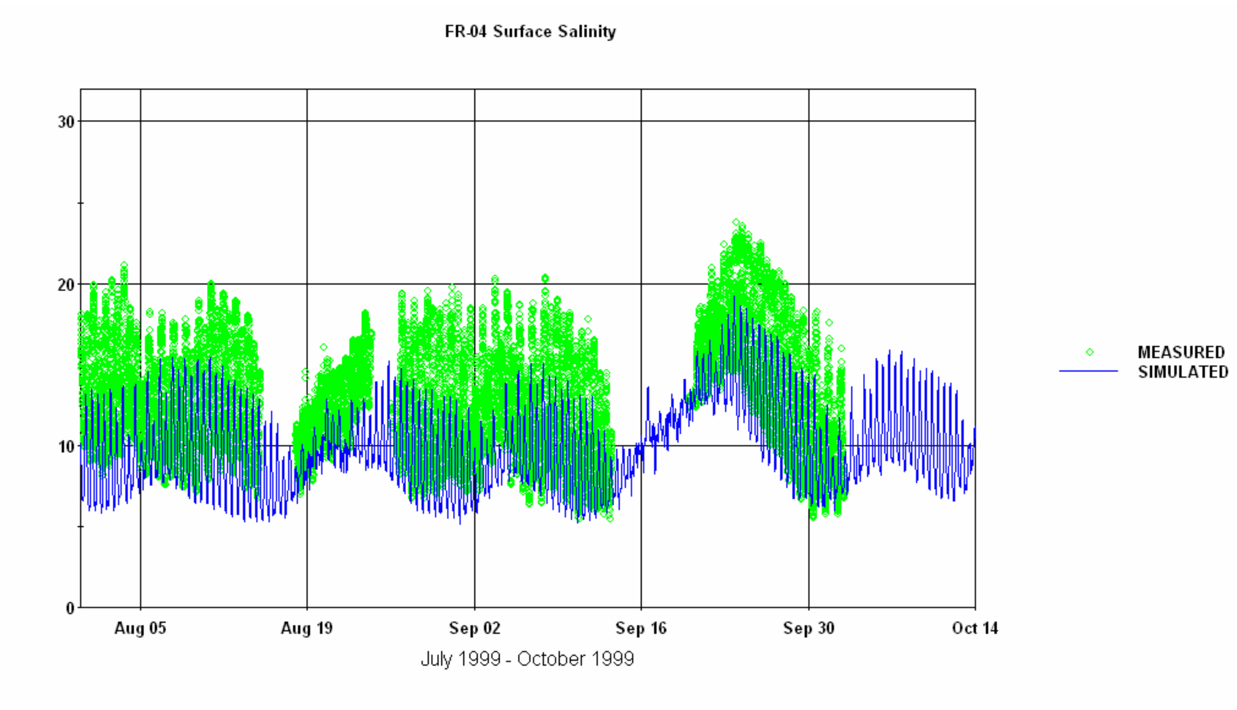


Figure J-6 Salinity (ppt) Calibration at FR-04 (Surface) for July 31, 1999 through October 13, 1999

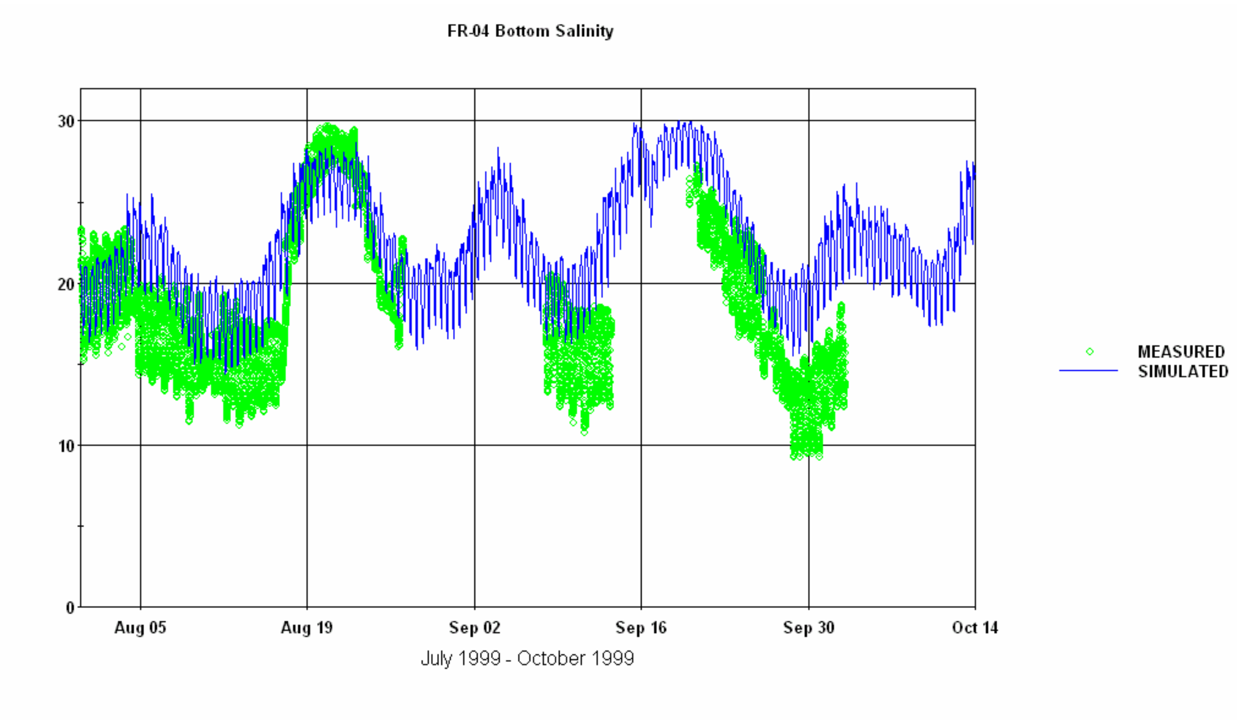


Figure J-7 Salinity (ppt) Calibration at FR-04 (Bottom) for July 31, 1999 through October 13, 1999

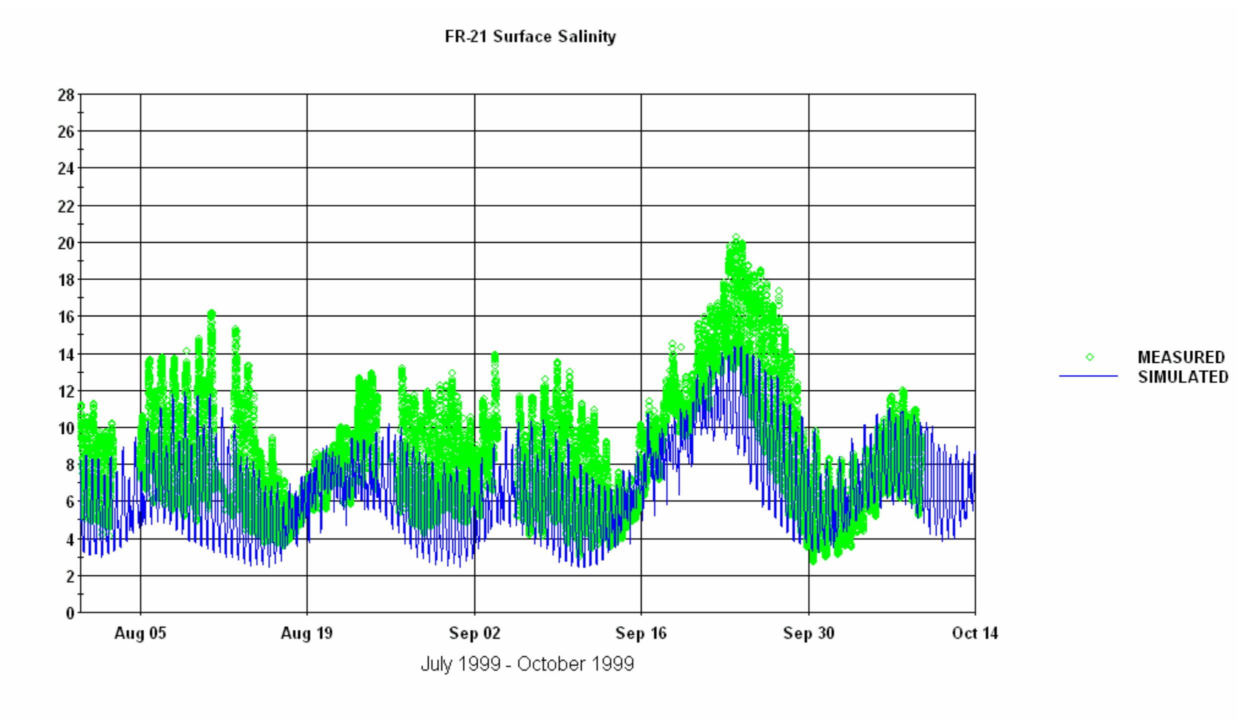


Figure J-8 Salinity (ppt) Calibration at FR-21 (Surface) for July 31, 1999 through October 13, 1999

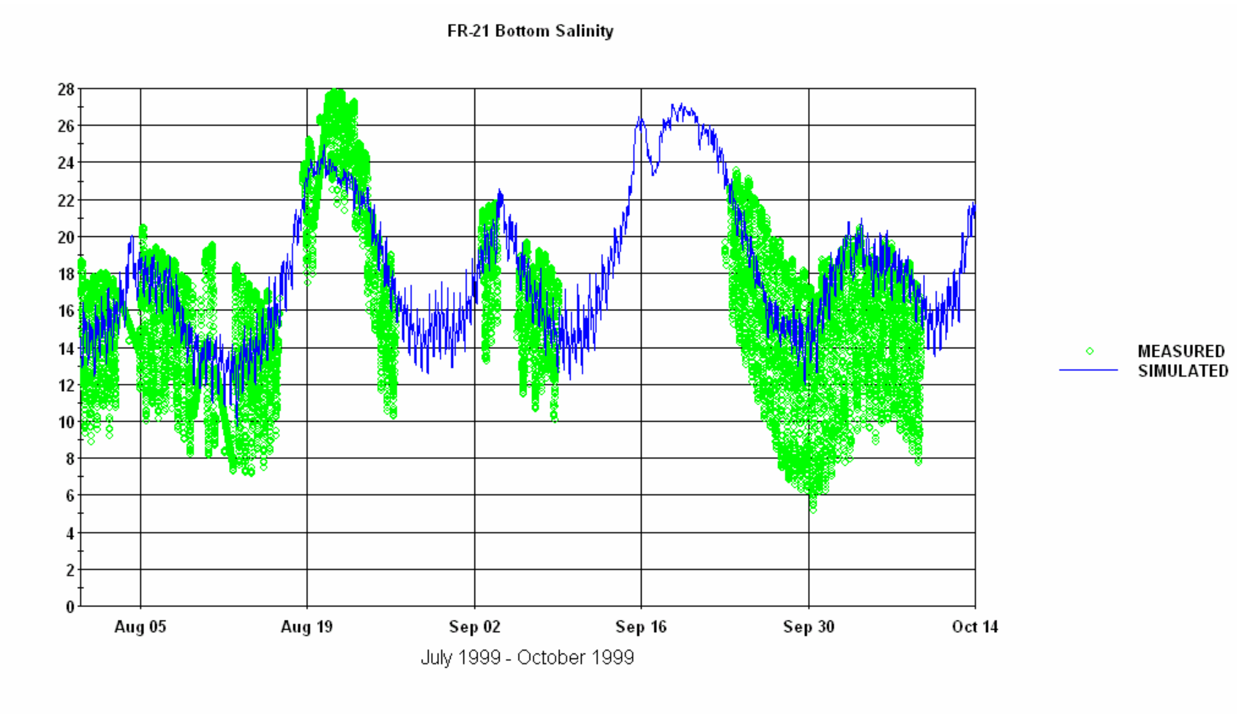


Figure J-9 Salinity (ppt) Calibration at FR-21 (Bottom) for July 31, 1999 through October 13, 1999

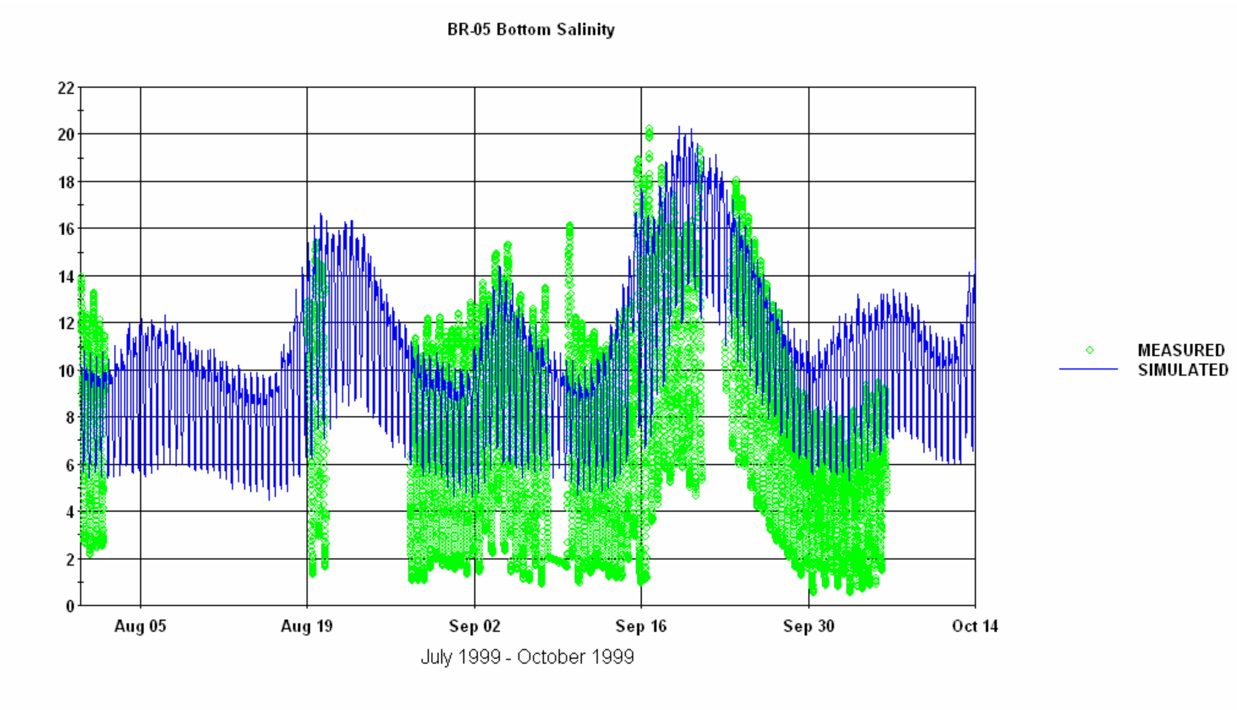


Figure J-10 Salinity (ppt) Calibration at BR-05 (Bottom) for July 31, 1999 through October 13, 1999

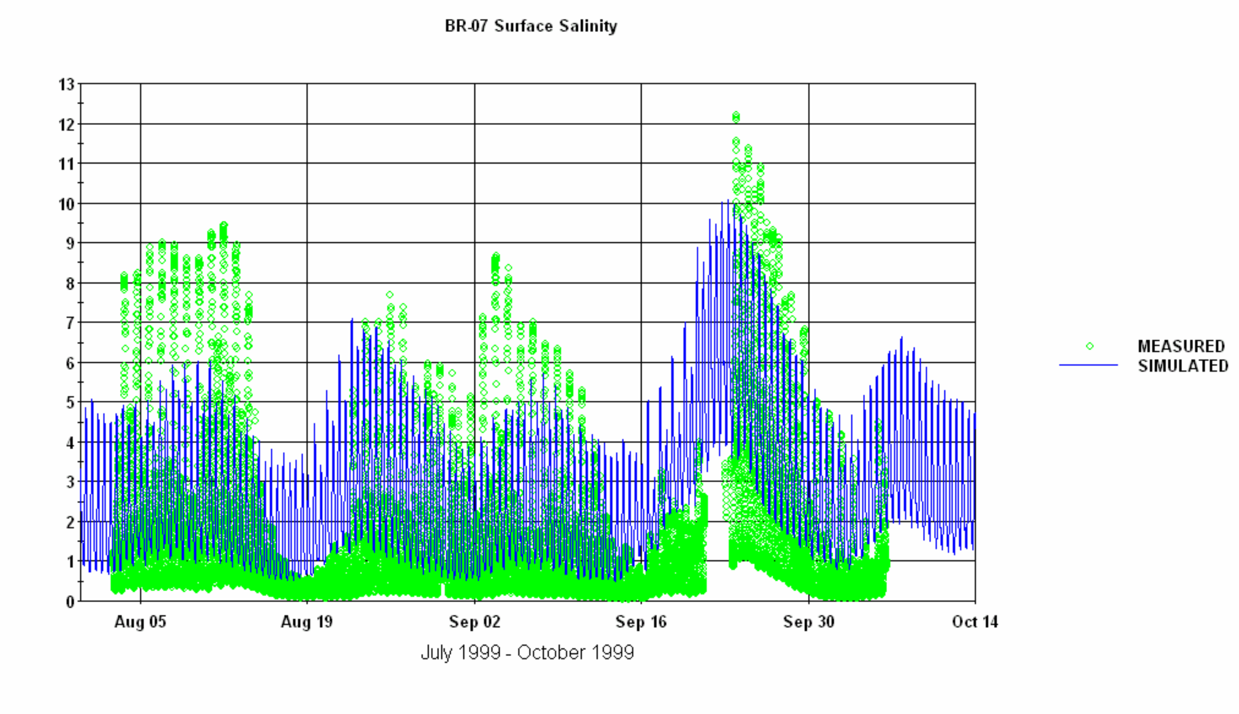


Figure J-11 Salinity (ppt) Calibration at BR-07 (Surface) for July 31, 1999 through October 13, 1999

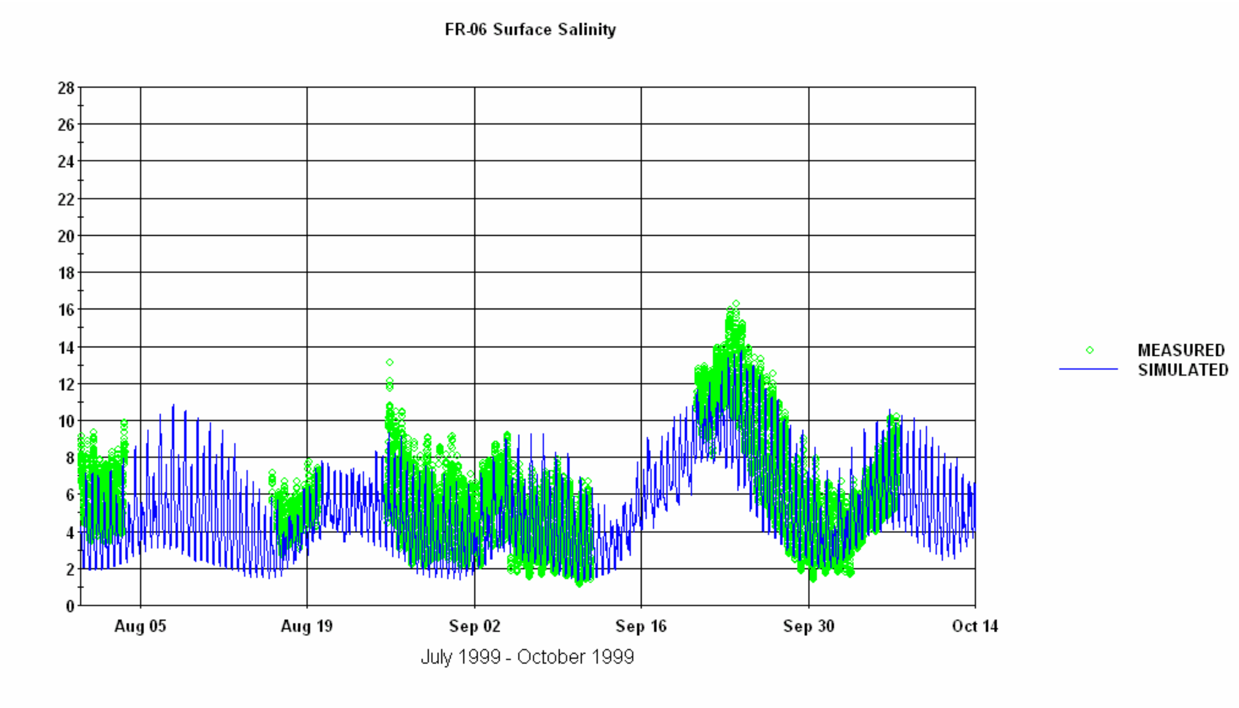


Figure J-12 Salinity (ppt) Calibration at FR-06 (Surface) for July 31, 1999 through October 13, 1999

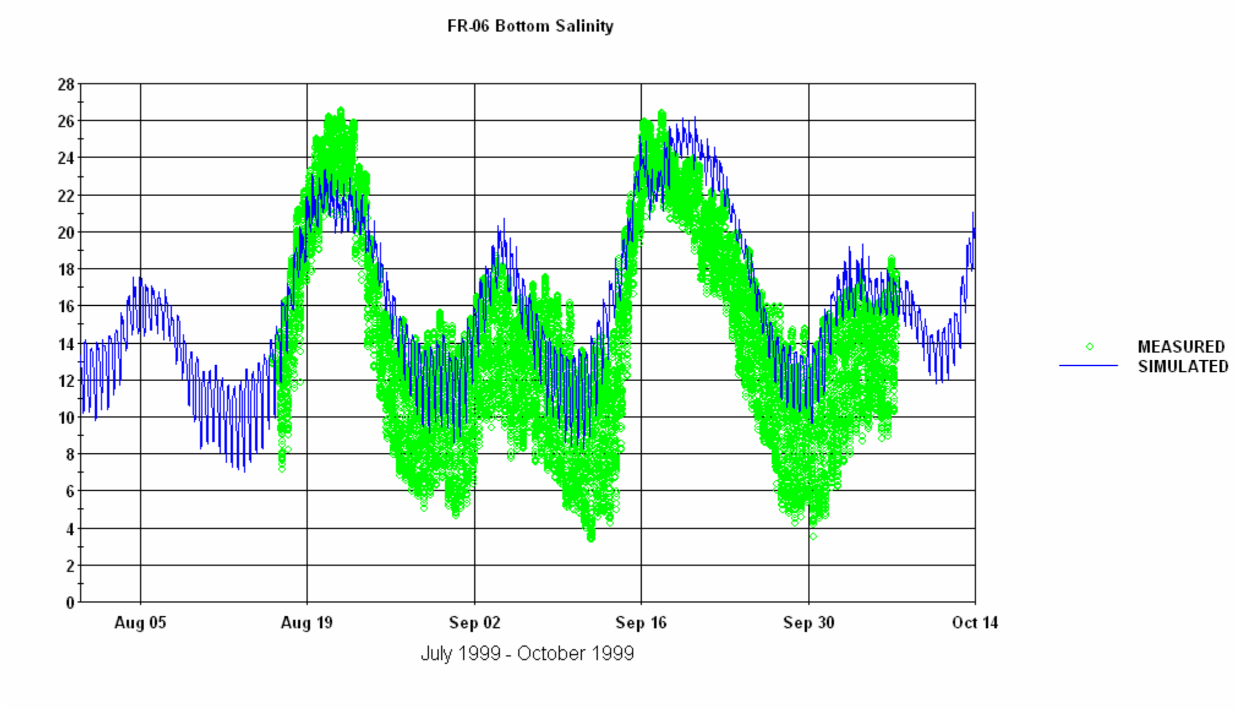


Figure J-13 Salinity (ppt) Calibration at FR-06 (Bottom) for July 31, 1999 through October 13, 1999

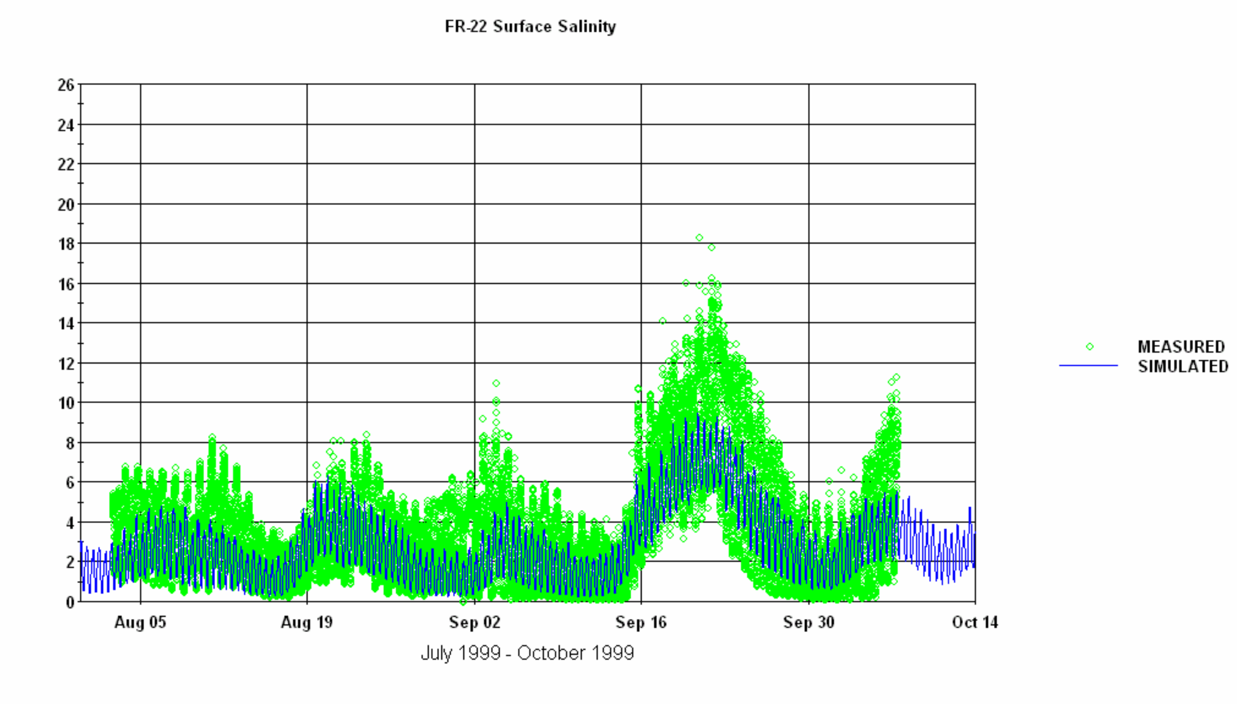


Figure J-14 Salinity (ppt) Calibration at FR-22 (Surface) for July 31, 1999 through October 13, 1999

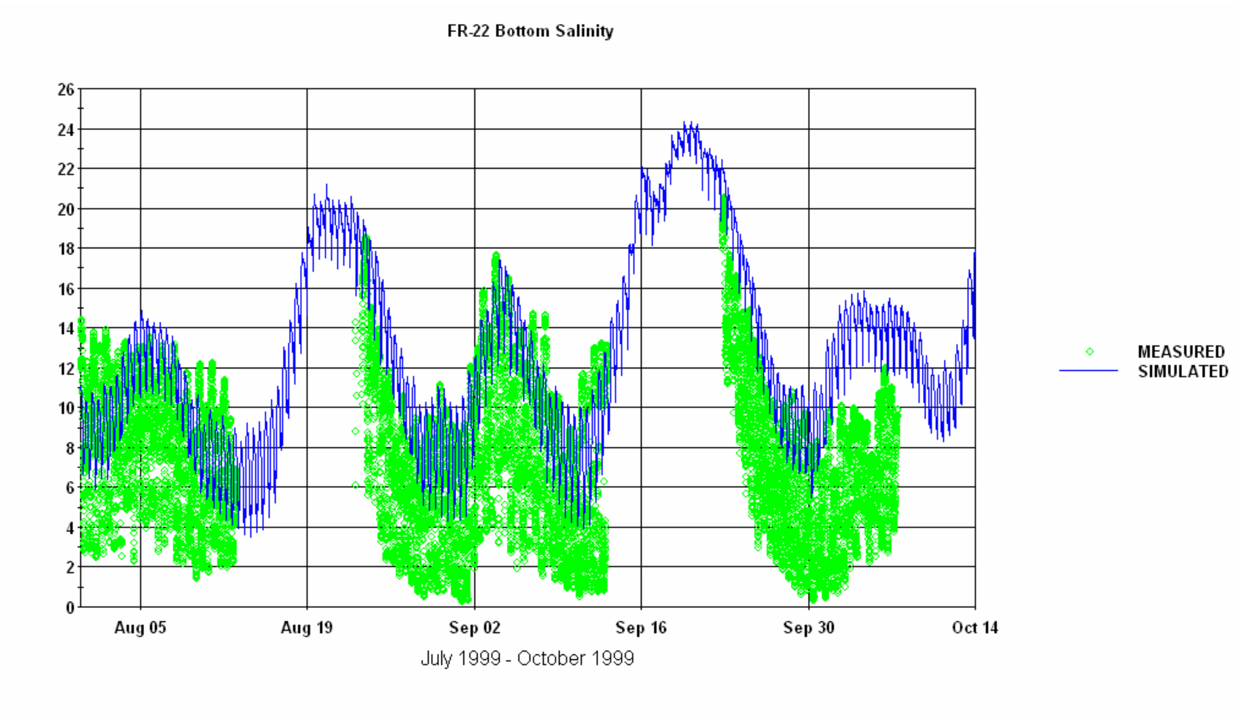


Figure J-15 Salinity (ppt) Calibration at FR-22 (Bottom) for July 31, 1999 through October 13, 1999

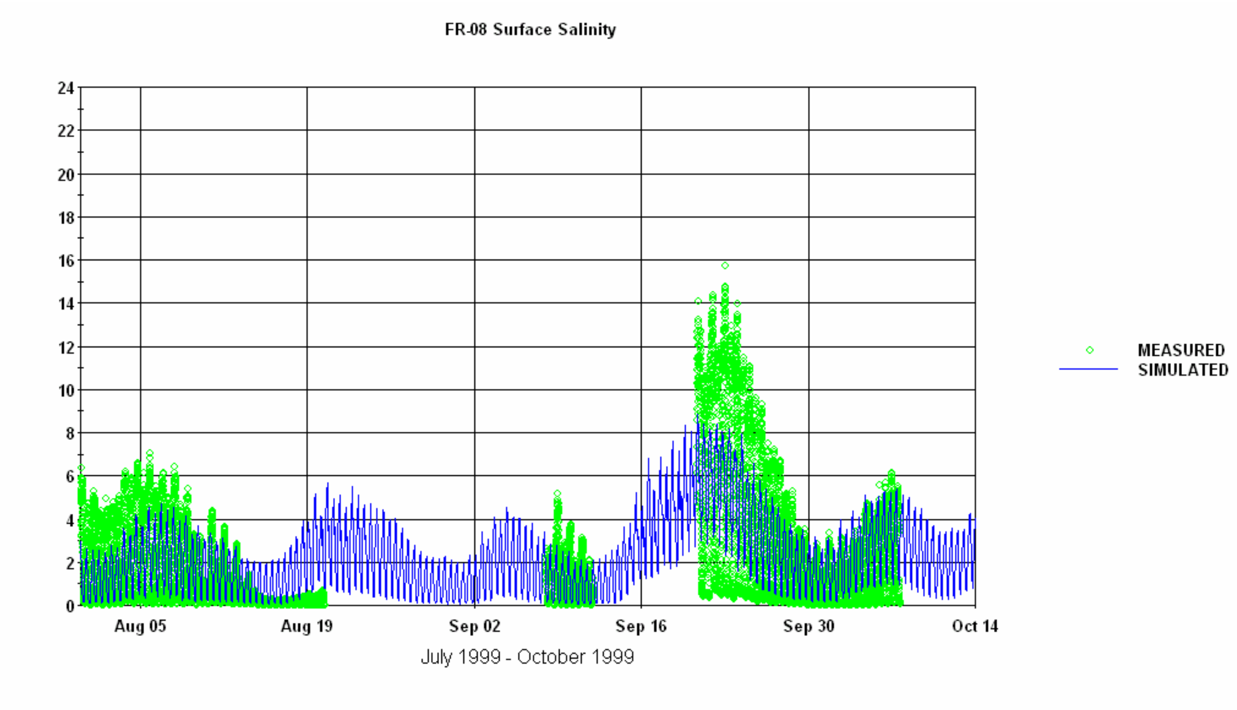


Figure J-16 Salinity (ppt) Calibration at FR-08 (Surface) for July 31, 1999 through October 13, 1999

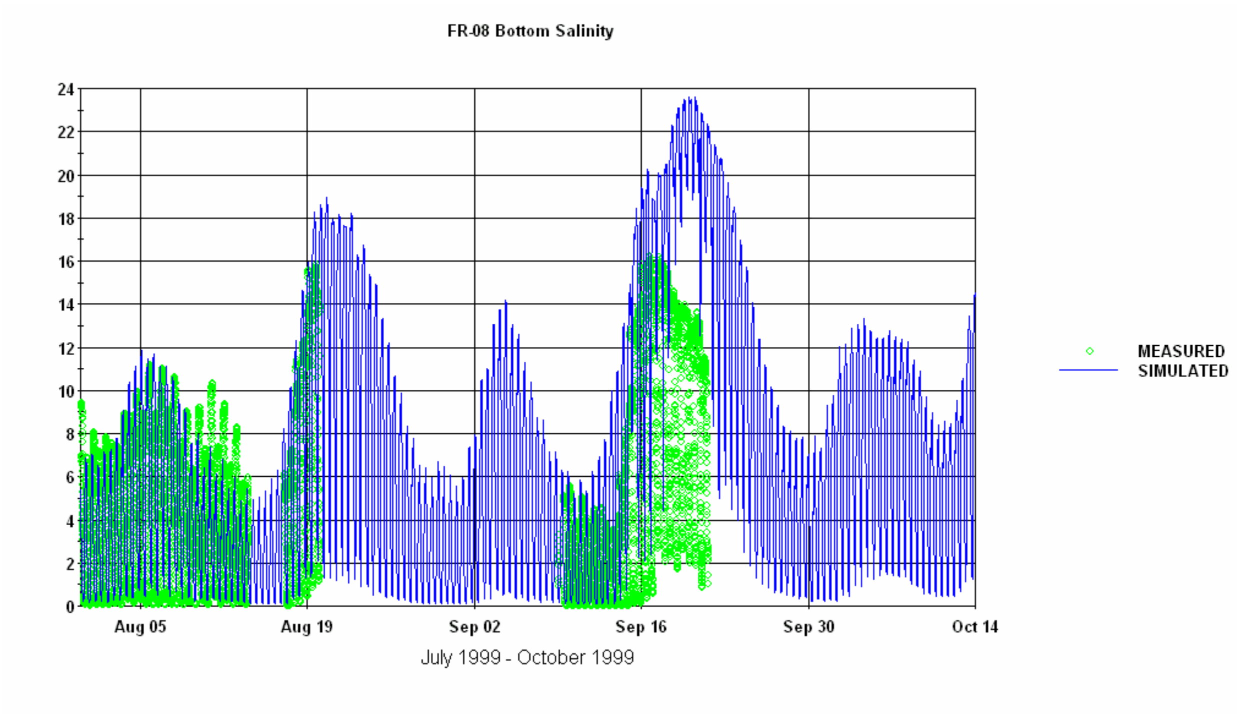


Figure J-17 Salinity (ppt) Calibration at FR-08 (Bottom) for July 31, 1999 through October 13, 1999

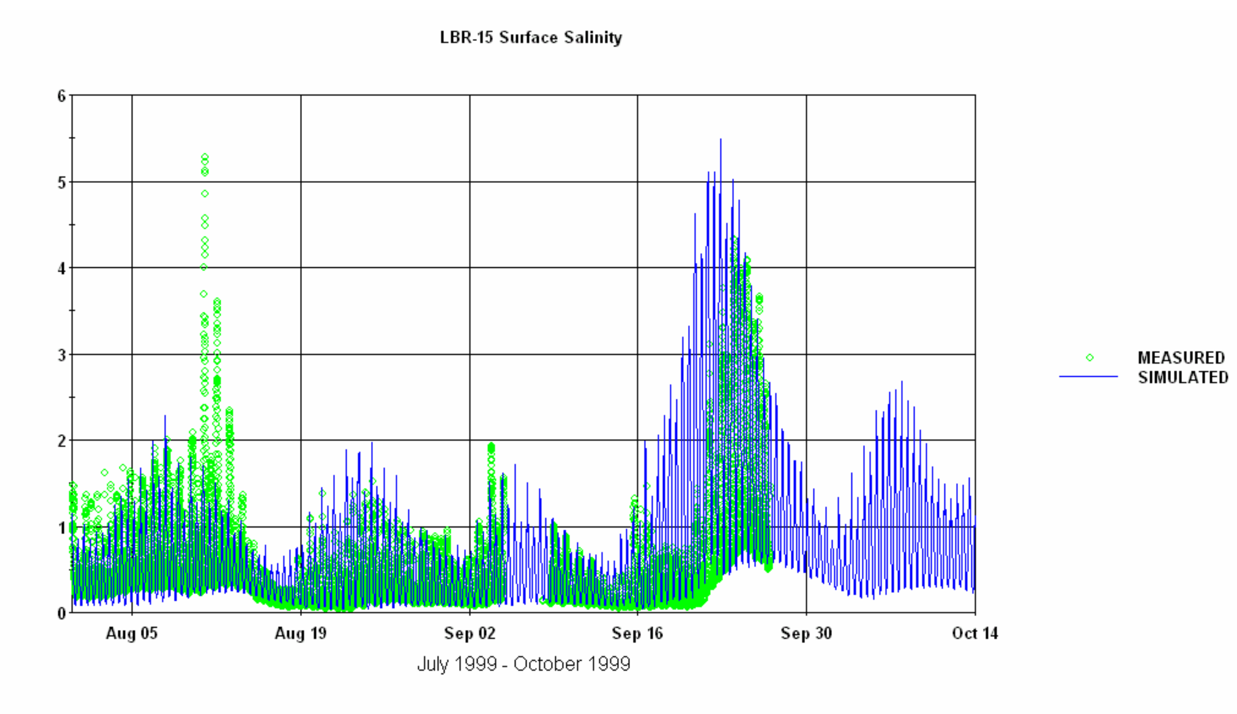


Figure J-18 Salinity (ppt) Calibration at LBR-15 (Surface) for July 31, 1999 through October 13, 1999

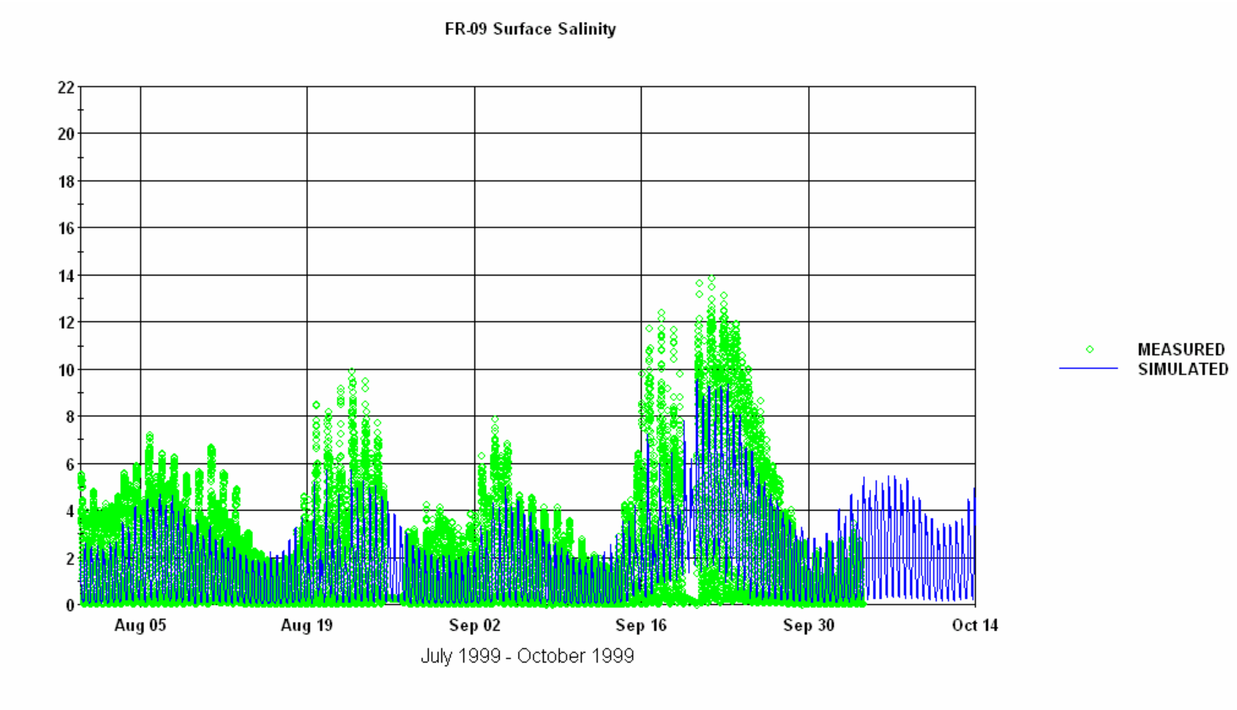


Figure J-19 Salinity (ppt) Calibration at FR-09 (Surface) for July 31, 1999 through October 13, 1999

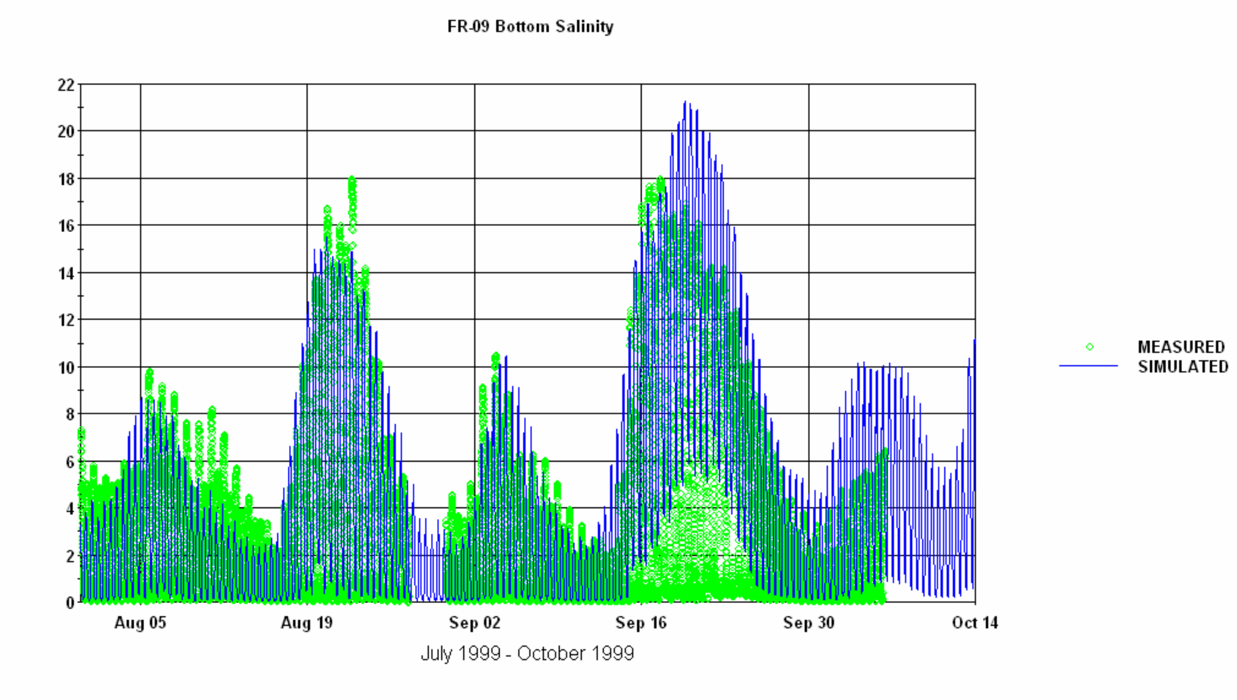


Figure J-20 Salinity (ppt) Calibration at FR-09 (Bottom) for July 31, 1999 through October 13, 1999

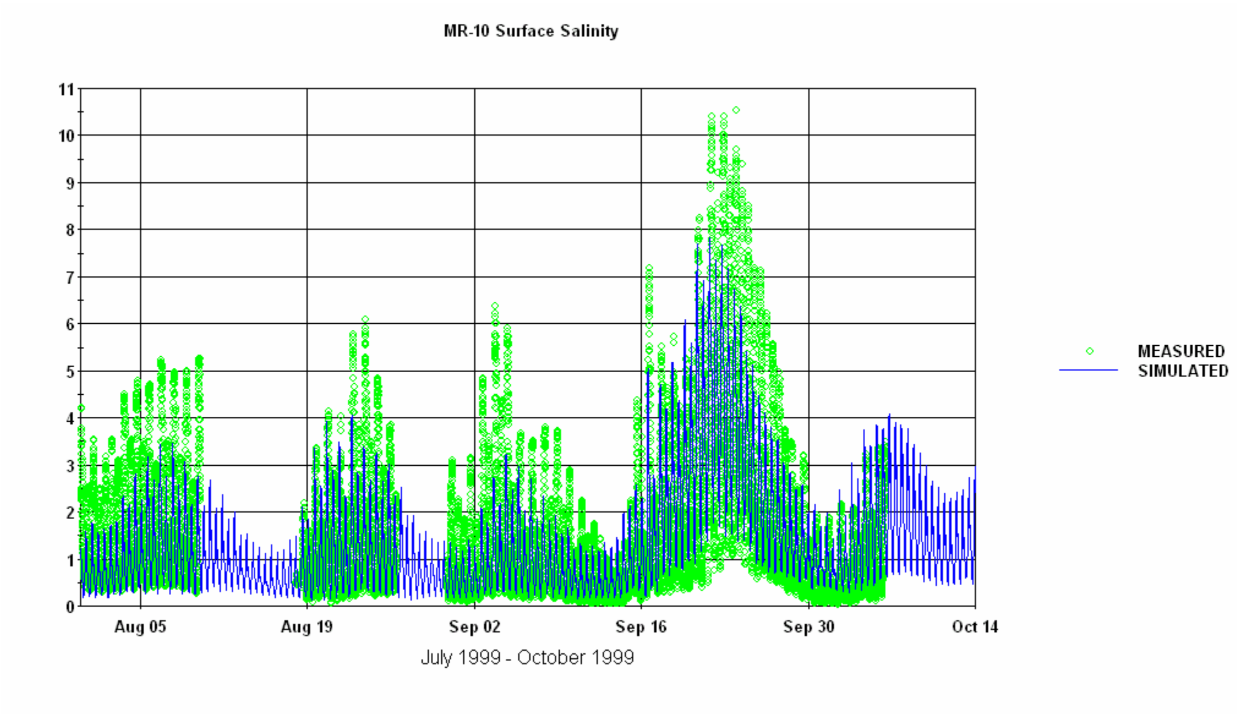


Figure J-21 Salinity (ppt) Calibration at MR-10 (Surface) for July 31, 1999 through October 13, 1999

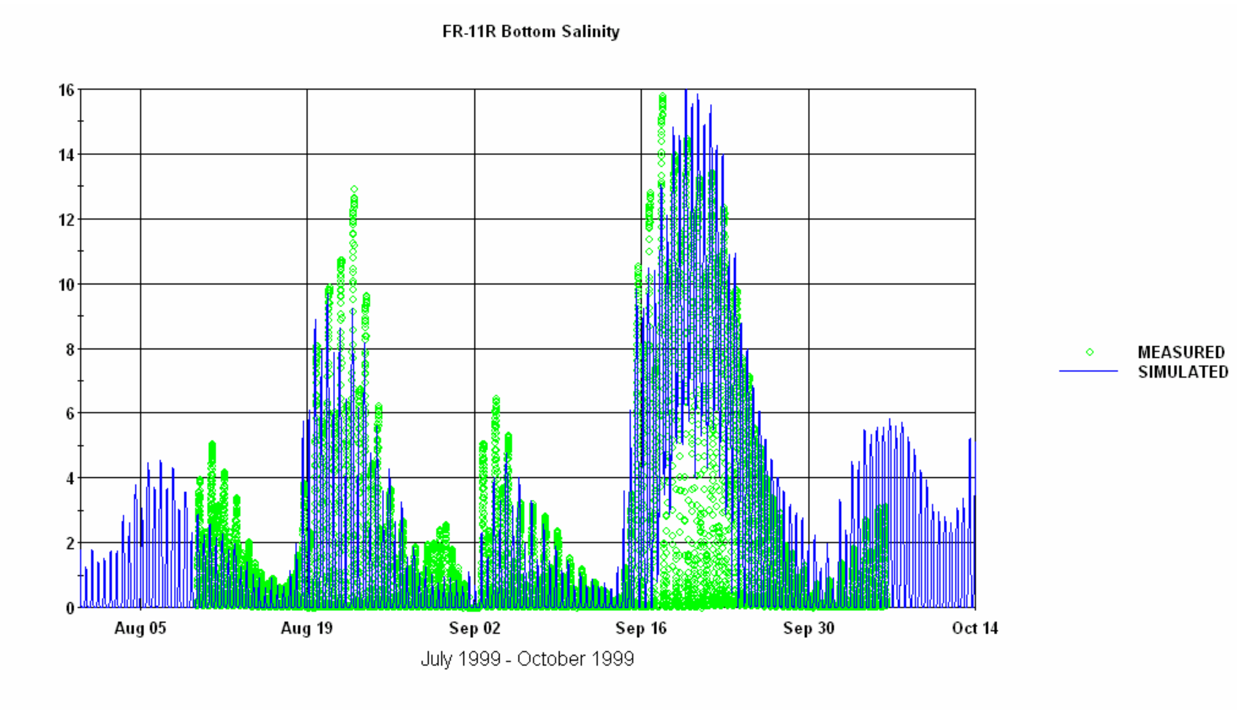


Figure J-22 Salinity (ppt) Calibration at FR-11R (Bottom) for July 31, 1999 through October 13, 1999

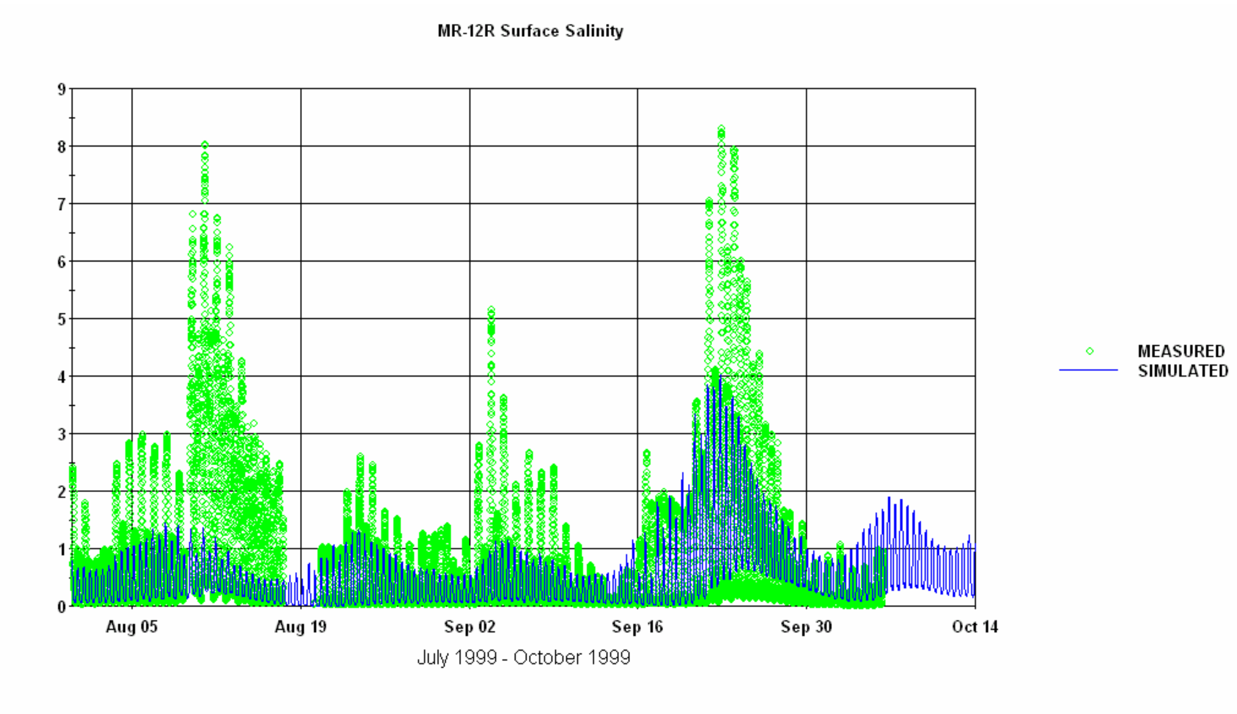


Figure J-23 Salinity (ppt) Calibration at MR-12R (Surface) for July 31, 1999 through October 13, 1999

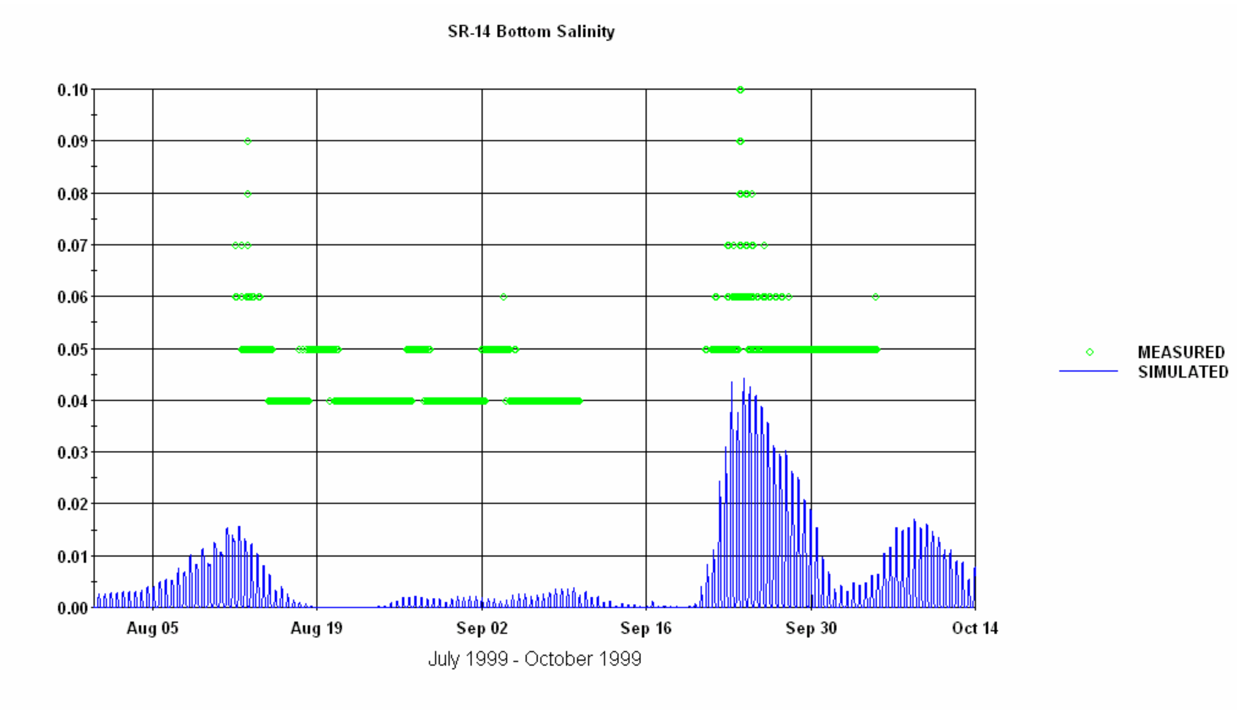


Figure J-24 Salinity (ppt) Calibration at SR-14 (Bottom) for July 31, 1999 through October 13, 1999

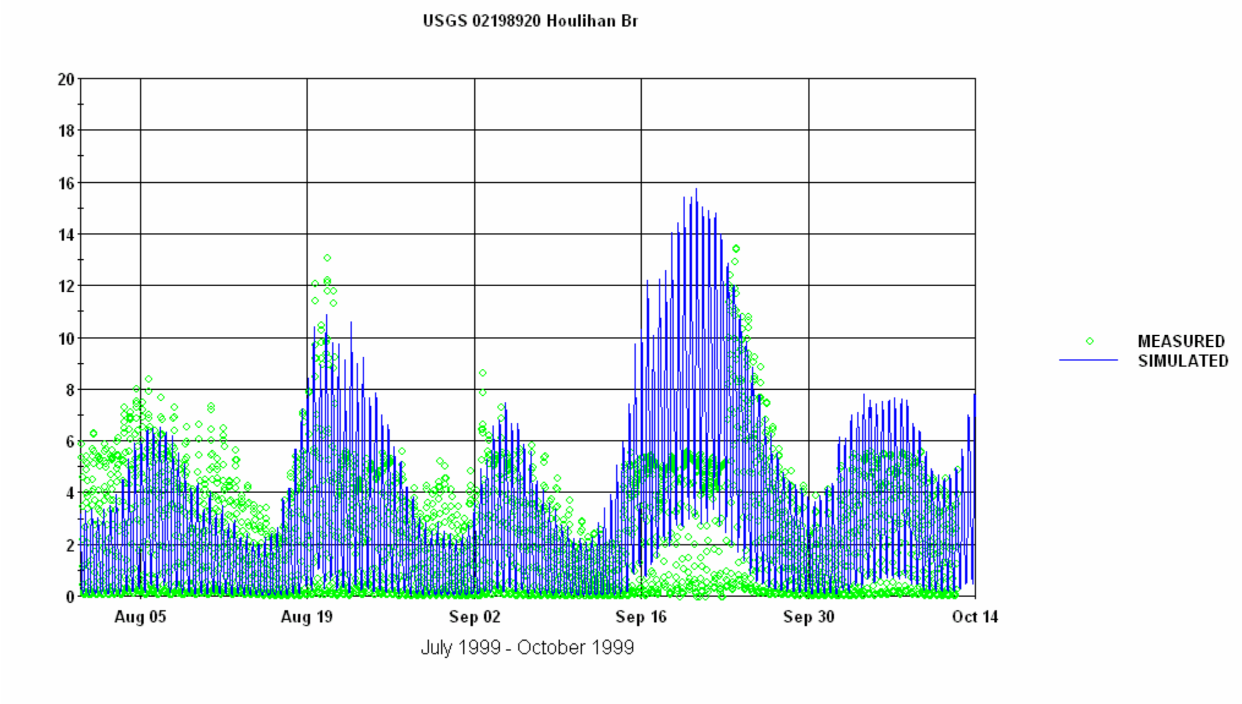


Figure J-25 Salinity (ppt) Calibration at Houlihan Bridge/Port Wentworth (Mid-depth) for July 31, 1999 through October 13, 1999

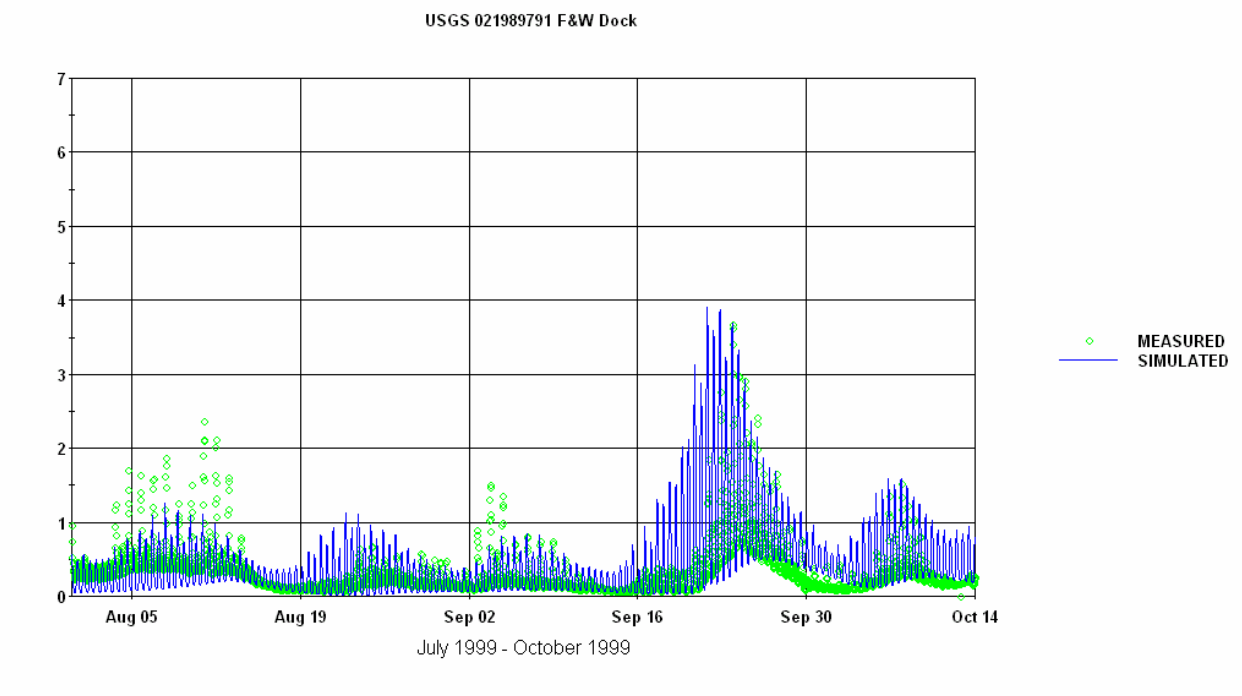


Figure J-26 Salinity (ppt) Calibration at US F&W Docks (Mid-depth) for July 31, 1999 through October 13, 1999

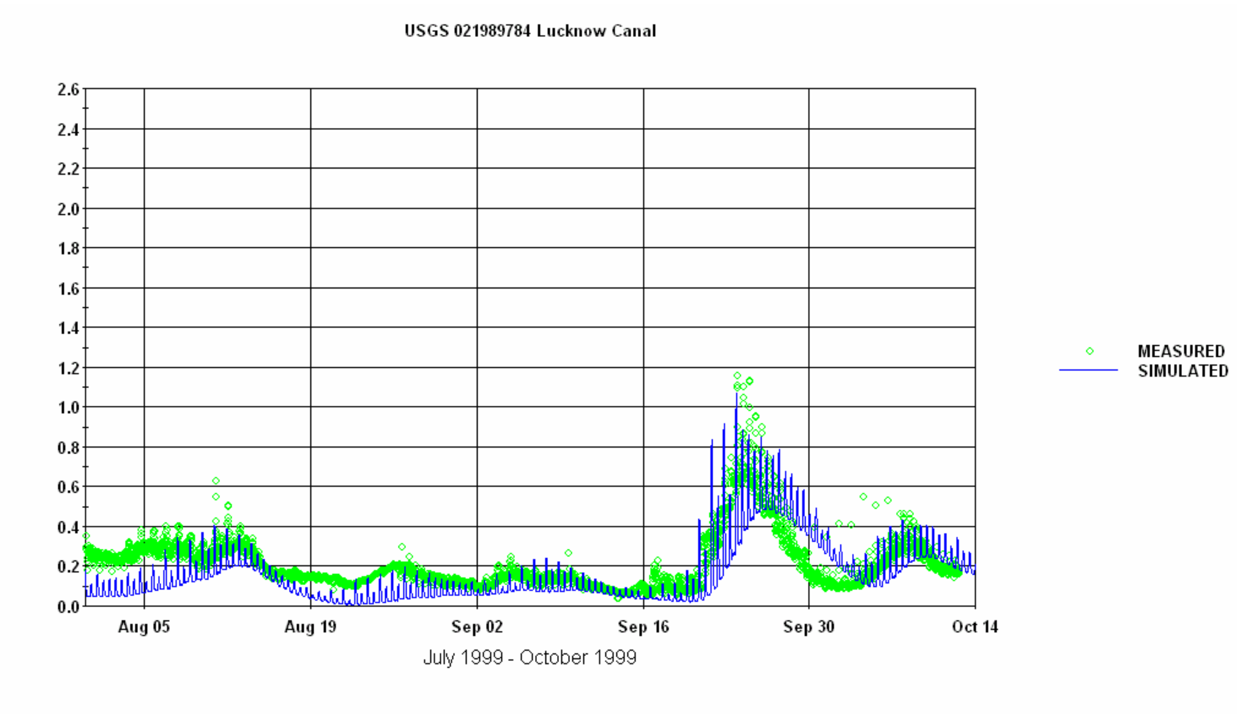


Figure J-27 Salinity (ppt) Calibration at Lucknow Canal (Mid-depth) for July 31, 1999 through October 13, 1999

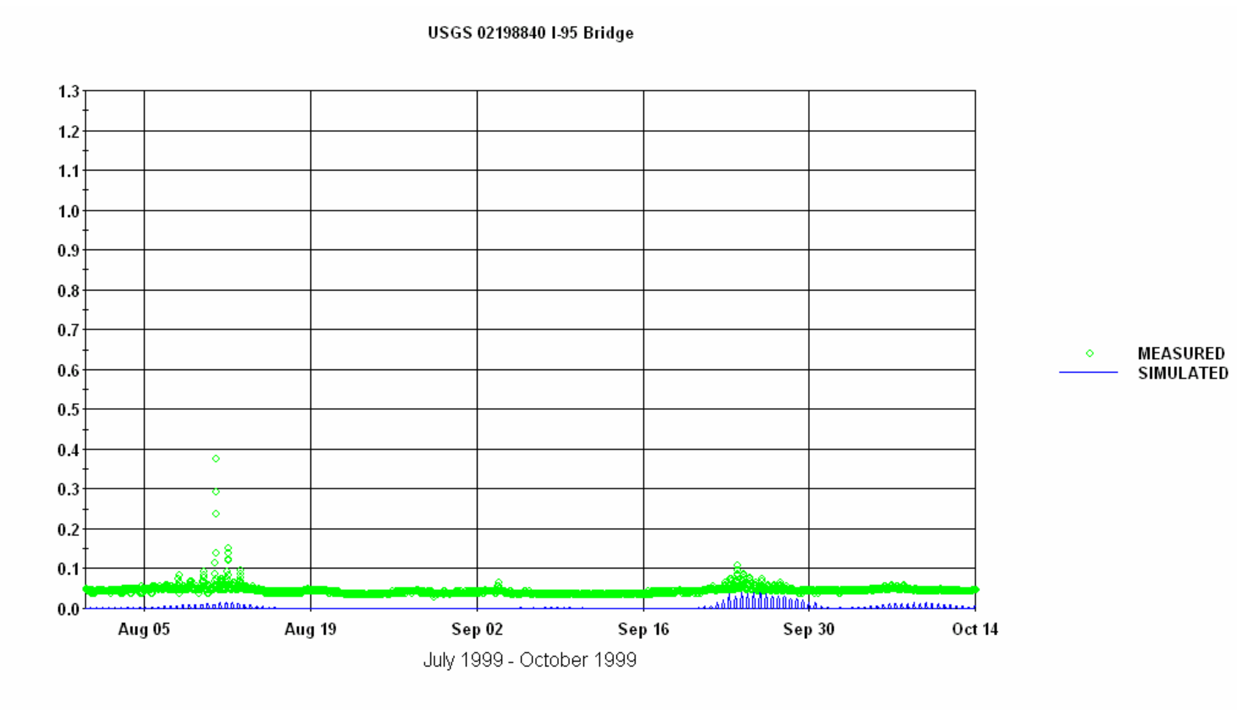


Figure J-28 Salinity (ppt) Calibration at I-95 Bridge (Mid-depth) for July 31, 1999 through October 13, 1999

APPENDIX K 1997 SALINITY COMPARISONS

Table K-1 Summary Percentiles for Salinity (ppt) for July 9, 1997 through October 6, 1997

July 9 - October 6, 1997 [Julian Days 190-279]														
Stations	Depth*	Simulated			Measured			Difference			Percent Difference			Evaluation Criteria
		10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	(ppt)
FR-02	S	9.2	13.5	24.5	10.2	15.0	21.8	-1.0	-1.5	2.7	10.1	10.2	-12.4	>5
FR-02	B	25.2	30.5	33.0	19.8	25.4	29.1	5.4	5.1	3.9	-27.1	-20.0	-13.5	>5
SC-03	B	13.1	15.7	18.2	11.2	14.4	18.3	1.9	1.3	-0.1	-17.4	-9.2	0.6	>5
FR-04	S	5.3	8.6	12.3	5.1	9.2	14.7	0.2	-0.6	-2.4	-3.4	6.2	16.3	>5
FR-04	B	15.9	22.2	26.6	12.8	18.6	23.3	3.1	3.6	3.3	-24.4	-19.3	-14.3	>5
BR-05	B	6.0	9.9	13.9	1.0	5.4	10.3	5.0	4.5	3.6	-498.0	-82.9	-35.2	>5
FR-06	S	1.2	3.6	6.6	1.4	3.9	7.0	-0.2	-0.3	-0.4	11.1	6.5	6.0	<5
FR-06	B	6.4	16.2	20.8	2.8	10.5	17.4	3.6	5.7	3.4	-127.8	-54.1	-19.3	>5
BR-07	B	0.4	2.9	6.9	0.1	0.4	3.3	0.3	2.5	3.6	-320.5	-636.5	-109.5	<5
FR-08	S	0.1	1.4	4.3	0.1	0.4	5.3	0.0	1.0	-1.0	15.3	-253.5	18.9	<5
FR-08	B	0.1	3.7	14.7	0.1	1.2	10.0	0.0	2.5	4.7	-23.6	-209.3	-47.3	<5
FR-09	B	0.0	1.4	9.8	0.0	0.3	5.3	0.0	1.1	4.5	0.0	-381.7	-84.4	<5
MR-10	B	0.2	0.7	2.8	0.1	0.5	2.9	0.1	0.2	-0.1	-54.9	-38.1	3.4	<5
FR-11	B	0.0	0.0	0.1	0.0	0.0	0.2	0.0	0.0	-0.1	0.0	0.0	31.5	<5
MR-12	B	0.0	0.1	0.6	0.0	0.1	0.9	0.0	0.0	-0.3	0.0	26.9	35.5	<5
LBR-13	B	0.0	0.0	0.1	0.0	0.1	0.2	0.0	-0.1	-0.1	0.0	83.8	63.0	<5
USGS02198920 (Houlihan Bridge)	M	0.0	1.3	6.8	0.0	0.3	5.4	0.0	1.1	1.4	0.6	-421.6	-26.1	<5
USGS02198791 (US F&W Docks)	M	0.0	0.1	0.7	0.0	0.1	0.3	0.0	0.1	0.4	55.3	-91.1	-155.4	<5
USGS021989784 (Lucknow Canal)	M	0.0	0.0	0.2	0.0	0.1	0.2	0.0	0.0	0.0	82.6	44.0	-6.6	<5
USGS02198840 (I-95)	M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	97.8	<5

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

Statistic Applicable for Criteria
Meets Criteria

Table K-2 Summary Statistics for Salinity (ppt) for July 9, 1997 through October 6, 1997

July 9 - October 6, 1997 [Julian Days 190-279]										
Station	Depth*	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	18002	-0.29	2.33	2.90	15.31	5.62	15.60	4.35	0.74
FR-02	B	17704	4.85	4.86	5.34	29.78	3.17	24.93	3.37	0.59
SC-03	S	18022	1.13	2.30	2.83	15.71	1.92	14.58	2.81	0.20
FR-04	B	17955	-0.94	1.77	2.26	8.71	2.76	9.64	3.62	0.68
FR-04	B	14958	3.32	3.43	4.11	21.64	4.00	18.32	3.99	0.67
BR-05	S	15465	4.32	4.46	5.00	9.86	3.03	5.54	3.46	0.50
FR-06	B	20134	-0.26	1.06	1.43	3.84	2.02	4.10	2.16	0.60
FR-06	S	19087	4.36	4.51	5.37	14.72	5.40	10.37	5.22	0.68
BR-07	B	2.1427	2.26	1.97	2.60	2.38	1.14	1.82	0.30	0.11
FR-08	B	21744	0.18	0.85	1.27	1.83	1.65	1.65	2.37	0.75
FR-08	S	21030	2.54	2.67	3.94	5.76	5.63	3.22	3.88	0.74
FR-09	B	19866	1.67	1.73	2.74	3.29	4.13	1.62	2.58	0.79
MR-10	B	17767	0.07	0.45	0.70	1.14	1.22	1.07	1.42	0.76
FR-11	B	13321	-0.03	0.10	0.31	0.10	0.38	0.13	0.43	0.52
MR-12	B	22750	-0.11	0.17	0.35	0.21	0.32	0.32	0.54	0.68
LBR-13	B	16083	-0.08	0.09	0.20	0.04	0.07	0.12	0.22	0.39
USGS02198920 (Houlihan Bridge)	M	4273	0.78	1.00	1.55	2.47	2.83	1.69	2.60	0.78
USGS02198791 (US F&W Docks)	M	4273	0.15	0.18	0.33	0.29	0.39	0.14	0.20	0.44
USGS021989784 (Lucknow Canal)	M	4140	-0.03	0.06	0.09	0.08	0.11	0.11	0.11	0.50
USGS02198840 (I-95)	M	4273	-0.04	0.04	0.04	0.00	0.00	0.04	0.01	0.15

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

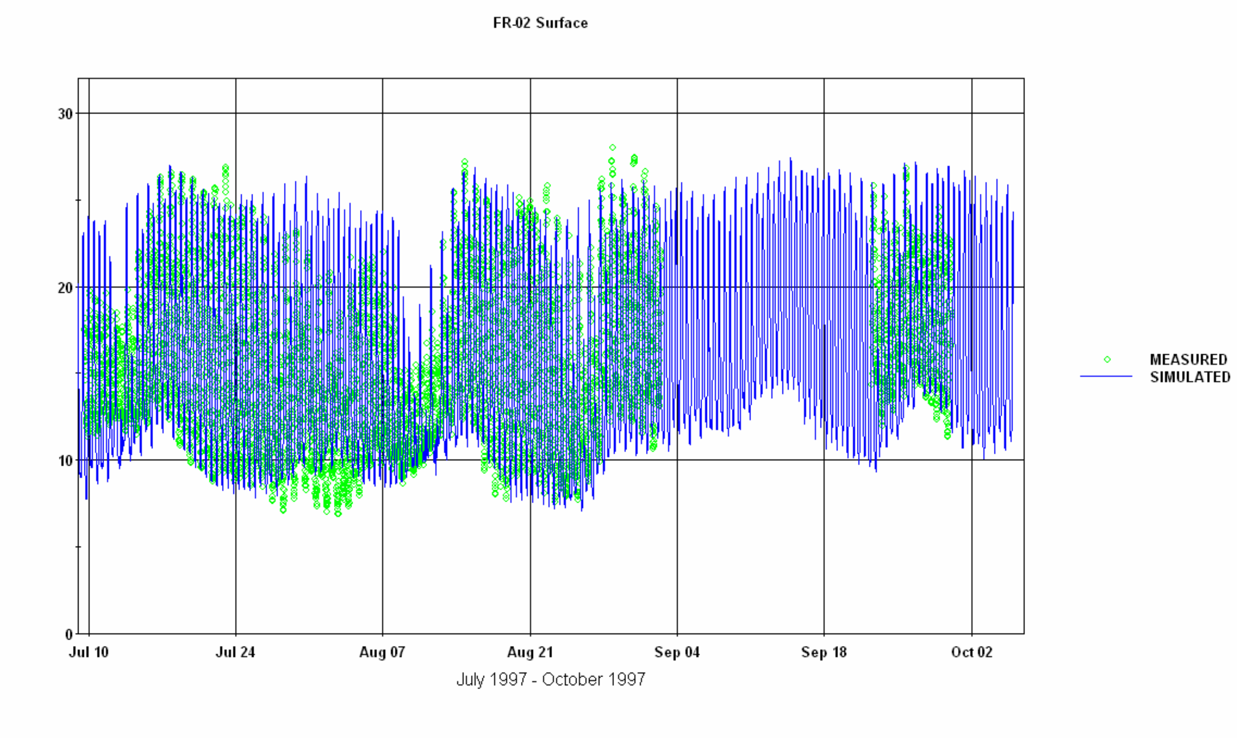


Figure K-1 Salinity (ppt) Calibration at FR-02 (Surface) for July 9, 1997 through October 6, 1997

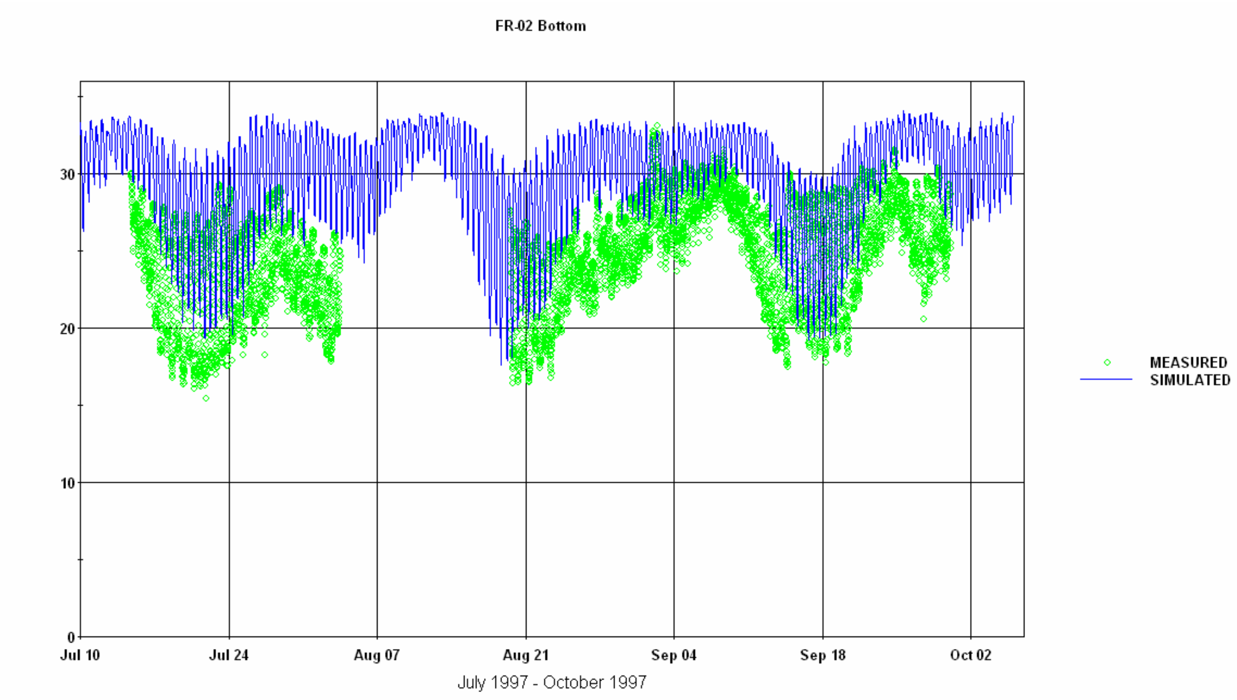


Figure K-2 Salinity (ppt) Calibration at FR-02 (Bottom) for July 9, 1997 through October 6, 1997

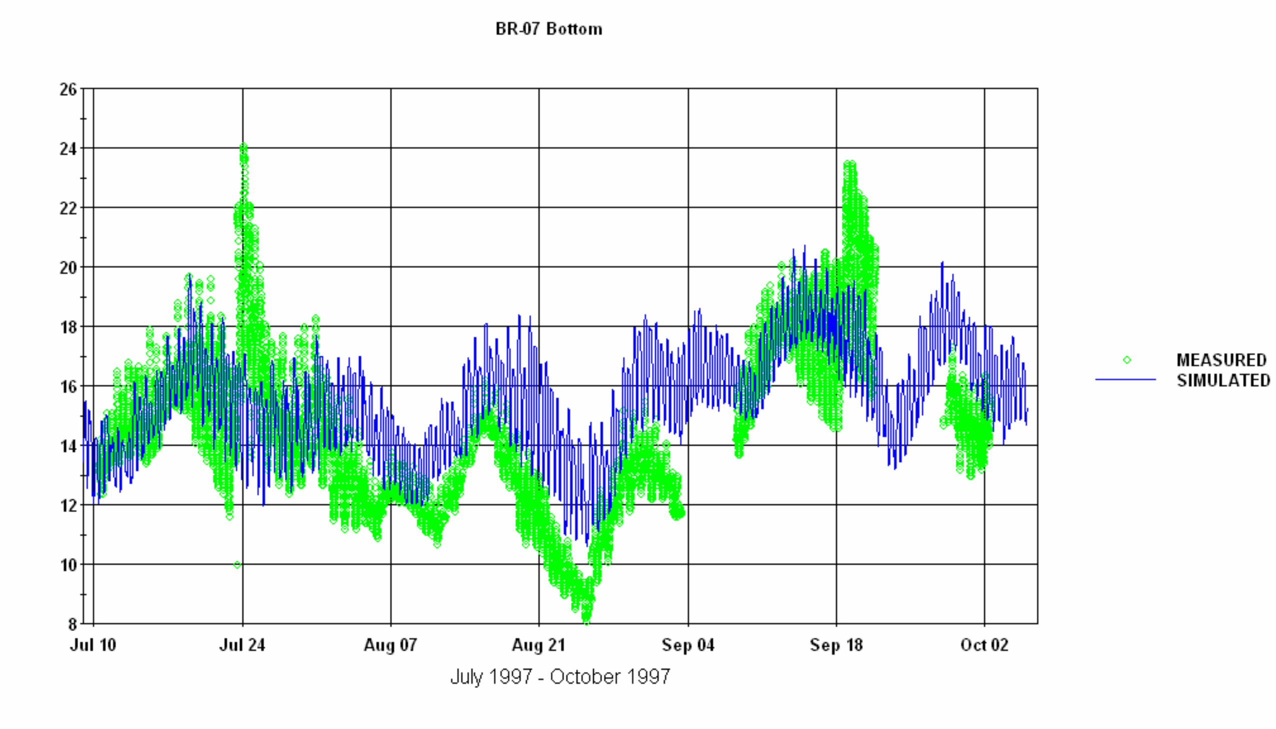


Figure K-3 Salinity (ppt) Calibration at SC-03 (Bottom) for July 9, 1997 through October 6, 1997

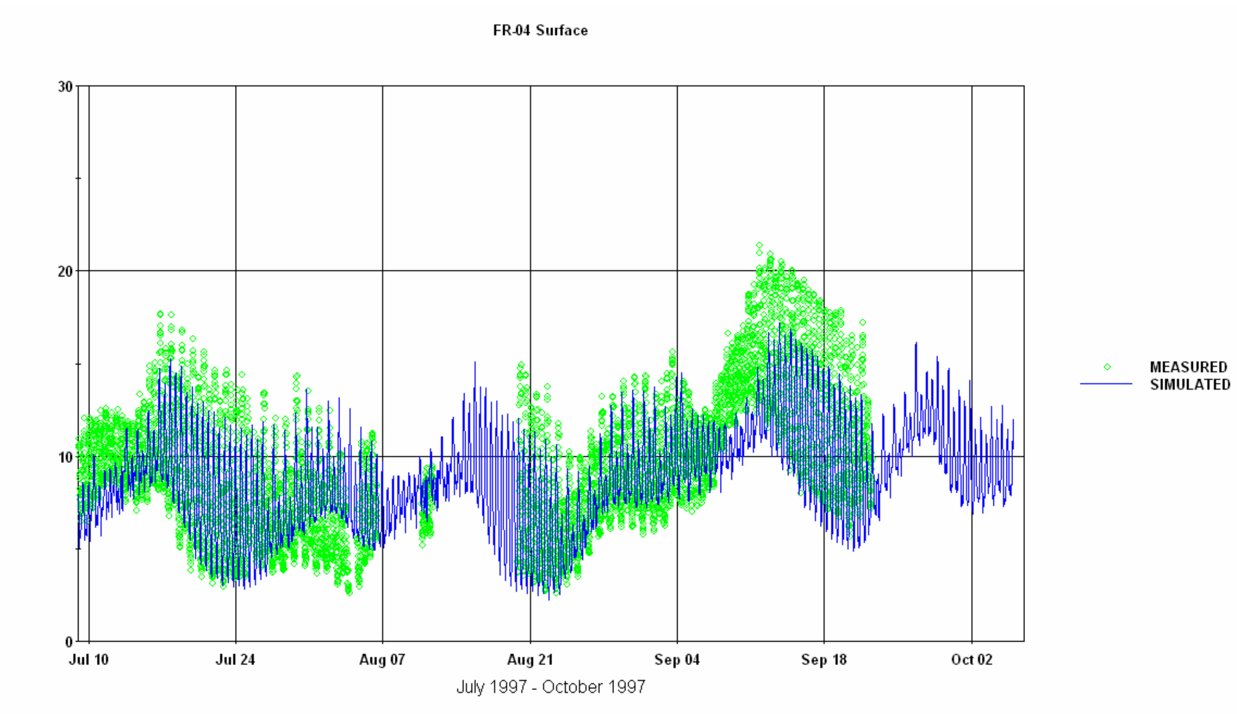


Figure K-4 Salinity (ppt) Calibration at FR-04 (Surface) for July 9, 1997 through October 6, 1997

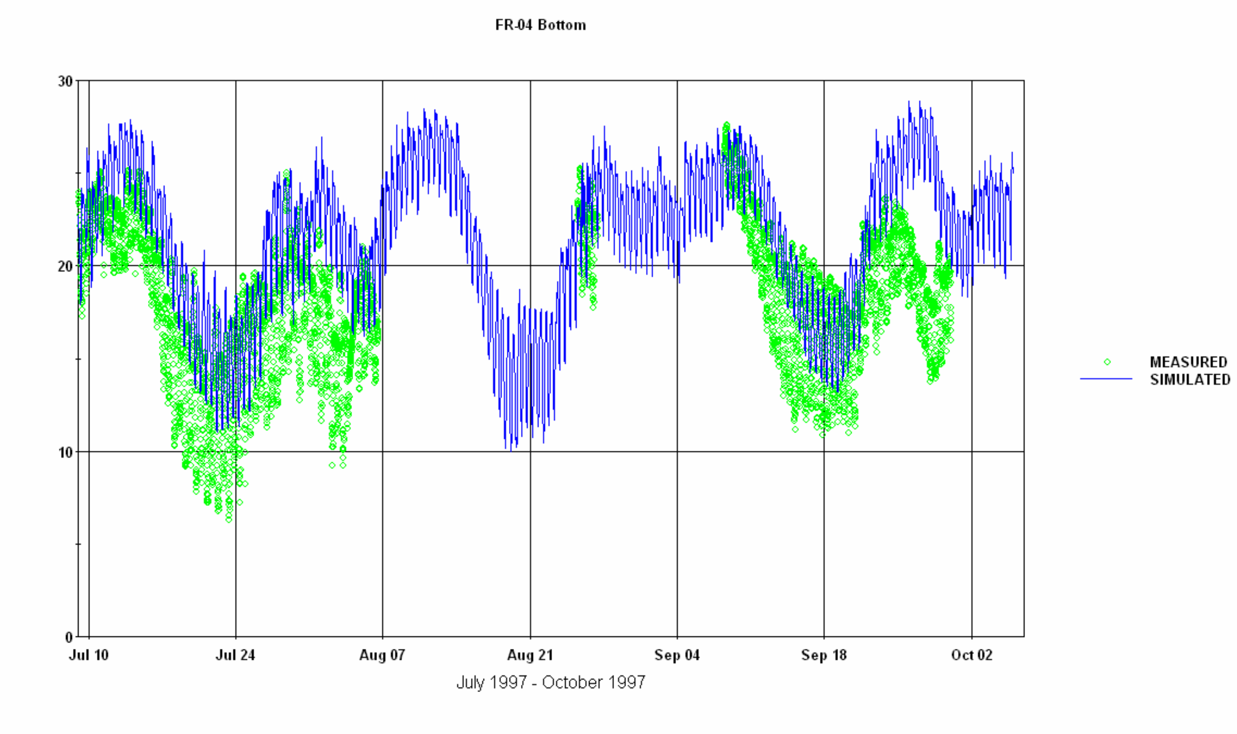


Figure K-5 Salinity (ppt) Calibration at FR-04 (Bottom) for July 9, 1997 through October 6, 1997

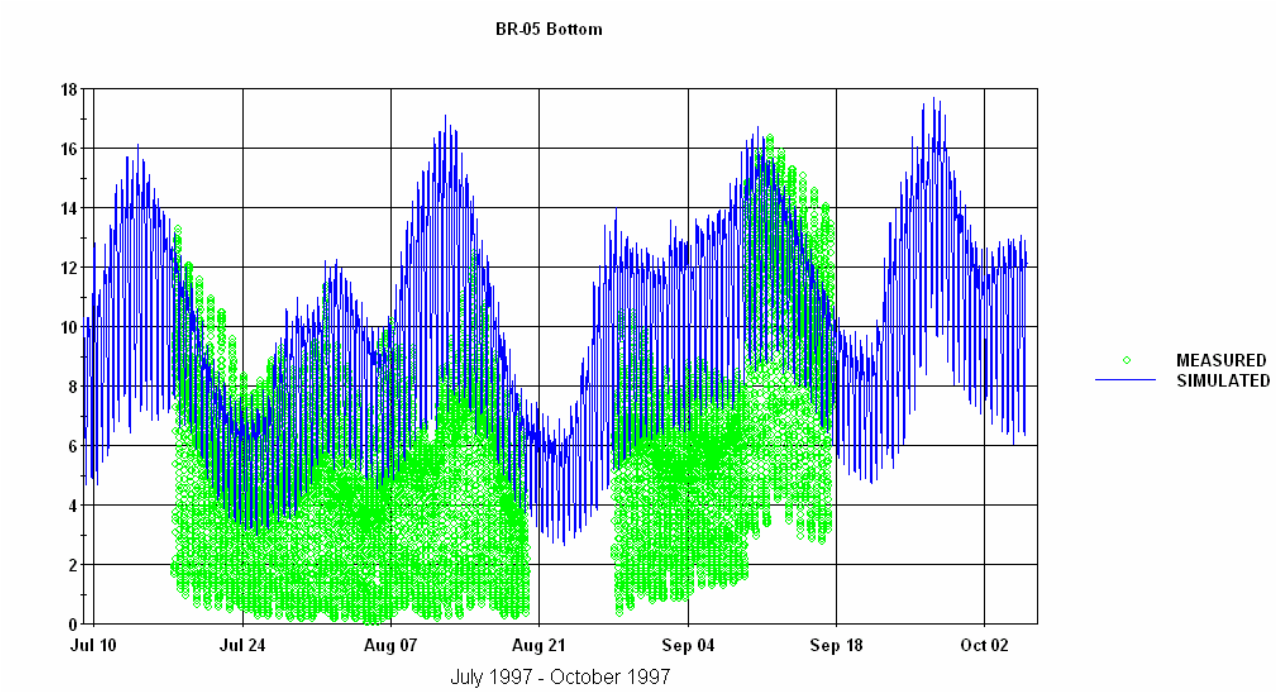


Figure K-6 Salinity (ppt) Calibration at BR-05 (Bottom) for July 9, 1997 through October 6, 1997

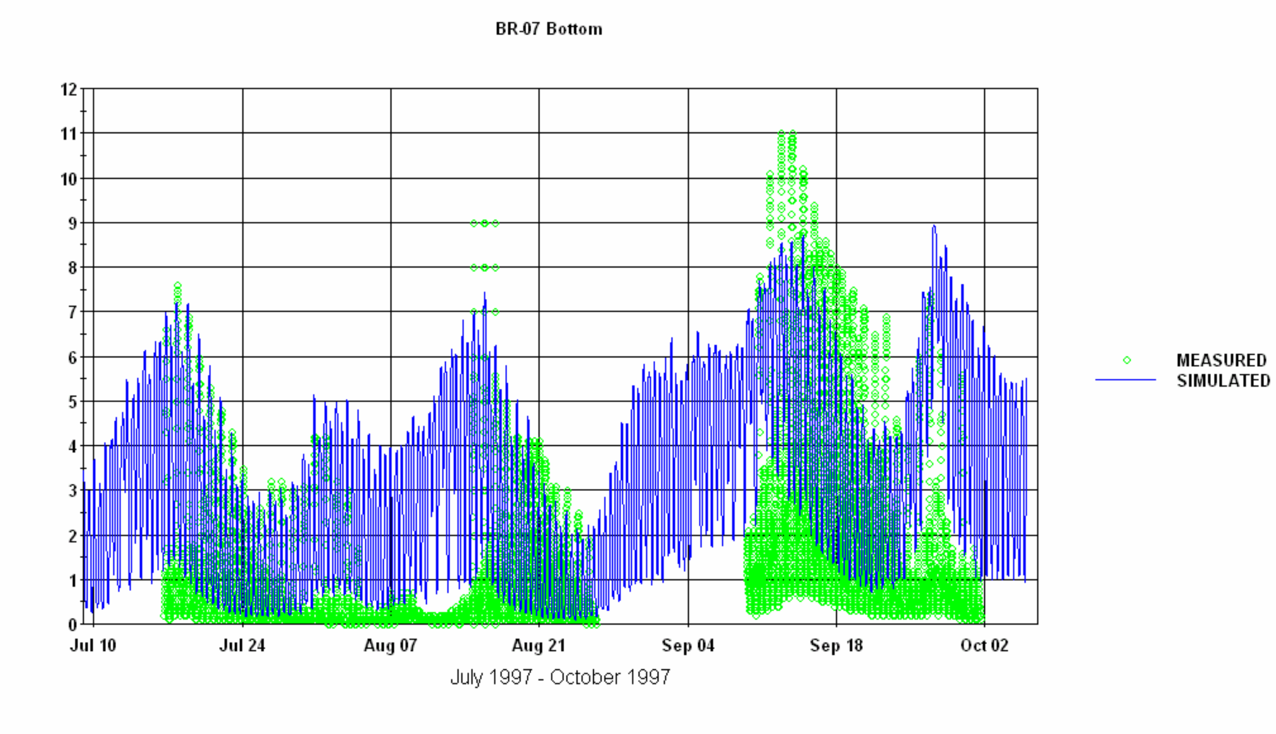


Figure K-7 Salinity (ppt) Calibration at BR-07 (Bottom) for July 9, 1997 through October 6, 1997

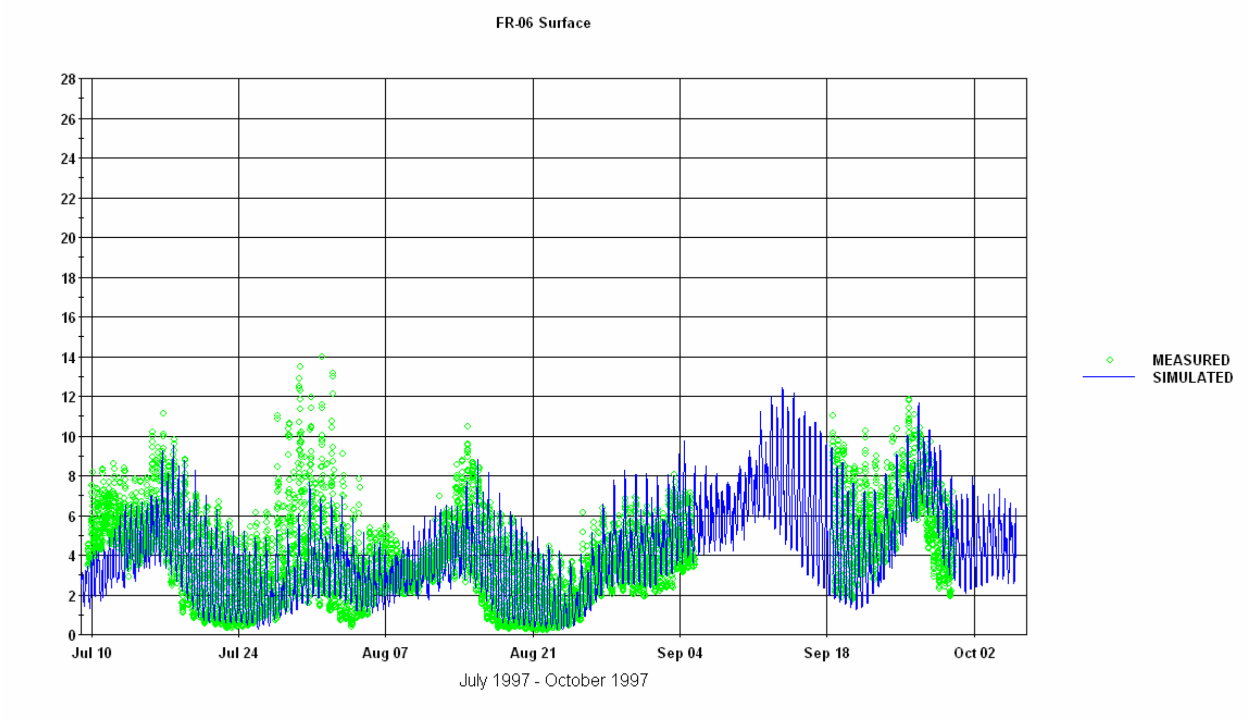


Figure K-8 Salinity (ppt) Calibration at FR-06 (Surface) for July 9, 1997 through October 6, 1997

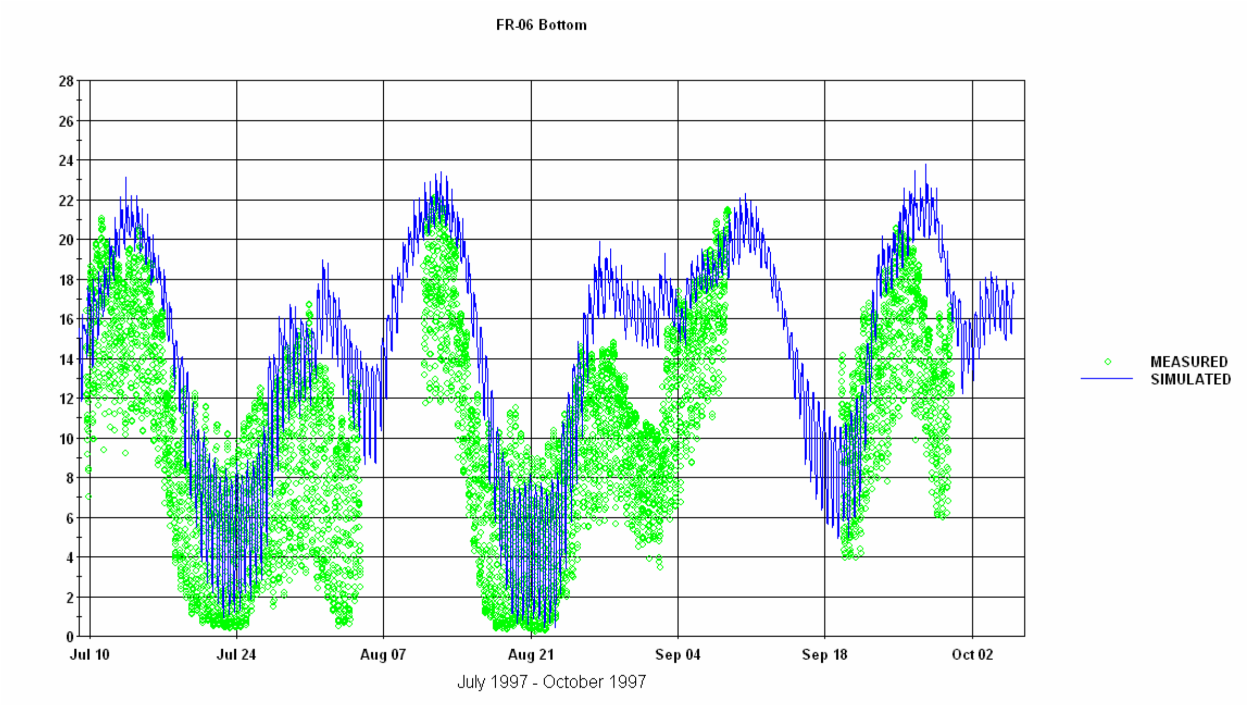


Figure K-9 Salinity (ppt) Calibration at FR-06 (Bottom) for July 9, 1997 through October 6, 1997

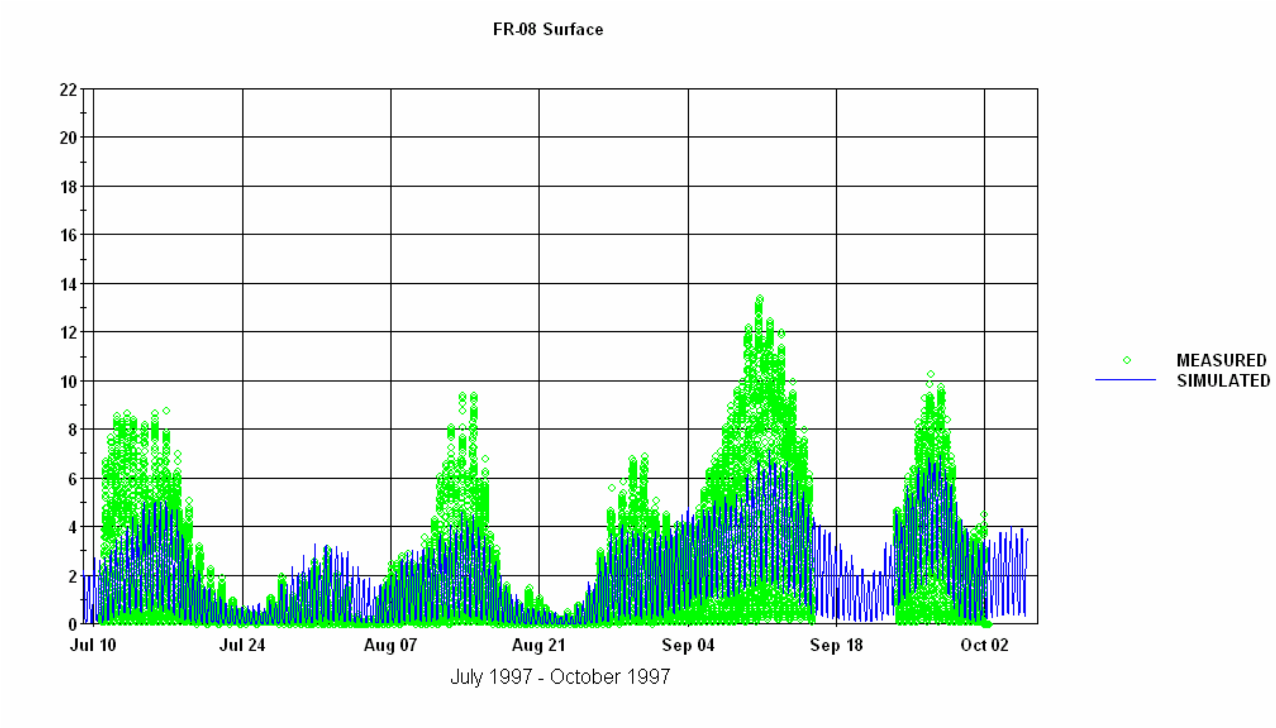


Figure K-10 Salinity (ppt) Calibration at FR-08 (Surface) for July 9, 1997 through October 6, 1997

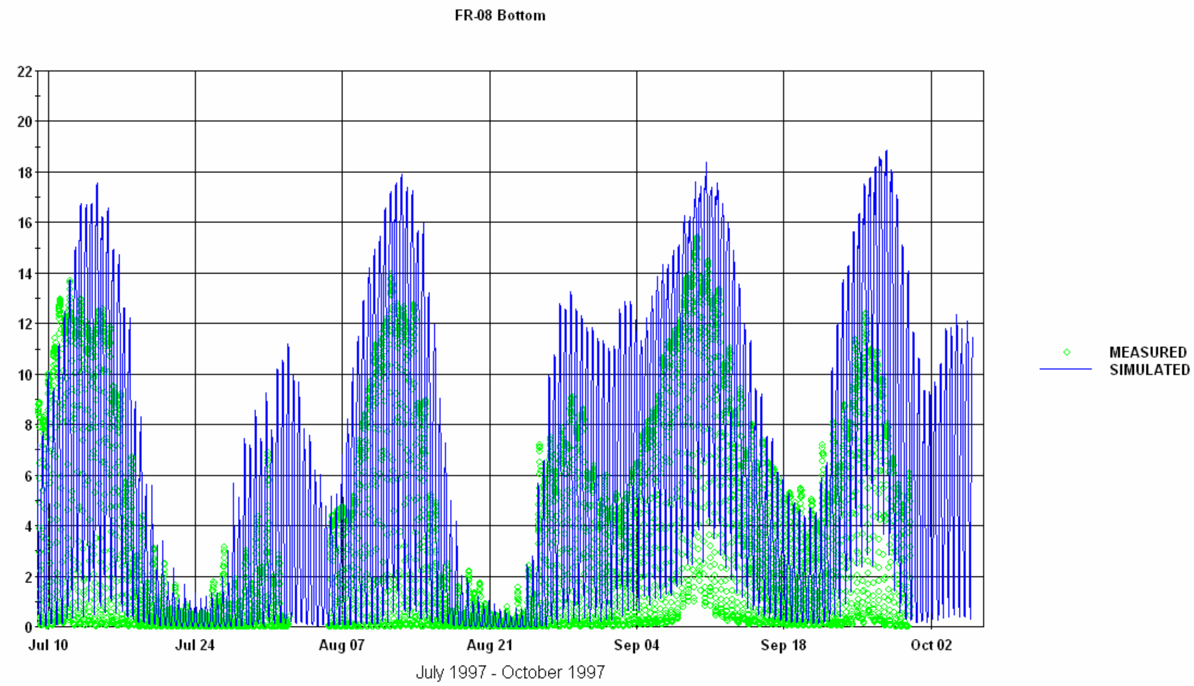


Figure K-11 Salinity (ppt) Calibration at FR-08 (Bottom) for July 9, 1997 through October 6, 1997

