OCS Study
MMS 99-0051

EXECUTIVE SUMMARY

ENVIRONMENTAL SURVEY OF IDENTIFIED SAND RESOURCE AREAS OFFSHORE ALABAMA

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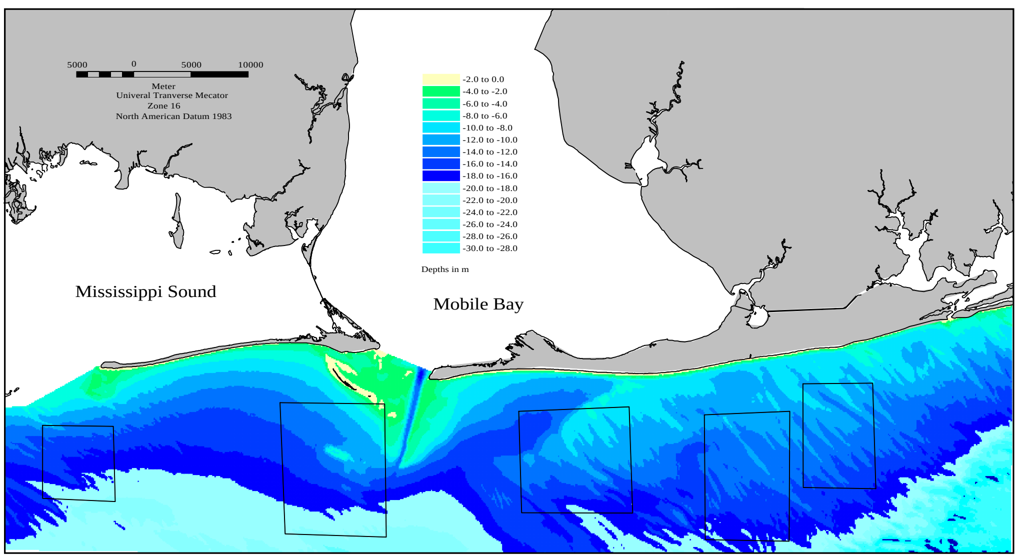

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Environmental Survey Of Identified Sand Resource Areas Offshore Alabama

September 1999

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INTRODUCTION

In recent years, there has been increasing interest in sand and gravel mining on the Outer Continental Shelf (OCS). The U.S. Minerals Management Service (MMS) has significant responsibilities with respect to the potential environmental impacts of sand and gravel mining. Existing regulations governing sand and gravel mining provide a framework for comprehensive environmental protection during operations. Guidelines for protecting the environment stem from a wide variety of laws, including the OCS Lands Act (OCSLA), National Environmental Policy Act (NEPA), Endangered Species Act, Marine Mammals Protection Act, and others. Regulations require activities to be conducted in a manner which prevents or minimizes the likelihood of any occurrences that may cause damage to the environment. The MMS takes a case-by-case approach in conducting environmental analyses, as required by NEPA and the Council on Environmental Quality (CEQ) regulations.

Currently, at least eight Federal-State task forces, several cooperative agreements, at least five negotiated agreements, and four environmental surveys exist to ensure substantive government and public involvement and attention to regional, State, and local concerns regarding leasing, engineering, economic, and environmental aspects of sand and gravel mining. Under the OCSLA, the MMS is required to conduct environmental studies to obtain information useful for decisions related to negotiated agreements and lease activities.

To this end, the MMS initiated four environmental studies along the Atlantic and Gulf coasts in 1997 to provide information for programmatic marine mining decisions at MMS Headquarters and OCS Regional Offices. This Executive Summary presents results of the first of four environmental studies administered through the MMS International Activities and Marine Minerals Division (INTERMAR). The study, entitled "Environmental Study of Identified Sand Resource Areas Offshore Alabama", was initiated by Aubrey Consulting, Inc. (ACI) in April 1997 under MMS Contract No. 14-35-01-97-CT-30840. The Final Report was prepared by Applied Coastal Research and Engineering, Inc. (Applied Coastal) in cooperation with Continental Shelf Associates, Inc. (CSA), ACI, and Barry A. Vittor & Associates, Inc. (BVA) and is cited as:

Byrnes, M.R., R.M. Hammer, B.A. Vittor, J.S. Ramsey, D.B. Snyder, K.F. Bosma, J.D. Wood, T.D. Thibaut, N.W. Phillips, 1999. Environmental Survey of Identified Sand Resource Areas Offshore Alabama. U.S. Department of Interior, Minerals Management Service, Office of International Activities and Marine Minerals (INTERMAR), Herndon, VA. OCS Report MMS 99-0052, 322 pp. + 113 pp. appendix.

STUDY AREA

The inshore portion of the Alabama continental shelf, seaward of the Federal-State boundary and within the Exclusive Economic Zone (EEZ), encompasses the project study area (Figure 1). The seaward limit of the study area is defined by the 30^{o}N latitude line. The project area is located within the east Louisiana-Mississippi-Alabama Shelf (ELMAS). The continental shelf surface within the study area is relatively broad and featureless west of Mobile Bay entrance; however, the Alabama shelf east of the entrance channel contains many northwest-southeast trending shoreface sand ridges, as well as other shoals (Figure 1).

Five potential sand resource areas were defined within the study area through a Federal-State cooperative agreement between MMS INTERMAR and the Geological Survey of Alabama (GSA). For the present study, four borrow sites within Sand Resource Areas 1 through 4 were defined to evaluate potential impacts of sand mining for beach replenishment. Sand Resource Area 5 was not included in the analysis because it is away from beach areas of greatest replenishment need, and the sediment was least compatible with native beach sand.

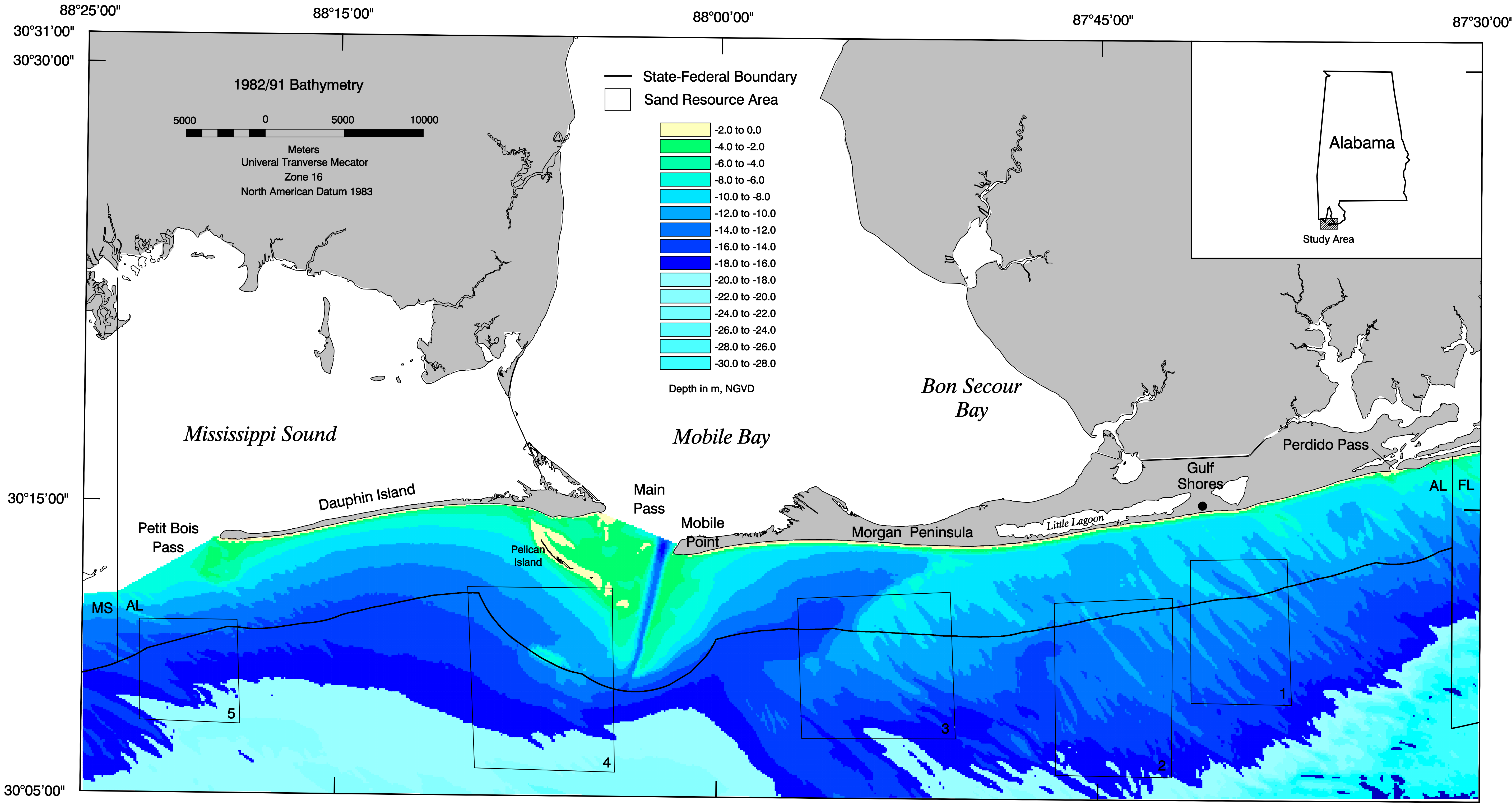

Figure 1. Location of Alabama study area and potential sand resource sites.

STUDY PURPOSE

The primary purpose of this study was to address environmental concerns raised by the potential for dredging sand from the OCS offshore the State of Alabama for beach replenishment and to document the findings in a technical report. The primary environmental concerns focused on biological and physical components of the environment. To this end, seven study objectives were identified:

- Compile and analyze existing oceanographic literature and data sets to develop an understanding of existing environmental conditions offshore Alabama and the ramifications of dredging operations at selected sand borrow sites;
- Design and conduct biological and physical field data collection efforts to supplement existing resources;
- Analyze the physical and biological field data sets to address basic environmental concerns regarding potential sand dredging operations;
- Use physical processes field data sets and wave climate simulations to predict wave transformation under natural conditions and in the presence of proposed dredging activities;
- Determine existing coastal and nearshore sediment transport patterns using historical data sets, and predict future changes resulting from proposed sand dredging operations;
- Evaluate the potential cumulative environmental effects of multiple dredging scenarios; and
- Develop a document summarizing the information generated to assist with decisions concerning preparation of an Environmental Assessment/Impact Statement to support a negotiated agreement.

