NUMERICAL MODELING STUDIES SUPPORTING NEARSHORE PLACEMENT OF DREDGED MATERIAL FROM THE SAVANNAH RIVER ENTRANCE CHANNEL

Joseph Z. Gailani[1] and S. Jarrell Smith[1]

ABSTRACT

The Savannah Harbor Federal Navigation Channel provides passage for ocean-going vessels via a 34-km dredged channel from the city of Savannah to the ocean. Eighteen km of this channel extend from the inner continental shelf to the river mouth and is exposed to coastal oceanographic conditions. The U.S. Army Engineer District, Savannah (SAS), which oversees the Federal Navigation Project, is investigating alternate open water dredged material placement sites (ODMPS) for the estimated 600,000 m^3 yr^{-1} dredged annually from the entrance channel. This dredged sediment is predominately fine-grained sand, but the quantity of silt and clay prevents the material from being treated as high-quality beach sediment. Present dredging practice includes offshore placement of ebb channel material into an offshore ODMPS. This practice removes sediment from the littoral transport zone and regional sediment system. Prior to dredging of the federal navigation channel, natural processes bypassed sediment across the river mouth. Removing sediment from the regional system may contribute to long-term shoreline erosion immediately downdrift (south) of the channel.

SAS is interested in reproducing natural sediment bypassing through nearshore placement of sediment intercepted and dredged from the entrance channel. The U.S. Army Engineer Research and Development Center performed a study for SAS that addressed multiple issues related to nearshore placement. As one part of this effort, hydrodynamic and sediment transport numerical models were developed for the river mouth and ebb delta. Numerical models were developed and used to evaluate nearshore placement alternatives that may provide littoral zone nourishment (and represent reasonable cost alternatives to present offshore placement procedures). An additional issue associated with nearshore placement and addressed in this effort is transport of dredged material back into the nearby navigation channel (increasing dredging requirements). The numerical modeling study concludes that adverse impacts associated with nearshore placement are expected to be small, but some locations on the ebb shoal complex are more favorable to achieve project objectives. Study results are assisting SAS to developing a Dredged Material Management Plan (DMMP) for the Savannah Harbor Federal Navigation Project that utilizes dredged material beneficially within a Regional Sediment Management (RSM) plan for the Savannah River and Georgia coast.

Keywords: Beneficial use, littoral nourishment, sediment management, sediment transport, coastal

INTRODUCTION

The Savannah Harbor Entrance Channel (Figure 1) begins on the continental shelf, cuts through the ebb shoal, and enters the Savannah River. The channel then continues 16 km up the river to Savannah harbor. The channel designated depth is 13.4 m (44 ft). At the Savannah River entrance, there are jetties on either side to inhibit channel infilling. On the coast south of the river mouth is Tybee Island. There are significant wetlands behind Tybee Island and to the north of the river. Like most inlets and river mouths, the Savannah River mouth is geologically dynamic. In its natural state, sandy sediment would predominantly remain in the nearshore, bypassing the river mouth through channel switching and other processes. Construction and maintenance of the Savannah River Federal Navigation Channel intercepts much of the sandy sediment that would ordinarily bypass to the south. Following navigation improvements to the entrance channel in the late 1800s, the north Tybee shoreline receded, resulting in alterations in the littoral transport patterns along the northern half of the island. The ebb shoal attachment bar at Tybee Island has migrated south, reducing the sediment source to north Tybee. The resulting shoreline evolution includes shoreline recession in the north and accretion in the south. Figure 2 shows shoreline evolution from 1866 to 1982. The attachment bar of 1866 is much farther north than the existing attachment bar.

SAS has performed multiple studies and executed several beach fill and sand retention projects to stabilize the north half of Tybee Island. SAS requested the U.S. Army Engineer Research and Development Center (ERDC) support in

[1] Research Hydraulic Engineer, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, ATTN: CEERD-HC-C; 3909 Halls Ferry Road; Vicksburg, MS 39180
phone: 601.634.4851
email: Joe.Z.Gailani@erdc.usace.army.mil

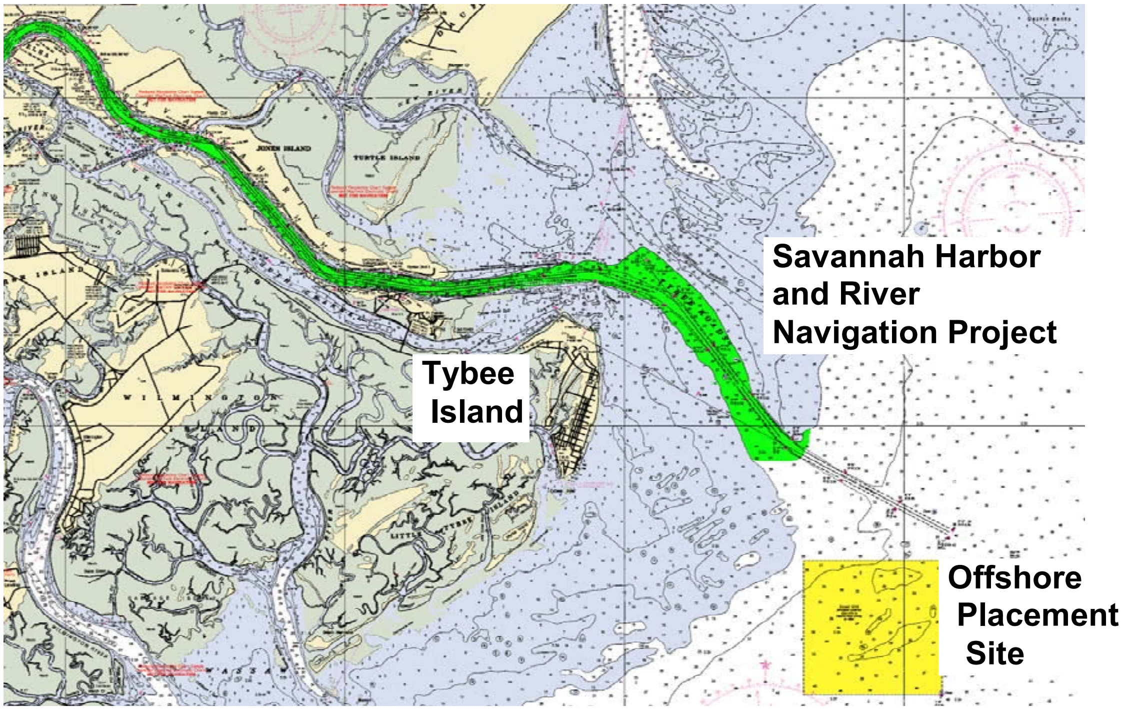

Figure 1. Map of Savannah River Entrance, Lower Portions of the Federal Navigation Project, and Tybee Island.

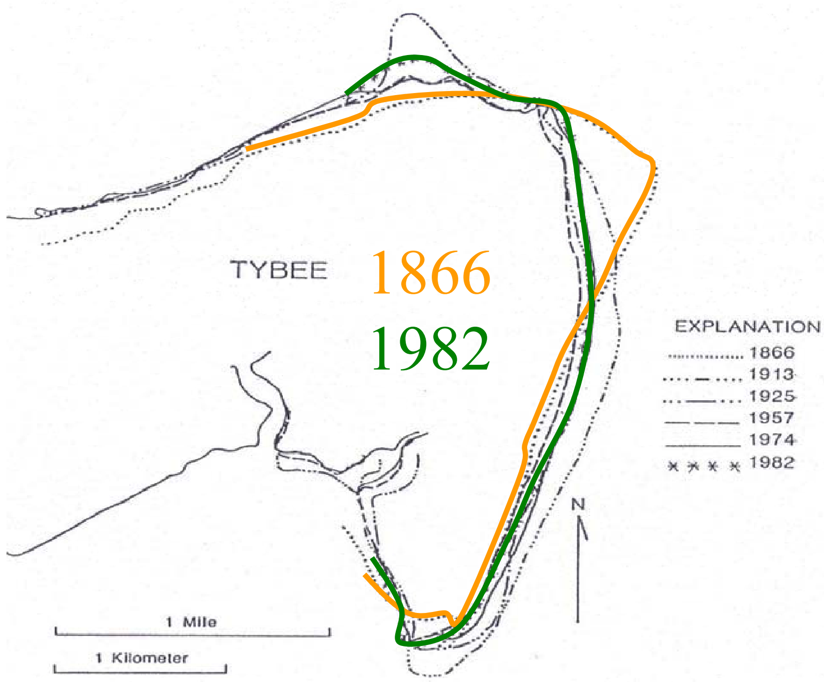

Figure 2. Shoreline evolution of Tybee Island 1866-1982 (adapted from Oertel et al 1985).

executing a study that covered multiple aspects of nearshore placement for littoral nourishment. This paper will focus on one objective of this study. This objective is to determine if dredged material, which is predominately sand, but not of beach quality, can be placed in the nearshore to nourish the littoral system and stabilize the north Tybee shoreline. Present dredging practices place entrance channel dredged material offshore (Figure 1) where it is isolated from the littoral and regional sediment system. Placement in the nearshore would maintain this sediment in the regional system. This practice is appealing to SAS and the Corps in general as Corps policy progresses toward regional sediment management and away from project-specific management. However, long-term transport trends must be interpreted to assess potential positive and negative impacts of nearshore placement.