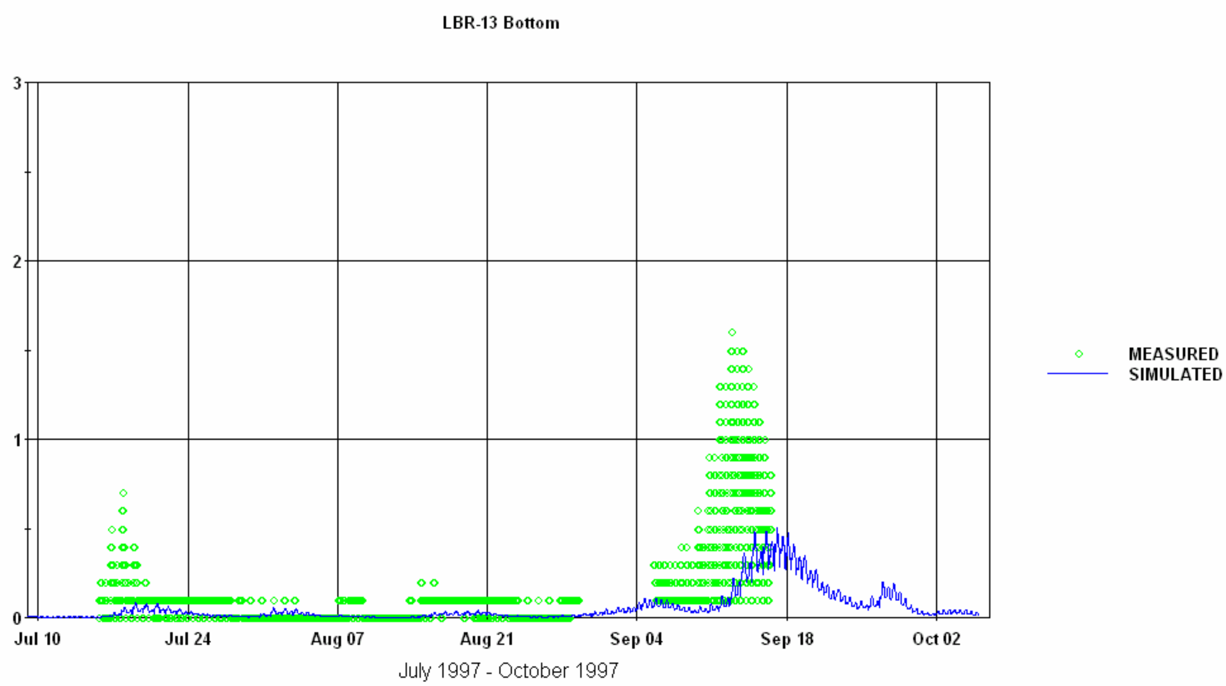


Figure K-12 Salinity (ppt) Calibration at LBR-13 (Bottom) for July 9, 1997 through October 6, 1997

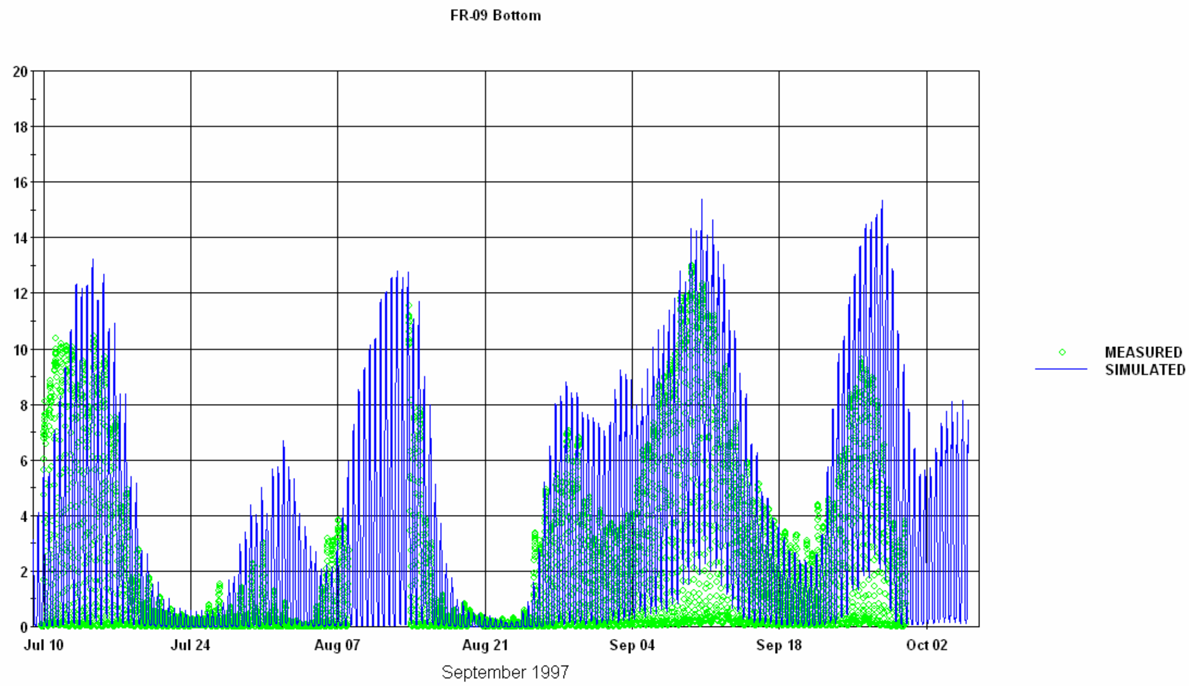


Figure K-13 Salinity (ppt) Calibration at FR-09 (Bottom) for July 9, 1997 through October 6, 1997

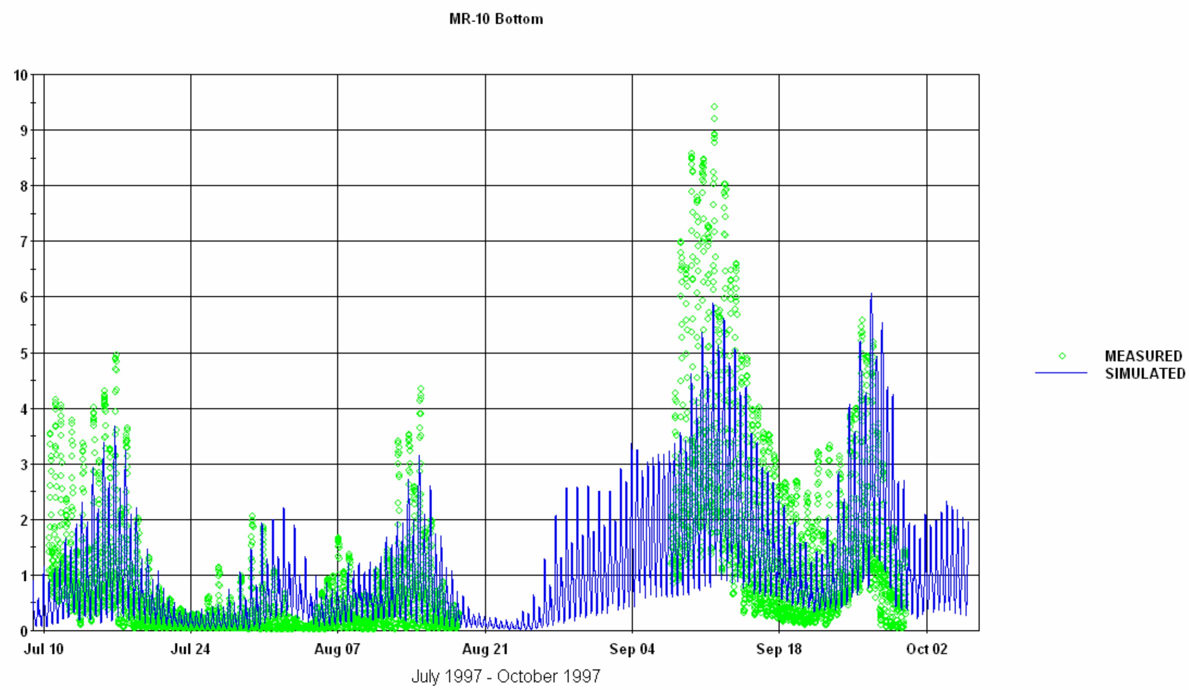


Figure K-14 Salinity (ppt) Calibration at MR-10 (Bottom) for July 9, 1997 through October 6, 1997

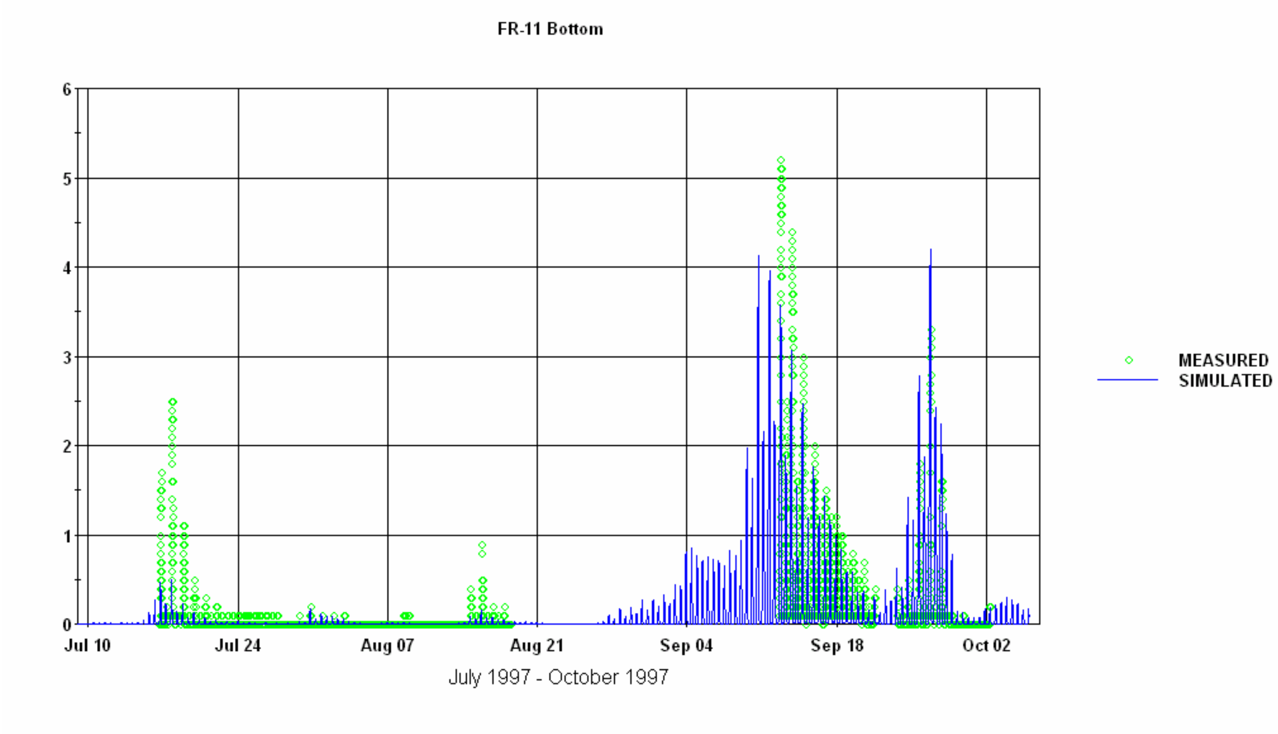


Figure K-15 Salinity (ppt) Calibration at FR-11 (Bottom) for July 9, 1997 through October 6, 1997

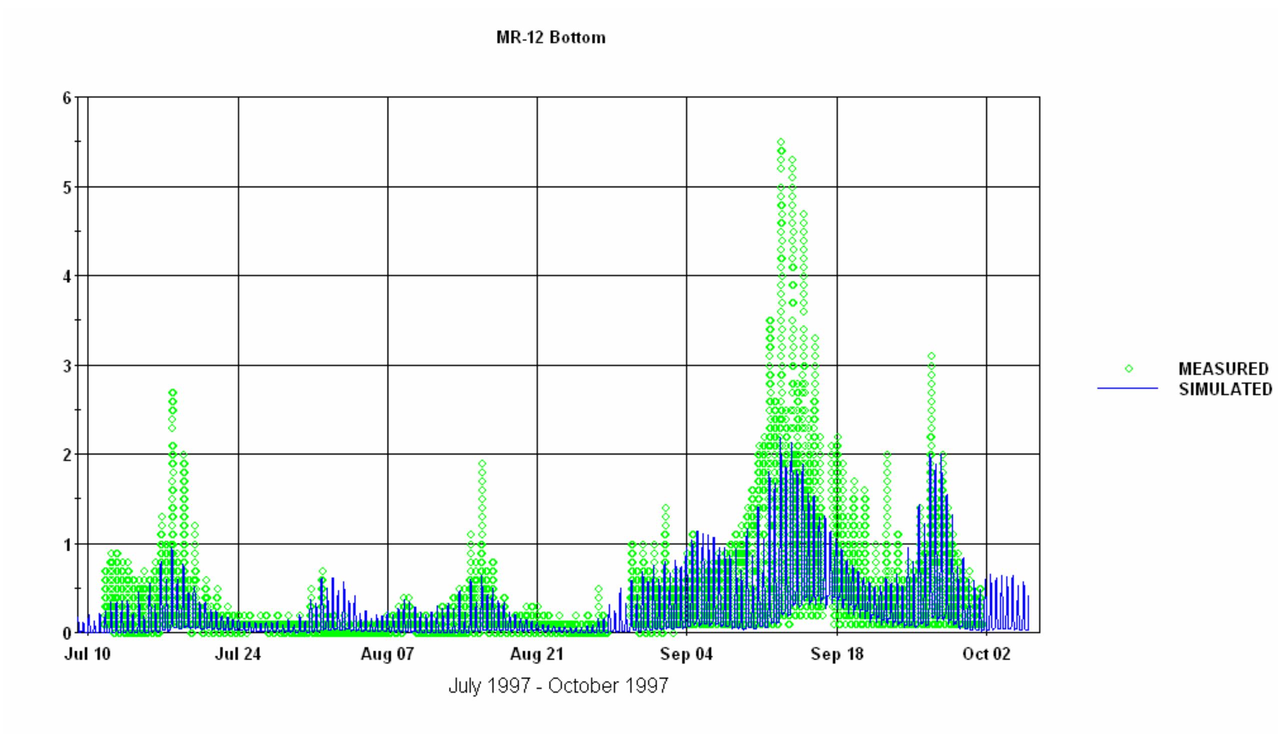


Figure K-16 Salinity (ppt) Calibration at MR-12 (Bottom) for July 9, 1997 through October 6, 1997

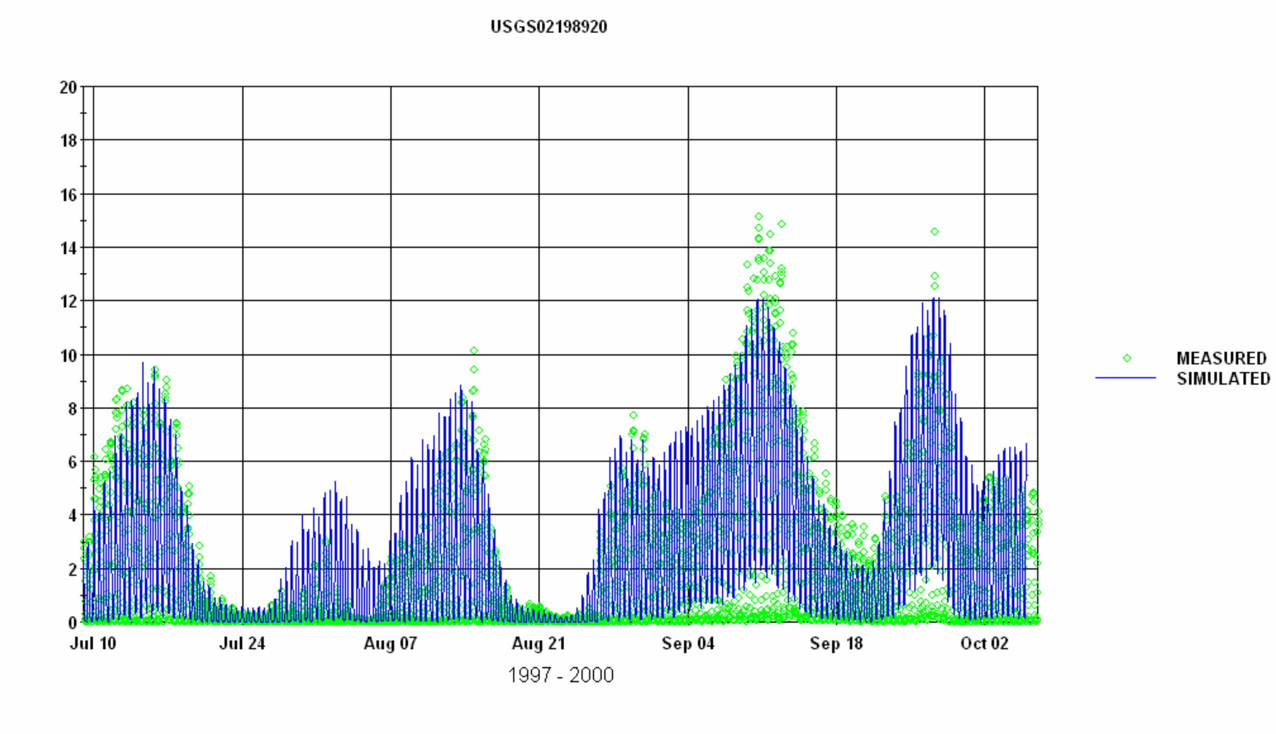


Figure K-17 Salinity (ppt) Calibration at Houlihan Bridge/Port Wentworth (Mid-depth) for July 9, 1997 through October 6, 1997

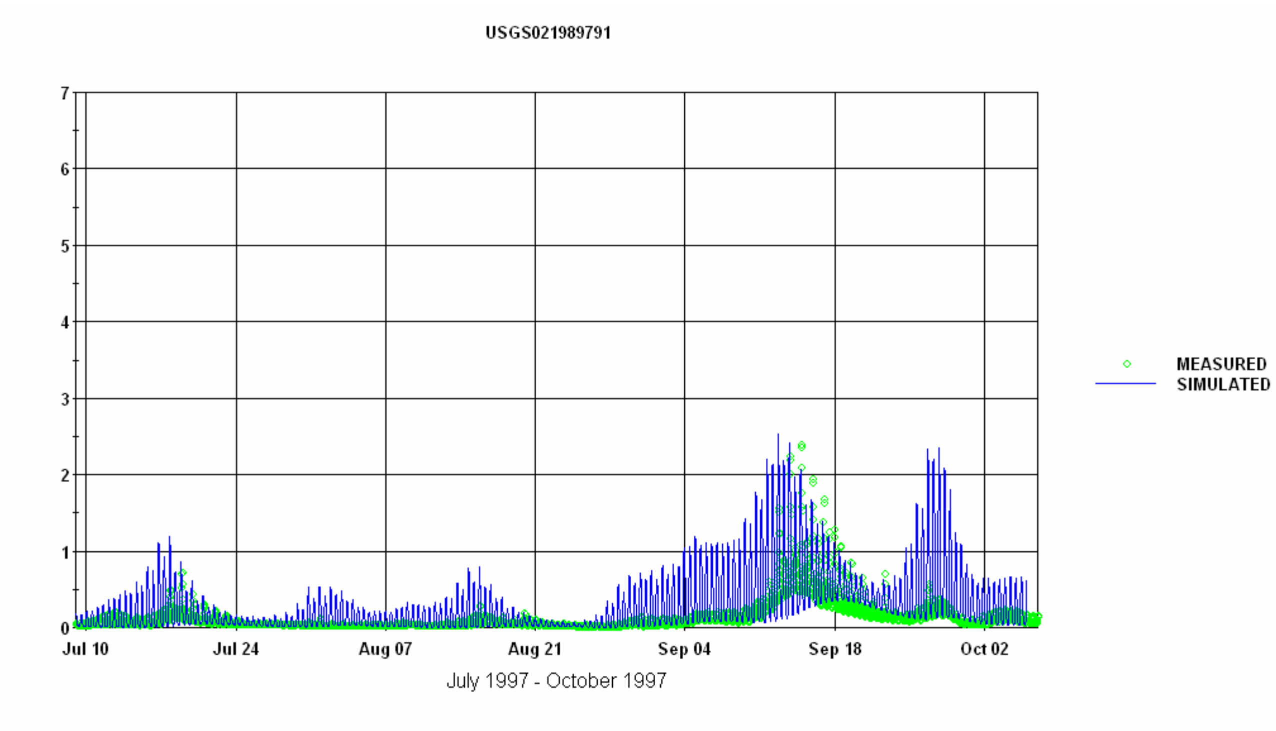


Figure K-18 Salinity (ppt) Calibration at US F&W Docks (Mid-depth) for July 9, 1997 through October 6, 1997

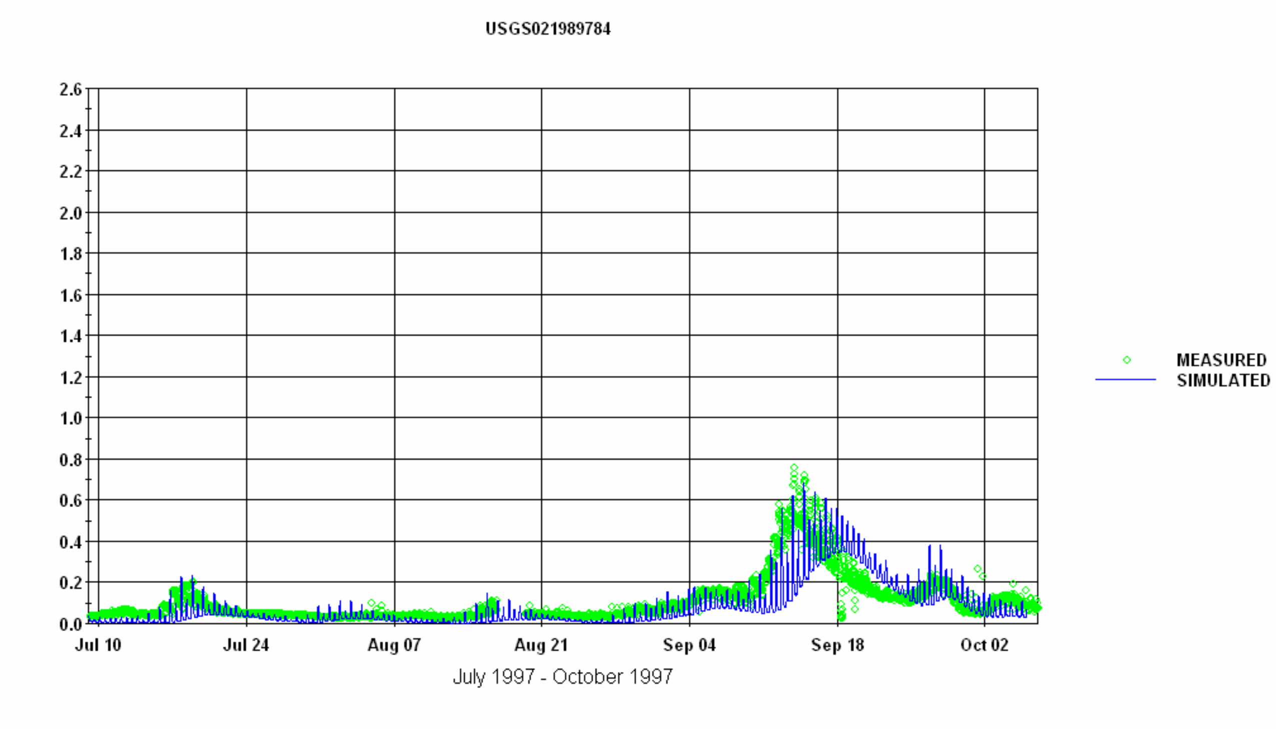


Figure K-19 Salinity (ppt) Calibration at Lucknow Canal (Mid-depth) for July 9, 1997 through October 6, 1997

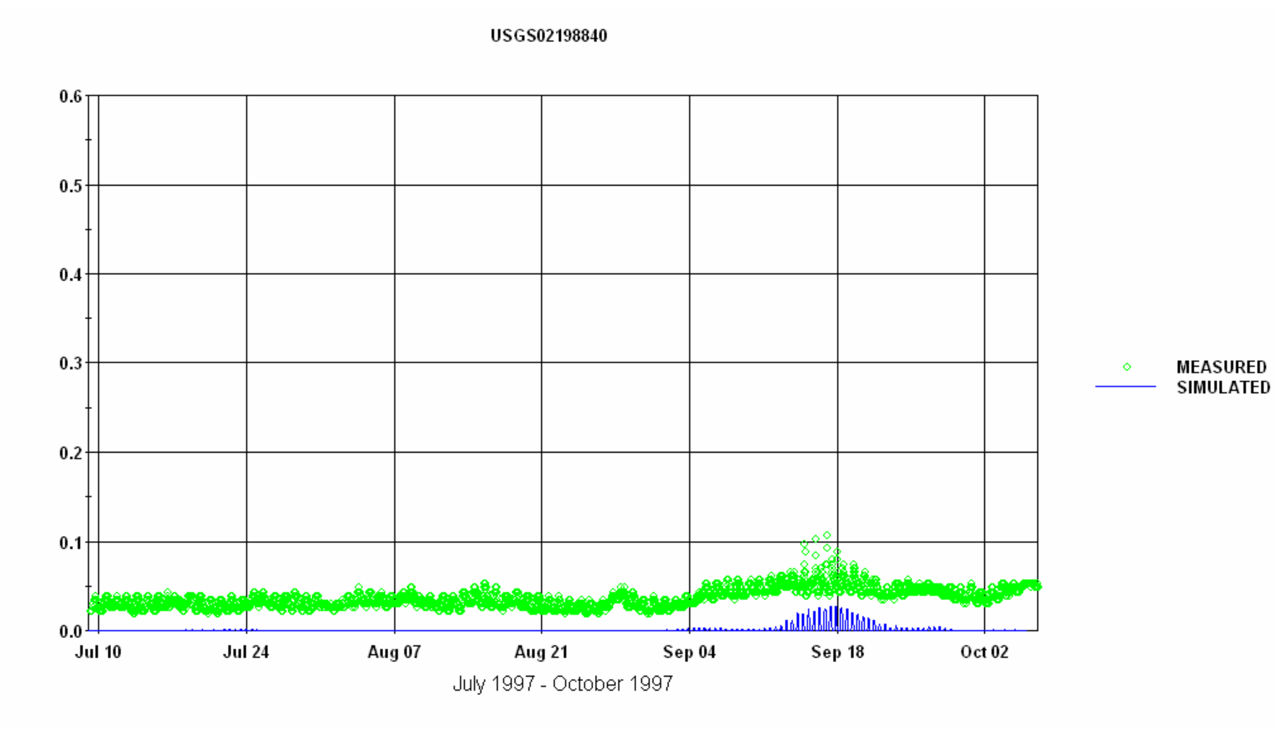


Figure K-20 Salinity (ppt) Calibration at I-95 Bridge (Mid-depth) for July 9, 1997 through October 6, 1997

APPENDIX L 7-YEAR WATER SURFACE COMPARISONS

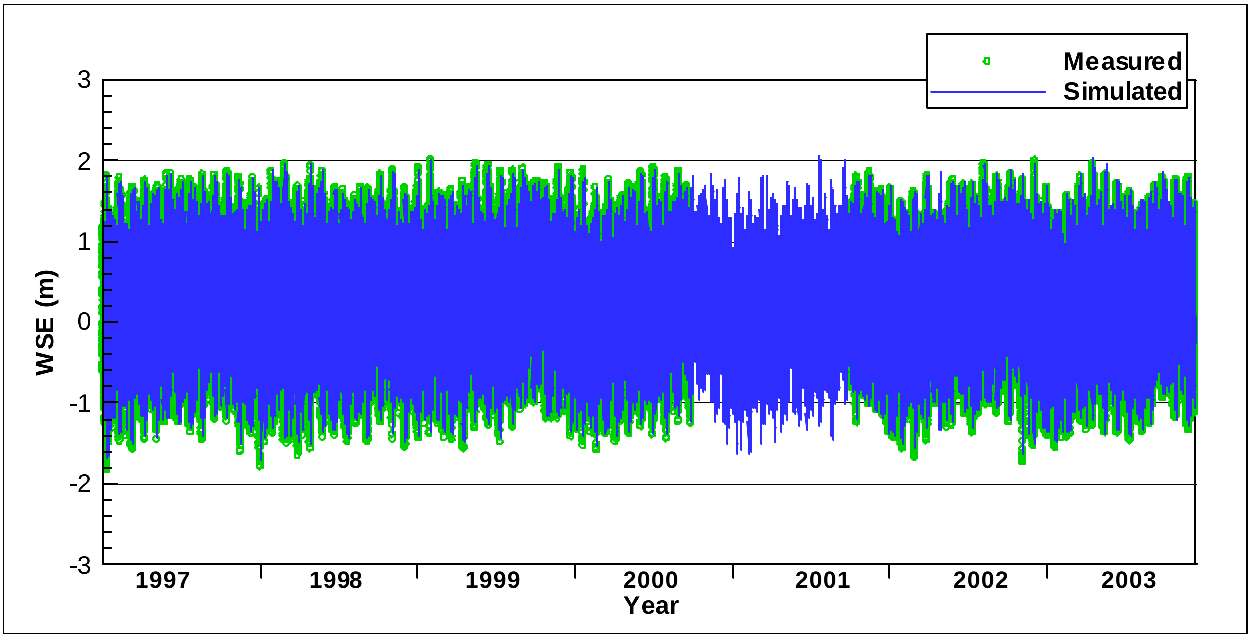


Figure L-1 7-Year Water Surface Comparison at USGS 02198980 Ft. Pulaski

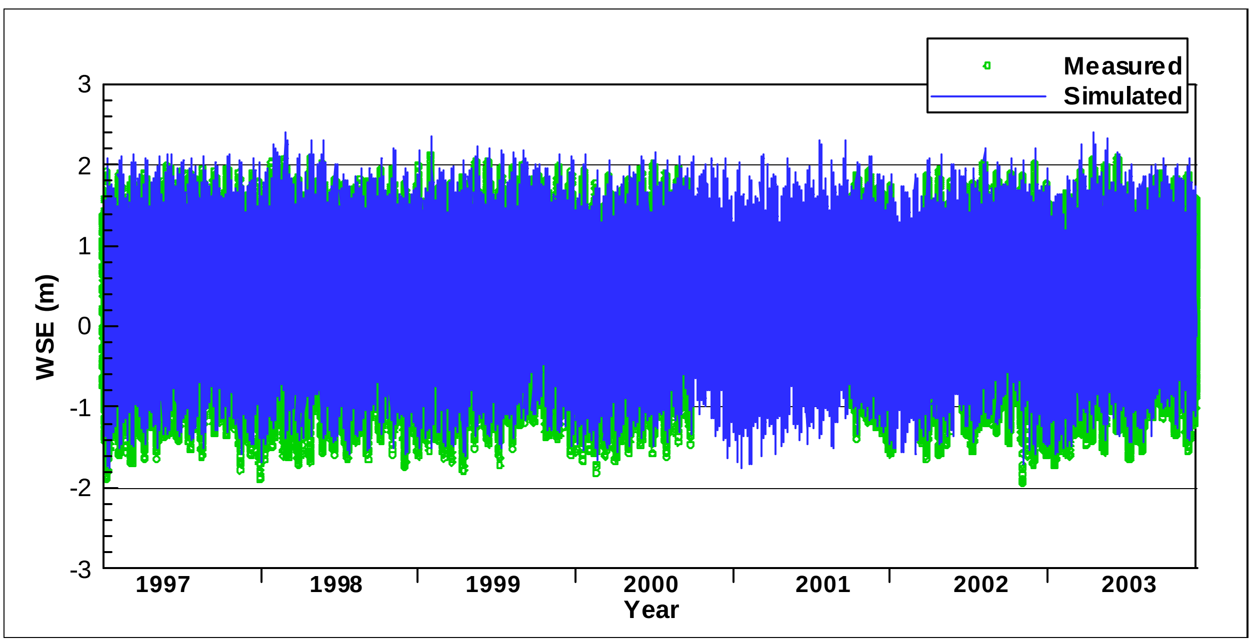


Figure L-2 7-Year Water Surface Comparison at USGS 02198977 Broad St.

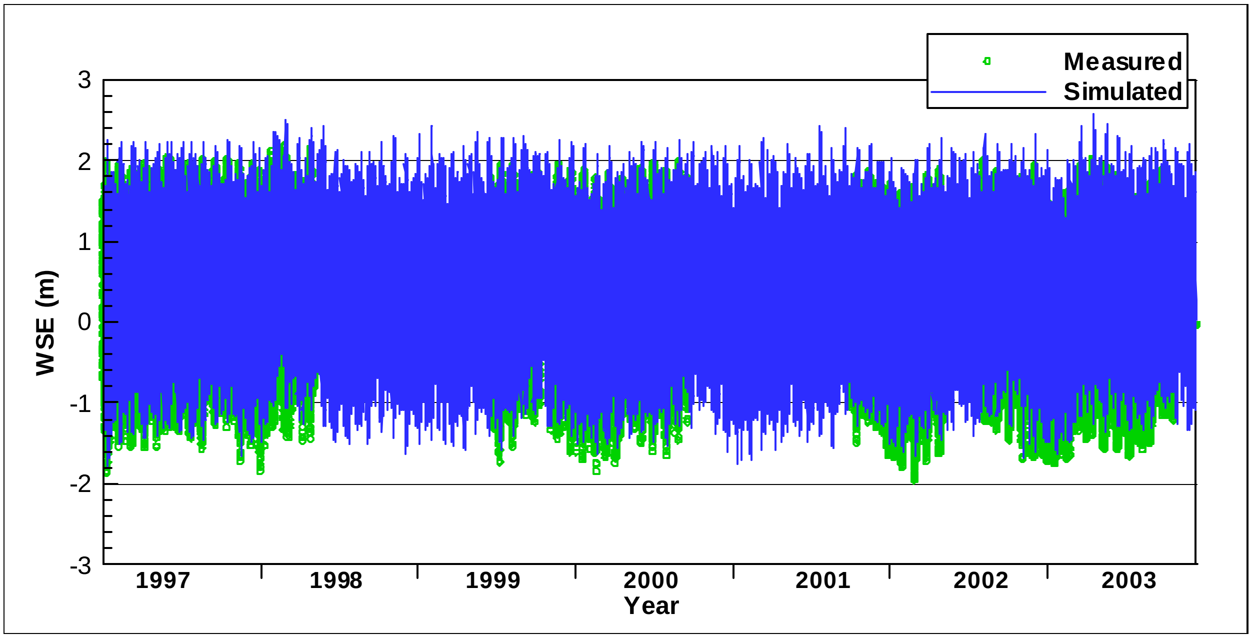


Figure L-3 7-Year Water Surface Comparison at USGS 02198920 Houlihan Bridge

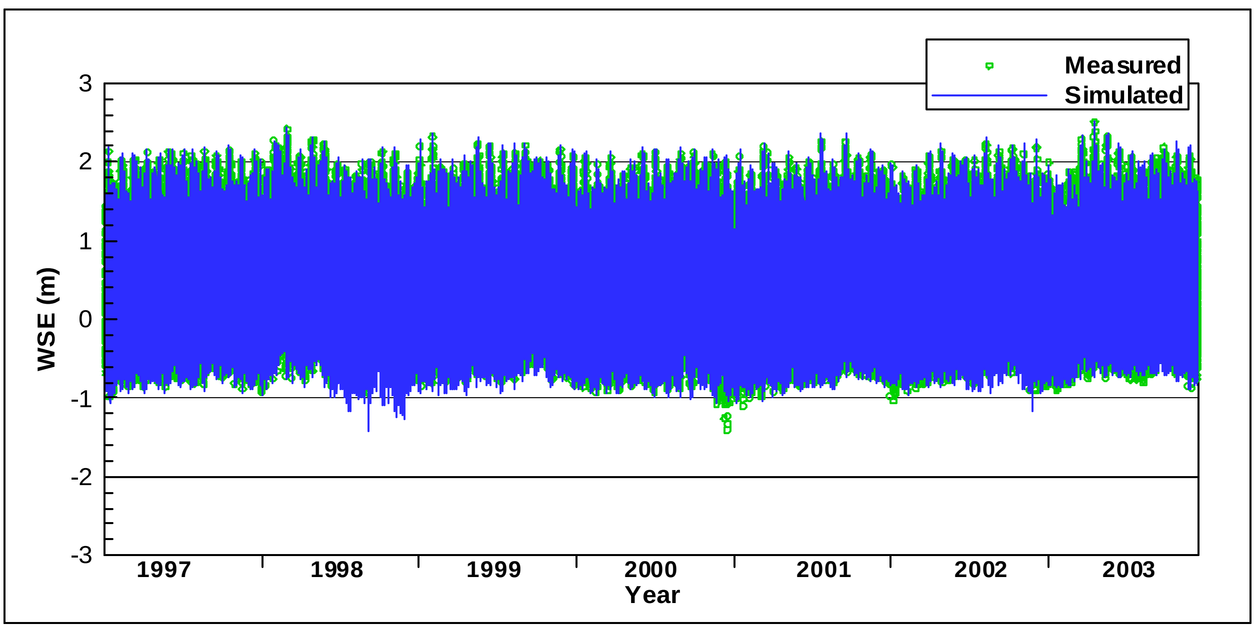


Figure L-4 7-Year Water Surface Comparison at USGS 02198979 Limehouse Creek

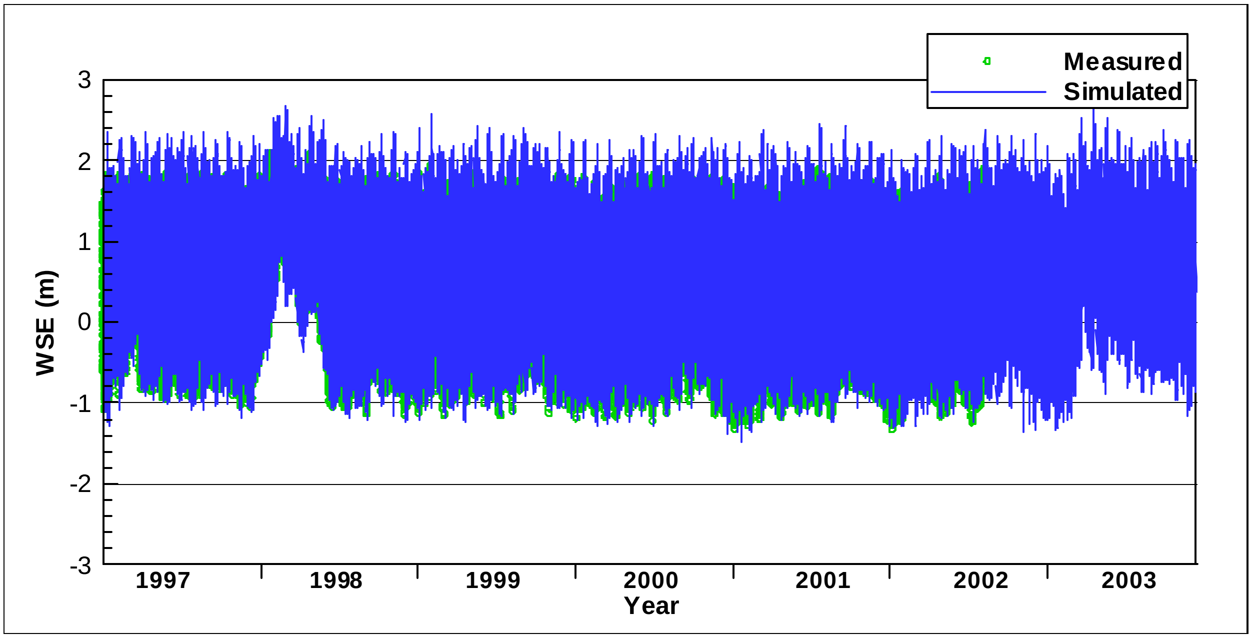


Figure L-5 7-Year Water Surface Comparison at USGS 02198840 I-95 Bridge

APPENDIX M 7-YEAR SALINITY COMPARISONS

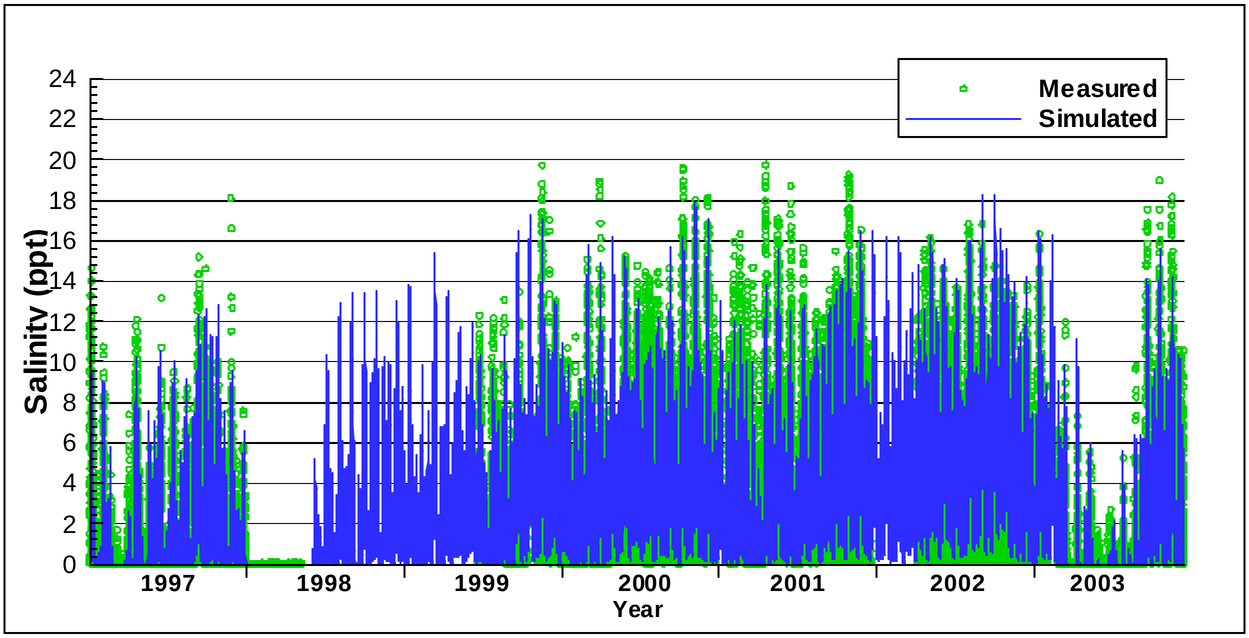


Figure M-1 7-Year Salinity Comparison at USGS 02198920 Houlihan Bridge (mid-depth)

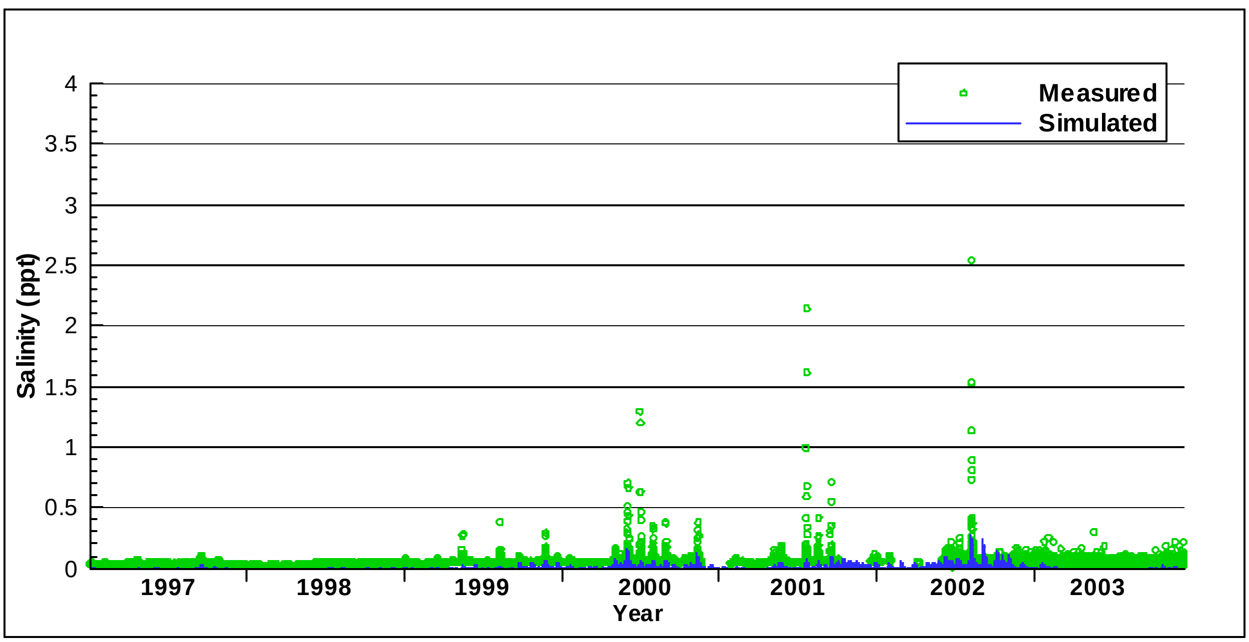


Figure M-2 7-Year Salinity Comparison at USGS 02198840 I-95 Bridge (mid-depth)

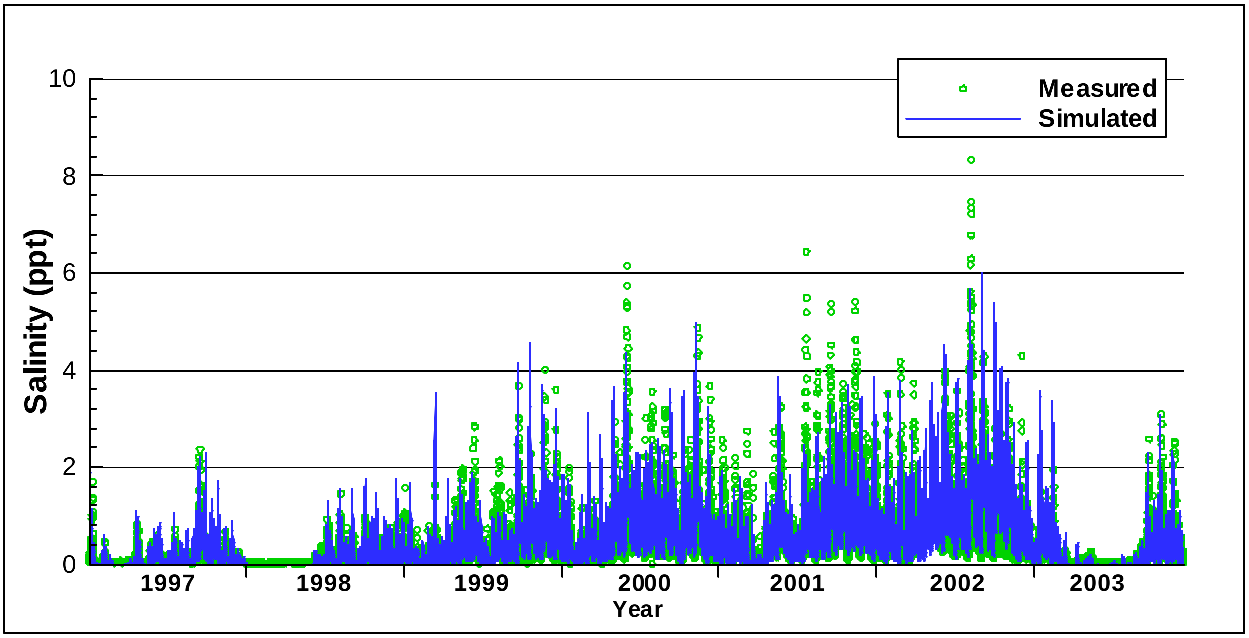


Figure M-3 7-Year Salinity Comparison at USGS 02198791 F&W Docks (mid-depth)

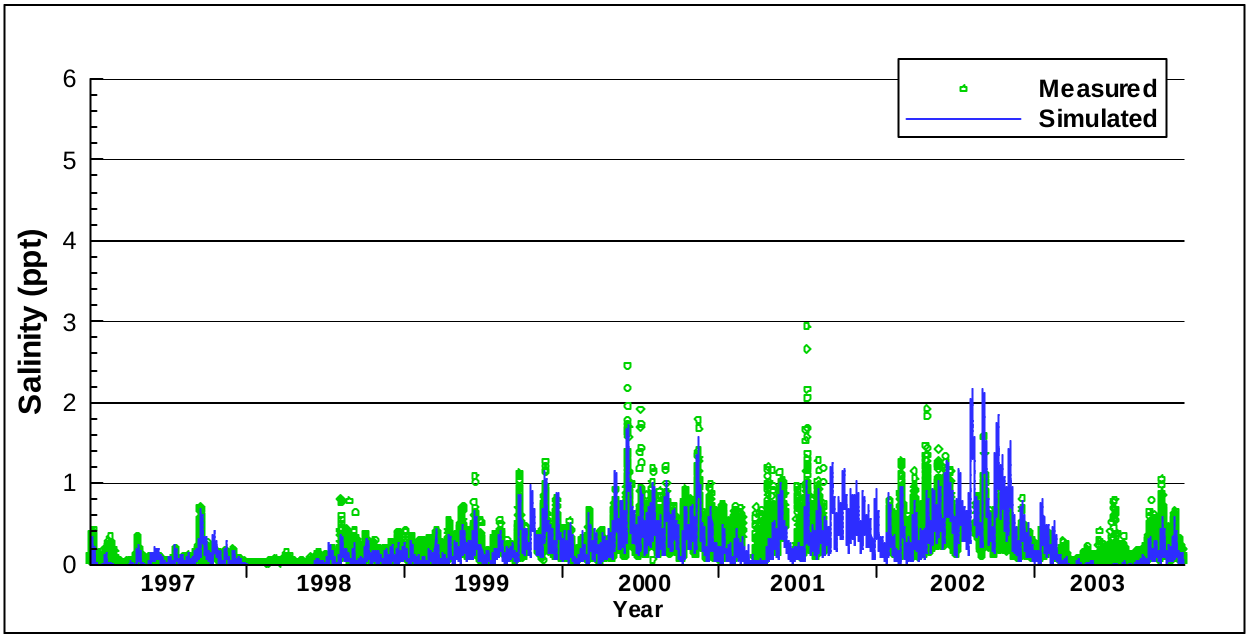


Figure M-4 7-Year Salinity Comparison at USGS 021989784 Lucknow Canal (mid-depth)

APPENDIX N 1999 AMMONIA COMPARISONS

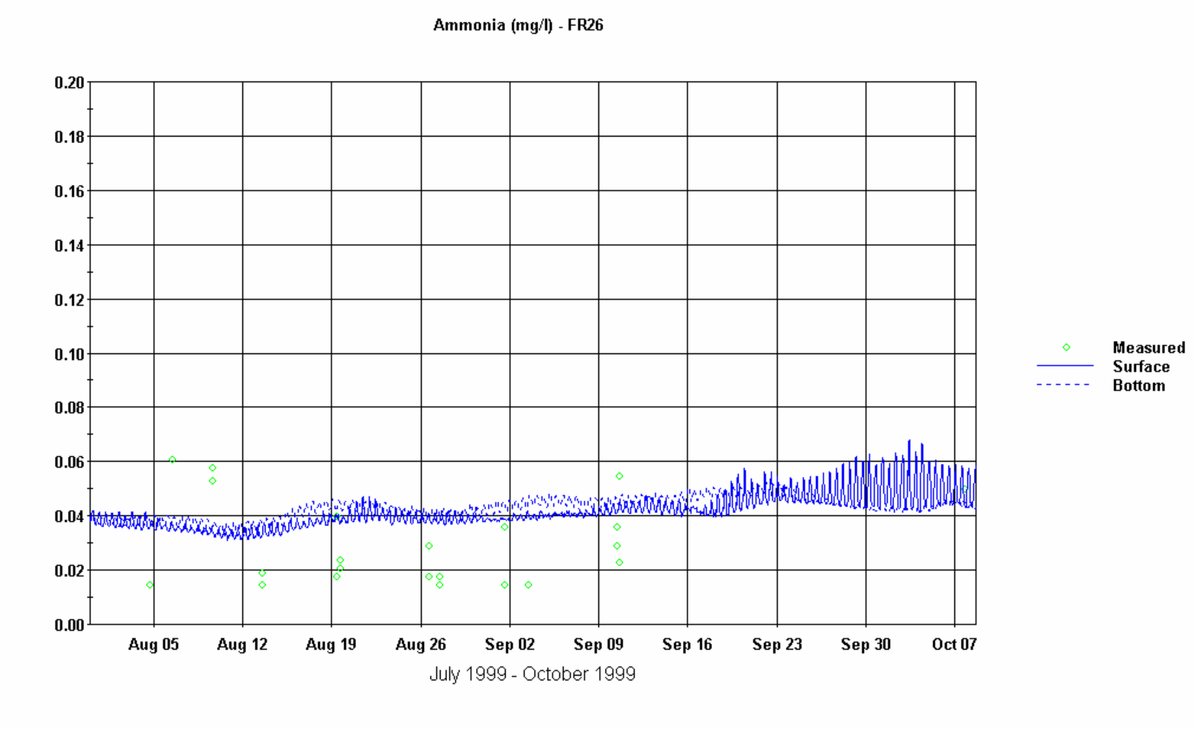


Figure N-1 Ammonia Calibration at FR-26 for July 31 through October 13, 1999

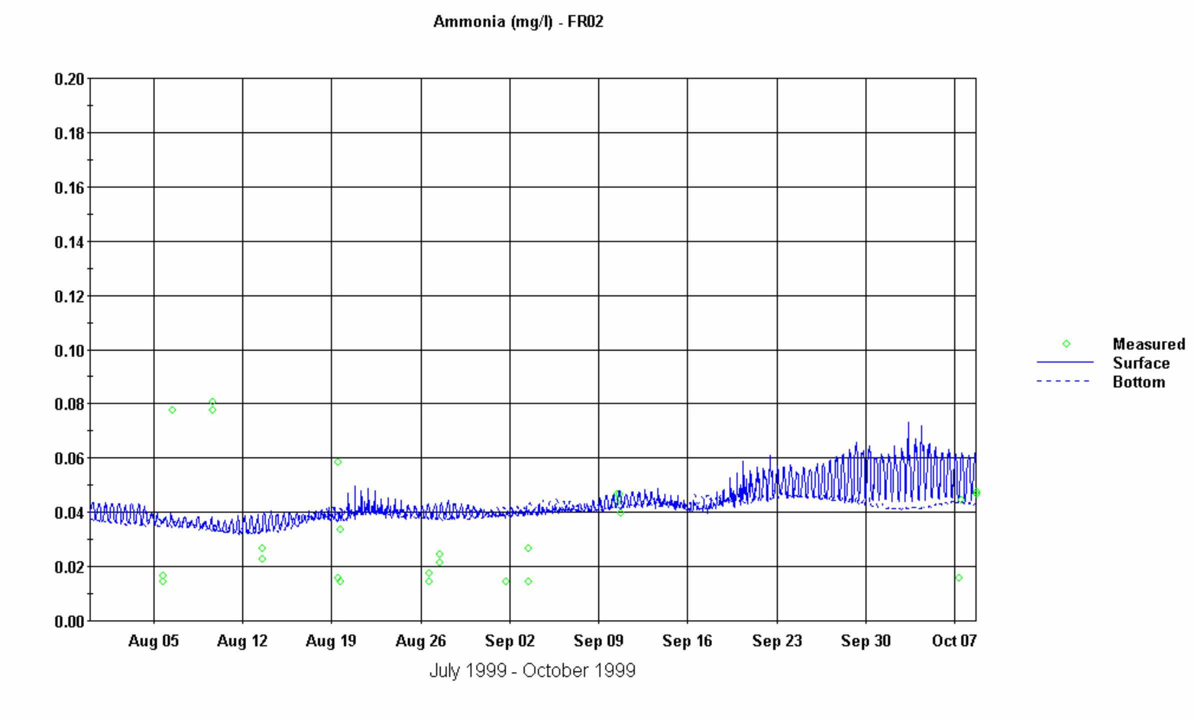


Figure N-2 Ammonia Calibration at FR-02 for July 31 through October 13, 1999

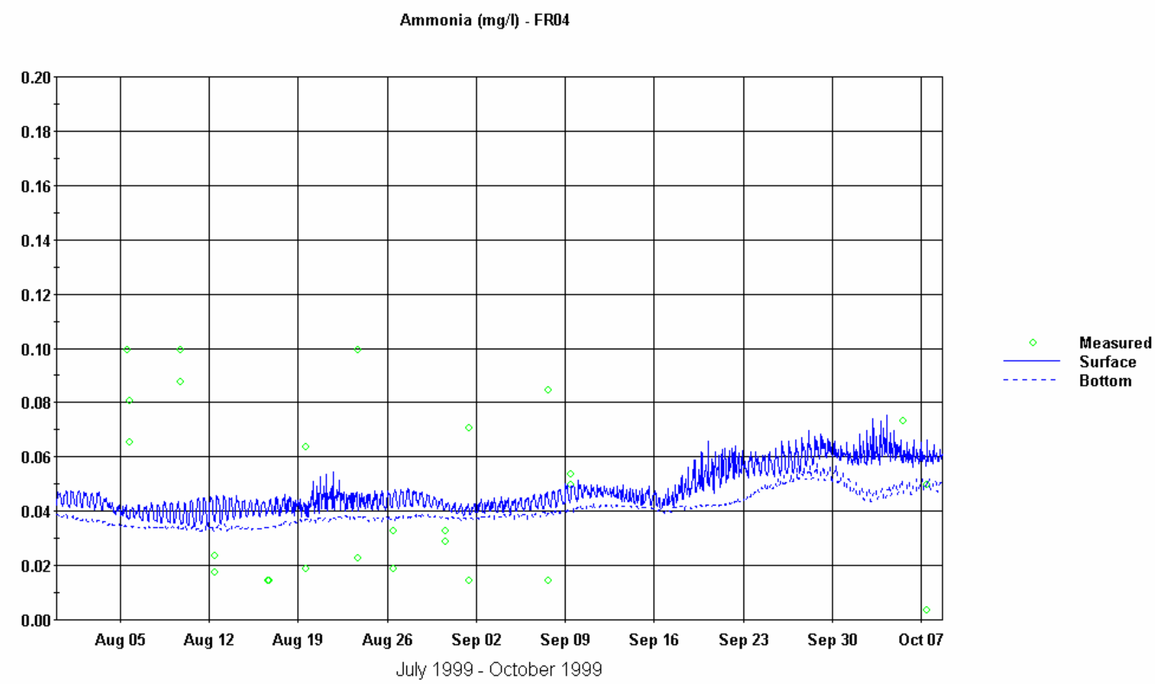


Figure N-3 Ammonia Calibration at FR-04 for July 31 through October 13, 1999

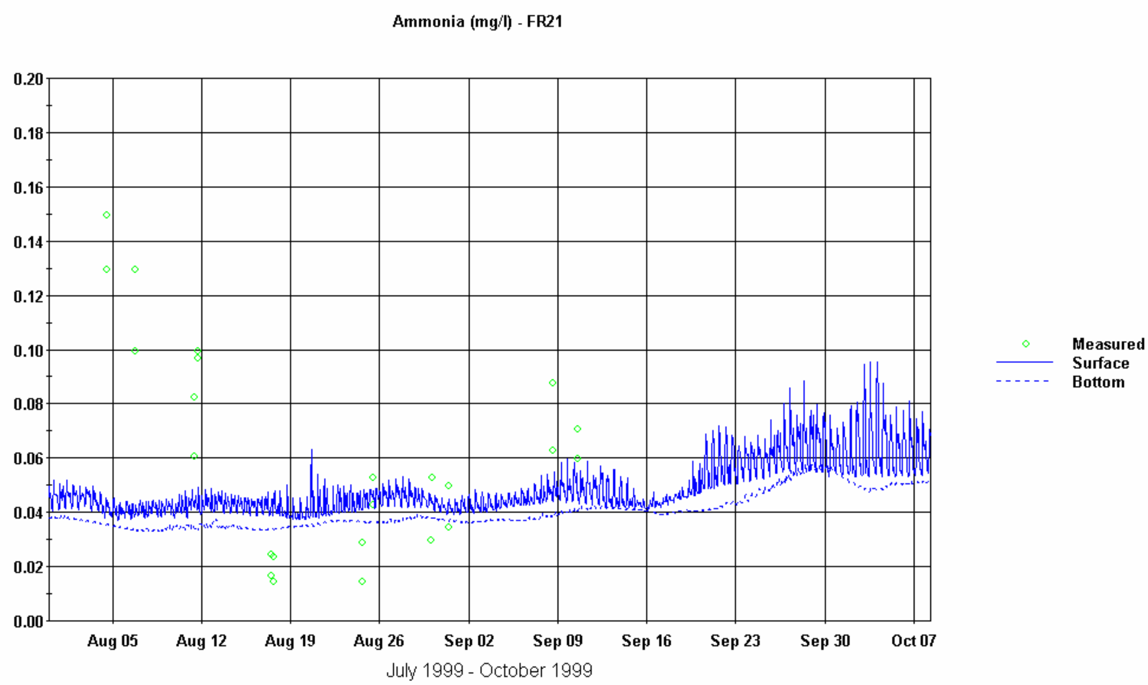


Figure N-4 Ammonia Calibration at FR-21 for July 31 through October 13, 1999

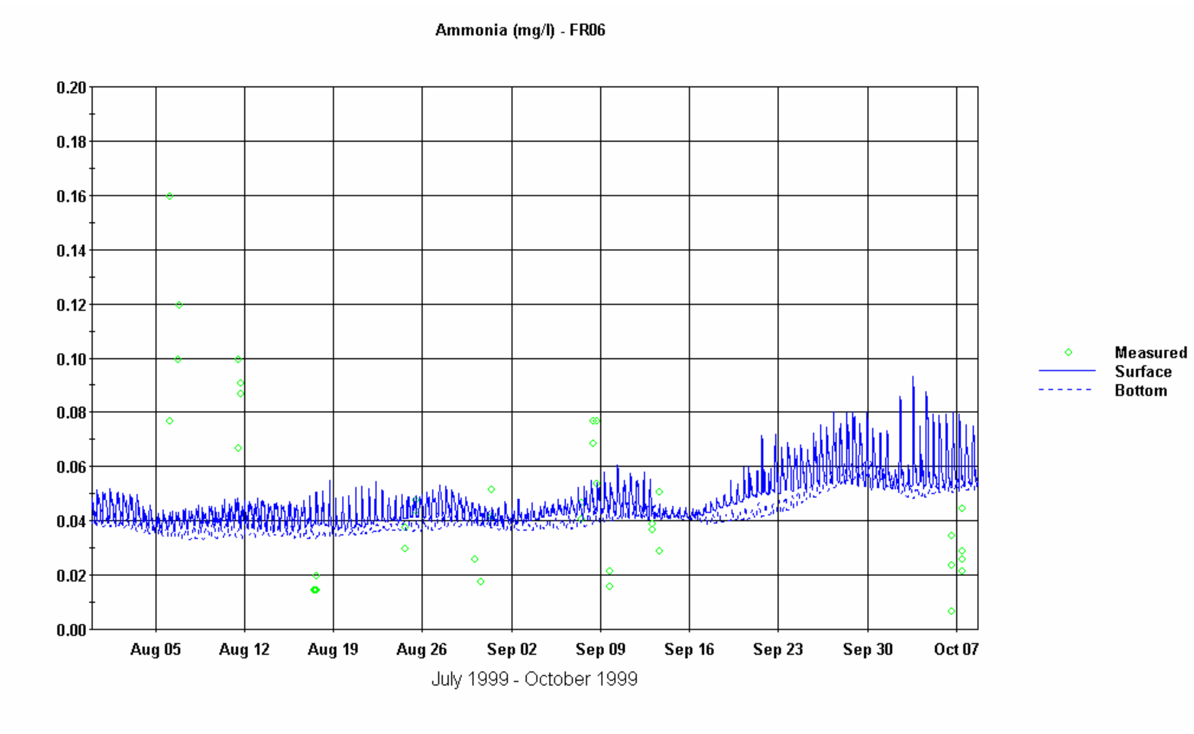


Figure N-5 Ammonia Calibration at FR-06 for August 1, 1999 through October 14, 1999

