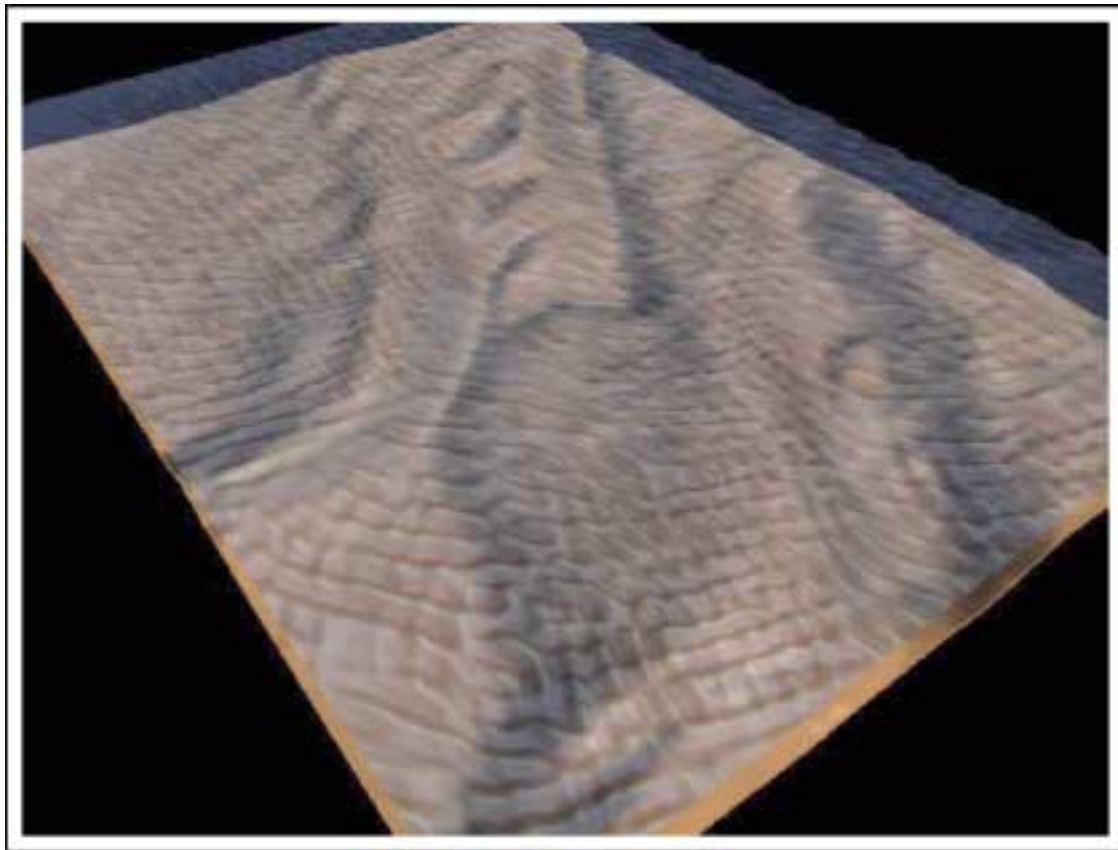


**OCS STUDY  
MMS 2001-089**

**FINAL REPORT  
DEVELOPMENT AND DESIGN OF BIOLOGICAL AND PHYSICAL MONITORING  
PROTOCOLS TO EVALUATE THE LONG-TERM IMPACTS OF OFFSHORE  
DREDGING OPERATIONS ON THE  
MARINE ENVIRONMENT**



**PREPARED FOR:  
U.S. DEPARTMENT OF THE INTERIOR  
MINERALS MANAGEMENT SERVICE  
International Activities and Marine Minerals Division  
Under Contract Number 14-35-0001-31051**

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PROTOCOLS TO EVALUATE THE LONG-TERM IMPACTS OF OFFSHORE  
DREDGING OPERATIONS ON THE MARINE ENVIRONMENT**

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October 2001

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# **MONITORING PROTOCOLS FOR ENVIRONMENTALLY SOUND MANAGEMENT OF FEDERAL OFFSHORE BORROW AREAS ALONG THE U.S. EAST AND GULF OF MEXICO COASTS**

## **1.0 PROJECT INTRODUCTION**

The Minerals Management Service (MMS) International Activities and Marine Minerals Division (INTERMAR) has the responsibility for administering the Department of the Interior's role in mineral resource development other than oil, gas, and sulfur on the outer continental shelf (OCS). MMS does not develop and maintain a schedule of lease offering for OCS sand resources. Rather, the leasing process for OCS sand must begin by a request from potential users of the sand. Only recently have OCS sand resources been considered as feasible sources of sand for beach nourishment. Between 1995 and 2001, MMS conveyed 14,600,000 cubic yards of OCS sand for ten projects.

