CALIBRATION OF A 3-D HYDRODYNAMIC AND SALINITY MODEL OF THE SAVANNAH RIVER ESTUARY

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Abstract. In support of an Environmental Impact Statement (EIS) for a proposed harbor expansion project a three-dimensional hydrodynamic model was applied to serve as a tool to determine potential project impacts. The hydrodynamic model simulated salinity, currents, water surface elevation, and volume flows for the entire Lower Savannah River Estuary system (over 60 river miles). The model was calibrated and validated over two 100-day periods in 1999 and 1997, respectively. The model proved to be capable of reproducing complex, transient physical phenomena in this extremely dynamic system and provided good agreement with observed values of surface elevation, currents, and salinity. The model will be used to directly calculate project induced changes to the hydrodynamic and salinity environment, and will also provide the input to several other studies, including: a water quality model, a marsh vegetation model, and a river sedimentation model.

INTRODUCTION

This report presents the application of a three-dimensional hydrodynamic and salinity model to the Lower Savannah River Estuary for the purpose of evaluating navigation channel expansion induced impacts. The estuary is a unique ecosystem where a busy port and a large wildlife refuge co-exist. In order to maintain this delicate balance, the environmental impacts of the proposed navigation project expansion must be carefully evaluated. In support of an EIS for the project, extensive monitoring data was collected in the estuary and a three-dimensional hydrodynamic and salinity model was applied to further the understanding of the estuary as an integrated system, and to provide a tool for a quantitative assessment of project impacts. The calibrated model also provides a working tool to evaluate various mitigation alternatives and management practices.

The following sections describe the characterization of the Lower Savannah River Estuary, describe the model and its application to the estuary, and summarize the results of the model calibration.

CHARACTERIZATION OF THE ESTUARY

For the purposes of this study, the Lower Savannah River Estuary consists of the following sections (Figures 1 and 2): (1) The main trunk of the Savannah River from the Interstate-95 (I-95) Bridge down to the river mouth at Fort Pulaski; (2) The South Channel from Fort Jackson to the Atlantic Ocean; and (3) The Back River, the Little Back River, and the Middle River, including the areas within the Savannah National Wildlife Refuge (SNWR). The harbor comprises the lower 21.3 miles of the Savannah River and about 11 miles of channel across the bar to the Atlantic Ocean. The design depth for the Inner Harbor portion of the Federal navigation channel is 42 feet MLW, and the expansion project will deepen the channel by a maximum of 6 feet.

The hydrology of the study area is described primarily by the tides and the freshwater influx. The estuary experiences a large semi-diurnal tide with an average range of 6.8 feet at the mouth of the estuary, increasing to an average of 7.9 feet at the upper limit of the harbor. The average freshwater influx is 11,600 cubic feet per second.

To accurately characterize the hydrodynamics and salinity throughout the estuary, an extensive data collection effort was conducted in the estuary during three-month long periods in 1997 and 1999. The monitoring data included, in part: continuous water surface elevation, salinity, and temperature at 21 stations (including surface and bottom instruments at 8 station in the navigation channel) as shown in Figures 1 and 2; acoustic Doppler current profiler (ADCP) transect measurements at 29 locations; continuous cur-

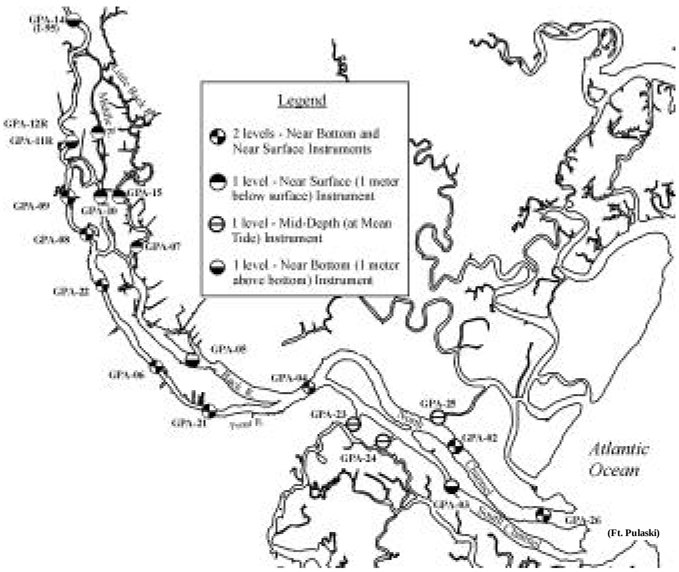

Figure 1. Lower Savannah River Estuary monitoring stations below I-95.