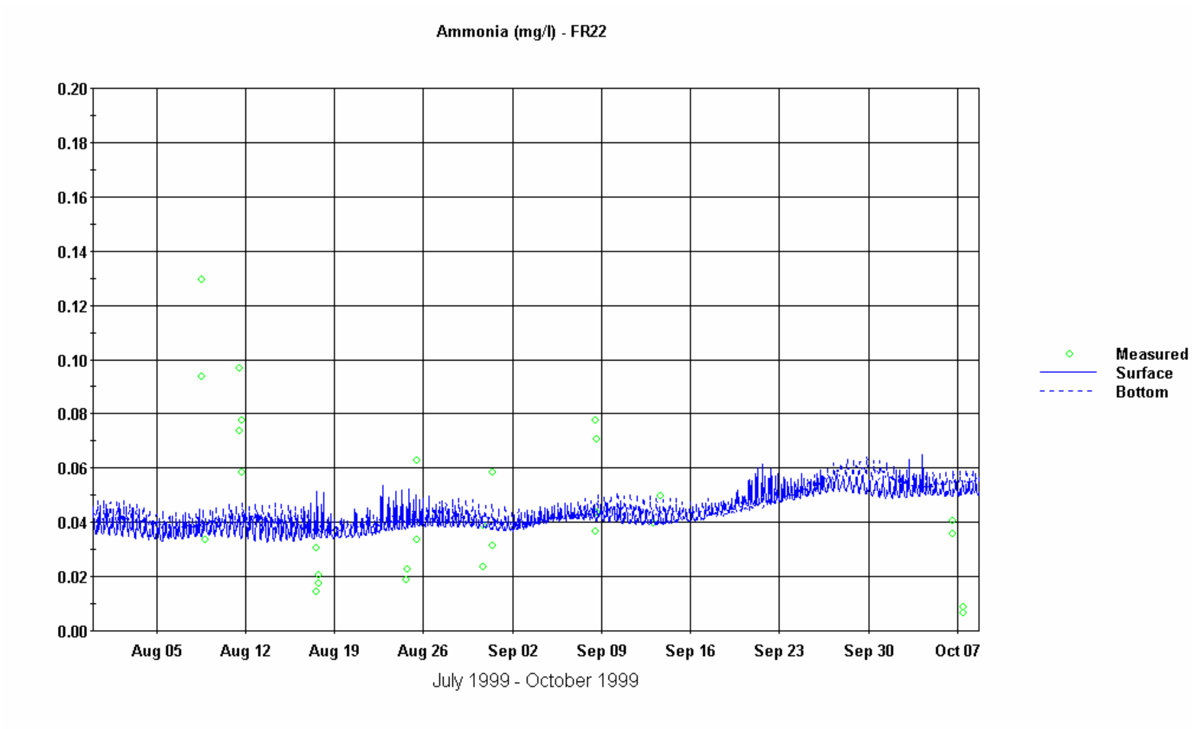


Figure N-6 Ammonia Calibration at FR-22 for July 31 through October 13, 1999

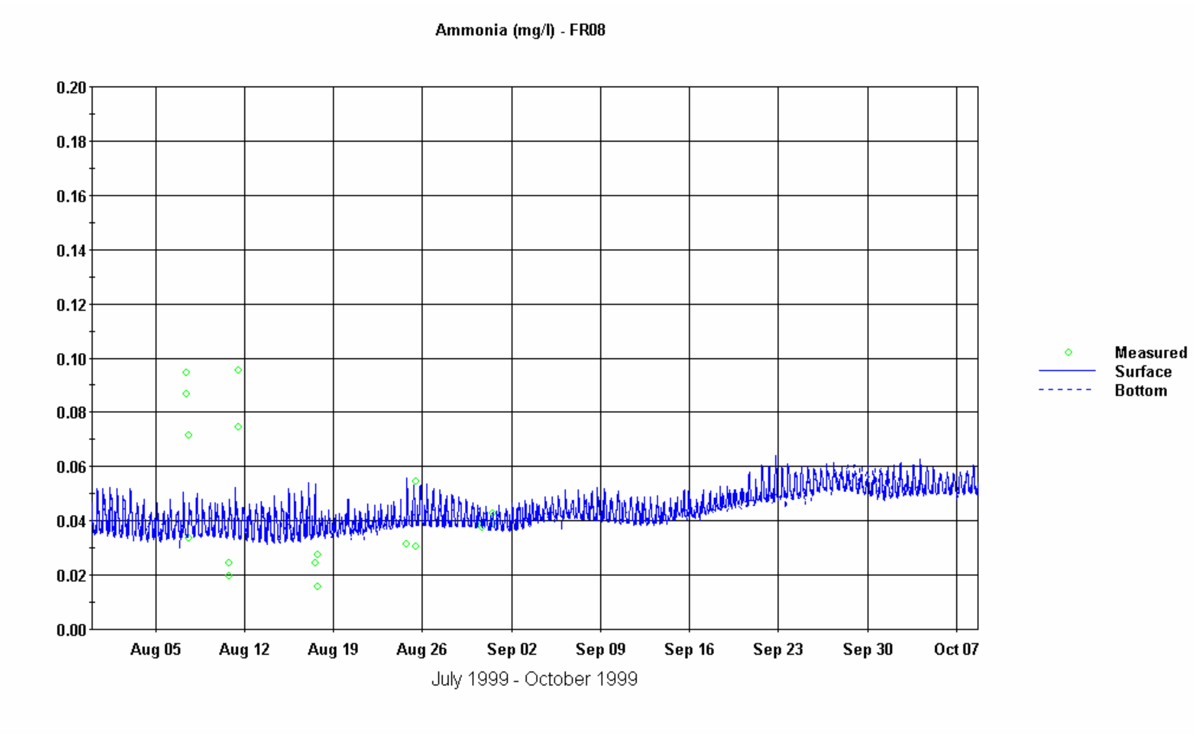


Figure N-7 Ammonia Calibration at FR-08 for July 31 through October 13, 1999

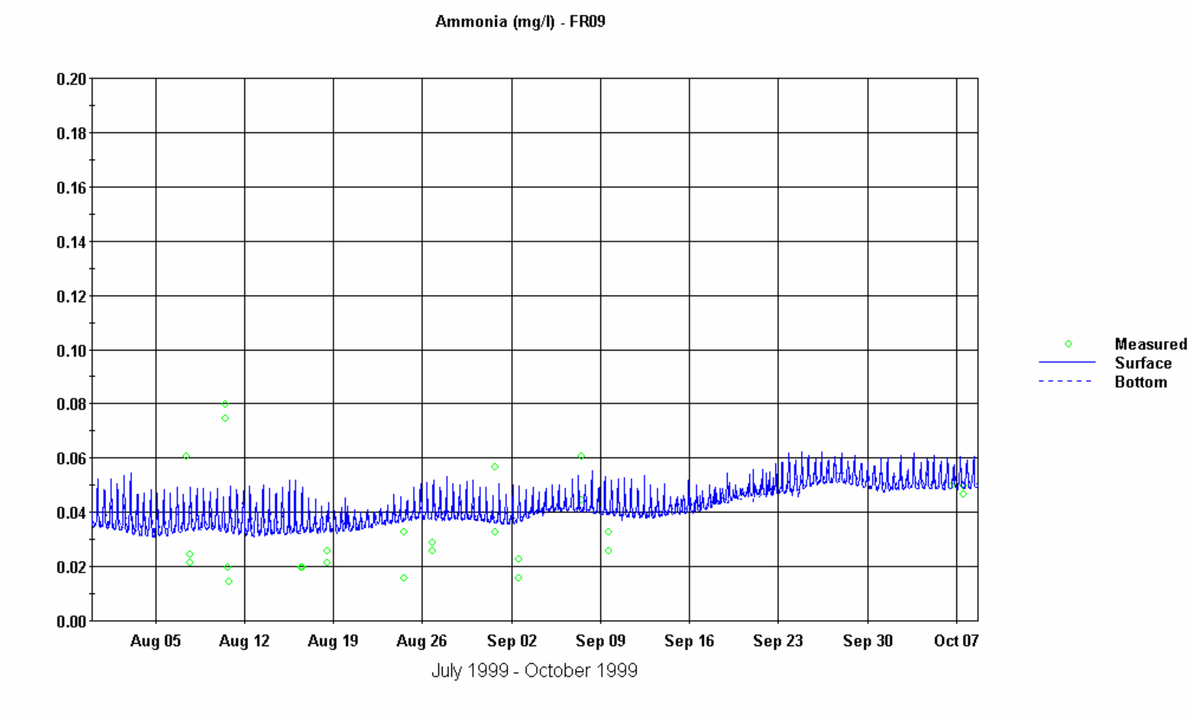


Figure N-8 Ammonia Calibration at FR-09 for July 31 through October 13, 1999

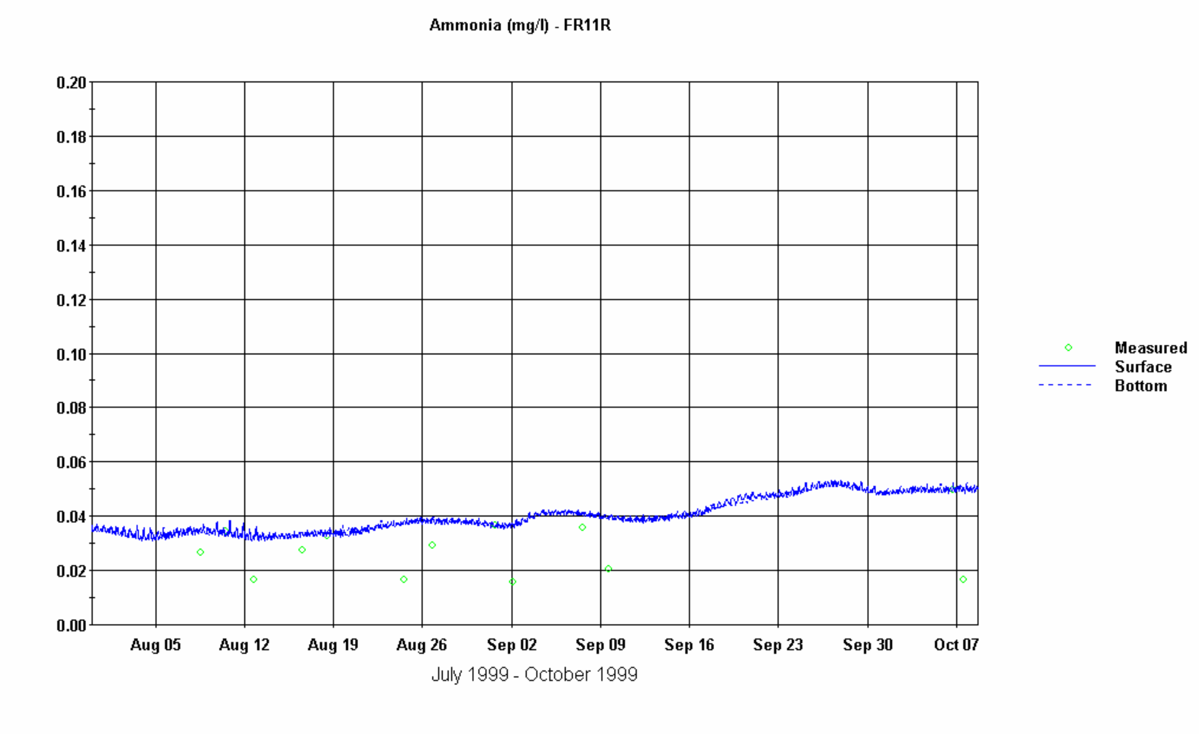


Figure N-9 Ammonia Calibration at FR-11R for July 31 through October 13, 1999

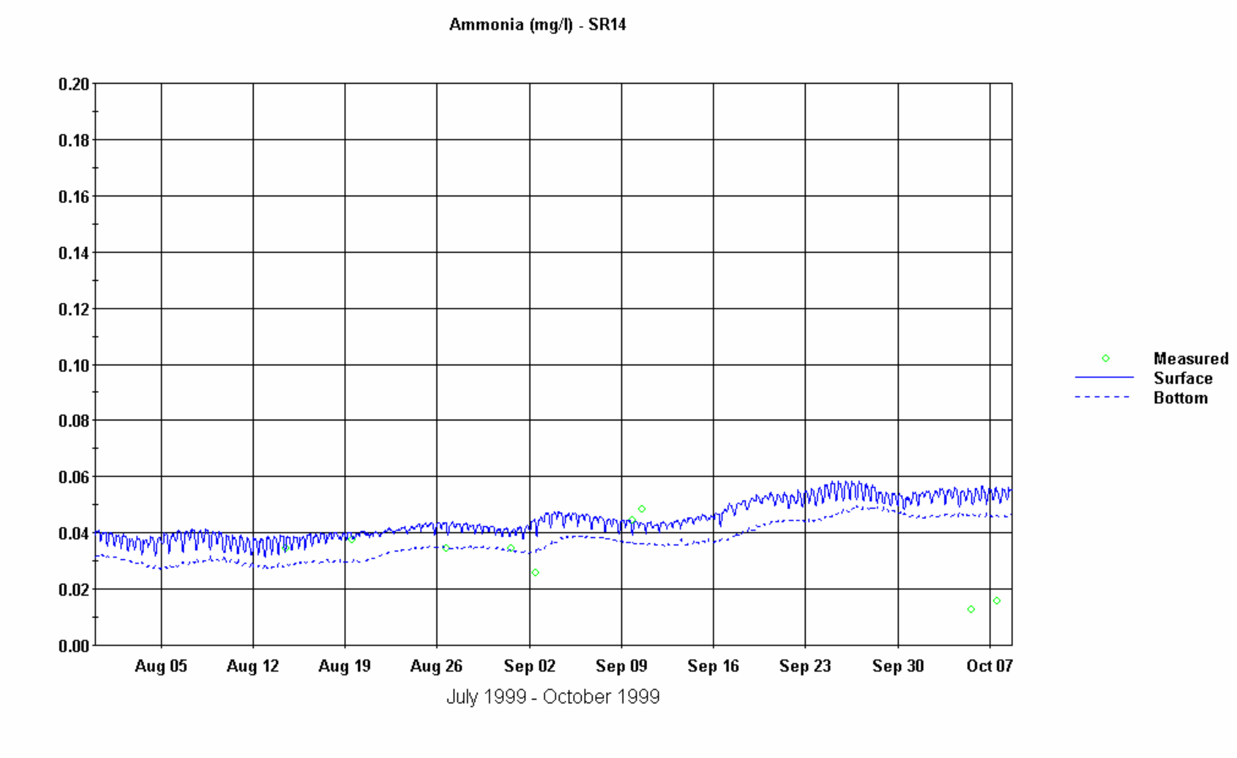


Figure N-10 Ammonia Calibration at SR-14 for July 31 through October 13, 1999

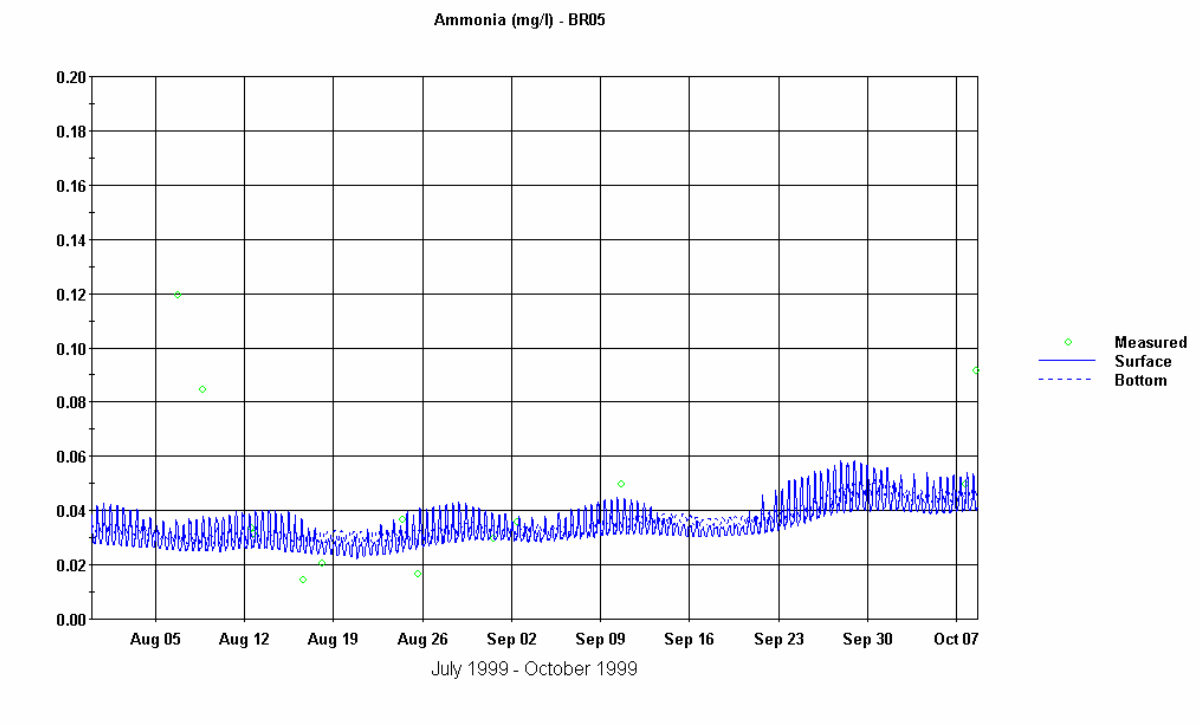


Figure N-11 Ammonia Calibration at BR-05 for July 31 through October 13, 1999

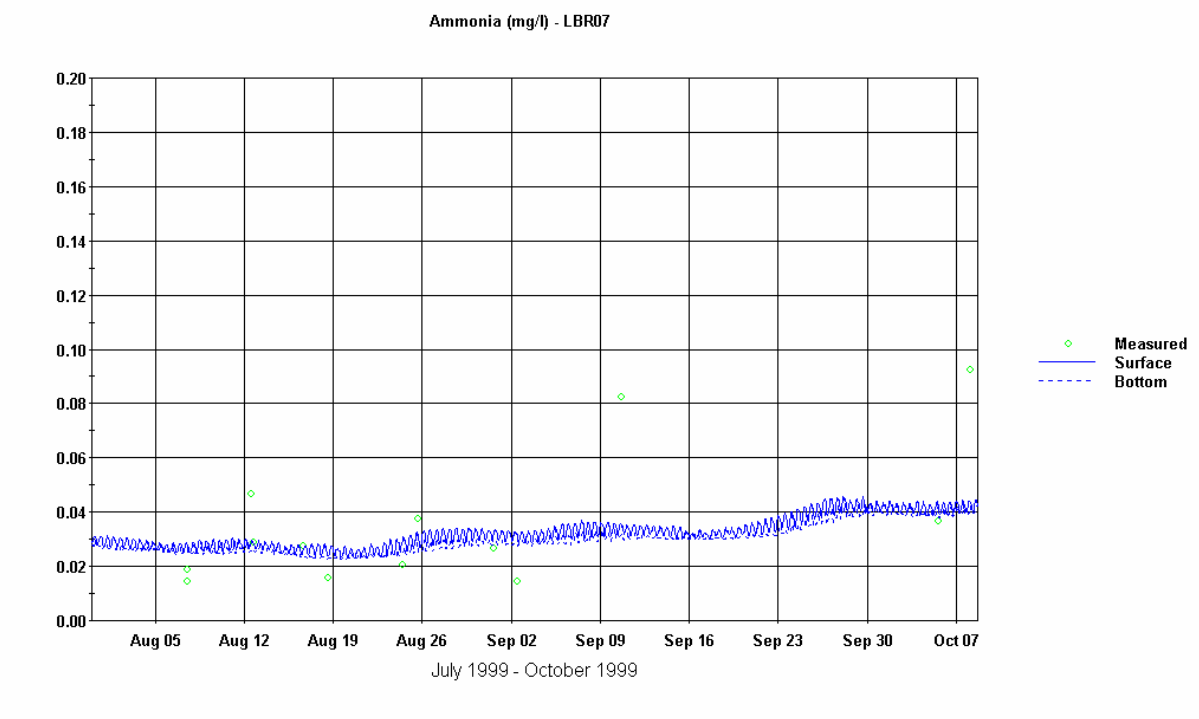


Figure N-12 Ammonia Calibration at LBR-07 for July 31 through October 13, 1999

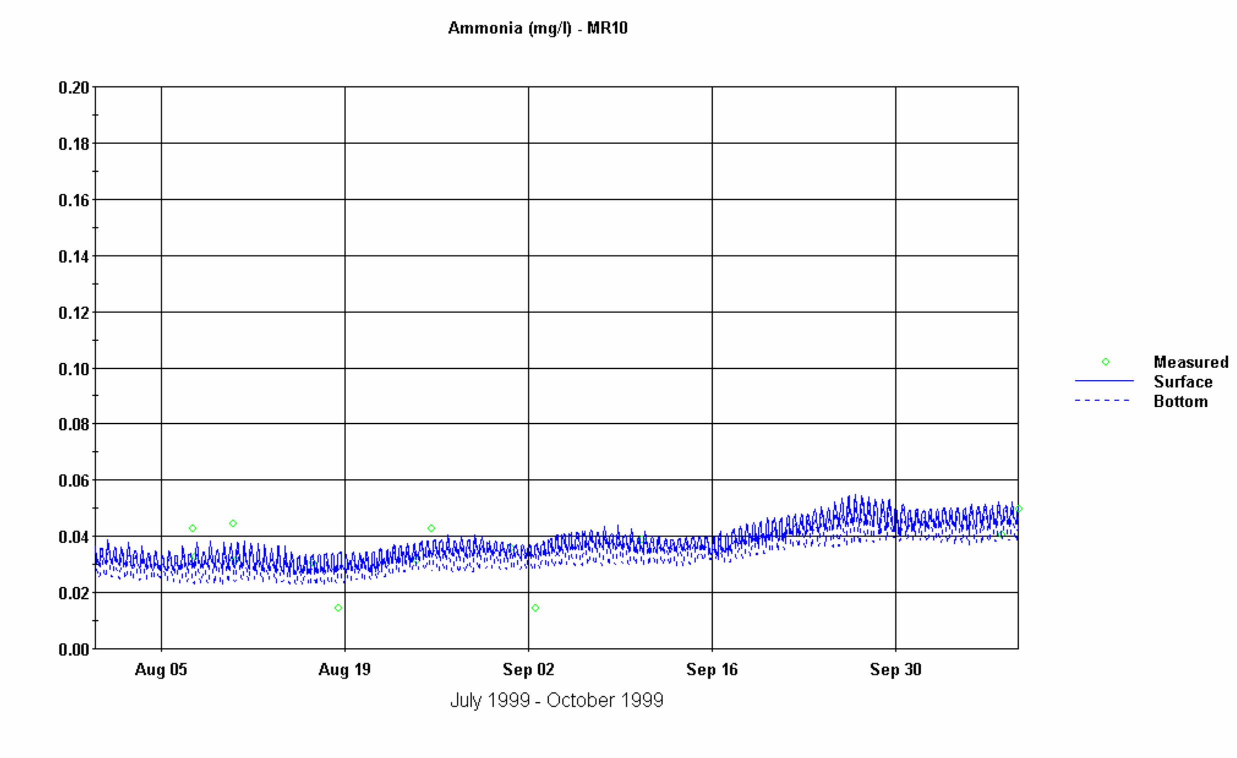


Figure N-13 Ammonia Calibration at MR-10 for July 31 through October 13, 1999

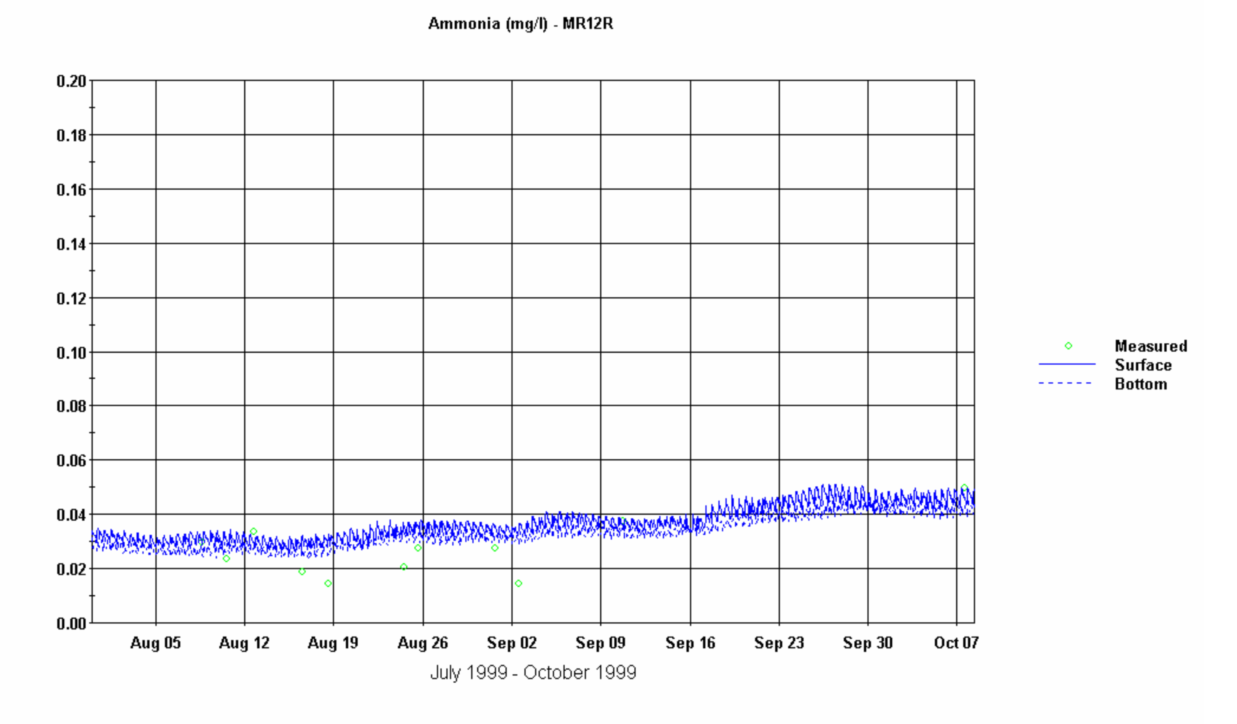


Figure N-14 Ammonia Calibration at MR-12R for July 31 through October 13, 1999

APPENDIX O 1999 CBODu COMPARISONS

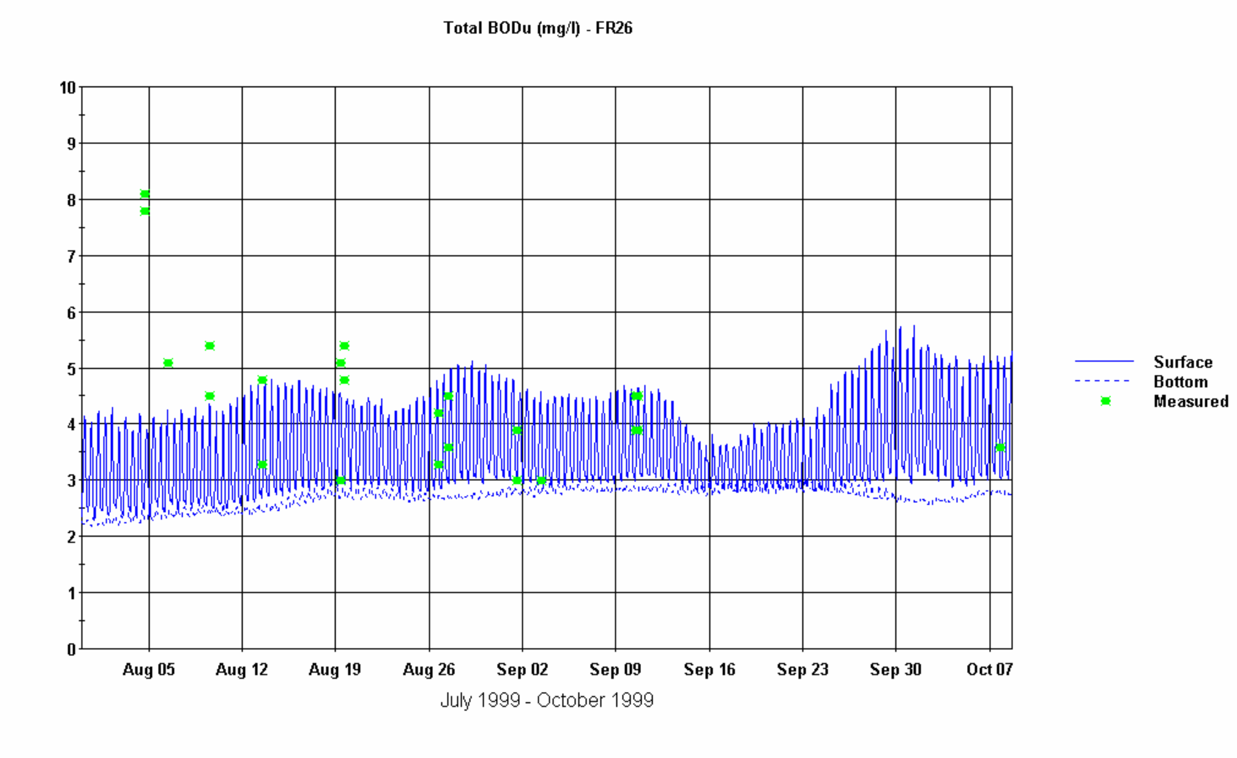


Figure O-1 CBODu Calibration at FR-26 for July 31 through October 13, 1999

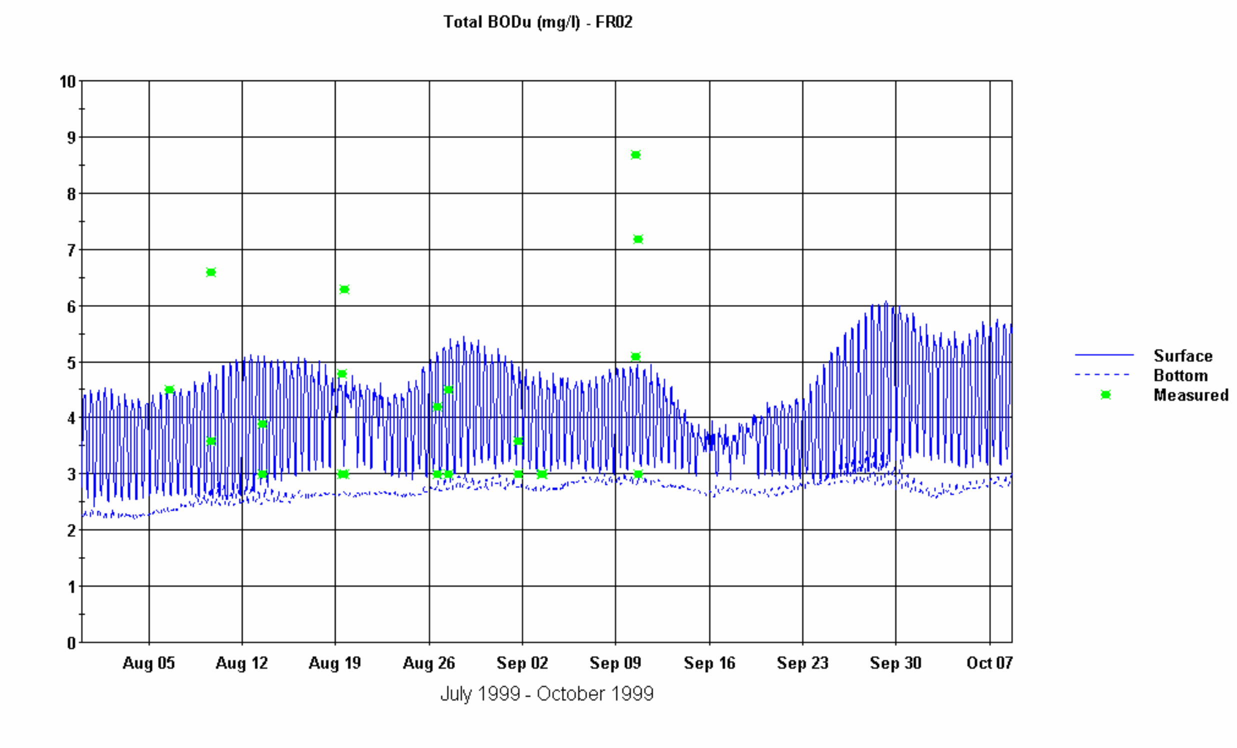


Figure O-2 CBODu Calibration at FR-02 for July 31 through October 13, 1999

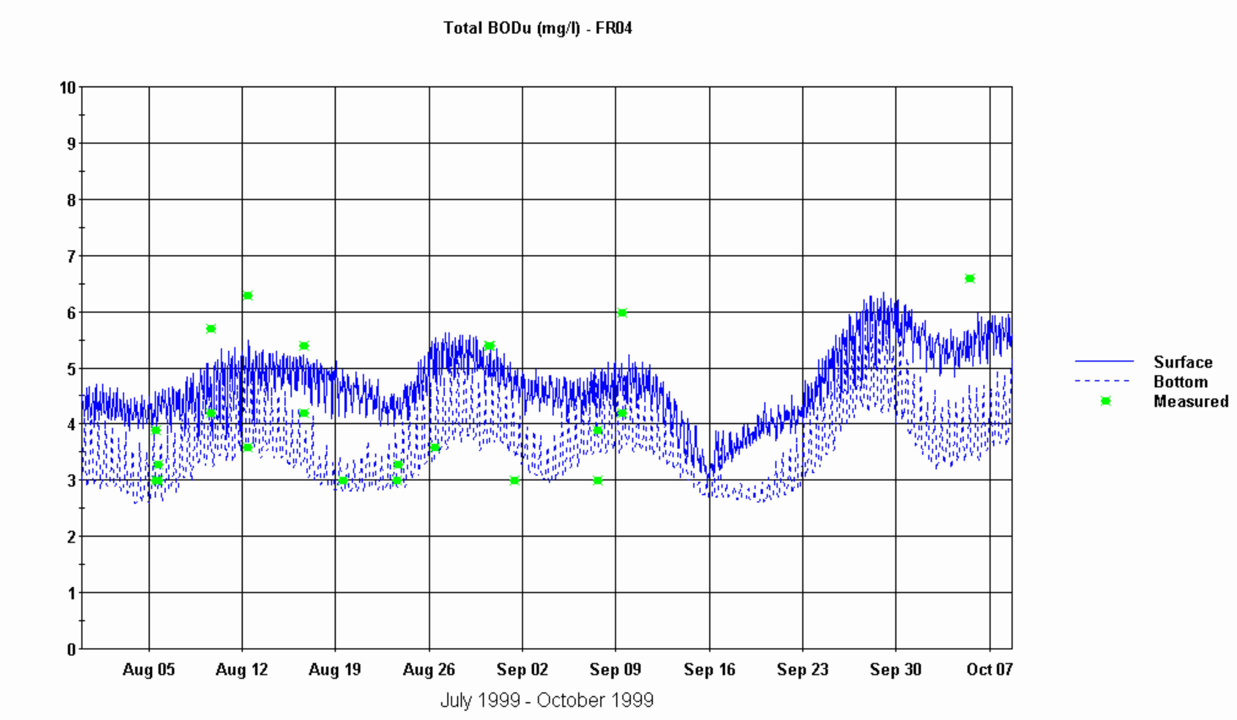


Figure O-3 CBODu Calibration at FR-04 for July 31 through October 13, 1999

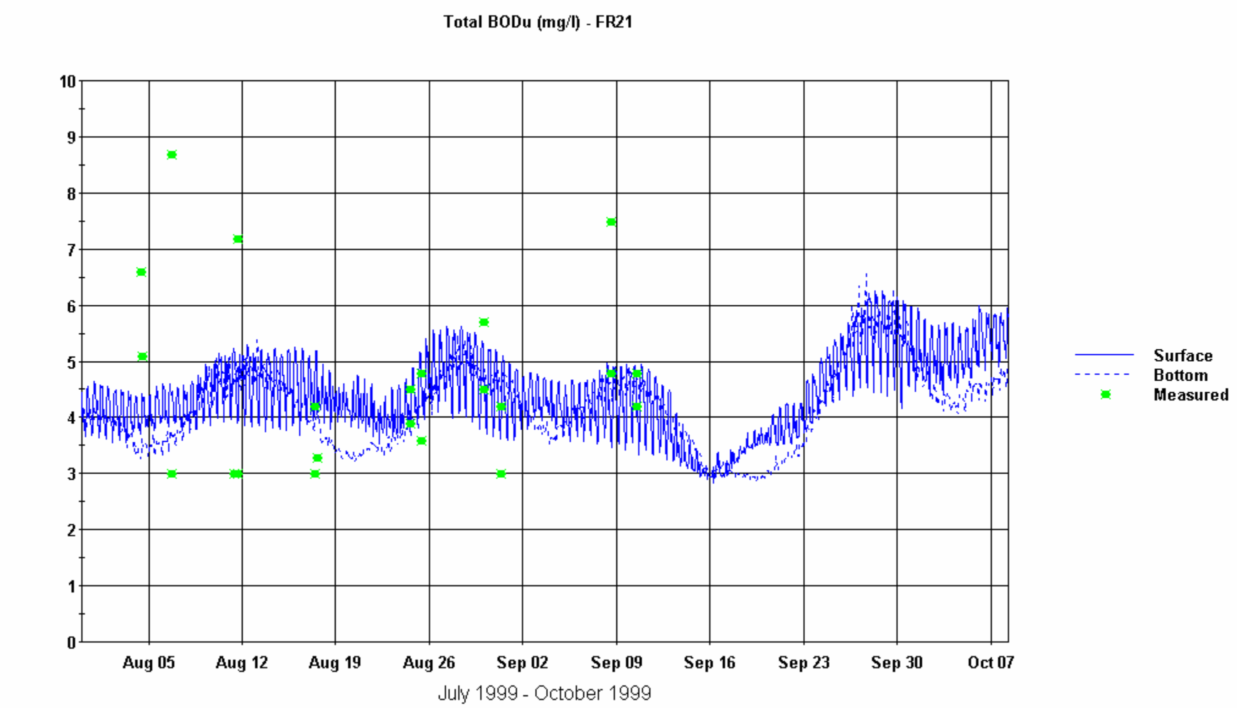


Figure O-4 CBODu Calibration at FR-21 for July 31 through October 13, 1999

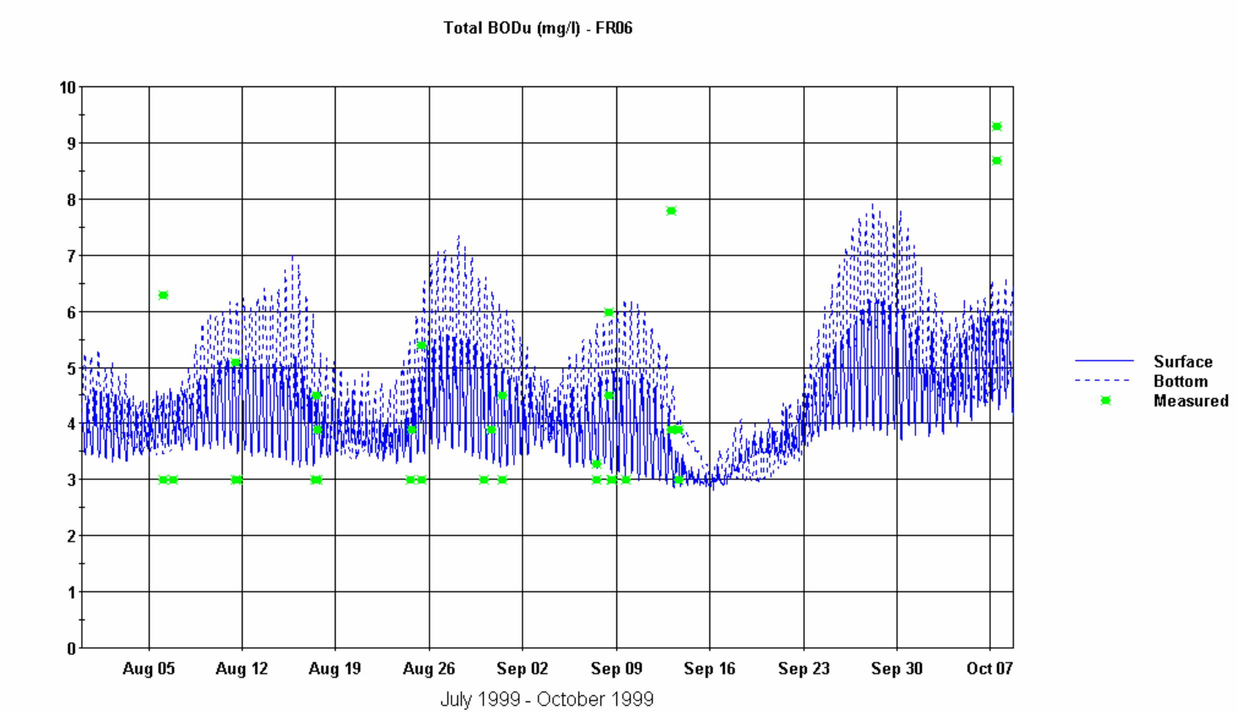


Figure O-5 CBODu Calibration at FR-06 for July 31 through October 13, 1999

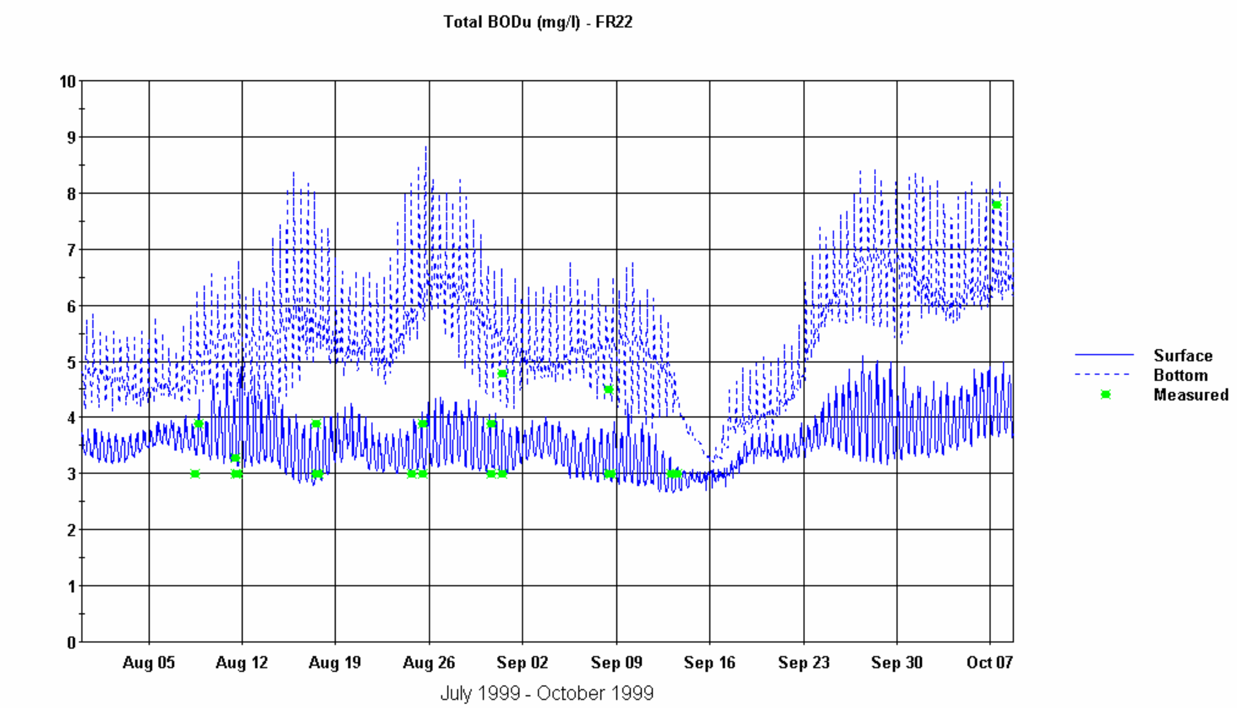


Figure O-6 CBODu Calibration at FR-22 for July 31 through October 13, 1999

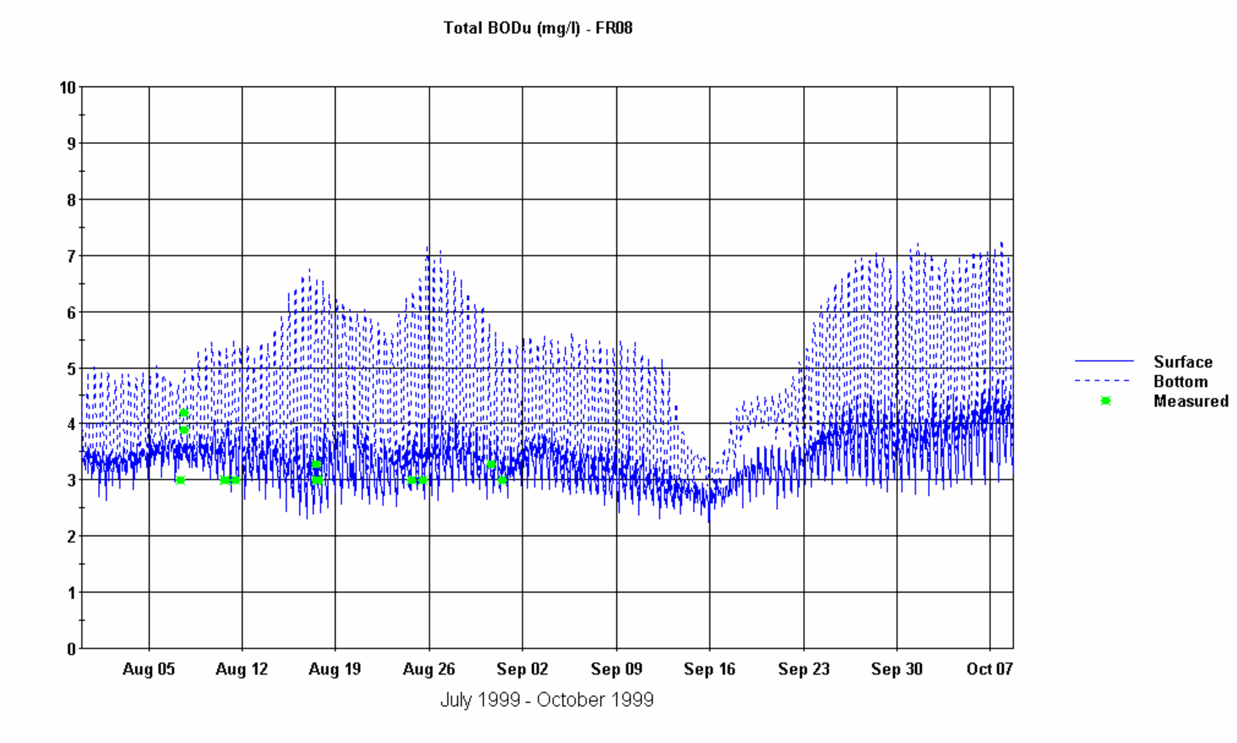


Figure O-7 CBODu Calibration at FR-08 for July 31 through October 13, 1999

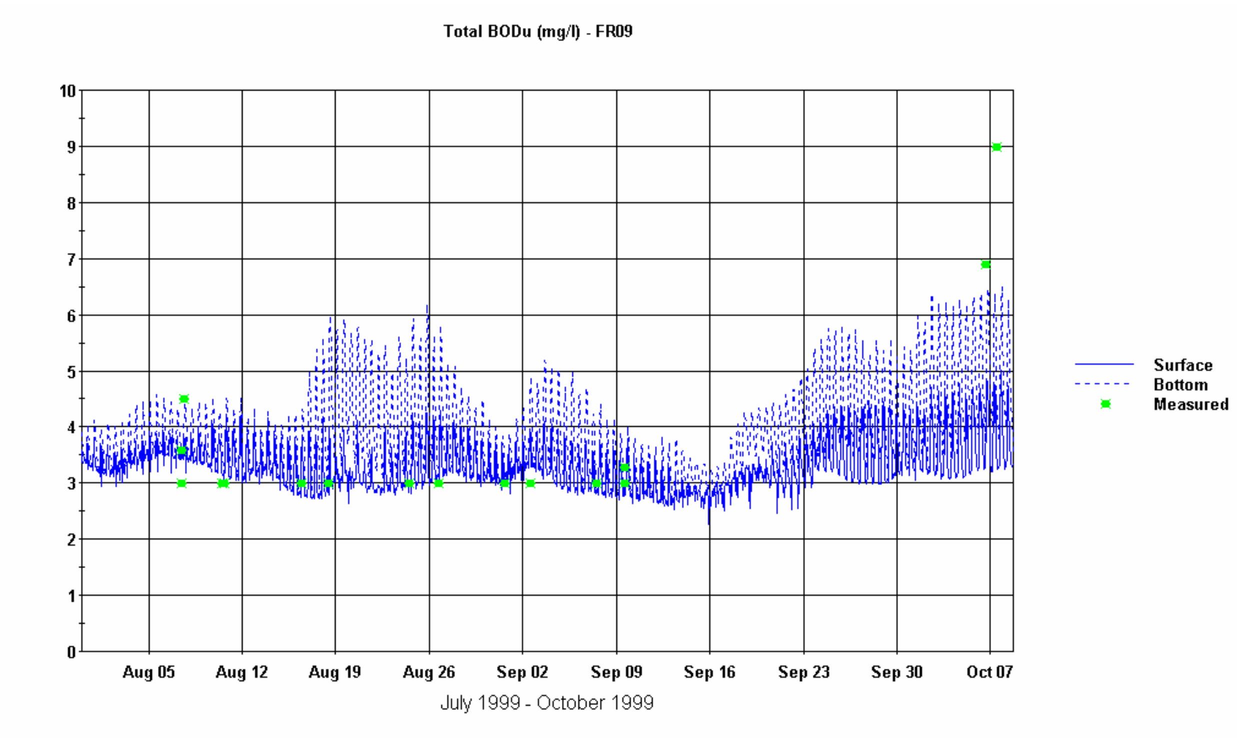


Figure O-8 CBODu Calibration at FR-09 for July 31 through October 13, 1999

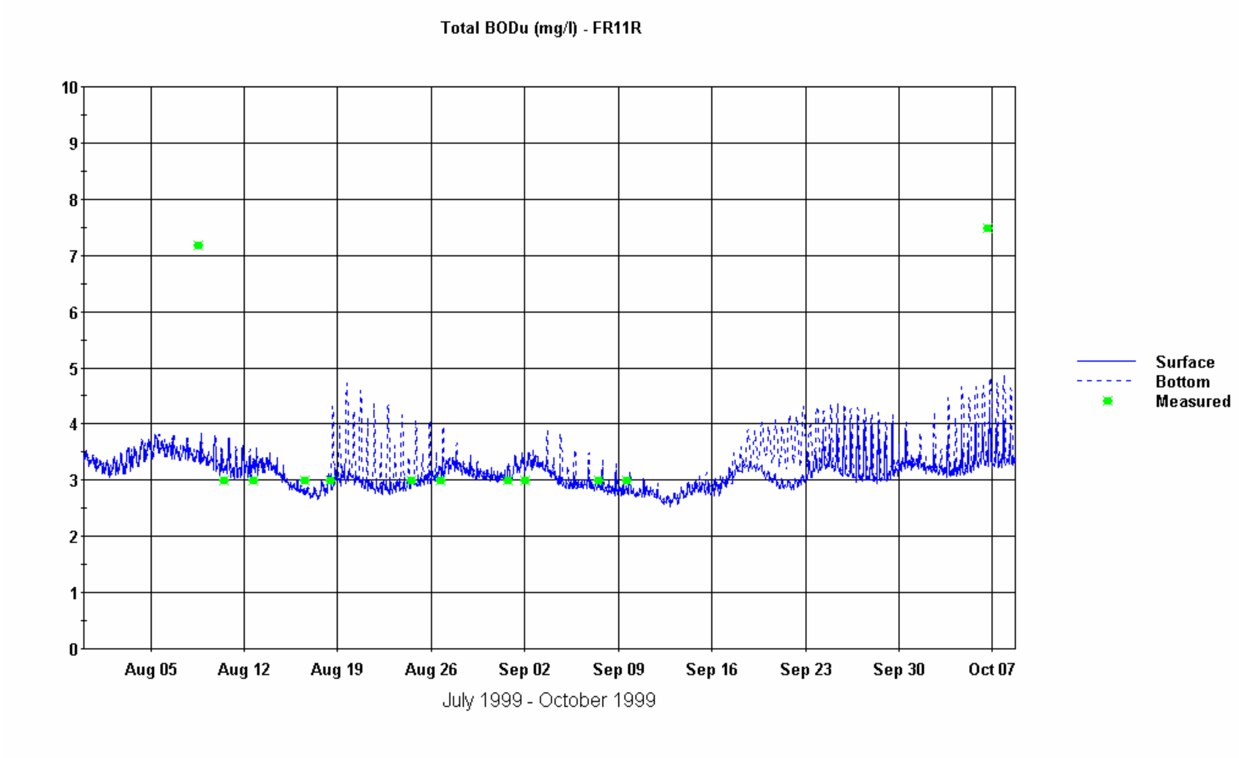


Figure O-9 CBODu Calibration at FR-11R for July 31 through October 13, 1999

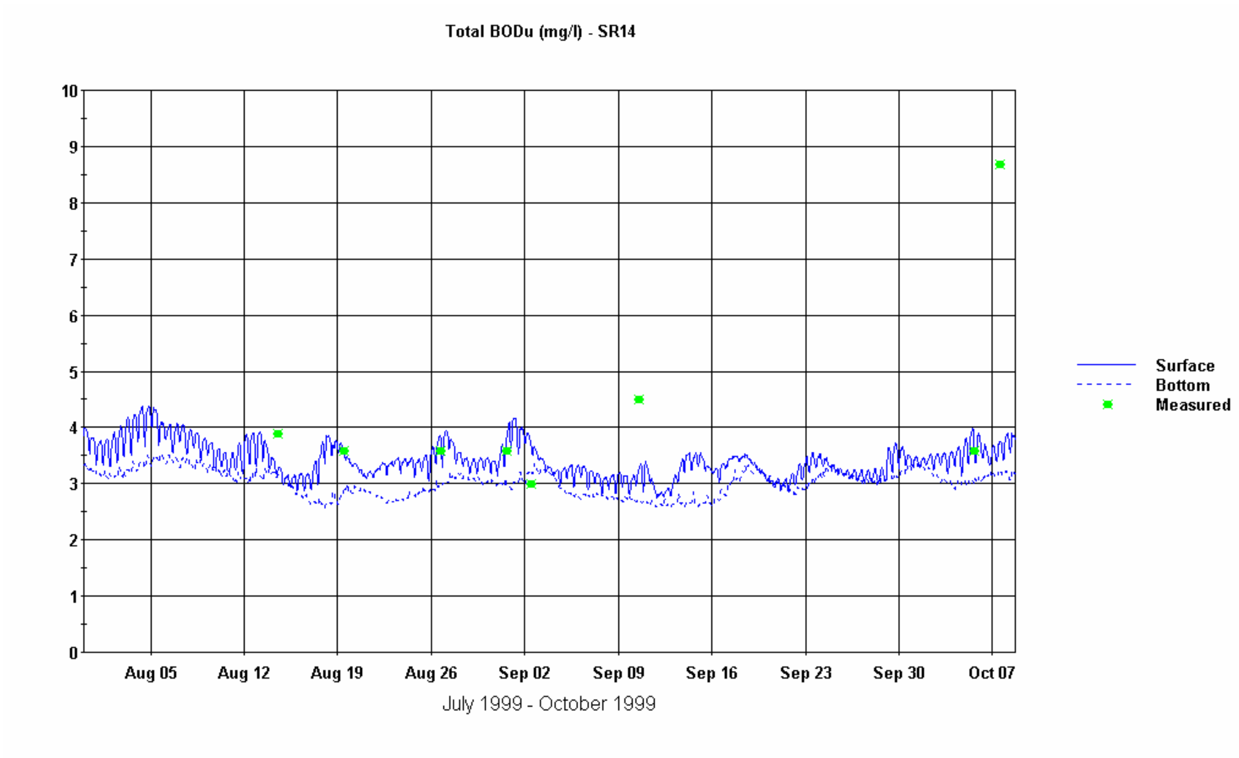


Figure O-10 CBODu Calibration at SR-14 for July 31 through October 13, 1999

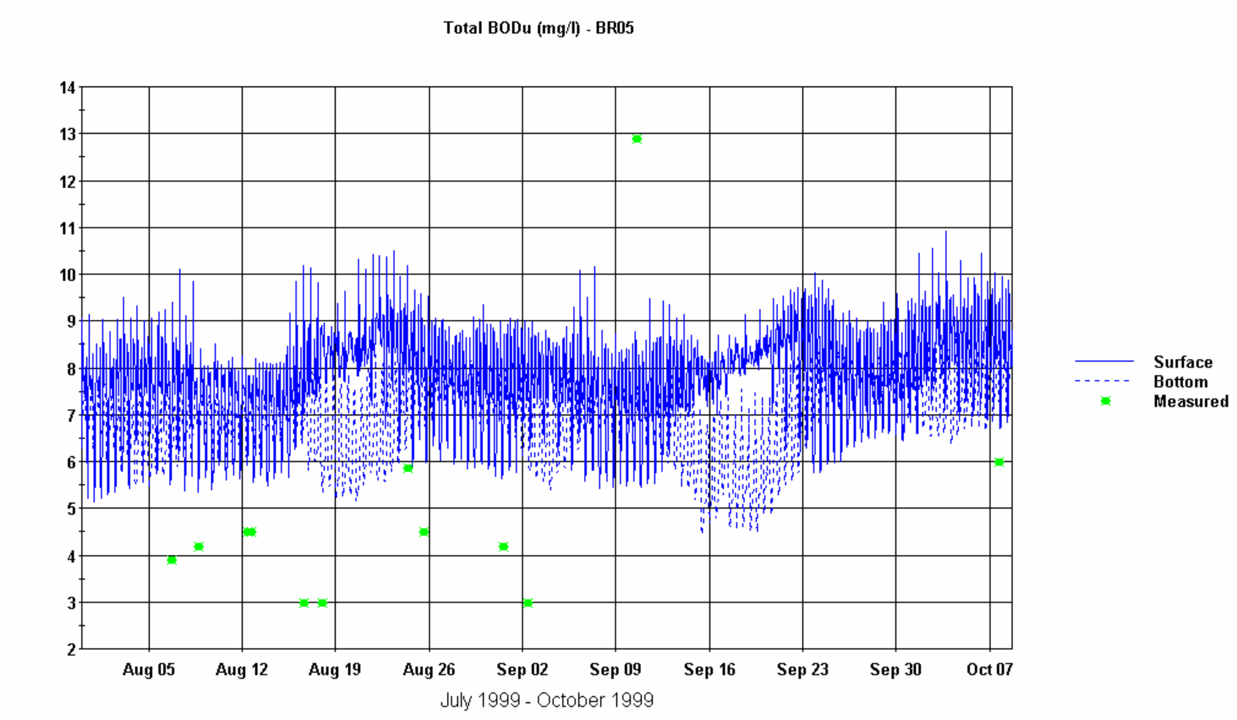


Figure O-11 CBODu Calibration at BR-05 for July 31 through October 13, 1999

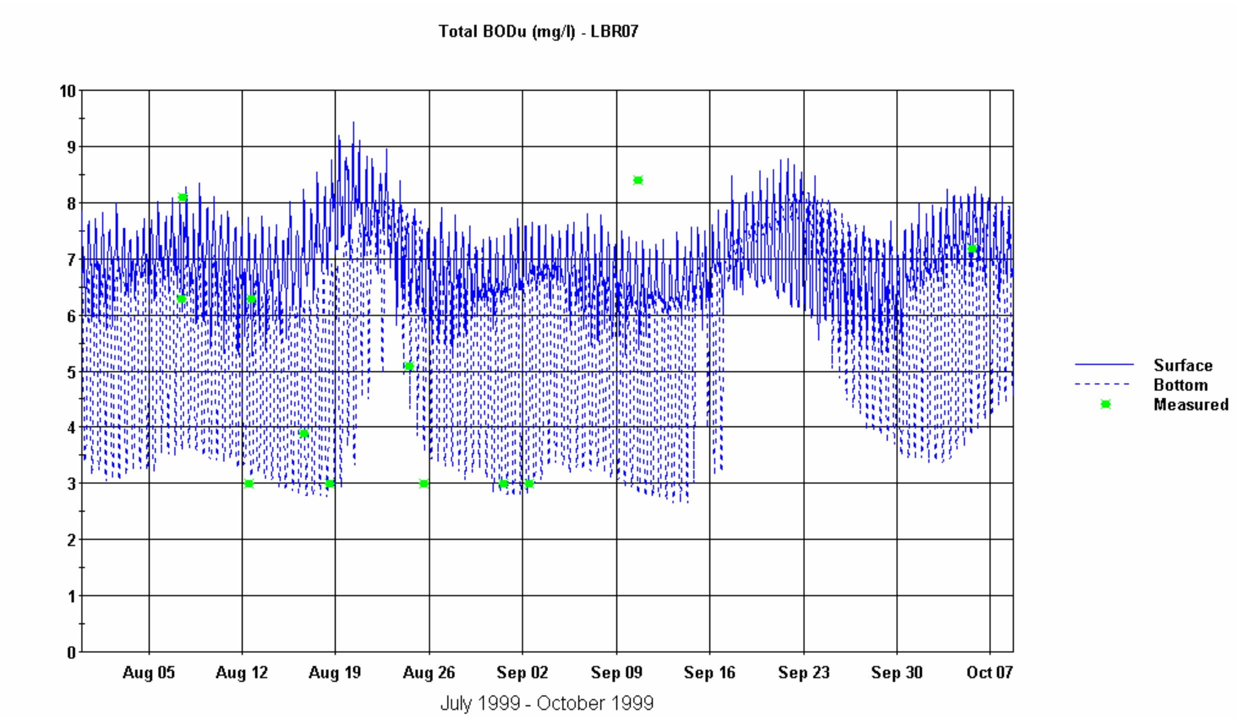


Figure O-12 CBODu Calibration at LBR-07 for July 31 through October 13, 1999

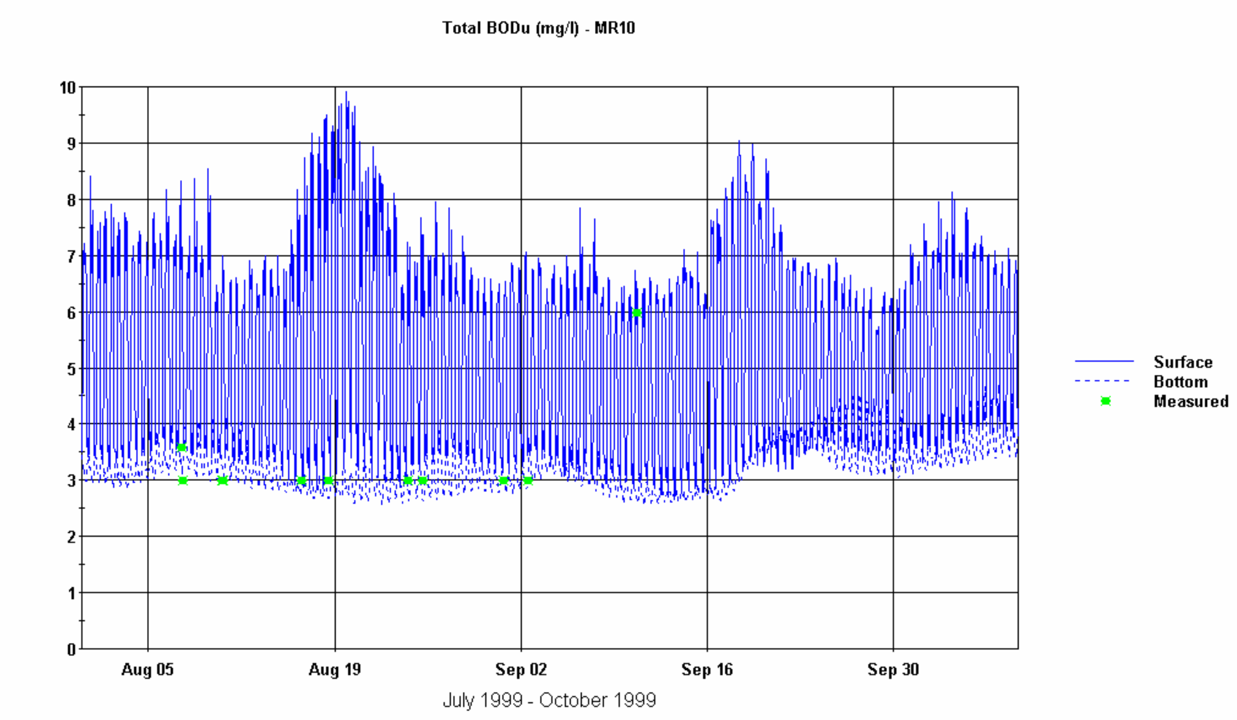


Figure O-13 CBODu Calibration at MR-10 for July 31 through October 13, 1999

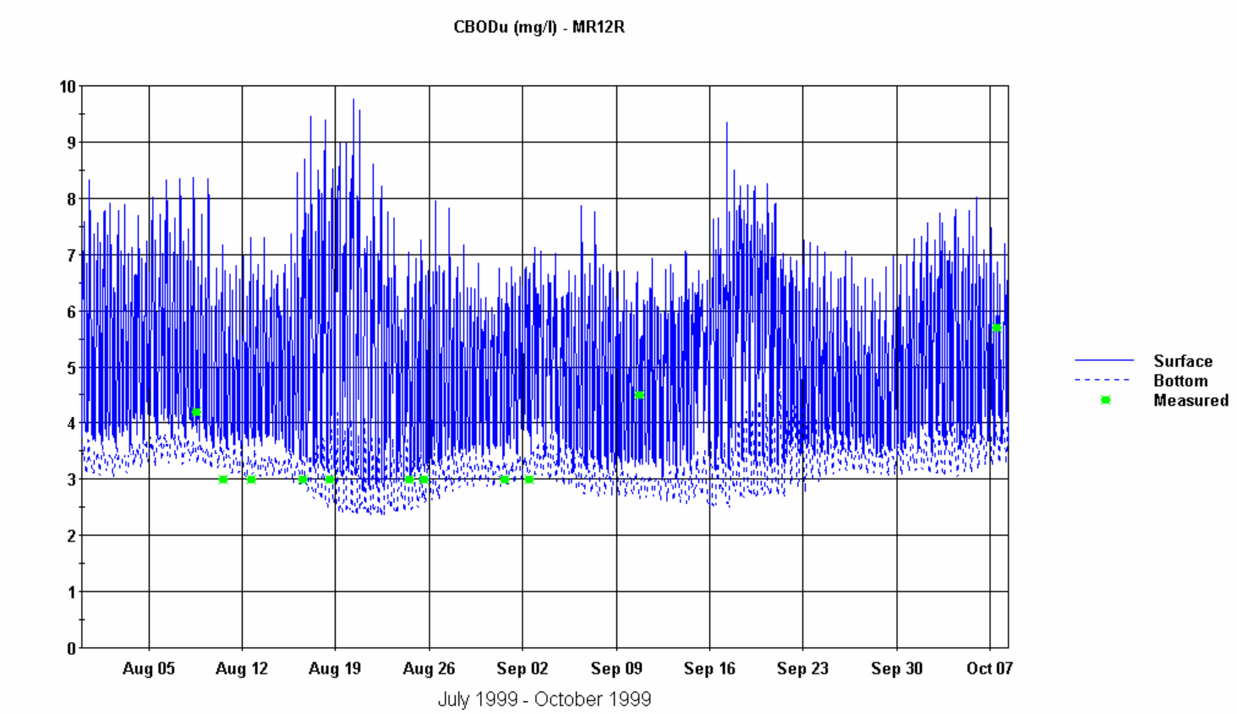


Figure O-14 CBODu Calibration at MR-12R for July 31 through October 13, 1999

APPENDIX P 1999 DISSOLVED OXYGEN: USGS CORRECTED DATA

Table P-1 Summary Percentiles for Dissolved Oxygen (mg/l) for July 31, 1999 through October 13, 1999

July 31 - October 13, 1999 [Julian Days 213-285]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S	3.4	5.2	6.8	4.1	4.8	5.2	0.7	-0.4	-1.6
FR-02	B	3.2	3.7	4.4	3.9	4.2	4.4	0.7	0.5	0.0
FR-04	S	3.5	4.3	5.3	3.6	4.2	4.9	0.1	-0.1	-0.4
FR-04	B	2.5	3.6	5.2	3.2	3.6	4.3	0.7	0.0	-0.9
FR-06	S	4.4	6.0	7.2	4.4	5.4	6.1	0.0	-0.6	-1.1
FR-06	B	2.2	3.6	3.9	3.0	3.7	4.0	0.8	0.1	0.1
FR-08	S	4.4	6.0	7.2	4.4	5.4	6.1	0.0	-0.6	-1.1
FR-08	B	2.7	4.0	6.5	3.1	3.8	4.7	0.4	-0.2	-1.8
FR-09	S	3.8	5.3	6.4	4.6	5.6	6.3	0.8	0.3	-0.1
FR-09	B	3.4	5.2	6.4	3.9	4.7	5.7	0.5	-0.5	-0.7
MR-10	S	4.5	5.5	6.3	5.5	6.2	6.7	1.0	0.7	0.4
FR-11R	B	4.8	6.3	6.9	4.9	5.8	6.4	0.1	-0.5	-0.5
SR-14	B	6.0	6.6	7.5	5.5	6.1	6.5	-0.5	-0.5	-1.0
SR-16	B	6.5	7.0	7.4	6.4	7.0	7.3	-0.2	0.0	-0.2
FR-21	S	3.1	4.4	5.0	3.9	4.8	5.4	0.8	0.4	0.4
FR-21	B	2.5	3.4	4.2	2.9	3.8	4.1	0.4	0.4	-0.1
FR-22	S	4.1	5.1	6.2	4.5	5.5	6.0	0.4	0.4	-0.2
FR-22	B	2.7	3.7	5.2	2.9	3.8	4.5	0.2	0.1	-0.7

* S = Surface
B = Bottom

Table P-2 Summary Statistics for Dissolved Oxygen (mg/l) for July 31, 1999 through October 13, 1999

July 31 - October 13, 1999 [Julian Days 213-285]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	8116	-0.40	1.08	1.33	5.12	1.29	4.72	0.40	0.05
FR-02	B	794	0.45	0.53	0.64	3.73	0.42	4.17	0.18	0.00
FR-04	S	9750	-0.06	0.68	0.90	4.29	0.91	4.24	0.51	0.10
FR-04	B	10643	-0.06	0.63	0.86	3.74	1.02	3.67	0.40	0.32
FR-06	S	11922	-0.54	0.99	1.22	5.85	1.12	5.32	0.61	0.10
FR-06	B	15018	0.23	0.33	0.46	3.33	0.65	3.56	0.38	0.67
FR-08	S	11922	-0.54	0.99	1.22	5.85	1.12	5.32	0.61	0.10
FR-08	B	4896	-0.46	0.99	1.34	4.36	1.52	3.89	0.61	0.36
FR-09	S	16868	0.36	0.78	0.93	5.17	0.95	5.53	0.61	0.22
FR-09	B	15358	-0.26	0.73	0.91	5.00	1.19	4.74	0.71	0.48
MR-10	S	15610	0.73	0.85	1.03	5.43	0.69	6.16	0.51	0.08
FR-11R	B	14761	-0.36	0.67	0.82	6.10	0.84	5.74	0.60	0.26
SR-14	B	12362	-0.63	0.80	1.02	6.71	0.55	6.07	0.42	0.12
FR-21	S	18534	0.50	0.65	0.87	4.22	0.75	4.73	0.57	0.21
FR-21	B	9451	0.17	0.37	0.51	3.42	0.74	3.59	0.47	0.61
FR-22	S	18948	0.22	0.57	0.70	5.14	0.85	5.36	0.55	0.39
FR-22	B	12379	-0.05	0.51	0.68	3.78	0.96	3.73	0.58	0.51

* S = Surface
B = Bottom

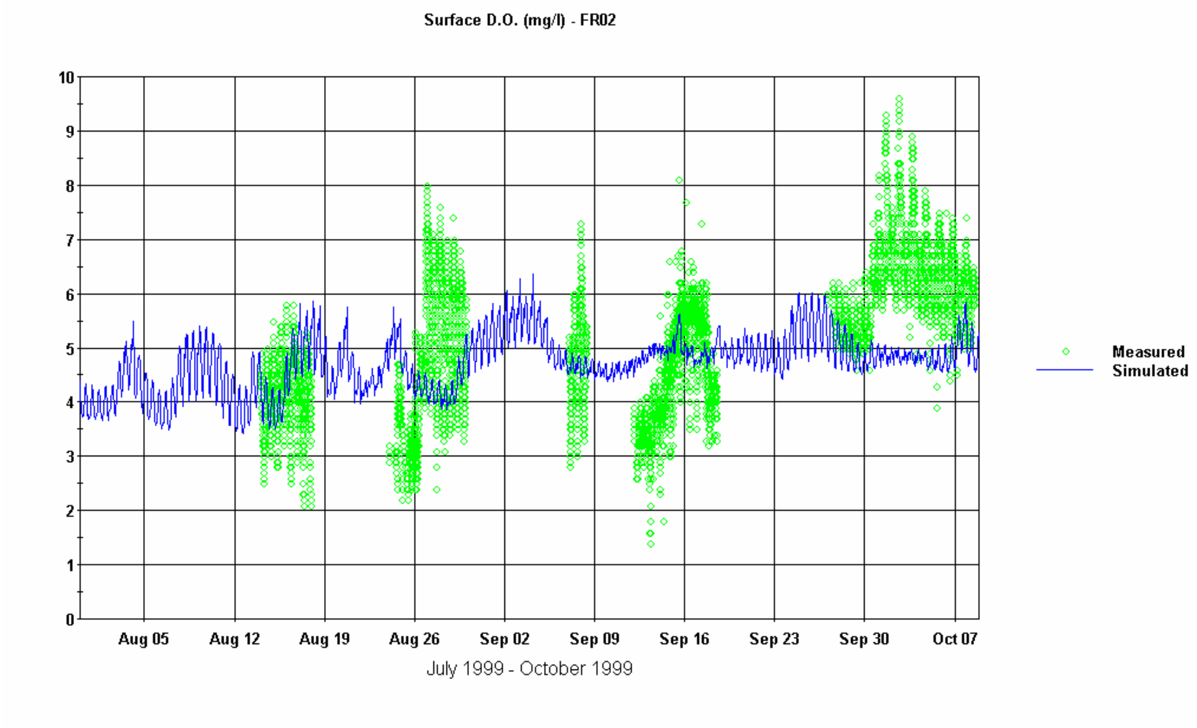


Figure P-1 Dissolved Oxygen Calibration at FR-02 (Surface) for July 31 through October 13, 1999

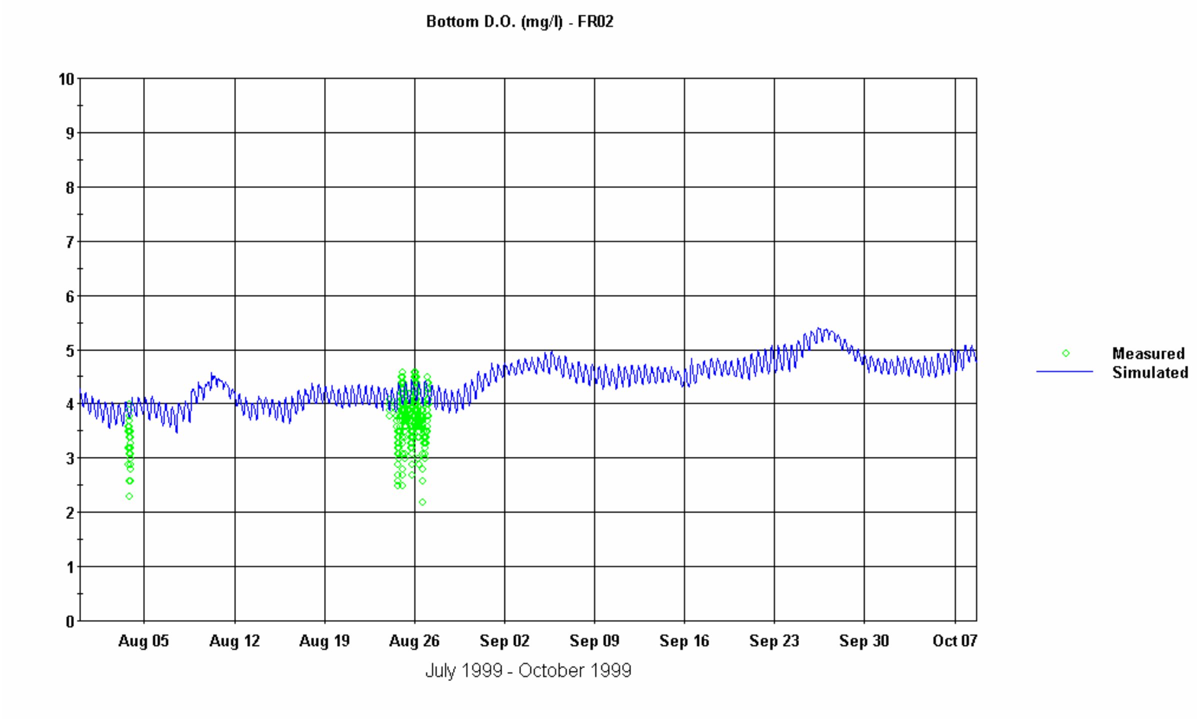


Figure P-2 Dissolved Oxygen Calibration at FR-02 (Bottom) for July 31 through October 13, 1999

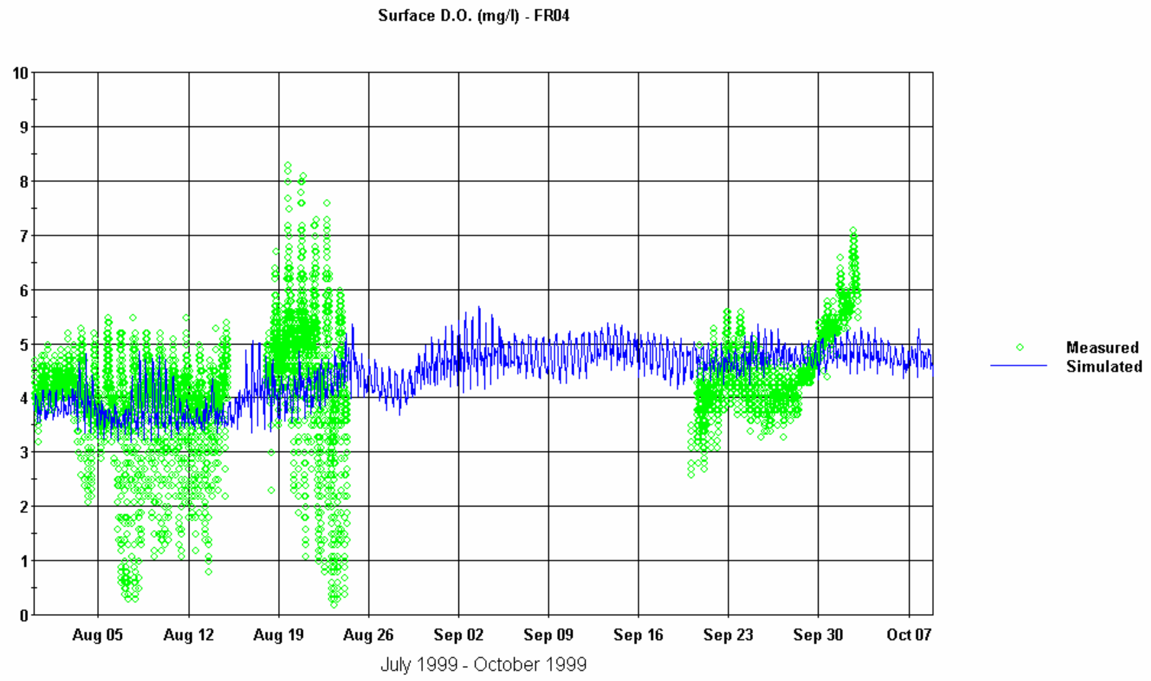


Figure P-3 Dissolved Oxygen Calibration at FR-04 (Surface) for July 31 through October 13, 1999

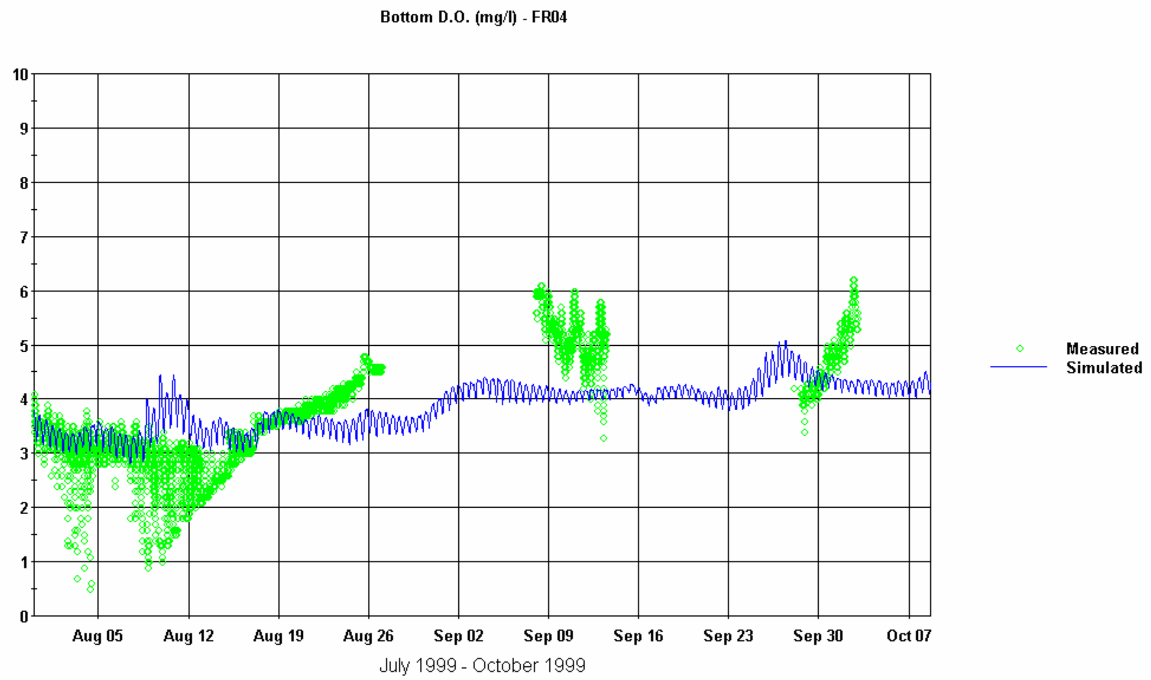


Figure P-4 Dissolved Oxygen Calibration at FR-04 (Bottom) for July 31 through October 13, 1999

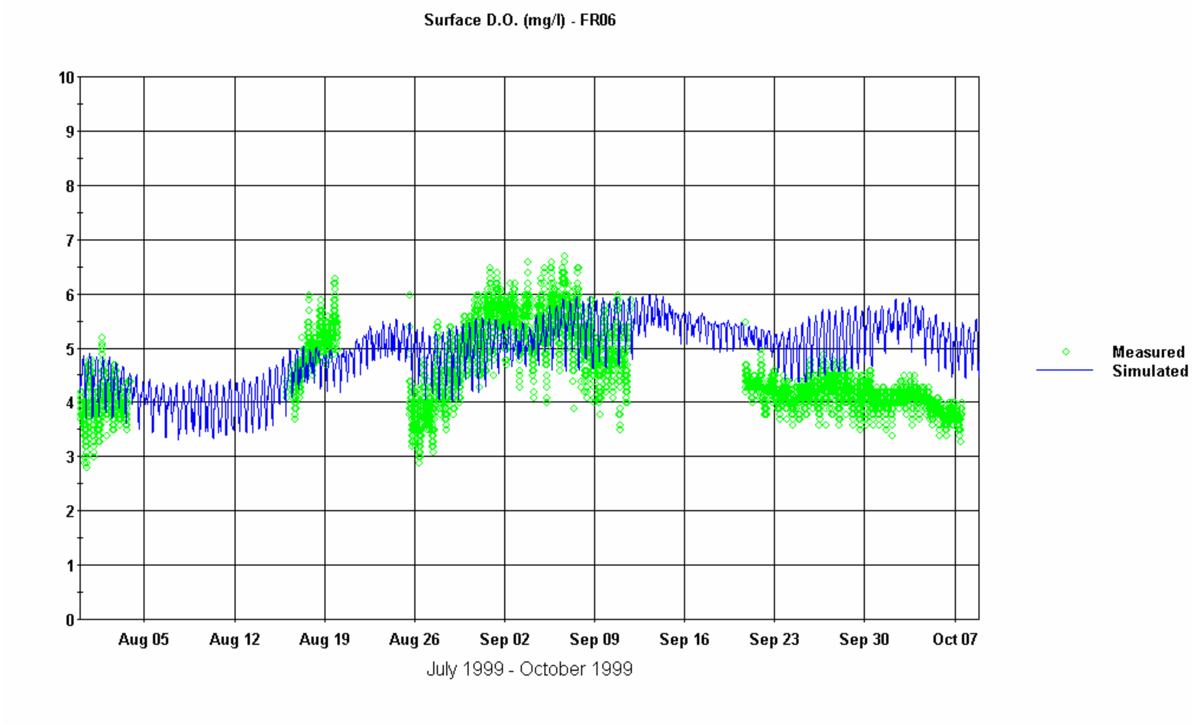


Figure P-5 Dissolved Oxygen Calibration at FR-06 (Surface) for July 31 through October 13, 1999

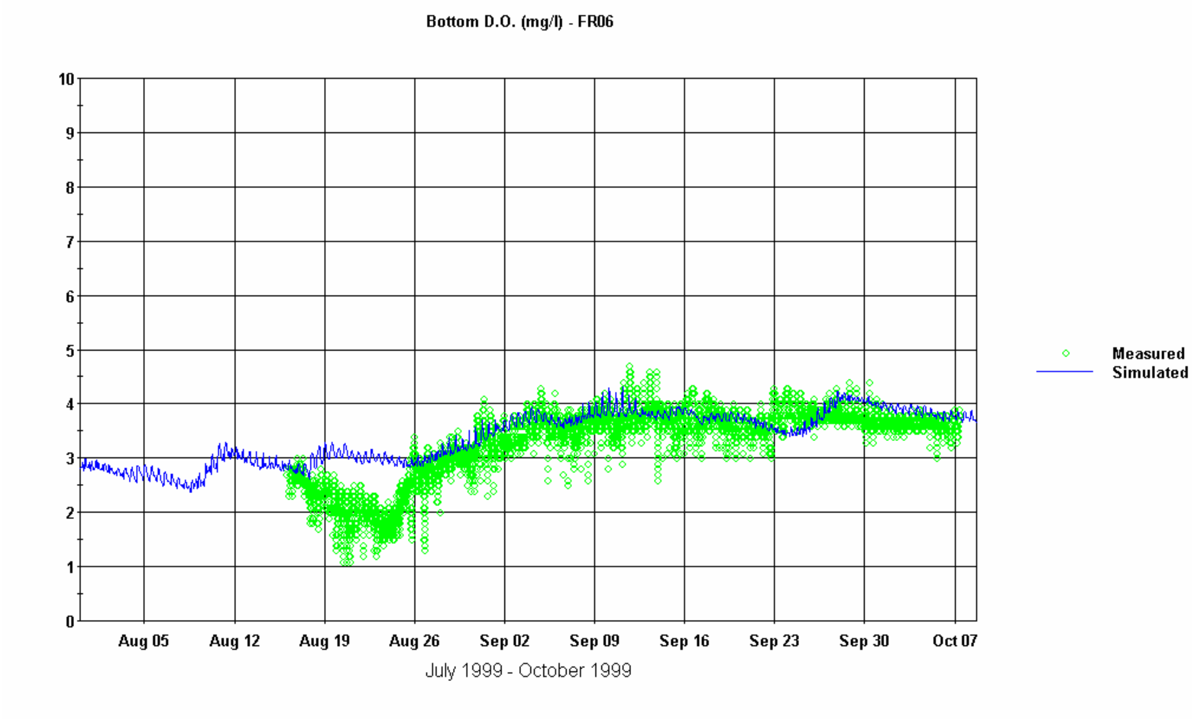


Figure P-6 Dissolved Oxygen Calibration at FR-06 (Bottom) for July 31 through October 13, 1999

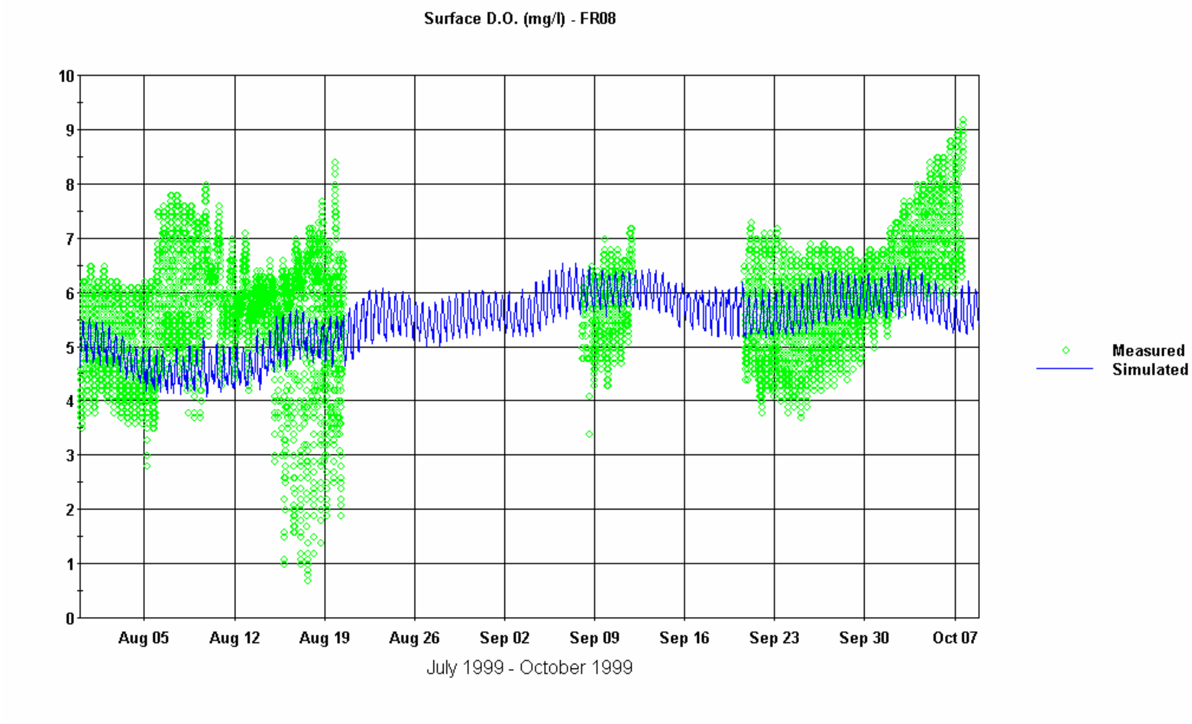


Figure P-7 Dissolved Oxygen Calibration at FR-08 (Surface) for July 31 through October 13, 1999

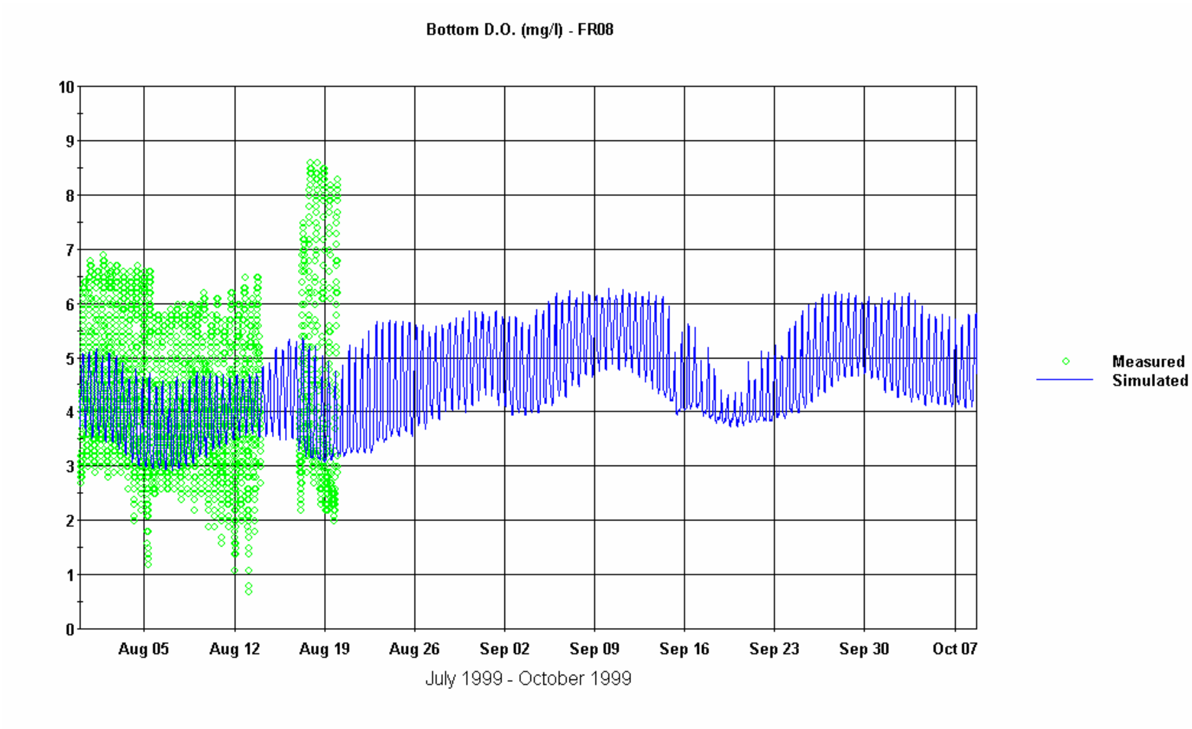


Figure P-8 Dissolved Oxygen Calibration at FR-08 (Bottom) for July 31 through October 13, 1999

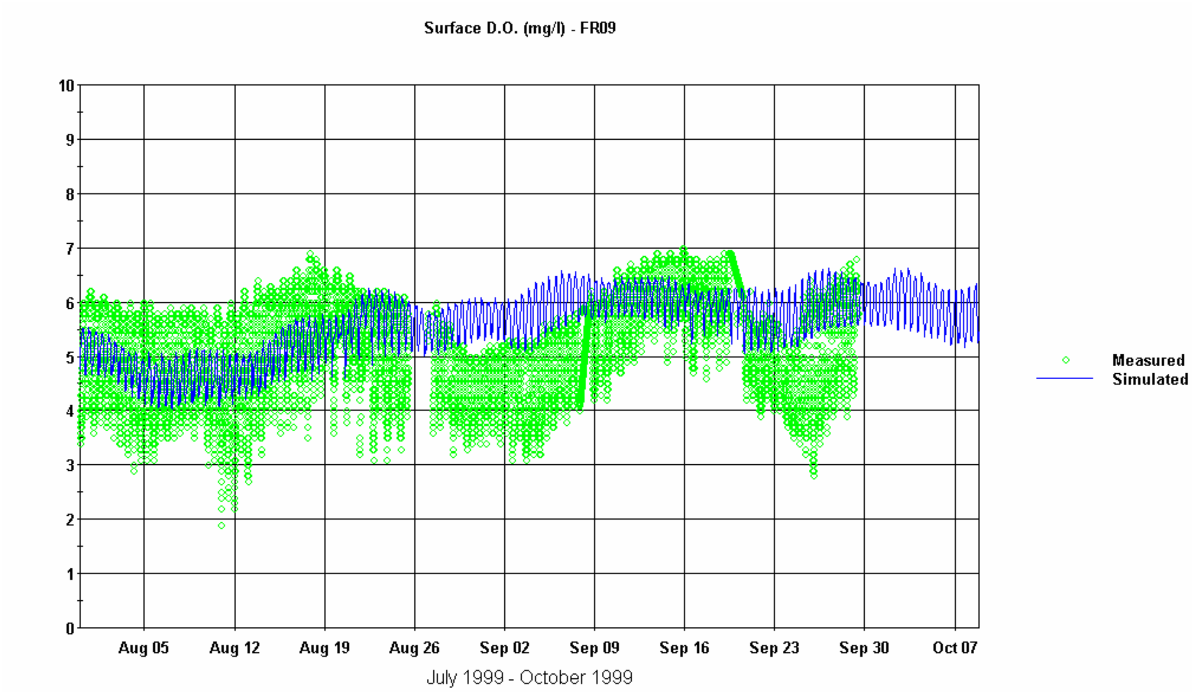


Figure P-9 Dissolved Oxygen Calibration at FR-09 (Surface) for July 31 through October 13, 1999

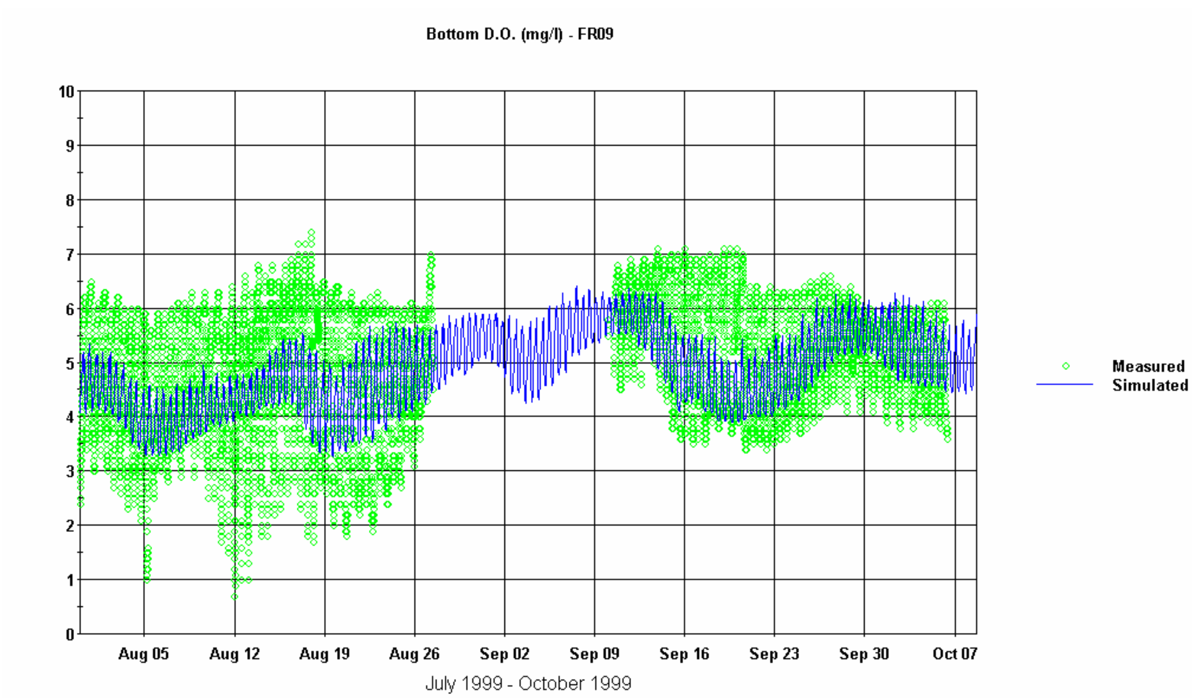


Figure P-10 Dissolved Oxygen Calibration at FR-09 (Bottom) for July 31 through October 13, 1999

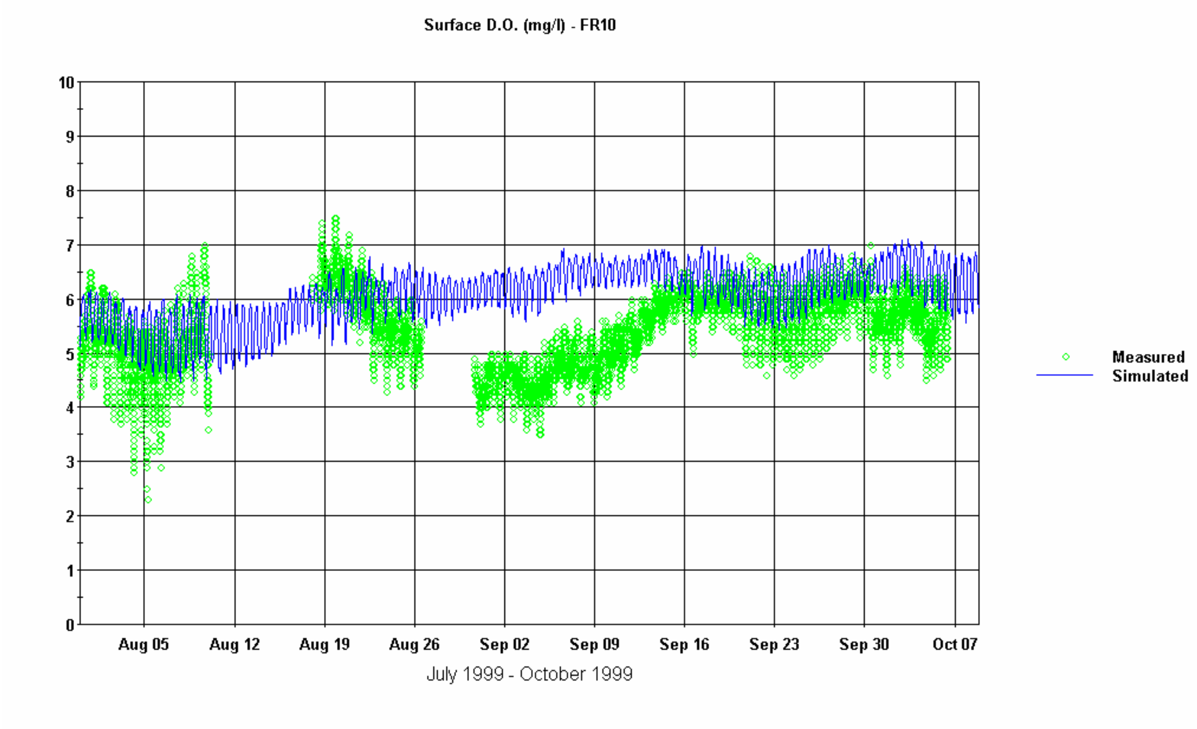


Figure P-11 Dissolved Oxygen Calibration at MR-10 (Surface) for July 31 through October 13, 1999

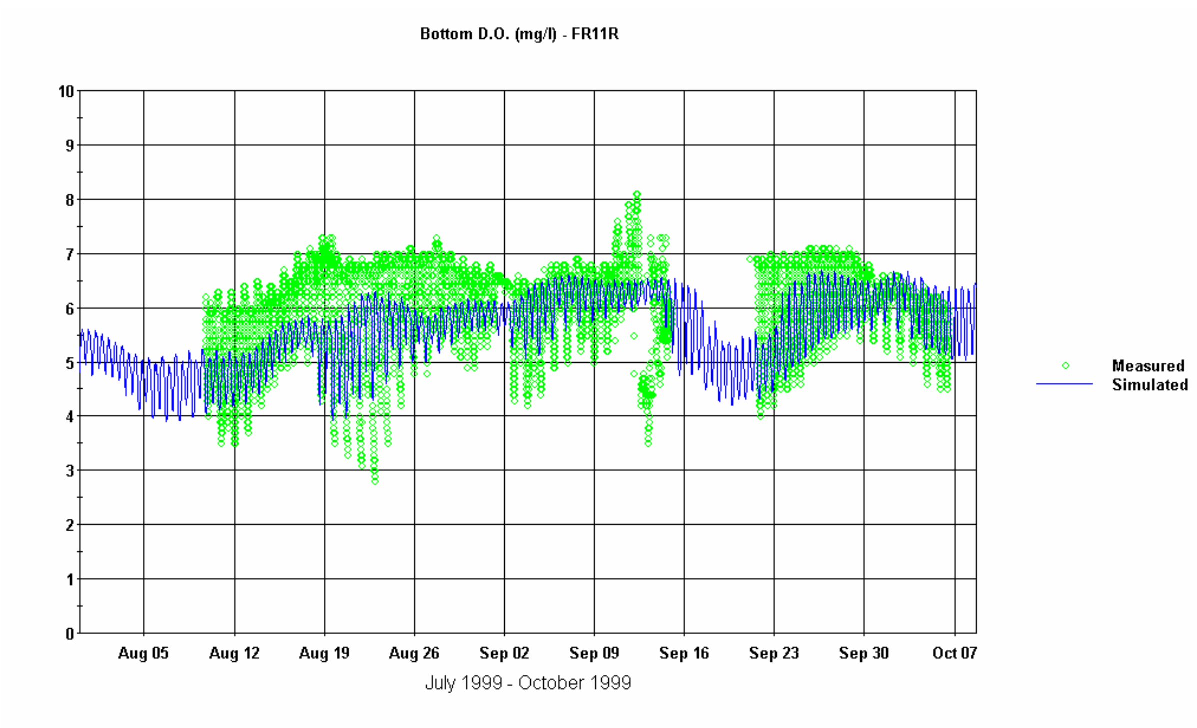


Figure P-12 Dissolved Oxygen Calibration at FR-11R (Bottom) for July 31 through October 13, 1999

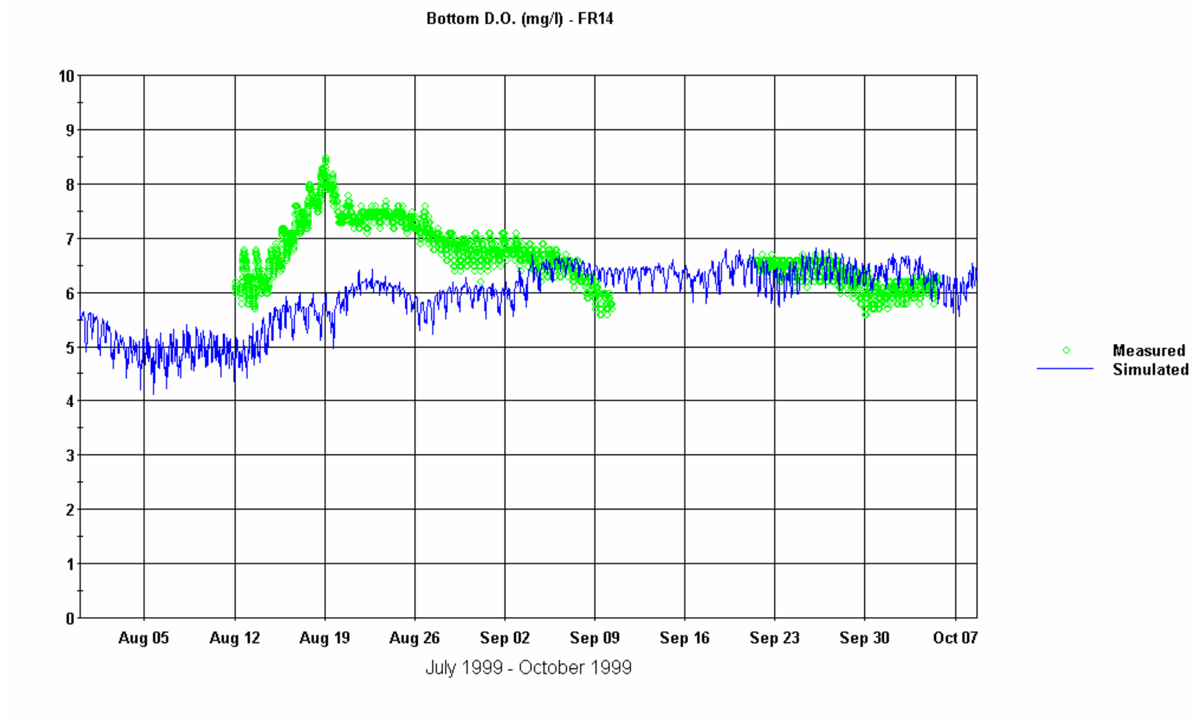


Figure P-13 Dissolved Oxygen Calibration at SR-14 (Bottom) for July 31 through October 13, 1999

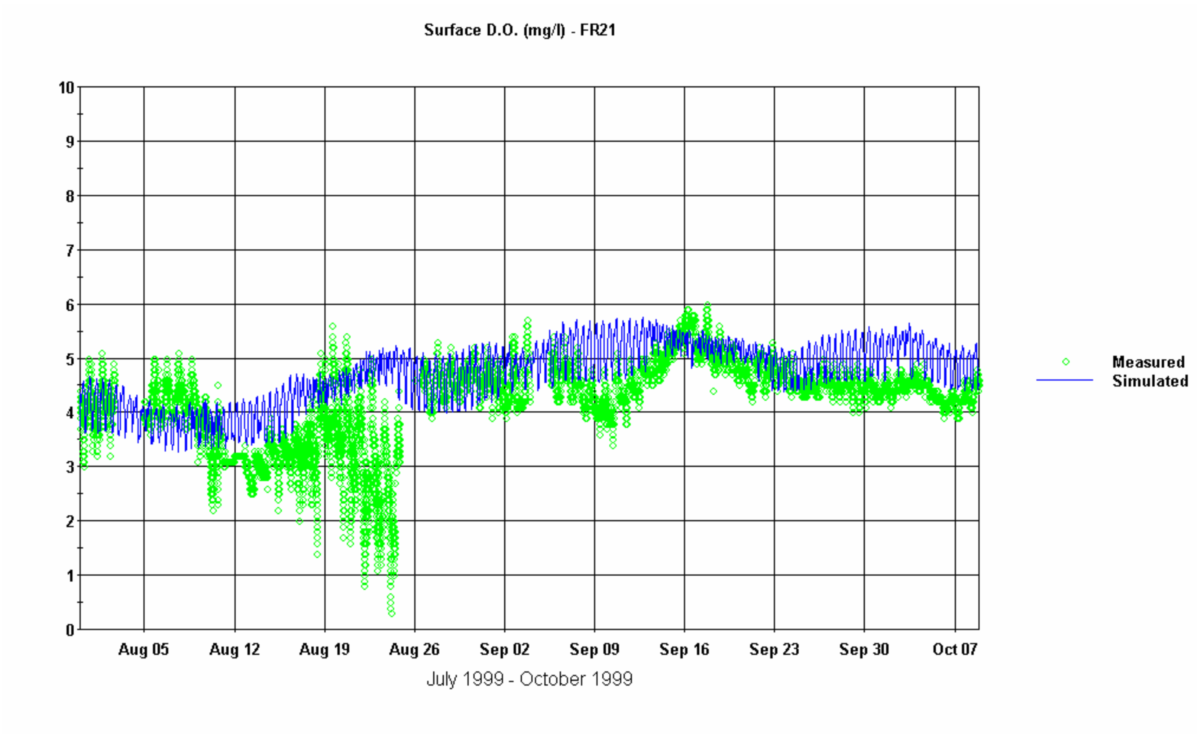


Figure P-14 Dissolved Oxygen Calibration at FR-21 (Surface) for July 31 through October 13, 1999

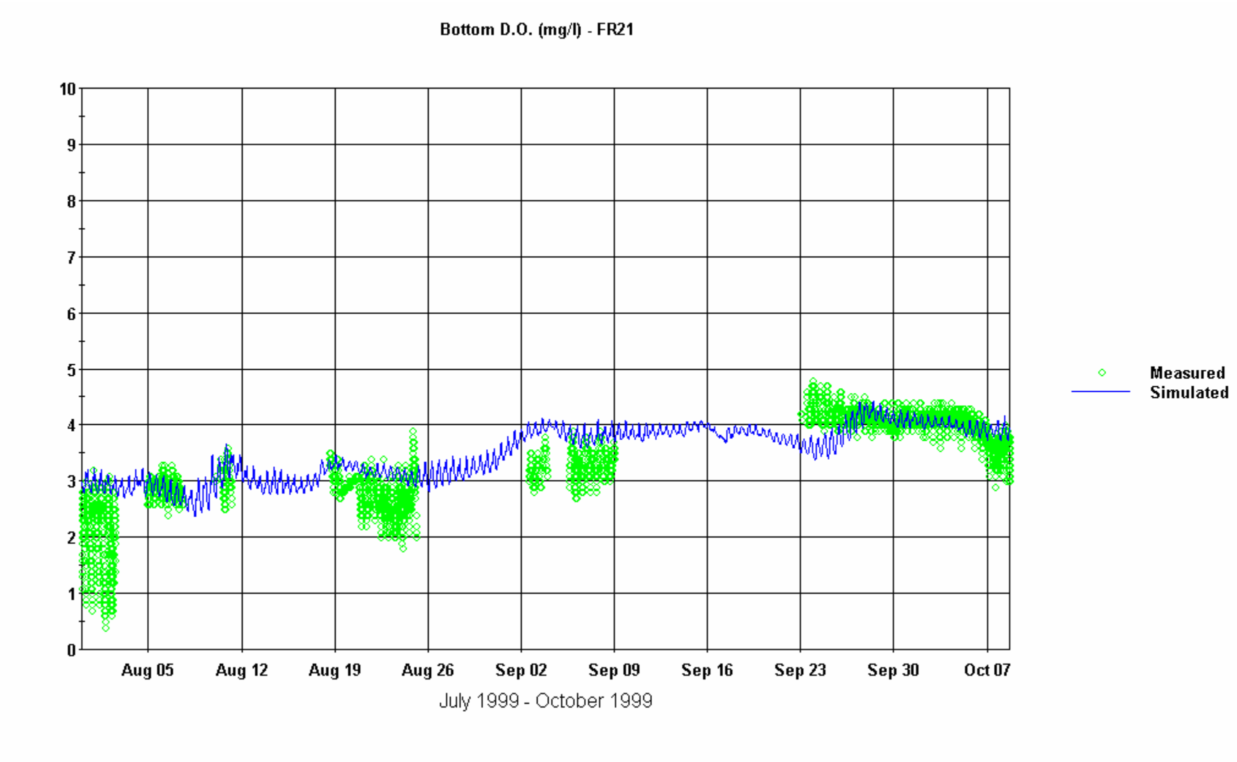


Figure P-15 Dissolved Oxygen Calibration at FR-21 (Bottom) for July 31 through October 13, 1999

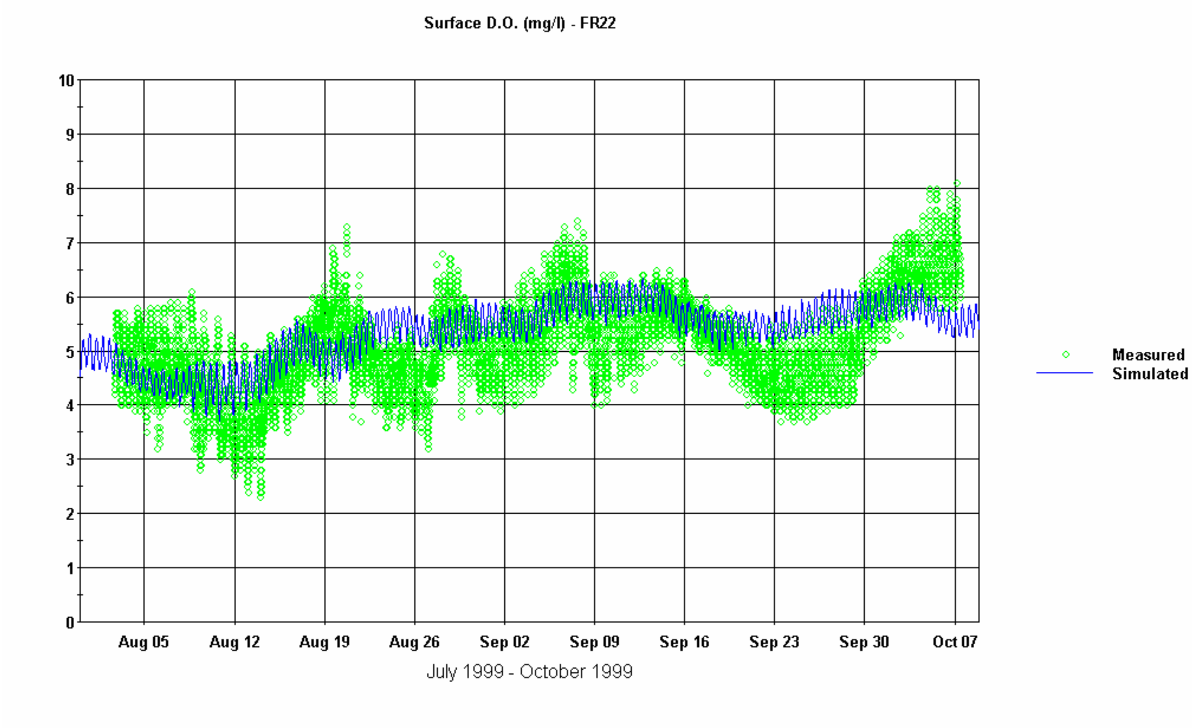


Figure P-16 Dissolved Oxygen Calibration at FR-22 (Surface) for July 31 through October 13, 1999

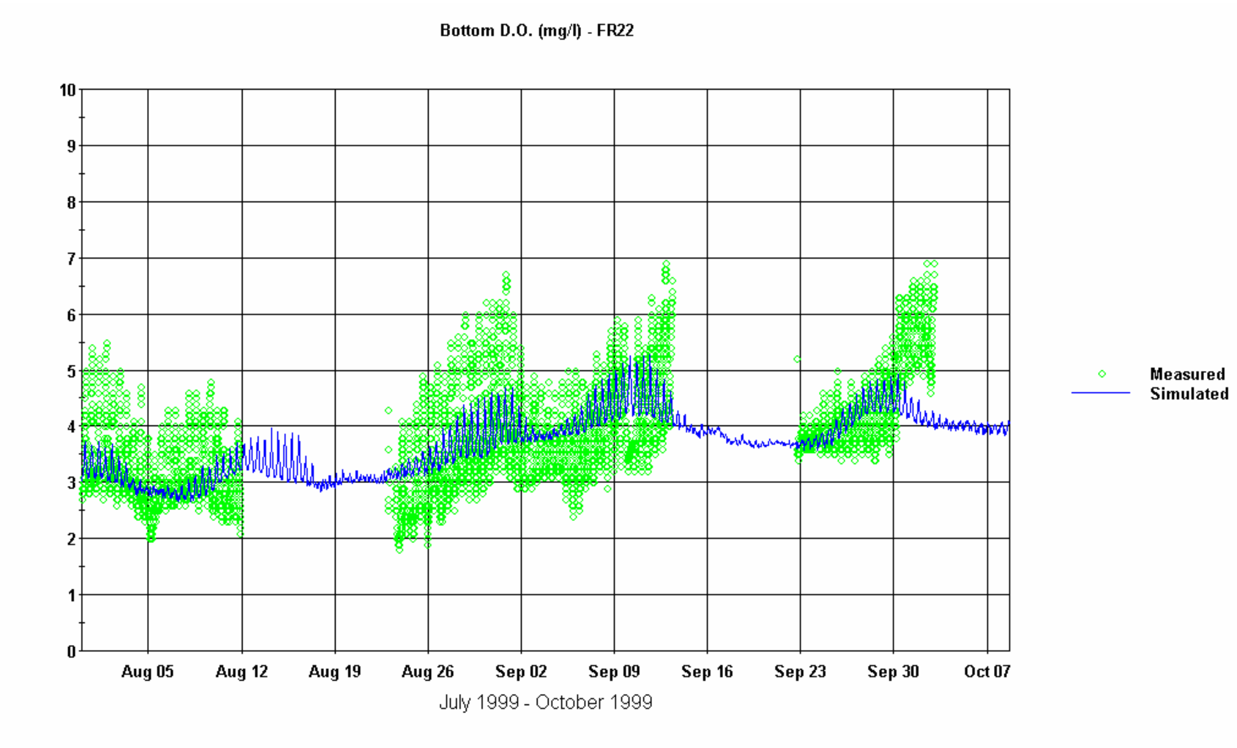


Figure P-17 Dissolved Oxygen Calibration at FR-22 (Bottom) for July 31 through October 13, 1999

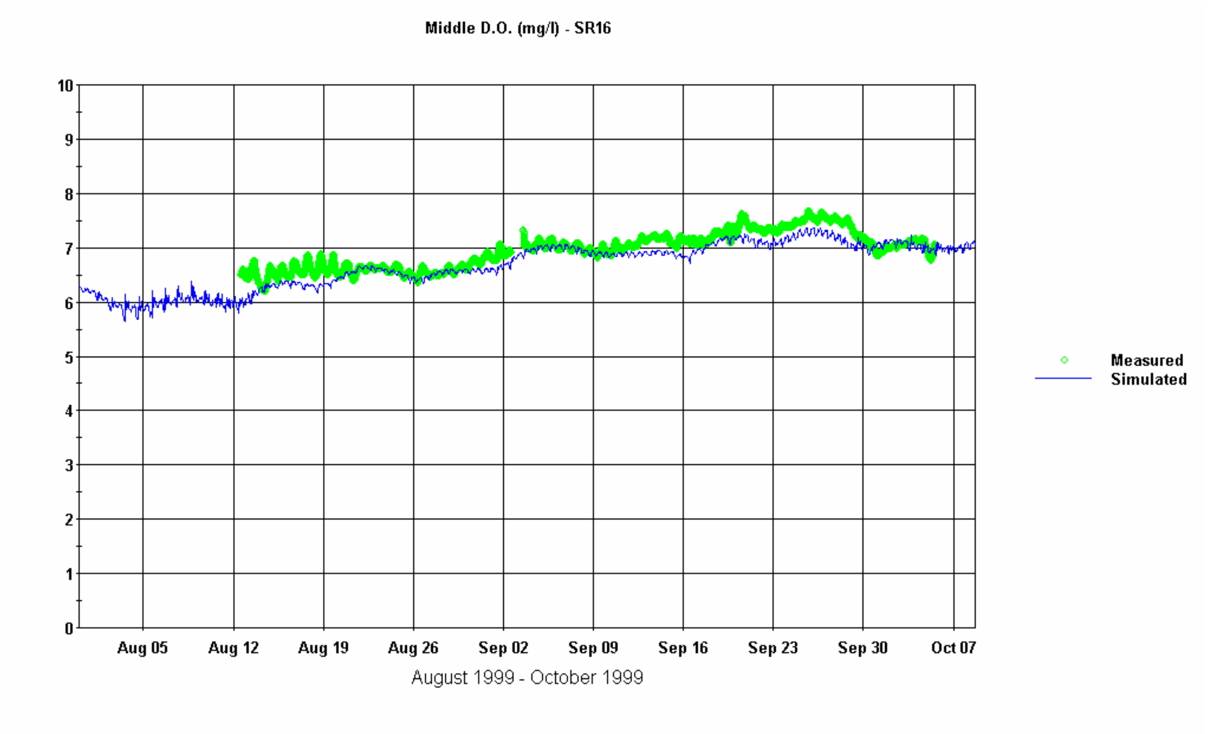


Figure P-18 Dissolved Oxygen Calibration at SR-16 (Mid-Depth) for July 31 through October 13, 1999

Table P-3 Summary Percentiles for Dissolved Oxygen (mg/l) for July 31, 1999 through August 15, 1999

July 31 - August 15, 1999 [Julian Days 213-226]										
Stations	**Depth***	**Measured**			**Simulated**			**Difference**		
		10% (mg/L)	**50% (mg/L)**	**90% (mg/L)**	**10% (mg/L)**	**50% (mg/L)**	**90% (mg/L)**	**10% (mg/L)**	**50% (mg/L)**	**90% (mg/L)**
FR-02	S	3.1	3.8	4.5	3.6	3.9	4.5	0.5	0.1	0.0
FR-02	B									
FR-04	S	3.1	4.1	4.6	3.5	3.7	4.2	0.4	-0.4	-0.4
FR-04	B	2.1	3.0	3.4	3.1	3.4	3.8	1.0	0.4	0.4
FR-06	S	3.6	4.0	4.4	3.9	4.4	4.8	0.3	0.4	0.4
FR-06	B									
FR-08	S	4.3	5.8	7.0	4.3	4.7	5.1	0.1	-1.1	-1.9
FR-08	B	2.8	4.0	6.3	3.1	3.8	4.7	0.3	-0.2	-1.6
FR-09	S	3.6	4.7	6.0	4.3	4.8	5.2	0.7	0.1	-0.8
FR-09	B	3.1	4.5	6.0	3.6	4.2	4.8	0.5	-0.3	-1.2
MR-10	S	4.3	5.1	6.0	4.8	5.6	6.0	0.5	0.5	0.0
FR-11R	B	4.1	5.7	6.2	4.3	4.9	5.2	0.2	-0.8	-1.0
SR-14	B									
SR-16	B	6.5	7.0	7.4	6.4	7.0	7.3	-0.2	0.0	-0.2
FR-21	S	3.0	3.9	4.5	3.5	3.9	4.3	0.5	0.0	-0.2
FR-21	B	1.5	2.7	3.1	2.7	2.9	3.2	1.2	0.2	0.1
FR-22	S	3.4	4.4	5.3	4.1	4.5	4.8	0.7	0.1	-0.5
FR-22	B	2.5	3.0	4.0	2.8	3.0	3.4	0.3	0.0	-0.6

* S = Surface
B = Bottom

Table P-4 Summary Statistics for Dissolved Oxygen (mg/l) for July 31, 1999 through August 15, 1999

July 31 - August 15, 1999 [Julian Days 213-226]										
Station	**Depth**	**N**	**ME**	**AME**	**RMS**	**Mean Obs**	**StDev Obs**	**Mean Pred**	**StDev Pred**	**R^2**
FR-02	S	254	0.16	0.38	0.45	3.81	0.52	3.97	0.35	0.34
FR-02	B									
FR-04	S	4286	-0.14	0.55	0.76	3.93	0.76	3.80	0.28	0.05
FR-04	B	4234	0.58	0.64	0.95	2.86	0.58	3.43	0.29	0.20
FR-06	S	1100	0.36	0.40	0.47	4.04	0.35	4.39	0.31	0.30
FR-06	B									
FR-08	S	4286	-0.97	1.15	1.38	5.65	0.99	4.68	0.31	0.03
FR-08	B	4032	-0.40	0.89	1.14	4.30	1.31	3.90	0.58	0.36
FR-09	S	4286	-0.03	0.72	0.80	4.79	0.95	4.76	0.36	0.33
FR-09	B	4234	-0.34	0.82	1.00	4.56	1.17	4.21	0.45	0.42
MR-10	S	2880	0.33	0.53	0.64	5.13	0.64	5.46	0.45	0.29
FR-11R	B	1430	-0.55	0.77	0.88	5.33	0.83	4.77	0.35	0.34
SR-14	B									
FR-21	S	3654	0.17	0.53	0.65	3.74	0.58	3.90	0.31	0.01
FR-21	B	1768	0.38	0.48	0.72	2.56	0.62	2.94	0.20	0.05
FR-22	S	3525	0.09	0.50	0.63	4.37	0.71	4.46	0.28	0.24
FR-22	B	3422	-0.11	0.38	0.51	3.15	0.60	3.03	0.24	0.36

* S = Surface
B = Bottom

Table P-5 Summary Percentiles for Dissolved Oxygen (mg/l) for August 15, 1999 through August 30, 1999

August 16 - August 30, 1999 [Julian Days 227-241]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S	3.0	4.3	6.3	4.0	4.3	5.2	1.0	0.0	-1.1
FR-02	B	3.3	3.7	4.4	4.0	4.2	4.4	0.7	0.5	0.0
FR-04	S	3.0	4.7	5.7	3.8	4.2	4.6	0.8	-0.5	-1.1
FR-04	B	3.2	3.8	4.5	3.3	3.6	3.7	0.1	-0.2	-0.8
FR-06	S	3.7	4.6	5.3	4.3	4.8	5.2	0.6	0.2	-0.1
FR-06	B	1.8	2.4	3.0	2.8	3.0	3.2	1.0	0.6	0.2
FR-08	S	3.5	6.0	6.9	4.7	5.1	5.5	1.2	-0.9	-1.4
FR-08	B	2.4	3.4	8.3	3.1	3.5	5.0	0.7	0.1	-3.3
FR-09	S	4.1	5.5	6.3	4.9	5.5	6.0	0.8	0.0	-0.3
FR-09	B	2.7	5.2	6.4	3.6	4.6	5.4	0.9	-0.6	-1.0
MR-10	S	5.1	5.9	6.7	5.6	6.1	6.5	0.5	0.2	-0.2
FR-11R	B	5.0	6.7	7.0	4.9	5.6	6.1	-0.1	-1.1	-0.9
SR-14	B	6.8	7.4	7.8	5.5	5.8	6.2	-1.3	-1.6	-1.6
SR-16	B	6.5	6.6	6.8	6.4	6.6	6.7	-0.1	0.0	0.0
FR-21	S	2.2	3.5	4.7	4.0	4.6	5.0	1.8	1.1	0.3
FR-21	B	2.4	2.8	3.2	3.0	3.2	3.3	0.6	0.4	0.1
FR-22	S	4.1	5.0	5.8	4.8	5.2	5.7	0.7	0.2	-0.1
FR-22	B	2.2	3.0	4.7	3.2	3.4	3.9	1.0	0.4	-0.8

* S = Surface
B = Bottom

Table P-6 Summary Statistics for Dissolved Oxygen (mg/l) for August 15, 1999 through August 30, 1999

August 16 - August 30, 1999 [Julian Days 227-241]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	2415	-0.02	1.09	1.36	4.46	1.19	4.44	0.47	0.04
FR-02	B	737	0.45	0.53	0.64	3.75	0.40	4.20	0.15	0.03
FR-04	S	1853	-0.35	1.05	1.33	4.56	1.21	4.20	0.32	0.01
FR-04	B	3254	-0.33	0.41	0.53	3.86	0.44	3.53	0.17	0.12
FR-06	S	2243	0.24	0.59	0.74	4.55	0.63	4.78	0.33	0.00
FR-06	B	3933	0.61	0.63	0.77	2.39	0.47	3.00	0.14	0.01
FR-08	S	1608	-0.46	1.22	1.41	5.60	1.39	5.13	0.28	0.08
FR-08	B	864	-0.78	1.47	2.02	4.61	2.25	3.83	0.71	0.43
FR-09	S	3742	0.13	0.66	0.81	5.36	0.84	5.50	0.39	0.11
FR-09	B	3654	-0.29	0.87	1.03	4.85	1.39	4.56	0.63	0.59
MR-10	S	2315	0.16	0.65	0.75	5.88	0.63	6.04	0.34	0.00
FR-11R	B	4245	-0.74	0.90	1.00	6.27	0.90	5.53	0.47	0.46
SR-14	B	4245	-1.48	1.48	1.55	7.32	0.37	5.83	0.27	0.01
FR-21	S	3796	0.98	1.09	1.45	3.55	0.95	4.53	0.37	0.02
FR-21	B	1883	0.38	0.41	0.48	2.80	0.32	3.18	0.12	0.24
FR-22	S	4286	0.26	0.60	0.74	4.96	0.65	5.23	0.33	0.01
FR-22	B	1706	0.21	0.62	0.72	3.24	0.91	3.46	0.29	0.74

* S = Surface
B = Bottom

Table P-7 Summary Percentiles for Dissolved Oxygen (mg/l) for August 30, 1999 through September 13, 1999

August 31 - September 13, 1999 [Julian Days 242 - 255]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S	3.1	3.8	5.8	4.5	4.8	5.0	1.4	1.0	-0.8
FR-02	B									
FR-04	S									
FR-04	B	4.7	5.3	5.9	4.0	4.1	4.2	-0.7	-1.2	-1.7
FR-06	S	4.7	5.3	5.9	4.8	5.3	5.8	0.1	0.0	-0.1
FR-06	B	3.1	3.6	3.9	3.4	3.7	3.9	0.3	0.1	0.0
FR-08	S	4.8	5.7	6.6	5.8	6.0	6.3	1.0	0.3	-0.3
FR-08	B									
FR-09	S	3.8	5.1	6.2	5.4	6.0	6.4	1.6	0.9	0.2
FR-09	B	4.9	5.9	6.7	5.6	5.9	6.2	0.7	0.0	-0.5
MR-10	S	4.2	4.7	5.5	5.9	6.4	6.7	1.7	1.7	1.2
FR-11R	B	5.2	6.4	6.8	5.7	6.1	6.5	0.5	-0.3	-0.3
SR-14	B	6.0	6.6	6.9	5.9	6.3	6.6	-0.1	-0.3	-0.3
SR-16	B	6.8	7.0	7.1	6.7	7.0	7.1	-0.2	0.0	0.0
FR-21	S	4.0	4.5	4.9	4.5	5.0	5.6	0.5	0.5	0.7
FR-21	B	3.0	3.3	3.6	3.7	3.8	4.0	0.7	0.5	0.4
FR-22	S	4.6	5.4	6.2	5.3	5.8	6.2	0.7	0.4	0.0
FR-22	B	3.1	3.8	5.3	3.7	4.1	4.7	0.6	0.3	-0.6

* S = Surface
B = Bottom

Table P-8 Summary Statistics for Dissolved Oxygen (mg/l) for August 30, 1999 through September 13, 1999

August 31 - September 13, 1999 [Julian Days 242 - 255]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	873	0.62	1.08	1.24	4.14	1.02	4.76	0.15	0.06
FR-02	B									
FR-04	S									
FR-04	B	1193	-1.21	1.21	1.28	5.29	0.44	4.09	0.08	0.08
FR-06	S	3737	-0.06	0.44	0.54	5.32	0.49	5.26	0.37	0.07
FR-06	B	4286	0.13	0.22	0.28	3.57	0.32	3.70	0.21	0.39
FR-08	S	1125	0.31	0.59	0.70	5.73	0.74	6.04	0.22	0.37
FR-08	B									
FR-09	S	4286	0.93	0.99	1.13	5.01	0.86	5.94	0.35	0.50
FR-09	B	489	-0.01	0.47	0.55	5.88	0.67	5.87	0.27	0.37
MR-10	S	4030	1.59	1.59	1.64	4.80	0.47	6.38	0.28	0.22
FR-11R	B	4234	-0.16	0.55	0.70	6.23	0.71	6.08	0.32	0.09
SR-14	B	3406	-0.31	0.49	0.59	6.54	0.34	6.24	0.26	0.15
FR-21	S	3816	0.54	0.65	0.76	4.49	0.35	5.03	0.41	0.00
FR-21	B	1391	0.53	0.54	0.60	3.30	0.26	3.83	0.12	0.00
FR-22	S	4286	0.32	0.48	0.58	5.44	0.63	5.76	0.30	0.46
FR-22	B	4222	0.09	0.56	0.69	4.04	0.85	4.13	0.37	0.38

* S = Surface
B = Bottom

Table P-9 Summary Percentiles for Dissolved Oxygen (mg/l) for September 13, 1999 through September 28, 1999

September 14 - September 28, 1999 [Julian Days 256 - 270]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S	3.8	5.1	5.9	4.7	4.9	5.3	0.9	-0.2	-0.6
FR-02	B	4.4	5.0	5.5	4.0	4.1	4.2	-0.4	-0.9	-1.3
FR-04	S	3.7	4.2	4.9	4.5	4.7	5.0	0.8	0.5	0.1
FR-04	B	3.5	3.8	4.0	3.5	3.7	3.9	0.0	-0.1	-0.1
FR-06	S	3.9	4.2	4.5	4.6	5.2	5.5	0.7	1.0	1.0
FR-06	B									
FR-08	S	4.3	5.2	6.8	5.3	5.6	6.2	1.0	0.4	-0.6
FR-08	B									
FR-09	S									
FR-09	B	3.8	5.7	6.8	4.0	4.8	5.7	0.2	-0.9	-1.1
MR-10	S	5.3	5.9	6.3	5.8	6.4	6.8	0.5	0.5	0.5
FR-11R	B	4.7	6.1	7.0	4.8	5.7	6.5	0.1	-0.4	-0.5
SR-14	B	6.2	6.5	6.6	6.0	6.4	6.7	-0.2	-0.1	0.1
SR-16	B	7.1	7.3	7.5	7.0	7.2	7.4	-0.2	-0.1	-0.1
FR-21	S	4.4	4.8	5.4	4.6	5.1	5.4	0.2	0.3	0.0
FR-21	B	4.0	4.2	4.6	3.5	3.8	4.2	-0.5	-0.4	-0.4
FR-22	S	4.2	5.1	5.8	5.3	5.6	6.0	1.1	0.5	0.2
FR-22	B	3.6	3.8	4.4	3.7	3.9	4.3	0.1	0.1	-0.1

* S = Surface
B = Bottom

Table P-10 Summary Statistics for Dissolved Oxygen (mg/l) for September 13, 1999 through September 28, 1999

September 14 - September 28, 1999 [Julian Days 256 - 270]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	1706	0.04	0.70	0.82	4.93	0.83	4.97	0.21	0.02
FR-02	B	382	-0.84	0.86	0.93	4.95	0.42	4.11	0.07	0.08
FR-04	S	2328	0.53	0.66	0.75	4.23	0.48	4.75	0.18	0.02
FR-04	B	4286	-0.02	0.22	0.28	3.75	0.22	3.73	0.17	0.00
FR-06	S	2279	0.88	0.88	0.92	4.23	0.23	5.10	0.32	0.34
FR-06	B									
FR-08	S	2284	0.19	0.75	0.86	5.48	0.97	5.67	0.32	0.30
FR-08	B									
FR-09	S									
FR-09	B	3645	-0.56	0.77	0.97	5.38	1.17	4.82	0.65	0.59
MR-10	S	4259	0.48	0.52	0.62	5.85	0.38	6.34	0.37	0.25
FR-11R	B	2338	-0.26	0.76	0.95	5.98	0.93	5.71	0.68	0.16
SR-14	B	1827	-0.13	0.23	0.30	6.47	0.15	6.34	0.24	0.02
FR-21	S	4293	0.23	0.36	0.43	4.87	0.38	5.10	0.28	0.18
FR-21	B	1269	-0.49	0.50	0.60	4.27	0.20	3.78	0.25	0.01
FR-22	S	4293	0.56	0.61	0.74	5.04	0.61	5.60	0.26	0.43
FR-22	B	1531	-0.01	0.23	0.36	3.95	0.46	3.94	0.27	0.38

* S = Surface
B = Bottom

Table P-11 Summary Percentiles for Dissolved Oxygen (mg/l) for September 28, 1999 through October 13, 1999

September 29 - October 13, 1999 [Julian Days 271-285]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S	4.7	4.7	4.8	4.6	4.6	4.6	-0.1	-0.1	-0.1
FR-02	B									
FR-04	S	4.7	4.7	4.7	4.6	4.6	4.6	-0.1	-0.1	-0.1
FR-04	B	4.3	4.3	4.3	4.2	4.2	4.2	-0.1	-0.1	-0.1
FR-06	S	5.2	5.2	5.3	4.7	4.9	5.0	-0.5	-0.3	-0.3
FR-06	B	3.8	3.8	3.9	3.7	3.8	3.8	-0.1	-0.1	-0.1
FR-08	S	5.6	5.7	5.7	5.4	5.5	5.6	-0.2	-0.2	-0.2
FR-08	B									
FR-09	S									
FR-09	B	5.0	5.1	5.2	4.6	4.7	4.7	-0.4	-0.5	-0.4
MR-10	S	6.2	6.2	6.3	5.9	6.0	6.1	-0.3	-0.2	-0.2
FR-11R	B	5.8	5.9	6.0	5.3	5.5	5.6	-0.5	-0.4	-0.4
SR-14	B	6.2	6.3	6.3	6.1	6.1	6.2	-0.1	-0.1	-0.1
SR-16	B	7.1	7.2	7.2	7.1	7.1	7.1	-0.1	-0.1	0.0
FR-21	S	4.7	4.9	5.0	4.5	4.6	4.6	-0.2	-0.3	-0.4
FR-21	B	3.9	4.0	4.0	3.8	3.8	3.9	-0.2	-0.1	-0.1
FR-22	S	5.6	5.6	5.7	5.4	5.5	5.5	-0.2	-0.1	-0.1
FR-22	B	4.2	4.2	4.2	4.1	4.1	4.1	-0.1	-0.1	-0.1

* S = Surface
B = Bottom

Table P-12 Summary Statistics for Dissolved Oxygen (mg/l) for September 28, 1999 through October 13, 1999

September 29 - October 13, 1999 [Julian Days 271-285]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	2871	4.79	4.81	4.84	4.90	4.93	4.85	4.87	4.96
FR-02	B									
FR-04	S	1284	4.74	4.76	4.78	4.87	4.94	4.80	4.83	4.98
FR-04	B	1292	4.33	4.34	4.36	4.40	4.42	4.36	4.38	4.43
FR-06	S	2577	5.31	5.34	5.37	5.46	5.50	5.40	5.43	5.55
FR-06	B	2516	3.88	3.90	3.92	3.97	3.99	3.94	3.95	4.01
FR-08	S	2620	5.75	5.78	5.81	5.97	6.04	5.86	5.91	6.08
FR-08	B									
FR-09	S									
FR-09	B	3336	5.22	5.29	5.36	5.57	5.65	5.43	5.50	5.76
MR-10	S	2127	6.39	6.45	6.52	6.71	6.75	6.59	6.66	6.79
FR-11R	B	2514	6.06	6.12	6.18	6.35	6.38	6.25	6.30	6.41
SR-14	B	2234	6.34	6.37	6.40	6.47	6.49	6.42	6.45	6.51
FR-21	S	3138	5.04	5.07	5.12	5.24	5.28	5.17	5.21	5.31
FR-21	B	3352	3.98	4.00	4.02	4.07	4.08	4.03	4.05	4.10
FR-22	S	2561	5.68	5.71	5.75	5.88	5.93	5.79	5.83	5.99
FR-22	B	1498	4.27	4.28	4.30	4.41	4.45	4.32	4.37	4.48

* S = Surface
B = Bottom

APPENDIX Q 1997 DISSOLVED OXYGEN

Table Q-1 Summary Percentiles for Dissolved Oxygen (mg/l) for July 10 through October 6, 1997

July 10 - October 6, 1997 [Julian Days 191-279]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S	4.2	4.9	5.8	4.4	4.9	5.7	0.3	0.1	-0.2
FR-02	B	3.9	4.8	5.7	4.2	4.6	4.9	0.3	-0.3	-0.8
FR-04	S	3.4	5.1	6.1	4.2	4.8	5.4	0.7	-0.3	-0.7
FR-04	B	3.4	4.1	4.5	3.6	4.0	4.3	0.2	-0.1	-0.2
FR-06	S	3.9	4.9	6.2	4.9	5.6	6.1	1.0	0.7	-0.1
FR-06	B	3.4	3.9	4.6	3.4	3.7	4.3	0.1	-0.2	-0.3
FR-08	S	4.9	6.1	7.0	5.5	6.1	6.6	0.6	0.0	-0.4
FR-08	B	3.5	5.1	7.0	3.9	5.1	6.2	0.4	0.0	-0.9
FR-09	B	4.3	5.9	7.1	4.5	5.7	6.8	0.2	-0.1	-0.3
MR-10	B	5.0	5.9	6.7	5.1	5.5	6.1	0.1	-0.5	-0.6
FR-11	B	6.0	6.6	7.2	6.1	6.5	7.0	0.1	-0.1	-0.3
SR-14	B	6.7	7.4	8.1	6.3	6.9	7.7	-0.4	-0.5	-0.4

* S = Surface
B = Bottom

Table Q-2 Summary Statistics for Dissolved Oxygen (mg/l) for July 10 through October 6, 1997

July 10 - October 6, 1999 [Julian Days 191-279]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	5573	0.05	0.50	0.65	4.95	0.71	5.00	0.45	0.21
FR-02	B	5437	-0.24	0.51	0.66	4.80	0.73	4.56	0.29	0.31
FR-04	S	5925	-0.15	0.64	0.80	4.93	0.94	4.78	0.46	0.30
FR-04	B	6316	-0.04	0.35	0.44	4.02	0.42	3.97	0.26	0.06
FR-06	S	10029	0.58	0.87	1.04	4.95	0.96	5.53	0.47	0.19
FR-06	B	6905	-0.15	0.40	0.50	3.95	0.49	3.81	0.37	0.15
FR-08	S	10716	0.07	0.45	0.55	5.98	0.81	6.05	0.43	0.61
FR-08	B	10390	-0.08	1.11	1.38	5.15	1.37	5.08	0.84	0.09
FR-09	B	6570	-0.12	0.48	0.61	5.81	1.04	5.69	0.80	0.67
MR-10	B	8880	-0.35	0.61	0.74	5.87	0.66	5.52	0.39	0.09
FR-11	B	6446	-0.07	0.33	0.46	6.59	0.49	6.52	0.38	0.24
SR-14	B	10374	-0.45	0.47	0.58	7.41	0.54	6.97	0.51	0.57