MMS expects that OCS sand resources will be long-term sources of sand borrow material for coastal erosion management because of:

- The general diminishing supply of onshore and nearshore sand;
- Impact of sea level rise and other natural and human-induced factors leading to increased erosion;
- The renourishment cycles for beaches or coastal areas requiring quantities of sand not currently available from State sources; and
- Immediate/emergency repair of beaches and coastal damage from severe coastal storms.

In preparation for an increase in the demand for OCS sand, MMS has entered into cooperative agreements with nine states to identify and study potential OCS borrow sites. They have also funded baseline marine biological and physical oceanographic environmental studies at identified sites, as well as studies of the potential impacts of sand dredging, including modeling studies to determine the risk of shoreline erosion as a result of sand dredging.

To date, coastal erosion management projects utilizing Federal OCS sand resources have been examined on a case-by-case, project-specific basis. These resources must be managed on a long-term, large scale, system-wide basis to ensure that environmental damage will not occur as a result of continual and prolonged use. Sand sources that are to be used repeatedly may require additional biological and physical monitoring to ensure that unacceptable impacts to the marine and coastal environments do not occur. Therefore, MMS funded this current study to develop biological and physical monitoring templates for the Federal OCS sand resources. The project consists of the following components:

- Development of field monitoring systems to evaluate the physical and biological impacts of using Federal offshore borrow areas on a long-term basis;
- Examination of the feasibility, appropriateness, and desirability of putting these monitoring systems into place and identification of the need for collection of supplemental biological data or physical modeling information in the Federal borrow areas;

- Identification, review, and evaluation of environmental work or mechanisms (organizational, economic) that may be needed to offset any potential adverse impacts; and
- Identification of the need for and collection of any additional geological/geo-physical data to define available sand supplies for planned projects within the study areas.

An additional component of the project is to formulate options and recommendations for including Federal, State, and local governments and other stake-holders in an overall planning process to manage the Federal offshore borrow sites in an environmentally responsible and cost-effective manner over a long-term period. The results of that component of the project have been presented in a separate report (MMS 2001-090).

## 2.0 PROJECT OVERVIEW

The primary objectives of the project were to design a monitoring program that can be used to evaluate the potential physical and biological impacts resulting from the long-term use of OCS sand, and to prepare protocols for the monitoring plan elements. The focus is on long-term impacts because of the expectation that the borrow sites will be repeatedly dredged over time. The characteristics of the identified borrow sites have greatly influenced the overall monitoring plan design. Therefore Section 2.1 contains short summaries of these sites. As can be seen in these summaries, many of the sites are not connected to the nearshore sediment transport system, thus they will have patterns of recovery from dredging that may be different from nearshore sand habitats.