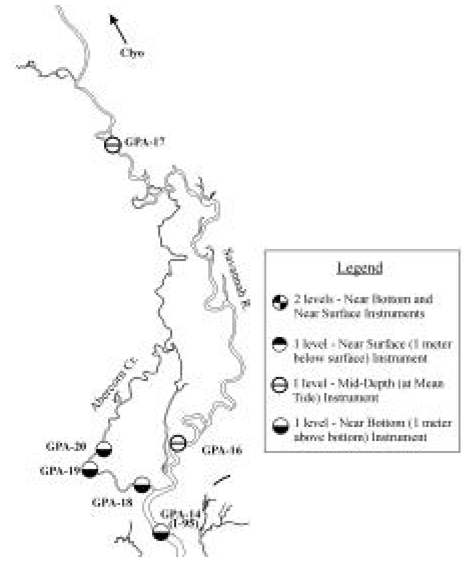

Figure 2. Lower Savannah River Estuary monitoring stations above I-95.

rent velocity measurements at 8 stations, and weekly discrete samples at 32 stations.

The monitoring data identified some important characteristics relative to the temporal and spatial distribution of the salinity within the Lower Savannah River Estuary. The data showed that the maximum salinity intrusion along the Front River occurs primarily during neap tide conditions. This phenomenon can be attributed to the lower energy environment that occurs during neap tide conditions. During neap tide conditions, there is insufficient energy to break down the vertical salinity stratification, and the higher density, higher salinity water in the bottom layer is able to intrude further into the estuary. The spring tide conditions increase vertical mixing in the river, break down the stratification, and result in less salinity intrusion into the estuary. The model development and calibration focused on reproducing the stratification/destratification and resulting salinity intrusion characteristics.

HYDRODYNAMIC MODEL DESCRIPTION

In order to accurately simulate the complex geometric and bathymetric features of the Lower Savannah Estuary, a general curvilinear coordinate, boundary-fitted, hydrodynamic, and transport modeling system was utilized. The models are contained within the modeling system called WQMAP (Water Quality Mapping and Analysis Program). The hydrodynamic model and the mass transport model equations are written and solved on the boundary conforming, transformed grid, using the well-known finite difference solution technique. A detailed description of the hydrodynamic model is presented in Muin and Spaulding (1997). The hydrodynamic model was applied in a 3-D, baroclinic, coupled, prognostic mode to predict water surface elevation, currents, salinity and temperature in the estuary.

Several modifications to the hydrodynamic model were necessary for the Savannah Estuary application. First, a marsh boundary was developed to properly represent the storage of water in the extensive relic rice bays in the estuary (Mendelsohn et al., 2001). The marsh boundaries allow the flow of water in and out of a specified storage area.

Second, a river slope algorithm was implemented in the model. The reproduction of the river slope in the upper part of the estuary was necessary to reproduce the mean water level setup and tidal amplitude damping shown in the measured data. The river slope was included in the model to simulate the increase in the upstream, river bottom elevation observed between GPA-14 and the upriver boundary.

Third, a vertical mixing algorithm was required to reproduce the stratification/destratification processes observed in the model. After initial, unsuccessful attempts to recreate the observed stratification/destratification process using 1 and 2 equation turbulence closure models a unique vertical mixing scheme, based on a log function of tidal energy, was developed and implemented (Mendelsohn et al., 1999). The log law vertical mixing function allowed the model to efficiently reproduce the observed stratification and collapse which is the controlling factor in the prediction of salinity intrusion in the estuary.

MODEL APPLICATION

The input data required for the hydrodynamic model includes geographic representation (i.e., a model grid and bathymetry) and boundary conditions (i.e., open tidal boundary conditions, river flows, wind and temperature). The model grid extends from offshore Tybee Island (RM -6.0) to the US Geological Survey (USGS) gauging station at Clyo (RM 61), as shown in Figure 3. Coastline data was derived from existing National Oceanic and Atmospheric Administration (NOAA) basemaps and updated to the most recent rectified aerial photography in the region. Bathymetry was developed primarily from National Ocean Service (NOS) and local US Army Corps of Engineers (USACE) surveys.

