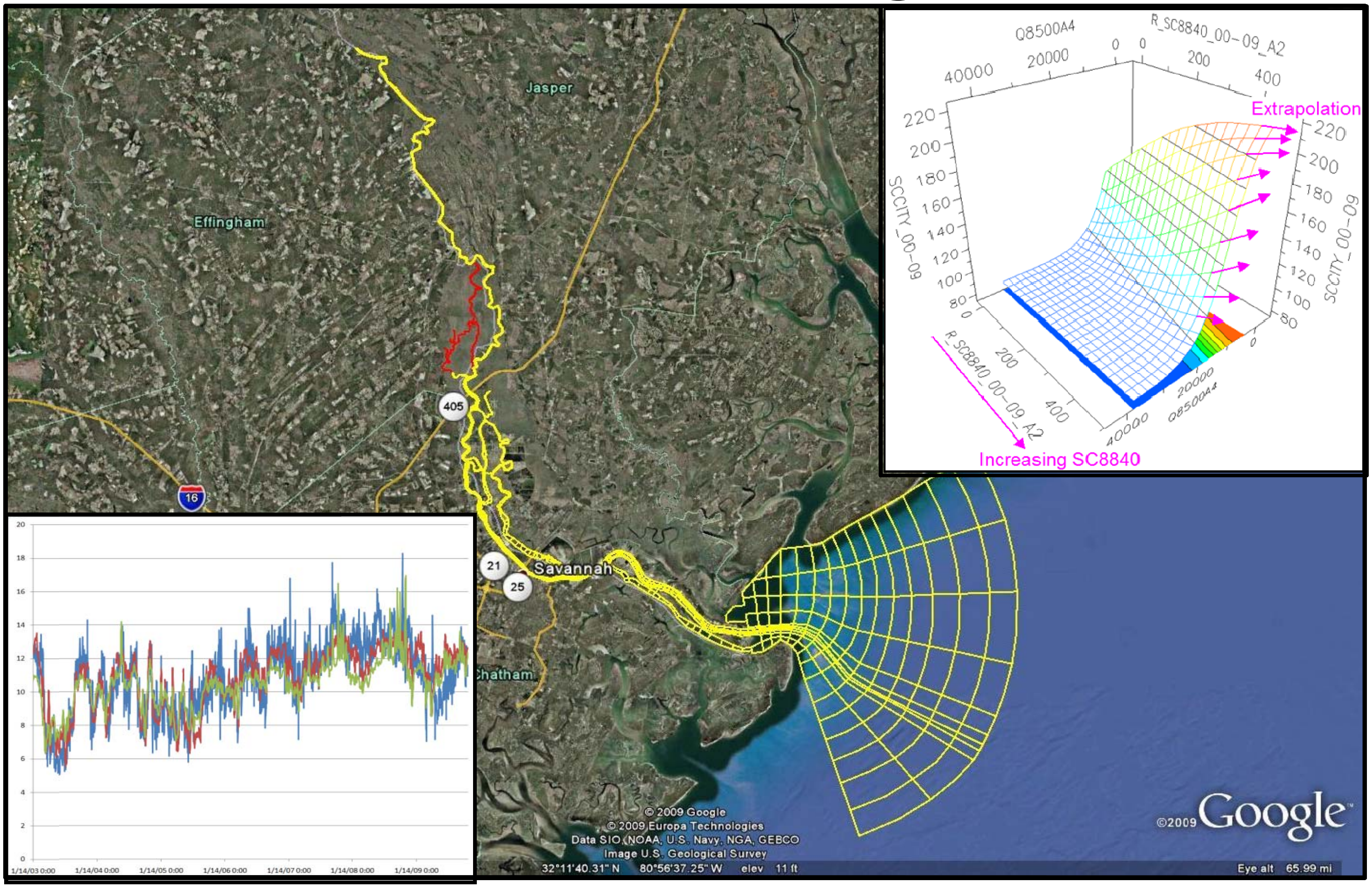
Chloride Modeling
Savannah Harbor Expansion Project
Savannah, Georgia



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Revision History

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1.0 INTRODUCTION

The United States Army Corps of Engineers (USACE), Savannah District is working with the Georgia Ports Authority (GPA) to evaluate the deepening of the navigation channel in Savannah Harbor. This effort is called the Savannah Harbor Expansion Project (SHEP). The project is intended to identify the impacts and mitigation strategies of deepening the harbor from its presently authorized 42-foot depth Mean Lower Low Water (MLLW), up to a depth of 48-feet MLLW. The SHEP is examining ways to mitigate for potential adverse effects on chloride concentrations at the City of Savannah's intake.

2.0 BACKGROUND

In a previous effort in 2006, Tetra Tech was contracted by the United States Army Corps of Engineers (USACE) to perform a data analysis of chloride concentrations in Abercorn Creek upstream of the Interstate 95 Bridge on the Savannah River. Chloride is one of the major inorganic anions, or negative ions, in saltwater and freshwater. Saltwater is comprised mostly by chloride (55%) and sodium (31%) ions with sulfate, magnesium, calcium, potassium, and bicarbonate ions comprising the remaining 14%.

The purpose of the chloride data analysis was to determine a prediction of chloride concentrations (or chloride model) on Abercorn Creek in response to downstream harbor modifications and potential increase in salinity in the Lower Savannah River Estuary. The City of Savannah (City) owns and operates an Industrial and Domestic drinking water supply intake located on Abercorn Creek approximately two miles from the confluence with the Savannah River. The City collects samples at the water treatment plant daily to monitor various chemical constituents in the influent. Due to the proximity of Savannah to the coast, the rise and fall of daily tides causes the physical and chemical characteristics of the source water to change continuously. This constant change adds to the complexity of the treatment process and requires the highest degree of vigilance by the operations staff. The overall goal of this study was to provide an analysis of the potential for proposed harbor modifications (i.e., deepening of the navigation channel) to cause an increase in the chloride concentrations at the City of Savannah's freshwater intake on Abercorn Creek.

The previous study developed a relationship between upstream flow and chloride measurements within the system, investigated the impact of past harbor deepening on chloride levels at the intake, identified other potential sources of chlorides, and developed a predictive model for chloride concentrations. During the study which developed the chloride predictive tool, a scarcity of data was noted and uncertainties were recognized. Continuing questions about the accuracy of the predictive tool and the magnitude of the uncertainties initiated the collection of additional data collection followed by a review of the chloride predictive tool.

The objective of this project was to confirm/refine the prediction of chloride concentrations at the City of Savannah's water intake on Abercorn Creek for existing and deepening conditions. This effort would be performed prior to the proposed harbor deepening. This new effort used the existing Environmental Fluid Dynamics Code (EFDC) model for the Savannah Harbor Expansion Project (SHEP) and artificial neural network (ANN) models integrated into a Decision Support System (DSS) models to predict chloride levels the City of Savannah water intake.

The United States Geological Survey (USGS) has been monitoring the upper Savannah River and Estuary for flow, conductivity (salinity), temperature, and chloride. Conductivity and specific conductance are used interchangeably as specific conductance is conductivity at 25 degrees C. The data collection started in July 2009 and continues through continuous gaging and event sampling. These data through the end of 2009 were the basis for the chloride analysis and modeling work described in this report.

3.0 TECHNICAL APPROACH

The work was performed as a two-paralleled modeling approach. The modeling was performed by Tetra Tech with the EFDC hydro modeling and ADMs for the ANN modeling DSS. There are chloride prediction by the EFDC and the ANN models. The two modeling efforts complement each other by using the rigorous analysis of the ANN model empirical relationships with the mechanistic approach for simulating the harbor deepening with the hydro model.

3.1 Data Compilation and Processing

Tetra Tech assembled and compiled the data provided by the USGS and the City of Savannah. All data were organized in a database for use in data analysis and the models. The key stations used in the data and models were as follows:

- 02198810 – Abercorn Creek (flows, water surface, chloride, temperature, and conductivity)
- 02196485 – Bear Creek (flow, water surface, flow splits for Abercorn and Little Collis Creeks)
- 02198840 – I-95 Bridge (water surface, chloride, temperature, and conductivity)
- 02198920 – Houlihan Bridge (flow, water surface, chloride, temperature, and conductivity), with separate flow gages for Front, Middle and Back Rivers
- 02198745 – Plant McIntosh (water surface, chloride, temperature, and conductivity)
- City Intake collected by the City (chloride)

USGS collects data at 02198840 (I-95 Bridge), 02198920 (Houlihan Bridge), 02198810 (Abercorn Creek), and 02198745 (Plant McIntosh). The City collects chloride samples at the water plant (water pumped from Abercorn Creek), same location as 02198810 (Abercorn Creek) monitored by USGS.

Table 3-1 and Figure 3-1 show the stations used in the EFDC model calibration and validation. All data were uploaded into the Water Resources Database (WRDB) for use in data summaries and model development. The data were gathered through 2009 to extend time period for model simulations. USGS established new gages on Abercorn Creek, Bear Creek, and at Plant McIntosh to collect flow, water-surface elevation, temperature, and conductivity on a 15-minute interval. The USGS also installed ISCO automatic samplers to collect discrete samples of chloride for use in the calibration of the model. USGS sampling sites are located at I-95 Bridge, Houlihan Bridge, Abercorn Creek, and Plant McIntosh. The City of Savannah collects samples at the water plant rather than at the end of the intake pipe on Abercorn Creek, same locations as USGS 02198810. These samples are taken hourly throughout the day and then composited as a daily chloride concentrations, along with many other parameters, at the water treatment facility. The conductivity values from USGS gages were converted to salinity to allow comparison with the model. This was accomplished using a well-established algorithm developed to define the relationship of specific conductance to the chemical composition in seawater and dilutions of seawater, as in estuaries (Miller and others 1988).

Table 3-1 Summary Table of Stations

Station ID	Station Description	Parameters
02198500	Savannah River Near Clyo, GA	Flow
02198745	Savannah River Near Rincon, GA (Plant McIntosh)	Water surface and chloride, recently added temperature and conductivity
02198768	Bear Creek Near Rincon, GA	Flow, water surface, recently added flow splits for Abercorn and Little Collis Creeks
02198810	Abercorn Creek Near Savannah, GA (City's Intake)	Flow, water surface, chloride, recently added temperature and conductivity
02198840	Savannah River Near Port Wentworth (I-95 Bridge)	Water surface, chloride, temperature, conductivity
02198920	Savannah River at GA 25 at Port Wentworth (Houlihan Bridge)	Flow, water surface, chloride, temperature, conductivity
02198950	Middle River at GA 25 at Port Wentworth (Houlihan Bridge)	Flow
021989792 (320955081074600)	Little Back River at GA 25 at Port Wentworth (Houlihan Bridge)	Flow
02198980	Savannah River at Fort Pulaski, GA	Flow, conductivity
021989773	Savannah River at USACE Dock at Savannah, GA	Conductivity
321313081075100	Union Creek below I-95 nr Hardeeville, SC	Flow
City of Savannah	City's Intake on Abercorn Creek	Chloride, conductivity, temperature

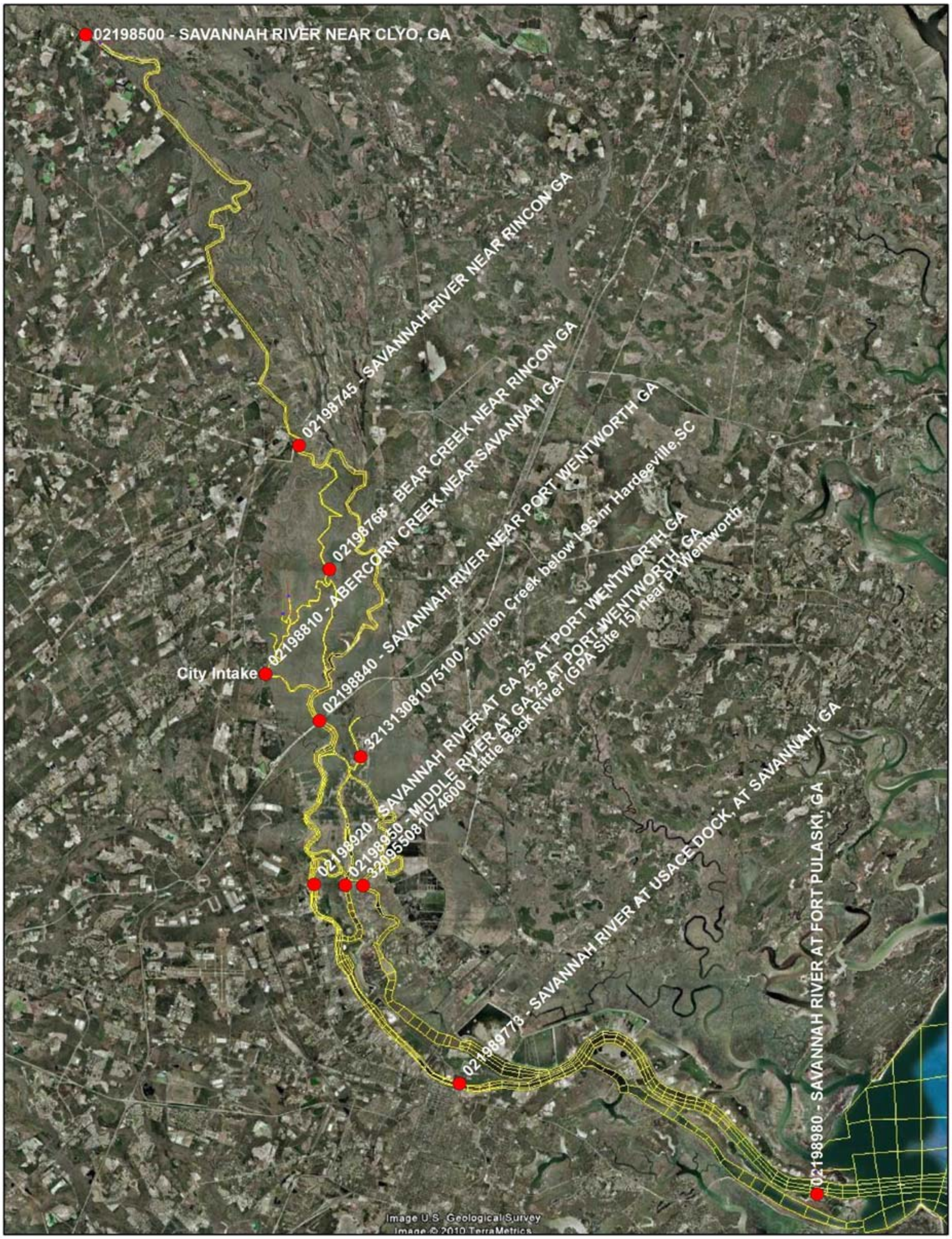


Figure 3-1 Location of Monitoring Stations Used in the EFDC Model

3.2 Characterization of Data

Salinity intrudes into the Lower Savannah River Estuary from the ocean and the location of the saltwater-freshwater interface is a balance between upstream river flows and downstream tidal forcing. During periods of low streamflow, salinity is able to intrude upstream; subsequently, the saltwater-freshwater interface is moved upstream. The daily max specific conductance for the I-95 gages and daily mean streamflow for Clyo for the period 2006 to 2008 is shown in Figure 3-2. The data shows that the large salinity intrusion events occur when Savannah River streamflow are less than approximately 6,000 ft^3/s at the occurrence of 28-day spring tide.

The salinity dynamics at the City's intake, approximately three miles from the I-95 gage, is significantly different from the dynamics at the I-95 Bridge. The sharp salinity intrusions experienced at I-95 are dampened at the intake. Figure 3-3 shows nine years of Clyo streamflow and specific conductance data at I-95 and the intake. The specific conductance at I-95 shows rapid increases when streamflow decrease to 6,000 ft^3/s. The specific conductance at the intake does not show rapid increases but rather gradual increases. The plot shows that with decreasing Clyo streamflow, specific conductance at I-95 can increase to close to 800 micro-Siemens per centimeter (µS/cm) whereas at the intake the specific conductance values are less than 200 µS/cm. The time delay between the I-95 gage and the Intake is short for specific conductance (less than 1 hour). Figure 3-4 shows the specific conductance at the two gages for a salinity intrusion event in September 2010. Although the intrusion is greatly dampened between the two gages, the graph shows that there is only a small delay in the timing. The natural dampening of the salinity intrusion at the intake may be due to differences channel geometries and channel depths at the confluence of Abercorn Creek and the Savannah River, watershed dynamics in Abercorn and Bear Creeks, or differences in slopes between Abercorn Creek and the Savannah River.

Specific conductance and chlorides at the plant appear to follow a similar trend with the chlorides, like specific conductance, increasing during periods of low streamflow and decreasing during period of high streamflow (Figure 3-5). A scatter plot of specific conductance and chlorides at the intake shows substantial variability between the two parameters (Figure 3-6). The correlation between the two parameters is low with a coefficient of determination (R^2) of 0.57 indicating that only 57 percent of the variability in chlorides is explained by specific conductance and suggests that the large portion (43 percent) of the variability in chlorides is not explained by salinity intrusion in the upper reaches of the Lower Savannah River Estuary.

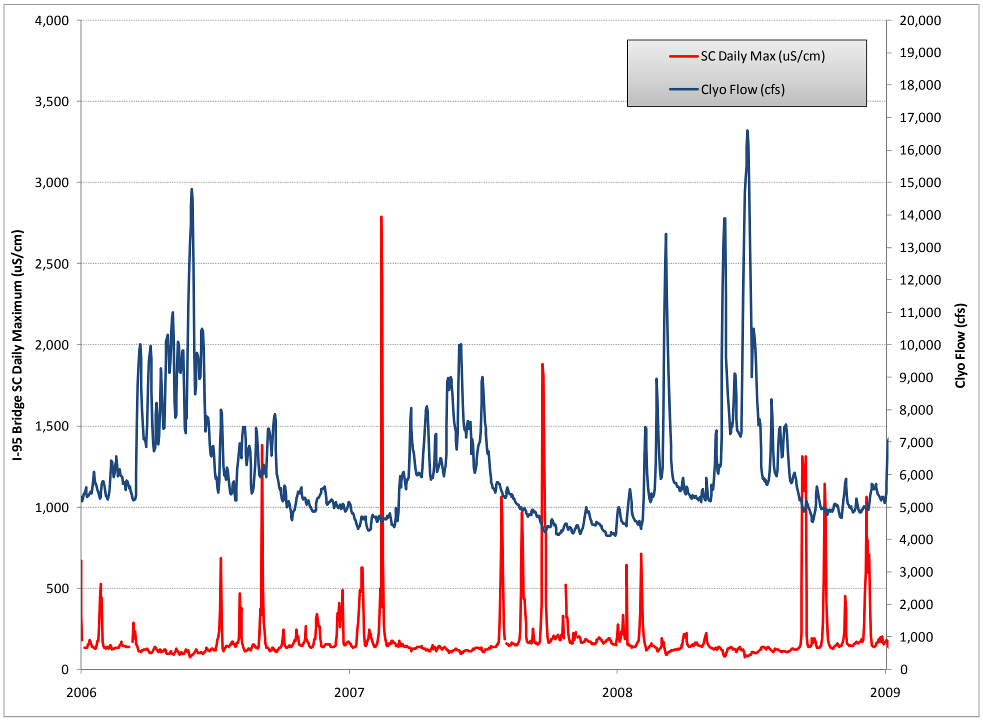


Figure 3-2 Plot of Clyo Flow and I-95 Bridge Conductivity (2006 - 2008)

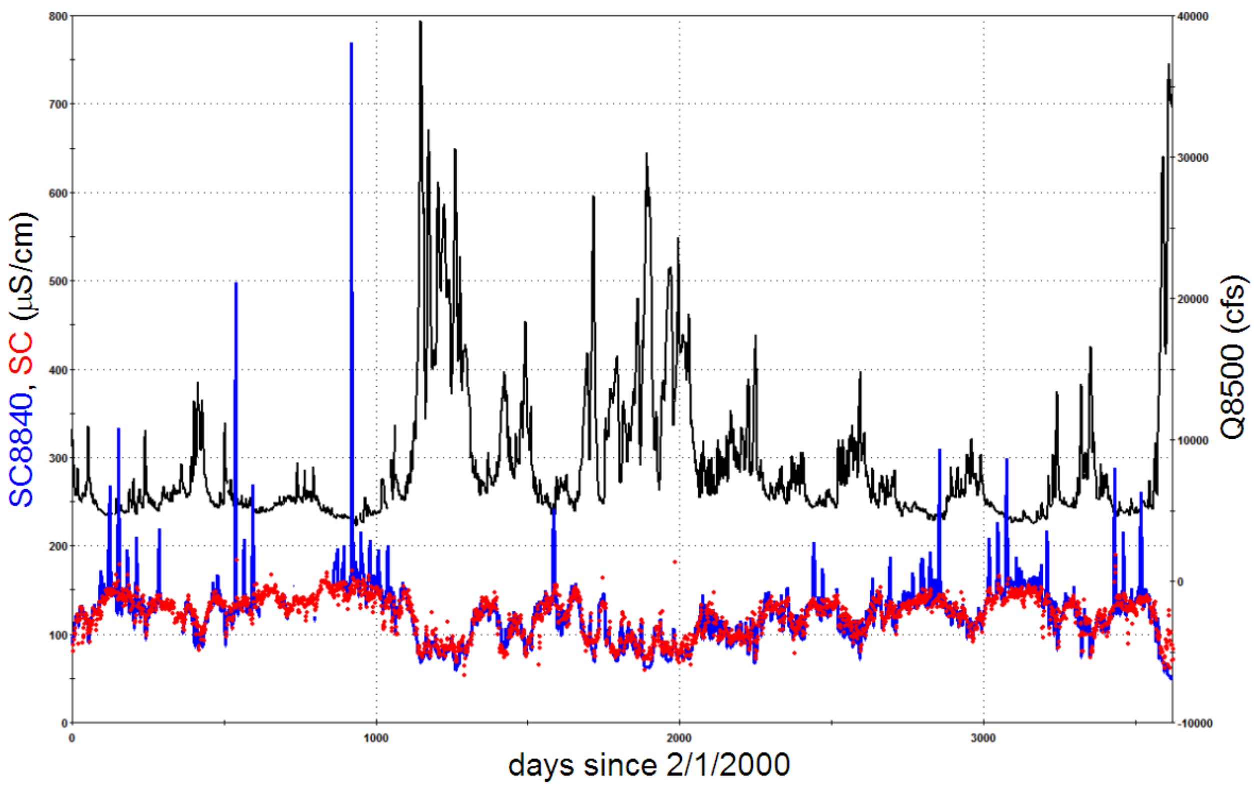


Figure 3-3 Plot of Clyo Flow and I-95 Bridge and Intake Conductivity (2000 - 2009)

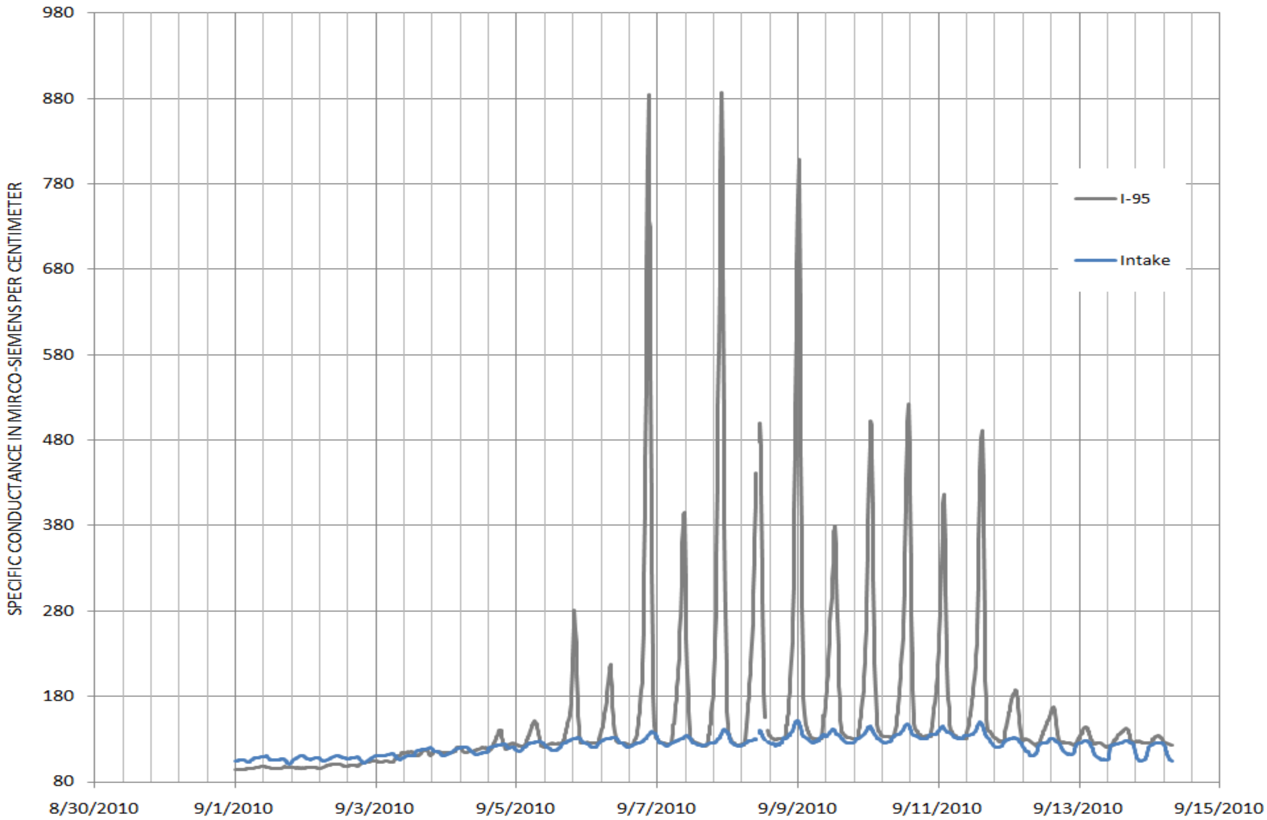


Figure 3-4 Specific conductance at the I-95 and Intake gages for a salinity intrusion event in September 2010.

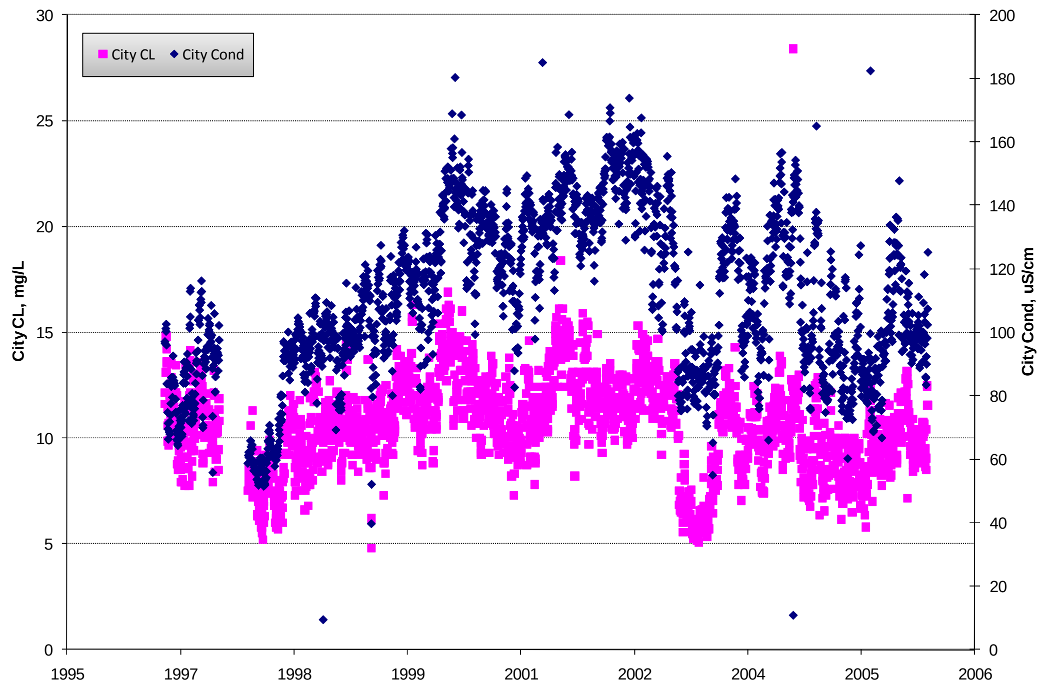


Figure 3-5 Plot of Conductivity and Chloride at the Intake (1997-2005)

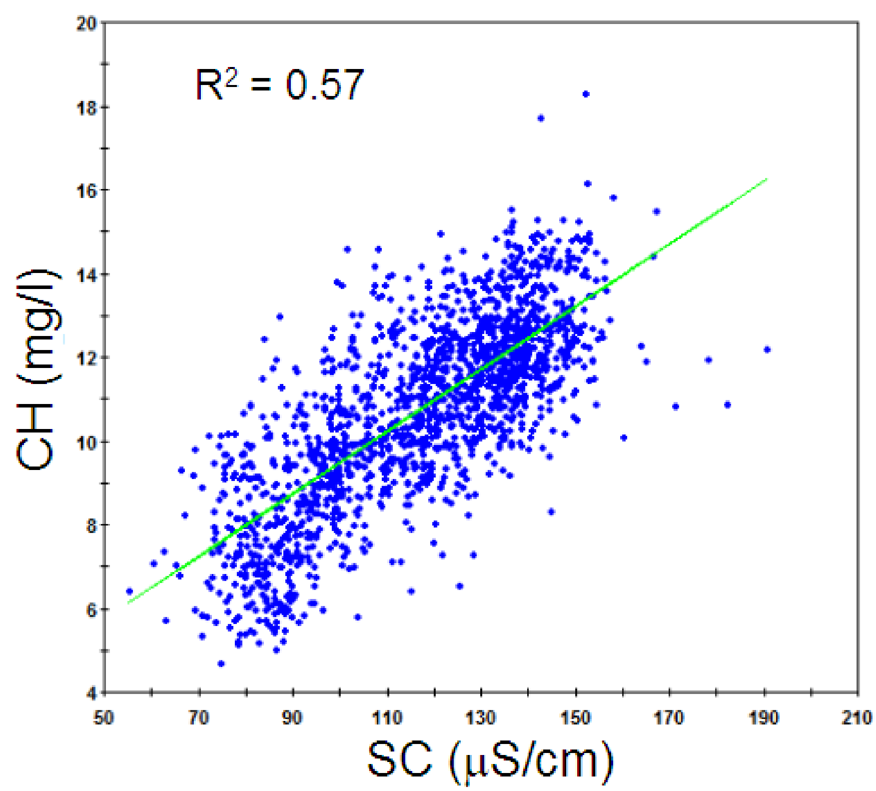


Figure 3-6 Scatter Plot of Specific Conductance and Chlorides at the Intake

3.3 EFDC Model

Hydrodynamic and water quality models were developed and determined to be acceptable in March 2006 by the United States Environmental Protection Agency (USEPA), United States Fish and Wildlife Services (USFWS), Georgia Environmental Protection Division (GAEPD), and South Carolina Department of Health and Environmental Control (SCDHEC) to identify dissolved oxygen levels throughout Savannah Harbor (Tetra Tech 2006).

The EFDC model is 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. EFDC has proven to capture the complex hydrodynamics in systems similar to that of Savannah Harbor. 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. 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 3-D 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 EFDC model was revised to include more cells in the Abercorn Creek and Bear Creek region to better simulate the flow connections upstream of the City's intake. This modification to the grid did not affect the other EFDC calculations and the impact predictions based on those calculations. The EFDC grid allowed for flow paths from the harbor to the City's intake along with the other upstream connections such as Bear Creek, Little Collis Creek, and Little Abercorn Creek. Depths and widths for the model grid will be gathered from existing USGS topo quad maps and existing USACE measurements.

The EFDC hydro model was calibrated to the USGS and City datasets. The flow and water surface elevation on Houlihan Bridge, Abercorn Creek and Bear Creek, along with water surface elevation at I-95 Bridge and Plant McIntosh were used to calibrate the water movement. The EFDC model calibration is consistent with the hydro calibration presented in Tetra Tech's report in January 2006. All models were run through the 2009 time period. The EFDC was run with chloride as a conservative substance at the seaward and riverine boundary to predict chloride concentrations at the intake.

The geometry and bathymetry of the rivers and harbor were defined in the EFDC model grid by a curvilinear, orthogonal grid to approximate the physical dimensions of the water body. The grid was extended to include Abercorn, Bear and Big Collis creeks to better represent the hydrodynamics in the immediacy of the City of Savannah water intake at Abercorn Creek. Figure 3-6 shows the extended grid and Figure 3-7 shows the whole grid including the extension. Limited data were used for the bathymetry. USGS inverts with respect to NGVD at Clyo and City Intake as well as bathymetry measurements on the Savannah River in the vicinity of the I-95 Bridge were used to determined inverts at the extended area. A uniform slope between those points was interpolated for the extended grid. The channel width of the new grid segments were adjusted based on flow measurements at City Intake and Bear Creek, the final width of the added creeks are:

- Abercorn Creek from Savannah River up to Rancoon Creek: 60 meter
- Abercorn Creek from Rancoon Creek up to Bear Creek: 20 meter
- Big Collis from Savannah River up to Bear Creek: 15 meter
- Bear Creek: 10 meter

Appendix A contains the EFDC modeling report and calibration.

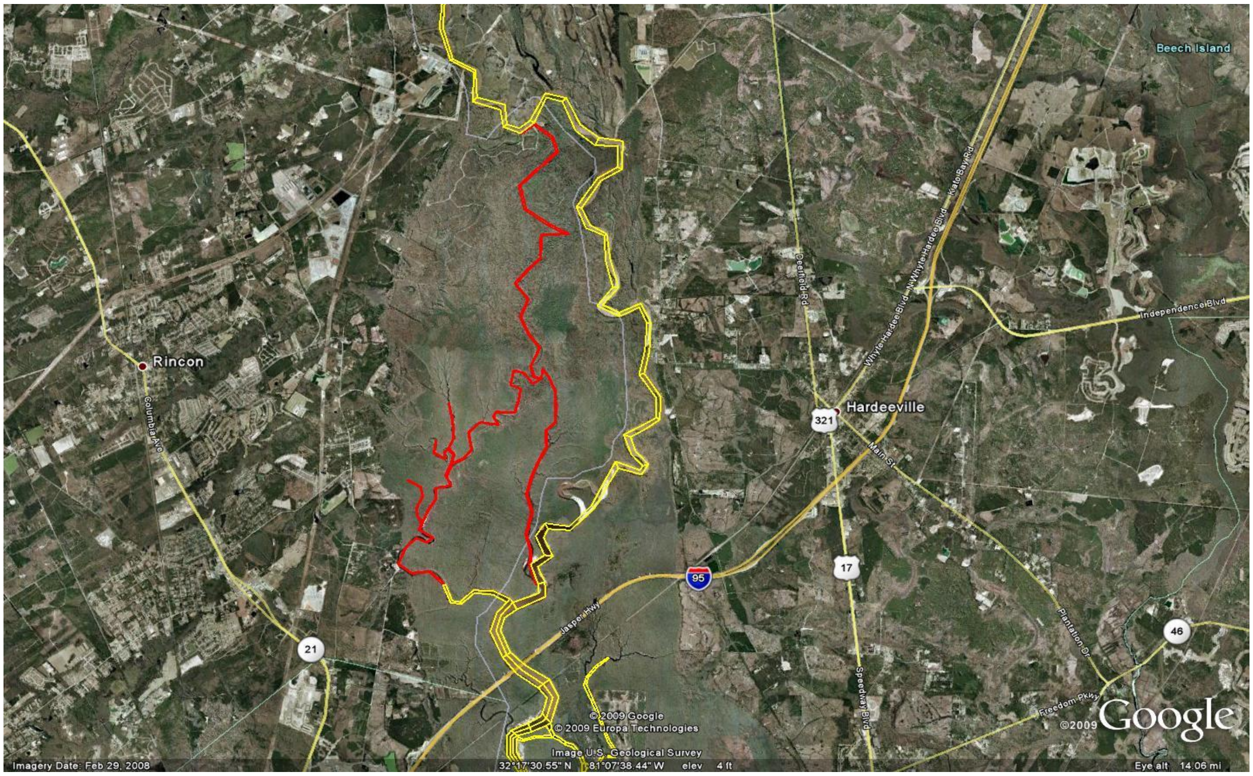


Figure 3-7 Model Grid Extension to include Abercorn, Bear and Big Collis Creeks

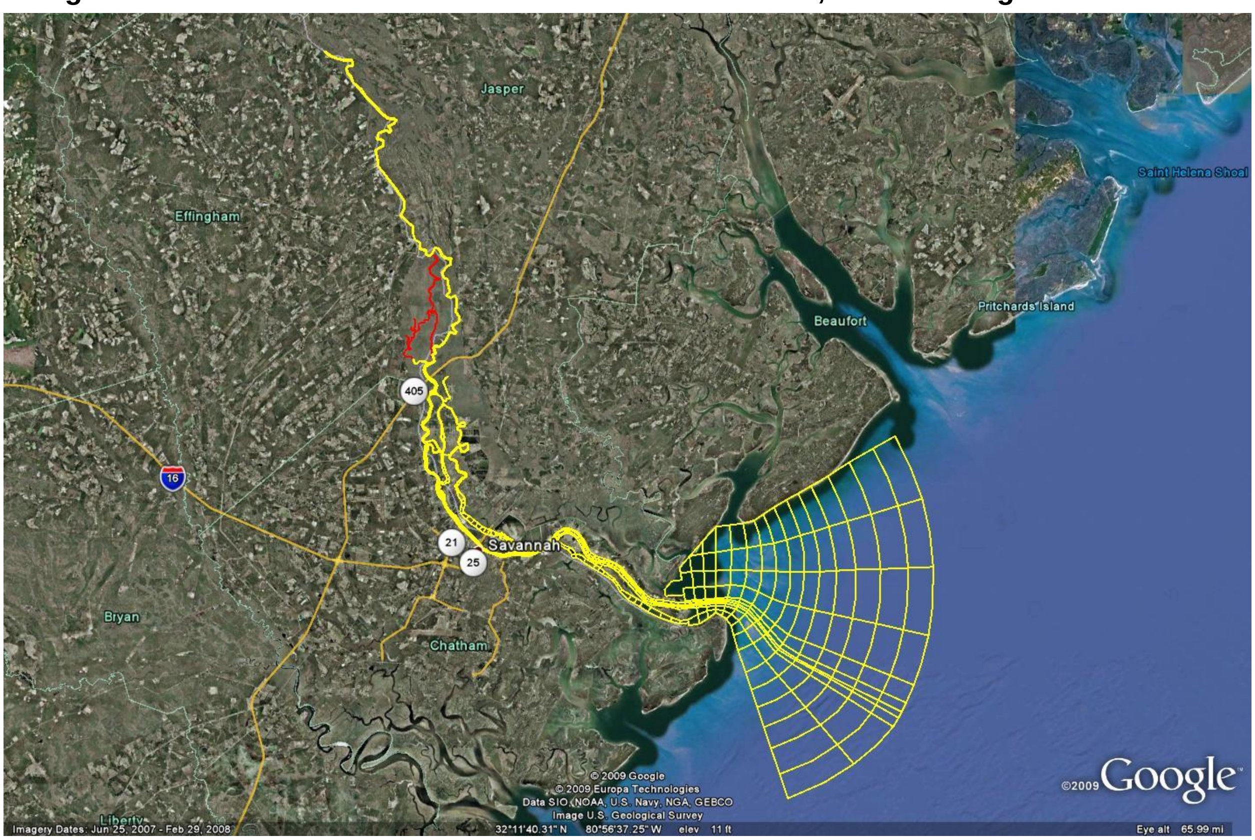


Figure 3-8 Existing Model Grid with New Extension

3.4 Development of ANN Model and DSS

The development of the Artificial Neural Network (ANN) models and Decision Support System (DSS) was completed and called the "Savannah Chlorides Model", hereafter called the "SCM". SCM is a DSS built around a suite of empirical models that predict the daily-measured conductivity and chlorides concentration (chlorides) at the City of Savannah's (City) water treatment plant (WTP). Hydrologic and water-quality behaviors in the study area have been measured at a number of gaging stations operated by the USGS since the mid 1980's.

A generalized schematic of the SCM architecture for predicting specific conductance and chloride concentrations is shown in figure 3.7. The approach is essentially a two-stage model where the first stage predicts specific conductance at the intake and the second stage is predicting chloride concentrations at the intake using the predicted specific conductance at the intake. An error correction model is then used to minimize the error in the predicted chloride concentrations. For this application, two ANN models were developed to fit the data. These were called ANN M1 and ANN M2. The appendix describes the development of both ANN models but for this summary report, all results are presented with the M2 model. For consistency in this report, the ANN M2 model will be referred to as just the ANN model.

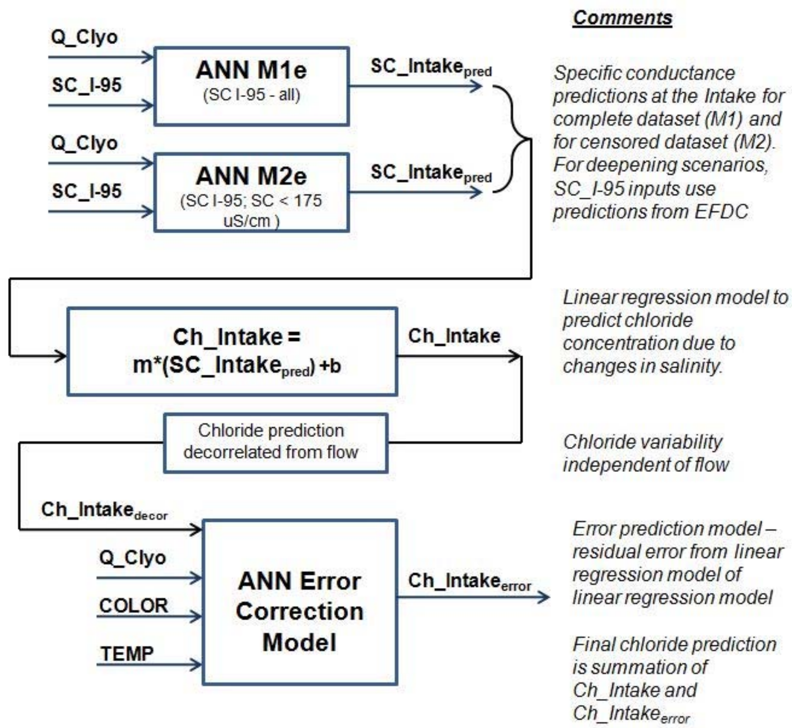


Figure 3-9 Schematic showing the empirical models, their generalized inputs, and interactions.

3.4.1 Artificial Neural Network Models

Natural resource managers and users face difficult challenges when managing the interactions between natural and man-made systems. At considerable cost, complex mathematical (mechanistic) models based on first principles physical equations are often developed and operated by senior scientists to evaluate options for using a resource while minimizing harm. However, varying technical abilities and financial constraints among different stakeholders effectively restricts access to relevant scientific knowledge and tools. There is a need to provide equal access to the knowledge and tools required for informed decision-making. DSS technology can help meet this need.

The parallel modeling approach used in this study included the development of ANN model(s) to predict chloride levels at the City's intake. The ANN model were developed using the historical datasets on multiple parameters such as flow, gage height (water surface elevation), and conductivity from the USGS gaging network and historical data from the City's water treatment plant. The USGS developed a preliminary two-stage ANN models in December 2008 that predicts chloride using inputs with satisfactory results. Those models were refined by ADMS.