In meeting these objectives, the Final Report provides valuable information regarding environmental concerns examined relative to proposed future sand dredging in support of beach replenishment needs from offshore Alabama. This Executive Summary highlights results of the study relative to project objectives.

SUMMARY AND CONCLUSIONS

The primary purpose of this study was to address environmental concerns raised by the potential for dredging sand from the OCS offshore the State of Alabama for beach replenishment. Primary concerns focused on physical and biological components of the environment at five proposed sand resource areas. Wave transformation and sediment transport numerical modeling were employed to simulate the physical environmental effects of proposed sand dredging operations to ensure that offshore sand resources are developed in an environmentally sound manner. Biological data were collected and analyzed to assess the potential impacts of offshore dredging activities to benthic and pelagic communities within the study area to minimize or preclude long-term adverse environmental impacts at potential borrow sites.

The following discussion provides a summary of results and conclusions regarding the potential environmental effects of sand mining on the OCS for replenishing sand to eroding beaches. Because benthic and pelagic biological characteristics are in part determined by spatially varying physical processes throughout the study area, physical processes analyses are summarized first.

Wave Transformation Numerical Modeling

The spectral wave transformation model REF/DIF S was employed in this study to evaluate changes in wave propagation across the Alabama continental shelf relative to potential sand mining scenarios. An assessment of potential impacts caused by dredging offshore borrow sites can be determined using numerical wave modeling to estimate refraction, diffraction, shoaling, and wave breaking. Wave refraction and diffraction generally result in an uneven distribution of wave energy along the coast that affects sediment transport in the region. Wave modeling results provide information on wave propagation across the continental shelf to the shoreline, revealing areas of wave energy convergence and divergence. These data then provide the basis for nearshore circulation and sediment transport models. In addition, a primary advantage of wave modeling is its ability to simulate multiple scenarios. The model domain can be modified (e.g., comparison of existing and post-dredging scenarios, different structural configurations, evaluation of varying beach nourishment templates, etc.) to determine the effect various seafloor changes have on the wave climate. Wave input also can be modified to simulate a wide range of wave conditions (e.g., storm events, seasonal variations) to determine changing impacts on shoreline response.

Wave Data

A detailed understanding of local wave climate is required to produce representative wave modeling simulations. The U.S. Army Corps of Engineers Wave Information Study (WIS) has met a critical need for wave information in coastal engineering studies since the 1980s. WIS contains time series information of spectrally-based, significant wave height, peak period, peak direction, and wind speed and direction produced from a computer hindcast model. The 20-yr (1976-1995) WIS data for offshore Alabama (WIS stations G1047 and G1046) offer a detailed description of the regional wave climate for developing representative wave spectra.

Rather than selecting the most common wave heights and directions as model input, a detailed analysis was conducted to summarize existing WIS data into average seasonal wave conditions and spectra. Each season may contain distinct differences in energy and/or directional spectra, and consequently produce varying impacts at borrow locations. Simulation of average seasonal characteristics provides a method to identify these changes. For example, if there is a difference in mean direction of wave approach during summer and winter seasons, simulations for these two seasons may result in varying impacts caused by removal of sediment from potential borrow sites. Spectra developed for the Alabama coast indicate that all seasonal waves propagate from east-to-west. Therefore, seasonal spectra do not incorporate the effects of occasional reversals in wave direction.

Directional and energy spectra were estimated for the 50-yr event through comparisons of previous storm spectra and application of Borgman's spreading function and a TMA spectra, respectively. The observed spectra were used for comparison purposes only because the 50-yr storm does not represent a specific hurricane or storm event. A storm surge value also was included in the wave modeling simulation to represent increased water level experienced during the passage of a large storm event. Surge values for 25 storms between 1772 and 1969 were used in an extremal analysis to estimate the value of a 50-year storm surge. A storm surge height of 3.0 m was determined from the extremal analysis and used as input for model simulations.

Existing Conditions

Model simulations were performed for existing conditions (pre-dredging) with seasonal spectra and a 50-yr storm spectrum. Figure 2 illustrates REF/DIF S results for the Dauphin Island grid for a typical spring season. The color map corresponds to the distribution of significant wave height (m) throughout the modeling domain. Solid black lines represent bathymetric contours, and land masses are shown in brown.

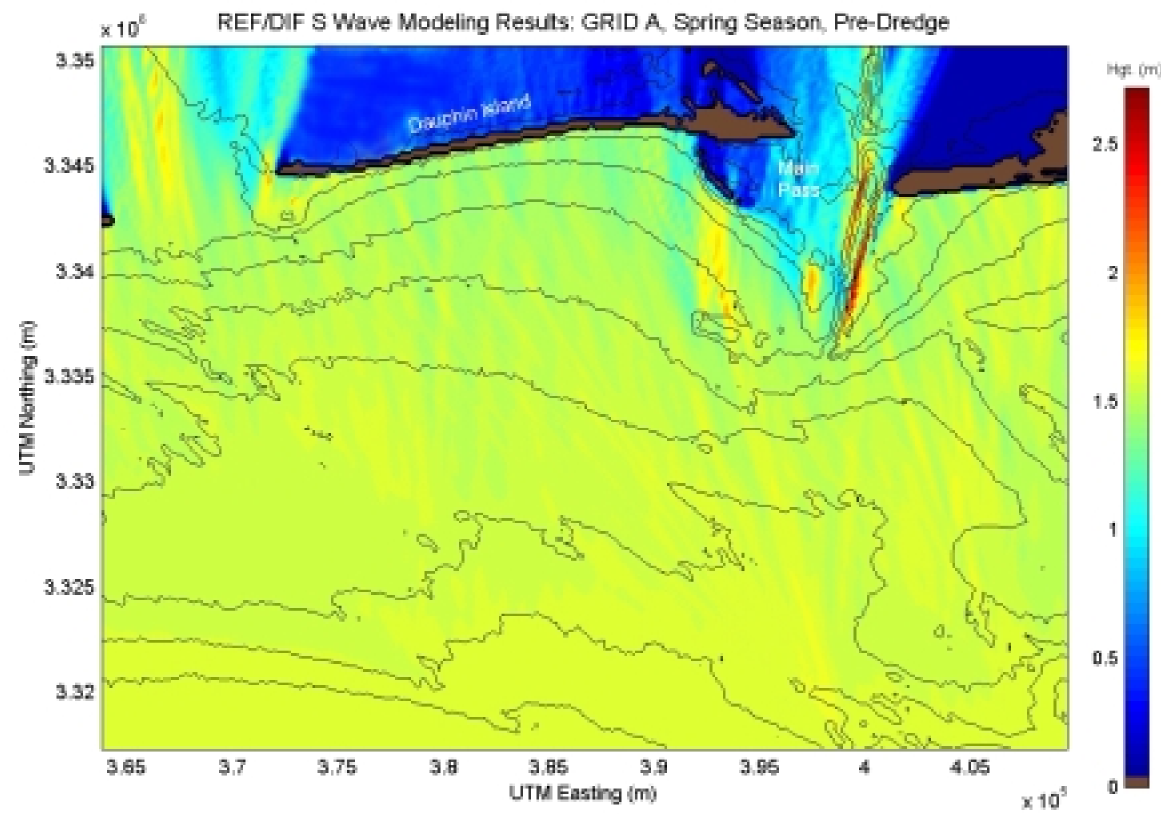

Figure 2. Spectral wave modeling results for existing conditions and a typical spring season.

Wave focusing, divergence, and shadowing occur at several locations around Dauphin Island. Significant wave focusing is evident behind the Mobile Outer Mound disposal area (shoal feature west of Main Pass channel). Wave refraction around this feature creates increased wave heights of approximately 0.25 to 0.5 m in the lee of the disposal area, and decreased wave heights adjacent to the mound. Wave focusing caused by Mobile Outer Mound produces an increase of energy that advances towards Pelican Island. Pelican Island offers a natural protective buffer against wave action for the eastern end of Dauphin Island, as indicated by the shadow zone behind the Pelican Island region. Wave focusing caused by Mobile Outer Mound most likely results in increased erosion at Pelican Island, which may significantly consume this protective wave buffer during a storm event.

A similar increase in wave energy is evident near the western end of Dauphin Island as the bathymetric contours refract waves towards the western tip of Dauphin Island. Because the western end of Dauphin Island is the terminal end to net longshore sediment transport (east-to-west), an increase in wave energy in this region will not create significant erosion, though sediment transported into the region may be moved north and into Mississippi Sound as it encounters Petit Bois Pass. A significant amount of wave energy propagates through the pass between Dauphin Island and Petit Bois Island into Mississippi Sound as the bathymetry in this region remains relatively deep.

The existing conditions simulation for the winter season produces results that are very similar to the results discussed for a typical spring season. Minor differences appear due to the increased significant wave height and subtle changes in the frequency and directional spread of the incident spectrum. Slightly larger wave energy increases are located in areas where wave shoaling was identified for the spring season, although the maximum increase is greater for the spring season near the dredged navigational channel into Mobile Bay.

During a typical summer season, average wave heights are significantly reduced (approximately 0.3 to 0.5 m) in regions where wave shoaling is apparent. Wave focusing caused by Mobile Outer Mound and regions near the dredged navigational channel is less concentrated and less severe. This is the result of a combination of reduced wave energy during the summer season, the change in peak spectral wave direction, and a broader directional spectrum. A slight increase in wave energy is allowed to proceed through the area between Pelican Island and the subaerial portion of the ebb shoal due to the angle of wave approach. Fall season results are similar to results for a typical summer season, except wave heights during the fall season are 0.5 to 0.6 m higher than in summer.

