HYDRODYNAMIC AND SEDIMENT TRANSPORT MODELING FOR A NEW CONTAINER TERMINAL

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ABSTRACT

This paper presents a summary of the numerical model studies used to evaluate the potential environmental impacts to the Cooper River associated with the SC State Ports Authority's (SCSPA) proposed port expansion at Charleston, South Carolina. The studies were conducted in support of a comprehensive Environmental Impact Statement (EIS) required for permitting of the project. The project includes a new 3,510 ft wharf, berth and turning basin located at a former naval base. Several alternatives to the proposed project were evaluated for the EIS, including terminals across the river at Daniel Island and Clouter Island, as wells as different wharf alignments at the proposed site.

The Environmental Fluid Dynamics Code (EFDC) was used to simulate the changes to the river currents, salinity, and sedimentation patterns caused by the project. The hydrodynamics of the model were calibrated using in-stream continuous monitoring data of water surface elevation and salinity from nine USGS gages, as well as flow and velocity measurements collected by ATM at six transects near the project site.

The model was used to simulate the project changes to current patterns in the river. Areas of particular interest included an adjacent marina managed by the county parks service and nearby piers used by the federal law enforcement training center.

The model was used to simulate changes to salinity near the project site and further upriver. Potential salinity intrusion impacts are an issue of concern because of an upriver freshwater intake at the Back River reservoir. Dam flows into the river are currently used as a management tool to avoid salinity intrusion to the Back River. The model was used to demonstrate that the project would not affect salinity intrusion to the Back River.

The sediment transport component of the model was calibrated using suspended sediment data collected by ATM in conjunction with historical sedimentation patterns in the navigation channel. The model was used to show the relative differences in maintenance dredging rates that would be required for each of the project alternatives. The study also estimated the total maintenance dredging rate for the proposed project.

The EFDC model currents were exported to the SSFATE model in order to simulate suspended sediment impacts from dredging operations. The model currents were also exported for input to a ship simulator set up by Marine Safety International for simulation, testing and evaluation by captains of the Charleston Branch Pilots.

The model results were also used to support conclusions regarding potential impacts to dissolved oxygen in the river near the project site, which is considered impaired (not meeting the water quality standard).

This paper presents a demonstration of the use of a single numerical model to support multiple aspects of a detailed environmental impact study of a port project, both by directly quantifying impacts to hydrodynamics and sediment transport as well as linking to other models such as SSFATE.

Keywords: EFDC, hydrodynamic, modeling, EIS, environmental impact study, Charleston, port, sediment.

INTRODUCTION

This paper presents a summary of the numerical model studies used to evaluate the potential environmental impacts to the Cooper River associated with the SC State Ports Authority's (SCSPA) proposed port expansion at Charleston, South Carolina. The studies were conducted in support of a comprehensive Environmental Impact Statement (EIS) required for permitting of the project.

The project includes a new 3,510 ft wharf, berth and turning basin located at the Charleston Naval Complex (CNC), which is the site of a former naval base. The terminal is located on the lower Cooper River, as shown in Figure 1.

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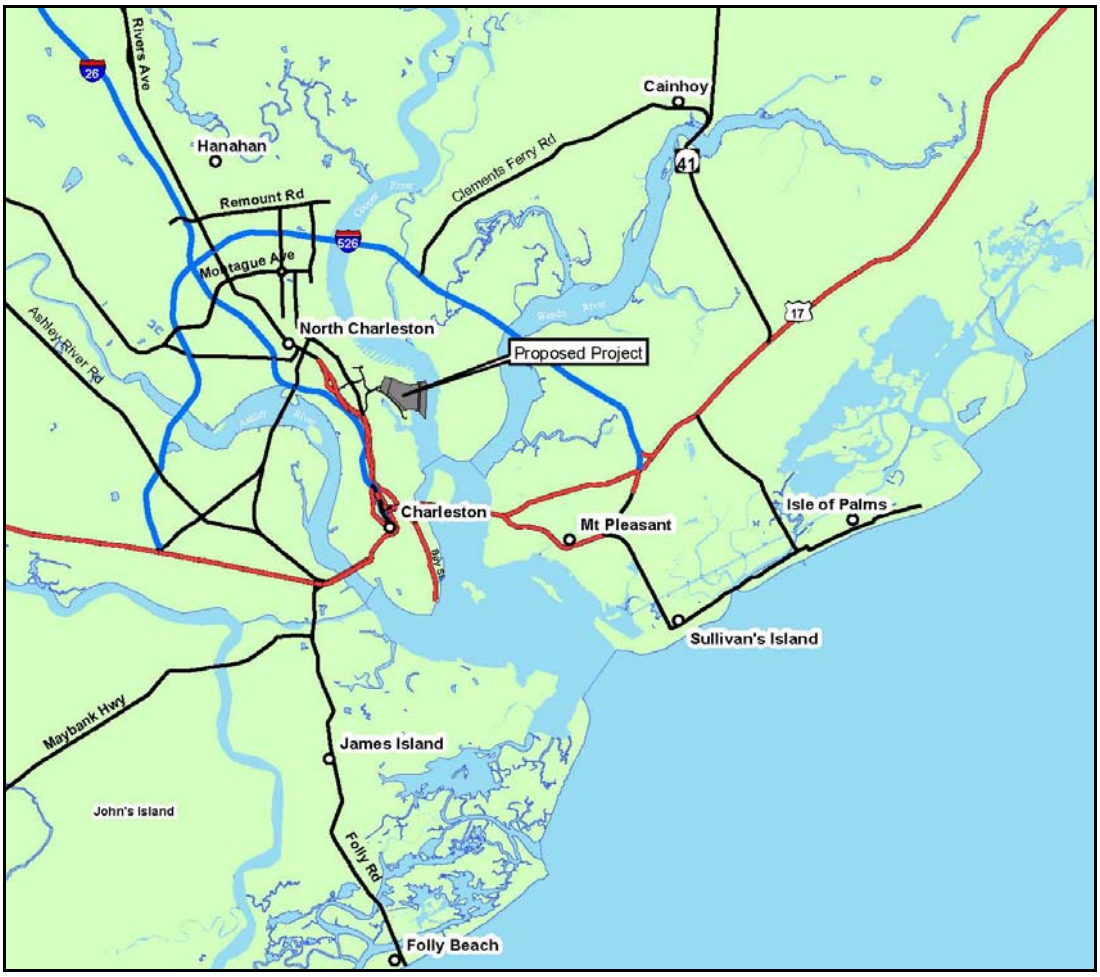

Figure 1. Project location map.

The project will require the excavation and disposal of approximately 6.5 million cubic yards of fine grained sediment to construct the wharf, berth and turning basin. The dredging method has not yet been determined, but either a hydraulic cutterhead or clamshell dredge would likely be employed. Also, about 6.5 million cubic yards of suitable fill material will be imported to surcharge the underlying sediments and to raise the existing grade to the final design elevation.

The EIS for the project must assess the potential impacts to the river environment. A project of this scale can potentially affect the river environment in many ways, either during construction operations (e.g., sediments suspended during dredging activities) or as a result of the project changes to the river geometry (i.e., the deepening of the berth and turning basin). The changes to the river geometry can potentially cause changes to river currents, salinity concentrations, sediment transport patterns and dissolved oxygen concentrations. Numerical models are commonly used as tools to estimate these potential impacts.

For this study, the Environmental Fluid Dynamics Code (EFDC) model was used as the basis for quantifying the project impacts. This model was chosen for several reasons: (1) it is familiar to reviewing agencies, such as the US Environmental Protection Agency (EPA) and the South Carolina Department of Health and Environmental Conservation (SCDHEC), (2) it is capable of simulating three dimensional hydrodynamics, salinity and sediment transport, (3) it can be linked with other models such as WASP to simulate water quality or SSFATE to simulate suspended sediments from dredging operations, and (4) it is the same model being used for the development of a Total Maximum Daily Load (TMDL) of oxygen demanding substances to the river. The desire to use the same model as that used for the TMDL stems from the desire to minimize the potential for reviewing agencies to have to reconcile conflicting model results from two different models.

The following sections describe the physical setting in the harbor and the model application for predicting the impact to hydrodynamics, salinity, dissolved oxygen and shoaling in the harbor. Also, the linking of the model to SSFATE to predict suspended sediment transport during dredging operations is described.

PHYSICAL SETTING

The primary mechanism providing hydrodynamic forcing to the system are the tides propagating into the Harbor through the Charleston Harbor Entrance. The inlet, which connects the Charleston Harbor to the Atlantic Ocean, is approximately 1 mile wide. The channel is jettied out a distance of 3 miles from the entrance. Portions of the jetties are emergent at low tide and submerged at high tide while the rest remain emergent throughout the tidal cycle.