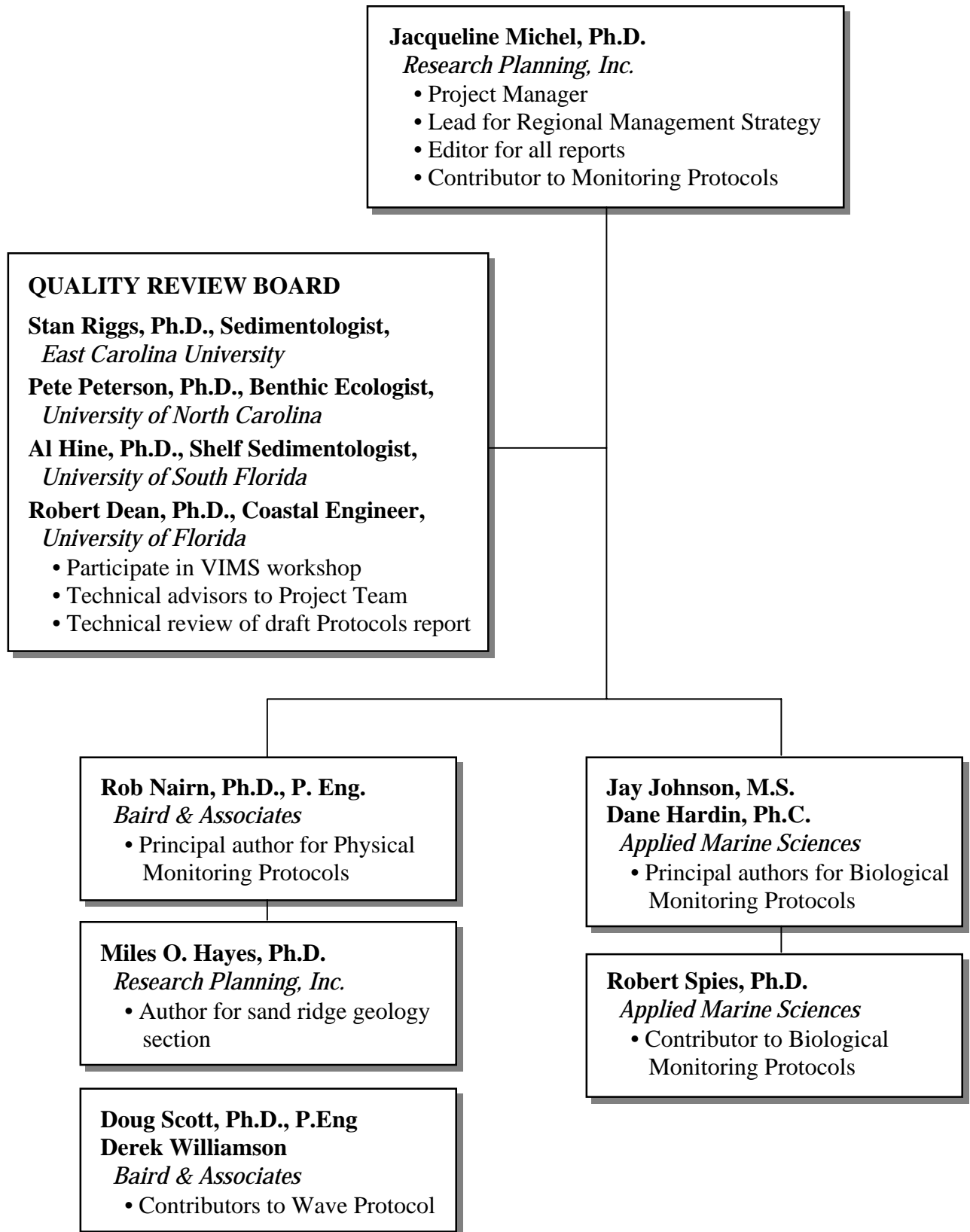
Figure 2.1 shows the project team and responsibilities of each team member. The project organization included a Quality Review Board that provided technical assistance to the project team and an independent internal review of the protocols report. Listed below are the qualifications and responsibilities of the three principal authors of the report.

### Jacqueline Michel, Ph.D. – Research Planning, Inc.: Project Manager/Geochemist

- Over 20 years experience in the highly multi-disciplinary areas of oil spill planning, response, and natural resource damage assessment
- Mapped most of the U.S. coastline as part of Environmental Sensitivity Index projects, including shoreline habitats, biological resources, and human-use resources
- Prepared guidance documents and standard methods for field monitoring programs for Natural Resource Damage Assessments
- Author of over 150 peer-reviewed papers, technical reports, and conference papers
- Committee member of three National Academy of Science committees, two for the Ocean Studies Board, and one for the Marine Board
- Author of the report on the Regional Management Strategy, Final Editor for all reports

### Robert B. Nairn, Ph.D., P.Eng. - Baird & Associates: Coastal Engineer/Planner

- Developed an internationally recognized process-based longshore and cross-shore transport model for nearshore and foreshore areas
- Extensive experience with analyzing sand transport rates and pathways, sediment budgets, and descriptive models for long term sea bed transport
- Extensive experience in the testing and application of wave transformation models,
- Has commissioned and interpreted geophysical surveys of sea bed conditions including: side scan, multi-beam, shallow seismic, air-borne LIDAR (SHOALS) in support of coastal process assessment investigations
- Leading author of a section of the new USACE Coastal Engineering Manual chapter on cohesive sediment erosion/transport and deposition
- Developed a method for quantifying impact of coastal engineering projects (including dredging) on fish habitat, identifying techniques and protocols to determine physical impacts that were then translated to impacts on productivity of biological communities through a large empirical database
- Principal Author for the Sections on Physical Monitoring Protocols