* S = Surface
B = Bottom

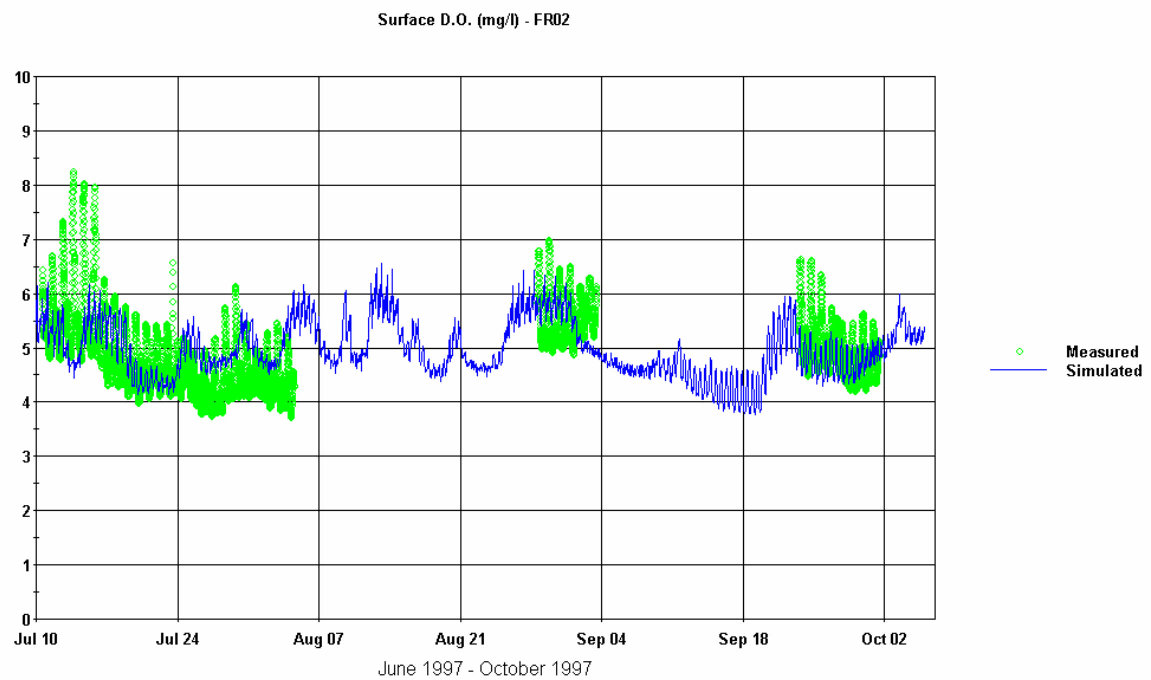


Figure Q-1 Dissolved Oxygen Calibration at FR-02 (Surface) for July 10 through October 6, 1997

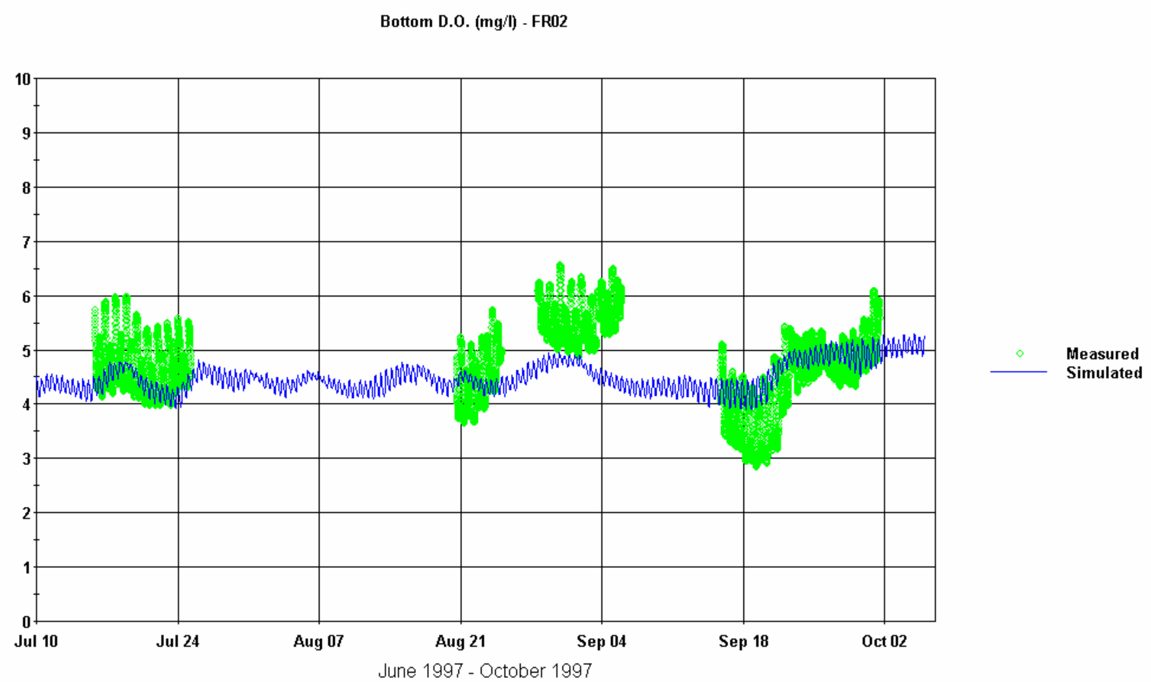


Figure Q-2 Dissolved Oxygen Calibration at FR-02 (Bottom) for July 10 through October 6, 1997

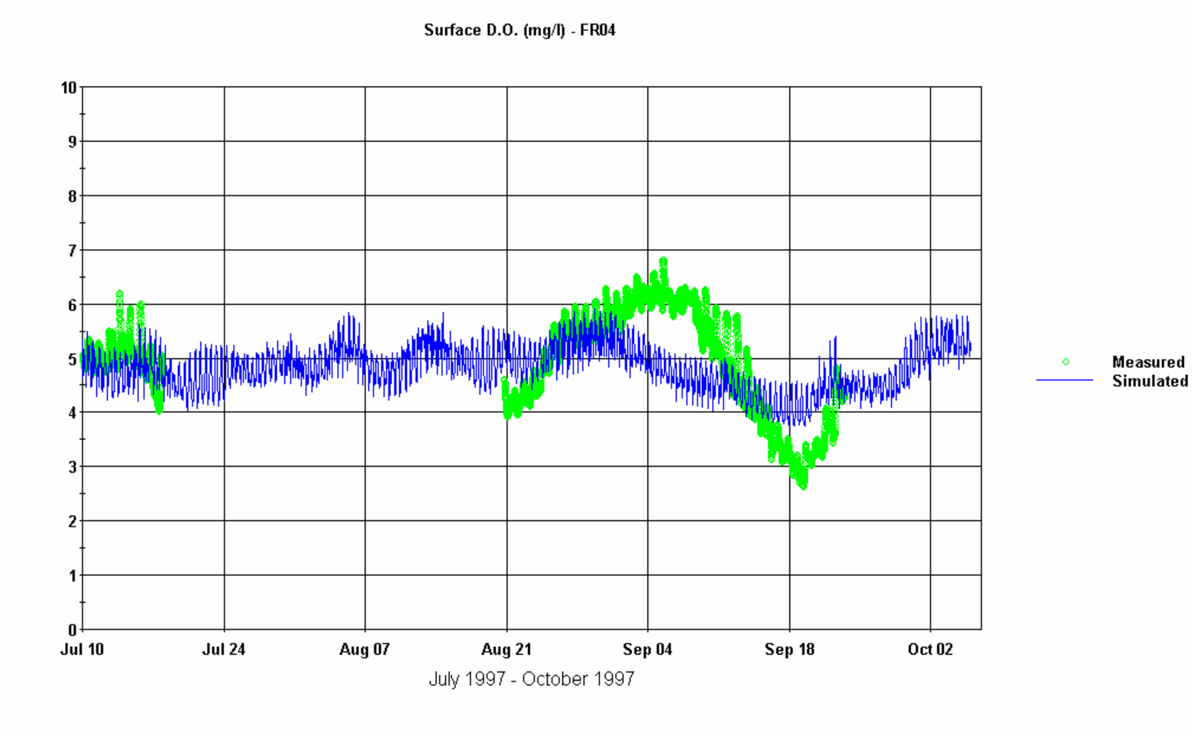


Figure Q-3 Dissolved Oxygen Calibration at FR-04 (Surface) for July 10 through October 6, 1997

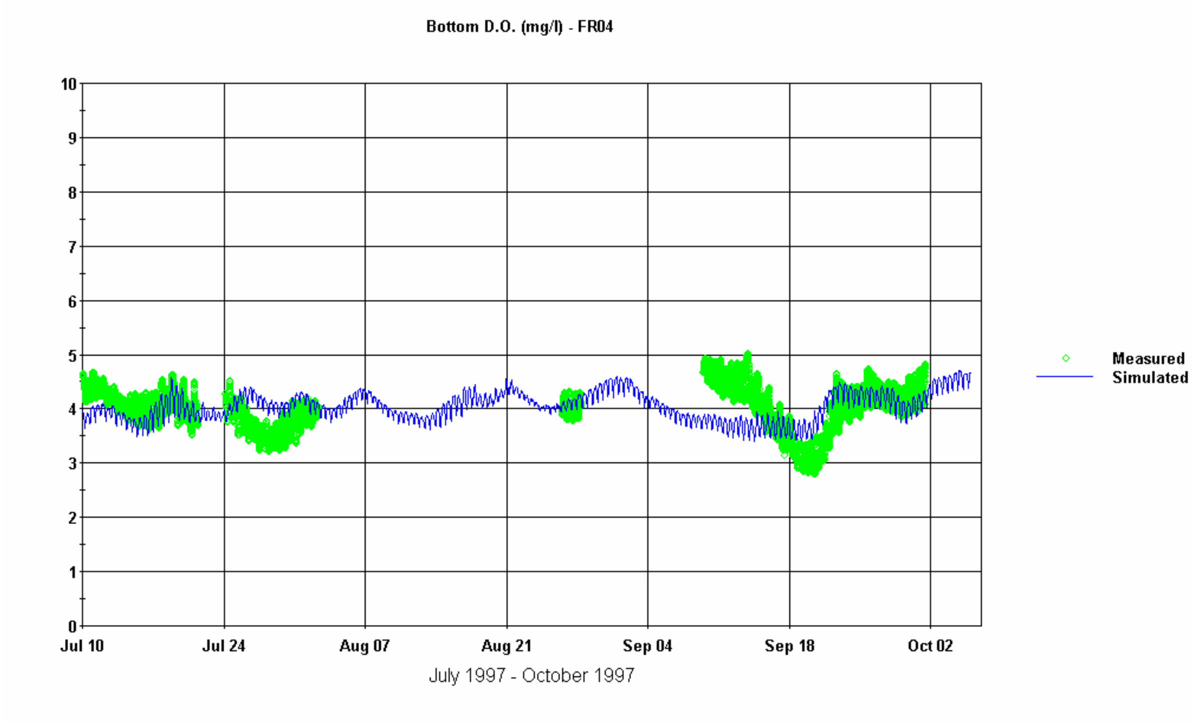


Figure Q-4 Dissolved Oxygen Calibration at FR-04 (Bottom) for July 10 through October 6, 1997

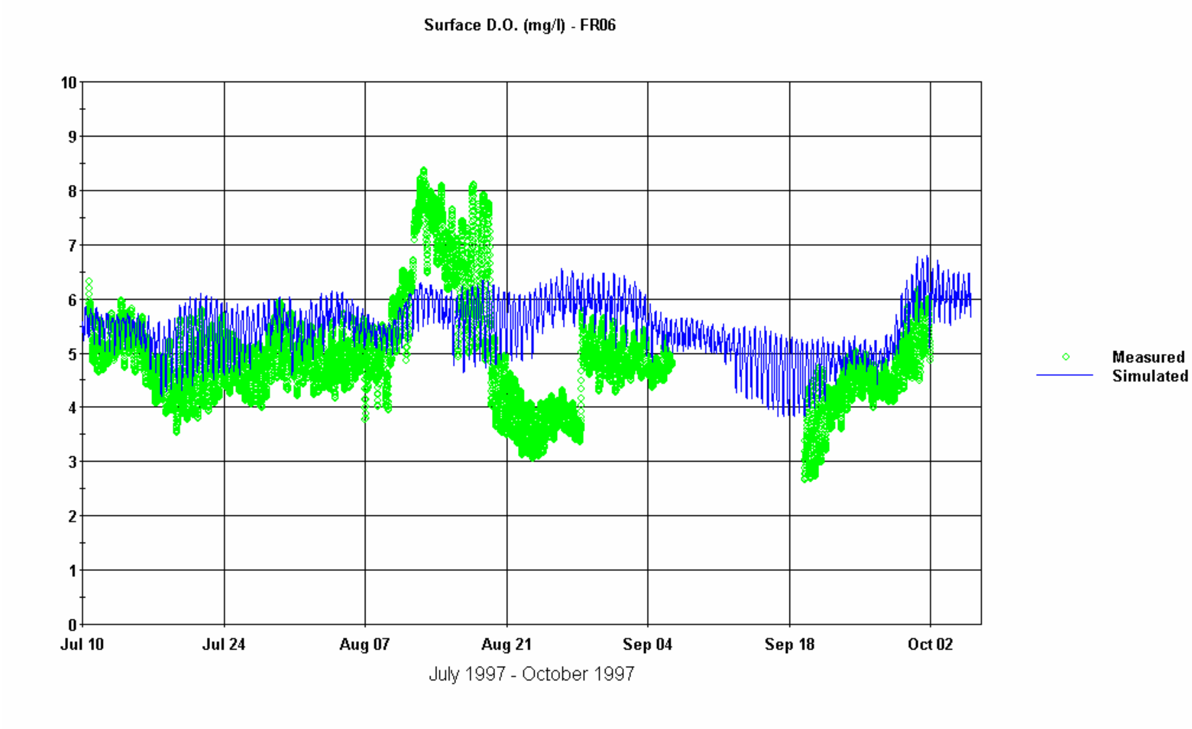


Figure Q-5 Dissolved Oxygen Calibration at FR-06 (Surface) for July 10 through October 6, 1997

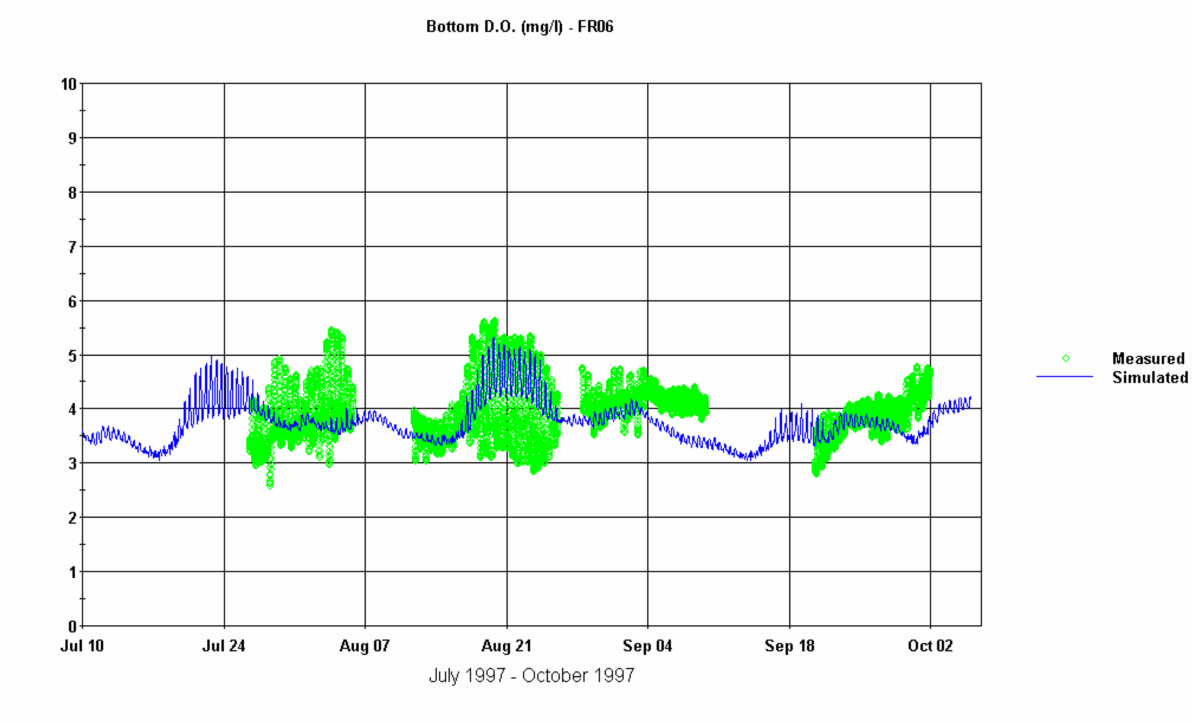


Figure Q-6 Dissolved Oxygen Calibration at FR-06 (Bottom) for July 10 through October 6, 1997

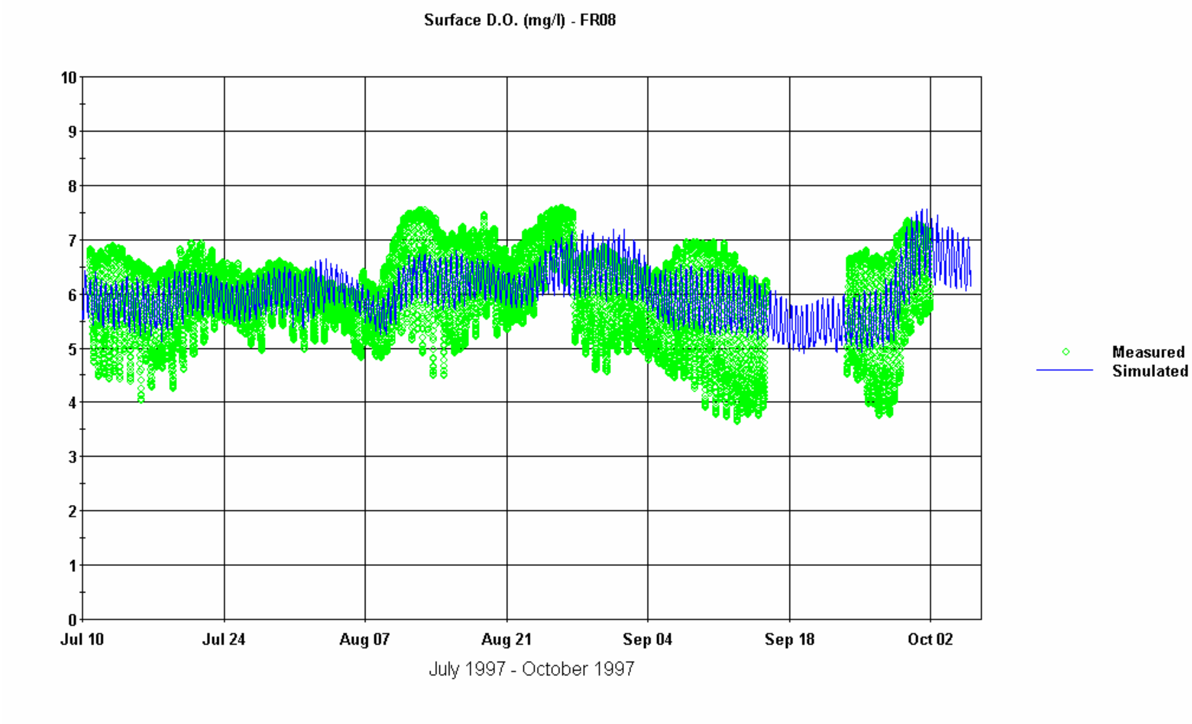


Figure Q-7 Dissolved Oxygen Calibration at FR-08 (Surface) for July 10 through October 6, 1997

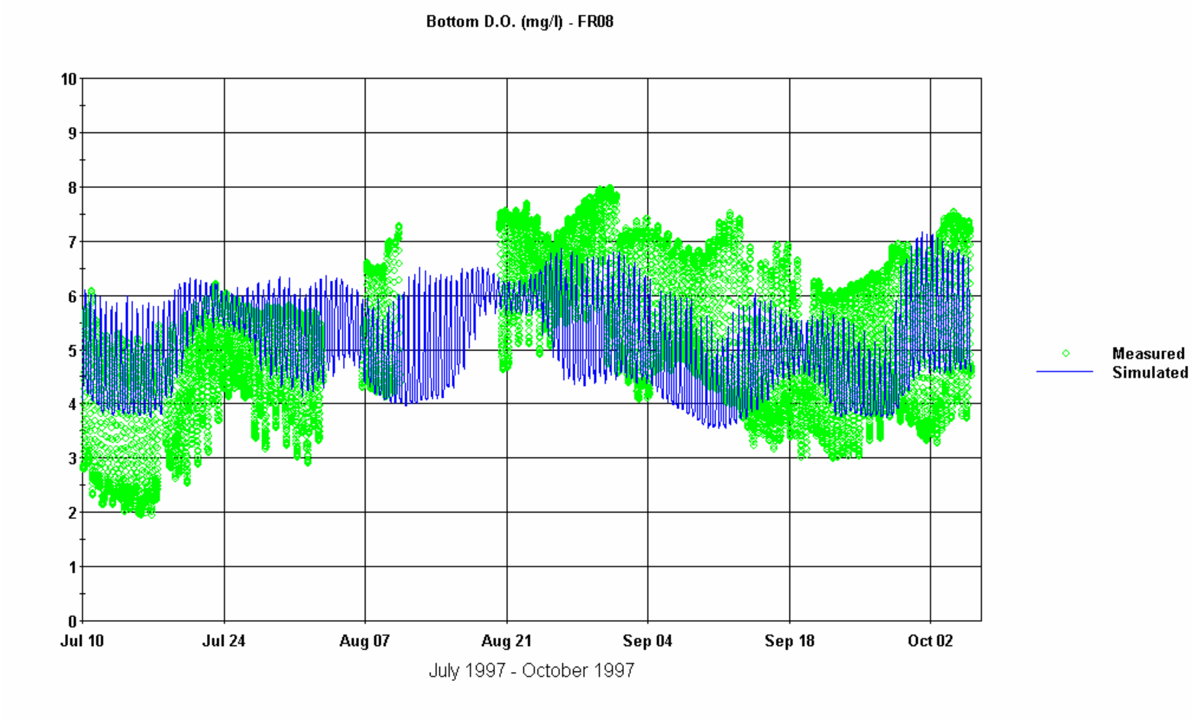


Figure Q-8 Dissolved Oxygen Calibration at FR-08 (Bottom) for July 10 through October 6, 1997

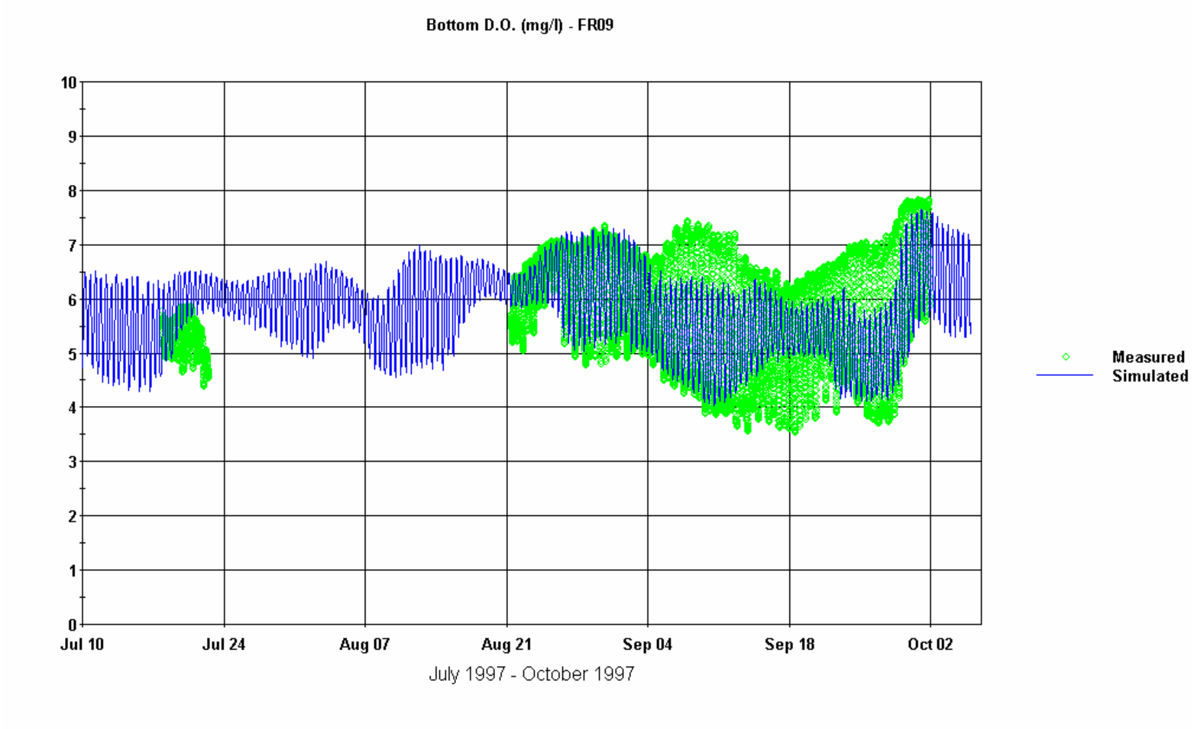


Figure Q-9 Dissolved Oxygen Calibration at FR-09 (Bottom) for July 10 through October 6, 1997

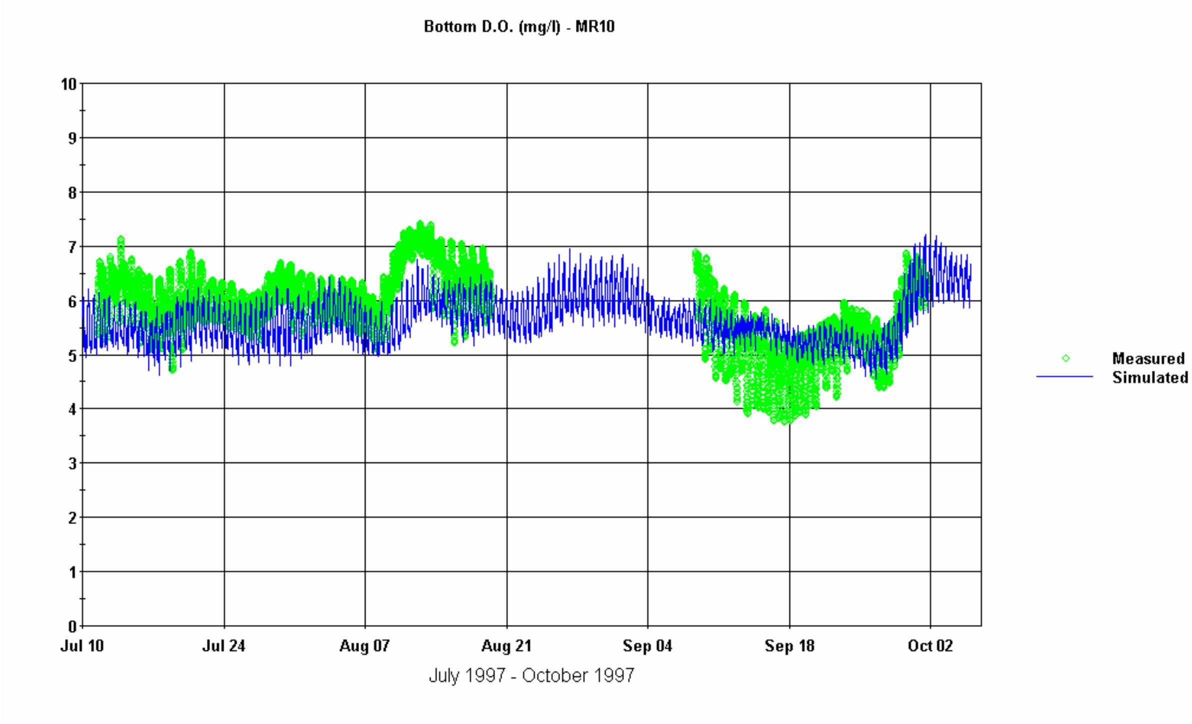


Figure Q-10 Dissolved Oxygen Calibration at FR-11 (Bottom) for July 10 through October 6, 1997

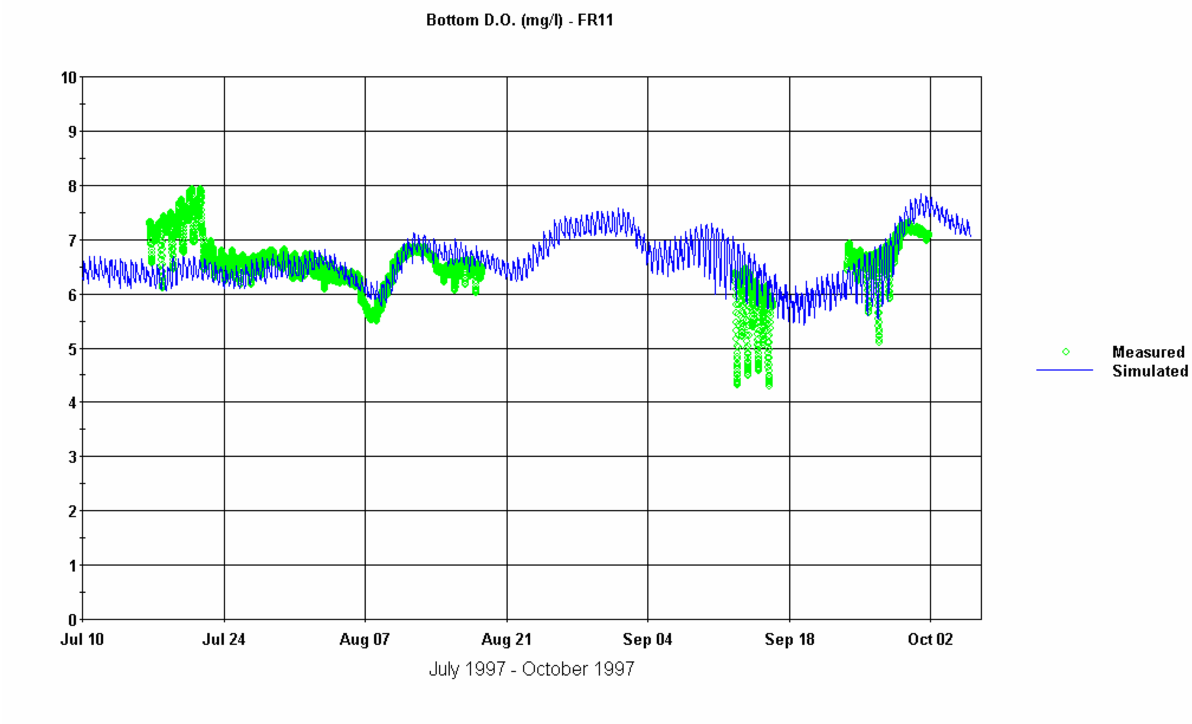


Figure Q-11 Dissolved Oxygen Calibration at MR-10 (Bottom) for July 10 through October 6, 1997

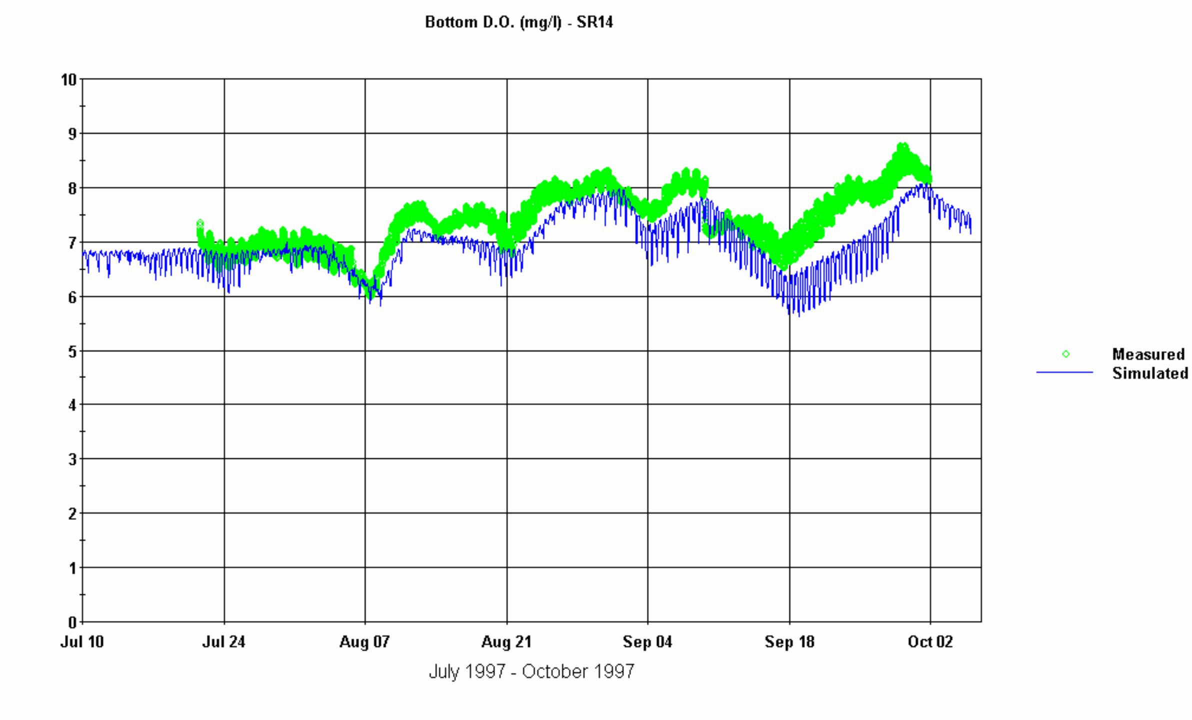


Figure Q-12 Dissolved Oxygen Calibration at SR-14 (Bottom) for July 10 through October 6, 1997

Table Q-1 Summary Percentiles for Dissolved Oxygen (mg/l) for July 10 through July 23, 1997

July 10 - July 23, 1997 [Julian Days 191-204]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S	4.4	5.1	6.2	4.3	5.0	5.6	-0.1	0.0	-0.6
FR-02	B	4.2	4.6	5.5	4.2	4.5	4.7	0.0	-0.1	-0.7
FR-04	S	4.6	5.0	5.4	4.4	4.8	5.2	-0.2	-0.2	-0.2
FR-04	B	3.8	4.1	4.5	3.7	3.9	4.2	-0.1	-0.2	-0.3
FR-06	S	4.1	5.0	5.5	4.8	5.4	5.8	0.7	0.5	0.2
FR-06	B									
FR-08	S	4.9	6.1	6.7	5.5	5.9	6.3	0.6	-0.1	-0.4
FR-08	B	2.3	3.7	5.3	3.9	5.1	6.0	1.6	1.4	0.8
FR-09	B	4.9	5.3	5.8	5.3	6.0	6.4	0.4	0.7	0.7
MR-10	B	5.5	6.1	6.6	5.1	5.4	5.9	-0.4	-0.6	-0.6
FR-11	B	6.7	7.3	7.7	6.2	6.4	6.6	-0.5	-0.9	-1.1
SR-14	B	6.8	6.9	7.1	6.3	6.8	6.8	-0.4	-0.2	-0.3

* S = Surface
B = Bottom

Table Q-2 Summary Statistics for Dissolved Oxygen (mg/l) for July 10 through July 23, 1997

July 10 - July 23, 1997 [Julian Days 191-204]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	1795	-0.19	0.50	0.73	5.19	0.79	5.00	0.50	0.23
FR-02	B	1040	-0.26	0.37	0.51	4.71	0.52	4.45	0.21	0.30
FR-04	S	1134	-0.17	0.37	0.48	5.00	0.34	4.84	0.28	0.00
FR-04	B	1634	-0.20	0.25	0.29	4.12	0.24	3.93	0.19	0.31
FR-06	S	1783	0.46	0.53	0.62	4.90	0.53	5.36	0.38	0.39
FR-06	B									
FR-08	S	1738	-0.03	0.40	0.47	5.91	0.70	5.88	0.30	0.75
FR-08	B	1730	1.23	1.26	1.42	3.76	1.15	4.99	0.83	0.63
FR-09	B	658	0.64	0.69	0.77	5.30	0.35	5.94	0.45	0.23
MR-10	B	1661	-0.57	0.67	0.80	6.05	0.41	5.48	0.31	0.04
FR-11	B	924	-0.85	0.85	0.91	7.24	0.37	6.39	0.16	0.24
SR-14	B	210	-0.27	0.28	0.33	6.92	0.15	6.65	0.20	0.15

* S = Surface
B = Bottom

Table Q-3 Summary Percentiles for Dissolved Oxygen (mg/l) for July 24 through August 7, 1997

July 24 - August 7, 1997 [Julian Days 205 -219]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S	3.9	4.3	5.0	4.6	4.9	5.4	0.7	0.5	0.5
FR-02	B	4.4	4.8	5.4	4.0	4.3	4.5	-0.3	-0.5	-0.9
FR-04	S									
FR-04	B	3.4	3.8	4.1	4.0	4.1	4.3	0.5	0.4	0.2
FR-06	S	4.4	4.9	5.4	5.1	5.6	5.9	0.7	0.7	0.5
FR-06	B	3.3	3.8	4.6	3.6	3.7	4.0	0.3	0.0	-0.7
FR-08	S	5.3	6.0	6.4	5.7	6.0	6.4	0.3	0.1	-0.1
FR-08	B	3.7	5.1	5.8	4.5	5.5	6.1	0.8	0.4	0.3
FR-09	B									
MR-10	B	5.7	6.0	6.4	5.1	5.5	6.0	-0.6	-0.5	-0.3
FR-11	B	6.3	6.5	6.7	6.2	6.4	6.7	-0.1	-0.1	-0.1
SR-14	B	6.5	6.9	7.1	6.4	6.8	6.9	-0.1	-0.1	-0.2

* S = Surface
B = Bottom

Table Q-4 Summary Statistics for Dissolved Oxygen (mg/l) for July 24 through August 7, 1997

July 24 - August 7, 1997 [Julian Days 205 -219]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	1654	0.56	0.63	0.71	4.40	0.42	4.96	0.30	0.07
FR-02	B	175	-0.56	0.56	0.63	4.82	0.38	4.26	0.17	0.45
FR-04	S									
FR-04	B	1292	0.36	0.39	0.45	3.76	0.27	4.13	0.13	0.05
FR-06	S	2010	0.64	0.64	0.70	4.90	0.38	5.54	0.32	0.44
FR-06	B	1469	-0.11	0.45	0.58	3.87	0.53	3.76	0.15	0.02
FR-08	S	2005	0.10	0.24	0.30	5.91	0.41	6.01	0.27	0.55
FR-08	B	1452	0.50	0.74	0.92	4.92	0.78	5.42	0.59	0.16
FR-09	B									
MR-10	B	2003	-0.46	0.56	0.69	6.01	0.28	5.55	0.35	0.09
FR-11	B	2015	-0.07	0.18	0.21	6.49	0.20	6.42	0.17	0.18
SR-14	B	2012	-0.14	0.18	0.22	6.82	0.22	6.68	0.20	0.43

* S = Surface
B = Bottom

Table Q-5 Summary Percentiles for Dissolved Oxygen (mg/l) for August 8 through August 22, 1997

August 8 - August 22, 1997 [Julian Days 220-234]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S									
FR-02	B	3.8	4.2	5.1	4.4	4.5	4.6	0.6	0.3	-0.6
FR-04	S									
FR-04	B									
FR-06	S	4.1	6.2	7.7	5.1	5.7	6.2	1.0	-0.4	-1.5
FR-06	B	3.3	3.7	5.1	3.4	3.6	4.9	0.1	-0.1	-0.2
FR-08	S	5.3	6.4	7.3	5.7	6.2	6.6	0.4	-0.3	-0.7
FR-08	B									
FR-09	B									
MR-10	B	5.8	6.6	7.1	5.3	5.8	6.3	-0.6	-0.8	-0.8
FR-11	B	6.1	6.5	6.8	6.1	6.7	6.9	0.0	0.2	0.1
SR-14	B	6.9	7.4	7.6	6.4	7.0	7.1	-0.6	-0.4	-0.5

* S = Surface
B = Bottom

Table Q-6 Summary Statistics for Dissolved Oxygen (mg/l) for August 8 through August 22, 1997

August 8 - August 22, 1997 [Julian Days 220-234]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S									
FR-02	B	214	0.16	0.41	0.47	4.33	0.49	4.49	0.07	0.58
FR-04	S									
FR-04	B									
FR-06	S	1989	-0.34	1.02	1.17	6.03	1.29	5.69	0.39	0.32
FR-06	B	1473	0.01	0.34	0.44	3.92	0.62	3.93	0.57	0.53
FR-08	S	1965	-0.21	0.45	0.54	6.36	0.73	6.16	0.33	0.65
FR-08	B									
FR-09	B									
MR-10	B	1649	-0.75	0.81	0.94	6.54	0.49	5.79	0.37	0.03
FR-11	B	1514	0.12	0.18	0.21	6.51	0.28	6.63	0.30	0.66
SR-14	B	2013	-0.45	0.46	0.48	7.30	0.28	6.85	0.30	0.72

* S = Surface
B = Bottom

Table Q-7 Summary Percentiles for Dissolved Oxygen (mg/l) for August 23 through September 6, 1997

August 23 - September 6, 1997 [Julian Days 235 - 249]										
Stations	**Depth***	**Measured**			**Simulated**			**Difference**		
		10% (mg/L)	**50% (mg/L)**	**90% (mg/L)**	**10% (mg/L)**	**50% (mg/L)**	**90% (mg/L)**	**10% (mg/L)**	**50% (mg/L)**	**90% (mg/L)**
FR-02	S	5.1	5.4	6.2	5.0	5.6	6.0	-0.1	0.1	-0.2
FR-02	B	4.8	5.5	6.2	4.3	4.6	4.9	-0.5	-0.9	-1.3
FR-04	S	4.2	5.2	5.7	4.7	5.2	5.6	0.5	0.0	-0.1
FR-04	B	3.8	4.1	4.3	4.0	4.1	4.2	0.2	0.1	0.0
FR-06	S	3.6	4.7	5.3	5.4	5.9	6.3	1.8	1.2	1.1
FR-06	B	3.5	4.1	4.5	3.7	3.9	4.2	0.2	-0.2	-0.3
FR-08	S	5.1	6.3	7.3	5.9	6.3	6.9	0.8	0.0	-0.4
FR-08	B	4.7	6.6	7.6	4.5	5.4	6.5	-0.3	-1.2	-1.1
FR-09	B	5.2	6.6	7.1	5.2	6.3	7.1	0.0	-0.3	0.0
MR-10	B									
FR-11	B									
SR-14	B	7.6	7.9	8.1	7.0	7.6	7.8	-0.6	-0.3	-0.3

* S = Surface
B = Bottom

Table Q-8 Summary Statistics for Dissolved Oxygen (mg/l) for August 23 through September 6, 1997

August 23 - September 6, 1997 [Julian Days 235 - 249]										
Station	**Depth**	**N**	**ME**	**AME**	**RMS**	**Mean Obs**	**StDev Obs**	**Mean Pred**	**StDev Pred**	**R^2**
FR-02	S	835	-0.04	0.52	0.60	5.55	0.44	5.51	0.38	0.00
FR-02	B	1463	-0.88	0.89	0.99	5.47	0.53	4.59	0.22	0.28
FR-04	S	1478	0.16	0.40	0.52	5.02	0.60	5.18	0.31	0.33
FR-04	B	275	0.07	0.14	0.16	4.05	0.16	4.12	0.08	0.19
FR-06	S	1988	1.38	1.38	1.55	4.48	0.65	5.85	0.35	0.00
FR-06	B	1662	-0.14	0.36	0.45	4.08	0.40	3.94	0.26	0.05
FR-08	S	1992	0.17	0.53	0.62	6.21	0.79	6.38	0.38	0.50
FR-08	B	2009	-0.96	1.28	1.62	6.37	1.04	5.41	0.80	0.00
FR-09	B	1965	-0.10	0.26	0.34	6.29	0.73	6.18	0.68	0.81
MR-10	B									
FR-11	B									
SR-14	B	2008	-0.38	0.39	0.45	7.86	0.20	7.48	0.32	0.48

* S = Surface
B = Bottom

Table Q-9 Summary Percentiles for Dissolved Oxygen (mg/l) for September 7 through September 20, 1997

September 7 - September 20, 1997 [Julian Days 250-263]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S									
FR-02	B	3.1	3.9	4.5	4.0	4.3	4.4	0.8	0.4	0.0
FR-04	S	3.1	4.4	6.1	3.9	4.4	4.8	0.8	-0.1	-1.3
FR-04	B	3.2	4.2	4.8	3.5	3.7	3.8	0.3	-0.5	-0.9
FR-06	S									
FR-06	B	3.9	4.1	4.3	3.3	3.4	3.5	-0.6	-0.7	-0.8
FR-08	S	4.1	5.4	6.8	5.3	5.8	6.4	1.3	0.4	-0.5
FR-08	B	3.8	4.7	6.7	3.7	4.6	5.5	-0.1	-0.1	-1.2
FR-09	B	4.0	5.2	7.0	4.4	5.3	6.1	0.4	0.0	-0.8
MR-10	B	4.2	5.2	6.2	5.1	5.4	5.7	0.9	0.2	-0.5
FR-11	B	4.8	6.0	6.4	6.0	6.4	6.8	1.1	0.4	0.4
SR-14	B	6.9	7.3	8.1	6.0	6.9	7.7	-0.8	-0.4	-0.4

* S = Surface
B = Bottom

Table Q-10 Summary Statistics for Dissolved Oxygen (mg/l) for September 7 through September 20, 1997

September 7 - September 20, 1997 [Julian Days 250-263]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S									
FR-02	B	624	0.42	0.49	0.58	3.81	0.53	4.23	0.18	0.64
FR-04	S	1824	-0.15	0.78	0.92	4.51	1.09	4.36	0.33	0.42
FR-04	B	1483	-0.38	0.57	0.65	4.06	0.59	3.68	0.14	0.35
FR-06	S									
FR-06	B	389	-0.70	0.70	0.71	4.12	0.16	3.42	0.07	0.50
FR-08	S	1252	0.36	0.64	0.76	5.44	1.02	5.80	0.38	0.88
FR-08	B	1814	-0.44	1.03	1.37	5.00	1.10	4.56	0.70	0.00
FR-09	B	1870	-0.08	0.52	0.63	5.36	1.10	5.28	0.63	0.77
MR-10	B	1620	0.19	0.59	0.73	5.22	0.69	5.41	0.20	0.01
FR-11	B	536	0.55	0.55	0.66	5.82	0.56	6.37	0.30	0.63
SR-14	B	1869	-0.46	0.54	0.62	7.33	0.42	6.87	0.61	0.52

* S = Surface
B = Bottom

Table Q-11 Summary Percentiles for Dissolved Oxygen (mg/l) for September 21 through October 6, 1997

September 21 - October 6, 1997 [Julian Days 264 -279]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S	4.4	4.9	5.6	4.4	4.7	5.1	0.0	-0.2	-0.4
FR-02	B	4.4	4.8	5.3	4.7	4.9	5.1	0.3	0.0	-0.2
FR-04	S	3.2	3.7	4.4	4.1	4.4	4.9	0.9	0.8	0.5
FR-04	B	3.7	4.2	4.5	3.9	4.2	4.4	0.3	0.0	-0.1
FR-06	S	4.0	4.6	5.5	4.7	5.1	6.1	0.7	0.5	0.7
FR-06	B	3.4	3.9	4.3	3.4	3.7	3.8	0.0	-0.2	-0.5
FR-08	S	4.3	5.9	7.2	5.1	5.8	7.1	0.8	-0.1	-0.1
FR-08	B	3.6	4.9	6.8	3.8	4.7	6.5	0.3	-0.1	-0.3
FR-09	B	4.2	6.1	7.7	4.3	5.4	6.8	0.1	-0.7	-0.8
MR-10	B	4.9	5.5	6.4	4.9	5.3	6.3	0.0	-0.2	0.0
FR-11	B	6.5	6.8	7.2	5.9	6.8	7.6	-0.6	0.0	0.4
SR-14	B	7.4	8.0	8.4	6.3	7.0	7.9	-1.1	-1.0	-0.5

* S = Surface
B = Bottom

Table Q-12 Summary Statistics for Dissolved Oxygen (mg/l) for September 21 through October 6, 1997

September 21 - October 6, 1997 [Julian Days 264 -279]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	1152	-0.21	0.33	0.42	4.97	0.49	4.76	0.27	0.44
FR-02	B	1497	0.03	0.26	0.34	4.83	0.46	4.86	0.17	0.63
FR-04	S	482	0.73	0.76	0.86	3.76	0.47	4.48	0.30	0.12
FR-04	B	1495	0.04	0.24	0.31	4.15	0.34	4.19	0.17	0.20
FR-06	S	1558	0.62	0.62	0.69	4.64	0.56	5.25	0.56	0.72
FR-06	B	1550	-0.25	0.34	0.45	3.89	0.35	3.64	0.15	0.00
FR-08	S	1192	0.14	0.57	0.67	5.82	1.03	5.96	0.70	0.61
FR-08	B	2141	-0.16	1.23	1.48	5.06	1.24	4.90	0.93	0.01
FR-09	B	1701	-0.50	0.64	0.77	5.94	1.19	5.44	0.89	0.78
MR-10	B	1518	-0.14	0.46	0.53	5.56	0.53	5.42	0.56	0.30
FR-11	B	1171	-0.03	0.30	0.36	6.84	0.34	6.81	0.62	0.77
SR-14	B	1691	-0.92	0.92	0.98	7.99	0.37	7.07	0.61	0.76

* S = Surface
B = Bottom

APPENDIX R 1999 DISSOLVED OXYGEN DEFICIT (MOVING AVERAGE) COMPARIONS

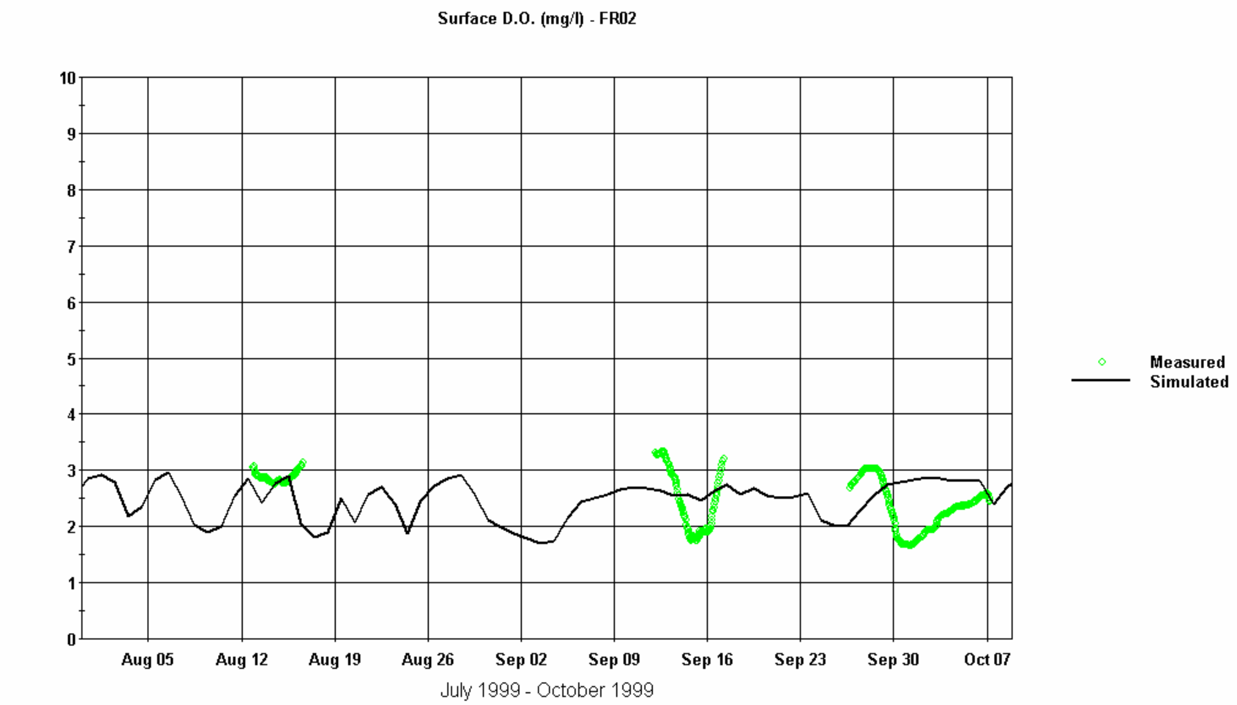


Figure R-1 Dissolved Oxygen Deficit Moving Average at FR-02 (Surface) for July 31 through October 13, 1999

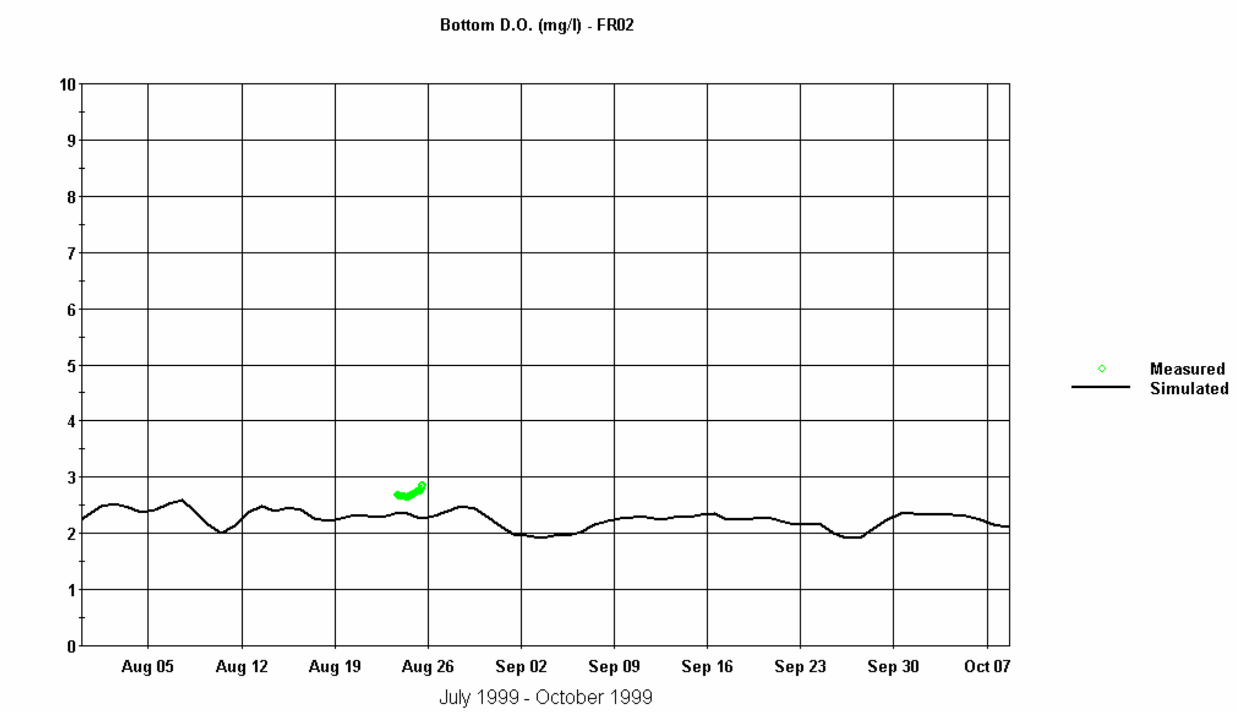


Figure R-2 Dissolved Oxygen Deficit Moving Average at FR-02 (Bottom) for July 31 through October 13, 1999

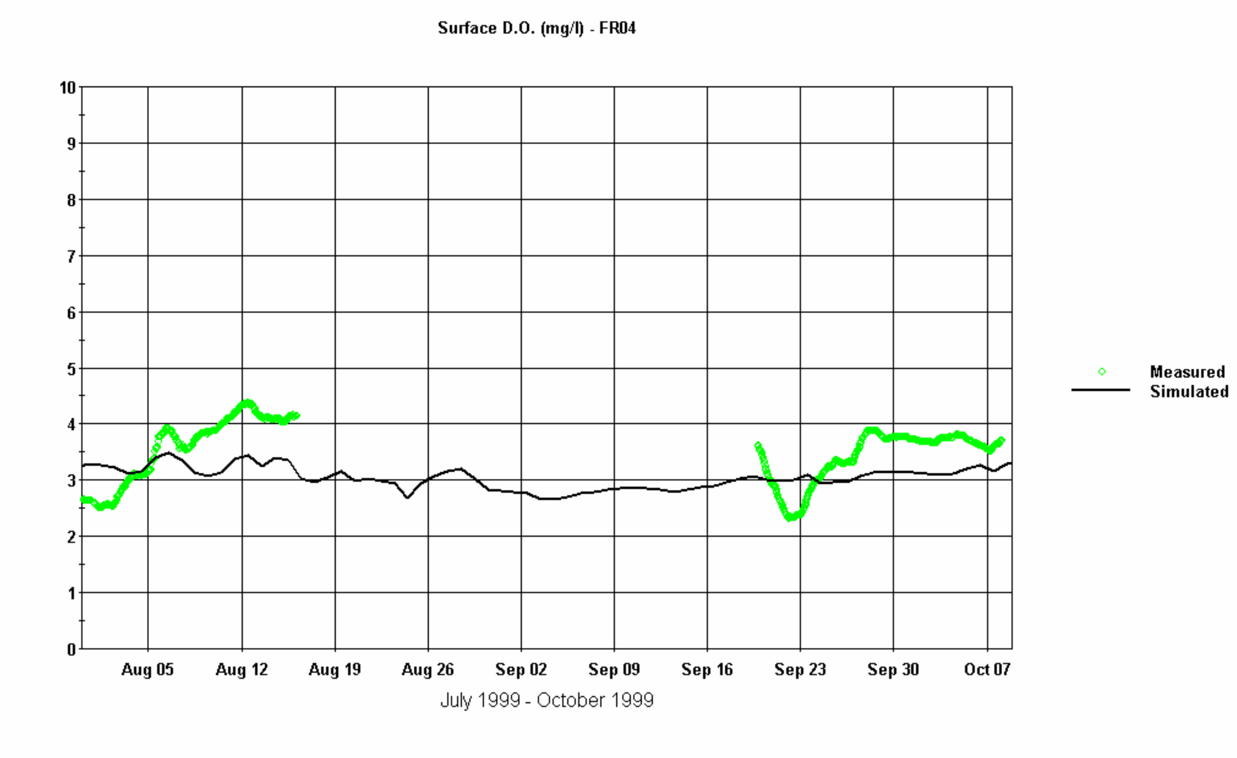


Figure R-3 Dissolved Oxygen Deficit Moving Average at FR-04 (Surface) for July 31 through October 13, 1999

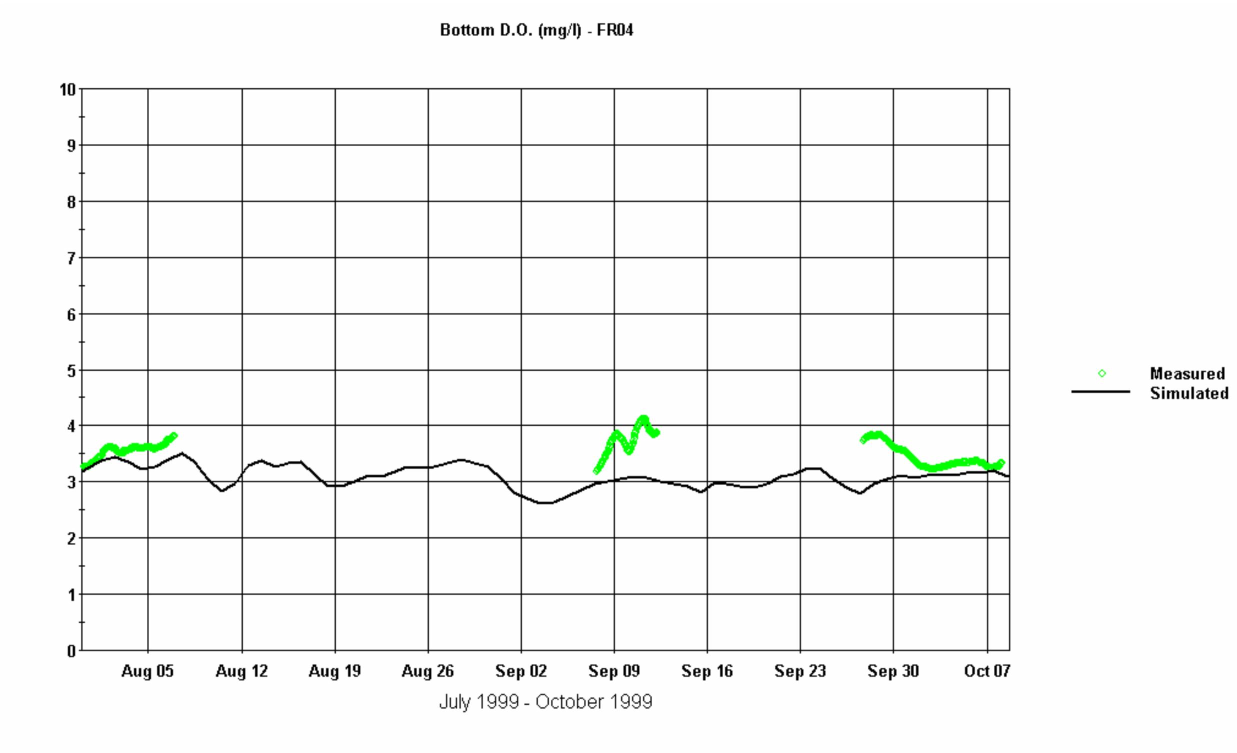


Figure R-4 Dissolved Oxygen Deficit Moving Average at FR-04 (Bottom) for July 31 through October 13, 1999

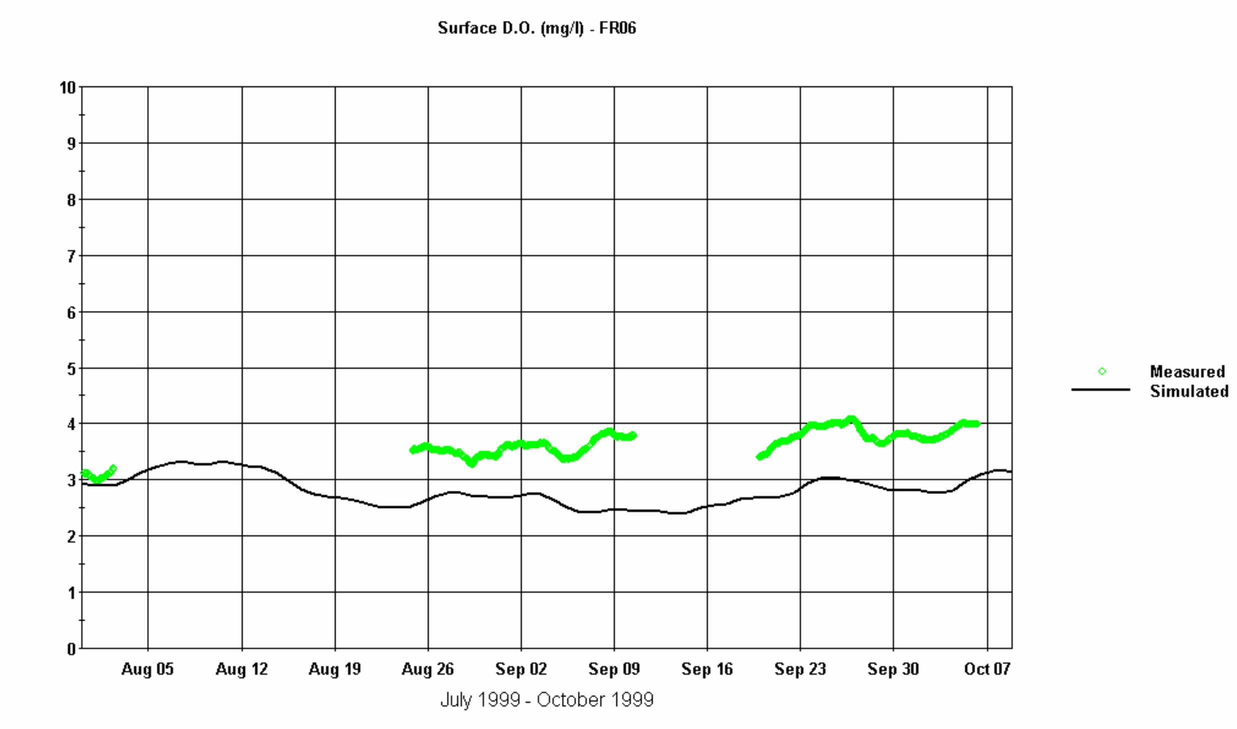


Figure R-5 Dissolved Oxygen Deficit Moving Average at FR-06 (Surface) for July 31 through October 13, 1999

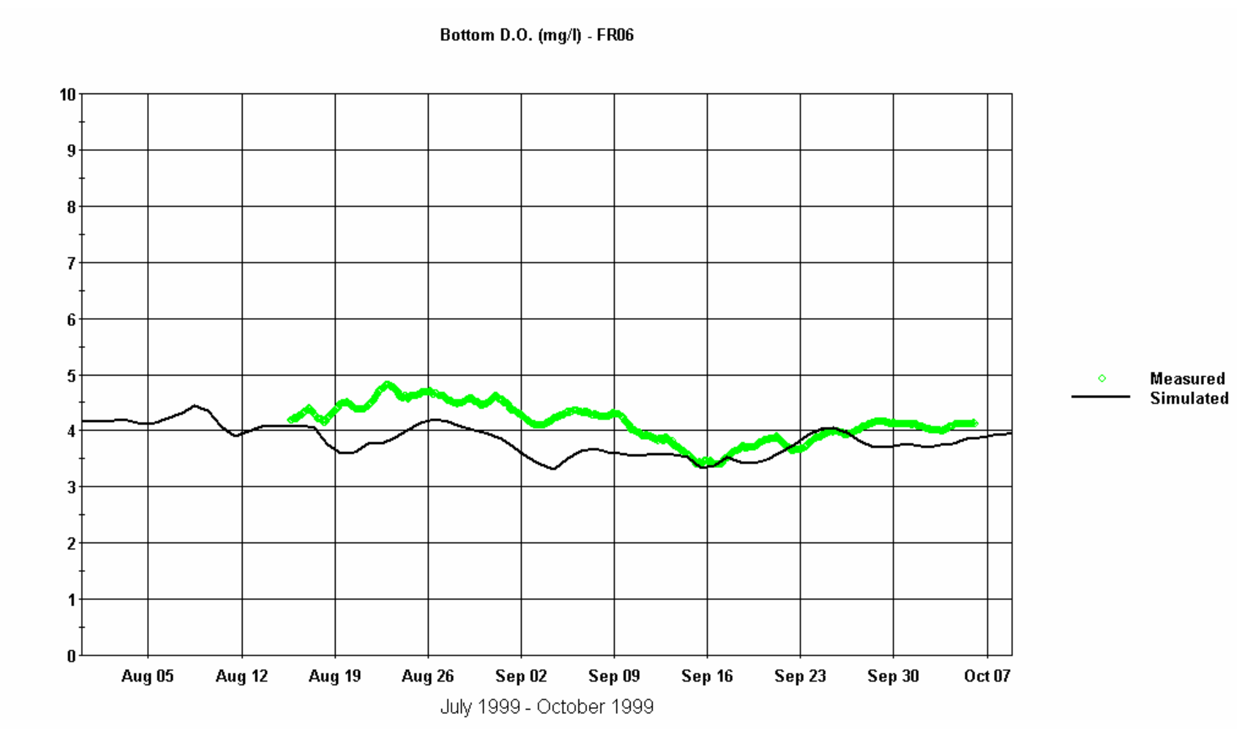


Figure R-6 Dissolved Oxygen Deficit Moving Average at FR-06 (Bottom) for July 31 through October 13, 1999

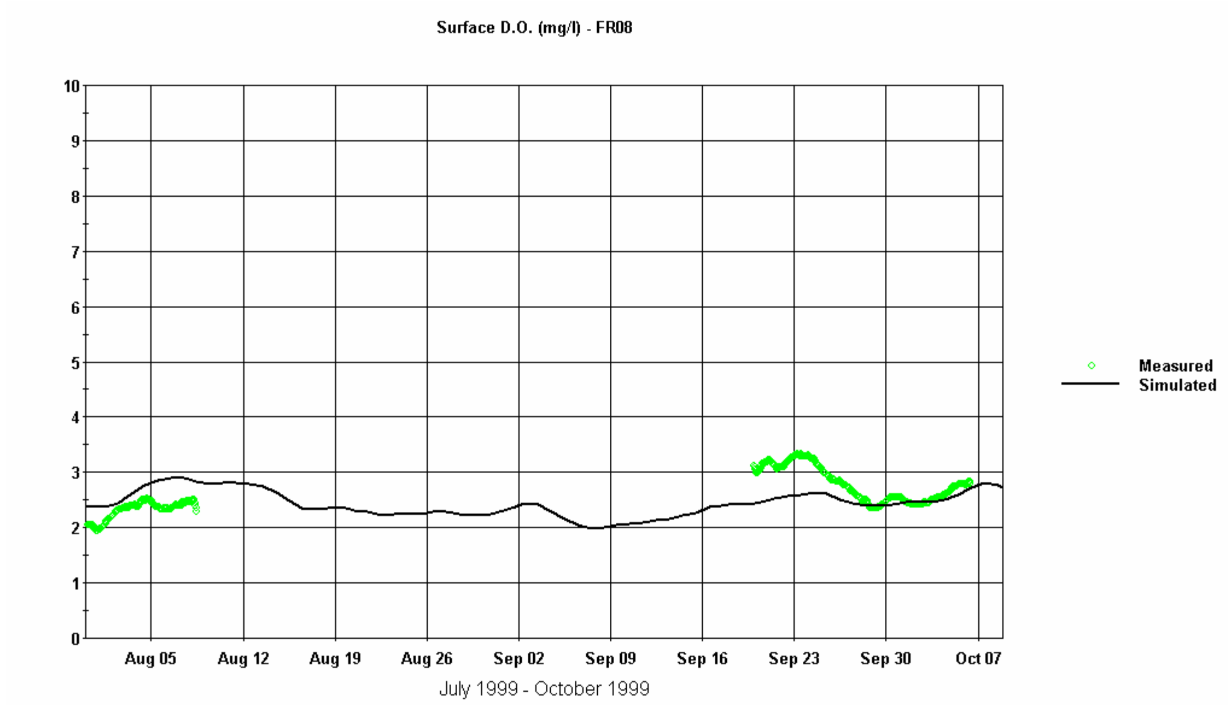


Figure R-7 Dissolved Oxygen Deficit Moving Average at FR-08 (Surface) for July 31 through October 13, 1999

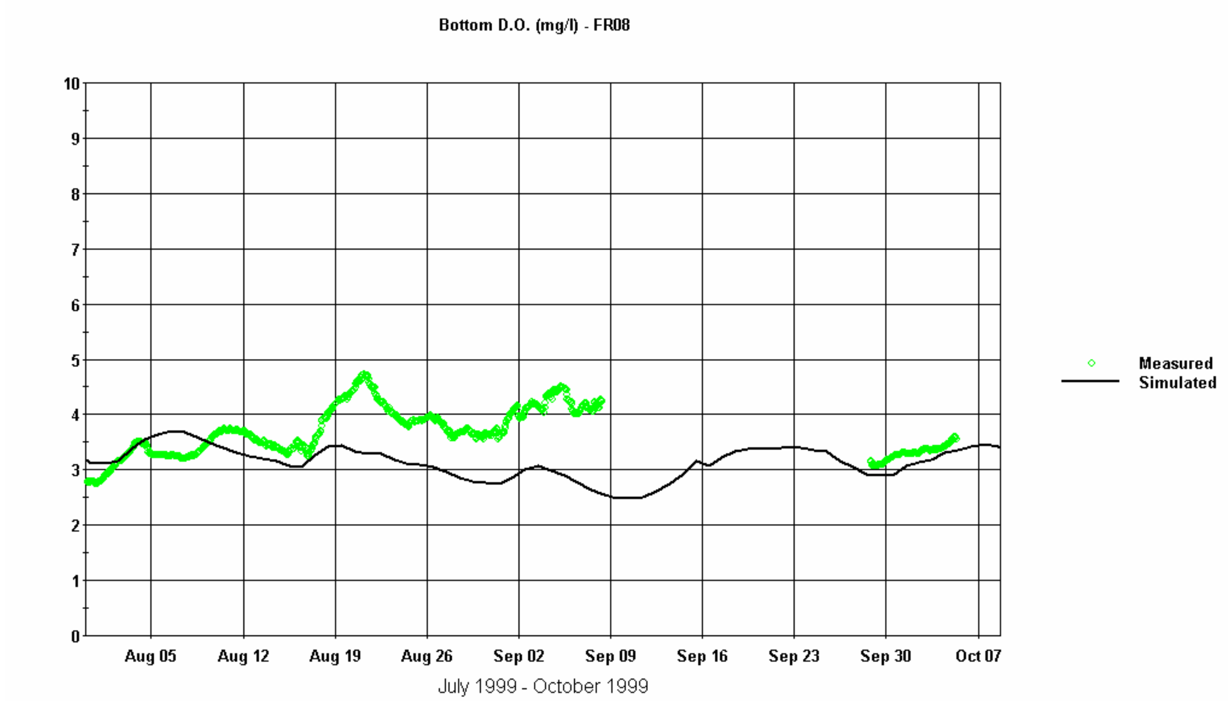


Figure R-8 Dissolved Oxygen Deficit Moving Average at FR-08 (Bottom) for July 31 through October 13, 1999

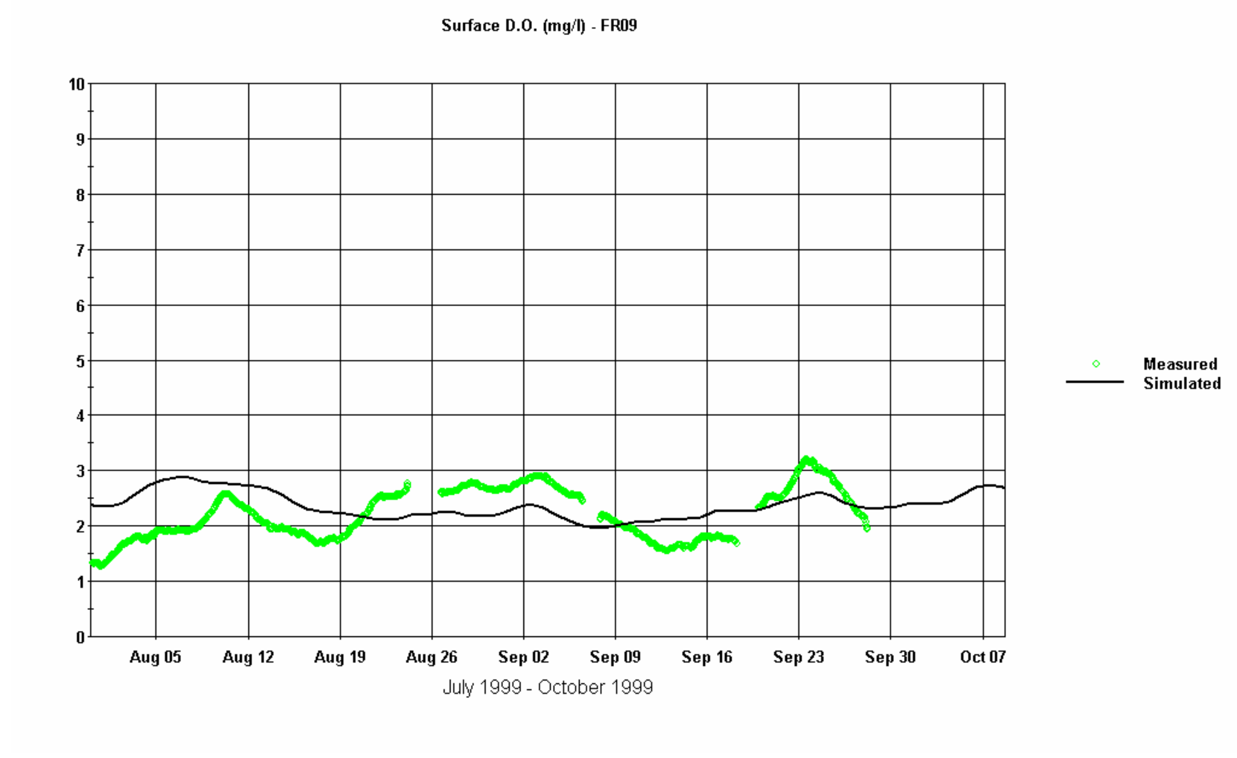


Figure R-11 Dissolved Oxygen Deficit Moving Average at FR-09 (Surface) for July 31 through October 13, 1999

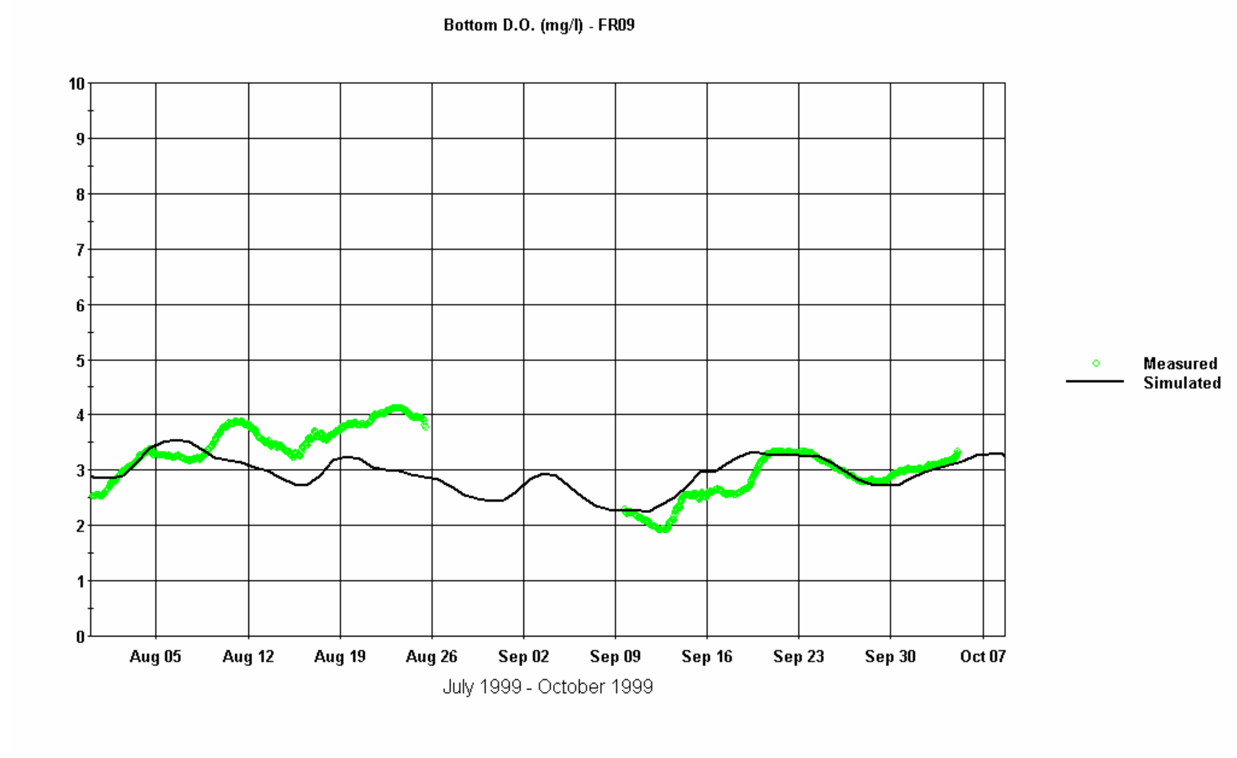


Figure R-9 Dissolved Oxygen Deficit Moving Average at FR-09 (Bottom) for July 31 through October 13, 1999

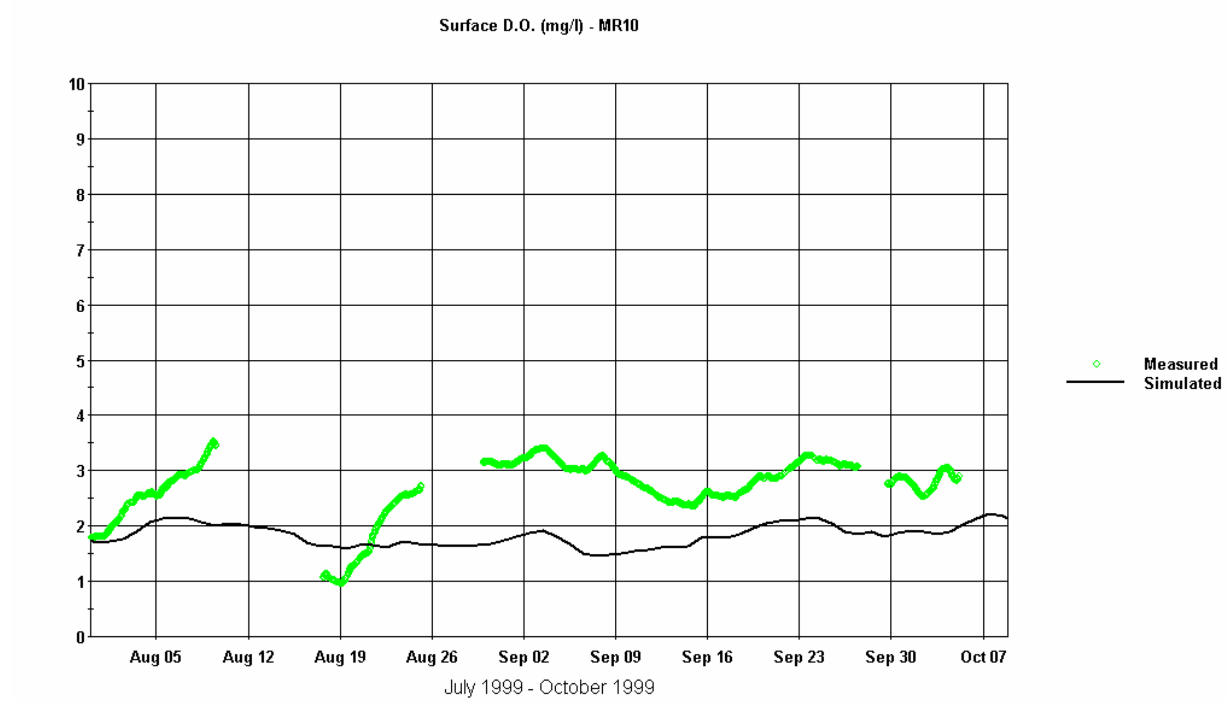


Figure R-10 Dissolved Oxygen Deficit Moving Average at MR-10 (Surface) for July 31 through October 13, 1999

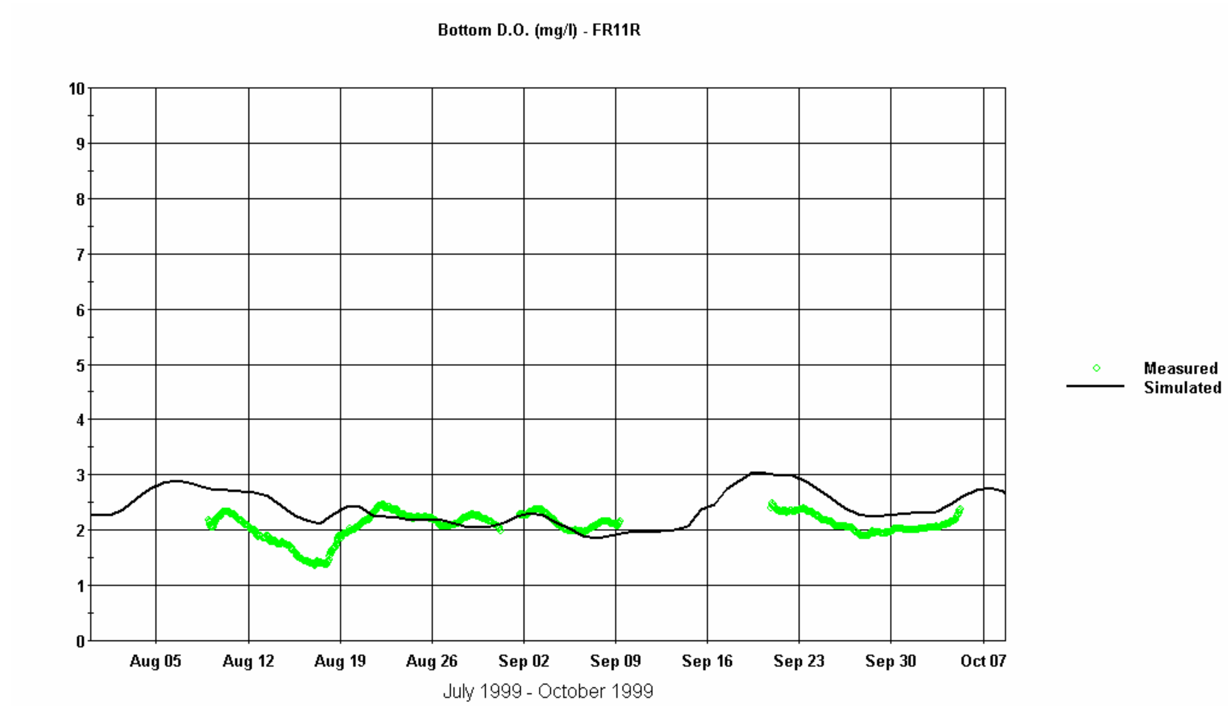


Figure R-11 Dissolved Oxygen Deficit Moving Average at FR-11R (Bottom) for July 31 through October 13, 1999

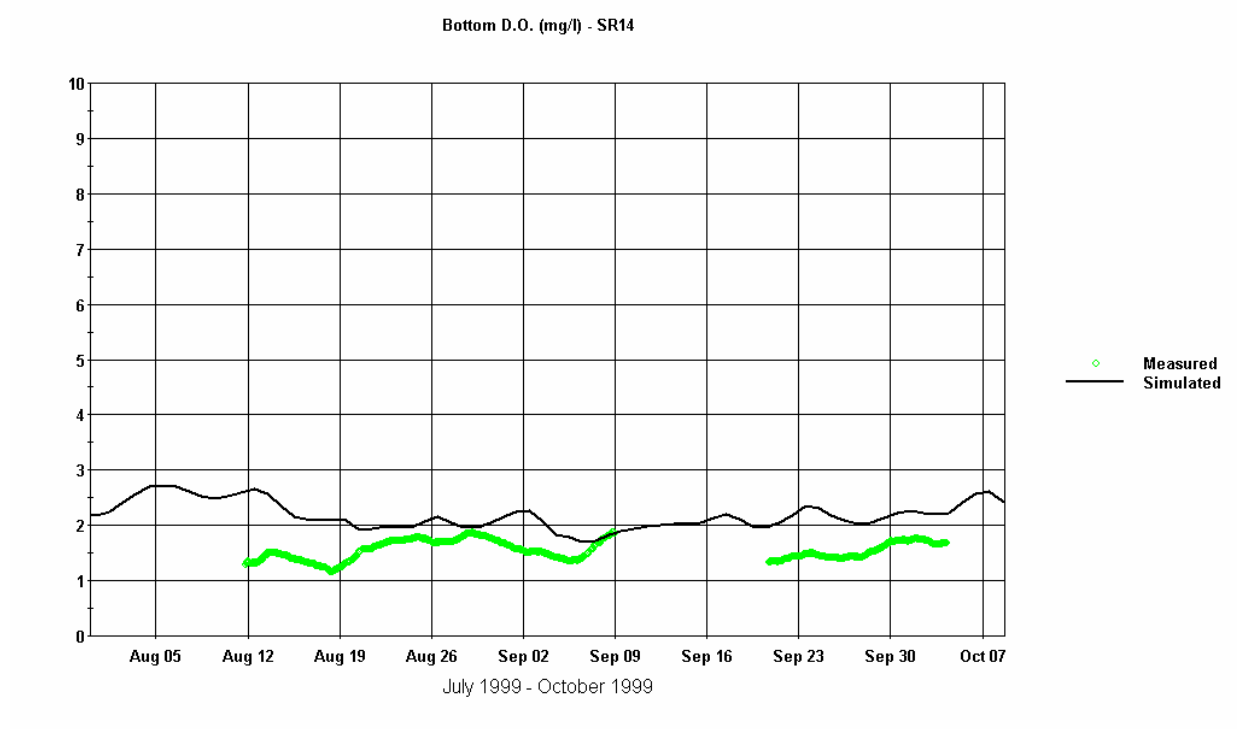


Figure R-12 Dissolved Oxygen Deficit Moving Average at SR-14 (Bottom) for July 31 through October 13, 1999

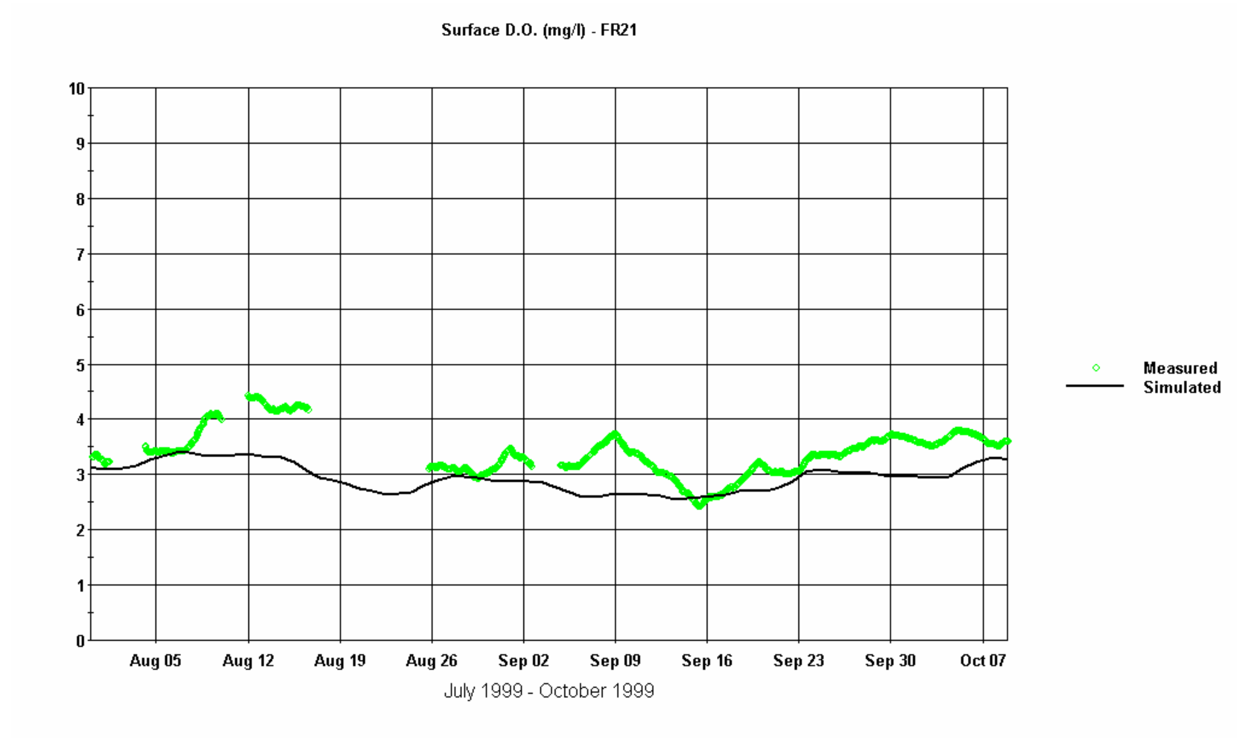


Figure R-13 Dissolved Oxygen Deficit Moving Average at FR-21 (Surface) for July 31 through October 13, 1999

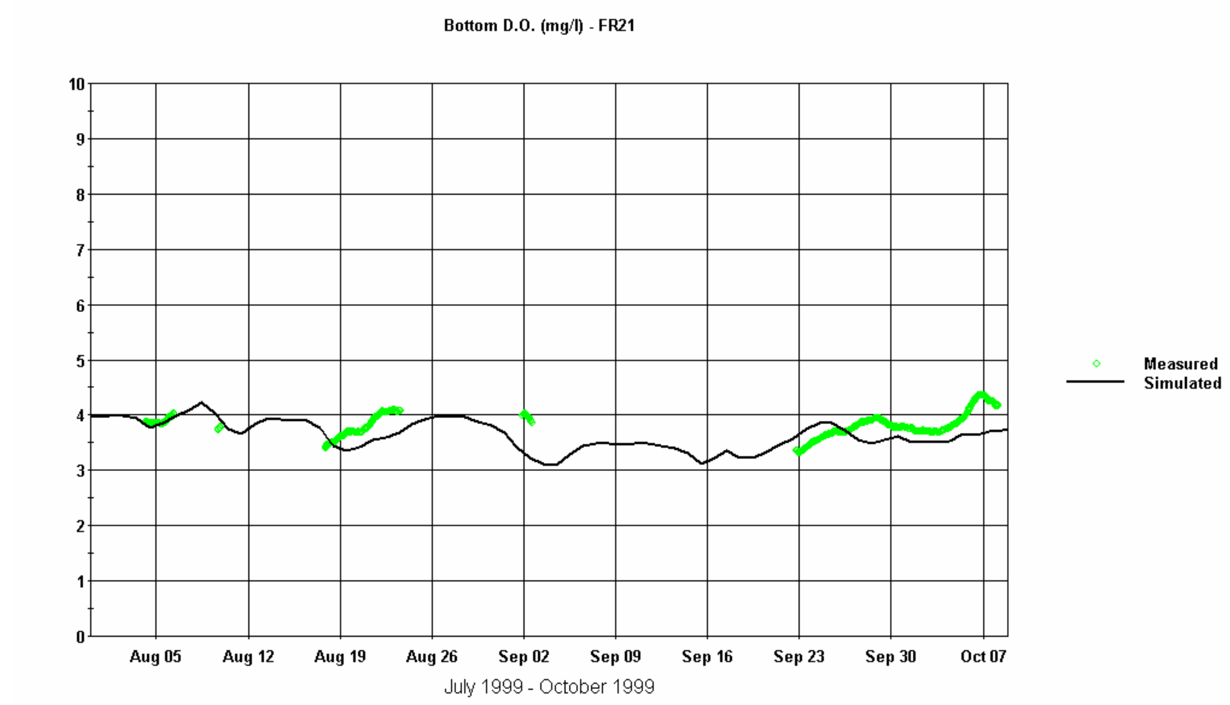


Figure R-14 Dissolved Oxygen Deficit Moving Average at FR-21 (Bottom) for July 31 through October 13, 1999

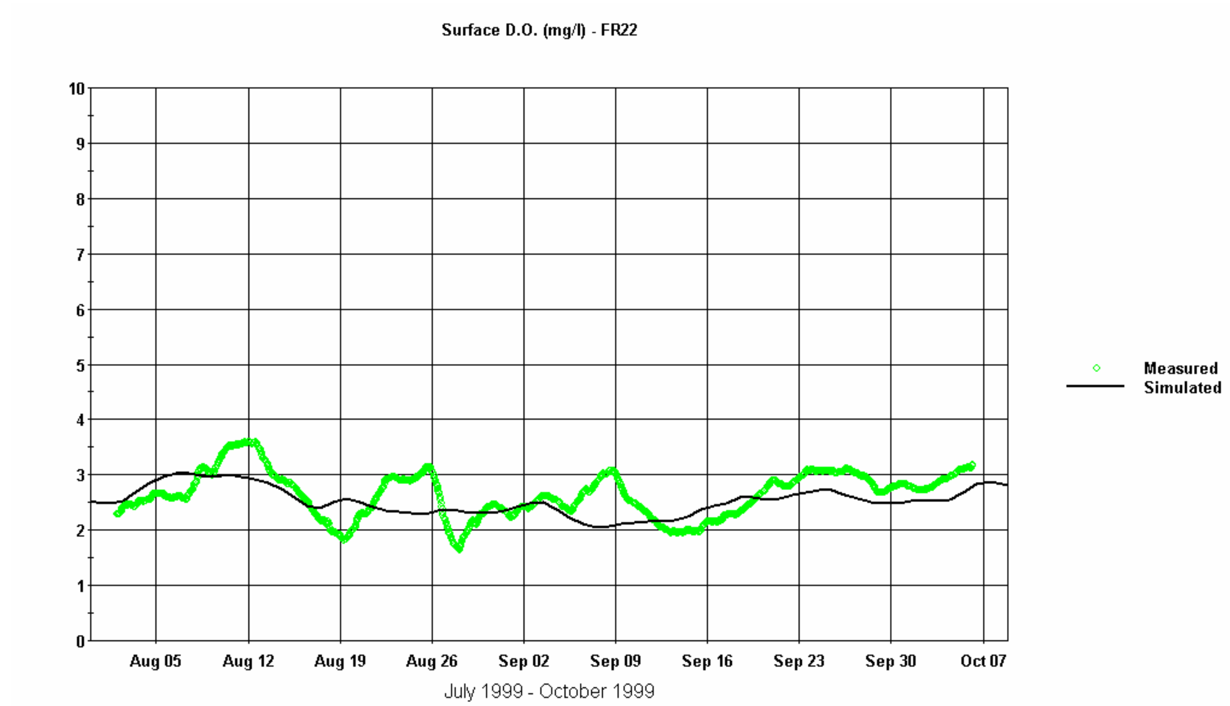


Figure R-15 Dissolved Oxygen Deficit Moving Average at FR-22 (Surface) for July 31 through October 13, 1999

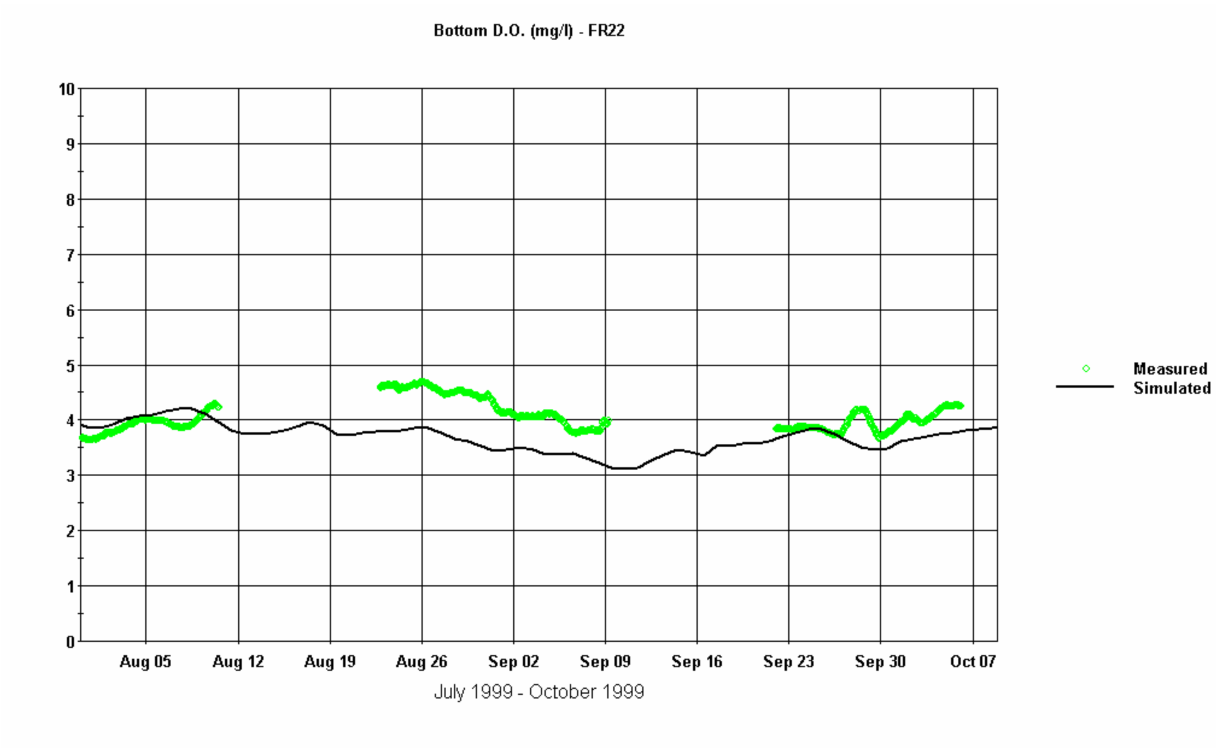
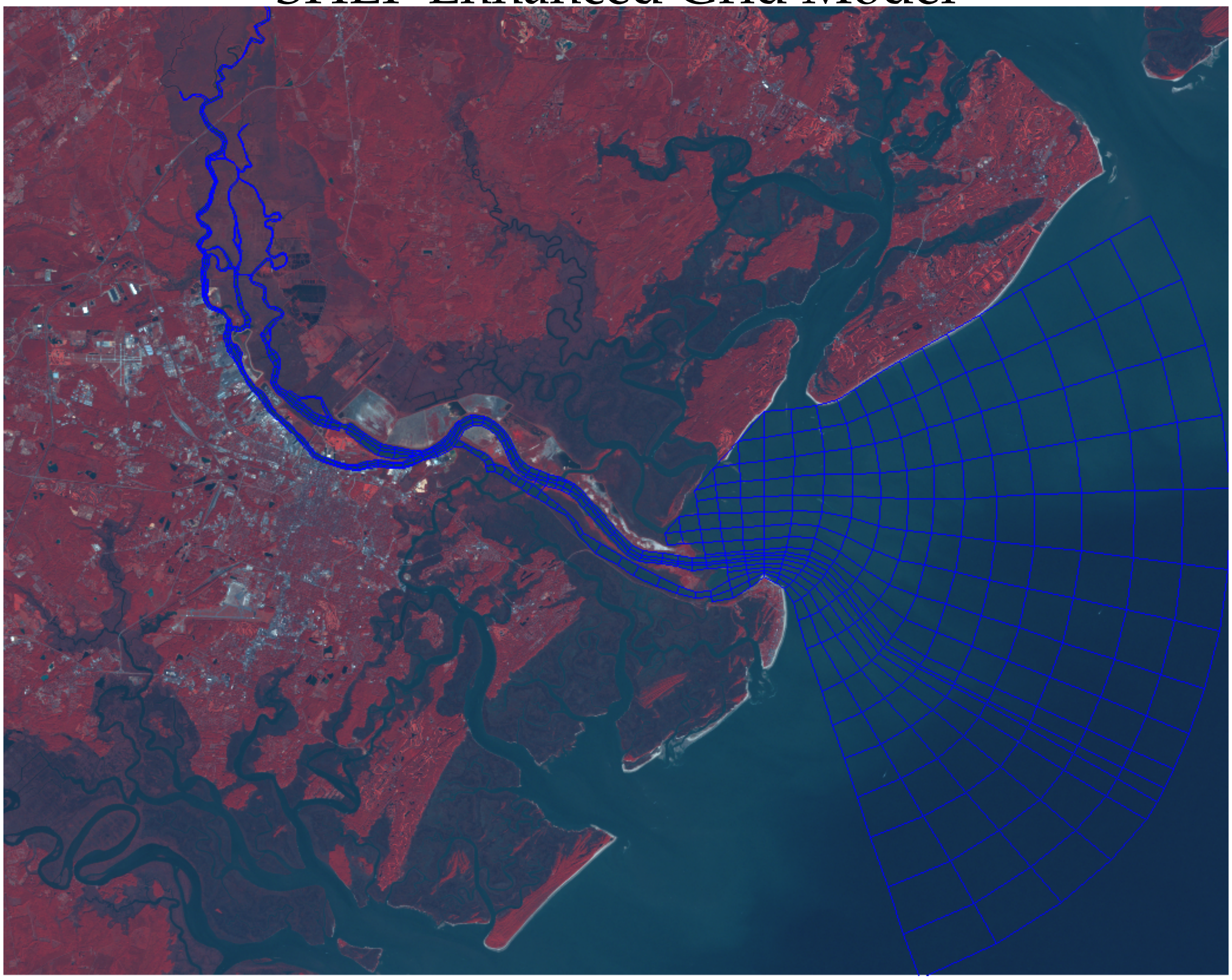


Figure R-16 Dissolved Oxygen Deficit Moving Average at FR-22 (Bottom) for July 31 through October 13, 1999

APPENDIX S UNCERTAINTY ANALYSIS OF THE SHEP ENHANCED GRID MODEL

Uncertainty Analysis of the SHEP Enhanced Grid Model



Prepared by:
Kinetic Analysis Corporation
Savannah, GA, USA

May 18, 2005

Contents

Chapter 1

Executive Summary

The Enhanced Grid version of the EFDC model of the lower Savannah River was examined and compared to long term station data at four locations. Unlike the TMDL version of the model, a complete seven year run was not possible with the same configuration used for the calibration/verification runs using data from 1997 and 1999. The results in this report are based on two runs, one of three years, the other of four, on either side of a critical condition causing abnormal model termination. This termination appears to be the result of instabilities caused by combinations of time step, model grid, and unusual flow conditions.