The tides range is 5.09 feet (1.55 m) on average and 5.90 feet (1.80 m) during typical spring tide conditions. These tides extend and amplify up the Wando and Ashley Rivers. On the Cooper River, the tides are felt as high as at the Pinopolis Dam at the upstream end of the west branch of the river. However, there is significant damping of the tidal wave in the area around the "Tee," where the river splits into east and west branches.

A significant component of the hydraulics within the Charleston Harbor System is driven by the extensive tidal marshes that line the three tributaries and the harbor area. Fed by small feeder creeks, these areas provide extensive inter-tidal exchange and storage of water. Additionally, these inter-tidal marsh areas provide a mechanism for exchange of nutrients and oxygen demanding material with the adjacent receiving waters. Other significant water storage features are the former rice fields that line the east and west branches of the Cooper River above the "Tee."

In the 1930s, the Santee-Cooper Project created two freshwater lakes by diverting the flows from the Santee River and using the naturally high topographic relief at the upper end of the Cooper River. Two dams that generated hydroelectric power were created: the Wilson Dam which discharged to the Santee River, and the Pinopolis Dam which discharged to the upper Cooper River. The flows diverted to the west branch of the Cooper River altered it from a tidal slough to a riverine system with a significant freshwater discharge (approximately 15,600 cfs average). The increased freshwater discharge with its associated sediment load created problems in the lower harbor. In 1985, a portion of the freshwater inflow to the Cooper River was diverted back to the Santee River, and the freshwater flows were reduced to a weekly average of 4,500 cfs.

HYDRODYNAMICS

EFDC is public domain software with a hydrodynamic model based on the three-dimensional shallow water equations of motion, and it includes dynamically coupled salinity and temperature transport. The physics of the EFDC model are similar to the Blumberg-Mellor model (Blumberg and Mellor, 1987) and the U.S. Army Corps of Engineers' CH3D model (Johnson et al., 1993). The EFDC model was originally developed by Dr. John Hamrick at the Virginia Institute of Marine Science for estuarine and coastal applications and is considered public domain software. EFDC is currently supported by Tetra Tech for USEPA ORD, USEPA Region 4, and USEPA Headquarters.

Hydrodynamic Model Setup and Calibration

The EFDC model is capable of one-, two- and three-dimensional simulations. The Lower Cooper River is partially mixed, and therefore, the model was set up in three-dimensional mode in order to simulate the salinity stratification in the river.

The computational grid mesh, shown in Figure 2, was designed to represent the estuary with increased resolution in the area of interest in the Lower Cooper River. An enlargement of the grid in the project area can be seen at the left corner of the figure. The grid extends from the offshore of the jetties to the Pinopolis Dam at the upper end of the Cooper River, to Guerin Creek and Ward Bridge on the Wando River, and past Gregg Landing on the Ashley River. The marsh coverage in the Charleston Harbor Estuary is extensive and plays a key role in the hydrodynamics and water quality. Therefore, the marsh areas are also represented by the model grid. The marsh areas of the system are represented by wide cells that follow the secondary tributaries and feeder creeks. Although EFDC is capable of simulating wetting and drying of grid cells, the marsh grid cells were not allowed to go dry in this model application (i.e., the marsh cells were given a depth slightly lower than low water). The grid cell sizes range from 75 to 100 m wide near the proposed project site to about 1,300 m wide in the offshore area.

The model calibration period in 2004 includes monitoring data collected by the US Geological Survey (USGS) gages in the river (including water surface elevations and salinity at surface and bottom depths). It also includes

acoustic doppler current profiler (ADCP) monitoring data conducted by Applied Technology and Management (ATM) at six transects in the Lower Cooper River.

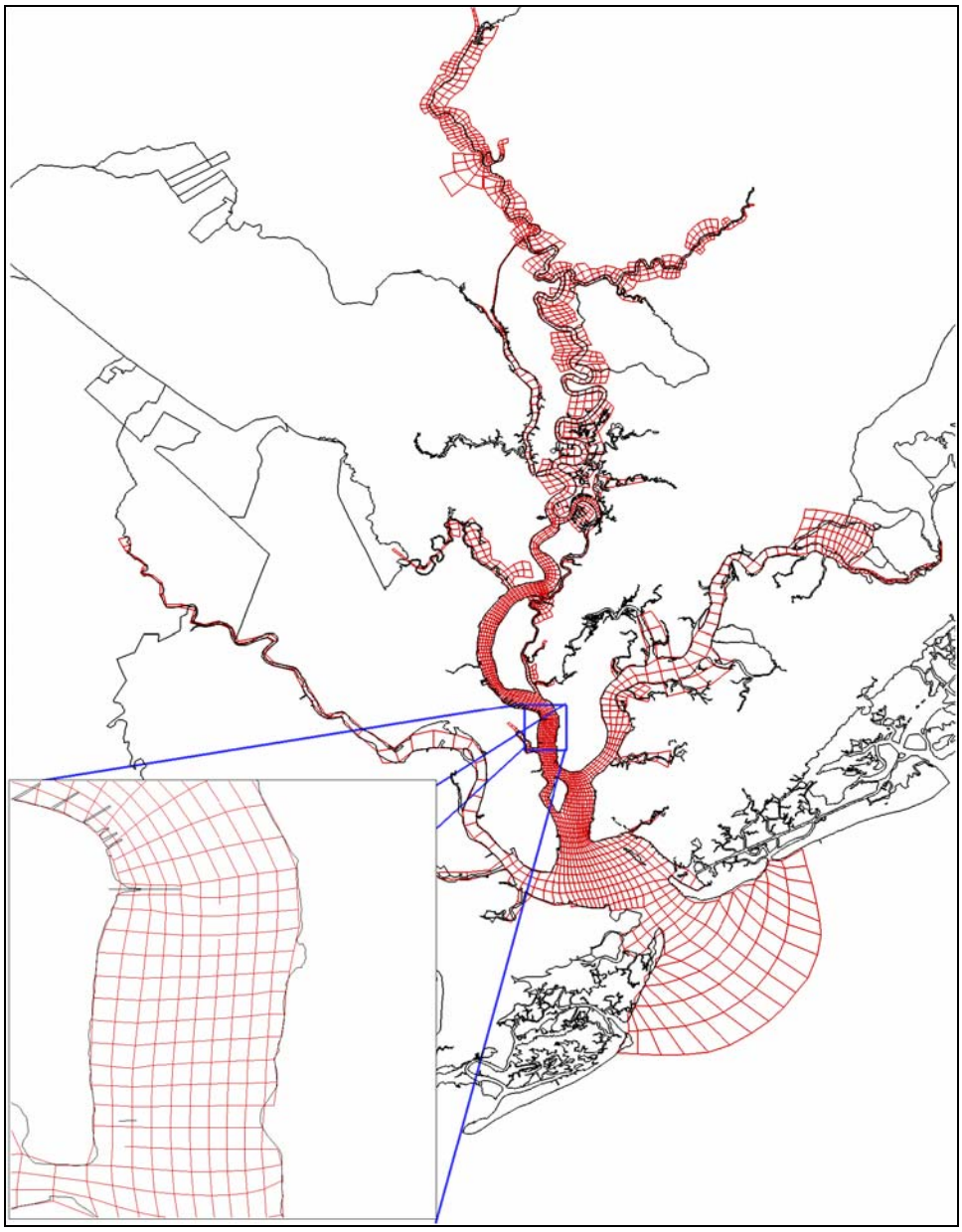

Figure 2. Model grid mesh.

The first step in the model calibration process was determining the model time step at which the model becomes stable. The advective time step was 2 seconds due to the high currents at many locations along the river.

Bottom friction was adjusted to provide the good agreement between observed and simulated water surface elevations and currents. For the EFDC model, the user controls bottom friction by specifying a log law bottom roughness height. A uniform bottom roughness height of 0.01 m was found to result in a reasonable model calibration.

The water surface elevation comparisons showed reasonable agreement, as shown for three representative locations in Figure 3, and the model reproduces the general damping of the tidal signal as it progresses up the river. The root mean square error (RMSE) for water surface elevation ranged between 0.05 m near the harbor entrance at Fort Sumter, to 0.08 m near the proposed project site, and up to 0.15 m in areas away from the project (18 miles upriver).

The salinity component of the model calibration required adjustment of the coefficients that control vertical mixing in the model. Most of the coefficients remained the default values commonly used in EFDC for the Mellor Yamada 2.5 turbulence closure scheme (Mellor & Yamada, 1982), which are based on empirical data. The only variables adjusted during the model calibration process were the minimum kinematic eddy viscosity and the minimum eddy diffusivity. Using the default values for these variables resulted in over-stratification of the salinity in the estuary. The calibrated model used a value of 1e-4 m2/s for both variables to obtain reasonable agreement between the simulated and observed salinities. Example comparisons of simulated and measured salinity are shown in Figure 6.