**Figure 2.1.** Project organization chart and responsibilities.

Jay A. Johnson, M.S. Applied Marine Sciences, Inc.: Senior Oceanographer

- Over 20 years experience as a biological oceanographer and marine ecologist dealing with complex scientific, regulatory and environmental issues involving sensitive legal and public issues
- Has specialized in assessing the impacts of industrial activities, discharges and accidental releases to marine and estuarine environments
- Has been involved in the design and implementation of multi-year marine monitoring programs at coastal power stations, municipal wastewater treatment plants, industrial dischargers and offshore oil and gas exploration and production facilities.
- Experienced in assessing routine and catastrophic impacts to soft and hard bottom benthic communities as well as nekton and plankton communities in the intertidal, near shore, and deep offshore regions
- Designed, managed and participated in environmental baseline and impact monitoring assessment programs in Alaska, the Gulf of Mexico, the U.S. West Coast as well as Russia, Kazakhstan the Middle East and Europe
- Contributing author for development of international guidelines for oil and gas operations in fragile and sensitive environments
- Principal Author for Sections on the Biological Monitoring Protocols

Dane D. Hardin, Ph.C. Applied Marine Sciences, Inc.: Senior Marine Biologist

- Over 25 years experience in the study of aquatic ecology
- Specializes in the application of statistically sound sampling and analytical methods to the study of natural variations and anthropogenic influences on marine benthic communities
- Has served as Program Manager and Principal Investigator on several studies funded by the US Department of the Interior Minerals Management Service investigating natural and human-induced variation in intertidal and subtidal communities in the Pacific and Gulf of Mexico Outer Continental Shelf regions
- Has been actively involved in the Regional Monitoring Program for Trace Substances in San Francisco Bay (RMP) assisting in the design and execution of the water, sediment and bivalve bioaccumulation components
- Has contributed to the design of photoquadrat sampling techniques, laser-aided quantitative sampling, and intertidal point-contact sampling methodologies. His contributions to laser-aided quantitative sampling have become the state-of-the-art technique in photographic sampling of benthic epifauna with remotely operated vehicles
- Has 19 peer-reviewed publications in scientific journals and 100+ professional reports and presentations
- Principal Author for Sections on the Biological Monitoring Protocols

An important part of the project was a workshop held in December 2000 at the Virginia Institute of Marine Science. The objective of the workshop was to have scientific review of the proposed monitoring protocols before preparation of the draft report. The workshop was attended by representatives from the U.S. Army Corps of Engineers and many of the researchers funded by MMS on geological and oceanographic assessments of potential borrow sites, baseline environmental studies of these sites, monitoring studies of dredged sites, and assessments of the environmental impacts of dredging. Appendix A includes a summary of the workshop and a list of participants. Following the workshop, the project team carefully evaluated the comments and recommendations made by workshop attendees and discussed them with the MMS project COTR. The protocols included in this report reflect the input provided at that workshop.

The project results are presented in the following sections:

Section 2.1: Summarizes the available information on known OCS borrow sites.

Section 3: Describes the project approach, the questions that the monitoring program addresses, a summary of the direct and indirect impacts likely to occur from OCS sand dredging, and the rationale for the six monitoring elements selected.

Section 4: Includes the six Monitoring Protocols. They are formatted as stand-alone templates that include data collection and analysis methods, data specifications, and deliverables. It includes a section on Adaptive Management that is a key component of the monitoring design.

Section 5: Suggests the use of a review/advisory board to adapt the study designs based on the information obtained from on-going studies.

Section 6: Provides estimated ranges of costs for the monitoring elements.

Section 7: Identifies data gaps and summarizes the characteristics of ridge and shoal features, the primary type of sand borrow site identified to-date.

Section 8: Makes recommendations for management of data from the monitoring programs.

Section 9: Includes the references cited in the text and reviewed by the project team.

## **2.1 Description of Borrow Sites**

A number of OCS borrow sites have been identified, many have been studied as part of Environmental Reports summarized in Section 3.1, and some have even been dredged to provide sand for beach nourishment projects. Figure 2.2 shows the approximate locations of the borrow sites that have been identified.

This section provides a summary of the characteristics of the identified borrow sites to provide context for the understanding of possible impacts and the development of monitoring protocols. The following series of tables and figures present a summary of some key

characteristics of each of the identified borrow sites. It is important to note that the “estimated reserves” only present an approximate upper bound on the possible volume of sand available for beach nourishment projects. The reserves estimates have not accounted for a range of size limiting constraints including, but not limited to, presence of infrastructure and potential impacts of removing entire reserves.