Even with the stability problems, the Enhanced Grid model appears to represent a significant improvement over the TMDL model. It has the potential to become an extremely useful tool in studying the lower Savannah River. However, the inability to conduct seven year test runs is a source of serious concern with respect to the suitability of the model for predictive purposes. Therefore, Kinetic Analysis Corporation does not recommend the operational use of the Enhanced Grid model for predictive modeling of bathymetric changes until the stability issues can be resolved.

Part I

Introduction and Analysis

Chapter 2

Introduction and Methodology

2.1 Introduction

This document contains the final report of Kinetic Analysis Corporation (KAC) on an analysis of the uncertainty in predictions from the Enhanced Grid (ENHG) configuration of the EFDC Model of the lower Savannah River. An Uncertainty Analysis essentially consists of running a model under known conditions, then varying the input variables in such as way as to observe the reaction of the model so as to be able to anticipate the predictive ability of the model. In this study, emphasis is made on salinity calculations at the four USGS long term monitoring stations. Salinity is a good indicator of overall performance of the model as the transport of salt is dependent on both the horizontal and vertical mixing and mass transport in the model. Additional analysis is provided on the potential for the uncertainty in salinity to propagate through to dissolved oxygen calculations.

KAC initially attempted to conduct this study in the same manner as that used to evaluate the TMDL model (see the Draft Report, Uncertainty Analysis of the TMDL model). In summary, KAC obtained the source code and input file configuration from TetraTech. KAC then compiled the code and executed seven year runs (Jan 97 - Dec 03) for the official configuration of the model as well as other configurations with modified time steps, bottom depths, friction, etc. In all cases the model was stable and produced usable results. This approach proved unsuccessful with the ENHG configuration. Numerous delays crept in to the process because both TetraTech (Tt) and KAC were unable to successfully run a complete seven year baseline using the same configuration and input files used for the calibration and verification runs. After considerable analysis and discussion, three issues were identified:

1) Different configuration files (due to numerous experiments by multiple individuals in both organizations attempting to address the problem);

2) Different compilers and settings;

3) Model stability at different step sizes and configurations.

Once the configuration file issue was resolved, it appeared at first that the difference in compilers was causing problems, and considerable time and effort was spent exploring the impact of various operating systems, compilers, and compiler options on the code. The final result of those analyses were that the EFDC code is relatively portable and stable, and provided care is taken to ensure identical floating point treatment, platform and compiler choice is not a factor. Results are nearly identical even across a wide range of platforms and compiler selections.

The underlying reason for the differing results now appears to be that the ENHG model has marginal stability at some combinations of step time, flow and tides. These conditions were not encountered during the calibration or verification periods in 97 and 99. The normally negligible differences between compilers and options grew exponentially during conditions of marginal stability, resulting in crashes at different times depending on the exact platform, compiler, and even configuration of a given compiler. The following figure (2.1) shows the relative flow frequencies at Clyo for the overall study period (97-03), a longer term (1986-03), and the two subsets.

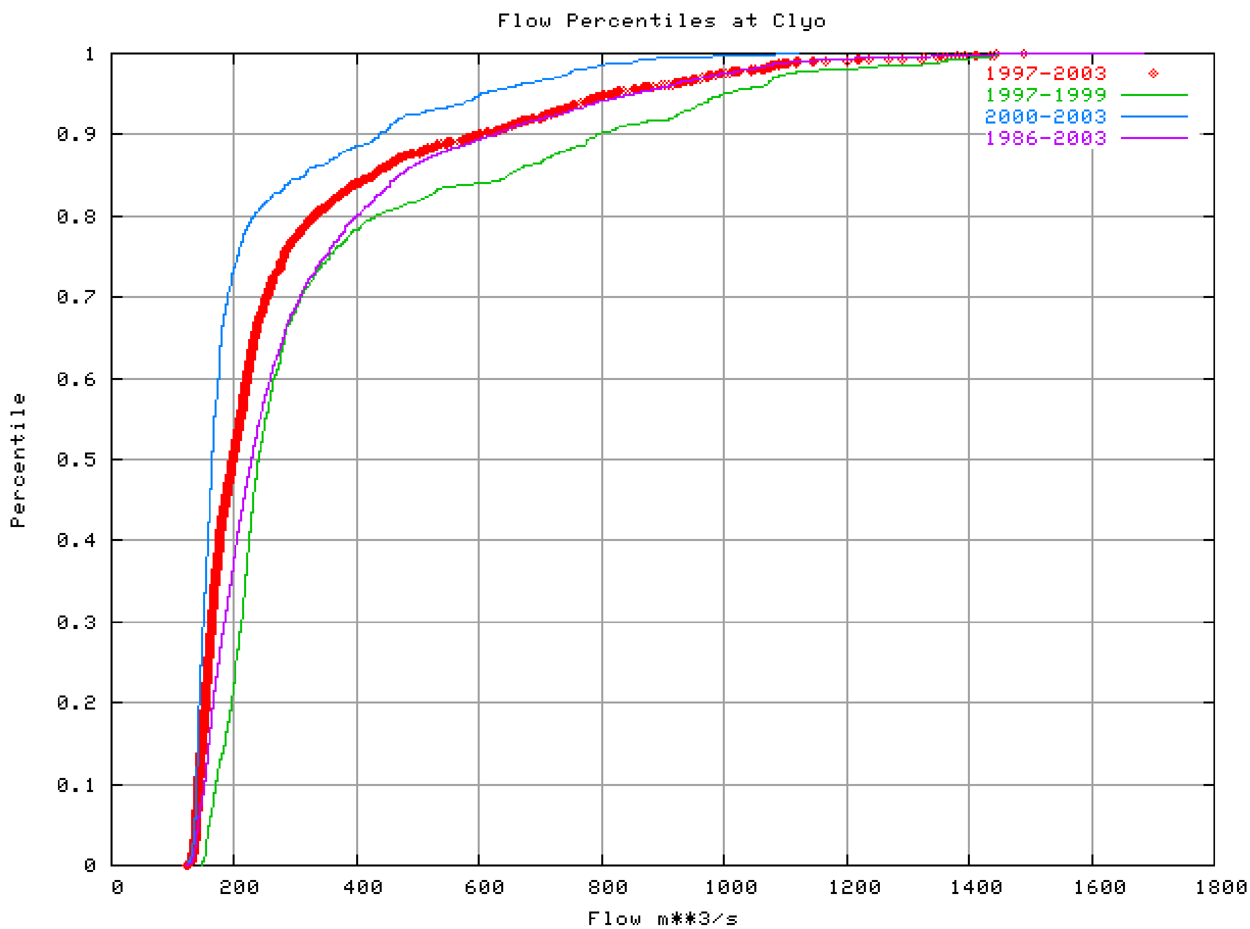


Figure 2.1: Flow percentiles at Clyo

As is readily seen, the two subsets form two distinct populations from either the overall study period or of the longer term data, especially when the low to medium flows are examined (figure 2.2) The 2000-2003 time frame is anomalous in many respects. For example, in the 1986 to 2003 time frame, only 10 percent of daily flows were less than 150 m**3/s. In the 2000-2003 time frame, over 30 percent of the flows were under this value, while in the 1997-1999 time frame, less than 2 percent of flows were below 150 m**3/s. Given that the model was calibrated to the 1997-1999 time frame, the high frequencies of low flows in the 2000-2003 time frame make it a good test of the model under "unknown" conditions, and a successful run is highly desirable.

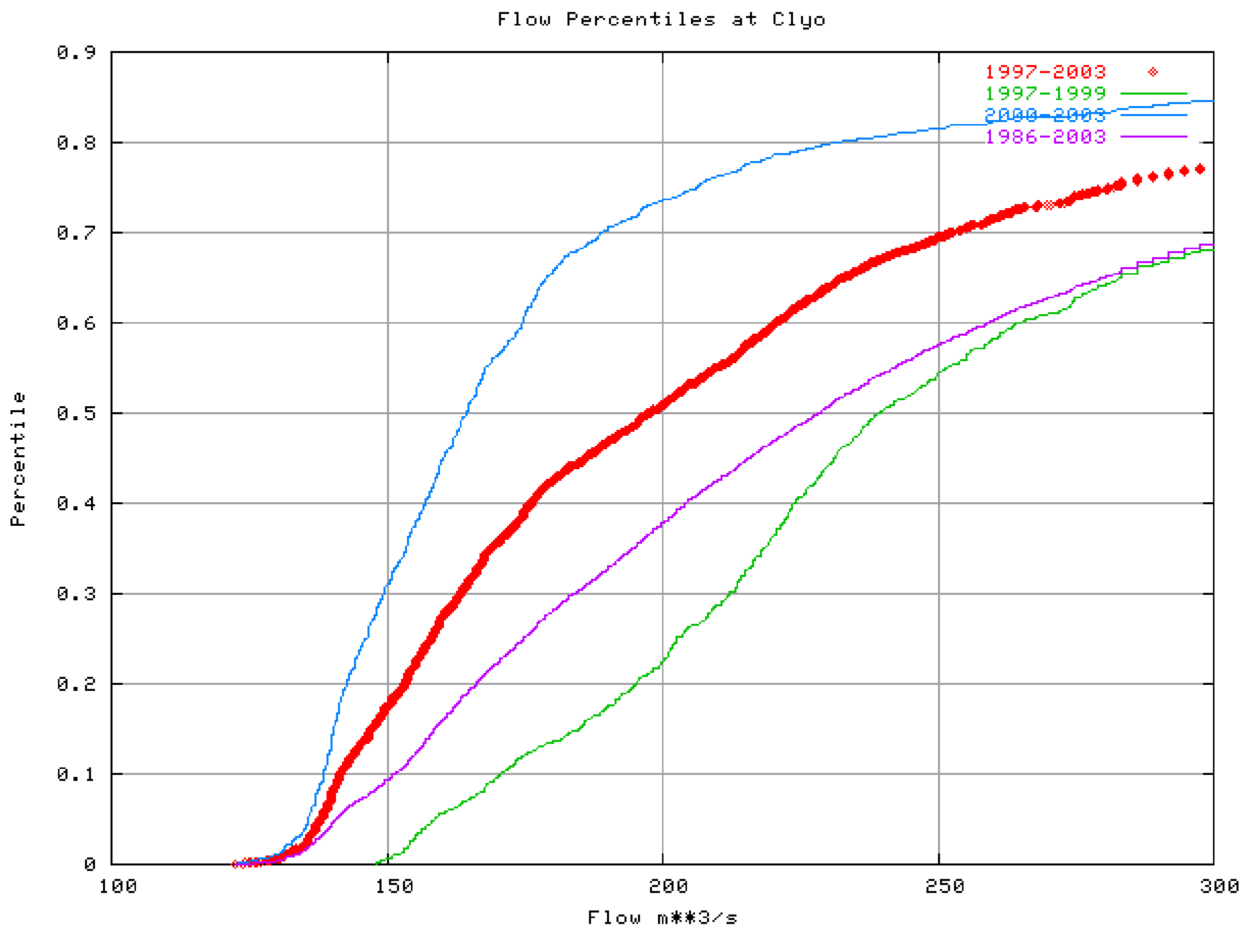


Figure 2.2: Flow percentiles at Clyo, 100-300 m**3/s

In conclusion, issues one and two (configuration and compiler/platform) have been resolved to the satisfaction of both Tt and KAC, with issue three, the stability of the model under different combinations of flow, time step, and boundary, remaining unresolved. KAC has made several recommendations to Tt to further explore this matter. As of the date of this report and the conclusion of the calibration/verification phase, the full cause and impact of these instability issues remain unresolved. In order to complete this report, two independent runs were made to avoid the point at which the model aborted. KAC has several recommendations based on this experience, which are included in chapter 5.

This document contains three major sections:

1) This introduction;
2) A comparison of the available results of the ENHG model with the TMDL model;
3) The potential impact of error in salinity on dissolved oxygen calculations in WASP;
4) Recommendations and observations;
5) Supporting graphics.

2.2 Methodology

As much as possible, this study was conducted in the same manner as the assessment of the TMDL model. As noted above, the model was compiled locally on using the Intel, Lahey, and GNU Fortran compilers on both Linux (2.6.4-52-smp and 2.6.9-1.667smp kernels) and Microsoft Windows XP sp1 platforms. The graphs and data to support this analysis were created using the Linux/Intel combination for performance reasons. TetraTech provided the results of their runs (1997-1999 and 2000-2003), which were compared to the local runs and found to be virtually identical.

Unlike the TMDL model, which was run with multiple, alternate scenarios to more fully assess the potential uncertainty in forecasts, the ENHG grid was only run operationally using the provided configuration. Tests were run with alternate configurations, however, some were stable while others were not. Therefore, these alternate scenarios were not analyzed.

For each available data point at a station, the observed value was compared with closest modeled value to that point. This resulted in from 22,000 (Houlihan) to over 70,000 (FWS) points of comparison. The difference between observed and computed was tabulated by salinity, flow at Clyo, and tides, enabling the stratification of error by any of these three variables. Error by salinity is the pure error in the model, while stratification of error by flow and by tides provide indications of how error changes with changes in these two key boundary conditions. These output files were analyzed using the ”R” statistics package:

R Development Core Team (2004). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

The graphics were created using C shell scripts and the GNUplot program, version 3.7. Note that some of the graphs are clipped, or contain bins with zero values, due to the lack of data resulting from the inability to complete the seven year run.

This document was produced using the LaTEX text processing system.

Chapter 3

Comparisons with TMDL model

These graphs show the median errors and 50 percent error limits for both the TMDL model, the two runs of the ENHG configuration, the combined results of the split ENHG run. The ”A” run is 1997-1999, while the ”B” runs is from 2000-2003. As can be seen from these graphs, the performance of of the ENHG model is not consistent between the two periods. This is unlike the TMDL model, which had relatively consistent error bands when partitioned in to two runs.

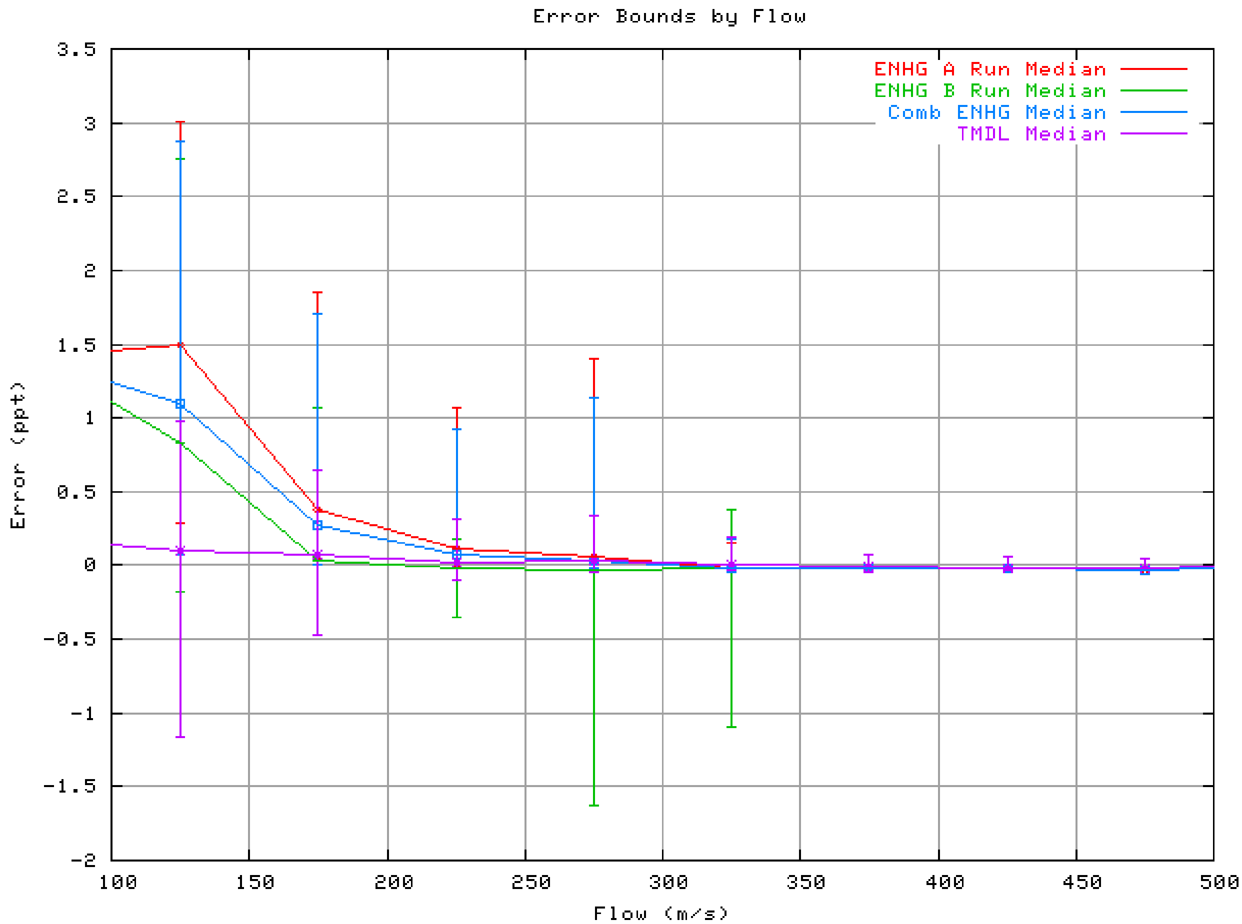


Figure 3.1: Comparison of error bounds, TMDL vs. ENHG at Houlihan Bridge

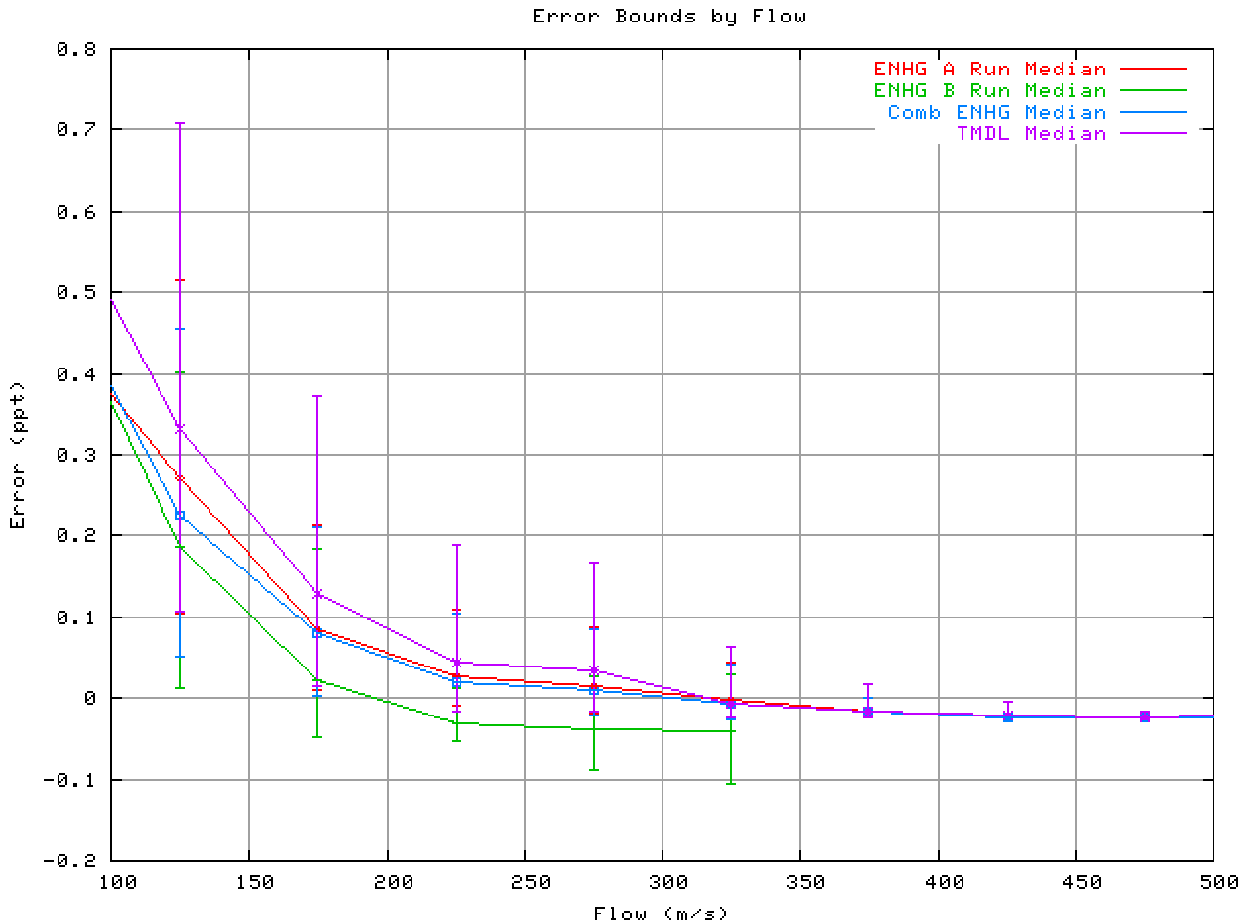


Figure 3.2: Comparison of error bounds, TMDL vs. ENHG at US FWS Dock

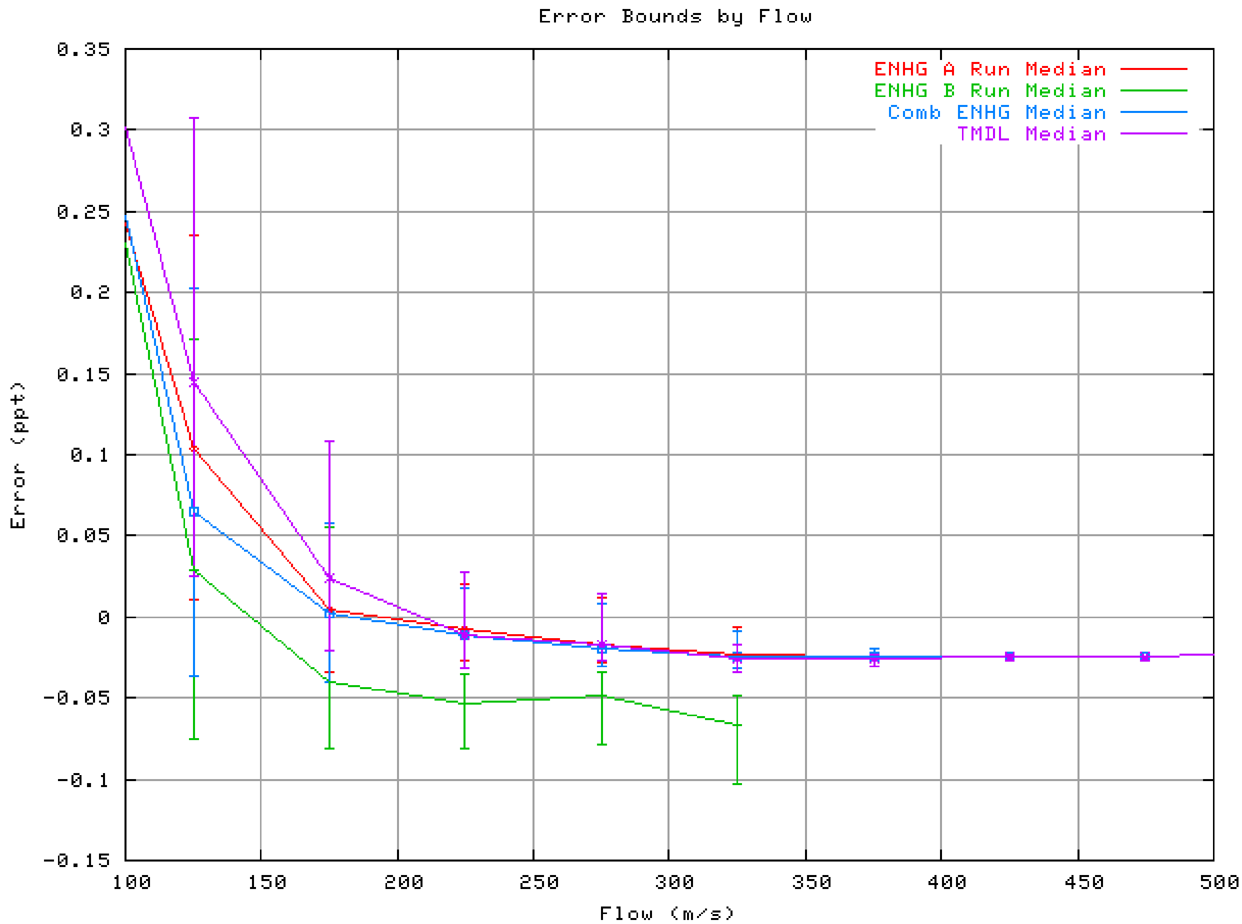


Figure 3.3: Comparison of error bounds, TMDL vs. ENHG at Lucknow Canal

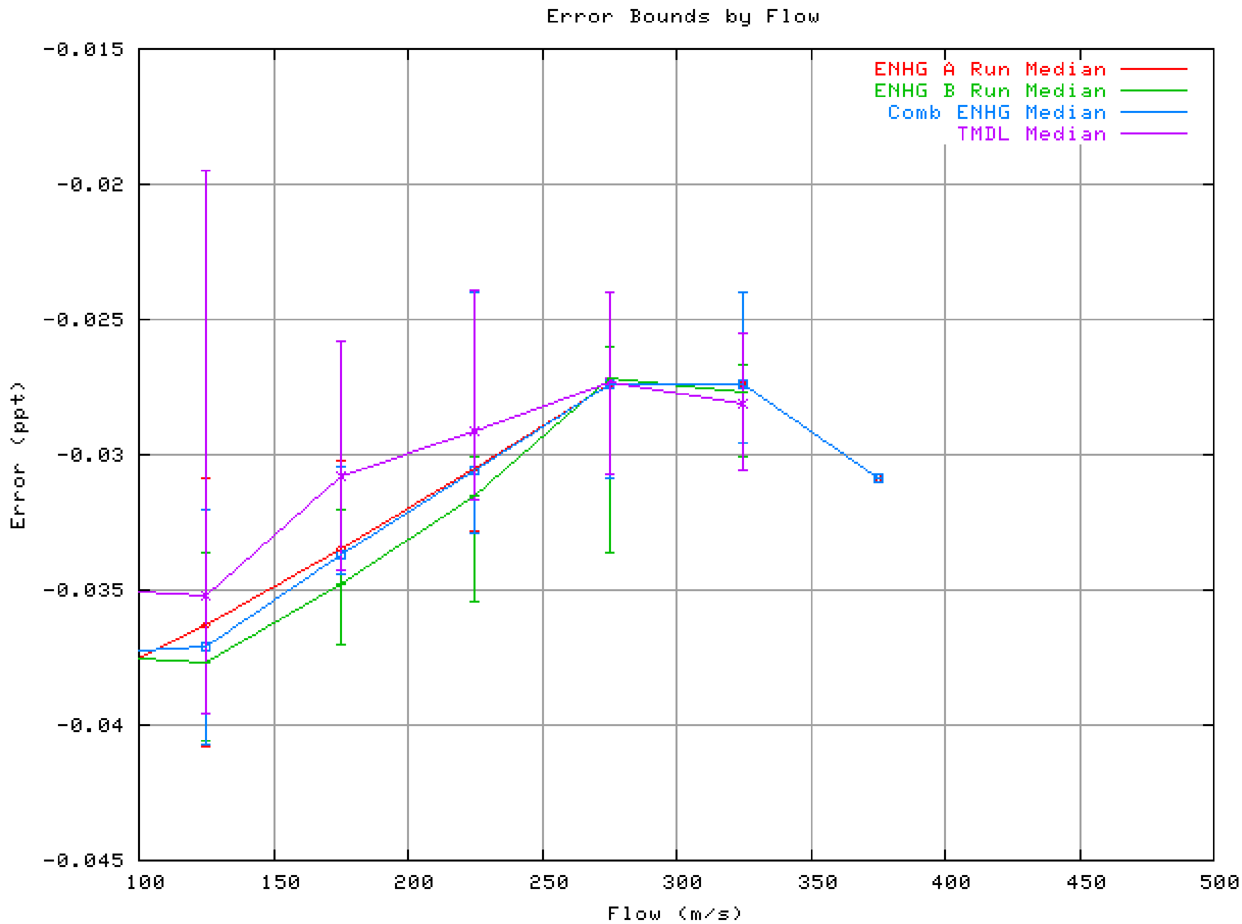


Figure 3.4: Comparison of error bounds, TMDL vs. ENHG at I-95 Bridge

Chapter 4

Assessment of induced error in DO calculations

In order to assess the potential impact of salinity errors on DO calculations, the impact of salinity errors on dissolved oxygen (DO) saturation was estimated as follows. For each salinity comparison, the concurrent DO saturation value was computed (Brown, Skougstad, and Fishman, 1970) for both observed and modeled salinity/temperature combinations. The difference between the computed saturation values is here called the "induced error". It provides an indication of the potential propagation of error into the water quality calculations.

Note that these should be considered lower limits to DO errors. In other words, the dissolved oxygen uncertainty can probably be no better than that indicated below, since the DO calculation depends in part on salinity.

4.1 Performance on 1997-1999 run

This series of graphs shows induced DO error based on the 1997-1999 run.

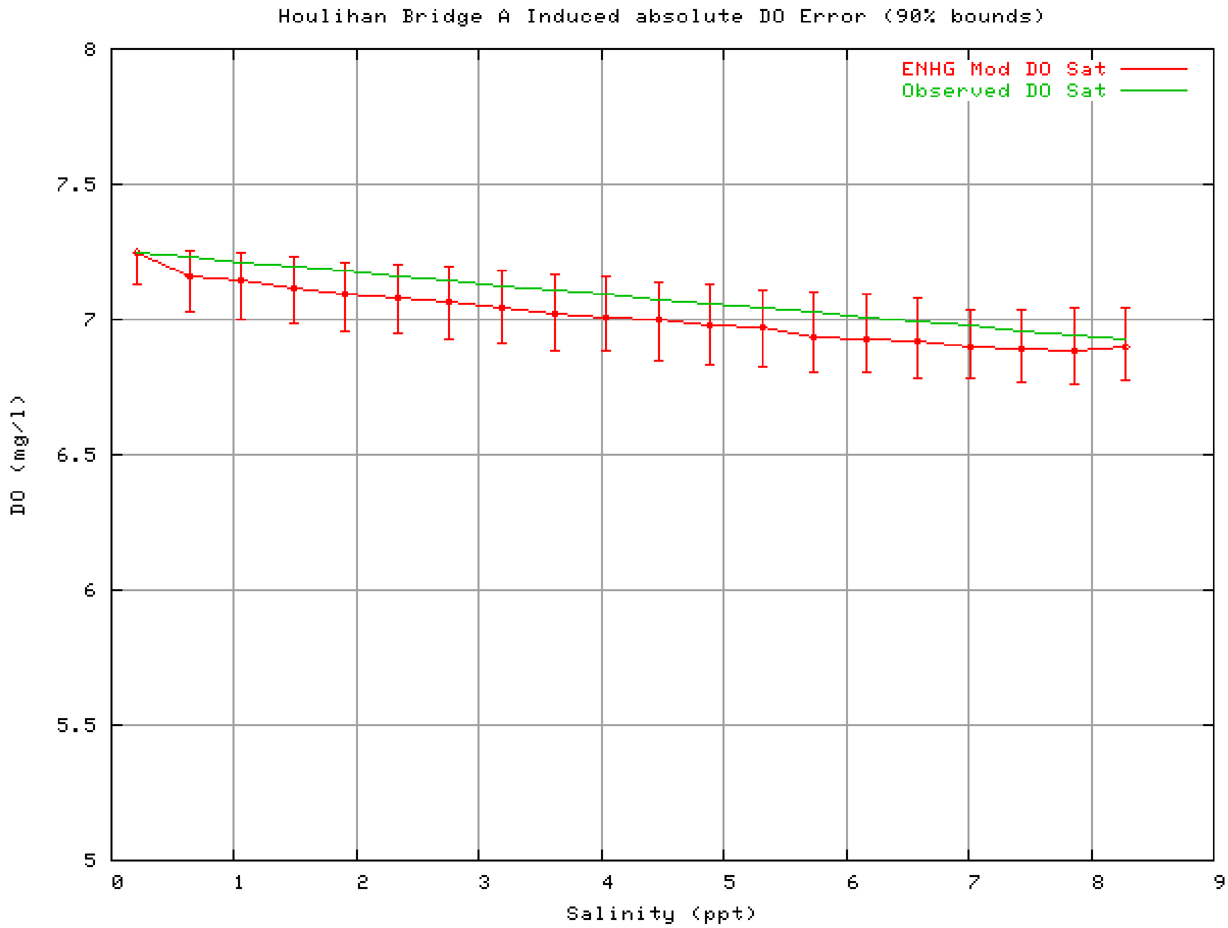


Figure 4.1: DO Absolute Error Analysis, Houlihan Bridge, 97-99

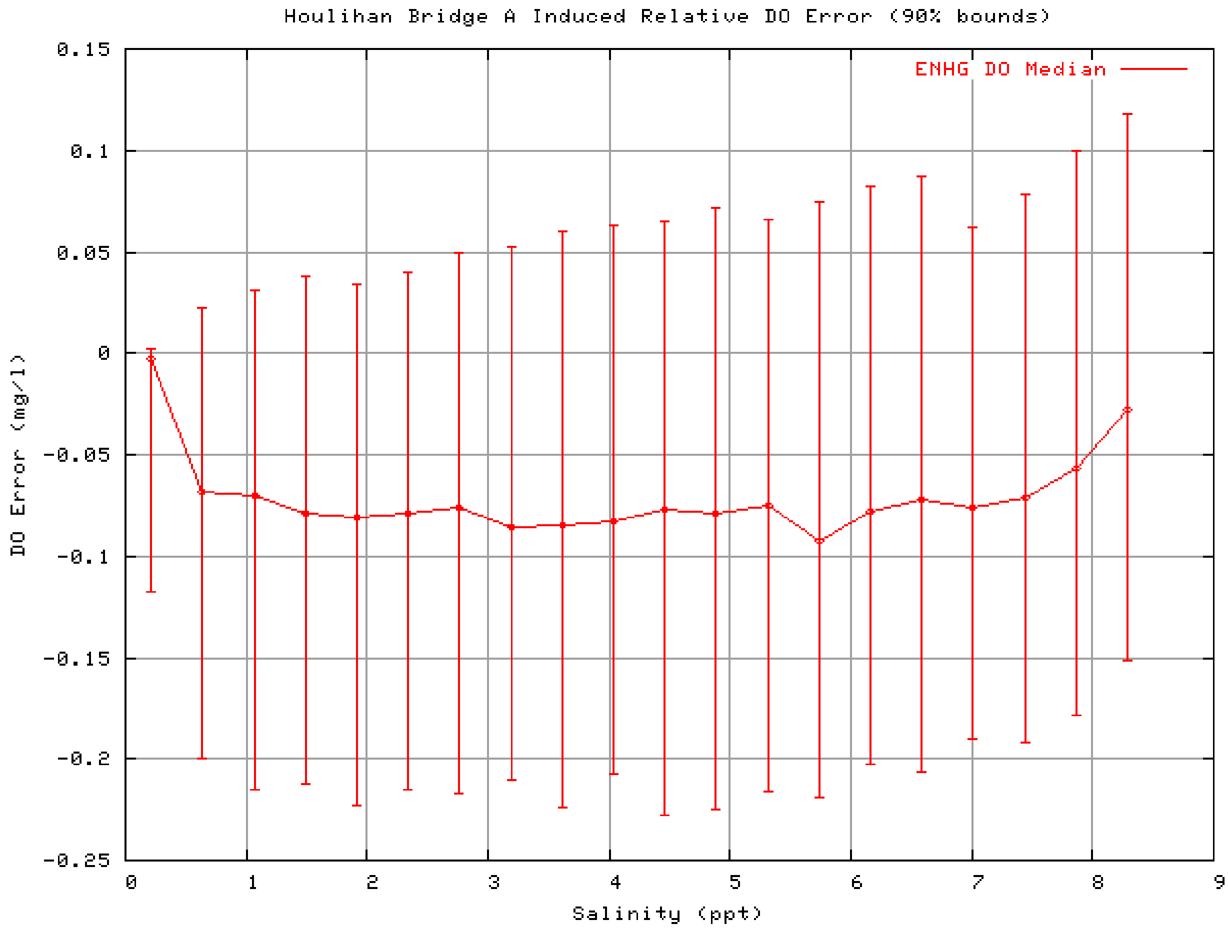


Figure 4.2: DO Relative Error Analysis, Houlihan Bridge, 97-99

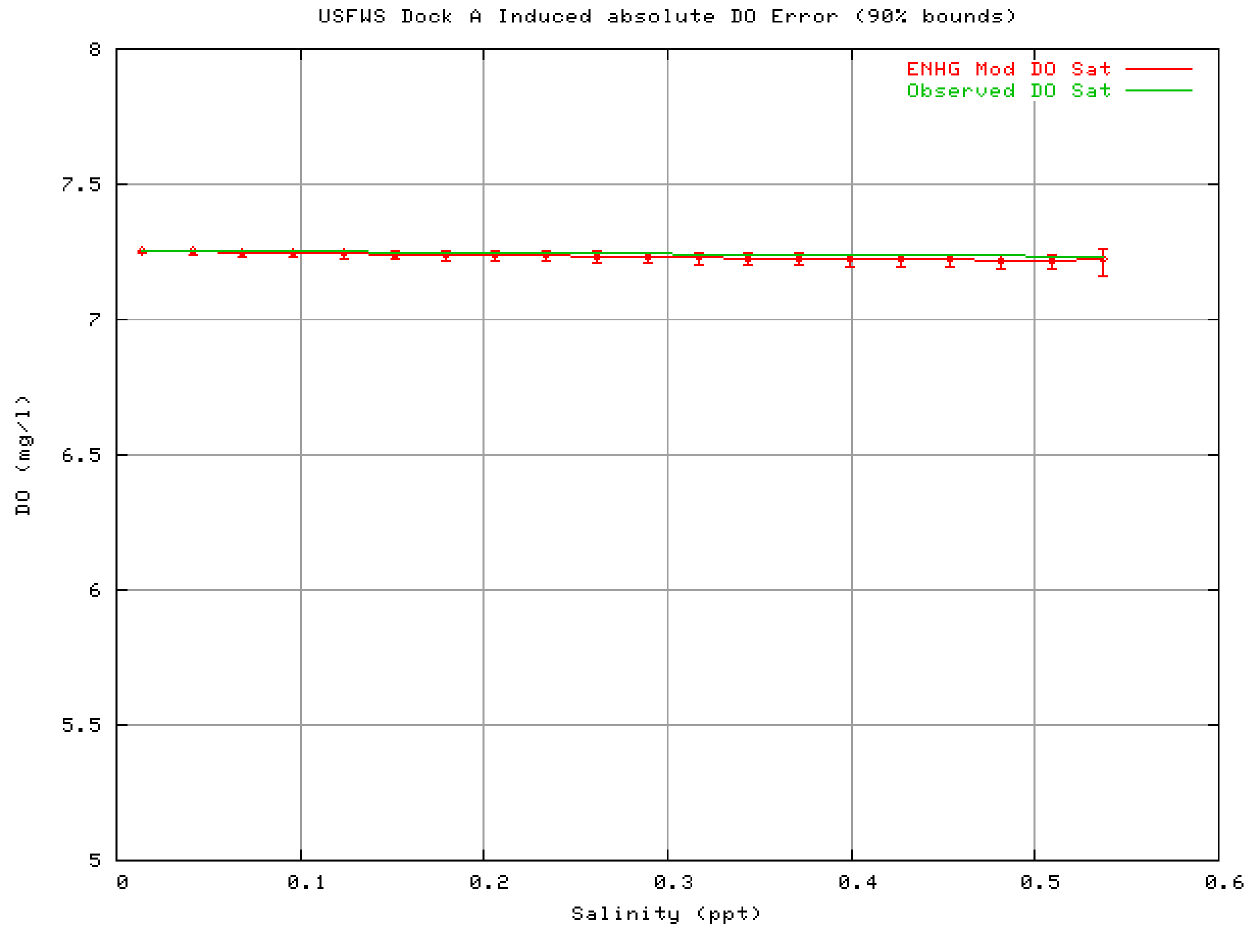


Figure 4.3: DO Absolute Error Analysis, USFWS Dock, 97-99

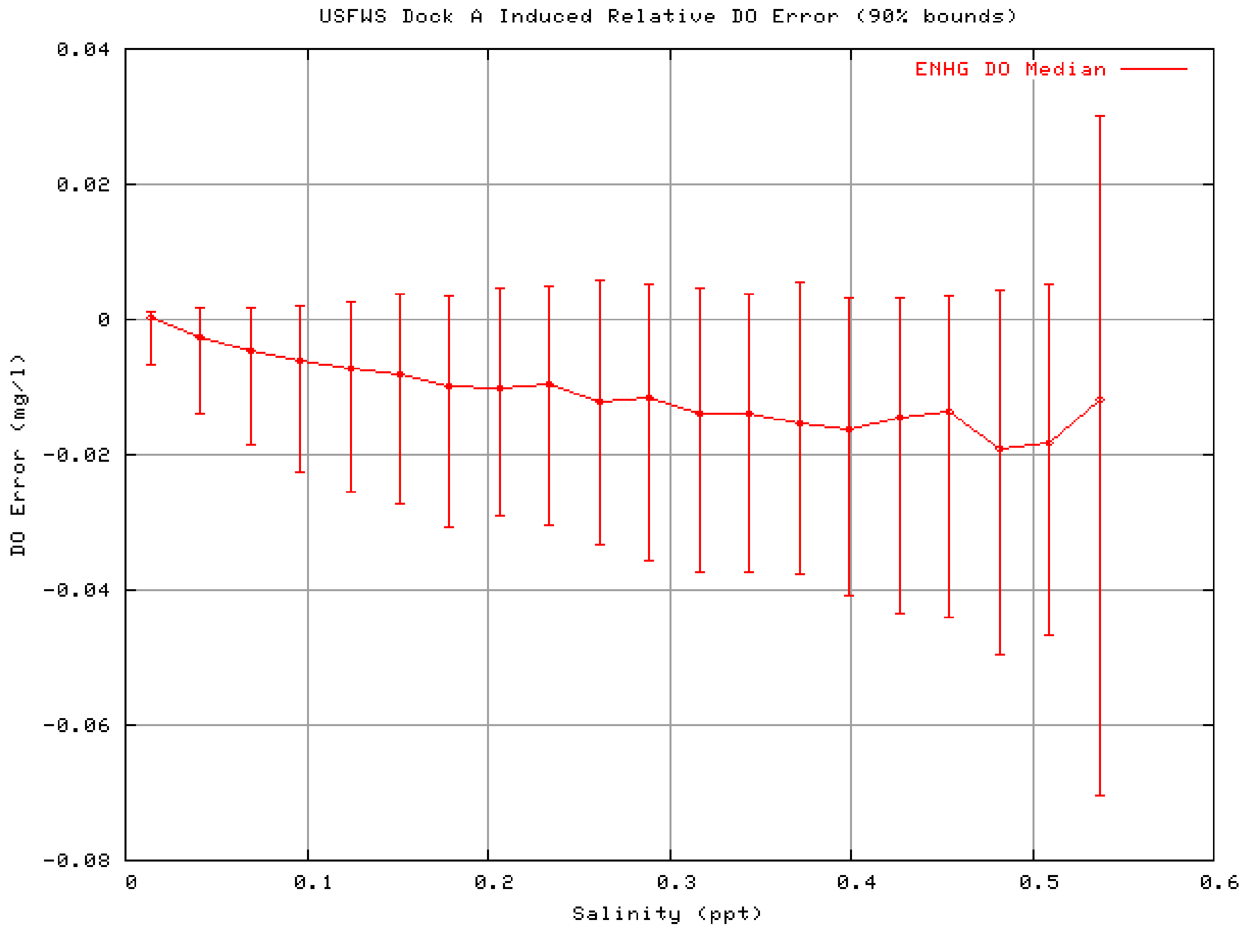


Figure 4.4: DO Relative Error Analysis, USFWS Dock, 97-99

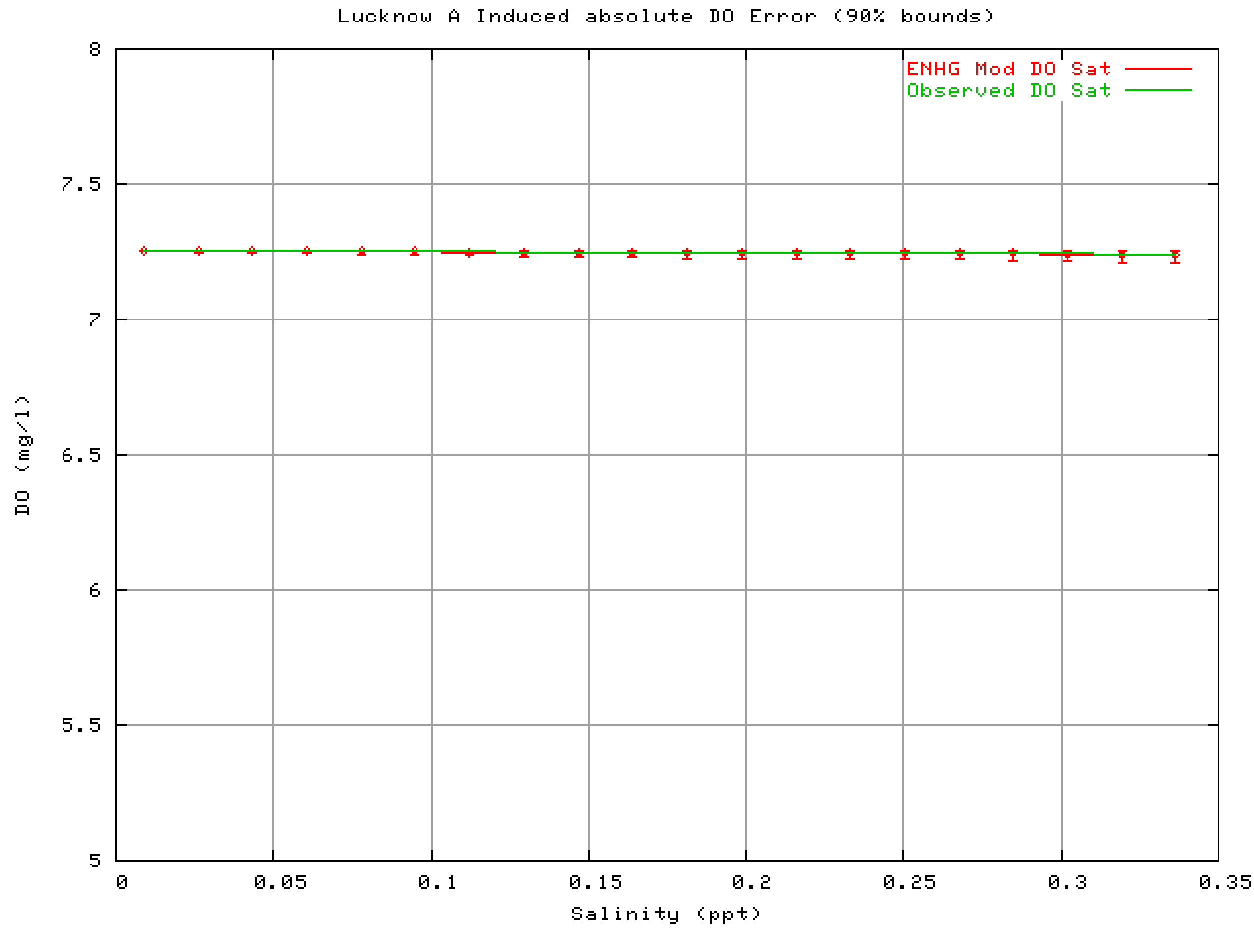


Figure 4.5: DO Absolute Error Analysis, Lucknow Canal, 97-99

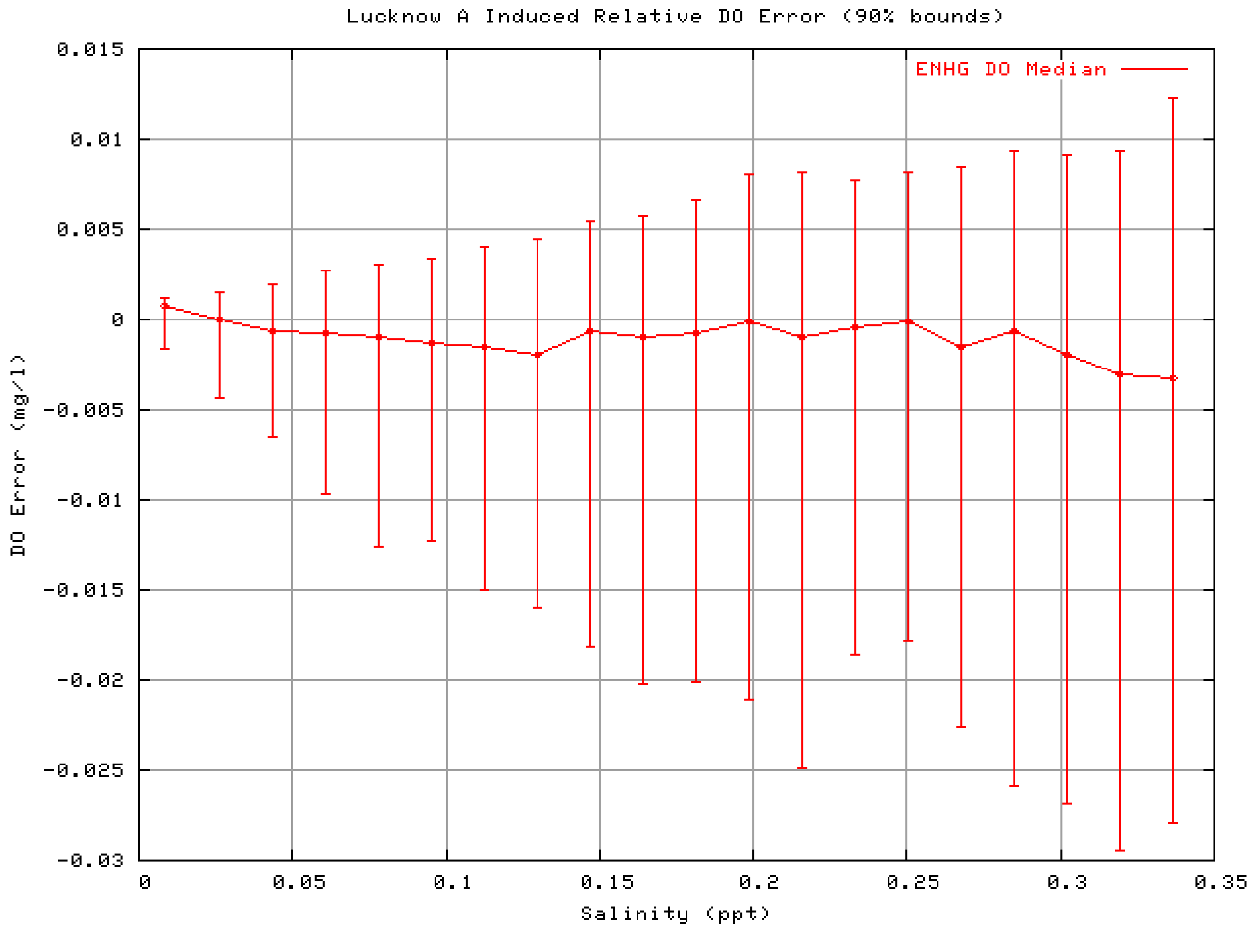


Figure 4.6: DO Relative Error Analysis, Lucknow Canal, 97-99

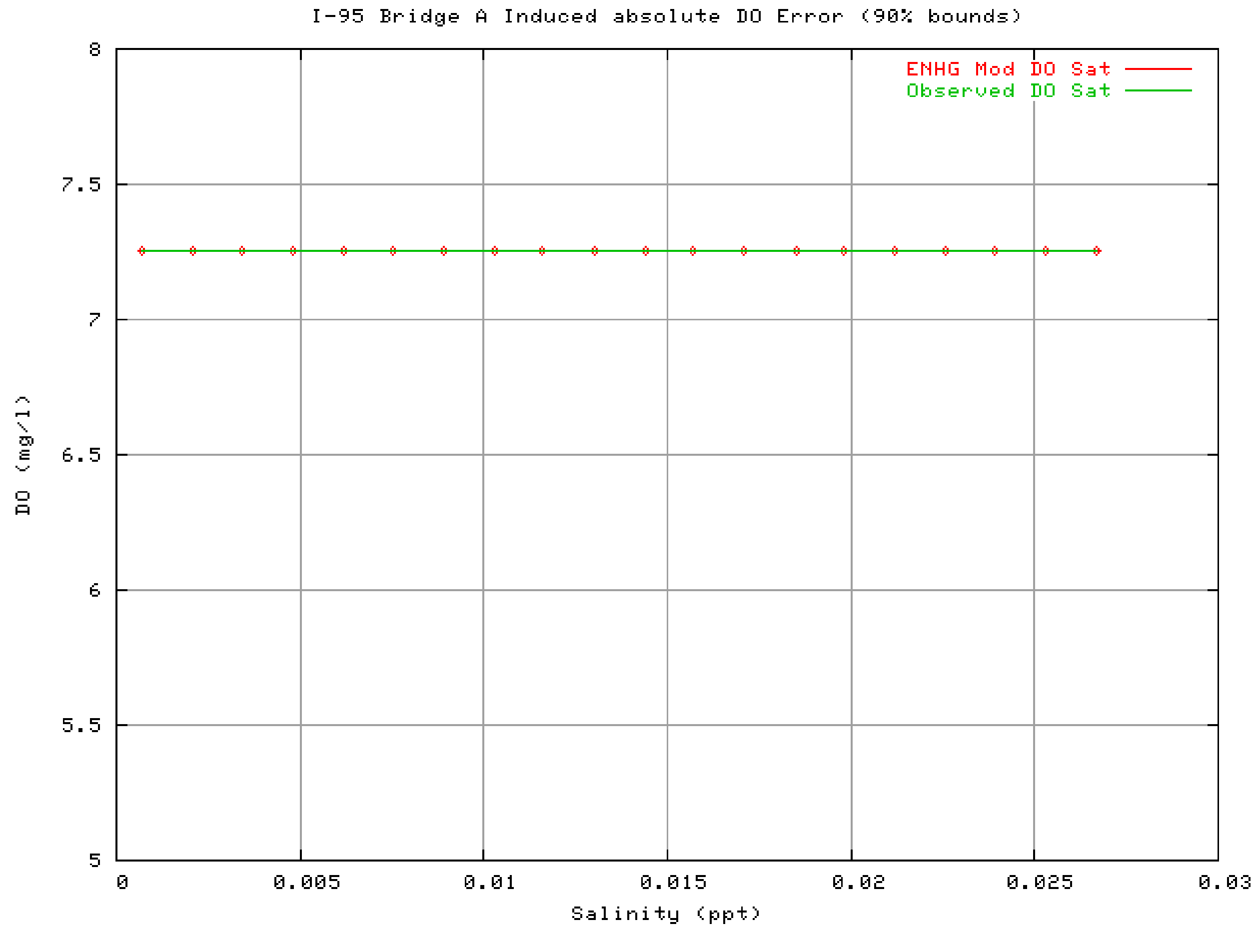


Figure 4.7: DO Absolute Error Analysis, I-95 Bridge, 97-99

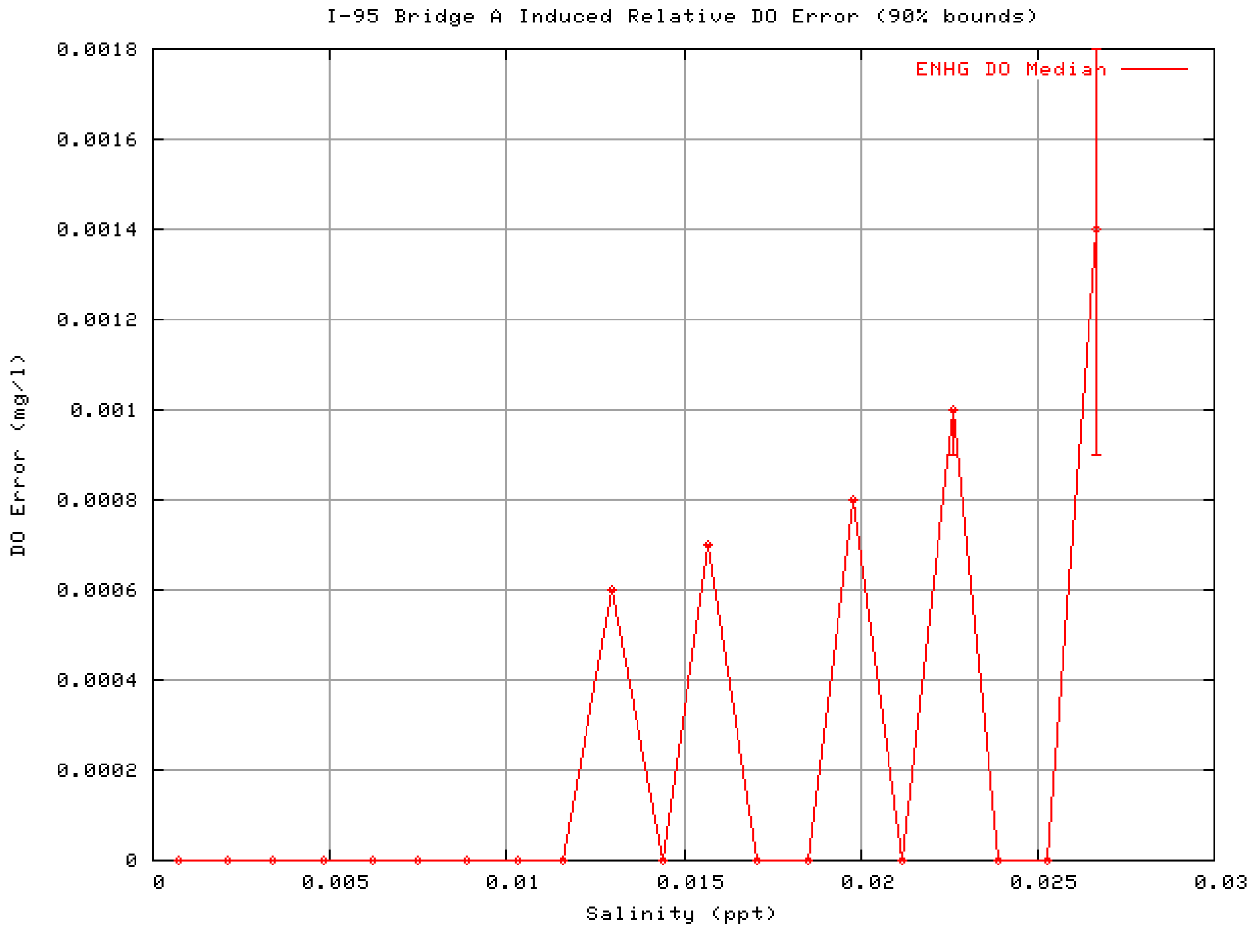


Figure 4.8: DO Relative Error Analysis, I-95 Bridge, 97-99

4.2 Performance on 2000-2003 run

This series of graphs shows induced DO error based on the 2000-2003 run.

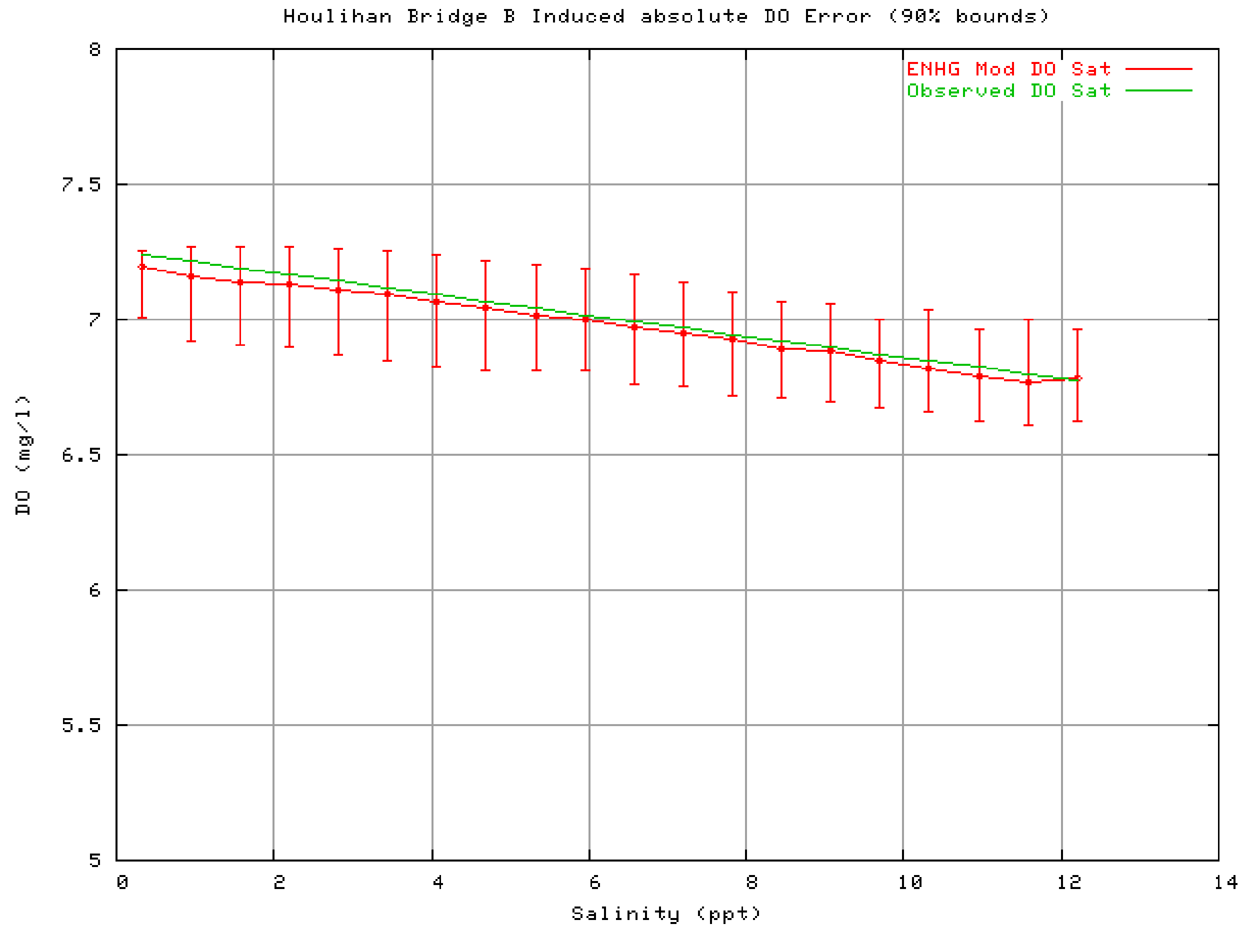


Figure 4.9: DO Absolute Error Analysis, Houlihan Bridge, 00-03

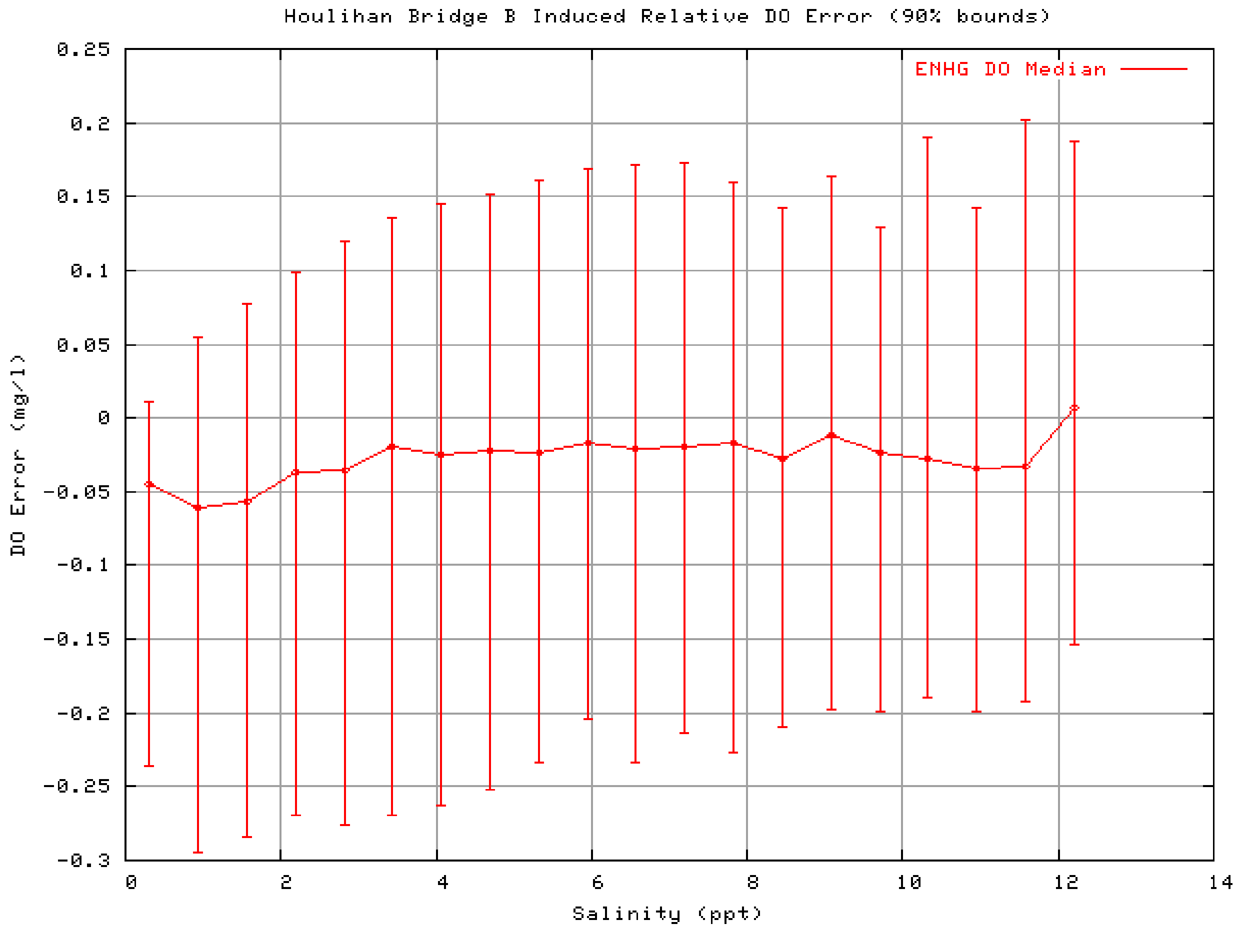


Figure 4.10: DO Relative Error Analysis, Houlihan Bridge, 00-03

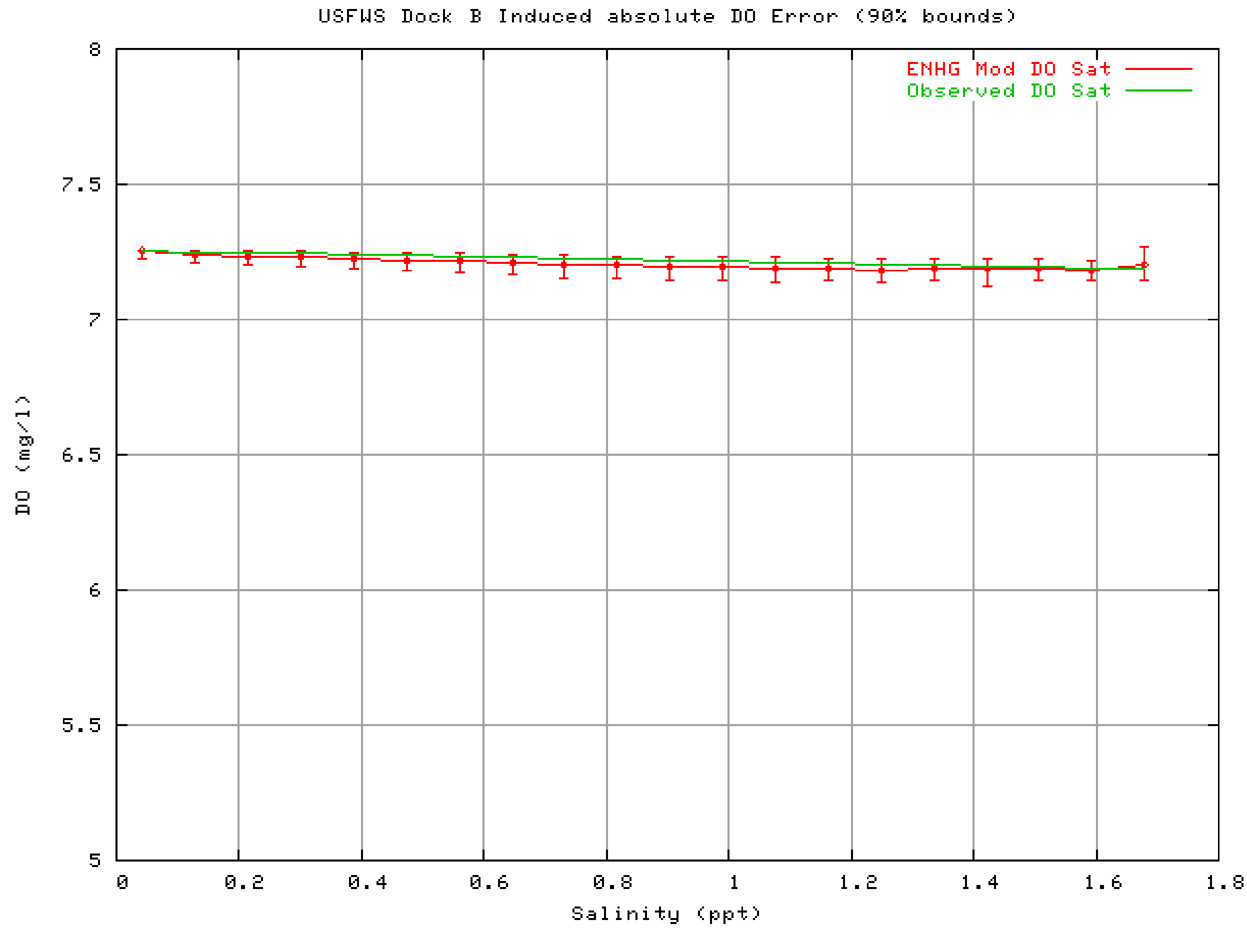


Figure 4.11: DO Absolute Error Analysis, USFWS Dock, 00-03

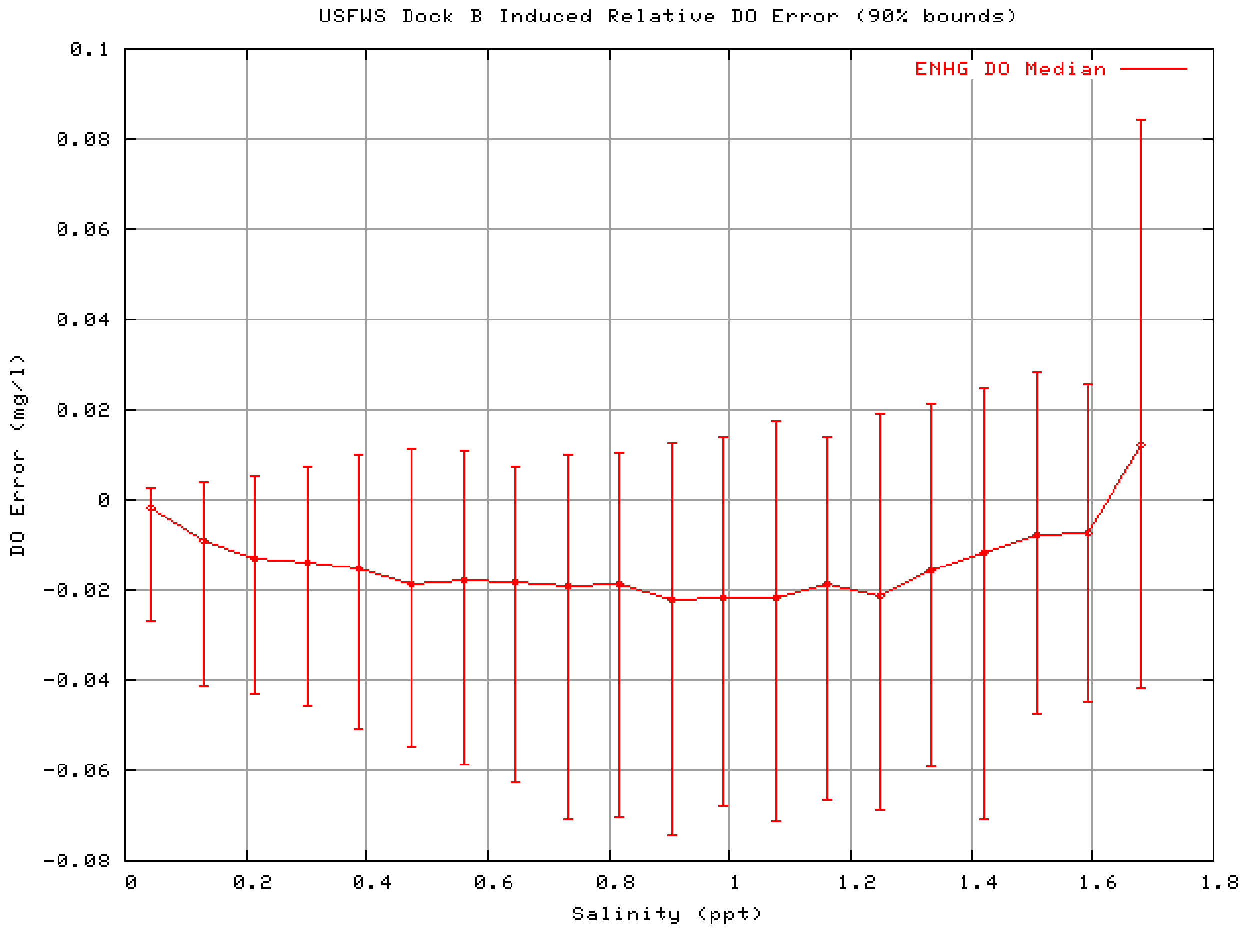


Figure 4.12: DO Relative Error Analysis, USFWS Dock, 00-03

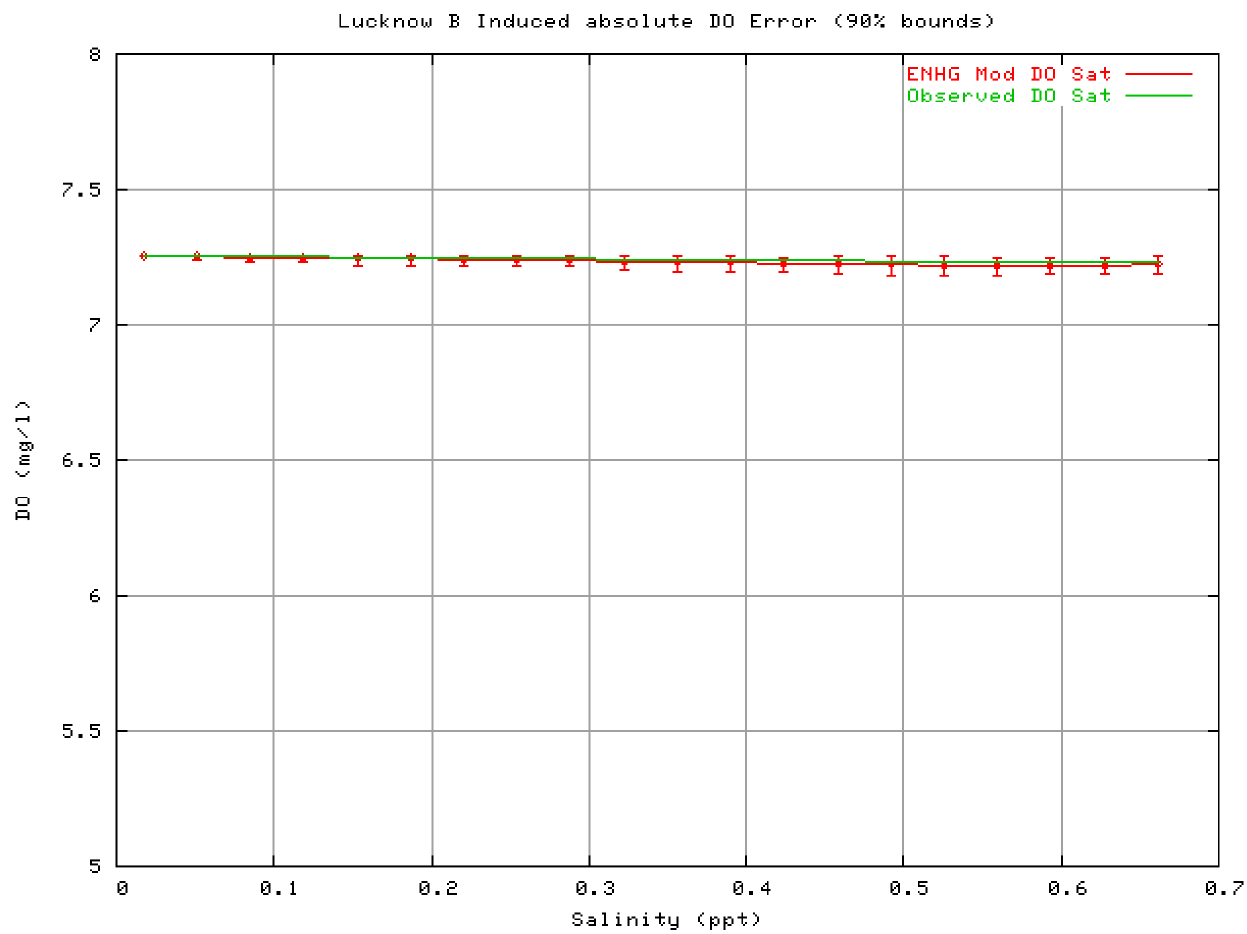


Figure 4.13: DO Absolute Error Analysis, Lucknow Canal, 00-03

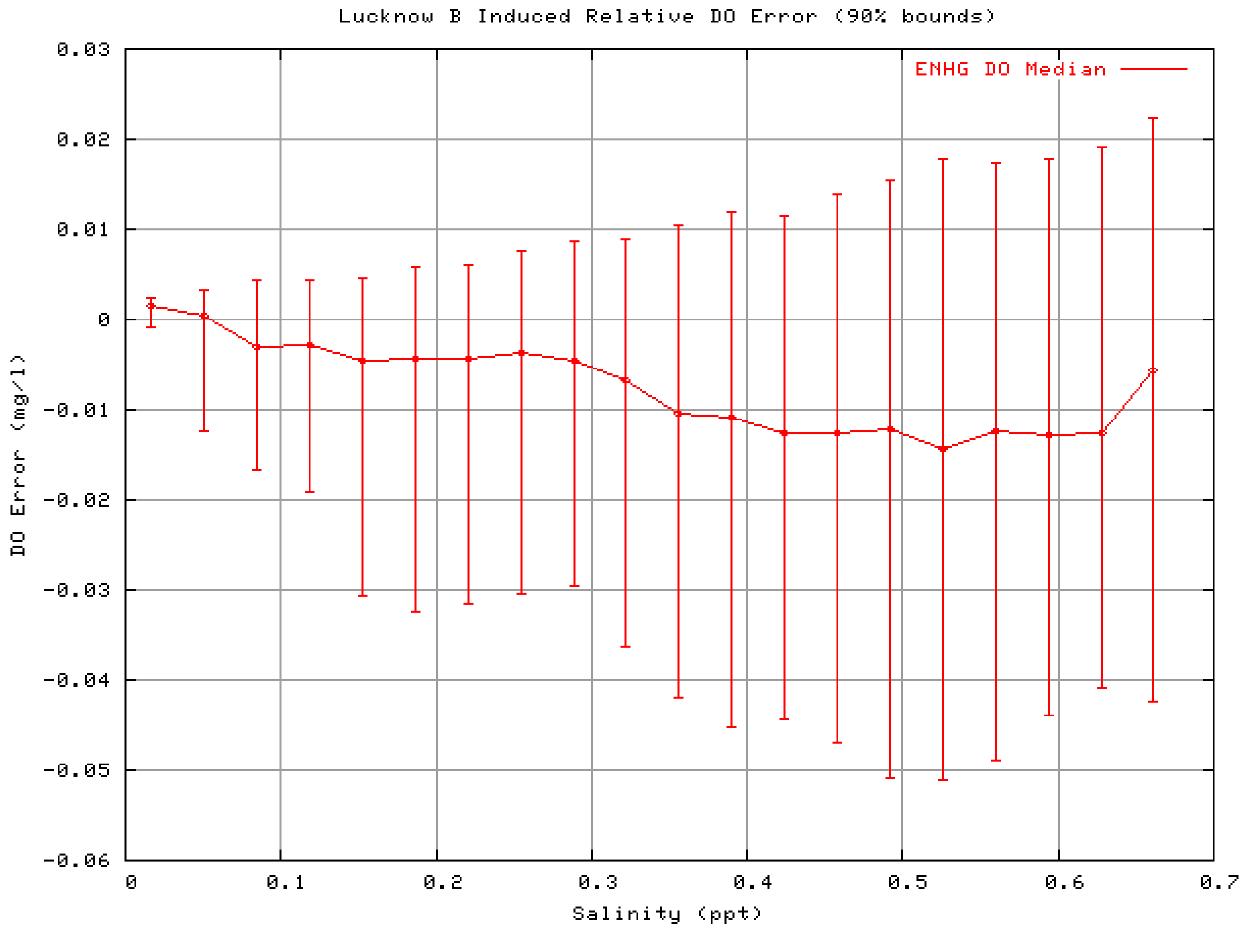


Figure 4.14: DO Relative Error Analysis, Lucknow Canal, 00-03

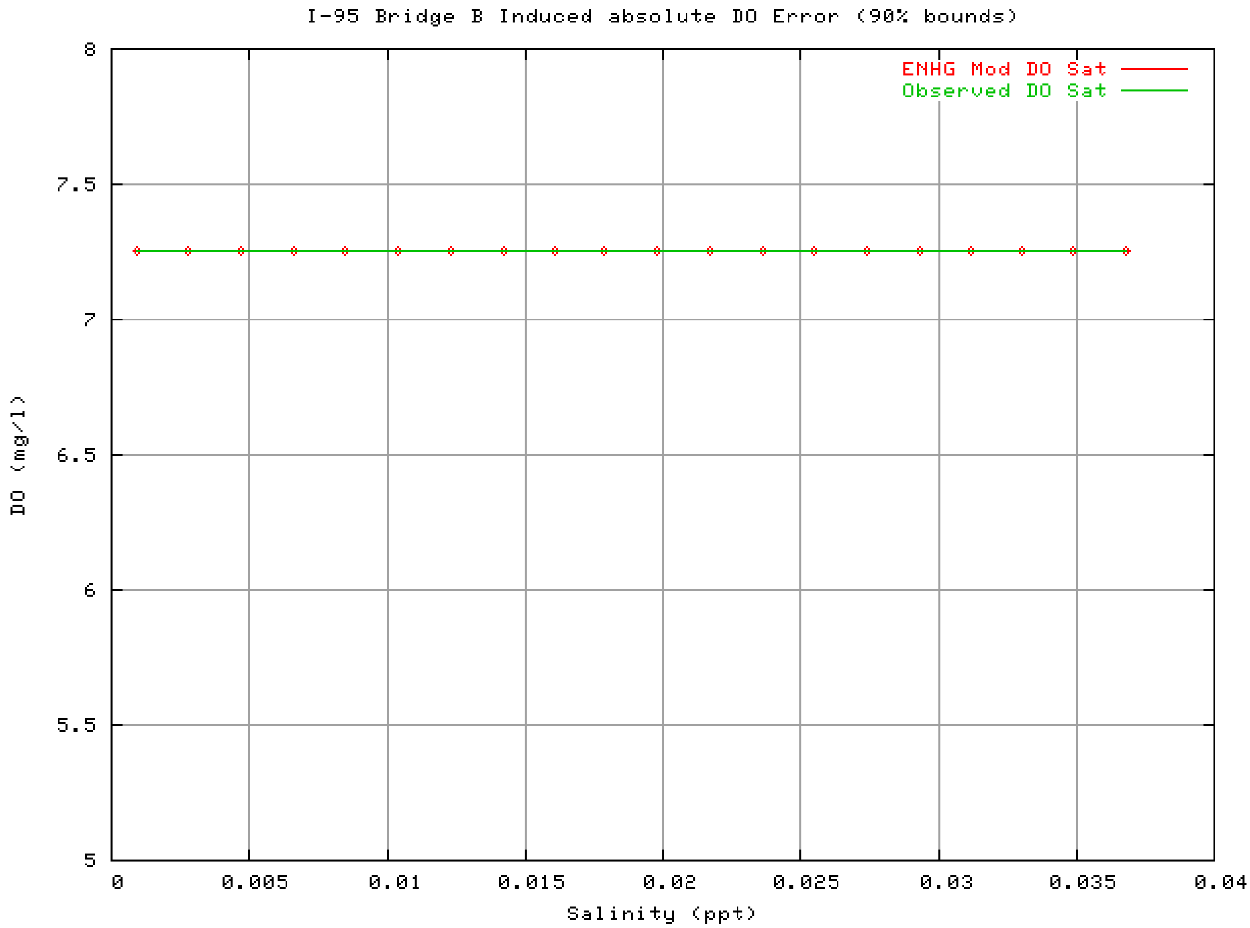


Figure 4.15: DO Absolute Error Analysis, I-95 Bridge, 00-03

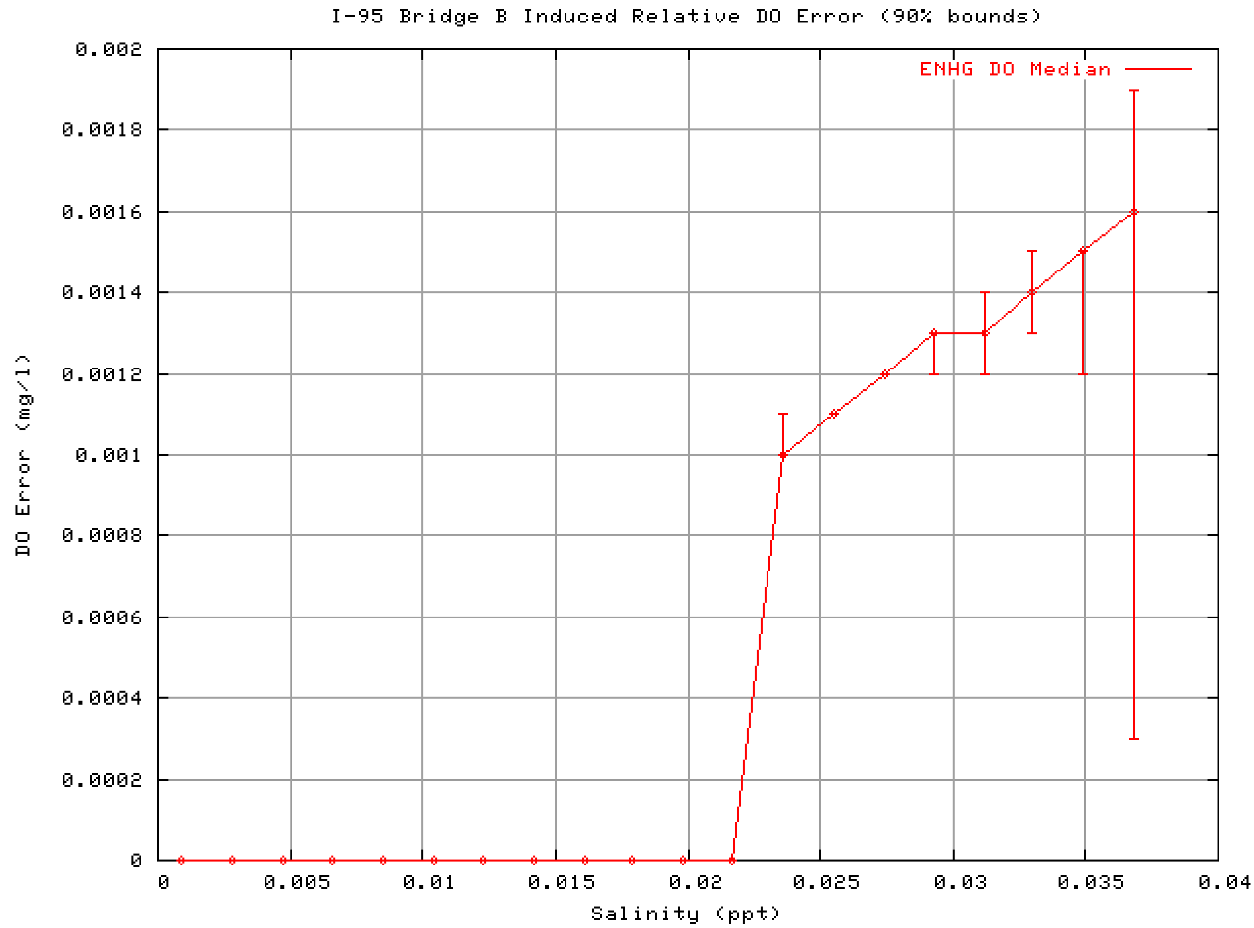


Figure 4.16: DO Relative Error Analysis, I-95 Bridge, 00-03

Chapter 5

Findings and Recommendations

5.1 Findings: Available Data

If proper caution is used there is sufficient data for the calibration and verification of hydrodynamic models of the lower Savannah River. As noted in the draft report, the restriction of detailed data to two summer periods has created a risk of overcalibration of the model to those conditions. The strong difference in performance between the 97-99 time frame and the 00-03 time frame raises this as a potential issue with the ENHG Model, although it is believed here that other factors are at work. For derived quantities such as dissolved oxygen, the acquisition of additional data would be highly desirable. In addition, secondary data such as rainfall and other meteorology could be significantly improved by incorporating data from KHXD (Hilton Head), buoy data, NEXRAD, and surface analyses.

During the evaluation process concerns were raised as to quality control and uncertainty of input data sets, especially with respect to sensor error, tides and boundary salinity. While it is dangerous to argue that a data set is flawed because it causes a model to crash, especially when other configurations do not, it is interesting to note that a modified water surface elevation file enabled to model to run the full seven year time frame. Given that a model is only as good as its input data, it is recommended that key input data bases (such as tide and salinity boundaries) be subjected to a quality control process.

5.2 Findings: ENHG Model

The ENHG model has the potential to be a significant improvement relative to the TMDL model. Median errors decreased at three of the four stations, and error bands decreased at all four sites in the "part A" runs (1997-1999). Improved frequency distribution estimates were noted at three sites, while at the fourth (I-95) frequency distributions were about the same. Unfortunately, neither TetraTech nor Kinetic Analysis Corporation were able to conduct a successful 7 year run of the Enhanced Grid model using observed boundary conditions. As noted above, the analyses in this report were based on two runs on either side of a critical point at which the model became unstable. This a source of serious concern with respect to the usability of the model for predictive purposes. When the ″part B″ runs were assessed, median errors and error bands were significantly different than the part ″A″ runs. Given the different flow characteristics between the two data sets, this potentially indicates that the instability in the model is impacting uncertainty in the model across the lower range of flows. This is especially evident at the FWS (Figure 3.2) and Lucknow (Figure 3.3) sites. Note the very distinct differences in median errors, especially in the 150-250 cubic meters per second bands which comprise over 40 percent of flows during the study period. These differences potentially indicate problems with the geometry of the back river or marsh depiction. The graphs in chapter 14 contain plots showing error by phase of the tide cycle. It is interesting to note that the model has higher errors in the outgoing phase of the tide cycle than on the inbound phase. One potential source of this phenomena is marsh depiction and storage, although there are many other possibilities, including bottom roughness, channel geometry, bathymetry, and so forth.

5.3 Recommendations

The primary issue found by KAC is the inability of the model to complete a seven year simulation. This restricted our ability to fully assess the undertainty in the model in a similar fashion to the TMDL model. Therefore, KAC does not recommend the use of the ENHG model for primary decision making until such time as the source of the instability can be properly diagnosed, corrected, and a continuous seven year run can be conducted. The preferred, and recommended, approach is to continue development work on the model to create a configuration that can complete a seven year run without aborting. Otherwise, doubts will remain as to the stability of the model. An alternative is to conduct a series of runs at different step sizes and channel geometries to ensure that the model is stable throughout the range of intended uses during the calibration/verification period. These runs should be compared to similar TMDL model runs to ensure the ENHG results are rational.

Additional specific recommendations:

1) Version control should be implemented for both source code and input files;

2) The model should complete a 7 year run using scientifically defensible boundary conditions and channel configuration, or, sufficient simulations with projected bathymetry should be conducted with varying time steps and analyzed to ensure model stability;

3) Assess the potential to promote all floating point variables from ″real″ to ″double precision″, respecting the possibility that this may introduce unacceptable noise in the numerical solutions;

4) Assess boundary conditions, bottom friction, and geometry, especially in the upper and back rivers, to ensure the geometry is not introducing noise into the solutions;

5) Evaluate marsh depiction, especially with respect to storage and release;

6) Additional quality control, and perhaps a formal uncertainty assessment, should be done on the input data sets. The water surface elevation/tide data should be a special

focus.

Part II

Supporting Graphics

Chapter 6

Houlihan Bridge A 97-99 ENHG Model

These plots show the results of the 1997-1999 simulations (part ”A”).

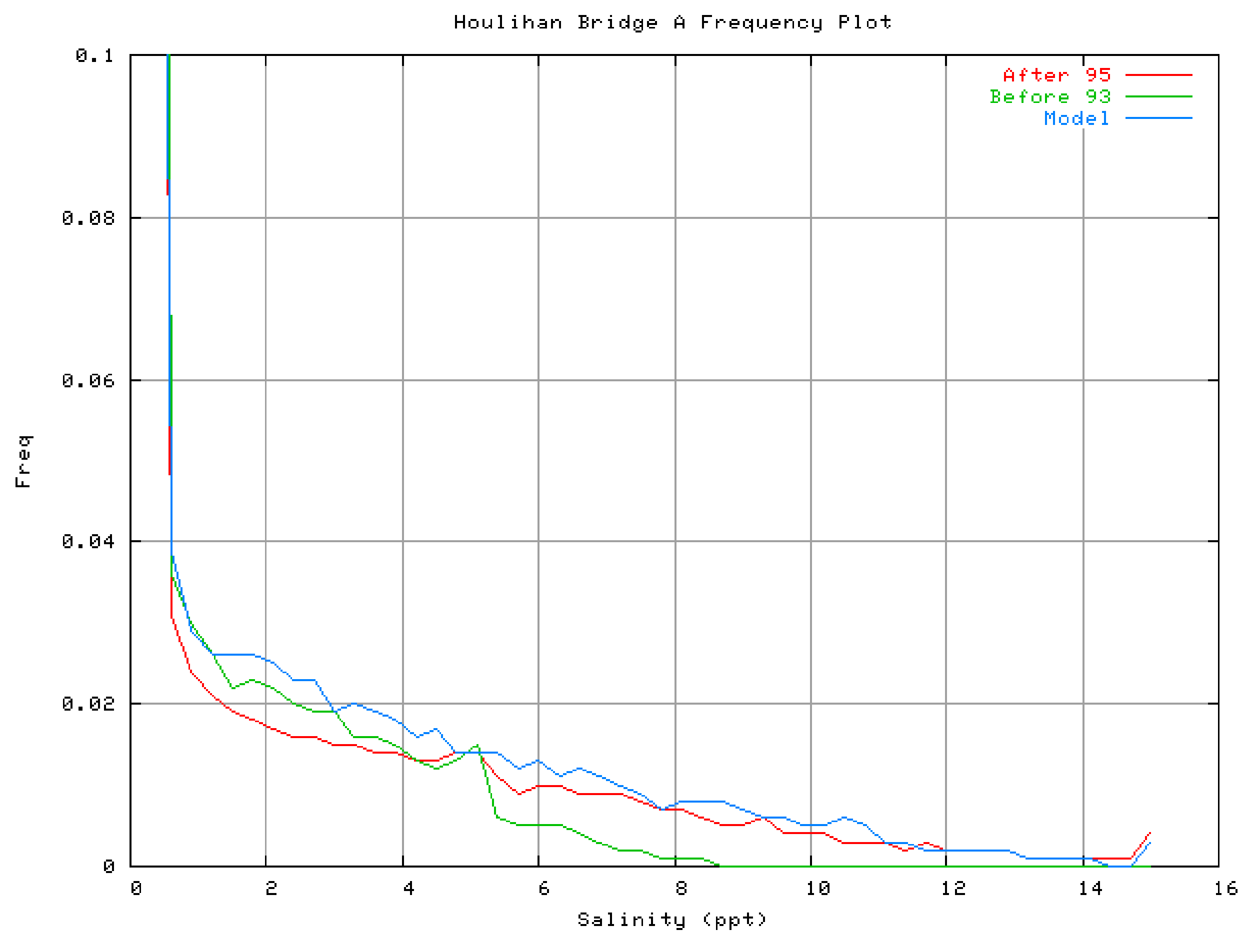


Figure 6.1: Salinity by Frequency of Occurrence

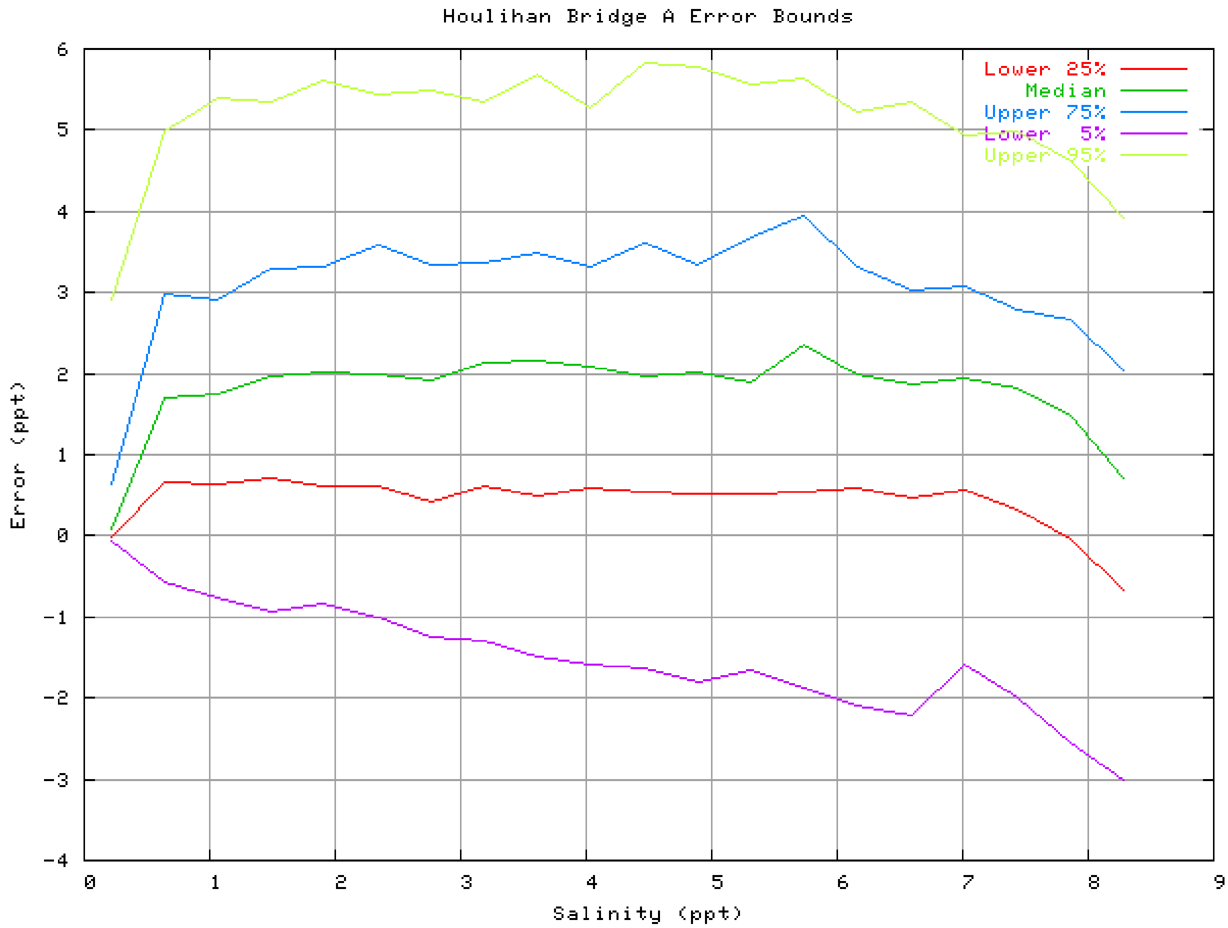


Figure 6.2: Error bounds by Salinity

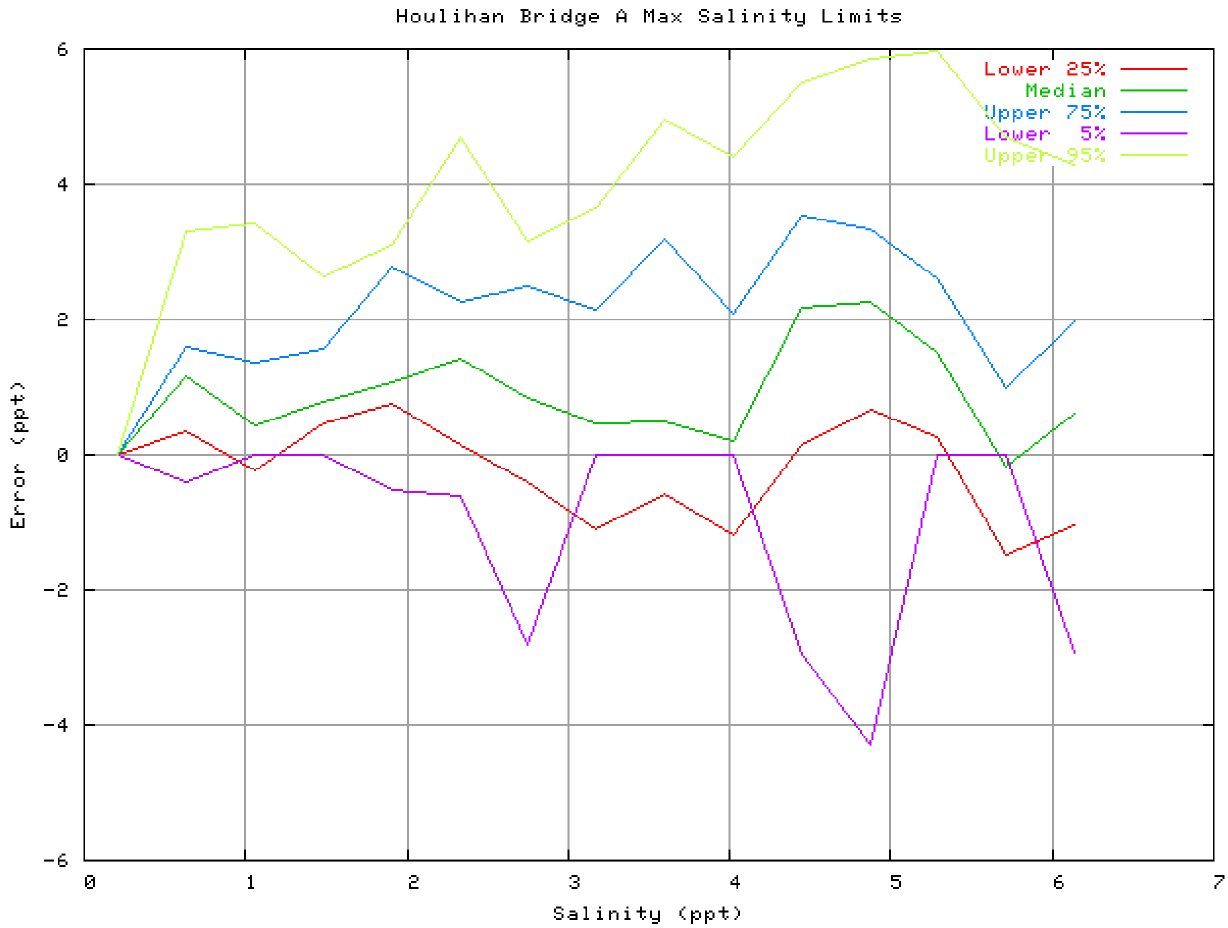


Figure 6.3: Daily Maximum Limits

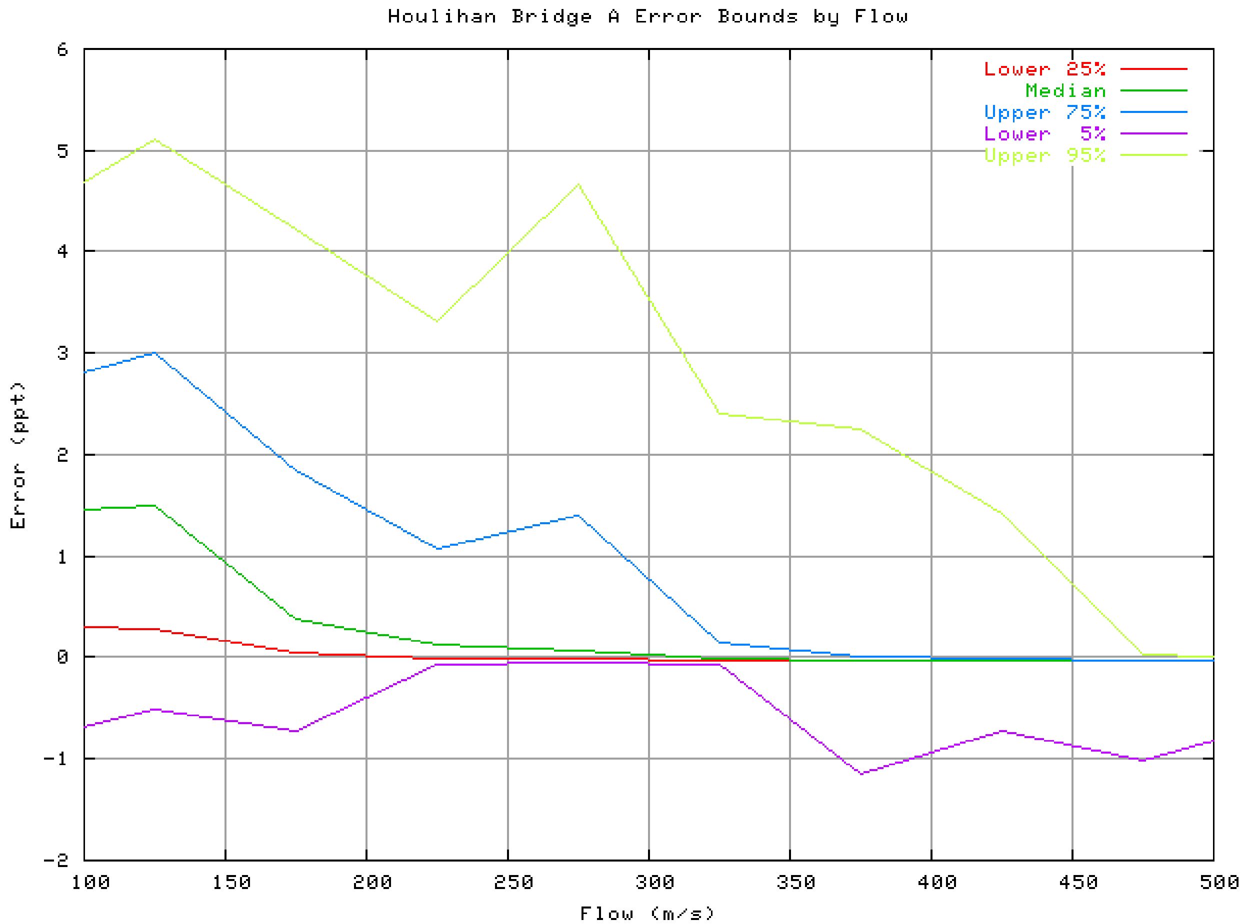


Figure 6.4: Error bounds by flow at Clyo

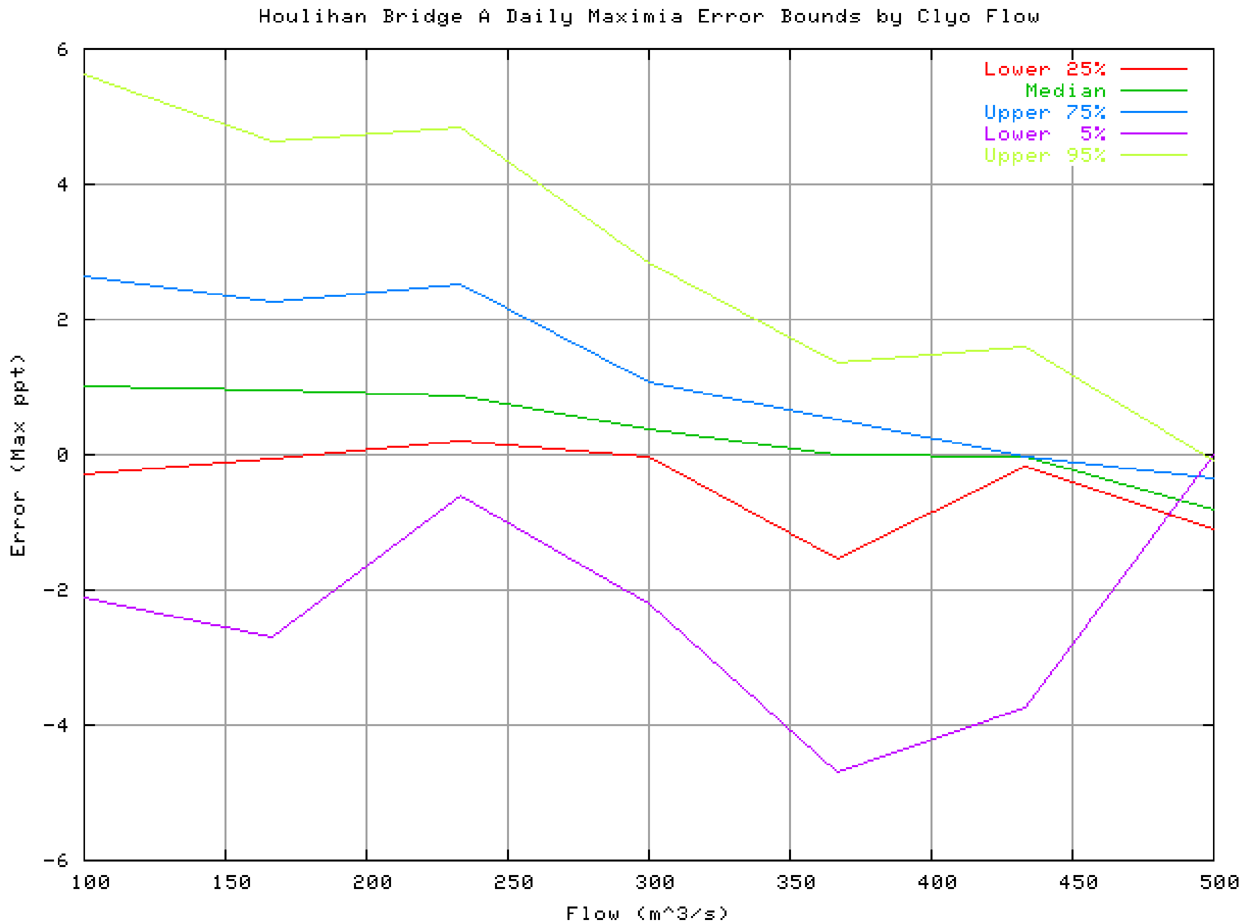


Figure 6.5: Daily Maxima error bounds by flow at Clyo

Chapter 7

Houlihan Bridge B 00-03 ENHG Model

These plots show the results of the 2000-2003 simulations (part ”B”).