An ANN model is an empirical flexible mathematical structure capable of describing complex nonlinear relations between input and output data sets. The structure of ANN models is loosely based on the biological nervous system (Hinton 1992). Although numerous types of ANNs exist, the most commonly used type of ANN is the multi-layer perceptron (MLP) (Rosenblatt 1958). As shown on Figure 3-8, MLP ANNs are constructed from layers of interconnected processing elements called neurons, each executing a simple "transfer function." All input layer neurons are connected to each hidden layer neuron and each hidden layer neuron is connected to each output neuron. There can be multiple hidden layers, but a single layer is sufficient for most problems.

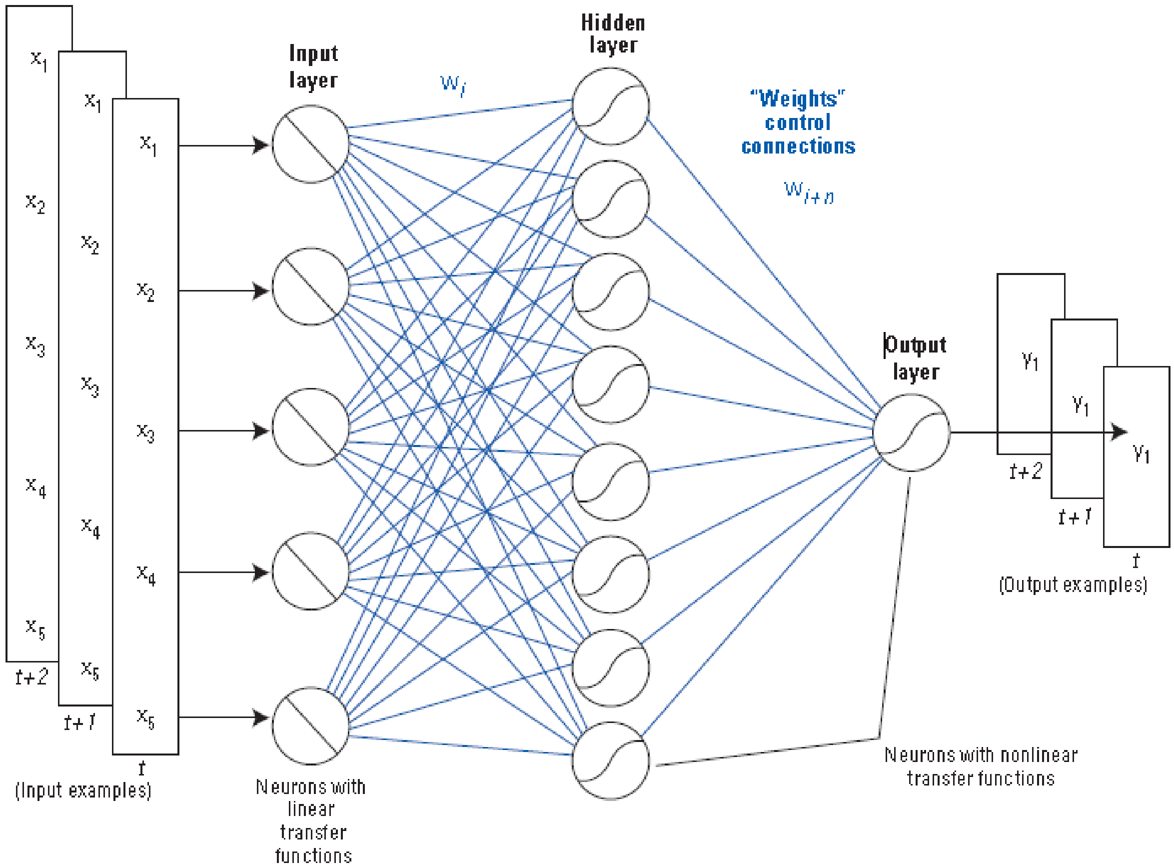


Figure 3-10 Schematic Diagram Showing Mulit-layer Perceptron Artificial Nerural Network Architecture

Typically, linear transfer functions are used to simply scale input values from the input layer to the hidden layer and generally fall within the range that corresponds to the mostly linear part of the s-shaped sigmoid transfer functions used from the hidden layer to the output layer (Figure 3-8). Each connection has a "weight" w_i associated with it, which scales the output received by a neuron from a neuron in an antecedent layer. The output of a neuron is a simple combination of the values it receives through its input connections and their weights, and the neuron's transfer function.

An ANN is "trained" by iteratively adjusting its weights to minimize the error by which it maps inputs to outputs for a data set composed of input/output vector pairs. Simulation accuracy during and after training can be measured by a number of metrics, including R^2 and root mean square error (RMSE). An algorithm that is commonly used to train MLP ANN models is the back error propagation (BEP) training algorithm (Rumelhart and others 1986). Jensen (1994) describes the details of the MLP ANN, the type of ANN used in this study. Multi-layer perceptron ANNs can synthesize functions to fit high-dimension, non-linear multivariate data. Devine and Roehl (2003) and Conrads and Roehl (2005) describe their use of MLP ANN in multiple applications to model and control combined man-made and natural systems including disinfection byproduct formation, industrial air emissions monitoring, and surface-water systems impacted by point and non-point source pollution.

Experimentation with a number of ANN architectural and training parameters is a normal part of the modeling process. For the modeling of the Saluda and Congaree Rivers, a number of candidate ANNs were trained and evaluated for their statistical accuracy and their representation of process physics. Interactions between combinations of variables also were considered. Finally, a satisfactory model can be exported for end-user deployment.

In general, a high-quality simulation model can be obtained when:

- The data ranges are well distributed throughout the range of hydrologic conditions of interest.
- The input variables selected by the modeler share “mutual information” about the output variables.
- The form “prescribed” or “synthesized” for the model used to “map” (correlate) input variables to output variables is a good one. Techniques such as OLS and physics-based finite-difference models prescribe the functional form of the model’s fit of the calibration data. Machine-learning techniques like ANNs synthesize a best fit to the data.

3.4.2 Decision Support Systems

Natural-resource managers and stakeholders face difficult challenges when managing interactions between natural and man-made systems. Even though the collective interests and computer skills of the community of managers, scientists, and other stakeholders are quite varied, equal access to the scientific knowledge is needed for them to make the best possible decisions. Dutta and others (1997) define decision support systems (DSSs) as, “systems helping decision-makers to solve various semi-structured and unstructured problems involving multiple attributes, objectives, and goals… Historically, the majority of DSSs have been either computer implementations of mathematical models or extensions of database systems and traditional management information systems.” Environmental resource managers commonly use complex mathematical (mechanistic) models based on first principle physical equations to evaluate options for using the resource without damage. While there appears to be no strict criteria that distinguish a DSS from other types of programs, Dutta and others (1997) suggest that artificial intelligence (AI) is a characteristic of more advanced DSSs: “With the help of AI techniques DSSs have incorporated the heuristic models of decision makers and provided increasingly richer support for decision making. Artificial intelligence systems also have benefited from DSS research as they have scaled down their goal from replacing to supporting decision makers.”

Three DSSs in South Carolina and Georgia have previously been developed to support the permitting of three water reclamation facilities that discharge into South Carolina’s Beaufort River estuary (Conrads and others 2003), to evaluate the environmental effects of a proposed deepening of the Savannah Harbor (Conrads and others 2006), and to evaluate the effects of reservoir releases in North Carolina on salinity intrusion along the Grand Strand of South Carolina (Conrads and Roehl 2007). These DSSs are spreadsheet applications that provided predictive models with real-time databases for ANN model simulation, graphical user interfaces, and displays of results. Additional features include optimizers, integrations with other models and software tools, and color contouring of simulation output data. These features make the DSSs easily distributable and immediately usable by all water-resource managers.

A DSS was also developed to integrate the historical database, output from EFDC, ANN models, model simulation controls, streaming graphics, and model out. Output from EFDC was used as input to the ANN models to simulation various harbor deepening scenarios. The EFDC output simulated changes (delta) from a historical condition at the USGS gages. All models were run through the 2009 time period.

The DSS was developed as Microsoft Excel™/Visual Basic for Applications1 (VBA) programs. This allowed the DSS to be prototyped, easily modified, and distributed in a familiar form. The DSS will be operated through a graphical user interface (GUI) and allows the end user to interact with the ANN models.

Appendix B contains the ANN modeling report.

4.0 MODELING SCENARIOS (IMPACTS AND MITIGATION)

Once the EFDC and ANN models were developed for the existing conditions, the modeling scenarios were performed. The EFDC model was used to simulate a 2-, 3-, 4-, 5-, and 6-foot deepening which represents a 44-, 45-, 46-, 47-, and 48-foot channel depths. The EFDC model provided changes in water surface elevation, flow, and salinity to the ANN model to determine the change in chloride at the City's intake.

4.1 Mitigation Plans for Salinity and Wetlands

The USACE Savannah District used the EFDC to determine the appropriate measures to mitigate for salinity and wetland impacts. Based on analysis of the model output the flow-altering mitigation plans that were found to be the most effective at reducing salinity impacts and protecting fresh water tidal marshes are Plan 6A for the 48 ft, 47 ft, 46 ft, and 45 ft channel depths and 6B for the 44 ft channel depth. Although the plans do not fully mitigate for all impacts to the estuary, they are expected to provide substantial benefits to the fresh water marsh ecosystems adjacent to the Back and Little Back Rivers.

Plan 6B is the proposed flow-altering mitigation plan for the 44 ft channel depth. The features of this plan include a diversion structure on Front River, closure of the lower (western) arm at McCoy Cut, closure of Rifle Cut, filling of the Sediment Basin and removal of the tide gate abutments and piers. This plan provides potential for additional fresh water flows to enter the Back River System at McCoy Cut, without exiting through the lower (western) arm, and flow downstream through Middle, Back and Little Back Rivers. It also has features that will limit saltwater intrusion to the Back River area through the sediment basin and Rifle Cut.

Plan 6A is the proposed mitigation plan for the 45, 46, 47 and 48 ft channel depths. This plan includes all the features of Plan 6B and one additional feature, channel deepening on McCoy Cut, upper Middle and Little Back Rivers. This additional feature in combination with the features in Plan 6B maximizes the potential for additional fresh water flows to enter the Back River System at McCoy Cut and flow downstream through Middle, Back and Little Back Rivers.

Figures 4-1 and 4-2 were provided by the USACE Savannah District and depict the different features for Plan 6A and 6B, respectively.

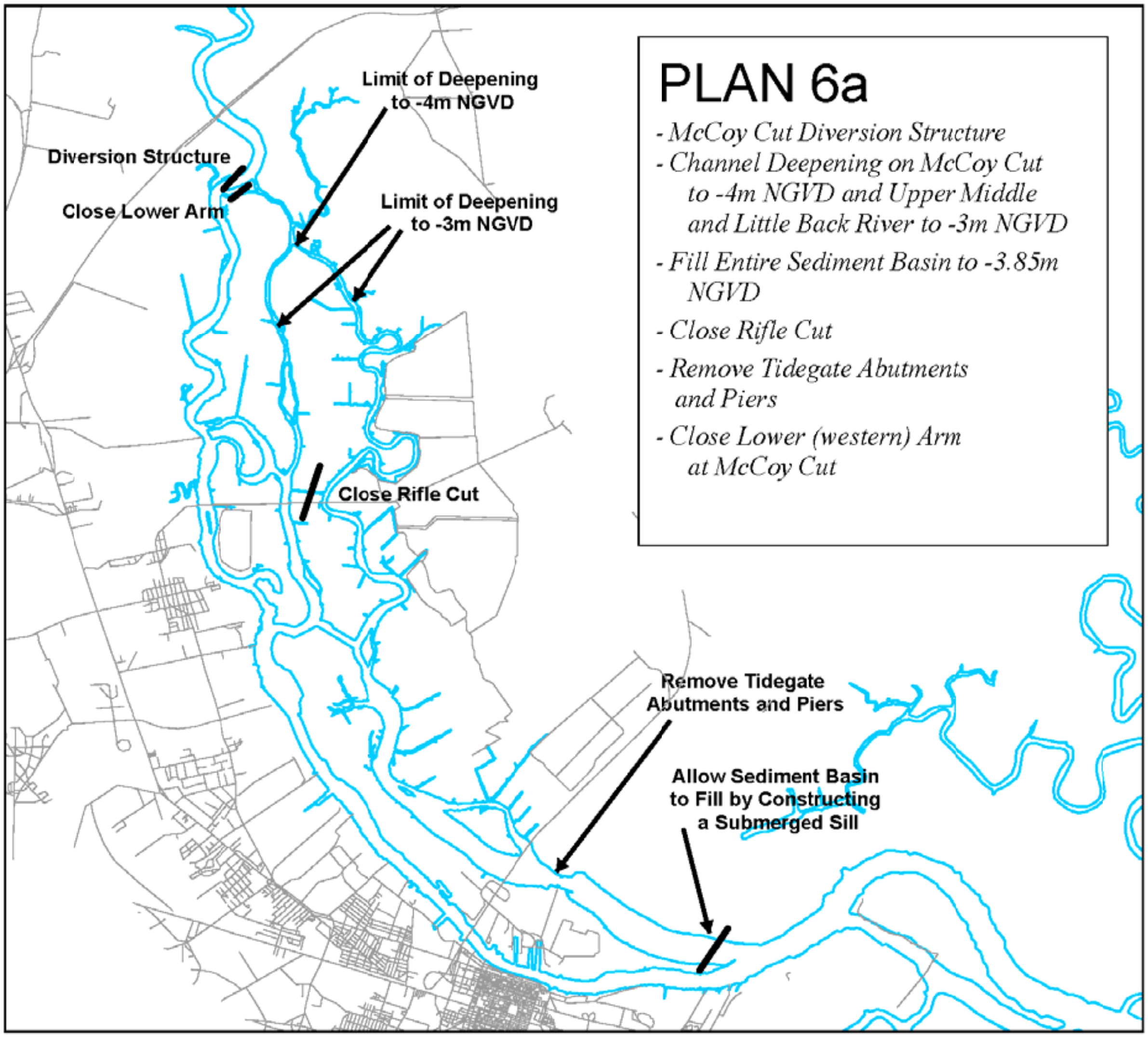


Figure 4-1 Mitigation Plan 6A (courtesy of the USACE Savannah District)

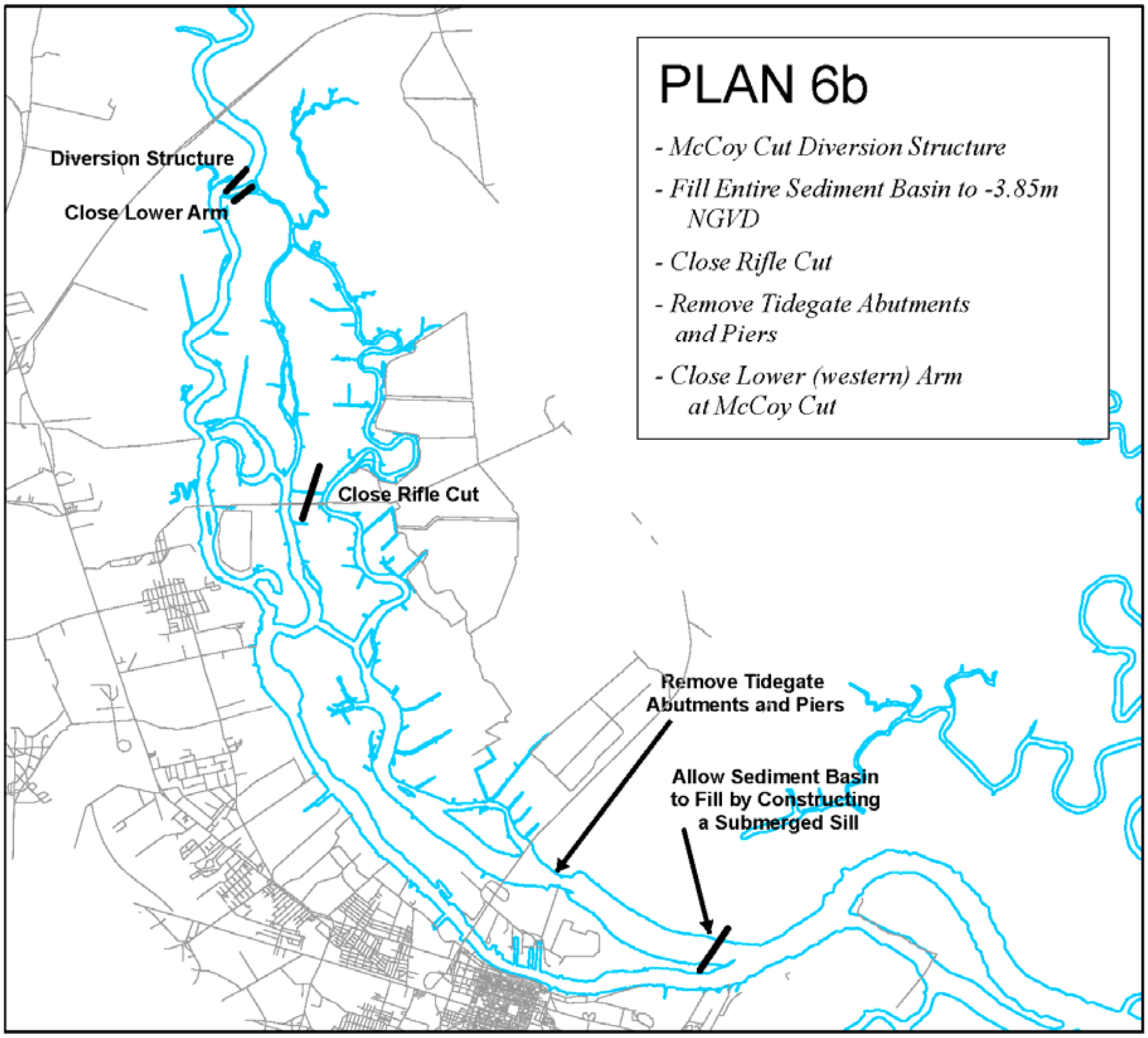


Figure 4-2 Mitigation Plan 6B (courtesy of the USACE Savannah District)

5.0 EFDC MODELING IMPACTS

The EFDC model was run with the deepening scenarios discussed in Section 4. Staring with existing conditions, the navigation channel cells were increased 2 feet up to 6 feet. EFDC results are shown in the following figures and tables. A summary is listed below:

- Figure 5-1 6-feet Deepening
- Figure 5-2 5-feet Deepening
- Figure 5-3 4-feet Deepening
- Figure 5-4 3-feet Deepening
- Figure 5-5 2-feet Deepening
- Figure 5-6 6-feet Deepening with Mitigation 6A
- Figure 5-7 5-feet Deepening with Mitigation 6A
- Figure 5-8 4-feet Deepening with Mitigation 6A
- Figure 5-9 3-feet Deepening with Mitigation 6A
- Figure 5-10 2-feet Deepening with Mitigation 6B

For each figure, a time series plot of the existing conditions, deepened conditions, and measured existing are shown. Also, a table of frequency and magnitude were developed for a wet and dry year. These two years were developed by examining the Clyo (02198500) flow record and precipitation analysis. The wet year was determined to be 2003 and the dry year was 2002. A flow analysis was conducted by examining the annual averages for the Clyo flow gage for all years with complete annual records. This included 75 years from 1929 to 2009 with four years, from 1934 through 1937, not included. These four years were not part of the analysis because the gage was discontinued and 1929 was excluded from the analysis because a full year was not measured. Table 5-1 shows the nine year period (2001 through 2009) and the associated ranking during the 75 year record. These values are in order based on their ranking with a 1st ranking equal to the highest annual average year and the 75th ranking equal to the lowest annual average year. The dry year is clearly 2002 at 5,289 cfs because it is the lowest (75th ranking) annual flow year on record. The wet year is 2003 with a 21st ranking and annual flow of 13,440 cfs. 2005 was a candidate year as well at 18th ranking. Table 5-2 shows a summary of computed statistics based on the daily flow record from October 1, 1929 through September 30, 2009.

Table 5-1 Annual Flow Statistics Summary

Year	Flow (cfs)	Rank
2005	13,810	18
2003	13,440	21*
2004	8,224	59
2006	7,896	62
2007	6,666	69
2001	6,454	70
2009	6,266	72
2008	5,495	74
2002	5,289	75**

*Selected as Wet Year
**Selected as Dry Year

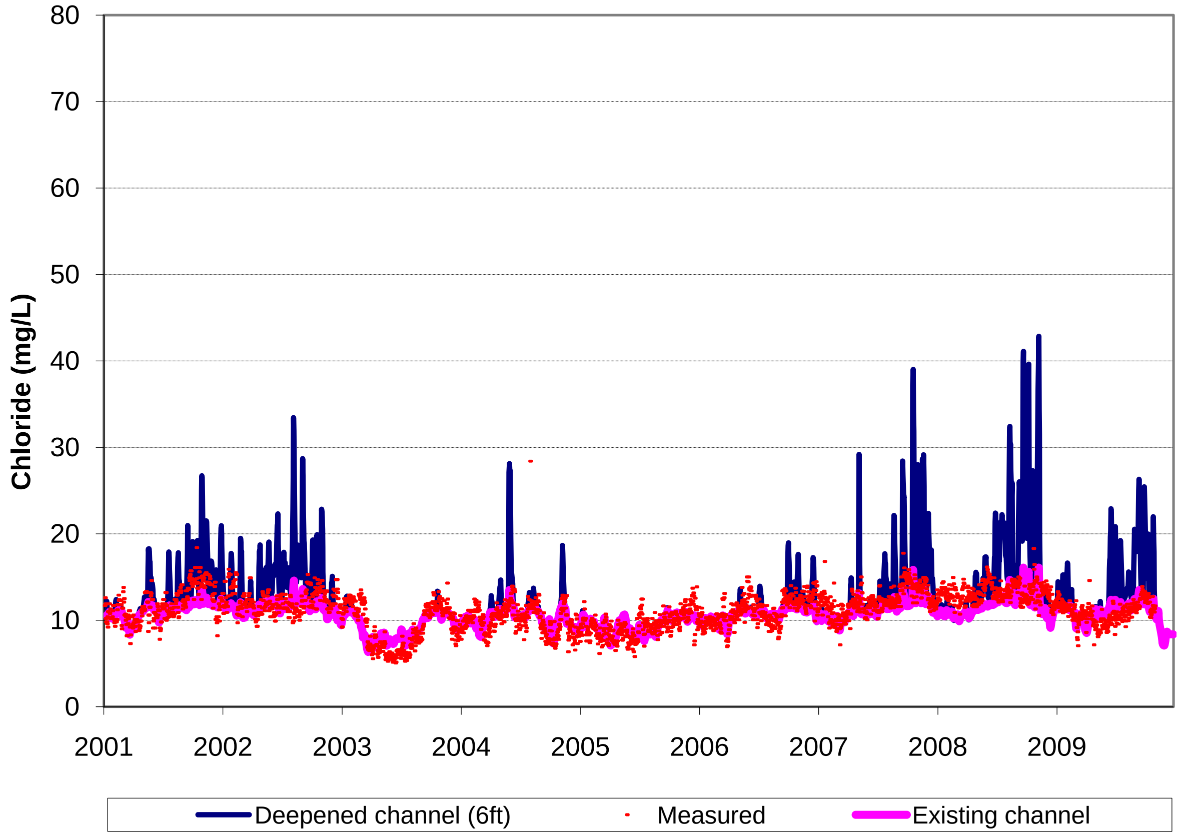
Table 5-2 Daily Flow Statistics Summary

Statistic	Flow (cfs)
min	1,950
5%	4,850
10%	5,420
25%	6,670
50%	8,560
75%	13,100
90%	21,030
95%	28,000
max	127,000

The model results were post-processed for each of those two years to determine the number of consecutive days greater than 15, 20, 25, 30, and 35 mg/L. The consecutive days range from 2 to 10 days. An example would be there are 10 times in a year where the concentration is larger than 20 mg/L for 3 consecutive days. The time series plot and frequency/magnitude tables characterize the difference between the existing conditions and the deepening scenario.

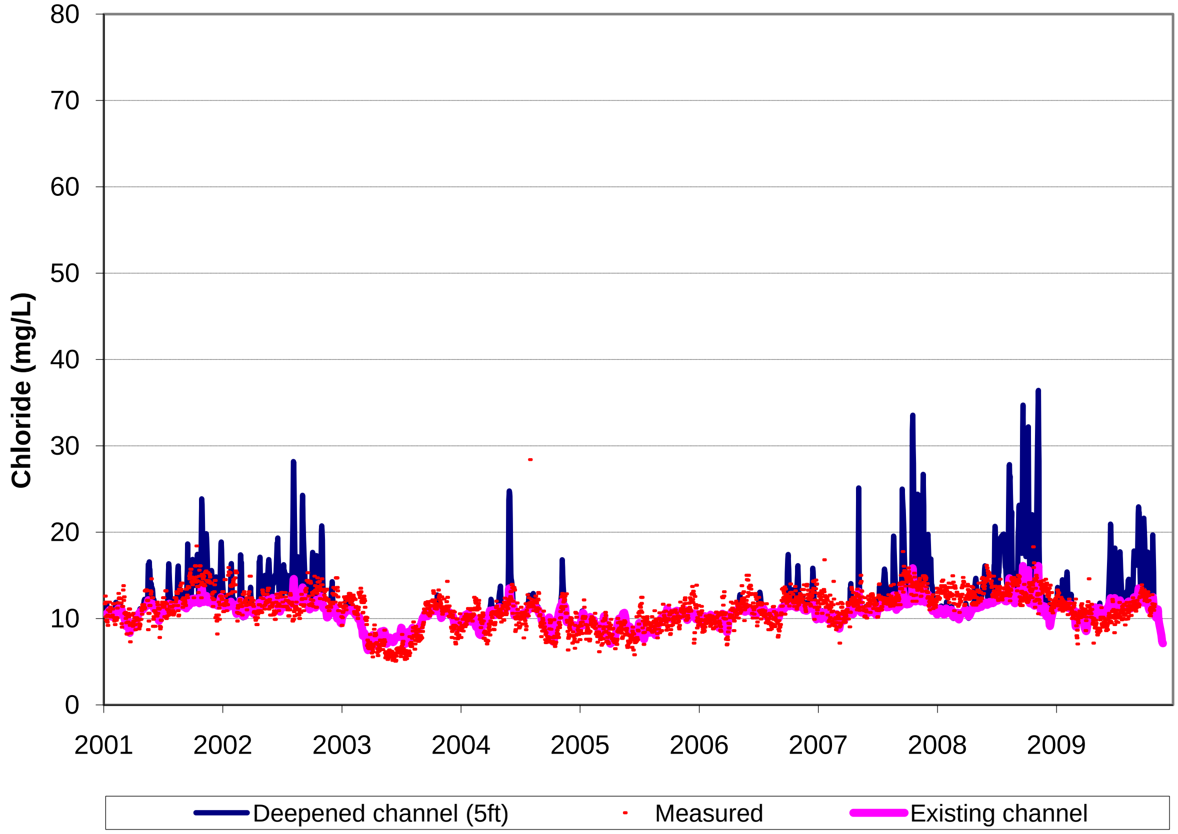
The EFDC model results show a large increase in chloride peaks compared to the existing conditions. The peaks occur during low-flow, high tide, and spring tide conditions. The base concentrations remain the same and these events occur during higher flows when Abercorn Creek is well flushed.

Location of results for Figures 5-1 through 5-10 is at the City of Savannah's intake.



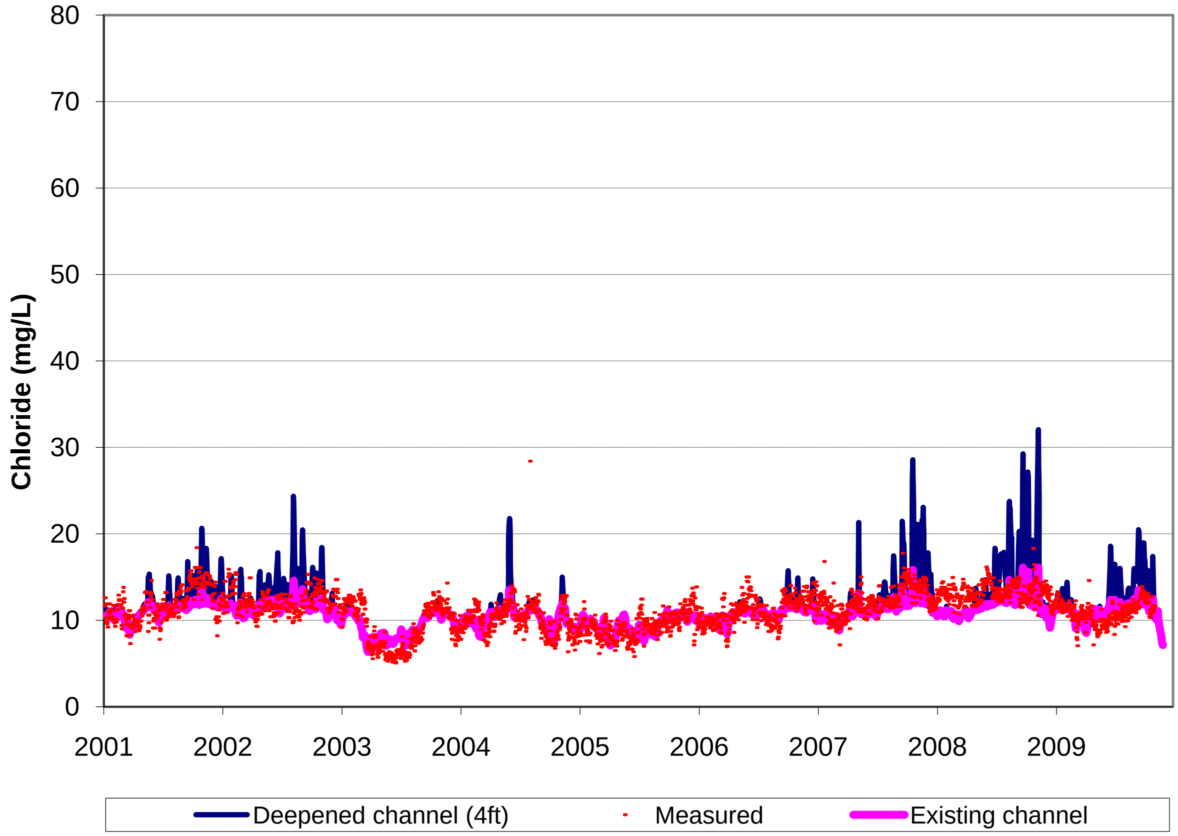
Daily Average Chloride (mg/L)																			
Number of Occurrences																			
		Wet year (2003)									Dry year (2002)								
		consecutive days									consecutive days								
		2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
Existing	>15 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deepened 6ft	>15 mg/L	0	0	0	0	0	0	0	0	0	104	89	76	64	52	44	35	29	23
	>20 mg/L	0	0	0	0	0	0	0	0	0	15	11	7	4	2	1	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	5	3	1	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 5-1 EFDC Impact Results 6-feet Deepening



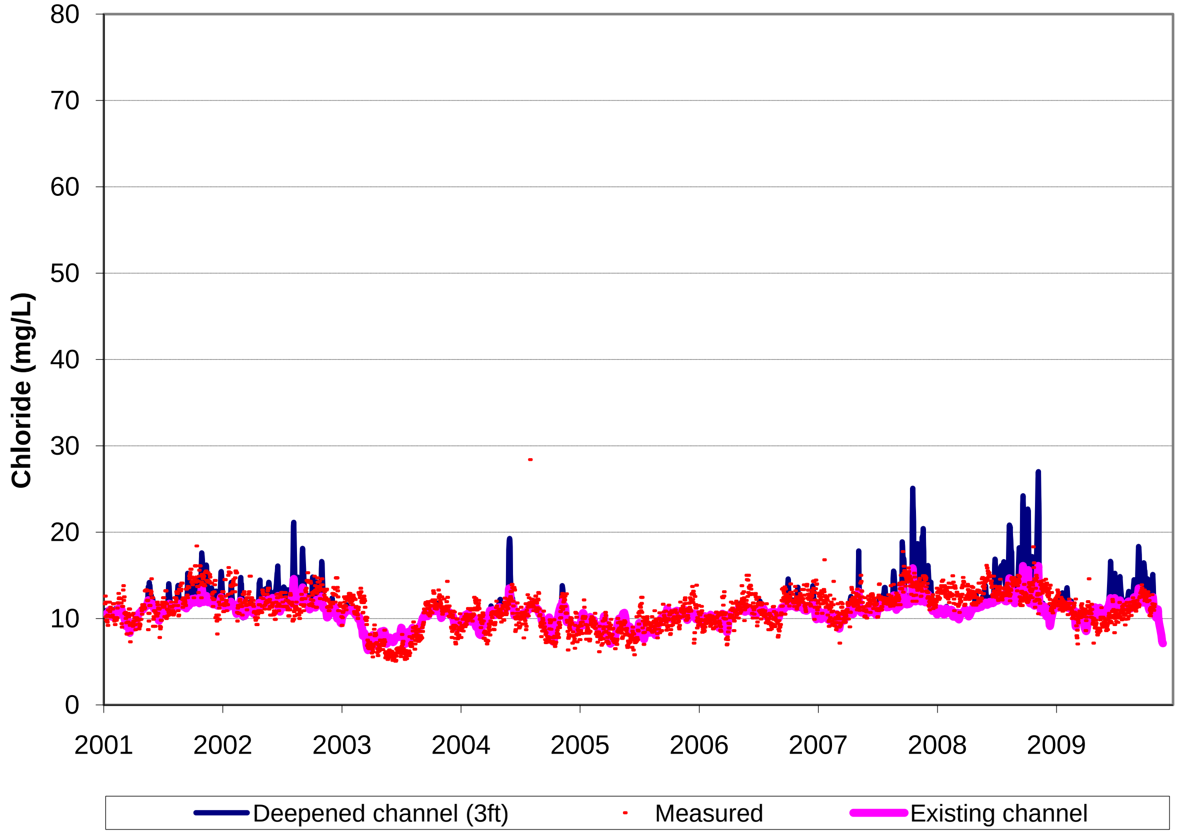
Daily Average Chloride (mg/L)																			
Number of Occurrences																			
		Wet year (2003)									Dry year (2002)								
		consecutive days									consecutive days								
		2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
Existing	>15 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deepened 5 ft	>15 mg/L	0	0	0	0	0	0	0	0	0	68	56	42	30	20	14	10	6	4
	>20 mg/L	0	0	0	0	0	0	0	0	0	10	7	4	2	1	0	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 5-2 EFDC Impact Results 5-feet Deepening



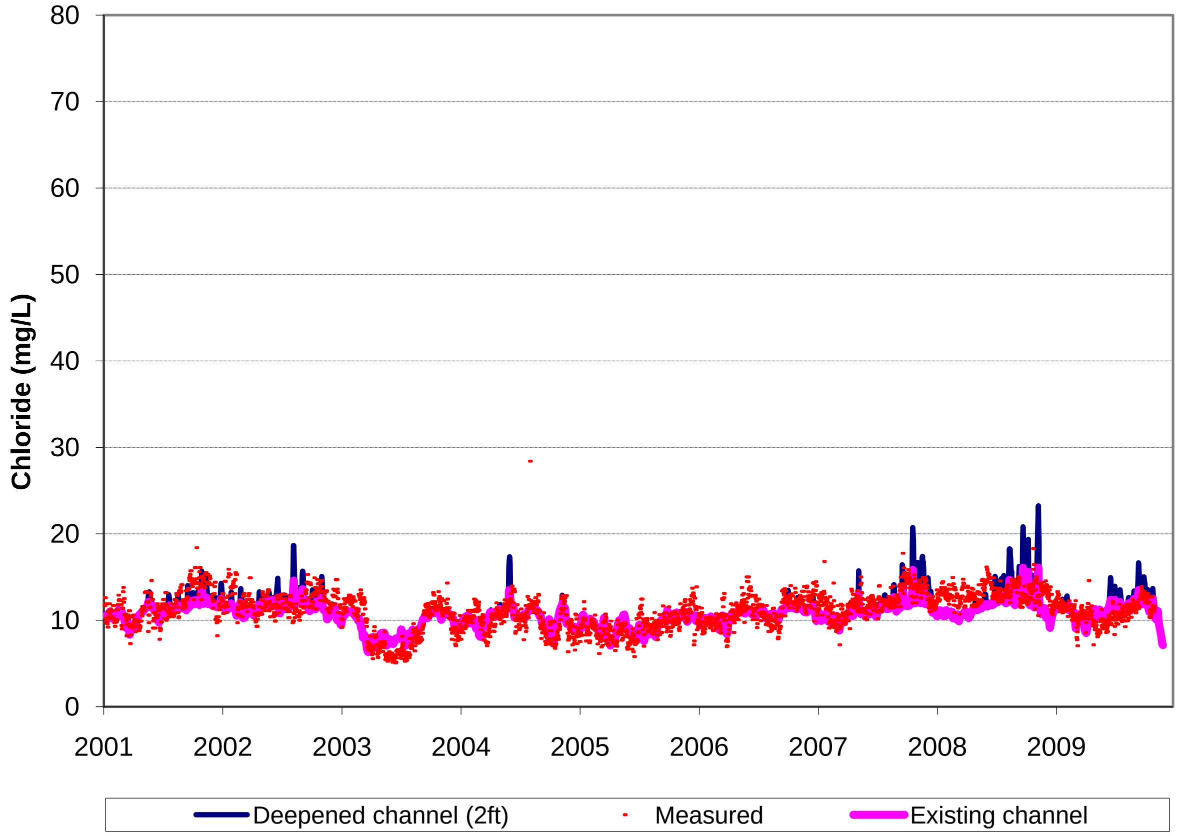
Daily Average Chloride (mg/L)																			
Number of Occurrences																			
		Wet year (2003)									Dry year (2002)								
		consecutive days									consecutive days								
		2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
Existing	>15 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deepened 4ft	>15 mg/L	0	0	0	0	0	0	0	0	0	31	22	16	12	9	6	4	2	1
	>20 mg/L	0	0	0	0	0	0	0	0	0	3	2	1	0	0	0	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 5-3 EFDC Impact Results 4-feet Deepening



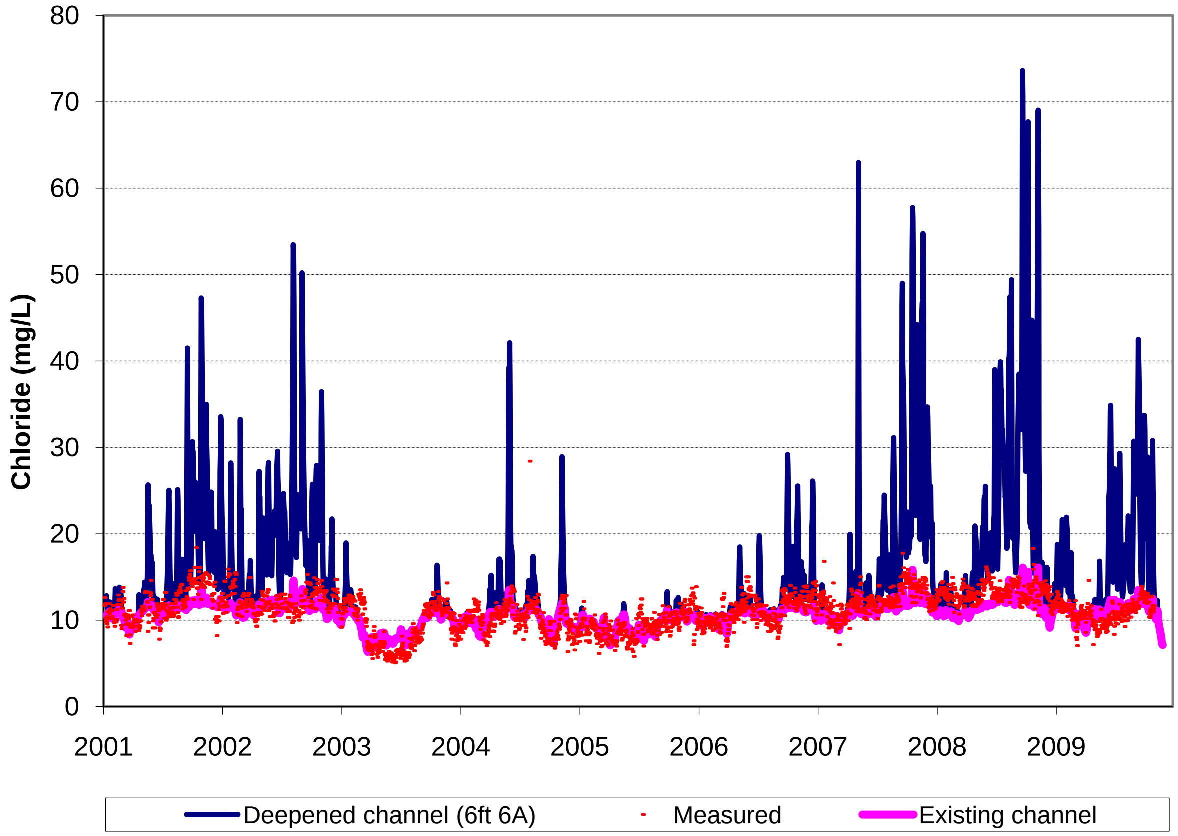
Daily Average Chloride (mg/L)																			
Number of Occurrences																			
		Wet year (2003)									Dry year (2002)								
		consecutive days									consecutive days								
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Existing	**>15 mg/L**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deepened 3ft	**>15 mg/L**	0	0	0	0	0	0	0	0	0	14	10	6	4	2	1	0	0	0
	>20 mg/L	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 5-4 EFDC Impact Results 3-feet Deepening



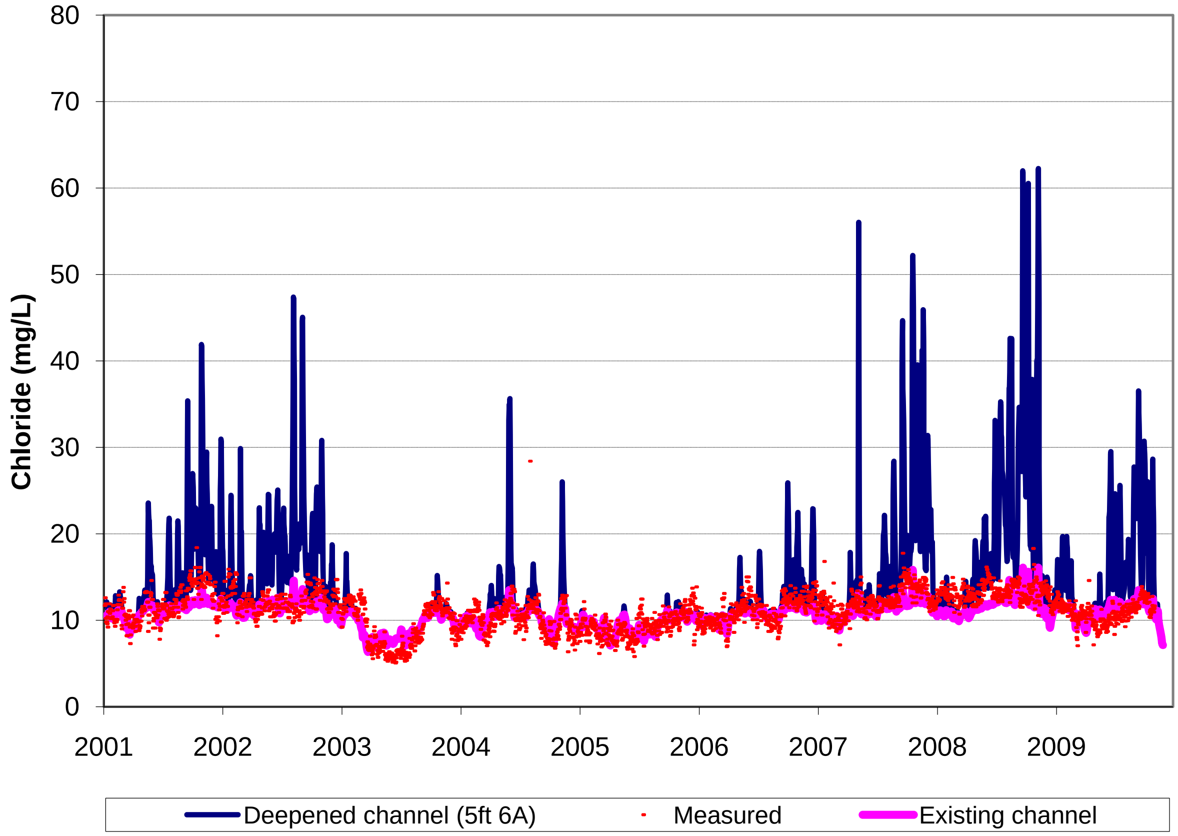
Daily Average Chloride (mg/L)																			
Number of Occurrences																			
		Wet year (2003)									Dry year (2002)								
		consecutive days									consecutive days								
		2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
Existing	>15 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deepened 2ft	>15 mg/L	0	0	0	0	0	0	0	0	0	7	5	3	1	0	0	0	0	0
	>20 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 5-5 EFDC Impact Results 2-feet Deepening