HYDRODYNAMIC AND WAVE MODELING

Temporal and spatial current and wave distributions near the beach, over the ebb shoal, and at the inlet are required to assess sediment transport for nearshore BU placement options. Current direction and magnitude and water surface elevations induced by tides, winds, and river inflows at and around proposed placement sites were modeled by applying the ADvanced CIRCulation (ADCIRC) hydrodynamic model (Luettich, Westerink, Scheffner 1992). ADCIRC is a finite element model and therefore can be run on highly flexible, irregularly spaced grids. Fine resolution can be specified in the area of interest (ebb shoal, entrance channel) and coarse resolution in areas distant from the region of interest. Modeling a large domain permits hydrodynamic modeling due to wind-forcings. For this application, ADCIRC was forced at the upstream model boundary condition of the Savannah River with U.S. Geological Survey (USGS) flow station data. Figure 3 shows the ADCIRC grid for the entire domain. The grid extends for several hundred km in each direction. ADCIRC nodes, where current and water elevation are calculated, are identified as intersection of lines on the grid. Tidal harmonics were used to drive the offshore ADCIRC boundary. Regional atmospheric conditions were used to drive the model. Fine cell spacing of approximately 50 m was used over the ebb shoal and at the entrance. This spacing provides sufficient information on current variability in the nearshore to define transport gradients for the purpose of assessing dredged material placement. The domain covered several thousand km^2 and grid spacing far from the area of interest was on the order of tens of kilometers.

A 24-year record of wave conditions was selected as the period of analysis for potential transport. It is computationally impractical to perform 24 year ADCIRC simulations. Therefore, only tidal forcings and a constant

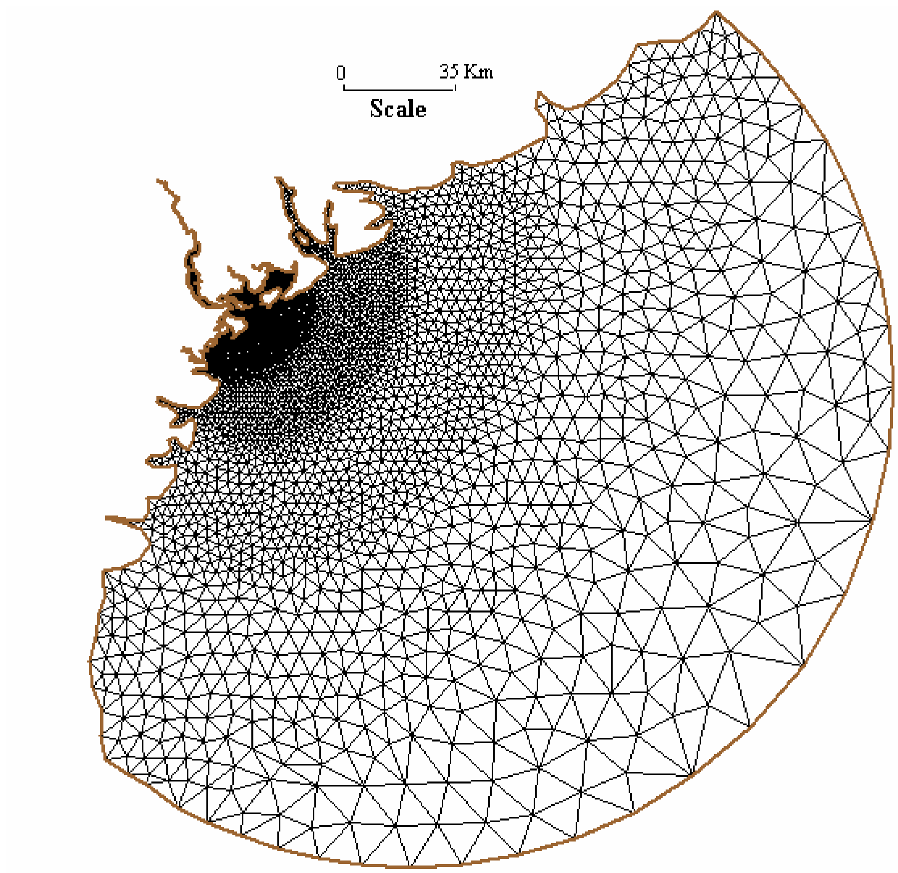

Figure 3. Map of the ADCIRC domain.

river flow were used for the 24 year transport assessment. A typical spring/neap tidal cycle was modeled using ADCIRC (a 30-day simulation) and repeated to represent 24 years of hydrodynamics. In addition, shorter periods were modeled to include wind driven currents, including a representative active month defined as 90th percentile winter wave energy (November 1979) and typical operation period (January 1992). The reader is referred to Gailani et al 2003 for details of how these two representative months were chosen. In addition, hydrodynamic data were collected by SAS for a 2-week period in December 1999. This period was used to calibrate the ADCIRC model. Details of ADCIRC grid generation, resolution, bathymetric input, calibration, and simulation results are provided in (Gailani et al, 2003). Data were saved hourly at each node on the ADCIRC grid.

Wave action is another critical component for estimating nearshore sediment transport. Wave-influenced sediment transport will be significant at nearshore dredged material placement sites. Waves generate orbital velocities that suspend sediment for transport by mean currents. In addition, as waves enter shallow water, the orbital velocities become asymmetric and induce undertow, producing a net transport without the mean currents. An additional mechanism for wave-driven transport, longshore currents, was not assessed in these simulations. Implementation of methods to account for wave-generated currents and transport will be discussed later in this paper. Offshore wave conditions for the 24-year simulation periods were extracted from the Wave Information Study (WIS) 1976-1995 hindcast (Brooks and Brandon, 1995). The WIS hindcast provides hourly significant wave height, associated period, and direction. These conditions were transformed from the offshore hindcast station to the nearshore through the STeady-state spectral WAVE model (STWAVE). STWAVE (Resio 1987, 1988a, 1988b; Smith et al. 2001) is a half-plane, phase-averaged, spectral wave transformation model. STWAVE simulates depth-induced refraction and shoaling, current-induced refraction and shoaling, depth- and steepness-induced wave breaking, wave growth from wind input, non-linear wave-wave interactions, and energy dissipation due to white capping. Inputs include bathymetry, offshore wave conditions, and wind conditions. Output includes fields of significant wave height, peak period, and direction over the nearshore region simulated.

For the Savannah Harbor Entrance Channel application, waves were transformed using STWAVE from WIS station 33 (Brooks and Brandon, 1995) to the nearshore through a nested grid STWAVE application (Smith and Smith 2002). Waves are transformed from the offshore over a typically coarse "parent" STWAVE grid and the transformed wave spectra are saved along the offshore boundary of the more finely resolved "nested" grid. Nested grid simulations begin with the saved conditions from the parent grid and transform these waves over a more finely resolved grid towards shore. The STWAVE wave model was used to predict nearshore wave height, period, and direction over the ebb shoal and inlet at 50 m grid spacing. Details of the STWAVE grid generation, resolution, input and results are provided in (Gailani et al., 2003).

As stated previously, a long-term simulation is required to evaluate transport and shoreline change effects resulting from nearshore placement of dredged material. Statistics were developed from the 24-year WIS station 33 wave hindcast to define the long-term wave climate. The wave climate was characterized by "binning" the offshore wave conditions by wave height, wave period, and wave direction (Table 1). 277 of the possible 512 bins were required to cover the 24-year hindcast (Gailani et al, 2003). The structured STWAVE grid point locations do not correspond to the unstructured ADCIRC nodes (Figure 3) in the region of interest. Transport calculations are performed at user-specified points within the ADCIRC and STWAVE domains. Therefore, wave, current and elevation model output are interpolated onto each transport point to develop co-located wave-current conditions.

Table 1. Wave climate definition.

