# NUMERICAL MODEL STUDIES TO SUPPORT DEVELOPMENT OF DANIEL ISLAND TERMINAL ON THE WANDO RIVER, CHARLESTON, SOUTH CAROLINA - FEBRUARY 1999

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## INTRODUCTION

The South Carolina State Port Authority is engaged in a large terminal development project involving two terminals on Daniel Island. The U.S. Army Engineers District, Charleston, (SAC) is performing economic and environmental analyses on channel designs. At WES, studies continue to evaluate new channel designs to access the terminal on the Wando River side, and on present navigation and sedimentation problems near the intersection of the Wando River, Hog Island, and Drum Island Reaches in Charleston Harbor. Future navigation conditions and maintenance dredging requirements will benefit from optimal channel design.

A navigation study was conducted to evaluate and optimize channel designs which will provide access to a proposed new 5,000-ft wharf on the Wando River side of Daniel Island for container ships up to 140-ft wide (POC: Dennis Webb, CEWES-CN-N). Three channel designs to service the terminal have been developed, tested, and revised. Testing of the revised plans was done in November 1998. A maneuvering problem presently exists at the intersection where, during strong ebb tides, currents hinder large vessels from turning into Drum Island Reach. The navigation simulator has been used to test solutions for this problem.

Hydrodynamic, sedimentation, and salinity models are being applied to support the navigation simulations, to solve present problems and avoid future ones, and to assess possible impacts of new channels (POC: Allen Teeter, CEWES-CE-TS). A sedimentation problem presently exists near the Drum Island/Wando River Reach intersection which field data have shown to be associated with an eddy attached to the north end of Drum Island. The hydrodynamic model reproduces this feature. The shoal grows from the channel toe at the center of the eddy where currents are low in the position indicated by the model. The shoal has required dredging at intervals less than a year. The sedimentation model will test possible solutions to this problem, and gage the maintenance dredging requirements of channels developed by the navigation study. Sedimentation of alternate channel designs will also be gaged with the model. A salinity model will be verified, and used to test the effects of the select channel design on salinity intrusion.

As of February 1999, the hydrodynamic model has been used to generate current field for the ship simulator study. After recent plan modifications, the numerical model meshes required modifications to bring all nodes into alignment. The hydrodynamic results presented here were generated using these revised meshes. The sedimentation and salinity models will be used over the next couple of months to predict sediment impacts, maintenance dredging requirements, and changes in salinity distributions resulting from the channel designs. Sedimentation impacts will be examined in the vicinity of the planned channel and wharf. Salinity effects will concentrate on possible changes to conditions at the entrance to Bushy Park at river mile 42 of the Cooper River.

## BACKGROUND

The Wando, Cooper, and Ashley Rivers are subestuaries which converge and form the estuary of Charleston Harbor. The mean tide range at the Customs House gage at Charleston (approximately 2.5 miles from the study area) is 5.2 ft (1.6 m* ). Prior to 1942, freshwater inflows to Charleston Harbor were 82 cfs (cubic feet per sec* ) from the Wando, 72 cfs from the Cooper, and 261 cfs from the Ashley River. The average inflow from the Cooper river was 15,600 cfs between 1942 and 1986, and has been 4,500 cfs since 1986 as a result of the Army Corps of Engineers' Cooper River Diversion and Rediversion Projects. These increased flows were used for hydropower generation. Harbor maintenance dredging increased from 0.1 to 10 million cubic yards per year as a result of the diversion which increased sediment inflow and changed estuarine conditions (Teeter 1989). Harbor maintenance dredging decreased appreciably after the rediversion.

There was a dramatic change in sedimentation in the Harbor after the 1986 Cooper River rediversion which could have led to the adjustments in channel cross sections and to impacts on shallow water and shoreline areas. The U.S. Army Engineer District, Charleston is performing a study on the effects of the rediversion on cross sections in the Cooper River. Bank-to-bank bathymetric surveys have been performed in Charleston Harbor, but not in the Wando River. Still, this study should provide some important information on the response of the harbor to the rediversion, and on the third and forth factors listed earlier for the harbor in general. The Cooper River Rediversion Project reduced shoaling rates in the harbor. It is likely that some channel adjustment to the new flow and sedimentation conditions has occurred. The study report will be published soon by CESAC.