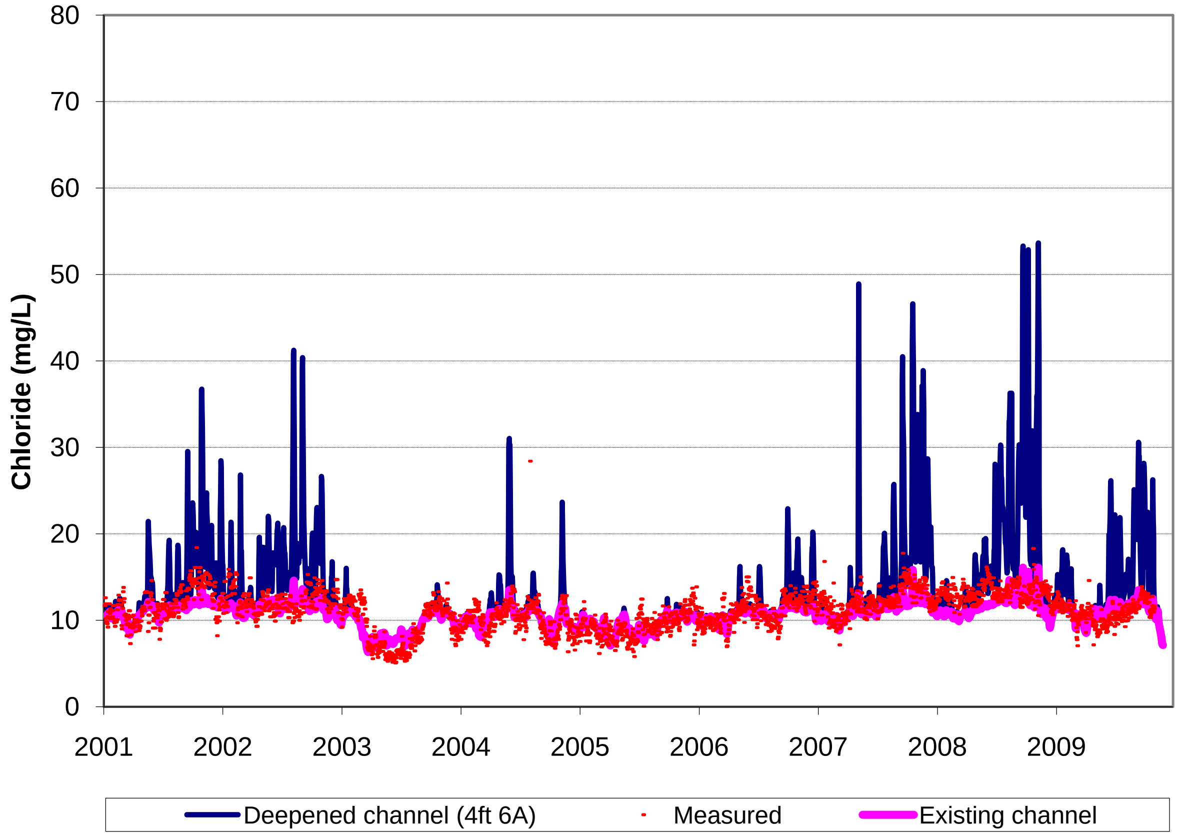
Daily Average Chloride (mg/L)																			
Number of Occurrences																			
		Wet year (2003)									Dry year (2002)								
		consecutive days									consecutive days								
		2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
Existing	>15 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deepened 6ft 6A	>15 mg/L	0	0	0	0	0	0	0	0	0	193	180	170	162	154	147	141	135	130
	>20 mg/L	0	0	0	0	0	0	0	0	0	101	86	73	62	52	44	37	32	27
	>25 mg/L	0	0	0	0	0	0	0	0	0	30	22	17	12	7	5	3	1	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	10	8	6	4	2	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	7	5	3	1	0	0	0	0	0

Figure 5-6 EFDC Impact Results 6-feet Deepening with Mitigation 6A



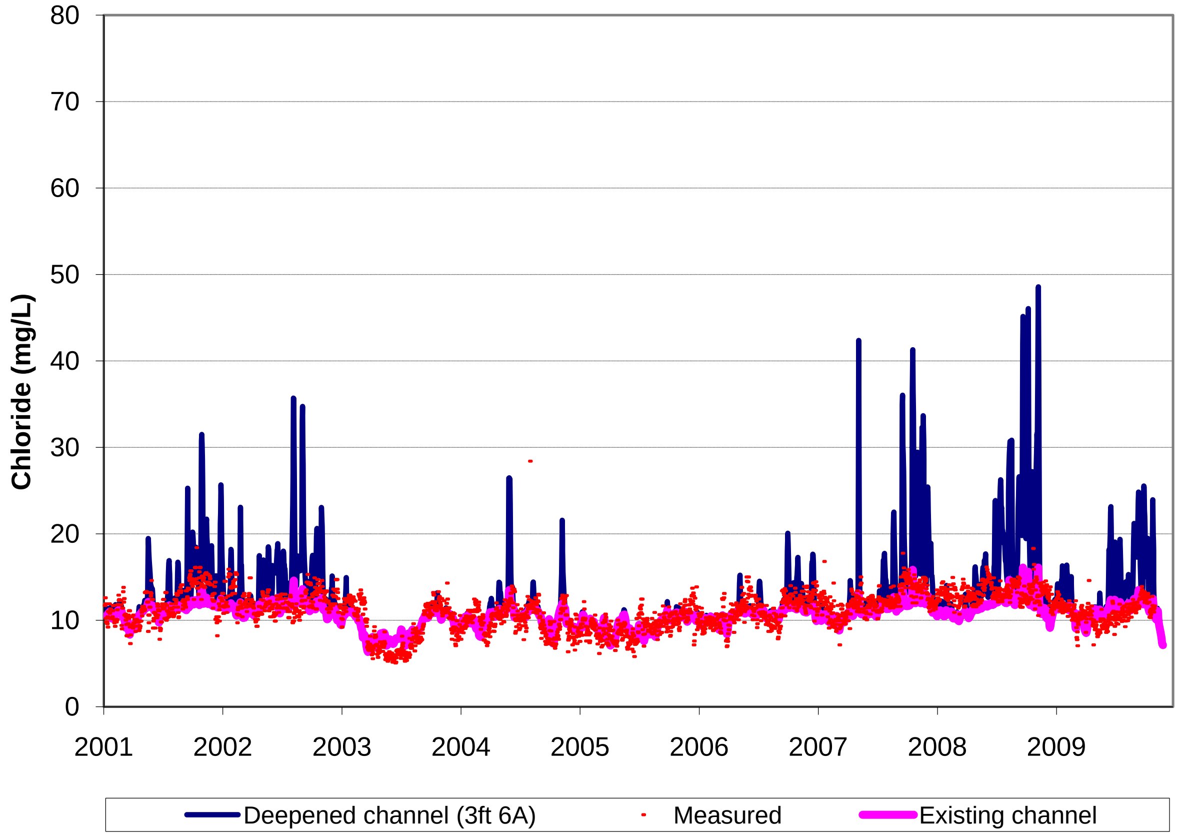
Daily Average Chloride (mg/L)																			
Number of Occurrences																			
		Wet year (2003)									Dry year (2002)								
		consecutive days									consecutive days								
		2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
Existing	**>15 mg/L**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deepened 5ft 6A	**>15 mg/L**	0	0	0	0	0	0	0	0	0	157	144	131	119	108	97	89	81	75
	>20 mg/L	0	0	0	0	0	0	0	0	0	55	43	31	22	15	10	7	4	2
	>25 mg/L	0	0	0	0	0	0	0	0	0	14	11	8	6	4	2	1	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	8	6	4	2	1	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	5	3	1	0	0	0	0	0	0

Figure 5-7 EFDC Impact Results 5-feet Deepening with Mitigation 6A



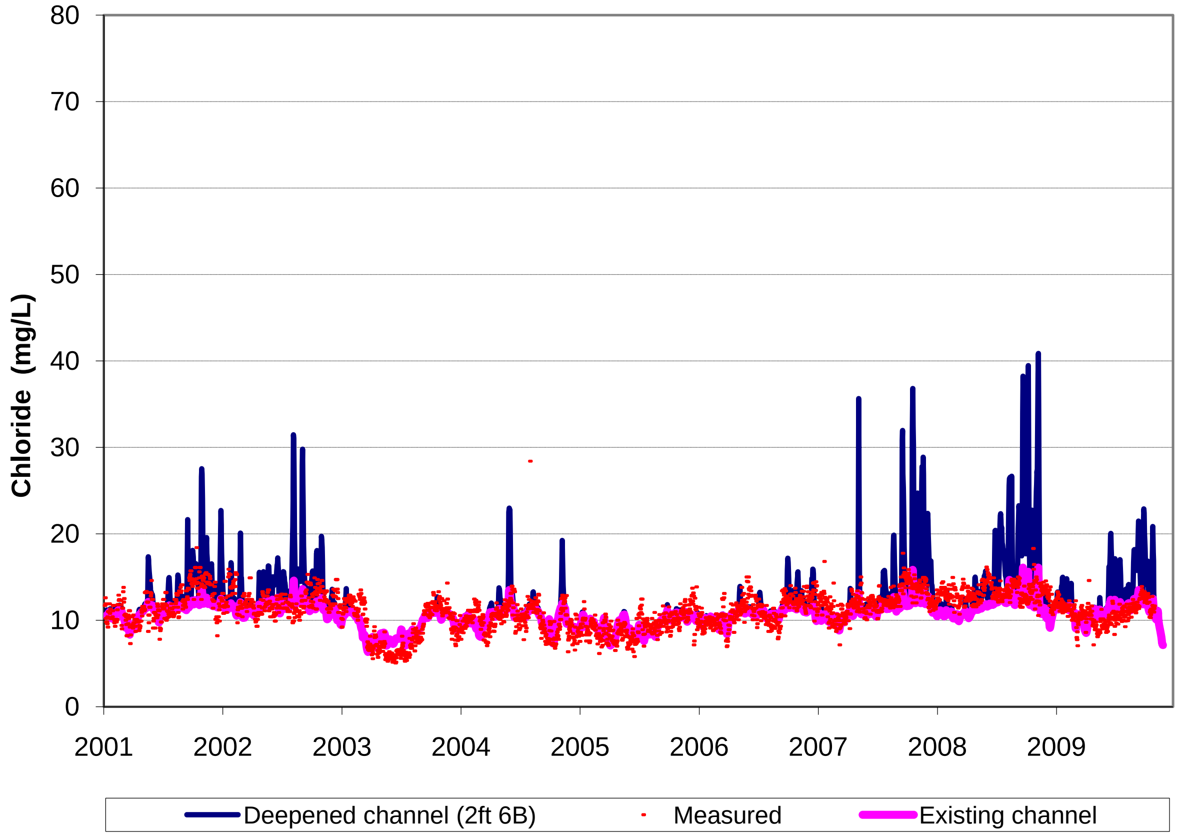
Daily Average Chloride (mg/L)																			
Number of Occurrences																			
		Wet year (2003)									Dry year (2002)								
		consecutive days									consecutive days								
		2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
Existing	>15 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deepened 4ft 6A	>15 mg/L	0	0	0	0	0	0	0	0	0	134	121	108	98	88	79	72	66	60
	>20 mg/L	0	0	0	0	0	0	0	0	0	28	20	13	9	6	4	2	1	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	11	8	6	4	2	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	5	3	1	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0

Figure 5-8 EFDC Impact Results 4-feet Deepening with Mitigation 6A



Daily Average Chloride (mg/L)																			
Number of Occurrences																			
		Wet year (2003)									Dry year (2002)								
		consecutive days									consecutive days								
		2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
Existing	>15 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deepened 3ft 6A	>15 mg/L	0	0	0	0	0	0	0	0	0	106	94	83	72	63	56	51	46	41
	>20 mg/L	0	0	0	0	0	0	0	0	0	14	11	8	6	4	2	1	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	6	4	2	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

Figure 5-9 EFDC Impact Results 3-feet Deepening with Mitigation 6A



Daily Average Chloride (mg/L)																			
Number of Occurrences																			
		Wet year (2003)									Dry year (2002)								
		consecutive days									consecutive days								
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Existing	**>15 mg/L**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deepened 2ft 6B	**>15 mg/L**	0	0	0	0	0	0	0	0	0	53	41	30	21	16	11	7	4	2
	>20 mg/L	0	0	0	0	0	0	0	0	0	8	6	4	2	1	0	0	0	0
	>25 mg/L	0	0	0	0	0	0	0	0	0	5	3	1	0	0	0	0	0	0
	>30 mg/L	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	>35 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 5-10 EFDC Impact Results 2-feet Deepening with Mitigation 6B

6.0 SAVANNAH CHLORIDE MODEL IMPACTS

The EFDC model prediction of specific conductance for the existing and deepening scenarios were subtracted to calculate deltas at I-95 Bridge. This information was used as inputs to the SCM to predict the delta of chloride at the City's Intake. The delta chloride at the intake was added to the existing conditions measured by the City's dataset. The SCM output includes the chloride predictions by the ANN M1 and ANN M2 models and the EFDC model. Table 6-1 lists the model performance statistics for the models. (It should be noted that the ANN M1 and ANN M2 models have the same performance for actual conditions. The two models differ in how they extrapolate the chloride response to deepening scenarios and mitigation.) The models' R^2 values are similar to the correlation between salinity and chlorides at the intake (figure 3-5). SCM results (ANN and EFDC models) are shown in the following figures and tables. The simulation period for the SCM is January 14, 2003 to October 31, 2009.

Table 6-1 Model performance statistic for the ANN M2 and EFDC models

[Std dev, standard deviation; R2, coefficient of determination]

Statistic	Measured	ANN	EFDC
Minimum	5.05	5.51	6.33
Maximum	18.30	13.72	16.95
Mean	10.81	10.84	10.46
Range	13.25	8.21	10.62
Std dev	2.15	1.83	1.41
Count	2483	2417	2483
Pearson		0.82	0.75
R^2		0.67	0.57
mean error		-0.03	0.38
RMSE		1.24	1.47
Percent model error		9.3%	17.9%

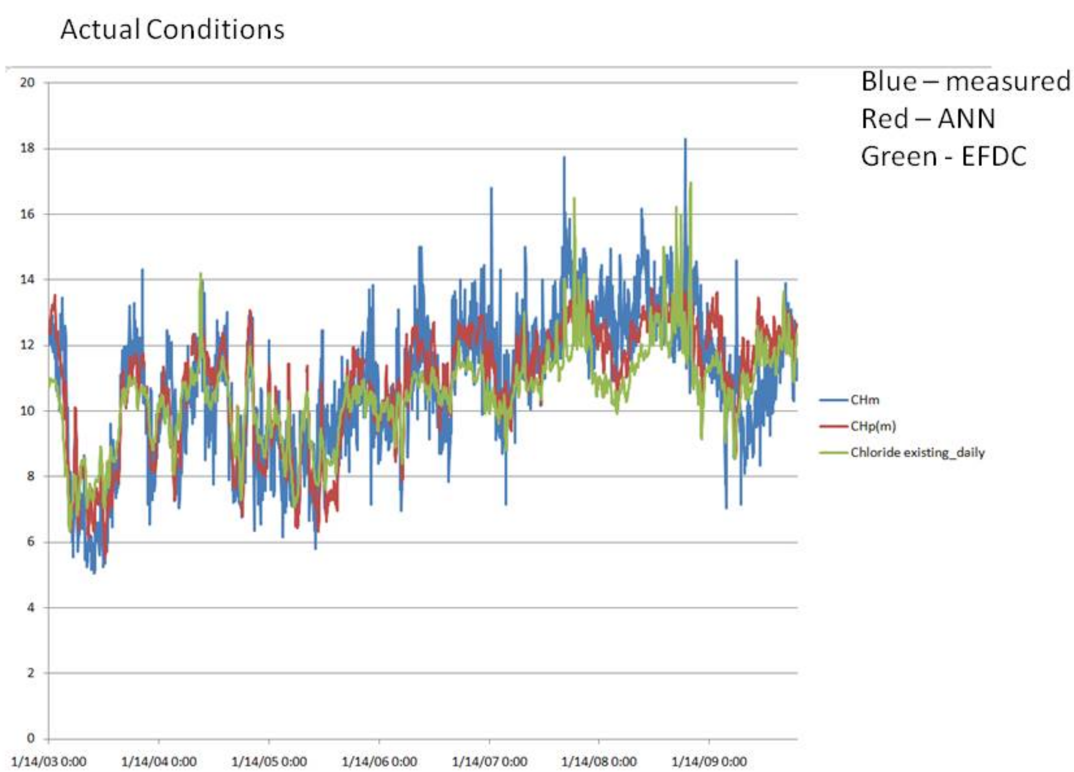
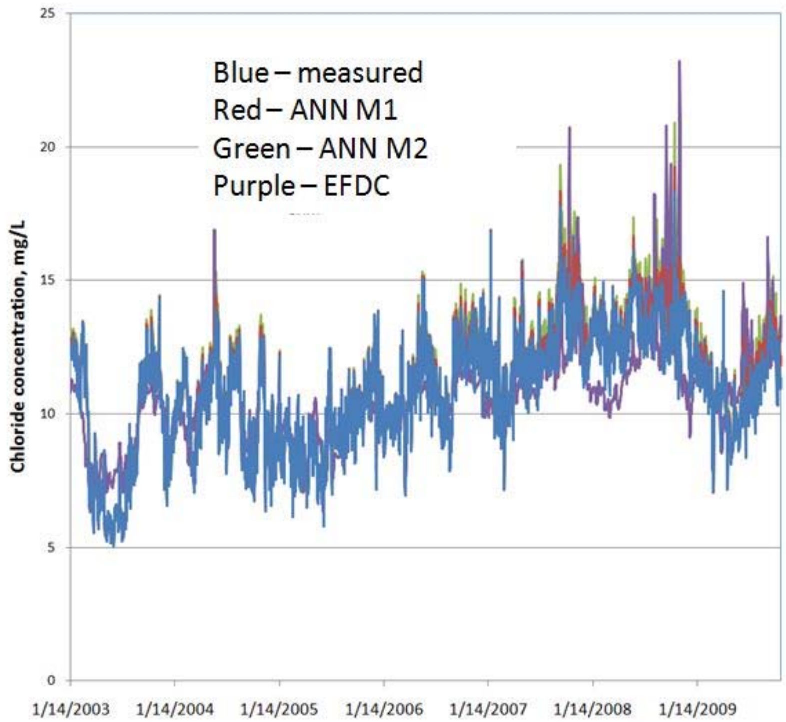


Figure 6-1 Measured and Modeled (EFDC and ANN) of Existing Conditions



	Max Conc.
Measured	18.3
ANN M1	19.3
ANN M2	20.9
EFDC	23.2

Figure 6-2 Model Simulations of 2-feet Deepening

2 ft Deepening: Duration

Criteria =12 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	442	519	662	280
>7	300	358	502	204
>14	214	252	371	135
>30	113	155	218	73
>60	61	34	85	6
>120	1	0	0	0
Max	121	75	97	66

Criteria =15 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	0	15	72	31
>7	0	2	29	3
>14	0	0	5	0
>30	0	0	0	0
>60	0	0	0	0
>120	0	0	0	0
Max	3	9	19	10

Criteria =25 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	0	0	0	0
>7	0	0	0	0
>14	0	0	0	0
>30	0	0	0	0
>60	0	0	0	0
>120	0	0	0	0
Max	0	0	0	0

Count of consecutive days with concentrations greater than specified value

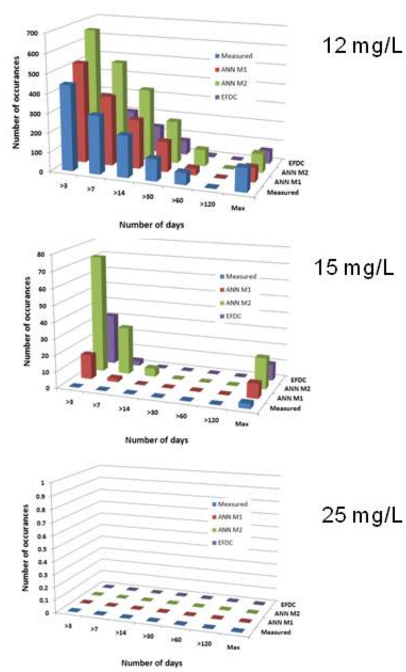
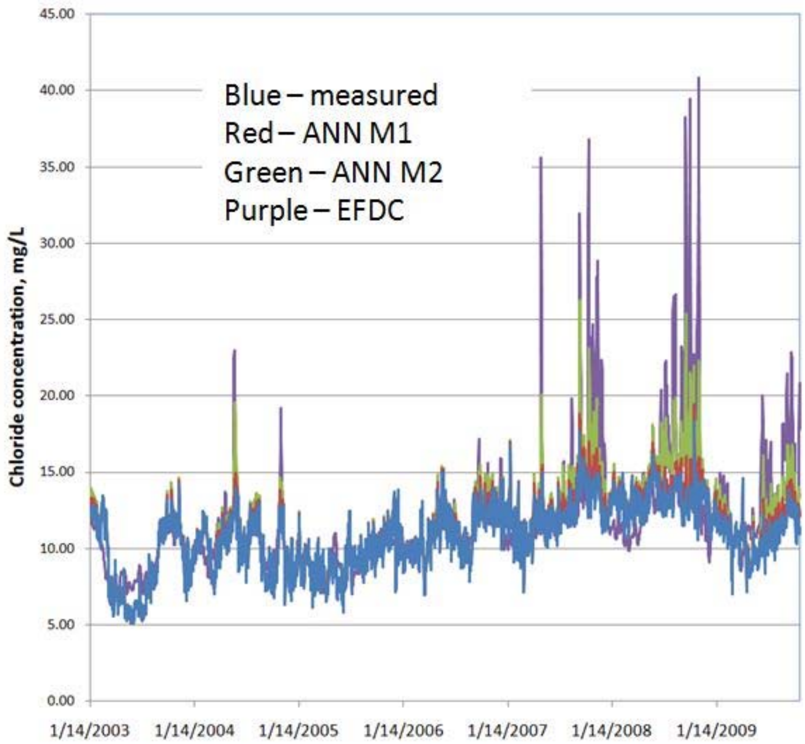


Figure 6-3 Model Simulations of 2-feet Deepening (Tabular)



	Max Conc.
Measured	18.3
ANN M1	19.5
ANN M2	26.3
EFDC	40.9

Figure 6-4 Model Simulations of 2-feet Deepening with Mitigation 6B

2 ft Deepening with Mitigation 6B: Duration

Criteria =12 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	442	619	736	563
>7	300	462	577	463
>14	214	332	439	370
>30	113	200	296	267
>60	61	71	143	178
>120	1	0	8	70
Max	121	97	128	190

Criteria =15 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	0	34	167	170
>7	0	10	99	98
>14	0	2	42	39
>30	0	0	0	8
>60	0	0	0	0
>120	0	0	0	0
Max	3	16	28	38

Criteria =25 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	0	0	0	13
>7	0	0	0	1
>14	0	0	0	0
>30	0	0	0	0
>60	0	0	0	0
>120	0	0	0	0
Max	0	0	2	8

Count of consecutive days with concentrations greater than specified value

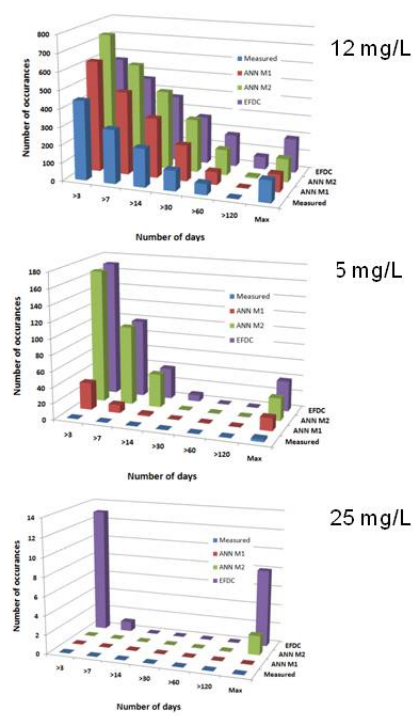
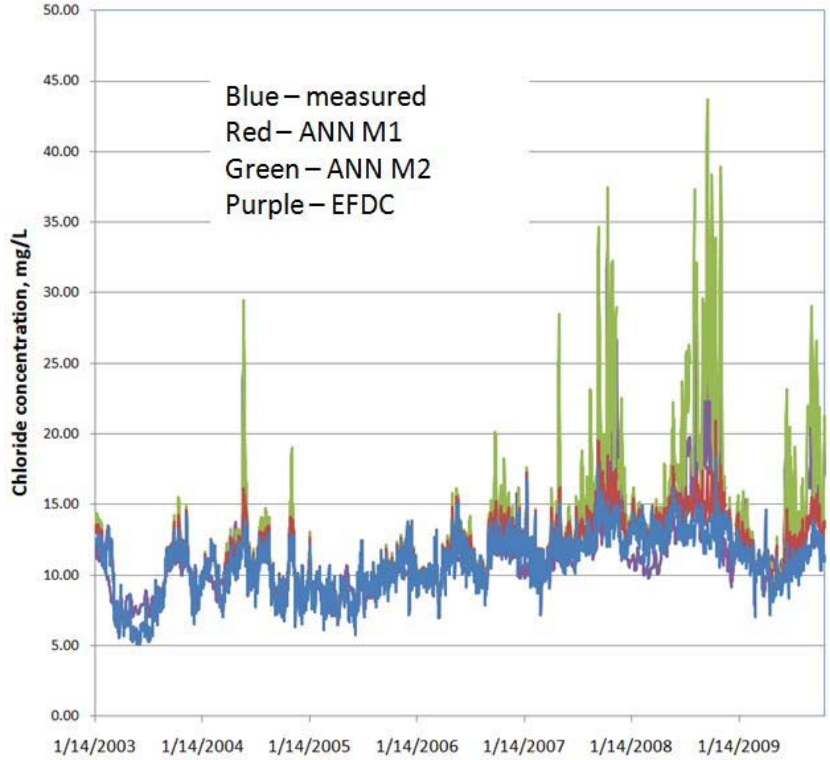


Figure 6-5 Model Simulations of 2-feet Deepening (Tabular) with Mitigation 6B



	Max Conc.
Measured	18.3
ANN M1	20.9
ANN M2	43.7
EFDC	36.4

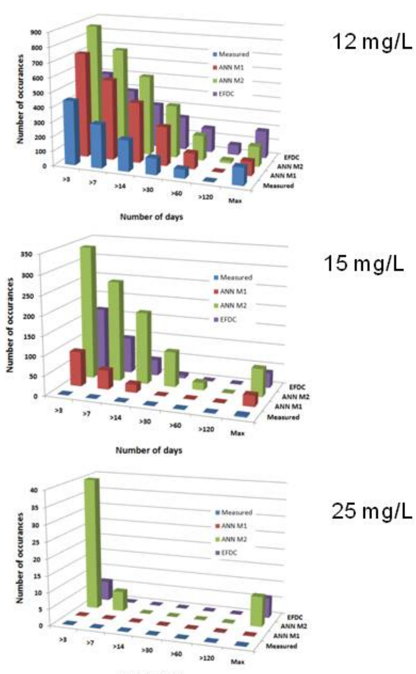
Figure 6-6 Model Simulations of 5-feet Deepening

5 ft Deepening: Duration

Criteria =12 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	442	718	872	498
>7	300	552	719	388
>14	214	414	548	302
>30	113	267	361	228
>60	61	108	172	168
>120	1	0	18	68
Max	121	97	138	188

Criteria =15 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	0	89	340	163
>7	0	49	257	92
>14	0	21	184	41
>30	0	0	90	8
>60	0	0	19	0
>120	0	0	0	0
Max	3	28	71	38

Criteria =25 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	0	0	40	6
>7	0	0	6	0
>14	0	0	0	0
>30	0	0	0	0
>60	0	0	0	0
>120	0	0	0	0
Max	0	0	9	6

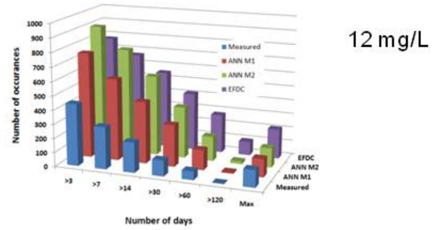


Count of consecutive days with concentrations greater than specified value

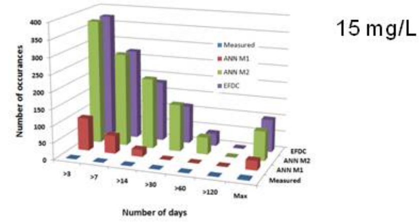
Figure 6-7 Model Simulations of 5-feet Deepening (Tabular)

5 ft Deepening with Mitigation: Duration

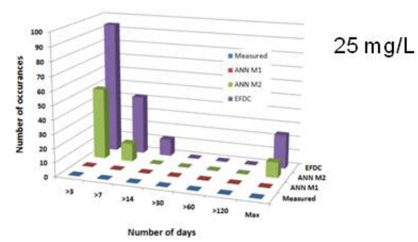
Criteria =12 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	442	751	901	776
>7	300	583	749	668
>14	214	441	572	552
>30	113	298	367	413
>60	61	143	175	275
>120	1	8	18	98
Max	121	128	138	211



Criteria =15 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	0	98	372	373
>7	0	54	278	271
>14	0	21	211	181
>30	0	0	141	114
>60	0	0	51	38
>120	0	0	0	0
Max	3	28	88	98

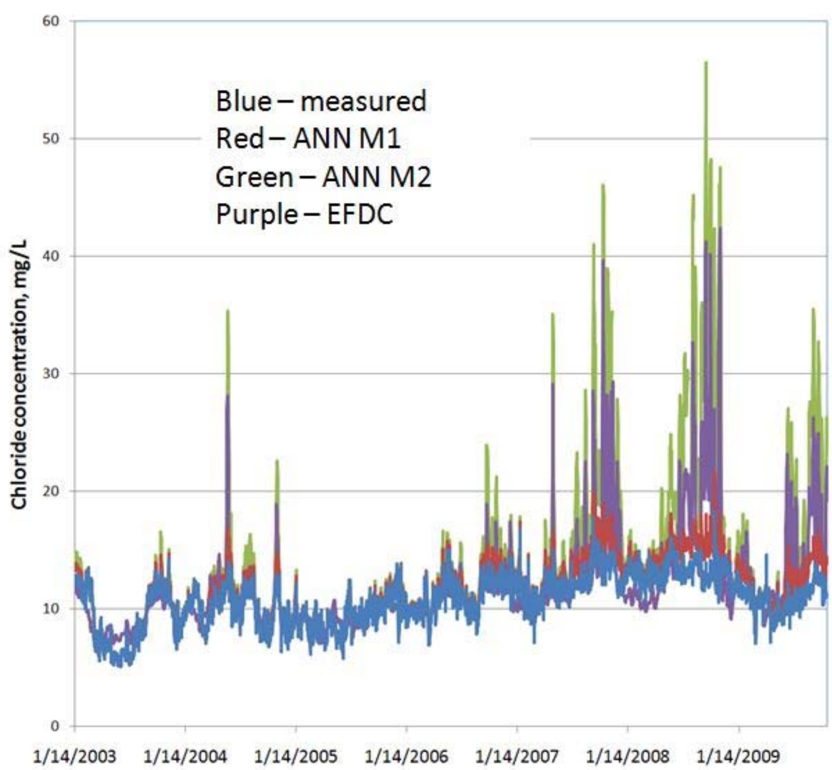


Criteria =25 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	0	0	51	94
>7	0	0	13	42
>14	0	0	0	12
>30	0	0	0	0
>60	0	0	0	0
>120	0	0	0	0
Max	0	0	11	24



Count of consecutive days with concentrations greater than specified value

Figure 6-8 Models Simulations of 5-feet Deepening with Mitigation 6B



	Max Conc.
Measured	18.3
ANN M1	21.7
ANN M2	56.5
EFDC	42.4

Figure 6-9 Model Simulations of 6-feet Deepening

6 ft Deepening: Duration

Criteria =12 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	442	789	922	573
>7	300	628	766	457
>14	214	469	591	356
>30	113	311	369	265
>60	61	153	177	171
>120	1	18	20	69
Max	121	138	140	189

Criteria =15 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	0	140	418	216
>7	0	69	318	130
>14	0	26	241	60
>30	0	0	163	17
>60	0	0	54	0
>120	0	0	0	0
Max	3	28	88	47

Criteria =25 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	0	0	97	19
>7	0	0	54	0
>14	0	0	24	0
>30	0	0	6	0
>60	0	0	0	0
>120	0	0	0	0
Max	0	0	36	7

Count of consecutive days with concentrations greater than an specified value

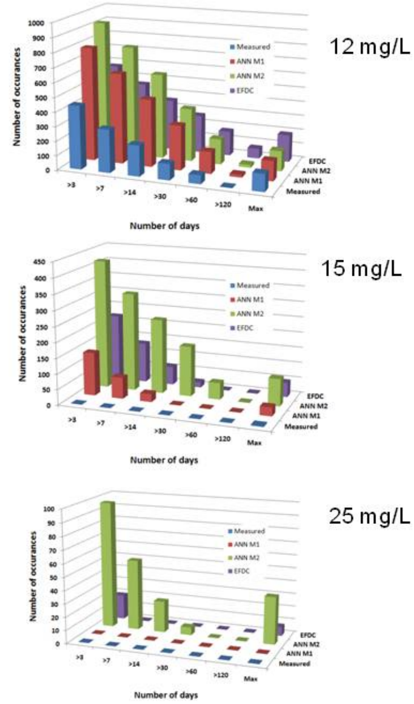


Figure 6-10 Model Simulations of 6-feet Deepening (Tabular)

6 ft Deepening with Mitigation 6A: Duration

Criteria =12 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	442	801	949	839
>7	300	637	800	738
>14	214	477	630	643
>30	113	313	412	517
>60	61	153	217	358
>120	1	18	22	175
Max	121	138	140	212

Criteria =15 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	0	140	437	454
>7	0	77	322	342
>14	0	28	228	253
>30	0	0	145	197
>60	0	0	55	137
>120	0	0	0	38
Max	3	28	88	158

Criteria =25 mg/L	Measured	ANN M1	ANN M2	EFDC
>3	0	0	85	129
>7	0	0	40	70
>14	0	0	10	27
>30	0	0	0	6
>60	0	0	0	0
>120	0	0	0	0
Max	0	0	23	36

Count of consecutive days with concentrations greater than an specified value

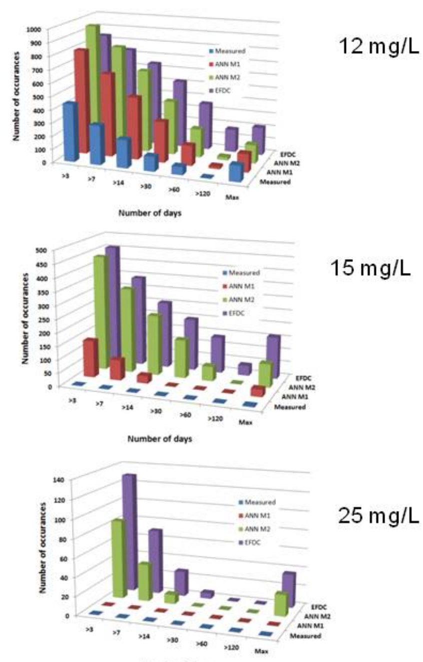


Figure 6-11 Model Simulations of 6-feet Deepening with Mitigation 6B

7.0 CONCLUSION

The models were run with the existing conditions as well as the five deepening scenarios with and without mitigation in the harbor for salinity and wetlands. For purposes of a conclusion to this report, the 5 and 6 feet depths are discussed below. The 5 foot deepening, or 47' depth, is referred to elsewhere in the GRR as the "tentative NED Plan" (NED=National Economic Development), and the 6 foot deepening, or 48' channel, is referred to as the "maximum authorized plan."

In conclusion, Figures 7-1 and 7-2 shows the model results for the 5-feet with and without mitigation and Figures 7-3 and 7-4 shows the model results for the 6-feet with and without mitigation.