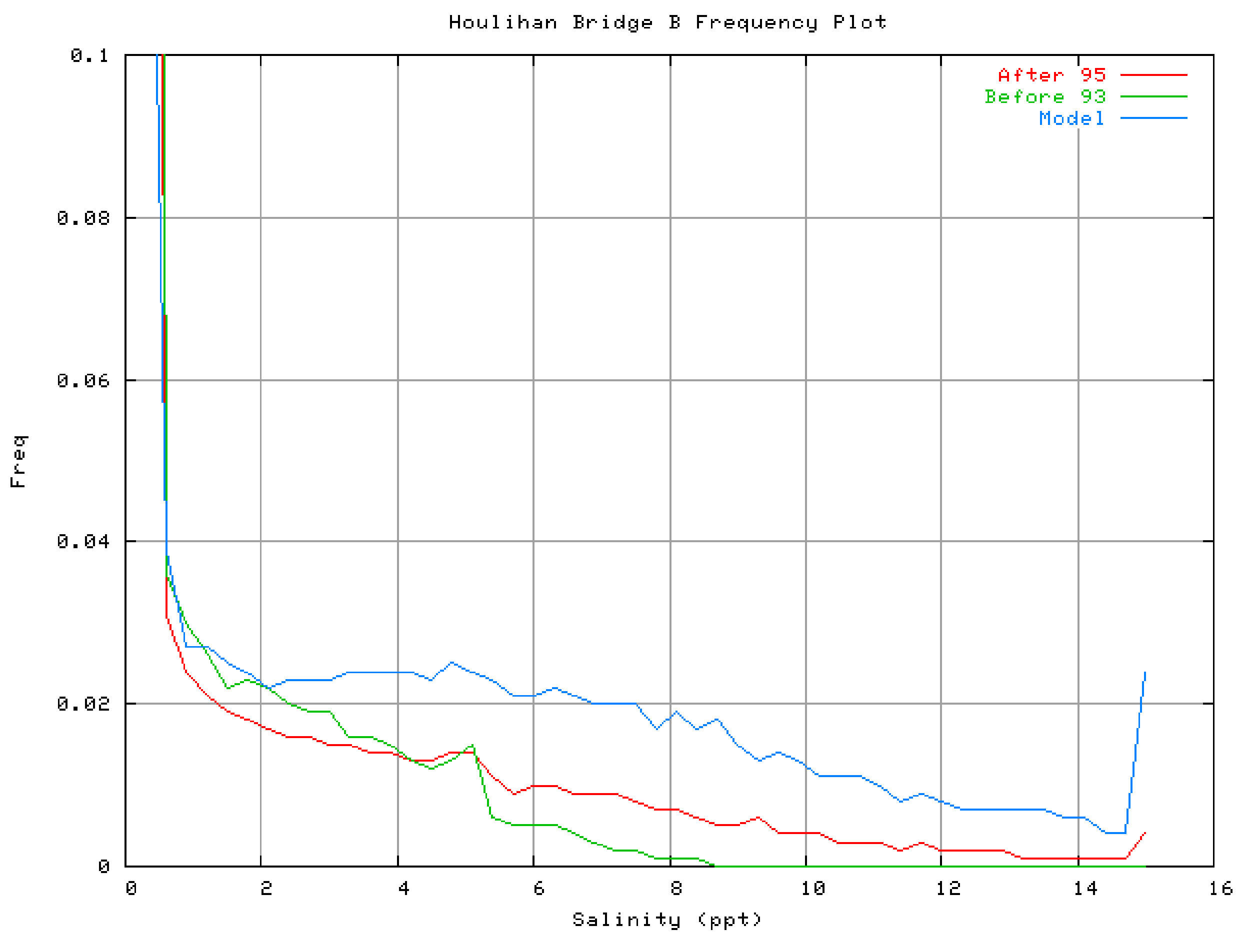


Figure 7.1: Salinity by Frequency of Occurrence

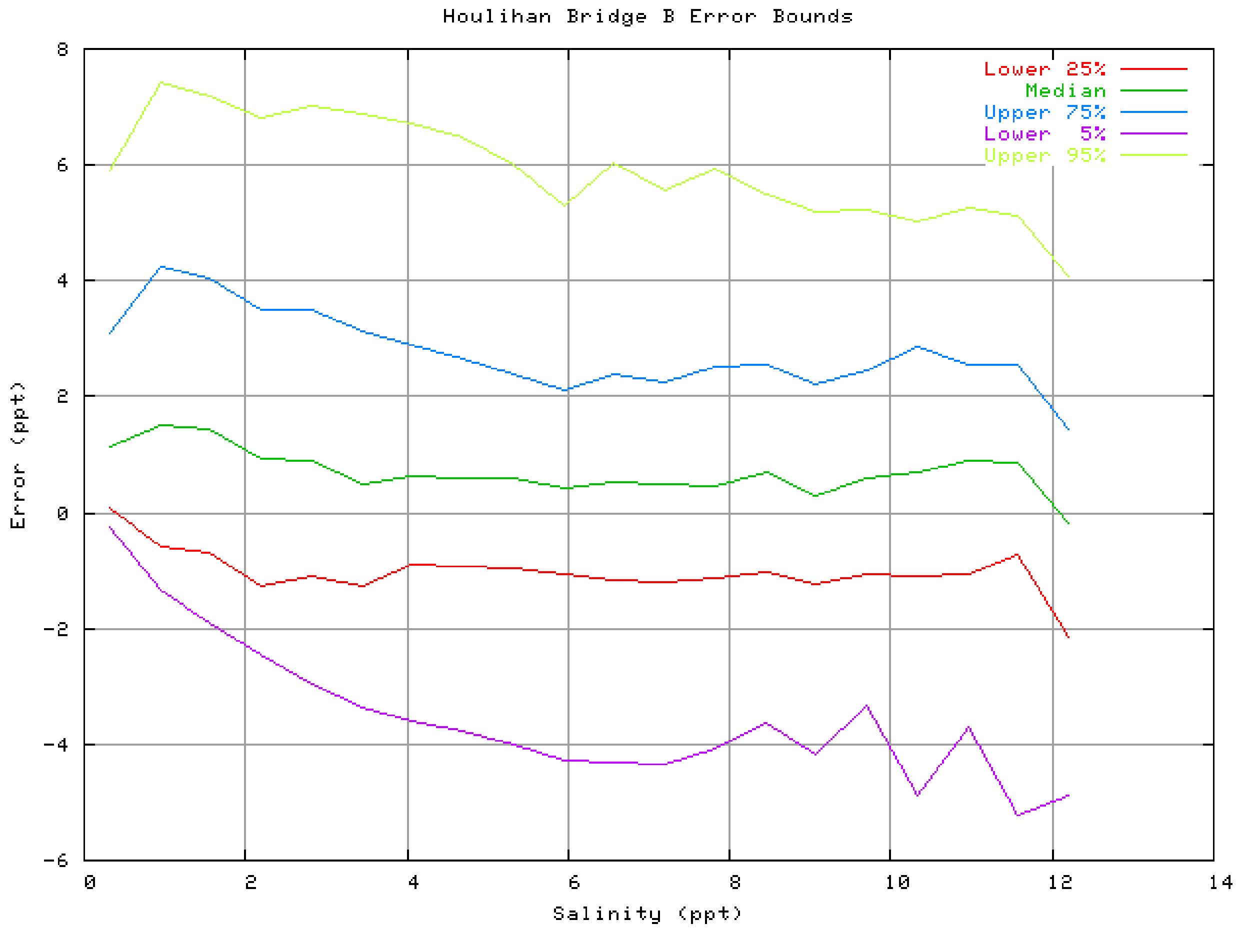


Figure 7.2: Error bounds by Salinity

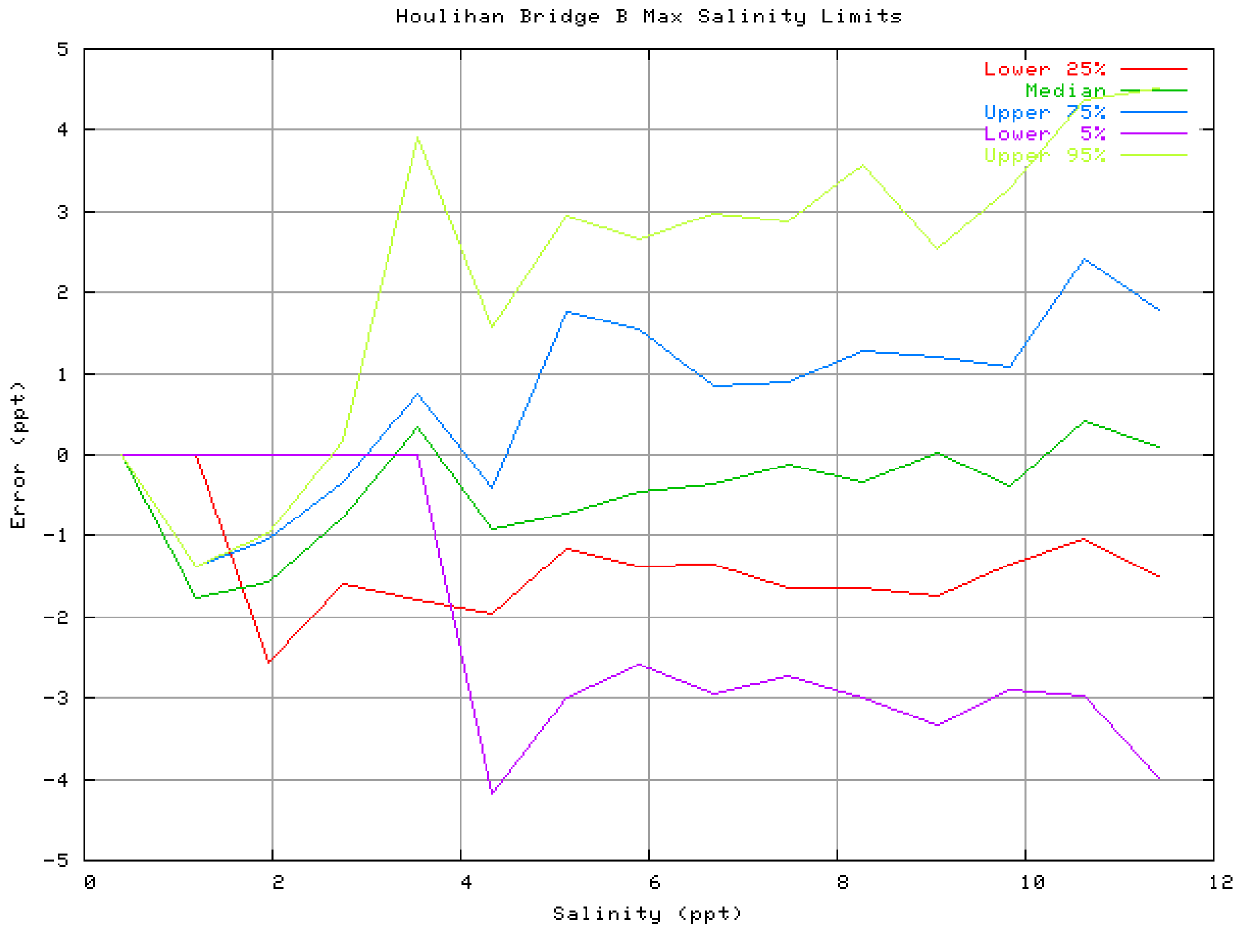


Figure 7.3: Daily Maximum Limits

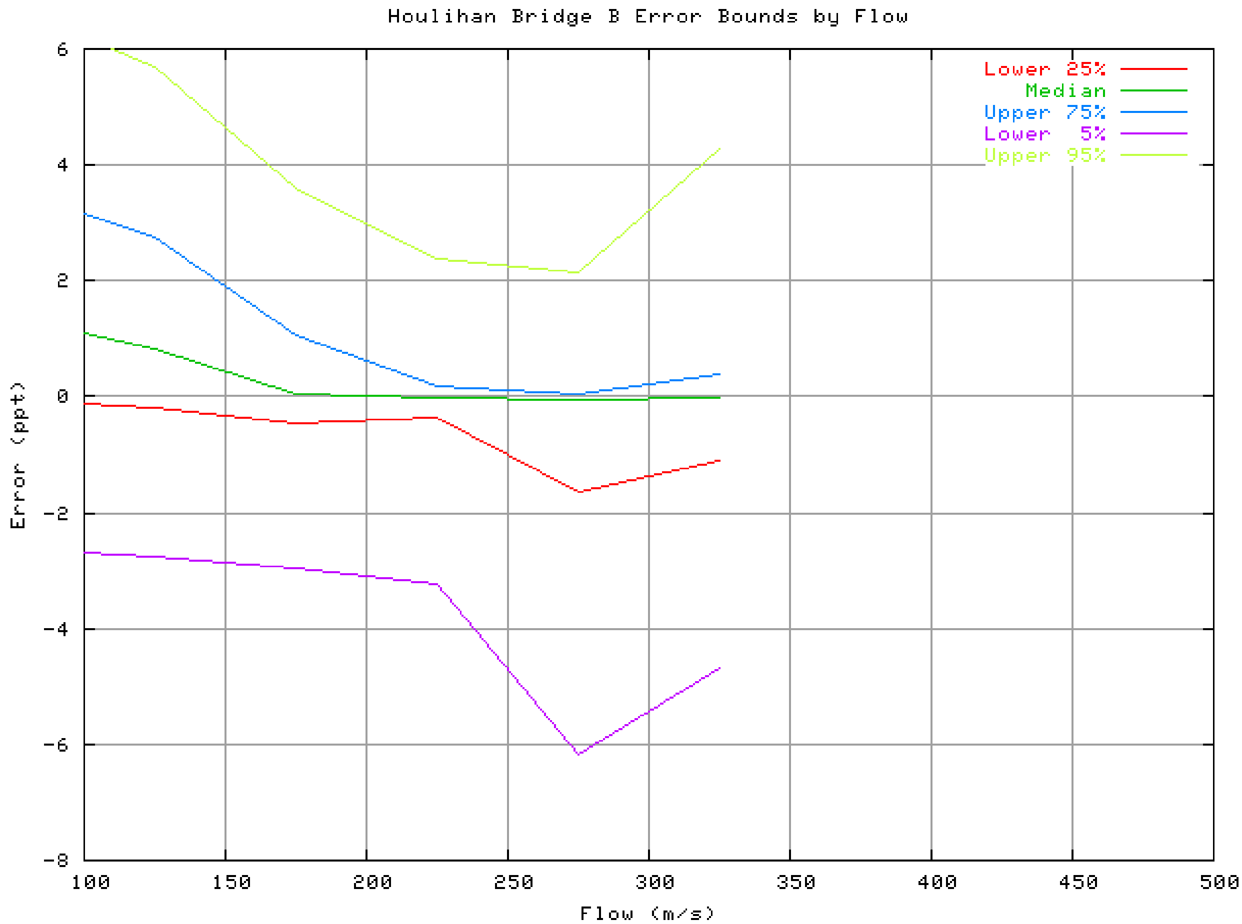


Figure 7.4: Error bounds by flow at Clyo

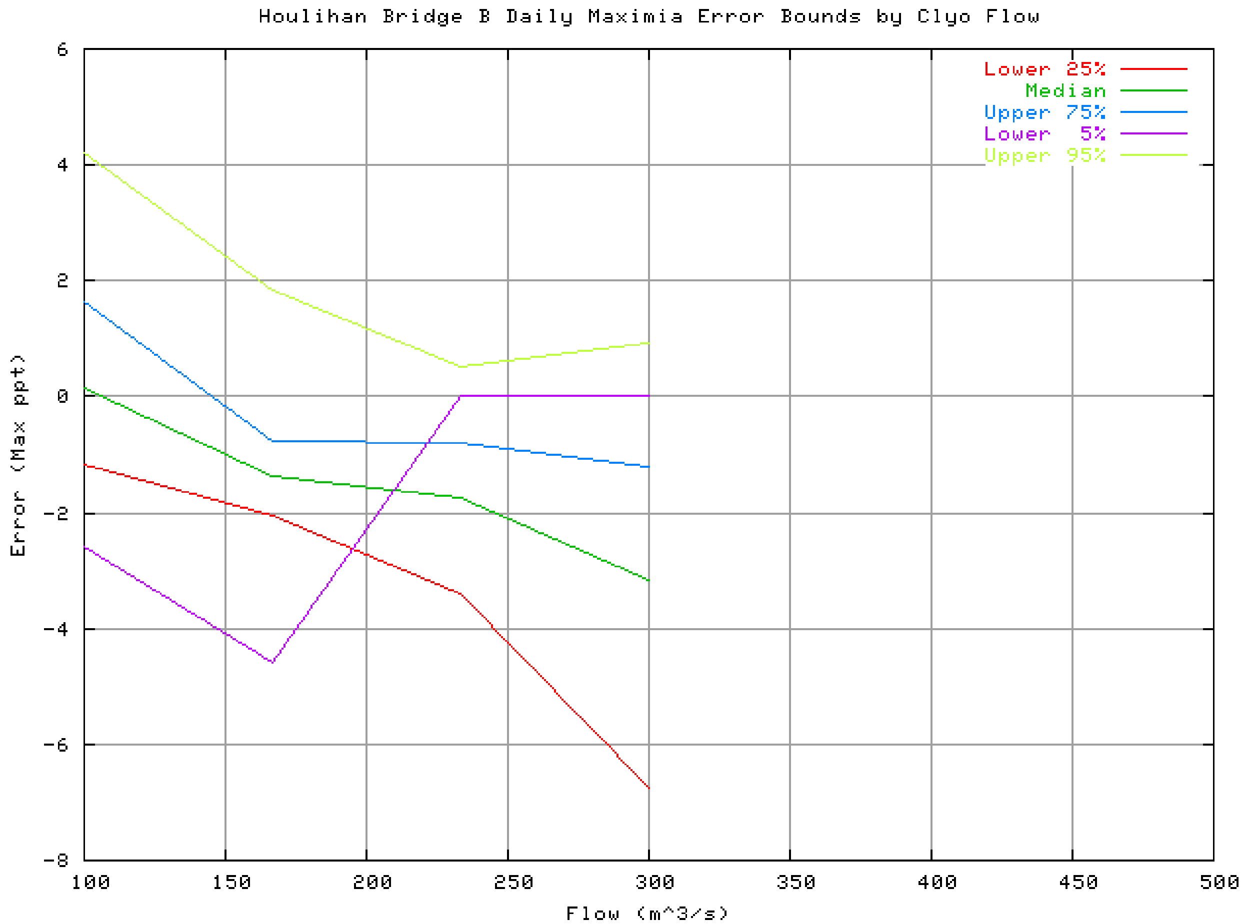


Figure 7.5: Daily Maxima error bounds by flow at Clyo

Chapter 8

US FWS Dock A 97-99 ENHG Model

These plots show the results of the 1997-1999 simulations (part ”A”).

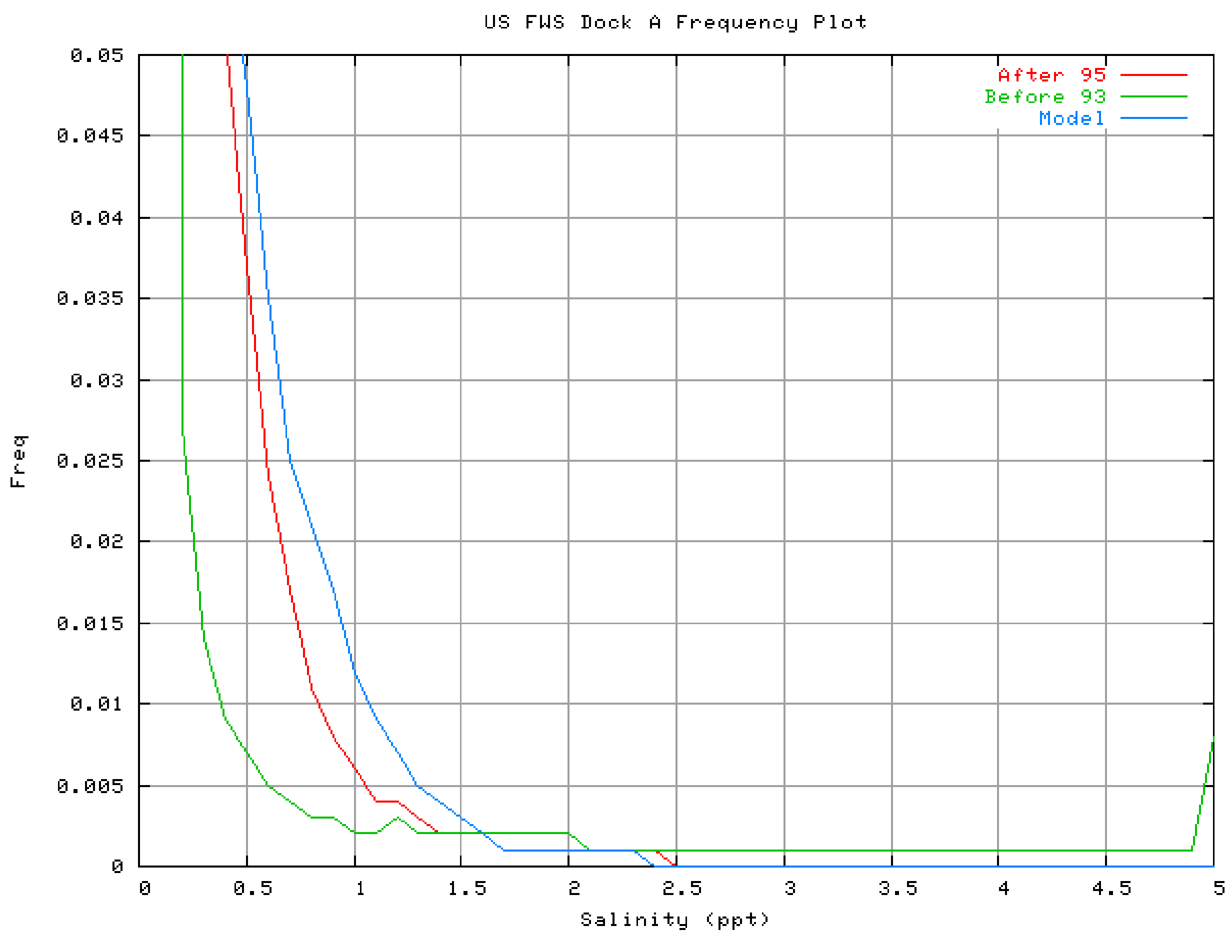


Figure 8.1: Salinity by Frequency of Occurrence

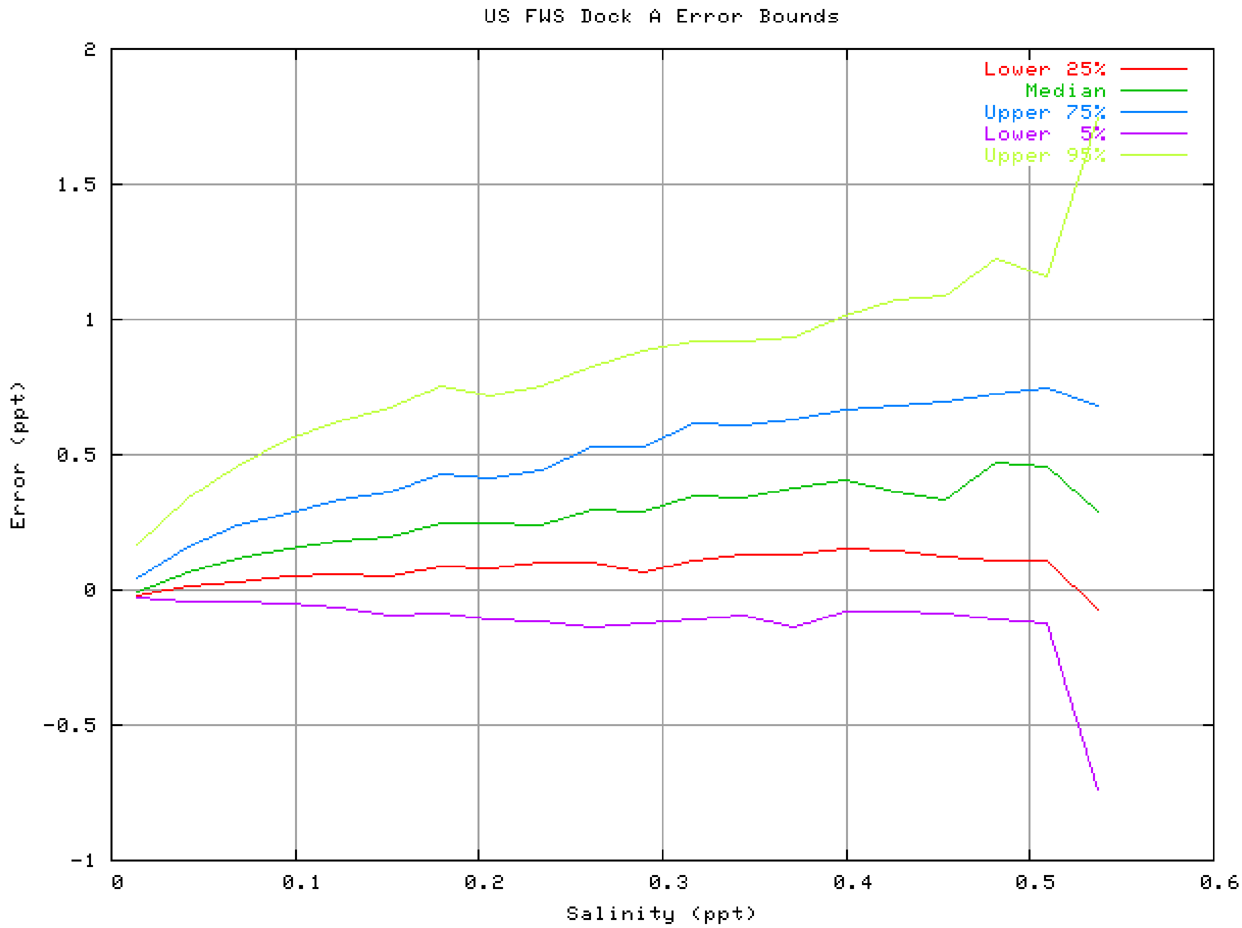


Figure 8.2: Error bounds by Salinity

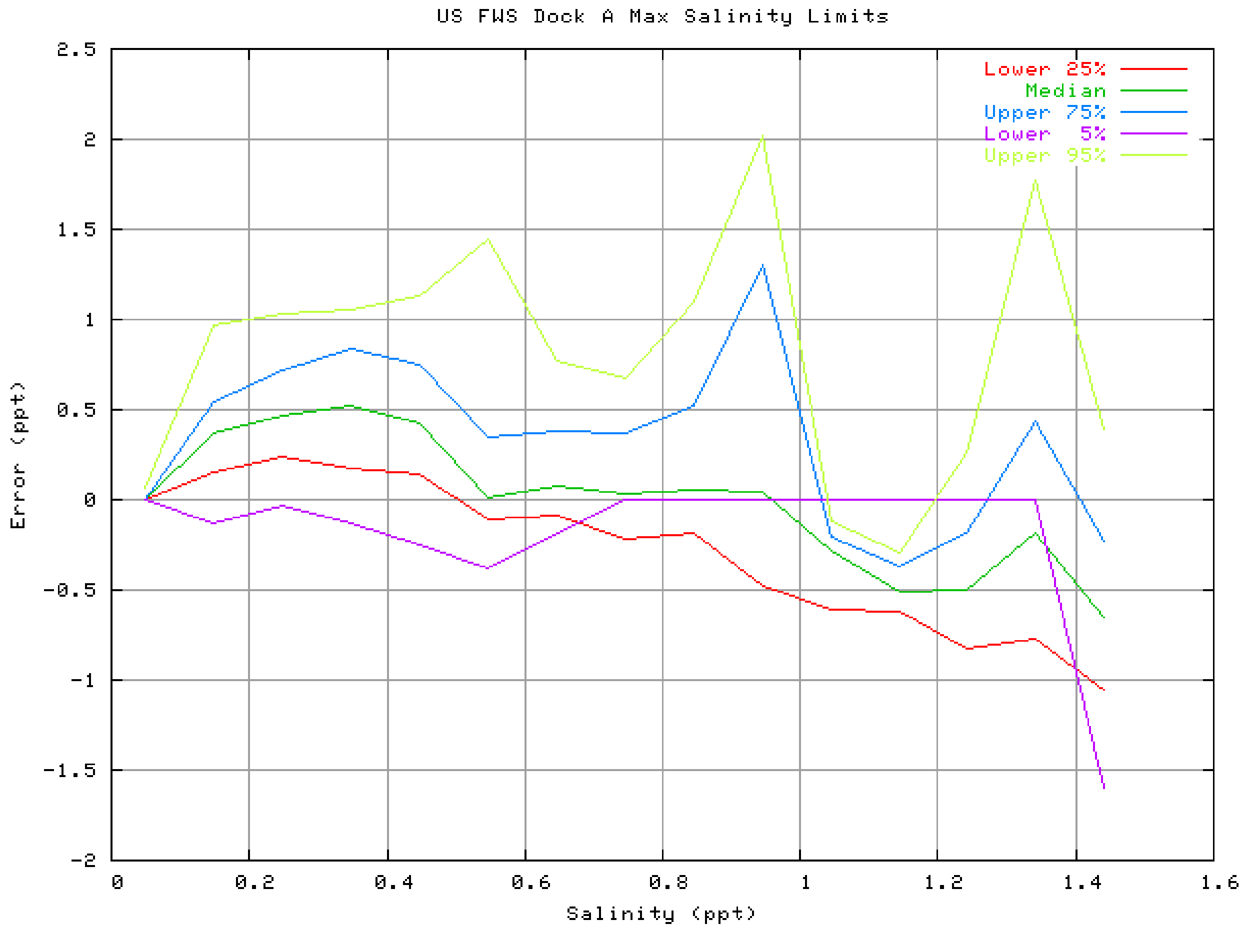


Figure 8.3: Daily Maximum Limits

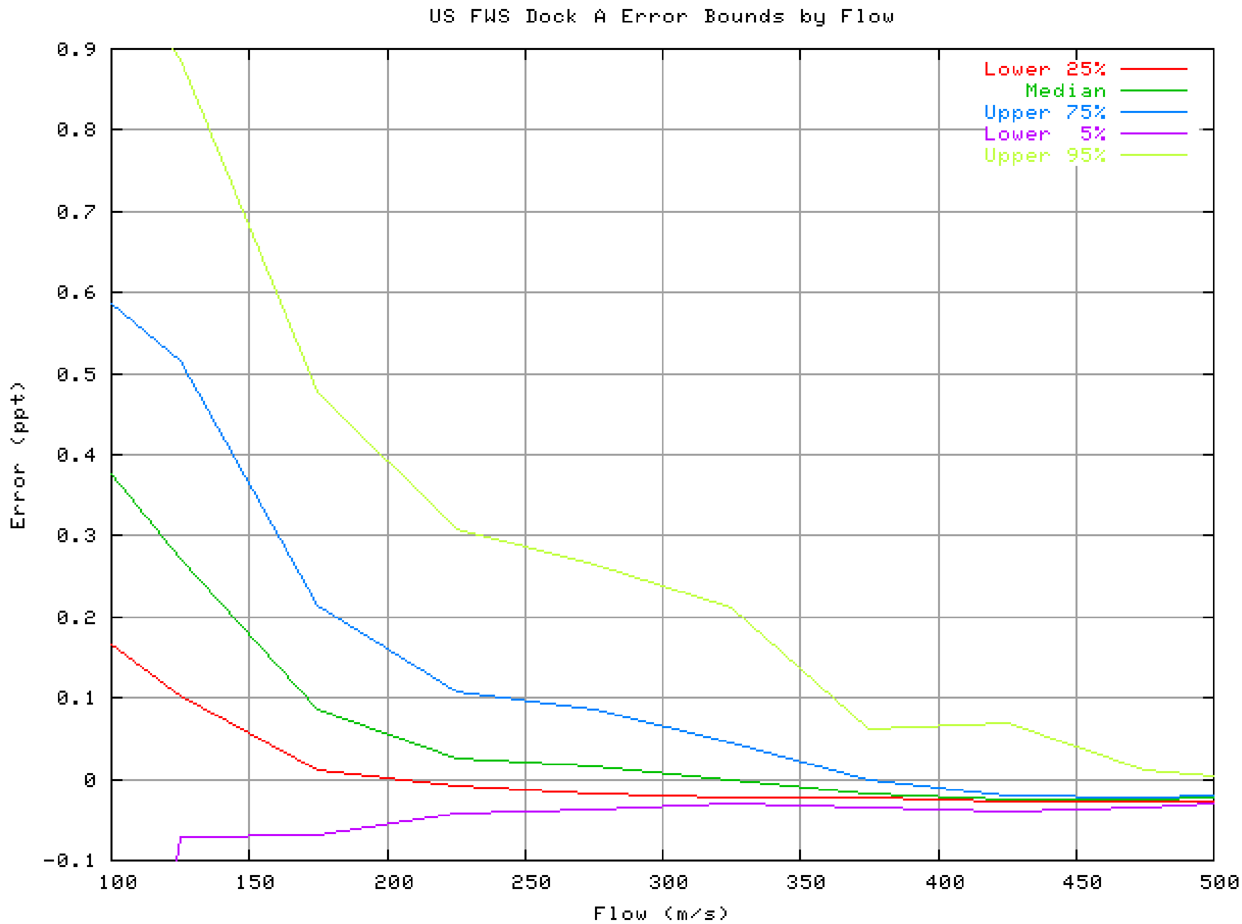


Figure 8.4: Error bounds by flow at Clyo

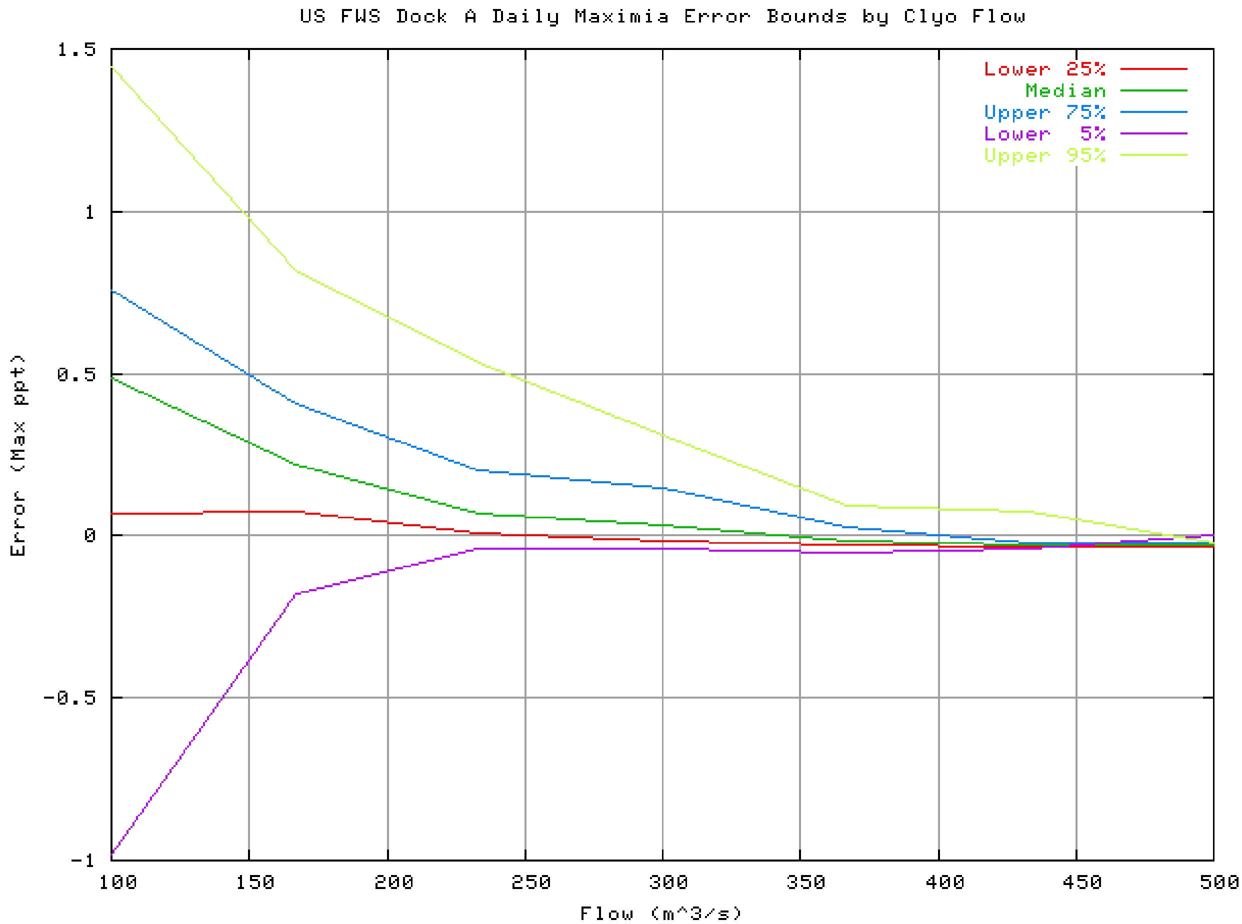


Figure 8.5: Daily Maxima error bounds by flow at Clyo

Chapter 9

US FWS Dock B 00-03 ENHG Model

These plots show the results of the 2000-2003 simulations (part ”B”).

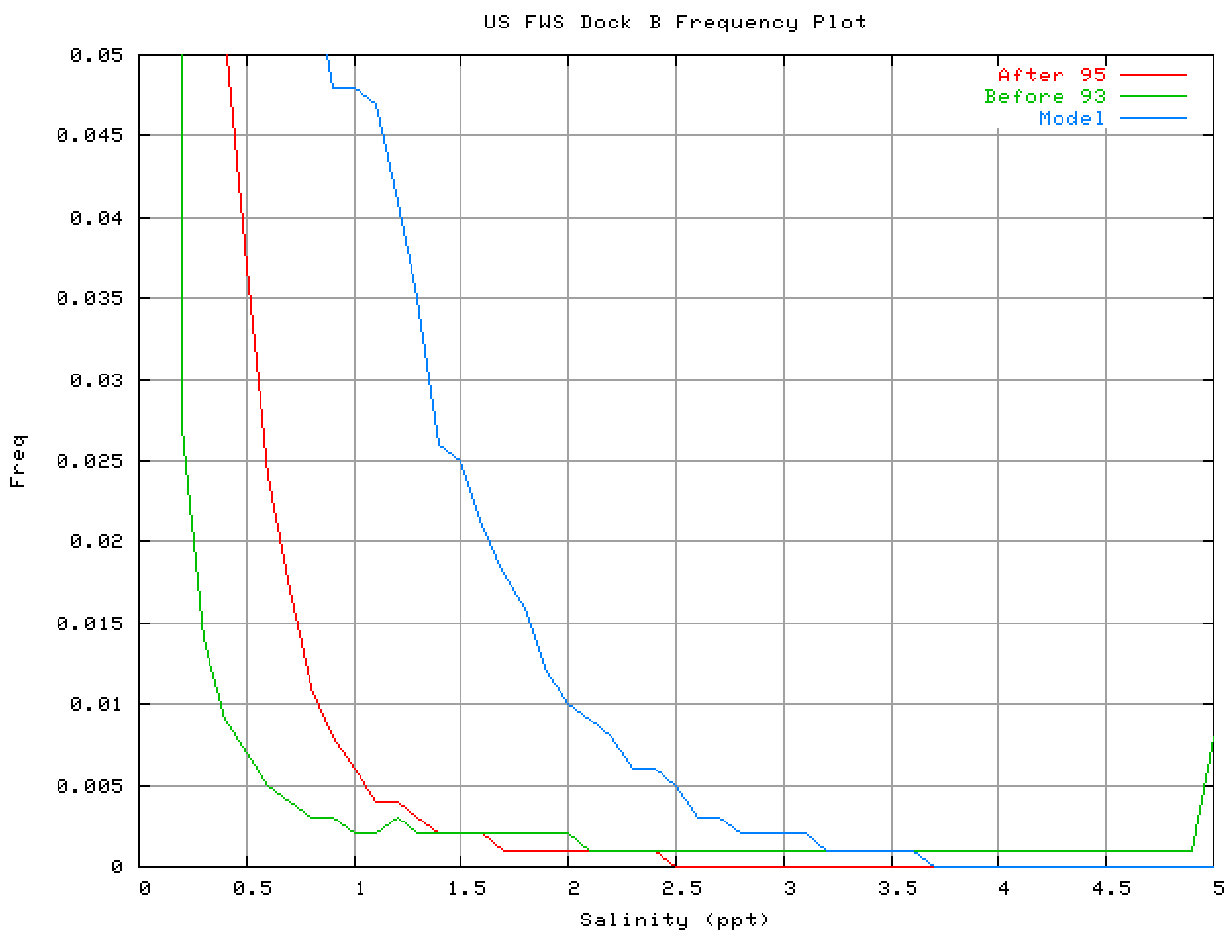


Figure 9.1: Salinity by Frequency of Occurrence

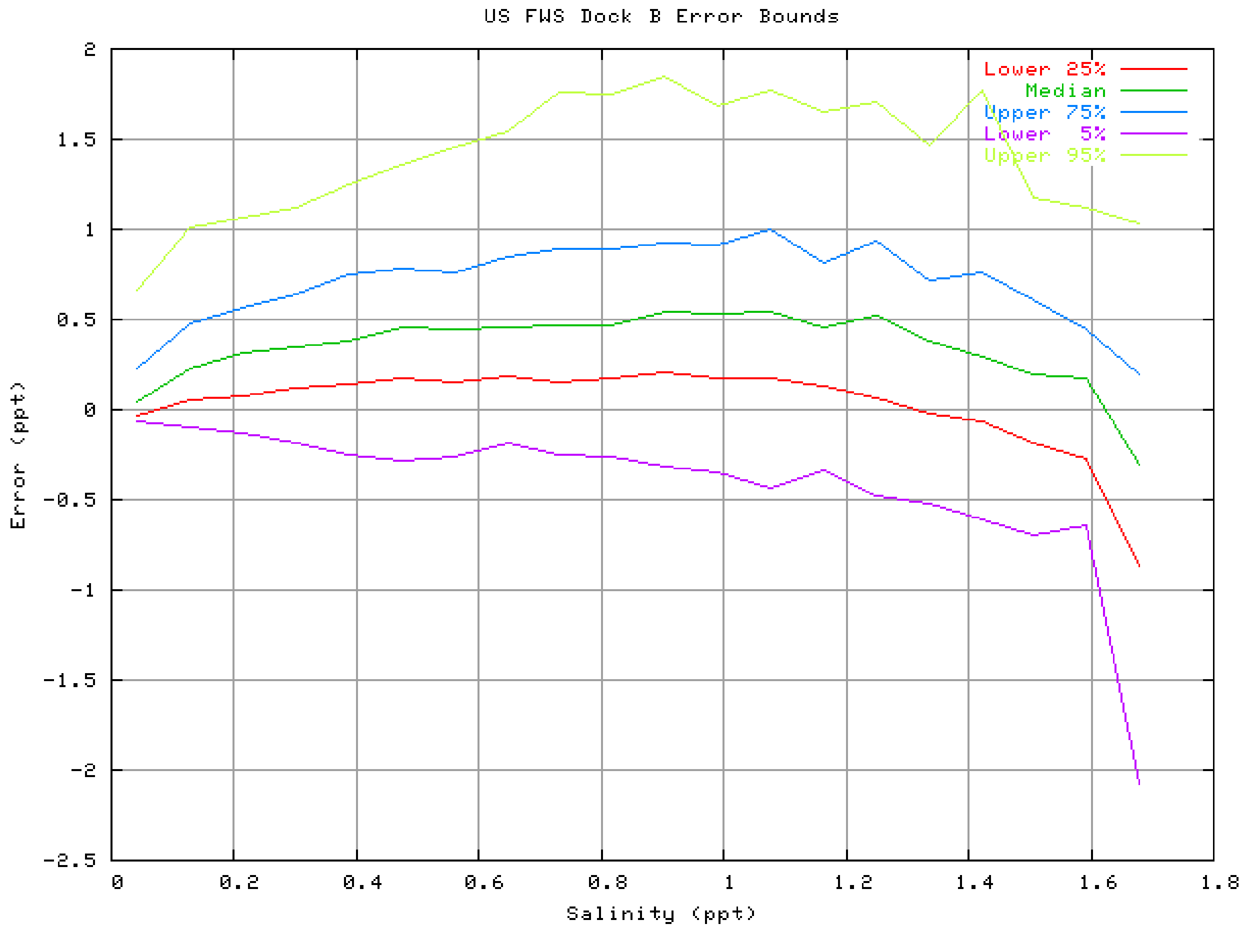


Figure 9.2: Error bounds by Salinity

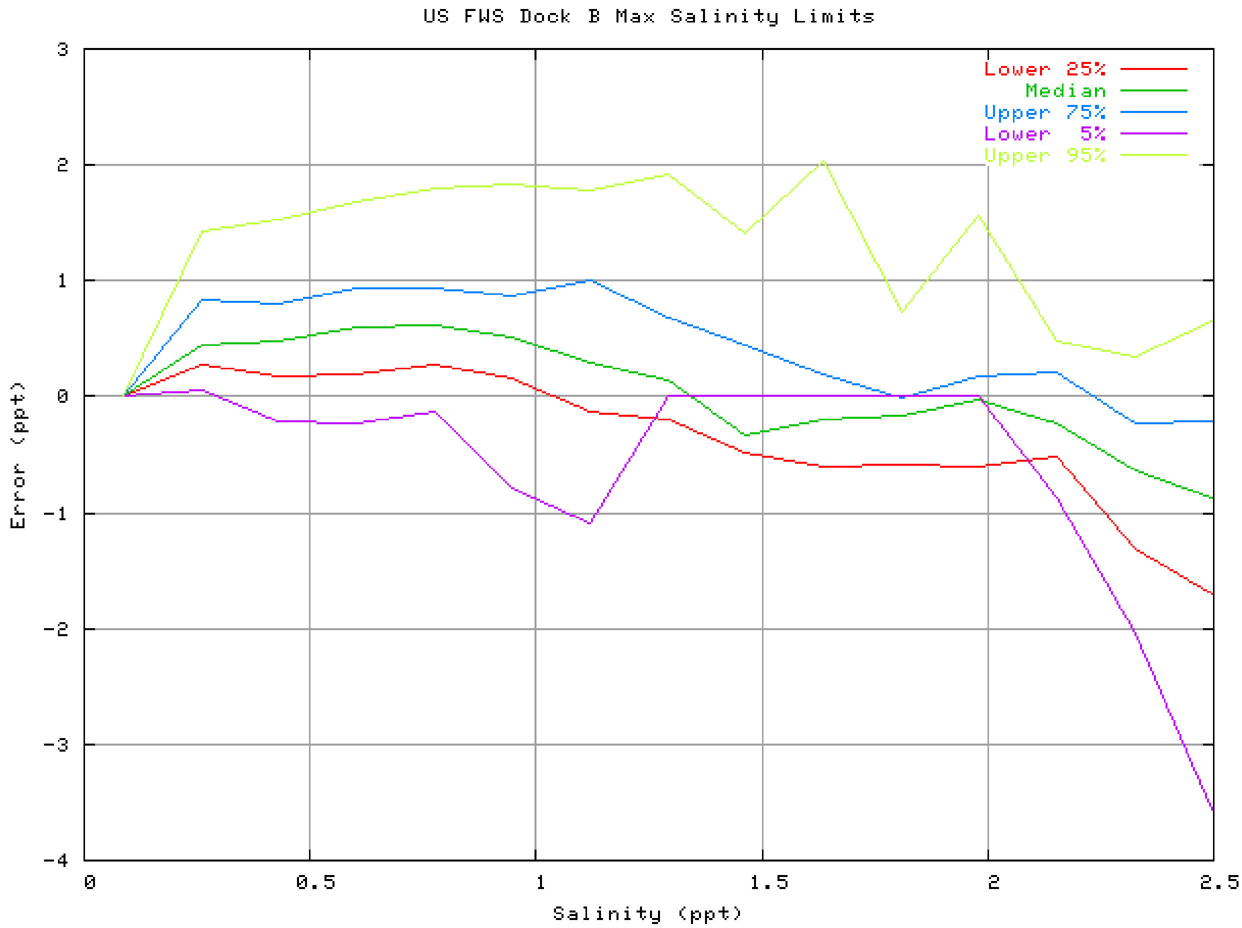


Figure 9.3: Daily Maximum Limits

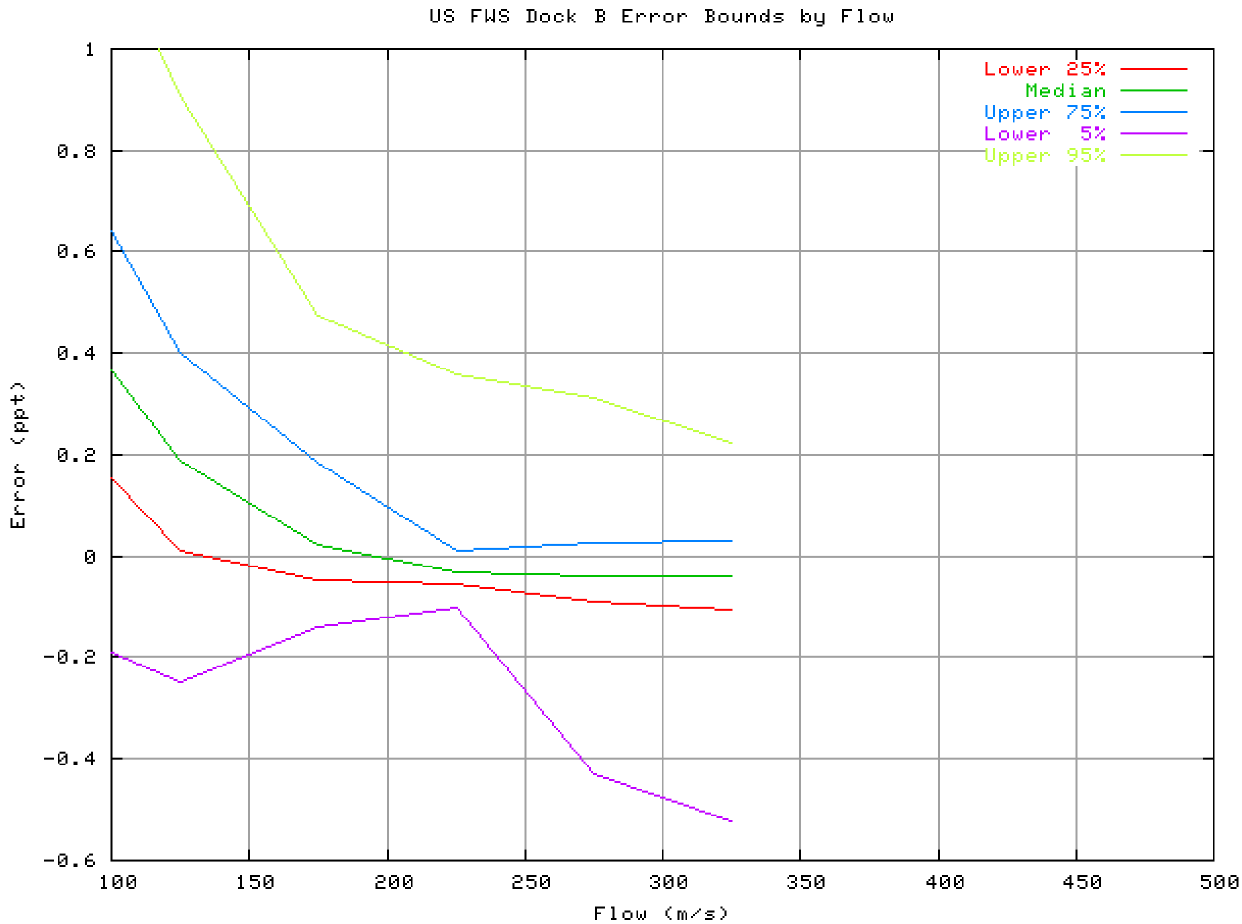


Figure 9.4: Error bounds by flow at Clyo

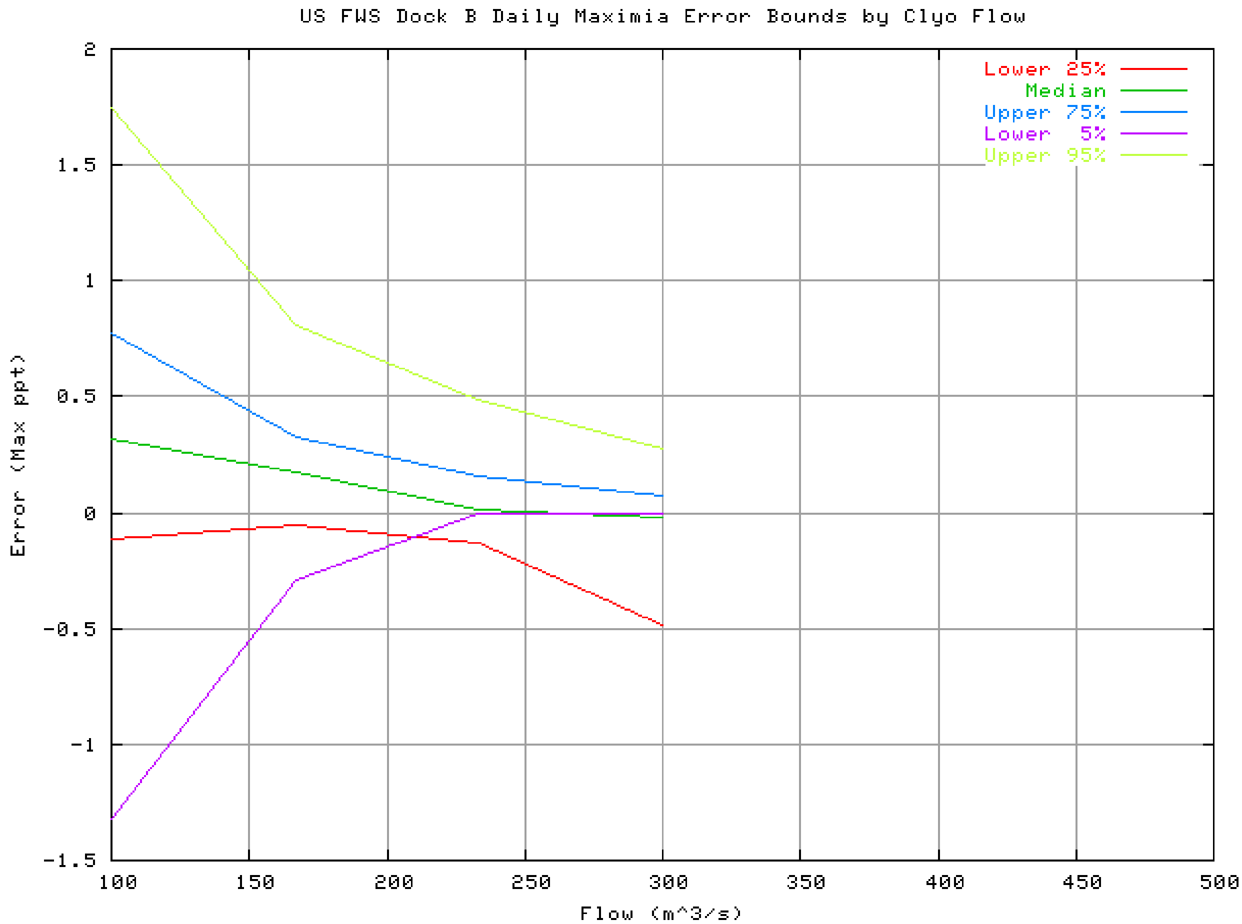


Figure 9.5: Daily Maxima error bounds by flow at Clyo

Chapter 10

Lucknow Canal A 97-99ENHG Model

These plots show the results of the 1997-1999 simulations (part ”A”).

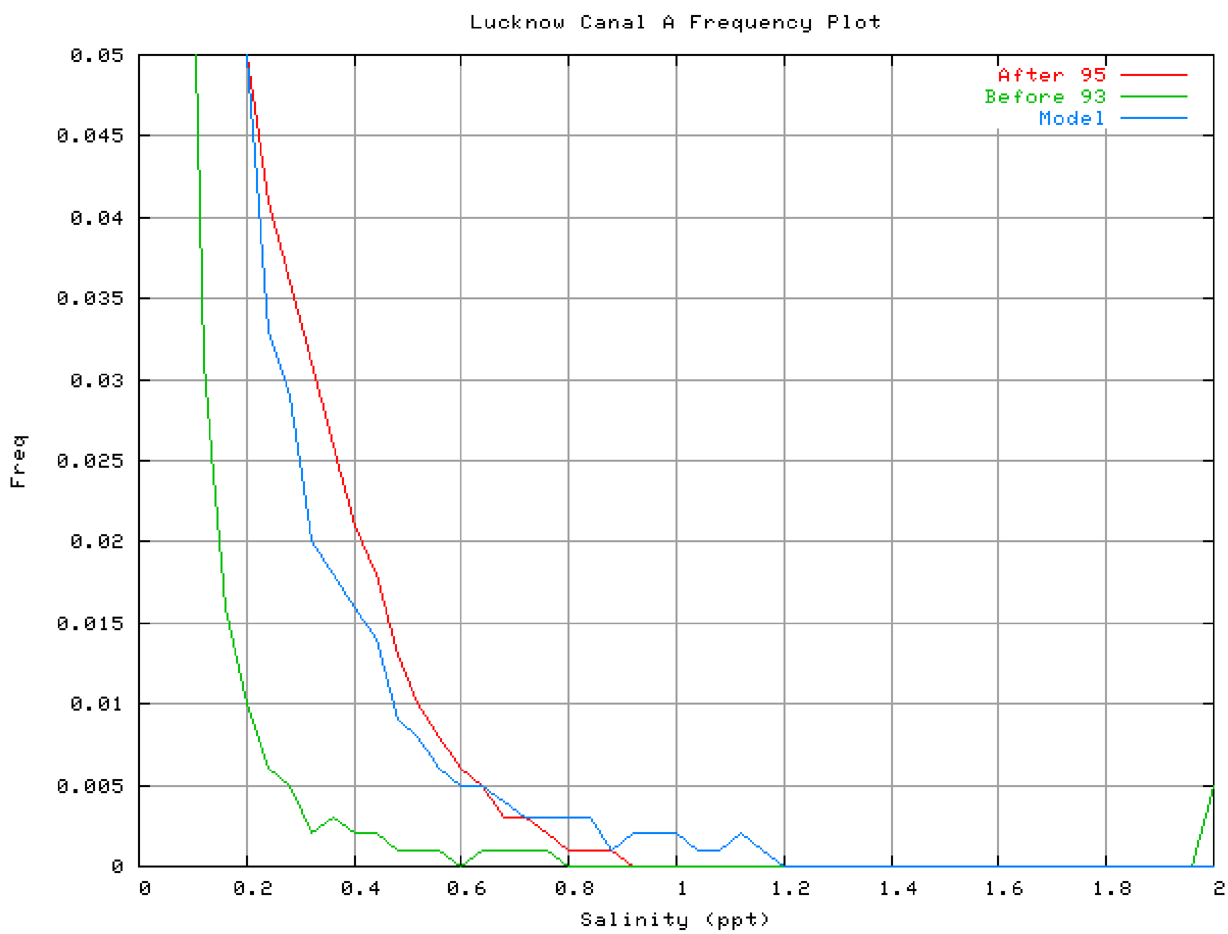


Figure 10.1: Salinity by Frequency of Occurrence

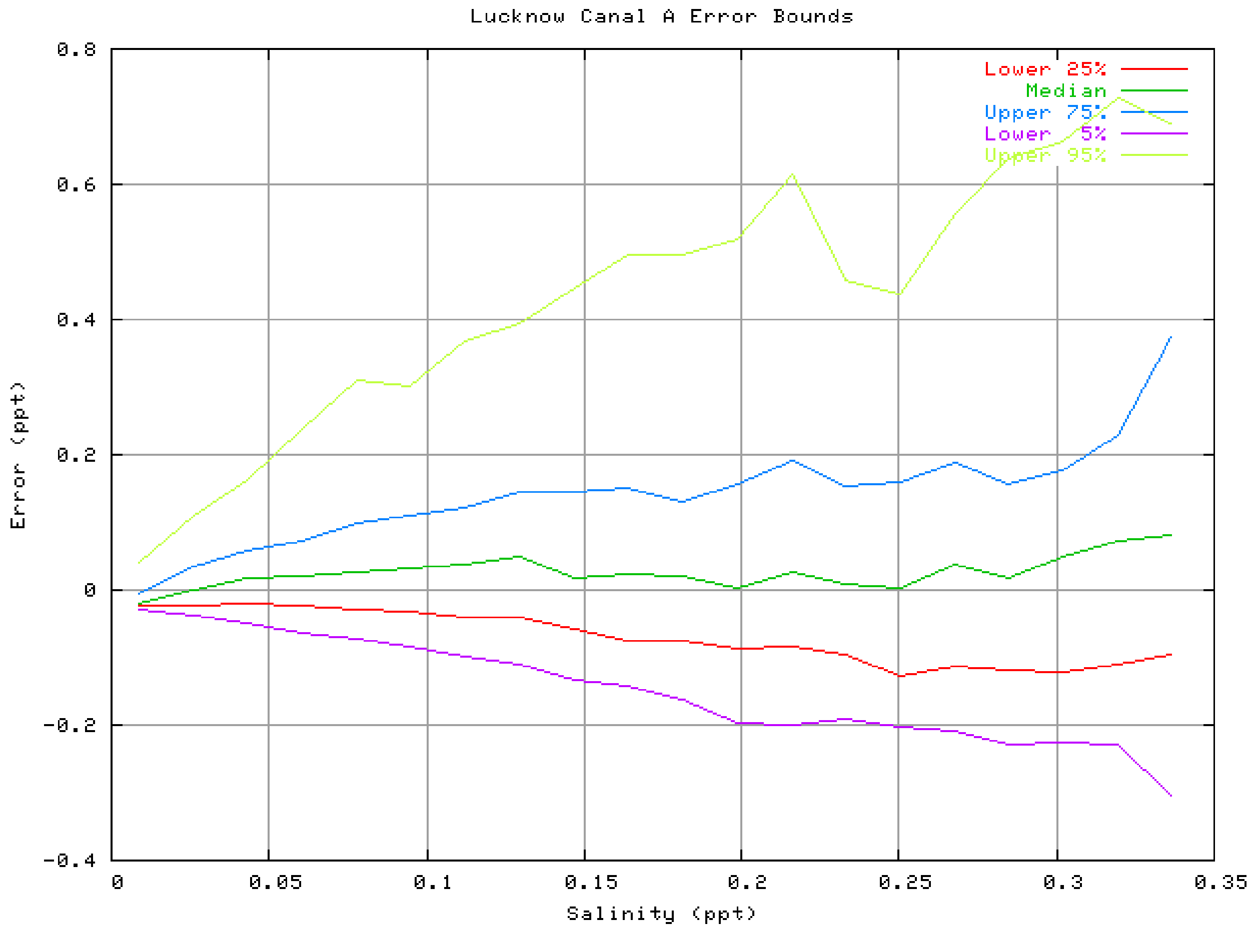


Figure 10.2: Error bounds by Salinity

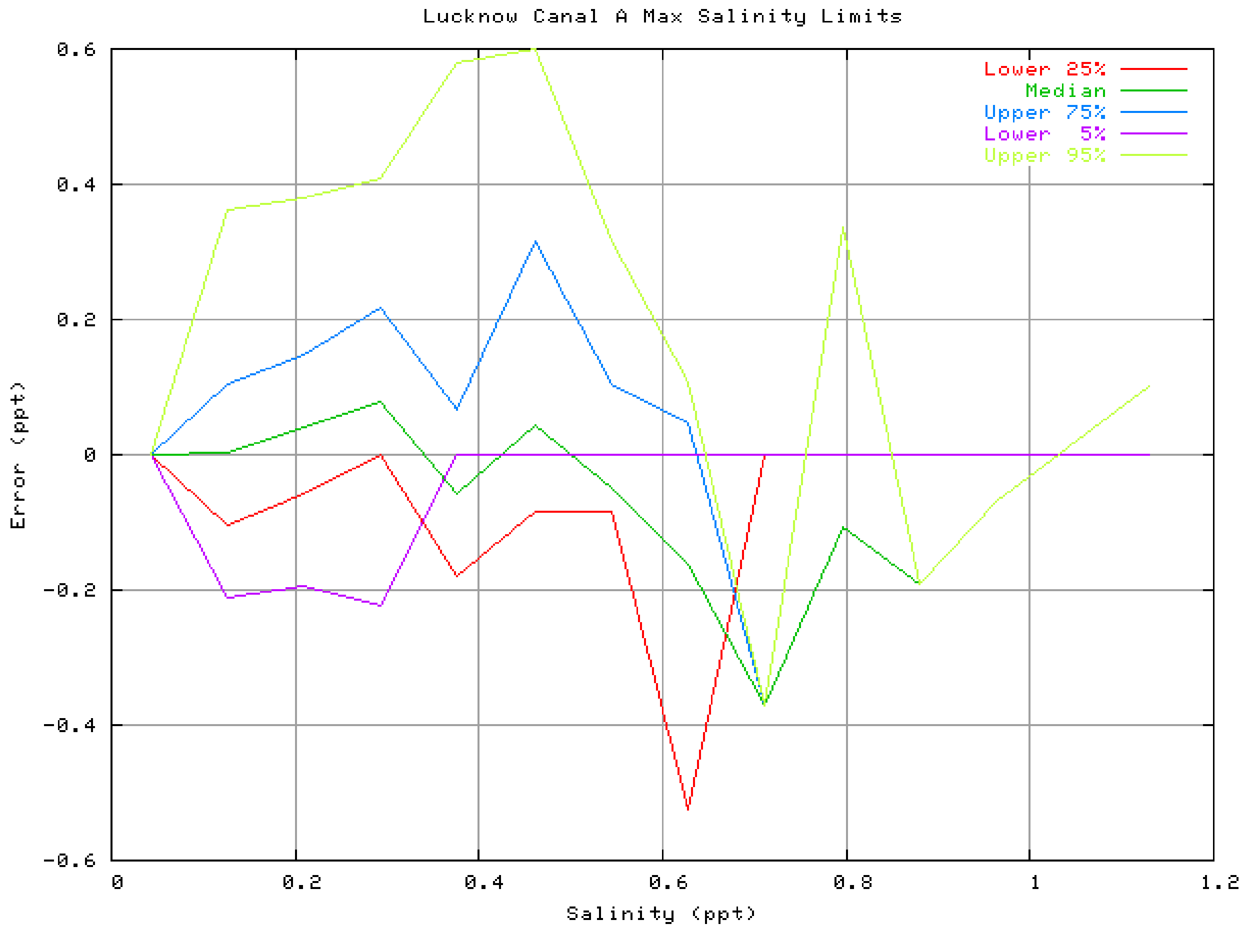


Figure 10.3: Daily Maximum Limits

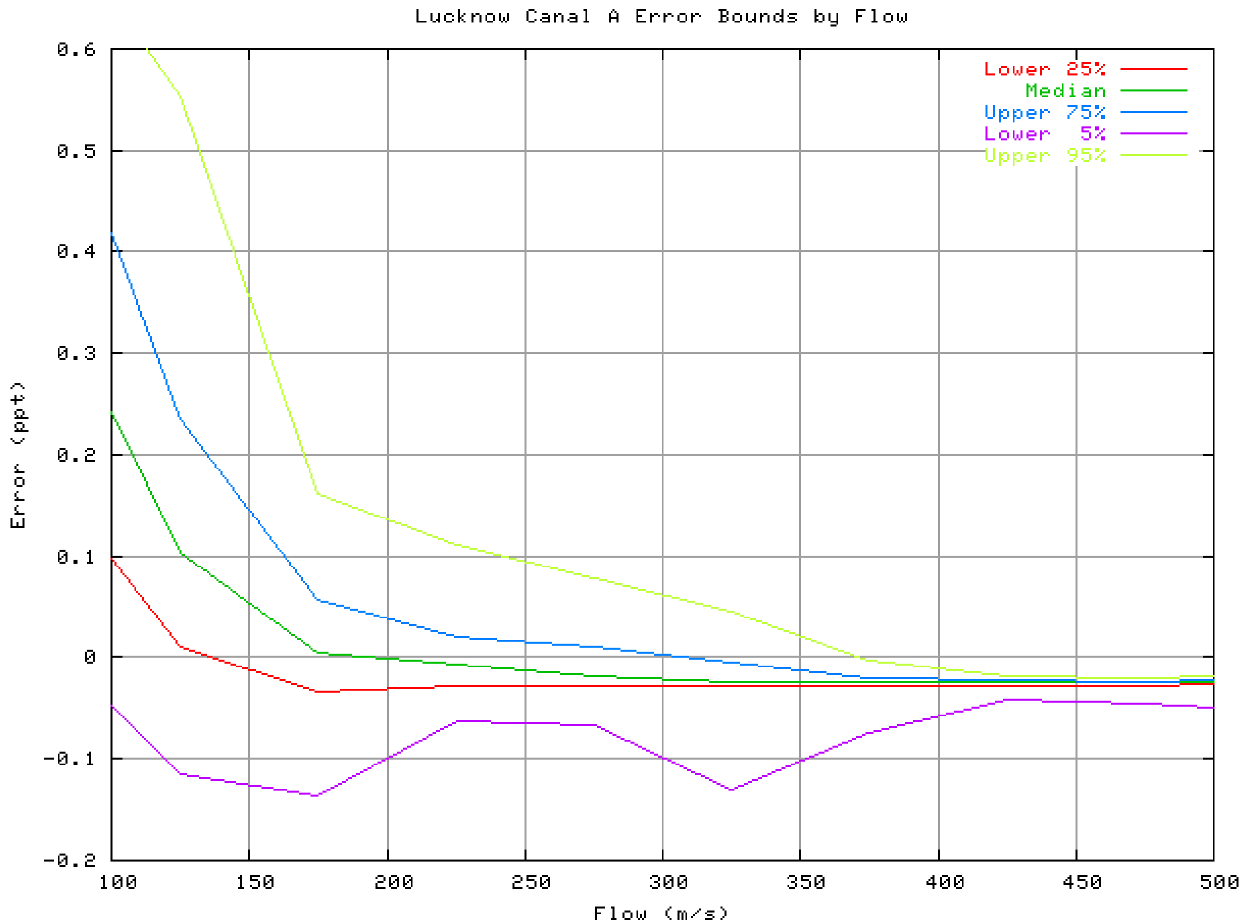


Figure 10.4: Error bounds by flow at Clyo

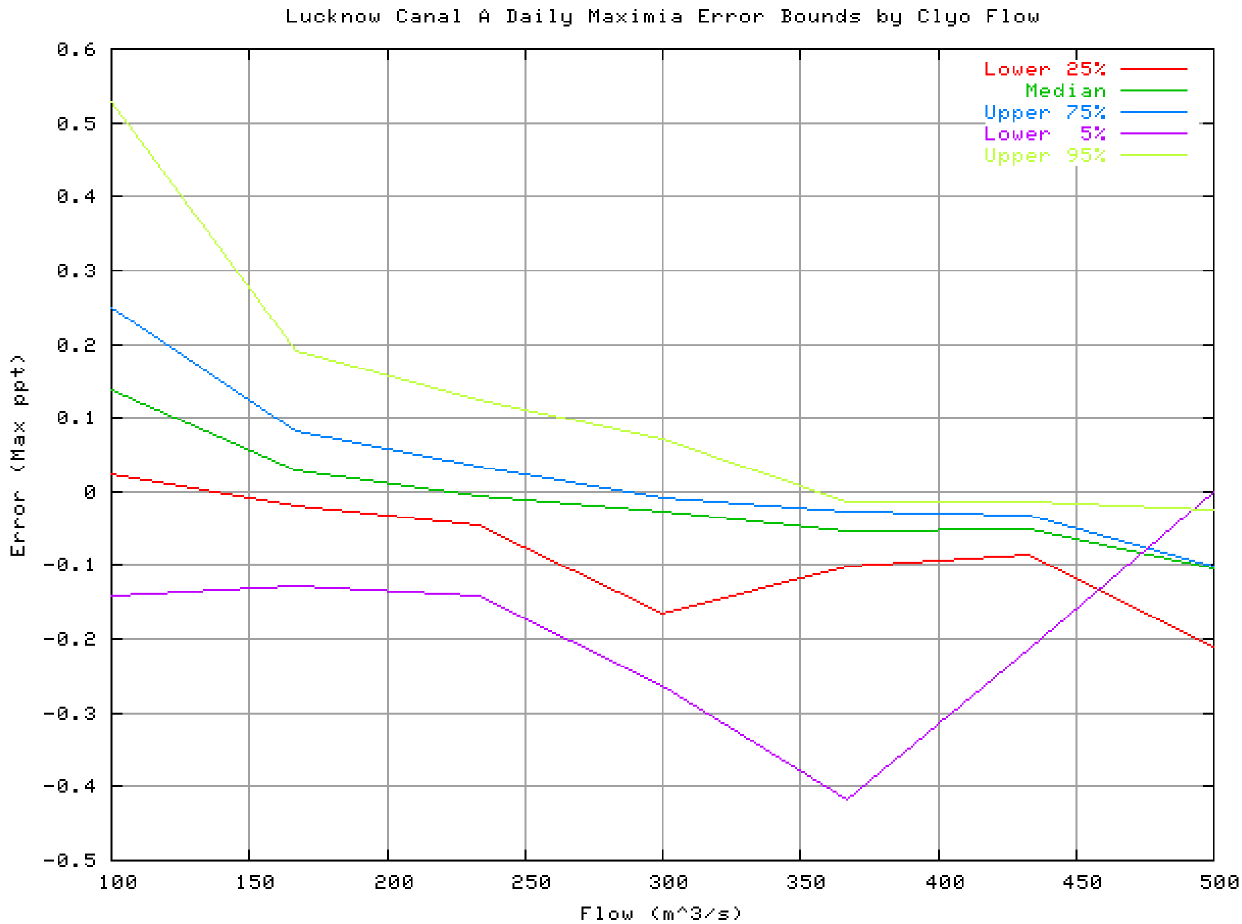


Figure 10.5: Daily Maxima error bounds by flow at Clyo

Chapter 11

Lucknow Canal B 00-03 ENHG Model

These plots show the results of the 2000-2003 simulations (part "B").

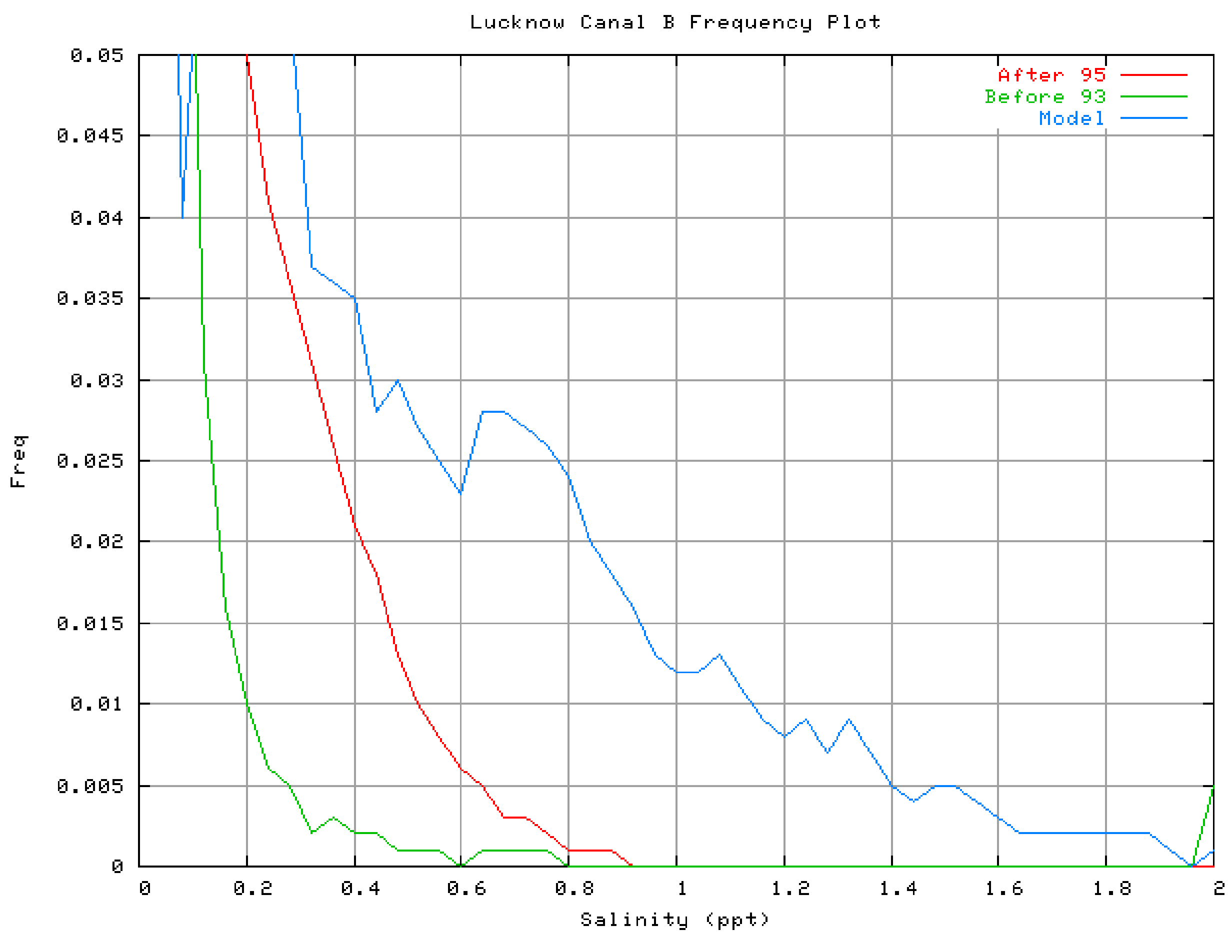


Figure 11.1: Salinity by Frequency of Occurrence

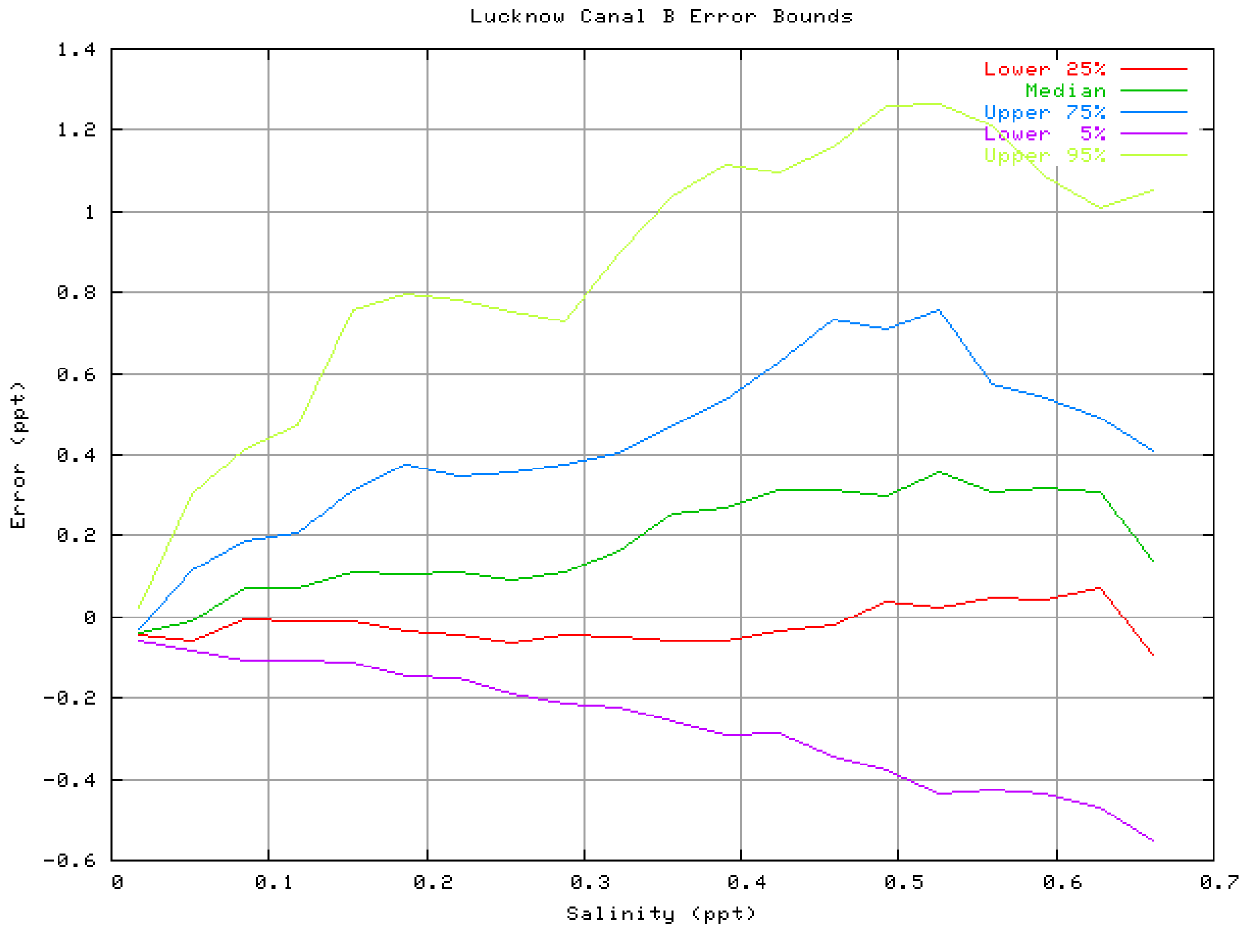


Figure 11.2: Error bounds by Salinity

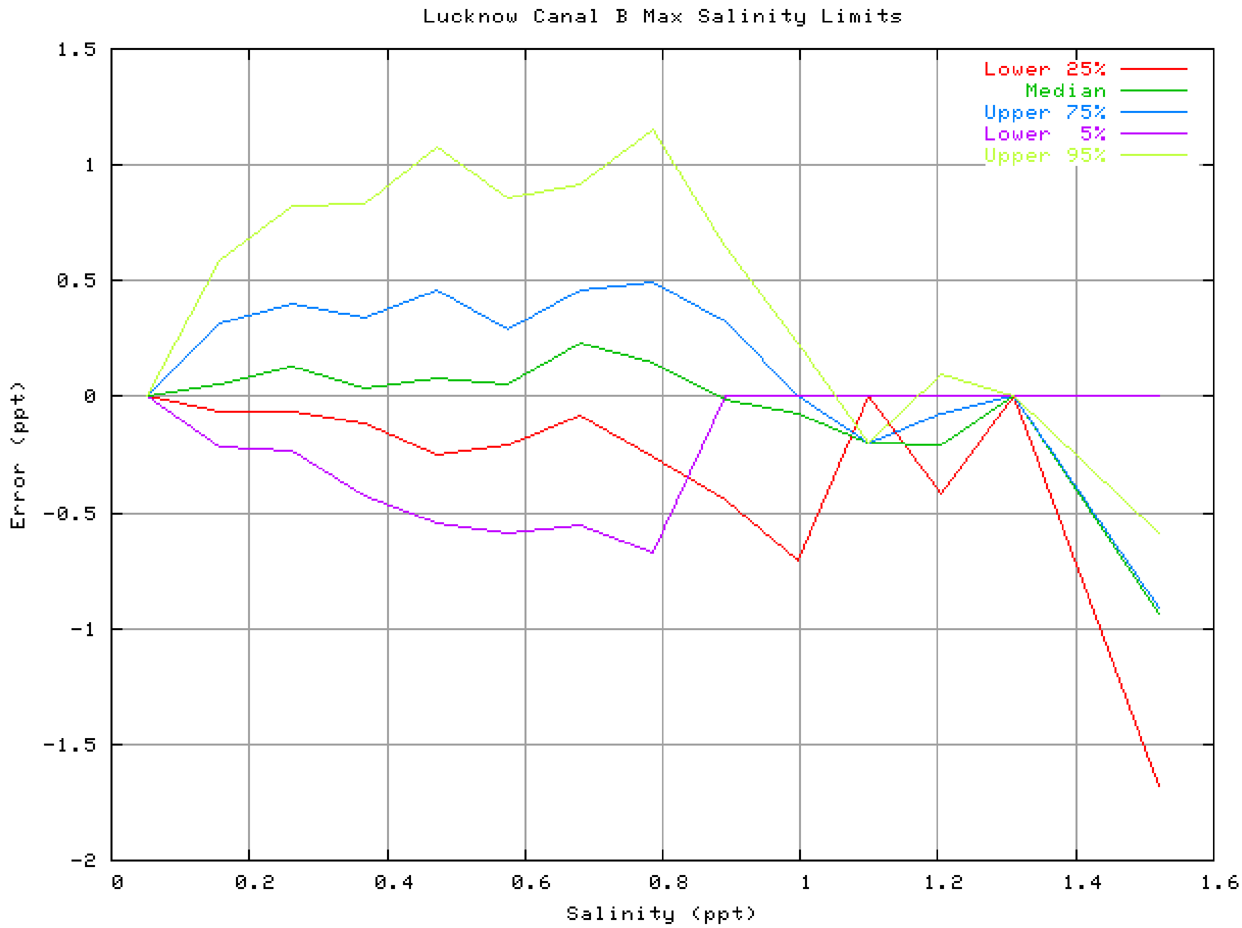


Figure 11.3: Daily Maximum Limits

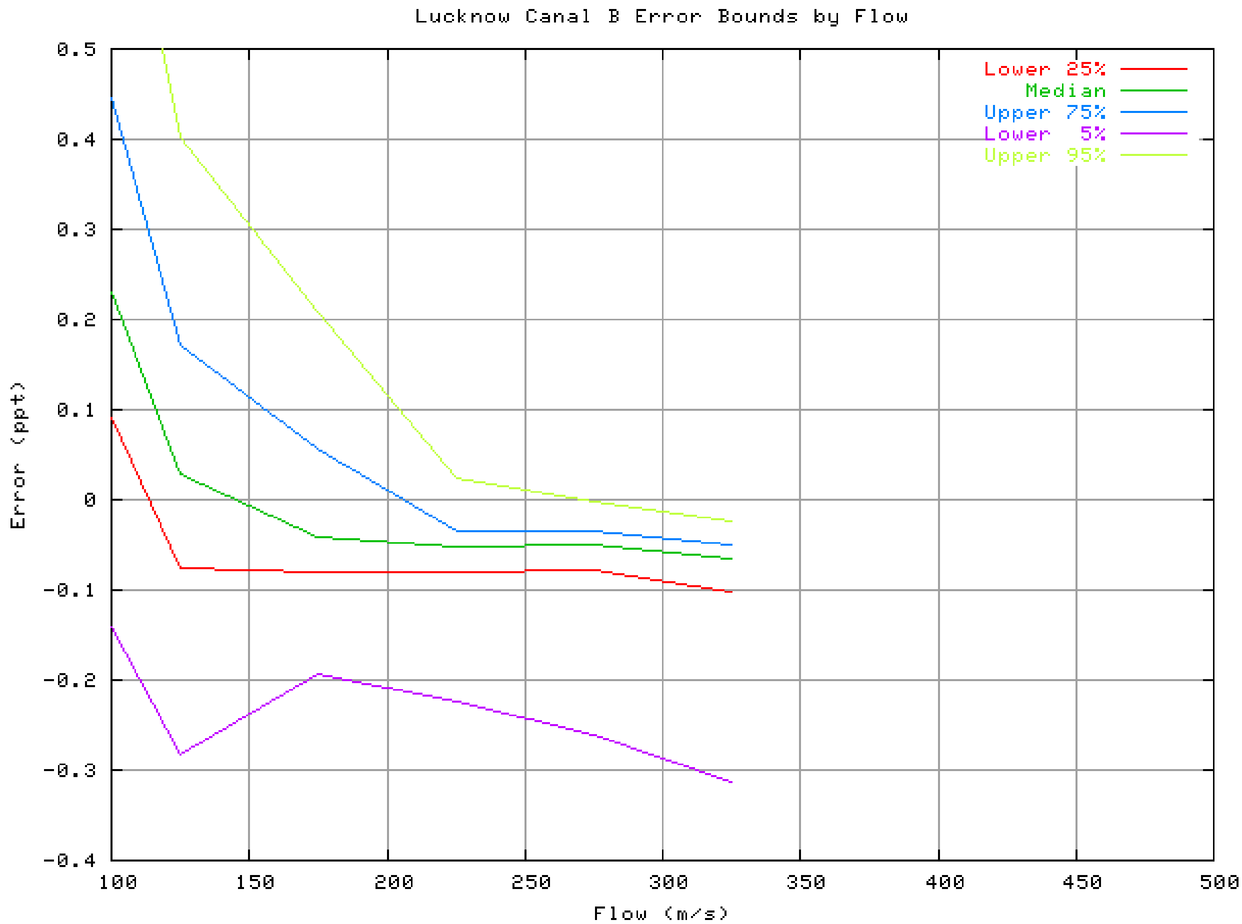


Figure 11.4: Error bounds by flow at Clyo

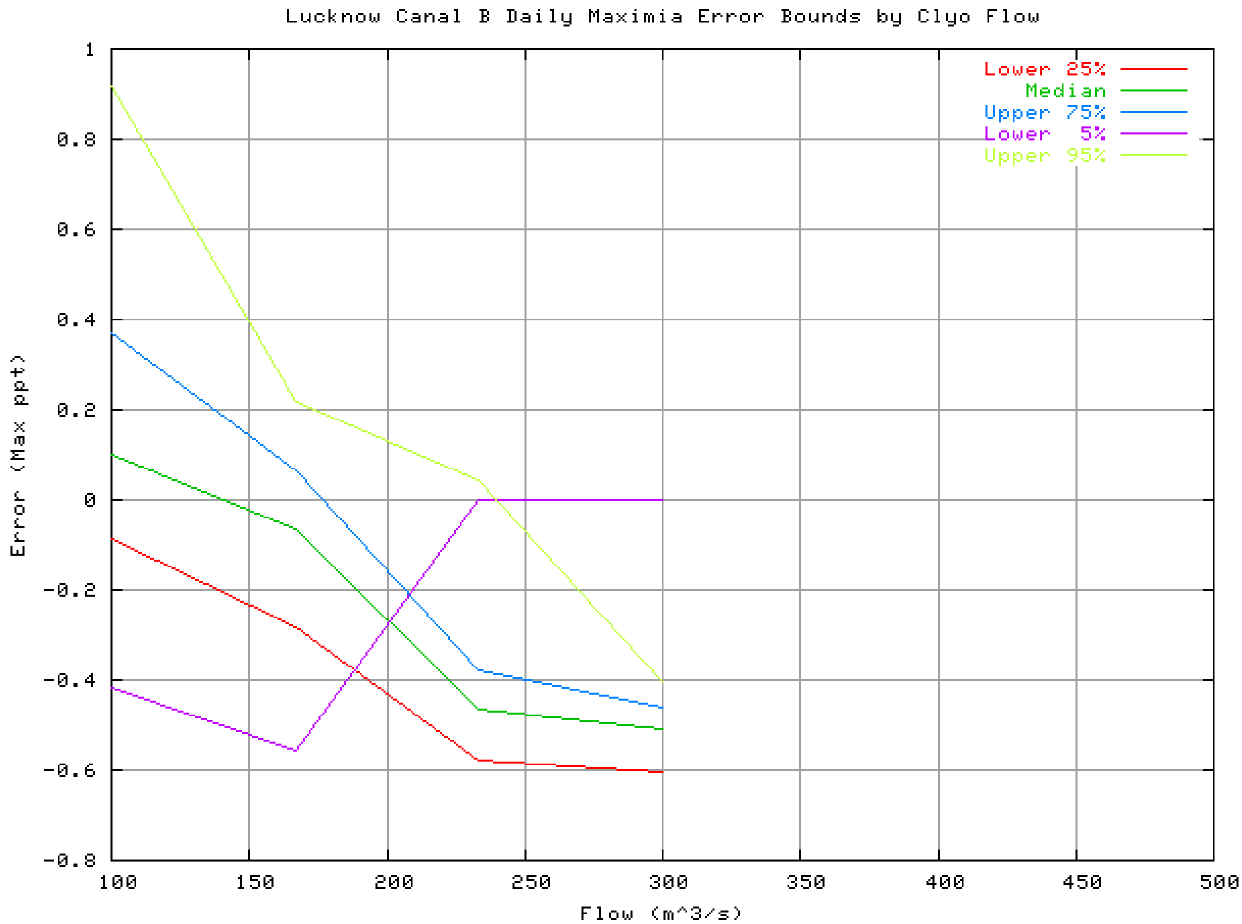


Figure 11.5: Daily Maxima error bounds by flow at Clyo

Chapter 12

I-95 Bridge A 97-99 ENHG Model

These plots show the results of the 1997-1999 simulations (part ”A”).