Bin	Wave Height (m)	Wave Period (sec)	Wave Direction (deg true)
1	0.0 to 0.5	3 to 6	50.5 to 65.5
2	0.5 to 1.0	6 to 8	65.5 to 80.5
3	1.0 to 1.5	8 to 10	80.5 to 95.5
4	1.5 to 2.0	10 to 12	95.5 to 110.5
5	2.0 to 2.5	12 to 14	110.5 to 125.5
6	2.5 to 3.0	14 to 16	125.5 to 140.5
7	3.0 to 4.0	16 to 18	140.5 to 155.5
8	> 4.0	> 18	155.5 to 170.5

The 2-m tide range (mesotidal) at the site and the shallow, complex shoal structure at the Savannah River Entrance require that water-level be considered in wave transformation. Figure 4 illustrate the influence of water level on nearshore wave conditions. Identical wave conditions were applied to the offshore boundary of the parent grid, but

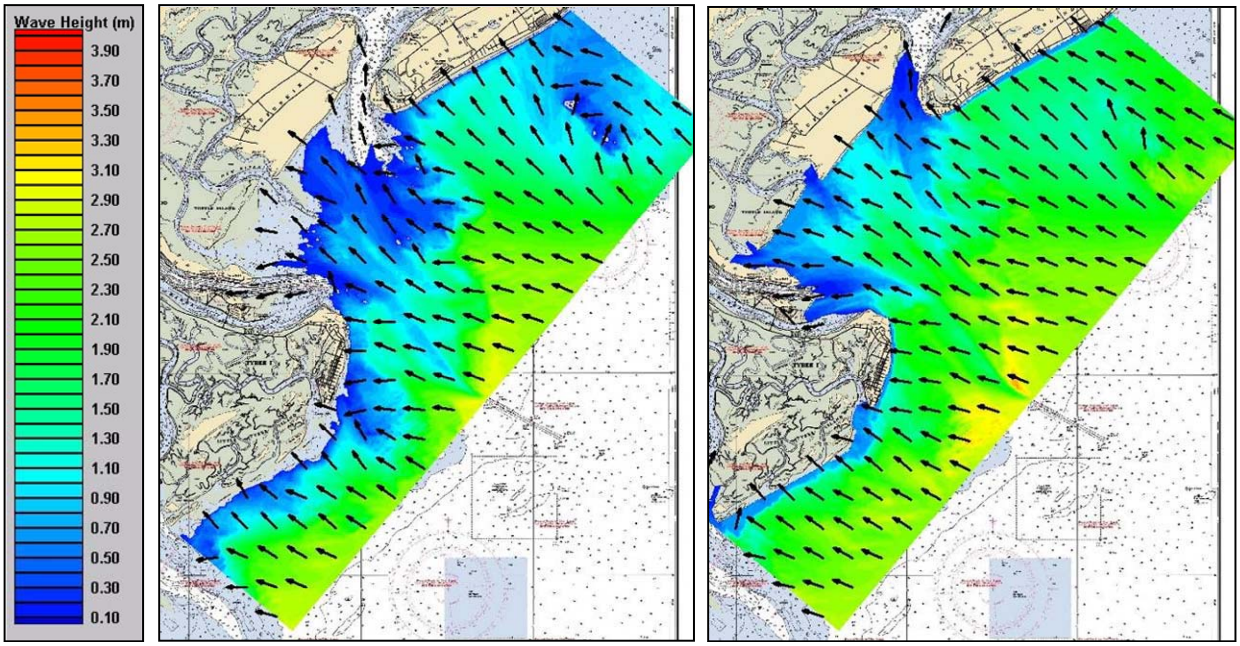

Figure 4. Nearshore transformation of identical offshore wave conditions for low tide (left) and high tide (right).

significant differences in nearshore wave height and wave direction are evident over the ebb shoal and the nearshore. Therefore, each of the 277 wave conditions were simulated with 3 water levels: average low tide (-1.05 m Mean Tide Level (MTL)), mean tide (0.00 m MTL), and average high tide (+1.05 m MTL). The resulting 831 wave and water-level conditions were simulated on the parent grid and then applied to the nested grid.

Hydrodynamics (currents and waves) are the drivers of sediment transport. Dredged material mounds placed in the nearshore will migrate or disperse under the power of waves and currents. One objective of this study is to determine how the mounds will disperse over time so that placement locations can be selected to optimize benefits and minimize negative impacts. Although highly energetic, significant time may be required to disperse the volumes of sediment designated for nearshore placement. Quantitative nearshore sand transport models generally fall into two categories: 1) long-term 1-D morphologic change models for cross-shore or long-shore change or 2) 2-D or 3-D short-term eularian sediment transport models. The first type of model generally applies some sort of equilibrium profile concept. These models are not applicable to long-term fate of dredged material mounds because the mound is a perturbation which the model is not designed to assess. In addition, transport from these mounds is inherently two-dimensional. The second type of nearshore model cannot reliably simulate long-term (24-year) evolution, which is required to assess optimal placement for beneficial use. Even if transport could be assessed through a series of eularian applications, project budget constraints and computational requirements would not permit such an effort. Therefore, new methods were developed to rapidly assess transport pathways and trends for multiple scenarios. These methods were used to qualitatively compare and assess placement locations. A model, called GTRAN (Jensen et al, 2002) was developed at ERDC for this purpose. The two primary issues addressed using GTRAN are 1) dredged material placed in the nearshore re-entering and depositing in the navigation channel and 2) dredged material as a source of sediment to the Tybee Island littoral system. The remainder of this paper will describe the development and application of a GTRAN and a presentation/interpretation of model results for assessing channel infilling and littoral feeding issues.

GTRAN supplies transport magnitude in 30-degree directional bins for the period simulated. GTRAN input includes ADCIRC grid, ADCIRC hydrodynamic output files and STWAVE output files, and sediment descriptions. Surface waves in the nearshore region produce stresses and near-boundary effects that are not represented in the ADCIRC hydrodynamics. Wave-generated currents and asymmetry in the wave orbital motions may be significant or dominant factors in nearshore hydrodynamics and must be addressed in nearshore transport studies. These processes are approximated in GTRAN.

In order to numerically estimate sediment transport, certain simplifying assumptions and representations of the natural processes must be developed and applied within GTRAN. These assumptions are standard practice in the field of numerical modeling and are not unique to sediment transport models in general or GTRAN specifically. Approximations developed for GTRAN are provided below. Discussion is confined to general statements and descriptions. The reader is referred to Gailani et al 2003 for additional detail.

Longshore transport is defined as the quantity of nearshore sediment transport generated along the coast by the effects of breaking waves and associated longshore currents. At Savannah, shore-parallel tidal and wind-driven currents augment this transport. The distinction between transport in the nearshore region and offshore (deep water) region is primarily in the transport processes of the two regions. In offshore transport, waves produce additional bottom shear stresses and increase turbulence that suspends sediment near the bottom. Surface waves contribute little to transport direction, and ocean circulation currents transport the suspended sediment. In the most general terms, the waves act as a stirring mechanism, and the currents transport the sediment. In the case of nearshore transport, breaking waves also impart increased shear stress and turbulence on the bottom sediments. In addition, breaking waves exert a stress that generates longshore currents and transport along with tidal and wind-driven currents. Wave-generated longshore currents are difficult to estimate over complex bathymetry, and become quite complex and non-linearly coupled with the tidal and wind-generated circulation. Because of these complexities and the strong influence of tidal currents in the study area, wave-generated longshore current and transport are not represented in the GTRAN sediment transport calculations.

The impact of the missing longshore transport can be qualitatively evaluated through assessment of longshore transport estimated by the 1-D longshore transport GENESIS model (Gravens et al 1991; Hanson and Kraus 1989). GENESIS simulations were performed for Tybee Island and indicate a northerly net longshore transport direction north of central Tybee Island. The longshore transport estimated by GENESIS at the north terminal groin is north-directed at 84,000 m^3/yr. These same GENESIS simulations indicated net southward-directed transport south of the attachment bar. These longshore transport rates are due to the wave-generated component not included in GTRAN and neglect the effects of tidal and wind-generated currents on longshore transport.

In addition to longshore currents, waves generate an offshore-directed current or ‘undertow’ to balance the shoreward mass flux that occurs above wave troughs. Undertow is a primary factor in seaward-directed sediment transport during storms (Miller et al. 1999). Undertow exists in the lower water column, influencing the sediment bed and is therefore a strong mechanism for offshore sediment transport during large wave events. A simple estimation of undertow derived through mass balance was implemented in GTRAN. The undertow estimate (or Stokes velocity), U_{Stokes} as described in Nielsen (1992) is:

$$U_{stokes} = \frac{-g\,H^2}{8\,c\,h} \tag{1}$$

where g = gravitational acceleration, H = wave height, c = wave celerity, and h = water depth.

Wave asymmetry is the imbalance of forward (onshore) and backward (offshore) components of the bottom orbital velocities resulting from the non-linear behavior of surface waves in shallow water. Wave asymmetry becomes a mechanism for shoreward sediment transport primarily during milder wave conditions (when undertow is small). In deep water, waves have a sinusoidal form and generate equal backward and forward bottom velocities. As waves approach shallow water, wave crests become short and steep, while the troughs become long and flat. Near the bed, orbital velocities include short-bursts of fast, forward velocity under the steep wave crest and slower, longer duration backward velocity under the trough. These intense forward bursts generally transport more sand than the longer-duration, lower-magnitude offshore velocities. The mechanics of wave asymmetry impact on near-bottom orbital velocities and sediment transport are complex but fairly well understood. Detailed descriptions are available in numerous coastal transport books including Fredsoe and Deigaard (1992) and Nielsen (1992). The transport methods in GTRAN include the effect of wave asymmetry on transport.