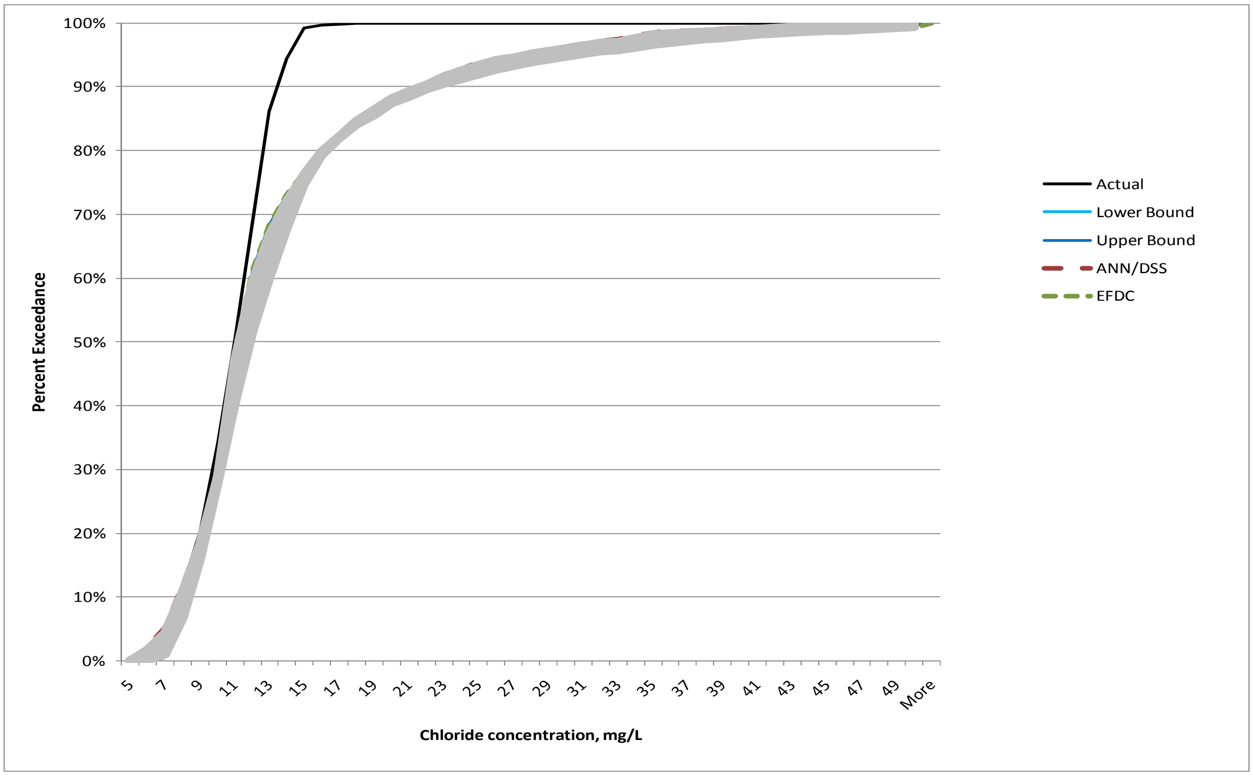


Figure 7-1 5-feet Deepening Results

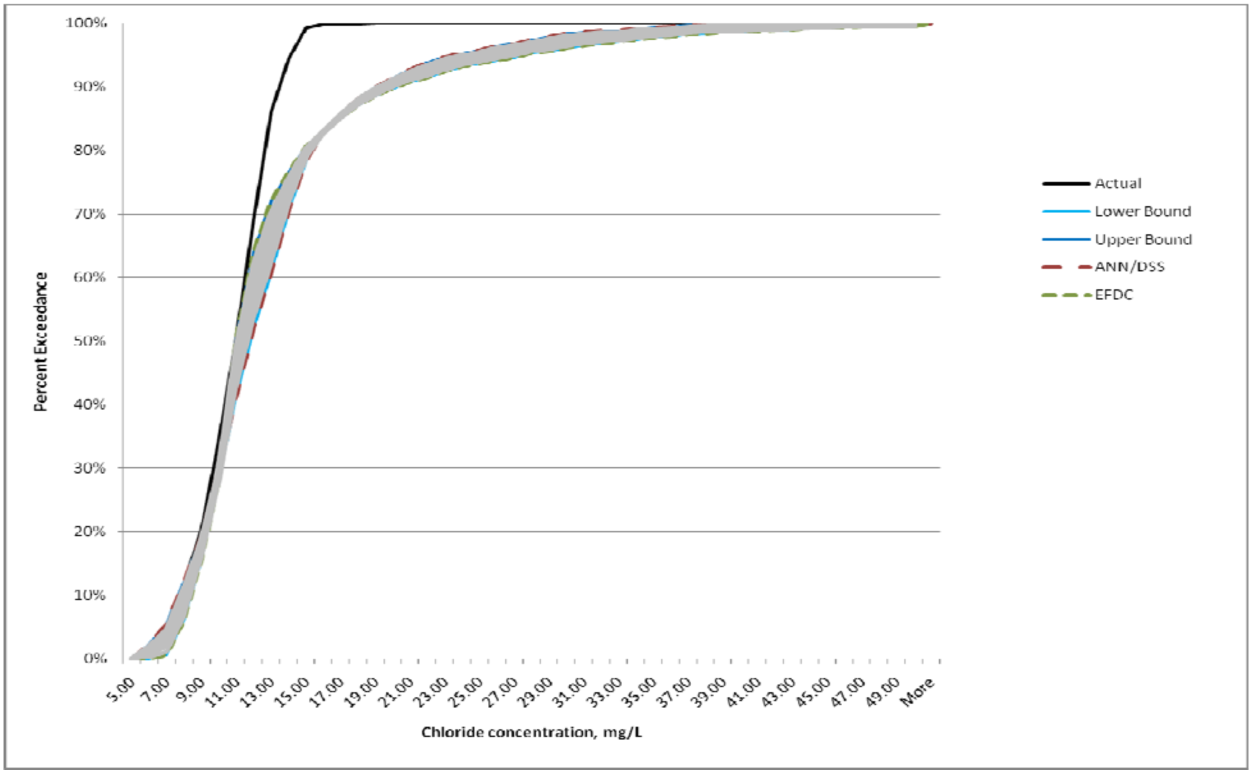


Figure 7-2 5-feet Deepening with Mitigation 6A Results

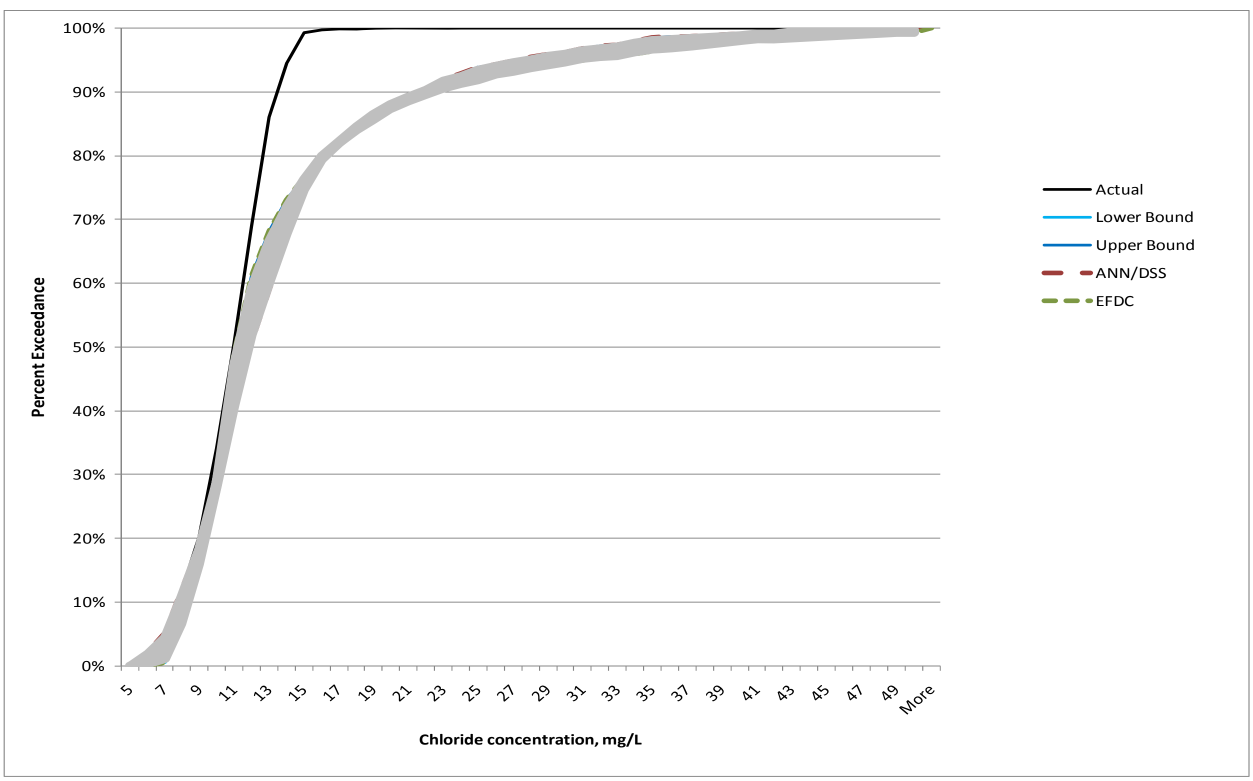


Figure 7-3 6-feet Deepening Results

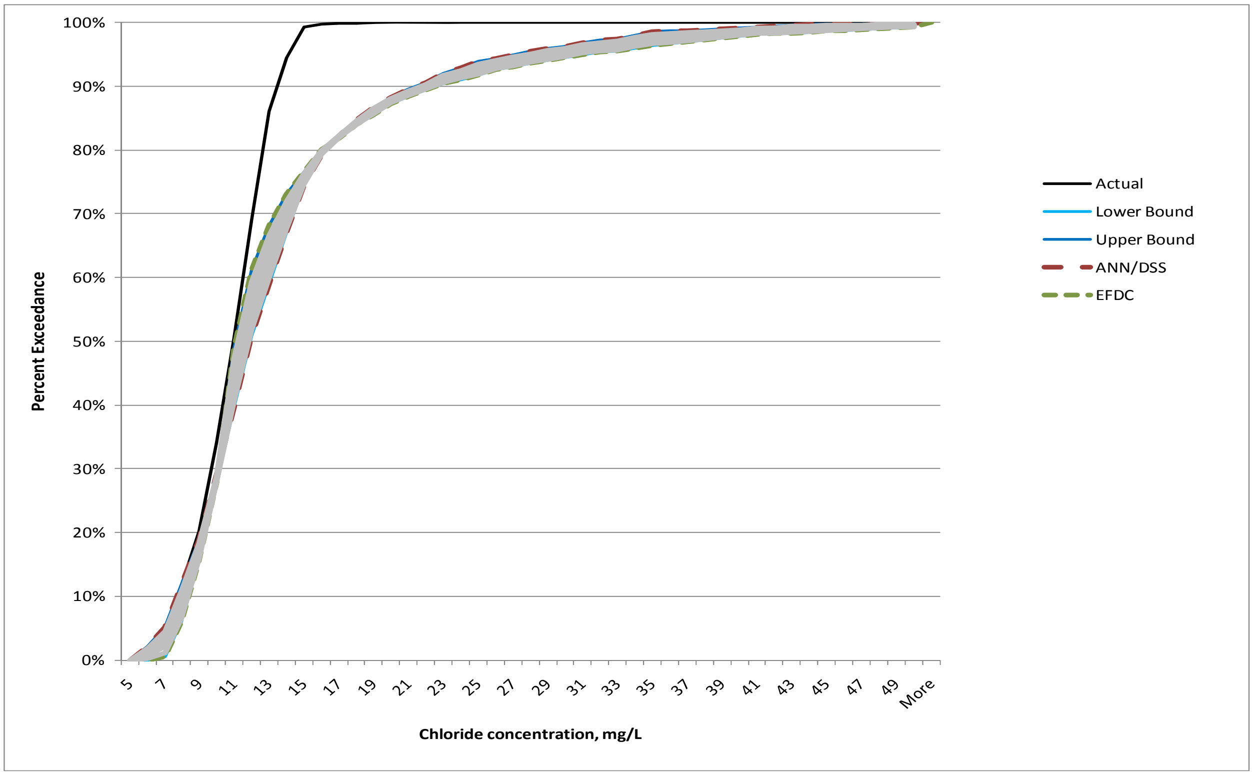


Figure 7-4 6-feet Deepening with Mitigation 6A Results

The two methodologies do show some consistency with each other. They are both predicting an increase in chloride concentrations due to deepening of the navigation channel. The deeper the channel depth, the larger impact on chlorides at the intake. The SCM model shows almost no change from deepening with mitigation compared to deepening only (without mitigation), but the EFDC method shows a significant difference. The reason is the EFDC model predicts higher peaks and the SCM plateaus at the higher concentration. This is a function of the model training and the datasets available above 20 mg/L.

Table 7-1 shows a summary of the results in tabular format.

Table 7-1 Annual Flow Statistics Summary

Scenario	50th Percentile			75th Percentile			95th Percentile		
	Existing	Lower	Upper	Existing	Lower	Upper	Existing	Lower	Upper
5-feet	11.5	11.5	12.5	13	15	15.6	13	15	15.6
5-feet with Mitigation 6A	11.5	11.5	12.5	13	15	15.6	13	15	15.6
6-feet	11.5	11.5	12.5	13	15	15.6	13	27.6	31.5
6-feet with Mitigation 6A	11.5	11.5	12.5	13	15	15.6	14.6	27.6	31.5

At the lower ranges (below 75 percent), there is virtually no change in the with and without mitigation. For example at the 75th percentile, the existing conditions are 13 mg/L and the deepening is expected to increase the concentration to 15 to 16 mg/L. At the higher ranges or peaks (great than or equal to 95 percent), the predicted increases are much higher. For example at the 95^{th} percentile, the existing conditions are 15 mg/L and the deepening will increase from 27 to 32 mg/L.

We also believe there is a physical limitation of salinity (or chloride) reaching the City's Intake. The invert of Abercorn Creek at the confluence of the Savannah River is higher than the invert of the river. Therefore, this acts a barrier or "lip" to keep salinity levels lower on Abercorn Creek. The EFDC model represents this "lip" as best it can but the grid cells are fairly coarse. It does appear in the EFDC predictions that the salinity climbs up the "lip" and into Abercorn Creek more often on the deepening scenarios with mitigation, and therefore, the EFDC predictions are higher with mitigation.

The system is not well mixed at Houlihan Bridge but typically is by I-95 Bridge. We did not have surface and bottom data at I-95 Bridge or Abercorn confluence during the modeling effort but it does appear from modeling results and the data comparisons between I-95 Bridge and the City's Intake that the salinity/chloride is not traveling upstream on Abercorn Creek. In September 2010, the USGS performed monitoring in this area to better understand this phenomenon, see Figures 7-5 and 7-6. A summary of the data is provided below:

1. There is substantial dampening of the intrusion in the reach of the Savannah River above I-95. Peak SC values at I-95 between 800 and 900 uS/cm were only between 250 and 350 uS/cm at the mouth of Abercorn Creek. See Figure 7-5.
2. There is a similar proportional reduction at the mouth of Abercorn Creek. Values around 350 in the Savannah were reduced below 225 in Abercorn Creek.
3. From the profiling data, the system is well mixed.
4. Being well mixed, the "sill" at the mouth of Abercorn Creek does not limit higher saline water from entering Abercorn like it might if the system were stratified. The "sill" does limit the amount or volume of well mixed water that exchanges with Abercorn Creek.

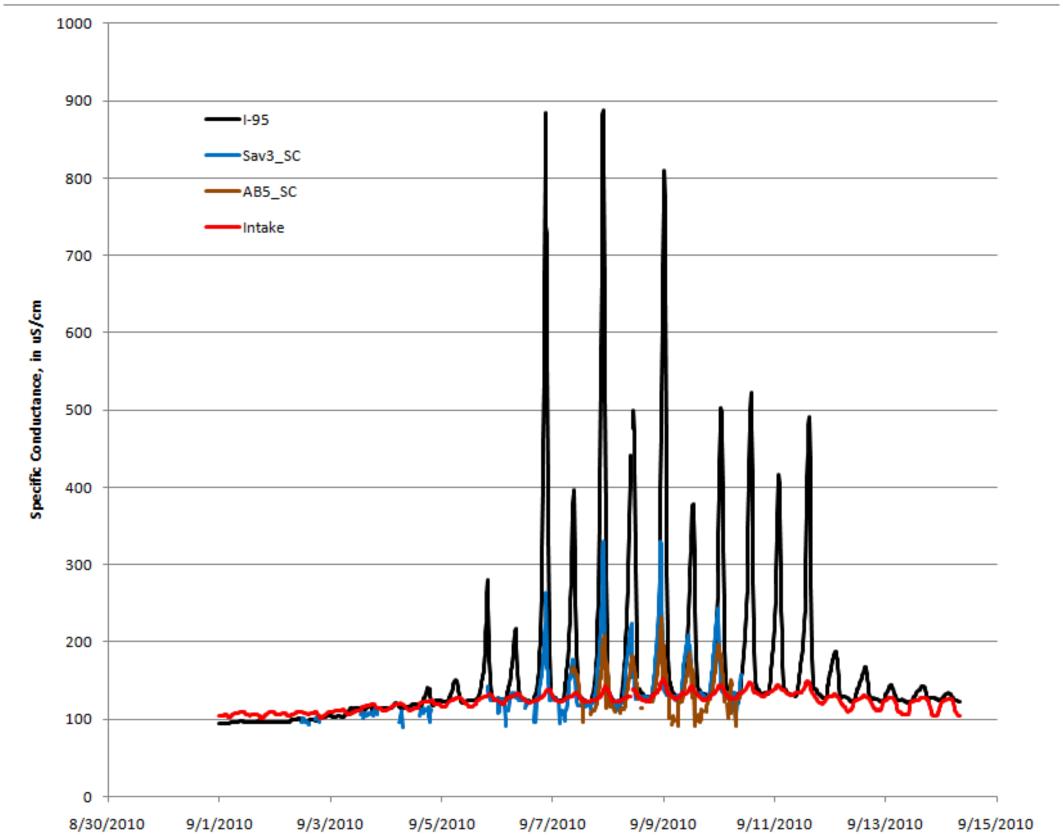


Figure 7-5 Dampening Effect of Specific Conductance From I-95 to the Intake

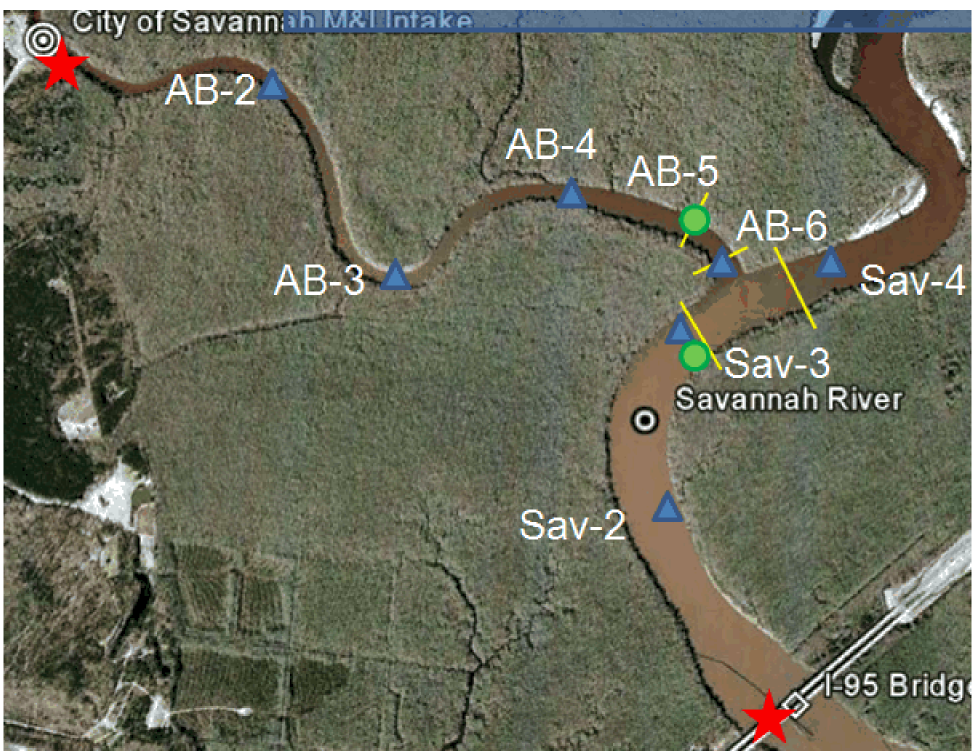


Figure 7-6 USGA Monitoring Stations in Sept-Nov 2010

The two-pronged modeling approach provided both a mechanistic and empirical approach for determining the chloride concentrations at the City's intake. Both modeling approaches have limitations. The mechanistic model does not fit the data as well because of the difficulty in representing all of the physical processes (flows, flushing, marshes, tides, etc.) accurately in the system. But the mechanistic model can do quite well simulating a physical change in the system and predicting future responses. The empirical model matches the data of the existing (or measured) conditions more closely because it is "trained" on the data. But the empirical model can have trouble representing a future change in the physics of the system because there are no data for this simulated scenario and the future conditions are only as good as the extrapolation to those conditions. Therefore, we used the strengths of both models. The results presented in this Conclusion Section represent a combination of the EFDC and SCM results as a "band" of predictions. We accept there is uncertainty in the data and models, and believe these plots and results are the best way to summarize the work.

8.0 REFERENCES

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APPENDICES

APPENDIX A

EFDC Modeling Report, Tetra Tech

Chloride Model Development for the Savannah Harbor and River Estuary

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December 31, 2010

Table of Contents

1.0 Introduction

Tetra Tech, Inc. (Tetra Tech) developed an EFDC hydrodynamic model for the Savannah Harbor in support of the Savannah Harbor Expansion Project (SHEP). The SHEP EFDC model was used for the effort described herein and was used to calibrate and validate to the harbor data, including chloride concentrations. This new work was based, in part, on work developed previously. In 2006, Tetra Tech was contracted by the United States Army Corps of Engineers (USACE) to perform a data analysis of chloride concentrations in Abercorn Creek upstream of the Interstate 95 Bridge on the Savannah River. The purpose of the chloride data analysis was to determine a prediction of chloride concentrations on Abercorn Creek in response to downstream harbor modifications. Due to data limitations, the chloride analysis showed a regression to chloride concentrations from upstream along with a prediction of the additional chloride due to harbor deepening.

The City of Savannah (City) owns and operates an Industrial and Domestic drinking water supply intake located on Abercorn Creek approximately two miles from the confluence with the Savannah River. The City collects samples at the water treatment plant daily to monitor various chemical constituents in the influent. Due to the proximity of Savannah to the coast, the rise and fall of daily tides causes the physical and chemical characteristics of the source water to change continuously. The USGS is monitoring the upper Savannah River and Estuary for flow, conductivity (salinity), temperature, and chloride. The data collection started in July 2009 and continued through the end of 2010. These data are the basis for the chloride EFDC model calibration and validation.

The previous study developed a relationship between upstream flow and chloride measurements within the system, investigating the impact of past harbor deepening on chloride levels at the intake, identifying other potential sources of chlorides, and developing a predictive model for chloride concentrations. During the study which developed the chloride predictive tool, a scarcity of data was noted and uncertainties were recognized. Continuing questions about the accuracy of the predictive tool and the magnitude of the uncertainties has led to a call for additional data collection followed by a review of the chloride predictive tool.

To address this concern, mechanistic and empirical modeling approaches were used to simulate chloride concentrations at the City's intake to evaluate potential effects from deepening the Savannah Harbor. The first approach modified the mechanistic Environmental Fluid Dynamics Code (EFDC) model used for evaluating potential harbor deepening effects for the Environmental Impact Statement (EIS). Model modifications included schematizing the upper reaches of the model to include Bear Creek, Little Collis Creek, and Little Abercorn Creek in the model grid to improve flow and transport simulations in Abercorn Creek. Chloride concentrations were modeled directly with EFDC as a conservative tracer. The EFDC model uses boundary input data of streamflow, riverine and harbor chloride concentrations, and coastal water levels.

The second approach to simulate chloride concentrations was to develop empirical models directly from the available data using artificial neural network (ANN) models. The ANN models use streamflow and specific conductance (field measurement for salinity) time series for inputs. The two modeling approaches were integrated into a decision support system (DSS) that combines the historical database, output from EFDC, ANN models, ANN model simulation controls, streaming graphics, and model output. The DSS was developed as Microsoft Excel™/Visual Basic for Applications5 (VBA) programs. This allowed the DSS to be prototyped, easily modified, and distributed in a familiar form. The two models were used to simulate various harbor deepening scenarios; however, to accommodate the geometry changes in the harbor, the ANN models used the EFDC model-simulated salinity changes for a historical condition as input. The DSS operates through a graphical user interface (GUI) and allows the end user to interact with the ANN models and EFDC output.

2.0 Study Area Description

The Savannah River basin includes portions of North Carolina, South Carolina, and Georgia and flows through the Blue Ridge Mountain, Piedmont, and Coastal Plain provinces. The Savannah River forms the boundary between South Carolina and Georgia and begins at Hartwell Reservoir by the confluence of the Seneca and Tugaloo Rivers. From this point, it flows southeast to the port city of Savannah, Georgia where it empties into the Atlantic Ocean. (River Basin Center)

The city of Savannah owns and operates the 75 Million Gallons per Day (MGD) Industrial and Domestic (I&D) Water Treatment Plant. The plant was constructed in 1947 as a 35 MGD conventional surface water treatment plant. The treatment plant and its associated processes have been improved and/or upgraded over the years to its current 75 MGD maximum capacity.

The raw water source for this facility is Abercorn Creek, a tributary of the Savannah River. Due to the proximity of Savannah to the coast, the rise and fall of daily tides causes the physical and chemical characteristics of the source water to change continuously. This constant change adds to the complexity of the treatment process and requires the highest degree of vigilance by the operations staff. Figure 2-1 provides a location map of the watershed, location of the water intake on Abercorn Creek, and the United States Geological Survey (USGS) data collection stations.

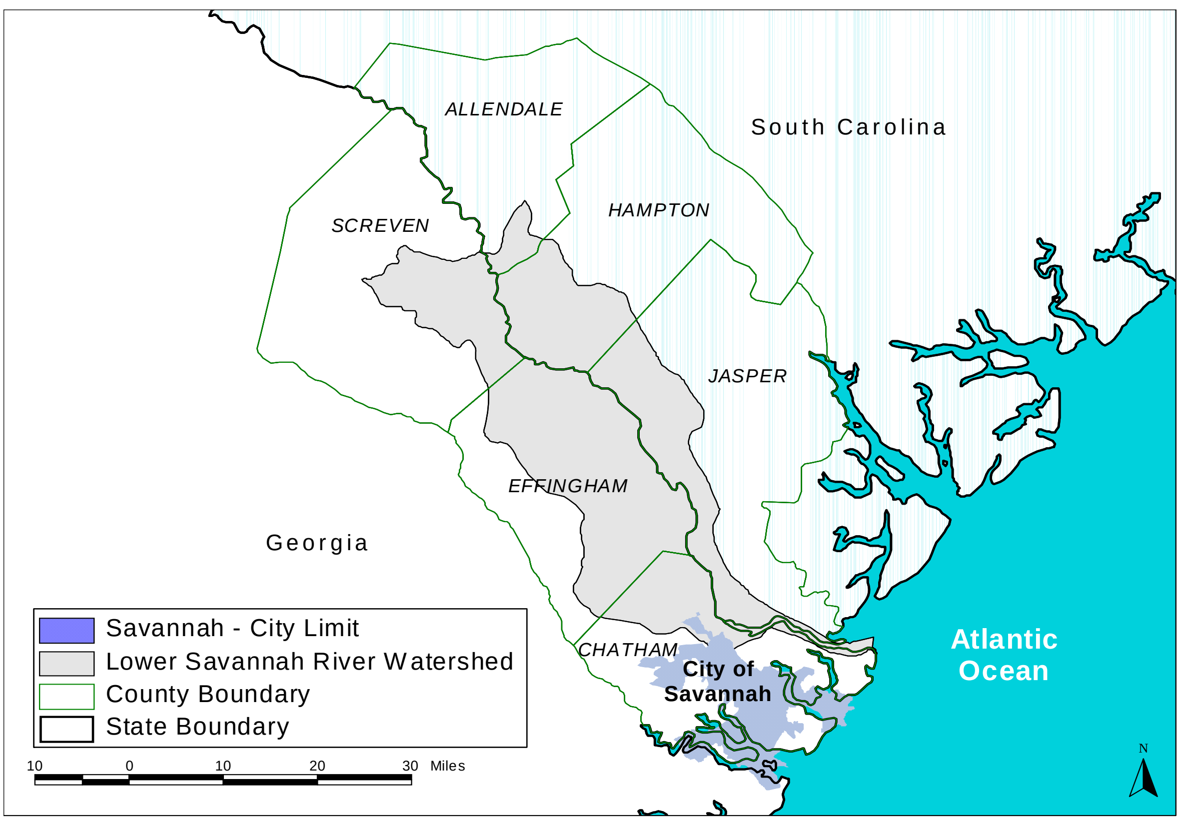

Figure 2-1 Location Map of the Savannah River Watershed

3.0 Data Summary

Tetra Tech assembled and compiled the data provided by the USGS and the City of Savannah. Table 3-1 and Figure 3-1 show the stations used in the EFDC model calibration and validation. All data were uploaded into the Water Resources Database (WRDB) for use in data summaries and model development. The data were gathered through 2009 to extend the model.

USGS established new gages on Abercorn Creek, Bear Creek, and at Plant McIntosh to collect flow, temperature, and conductivity. Also, ISCO samplers were installed to collect grab samples of chloride for use in the calibration of the model. USGS sampling stations are located at 02198840 (I-95 Bridge), 02198920 (Houlihan Bridge), 02198810 (Abercorn Creek), and 02198745 (Plant McIntosh). The USGS collected 15-min and daily flow, water surface elevation, temperature, and conductivity data through December 2009. Also, USGS gathered ISCO chloride data through September 2009. The City of Savannah obtains grab samples at the water plant rather than at the end of the intake pipe on Abercorn Creek, same as USGS 02198810. These samples are taken hourly throughout the day and then composited as a daily chloride concentrations, along with many other parameters, at the water treatment facility. The conductivity values from USGS gages were converted to salinity to allow comparison with the model. This was accomplished using a well-established algorithm developed to define the relationship of specific conductance to the chemical composition in seawater and dilutions of seawater, as in estuaries (USGS 1988).

Table 3-1 Summary Table of Stations

Station ID	Station Description	Parameters
02198500	Savannah River Near Clyo, GA	Flow
02198745	Savannah River Near Rincon, GA (Plant McIntosh)	Water surface and chloride, recently added temperature and conductivity
02198768	Bear Creek Near Rincon, GA	Flow, water surface, recently added flow splits for Abercorn and Little Collis Creeks
02198810	Abercorn Creek Near Savannah, GA (City's Intake)	Flow, water surface, chloride, recently added temperature and conductivity
02198840	Savannah River Near Port Wentworth (I-95 Bridge)	Water surface, chloride, temperature, conductivity
02198920	Savannah River at GA 25 at Port Wentworth (Houlihan Bridge)	Flow, water surface, chloride, temperature, conductivity
02198950	Middle River at GA 25 at Port Wentworth (Houlihan Bridge)	Flow
021989792 (320955081074600)	Little Back River at GA 25 at Port Wentworth (Houlihan Bridge)	Flow
02198980	Savannah River at Fort Pulaski, GA	Flow, conductivity
021989773	Savannah River at USACE Dock at Savannah, GA	Conductivity
321313081075100	Union Creek below I-95 nr Hardeeville, SC	Flow
City of Savannah	City's Intake on Abercorn Creek	Chloride, conductivity, temperature

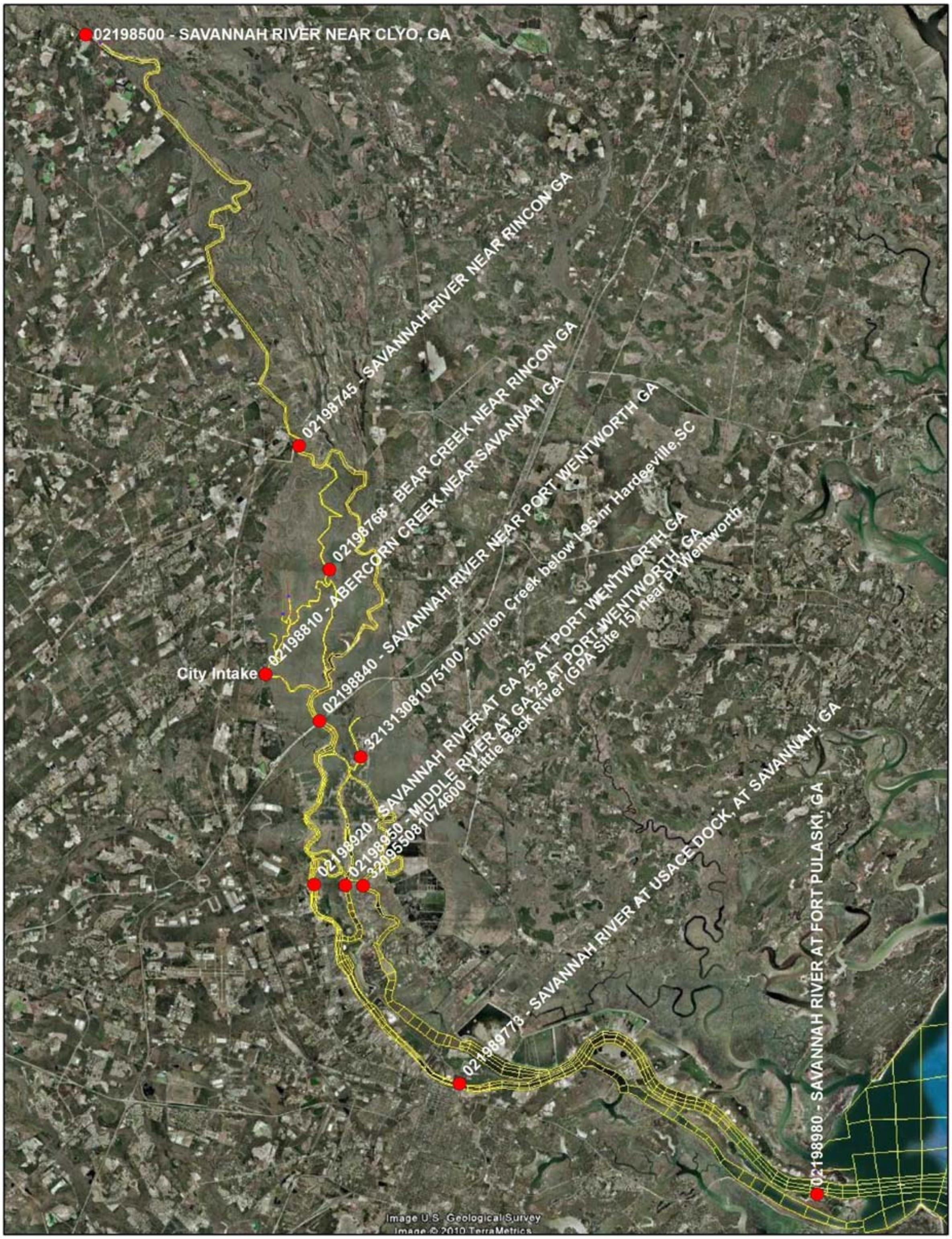

Figure 3-1 Location of Monitoring Stations Used in the EFDC Model

4.0 EFDC Model Development

4.1 EFDC Model

The SHEP EFDC model was revised to include more cells in the Abercorn Creek and Bear Creek region to better simulate the flow connections upstream of the City's intake. This modification to the grid was not expected to affect the other EFDC calculations and the impact predictions based on those calculations. The EFDC grid allowed for flow paths from the harbor to the City's intake along with the other upstream connections such as Bear Creek, Little Collis Creek, and Little Abercorn Creek. Depths and widths for the model grid were gathered from existing USGS topographic quadrangle maps and existing USACE measurements.

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. EFDC has proven to capture the complex hydrodynamics in systems similar to that of Savannah Harbor. The EFDC hydrodynamic and sediment transport model linked with the WASP water quality model provides the most appropriate combination of features necessary for the project study. The EFDC based model is capable of 1, 2, and 3-D spatial resolution. The model employs a curvilinear-orthogonal horizontal grid and a sigma, or terrain following, vertical grid. The 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).

4.2 Model Approach

The EFDC model was calibrated to the USGS and City datasets. The EFDC model was validated to the existing flow and water surface elevation on Houlihan Bridge, Abercorn Creek and Bear Creek, along with water surface elevation at I-95 Bridge and Plant McIntosh. Temperature, conductivity, and chloride were used to calibrate the chloride concentrations moving downstream in the Savannah River and upstream salinity from the harbor. The EFDC model calibration should be consistent with the hydro calibration presented in Tetra Tech's report in January 2006. All models will be run through the 2009 time period. Proposed additional secondary modeling approach - EFDC will also be run with chloride as a conservative substance to predict chloride concentrations at the intake.

4.3 Model Grid Extension

The geometry and bathymetry of the rivers and harbor were defined in the EFDC model grid by a curvilinear, orthogonal grid to approximate the physical dimensions of the water body. The grid was extended to include Abercorn, Bear and Big Collis creeks to better represent the hydrodynamics in the immediacy of the City of Savannah water intake at Abercorn Creek. Figure 4-1 shows the extended grid and Figure 4-2 shows the whole grid including the extension.

The EFDC grid extensions had one vertical layer since the Z-grid was used. More discussion on the Z-grid in Section 4.4 (next section).

Limited data were used for the bathymetry. USGS inverts with respect to NGVD at Clyo and City Intake as well as bathymetry measurements on the Savannah River in the vicinity of the I-95 bridge were used to determined inverts at the extended area. A uniform slope between those points was interpolated for the extended grid.

The channel width of the new grid segments were adjusted based on flow measurements at City Intake and Bear Creek, the final width of the added creeks are:

- Abercorn Creek from Savannah River up to Rancoon Creek: 60 meter
- Abercorn Creek from Rancoon Creek up to Bear Creek: 20 meter
- Big Collis from Savannah River up to Bear Creek: 15 meter
- Bear Creek: 10 meter

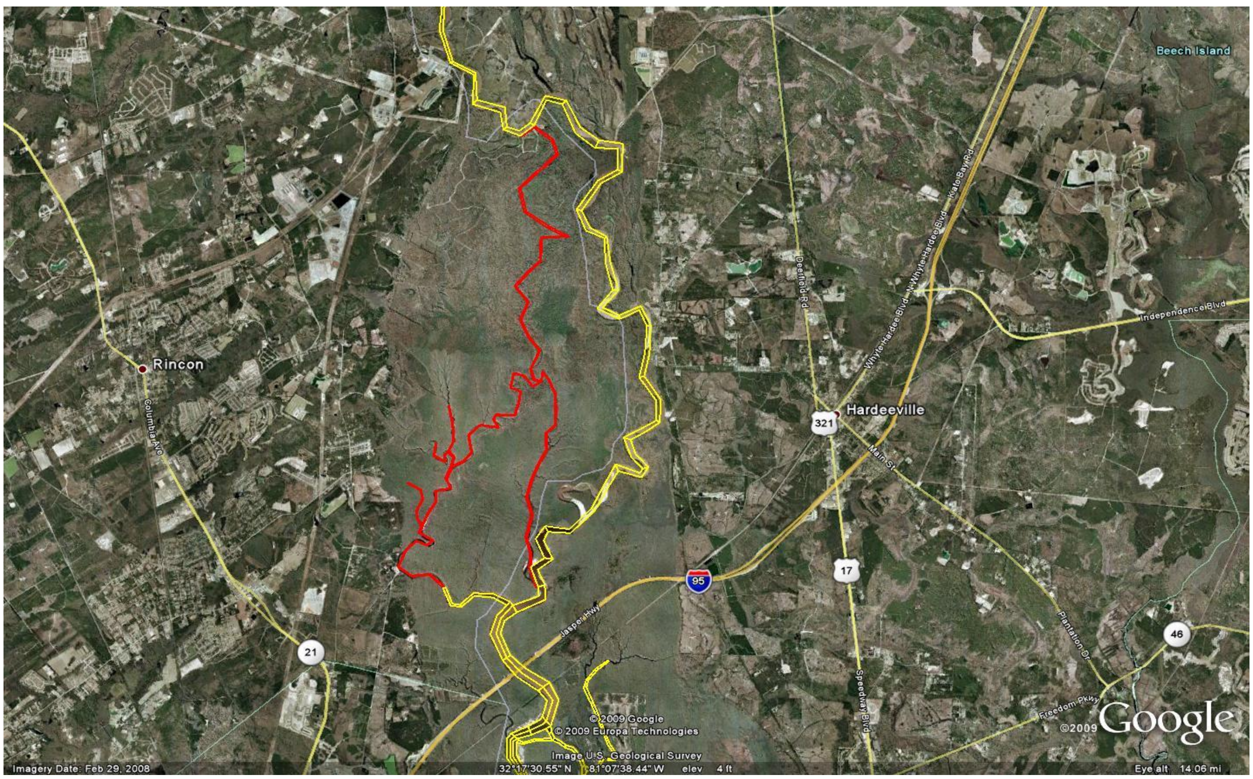

Figure 4-1 Grid Extension to include Abercorn, Bear and Big Collis Creeks.

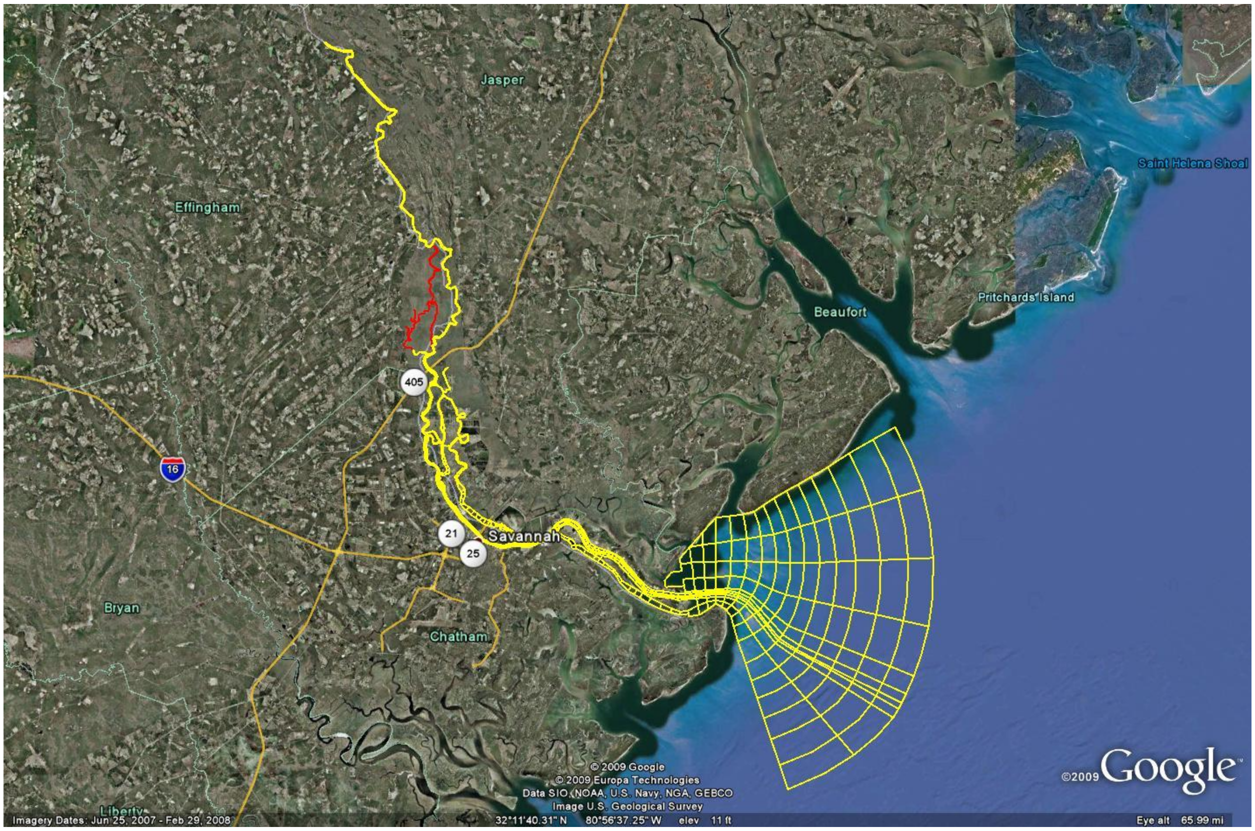

Figure 4-2 Existing Grid with new extension.

4.4 Validation and Calibration

The EFDC model was calibrated and validated in the Tetra Tech, 2006 report. Since that time, EPA has switched from a Sigma grid to a Z-grid and updated through 2007. In this work, Tetra Tech has used the Z-grid implementation.

Tetra Tech validated the modified model, Z-grid and extended grid, to water surface elevation, flow, and salinity. Figures 4-3 to 4-8 present a comparison of measured and simulated water surface elevation at Fort Pulaski, Houlihan Bridge on the Front River and I-95 Bridge. These comparisons show that the model developed for the present study show the same degree of accuracy as the original model calibrated and validated in 2006. Figures 4-9 and 4-10 show water surface elevation comparisons on Abercorn Creek at the City of Savannah water intake. This station is located on the extended grid area and can be considered part of the calibration of the expansion. The comparison shows that the model compares well with the measured data at this location showing similar concordance that the previous stations.

Figures 4-11 and 4-12 present the salinity comparison at the stations USACE Docks and Houlihan Bridge on the Front River. These figures show that the model is able to reproduce the same trends and values of the previous calibrated version of the model.

Figures 4-13 to 4-16 show flow comparisons at Houlihan Bridge at the Front and Middle Rivers. These figures validate the present model which present accurate flow distributions between the different branches of the Savannah River at Houlihan Bridge.

Figures 4-17 to 4-20 present flow comparisons at the City Intake on Abercorn Creek and on Bear Creek just before its affluence into Abercorn Creek. These comparisons are calibrations of the present model in the extended area and were used to determine the final geometry of the new grid cells.

The new EFDC model was used to calibrate to the chloride data collected by the City of Savannah (1988 to current) and USGS ISCO data (2009). Chlorides were modeled independently from salinity as a conservative substance. The open boundary value for chlorides was based on the salinity value at the open boundary according to the 1967 International Agreement on Sea Water. The relationship of salinity to chloride was S/C=1.80655. The chloride boundary value at the ocean open boundary was 19,300 mg/L. Chlorides boundary values at Clyo were dependent of flow at the station obtained from a correlation based on measured data. The values at Clyo oscillate between 4.2 and 11 mg/L.

Figures 4-21 to 4-28 show comparisons of modeled and measured chlorides at Houlihan on the Front River, at the I95 Bridge and MacIntosh on the Savannah River and at the City of Savannah water intake on Abercorn Creek.

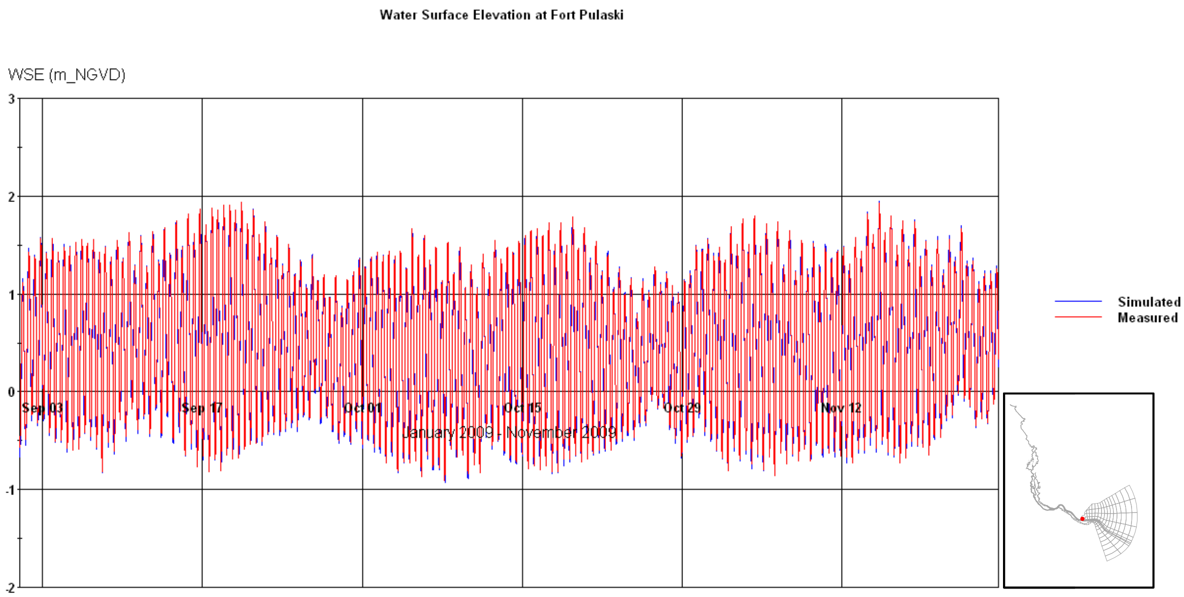

Figure 4-3 Water Surface Elevation comparison at Fort Pulaski.