Figure 3 illustrates results for a typical spring season along the Morgan Peninsula. Areas of wave convergence and divergence seaward of the Morgan Peninsula shoreline are caused by the irregular bathymetry and the southwest-oriented seaward extending shoal located at approximately 414,000 Easting; 3,337,500 Northing. Wave energy converges in regions where bathymetric contours are aligned shore perpendicular as waves refract to match the bathymetry. In areas where bathymetric contours experience sudden changes in the alongshore direction, wave convergence and divergence are apparent.

Because of the irregular nature of the nearshore shoals, wave approach angles experience significant changes on the continental shelf. Summer, fall, and winter season results for Morgan Peninsula indicate similar patterns of wave convergence and divergence. There are no visible differences in wave height patterns for different seasons. The winter season is slightly more energetic (wave heights approximately 0.2 to 0.3 m greater). However, spring and fall results are almost identical, with only a slight variation in directional spreading.

Storm wave propagation patterns are similar to those documented for seasonal trends. For example, during a 50-yr storm, Mobile Outer Mound concentrates a 4.0- to 4.5-m wave field on southeast Pelican Island and a significant reduction in wave height is evident adjacent to this area. Wave shoaling in other areas (e.g., the dredged navigation channel) appears to be less important when considering larger storm waves. Wave approach directions are modified further offshore because large storm waves interact with the seafloor in deeper water than average seasonal waves.

Existing Conditions Versus Post-Dredging Seasonal Results

Differences in wave heights between pre- and post-dredging simulations were computed at each grid point within the model domain to document potential impacts caused by specific sand mining scenarios. Pre-dredging wave simulations were subtracted from the post-dredging wave results so that positive (negative) differences indicate an increase (decrease) in wave height related to sand mining at potential borrow sites. Figure 4 shows the difference plot for the spring season, indicating that sand mining potentially creates a zone of decreased wave energy behind the sand borrow site and increased energy adjacent to the borrow site. A maximum increase and decrease of approximately 0.2 m (11% change relative to offshore significant wave height) result from the sediment extraction scenario for Resource Area 4 during the typical spring season. Increased wave energy is focused near the southwest end of Pelican Island and on the eastern end of Dauphin Island. Increased wave heights dissipate relatively quickly once breaking begins. A decrease in wave energy is evident in the lee of the borrow site, and therefore reduces the magnitude of wave height focused by Mobile Outer Mound. Because wave energy focused on Pelican Island is reduced during a typical spring season, potential sand mining operations may be beneficial for protecting Pelican Island.

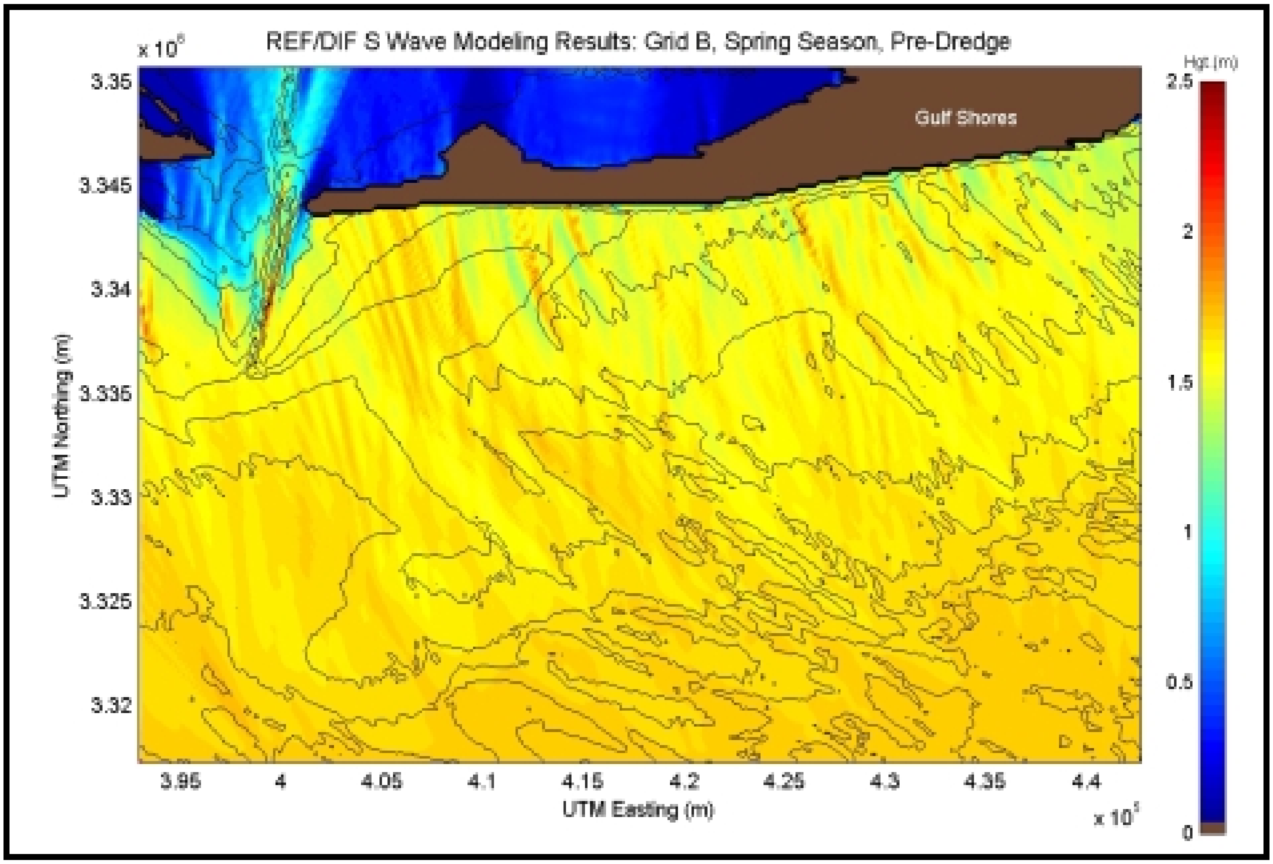

Figure 3. Spectral wave modeling results for existing conditions and a typical spring season.

Winter season differences indicate a slight shift in the impact zone to the east due to variations in peak spectral wave approach. The magnitude of wave height differences is slightly smaller than the spring simulations and the western edge of Pelican Island experiences an insignificant increase in wave height (0.02 to 0.04 m). For fall and summer seasons, wave transformation trends were similar, and the impact of potential sand excavation scenarios was insignificant (changes less than 0.06 m). During the summer season, waves were smaller, consisted of shorter periods, and the directional spread was quite wide. Modifications to the wave field were not well-defined, and changes were negligible. The fall season model runs produced slightly larger changes in wave height differences on a portion of Pelican Island; however, changes were determined to be insignificant (5- to 6-cm increase) relative to source wave data (WIS).

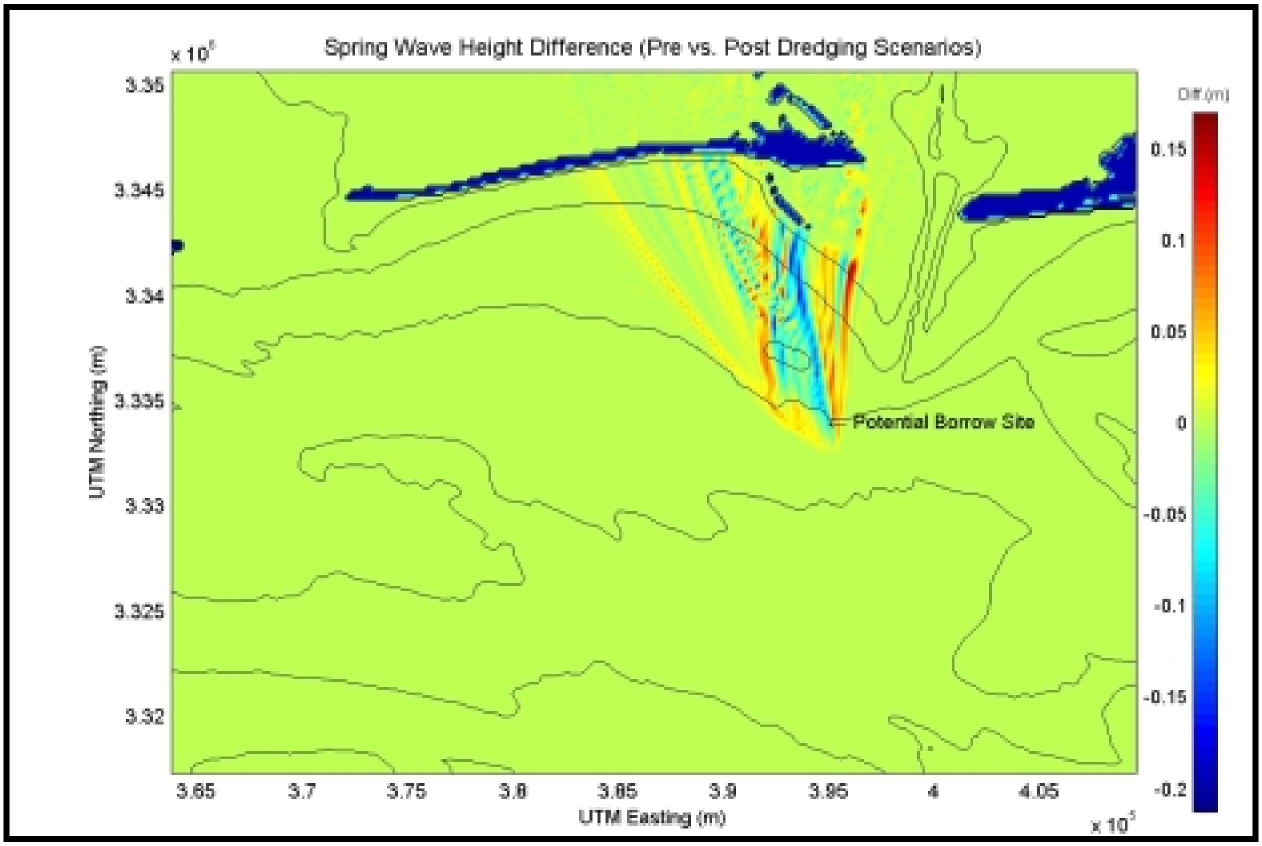

Figure 4. Wave height modifications resulting from potential offshore mining at Area 4 for a typical spring season. Hot colors (reds) identify areas of increased wave height, while cold colors (blues) identify areas of decreased wave height.