The model was confirmed using comparisons to observed 1996 water levels, flows and salinity. The comparisons showed similar good agreement as the model calibration comparisons.

Predicted Impacts to Hydrodynamics and Salinity

Six different model grids were used to simulate the existing and project alternative conditions: the proposed project at the CNC, two other alternative layouts at the CNC site, as well as alternative project locations at Daniel Island (directly across the river from the proposed project site) and Clouter Island (across and upriver from the CNC site). The project alternative grids are shown in Figures 5 through 10. The two alternate designs at the proposed project site (hereafter referred to as CNC Option A and CNC Option B) were included to demonstrate the differences that would occur if certain design elements were modified. The CNC Option A grid represents a design with the berth located much closer to the existing shoreline (which would result in less construction fill into the Cooper River). The CNC Option B grid represents a design with the turning basin extended to the north, and it truncates the existing Daniel Island Bend contraction dike.

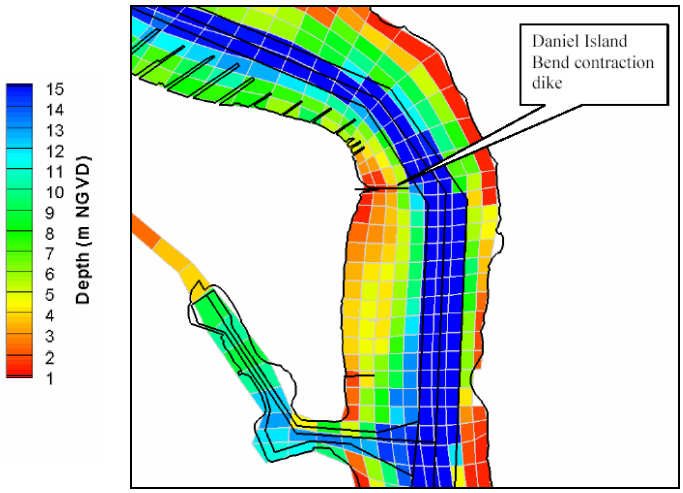

Figure 5. Model grid for the existing conditions.

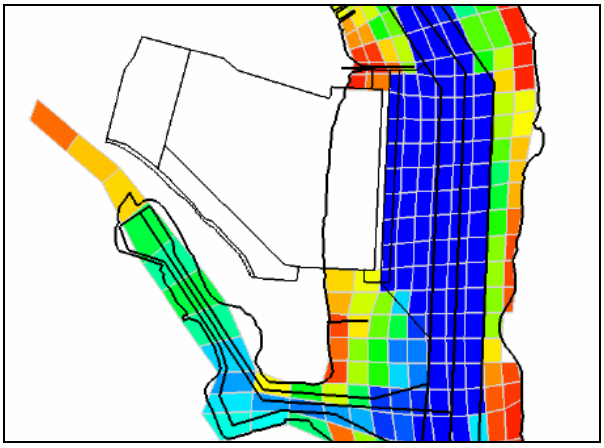

Figure 6. Model grid for the proposed project.

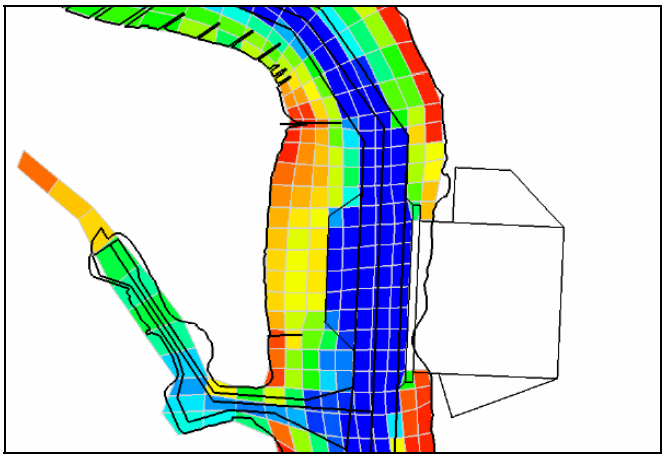

Figure 7. Model grid for the Daniel Island alternative.

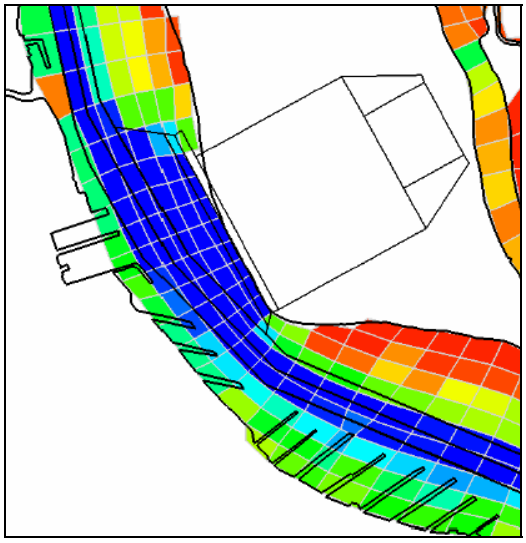

Figure 8. Model grid for the Clouter Island alternative (north of CNC).

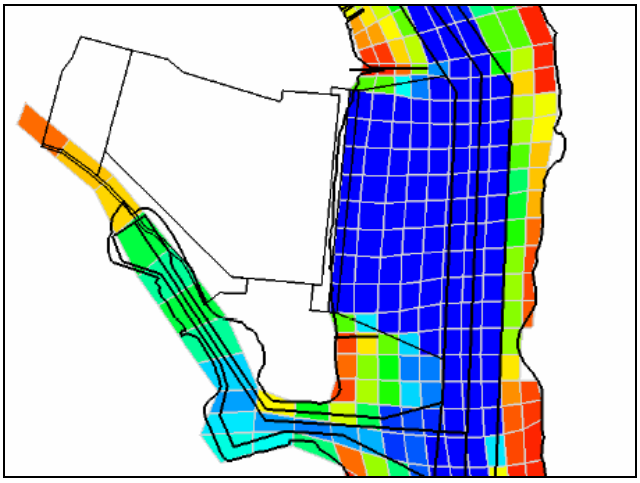

Figure 9. Model grid for Option A at the CNC.

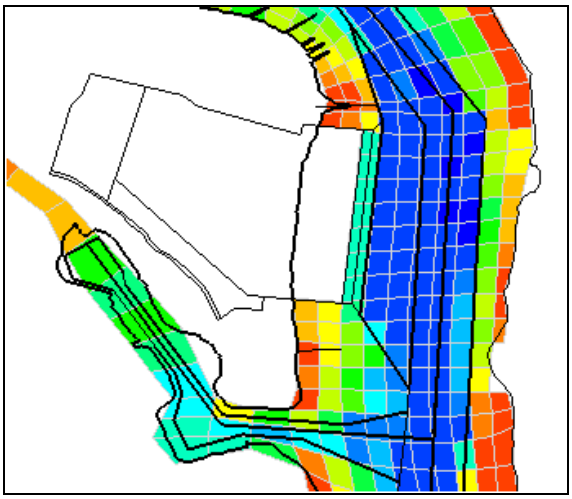

Figure 10. Model grid for Option B at the CNC.

The model results indicate that the project construction would cause some localized changes to the current field, but none of the scenarios would cause changes to currents in areas away from the project site. The current plot in Figure 11 shows that the project would eliminate the gyre that presently forms between the contraction dikes at Daniel Island Bend and just north of Shipyard Creek. In contrast, CNC Option A would cause a gyre in the turning basin area similar to the gyre that occurs there with the existing conditions. This would cause much greater sedimentation in the turning basin than that anticipated for the proposed project.

The model predicted percentiles of salinity concentrations were calculated along the centerline of the navigation channel in the Lower Cooper River. Longitudinal profiles of the simulated 50th and 90th percentile salinity concentrations were evaluated for the study. The model simulations predicted that the proposed project would cause minimal adverse impacts to salinity upstream and downstream from the terminal. Examination of the model results indicates that the project alternatives would cause only small changes to the 50th and 90th percentile salinity concentrations along the navigation channel in the Lower Cooper River. For the proposed project, the Daniel Island Alternative and the Clouter Island Alternative, the changes are all less than 1 ppt (i.e., less than 5 percent change in salinity concentration). Of particular interest to the USACE, who regulates the freshwater flow from the upriver dam to prevent salinity intrusion to the Bushy Park Reservoir (a freshwater reservoir 27 miles upriver from the proposed project site), the model predictions showed that the project would cause negligible impacts to salinity intrusion events that affect the Bushy Park Reservoir.