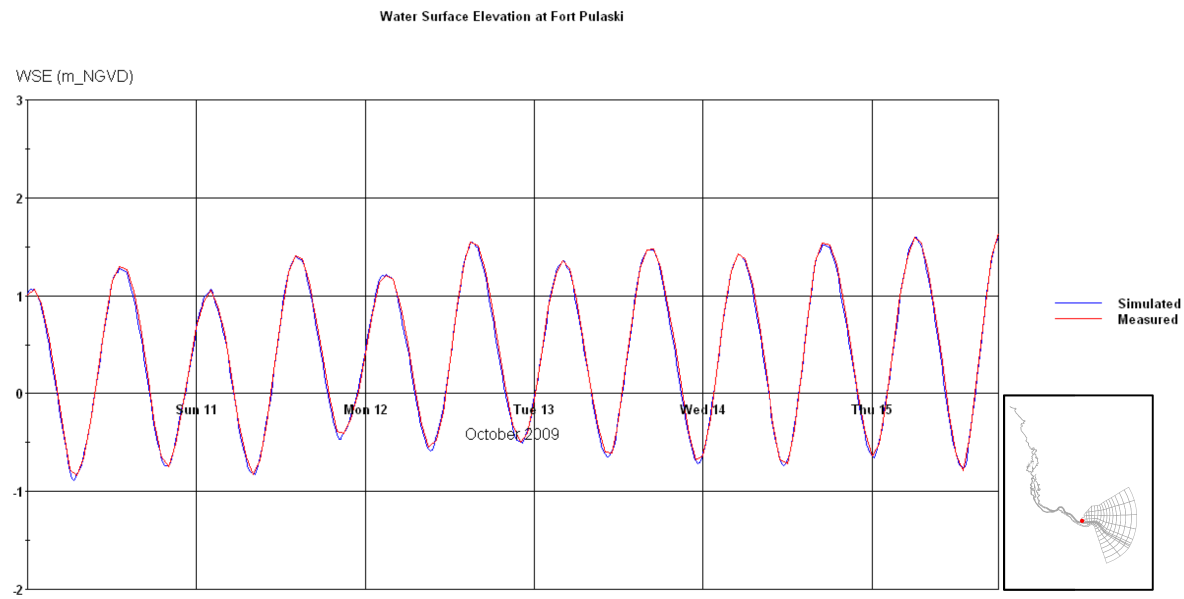

Figure 4-4 Water Surface Elevation comparison at Fort Pulaski.

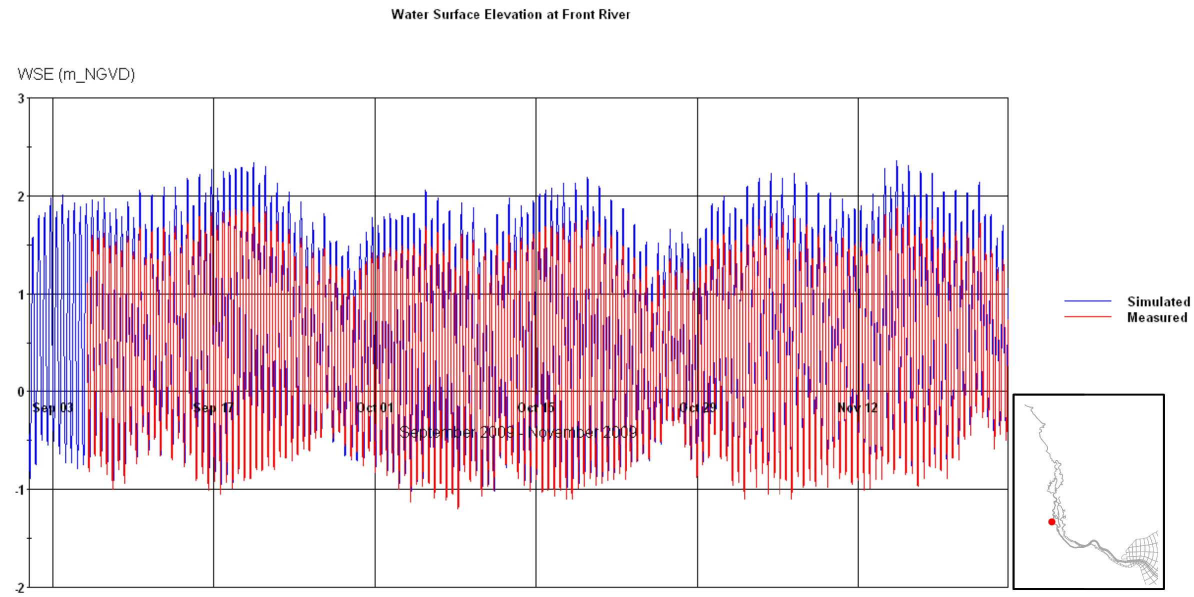

Figure 4-5 Water Surface Elevation comparison at Houlihan Bridge on the Front River.

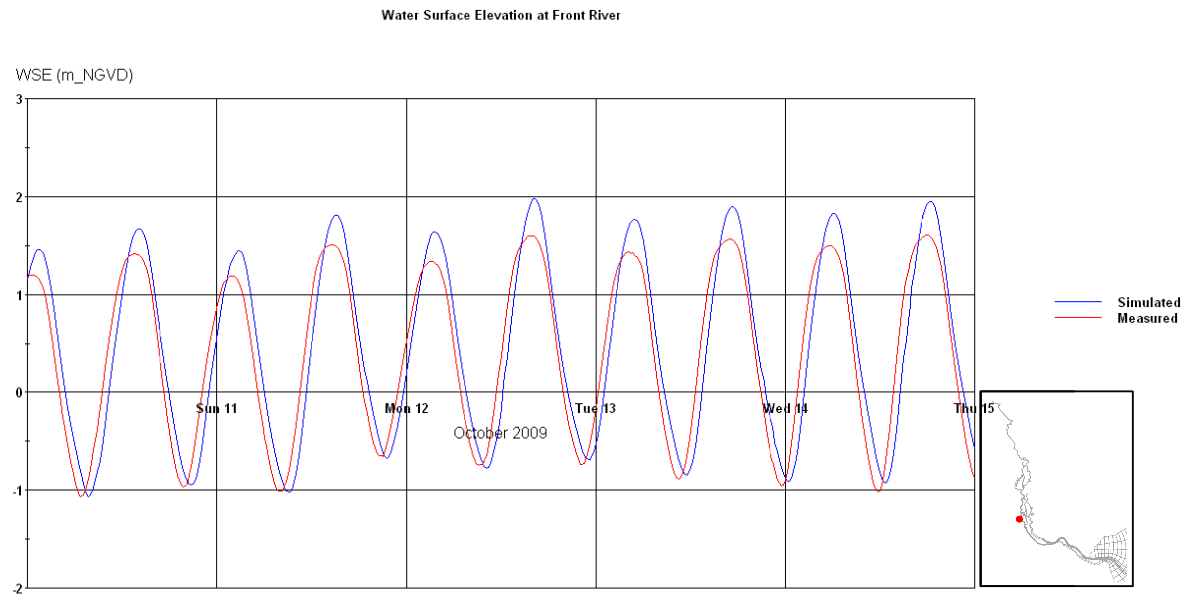

Figure 4-6 Water Surface Elevation comparison at Houlihan Bridge on the Front River.

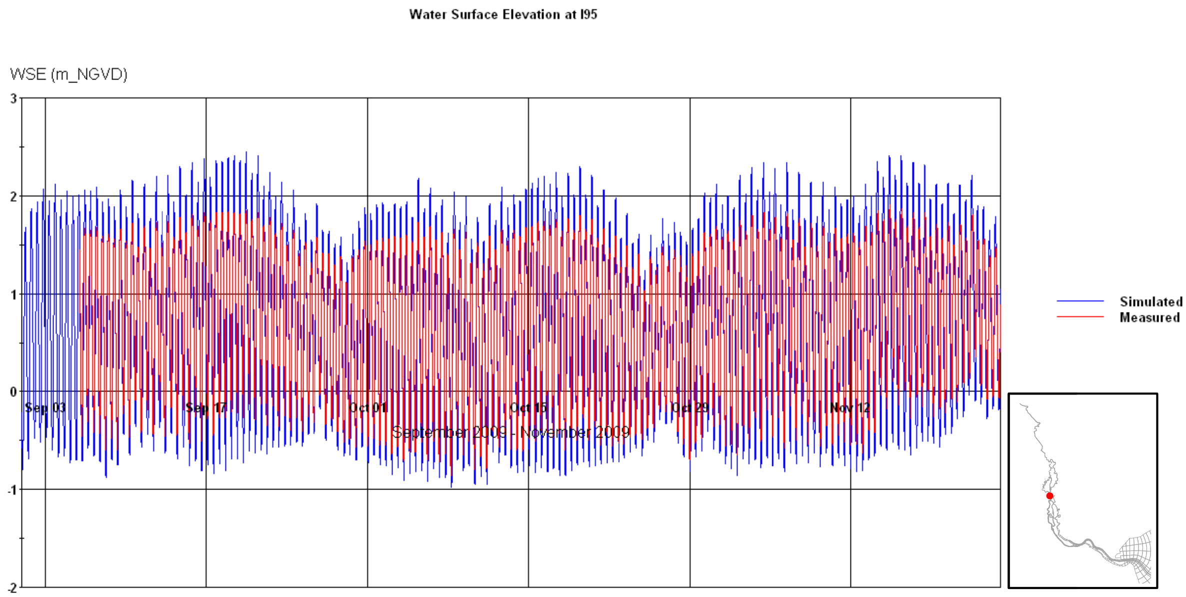

Figure 4-7 Water Surface Elevation comparison at I-95 Bridge.

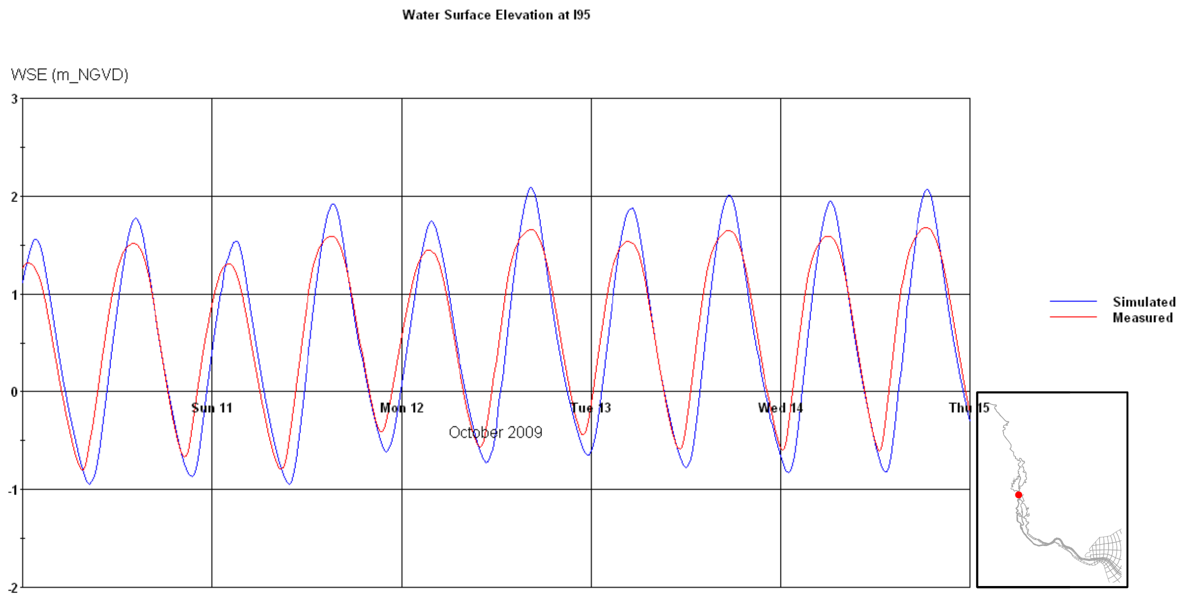

Figure 4-8 Water Surface Elevation comparison at I-95 Bridge.

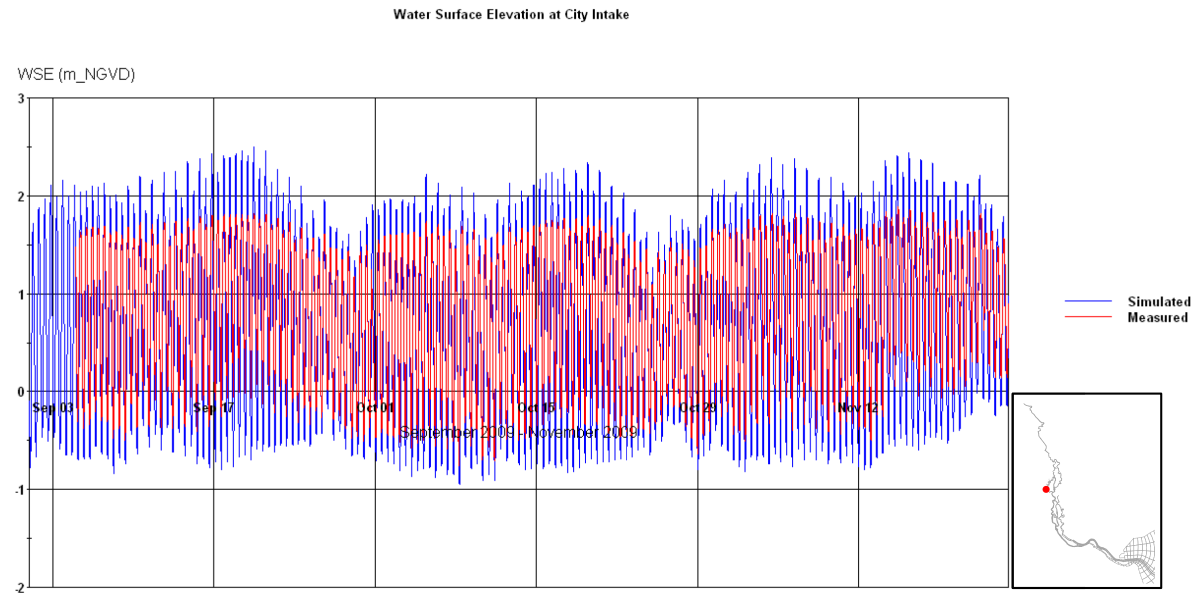

Figure 4-9 Water Surface Elevation comparison at the City water intake on Abercorn Creek.

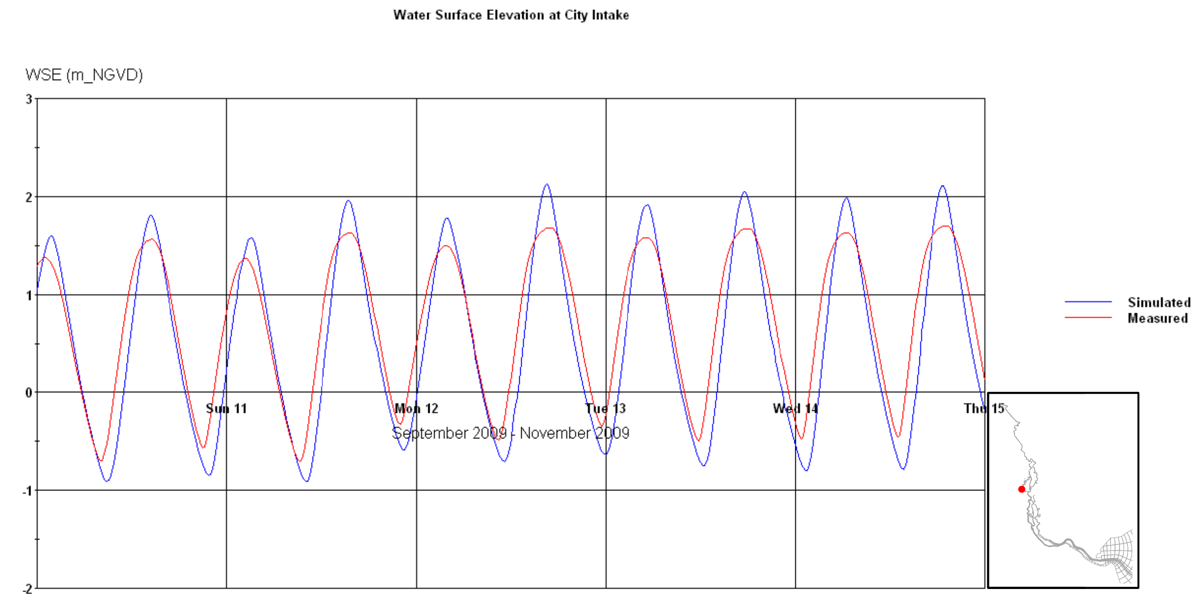

Figure 4-10 Water Surface Elevation comparison at the City water intake on Abercorn Creek.

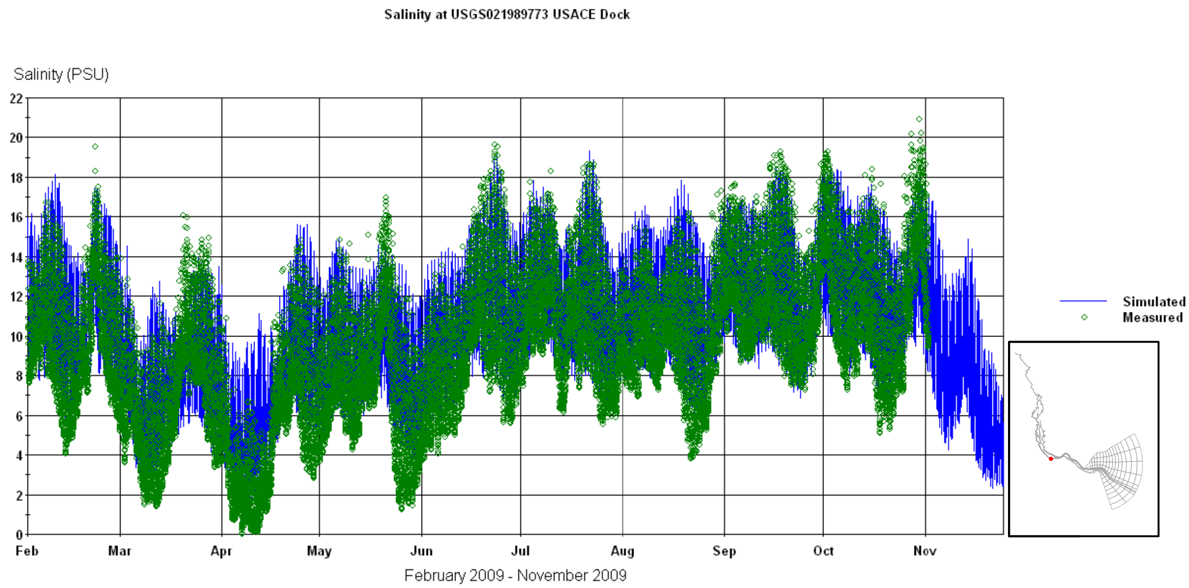

Figure 4-11 Salinity comparison at the USACE Docks on the Front River.

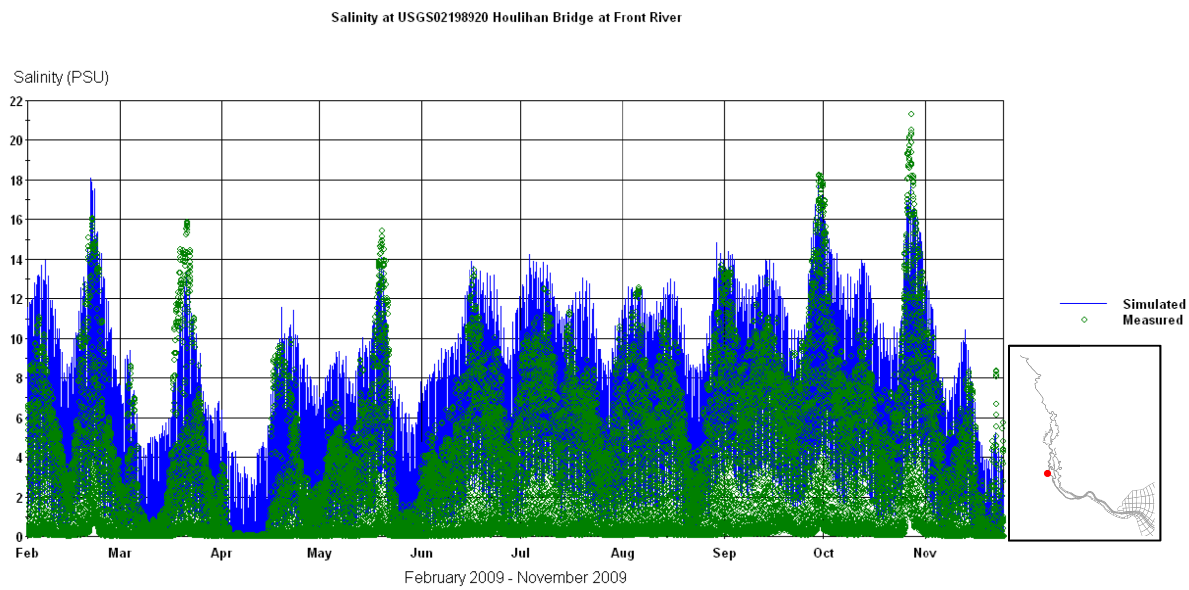

Figure 4-12 Salinity comparison at Houlihan Bridge on the Front River.

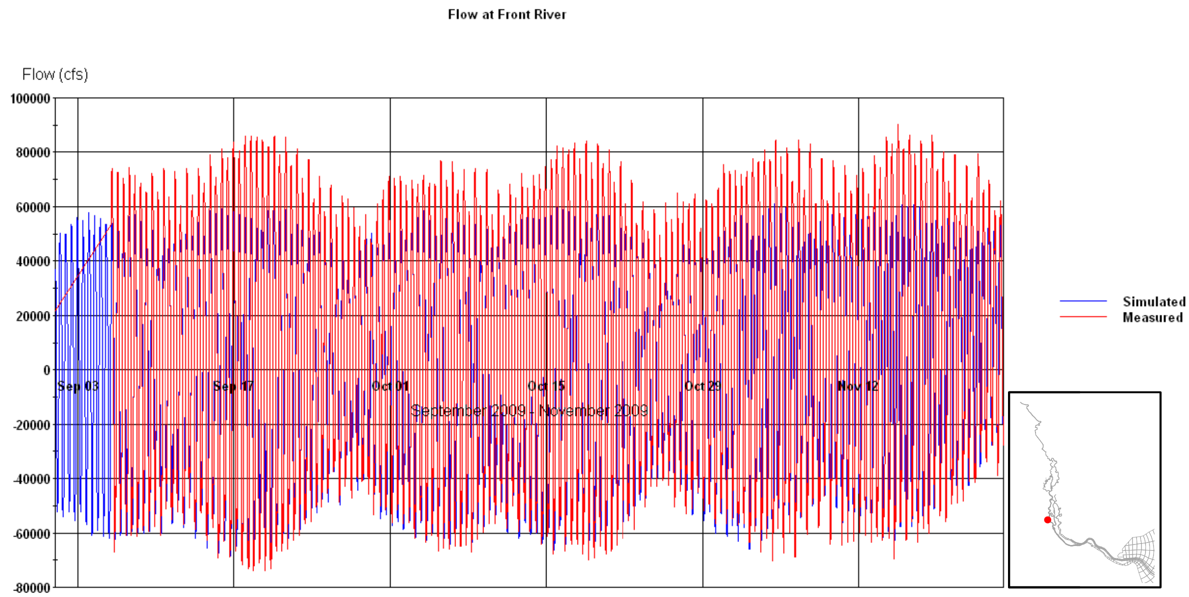

Figure 4-13 Flow comparison at Houlihan Bridge on the Front River.

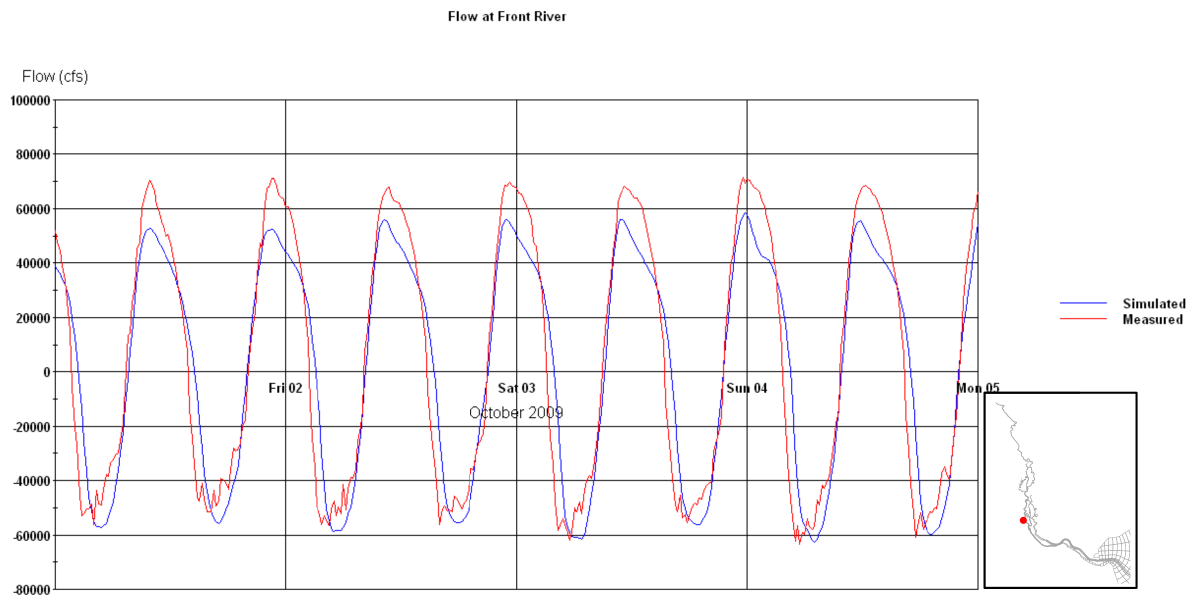

Figure 4-14 Flow comparison at Houlihan Bridge on the Front River.

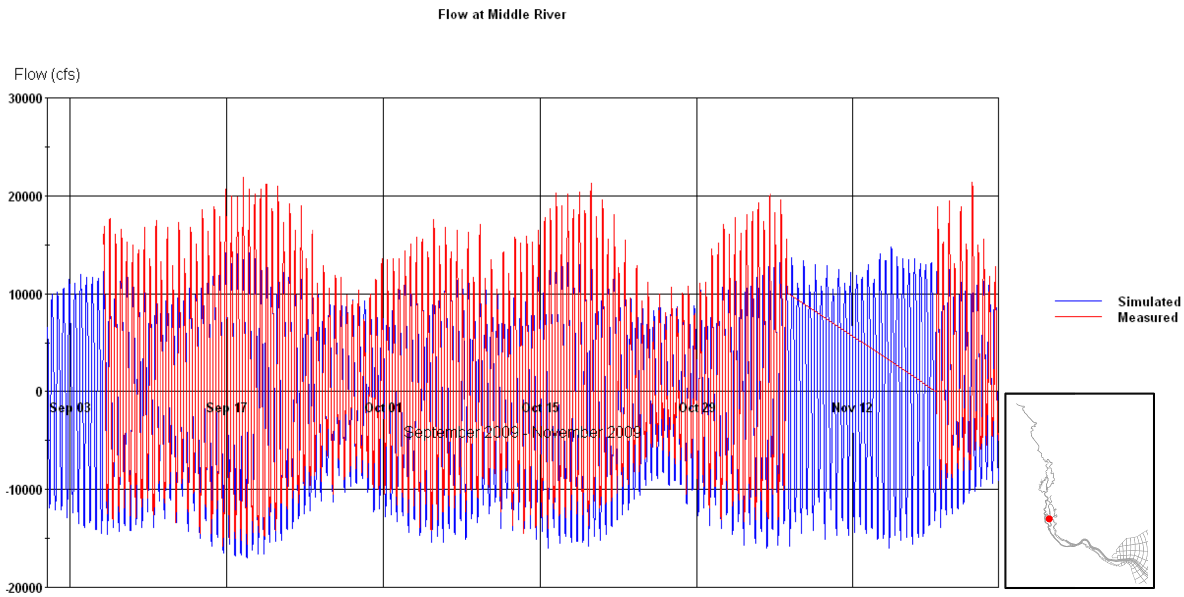

Figure 4-15 Flow comparison at Houlihan Bridge on the Middle River.

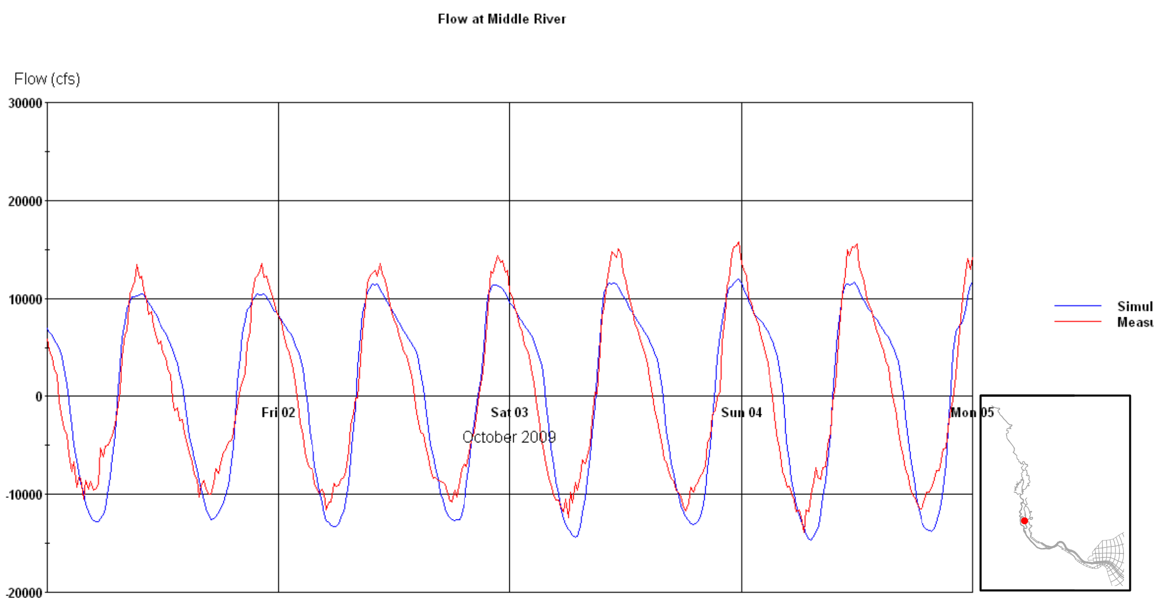

Figure 4-16 Flow comparison at Houlihan Bridge on the Middle River.

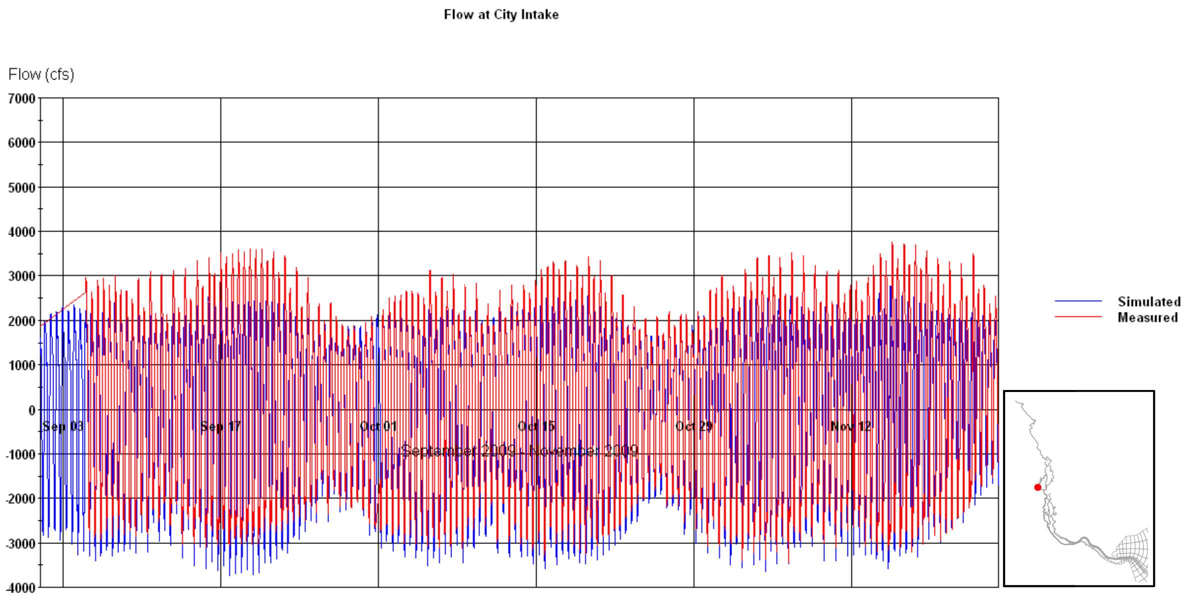

Figure 4-17 Flow comparison at the City water intake on Abercorn Creek.

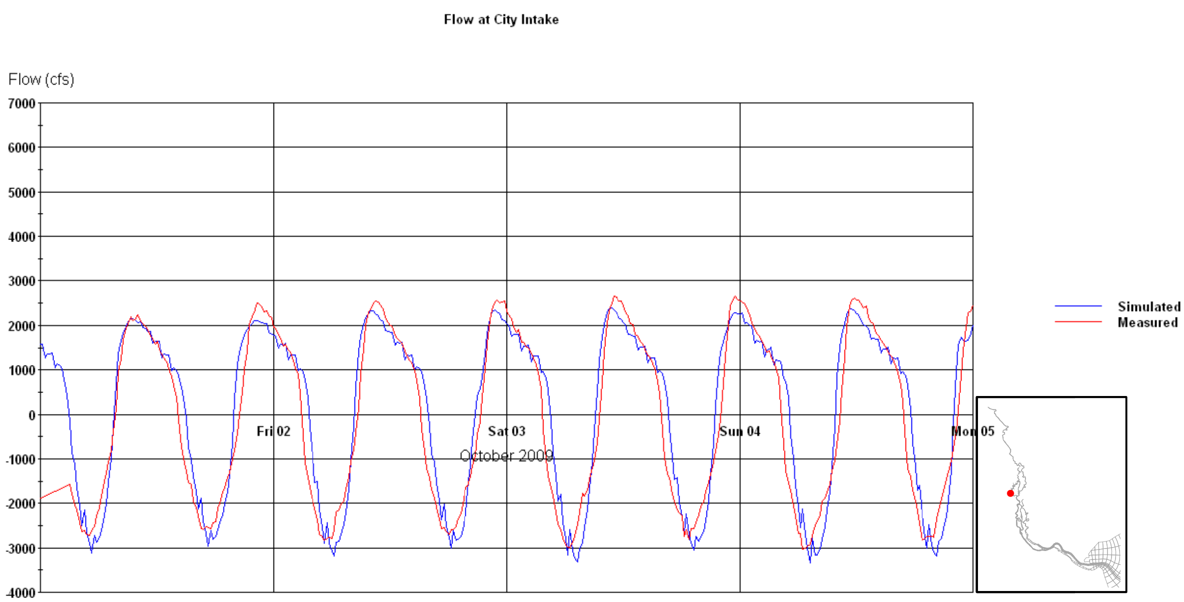

Figure 4-18 Flow comparison at the City water intake on Abercorn Creek.

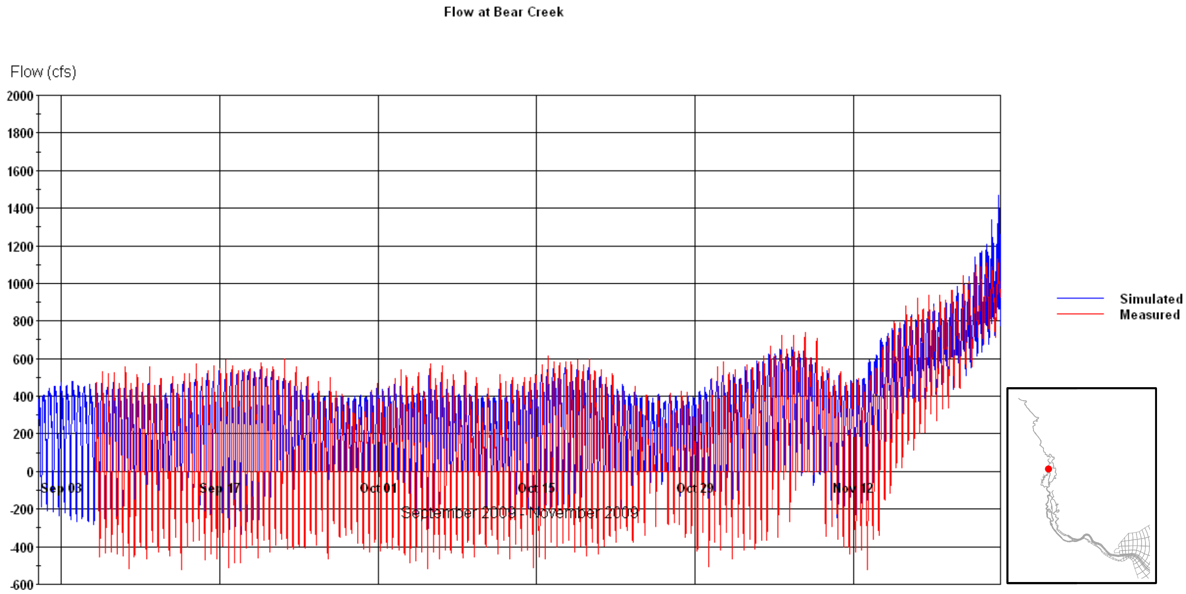

Figure 4-19 Flow comparison at Bear Creek.

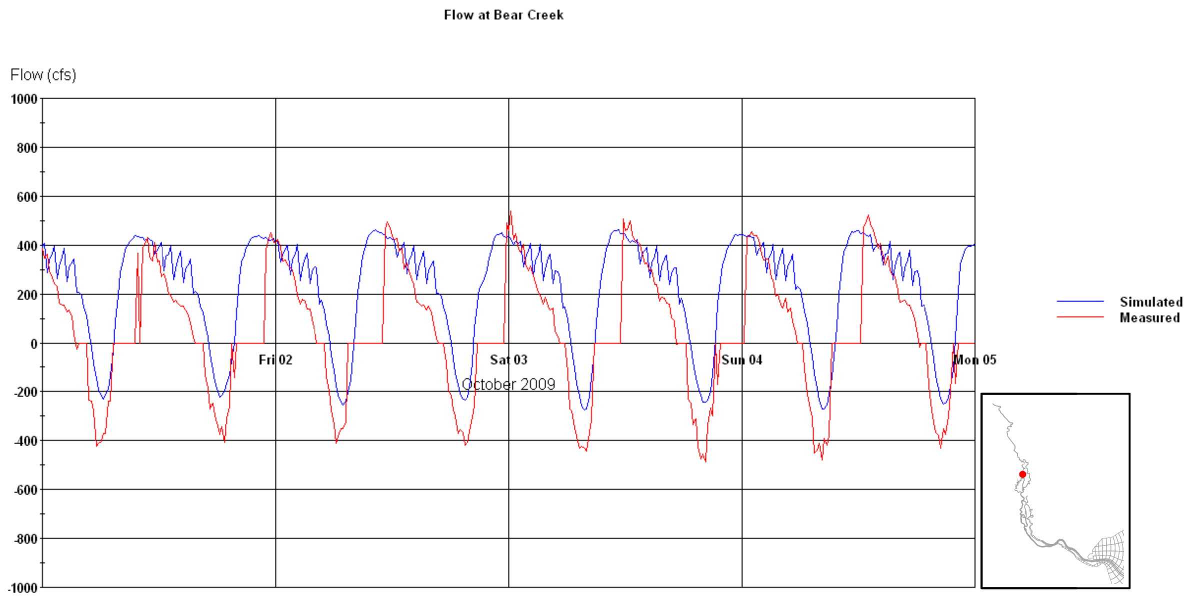

Figure 4-20 Flow comparison at Bear Creek.

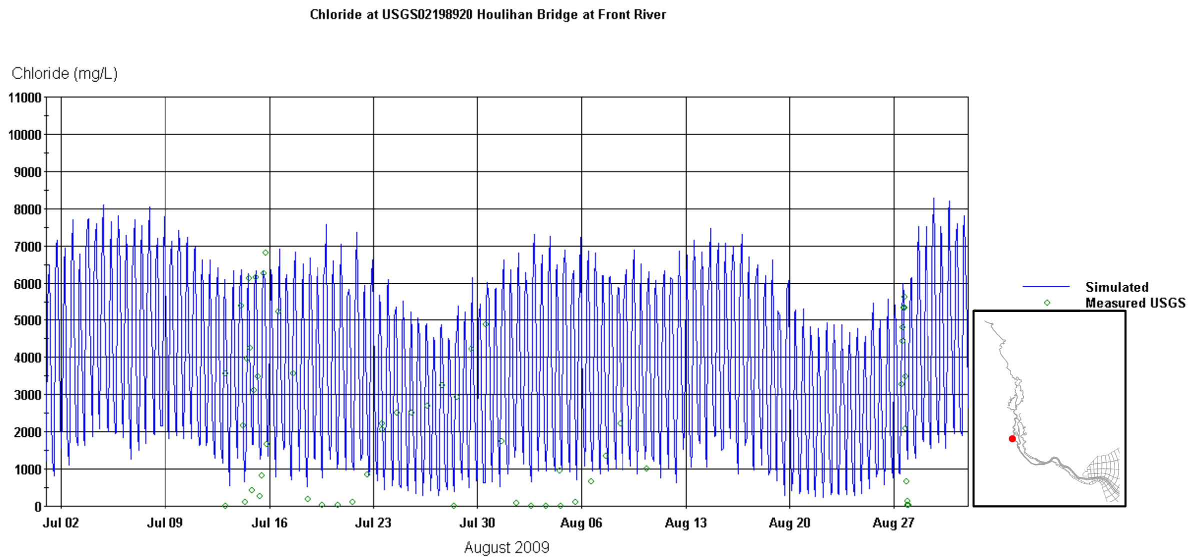

Figure 4-21 Chlorides comparison at Houlihan Bridge on the Front River.

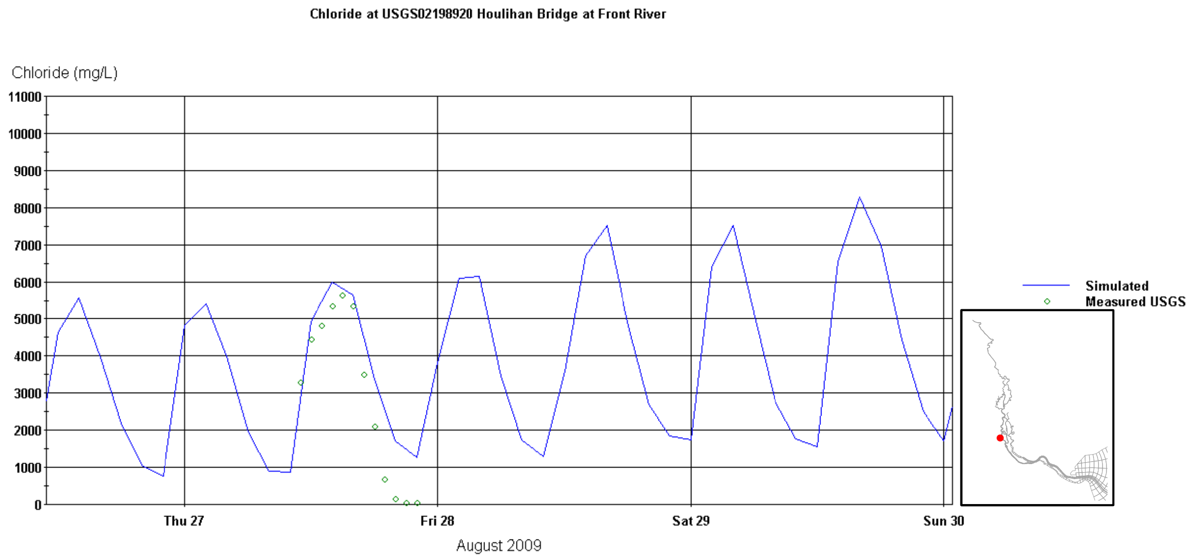

Figure 4-22 Chlorides comparison at Houlihan Bridge on the Front River.