Figure 5 illustrates wave height differences for the spring season along the Morgan Peninsula. Wave heights were modified by the dredged regions as waves are refracted away from each borrow site by local changes in water depth, creating a shadow zone directly behind the borrow site and an increase in wave height in adjacent waters. This phenomenon is evident at the proposed sand borrow sites in Areas 1, 2, and 3. A maximum wave height increase of 0.4 m at the western edge of Areas 2 and 3 is caused by the large sediment extraction scenarios for the typical spring season. A maximum decrease of 0.4 m is evident in the lee of the dredged locations. The shadow zone behind the Area 2 borrow site is more concentrated due to the orientation of the dredged area. Wave height modifications are larger for borrow sites offshore Morgan Peninsula, with maximum changes in wave height approaching 0.3 to 0.4 m. The increase in wave height is due to borrow site location relative to the shoreline and borrow site size and orientation. However, waves dissipate energy as they advance toward the shoreline and negligible increases in wave height (0.1 m or less) are observed at potential impact areas along the coastline.

During summer, winter, and spring, patterns of wave modifications are comparable. Maximum increases/decreases in wave height are slightly smaller (±0.2 to 0.3 m) than observed during spring. In fall, modifications to the wave field are less consolidated due to the less direct wave approach direction. During summer and winter, a small area of increased wave height observed at the western edge of the borrow site within Resource Area 3 appears to propagate to the shoreline (at approximately 412,500 Easting; 3,344,000 Northing). However, changes at the shoreline are negligible.

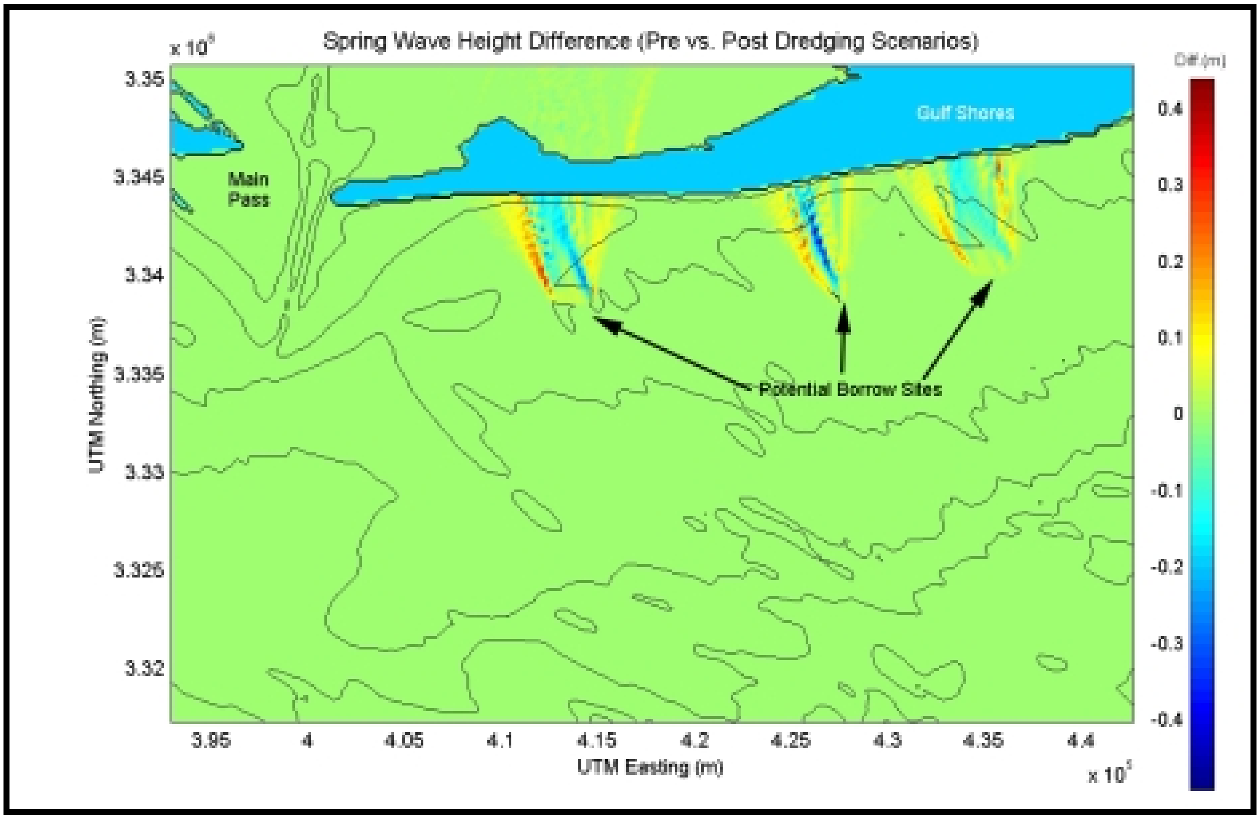

Figure 5. Wave height modifications resulting from potential offshore mining at Areas 1, 2, and 3 for a typical spring season. Hot colors (reds) identify areas of increased wave height, while cold colors (blues) identify areas of decreased wave height.

Overall, the impact caused by potential offshore dredging at sand borrow sites during normal conditions is relatively small. At most, only minor changes are expected in the wave field and the nearshore sediment transport potential.

Differences in wave heights also were computed for 50-yr storm simulations to identify potential impacts of offshore sand mining. A similar distribution of wave energy change as that indicated in the seasonal results is illustrated (i.e., wave energy reduction directly behind the dredged area and an adjacent increase in energy). Changes indicate a maximum increase in wave height of approximately 1.5 m (20% increase over offshore wave heights), and a wave height reduction of 1.5 to 2.0 m is observed in the shadow zones of borrow sites.

Seaward of Dauphin Island, a significant amount of wave energy is dissipated before waves reach the shoreline as modifications to wave heights are less than 0.5 m along most of Pelican Island. As with seasonal results, a beneficial reduction in wave height is obtained due to borrow site characteristics and Mobile Outer Mound for a portion of Pelican Island. However, a smaller amount of the wave energy dissipates before reaching the shoreline landward of borrow sites in Resource Areas 1, 2, and 3. Therefore, during storm events, changes may be large enough to result in significant impacts at certain locations along the eastern Alabama shoreline.

Sand borrow sites within Resource Areas 1, 2, and 3, which are located closer to the shoreline than Area 4, have a greater impact on the wave field. A smaller amount of wave energy is dissipated before reaching the shoreline, and changes to wave heights are large enough to result in measured impacts at certain locations along Morgan Peninsula.

Circulation and Sediment Transport Dynamics

Current measurements and analyses and wave transformation modeling provided baseline information on incident processes impacting coastal environments under existing conditions and with respect to proposed sand mining activities for beach replenishment. However, the most important data set for understanding physical processes impacts from offshore sand extraction contains quantified changes in sediment transport dynamics resulting from potential sand extraction scenarios relative to existing conditions. As such, tidal-, wave-, and wind-induced currents were evaluated with respect to sediment transport at the shoreline on the continental shelf.

In addition to documenting dominant circulation patterns, three independent sediment transport analyses were completed to evaluate impacts due to sand mining. First, historical sediment transport trends were quantified to document regional, long-term sediment movement throughout the study area using historical bathymetry data sets. Erosion and accretion patterns were documented, and sediment transport rates in the littoral zone and at offshore borrow sites were evaluated to assess potential changes due to offshore sand dredging activities. Second, sediment transport patterns at proposed offshore borrow sites were evaluated using wave modeling results and current measurements. Post-dredging wave model results were integrated with regional current measurements to estimate sediment transport trends for predicting borrow site infilling rates. Third, nearshore currents and sediment transport were modeled using wave modeling output to document potential impacts to the longshore sand transport system (beach erosion and accretion). All three methods were compared for evaluating consistency of measurements relative to predictions, and potential impacts were identified.

Currents and Circulation

Circulation patterns observed at specific areas within the study region were evaluated within the context of potential offshore sand mining operations. Long-term historical observations were analyzed to provide an understanding of temporal variations of inner shelf circulation (time scales of hours to months), while short-term field survey data sets provided detail regarding spatial variability within specific borrow sites. Combined, the analyses presented describe circulation characteristics within the study region, including major forcing influences, time scales of variability, and magnitude of resulting currents.

Two current meter data sources were used for evaluating seasonal and annual variations in flow throughout the study area. Continental Shelf Associates, Inc. (CSA) provided current meter observations at Resource Area 4 between September 28, 1987 and October 24, 1988. The mooring was deployed west of the main ship channel and due east of the dredged material disposal mound. Observations represent a year-long record of near-bottom currents (approximately 1.6 m above the seafloor in approximately 12-m water depth). These data were used to develop an understanding of the most-frequent flow characteristics near Area 4.

The second data set resulted from an Environmental Protection Agency (EPA) study offshore of Gulf Shores, AL. A series of five moorings were deployed in Resource Areas 1 and 2. Data were collected between late March 1986 and late March 1987. Data coverage at any single mooring site was sporadic during this time. A nearshore site, named Gulf Shores Current

Meter Mooring 1 (GSCM1), had observations collected in approximately 5-m water depth with a single meter located approximately at mid-depth (GSCM1M) within Sand Resource Area 1. These data were almost complete for the period April 1986 to March 1987. A second location (GSCM4) was within Area 2 in approximately 10-m water depth and yielded observations at near-bottom (GSCM4B) and near-surface depths (GSCM4S). Data were collected at both depths during the period early May 1986 to mid-November 1986. These three data sets formed the basis for developing an understanding of flow field characteristics for Areas 1, 2, and 3.

In addition, field measurements of currents within Areas 2 and 4 were conducted as part of this study in Spring and Fall of 1997. The purpose of these measurements was to observe spatial flow variations in eastern and western portions of the study area. Four surveys were completed; two surveys in each of Areas 2 and 4. Results of the surveys yielded observations on flow variations throughout the region, and were used in concert with long-term historical current data to augment our understanding of flow characteristics on the inner continental shelf offshore Alabama. The observations support the results of historical data analyses, suggesting the flow offshore Alabama is dependent upon local bathymetry and changes in wind conditions; tides appear to have little effect on the observed flow.