River flow data from USGS gauging station #02198500 at Clyo was used for the upstream inflow input, and the NOS tide station #8670870 at Fort Pulaski was used for the tidal time series input. Measured salinity at station GPA-26 (at Ft Pulaski) was used for the offshore salinity boundary.

The marsh boundaries were developed to independently allow the flow of water, salinity and temperature in and out of specified surface areas for each of the many independent marshes throughout the system.

MODEL CALIBRATION

Model calibration and validation were performed on the 1999 and 1997 data sets, respectively. Comparisons for the model calibration are provided both graphically and statistically to show the model's ability to represent the dynamic changes within the system over a wide range of flow and tide conditions.

The calibration process primarily included the adjustment of bottom friction, horizontal and vertical dispersion until good agreement were obtained between the simulated and observed water surface elevation, salinity, currents and flows. The bottom friction was specified by the drag coefficient, C_D, which varied from 0.003 at the entrance of the estuary and gradually increased up to a maximum of 0.05 at the upriver end. The higher friction in the upper portion of the model was required in order to reproduce the river setup. A horizontal dispersion of 1.0 m^2/s was used. The vertical dispersion roughly varies between 0.0004 and 0.012 but is calculated dynamically and varies spatially, based on tidal energy and local vertical density gradient.

The comparison of water surface elevation percentiles along the Front River is shown in Figure 4. The comparison shows that the model is capable of reproducing the trend of increasing mean water level gradually with river mile between Fort Pulaski and I-95 and sharply increasing upstream to Clyo. Also, the predicted tidal range closely follows the trend in the observations with a slight increase in the harbor area and a subsequent decrease, beginning at I-95, to zero at Clyo.

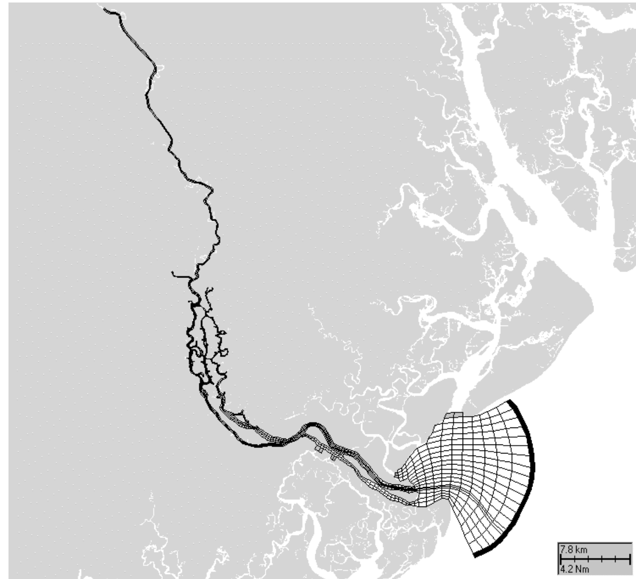

Figure 3. Model grid.

The comparison of salinity concentration percentiles is shown in Figure 5 for the Front River surface and bottom, respectively. The model clearly captures both the trends and magnitudes in salinity along Front River, varying from high salinity at the entrance and decreasing salinity upriver. The percentile analysis shows that while the model adequately predicts the mean salinity along the river, the dynamic range predicted by the model is somewhat smaller than that of the observations.

A salinity time series comparison at GPA-06 is presented in Figure 6. This figure demonstrates the model ability to reproduce the stratification/destratification process that occurs in the estuary.

CONCLUSIONS

Comparison between model predictions and observations at each station throughout the estuary indicate that the model is capturing the important physical processes in the estuarine system. Simulation of the stratification cycle allowed for prediction of variations in salinity intrusion. The model is capable of reproducing complex, transient physical phenomena in this extremely dynamic system and is in good agreement with observed values of surface elevation, currents, and salinity.