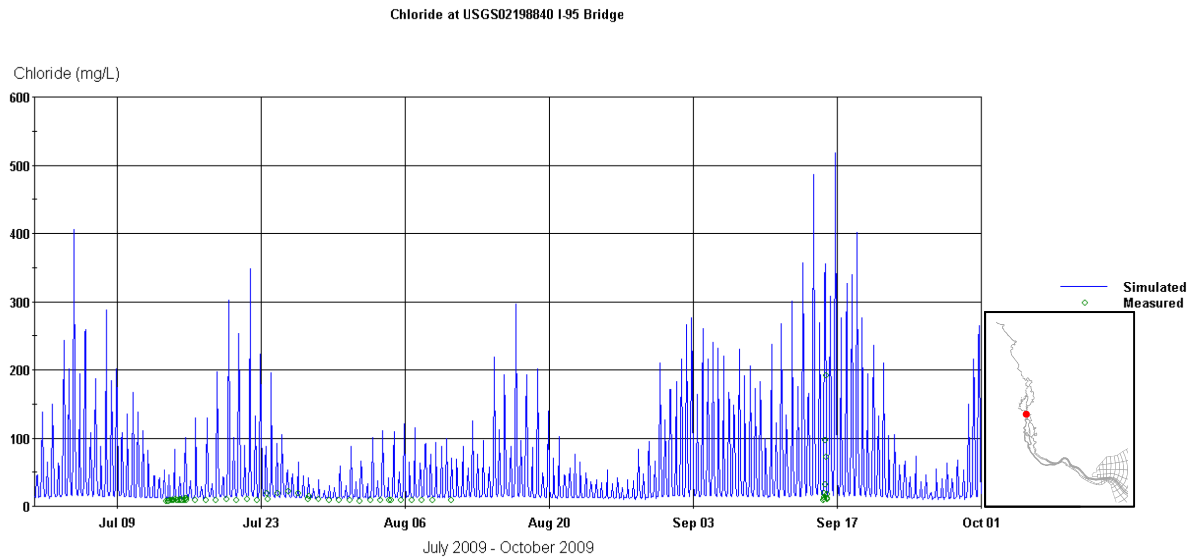

Figure 4-23 Chlorides comparison at I-95 Bridge.

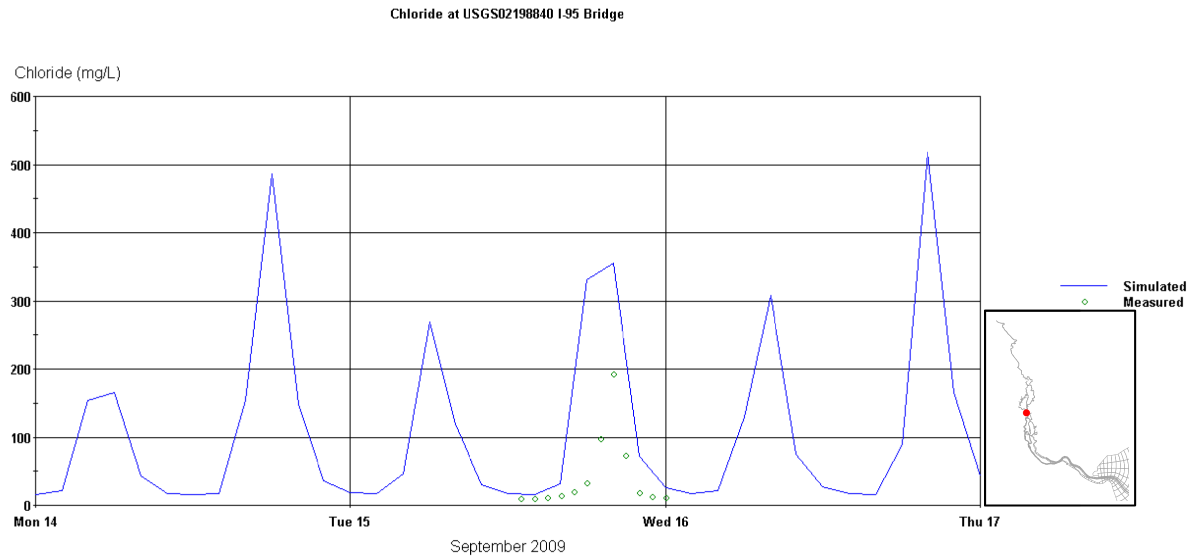

Figure 4-24 Chlorides comparison at I-95 Bridge.

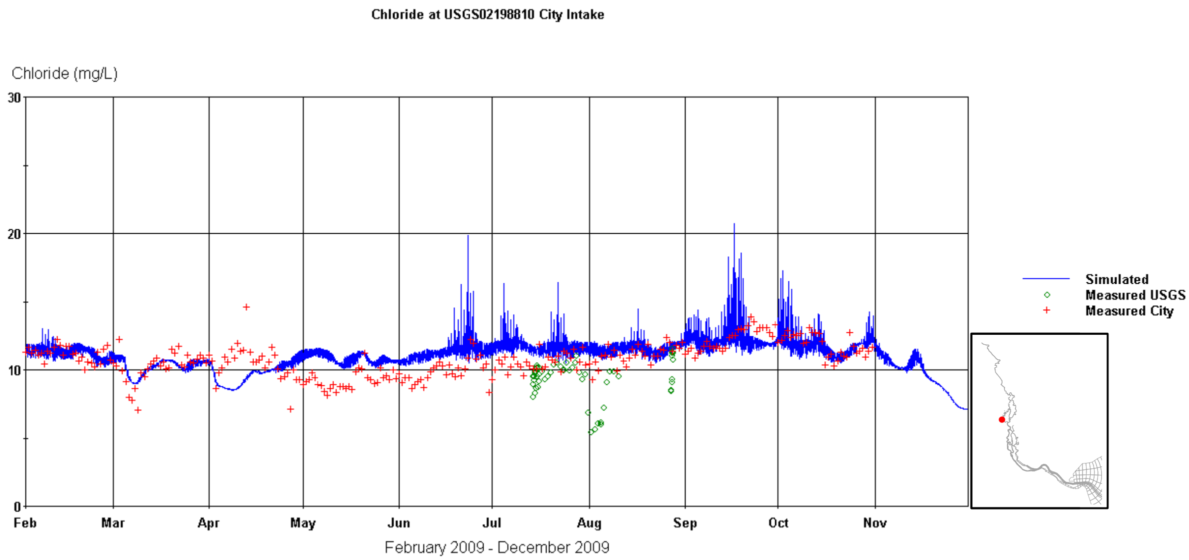

Figure 4-25 Chlorides comparison at the City water intake on Abercorn Creek.

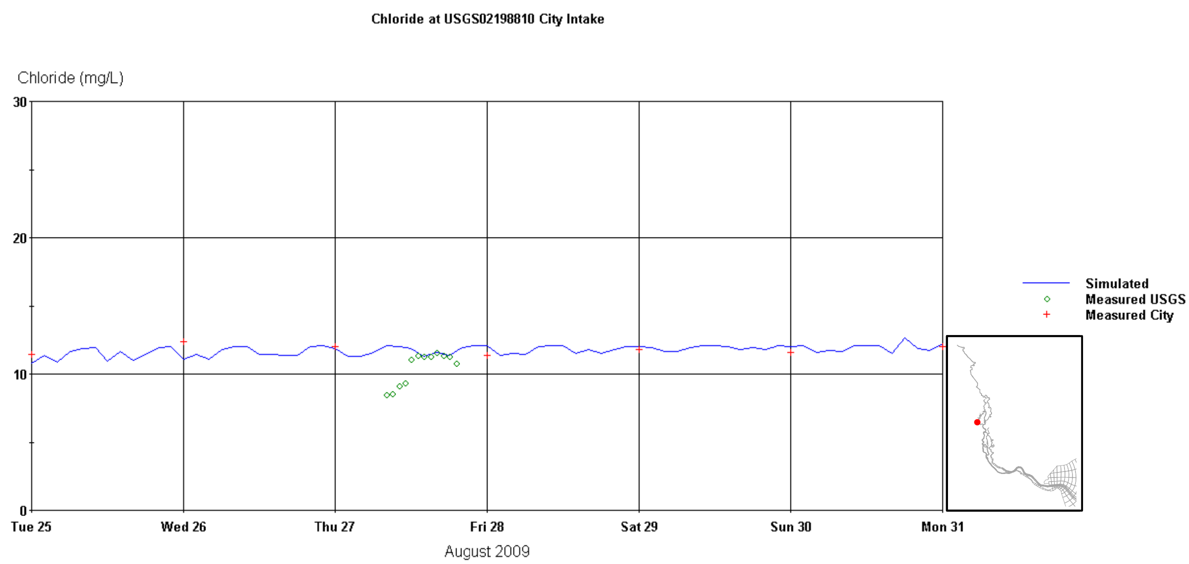

Figure 4-26 Chlorides comparison at the City water intake on Abercorn Creek.

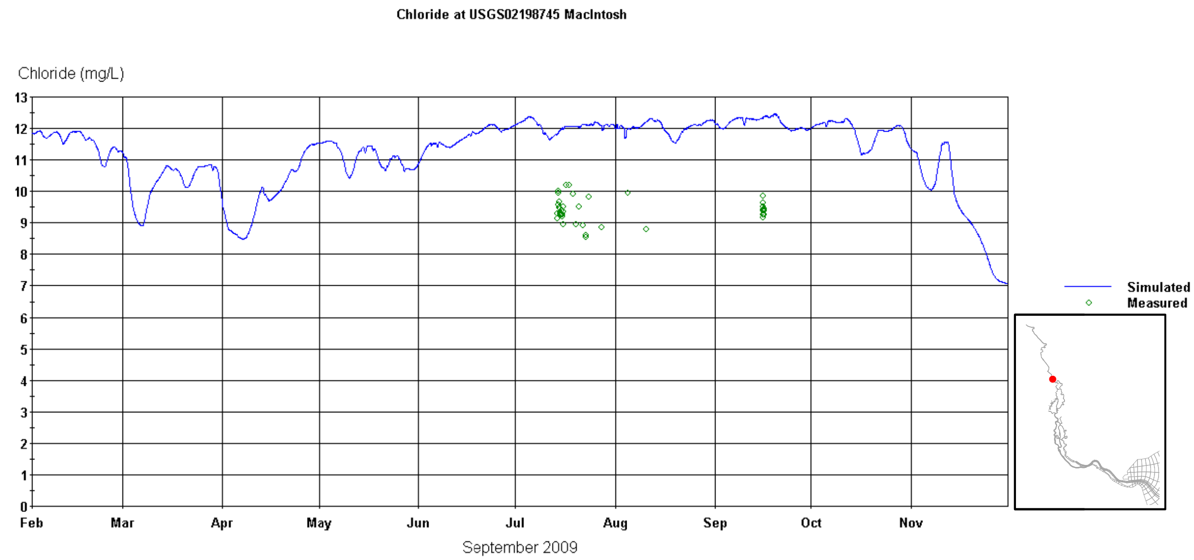

Figure 4-27 Chlorides comparison at MacIntosh.

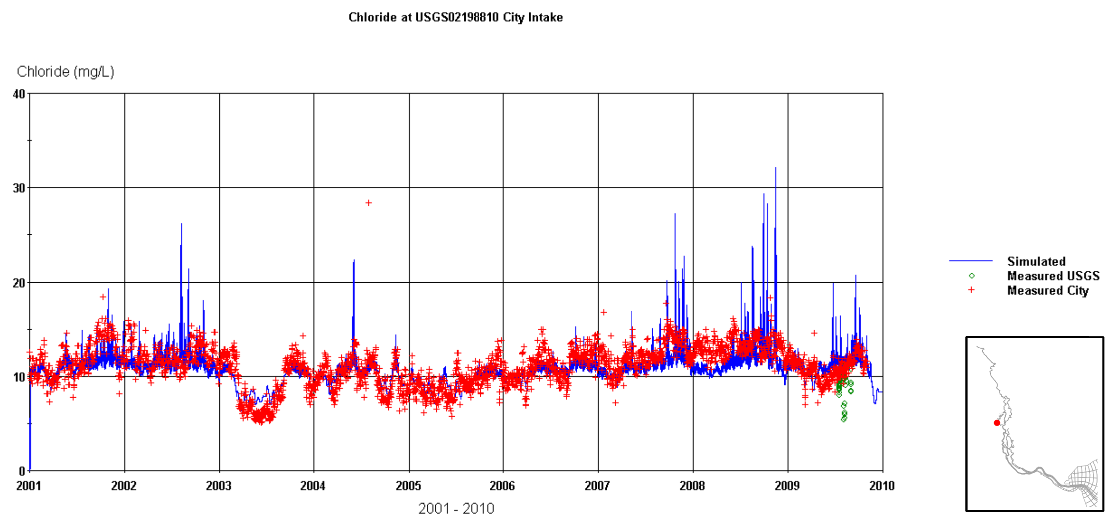

Figure 4-28 Chlorides comparison at the City water intake on Abercorn Creek.

4.5 Downstream Chloride Boundary

A sensitivity analysis on the open boundary value was performed. The goal was to assess the influence of the salinity to chloride ratio used for the open boundary on the chloride at the City of Savannah water intake on Abercorn Creek. As stated before a salinity to chloride ratio of S/C=1.80655 Chlorides based on the 1967 International Agreement on Sea Water was used to obtained the chlorides open boundary condition value.

The open boundary chloride values were changed based on the following ratios:

- S/C = 1.75
- S/C = 1.85

Obtaining open boundary values of chlorides of 20,000 and 18,900 mg/L respectively. Figure 4-29 presents the comparison of chlorides for the different sensitivity runs at the open boundary. Figure 4-30 shows the comparison of chlorides at the City of Savannah water intake on Abercorn Creek for the sensitivity runs. As can be seen, a slight change in the open boundary value or in the accuracy of the 1967 International Agreement on Sea Water S/C ratio has no influence in the chlorides values at this location.

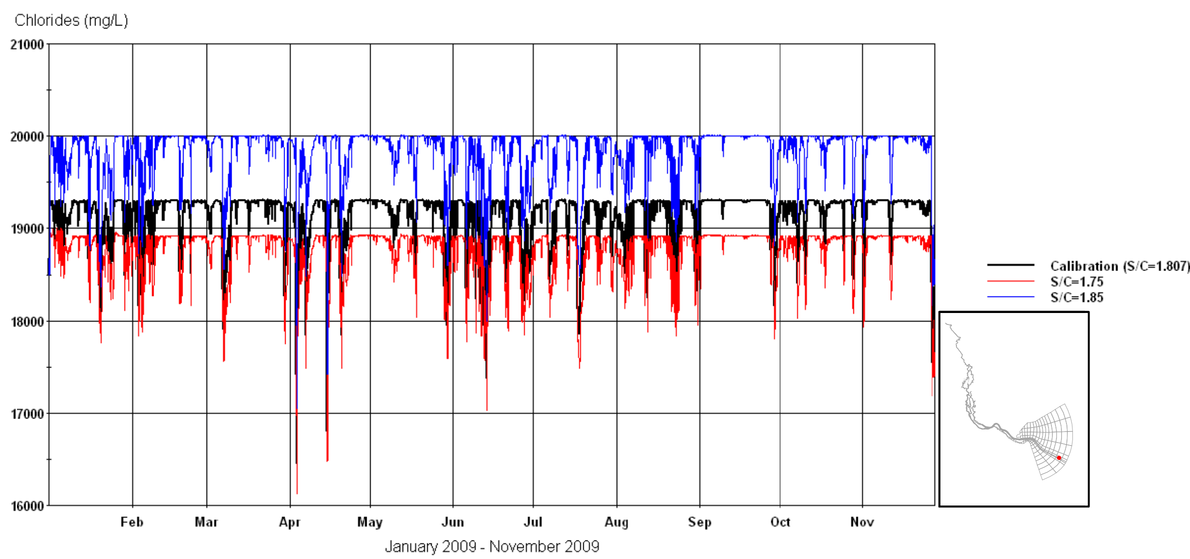

Figure 4-29 Chlorides at the open boundary.

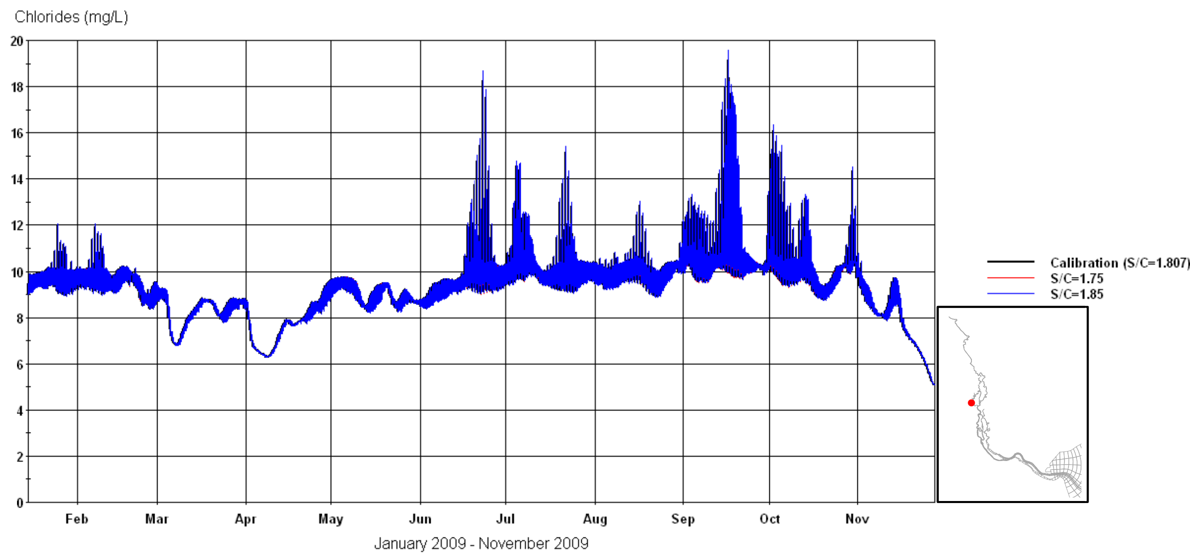

Figure 4-30 Chlorides at the City water intake on Abercorn Creek.

4.6 Upstream Chloride Boundary

A previous analysis of flow and chloride data from the USGS station at Clyo (02198500) was conducted to better understand the relationship of these parameters throughout the Lower Savannah River watershed. There are a total of 28 chloride observations from this station between 1988 and 1994. By plotting these values directly against a flow time-series from the same station, as in Figure 4-31, an apparent power function between the two can be observed. A best-fit line of this nature may be plotted through the points yielding an R^2 of 0.759, indicating quite a strong relationship between flow and chlorides at this station. A plot of the data and the relationship between the two parameters is provided in Figure 4-32. The power function is represented by the following equation;

$$CL = 92.118*FLOW^{-0.436}$$

Figure 4-31 Flow and Chloride Observations at Clyo, GA (USGS 02198500).

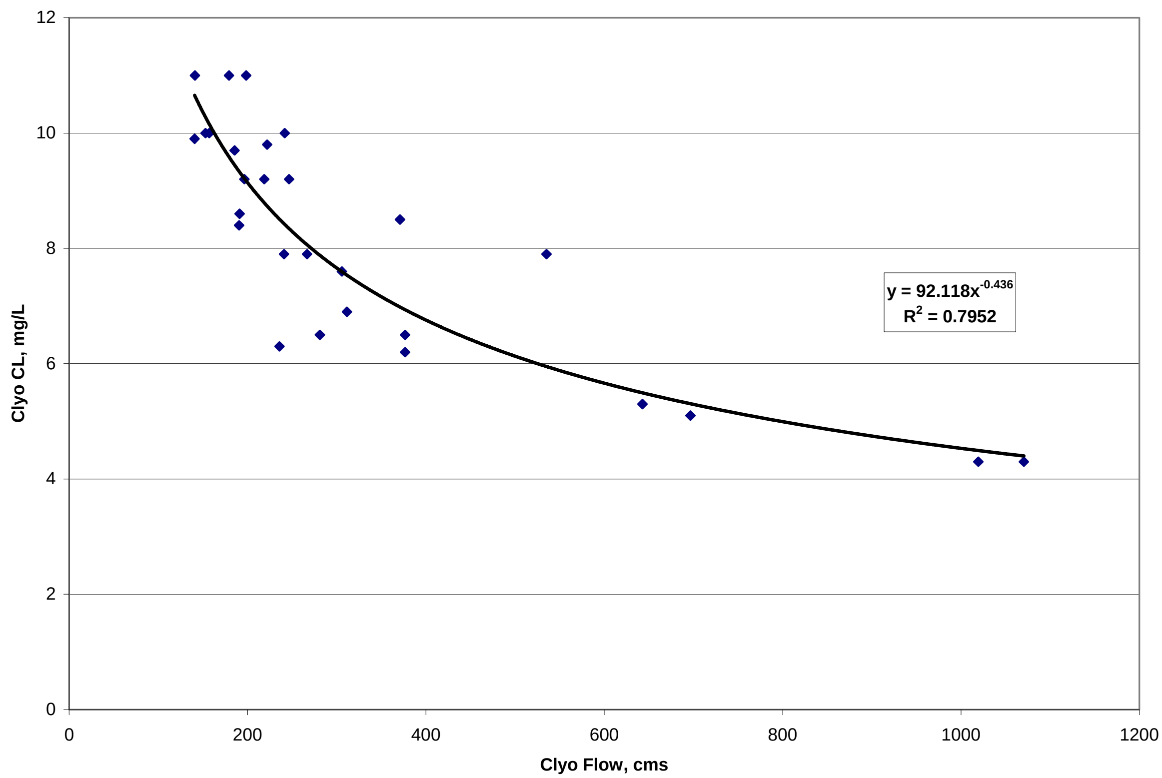

Figure 4-32 Correlation of Flow and Chloride Measurements at Clyo, GA (USGS 02198500).

The chlorides boundary condition at Clyo was based on a regression of chlorides versus flows measurements. Chloride data at Clyo were scarce and outdated so the regression was done with the City of Savannah water intake data (Figure 4-33). A power relation was used between flows and chlorides data. This relationship is fairly constant at high flows with a concentration of freshwater chlorides at 5 mg/L. Then increasing to above 10 mg/L with low flow values. A very similar relationship is obtained with chlorides data measured at Clyo but the relationship using water intake data was considered more précised by being based on more data.

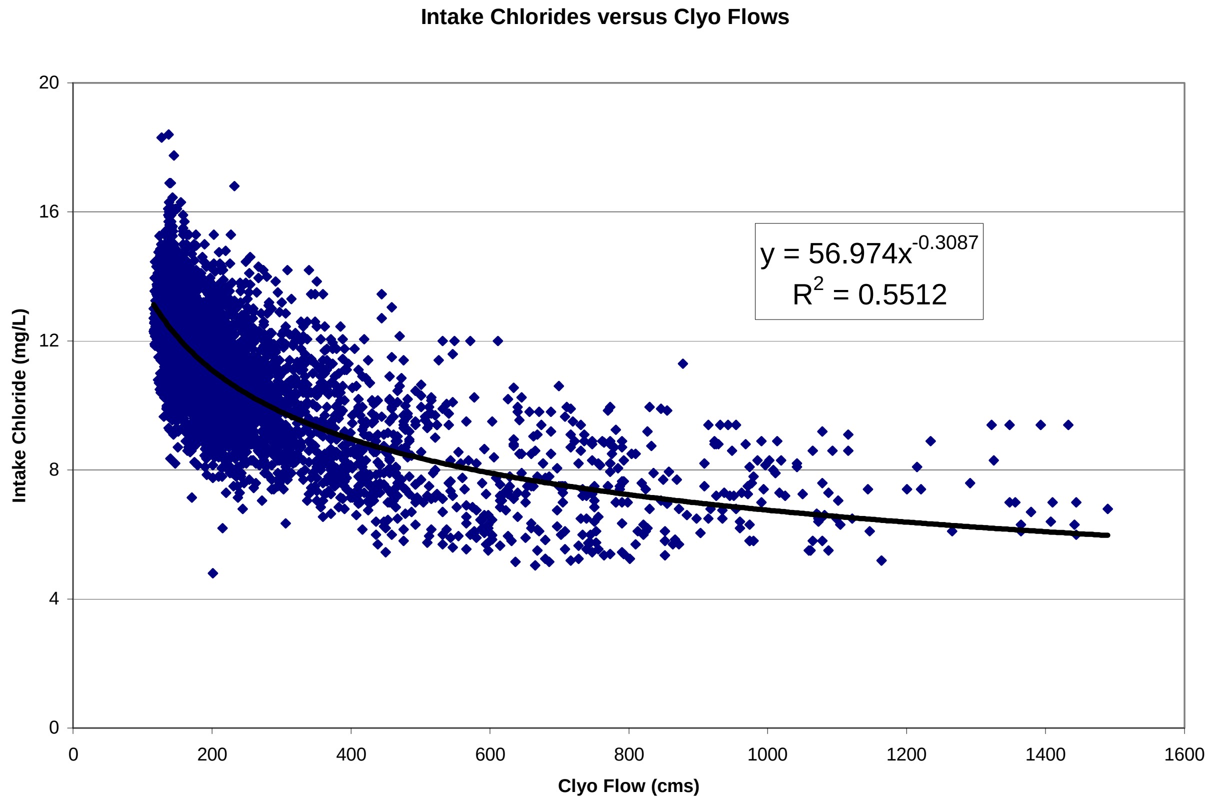

Figure 4-33 Revised Upstream Chloride Relationship with Flow.

5.0 Summary

The EFDC model was used to simulate the chloride dynamics at the City of Savannah's intake. The EFDC model was applied and documented in a 2006 report with the calibration to 1999 and validation to 1997 data. For this effort, the EFDC model was extended through 2009 to compare to the USGS and City of Savannah chloride data. Since the EFDC model had been calibrated before to the hydrodynamic data, Tetra Tech validated with the 2009 water surface elevation, flow, and salinity data. The EFDC model was then calibrated to the chloride data collected at the City's intake starting in 2001 through 2009. The EFDC model compared well to the City's data during dry and wet periods.

The next step is to run the deepening scenarios in the EFDC and examine the chloride response at the City's intake. Also, the EFDC model will deliver delta values of the existing and deepening conditions to the neural net model to predict a response at the City's intake. This work is expected to be completed in May 2010.

6.0 References

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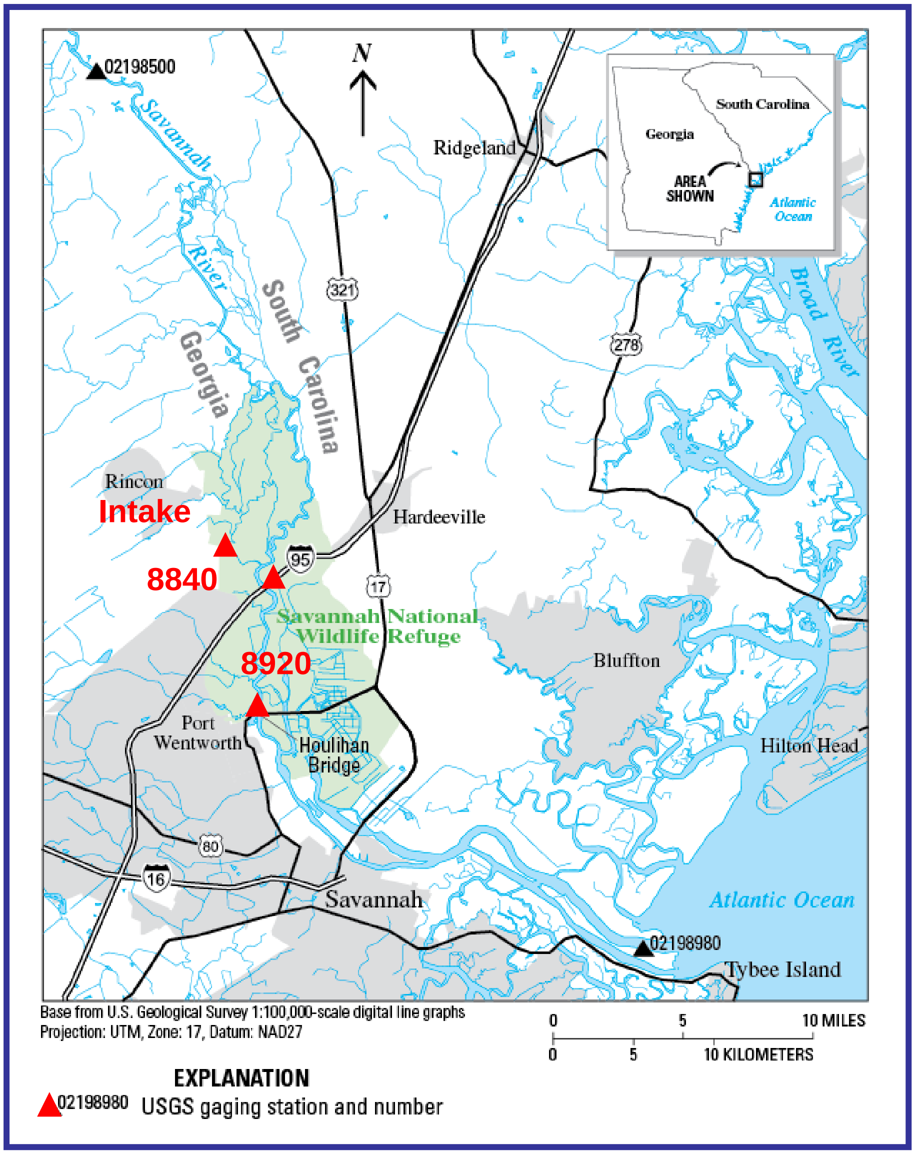
APPENDIX B

ANN Modeling Report, ADMs

SCM: Savannah Chlorides Model



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1. INTRODUCTION

This document describes how to install and operate the "**S**avannah **C**hlorides **M**odel", hereafter called the "SCM". SCM is a "decision support system" (DSS) built around a suite of hydrologic models that predict the daily-measured specific conductivity and chlorides concentration (chlorides) at the City of Savannah's (City) water treatment plant (WTP). The study area is shown in Figure 1.1. Hydrologic behaviors in the study area have been measured at a number of gaging stations operated by the U.S. Geological Survey (USGS) since the mid 1980's.

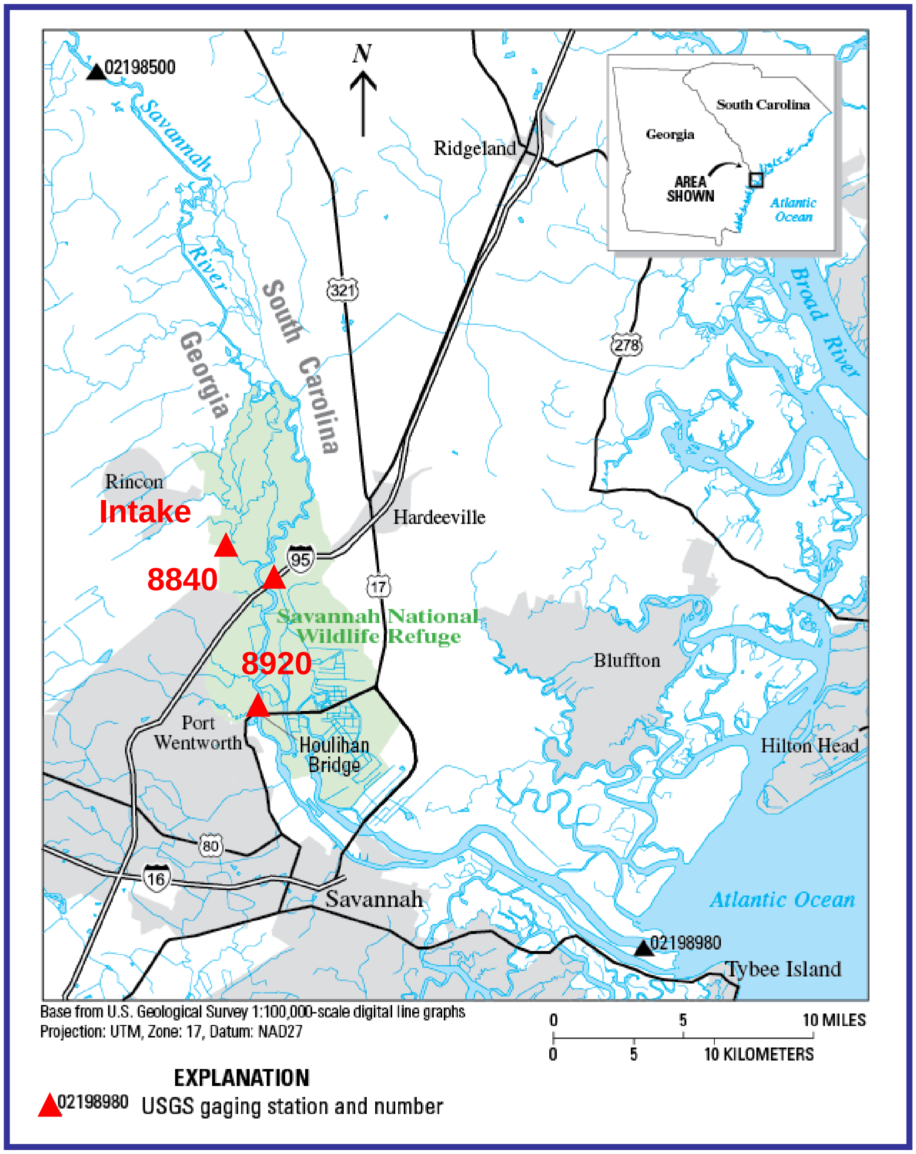


Figure 1.1 (right). Study area showing USGS gage locations (red triangles) where specific conductivity and water level were measured.

1.1 Decision Support Systems

Natural resource managers and users face difficult challenges when managing the interactions between natural and man-made systems. At considerable cost, complex mathematical (mechanistic) models based on first principles physical equations are often developed and operated by senior scientists to evaluate options for using a resource while minimizing harm. However, varying technical abilities and financial constraints among different stakeholders effectively restricts access to relevant scientific knowledge and tools. There is a need to provide equal access to the knowledge and tools required for informed decision-making. DSS technology can help meet this need.

Dutta and others (1997) describe DSSs as, *"computer-based systems helping decision-makers to solve various semi-structured and unstructured problems involving multiple attributes, objectives, and goals…Historically, the majority of DSS have been either computer implementations of mathematical models or extensions of database systems and traditional management information systems…With the help of AI (Artificial Intelligence) techniques DSS have… provided increasingly richer support for decision-making."* Roehl and others (2006) describe how the developers of SCM have proven the efficacy of DSS technology for environmental regulation through the development of DSSs for wasteload permitting on South Carolina's Beaufort River estuary, and for assessing the environmental impacts of a proposed harbor deepening in the Lower Savannah River. On the Pee River, the issue that led to the development of SCM is the regulation of hydroelectric generation in North Carolina to protect coastal fresh water intakes in South Carolina from salinity intrusions.

1.2 Modeling and Artificial Neural Networks

When a DSS is built around a model, the model is the DSS's most important component because ostensibly it can correctly predict, *"What will happen if we do A instead of B?"* Models are often complicated and expensive to develop. While good packaging can broaden their usefulness, a model lacking scientific credibility can delay the resource management process indefinitely. Calibrating a model is a process of fitting a line or surface (function) through data from two or more variables. This can be difficult when the data is noisy or incomplete, and the variables for which data is available may only be able to provide a partial explanation of the causes of variability. Functions are either prescribed or synthesized. The functions prescribed by mechanistic models are physical equations, which incorporate tunable coefficients that are adjusted by modelers to match calibration data. Linear regression is the most common empirical modeling technique. It prescribes straight lines, planes, or hyper-planes to fit calibration data. The insurmountable problem with prescriptive modeling techniques is that if their functions are inherently unable to fit the variable relationships that are manifested in the data, a representative model is unobtainable. In South Carolina, some mechanistic models that have cost millions of dollars and years of effort to develop were never accepted by the regulatory agencies and stakeholders.

According to Conrads and Roehl (2005), calibrating mechanistic estuary models is "particularly difficult due to low watershed gradients, poorly defined drainage areas, tidal complexities, and a lack of understanding of watershed and marsh processes." As described by Jensen (1994), artificial neural networks (ANN) are a machine learning technique from AI. Rather than prescribe functions, ANNs synthesize non-linear functions to fit multivariate data. Conrads and Roehl (1999) found that ANN models had prediction errors that were significantly lower than those of a state-of-the-practice mechanistic model when predicting water temperature, specific conductivity, and dissolved oxygen concentrations on Charleston's Cooper River estuary. Other benefits included shorter development time, fast execution that lets ANNs be coupled to numerical optimizers and embedded in spreadsheets, and integrating ANNs with mechanistic models to improve predictions of how non-point source loading from rainfall and tidal marsh fluxing affect dissolved oxygen concentrations.

1.2 Initial Observations

SCM's ANN models predict how the specific conductivity and chlorides concentration at the water intake, hereafter SC and CH respectively, vary with freshwater flows measured at the

Clyo gage (Q8500), and tidally forced specific conductivity measured at the "8840" gage (SC8840). Figure 1.2 shows the historical trends of SC8840, SC, and Q8500. Observe that the spikes in SC8840 occur during periods of low Q8500, and the low frequency (non-spiky) trend of SC8840 mirrors Q8500 and overlays SC. Figure 1.3 shows two views of the same 3D scatter plot of SC versus Q8500 and SC8840. The left view shows that the majority of the points (vectors) lie at SC8840 < 200 μS/cm. The few vectors at higher SC8840 values indicate that SC stops increasing with SC8840 (red arrow), which in Figure 1.2 corresponds to the lack of SC tracking the SC8840 spikes. The right view in Figure 1.3, with the horizontal axes rotated clockwise approximately 90 degrees, shows that some higher SC values occur at low values of SC8840. This suggests the possibility of measurement errors.

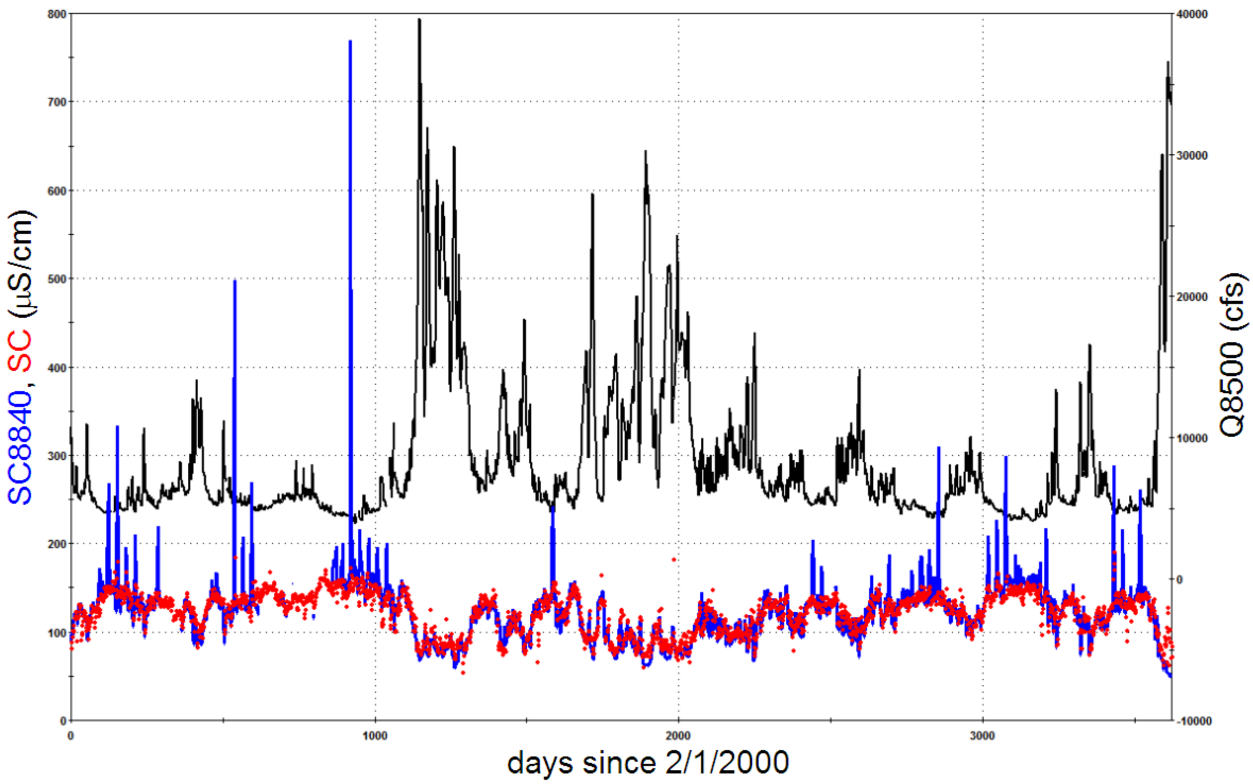


Figure 1.2. Historical SC8840, SC, and Q8500.

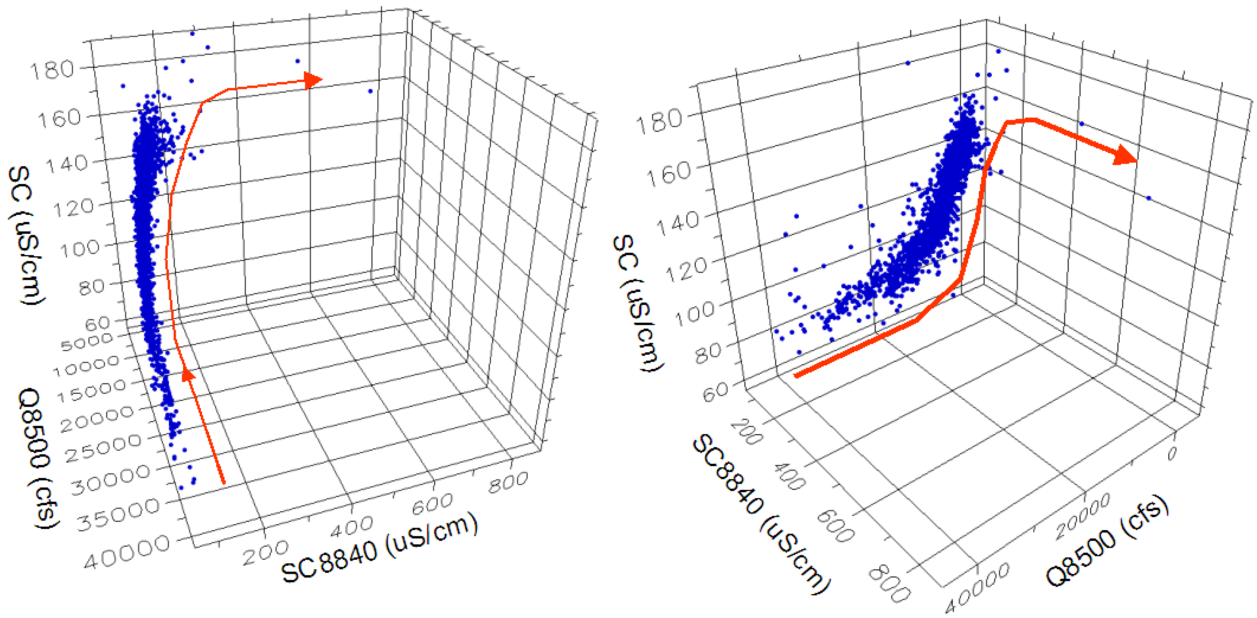


Figure 1.3. 3D scatter plot of SC, Q8500 and SC8840.