Total Observed Currents. Near-bottom currents west of the Mobile Bay entrance (Figure 6), typically were oriented along a northwest-southeast axis which is parallel to the bathymetry contours at the site. The strongest flow at this site was to the southeast with speeds of order 15 to 25 cm/sec occurring approximately 8 to 10% of the time. Occasional currents with speeds exceeding 25 cm/sec were observed, although these higher speed currents occurred less than 2% of the time.

Currents to the east of Mobile Bay, represented by rose diagrams for Gulf Shores Moorings 1M, 4S, and 4B, were strongest at the surface (Mooring 4S) and weakest at the bottom (Mooring 4B). Flow was stronger offshore (Mooring 4S) than nearer to shore (Mooring 1M), consistent with the variance plots detailed earlier. Currents from these sites also were oriented primarily in the alongshore direction. Strongest flow was observed at the surface (Mooring 4S). While surface flow was oriented to the west and northwest most commonly (approximately 33% of the time), this westward flow was typically weaker than flow to the east. Westward flow at Mooring 4S greater than 15 cm/sec occurred approximately 5% of the time, while eastward flow exceeding 15 cm/sec occurred approximately 17% of the time. Approximately 1% of the time, eastward flow exceeded 35 cm/sec, whereas westward flow never exceeded 35 cm/sec.

Seasonal Variability. Analysis of total observed currents provided evidence that currents along the inner shelf were controlled primarily by surface winds. Currents with 1 to 15 day periodicity (termed wind-driven currents) were shown to be the largest contributor to overall observed currents. Analysis of historical data sets also revealed that wind-driven currents were steered by local bathymetric features. Thus, predominant current directions were controlled not only by the direction of alongshore wind but also by the shape of the shoreline and bottom boundaries. Winds with a western component (from the south-southwest to north-northwest) appeared to drive flow generally in the alongshore direction to the east. The pattern reverses for winds from the east, which tend to push flow alongshore to the west. This understanding implies that seasonal variability of currents within the sand resource areas is likely to be governed by seasonal wind characteristics.

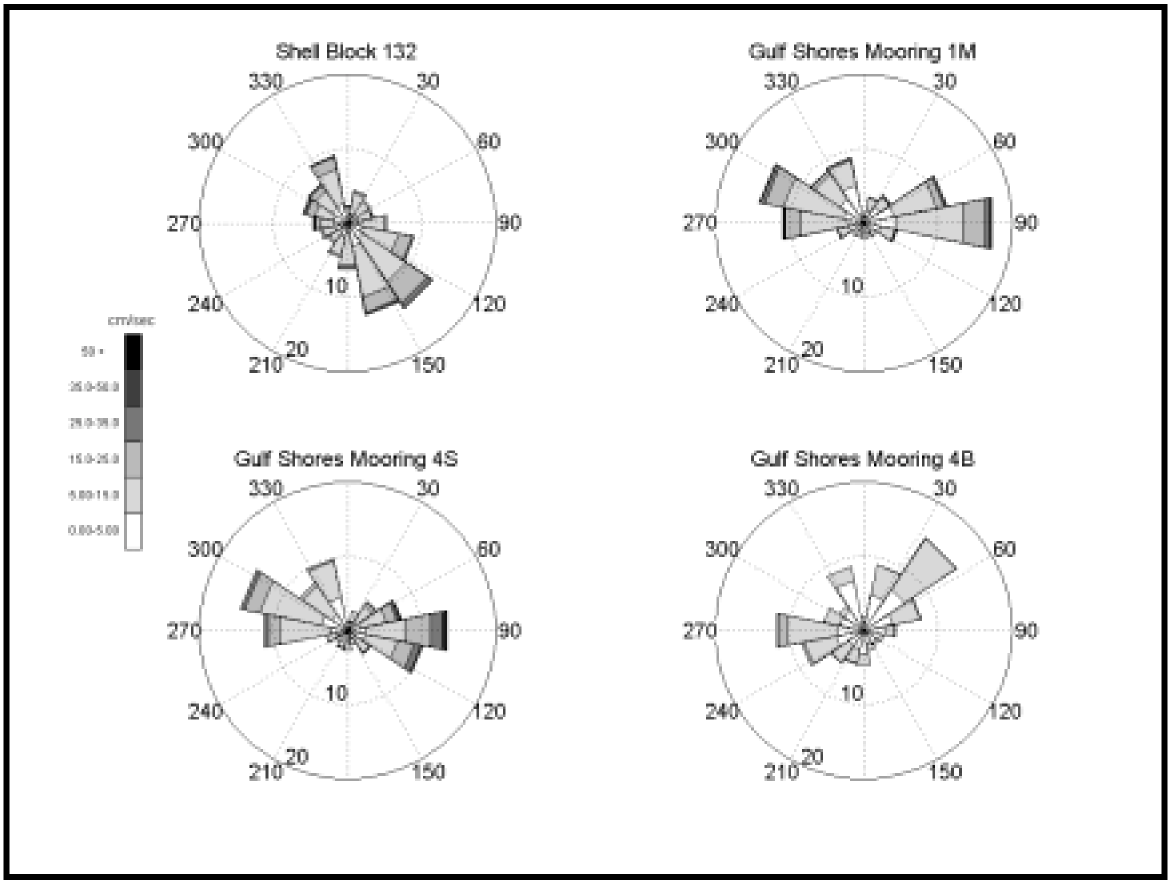

Figure 6. Rose diagrams illustrating four historical data sets of near-bottom currents in the study area. Spokes of the diagram represent compass directions (90=east, 270=west, etc). Circumferential lines represent percent occurrence, with the inner annulus representing 10%, and the outside diameter representing 20% occurrence. A 'pie slice' extending to the outer circumference means that 20% of the time, currents are flowing in that direction. Current speeds are represented by the shading of the pie slice, with white (no shading) portions representing the fraction of time currents are between 0 and 5 cm/sec and black portions indicating the percent occurrence of currents over 50 cm/sec.

Figure 7 shows the frequency-of-occurrence distribution of currents for winter (December to February), spring (March to May), summer (June to August), and fall (September to November) west of Mobile Bay entrance. This figure represents the directional distribution of flow during specific time periods. The data show that the direction of flow changed little with season and maintained a predominant orientation parallel to isobaths. Strengthened flow also occurred in winter, when flows exceeding 15 cm/sec occurred more frequently than at other times of year. Spring and summer diagrams show that currents exceeding 15 cm/sec occur less frequently in spring than in winter; the frequency of these stronger currents diminished further into summer. Currents observed between September and November were the weakest.

Existing literature suggests the wind climatology of this region is influenced in winter by periodic intrusions of cold Arctic air fronts and in summer by milder tropical air due to the northerly position of the Atlantic Bermuda High pressure zone. In winter, stronger northerly winds are more common, while in summer milder southern winds are predominant. Wind-driven currents maintain an alongshore direction (northwest to southeast) and are generally

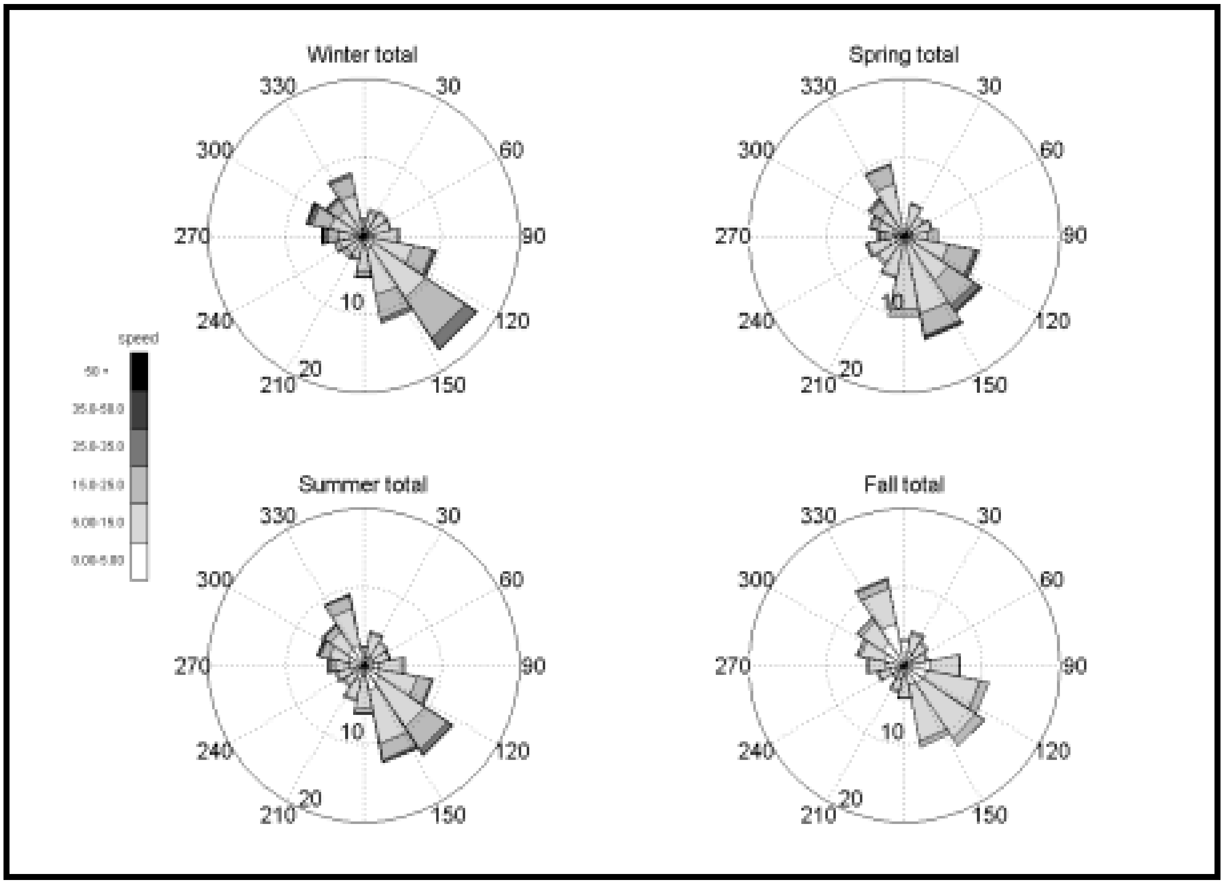

Figure 7. Rose diagrams for seasonal currents observed at Shell Block 132 (near-bottom currents). Individual plots represent the original time series divided into seasonal periods.

consistent with variations in seasonal wind strength. In summer, wind-driven currents exceed 5 cm/sec approximately 23% of the time and exceed 15 cm/sec only about 3% of the time. In winter, wind-driven currents exceed 5 cm/sec approximately 60% of the time, 15 cm/sec 13% of the time, and greater than 25 cm/sec 3% of the time. In summer, wind-driven flow did not exceed 25 cm/sec.