**Figure 2.2.** Locations of identified OCS borrow sites.

**Table 2.1.** New Jersey OCS borrow sites (see Figure 2.3).

**Location**

- 5 to 20 km offshore

**Description**

- 4 well-separated groups of sites

**Water Depth at Deposit**

- Less than 20 m deep

**Estimated Reserves**

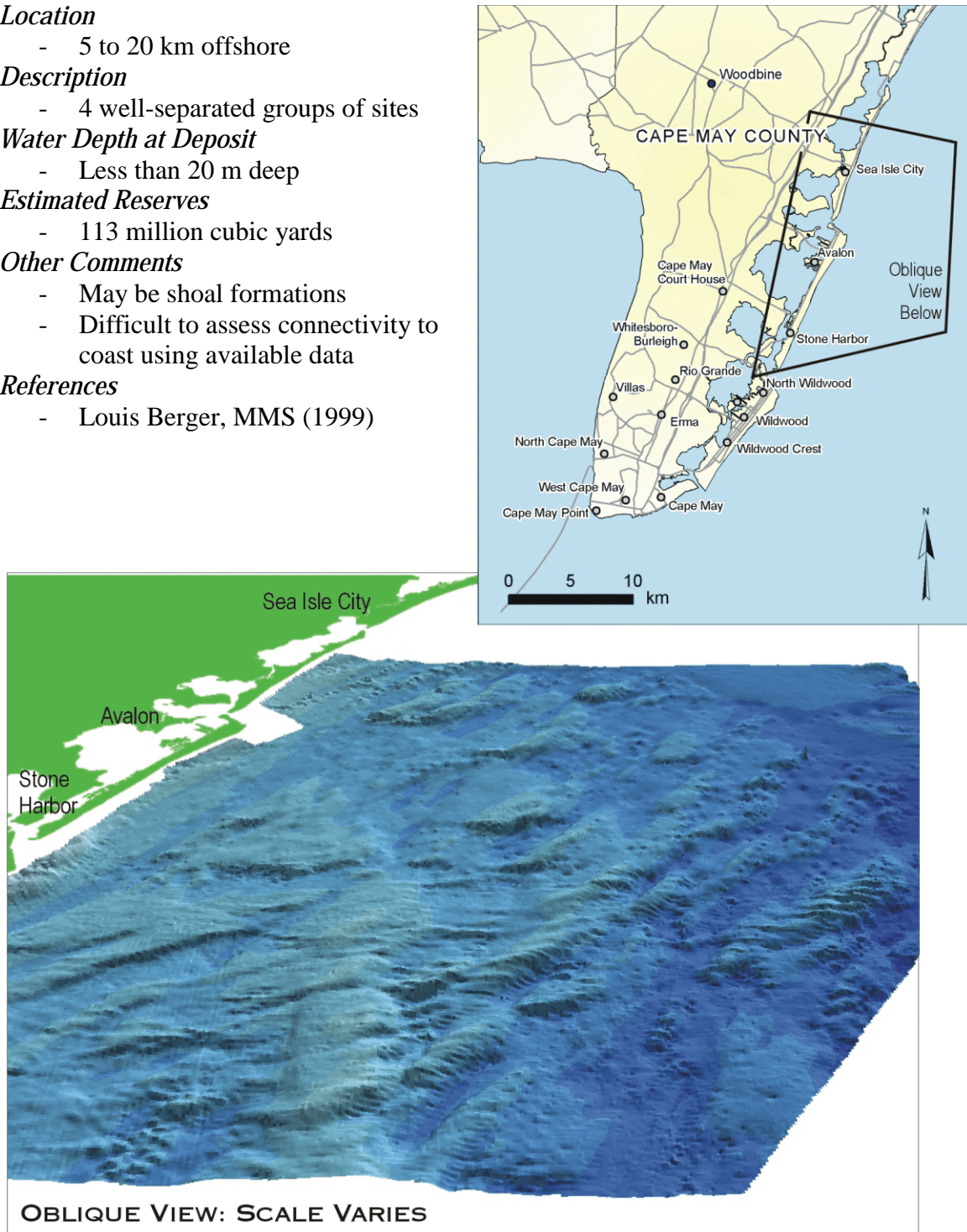
- 113 million cubic yards

**Other Comments**

- May be shoal formations
- Difficult to assess connectivity to coast using available data