Figure 1.4 shows the SC and CH trends, and Figure 1.5 is a scatter plot of CH versus SC. While there is apparent tracking, the extent of scatter and low R^2=0.57 is a bit surprising and suggests causes of CH variability that are unrelated to seawater intrusion, such as measurement error. The 3D scatter plot shown in two views in Figure 1.6 shows that increasing Q8500 nonlinearly reduces CH (arrow at left), and that CH increases linearly with SC at low Q8500 (arrow at right).

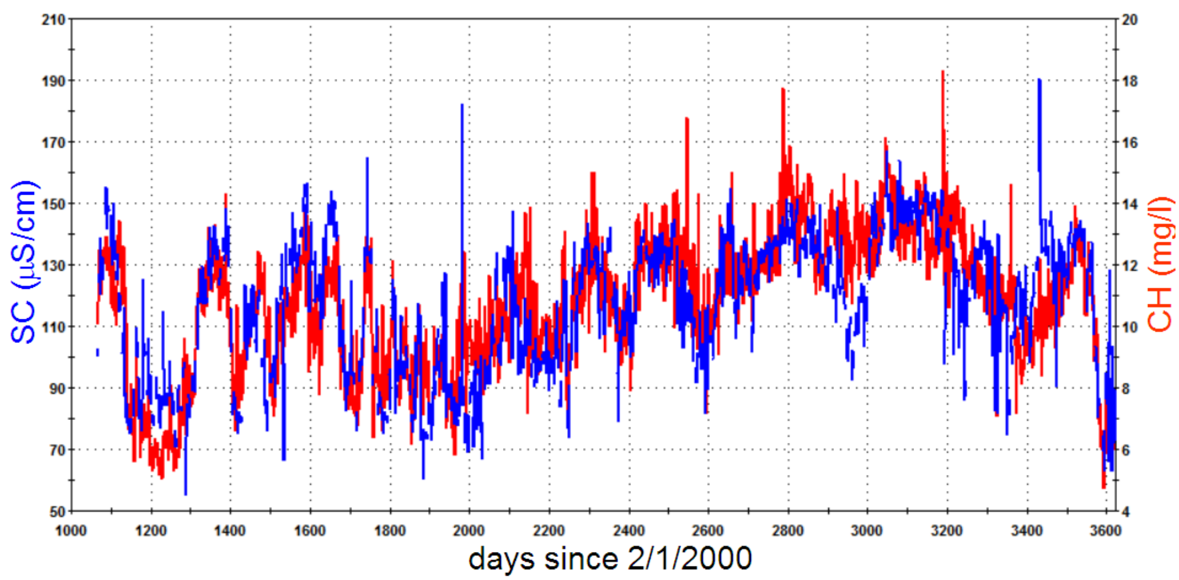


Figure 1.4. SC and CH.

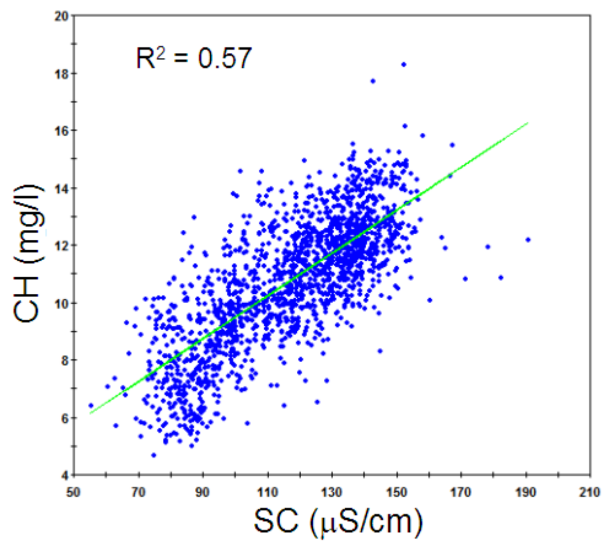


Figure 1.5. Scatter plot of CH and SC.

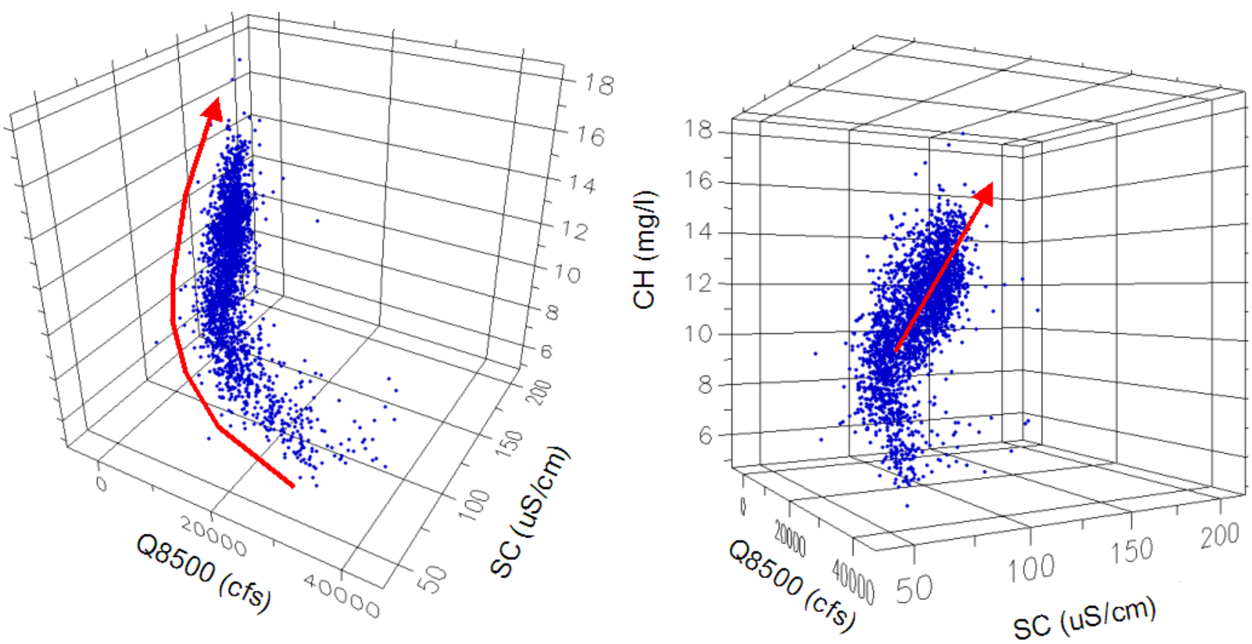


Figure 1.6. 3D scatter plot of CH, Q8500 and SC.

2. DESCRITION OF SCM'S MODELS

SCM is an EXCEL™/VBA (Visual Basic for Applications) program that integrates historical data, the computed results generated by a 3D EFDC hydrodynamic model, multiple artificial neural network (ANN) sub-models that comprise a "super-model" of SC and CH behavior, streaming graphics, and a graphical user-interface. The EFDC model was developed to evaluate harbor deepening and mitigation scenarios, and its output is used to bias the super model inputs to estimate the scenarios' impact on SC and CH. The data covers the period from 2/1/2000 to 10/31/2009 and is composed of daily average Q8500 and SC8840, maximum daily ambient temperature (TMAX) measured at the 8840 gage, SC, CH, and the City raw water color (COLOR) These data were used to develop the ANN's, and are included in the application so that the user may run long-term simulations to evaluate permutations of the actual historical record.

ADMS have applied ANN models to many dynamical systems, including riverine, estuary, and ground-water hydrologic systems. The ANN models are fully capable of accurately modeling complex, nonlinear dynamics with suitable input-output parameter representation schemes. After appropriate input parameter decorrleation, the resultant signals can be decompose into moving window averages and differences between moving window averages, which is similar to spectral band-pass filtering, but is reversible without information loss. In natural systems, window sizes are commonly related to variability brought by orbital motions, e.g., tides and seasons, and can be further confirmed by power spectra analysis. Input-output time delays can be estimated by cross-correlation. It is left to ANN machine-learning to fit (or "learn") these inputs nonlinearly, and rapid prototyping with sensitivity analysis to arrive at near optimal model configurations.

A generalized schematic of the SCM architecture for predicting specific conductance and chloride concentrations is shown in figure 2.1 The approach is essentially a two-stage model where the first stage predicts specific conductance at the intake and the second stage is predicting chloride concentrations at the intake using the predicted specific conductance at the intake. An error correction model is then used to minimize the error in the predicted chloride concentrations.

The development of an ANN-based model was undertaken to meet a number of

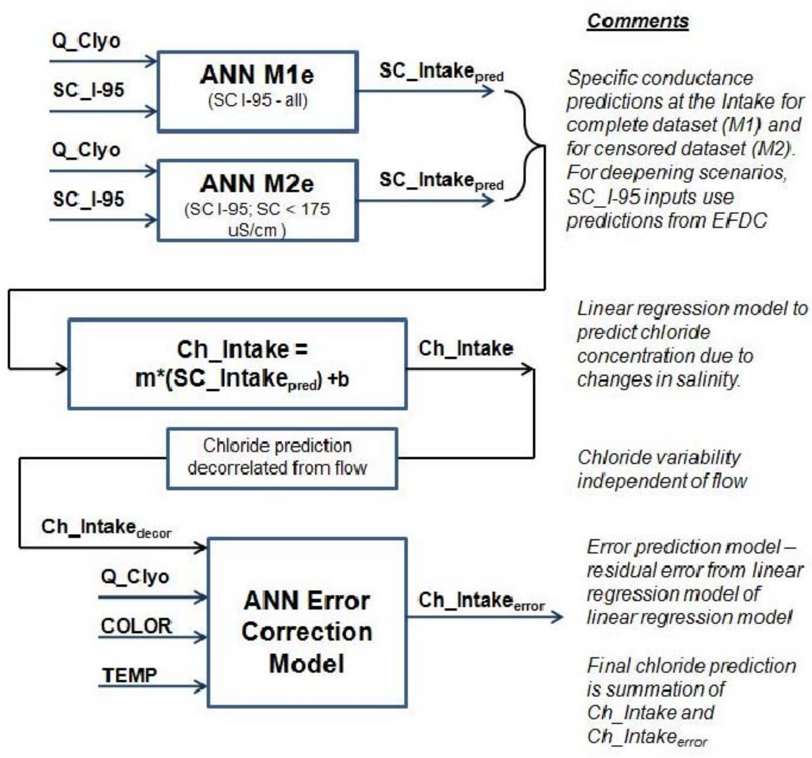


Figure 2-1. Schematic showing the architecture for the chloride concentration model.

objectives. The primary objective was to complement the findings obtained using a preexisting, but modified, EFDC application to the Lower Savannah River, which had been developed for an earlier study related to the harbor deepening (Tetra Tech, 2006). An earlier model application for the Savannah Estuary involved the development of ANN models that integrated the EFDC model output with a plant ecology model of the adjoining Savannah National Wildlife Refuge (Conrads and others, 2006). It was found that, while the EFDC application performed adequately on simulating historical hydrodynamic behaviors in the largest river channels, the ANN models were more accurate at simulating measured specific conductance behaviors in the upper extents of the estuary. For comprehensiveness, it made sense to use both modeling approaches for this important study.

The main technical objectives of the ANN model development included:

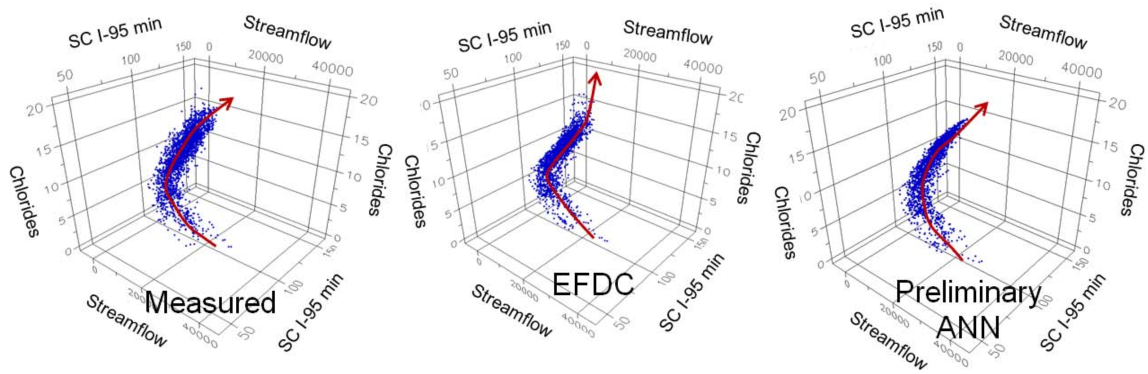
1) Simulate the important dynamics of the system of salinity intrusion from I-95 to the intake.
2) Extrapolate salinity condition to EFDC predicted deepening and mitigation conditions at I-95 having maximum salinities that are approximately three times higher than historical maximums.
3) Flexibly accommodate the consequences of intermediate results, such as the censoring of the higher specific conductance data (described below).

Sensitivity analysis is an integral part of the modeling process, which involves the systematic construction and evaluation of prototype models. It tells the model developer what parameters have predictive information about outputs of interest, and how best to configure the inputs to maximize the predictive performance of a model. Sensitivity analysis also provides indications of which inputs improve model performance and those that are unneeded. These indications are verified by adding, deleting, or reconfiguring inputs to prototypes and then evaluating them.

ADMS exhaustively evaluated alternative approaches to the ANN modeling of chlorides at the intake. Only the final models are documented in the report. A major concern that drove the chosen super-model's architecture was Objective #2, especially given the paucity of historical, saltwater intrusion events manifest in the data in hand. Such large extrapolations generally require that an empirical model's input-output relationships be explicitly defined when extrapolating, as they are in a mechanistic model.

Preliminary simulations using EFDC predicted that the salinity values at I-95 (station 02198840) will be much greater than the historical range. The three-dimensional scatter plots of streamflow at Clyo, GA, specific conductance (SC) at I-95, and chlorides at the Intake are shown in figure 2.2. The curved arrow through the data points shows how the actual data and EFDC and ANN models could be used to extrapolate conditions beyond the historical range. The plot of the data shows that there is a mild gradient or increase in chlorides with decreases in streamflow and increases in specific conductance. The data points from EFDC show a larger gradient and larger increases in chlorides with decreases in streamflow and increases in specific conductance. The data points from preliminary ANN models show a lower gradient, more closely matching the trend of the measured data.

Figure 2.2. Three-dimensional scatter plots of streamflow, specific conductance, and chlorides. Chloride values are measured or simulated with the EFDC or ANN models.



Because of the rarity of saltwater intrusion events, there are a limited number of data points that describe the relation between high specific conductance values at I-95 and the intake (figures 1.3). For example, the numbers of data points when specific conductance values at I-95 are above 300 µS/cm are less than five with a large degree of scatter. The USCOE was concerned that these few data points would determine the extrapolation of an ANN model and potentially under estimate the effect of deepening the harbor on chloride concentrations at the intake. To accommodate these concerns, it was decided to develop two chloride models for the intake (see figure 2.1 above). The first model (ANN M1) was developed using all the data. The second model (ANN M2) was developed using only data when specific conductance at I-95 was less than 175 µS/cm. Deleting these data removes the “plateau” effect and extrapolation by a well-fitted ANN model would show large increases in specific conductance at the intake with large increases of specific conductance at I-95. The ANN M1 model will have a low sensitivity to specific conductance at I-95 and the ANN M2 model will have a high sensitivity to specific conductance at I-95.

2.1 Detailed Description of the SC Super-Model

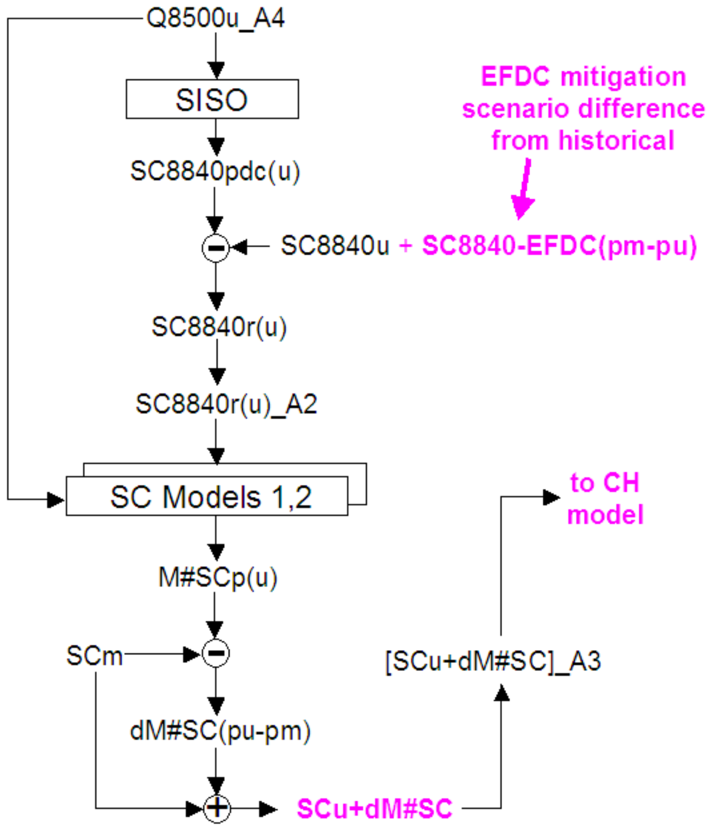


Figure 2.3. Super-model architecture for predicting SC.

Figure 2.3 shows how SC is predicted from measured and user-defined (user) inputs, denoted by suffixes m and u. Starting at upper left, SC is predicted as follows.

1. Q8500u_A4 = 4-day moving window average (MWA) of the user Q8500. SCM provides a number of options for inputting Q8500. Near optimal MWA window sizes were estimated using custom software called the “Tau-Tool”, which computes the window size and time delay at which an input is most highly correlated to an output per the Pearson coefficient. Here, no time delays were used.
2. SC8840pdc(u) = SC8840u predicted by a single-input-single-output (SISO) ANN from input Q8500u_A4 for the purpose of decorrelating it from Q8500u_A4, to which it is dependent and highly correlated. pdc(u) means predicted for decorrelating with user input.
3. SC8840-EFDC(pm-pu) = the difference between EFDC predictions of SC8840 with historical measured inputs and user mitigation scenario inputs. It is used to bias the SC8840u input to the ANNs that predict SC. (pm-pu) means predictions with measured inputs minus predictions with user inputs.
4. SC8840u + SC8840-EFDC(pm-pu) = SC8840u bias by SC8840-EFDC(pm-pu). SCM provides a number of options for inputting SC8840.
5. SC8840r(u) = SC8840u + SC8840-EFDC(pm-pu) SC8840pdc(u), the decorrelated SC8840u. r(u) means residual error with user inputs. Figure 2.4 shows the measured SC8840 with the ANN predictions and residual error, and the nonlinear predicted output

versus input relationship. Note that the low frequency SCC8840 variability is fitted well by the ANN, which misses the large spikes that largely result from tidal forcing.

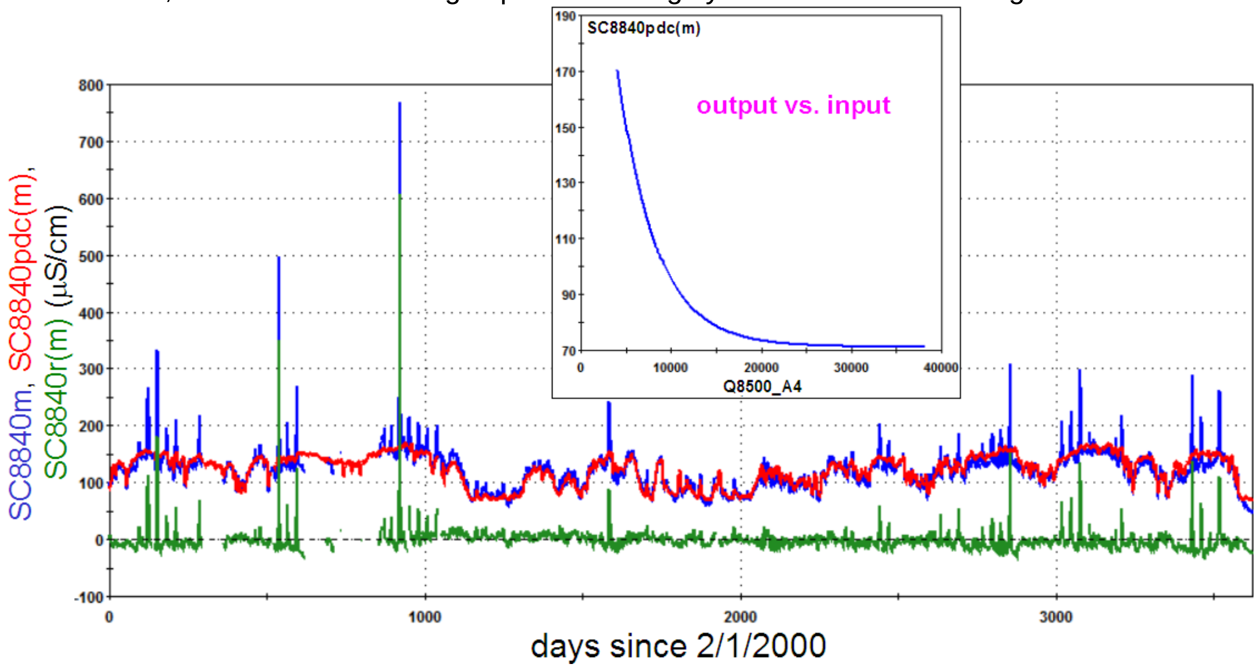


Figure 2.4. SISO ANN model for decorrelating SC8804 from Q8500_A4. Number of hidden layer neurons (HLN) = 1. Training (train) / testing (test) data statistics: number of input-output vectors (N) = 2,631 / 617; correlation coefficient (R^2) computed from the Pearson coefficient = 0.62 / 0.59; root mean squared error (RMSE) = 22 / 24 µS/cm.

6. SC8840r(u)_A2 = 2-day MWA of SC8840r(u).
7. M#SCp(u) = the ANN-predicted SCu. There are two ANN models, Model-1 and Model-2 that predict M1SCp(u) and M2SCp(u) from inputs Q8500u_A4 and SC8840r(u)_A2. The two models are architecturally the same, but different SC8840m data were used to train them in order to make them extrapolate differently. Model-1 was trained using vectors derived from the full range of SC8840m data as shown in Figure 1.3. To more closely match the predictions of EFDC, which predicts little attenuation of SC relative to SC8840, the vectors used to train Model-2 were derived from SC8840m < 175 µS/cm as shown in Figure 2.5.

   Figures 2.6 and 2.7 show the model results for Model-1 and Model-2, with the latter figure comparing the predictions of both models. While the differences appear small, Model-1 predicts some small spikes that Model-2 does not. Figure 2.8 shows the two models' "response surfaces", which visualize the models' input-output maps. Some notes: as a consequence of the cutting, Model-1's SC8840r()_A2 input range is an order of magnitude greater than for Model-2; at low Q8500, Model-1 extrapolates asymptotically with increasing SC8840r()_A2, whereas Model-2 extrapolates more linearly.

   The modeling problem for which SCM was developed anticipates that SC8840 could increase greatly above historical maximum values because of harbor deepening and subsequent mitigation to protect the Savannah National Wildlife Refuge from seawater inundation. The iQuest™ software used to develop the ANNs appropriately allows for some extrapolation using input values outside historical ranges, but not to the extent deemed necessary here. As shown in Figures 2.9 and 2.10, the approach taken here was: Model-1 and Model-2 were used to generate a set of input-output vectors from randomized inputs constrained to values within their historical ranges; additional vectors were created to define how SC would respond to SC8840 above historical values; new versions of the models, Model-1E and Model-2E, were trained using the synthetically created vectors. The linear extrapolations shown in Figures 2.9 and 2.10 at the indicated Q8500_A4 were generated by extending the line between model predictions at the endpoints of the last 1/100th of the SC8840r(m)_A2 historical ranges.

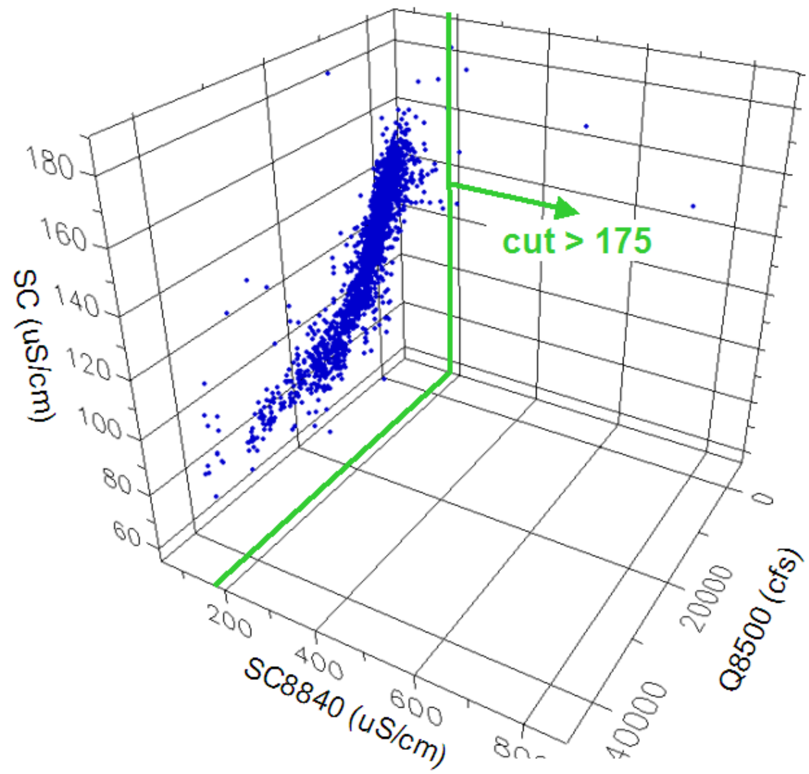


Figure 2.5. Cutting training vectors for SC Model-2.

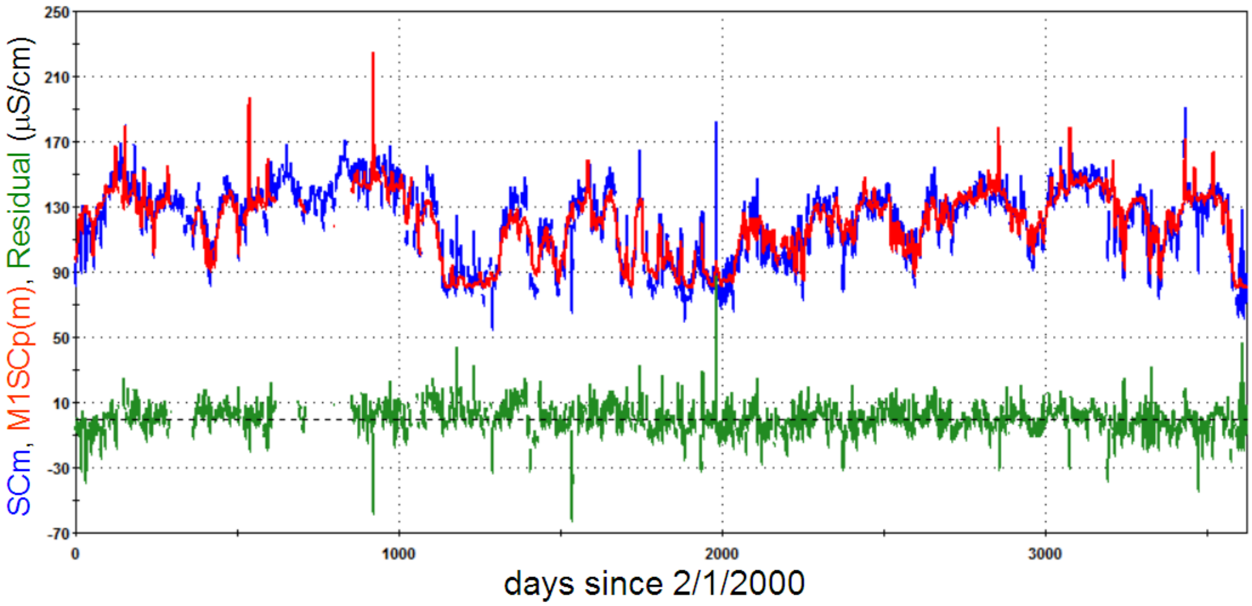


Figure 2.6. SC Model-1 results. HLN = 1; Train / test statistics: N = 1,312 / 900; R^2 = 0.82 / 0.84; RMSE = 9.2 / 9.2 µS/cm relative to a range of 135.5 µS/cm.

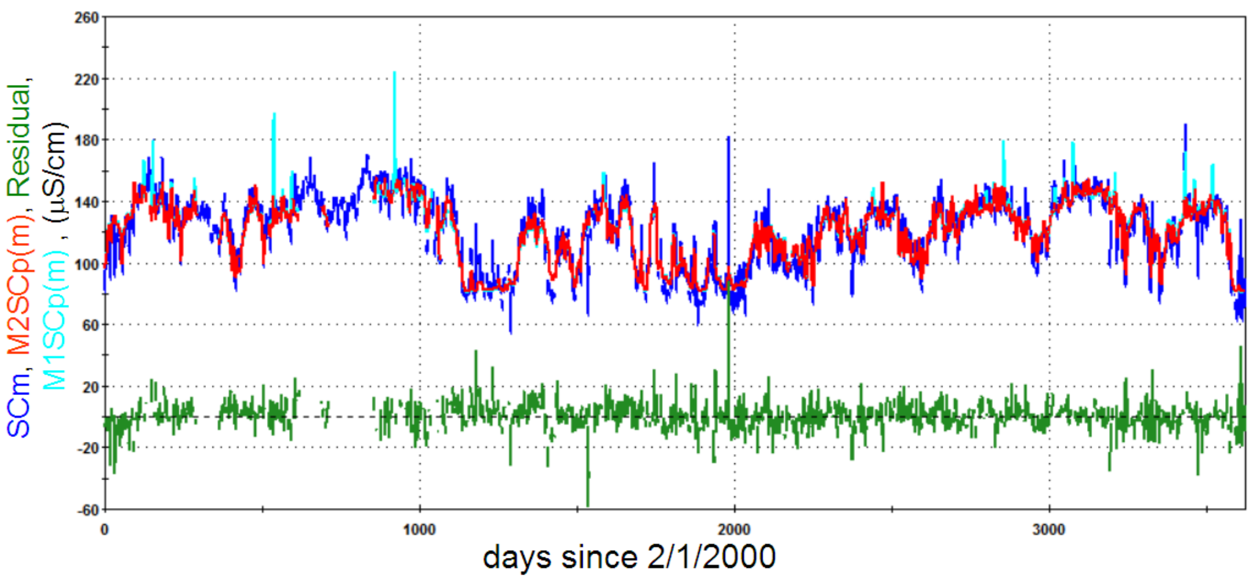


Figure 2.7. SC Model-2 results. HLN = 1; Train / test statistics: N = 1,247 / 851; R^2 = 0.83 / 0.85; RMSE = 8.7 / 8.5 µS/cm relative to a range of 127.2 µS/cm.

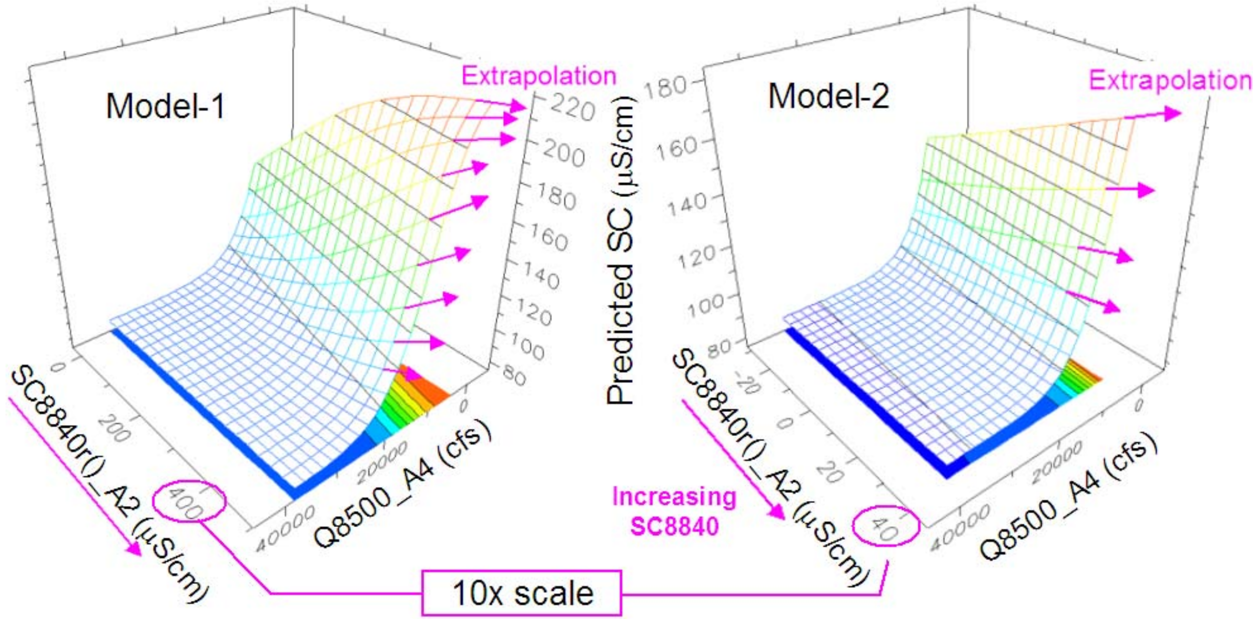


Figure 2.8. Model-1 and Model-2 response surfaces.

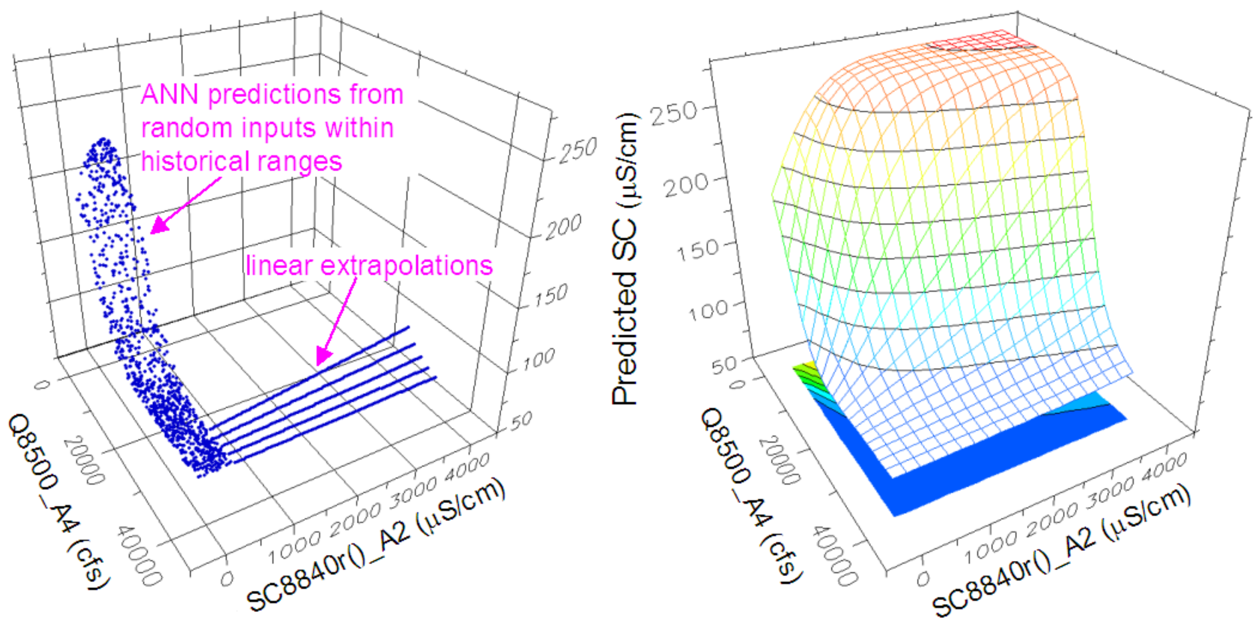


Figure 2.9. Model-1E train and test vector set (left) and response surface (right). HLN = 2; Train / test statistics: N = 317 / 1,183; R^2 = 1.00 / 1.00; RMSE = 2.4 / 2.5 µS/cm relative to a range of 147.3 µS/cm.

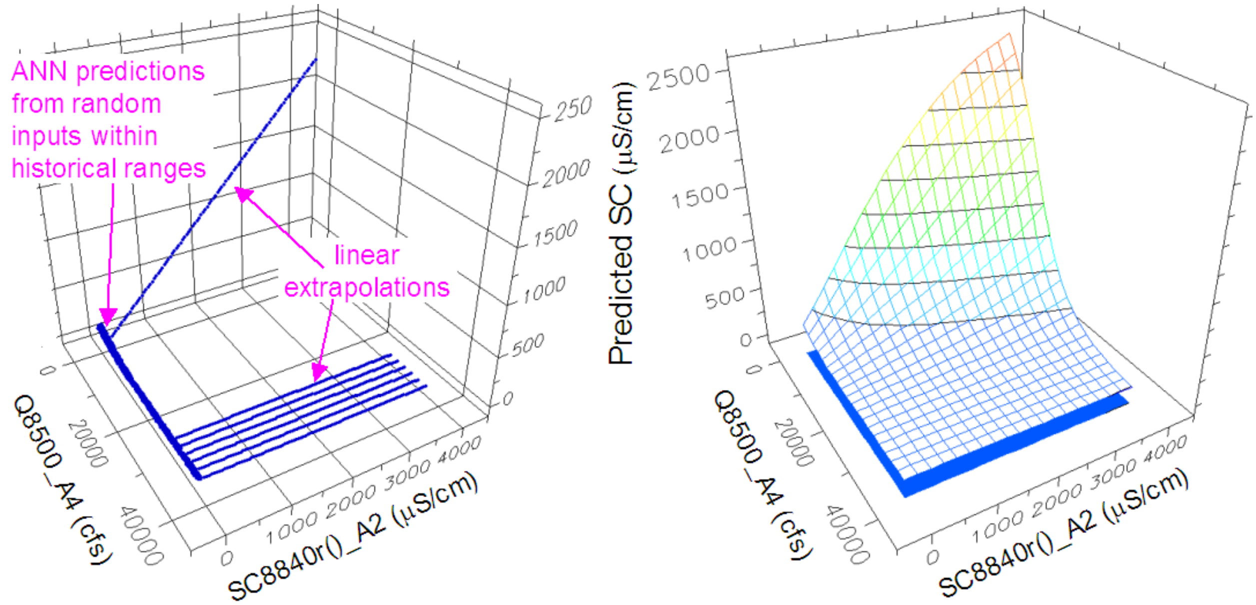


Figure 2.10. Model-2E train and test vector set (left) and response surface (right). HLN = 5; Train / test statistics: N = 326 / 1,374; R^2 = 1.00 / 1.00; RMSE = 9.2 / 10.5 µS/cm relative to a range of 2,266 µS/cm.

8. dM#SC(pu-pm) = SCm – M#SCp(u). At a given time step, this is the difference between the measured, historical SC and the Model-1E and Model-2E predictions made with user-defined inputs.
9. SCm+dM#SC = SCm + dM#SC(pu-pm), the final prediction of SCu.

2.2 Description of Chloride (CH) Super-Model

For developing the chloride model at the intake, two long-term datasets were used – the daily sampling data from intake and the gaging data from the river gage at I-95. The modeling process discovered how the physical system behaves to the fullest extent possible given the available data, and the subsequent final super-model is parsimonious in composition. Of the 20 parameters sampled by the City, only Color was significant for predicting chloride concentrations. Of the 4 measured parameters at I-95, specific conductance was the most significant (along with streamflow measured upstream) for predicting chloride concentrations.

Although the "super model" diagram (Figure 2.11) shows multiple models, some of these are decorrelation models or error correction models. The chloride predictions (linear regression model, M*[SCm=dM#SC]_A3+b, Figure 2.11) are made using output from two ANN specific conductance models (ANN M1 and M2) as inputs to the regression model. Part of the residual error from the regression model is predictable and an error correction model (CHprls() Model) is used to increase the accuracy of the chloride predictions. It should be noted that the type of ANN used is the multi-layer perceptron, which fits data with nonlinear hyperbolic tangent transfer functions. The only linear model used in the super-model is that relating chlorides to specific conductance at the intake, which ensued from observing that their historical relationship was found to be effectively linear (figure 1.6). This model allows chlorides to be predicted at highly extrapolated specific conductance values.

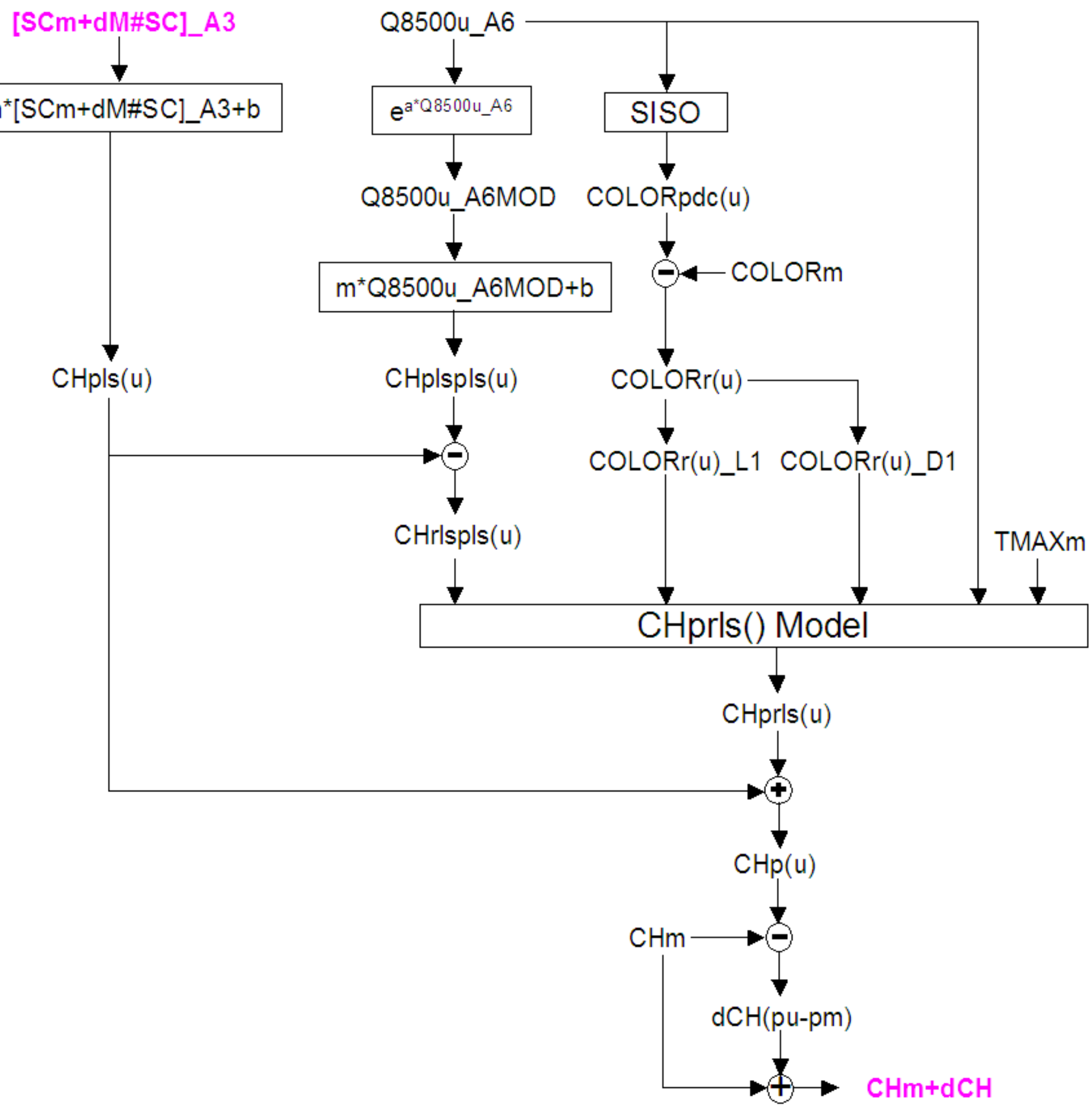


Figure 2.11. Super-model architecture for predicting CH.