A previous study of the Cooper River west of Daniel Island examined the effects of contraction training dikes (Teeter, et al., 1992). A comparison of bank-to-bank bathymetric surveys from 1934 and 1978 showed changes in the shallow areas near the shoreline away from the influence of the dikes. Typically these areas shoaled a couple feet, and the shoreline on the east bank of the Daniel Island Reach of the Cooper River advanced toward the channel. There were dramatic increases in sedimentation caused by the diversion of flow into the Cooper River, as described earlier. It is likely that sedimentation in the Wando River was also increased by the diversion. It is also likely that sediment beds and channel cross sections have or will re-adjust themselves to the 1986 rediversion which reduced sedimentation. No information was located on what effect the construction of the navigation channel had on flows in the Wando River.

*Development of marine transportation on the Wando River.*

A container ship terminal (Wando Terminal - State Pier 41) was constructed by the South Carolina State Ports Authority (SCSPA) in 1979 upstream from Hobcaw Point. A 1.5-mi*-long Federal navigation channel was constructed up the Wando River and past Hobcaw Point to connect the terminal to the Drum Island Reach of the Charleston Harbor channel.

The navigation channel was aligned to follow the previous natural channel, and the shallow water area off Hobcaw Point was naturally a narrow feature prior to 1979. The previous natural channel had deepened between 1964 and 1978, possibly as a result of the diking of the shallow water area which is now the southern end of Daniel Island. The dike extended along the 6 ft mean low water (mlw) contour on the opposite side of the channel from the study area, reducing the channel width. The charts show natural channel depths increased by 5-8 ft off Molasses Creek from 1964 to 1978. This indicates that current speeds in the channel off the study area increased during that time. Comparison of those charts also shows that the shoreline in the area of interest retreated by roughly 60 ft. (The date of the survey on which the 1964 charted shoreline was based is not known but could be 1934).

There are local concerns that the terminal and related activities have changed bed sediment conditions and caused or contributed to shoreline retreat in the area southeast of the Wando River Channel between Remley Point and the Wando Terminal, including Hobcaw Point. At the request of the SCSPA, the U.S. Army Engineer Waterways Experiment Station (WES) performed an investigation of sediment conditions and possible erosion due to channel or terminal activities near the subject site. At least five causes of shoreline retreat are thought to be possible here.

The overall channel cross section might enlarge as a result of increased tidal flows or decreases in sediment load, and affect the shoreline. The shoreline might suffer erosion by vessel waves and/or by wind waves. The shoreline would also retreat in response to increases in sea level. The following section describes what conclusions could be drawn from available information.

*Shoreline conditions near the mouth of the Wando River.*

The area of interest is a marsh fringed shoreline and adjacent mud, sand, and shell shallow sediment bottom. Depth contours of the area show that the shallow water area off Hobcaw Point is a relatively narrow feature which gives way offshore to the navigation channel.

Surface current patterns were observed by WES in June 1996 on maximum ebb and flood tidal phases. Maximum flood tidal current speeds in the shallowest water measured were about 1.0 ft/sec (0.3 m/sec^), while maximum ebb tidal currents were about 2.1 ft/sec. Maximum current speeds in the channel off Hobcaw Point were about 3.5 ft/sec and 5.5 ft/sec for flood and ebb tidal phases, respectively. Higher current speeds occur northwest of the navigation channel, away from Hobcaw Point. Maximum tidal discharges for the same period of measurement were about 153,000 cfs and 201,000 cfs for flood and ebb tidal phases, respectively.