SEDIMENT TRANSPORT MODELING

Environmental condition time series input to GTRAN were developed from the ADCIRC and STWAVE simulations as described previously. Additional wave-induced transport mechanisms are approximated within GTRAN. This paragraph describes sediment property input for GTRAN. Dredged material property input to GTRAN (grain size distribution, cohesive sediment erosion resistance) was developed from dredged material samples extracted from multiple locations in the entrance channel. Sediment sample testing indicated two important features that are critical to modeling fate of dredged material. First, the channel locations proposed for dredging and nearshore placement are predominately sandy. Second, erosion testing of these sediments (Gailani et al, 2003) indicated that these sediments quickly separate into suspended fine-grained sediment and bedload sand after initiation of erosion. Sediment transport represented in GTRAN is purely non-cohesive, but a cohesive sediment bed algorithm is included which represents erosion resistance from site-specific erosion data. Data indicate that fine-grained (cohesive) and sand particles separate immediately after initiation of erosion for Savannah River Entrance Channel sediment (Roberts et al 2003). The fine-grained sediment will not re-deposit in the energetic nearshore and will be carried offshore. Thus, the sand transport and erosion resistance assumptions in GTRAN are valid for this dredged material. These assumptions hold true for most sediments that behave as a cohesive bed, but are predominately comprised of non-cohesive sand.

From input wave, current, water elevation, and sediment bed conditions, GTRAN calculates sediment transport through a collection of well-documented and tested sediment transport methods. At each GTRAN point and time, a specific transport method is selected based on sediment and hydrodynamic conditions. Presently, no single coastal sediment transport method is applicable across all sediment transport regimes (wave-dominated, current-dominated, high-energy, low-energy, etc). Consequently, a system was developed in GTRAN to assess the dominant processes acting in the bottom boundary layer to select the appropriate sediment transport method for the hourly conditions at each node. Therefore, transport algorithms at a specific point are continually changing with environmental conditions. Requirements for the decision making process include estimates of mean and maximum bed stress (τ_{avg} and τ_{max}), critical stress for transport (τ_{cr}), shear velocity (u_*), and settling velocity (W_s). A brief description of GTRAN algorithm selection follows. If the maximum combined wave-current shear stress is less than critical, zero transport results. If the bottom stress is above critical, and τ_{max} is less than 15 percent larger than τ_{avg}, then the transport regime is considered current-dominated and van Rijn (1984) is used to estimate transport. If τ_{max} is more than 15 percent larger than τ_{avg} and the ratio of W_s to u_* is more than 1.0, then the bed stresses are mixed wave-current and the transport mode is bedload dominated. Under these conditions, the Soulsby (1997) mixed wave-current bedload formula is applied. For cases where the transport is influenced by combined wave-current stresses and the W_s to u_* ratio is less than one, the method of Wikramanayake and Madsen (1994a, 1994b) is applied. These cases are generally high-energy, wave-dominated climates.

RESULTS

The original scope of this study included assessment of transport at twelve possible dredged material mound placement sites. These twelve sites are labeled 1-12 in Figure 5. Two locations are riverine, long narrow areas near the channel (these do not have crest elevations, but rather are 1 m thick placements). Two locations are north of the north jetty at the entrance channel. One location is in the south channel. Seven locations are near Tybee Island, five close to the channel and two approximately mid-way between the channel and island. ADCIRC, STWAVE, and GTRAN were applied independently for various mound configurations at each location for the active (November 1979) and operational (January 1992) periods. Results were analyzed and the benefit/negative impact of each placement location and mound configuration was assessed. In addition, GENESIS runs were performed with and without mound conditions for each site to assess the impact on transport along Tybee Island.

The mound erosion studies described above considered specific pre-defined locations and configurations. However, the results of this analysis indicated a need to understand transport direction and magnitude throughout the nearshore region (pathways and trends). Placement site options should not be pre-defined, but rather should be based on regional transport pathways. This is specifically required to assess optimum placement of dredged material to benefit the beach and nearshore profiles. Berms at sites 1-5 in the original study will have virtually no impact on nearshore nourishment. Most of the material will move parallel to the channel, with strong indications that the material will re-enter the channel. Sites 1-5 were originally selected for assessment because of the low-cost of pipeline or barge placement. Sites 6 and 7 were selected because light-loaded barges could place material there. Assessment of sites 6 and 7 indicated that material placed further from the channel has more potential for littoral zone nourishment and less potential for rehandling. However, benefit to the littoral system was still marginal. Therefore, a second phase was added to the sediment transport study. This phase uses the GTRAN model applied over an array of points in the nearshore region to assess sediment pathways and aid in placement site selection that will most benefit the beach with minimal sediment rehandling.

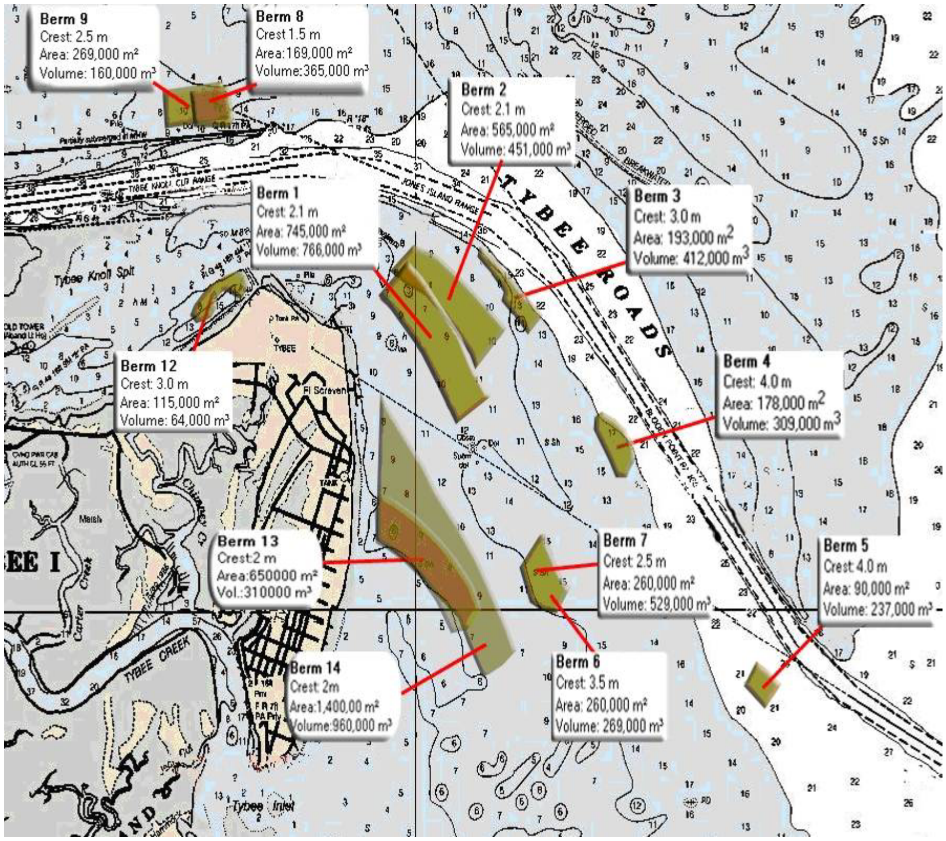

Figure 5. Locations of originally proposed mounds (1-9,12) and mounds determined to be optimal for nearshore placement (13-14).

Figure 6 shows a distribution of points selected for GTRAN simulations of general transport over the ebb shoal. Ambient bathymetry (no mounds) was used for transport simulations at these points and undertow was included. The following analyses and discussions are intended to estimate dominant sediment transport processes and sediment pathways for material placed in the nearshore and are not intended to simulate erosion from a mound.

GTRAN simulations were performed for the representative operational (January 1992) and active (November 1979) months. Figure 7a-b provides time-history of waves, currents, and transport at GTRAN points 70 and 83 (Figure 6) for November 1979. These time series can be utilized to assess relative activity at various locations. Transport magnitude variation between various points is an order of magnitude, with greatest transport rates near the channel (Figure 7b) and more modest near the coast of Tybee Island (Figure 7a). In addition, the majority of transport is during the two wave/wind-driven current events centered on November 3 and November 25. These time series demonstrate the episodic nature of sediment transport.

The net transport direction and relative magnitude at each point in the GTRAN grid are provided for the operational (Figure 8) and active (Figure 9) months. Rose plots of transport magnitude and direction are provided in Figure 10 for the active month. The remainder of this sub-section will describe the results in these two figures and their implications for nearshore transport of dredged material.