The calibrated hydrodynamic model will be used for running a three-dimensional dissolved oxygen (DO) model, currently under development. This DO model will provide the means to assess harbor expansion impacts, and will also provide a tool for the development of a Total Maximum Daily Load (TMDL) to be based on DO water quality standards being developed by USEPA.

These models provide a working tool that can be used to determine the effects of proposed harbor modifications on environmental resources. The models will be used to evaluate project impacts to fishery resources, which include the shortnose sturgeon (an endangered species) and the striped bass (a fish that is the subject of a long-term protection and recovery program). The hydrodynamic and salinity model will also be used to determine the affects of harbor expansion alternatives to the extensive marshes in the Savannah National Wildlife Refuge. The model will be used to predict the frequency of marsh flooding and the salinity of the waters that flood the marshes, which will be input to a marsh vegetation model.

LITERATURE CITED

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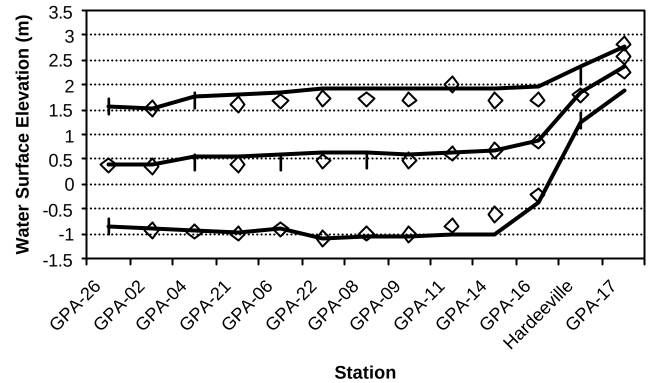

Figure 4. Measured (diamonds) and simulated (solid lines) water surface elevation percentile comparisons (5th, 50th and 95th) along Front River.

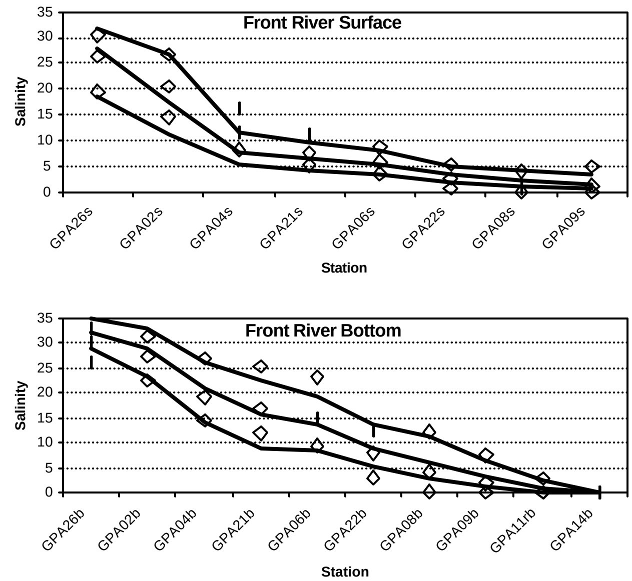

Figure 5. Measured (diamonds) and simulated (solid line) salinity percentiles (10^{th}, 50^{th} and 90^{th}).

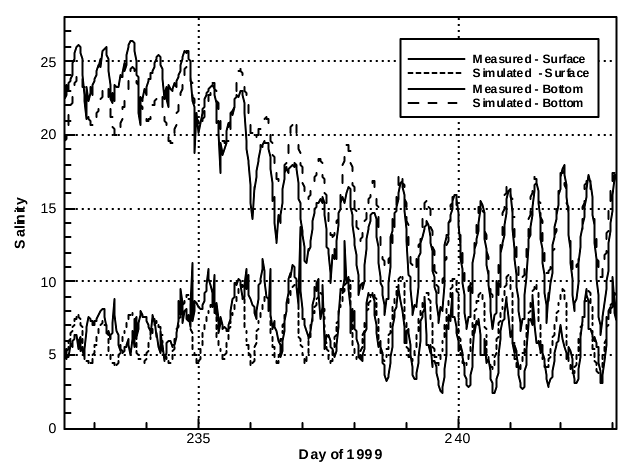

Figure 6. Time series of measured and simulated salinity at GPA-06.