Figure 2.11 shows how CH is predicted from measured and user-defined (user) inputs. Starting at the top, CH is predicted as follows.

1. [SCu+dM#SC]_A3 = 3-day MWA of SCu+dM#SC.
2. CHpls(u) = prediction of CH by SISO least squares (ls) using [SCm+dM#SC]_A3 as the input. Slope m=0.078045948, intercept b=1.639366438, R^2=0.59. Note the nearly linear relationship between CH_m and SC_m indicated in Figure 1.6.
3. Q8500u_A6 = 6-day moving window average (MWA) of the user Q8500.
4. Q8500u_A6MOD = Q8500u_A6modified by an exponential function, a=-0.0002, to effect a extrapolatable, nonlinear SISO ls prediction of CHpls(u). Note the nonlinear relationship between Q8500m and CHm indicated in Figure 1.7.

5. CHplspls(u) = prediction of CHpls(u) by SISO ls using Q8500u_A6MOD as the input. Slope m= -12.57226045, intercept b= 20.48142605, R^2=0.85.
6. CHrlspls(u) = CHpls(u) - CHplspls(u), which for measured inputs is the residual SIS ls model error, representing the CHpls() variability that is independent of Q8500u_A6. Figure 2.12 shows the trends of CHm, CHpls(m), CHplspls(m), and CHrlspls(m).

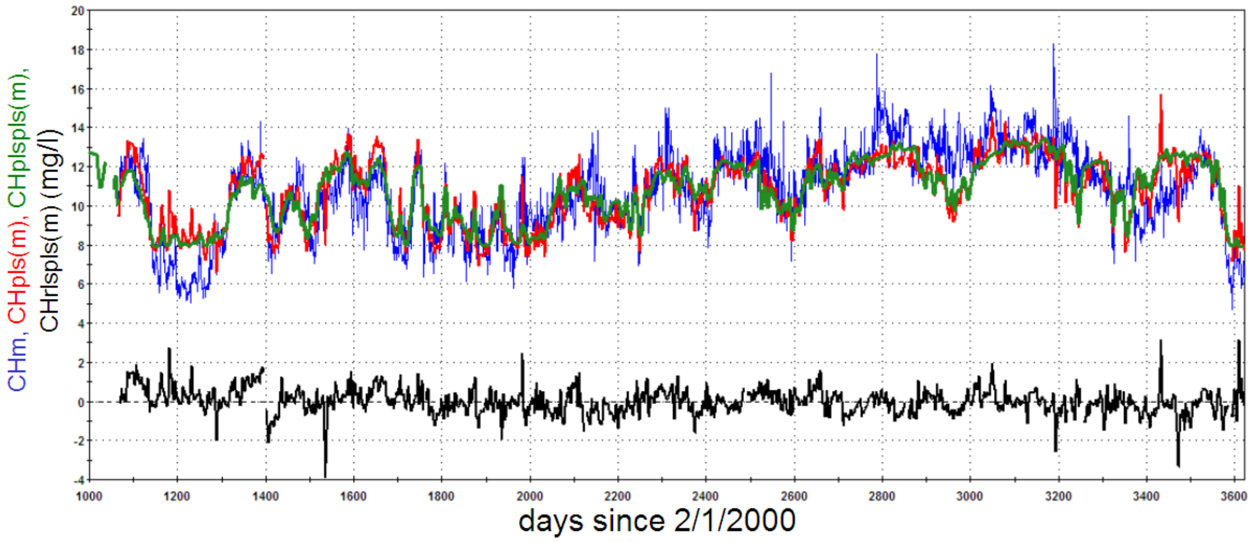


Figure 2.12. CHm, M#CHpls(m), M#CHplspls(m), and M#CHrlspls(m) trends.

7. COLORpdc(u) = prediction of COLORu by a single-input-single-output (SISO) ANN from input Q8500u_A6. The SISO ANN is used to decorrelate COLOR from Q8500u_A6, on which it is somewhat dependent. Results for this model are shown in Figure 2.13.
8. COLORr(u) = COLORm – COLORpdc(u), the decorrelated COLORu.
9. COLORr(u)_L1 = COLORr(u) time-lagged by one (daily) time step.
10. COLORr(u)_D1 = the 1-day time derivative of COLORr(u).

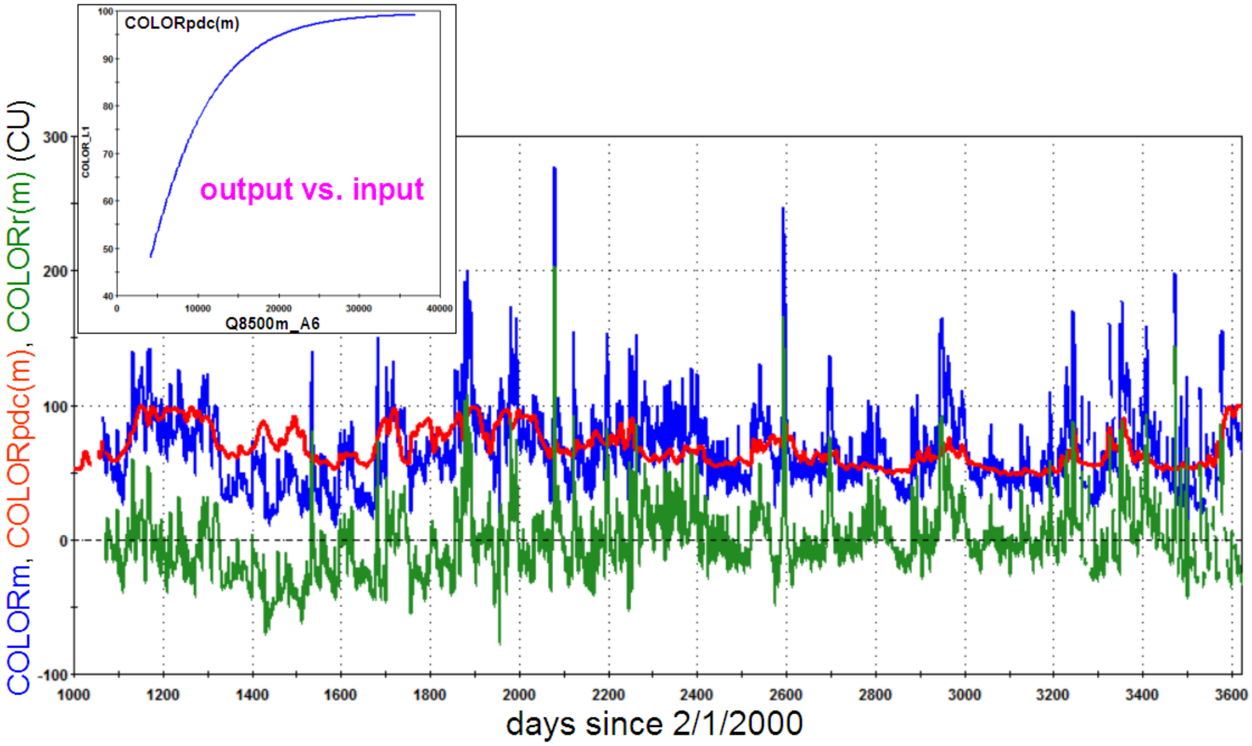


Figure 2.13. SISO ANN model for decorrelating COLOR from Q8500_A6. HLN = 1. Train / test statistics: N = 1,460 / 976; R^2 = 0.22/ 0.17; RMSE = 26 / 26 CU relative to a range of 267 CU.

11. CHrls(u) (not shown in Figure 2.9) = CHm – CHpls(u).
12. CHprls(u) = prediction of CHrls(u) by an ANN model having inputs CHrlspls(u), COLORr(u)_L1, COLORr(u)_D1, Q8500u_A6, and TMAXm. Results for this model are shown in Figure 2.14.
13. CHp(u) = CHpls(u) + CHprls(u), the straight model prediction of CHu. The predictions with measured inputs CHp(m) are shown in Figure 2.13.
14. dCH(pu-pm) =.CHm - CHp(u), the difference between the measured, historical CHm and the Model-1E and Model-2E predictions made with user-defined inputs.
15. CHm+dCH = CHm+dCH(pu-pm), the final prediction of CHu. Final results are shown in Figure 2.15.

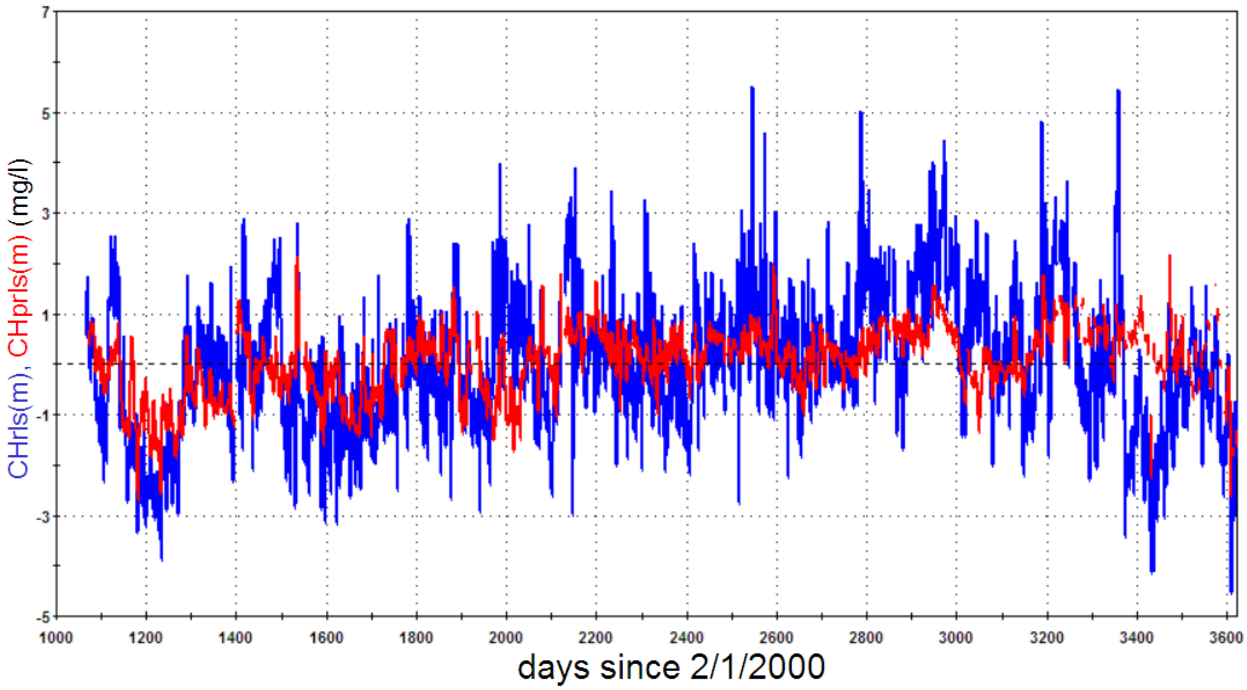


Figure 2.14. CHprls() model results. HLN = 1; Train / test statistics: N = 1,380 / 914; R^2 = 0.25 / 0.23; RMSE = 1.2 / 1.2 mg/l relative to a range of 8.3 mg/l.

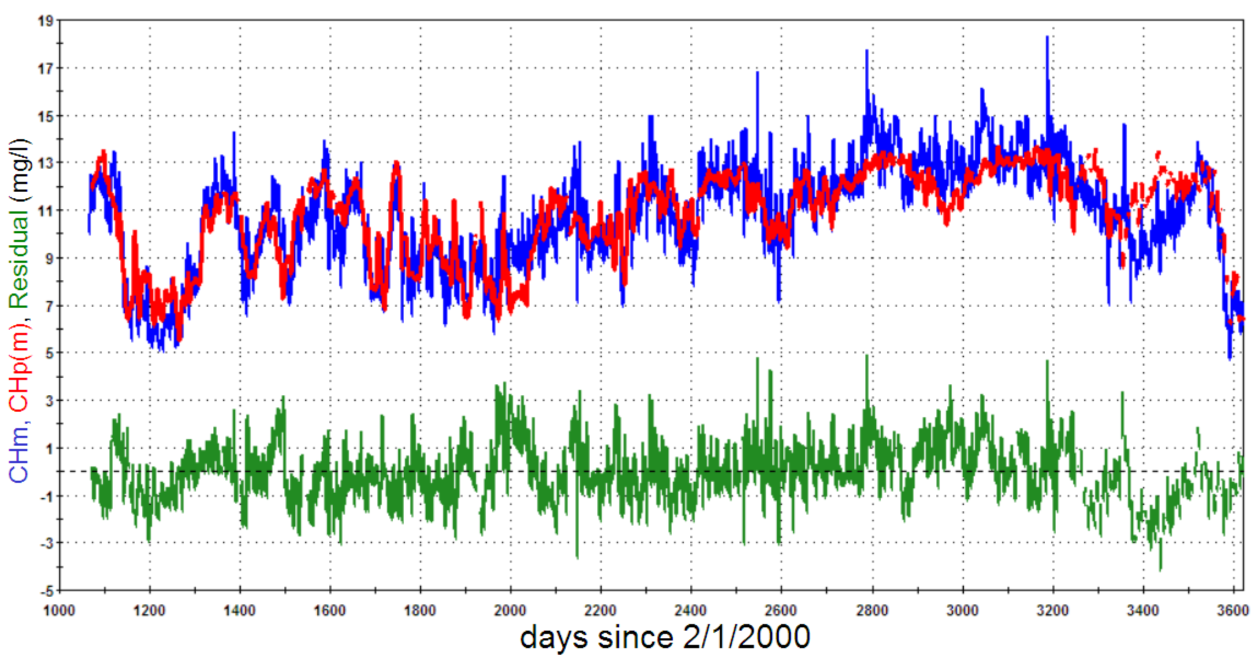


Figure 2.15. Comparison of CHm and CHp(m). Train / test statistics: N = 1,380 / 914; R^2 = 0.70 / 0.71; RMSE = 1.2 / 1.2 mg/l relative to a range of 13.6 mg/l.

Table 2 summarize the ANN models used to make the final chloride predictions at the intake.

Table 2. ANN models, inputs, outputs, number of hidden layer neurons, and statistic for training and testing datasets.
[HLN, hidden layer neurons; SC, specific conductance; N, number of data points; R^2, coefficient of determination; RMSE, root mean square error; CH, chloride]

Model	Inputs	Output	Number of HLN	Training			Testing		
				N	R^2	RMSE	N	R^2	RMSE
SC Model-1	4-day average flow	SC Intake	1	1,312	0.82	9.2	900	0.84	9.2
	2-day average I-95 SC (decorrelated)								
SC Model-2	4-day average flow	SC Intake	1	1,247	0.83	8.7	851	0.85	8.5
	2-day average I-95 SC (decorrelated)								
CH error correction model	6-day average flow	CH Intake error	1	1,380	0.25		914	0.23	
	1-day lag maximum water temperature								
	2-day lag color (decorrelated)								
	1-day change in color (decorrelated)								
	chloride intake (decorrelated)								

2.3 Other Parameters Evaluated

Time delays and time derivatives are important issues for building data-driven models. The best chloride dataset for developing the ANN models is the daily data collected by the City of Savannah at the Intake. The delays in the tidal water levels and salinity between the I-95 gage and the intake is on the order of minutes, so time delays between the two gages using daily data are not appropriate. A full dynamical analysis with extensive model prototyping was performed on data for this chlorides problem. The super-model incorporates freshwater flow inputs representing variability up to six days, color inputs representing two days, and intake specific conductance representing three days. It was found that no time delays were needed, perhaps because of the short distance between the intake and the I-95 boundary condition location.

The above models used inputs derived only from Q8500, SC8840, TMAX, and COLOR. Several other parameters were evaluated for inclusion in the models that predict SC and CH, but were found to not improve statistical measures of prediction accuracy. The other gage 8840 parameters evaluated were water level, tidal range, and rainfall. In addition to COLOR, the other utility measures of raw water quality parameters that were evaluated were: alkalinity, bicarbonate alkalinity, calcium hardness, carbon dioxide, dissolved oxygen, fluoride, iron, manganese, magnesium hardness, nitrates, pH, phosphorous, silica, sulfates, total dissolved solids, total organic carbon, total hardness, total suspended solids, and turbidity.

3. INSTALLATION AND REMOVAL

1. Create a folder called SCM at the top level of your C: drive

2. Extract all files from the distributed SCM-yyyymmdd.zip[1] file. The zip file contains the following application files:
   - SCM-yyyymmdd.xls – an EXCEL™ spreadsheet application.
   - 6 files with an "enn" extension – these are the ANN files.
   - NNCALC32.xll – a custom EXCEL™ add-in used to execute the *.enn files.
   - SCMUserGuide-yyyymmdd.doc – the MS Word file that you are reading right now.

3. Open your copy of MS EXCEL™ for Office 2000 (or newer). Insure that the standard EXCEL Add-Ins listed below are installed and checked "available".

   Analysis Toolpak
   Analysis Toolpak – VBA

   Add-Ins are accessed from EXCEL's Tools menu. If any are missing, it may be necessary to install them from your MS Office CD-ROM.

4. Set the macro security level of EXCEL™ to either medium or low using Tools > Macro > Security. SCM uses VBA macros for a variety of purposes and must be able to execute them to operate correctly.

5. Install the NNCALC32 custom Add-In that resides in the NNCALC folder described in Step 1. This may be accomplished by clicking on Tools > Add-Ins > Browse, the browse to the SCM folder you created, click on the NNCALC32 icon, then click OK.

6. Open the SCM-yyyymmdd.xls EXCEL™ spreadsheet application. When EXCEL™ asks if you want to run macros click "Enable Macros", otherwise SCM will not operate correctly.

   Select the "Setpoints" worksheet (Figure 3.1). At the top of "Setpoints" is a text box labeled "Where model files are located". The model files are the *.enn files of the ANNs. Type in the fully qualified path name of the folder set up in (1) above and save the Excel™ application using File > Save for the set up changes to be permanent.

   To check that the models are connected and operating correctly, select the "Controls" worksheet Figure 3.2). At upper right are some fields with the row headers "SC M1 / M2" and "CH M1 / M2", SC for specific conductivity and CH for chlorides. If these fields show numerical values and not an Excel™ or NNCALC32 error code, the application is properly configured and ready to use. If all of these fields show "?" or an error code then try exiting Excel™ and then reloading Excel™ and the SCM application.

   An error code indicates that an ANN cannot execute because either the NNCALC32 Add-In is not installed per (4) or NNCALC32 cannot find *.enn files because the folder path name in the "Where model files are located" text box is incorrect. If you cannot get SCM to operate, re-check the configuration items in (3)-(6) above.

7. To remove SCM, simply delete the folder created to hold the SCM files and it's contents.

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[1] yyyymmdd is the version date of the SCM image to be installed.

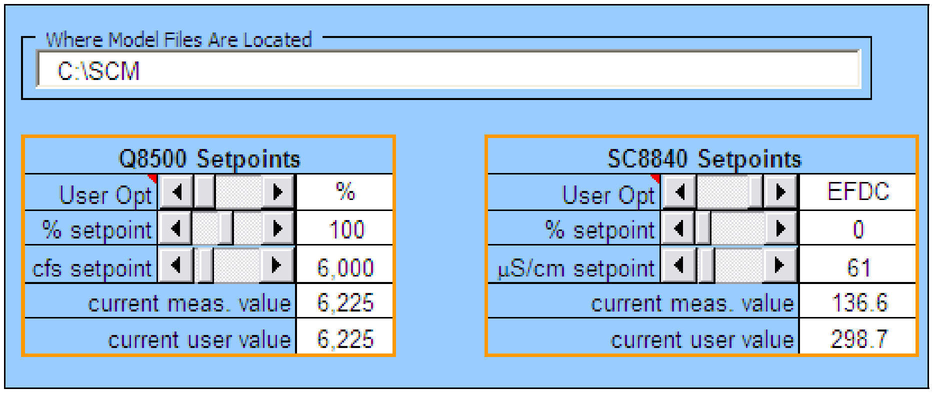

Figure 3.1. "Setpoints" worksheet, a component of SCM's GUI.

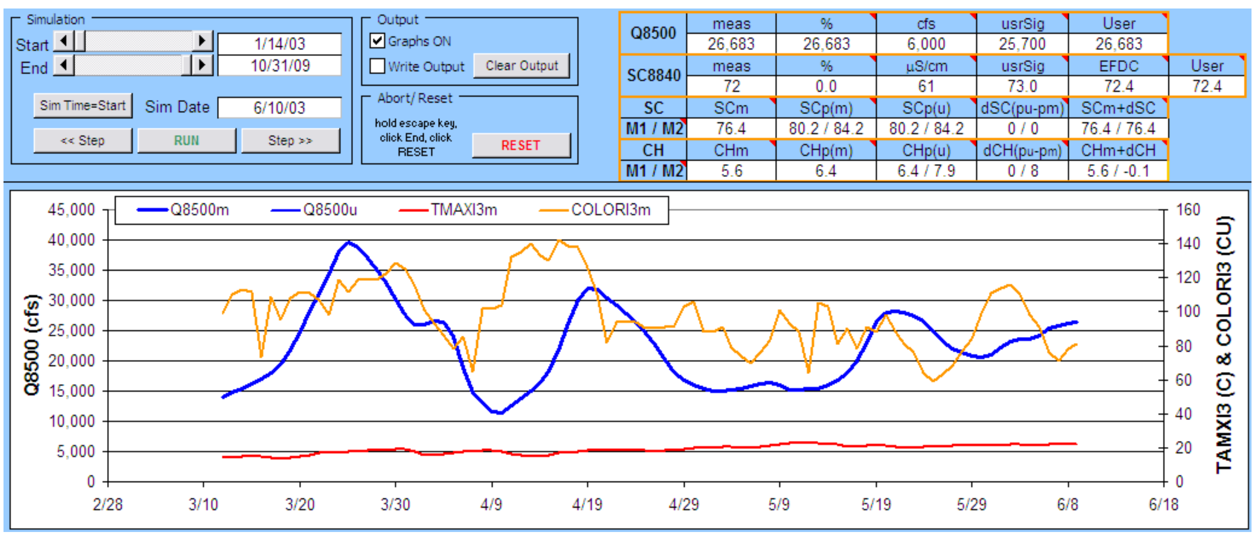

Figure 3.2. Upper portion of "Controls" worksheet showing "SC M1 / M2" and "CH M1 / M2" fields at upper right.

4. OPERATION

SCM is opened like any standard EXCEL™ workbook. Simply open the SCM-yyyymmdd.xls file and you are ready to go. SCM and its GUI is comprised of a number of worksheets that are detailed below.

4.1 "Info" Worksheet

The "Info" worksheet is automatically displayed when SCM is first loaded (Figure 4.1). It shows a map of the study area, and gives the application's version date and the contact information of its developers.

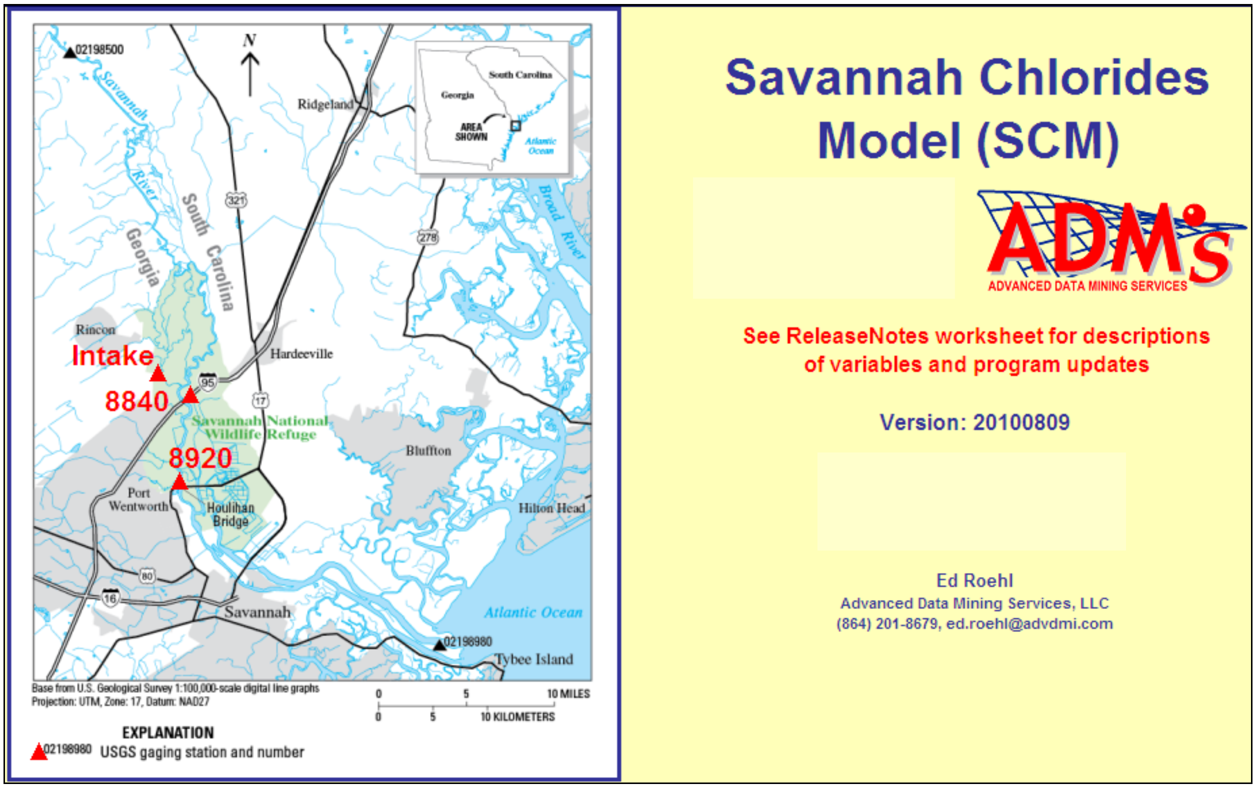

Figure 4.1. “Info” worksheet.

4.2 Variable Descriptions and “ReleaseNotes” Worksheet

SCM refers to many input and output variables in the form of row and column headers (Figure 4.2). Moving the mouse over a header marked with a red caret immediately above and to the right of the header will provide a description of the header variable. Descriptions of variables are also provided in the “ReleaseNotes” worksheet (Figure 4.3). This worksheet also describes SCM’s development history and any new features or changes.

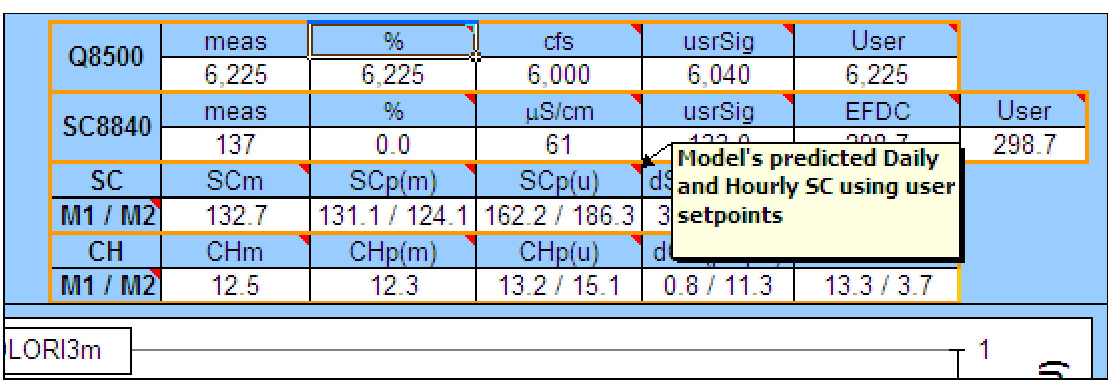

Figure 4.2. Online description of variable SCp(u) on “Controls” worksheet.

	DESCRIPTIONS OF OUTPUT VARIABLES (Scroll down to RELEASE NOTES below)
VARIABLE	DESCRIPTION
DATE	Date stamp
ROW	Database worksheet for identifier
Q8500 Input Opt	Q8500 user-input option selected on the "Setpoints" worksheet
Q8500m	Measured daily average Q8500 (cfs)
Q8500u	User input daily average Q8500 (cfs)
WL8840m	Measured daily average WL8840 (ft) - in "Database" worksheet for reference only
XWL8840m	Measured daily average titdal range XWL8840 (ft) - in "Database" worksheet for reference only
TMAXI3m	Measured 8840 daily average air temperature, interpolated up to 3 days to fill missing values
	RELEASE NOTES
DATE	CHANGE
20100325	First Release of SCM
"	Functionality to read EFDC output is not yet implemented pending further specification of how it is to operate; however, EFDC outpu SCM, pasted into SCM's "EFDC" worksheet, and run.
20100414	Modified output to provide more decimal places.
"	Added user controls and userdefined siganls for SC8840MIN to Controls, UserInputSignals (formerly usrHyds), Output, and the new

Figure 4.3. "ReleaseNotes" worksheet.

4.3 "Controls" Worksheet

The "Controls" worksheet (Figure 3.2) is the GUI component that lets the user set up and run simulations. At the top is a text box labeled "Where model files are located". It is used to configure SCM when it is first installed on a user's computer and is described further in section 3.0. As shown in Figure 4.4, "Start" and "End" dates for simulations can be set using the controls at upper left. The end date must be more recent than the start date. The "Sim Date" text box indicates the time stamp that is providing the current input values to SCM's models.

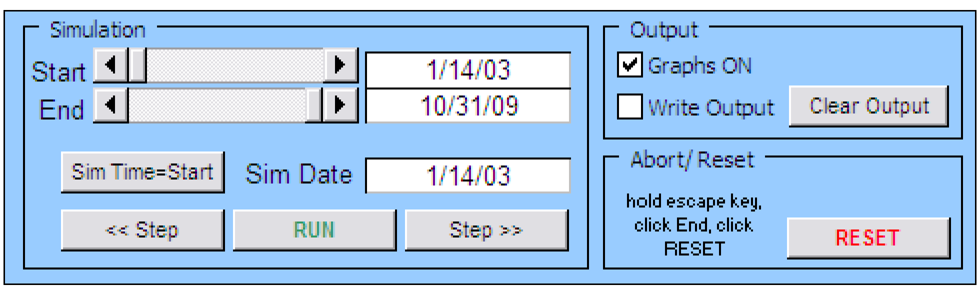

Figure 4.4. Simulation controls on "Controls" worksheet.

The "<<Step" and "Step>>" move the current time stamp backwards or forwards one time step each time they are clicked. "Sim Time=Start" sets the current time stamp to the Simulation "Start" date. "RUN" will start and run a simulation between the dates indicated by the Simulation "Start" and "End" dates.

The "Controls" worksheet provides numerical and streaming graphical information that can be observed during simulations or when incrementally stepping through time. This allows the user to examine specific periods and behaviors of interest in detail. SCM will also write inputs and output data to the "Output" worksheet. Because of the added computational load, simulations are slowed when streaming graphics and simulation output are generated. The "Graphs ON" and "Write Output" check boxes of the "Output" controls at lower center right in Figure 4.3 allow the user to toggle the streaming graphics "on" or "off". The "Clear Output" button erases all data in the “Output” worksheet to allow data from a new simulation to be recorded.

A simulation may be stopped at any time during a run by holding down the “Esc” key, after which a pop-up window will appear like that shown in Figure 4.5. Click on the “End” button to stop the simulation, then click the “Reset” button shown at lower right in Figure 4.4. The “Reset” button activates EXCEL’s™ automatic calculation feature (autocalc). Because the model programmatically manipulates autocalc for performance reasons, aborting a simulation can sometimes leave the model in a state where autocalc is not activated. This is remedied by clicking the “Reset” button.

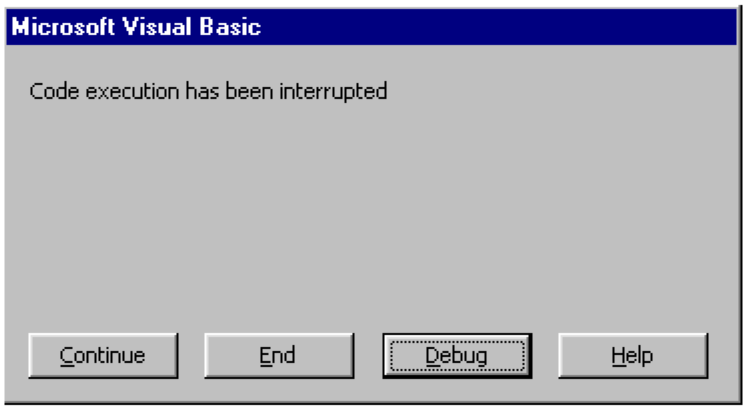

Figure 4.5. Pop-up window that appears when a simulation is interrupted using the “Esc” key.

4.4 “Setpoints”, “UserInputSignals”, and “EFDC” Worksheets

Figure 3.1 shows the “Setpoints” worksheet. The input parameters that can be manipulated by the user are Q8500 and SC8840, and there are several options for doing so. The following Q8500 inputs options are selected using its “User Opt” control.

- “%” - percent of historical flow. The “% setpoint” control is used to set the percentage.
- “cfs” - fixed flow rate. The “cfs setpont” control is used to set the flow rate.
- usrSig - user-defined signal, which the user can paste into the “UserInputSignals” worksheet (Figure 4.6). The “Clear usrSigs” button clears the “user Q8500” and “User SC8840” fields.

DATE	User Q8500	User SC8840
1/1/03	7560	104
1/2/03	7190	113
1/3/03	7000	125
1/4/03	6910	117
1/5/03	6850	118
1/6/03	7040	131
1/7/03	6920	129
1/8/03	6580	128
1/9/03	6370	124
1/10/03	6380	124
1/11/03	6430	132
1/12/03	6230	134
1/13/03	6060	134
1/14/03	6040	133

Clear usrSigs

NOTES
Paste the data for user-defined Q8500 and SC8840 signals into the columns at left.

It is left to the user to check the correctness of the user-defined input data and its synchronization with the given time stamps.

Figure 4.6. "UserInputSignals" worksheet.

The following SC8840 inputs options are selected using its "User Opt" control.

- "%" - percent of SC8840. The "% setpoint" control is used to set the percentage.
- "uS/cm" - fixed specific conductivity. The "µS/cm setpont" control is used to set the specific conductivity.
- usrSig - user-defined signal, which the user can paste into the "UserInputSignals" worksheet (Figure 4.6).
- "EFDC" – uses EFDC output data to bias the SC8840 historical data, which is then input to the models. The EFDC data is loaded into SCM as a comma separated value (CSV) file with a specified format. The EFDC data are loaded into the "EFDC" worksheet (Figure 4.7). The user must type the pathname of the EFDC file to be loaded into the "EFDC CSV File Path" text box. The "Load File Data" button loads the file, and the loaded data can be inspected in the cyan-colored fields of the worksheet. The "Clear File Data" button clears the data in the cyan fields. Note: only the data in the "SC8840-EFDCp(m)" and "SC8840-EFDCp(u)" columns is used by SCM.

Load File Data

Clear File Data

EFDC CSV File Path

C:\SCM-2\Channel5ftdeeperMitigation6AScenario-SCM.csv

NOTE - Hourly parameters predicted by EFDC are loaded by either pasting the data into the cyan-colored columns or loading it from a file having the prescribed format. The file loader will crash at the cell where any inappropriate data is encountered. It is left to the user to check the correctness of the user-defined input data and its synchronization with the given time stamps.

DATE	TIME	SALT8840-EFDCp(m)	SALT8840-EFDCp(u)	SC8840-EFDCp(m)	SC8840-EFDCp(u)	CH8840-EFDCp(m)	CH8840-EFDCp(u)
1/1/03	0:00	5.3E-05	0.000221	132.4199982	132.7400055	9.412433624	9.469901085
1/1/03	1:00	3.1E-05	0.000111	132.3699951	132.5299988	9.439320564	9.487821579
1/1/03	2:00	1.7E-05	6.3E-05	132.3500061	132.4400024	9.502119064	9.551641464
1/1/03	3:00	1E-05	4.2E-05	132.3300018	132.3999939	9.576375008	9.651046753
1/1/03	4:00	4E-05	4.2E-05	132.3899994	132.3999939	9.557168961	9.539047241
1/1/03	5:00	0.000334	0.002873	132.9499969	137.7700043	9.483275414	9.584448814
1/1/03	6:00	0.002017	0.044436	136.1399994	216.5500031	9.535814285	9.853849411
1/1/03	7:00	0.013364	0.117285997	157.6600037	354.3500061	9.600149155	10.11502266
1/1/03	8:00	0.020153999	0.082001999	170.5399933	287.6600037	9.612464905	10.02068138
1/1/03	9:00	0.007557	0.041283999	146.6499939	210.5800018	9.597166061	9.898773193
1/1/03	10:00	0.002049	0.01757	136.1999969	165.6399994	9.559149742	9.768639565
1/1/03	11:00	0.000741	0.007566	133.7200012	146.6699982	9.510479927	9.619592667
1/1/03	12:00	0.00034	0.003394	132.9600067	138.75	9.503297806	9.564650536
1/1/03	13:00	0.00017	0.001589	132.6399994	135.3300018	9.513816833	9.568307877
1/1/03	14:00	9.1E-05	0.00079	132.4900055	133.8099976	9.531633377	9.621137619
1/1/03	15:00	4.7E-05	0.000441	132.3999939	133.1499939	9.564516068	9.707937241

Figure 4.7. "EFDC" worksheet. The "Clear usrSigs" button clears the "user Q8500" and "User SC8840" fields.

4.5 "Database" and "Output" Worksheets

The "Database" worksheet contains the time series data used by SCM to run simulations (Figure 4.8). These data are described in the "ReleaseNotes" worksheet, and are derived from the raw field measurements. They are augmented by calculated variables whose values are calculated on-the-fly by SCM's computer code. The user should not alter data in the "Database" worksheet.

	DATE	ROW	Q8500m	WL8840m	XWL8840m	SC8840m	TMAXI3m	COLORI3m	SCI3m	CHm
	1/1/03	2	unk	unk	unk	unk	unk	unk	100.5	unk
	1/2/03	3	7418	unk	unk	unk	10.3	91	100.35	10.05
	1/3/03	4	7554	1.55	7.89	116.8	10.7	88	100.2	10.7
	1/4/03	5	7180	1.37	7.84	126.6	10.9	62	102.4	10.8
	1/5/03	6	6993	1.09	8.31	123.6	10.7	69	109.63	11.2
	1/6/03	7	6910	1.81	7.81	124.3	10.3	58	116.87	11.35
	1/7/03	8	6854	1.46	7.38	132.1	10.1	70	124.1	12.5
	1/8/03	9	7043	1.00	6.98	131.4	9.9	70	127	11.85
	1/9/03	10	6915	0.63	6.58	129.5	9.6	49	121.7	11.5
	1/10/03	11	6575	0.48	6.42	129.5	10	74	138.8	12.25
	1/11/03	12	6363	0.57	5.97	126.8	10.5	76	120	11.45
	1/12/03	13	6381	0.65	5.86	132.9	10.3	79	124.23	11.4
	1/13/03	14	6430	1.01	5.67	134.9	10.3	69	128.47	11
	1/14/03	15	6225	1.18	5.87	136.6	10	64	132.7	12.5
	1/15/03	16	6060	0.93	6.25	135.1	9.7	65	130.2	12.25
	1/16/03	17	6043	0.80	6.52	139.4	9.5	68	126.4	12.15
	1/17/03	18	6168	1.18	7.14	151.2	9.5	59	124.7	12.5
	1/18/03	19	6049	0.77	7.36	149.4	9.5	60	130.1	12.2

Figure 4.8. Example measured data from the “Database” worksheet.

The “Output” worksheet contains a record of key variables for a particular simulation run (Figure 4.9). The “Write Output” check box on the “Controls” worksheet must be checked for output to be written. The variables written to the “Output” worksheet are explained in “ReleaseNotes” worksheet. The user can copy output values into another EXCEL™ workbook for further analysis.

DATE	ROW	Q8500 Input Opt	Q8500m	Q8500u	WL8840m	XWL8840m	TMAXI3m	COLORI3m	SC8840-EFDC(pu-pm)	SC8840 Input Opt	SC8840m	SC8840u
1/14/03 0:00	15	usrSig	6225	6040	1.18	5.87	10	64	162.11	uS/cm	136.62	61
1/15/03 0:00	16	usrSig	6060	6170	0.93	6.25	9.7	65	190.46	uS/cm	135.06	61
1/16/03 0:00	17	usrSig	6043	6050	0.8	6.52	9.5	68	239.59	uS/cm	139.38	61
1/17/03 0:00	18	usrSig	6168	5870	1.18	7.14	9.5	59	167.53	uS/cm	151.18	61
1/18/03 0:00	19	usrSig	6049	5710	0.77	7.36	9.5	60	227.41	uS/cm	149.42	61
1/19/03 0:00	20	usrSig	5863	5710	1.04	7.96	9.1	59	189.09	uS/cm	149.36	61
1/20/03 0:00	21	usrSig	5709	6040	0.71	7.91	8.5	62	141.39	uS/cm	149.29	61
1/21/03 0:00	22	usrSig	5715	6040	0.24	8.2	8.1	57	128.24	uS/cm	150.14	61
1/22/03 0:00	23	usrSig	6045	5870	0.37	8.45	9	52	105.79	uS/cm	154.66	61
1/23/03 0:00	24	usrSig	6038	5860	1.1	8.21	9.3	43	73.1	uS/cm	158.98	61
1/24/03 0:00	25	usrSig	5869	5900	1.33	7.01	9.3	49	112.01	uS/cm	156.62	61
1/25/03 0:00	26	usrSig	5856	6010	0.64	7.01	8.7	45	115.49	uS/cm	145.38	61
1/26/03 0:00	27	usrSig	5898	5860	0.81	7.61	7.7	55	95.78	uS/cm	151.89	61
1/27/03 0:00	28	usrSig	6010	5790	0.99	7.43	7.6	54	99.05	uS/cm	151.5	61
1/28/03 0:00	29	usrSig	5852	6020	0.62	7.46	7.6	48	144.8	uS/cm	151.63	61
1/29/03 0:00	30	usrSig	5796	5860	1.08	7.54	7.9	44	156.15	uS/cm	152.78	61
1/30/03 0:00	31	usrSig	6023	5730	1.13	7.9	8.5	44	157	uS/cm	148.8	61
1/31/03 0:00	32	usrSig	5851	5870	1.07	8.03	9.4	44	160.93	uS/cm	151.38	61
2/1/03 0:00	33	usrSig	5734	6270	1.09	8.08	9.4	74	138.2	uS/cm	151.7	61
2/2/03 0:00	34	usrSig	5873	6740	1.08	7.91	10.1	78	96.37	uS/cm	148.37	61
2/3/03 0:00	35	usrSig	6280	7060	1	7.91	10.5	82	61	uS/cm	151.92	61
2/4/03 0:00	36	usrSig	6748	6840	0.94	7.97	10.7	45	27.63	uS/cm	151.66	61

Figure 4.9. Example output from the “Output” worksheet.

5. TECHNICAL ASSISTANCE

Please contact Ed Roehl of ADMs at (864) 292-1607, earoeh@aol.com, if you have problems with this model or for any other reason.

6. REFERENCES

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