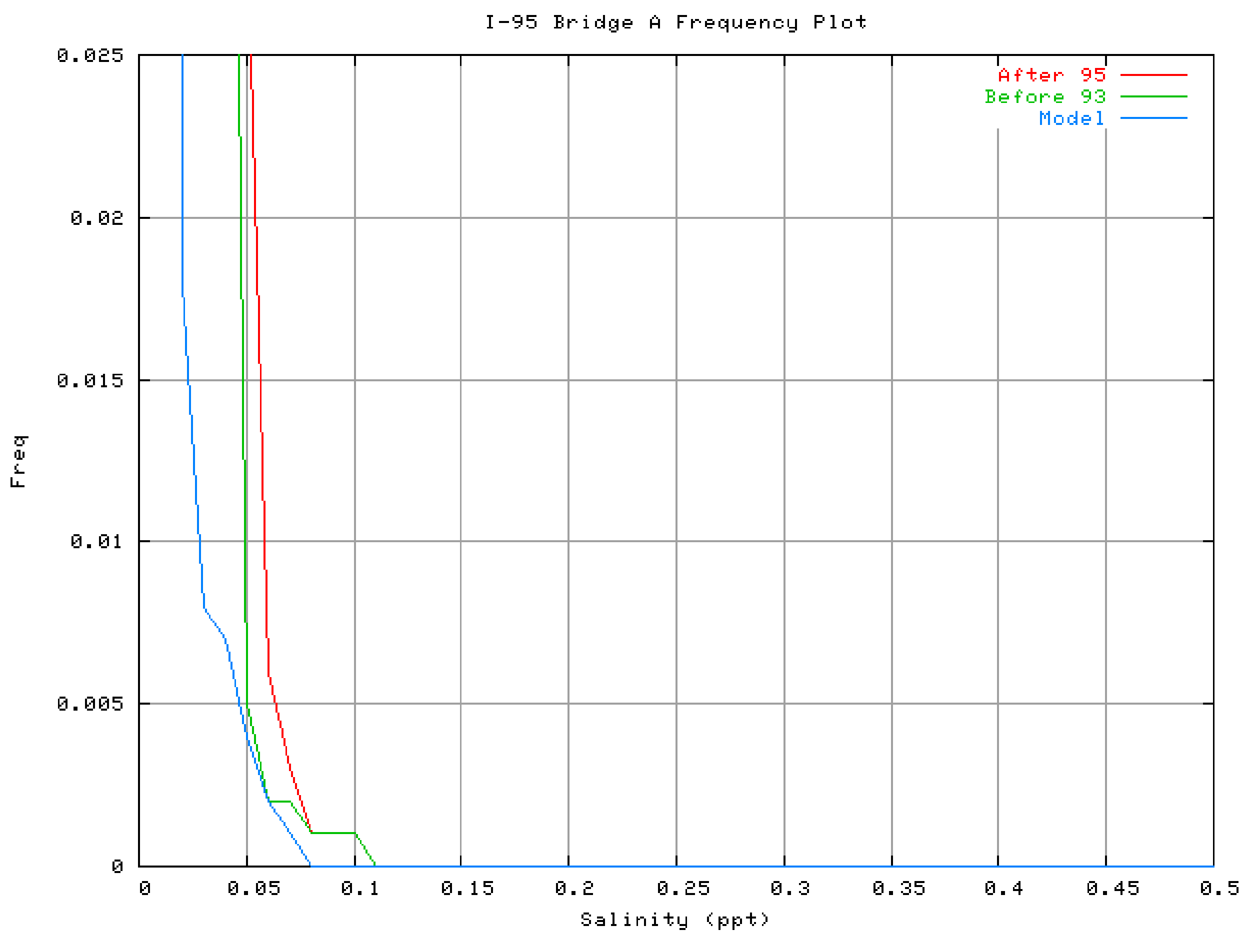


Figure 12.1: Salinity by Frequency of Occurrence

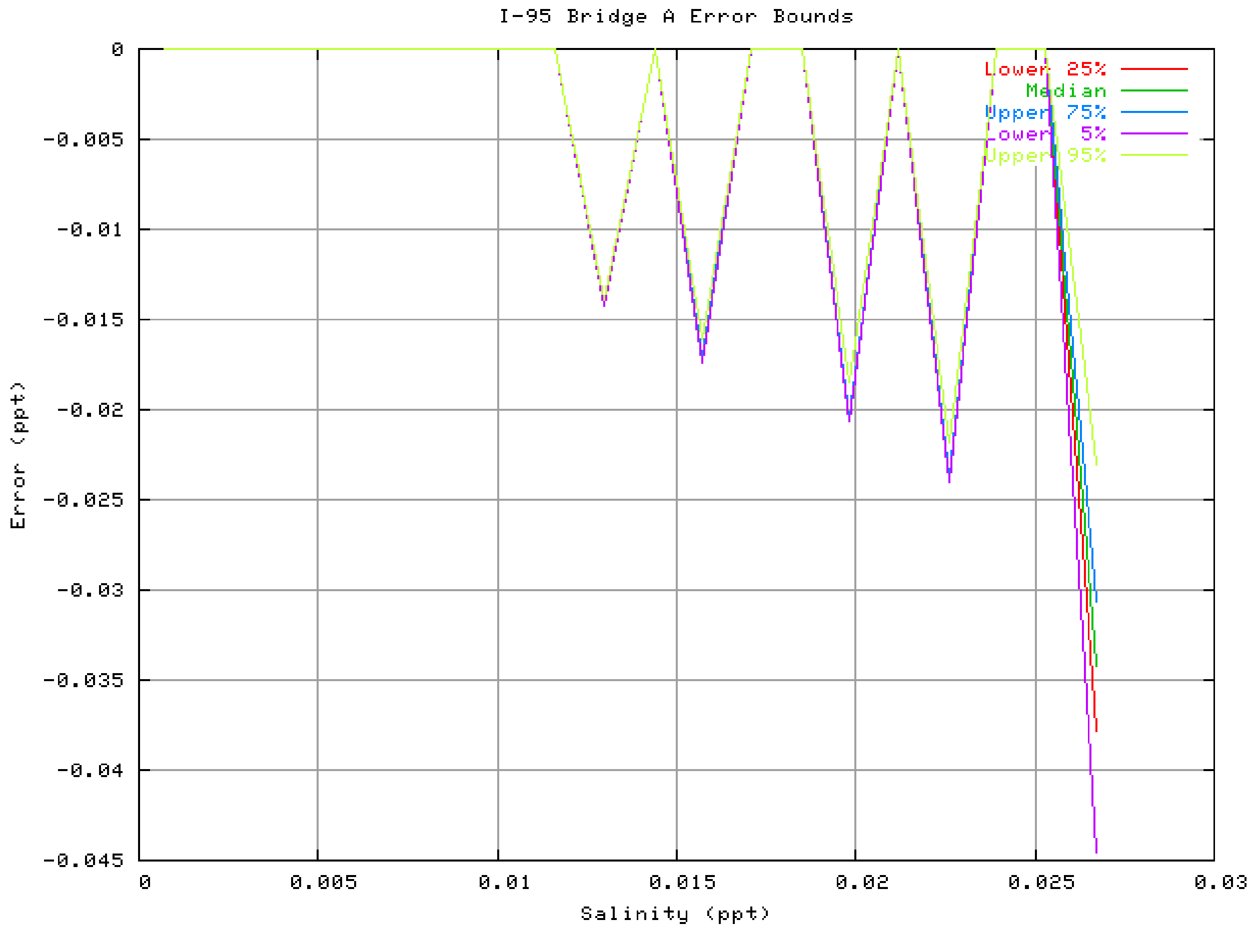


Figure 12.2: Error bounds by Salinity

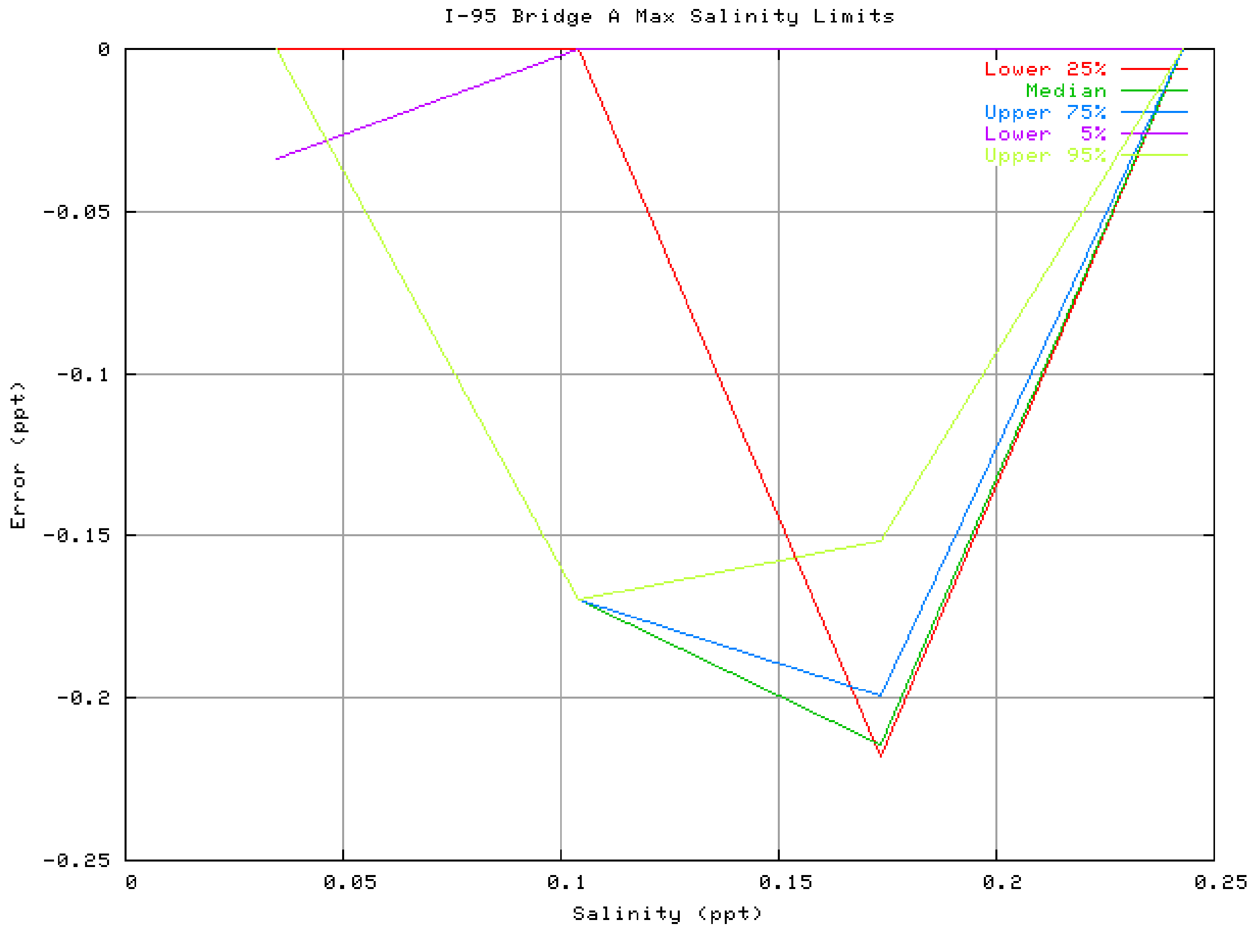


Figure 12.3: Daily Maximum Limits

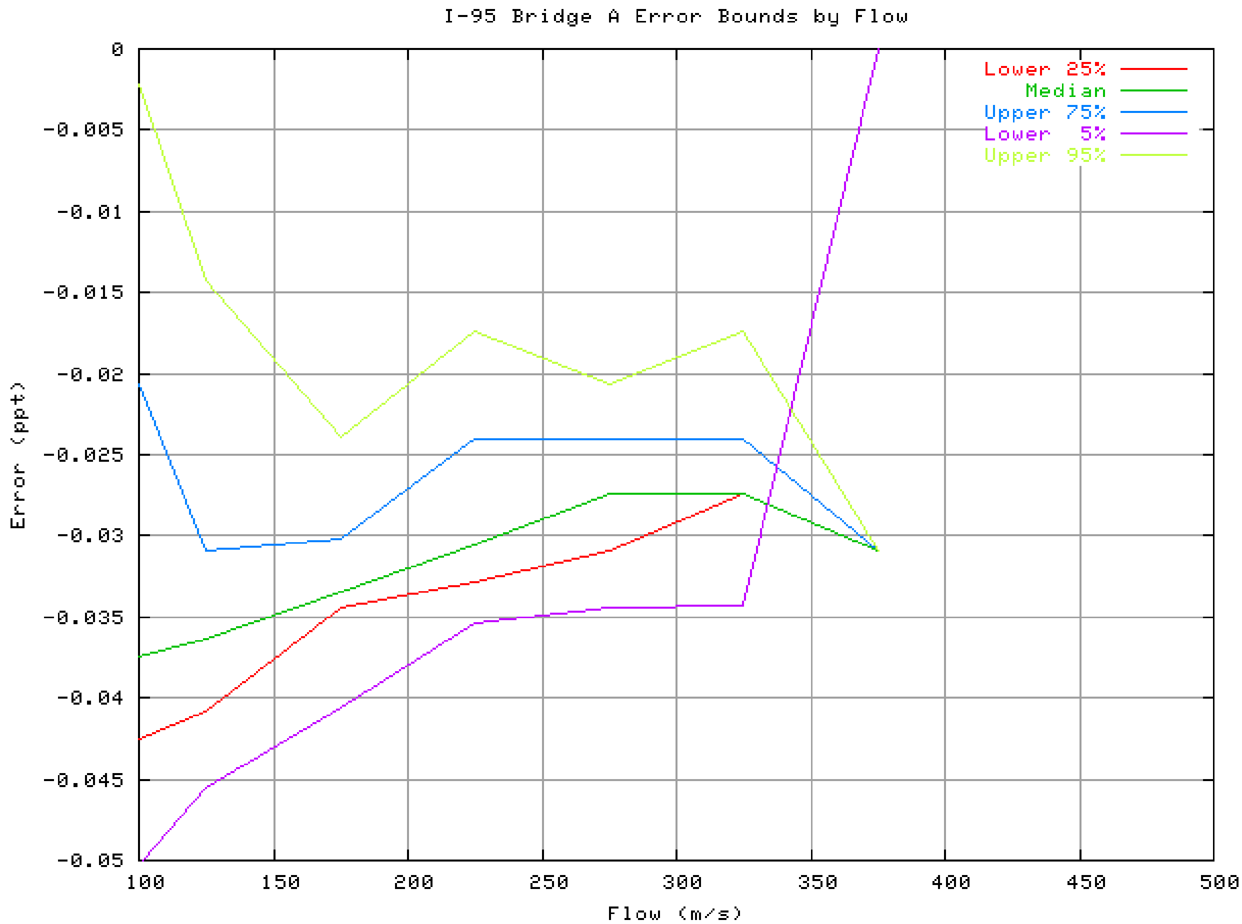


Figure 12.4: Error bounds by flow at Clyo

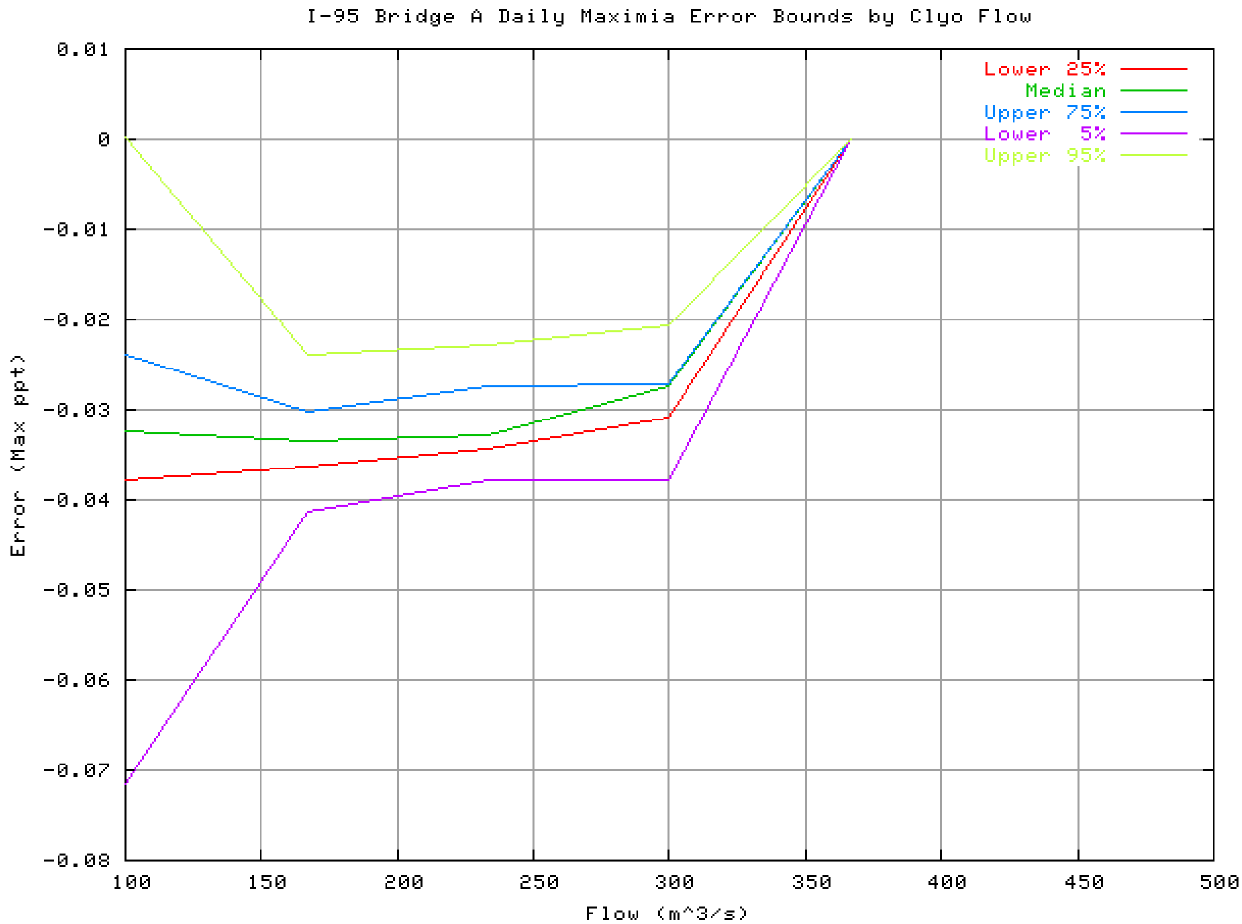


Figure 12.5: Daily Maxima error bounds by flow at Clyo

Chapter 13

I-95 Bridge B 00-03 ENHG Model

These plots show the results of the 2000-2003 simulations (part ”B”).

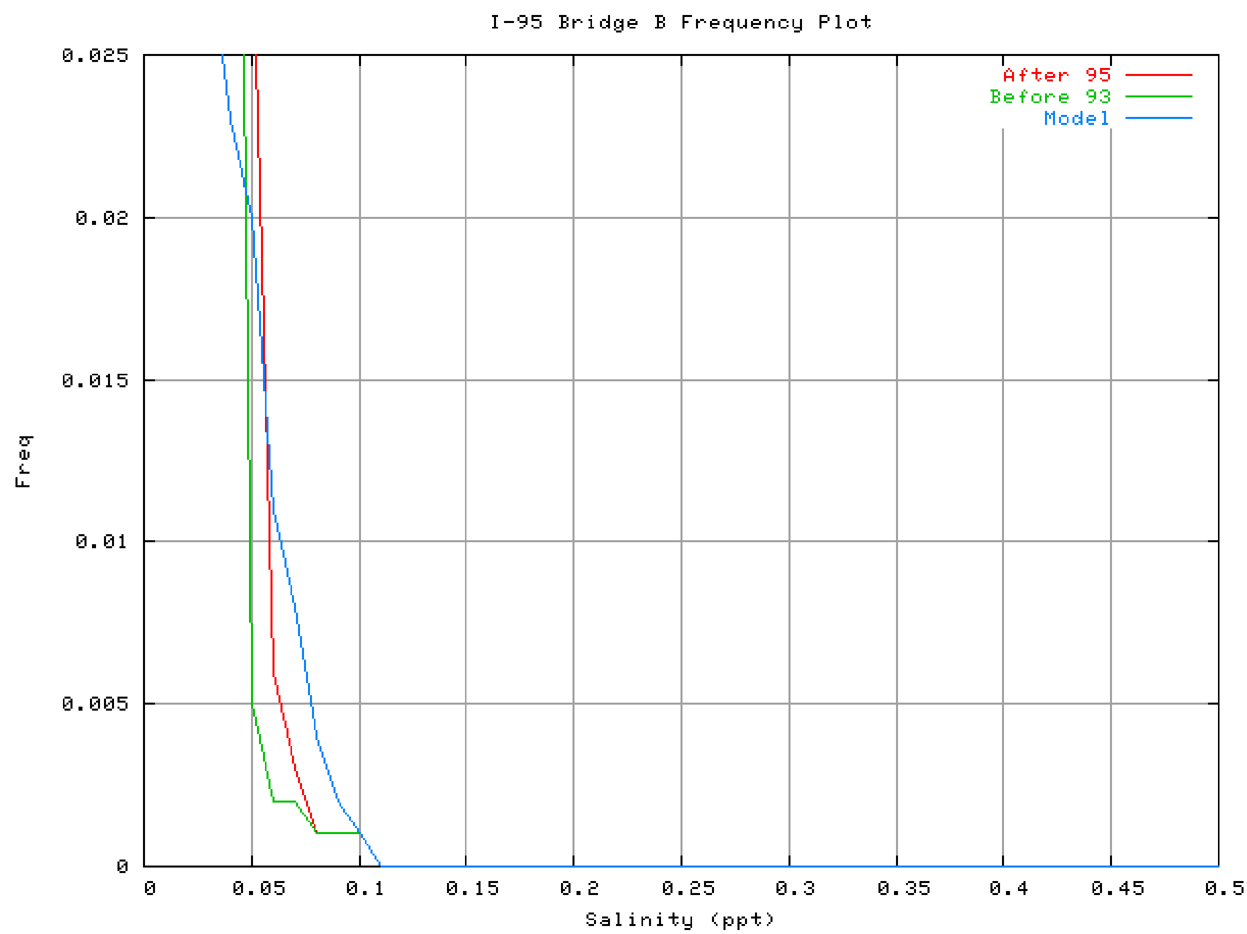


Figure 13.1: Salinity by Frequency of Occurrence

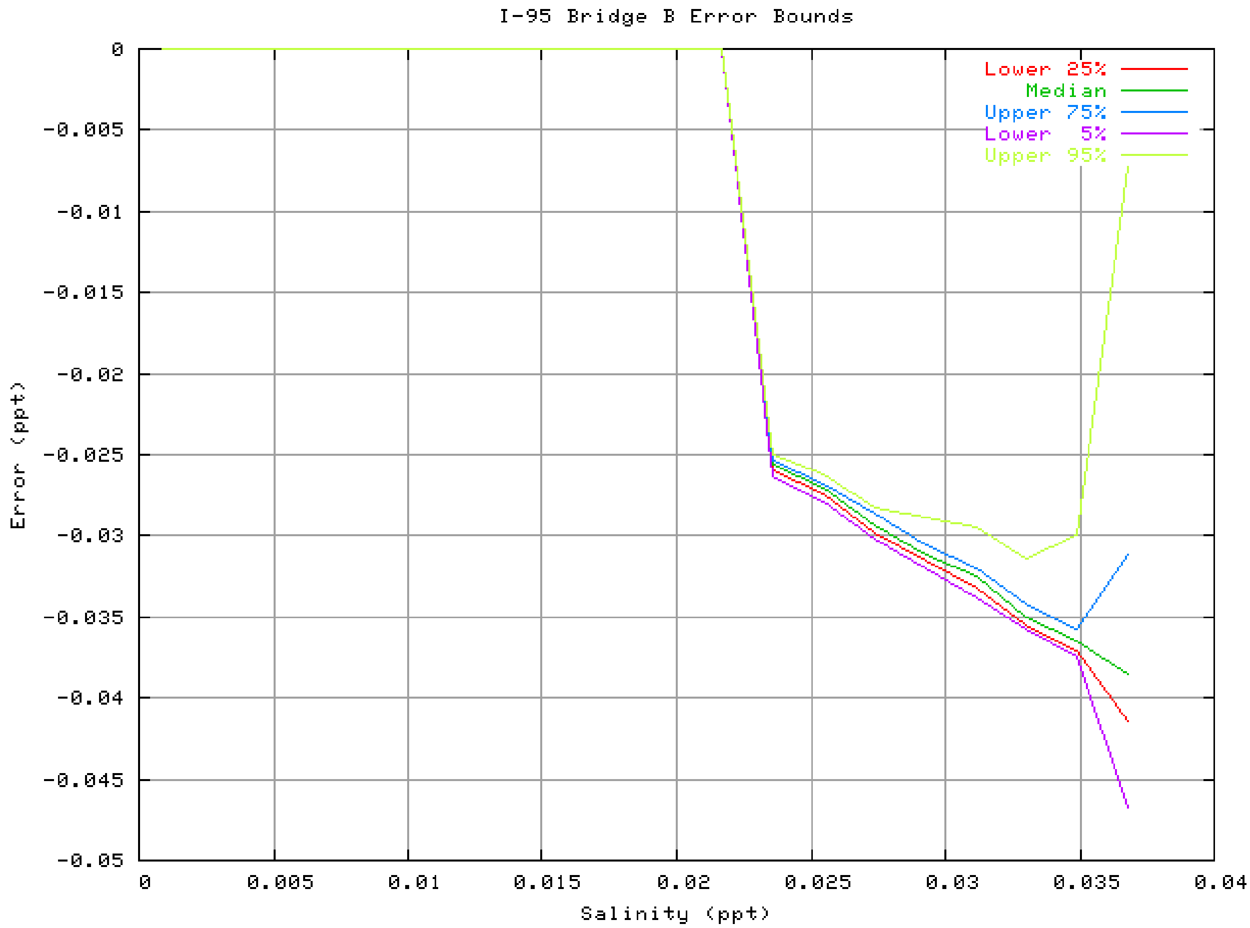


Figure 13.2: Error bounds by Salinity

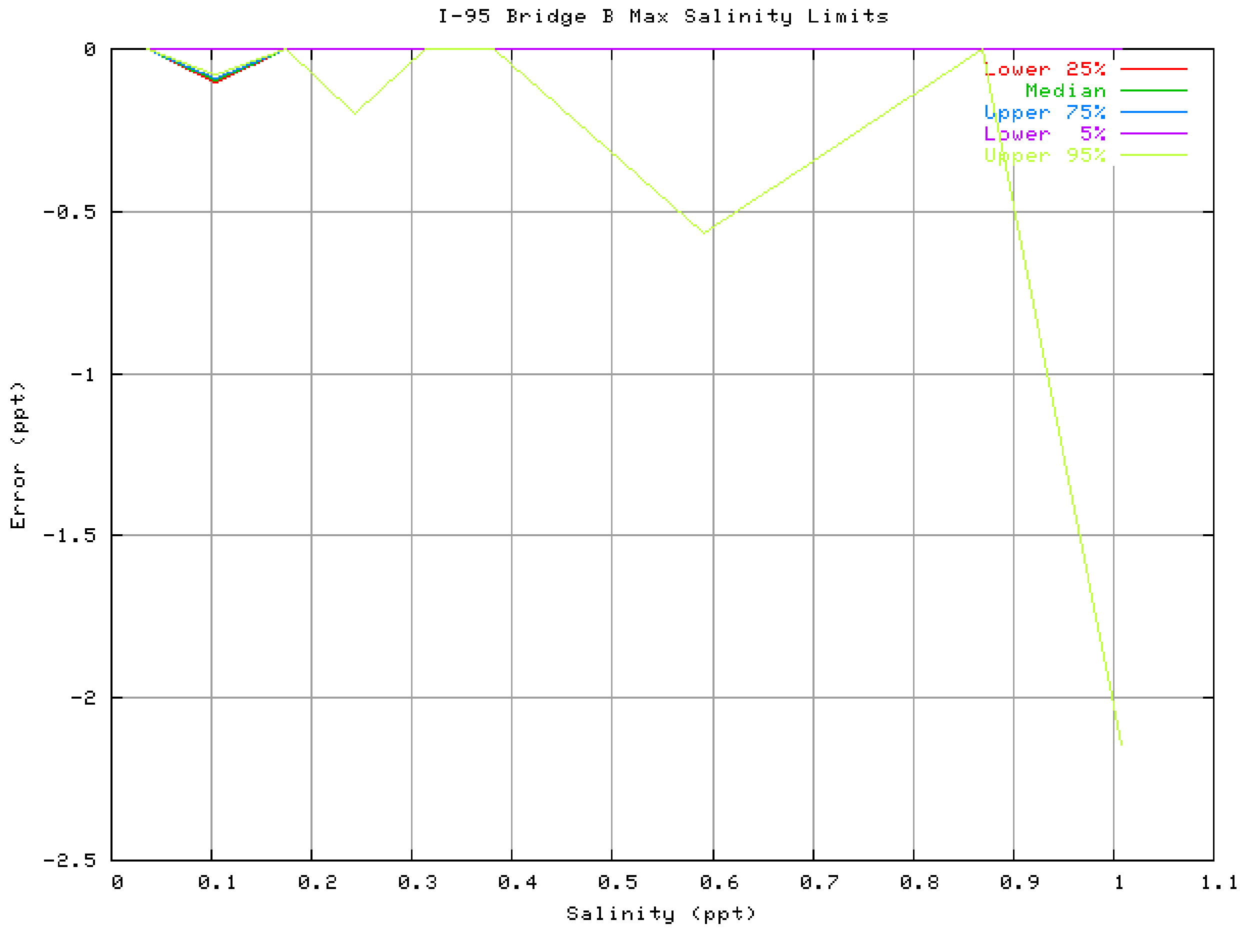


Figure 13.3: Daily Maximum Limits

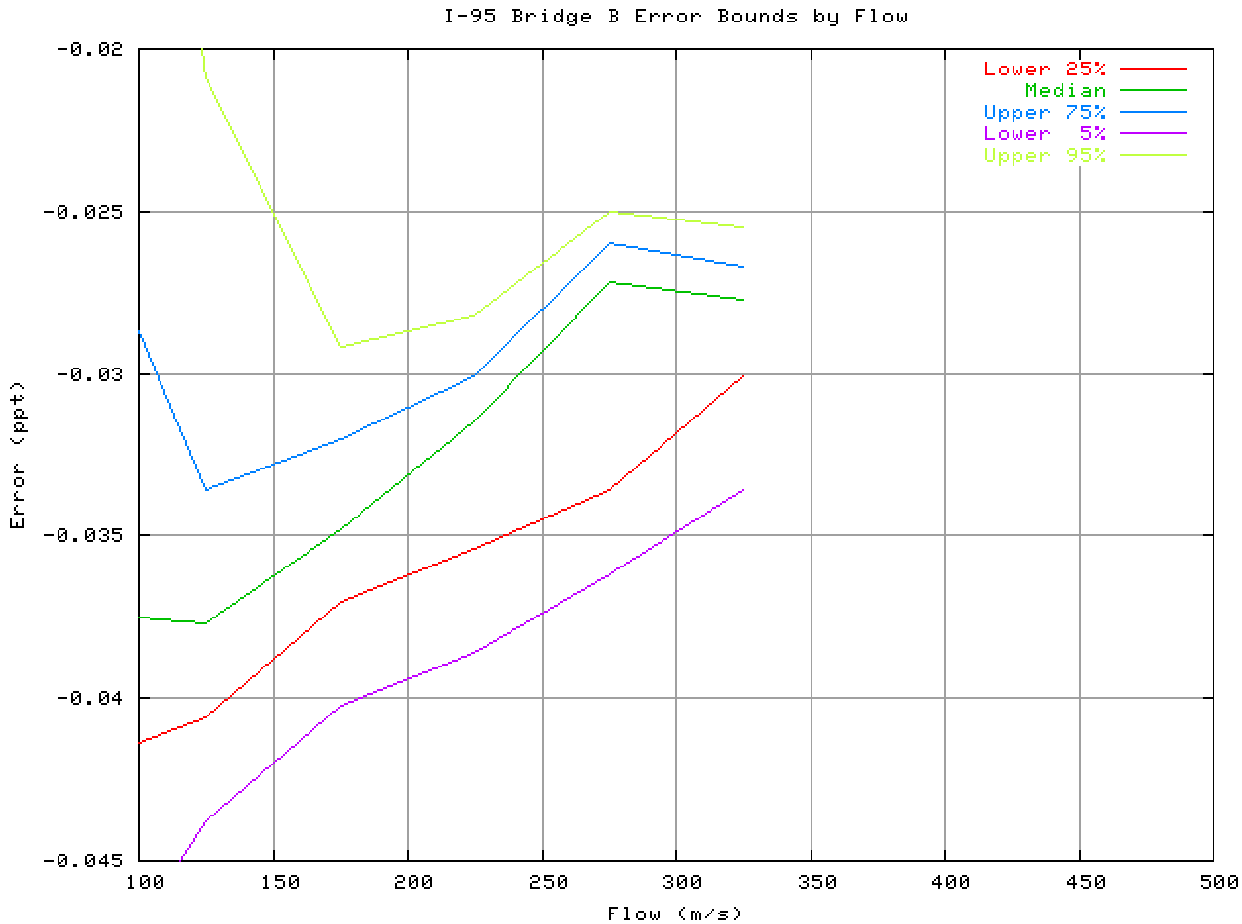


Figure 13.4: Error bounds by flow at Clyo

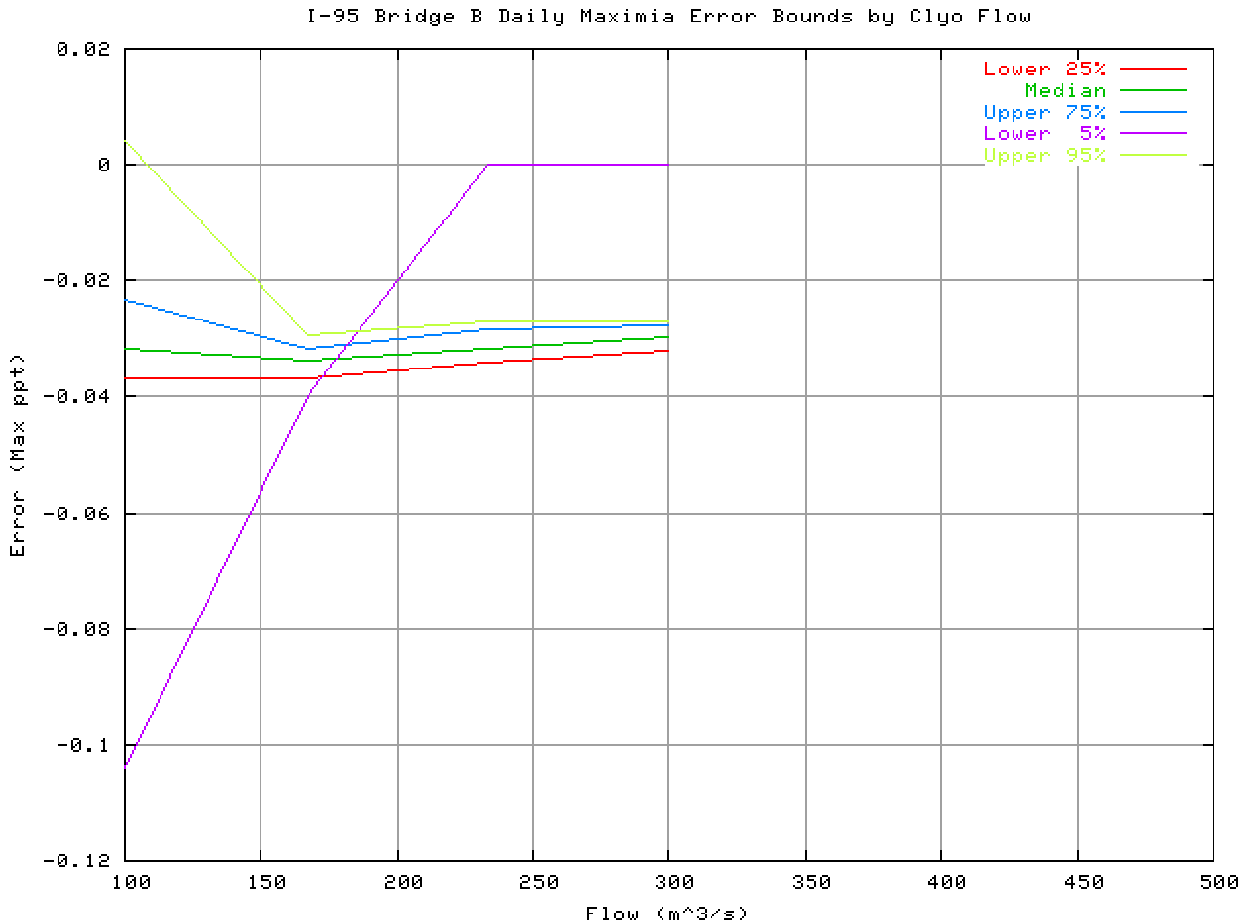


Figure 13.5: Daily Maxima error bounds by flow at Clyo

Chapter 14

Error by phase of tide cycle

One indication of the performace and sensitivity of the model is to display error by tide. The graphs below plot the error in salinity in terms of the magnitude and phase (incoming or outgoing) of the tide.

14.1 Performance on 1997-1999 run

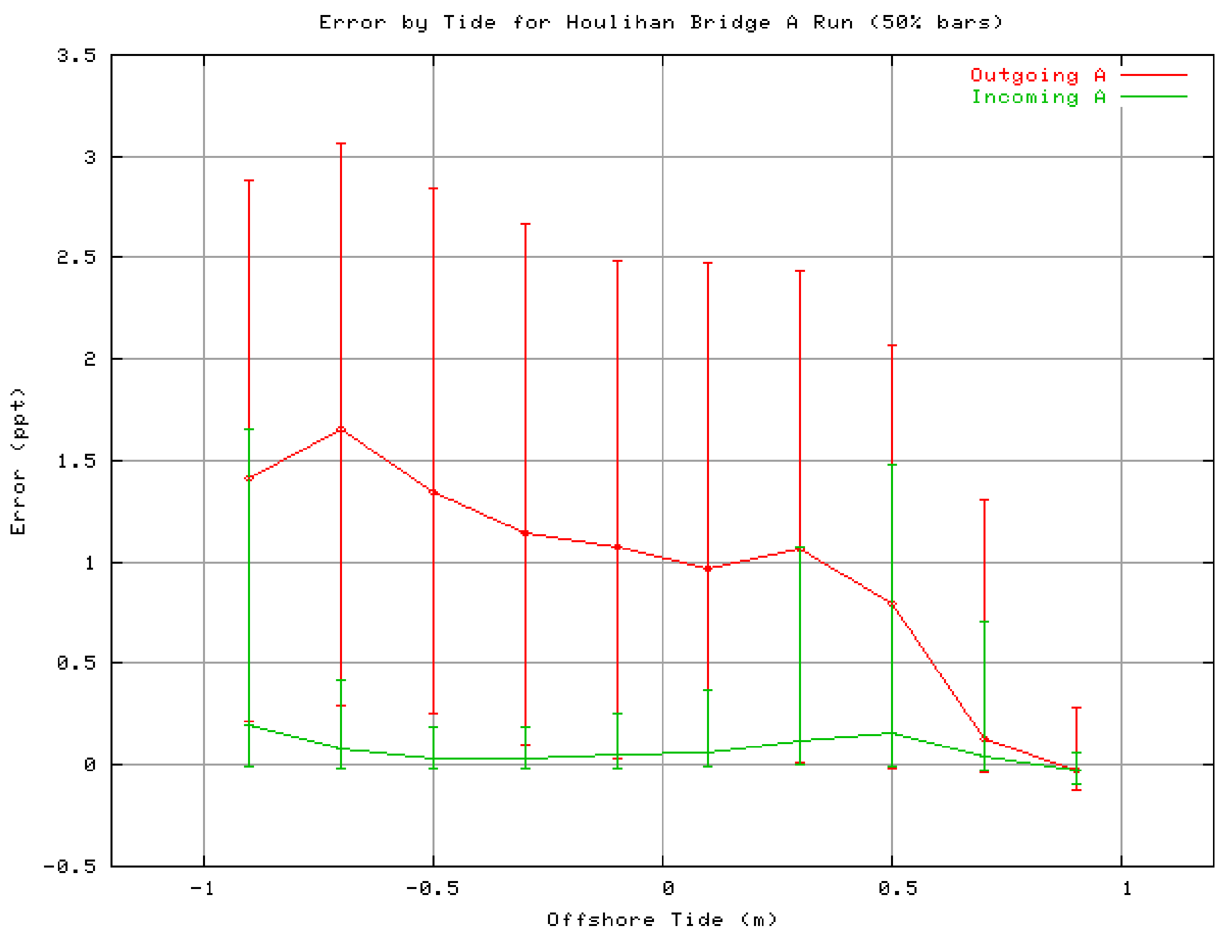


Figure 14.1: Error by tide, Houlihan Bridge, 97-99

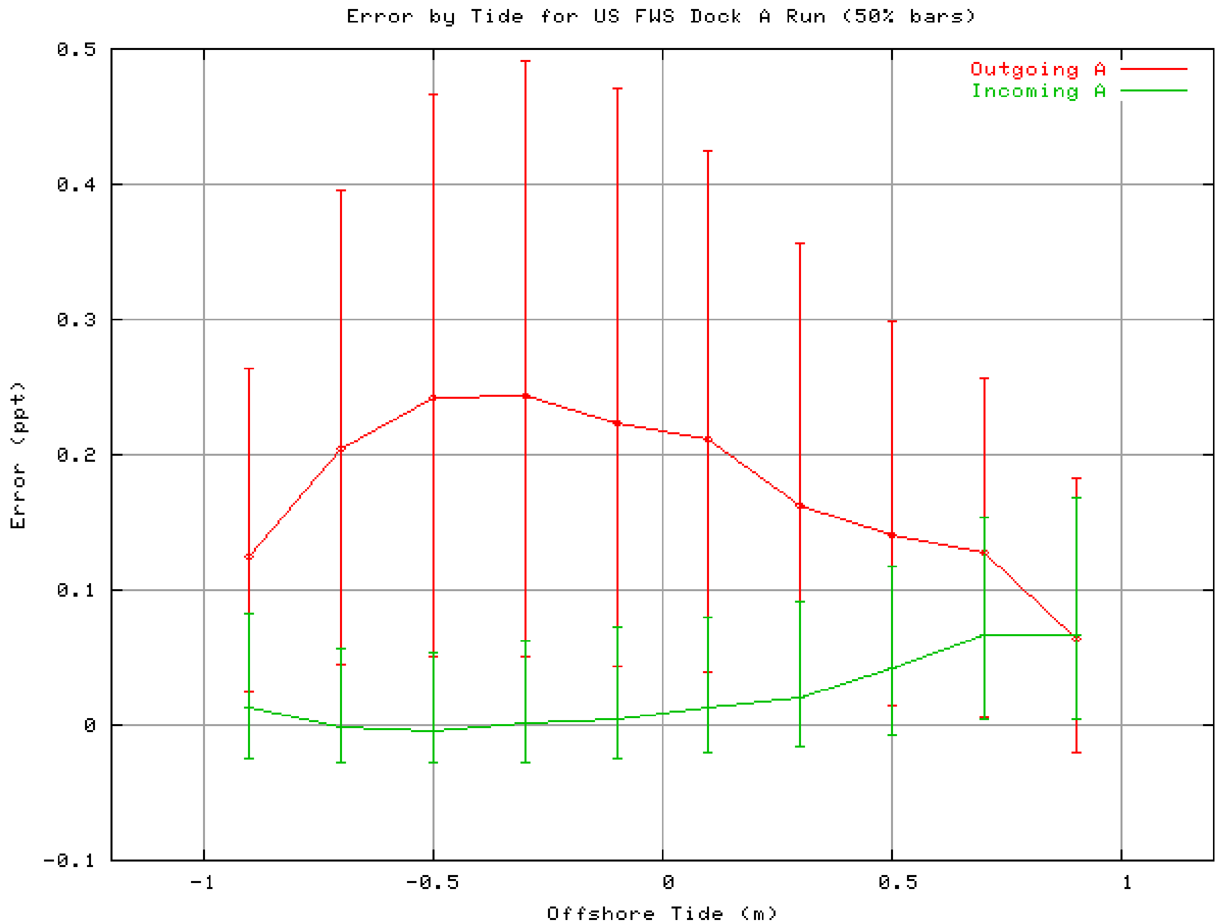


Figure 14.2: Error by tide, USFWS Dock, 97-99

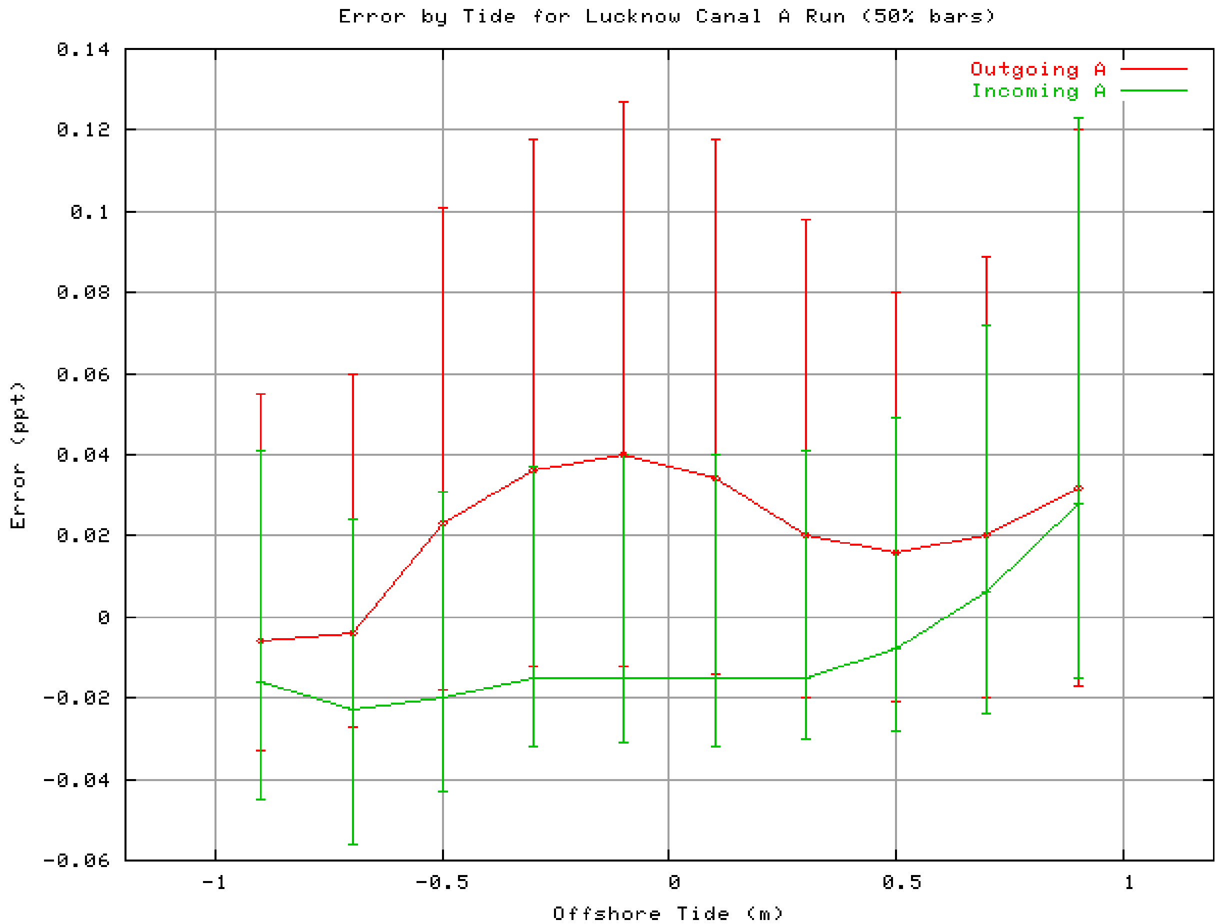


Figure 14.3: Error by tide, Lucknow Canal, 97-99

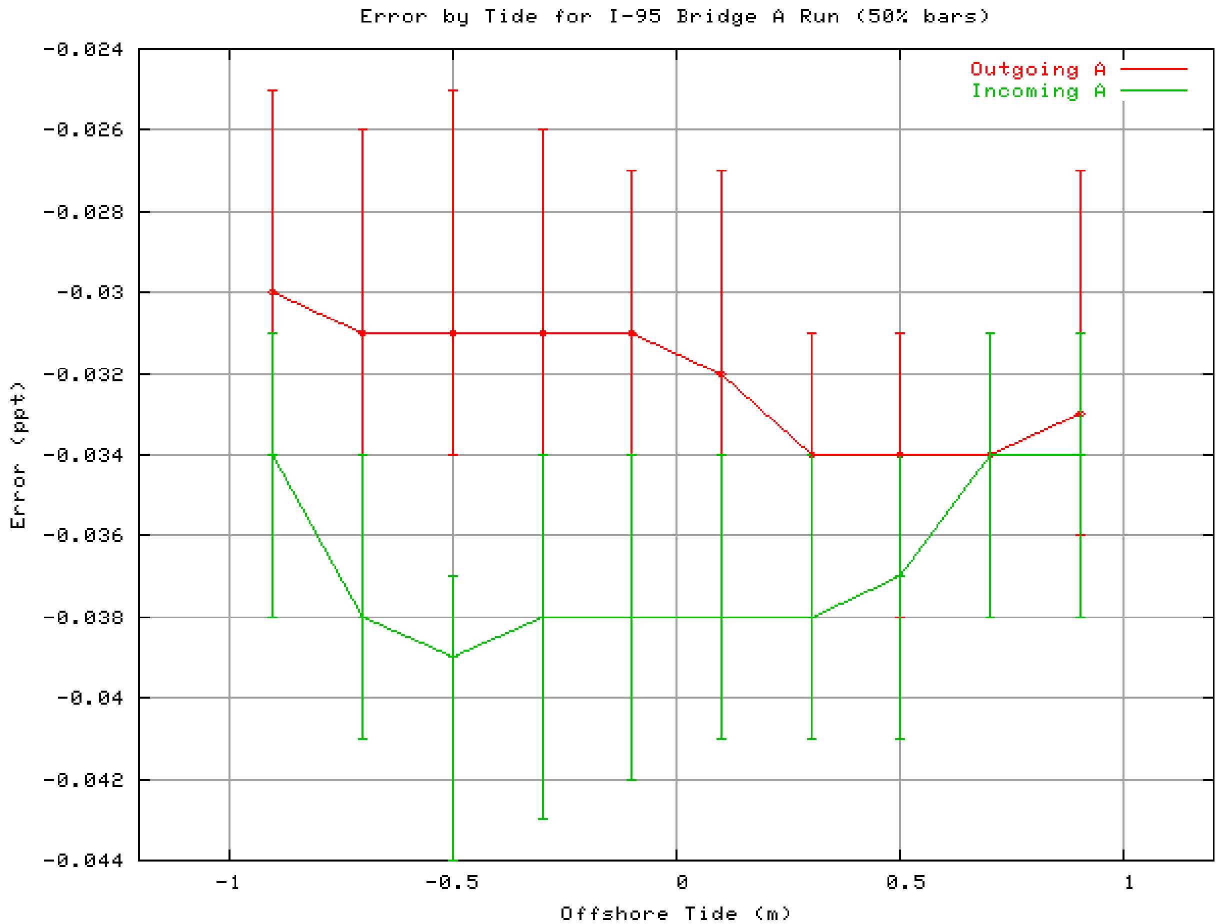


Figure 14.4: Error by tide, I-95 Bridge, 97-99

14.2 Performance on 2000-2003 run

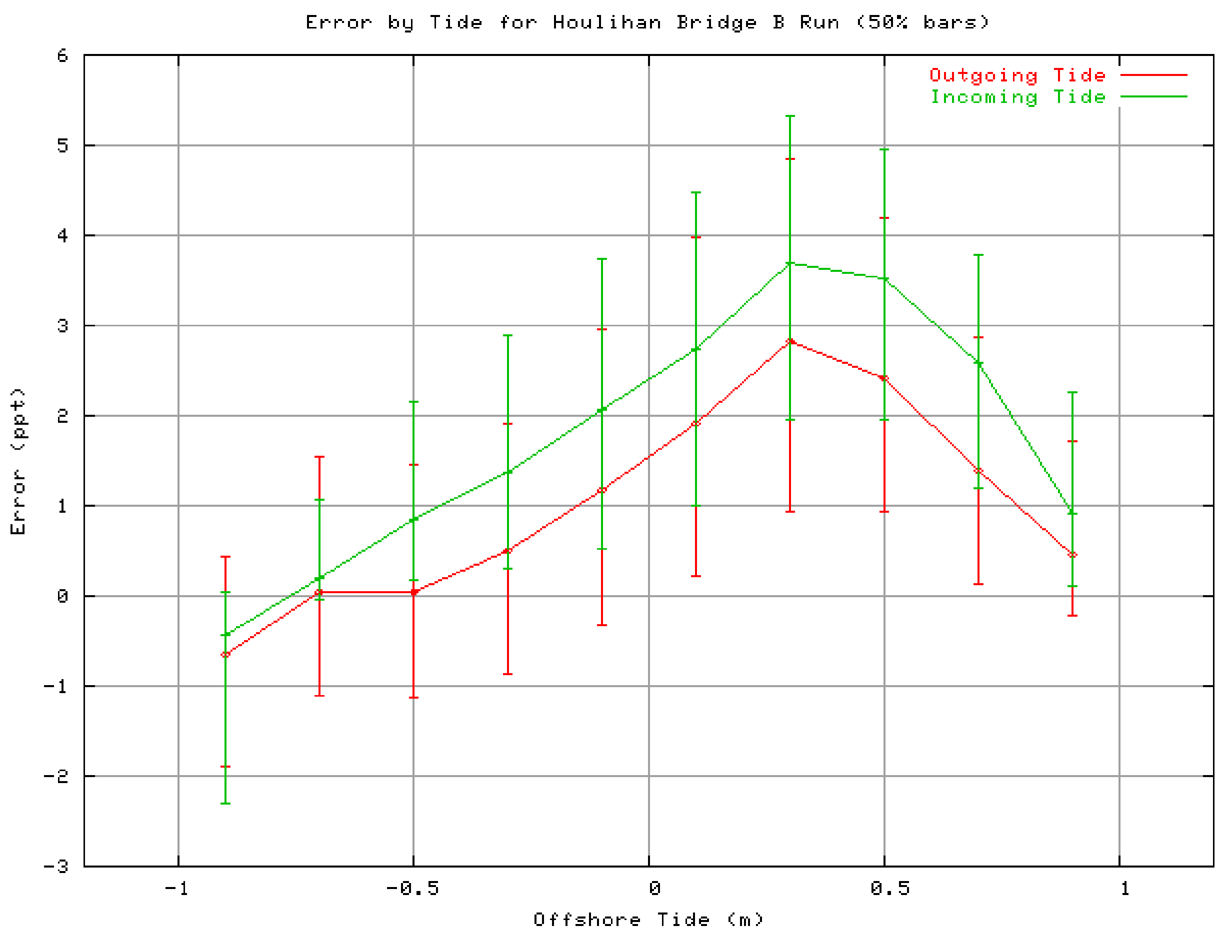


Figure 14.5: Error by tide, Houlihan Bridge, 00-03

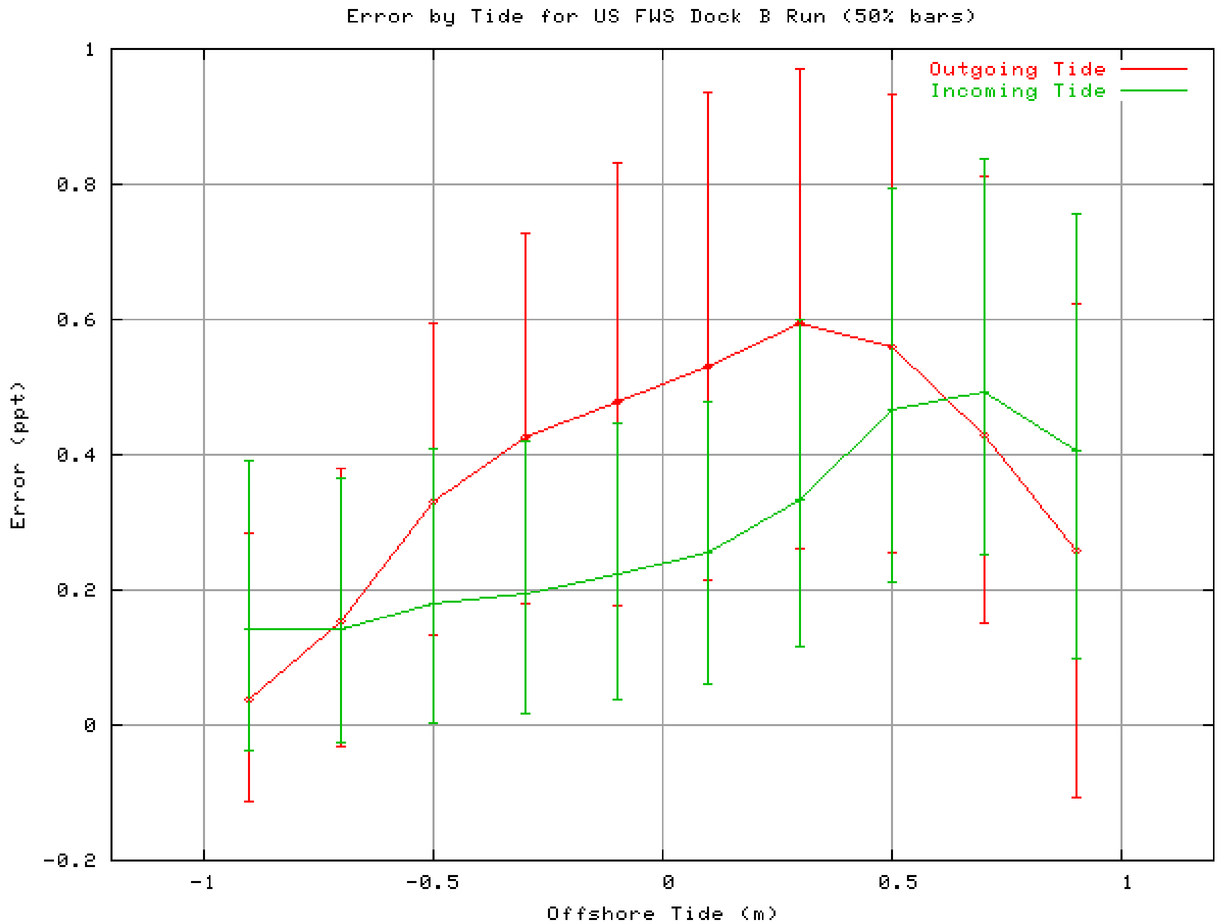


Figure 14.6: Error by tide, USFWS Dock, 00-03

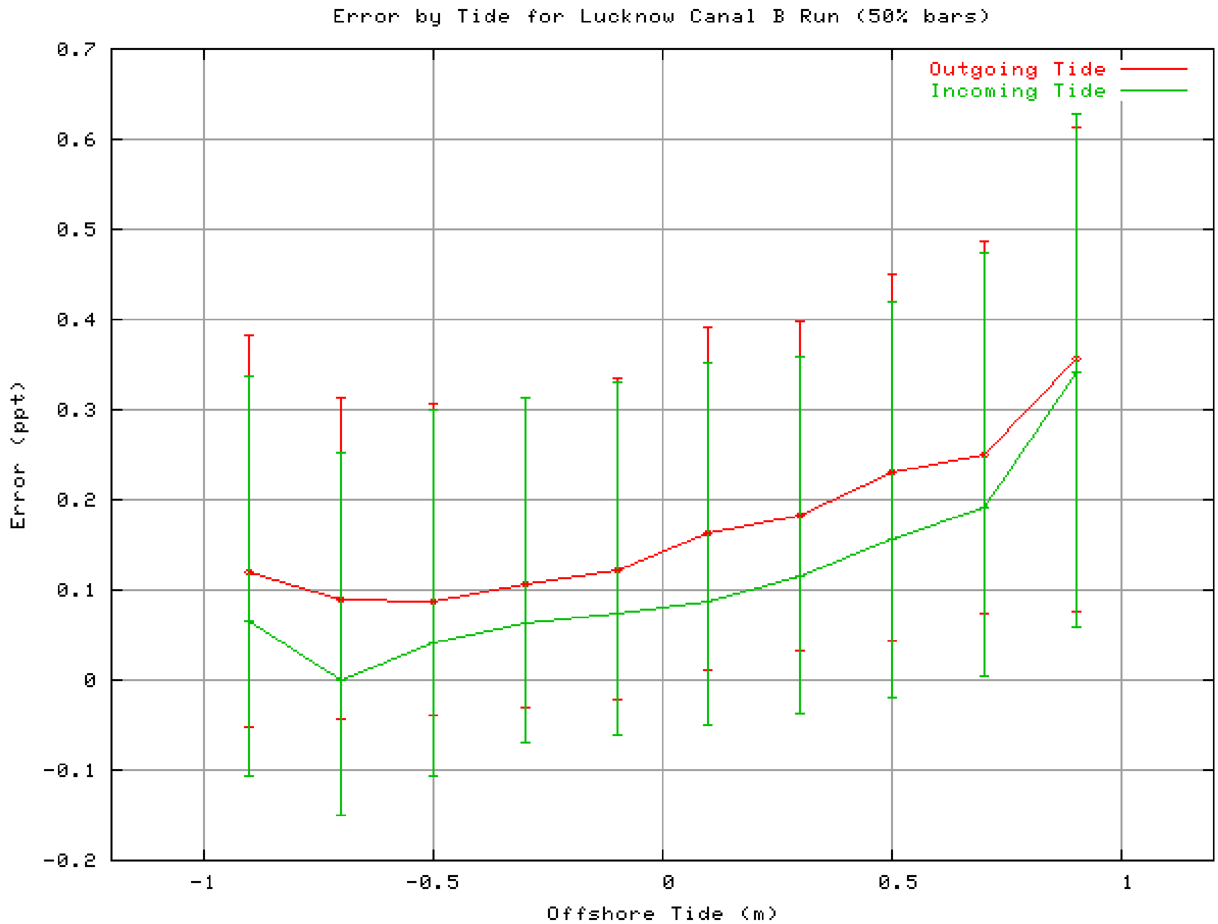


Figure 14.7: Error by tide, Lucknow Canal, 00-03

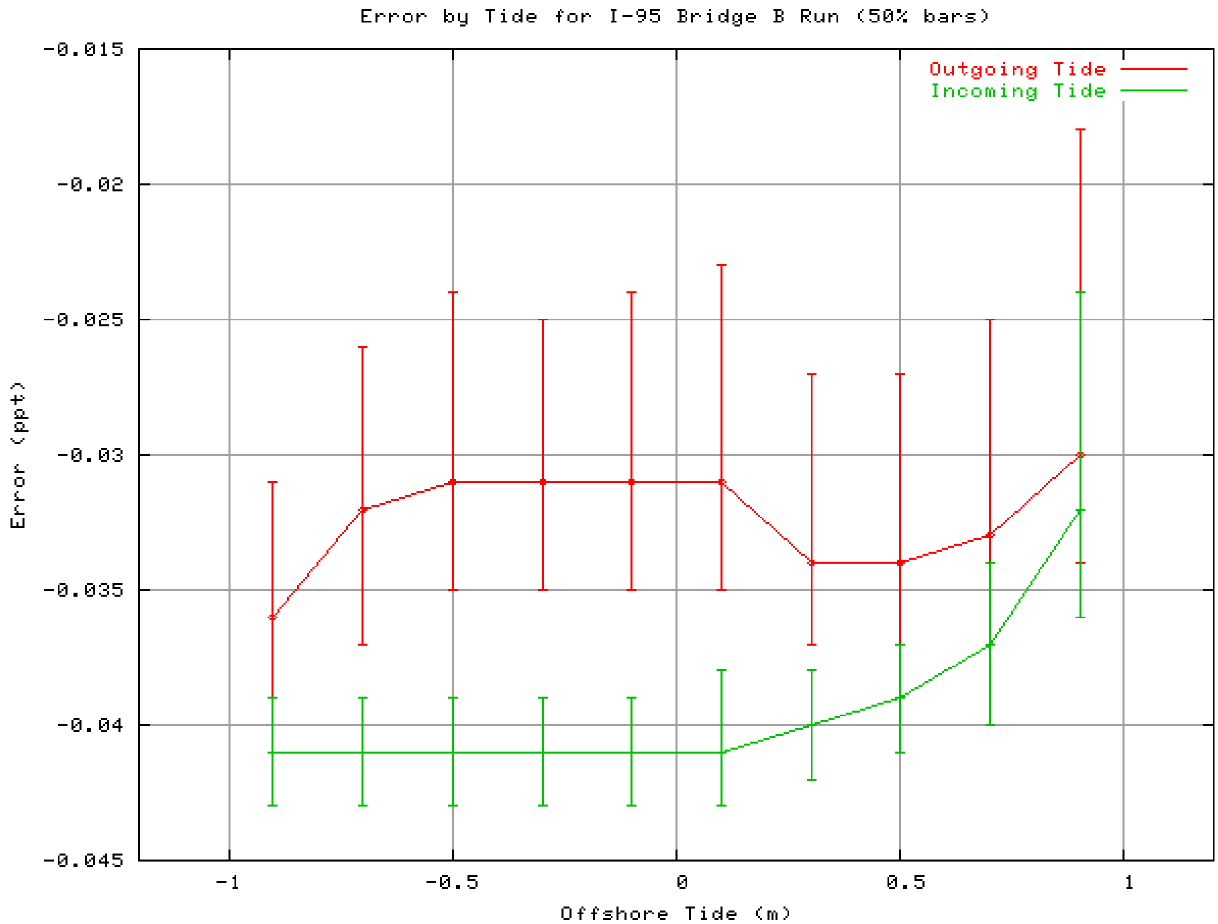


Figure 14.8: Error by tide, I-95 Bridge, 00-03

APPENDIX T 1999 DISSOLVED OXYGEN: ATM CORRECTED DATA

Table T-1 Summary Percentiles for Dissolved Oxygen (mg/l) for July 31, 1999 through October 13, 1999

July 31 - October 13, 1999 [Julian Days 213-285]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S	3.7	4.7	5.9	4.4	4.9	5.2	0.7	0.1	-0.7
FR-02	B	3.3	3.7	4.4	4.0	4.2	4.4	0.7	0.5	0.0
FR-04	S	2.7	4.0	4.7	3.6	4.5	4.9	0.8	0.5	0.2
FR-04	B	2.9	3.6	4.2	3.2	4.1	4.4	0.3	0.5	0.1
FR-06	S	3.7	4.1	4.5	4.5	5.2	5.7	0.8	1.1	1.2
FR-06	B	2.3	3.3	3.8	3.0	3.7	4.0	0.7	0.4	0.2
FR-08	S	4.1	5.5	6.5	4.5	5.5	6.1	0.4	0.0	-0.4
FR-08	B	2.2	3.9	5.7	3.3	4.4	5.6	1.1	0.5	-0.2
FR-09	S	4.4	5.7	6.8	4.6	5.6	6.3	0.2	-0.1	-0.5
FR-09	B	2.9	4.7	6.2	3.9	4.7	5.7	1.0	0.0	-0.5
MR-10	S	4.5	5.3	6.0	5.5	6.2	6.8	1.0	0.9	0.7
FR-11R	B	4.8	6.1	6.8	4.8	5.7	6.4	0.1	-0.4	-0.3
SR-14	B	6.1	6.5	7.2	5.9	6.3	6.8	-0.3	-0.2	-0.4
SR-16	B	6.5	7.0	7.4	6.3	6.9	7.2	-0.2	-0.1	-0.3
FR-21	S	3.2	4.4	4.9	3.9	4.9	5.4	0.7	0.5	0.6
FR-21	B	2.6	3.6	4.1	3.0	3.8	4.1	0.4	0.2	0.1
FR-22	S	4.2	5.2	6.0	4.5	5.5	6.0	0.2	0.3	0.0
FR-22	B	2.5	3.5	4.4	2.9	3.8	4.4	0.4	0.3	0.0

* S = Surface
B = Bottom

Table T-2 Summary Statistics for Dissolved Oxygen (mg/l) for July 31, 1999 through October 13, 1999

July 31 - October 13, 1999 [Julian Days 213-285]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	6096	0.01	0.65	0.81	4.80	0.89	4.81	0.39	0.17
FR-02	B	737	0.43	0.45	0.51	3.76	0.37	4.19	0.16	0.60
FR-04	S	10271	0.44	0.66	0.83	3.87	0.82	4.32	0.54	0.27
FR-04	B	6791	0.33	0.36	0.49	3.58	0.51	3.91	0.47	0.53
FR-06	S	10837	1.01	1.01	1.08	4.11	0.32	5.12	0.44	0.26
FR-06	B	14947	0.42	0.47	0.56	3.15	0.60	3.57	0.38	0.65
FR-08	S	7682	0.04	0.55	0.68	5.35	0.89	5.39	0.59	0.41
FR-08	B	13700	0.51	0.86	1.10	3.91	1.33	4.42	0.81	0.47
FR-09	S	16350	-0.07	0.59	0.74	5.59	0.86	5.52	0.61	0.30
FR-09	B	15124	0.11	0.61	0.79	4.63	1.24	4.74	0.72	0.65
MR-10	S	15388	0.87	0.95	1.06	5.28	0.63	6.15	0.52	0.20
FR-11R	B	13163	-0.23	0.46	0.60	5.90	0.78	5.68	0.61	0.50
SR-14	B	12346	-0.23	0.30	0.39	6.57	0.38	6.34	0.39	0.46
FR-21	S	16030	0.58	0.63	0.75	4.18	0.66	4.76	0.58	0.50
FR-21	B	7741	0.20	0.32	0.41	3.43	0.58	3.63	0.46	0.63
FR-22	S	18839	0.21	0.45	0.56	5.16	0.70	5.36	0.55	0.47
FR-22	B	12765	0.24	0.46	0.59	3.47	0.71	3.71	0.54	0.42

* S = Surface
B = Bottom

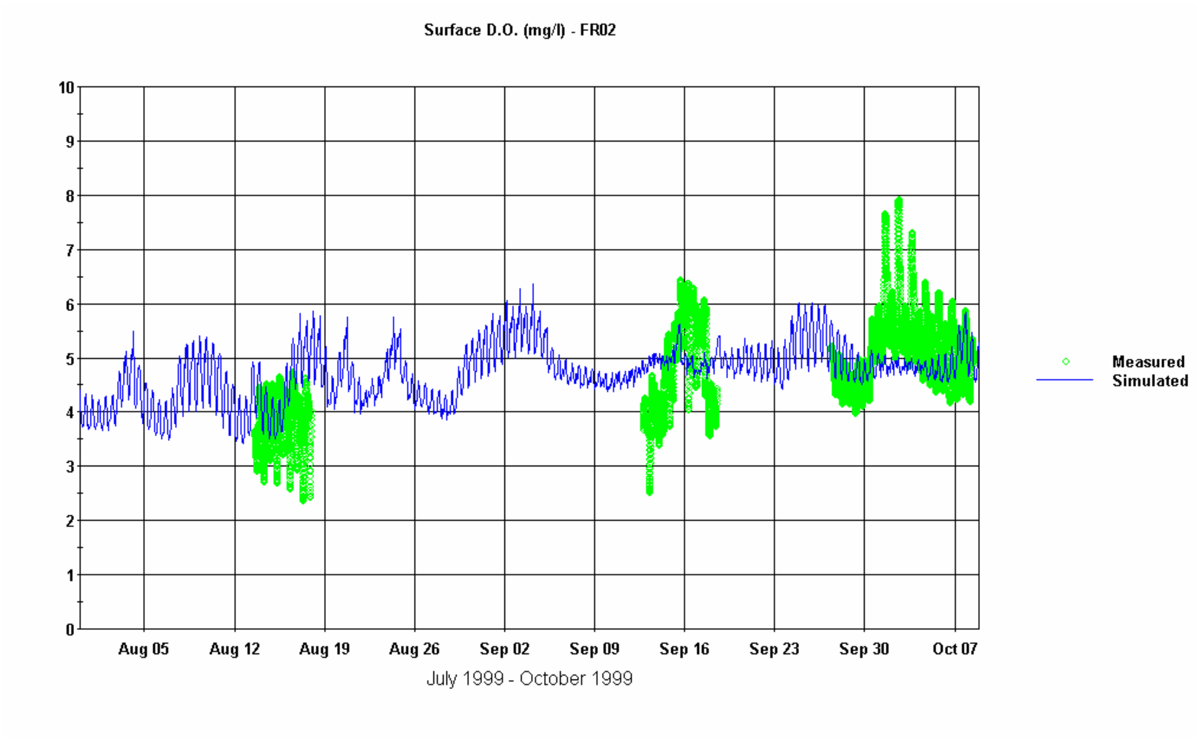


Figure T-1 Dissolved Oxygen Calibration at FR-02 (Surface) for July 31 through October 13, 1999

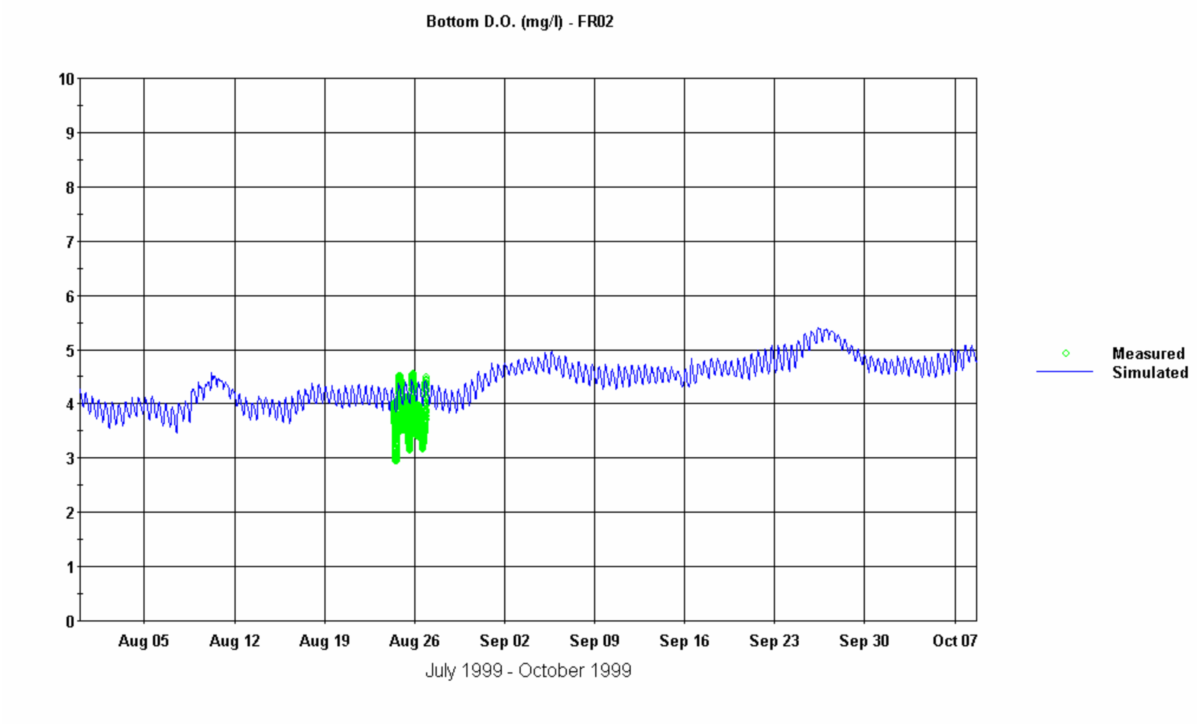


Figure T-2 Dissolved Oxygen Calibration at FR-02 (Bottom) for July 31 through October 13, 1999

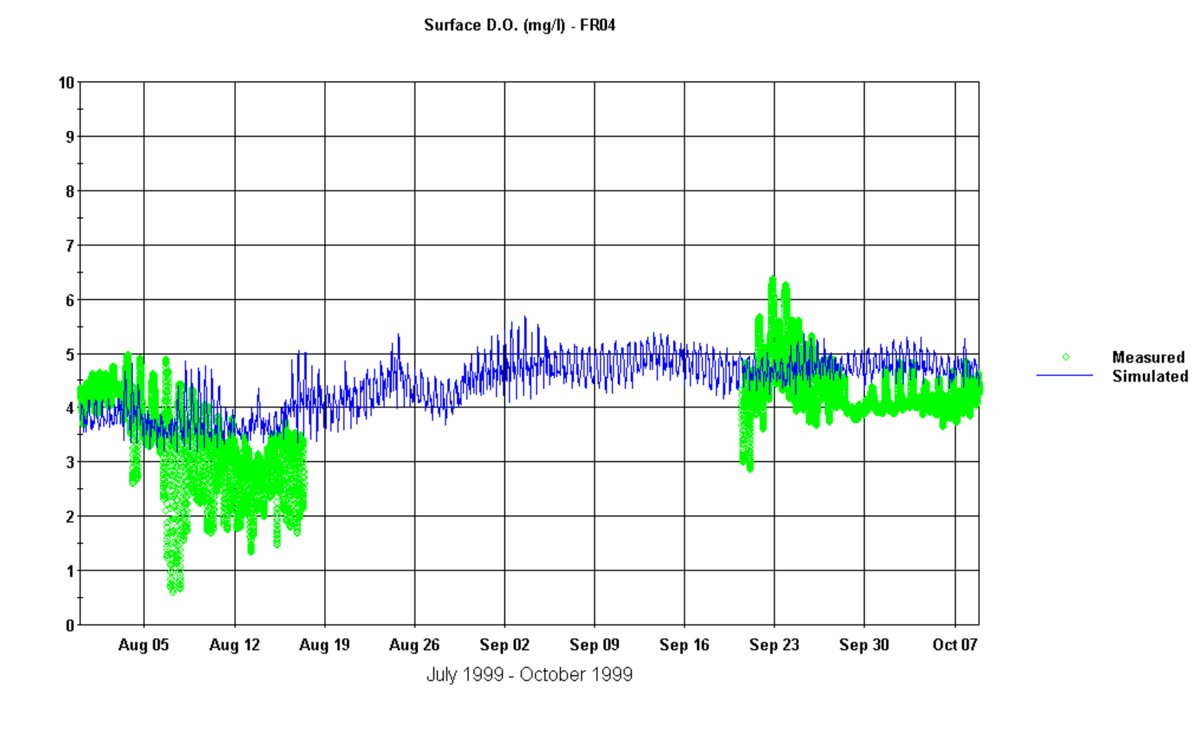


Figure T-3 Dissolved Oxygen Calibration at FR-04 (Surface) for July 31 through October 13, 1999

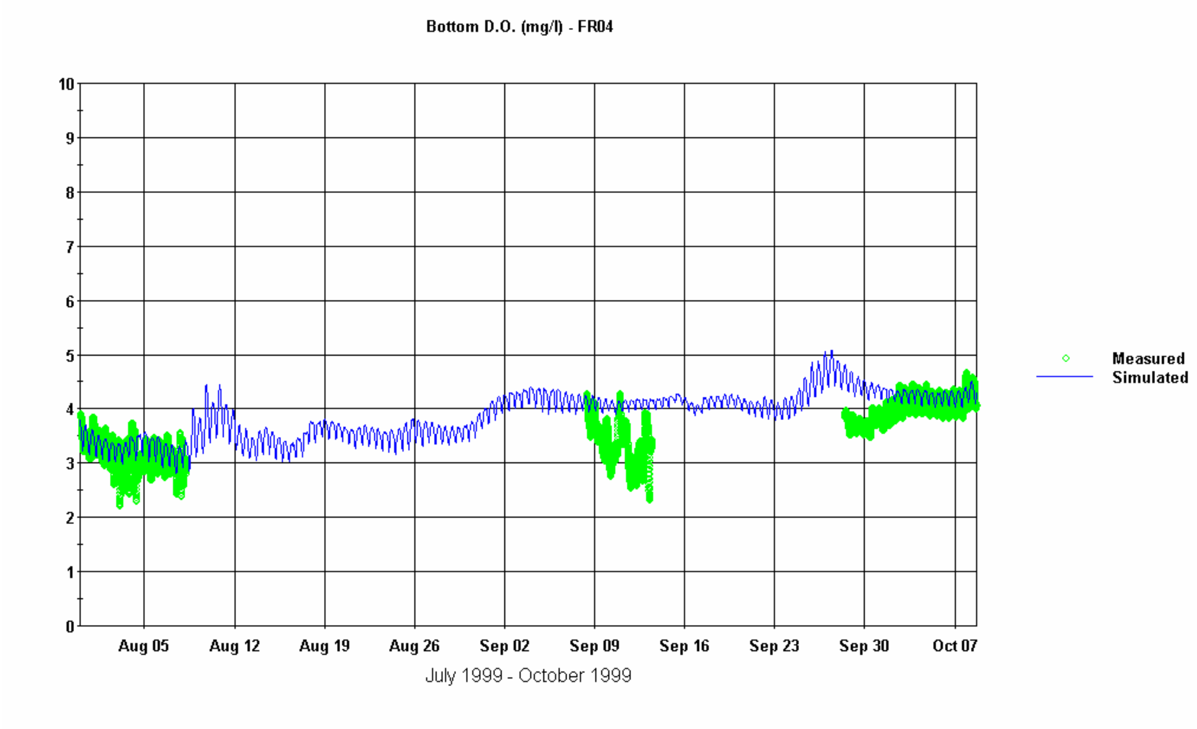


Figure T-4 Dissolved Oxygen Calibration at FR-04 (Bottom) for July 31 through October 13, 1999

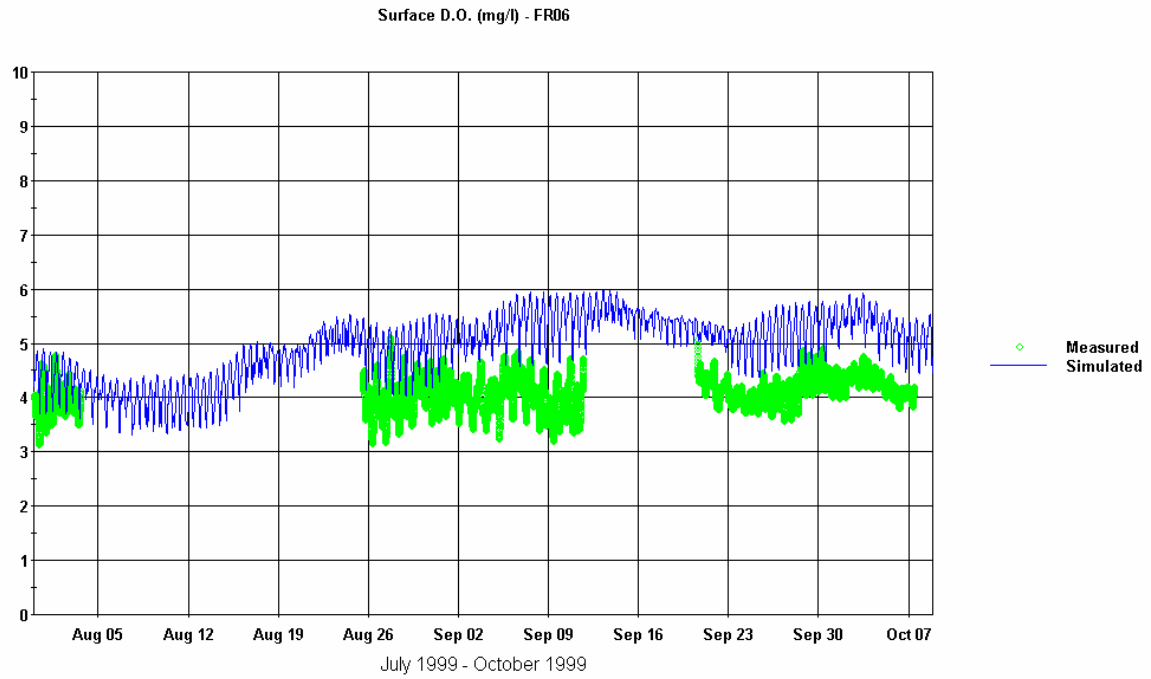


Figure T-5 Dissolved Oxygen Calibration at FR-06 (Surface) for July 31 through October 13, 1999

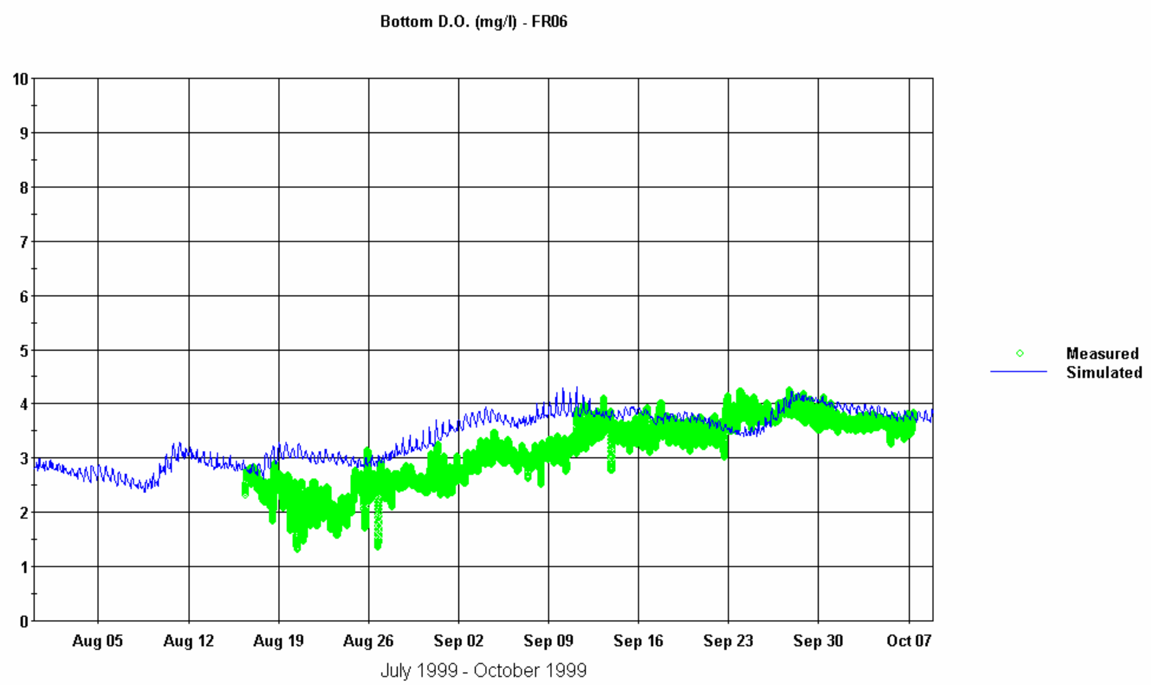


Figure T-6 Dissolved Oxygen Calibration at FR-06 (Bottom) for July 31 through October 13, 1999

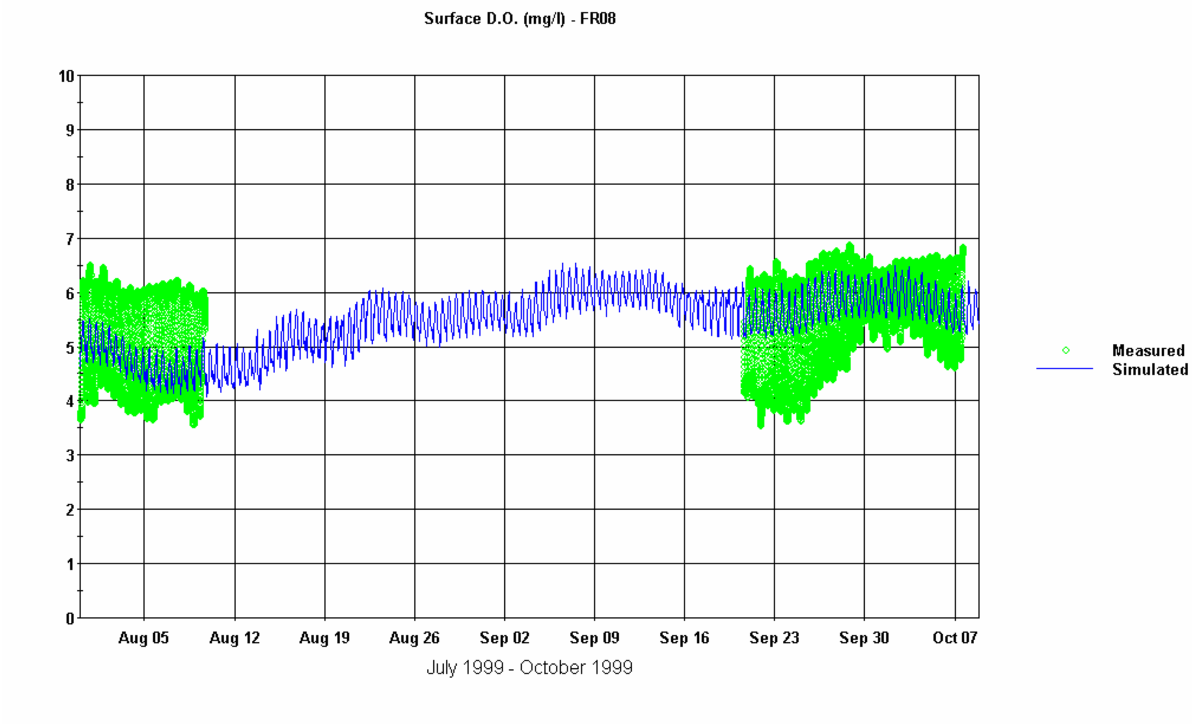


Figure T-7 Dissolved Oxygen Calibration at FR-08 (Surface) for July 31 through October 13, 1999

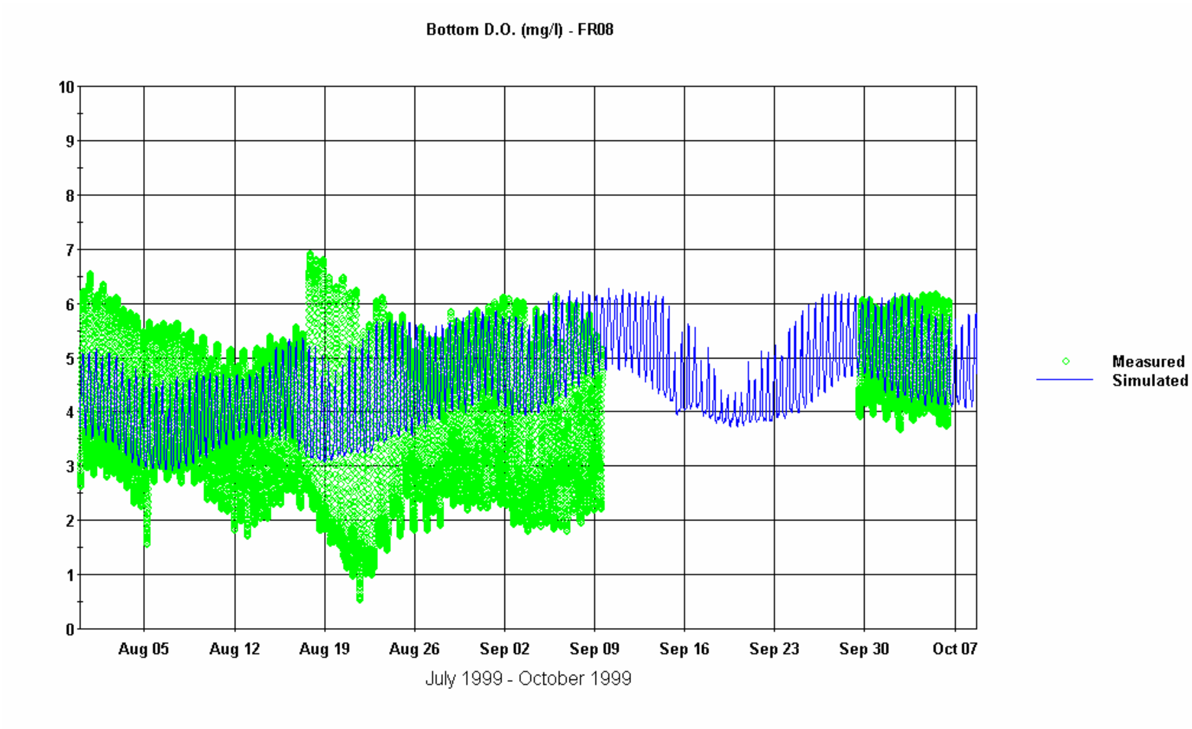


Figure T-8 Dissolved Oxygen Calibration at FR-08 (Bottom) for July 31 through October 13, 1999

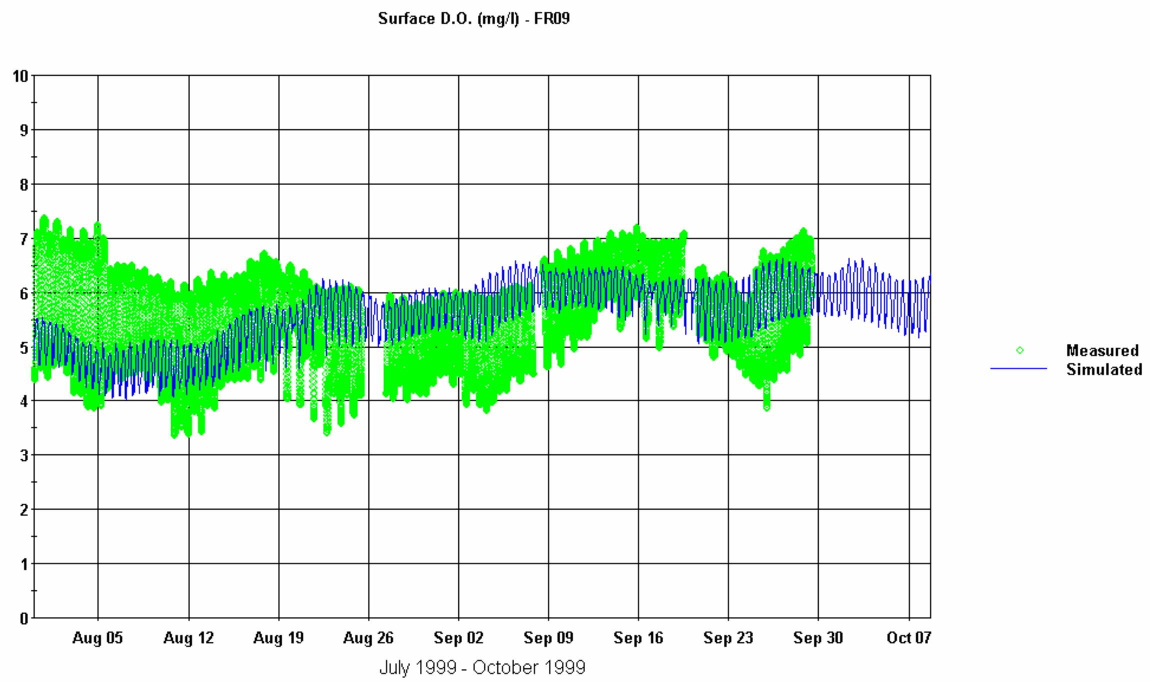


Figure T-9 Dissolved Oxygen Calibration at FR-09 (Surface) for July 31 through October 13, 1999

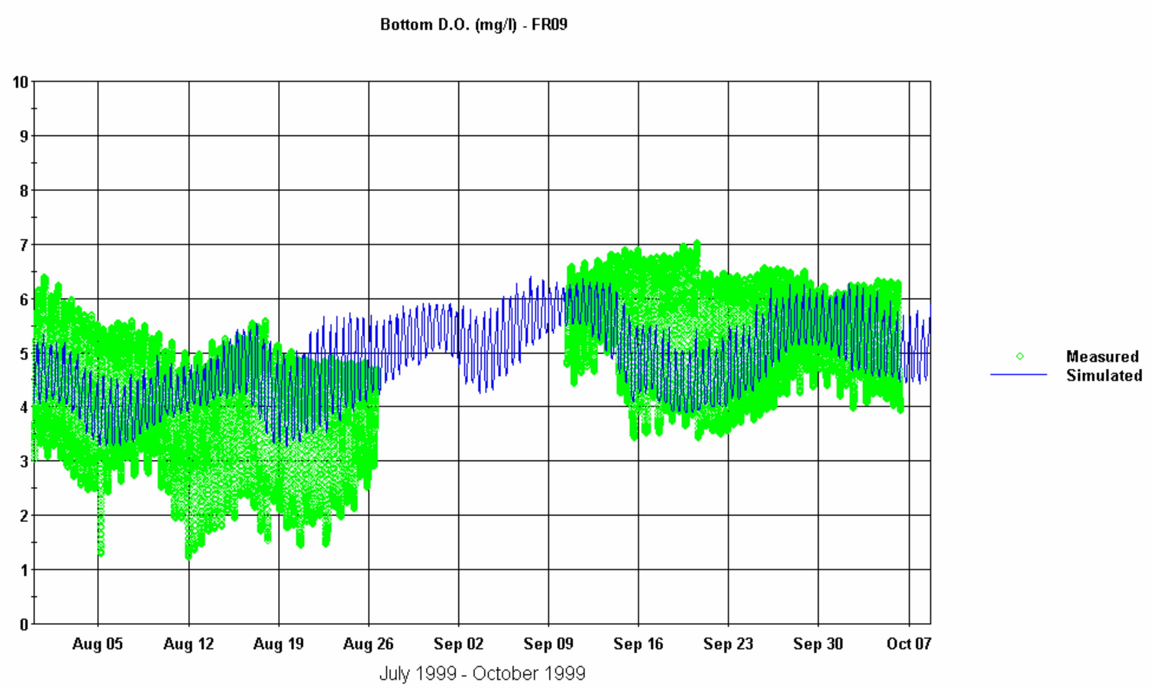


Figure T-10 Dissolved Oxygen Calibration at FR-09 (Bottom) for July 31 through October 13, 1999

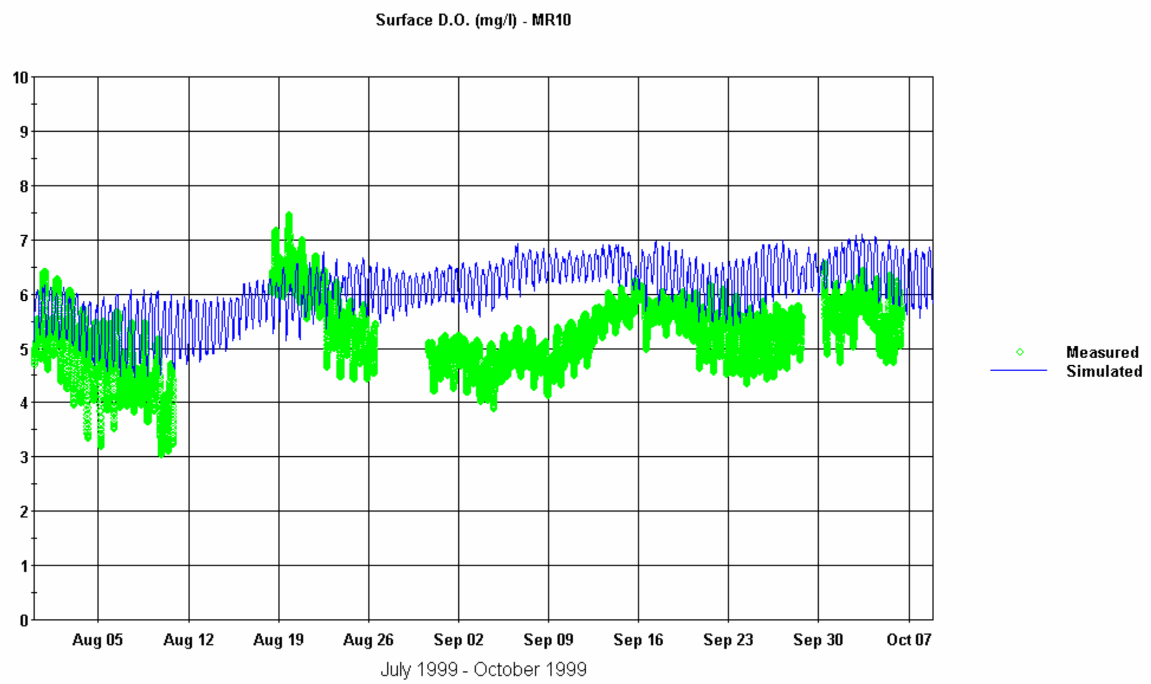


Figure T-11 Dissolved Oxygen Calibration at MR-10 (Surface) for July 31 through October 13, 1999

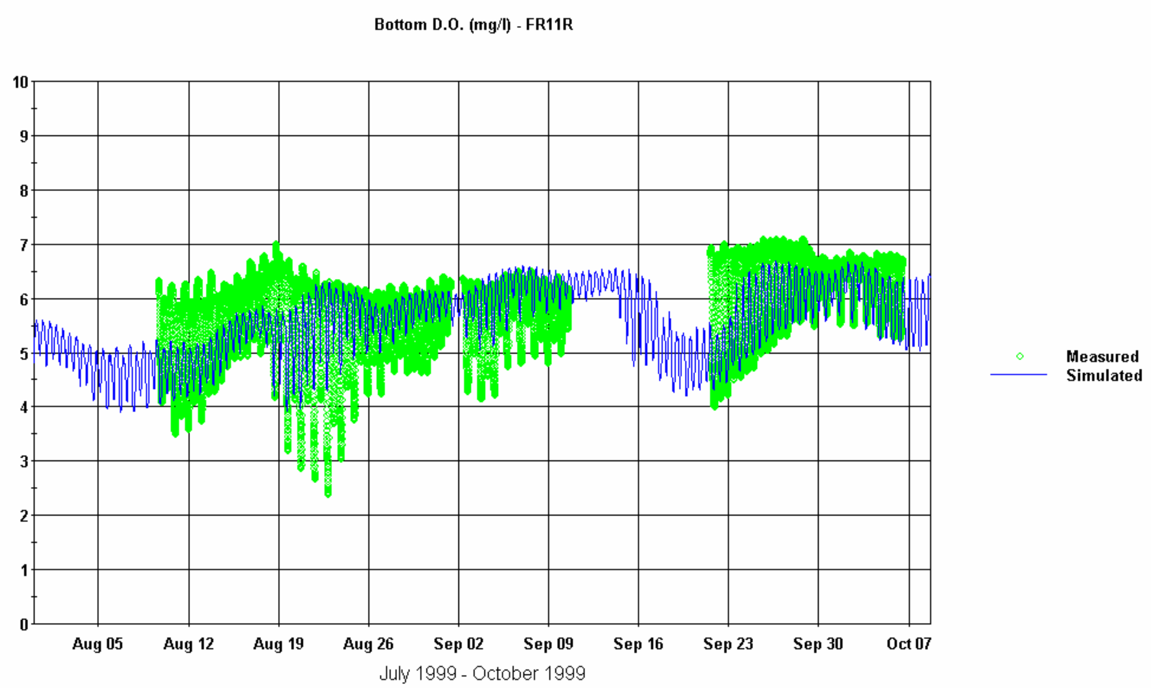


Figure T-12 Dissolved Oxygen Calibration at FR-11R (Bottom) for July 31 through October 13, 1999

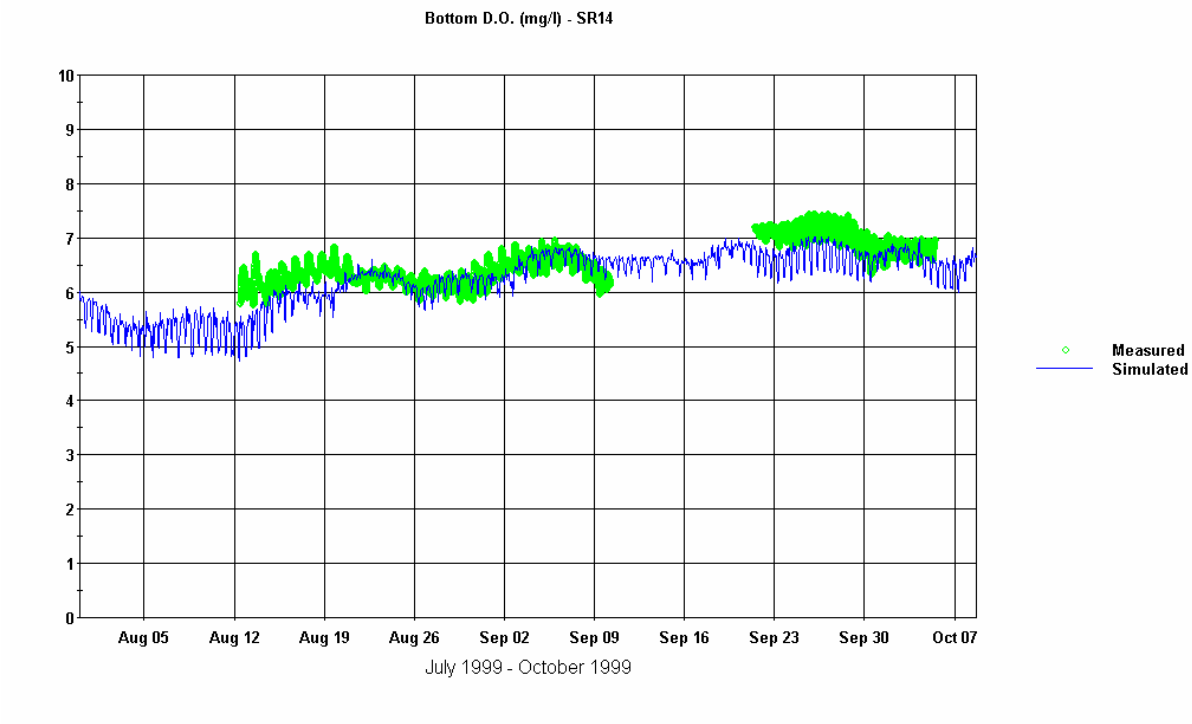


Figure T-13 Dissolved Oxygen Calibration at SR-14 (Bottom) for July 31 through October 13, 1999

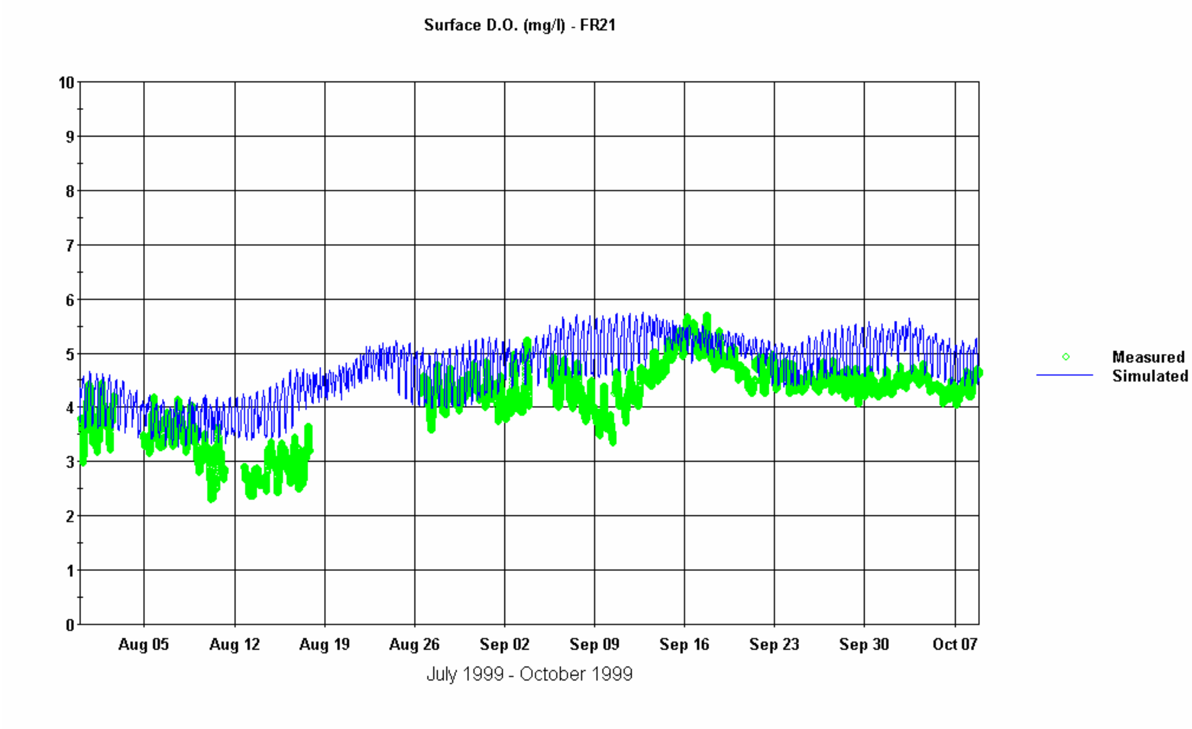


Figure T-14 Dissolved Oxygen Calibration at FR-21 (Surface) for July 31 through October 13, 1999