Analysis suggests that while local bathymetric features govern the predominant directional axis of flow, driving the current in the direction of the alongshore wind stress, it is the strength of the wind that gives an indication of the strength of the current. Throughout the year, flow observed west of the Mobile Bay entrance ran either to the southeast (if winds were generally out of the west) or to the northwest (if winds were generally out of the east). In winter, when wind speeds were relatively strong, wind-driven currents also were strong. In summer, when mild wind conditions were most common, flow was relatively weak.

Acoustic Doppler Current Profiler Field Surveys. Results the Spring and Fall 1997 field surveys illustrated the spatial influence of bathymetric features, tidal exchange between Mobile Bay and the inner shelf, and wind forcing on nearshore circulation patterns. Wind conditions prior to and during both surveys had significant westerly longshore components. As a result, the prevailing currents flowed generally eastward, consistent with previous analyses. This wind-driven longshore flow was influenced locally by bathymetric features, specifically the ebb-tidal delta of Main Pass, which tended to steer longshore flow to the south, while flow in areas farther offshore, removed from this coastal boundary, did not have such strong deflections. Spatial variation of flow was small at Area 2, east of Mobile Bay in an area of gently sloping bathymetry with no abrupt features.

Comparison of spring and fall survey results revealed some significant distinctions, the most obvious difference being the vertical structure of the water column and the resulting effect of this vertical stratification on the current field. In May, especially at Area 2, the water column appeared strongly stratified, due mostly to eastward advection of the freshwater plume discharged from Mobile Bay. Circulation was modified by vertical stratification, with the surface appearing to respond strongly to localized wind stress. Underlying layers had little direct response to these sudden changes. In October, when freshwater discharge from the Mobile Bay estuary is generally smaller than discharges during spring, there was little evidence of a stratified water column. Flow at the surface had similar characteristics as flow along the bottom. There seemed to be some dependence of the near-bottom flows on overlying near-surface flow. The lack of a stratified water column in October suggests that the freshwater plume had smaller influence on circulation dynamics during this season.

Tidal conditions also were quite different during the two surveys. In May, tides were in the tropic phase, at or near the largest range of elevations (approximately 0.45 m). In October, tides were in the equatorial phase, or the minimum range of the tide, and the water elevation changes during the survey were less than 15 cm. Tides were identified in the historical analysis to be a small contributor to overall circulation dynamics in this region; however, during the May survey in Area 2, a significant clockwise rotation was observed which dominated current direction variations. This rotation may have been tidal in origin, although the magnitude of the currents suggests other processes (possibly baroclinic). In October, when small water elevation changes were observed (as well as weak vertical stratification), no such rotational phenomena was observed. During the spring survey at Area 4, tidal currents were observed briefly along the bottom during flood tide, as denser shelf water entered the Bay during the rising tide. This suggests that tides, while generally of lesser importance than wind effects, may have localized and transient importance, such as during tropic tide phases when freshwater discharge is significant. At these times (tropic flood tides in springtime when discharge is high), tidal currents flooding into Mobile Bay may be relatively strong, with magnitudes of 15 to 25 cm/sec, versus more prevalent tidal currents of approximately 5 cm/sec.

Historical Sediment Transport Patterns

Regional geomorphic changes between 1917/20 and 1982/91 were documented for assessing long-term, net coastal sediment transport dynamics using National Ocean Service (NOS) shoreline and bathymetry surveys. Although these data do not provide information on the potential impacts of sand dredging from proposed borrow sites, they do provide a means of calibrating predictive sediment transport models relative to infilling rates at borrow sites and longshore sand transport.

Shelf Sediment Transport Dynamics. Bathymetric surfaces for 1917/20 and 1982/91 appear similar; however, a comparison of bathymetry data yields a difference plot that isolates areas of erosion and accretion between the two surfaces for documenting sediment transport patterns and quantifying trends (Figures 8 and 9). The most significant changes occurring during the 68-yr interval were associated with deposition (and erosion) at and seaward of the Mobile Bay entrance, erosion along Dauphin Island, deposition along the Morgan Peninsula shoreline, and alternating patterns of erosion and deposition on the shelf surface in the northwest-southeast-trending sand ridge field east of Mobile Bay.

Fluid flow and sediment transport at and seaward of the entrance to Mobile Bay is most dynamic for the study area. Spring runoff and storm-water outflow from Mobile Bay export substantial quantities of sediment to the shelf seaward and west of the entrance through suspended sediment transport. Polygons of green in this area represent zones of natural deposition and human-induced deposition through dredged material disposal (large dark green areas west of the channel near the Federal-State boundary; Figure 8). North of this site, deposition landward of an erosion zone near Pelican Island suggests a net flux of sediment towards the beaches from offshore shoals, feeding the longshore sediment transport system. However, significant sand transport to the beach has not occurred by 1986 because beach erosion is present landward of this accretion zone. In the western portion of the study area, south of Petit Bois Pass, alternating bands of erosion and accretion illustrate the dynamic nature of shelf sand ridge deposits.

Figure 9 illustrates historical sediment transport patterns east of Mobile Bay. Deposition and erosion in a thin band paralleling the coast indicate the zone of littoral sand transport. Seaward of this zone, shelf sediment transport is reflected by the migration of shoreface sand ridge deposits and alternating bands of erosion and accretion. Sand volume change calculations for these zones were used to estimate net sand transport rates alongshore and on the shelf surface. Historical transport rates were used to calibrate simulations of borrow site infilling and nearshore sand transport.

Regional Trends. Shoreline position and nearshore bathymetry change document four important trends relative to study objectives. First, the predominant direction of sediment transport throughout the study area is east-to-west. Western Dauphin Island has migrated to the west at a rate of 56 m/yr since 1917. Ebb-tidal shoals at Main Pass and Petit Bois Pass are skewed to the west, and the natural channel at Petit Bois Pass is aligned in a northeast-southwest direction. Deposition associated with outflow from Mobile Bay is illustrated primarily west of the channel, and a pattern of downdrift deposition (west) and updrift erosion (east) is documented for shoreface sand ridge deposits seaward of Morgan Peninsula.

Second, the most dynamic portion of the study area, in terms of sediment transport, is the ebb-tidal delta at Mobile Bay entrance. Areas of significant erosion and accretion are documented for the period 1917/20 to 1982/91, reflecting U.S. Army Corps of Engineers channel dredging and sediment disposal practice, wave and current dynamics at the entrance and influence on sediment deposition seaward and west of the ebb-delta, and the contribution of littoral transport from the east to channel infilling adjacent to Mobile Point.

Third, alternating bands of erosion and accretion on the continental shelf east of Main Pass illustrate relatively slow but steady reworking of the upper shelf surface as sand ridges migrate to the west. The process by which this is occurring suggests that a borrow site in these areas would fill with sand transported from an adjacent site at a rate of about 10,000 m^3/yr. Area 1 illustrates the largest variability in potential transport rates, whereas Areas 2 and 3 are fairly consistent for the period of record. Although long-term sand transport rates are relatively low, sediment filling the borrow area(s) would be primarily sand because the shelf surface in the area contains about 95% sand. For Area 4, the potential borrow site area appears to be accreting at a fairly rapid rate (approximately 66,000 m^3/yr), but much of the sediment encountered near the surface is silt and clay.

Finally, the net longshore transport rate determined from seafloor changes in the littoral zone between Perdido Pass and Main Pass indicate a gradient in transport to the west at a rate of about 106,000 m^3/yr. Variations in transport rate are evident in the patterns of change recorded on Figure 9. It appears that areas of largest net transport exist just east of Gulf Shores where coastal erosion is greatest in the littoral zone.