The special shoreline surveys performed for the SCSPA in 1979, 1981, 1992, and 1996, and summarized by George A.Z. Johnson, Jr., Inc (1997), show a trend of shoreline retreat, but due to un-certainty as to which elevations were contoured, quantification of that trend was not feasible. Apparently, different definitions of "shoreline" were used. The mean low water datum is the official water elevation used to define water-land intersection as delineated on NOS charts. However, the shoreline has recently been defined by the South Carolina Coastal Council in relation to the edge of marsh. The latest surveys follow both the 0.0 ft mlw and marsh-edge definitions.

The contour lines form two groups based on their proximity to each other. If the contour lines so grouped are assumed to define the shoreline and 0.0 ft mlw, then the earliest surveys tend to fall toward the Wando River and the 1996-1997 contour lines fall on the landward edge of the groups. Qualitatively then, the shoreline has retreated about 35 ft on average and the 0.0 ft mlw line has moved about 25 ft toward the shore over the period since 1979. There are appreciable local variations in these trends.

The shoals which occur at the mouths of Hobcaw and Molasses Creeks were charted on the 1964 and 1978 NOS charts in about the same configuration as they exist today. The southern entrance to Hobcaw Creek is actually more open now than in 1964. The navigation channel cut through the offshore edge of the shoal at the mouth of the northern entrance to Hobcaw Creek. The controlling depth entering Hobcaw Creek at this location is presently about 1-2 ft mlw, very similar to that indicated on the 1964 NOS chart. These shoals are bar formations common to tidal creeks where they intersect larger tidal rivers.

Bed sediment sampled during both site visits at about 10 ft mlw depths were found to be firm but with a thin surface flocculent layer indicating that sediments were neither eroding nor depositing rapidly. Samples taken during the 1997 field reconnaissance survey at about 5 to 2 ft mlw depths, bed sediments were typically overlain with 0.05-0.15 ft of brown sand, with soft fine-grained material below. At one location, 0.4 ft of surficial sand was encountered, and at two other sites, the sandy surface overlaid what appeared to be a stiff marl. Bed sediments were sandier and tougher toward Remley Point. Samples taken during the 1992 reconnaissance were restricted to 5-10 ft depths and did not encounter sand.

Sea level is rising on a global basis at about 0.0062 ft/yr based on records from 1890 to 1980 (Douglas 1991). Local sea level variations change with time, and depend on factors such as postglacial rebound, tectonic movements, and sedimentary subsidence. The local, apparent sea level rise at Charleston has been reported to be 0.0105 ft/yr based on 1930-1980 data (Douglas 1991) and 0.0112 ft/yr based on 1940-1986 data (Hicks and Hickman, 1988). While sea level rise should not affect the positions of elevation lines surveyed to a common vertical control, sea level rise leads to inundation of land and the loss of land through the erosive effects of water. The rise in sea level generally increases tidal prisms and tidal flows. Over the 18 years 1979-1997, the average sea level at Charleston has risen about 0.1948 ft or 2.33 inches.

The shoreline and shallow water depth contours between Remley Point and the Wando Terminal have moved landward by perhaps 1 ft per year. This retreat has been occurring at least since 1964 probably as a result of a combination of factors. Inspection of sediment conditions indicated that sediment degradation or erosion is a relatively slow process, not greatly affecting the characteristics of surficial bed sediments. None of the five factors assessed can be entirely ruled out as possible agents in the shoreline retreat.

Previous diking of Daniel Island, construction of the Wando Channel, and rediversion of the Cooper River have each affected channel cross sections, and may continue to do so for years before an equilibrium is established between sediments, flows, waves, and geometry of this channel. Waves produced by container vessels do not appear to be as important as wind waves or as waves produced by smaller displacement vessels in generating shear stress forces on the sediment bed. Vessel waves are solitary and infrequent in comparison to wind waves. Wind wave erosion of marsh edges was indicated, suggesting that wind waves may have eroded sediments at lower elevations as well. Sea level is rising in the harbor which also contributes to land loss along the shoreline.