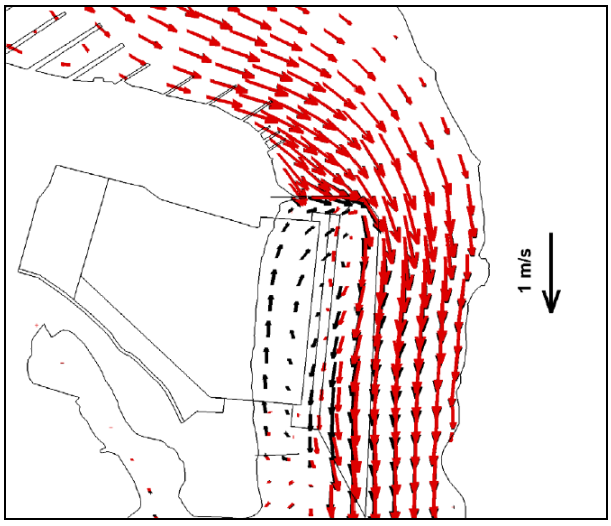

Figure 11. Pre- and post-project ebb current vectors for the proposed project simulation.

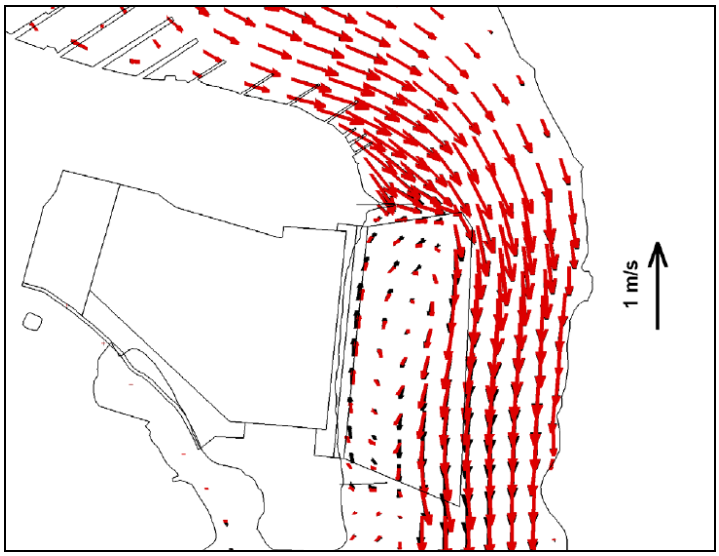

Figure 12. Pre- and post-project ebb current vectors for the CNC Option A simulation.

SEDIMENT TRANSPORT

The calibrated hydrodynamic model was used as the basis for sediment transport modeling. Two sediment transport models were used: the same EFDC code was used to simulate the transport of fine grained cohesive sediments in the estuary in order to assess the potential impacts to sedimentation; the SSFATE model was also used to predict the potential impacts associated with construction or maintenance dredging in the river.

EFDC Sediment Transport Modeling

The sediment transport model includes simulation of both cohesive and noncohesive sediments. However, because this model study focuses on cohesive sediment transport, only the cohesive sediment transport portion of the model formulation is described here. A full description of the sediment transport formulation is given in the draft EFDC Technical Memorandum "Theoretical and Computational Aspects of Sediment Transport in the EFDC Model" (Hamrick, 1999).

The sediment transport related inputs include boundary sediment concentrations, initial bed and water column sediments, and sediment transport coefficients. The suspended sediment concentration for the freshwater inflow at the upstream boundary was set to 30 mg/l. The suspended sediment concentration for the offshore open boundary was set to 5 mg/l. These are the same values as used in a previous sedimentation model study of the harbor conducted by the USACE Waterways Experiment Station (WES) using the RMA-10 model (Teeter et al., 2000).

The model was calibrated by adjusting the sediment transport coefficients within a reasonable range such that simulated suspended sediment concentrations compared reasonably well to observed values. The main variables adjusted during the model calibration included: constant settling velocity, critical deposition stress, surface erosion rate and, critical stress for surface erosion. Example comparisons of simulated and observed suspended sediment concentrations are shown in Figure 13. The field measurement of suspended sediments included collection and lab analysis of 185 discrete water samples. The samples were collected over four days (two during spring tide conditions and two during neap tide conditions), at four depths in the water column, and at five locations in the study area.

The model was confirmed by comparing predicted and observed dredging rates along the federal navigation channel in the Lower Cooper River (Figure 14). USACE maintenance dredging rates between 1998 and 2005 were analyzed by ATM and used in conjunction with dredging rates from 1988 to 1994 used for a previous study (Teeter et al., 1995) to provide a comparison data set for the model confirmation.

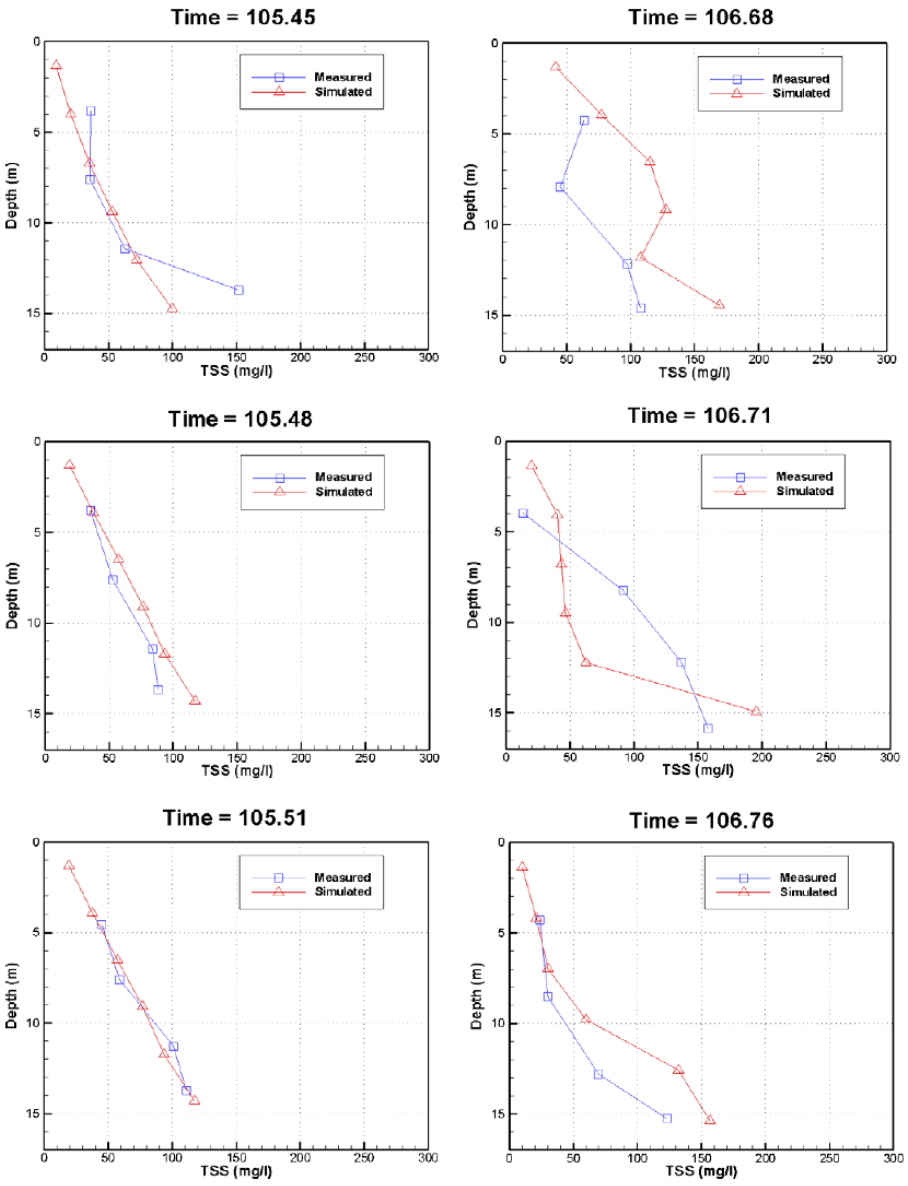

Figure 13. Measured and simulated suspended sediment concentrations near the proposed project site on April 15 and 16, 2003. (Note: time is in decimal day-of-year).

While the dredge volumes in a given year are a function of funding available for dredging that year, it is reasonable to assume that the long-term average dredging rate is a good indicator of the sedimentation rate in the channel. Long-term consecutive surveys of the river bottom during periods without dredging would provide the best data to quantify sedimentation rates. However, a review of survey records available from the USACE found that very few surveys meet the criteria of: (1) overlapping areas, and (2) no dredging in between surveys. For the few surveys meeting these criteria, the time-between the surveys is relatively short, and therefore only representative of shoaling conditions at that particular time. Therefore, the long-term dredging rates were used for comparison to the model results instead of surveyed sedimentation rates.