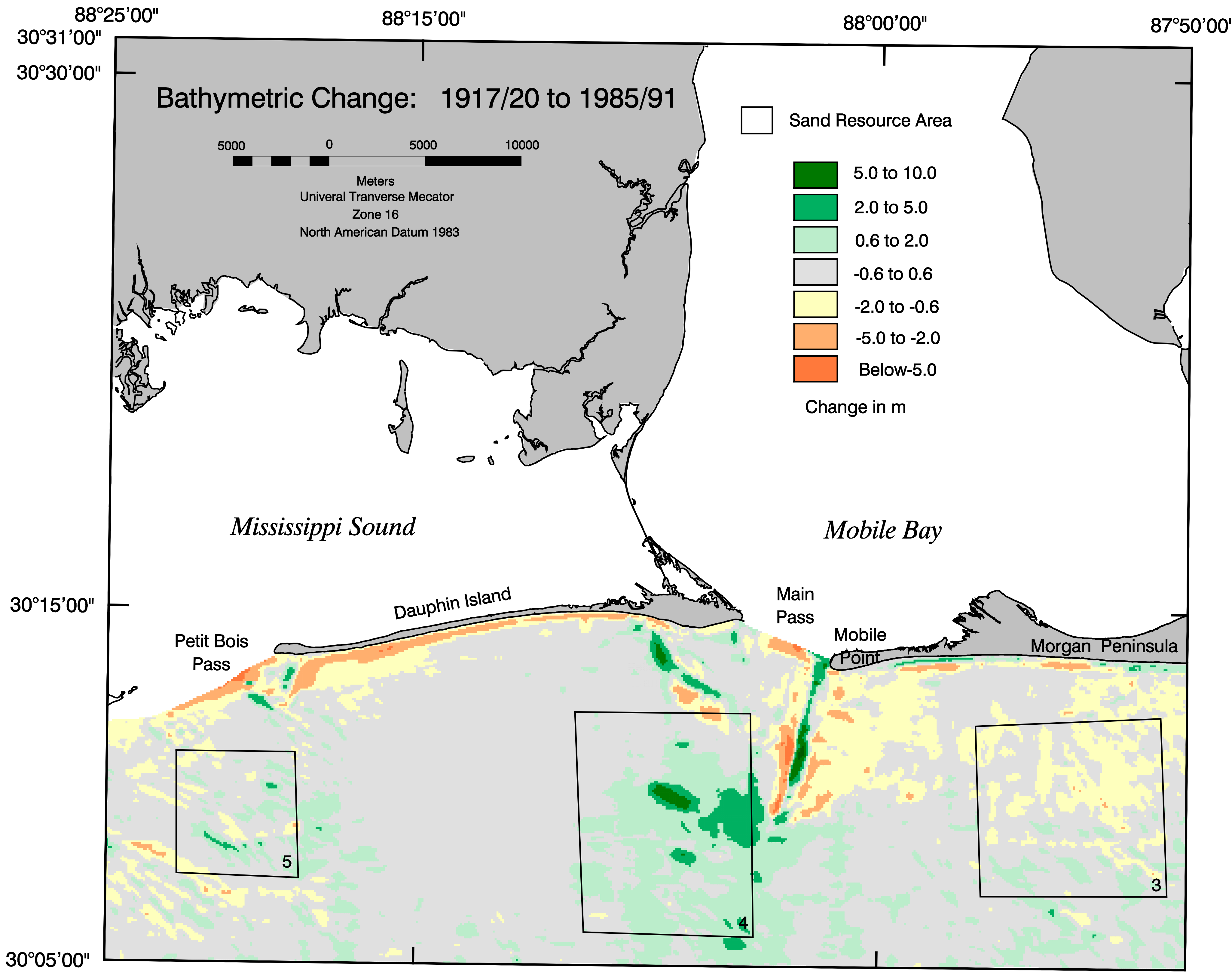

Figure 8. Nearshore bathymetry change (1917/20 to 1985/91) for the southwestern Alabama coastal zone.

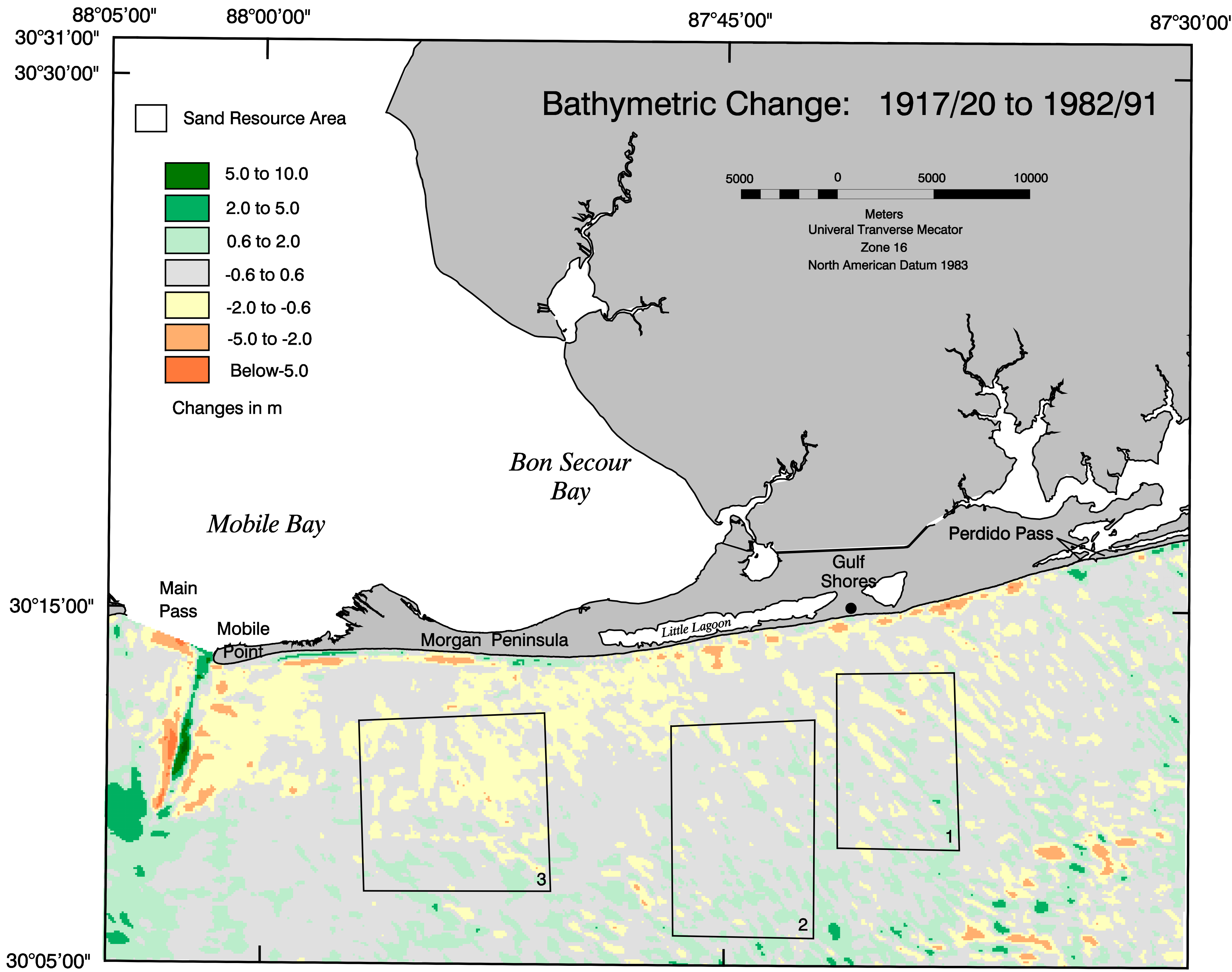

Figure 9. Nearshore bathymetry change (1917/20 to 1982/85) for the southeastern Alabama coastal zone.

Sediment Transport at Potential Borrow Sites

In addition to predicted modifications to the wave field, potential sand mining at offshore borrow sites results in minor changes to sediment transport pathways in and around the sites. Modification to bathymetry caused by sand mining influences local hydrodynamic and sediment transport processes, but areas adjacent to the borrow site do not experience dramatic changes in wave and transport characteristics.

Initially, sediment transport at borrow sites will experience mild changes after sand dredging activities. For example, sediment entering the dredged area will settle and have difficulty exiting. After several years of seasonal and storm activity, sediment will be deposited at the borrow sites, eventually re-establishing pre-dredging conditions. Given the water depths at the proposed borrow sites, it is expected that minimal impacts will occur during sediment infilling of the borrow site. Pre- and post-dredging differences will be reduced as sediment infills the borrow site, and wave and resulting sediment transport patterns will steadily return to pre-dredging conditions.

Table 1 includes information on the magnitude and direction of sediment transport into the sand resource areas, sand volume from the dredged area, and the approximate time to fill the dredged site. The analysis for infilling time assumes a constant rate of transport through each season and does not include the effects of modified bathymetry. For example, as the dredged region begins to fill, sediment transport dynamics and morphodynamics change. Therefore, sediment transport rates will fluctuate as the borrow site begins to fill. This dynamic, time-dependent process is not accounted for in the present analysis. In addition, the analysis does not include suspended sediment entering the local region. For example, a significant amount of fine material will enter the borrow site in Sand Resource Area 4 from Mobile Bay, significantly reducing the infilling time for that borrow area. Also, the two winter seasons are combined and weighted with other seasons to yield an average year. In spite of these assumptions, the analysis presented here does give an order of magnitude estimate of infilling times.

Table 1. Summary of seasonally-averaged sediment transport results using potential cumulative dredged sand volumes.

Resource Area	Magnitude of Sediment Transport (m^3/day)	Direction of Sediment Transport (to)	Dredged Sediment Volume (x 10^6 m^3)	Time to Fill Dredged Area (yr)
1	117	NW	5.8	136
2	40	N	1.7	116
3	50	NE	4.7	257
4	37	SE	8.4	622

The magnitude of sediment transport can be interpreted as the rate during an average day. In addition, the third column presents the associated seasonally-averaged direction. The magnitudes and directions may fluctuate from day to day, but the magnitude and direction presented here are for an average year. Transport rates range from a minimum of 37 m^3/day (13,500 m^3/yr) to a high of 117 m^3/day (42,700 m^3/yr). The fill time is determined by assuming a constant average infilling rate. The infilling times presented in Table 1 requires more than a century for all seasonal cases, likely due to the absence of storms in the analysis.

Sediment that replaces the dredged material will fluctuate based on location, time of dredging, and storm characteristics following dredging episodes. Borrow sites at Areas 1, 2, and 3 are expected to fill with the same material that was excavated (the entire shelf surface south of the Morgan Peninsula is at least 95% medium-to-fine sand). The sediment type in this region is consistent, high-quality, and compatible for beach replenishment. The potential borrow site at Area 4, however, likely will be filled with fine sediment (i.e., fine sand to clay) exiting Mobile Bay by natural processes or human activities (maintenance channel dredging and disposal). Because the potential transport rate plus sediment flux from Mobile Bay is substantially greater than shelf transport rates alone, the borrow site in Area 4 will fill faster than other borrow sites, limiting the likelihood for multiple dredging events from the same area.

Nearshore Sediment Transport Modeling

Potential effects of offshore sand mining on nearshore sediment transport patterns are of interest because dredged holes can intensify wave energy at the shoreline and create erosional hot-spots. Therefore, numerical techniques were developed to use the nearshore wave information derived from REF/DIF S to evaluate longshore sediment transport patterns. First, a wave-induced current model was developed to determine the magnitude and distribution of the surf zone current. Bathymetry, wave height, and radiation stress information from the wave modeling provided the site-specific data needed to compute wave-induced current patterns. Nearshore current distribution results then were incorporated into a longshore sediment transport model based on the wave energy dissipation rate in the surf zone. This approach yielded net longshore sediment transport rates for existing conditions, as well as post-dredging scenarios.