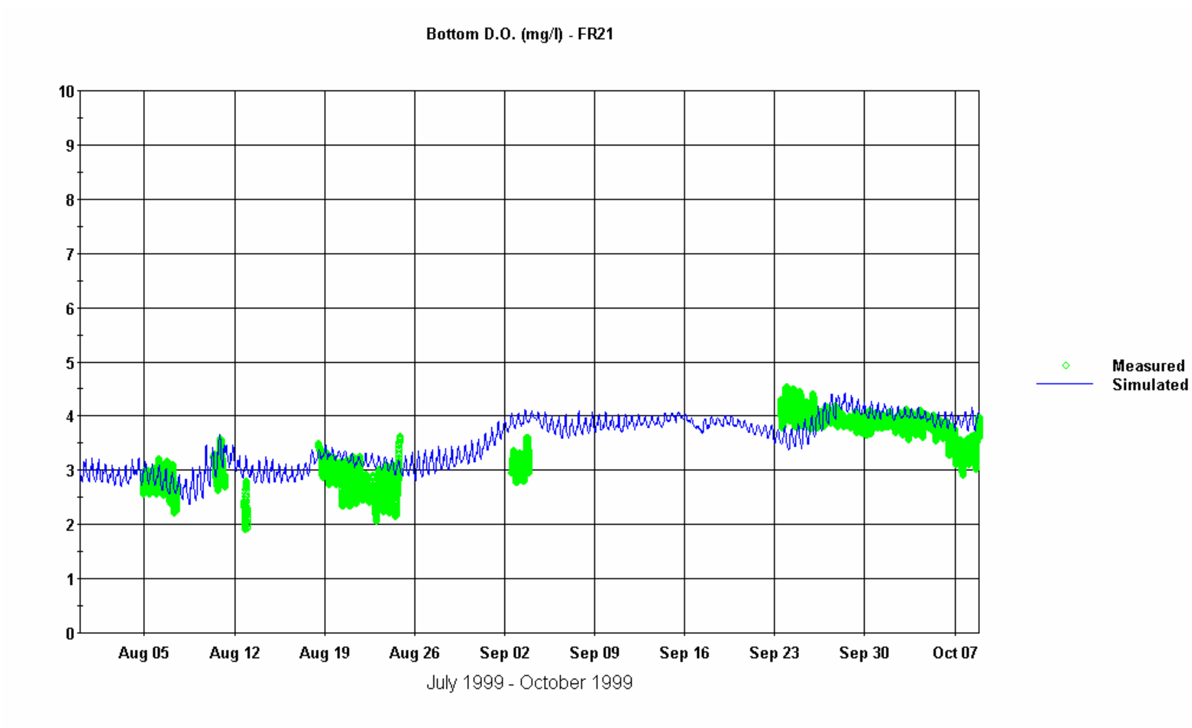


Figure T-15 Dissolved Oxygen Calibration at FR-21 (Bottom) for July 31 through October 13, 1999

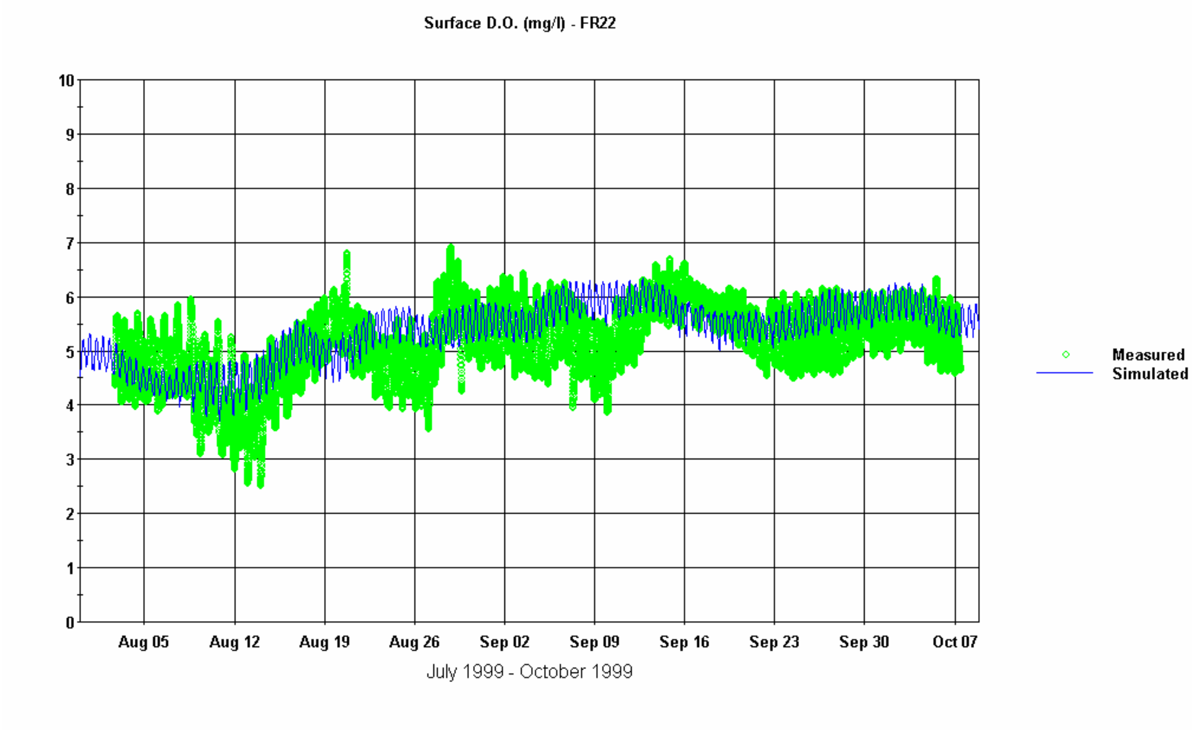


Figure T-16 Dissolved Oxygen Calibration at FR-22 (Surface) for July 31 through October 13, 1999

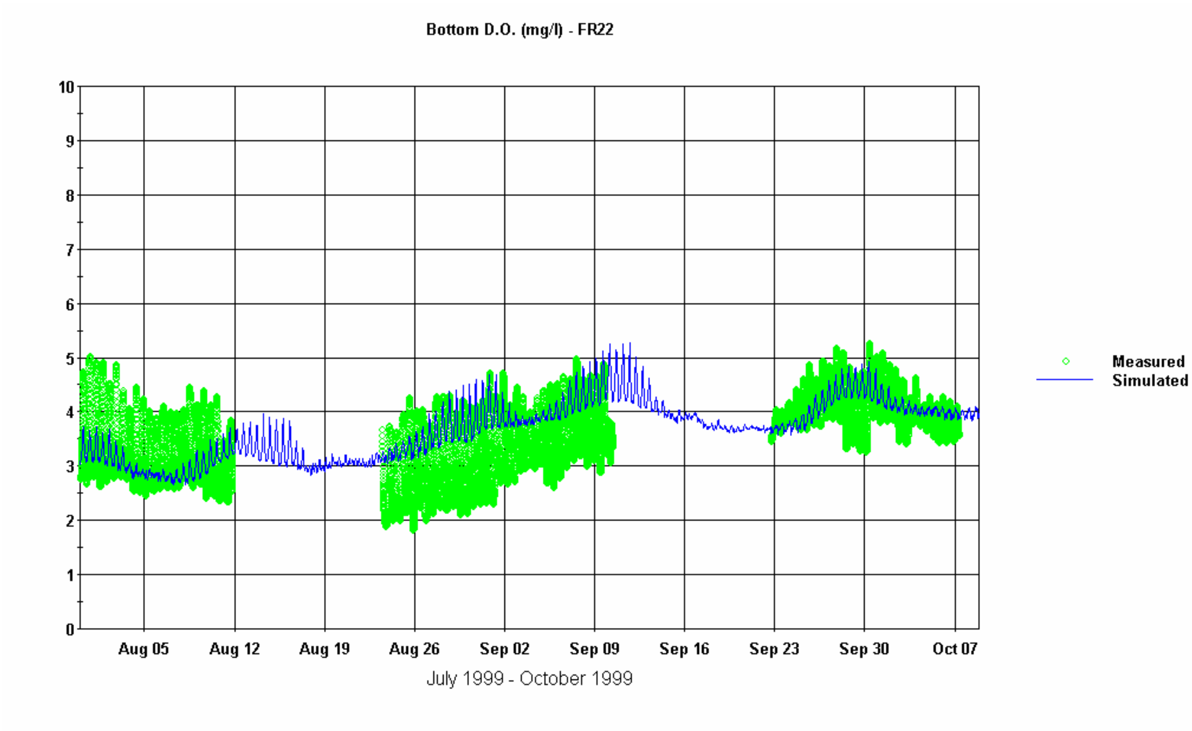


Figure T-17 Dissolved Oxygen Calibration at FR-22 (Bottom) for July 31 through October 13, 1999

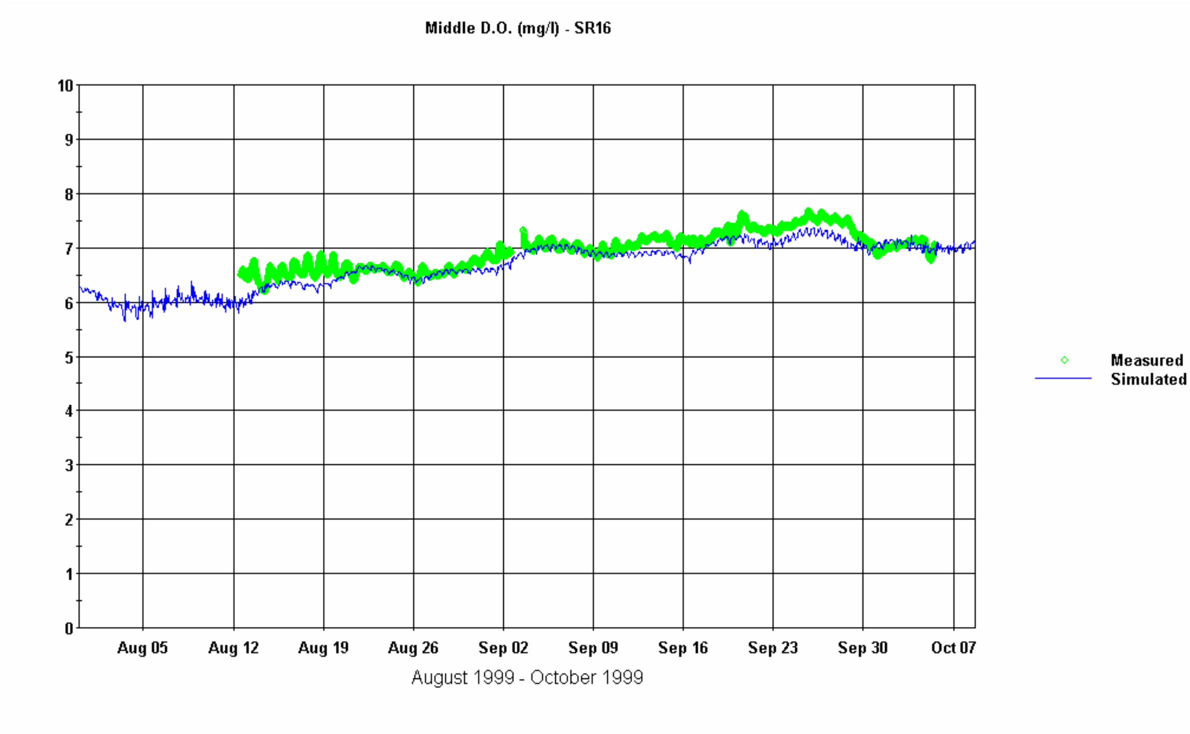


Figure T-18 Dissolved Oxygen Calibration at SR-16 (Mid-Depth) for July 31 through October 13, 1999

Table T-3 Summary Percentiles for Dissolved Oxygen (mg/l) for July 31, 1999 through August 15, 1999

July 31 - August 15, 1999 [Julian Days 213-226]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S	3.1	3.6	4.3	3.6	4.1	4.7	0.5	0.5	0.4
FR-02	B									
FR-04	S	2.4	3.5	4.4	3.5	3.7	4.2	1.1	0.2	-0.2
FR-04	B	2.8	3.2	3.5	3.1	3.3	3.5	0.3	0.2	0.0
FR-06	S	3.6	4.0	4.4	3.9	4.4	4.8	0.2	0.5	0.4
FR-06	B									
FR-08	S	4.0	4.9	6.1	4.3	4.7	5.2	0.3	-0.2	-1.0
FR-08	B	2.7	3.7	5.5	3.1	3.9	4.7	0.4	0.1	-0.8
FR-09	S	4.2	5.4	6.9	4.3	4.8	5.2	0.0	-0.6	-1.6
FR-09	B	2.8	4.1	5.5	3.6	4.2	4.8	0.8	0.1	-0.6
MR-10	S	4.0	4.9	5.7	4.8	5.6	6.0	0.8	0.7	0.3
FR-11R	B	4.1	5.7	6.2	4.3	4.9	5.2	0.1	-0.8	-1.0
SR-14	B									
SR-16	B									
FR-21	S	2.7	3.4	3.9	3.5	3.9	4.3	0.8	0.6	0.4
FR-21	B	2.5	2.9	3.2	2.6	2.9	3.3	0.2	0.0	0.1
FR-22	S	3.4	4.4	5.3	4.1	4.5	4.8	0.7	0.1	-0.5
FR-22	B	2.6	3.0	4.0	2.8	3.0	3.4	0.2	0.0	-0.6

* S = Surface
B = Bottom

Table T-4 Summary Statistics for Dissolved Oxygen (mg/l) for July 31, 1999 through August 15, 1999

July 31 - August 15, 1999 [Julian Days 213-226]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	398	0.45	0.51	0.59	3.68	0.47	4.13	0.41	0.41
FR-02	B									
FR-04	S	4267	0.35	0.66	0.88	3.45	0.81	3.80	0.28	0.03
FR-04	B	2362	0.16	0.22	0.29	3.15	0.30	3.31	0.18	0.39
FR-06	S	1033	0.41	0.44	0.52	3.98	0.31	4.39	0.33	0.26
FR-06	B									
FR-08	S	2785	-0.31	0.64	0.75	5.04	0.87	4.73	0.32	0.51
FR-08	B	4220	-0.04	0.57	0.71	3.97	1.10	3.92	0.58	0.67
FR-09	S	4286	-0.70	0.83	1.01	5.46	0.98	4.76	0.36	0.65
FR-09	B	4234	0.12	0.64	0.80	4.09	1.08	4.21	0.45	0.57
MR-10	S	3101	0.61	0.66	0.79	4.85	0.69	5.46	0.45	0.46
FR-11R	B	1454	-0.56	0.69	0.78	5.33	0.82	4.78	0.35	0.74
SR-14	B									
FR-21	S	3215	0.58	0.64	0.77	3.34	0.47	3.92	0.31	0.04
FR-21	B	1128	0.10	0.21	0.31	2.85	0.29	2.94	0.24	0.17
FR-22	S	3525	0.09	0.48	0.60	4.38	0.69	4.47	0.28	0.25
FR-22	B	3402	-0.14	0.36	0.50	3.17	0.56	3.03	0.24	0.27

* S = Surface
B = Bottom

Table T-5 Summary Percentiles for Dissolved Oxygen (mg/l) for August 15, 1999 through August 30, 1999

August 16 - August 30, 1999 [Julian Days 227-241]										
Stations	**Depth***	**Measured**			**Simulated**			**Difference**		
		10% (mg/L)	**50% (mg/L)**	**90% (mg/L)**	**10% (mg/L)**	**50% (mg/L)**	**90% (mg/L)**	**10% (mg/L)**	**50% (mg/L)**	**90% (mg/L)**
FR-02	S	3.0	4.0	4.5	3.6	4.6	5.4	0.6	0.7	0.8
FR-02	B	3.3	3.7	4.4	4.0	4.2	4.4	0.7	0.5	0.0
FR-04	S									
FR-04	B									
FR-06	S	3.5	3.9	4.4	4.3	4.9	5.3	0.8	1.0	0.9
FR-06	B	1.9	2.4	2.7	2.8	3.0	3.2	0.9	0.6	0.5
FR-08	S									
FR-08	B	1.6	3.2	5.4	3.3	4.1	5.4	1.7	0.9	0.0
FR-09	S	4.3	5.6	6.3	4.9	5.5	6.0	0.6	-0.1	-0.3
FR-09	B	2.1	4.1	4.9	3.6	4.6	5.4	1.5	0.5	0.5
MR-10	S	5.0	5.9	6.7	5.6	6.1	6.5	0.6	0.2	-0.2
FR-11R	B	4.5	6.0	6.4	4.9	5.6	6.1	0.4	-0.4	-0.4
SR-14	B	6.1	6.3	6.5	5.8	6.1	6.3	-0.3	-0.2	-0.2
SR-16	B	6.5	6.6	6.7	6.3	6.5	6.6	-0.2	-0.1	-0.1
FR-21	S	2.8	3.8	4.5	3.9	4.4	5.0	1.1	0.6	0.5
FR-21	B	2.4	2.8	3.2	3.0	3.2	3.3	0.6	0.4	0.1
FR-22	S	4.3	5.1	5.9	4.8	5.2	5.7	0.5	0.2	-0.2
FR-22	B	2.1	2.5	3.8	3.2	3.4	3.9	1.1	0.9	0.1

* S = Surface
B = Bottom

Table T-6 Summary Statistics for Dissolved Oxygen (mg/l) for August 15, 1999 through August 30, 1999

August 16 - August 30, 1999 [Julian Days 227-241]										
Station	**Depth**	**N**	**ME**	**AME**	**RMS**	**Mean Obs**	**StDev Obs**	**Mean Pred**	**StDev Pred**	**R^2**
FR-02	S	872	0.69	0.81	1.00	3.87	0.55	4.56	0.60	0.04
FR-02	B	737	0.43	0.45	0.51	3.76	0.37	4.19	0.16	0.60
FR-04	S									
FR-04	B									
FR-06	S	1222	0.94	0.94	0.99	3.95	0.37	4.88	0.37	0.43
FR-06	B	3850	0.64	0.65	0.73	2.36	0.33	3.00	0.14	0.01
FR-08	S									
FR-08	B	4233	0.76	1.03	1.22	3.46	1.50	4.22	0.77	0.70
FR-09	S	3741	0.08	0.51	0.64	5.42	0.74	5.50	0.39	0.26
FR-09	B	3420	0.80	0.87	1.04	3.75	1.09	4.55	0.64	0.69
MR-10	S	2300	0.20	0.66	0.76	5.85	0.65	6.05	0.35	0.00
FR-11R	B	4172	-0.21	0.49	0.64	5.73	0.82	5.53	0.47	0.47
SR-14	B	4233	-0.21	0.25	0.34	6.29	0.16	6.08	0.22	0.00
FR-21	S	1785	0.73	0.79	0.94	3.66	0.67	4.39	0.42	0.24
FR-21	B	1807	0.41	0.42	0.47	2.79	0.31	3.19	0.11	0.56
FR-22	S	4219	0.18	0.54	0.65	5.06	0.62	5.23	0.33	0.05
FR-22	B	1706	0.71	0.78	0.86	2.75	0.65	3.46	0.29	0.51

* S = Surface
B = Bottom

Table T-7 Summary Percentiles for Dissolved Oxygen (mg/l) for August 30, 1999 through September 13, 1999

August 31 - September 13, 1999 [Julian Days 242 - 255]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S									
FR-02	B									
FR-04	S									
FR-04	B	2.9	3.4	4.0	4.0	4.1	4.2	1.1	0.7	0.2
FR-06	S	3.6	4.1	4.5	4.8	5.3	5.8	1.1	1.2	1.3
FR-06	B	2.6	3.0	3.5	3.4	3.7	3.9	0.7	0.7	0.4
FR-08	S									
FR-08	B	2.3	3.5	5.6	4.1	5.0	5.8	1.9	1.4	0.2
FR-09	S	4.4	5.7	6.6	5.4	5.9	6.4	1.0	0.2	-0.2
FR-09	B	4.9	6.0	6.6	5.4	5.8	6.2	0.5	-0.1	-0.3
MR-10	S	4.5	4.9	5.4	5.9	6.4	6.7	1.5	1.5	1.3
FR-11R	B	5.0	6.1	6.3	5.6	6.1	6.5	0.6	0.0	0.1
SR-14	B	6.2	6.5	6.8	6.2	6.5	6.8	0.0	0.0	0.0
SR-16	B	6.8	7.0	7.1	6.6	6.9	7.0	-0.2	-0.1	-0.1
FR-21	S	3.9	4.3	4.7	4.5	5.0	5.6	0.7	0.8	0.9
FR-21	B	2.8	3.1	3.5	3.8	3.9	4.0	1.0	0.8	0.6
FR-22	S	4.7	5.4	6.1	5.3	5.8	6.2	0.7	0.3	0.1
FR-22	B	2.6	3.4	4.3	3.7	4.0	4.6	1.1	0.6	0.2

* S = Surface
B = Bottom

Table T-8 Summary Statistics for Dissolved Oxygen (mg/l) for August 30, 1999 through September 13, 1999

August 31 - September 13, 1999 [Julian Days 242 - 255]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S									
FR-02	B									
FR-04	S									
FR-04	B	1369	0.68	0.68	0.78	3.41	0.41	4.09	0.08	0.17
FR-06	S	3726	1.20	1.20	1.26	4.06	0.33	5.26	0.37	0.16
FR-06	B	4276	0.64	0.65	0.68	3.05	0.32	3.70	0.21	0.56
FR-08	S									
FR-08	B	3211	1.21	1.33	1.55	3.78	1.24	4.99	0.64	0.39
FR-09	S	4080	0.41	0.53	0.65	5.52	0.78	5.93	0.36	0.74
FR-09	B	777	0.01	0.34	0.43	5.82	0.61	5.83	0.31	0.55
MR-10	S	3969	1.46	1.46	1.49	4.92	0.36	6.38	0.28	0.27
FR-11R	B	3221	0.19	0.31	0.42	5.86	0.54	6.05	0.33	0.54
SR-14	B	3405	-0.01	0.18	0.22	6.48	0.23	6.47	0.24	0.30
FR-21	S	3781	0.77	0.81	0.92	4.27	0.32	5.04	0.41	0.01
FR-21	B	401	0.79	0.79	0.82	3.13	0.24	3.92	0.09	0.22
FR-22	S	4255	0.39	0.50	0.62	5.38	0.54	5.76	0.30	0.20
FR-22	B	3424	0.61	0.65	0.75	3.44	0.64	4.05	0.34	0.58

* S = Surface
B = Bottom

Table T-9 Summary Percentiles for Dissolved Oxygen (mg/l) for September 13, 1999 through September 28, 1999

September 14 - September 28, 1999 [Julian Days 256 - 270]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S	4.1	4.9	5.9	4.7	4.9	5.3	0.7	0.1	-0.6
FR-02	B									
FR-04	S	4.0	4.5	5.5	4.5	4.7	5.0	0.6	0.2	-0.5
FR-04	B									
FR-06	S	3.8	4.1	4.4	4.6	5.2	5.5	0.8	1.1	1.1
FR-06	B	3.3	3.6	4.0	3.5	3.7	3.9	0.2	0.1	0.0
FR-08	S	4.0	5.0	6.4	5.3	5.6	6.2	1.3	0.6	-0.3
FR-08	B									
FR-09	S	4.7	6.0	6.9	5.3	6.0	6.4	0.6	-0.1	-0.6
FR-09	B	3.8	5.3	6.6	4.0	4.9	5.7	0.3	-0.4	-0.9
MR-10	S	4.8	5.5	5.9	5.8	6.4	6.8	1.0	0.8	0.9
FR-11R	B	4.7	6.5	7.0	4.7	5.4	6.6	-0.1	-1.1	-0.5
SR-14	B	7.0	7.2	7.4	6.3	6.7	6.9	-0.6	-0.5	-0.4
SR-16	B	7.1	7.3	7.6	6.9	7.1	7.3	-0.2	-0.2	-0.3
FR-21	S	4.4	4.7	5.2	4.6	5.1	5.4	0.3	0.4	0.2
FR-21	B	3.9	4.0	4.4	3.5	3.8	4.2	-0.4	-0.3	-0.2
FR-22	S	4.8	5.6	6.1	5.3	5.6	6.0	0.5	0.0	-0.2
FR-22	B	3.7	4.0	4.6	3.7	3.8	4.3	0.0	-0.1	-0.3

* S = Surface
B = Bottom

Table T-10 Summary Statistics for Dissolved Oxygen (mg/l) for September 13, 1999 through September 28, 1999

September 14 - September 28, 1999 [Julian Days 256 - 270]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	1706	0.03	0.66	0.75	4.94	0.73	4.98	0.22	0.01
FR-02	B									
FR-04	S	2333	0.14	0.54	0.69	4.62	0.62	4.75	0.18	0.02
FR-04	B									
FR-06	S	2284	1.02	1.02	1.06	4.08	0.23	5.11	0.32	0.20
FR-06	B	4286	0.09	0.26	0.31	3.64	0.25	3.73	0.17	0.00
FR-08	S	2289	0.52	0.71	0.85	5.15	0.93	5.67	0.32	0.77
FR-08	B									
FR-09	S	3984	-0.02	0.45	0.54	5.92	0.79	5.90	0.37	0.64
FR-09	B	4233	-0.37	0.62	0.78	5.21	1.08	4.85	0.62	0.66
MR-10	S	4252	0.87	0.87	0.94	5.46	0.40	6.34	0.38	0.40
FR-11R	B	1815	-0.58	0.62	0.80	6.12	0.90	5.54	0.67	0.63
SR-14	B	1838	-0.50	0.50	0.53	7.17	0.16	6.67	0.23	0.34
FR-21	S	4278	0.33	0.40	0.47	4.77	0.33	5.10	0.28	0.16
FR-21	B	1267	-0.28	0.34	0.42	4.07	0.19	3.79	0.26	0.01
FR-22	S	4276	0.07	0.32	0.39	5.52	0.50	5.60	0.26	0.43
FR-22	B	1478	-0.14	0.19	0.24	4.05	0.35	3.92	0.26	0.71

* S = Surface
B = Bottom

Table T-11 Summary Percentiles for Dissolved Oxygen (mg/l) for September 28, 1999 through October 13, 1999

September 29 - October 13, 1999 [Julian Days 271-285]										
Stations	Depth*	Measured			Simulated			Difference		
		10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)	10% (mg/L)	50% (mg/L)	90% (mg/L)
FR-02	S	4.3	5.2	6.1	4.6	4.8	5.1	0.3	-0.3	-1.0
FR-02	B									
FR-04	S	3.9	4.1	4.5	4.6	4.8	5.1	0.7	0.7	0.6
FR-04	B	3.7	4.0	4.4	4.1	4.3	4.5	0.4	0.3	0.1
FR-06	S	4.1	4.3	4.6	4.8	5.4	5.7	0.8	1.0	1.1
FR-06	B	3.5	3.7	3.8	3.8	3.9	4.1	0.2	0.3	0.3
FR-08	S	5.0	5.9	6.6	5.5	5.8	6.2	0.5	0.0	-0.4
FR-08	B	4.0	4.8	6.0	4.3	4.9	5.9	0.3	0.1	-0.1
FR-09	S	5.2	6.7	7.1	5.6	6.1	6.4	0.4	-0.6	-0.7
FR-09	B	4.4	5.6	6.1	4.7	5.4	6.0	0.3	-0.1	-0.1
MR-10	S	5.1	5.6	6.2	6.0	6.6	7.0	0.9	1.0	0.8
FR-11R	B	5.7	6.6	6.8	5.5	6.2	6.5	-0.2	-0.4	-0.3
SR-14	B	6.6	6.9	7.2	6.3	6.7	6.8	-0.3	-0.2	-0.3
SR-16	B	6.9	7.1	7.5	7.0	7.1	7.1	0.0	-0.1	-0.3
FR-21	S	4.3	4.5	4.7	4.6	5.1	5.4	0.3	0.6	0.7
FR-21	B	3.5	3.8	4.0	3.8	4.0	4.2	0.4	0.2	0.2
FR-22	S	4.9	5.4	6.0	5.5	5.8	6.1	0.6	0.3	0.2
FR-22	B	3.5	3.9	4.7	4.0	4.1	4.5	0.5	0.2	-0.1

* S = Surface
B = Bottom

Table T-12 Summary Statistics for Dissolved Oxygen (mg/l) for September 28, 1999 through October 13, 1999

September 29 - October 13, 1999 [Julian Days 271-285]										
Station	Depth	N	ME	AME	RMS	Mean Obs	StDev Obs	Mean Pred	StDev Pred	R^2
FR-02	S	2867	-0.36	0.58	0.78	5.23	0.72	4.87	0.22	0.09
FR-02	B									
FR-04	S	3096	0.68	0.68	0.75	4.12	0.23	4.80	0.18	0.02
FR-04	B	3144	0.27	0.30	0.40	4.04	0.27	4.31	0.14	0.00
FR-06	S	2574	1.00	1.00	1.03	4.33	0.22	5.33	0.31	0.48
FR-06	B	2538	0.25	0.25	0.28	3.67	0.13	3.92	0.12	0.27
FR-08	S	2609	-0.01	0.33	0.38	5.86	0.60	5.85	0.28	0.77
FR-08	B	2036	0.05	0.35	0.45	4.95	0.83	5.00	0.62	0.72
FR-09	S	263	-0.33	0.55	0.60	6.38	0.72	6.05	0.33	0.63
FR-09	B	2460	0.01	0.27	0.33	5.38	0.67	5.39	0.46	0.79
MR-10	S	1768	0.88	0.88	0.95	5.65	0.39	6.53	0.36	0.33
FR-11R	B	2501	-0.34	0.36	0.42	6.42	0.43	6.08	0.41	0.70
SR-14	B	2222	-0.24	0.27	0.32	6.87	0.21	6.63	0.18	0.13
FR-21	S	4260	0.55	0.56	0.64	4.50	0.19	5.05	0.32	0.06
FR-21	B	3338	0.24	0.25	0.30	3.79	0.23	4.02	0.14	0.34
FR-22	S	2568	0.34	0.35	0.40	5.43	0.39	5.77	0.24	0.77
FR-22	B	2755	0.17	0.30	0.37	4.02	0.43	4.19	0.24	0.45

* S = Surface
B = Bottom

APPENDIX U INDEPENDENT TECHNICAL REVIEW (ITR) COMMENTS AND RESPONSES

Responses revised on November 9, 2005 based on October 26, 2005 Review meeting.

Review Subject: Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project
Author: Tetra Tech, Inc.
Author Telephone: 770-850-0949 x.102
Author Email: steven.davie@tetratech-ffx.com

Reviewer Name: Sung-Chan Kim
Reviewer Telephone: 601-634-3783
Reviewer Email: sung-chan.kim@erdc.usace.army.mil

EFDC and WASP7 were chosen to model hydrodynamics and water quality of the Savannah River. Two models are linked through an interface. Model grid coverage appears adequate. Grid resolution also appears appropriate (Figures 4-1 through 4-7).

1. COMMENT

Basis of Concern (law/policy):

Convergence test (Appendix A)

Significance of Concern:

Second sentence on A-4 states “slightly greater stratification” at Houlihan Bridge. Figure A-3 only shows surface salinity. It seems the differences between two grids diverge with time. If this is true, then it indicates failure in convergence test. Also nothing is quantified.

Specific Actions Needed to Resolve:

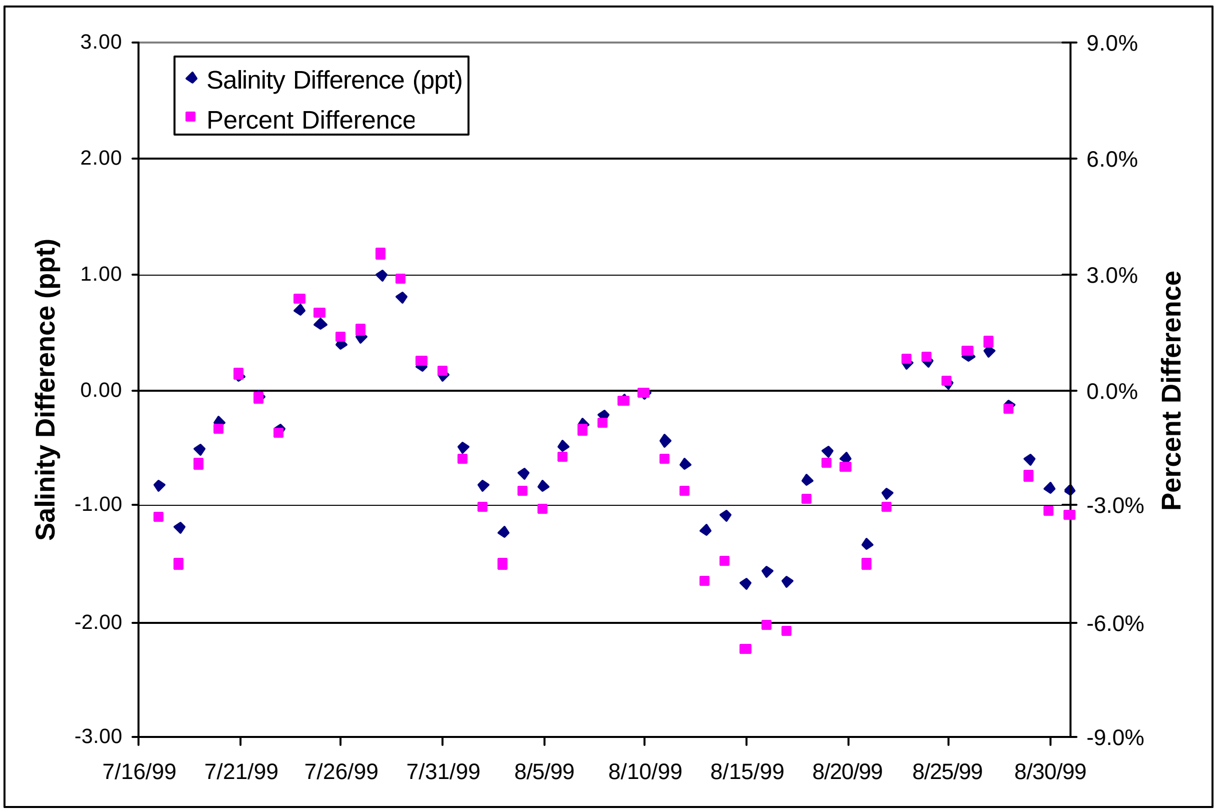
Add bottom salinity time series. It may be helpful to show the time series plots for differences to demonstrate there is no divergence. Need to devise a way to quantify the convergence.

Response and review action by author:

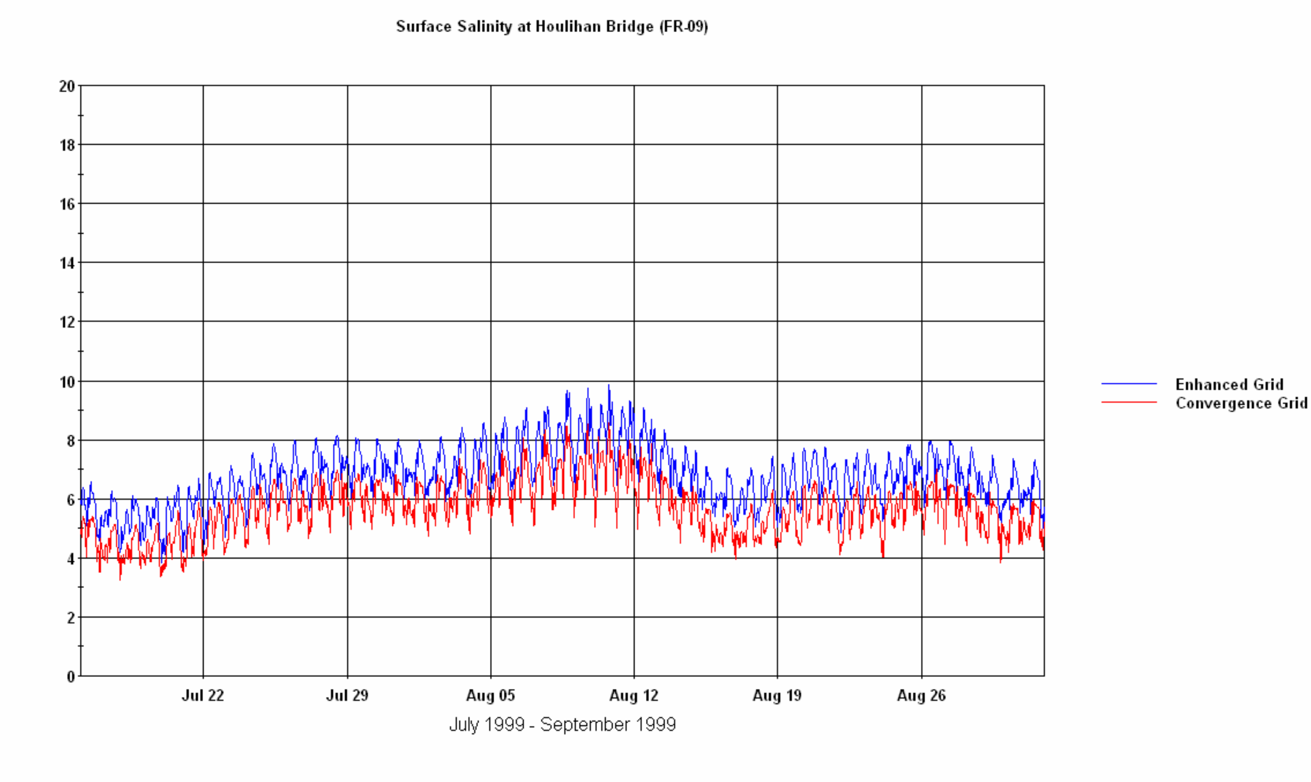
Figure A-2 shows bottom salinity at Houlihan Bridge, while Figure A-3 shows the surface salinity for comparison of Enhanced Grid and Convergence Grid results. The “slightly greater stratification” phrase should be modified to indicate that slightly less salinity (difference is more apparent at surface) is observed in the Convergence Grid results. The final modeling report will be updated and revised with this discussion. Quantification of the convergence grid test results has been performed and is presented in the following tables. Model spin up (15 days) has been excluded from these statistics.

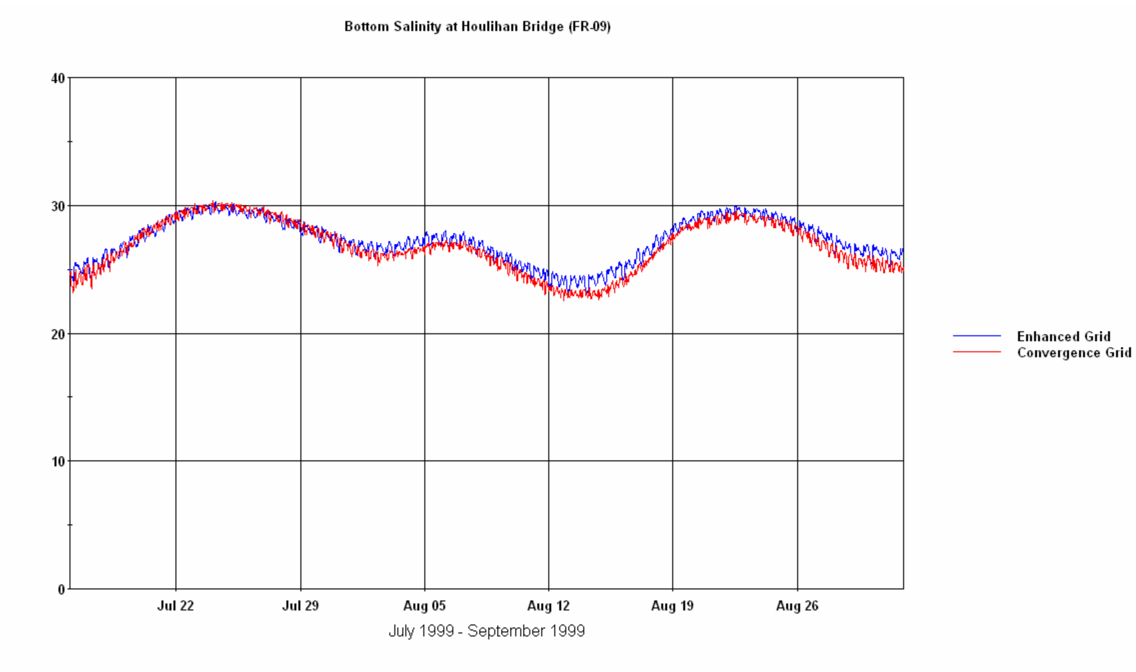
Site	Layer	Enhanced Grid Average Salinity (ppt)	Convergence Grid Average Salinity (ppt)	Average Difference (ppt)	Average Percent Difference
FR-09	**Bottom**	27.27	26.83	-0.43	-1.6%
FR-09	**Surface**	6.78	5.69	-1.09	-16.2%
SR-17	**Bottom**	0.005	0.006	0.001	21.9%

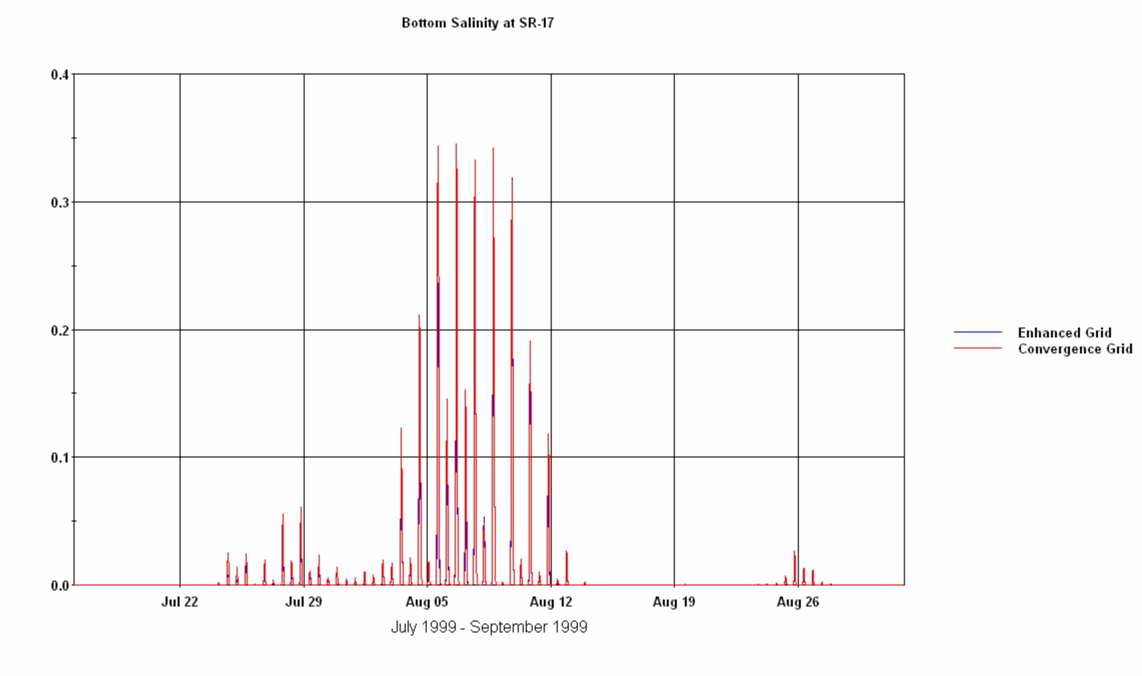
A plot of the daily average salinity difference and percent difference at FR-09 Bottom shows no consistent trend of difference (no divergence with time). The minor difference in system response for each grid may depend more on hydrologic or tidal conditions.



Here are the revised figures that will be included in the final report:


Surface Salinity at Houlihan Bridge (FR-09)
20
18
16
14
12
10
8
6
4
2
0
Jul 22
Jul 29
Aug 05
Aug 12
Aug 19
Aug 26
July 1999 - September 1999
Enhanced Grid
Convergence Grid


Bottom Salinity at Houlihan Bridge (FR-09)
40
30
20
10
0
Jul 22
Jul 29
Aug 05
Aug 12
Aug 19
Aug 26
July 1999 - September 1999
Enhanced Grid
Convergence Grid



Response by reviewer:

I concur. Comment closed.

2. COMMENT

Basis of Concern (law/policy):

Bottom roughness is set as 0.02 m.

Significance of Concern:

This indicates a physical roughness length of .6 m that is a big number.

Specific Actions Needed to Resolve:

It will be good to add more explanation for the nature of the roughness. It will be also good to put the values for the other estuaries for comparison.

Response and review action by author:

From developer Dr. John Hamrick in an email on May 30, 2005: "The value of 0.02 roughness is more reasonable. The 0.02 was used for all VIMS EFDC applications in the James River where the model did very well in predicting a lot of different things including salinity, current meter transects at James River Bridge, and frontal structure at Newport News Point. Conversely, the James model used an approximately 400 m grid and I think much of the Zo may be sub-grid scale topography. For the Savannah model, the attribution to lateral effects may have some bearing since the lateral resolution may not capture resistance of very shallow areas. Another possibility is the effect of moored ships and port structures. I have been working in Portland Oregon Harbor (Lower Willamette River) and we have played with adding various sub scale features such as piers and moored ships using the vegetation resistance. (Vegetation resistance is quite general in that it can represent any type of sub-grid scale obstacle in the flow view in terms of a projected obstruction area normal to flow per unit horizontal area. For example, piers or piles would be N*D*H/dx*dy, N = number of pilings per cell, D diameter, H water depth or fraction of water depth, dx*dy horizontal area). Adding such features greatly improved model predications for currents observations from zig-zag ADCP profiles in river. As to the sensitivity, there would not be much change between 0.015, 0.02, and 0.025. A value of 0.01 may be more appropriate for sensitivity. Of course, if we ultimately model sediment transport, the more important thing is the ability to separate the grain scale bed stress from the total bed stress. This has been done fairly successfully in the EFDC application to the Housatonic River PCB superfund site and is also being used in the above Portland Harbor application, which is also a contaminated sediment superfund site."

In a previous email from Dr. John Hamrick on May 27, 2005 with Dr. Kim: "I agree that the Zo of 0.03 m is rather large. I have typically used Zo ranging from 0.0005 to 0.02 for estuary applications. My rationale for the larger values is that, in addition to representing the actual bed grain scale roughness, the Zo accounts for larger scale effects which could include bed form drag, drag due to obstacles in flow, and drag implied by sub-grid scale topographic variability. The Zo is basically calibrated to achieve correct amplitude attenuation and phase propagate for the tide. With this in mind, other features such as unaccounted marsh storage, etc. could influence the choice of Zo globally to achieve the calibration to the tide. Of course, in an estuary where there is little apparent propagation and the tide has more of a standing wave characteristic, the tidal calibration can be relatively insensitive to Zo. In this case, larger values of Zo would tend to be used to increase vertical mixing if necessary to calibrate to stratification and length of salinity intrusion. In a strongly stratified estuary, such as Savannah, the turbulence model can tend to over stratify since phenomena such as internal wave breaking, which would enhance mixing, are not represented. I suggest that Steven and his group do some sensitivity, at least reducing Zo to 0.01. Looking ahead to sediment transport, EFDC includes a procedure to estimate the so called grain stress by partitioning the total stress into grain and form components. Typically, the grain component responsible for sediment resuspension can end up being from 5 to 50 percent of the total stress. I can provide some details on this if you are interested."

Response by reviewer:

I concur. Comment closed.

3. COMMENT

Basis of Concern (law/policy):

Salinity error was set to be within 10 % for salt water

Significance of Concern:

The criteria was difficult to meet. There is not enough explanation regarding the salinity simulation shown in Appendix J. It is difficult to see whether the federal expectation criteria was met. If not, there need to be an explanation.

Specific Actions Needed to Resolve:

Need more explanation and discussion of salinity distribution.

Response and review action by author:

The federal expectations document states that the proposed preliminary criteria should be viewed as performance goals to which model predictions could be compared and evaluated. The criteria alone should not be used for a pass/fail evaluation of the model calibration.

The criteria were established for the stations: GPA 5, 6, 7, 8, 9, 10, 11R, 12R, 15, and 22 and five USGS stations. The July 31-October 13 (Appendix J) calibration results show that the model met the criteria for USGS stations 80% (4/5) and for GPA stations 21% (3/14) for 10^{th} percentile and 29% (4/14) for 90^{th} percentile. Correlation of simulations and observations was meaningful (>0.6) for 80% of USGS stations and 79% (11/14) of GPA stations. The difference in meeting criteria for USGS and GPA sites can be explained partly by quality and duration of compared data. The average duration of data for USGS stations is 100% of the simulated period of time, and only 50-70% for GPA stations due to data gaps. This explains some problematic aspects of comparing percentiles of simulation results with incomplete data.

We agree that more detailed discussion of the salinity calibration is useful and this will be included in the revised final report.

Response by reviewer:

I concur. Comment closed.

4. COMMENT

Basis of Concern (law/policy):

Sediment oxygen demand

Significance of Concern:

The sediment diagenesis model of WASP7 was not activated. Instead SOD was set as a function of temperature and location in the system. Source of SOD would be carbons deposited during winter time. The limit of using this model should be clearly stated because full sediment diagenesis is not modeled. There may be yearly variation for summer SOD depending on the flow conditions of previous years.

Specific Actions Needed to Resolve:

State the limit of this model. Also state recommendation of having more SOD monitoring.

Response and review action by author:

We agree with the comment that a sediment diagenesis model may improve SOD representation within the WASP model. However, this version of WASP with sediment diagenesis is not available. The current version of WASP (WASP7) can only input SOD as a function of space and temperature, rather than simulating SOD with sediment diagenesis calculations. The current approach is based on using available observed data that are generalized by functions of spatial distribution and temperature. We agree that SOD effects dominate the dissolved oxygen results for the estuary and we support the idea of future SOD monitoring by cooperating agencies in the SHE project. Even though SOD data were collected in 1999 by EPA, additional SOD monitoring can be useful in areas such as the Back, Little Back, and Middle Rivers.

Response by reviewer:

I concur. Comment closed.

APPENDIX V SHE MODEL REVIEW TEAM COMMENTS AND RESPONSES

TETRA TECH, INC.
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REVISED TECHNICAL MEMORANDUM NO. 3

Date: October 25, 2005, Revised on November 14, 2005

To: Agency Technical Review Group

From: Steven Davie

Cc: Joe Hoke, Alan Garrett, and Bill Bailey - USACE Savannah District

Subject: Response to Agency Comments on the Savannah Harbor Models
Tt Project No. 16807-01

Tetra Tech, Inc. (Tetra Tech) has been developing the EFDC and WASP models for the Savannah Harbor Estuary. During this effort, Tetra Tech has developed two prior memorandums to communicate with the Agency Technical Review Group. Technical Memorandum No. 1 was distributed on December 10, 2004 dealing with the model grid enhancements. Technical Memorandum No. 2 was distributed on March 16, 2005 that entailed an update on the EFDC and WASP calibrations. This memo (No. 3) is a response to the agency comments outlined in the meeting on June 16, 2005 in Atlanta, Georgia.

During the June 16, 2005 meeting, the federal and state agencies made comments on the Final Modeling report dated May 20, 2005. The purpose of this meeting and discussion was to have an additional round of comments to address any concerns dealing with the model calibration. Agency letters were submitted to the USACE Savannah District that approved moving forward with the model while addressing the group's comments satisfactorily. The group had a wide-ranging discussion at the June meeting and the comments were categorized into 12 topics. The paragraph on the next page was the group's attempt to develop categories for the comments that describe the amount of effort expected to address a concern. The following discussion presents each of the 12 comments and Tetra Tech's response. These comments and responses were discussed at the October 26, 2005 meeting in Atlanta, Georgia. These issues will be considered further before using the models to identify impacts of the recommended plan.

Ways to address concerns with the models and the reports

The group categorized the concerns according to the level of action that is appropriate to fully address each concern. The following four categories were developed, roughly in order of the effort expected:

- **A** Explain better in the report, no modeling action needed.
- **B** Keep in mind when interpreting the model results.
- **C** Additional sensitivity model runs are needed.
- **D** Recalibrate / revise model.

(note: a "**C**" action could turn into a "**D**" action depending on the results)

Summary of concerns and actions to address each concern [option from above]:

COMMENT 1: [B] Marsh water quality loads:

a. **[A]** Inclusion in the enhanced grid
b. **[A]** Equal comparison between the TMDL and enhanced grids
c. **[C]** Is the CBODu too high?
d. **[C]** Mass exchange – flows and concentration
e. **[C]** Surface to bottom – CBODu vertical differences are a function of how marsh areas were loaded into the enhanced model

RESPONSE 1:

a. The enhanced grid contains 16 marsh cells: 3 along Front River, 4 along Middle River, and 9 along Back River. TMDL model grid had 9 marsh cells along Middle and Back River. Areas of TMDL model marshes were set in accordance with ATM Q-zones assessments. Marsh areas of enhanced grid model were based on the same Q-zone areas and adjusted during calibration process for capturing flows and salinity trends in upper part of estuary.
b. Total marsh CBODu loads for enhanced grid water quality model were set up equal to total marsh CBODu loads of the USEPA TMDL model (Greenfield, 2004). The last ones were quantified based on field measurements. The 9 TMDL model marsh loads were redistributed between 16 enhanced model marsh loads in accordance with their locations and areas.
c. The surface layer values of CBODu were too high in the calibration report. At that time, we were adding the loads from the marsh areas to the surface layer only. After our modification described in (e) below, the surface layer values are much lower and closer to the data.
d. Similar to the response (e), we feel that after the adjustment to the marsh loads, the mass exchange is more appropriate in the top three layers and the model results are closer correlated to the data.
e. Initial approach presented in Tetra Tech Report (May, 2005) was to input marsh CBODu loads in the surface layer (Figure 1). During the June meeting, there was a concern about high CBODu model results compared to the data and the stratification of CBODu in these areas. To address the concern Tetra Tech found it was appropriate to redistribute the loads between top three layers. The results of revised approach are shown in Figure 2 as an example on the Middle River (MR-12R). The load redistribution does not show any noticeable effect on CBODu and dissolved oxygen dynamics on the Front River.

RESPONSE 1 SUMMARY: Tetra Tech revised the WASP model by spreading the marsh loads into the top three layers instead of the surface layer only.

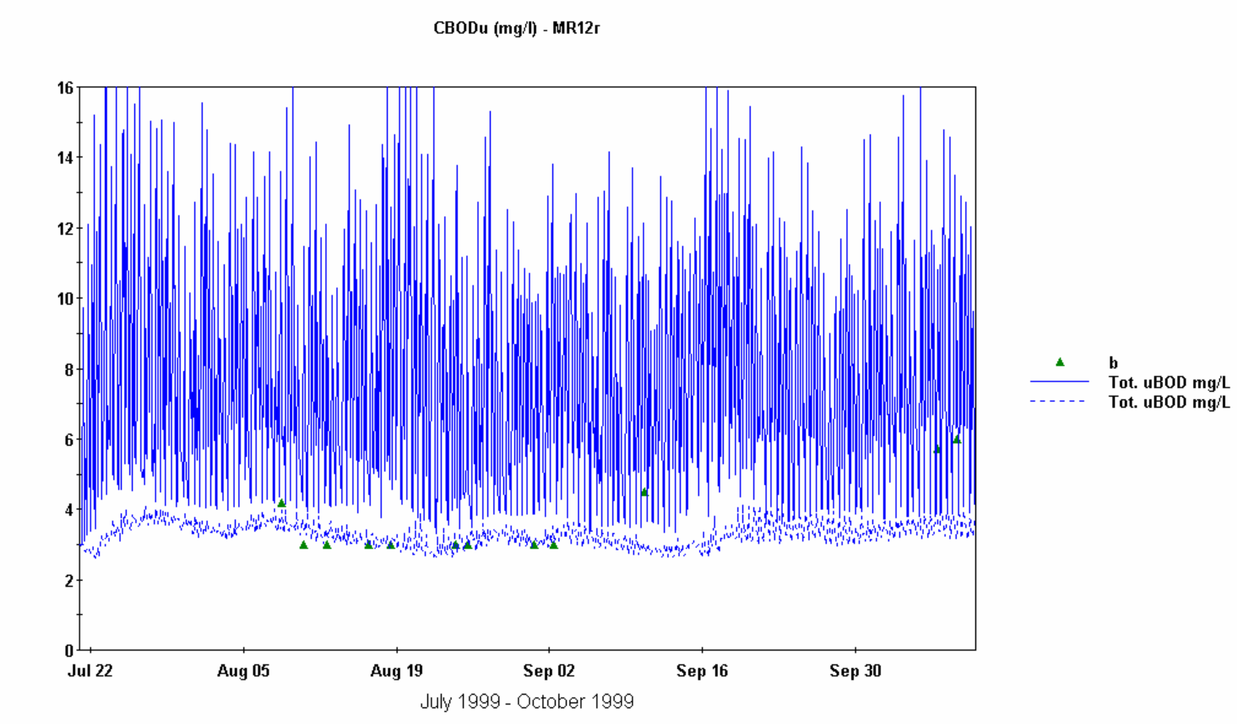

Figure 1 - Loads in the Surface Layer as Presented in the May 20, 2005 Report

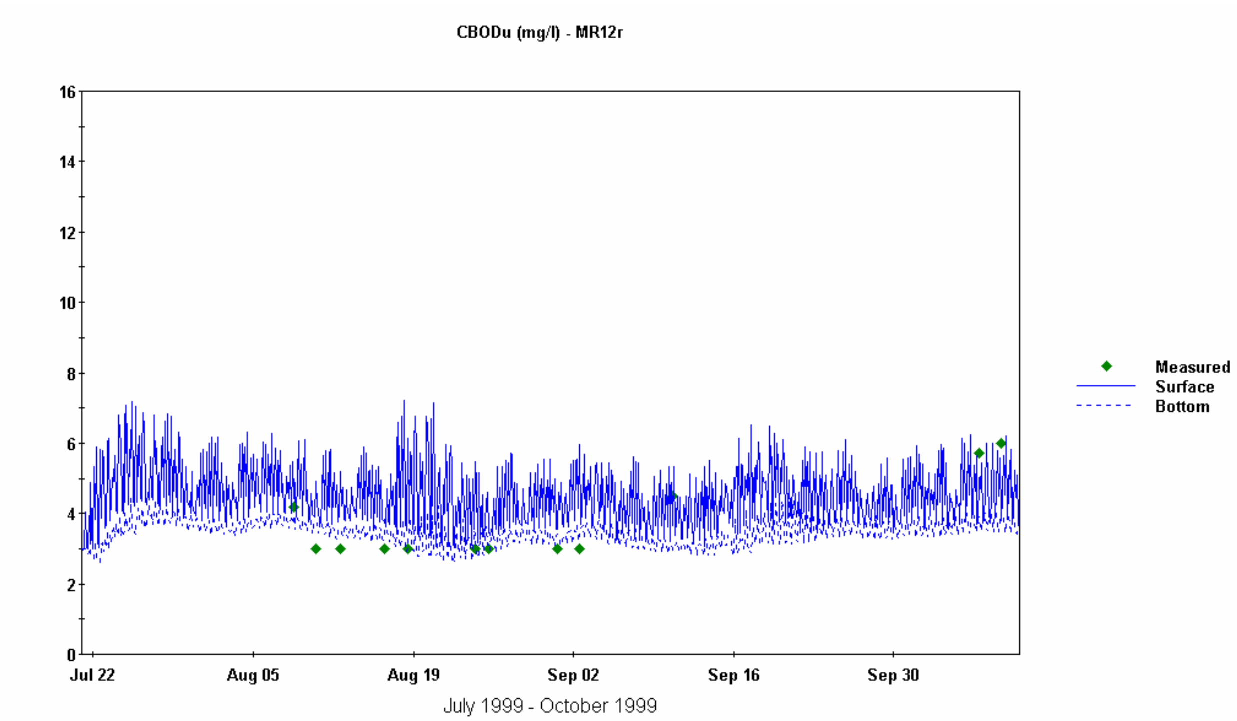

Figure 2 – Revised Approach with the Loads in the Top Three Surface Layers

COMMENT 2: [C] Offshore boundary:
a. Salinity 34 to 36 ppt versus 32.5 to 35 ppt, Mass flux surface to bottom – may need to re-distribute at FR-26.

RESPONSE 2a: The calibration boundary was determined to be a best-fit linear function from 32.5 ppt (surface) to 35 ppt (bottom). The issue was raised that based on "World Ocean Atlas" annual means, that regional annual mean value of surface salinity may be in the range 34-36 ppt. For comparison, data from Sabsoon site R2 that is located approx. 50 miles offshore from the mouth of the Savannah River indicate mean surface salinity of 36.0 ppt (range 31.5-36.5 in the period 1999-2002), however, this site is much farther from the effects of littoral freshwater inflows than the model boundary 17 miles offshore from Oysterbed Island. To assess model sensitivity and the possibility of improving the calibration, the EFDC model was run for 35 ppt (surface to bottom) and 36 ppt constant boundary conditions. Results were increased salinity in the lower Front River both at the surface and the bottom. As expected, predicted salinity was increased more at Ft. Pulaski (FR-26) than upstream at sites such as FR-08, for example. Results are shown in Figures 3 through 6 for FR-26 and FR-08. We conclude that increasing the offshore boundary condition for salinity does not improve the calibration.

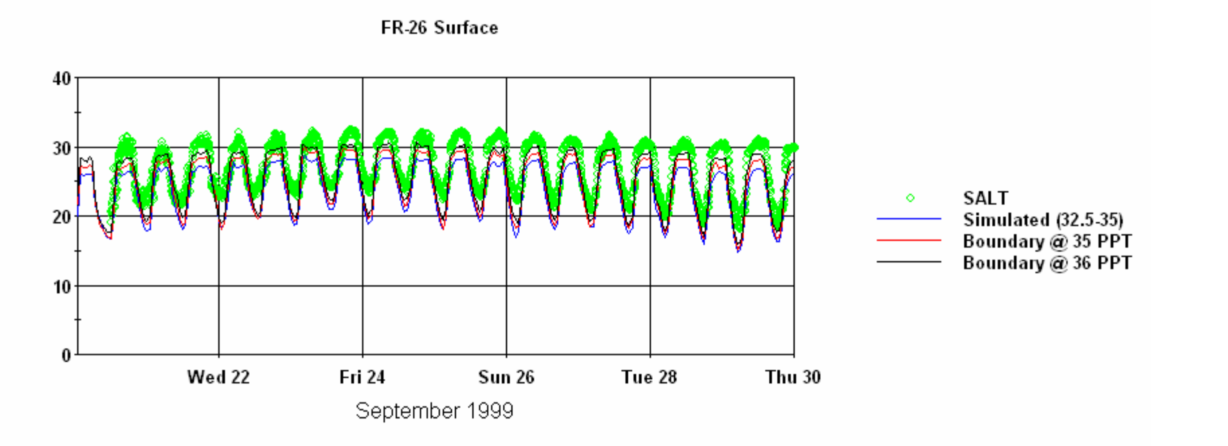

Figure 3 – Salinity Comparisons at FR-26 at the Surface

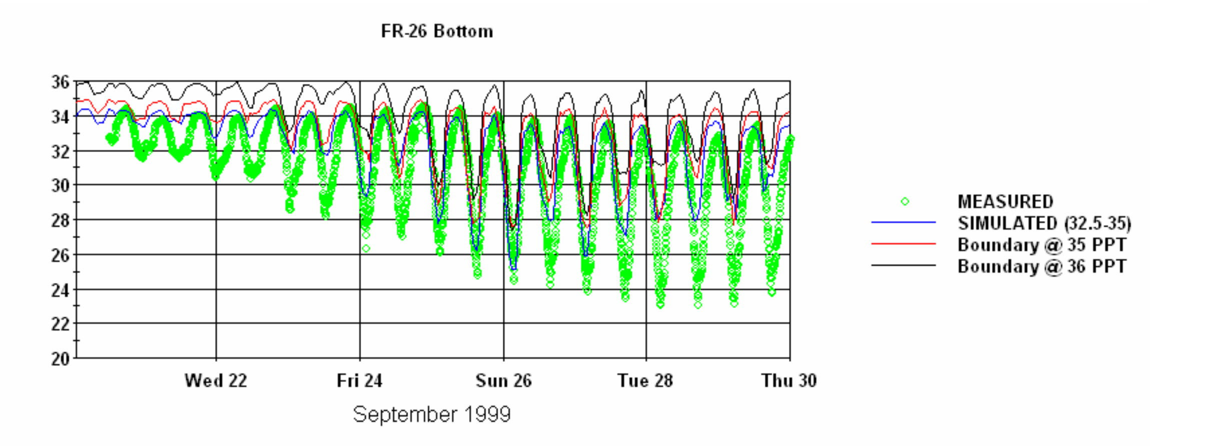

Figure 4 – Salinity Comparisons at FR-26 at the Bottom

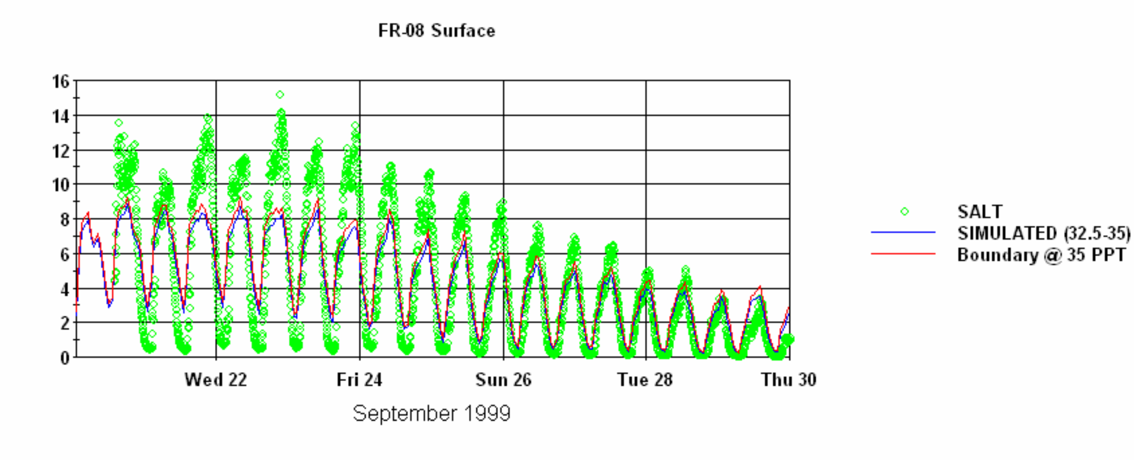

Figure 5 – Salinity Comparisons at FR-08 at the Surface

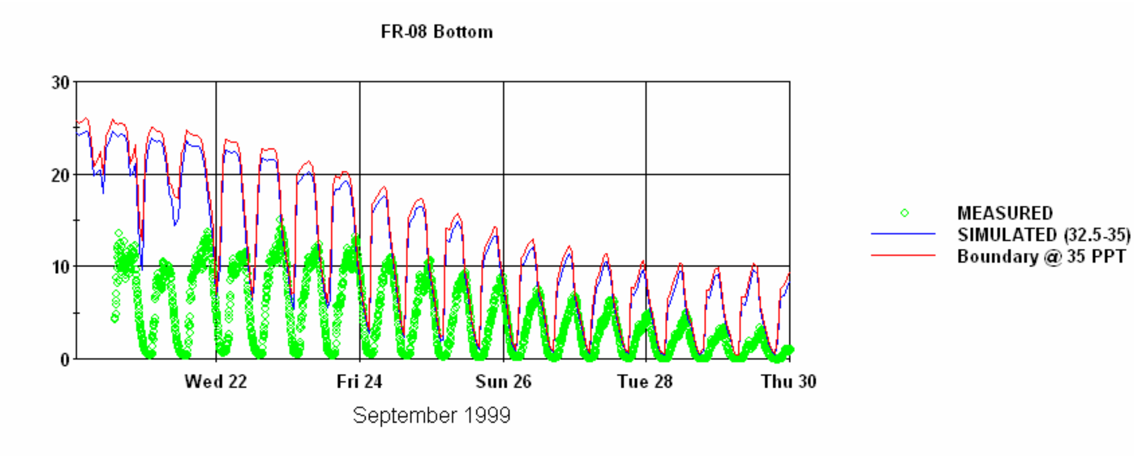

Figure 6 – Salinity Comparisons at FR-08 at the Bottom

b. Dissolved oxygen saturation 95 to 105% versus 90%

RESPONSE 2b: The water quality model calibration used an offshore dissolved oxygen boundary condition was approximately 6 mg/L for August 1999 (USEPA TMDL water quality model, Greenfield, 2004). Sensitivity tests were run for August 1999 calibration input. The dissolved oxygen boundary variations were set up as +/- 15%. The estimates of 10th and 50th percentiles were used for evaluation of the sensitivity. Tetra Tech agrees with 95-105% that was proposed for consideration by the Interagency WQ Team. 105% will be close to the used in sensitivity tests value (7 mg/L). The sensitivity analysis shows that the influence of the offshore D.O. boundary positive variation is most significant for bottom layers of downstream stations FR-02 (+ 13%), FR-04 (+ 8-9%), FR-06 (+6-8%), FR-21 (+ 5-8%), and FR-22 (+3-6%). The boundary effect becomes insignificant after FR-22. Surface layers of the model demonstrate low sensitivity to offshore D.O. boundary concentration variations. For these reasons, Tetra Tech is comfortable adjusting the downstream boundary condition from 90% to 95% of saturation.

c. Temperature

RESPONSE 2c: Summer (July-Sept.) mean surface temperature values were discussed at the offshore boundary in the range 28.0-28.5 degrees C from the "World Ocean Atlas." For comparison, mean surface temperature at Sabsoon R2 was calculated to be 27.6 degrees for 1999-2002. For the EFDC model, the temperature data from Station R2 were applied as the ocean boundary condition. These data were not available for the calibration period, only later time periods, so a harmonic sine curve with a least squares fit was used to develop a seasonal temperature boundary. For the 1999 model year, summer (July-Sept.) surface temperatures averaged 27.0 degrees. We do not believe that altering the temperature boundary condition would improve the calibration.

d. Larry Neal gave info "World Ocean Atlas 2001" with data
RESPONSE 2d: Tetra Tech used the "World Ocean Atlas" data in the discussions in 2a, 2b, and 2c.

e. CBOD decay rate – confirmed 0.5 multiplier on ocean cells
RESPONSE 2e: Tetra Tech confirmed that a 0.5 multiplier was used in the ocean cells (j = 8 to 15) and then adjusted back to 1 coming in the mouth of the river.

COMMENT 3: [C] Surface salinity:
a. Model appears to under predict surface salinity on the Front River. How does this impact the marsh succession modeling? The EFDC will output salinity for the neural net application, which feeds the marsh succession model. Right now, the neural net is using the USGS gages located between the Talmadge Bridge and I-95, located on Front and Back Rivers. These gages are considered to be mid-depth. The EFDC model is predicting salinity well at the bottom and at mid-depth but under predicting salinity at the surface.
RESPONSE 3: The model does under predict surface salinity in the Front River. Our response is discussed in 2a dealing with the offshore boundary. We do not believe it is related to the boundary, but rather related to the amount of mixing along the navigation channel. For the upper stations near the wildlife refuge, the model predictions match the data better for salinity peaks. For the marsh succession modeling, the EFDC model will deliver output to the Model to Marsh (M2M), which in turn, will deliver output to the Marsh Succession Model. Tetra Tech has developed a linkage with the M2M that passes model predicted deltas of salinity and water level in an output file. Originally, the M2M was using only the USGS gaging stations, but now uses additional sites. The specific locations and vertical layers (k-index) are described in the Table 1 below. K-index of 1 is the bottom layer and K-index of 6 is the surface layer.

Table 1 – Locations of Output for M2M Application

No.	Name	I-index	J-index	K-index
1	'WL8840'	14	127	
2	'WL8920'	14	95	
3	'WL8979'	39	114	
4	'WL8977'	13	59	
5	'WLGPA10'	26	96	
6	'WLGPA11'	14	113	
7	'WLGPA11r'	14	106	
8	'WLGPA12'	26	117	
9	'WLGPA12r'	26	113	
10	'WLGPA13'	31	123	
11	'Sal8840'	14	127	4
12	'Sal89784'	39	114	4
13	'Sal8920'	14	95	4
14	'Sal89791'	30	106	4
15	'SalGPA10'	26	96	6
16	'SalGPA 11'	14	113	1
17	'SalGPA11r'	26	106	1
18	'SalGPA12'	26	117	1
19	'SalGPA12r'	26	113	6
20	'SalGPA13'	31	123	1

COMMENT 4: [A & B] Ebb flows and currents:
a. Under prediction of the ebb flows and currents on the Little Back and Back Rivers
RESPONSE 4: Tetra Tech agrees that we are still under predicting the ebb flows only during spring tides. During neap and mid-tides, the model captures the flood and ebb flows well. During the spring tides, when we have a larger variation in water level from high to low tide, there is a significantly larger volume of water draining the estuary (ebbing) that the model is not capturing. We believe this is related to additional storage in the system in the marsh areas, irrigation ditches (Lucknow Canal), groundwater zones, etc. We are not sure why and have been comparing the measurements to explain where the additional water is coming from. We added more marsh storage to the model and did not see an improvement in our ebb flows. There is a longterm monitoring plan being developed by the federal agencies that will entail measuring continuous flow at the Front, Middle, and Little Back Rivers to improve our knowledge of the flow regime in the upper part of the estuary.

COMMENT 5: [A] Water level at SR-17 on the Upper Savannah River
a. Potential of adding marsh storage areas upstream of I-95 Bridge
b. Show comparisons at the USGS Hardeeville gage (show plot)

RESPONSE 5: Discussion of the EFDC model calibration raised the issue of the discrepancy in water surface elevation (stage) predictions at SR-17, which is an upstream site in the Savannah River, approximately 14 miles upstream of I-95. The model calibration under predicted stage and over predicted the magnitude of tidal oscillation, shown in Figure 7. It was hypothesized that the model was not accounting for the effects of marsh storage in the upper Savannah River (above I-95 Bridge). It was found that creating five marsh cells in the upper river dampens the tidal oscillation to the approximate range (~0.15 m or 0.5 ft) shown in the data (Figure 7). Furthermore, by increasing the bottom roughness on the Savannah River upstream of I-95, the baseline stage was increased resulting in an improved calibration at this site (Figure 8). The additional stage calibration in the upper Savannah River does not change the overall salinity results in the harbor. Based on the discussion and recommendations at the October 26 meeting, Tetra Tech will alter the EFDC model to improve the water surface elevation calibration in the upper Savannah River.

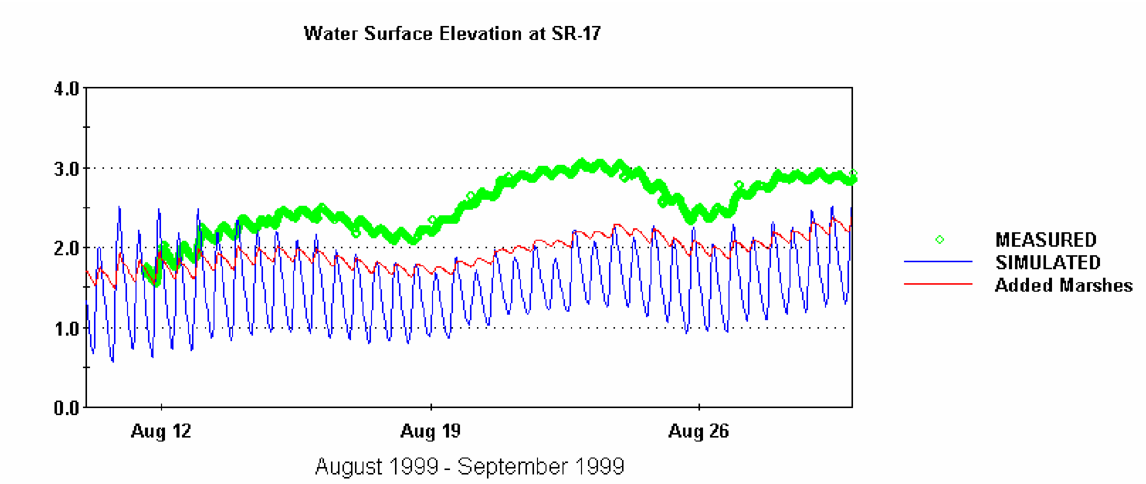

Figure 7 – Water Level at SR-17 with added marsh areas compared to May 2005 calibration

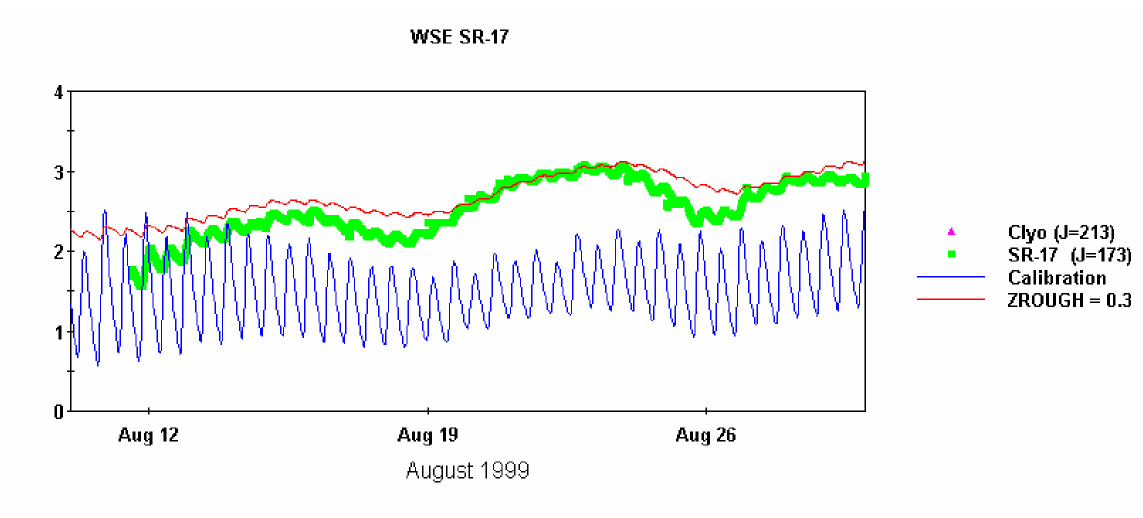

Figure 8 – Water Level at SR-17 with added marsh areas and added roughness on the Savannah River compared to May 2005 calibration

COMMENT 6: [C & A] Global versus source-specific BOD decay rates
a. Sensitivity of calibration
b. Sensitivity on allocation scenarios (more for TMDL)
RESPONSE 6: Tetra Tech has preliminarily setup two runs. The first run was a grouping in WASP according to the LTBOD results (decay rates). We used the WASP7 option that allows with three BOD classes and put the dischargers in the following categories:

- o K = 0.02 per day (IP, Wilshire)
- o K = 0.05 per day (Marshes, Fort James, Smurfit, President Street)
- o K = 0.07 per day (Hardeeville, Garden City, Travis Field, Upstream, and Ocean)

The second run was done to split a large discharger such as the IP paper mill into a labile (fast reacting) and refractory (slow reacting) load category. CBOD decay rates were reassigned in following order:

- K = 0.06 per day (Marshes, Upstream and Ocean, all point sources except IP)
- K = 0.2 per day (IP 15% of discharge) = labile load
- K = 0.02 per day (IP 85% of discharge) = refractory load

Results of both scenarios showed no change in the calibration of the time series plots and minor changes in the calibration statistics. For demonstration purposes, the second run is shown below. Figures 9 through 11 show the same results as the May 2005 report calibration. In summary, the single rate approach will be used for deepening impacts. EPA will address the use and sensitivity of multiple BOD decay rates in the TMDL allocation scenarios. Conclusions of these runs can be summarized by salinity is still the dominating factor for DO deficit (Stations FR06 and FR22).

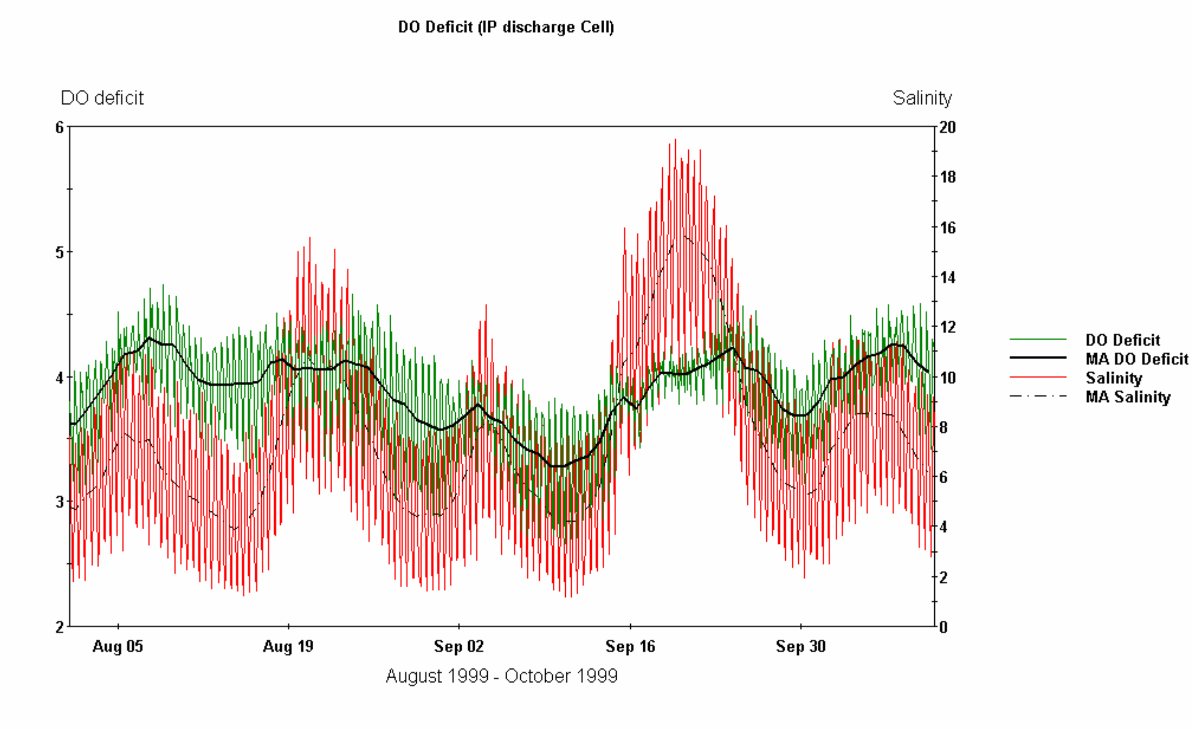

Figure 9 – DO deficit versus salinity at IP discharge (MA = Moving Average)

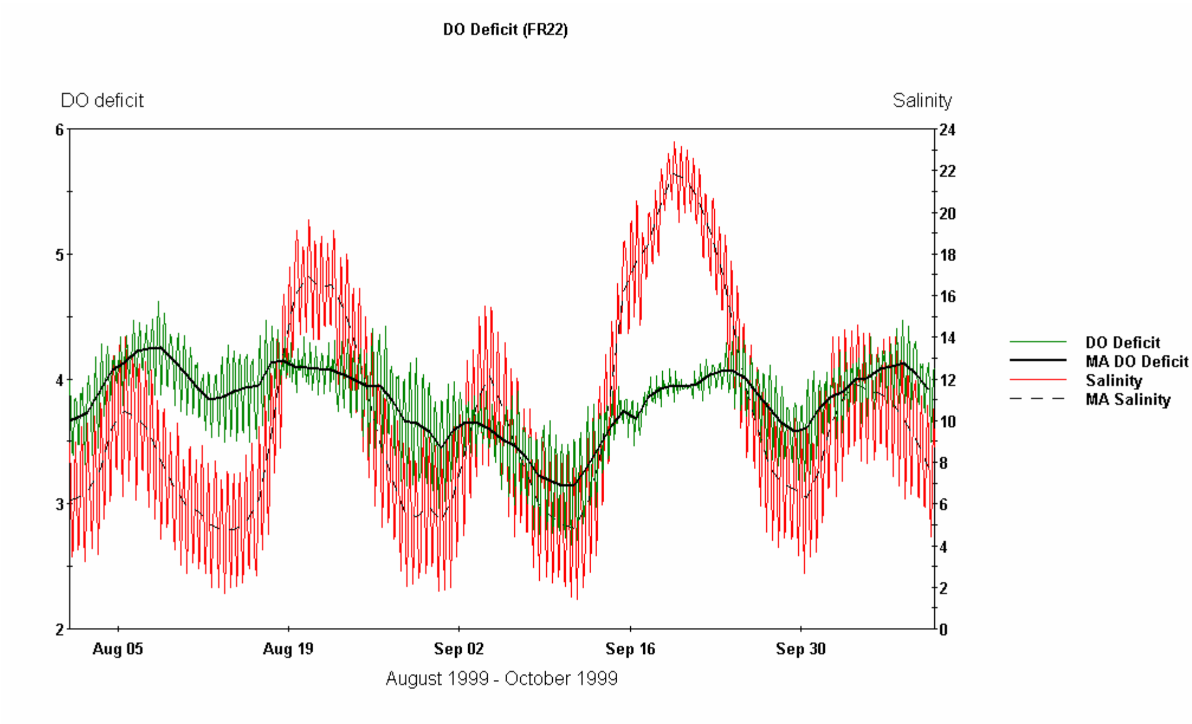

Figure 10 – DO deficit versus salinity at FR-22, downstream of IP Discharge (MA = Moving Average)

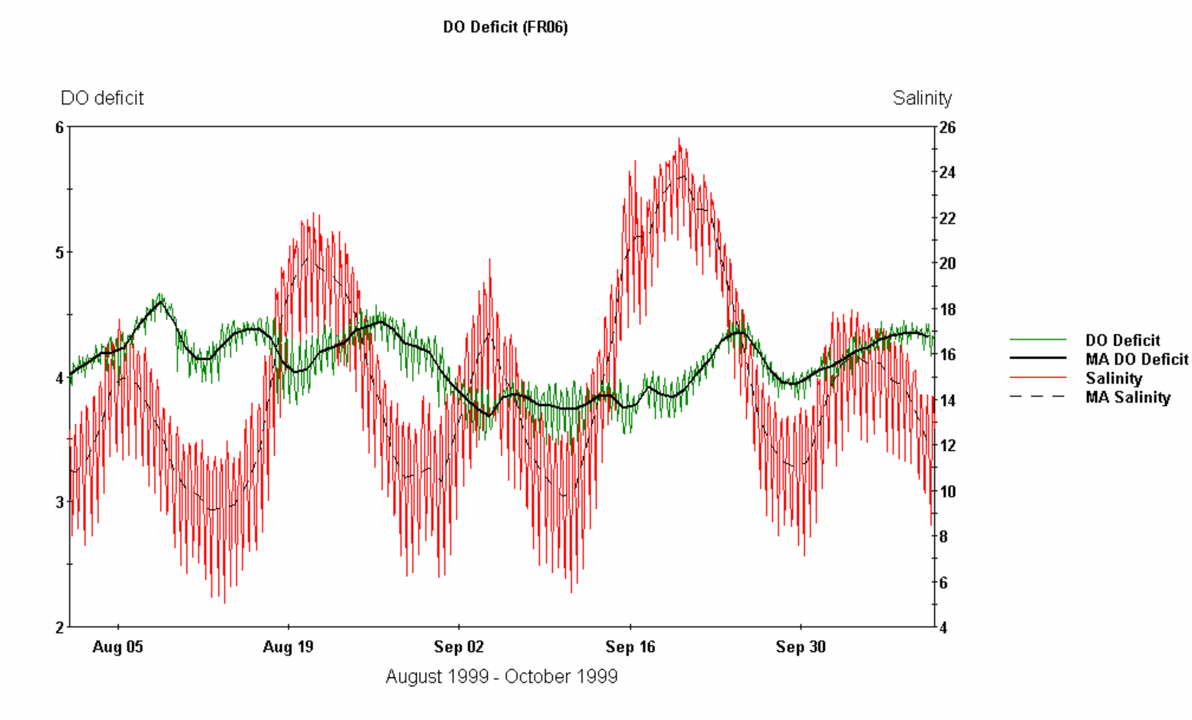

Figure 11 – DO deficit versus salinity at FR-06, downstream of IP discharge near Talmadge Bridge (MA = Moving Average)

COMMENT 7: [A] Check all point sources and heat loads, especially Plant MacIntosh (Harbor Committee will verify).
RESPONSE 7: We have not been able to verify the heat loads from MACTEC to date. From the previous comments, it appears that the flow used for Plan MacIntosh is lower than it should be. If the flows are adjusted higher, the delta temperature would be reduced to maintain their current heat load. The heat load table will be added to the report. Tetra Tech will contact Bob Scanlon and the Harbor Committee to verify.

COMMENT 8: [none] BOD loads from Corps' confined dredged sediment placement sites in SC and potential impacts on dissolved oxygen (future TMDL issue)
RESPONSE 8: No response needed at this time, may be included in the future as a TMDL issue. The clarification of the issue is presented in DHEC's June 2005 letter on the model review. The USACE will also collect data in these areas in the future.

COMMENT 9: [A] Grid convergence test:
a. Show results of the TMDL grid with the same depth;
b. Show results on TMDL grid, enhanced grid, and convergence grid on the same plots;
c. Show comparisons on the Middle and Little Back Rivers;
d. Perform moving average of results to reduce tidal noise; and
e. Quantification of grid convergence test results.

RESPONSE: In the May 2005 report, Figure A-2 shows bottom salinity at Houlihan Bridge, while Figure A-3 shows the surface salinity for comparison of Enhanced Grid and Convergence Grid results. The "slightly greater stratification" phrase should be modified to indicate that slightly less salinity (difference is more apparent at surface) is observed in the Convergence

Grid results. Quantification of the convergence grid test results has been performed and is presented in the following table (Table 2). Model spin up (15 days) has been excluded from these statistics.

Table 2 – Quantification of the Convergence Grid Test Results

Site	Layer	Enhanced Grid Average Salinity (ppt)	Convergence Grid Average Salinity (ppt)	Average Difference (ppt)	Average Percent Difference
FR-09	**Bottom**	27.27	26.83	-0.43	-1.6%
FR-09	**Surface**	6.78	5.69	-1.09	-16.2%
SR-17	**Bottom**	0.005	0.006	0.001	21.9%

A plot of the daily average salinity difference and percent difference at FR-09 Bottom shows no consistent trend of difference (no divergence with time), shown in Figure 12 and the minor difference in system response for each grid may depend more on hydrologic or tidal conditions.

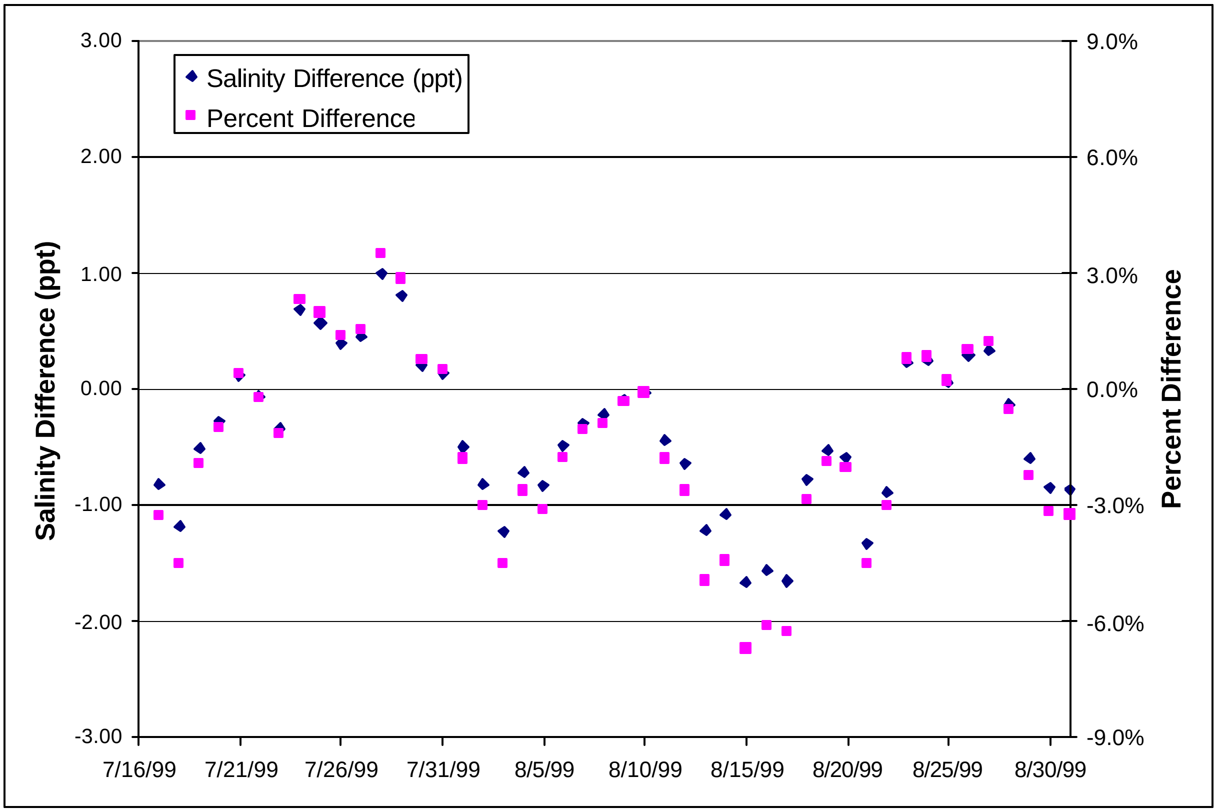

Figure 12 – Salinity and Percent Difference of Grid Convergence Results

The TMDL grid with equal bathymetry should not be compared because the surface area of the grid does not exactly match the enhanced or the convergence grid. The convergence grid is useful because the grid cells can be collapsed back to regenerate the enhanced grid. This could not be done with the TMDL grid.

COMMENT 10: [B & C] Delay in EFDC model salinity results at US F&W Dock comparisons of model versus data

RESPONSE 10: The model review group observed that the EFDC model shows a delay of salinity attenuation after high intrusion events in the Little Back River in the vicinity of the F&W Dock (USGS 021989791). Preliminary comments concerning the February 2005 draft EFDC model calibration described how the draft model completely flushed in the Little Back River (salinity dropped to zero in every tide cycle). The implementation of marshes in the final EFDC model calibration results in greater salinity retention in general. Attempts were made to modify the marsh parameters and dimensions to reduce the retention of salinity more within the range of measured data, however, no improvements from the draft calibration have been observed concerning this issue. Figure 13 below shows salinity at F&W Dock in the draft May 2005 calibration (without marshes) and in the final May 2005 calibration with marsh salinity retention.

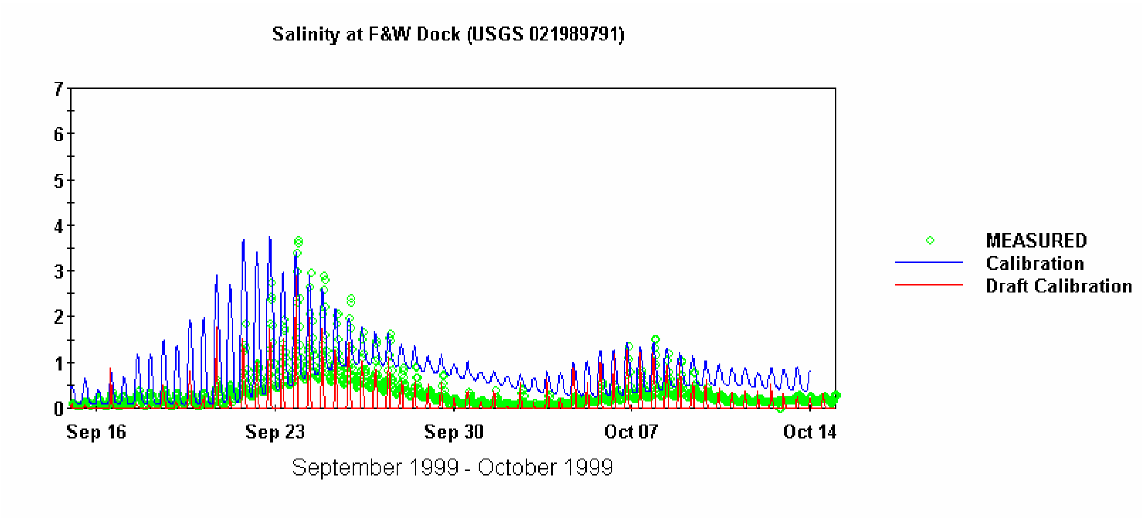

Figure 13 – Salinity and US F&W Dock with and without marshes

COMMENT 11: [A] Clearer description of 1999 versus 2002 bathymetry and why the 2002 bathymetry data is representative of 1997 through 2003 conditions in the harbor

RESPONSE 11: The 2002 and 1999 datasets were compared by analyzing cross-sections between the two surveys at many locations. Although there were some differences in alignment of the cross-sections, there was not a difference between the two surveys. Also, the survey data are grouped and averaged according to the model grid cell, and there was not a difference between 1999 and 2002 once this averaging occurred. Since dredging is a continuous operation in the navigation channel from year to year, the goal was to have a bathymetry that represents the current channel configuration, or depth, since the last deepening in 1994. It was determined that the 1999 and 2002 annual surveys are interchangeable in the model grid and best represent the existing (calibration) conditions. This text in the report has been modified.

COMMENT 12: UA/SA Analysis: The group concluded that the inability to run the models over a 7-year duration was the result of synthetic data that was developed to fill in a data gap around December 2000. The group concluded that the inability of the model to run over the entire 7-year period of data does not reflect on the structure of the model or its performance, and should not be a consideration of the model's usefulness for its intended purposes of predicting impacts of the Savannah Harbor Expansion Project, developing a dissolved oxygen TMDL, or permitting point source discharges.

RESPONSE 12: Tetra Tech agrees the 7-year run is important but in no way reflects on the stability of the model. In Section 11 of the report, Tetra Tech comments on the results of the Uncerntainty Analysis. Tetra Tech performed stability and mass balance tests with the model. The model was crashing during mid-December because there was not enough water in the Little Back River during this event. The high tide on Dec 17, 2000 was only 4 feet (compared to usual 6 to 8 feet) and the low tide on Dec 19, 2000 was –2 feet (compared to usual 0 to –1 feet). See Figure 14 below for a plot of the same time period at the St. Simons Island NOAA tide gage. This proves the event was a real phenomenon and later USGS reported that the Fort Pulaski data during this time period have been checked and are real data, not synthetic data as previously discussed. The TMDL grid ran through this period because the Back and Little Back Rivers were deeper (Tetra Tech updated the bathymetry based on the 2004 USGS survey data). Therefore, Tetra Tech believes it is not a stability issue, but rather a reality issue. The model will not run when the river bed is dry, and it is believed that parts of the upper system were very shallow (or dry) during this time period.

It is evident that sections of the Back and Little Back Rivers go dry during extremely low flows and low tide range (as documented in Dec 2000). Tetra Tech has since modified the PSER.inp (time series water level boundary file) by adjusting 10 data points out of 245,280 (0.004%), which was only 5 hours out of a 7-year record, and the model now runs for 7 years without going dry. Since December 2000 is not a critical period for the modeling scenarios, we felt justified altering the water level boundary for these limited data points. Figure 15 shows the altered water level boundary file for this time period.

In summary, the data during December 2000 proved to be valid and a real phenomenon occurred during this time period (some kind of offshore wind or pressure system). Since the 7-year model run became a critical issue among the Stakeholder Evaluation Group (SEG), Tetra Tech modified the water level boundary file to receive a continuous 7-year model run.

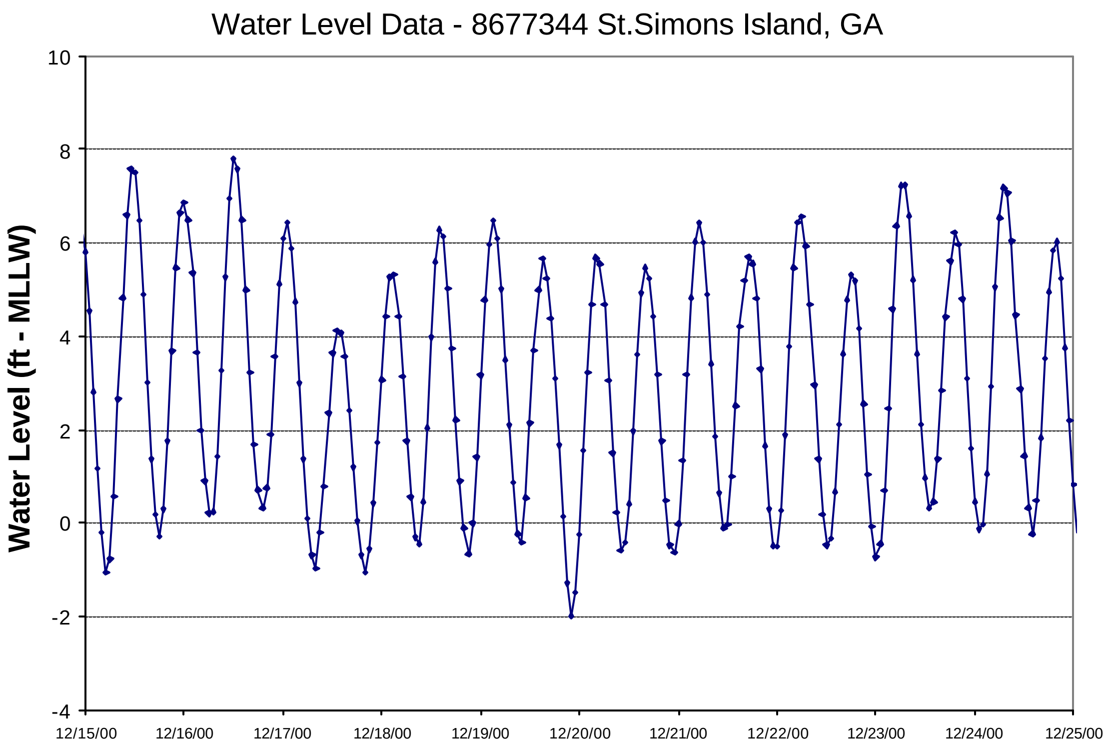

Figure 14 – Water level data measured at St Simons Island NOAA gage

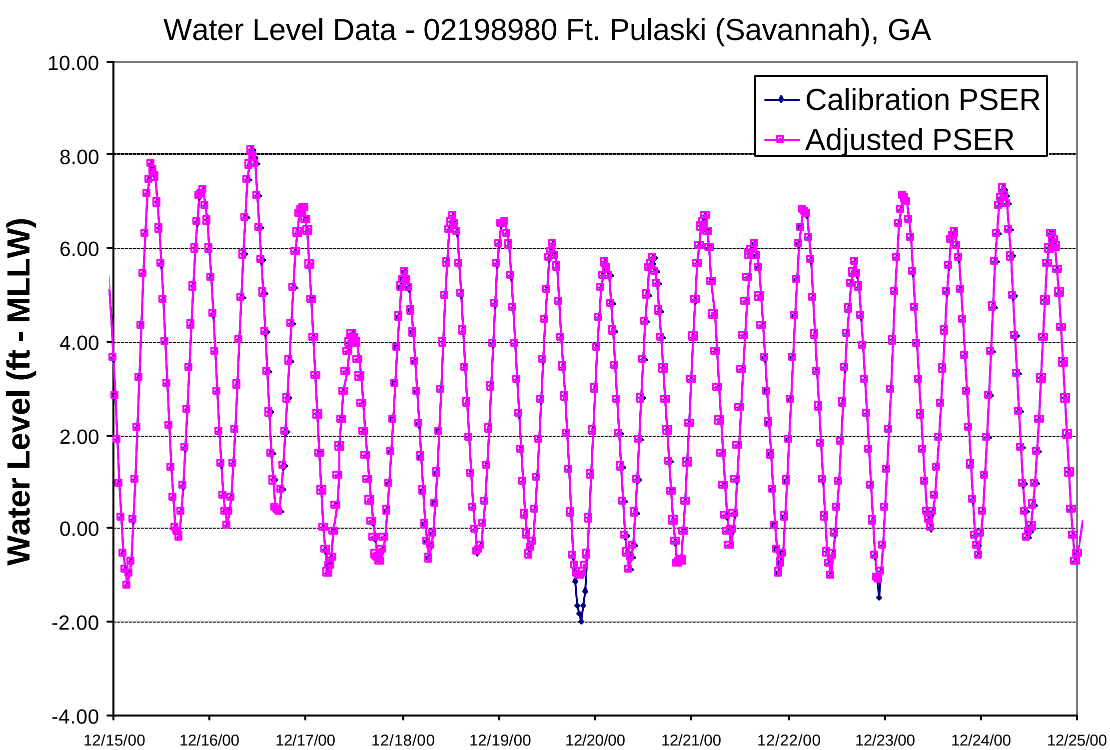

Figure 15 – Modified water level data for model boundary