Review of transport (Figure 8) at points 32-48 (from Figure 6) reveals that net transport is seaward along the navigation channel. These locations are also where the greatest magnitude of transport occurs. This is due to the strong, ebb-dominant tidal currents that influence transport in this area. The offshore bias of transport shown in the rose plots (Figure 10) is due to the addition of river flow to the tidal currents and stronger ebb currents for purely tidal conditions. This figure also indicates a gradient in transport magnitude suggesting a depositional zone in the channel. This depositional zone corresponds to the location of increased dredging volume documented in dredging records (Gailani et al, 2003). It should be noted that transport magnitude and direction on the outer edge of the ebb shoal (around channel stations 40-45) may not be accurate because wave-generated longshore currents not included in the GTRAN simulations may be significant here, particularly during storms with wave direction from the northeast.

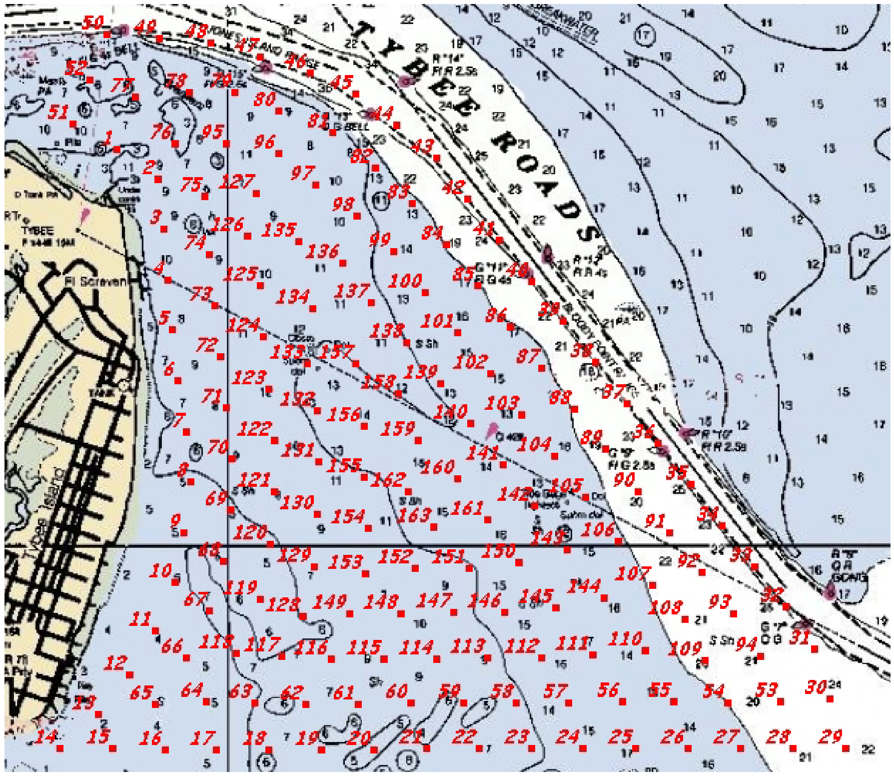

Figure 6. Locations selected for GTRAN calculation to determine sediment pathways over the nearshore.

Net transport vectors in the nearshore region of north Tybee Island generally indicate north-directed net transport with some offshore component. The offshore component is expected during a storm month when undertow is strongest. The rose plots indicate that there are periods of onshore transport even during this stormy month. The shoreward transport components (Figures 8-10) are greatest in 5-10 ft water depth and then decrease in shallower sites (<5 ft water depth). The decrease is due to the increased impact of undertow and decreased wave height (wave breaking) in the surf zone. . Sediment transport north of the ebb shoal is in tidal current directions, with a bias toward the north direction (flood cycle). This net north-direction of transport for both the operational and active periods provides some explanation for migration of the ebb shoal to the south over the past decades. The attachment bar is located at a nodal point in net transport during these two periods. North of the attachment bar, sediment moves northward. While the south directed transport indicated in the rose plots will nourish the ebb shoal, the north directed component erodes the ebb shoal. Since the north directed component is slightly larger, the net effect will be net sediment movement from the attachment bar of the ebb shoal toward the north (Figure 9). This does not, however, imply that the ebb shoal is disappearing. There are other sources of sediment to the attachment bar from the south and offshore. It does, however, indicate that the ebb shoal will move south as offshore and southerly sources nourish the shoal. It should be emphasized that these are one-month simulations. Transport during other months may be different. Therefore, the 24-year wave simulation described previously was applied in the GTRAN model, as will be described later.

Net transport on the attachment bar of the ebb shoal during the active and operational periods is generally offshore. This is due to the effect of strong undertow during winter storms. Less wave energy and weaker tidal currents exist over the nearshore portion of the attachment bar compared to the nearshore region to the north of the attachment bar. Consequently, transport magnitudes are smaller for locations close to shore on the attachment bar (points 8-10) than for similar locations north of the bar (points 3-6). Locations south of the attachment bar indicate a net offshore and southward transport during both the operational and active months. The net southward transport is stronger during the active month because of wind-generated southerly currents during the first week in the period. The net southerly direction coupled with the net northerly direction on the north side of the attachment bar does not necessarily imply risk to the bar stability. Both of the active and operational months included strong northerly winds. In addition, the time series transport data (Figure 7) indicate that transport during different periods of the month will be in different

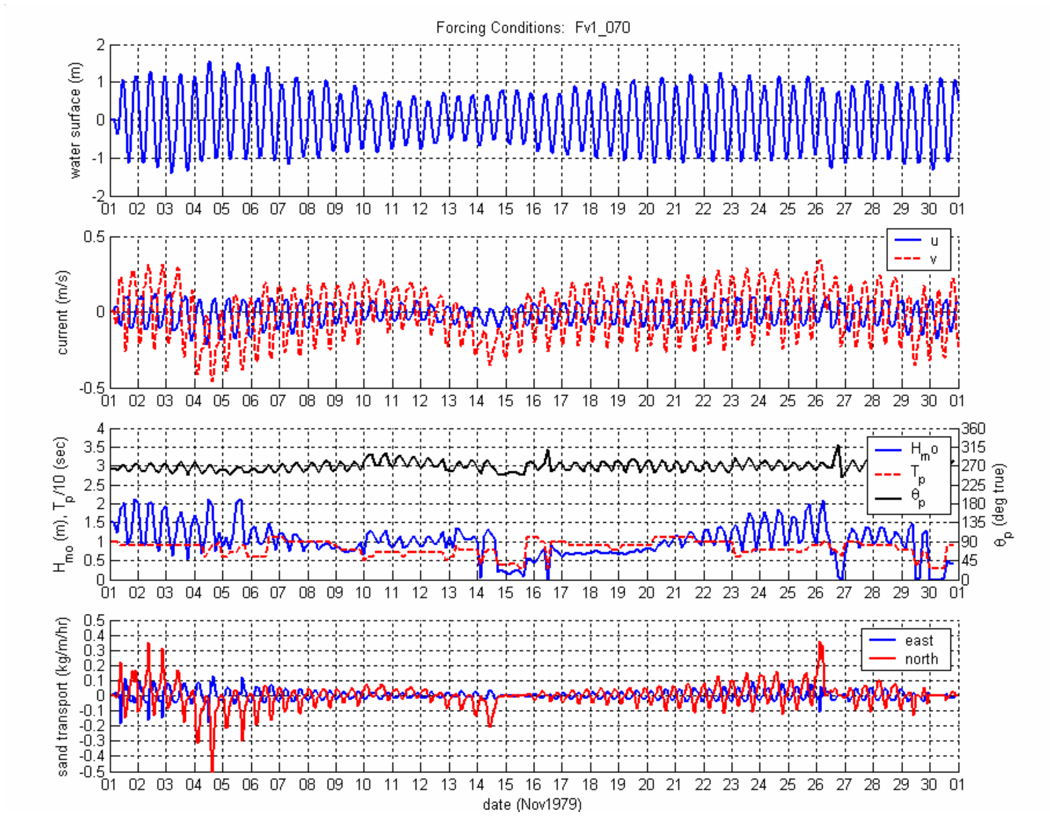

Figure 7a. Wave, current, and transport conditions for November 1979 at point 70.