Application of the REF/DIF S wave model, a wave-induced current model, and a longshore sediment transport model provided the basis for comparing existing conditions to post-dredging conditions with regards to coastal processes. Average annual sediment transport patterns for existing conditions, as well as post-dredging scenarios, were evaluated for the Morgan Peninsula and Dauphin Island sub-grids to determine whether offshore sand dredging would cause a significant effect on average littoral sand transport conditions. In addition, sediment transport effects were evaluated for the 50-yr storm event. Extremal conditions indicate worst-case scenarios, where potential impacts of dredging are amplified in the predicted longshore sediment transport rates.

Sand dredging impacts for Resource Areas 1, 2, and 3 illustrate that there is a defined, but somewhat minor, change in littoral transport. Due to naturally higher transport rates at the eastern end of coastal Alabama, the magnitude of impacts associated with Areas 1 and 2 appear to be higher than those associated with Area 3; however, the net transport rate landward of Area 3 is significantly lower than the rate associated with Areas 1 and 2. For all three sand resource sites, the maximum variation in annual littoral transport rate, along the beach landward of the site, is approximately 8% to 10% of the existing value. In general, the increase or decrease in longshore sediment transport rates associated with each potential sand resource area amounts to approximately 1% to 2% of the net littoral drift, distributed over an approximate 10 km stretch of shoreline.

The potential impacts of dredging Area 4 on littoral transport rates are insignificant in relation to Areas 1, 2, and 3. Average annual conditions indicate a relatively high percentage change in transport rates along the eastern portion of Dauphin Island; however, the existing net littoral drift is almost nonexistent at this location. The net effect of dredging Area 4 would be to direct a greater percentage of littoral sand transport to the east, with a maximum increase of approximately 8,000 m^3/yr.

Biological Field Surveys

Two biological field surveys (May and December 1997) were conducted to collect data in and around the five sand resource areas. The primary objective of the field surveys was to obtain descriptive data on benthic biological conditions (i.e., infauna, epifauna, demersal fishes, and sediment grain size) and water column characteristics (i.e., temperature, salinity, dissolved oxygen, and depth) in the five sand resource areas. A secondary objective was to obtain descriptive data on the infauna and sediment grain size adjacent to the five sand resource areas.

Twenty grab samples for infauna and sediment grain size were collected inside and outside (adjacent to) each sand resource area (16 samples inside and 4 samples outside). The goal in the placement of these sampling stations was to provide uniform coverage within a sand resource area and, at the same time, ensure that the samples would be independent of one another to satisfy statistical assumptions. This systematic sampling with an unaligned grid approach provides more uniform coverage of the target populations that, in many cases, yields more accurate estimates of the mean than simple random sampling. To achieve uniform sampling coverage, 4 x 4 grids (=16 cells) were placed over figures of each sand resource area. For Areas 1, 2, 3, and 5, the 16-cell grid was placed over a map of the entire sand source area in Federal waters. Because the sand resource site within Area 4 was very localized based on surficial sediment samples and subsurface cores, the 16-cell grid was placed over this specific target site within Area 4. To achieve independence, one sampling station then was randomly placed within each grid cell of each sand resource area. Randomizing within grid cells eliminated biases that could be introduced by unknown spatial periodicities in the sampling area.

To sample epifauna and demersal fishes, two trawl transects were located within each sand resource area. One east-west transect was placed near the northern boundary and one east-west transect was placed near the southern boundary of each sand resource area. This approach allowed characterization of the existing assemblages with respect to water depth. Water column measurements were made near the beginning point of each trawl transect prior to actual trawling.

Benthic Environment

Results of the biological field surveys in the five sand resource areas agreed well with previous descriptions of benthic assemblages in shallow waters off the Alabama coast. Benthic assemblages surveyed in the five sand resource areas consisted of members of the major invertebrate and vertebrate groups that are commonly found in the study region. Numerically dominant infaunal groups included numerous crustaceans, echinoderms, molluscans, and polychaetous annelids, while epifaunal invertebrate taxa consisted primarily of sea stars, squid, and various shrimps. Fishes such as Atlantic croaker (*Micropogonius undulatus*), longspine porgy (*Stenotomus caprinus*), silver seatrout (*Cynoscion nothus*), and spot (*Leiostomus xanthurus*) were numerical dominants during the 1997 surveys and these species consistently are among the most ubiquitous and abundant demersal taxa in the region.

Seasonality was apparent from the biological field surveys. Infaunal abundance was substantially higher during the May survey than was observed in December. Nearly half of the infaunal taxa sampled over the entire project were found in both May and December surveys; however, most (70%) of the remaining taxa were collected only during the May cruise, resulting in higher mean values of species richness compared to the December survey. Within season, sedimentary regime most affected infaunal assemblages. Sediment in the eastern areas (Areas 1, 2, and 3) was predominantly sand as compared to the western areas (Areas 4 and 5) which were a mixture of sand and mud at most stations. Spatial differences in community composition were obvious. Eastern areas tended to support assemblages numerically dominated by the gastropod *Caecum* spp. and included many arthropods, bivalves, and gastropods, while western areas supported assemblages that tended to be dominated by polychaetes in terms of abundance and species richness. *Caecum*-associated assemblages of the eastern areas apparently are restricted to the more stable environmental characteristics of those sand sediment areas, whereas the western areas support assemblages numerically dominated by those taxa capable of exploiting the fluctuating, riverine-influenced habitats nearer Mobile Bay.

Trawl catches of epifauna and demersal fishes from Areas 1 and 2 yielded the fewest taxa and individuals during both the May and December surveys, while Areas 3, 4, and 5 yielded the most individuals and taxa. Composition of demersal assemblages across the Alabama sand resource areas is influenced by fluctuating hydrographic parameters in the western areas relative to the more stable eastern areas.

Potential benthic effects from dredging will result from sediment removal, suspension/dispersion, and deposition. Potential effects are expected to be short-term and localized. Seasonality and recruitment patterns indicate that removal of sand between late fall and early spring would result in less stress on benthic populations. Early-stage succession will begin within days of sand removal, through settlement of larval recruits, primarily annelids and bivalves. Initial larval recruitment will be dominated by opportunistic infauna that were numerical dominants in the western sand resource areas during the biological surveys (e.g., *Magelona* sp. H, *Mediomastus* spp., and *Paraprionospio pinnata*). These species are well adapted to environmental stress and exploit suitable habitat (especially fine-grained sediments) when it becomes available. Later successional stages of benthic recolonization will be more gradual, involving taxa that generally are less opportunistic and longer lived. Immigration of motile crustaceans, annelids, and echinoderms into impacted areas also will begin soon after excavation.

Recolonization of Areas 1, 2, and 3 east of Mobile Bay should occur in a timely manner and without persistent inhabitation by transitional assemblages. Infaunal assemblages that typically inhabit the eastern portion of the study area should become reestablished within 2 years. Area 4 infaunal assemblages can be expected to recover more quickly than those in the eastern areas. Because of the physical environmental characteristics of Area 4, especially outflow of fresh water and fine sediment (silts and organics) from Mobile Bay, existing assemblages are comprised of species that colonize perturbed habitats. Infaunal assemblages that inhabit the western study areas would therefore become reestablished relatively rapidly, probably within 12 to 18 months. Given that the expected beach replenishment interval is on the order of a decade, and that the expected recovery time of the affected benthic community after sand removal is anticipated to be much less than that, the potential for significant cumulative benthic impacts is remote.

Pelagic Environment

Based on existing information, potential effects from offshore dredging could occur to transitory pelagic species. Dredging effects on most zooplankton from entrainment and turbidity should be minimal due to high spatial and temporal variability of the populations. If Area 4 is used as a sand source, an environmental window excluding summer and fall months could be considered to avoid dredging when shrimp and blue crab larvae are most prevalent, but only if additional data become available to determine the extent of impacts and justify the restriction. Dredging is unlikely to significantly affect squid populations in the vicinity of the sand resource areas. Although entrainment, attraction, and turbidity could occur from dredging, quantitative data are lacking to support the use of an environmental window for pelagic fishes.

The main potential effect of dredging on sea turtles is physical injury or death caused by the suction and/or cutting action of the dredge head. No significant effects on turtles are expected from turbidity, anoxia, or noise. Loggerheads are expected to be the most abundant turtle in the project area. Increased loggerhead densities may be expected during the nesting season, which extends from 1 May through 30 November. A schedule that avoids the loggerhead nesting season also would avoid potential impacts to occasional nesting green and leatherback turtles. Hawksbill and Kemp's Ridley turtles do not nest anywhere near the project area. It is not known whether sea turtles are likely to be brumating in bottom sediments of the project area during winter. Consequently, there is insufficient information to determine whether seasonal restrictions on dredging during winter months would be appropriate.

The two marine mammals most likely to be found in and near the project area are the Atlantic spotted dolphin and the bottlenose dolphin. There is no strong seasonal pattern in abundance for either species that would provide an appropriate basis for seasonal restrictions on the project. In addition, the likelihood of significant impact from physical injury, turbidity, or noise is low even if these animals are present.

Zooplankton, squids, fishes, sea turtles, and marine mammals were groups in the pelagic environment considered to be potentially affected by offshore dredging. No cumulative effects to any of these pelagic groups are expected from multiple sand mining operations.

Synthesis

The data collected, analyses performed, and simulations conducted for this study indicate that proposed sand dredging at sites evaluated on the Alabama OCS should have minimal environmental impact on fluid and sediment dynamics and biological communities. Short-term impacts to benthic communities are expected due to the physical removal of borrow material, but the potential for significant cumulative benthic impacts is remote. Additionally, no cumulative effects to any of the pelagic groups are expected from potential sand mining operations.

Minimal physical environmental impacts due to potential sand dredging operations have been identified through wave and sediment transport simulations. However, under normal wave conditions, the maximum change in sand transport dynamics is about 5% of existing conditions. Because wave and sediment transport predictions are only reliable to within about ±25%, predicted changes are not deemed significant. Although changes during storm conditions illustrate greater variation, the ability of models to predict storm wave transformation and resultant sediment transport is less certain.