The comparison of simulated deposition rates in the navigation channel and the 15-year average maintenance dredging rates in the channel is presented in Figure 15. The model over predicts shoaling in Daniel Island Reach and Drum Island Reach. However, the model results compare well in Port Terminal Reach and Shipyard River. The Port Terminal Reach has a turning area not unlike the proposed project. Therefore, the model should provide a conservative estimate of the shoaling rate in the proposed project turning basin and navigation channel.

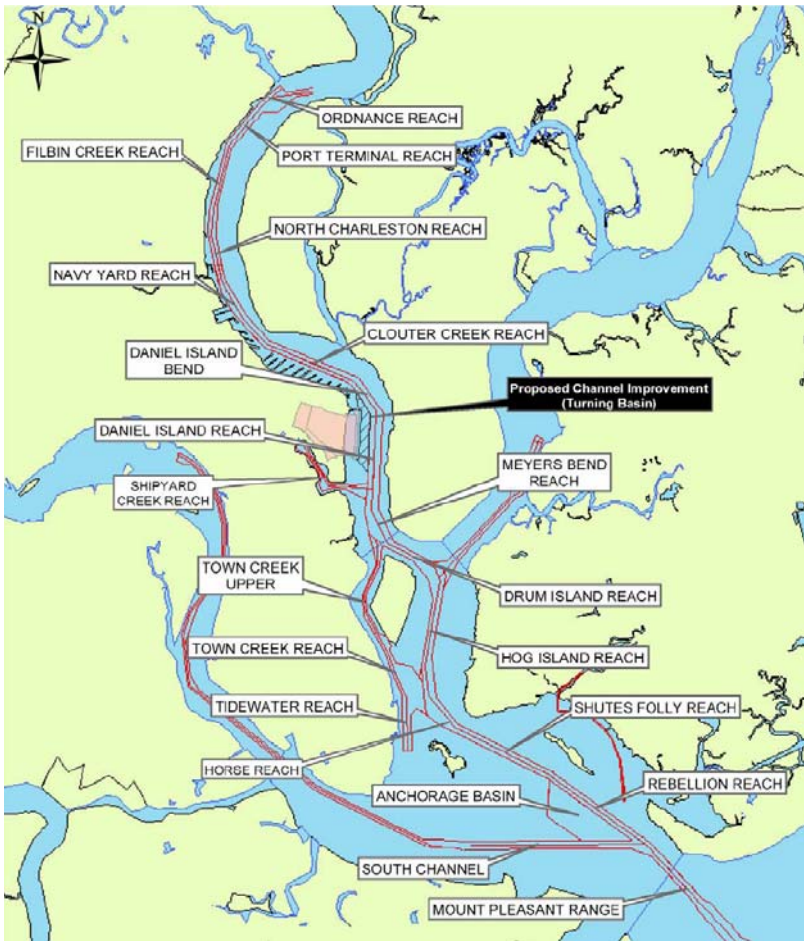

Figure 14. Federal navigation channel reaches in Charleston Harbor.

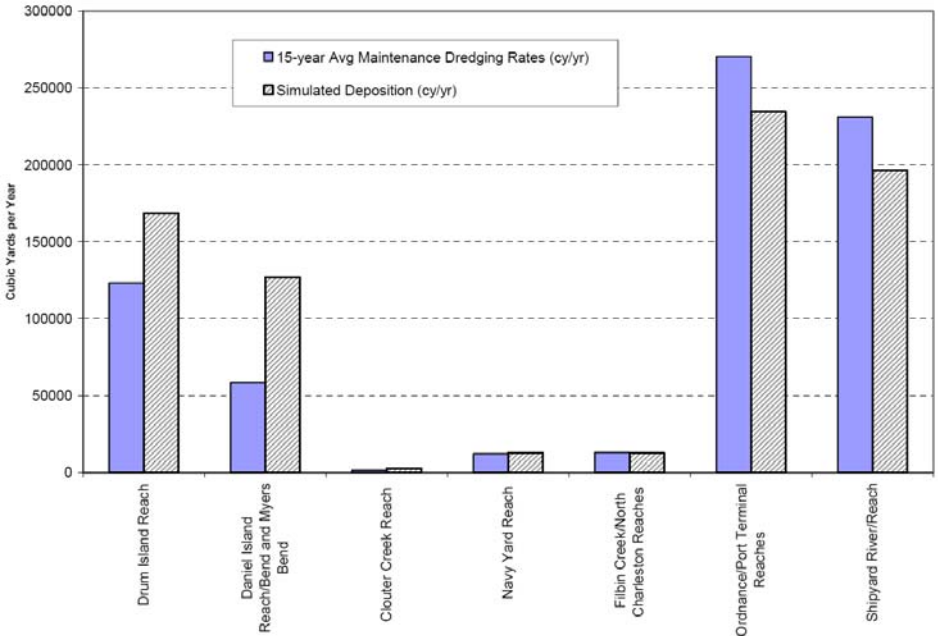

Figure 15. Measured and simulated deposition rates in the Lower Cooper River.

Following model setup and calibration, the model was used to simulate a 14-day period representative of typical spring/neap tidal variations (around the same period used for the sedimentation model calibration: April 14-28, 2003), and the change in bottom sedimentation patterns were calculated for each project alternative. For the analysis of impacts to sedimentation rates, the areas of scour (erosion) are disregarded, and therefore, the contour plots only depict the depositional areas (Figure 16).

Two locations of interest adjacent to the proposed project are shown in Figure 16: the Federal Law Enforcement Training Center (FLETC) piers to the north of the project site and the Cooper River Marina to the south of the project site. The model results at these sites indicate that the proposed project will not increase shoaling in these areas.

For each scenario, the sedimentation volumes were calculated for multiple segments (i.e., within the navigation channel reaches in the project area, the project berth and the project turning basin). Because of the uncertainty associated with the sedimentation model results, the results are best utilized as evaluating the relative change in sedimentation. Therefore, the simulated project alternative sedimentation volumes in each segment were divided by the simulated volume for the Base Case (referred to as a shoaling index in this report). The shoaling index results for the project alternatives are summarized in Tables 1 and 2. For reference, the average annual maintenance dredging rates are also provided in Table 1.

In addition to using the shoaling indices for evaluating the relative changes to sedimentation rates, the absolute changes must also be quantified in order for the USACE to quantify potential economic impacts to maintenance dredging of the navigation channel. Because the model results tend to over predict shoaling from Drum Island up through Daniel Island Bend, and the model results compare well to long-term average dredging rates in the navigation channel from Clouter Creek Reach up through the Filbin Creek Reach, the model is suitable for conservatively estimating impacts to long-term sedimentation rates in this area. The predicted shoaling rates for the project alternatives are given in Tables 3 and 4.

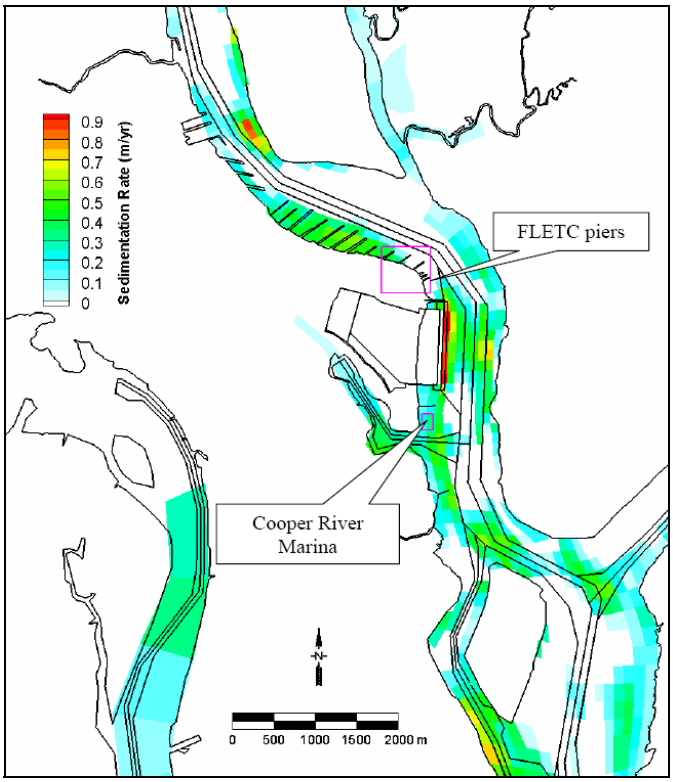

Figure 16. Simulated sedimentation patterns for the proposed project.

Table 1. Predicted shoaling indices for project alternatives and average maintenance dredging rates.