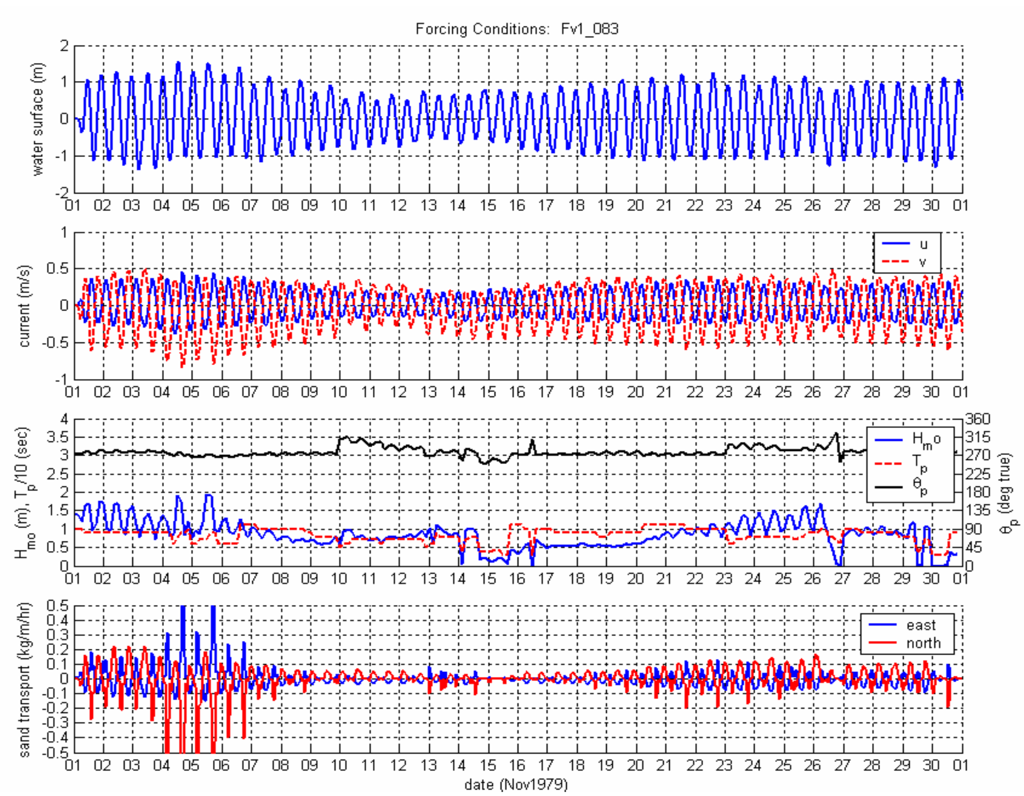

Figure 7b. Wave, current, and transport conditions for November 1979 at point 83.

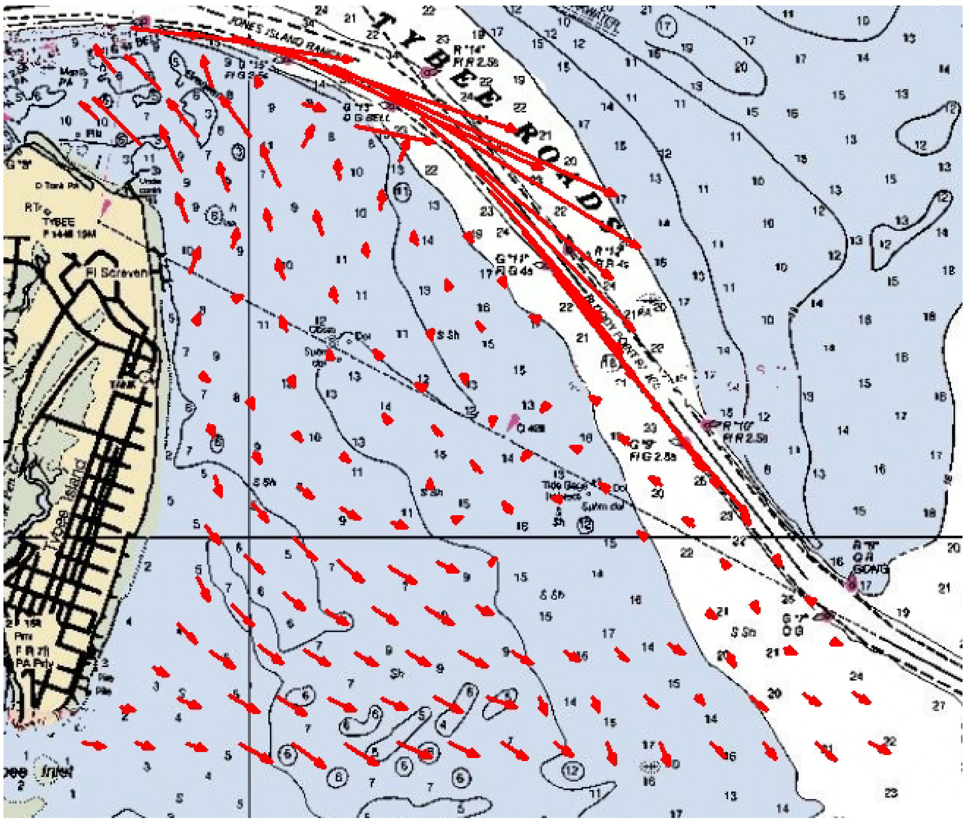

Figure 8. Net transport vectors for operational month (January 1992). Arrows represent magnitude and direction.

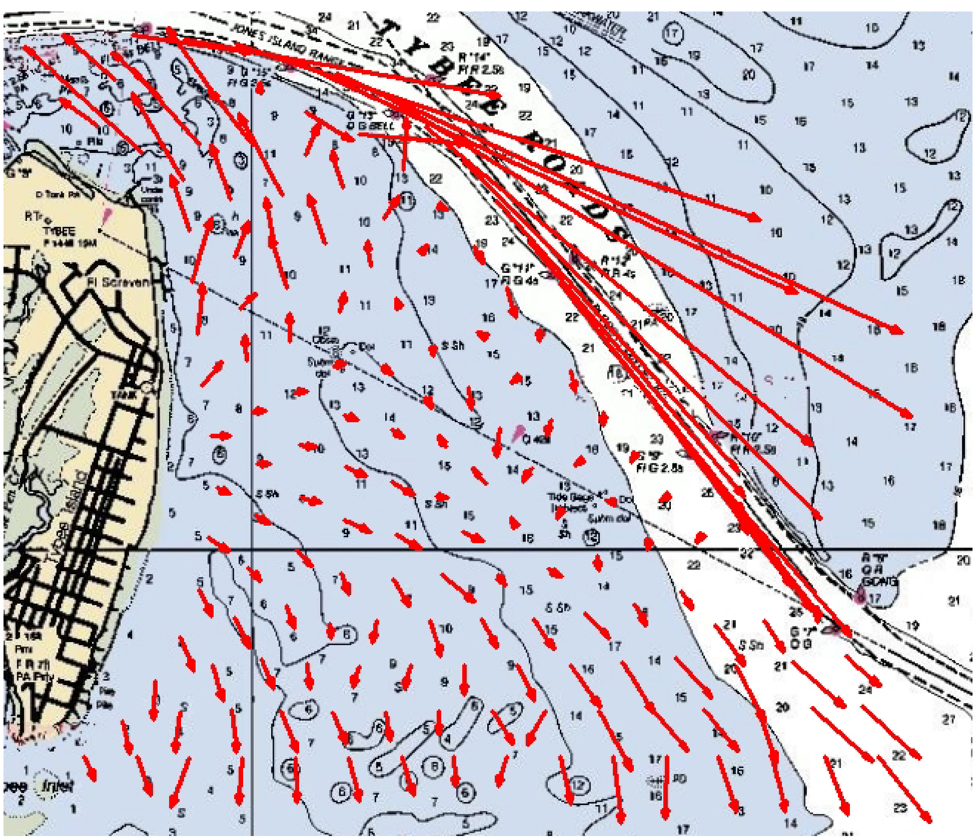

Figure 9. Net transport vectors for active month (November 1979). Arrows represent magnitude and direction.

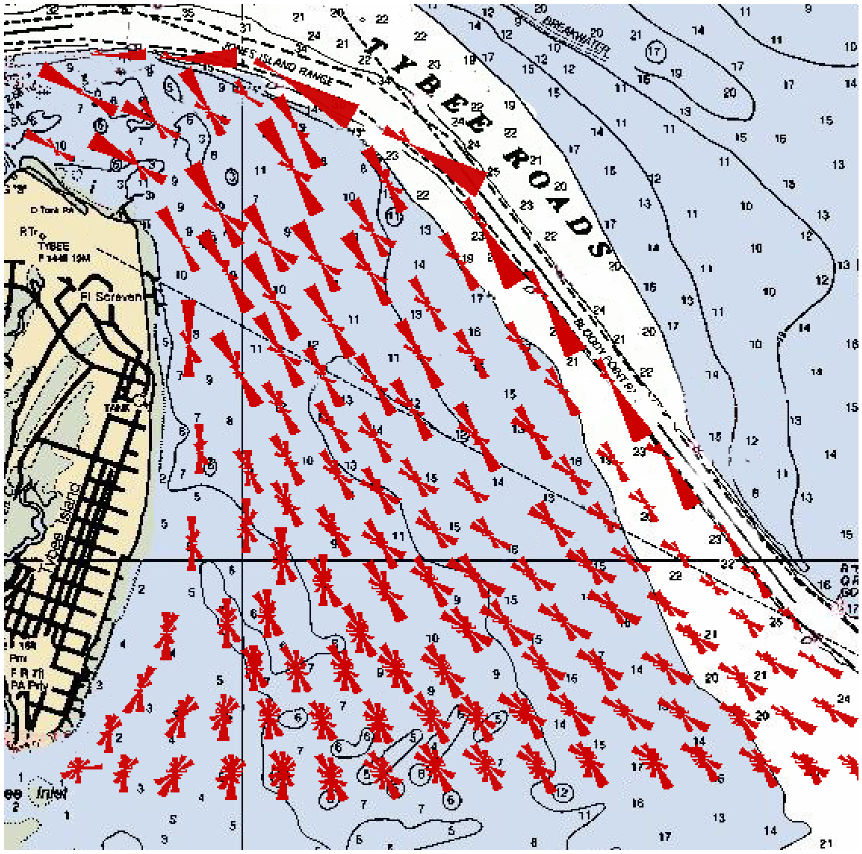

Figure 10. Rose plot for active month (November 1979).