## MODEL DESCRIPTION

The numerical model being applied in this study is RMA10-WES, a modified version of the model originally developed by Dr. Ian King of Resource Management Associates. It is an implicit finite element model which solves Reynolds-averaged Navier-Stokes equations of motion for shallow water waves over a combination of one-, two-, and three- dimensional elements. The model has wetting and drying capabilities for elements whose elevation is within the range of tidal water levels. Very shallow elements can also be prescribed as porous marsh elements with sub-element scale hydrologic features. The model has capabilities to compute time-varying vertical eddy viscosities and diffusivities based on an algebraic turbulence closure scheme. Likewise, horizontal eddy viscosities can be specified in the model explicitly, calculated within the model based on current speed and element size, or calculated using a Smagorinsky-type eddy viscosity scheme which accounts for unresolved sub-element scale dissipation.

A numerical mesh was developed to cover the entire Charleston Harbor, the Cooper River up to the Pinopolis Dam, and large parts of the Wando and Ashley Rivers. The mesh was based on a two-dimensional depth-averaged mesh developed for a previous study (Teeter et al. 1995). The previous mesh was verified to flows collected in 1992 and 1993. The new mesh has three-dimensional areas in the channel covering the Federal navigation projects from the ocean up the Cooper and Wando Rivers. Figure 29 shows the overall extent of the mesh and an indication of the horizontal resolution. Figure 30 shows the extent of 3-D elements in the mesh.

## HYDRODYNAMIC MODEL VERIFICATION

The hydrodynamic model was originally verified to tidal harmonic water levels for a previous navigation study. Flow distributions in navigation channel areas were checked against 1992 field data collected in Drum Island and Town Creek Reaches. Additional flow data were collected for this study in 1996 and inspection of those data indicated that the model needed adjustment in areas outside the navigation project. An adjustment and re-verification of the model mesh was to measured water levels, discharges, and currents.

## HYDRODYNAMIC MODEL TESTS OF CHANNEL PLANS

The existing channel condition consists of a 40 ft deep channel which follows the natural channel on the southeastern side on the waterway to a rectangular turning basin constructed abreast of the Wando Terminal. See Figure 31. The three plans involve 45-ft-deep channel areas to replace or supplement the existing channel and with connections to the existing turning basin. See Figures 32-34. The plan tests also include channel enlargements on the Cooper River side of Daniel Island, and the removal of the dike on the southwest corner of Daniel Island.

Model runs indicate that, as a result of greatly increasing cross sectional areas, current velocities in the Wando River abreast of the proposed Daniel Island Terminal will be reduced. Table 1 contains maximum flood and ebb current magnitudes for the base and plan conditions (at the same times as the base) at the Mount Pleasant Bridge, in the Wando River, and in the Drum Island Reach. Transect locations are shown in Figure 35. Bank-to-bank cross sectionally averaged current magnitudes were determined for times of maximum flood and ebb. Base versus plan differences are also shown. In the Wando River, average currents decreased 34 to 40 percent on ebb tidal flow, and 36 to 41 percent on flood tidal flow. The slightly greater decreases on flood versus ebb tidal phase may be due to the increased cross sections in the Drum Island and Daniel Island Reaches allowing greater flow through those channels.

Strength of flood and ebb current vector plots were made for the vicinity of Drum Island Reach and its intersection with the Wando River. Figures 1 and 2 show strength of flood vectors for the surface and bottom. Figures 3 and 4 show strength of ebb vectors for the surface and bottom. Figures 5 and 6 show base minus plan 1 during strength of flood at the surface and bottom. Note that if plan currents are greater than the base, no current vector is shown. Figures 9 and 10 show plan minus base corresponding to Figures 5 and 6. Figures 7 and 8 show base minus plan 1 during strength of ebb at the surface and bottom. Figures 11 and 12 show plan minus base current vectors corresponding to Figures 7 and 8. Figures 13-20 show vector difference plots for plan 2 corresponding to Figures 5-12. Figures 21-28 show vector difference plots for plan 3 corresponding to Figures 5-12. These plot, like the data presented in Table 1, indicate that plan currents are generally lower than base currents over most the the Wando River study area.