Name	Base Case	Proposed Project	Daniel Island Alternative	Clouter Island Alternative	15-year Avg. Maintenance Dredging Rates (cy/yr)
Drum Island Reach	1.0	0.8	1.0	1.0	123,300
Daniel Island Reach/ Bend and Myers Bend	1.0	2.0	1.0	1.0	58,400
Clouter Creek Reach	1.0	0.4	0.9	0.5	1,500
Navy Yard Reach	1.0	0.7	1.0	2.6	12,200
N. Charleston/ Filbin Creek Reaches	1.0	0.3	1.3	1.0	13,000
Shipyard Creek	1.0	1.0	1.0	1.0	231,000
Total navigation channel in lower Cooper R.	1.0	1.1	1.0	1.1	439,400
Turning basin	NA	1.0	0.4	1.4	NA
Berth	NA	1.0	0.6	1.2	NA
Berth and turning basin	NA	1.0	0.4	1.3	NA
Turning basin and navigation channel	1.0	1.4	1.1	1.5	NA

Table 2. Predicted shoaling indices for CNC project options.

Name	Base Case	Proposed Project	Option A	Option B
Drum Island Reach	1.0	0.8	0.9	0.9
Daniel Island Reach/ Bend and Myers Bend	1.0	2.0	1.0	1.5
Clouter Creek Reach	1.0	0.4	1.4	0.7
Navy Yard Reach	1.0	0.7	0.7	0.8
N. Charleston/ Filbin Creek Reaches	1.0	0.3	0.8	0.7
Shipyard Creek	1.0	1.0	1.0	1.0
Total navigation channel in lower Cooper R.	1.0	1.1	1.0	1.0
Turning basin	NA	1.0	2.6	1.1
Berth	NA	1.0	1.0	1.0
Berth and turning basin	NA	1.0	2.2	1.1
Turning basin and navigation channel	1.0	1.4	1.8	1.4

Table 3. Predicted shoaling rates for project alternatives (cubic yards x 10^4).

Name	Base Case	Proposed Project	Daniel Island Alternative	Clouter Island Alternative
Drum Island Reach	17	14	17	17
Daniel Island Reach/ Bend and Myers Bend	10	20	10	10
Clouter Creek Reach	0	0	0	0
Navy Yard Reach	4	3	4	11
N. Charleston/ Filbin Creek Reaches	1	0	1	1
Shipyard Creek	19	18	19	19
Total navigation channel in lower Cooper R.	51	56	51	57
Turning basin	NA	16	6	21
Berth	NA	6	3	7
Berth and turning basin	NA	21	9	28
Turning basin and navigation channel	51	71	56	78

Table 4. Predicted shoaling rates for CNC project options (cubic yards x 10^4).

Name	Base Case	Proposed Project	Option A	Option B
Drum Island Reach	17	14	16	15
Daniel Island Reach/ Bend and Myers Bend	10	20	10	15
Clouter Creek Reach	0	0	0	0
Navy Yard Reach	4	3	3	3
N. Charleston/ Filbin Creek Reaches	1	0	1	1
Shipyard Creek	19	18	18	19
Total navigation channel in lower Cooper R.	51	56	49	53
Turning basin	NA	16	41	17
Berth	NA	6	6	6
Berth and turning basin	NA	21	47	23
Turning basin and navigation channel	51	71	90	70

The results indicate that the proposed project would cause an increase in the total shoaling in the Federal navigation channel (on the order of $5x10^4$ cy/yr). Additionally, the proposed project would cause a shift in the shoaling pattern in the navigation channel. The results indicate that the proposed project would cause a 100 percent increase in shoaling of the Daniel Island Reach, Daniel Island Bend and Myers Bend portions of the navigation channel (this is on the order of a $5x10^4$ to $10x10^4$ cy/yr increase). The proposed project would also cause small reductions in shoaling of the other adjacent reaches ($3x10^4$ cy/yr in Drum Island Reach, Clouter Creek Reach, and $1x10^4$ cy/yr in N. Charleston/Filbin Creek Reaches). The proposed project would cause shoaling in the turning basin and berth area at a rate of approximately $21x10^4$ cy/yr.

The Daniel Island Alternative would not cause any increase in the total shoaling in the Federal navigation channel. The Daniel Island Alternative would cause shoaling in the turning basin and berth area at a rate of approximately $9x10^4$ cy/yr, which is 57 percent less than that predicted for the Proposed Project.

The Clouter Island Alternative would cause an increase in the total shoaling in the Federal navigation channel on the order of $6x10^4$ cy/yr, all of which occurs in the Navy Yard Reach of the channel. The Clouter Island Alternative would cause shoaling in the turning basin and berth area at a rate of approximately $28x10^4$ cy/yr, which is greater than that predicted for the Proposed Project.

For the design alternatives at the CNC (Tables 8-6 and 8-8), the Option A design would cause a small decrease in the total shoaling in the Federal navigation channel (on the order of $2x10^4$ cy/yr). The Option A design would cause no change in Daniel Island Reach/Bend and Myers Bend and small reductions in shoaling some of the other adjacent reaches (around $1x10^4$ cy/yr in Drum Island Reach, $1x10^4$ cy/yr in Shipyard Creek and $1x10^4$ cy/yr in the Navy Yard Reach). The Option A design would cause shoaling in the turning basin and berth area at a rate of approximately $47x10^4$ cy/yr, which is 220 percent more than that predicted for the Proposed Project.

The Option B design would cause an increase in the total shoaling in the Federal navigation channel (on the order of $2x10^4$ cy/yr). The Option B design would cause an increase in Daniel Island Reach/Bend and Myers Bend shoaling ($5x10^4$ cy/yr) and small reductions in shoaling some of the other adjacent reaches ($2x10^4$ cy/yr in Drum Island Reach and $1x10^4$ cy/yr in the Navy Yard Reach). The Option B design would cause shoaling in the turning basin and berth area at a rate of approximately $23x10^4$ cy/yr, which is 10 percent more than that predicted for the Proposed Project.

SSFATE Sediment Transport Modeling

The SSFATE (Suspended Sediment FATE) model was employed to evaluate the extent and nature of the suspended sediment plume that would be cause by dredging operations during construction of the proposed facility. The SSFATE model was developed by the U.S. Army Corps of Engineers (USACE) to simulate local sediment movement and deposition during dredge operations. It is a particle-based model that simulates the transport, dispersion, and settling of dredged material suspended in the water column at the dredge site. Additional details concerning SSFATE can be found in Johnson et al. (2000).

SSFATE Model Inputs

The SSFATE model requires input hydrodynamics and dredge source characteristics. The hydrodynamics simulated by the EFDC model were converted to the binary input file format required for the SSFATE model. The hydrodynamic data input to the SSFATE model also includes all of the necessary model geometry information such as water depths, and water body shape.

Multiple dredge source locations were simulated in order to evaluate the effects of dredging at different locations at the project site. The dredge source was located at the upstream and downstream edges of the proposed turning basin for each alternative in order to assess the maximum extent of suspended sediment plumes upstream and downstream of the project site.

Three types of dredging can be performed in SSFATE: cutterhead, clamshell, and hopper. The SCSPA has proposed to dredge 6.5 million cubic yards (Mcy) of material to construct the Proposed Project. It is reasonable to assume that the Proposed Project would use a large hydraulic dredge because of the large volume of new work material to be dredged. However, a clamshell type dredge could also be used, and therefore, both types of dredges were simulated in this study.

The hydraulic cutterhead dredge is presumably the dredge of choice, considering the project location and its proximity to the Daniel Island CDF. For a hydraulic cutterhead dredge, sediment suspension increases with higher speed of rotation, higher swing speed, larger cutter diameter, and greater depth of cut. SSFATE's default range of suspended sediment concentration for cutterhead dredge is 25 to 600 mg/l. Maximum concentrations for cutterhead dredges generally remain less than 500 mg/L and suspended sediment plumes are limited to within 500 m of the dredge (Havis, 1988; LaSalle, 1990). As a conservative assumption, a maximum expected suspended sediment concentration of 600 mg/l was used for the input concentration at the dredge site.

Dredge duration and efficiency are two important aspects in the modeling of suspended sediments. The exact dredge production rate for input to the model is unknown because the specific dredge to be used for the project is unknown. Production rates of dredges vary according to the material being dredged, dredging depth, horsepower of dredge pumps, pumping distance to disposal area, and other operational factors. For example, a 16-in. dredge typically produces between 240 and 875 cy of dredged material per hour, and a 24-in. dredge produces between 515 and 1615 cy/hr (USACE, 1983). For the SSFATE simulations, a production rate of 1,400 cu yd per hour was used. This is near the upper end of the range for large cutterhead dredges and it should provide a relatively conservative (i.e., high) estimate of the suspended sediment concentrations. In regard to dredge duration, the longer the dredge works, the more suspended sediment is entrained in the water column. The model was used to simulate a 14-day period of continuous dredging that spans a complete spring/neap tidal cycle. Suspended sediment plumes this tidal environment would affect areas for periods on the order of hours, therefore, longer run times are not necessary.