Net transport direction vectors and rose-plots for the 24-year wave hindcast are provided in Figures 11 and 12, respectively. It should be noted again that wind-generated currents are not included in these simulations. Comparison of one-month sediment transport simulations for tide-only and tide-plus-wind forcing indicate that wind forcing may contribute significantly to transport magnitude and net transport direction in the nearshore regions, particularly for areas further removed from the Savannah River entrance channel. The 24-year wave hindcast was originally performed for GENESIS simulations. Application to GTRAN is representative of low-wind conditions where wind-generated currents are negligible, but wave conditions represent the 24-year hindcast.

Long-term transport directions and relative magnitudes are similar to those for the one-month simulations except on and south of the attachment bar. Without the strong, south-directed, wind-generated currents experienced in the one-month simulations, nearshore currents south of the attachment bar are dominated by tidal flow from Savannah River. Therefore, there is an indicated net northerly transport direction (flood flow bias) for most locations south of the attachment bar. The November 1979 and January 1992 simulations indicated a net south-directed transport in this area. This indicates that low-wind conditions will favor transport towards the attachment bar from the south while high-wind conditions from the northeast will favor net transport off the south edge of the attachment bar. In addition, there is a noticeably stronger north-directed component to transport over the ebb shoal attachment bar. Long-term hydrodynamic simulations including wind forcing would assist in estimating the overall impact of wind-generated currents in the Tybee nearshore region. However, this effort is beyond the scope of this study.

Sediment transport model uncertainty is difficult to quantify, site-specific, and would require significant field data. This is particularly true when estimating erosion volumes from mounds. Erosion estimates, however, can be compared to various placement locations and options, as has been described in this section. The sediment pathways on the GTRAN grid are logical, given what is known about morphologic evolution, wave/current patterns, and dredging volumes in the area. Therefore, relative magnitude and direction of transport are relevant and can be used for assessing the benefit of various placement options. However, treatment of undertow and wave asymmetry has significant influence on transport direction and present understanding limits predictive capabilities over complex

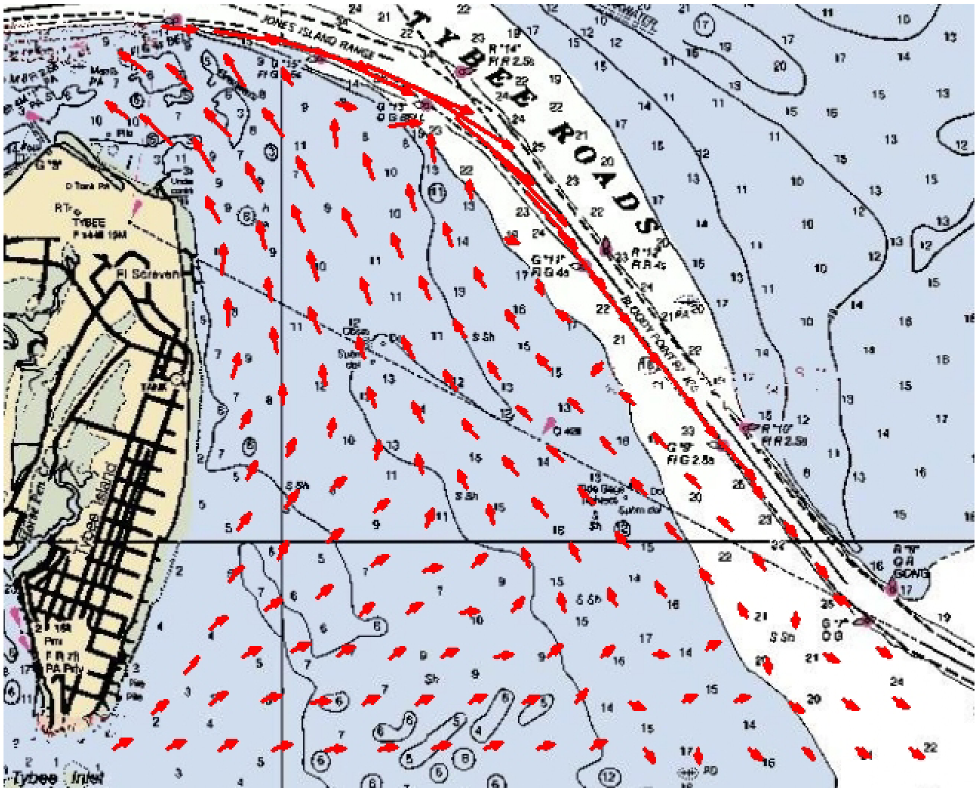

Figure 11. Net transport vectors for 24-year simulation (1976-1999). Note: not to same scale as presented in Figures 8 and 9.

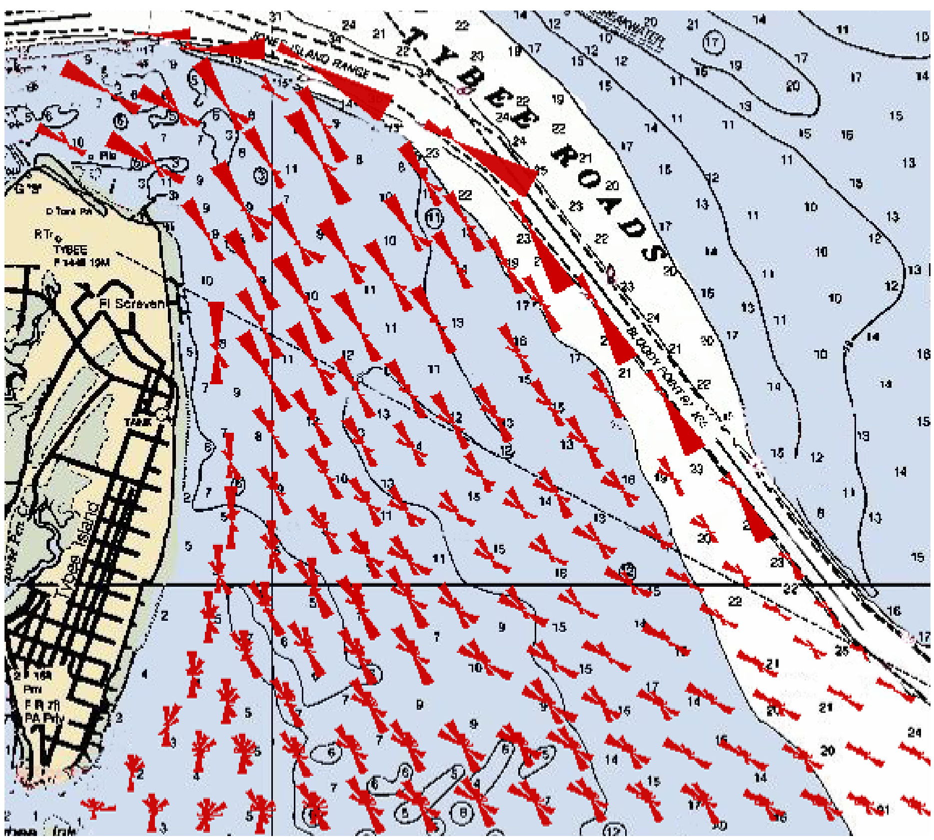

Figure 12. Transport rose at selected points for 24-year simulation (1976-1999).

RECOMMENDATIONS

Recommendations on nearshore placement of dredged material from the Savannah River Navigation channel are developed from knowledge of sediment transport processes near inlets and model simulations. Key issues addressed include 1) the effects of nearshore berms of dredged material on wave refraction and consequently on shoreline change at Tybee Island, 2) the likelihood that dredged material will re-enter the navigation channel and increase maintenance dredging volumes, and 3) the potential of nearshore-placed dredged material to provide sand to the littoral system of Tybee Island.