Residual or net flow velocities were calculated for three locations in the Wando River and tabulated in Table 2. Locations of these sites are given in Figure 35. Residual velocities were calculated by averaging the 30 minute time-varying model currents over a 12.5 hour period (model hours 37-49.5). This tidal cycle appeared to the most symmetric water level fluccuation of those tidal cycles simulated. Time-series currents are given in Plates 1-6 for model hours 12-72. Positive values indicate upstream flow in the direction of the flood tidal current. It is not possible to calculate precise residual currents due to the 30 minute model time step and sub-tidal frequency components in the tidal boundary conditions specified. Calculated residuals are therefore comparative rather than absolute.

Residual currents in the study area tend to be dominated by secondary currents generated at channel bends. Figures 36 and 37 show residual current vectors and magnitude contours for the base conditions at the surface and bottom. The magnitude of these vectors are generally much larger than the those presented in Table 2.

## INDICATION FOR SEDIMENTATION AND SALINITY INTRUSION

The maximum and average currents will be reduced in the plan channels compared to the existing condition. This indicates that sedimentation and maintenance dredging requirements will be greater in these channels as compared to the existing channel. The channel areas are also appreciably greater than the existing channel area. The previous analysis of the enlargement of the Daniel Island Reach (Plan 2-5, Teeter et al. 1995) indicated that a similar channel enlargement increased shoaling roughly 50 percent. (Much due to the 120 percent increase in the channel area.) However, in that study the addition of a dike in the model on the west bank of Daniel Island Reach reduced the predicted shoaling to about that of the base condition. Thus, 50 percent is probably an upper limit of expected shoaling increase.

As indicated in Table 2 the existing channel is flood dominated with positive surface and bottom residual currents. Residual vectors in the turning basin can be seen to be upstream in Figures 36 and 37. On the inside of the channel bend near the turning basin, residual vectors can be seen to be downstream. The plan channels move the flood- dominated flow to the Daniel Island side of the waterway. This should produce a favorable shoaling condition, at least along the proposed wharf. Shoaling can be expected to be most severe in the location of the existing channel.

Slight increases in salinities upstream from the proposed terminal might be indicated by increased flood currents and flood-dominated residuals along the proposed wharf. No increase in overall salinity intrusion is expected since the proposed channels do not increase the channel length beyond the existing condition.

In the spring of 1999, sedimentation and salinity models will be employed to assess plan impacts. Sedimentation conditions in the harbor will be examined. Salinity intrusion in the Cooper River and in the vicinity of the proposed wharf will be examined.

## REFERENCES

Douglas, B.C. 1991. Global sea level rise. J. of Geophysical Res., 96(C4), pp. 6981-6992.

George A.Z. Johnson, Jr., Inc. Jan 1997. Wando River Shoreline

Survey. 4 sheets for SCSPA, Charleston SC.

Hicks, S.D., and L.E. Hickman, Jr. 1988. United States sea level variations through 1986. Shore & Beach, 56(3), pp. 3-7.

Teeter, A.M. 1989. Effects of Cooper River rediversion flows on shoaling conditions at Charleston Harbor, Charleston, South Carolina. Tech. Rpt. HL-89-3, WES, Vicksburg, MS.

Teeter, A.M. 1992. Effects of a proposed Bushy Park entrance canal relocation, Cooper River, South Carolina. Techn. Rpt. HL-92-8, WES, Vicksburg, MS.

Teeter, A.M., Pankow, W., Heltzel, S.B., and S.C. Knowles. 1992. Effectiveness of contraction training dikes at Charleston Harbor, Charleston, South Carolina. Msc. Paper HL-92-1, WES, Vicksburg, MS.

Teeter, A.M., Callegan, C.J., and W.H. McAnally, Jr. 1995. Salinity and sedimentation modeling of the phase II Charleston Harbor Expansion, South Carolina. Draft report, WES, Vicksburg, MS.

Teeter, A.M., Benson, H., and C.J. Callegan. 1998. Shoreline conditions near Hobcaw Point, Wando River, Charleston Harbor, South Carolina. Draft report, WES, Vicksburg, MS.