Sediment characteristics of the new work material to be dredged were input to the model based on sediment grain size analysis of sediment borings from Charleston Harbor during the month of August 1994 (USACE, 1994). The boring results from the locations near the project site were chosen to be analyzed in order to get the representative sediment characteristics for this study. For the purposes of the SSFATE simulations, an averaged dredged sediment size distribution was specified: 25.7% gravel and coarse sand, 25.7% fine sand, 6.6% medium fine silt, 6.6% fine silt, and 35.4% clay.

Clamshell dredging could potentially be used for the proposed terminal expansion, although it is most likely a secondary option. Clamshells are generally used for more clay or clay-silt type material. Mechanical dredges (i.e., clamshell and bucket) are associated with sporadic higher suspended sediment concentrations than hydraulic (hopper and cutterhead) methods; although the inherent slower production rate of mechanical dredges results in overall lower hourly-averaged suspended sediment plume concentrations. Mechanical dredges generate suspended-sediments through the impact of the bucket on the bottom, withdrawal from the bottom, washing of material out of the bucket as it moves through the water column and above the water surface, and potential additional loss when the barge is loaded.

Near bed suspended sediment clamshell dredging concentrations vary from 200-800 mg/l. (ASA, 2001). Loose clay layers will result in higher concentrations, whereas, stiff clays with high density will result in lower suspensions. Closed buckets generally result in lower suspended sediment concentrations than those generated with open buckets. As a conservative assumption for clamshell dredging, a maximum expected suspended sediment concentration of 800 mg/l was used for the input concentration at the dredge site for this study.

The clamshell bucket typically ranges in capacity from 1 to 12 cubic yard and is mounted on a flat-bottomed barge or fixed-shore installation. Twenty to thirty scoop/dump cycles per hour is typical, but large variations exist in production rates because of the variability in depths and materials being excavated. To provide a conservative analysis (i.e., to simulate the maximum possible concentrations), the highest dredging capacity was used in this study, i.e., a dredge rate of 12cy/cycle × 30 cycles/hour = 360 cy/hr was used as input. In regard to dredge duration, the same 14 day time span was used to simulate continuous dredging.

In certain operations for clamshell dredging, an additional amount of material may be released into the water column from the surface. This is caused by overflow from the barge and can be modeled as a percent of the total rate that is being dredged. However, overflow is not allowed in the Cooper River; therefore, a zero percent overflow was used in this study.

For the clamshell dredging simulation, the sediment characteristics input to the model was the same as in the cutterhead dredge simulation.

SSFATE Model Results

The model outputs suspended sediment concentrations at discrete vertical "bins" in the water column (e.g., 0 - 2 m, 2 - 4 m, etc., down to the river bottom). As previously mentioned, the highest sediment concentrations occur closer to the bottom (for both cutterhead and clamshell type dredging). Therefore, the bulk materials concentration of the water column (i.e., the TSS) for the bottom two bins (12.5 – 15 m and 15 – 17.5 m) is presented in the SSFATE model results figures in order to show the highest suspended sediment concentrations in the water column.

Figure 17 presents the maximum suspended sediment plume for the hydraulic cutterhead dredge simulation. The maximum suspended sediment plume figure is not a snapshot, it represents peak values that occurred for each grid cell over the entire two week duration model run. Therefore, it shows the maximum ebb and flood plume concentrations over a full spring/neap tidal cycle. Additionally, the model simulations do not include background suspended sediment concentrations. The simulated suspended sediment plume concentrations can be added to the ambient concentrations for an estimate of total suspended sediment concentrations.

Figure 17 presents the maximum suspended sediment plume over the 14-day dredge period when the dredge source is located at the southern end of the Proposed Project turning basin. Bottom suspended sediment concentrations more than 100 mg/l above ambient concentrations occur only within 1,700 m of the dredging source. Concentrations more than 300 mg/l above the ambient concentrations only occur within 50 m of the dredge source (i.e., within the same model grid cell as the dredge source). Given that average observed ambient concentrations at the bottom are about 100 mg/l, the estimated total plume concentrations (simulated plume plus ambient concentrations) exceeding 400 mg/l occur only within 50 m of the dredge source.

Time series of simulated suspended sediment concentrations for the dredge source located at the south end of the Proposed Project turning basin are shown in Figure 18. These plots show the concentrations for the model grid cell at the dredge source location (top plot), the adjacent grid cells 50 m upstream and downstream of the dredge source location (middle plot) and 1,500 m upstream and downstream of the dredge source location (bottom plot). The results show the intermittent spikes in suspended sediment concentration as the plume moves upstream and downstream with the ebbing and flooding of the tides.

Bottom thickness of settled material is also calculated by the SSFATE model in order to analyze the settling impact. Results show that appreciable settling/burial is only very localized near the dredge source. It should be noted that SSFATE results do not include sediment voids in the settled material. The void volume accounts for the volume of air and water within sediment and can account for up to the same volume as the sediment itself. Therefore, doubling the SSFATE results is reasonable in order to account for the volume added by the air and water voids present. Bottom thickness analyses showed relatively small amounts of sediment settled out onto nearby areas. Two weeks of dredging resulted in 0.53 mm of bottom deposition within 100 m of the dredge (assuming twice the deposition thickness predicted by the SSFATE model). It should be noted that this is averaged over square 50 m by 50 m grid cells. The deposition right next to the dredge source may be higher, and other areas within the cell may be lower. At this rate, six months of dredging in the same spot results in only 6.9 mm (0.069 m) of deposition within 100 m of the dredge source. Areas more than 100 m from the dredge source experience much lower deposition rates. In reality, the dredge is constantly moving and impacts are spread out more evenly over the entire project footprint. In contrast, areas of the navigation project are known to shoal at rates of 0.3 m to 1.2 m per year. Altogether, the predicted bottom deposition resulting from the material suspended by dredging operations is insignificant as compared to typical background sedimentation rates observed in the estuary.

Clamshell dredging operations were also simulated with the SSFATE model. The instantaneous suspended sediment concentrations generated by a clamshell can exceed that observed during cutterhead dredging. However, averaged over time (an hour or more), the average suspended sediment plume concentration generated by clamshell dredging is less than that for cutterhead dredging because of the lower production rate (cutterhead dredging is continuous bottom excavation, whereas clamshell dredging is not). For this reason, the SSFATE model results show that the maximum sediment plume concentrations and bottom deposition rates for the clamshell dredge simulation are smaller than that for the cutterhead dredging. Therefore, clamshell dredging has less impact than cutterhead dredging when averaged over periods of an hour or more. It should be noted, however, that excavation by clamshell dredging would considerably longer than cutterhead dredging, and so impacts would either extend over a longer period of time or would be caused by more than one dredge.

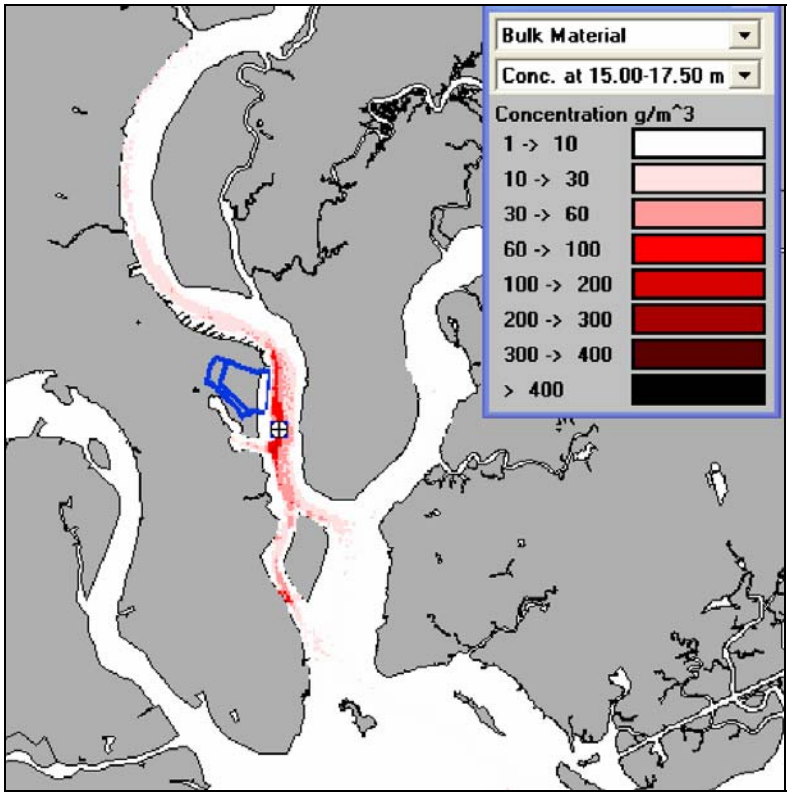

Figure 17. SSFATE simulated suspended sediment patterns during hydraulic cutterhead dredging operations.