The recommended location for nearshore placement of dredged material is adjacent to the transverse, shore-attached bar just offshore of central Tybee Island (Berms 13 and 14 in Figure 6). The dominant transport direction from these berms will be north (Figure 13), with some material moving shoreward, especially during low-wave conditions. This process will enhance the normal shoreline accretion experienced during mild conditions. Net movement will be offshore during storm conditions. However, even during these periods, this material will benefit and nourish the littoral system, thus reducing shoreline erosion. Any nearshore placement at north Tybee will result in some material eventually moving to the shoal north of the island. Some of this material will re-enter the channel. The likelihood of significant increases in maintenance dredging for nearshore placement along central Tybee Island is less than other alternatives for nourishing the north Tybee littoral system. Any placement south of the attachment bar will only add sand to an area that is already accreting and will not stabilize north Tybee. Berms 13 and 14 are the furthest locations from the north shoal and channel that will still provide littoral and beach nourishment to north Tybee. The additional costs of pumping sand to these berms is moderate and within the acceptable range. Adverse impacts to the shoreline (as predicted by GENESIS) are small relative to the present rate of shoreline change and are likely to be offset by the addition of sand to the Tybee Island littoral system.

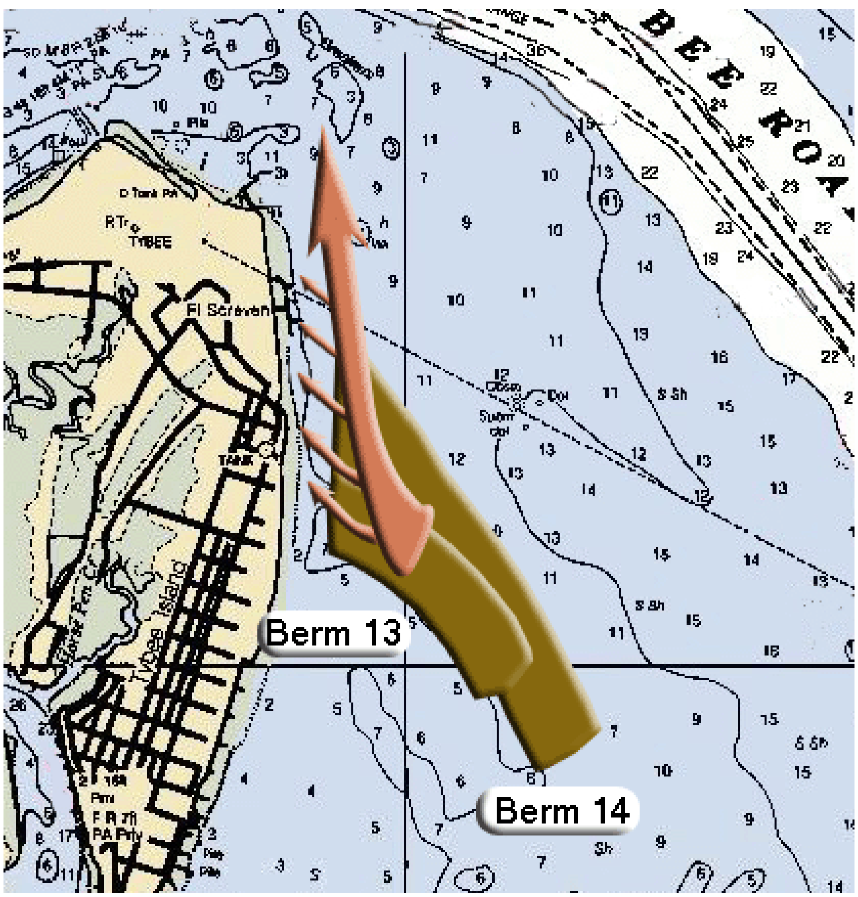

Figure 13. Net transport path for berms 13 and 14 (large arrow) with onshore transport component (small arrows). Note: other secondary transport directions are not included.

SUMMARY

Regional considerations of sediment management have expanded traditional considerations for dredged material handling. to include nearshore placement of dredged material containing significant sand fractions. The focus of this study was to identify favorable locations for nearshore placement of dredged material. Issues considered in the study include 1) the effects of nearshore berms of dredged material on wave refraction and consequently on shoreline change at Tybee Island, 2) the likelihood that dredged material will re-enter the navigation channel and increase maintenance dredging volumes, and 3) the potential of nearshore-placed dredged material to provide sand to the littoral system of Tybee Island.

The initial phases of this study indicated that regional transport patterns must be understood to optimize nearshore placement benefits while minimizing detrimental impacts. The second phase of the sediment study included analysis of these patterns. Placement sites were selected such that sand migration from these sites will nourish the littoral system of the sand-starved north Tybee nearshore region. The beneficial use sites were also selected to minimize movement of sand back into the navigation channel. Impact of wave transformation due to bathymetric change resulting from these placements was also assessed. Shoreline evolution changes for recommended placement locations were determined to be minor to moderate relative to beneficial impact of the additional sand.

ACKNOWLEDGEMENTS

This research was funded by the U.S. Army Corps of Engineers Savannah District and the Dredging Operations and Environmental Research Program of the U.S. Army Corps of Engineers.

REFERENCES

Brooks, R.M., and Brandon, W.A. (1995). "Hindcast Wave Information for the U.S. Atlantic Coast: Update 1976-1993 with Hurricanes" WIS Report 33, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Fredsoe, J. and Deigaard, R., (1992). *Mechanics of Coastal Sediment Transport*. World Scientific Publishing, Singapore, Advanced Series on Ocean Engineering, vol. 4.

Gailani, J.Z., Smith, S.J., Raad, L., and Ebersole, B.A. (2003). "Savannah Harbor Entrance Channel: Nearshore Placement of Dredged Material Study" Report prepared for the U.S. Army Corp of Engineers Savannah District by U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Gravens, M.B., Kraus, N.C., and Hanson, H. (1991). "GENESIS: Generalized Model for Simulating Shoreline Change, Report 2, Workbook and System User's Manual," Technical Report CERC-89-19, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hanson, H. and Kraus, N.C. (1989). "GENESIS: Generalized Model for Simulating Shoreline Change, Report 2, Workbook and System User's Manual," Technical Report CERC-89-19, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Jensen, R., Scheffner, N., Smith, S.J., Webb, D., and Ebersole, B.A. (2002). "Engineering studies in support of Delong Mountain Terminal project". Technical Report ERDC/CHL TR-02-26. US Army Engineer Research and Development Center, Vicksburg, MS.

Luettich, R. A., Westerink, J. J., and Scheffner, N. W. (1992). "ADCIRC: An advanced three-dimensional circulation model for shelves, coasts, and estuaries; Report 1, Theory and methodology of ADCIRC-2DDI and DCIRC-3DL," Technical Report DRP-92-6, U.S. Army Engineer research and Development Center, Vicksburg, MS

Nielsen, P., (1992). *Coastal Bottom Boundary Layers and Sediment Transport.* World Scientific Publishing, Singapore, Advanced Series on Ocean Engineering, vol. 4.

Oertel, G.F., Fowler, J.E., and Pope, J, (1985). "History of Erosion and Erosion Control Efforts at Tybee Island, Georgia" Miscellaneous Paper CERC-85-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Resio, D. T. (1987). ''Shallow-water waves. I: Theory.'' *Journal of Waterway, Port, Coastal, and Ocean Engineering*, ASCE, 113(3), 264–281.

Resio, D. T. (1988a). ''Shallow-water waves. II: Data Comparisons.'' *Journal of Waterway, Port, Coastal, and Ocean Engineering*, ASCE, 114(1), 50–65.

Resio, D. T. (1988b). ''A steady-state wave model for coastal applications.'' *Coastal Engineering*-1988, ASCE, New York, 929–940.

Roberts, J., Jepsen, R., and James, S., (2003). "Measurements of Sediment Erosion and Transport with the ASSET Flume." *ASCE Journal of Hydraulic Engineering*, Vol. 129, No. 11: 862-871.

Smith, J. M., and Smith, S. J. (2002). “Grid nesting with STWAVE,” ERDC/CHL CHETN I-66, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Smith, J. M., Sherlock, A. R., and Resio, D. T. (2001). “STWAVE: Steady-State Spectral Wave Model, user’s guide for STWAVE Version 3.0,” ERDC/CHL SR-01-01, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Soulsby, R.L., 1997. *Dynamics of Marine Sands.* Thomas Telford, London

Van Rijn, L.C., (1984). “Sediment Transport: part I: bedload transport; part ii: suspended load transport: part iii: bed forms and alluvial roughness”, *Journal of Hydraulic Engineering* 110(10): 1431-1456; 110(11): 1613-1641, 110(12): 1733-1754.

Wikramanayake, P.N., and Madsen, O.S., (1994a). “Calculation of suspended sediment transport by combined wave-current flows.” Contract Report DRP-94-7, U.S. Army Engineer Waterway Experiment Station, Vicksburg, MS, USA.

Wikramanayake, P.N., and Madsen, O.S., (1994b). “Calculation of movable bed friction factors”. Contract Report DRP-94-5, U.S. Army Engineer Waterway Experiment Station, Vicksburg, MS, USA.