DISSOLVED OXYGEN

The Proposed Project would potentially affect in-stream DO in four ways: (1) the physical changes to the river geometry can affect the reaeration of the water column by changing depth and current speed, (2) the changes in pollutant loading can increase the BOD and thereby decrease the DO concentration, (3) change in salinity concentration causes change in DO saturation concentration, and (4) change in circulation patterns can affect the residence time of BOD in the river. Through the initial scoping process for the EIS, the USACE decided not to model DO and to limit the scope of study to include qualitative evaluations of potential impacts to DO. Therefore, the hydrodynamic and salinity model results were reviewed to qualitatively evaluate the potential DO changes in the river.

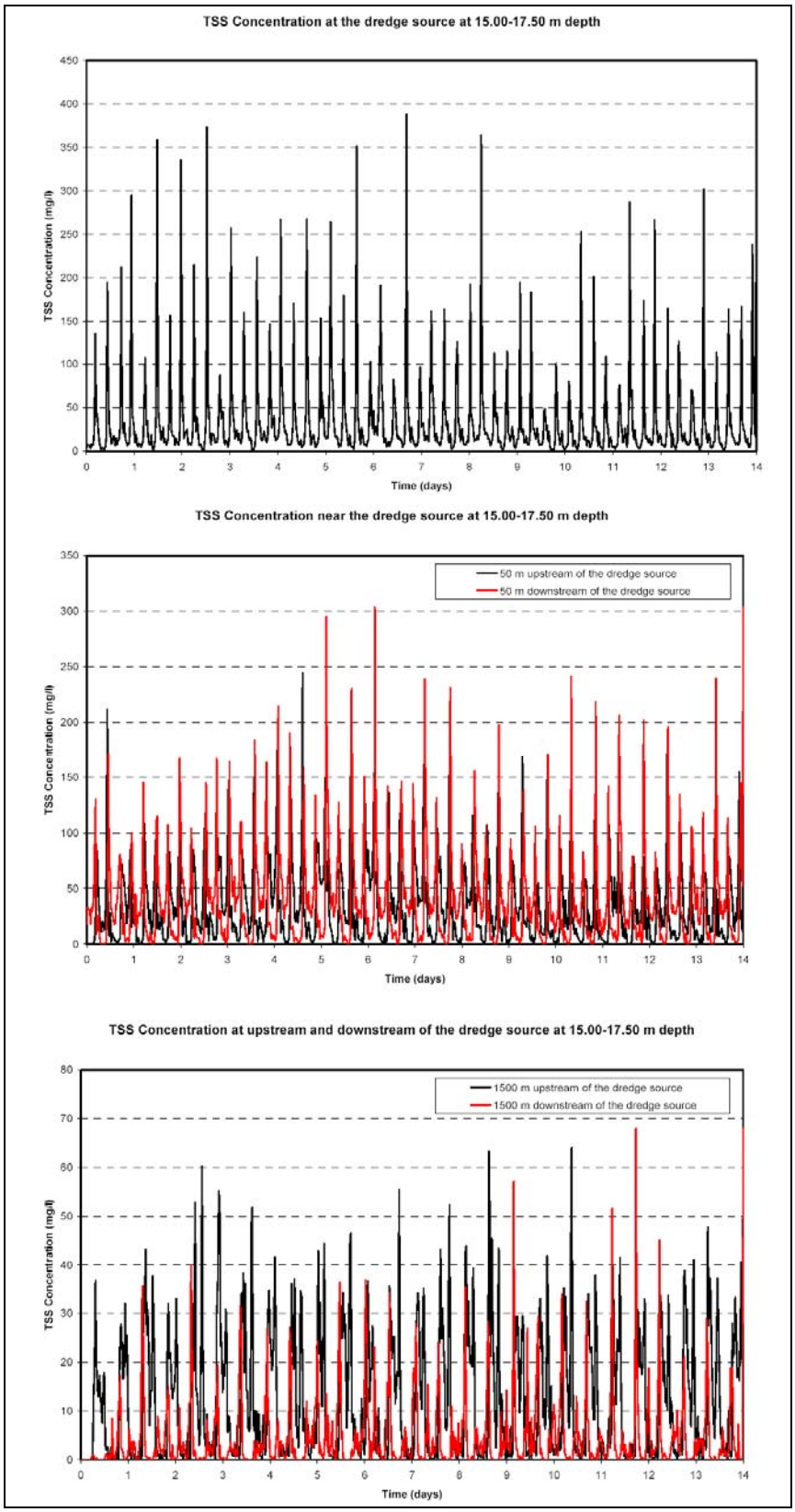

Figure 18. Time series of SSFATE simulated suspended sediment concentrations at various distances from the dredge source.

The hydrodynamic modeling results indicate that the project would cause a reduction in currents in the navigation channel at the project site. The current changes are less than 20 cm/s reduction in 50th percentile current speed and less than 10 cm/s reduction in 90th percentile current speed. This current speed reduction would result in a reduction in vertical mixing and reaeration, and thereby cause some small, localized reduction in DO concentration. The increase in depth would also directly result in a small decrease in reaeration of the lower portion of the water column.

The increase in the stormwater pollutant loading to Shipyard Creek and the Cooper River would also cause small changes in DO. The potential increase in UOD of the stormwater loading would be approximately 39,200 lb/yr. This conservatively high estimate would be only 0.2 percent of the load allocated by the TMDL for point-source discharges, and a much smaller fraction of the total load to the harbor (including non-point sources such as stormwater and marsh loadings). Therefore, this additional load would not appreciably alter the DO concentrations in the Lower Cooper River.

The changes in salinity concentration described above would affect DO saturation concentration, which, in turn, affects the DO concentration. The predicted change in 50th percentile surface salinity concentration in the navigation channel at the project site is -0.5 ppt, which equates to a 0.03 mg/l increase in DO saturation concentration (at 30°C). The predicted change in 50th percentile bottom salinity concentration in the navigation channel at the Proposed Project site is +0.1 ppt, which equates to a 0.01 mg/l decrease in DO saturation concentration. The average of the vertical water column (i.e., depth averaged) changes in DO saturation indicates that the project would not decrease the depth averaged DO saturation concentration. Altogether, it is expected that the project would likely result in very small, localized decreases in DO near the project site, particularly at the river bottom.

As mentioned previously, one of the reasons for utilizing the EFDC model for this study is that it is the same model being used for the development of a Total Maximum Daily Load (TMDL) of oxygen demanding substances to the river. With additional work, the model used for this study could be used to quantify potential DO impacts by using the same model boundary concentrations and kinetic rate coefficients as used for the TMDL model study.

SHIP SIMULATION STUDY

The hydrodynamic model also served other functions for the EIS study. The model simulated peak spring tide currents were exported and used for a ship simulation study. The ship simulator was used by the harbor pilots to dock and undock container vessels at the proposed terminal in order to identify potential navigational safety concerns and tug requirements.

CONCLUSIONS

This paper demonstrates the utility of a single numerical model to support multiple aspects of a detailed environmental impact study of a new container terminal project, both by directly quantifying impacts to hydrodynamics and sediment transport as well as linking to other models such as SSFATE to evaluate dredging related impacts.

The Environmental Fluid Dynamics Code (EFDC) was used to simulate the river currents, salinity, and sedimentation patterns in the Lower Cooper River. Comparisons to observed water levels, currents, salinity concentrations, suspended sediment concentrations and sediment deposition patterns demonstrate that the model reasonably represents the hydrodynamic and sediment transport environment in the river.

Model simulations of changes to salinity near the project site and further upriver demonstrated that the project would not affect salinity intrusion to the Back River (a freshwater reservoir upriver from the project site).

The sediment transport component of the model was used to show the relative differences in maintenance dredging rates that would be required for each of the project alternatives. The study also estimated the total maintenance dredging rate for the proposed project. The proposed project would have minimal effect to long-term maintenance dredging of the Federal navigation channel by altering the river geometry. Sedimentation modeling results indicate that the proposed project would cause an increase in the total shoaling in the Federal navigation channel on the order of 2×10^4 cy/yr. However, the proposed project is expected to cause shoaling at a rate on the order of 17×10^4 cy/yr in the turning basin area adjacent to the berth.

The EFDC model currents were exported to the SSFATE model in order to simulate suspended sediment impacts from dredging operations, although this required writing code to convert the EFDC output file format to that

required for SSFATE. The model results indicated that the large increases in suspended sediment concentrations would be limited to a localized area at the river bottom near the dredge (within 50 m). The increases are less than suspended sediment concentrations that occur during storm events (both in concentration and spatial extent), and therefore, these adverse impacts are considered minor.

The model results were also used to qualitatively evaluate potential impacts to dissolved oxygen in the river near the project site, which is considered impaired (not meeting the water quality standard). Based on the hydrodynamic and salinity model results, it is expected that the project would likely result in very small, localized decreases in DO near the project site, particularly at the river bottom. With additional work, the model could easily be used quantify the potential DO impacts.

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