**References**

- Louis Berger, MMS (1999)



**Figure 2.3.** Deposits offshore of New Jersey.



**Table 2.2.** Maryland/Delaware OCS borrow sites (see Figure 2.4).

**Location**

- 10 to 16 km offshore

**Description**

- Three shoals all aligned NE/SW
- Separated by 1 to 2 km wide channels

**Area Between Shore and Borrow Site**

- 15 to 20 m deep

**Water Depth at Deposit**

- 5 to 20 m deep

**Estimated Reserves**

- 422 million cubic yards

**Other Comments**

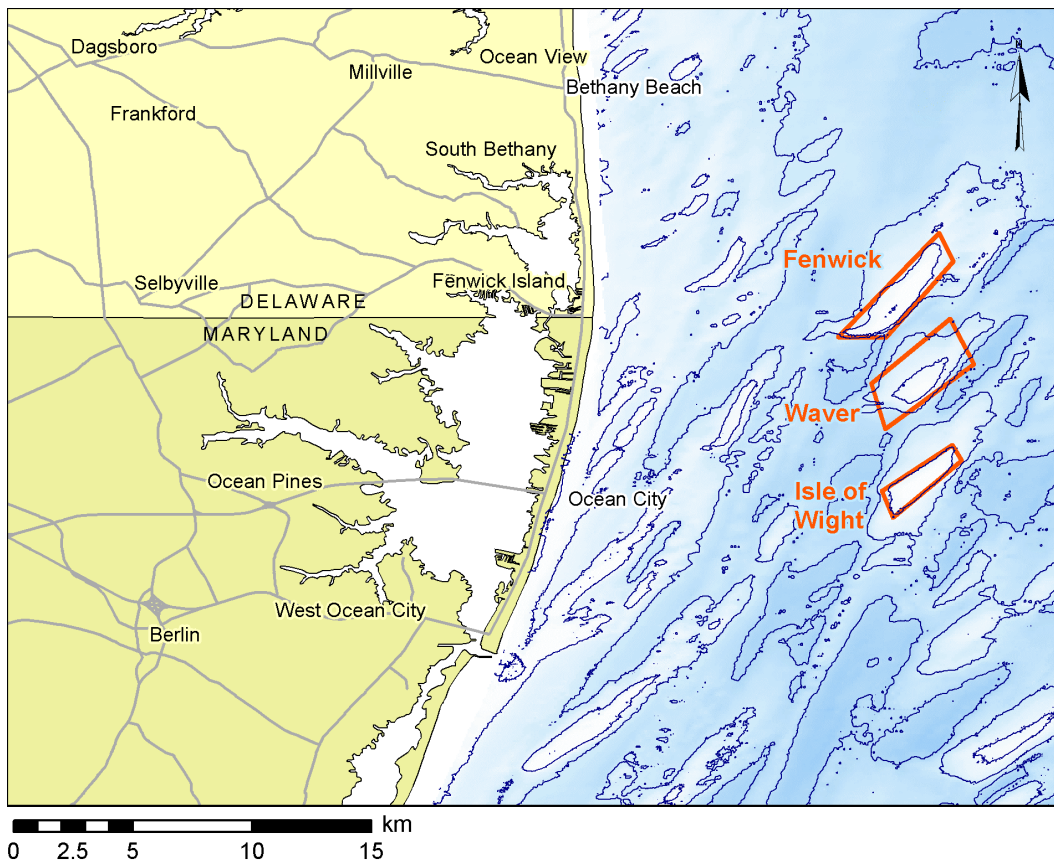
- Likely isolated from sediment transport paths (each other, coast or other areas)
- May be influenced by processes within Delaware and Chesapeake Bays

**References**

- OCS Study 2000-055, Virginia Institute of Marine Sciences (2000)

**Location**

- 6 to 9 km offshore of Sandbridge, VA



**Figure 2.4.** Bathymetry offshore of Northern Maryland showing three borrow sites.

**Table 2.3.** Virginia OCS borrow sites (see Figure 2.5).

*Description*

- Oriented N/S (slightly sub-parallel to coast)

*Area Between Shore and Borrow Site*

- Substrate is silty sand
- Approximately 14 m deep

*Water Depth at Deposit*

- 10 to 13 m deep

*Estimated Reserves*

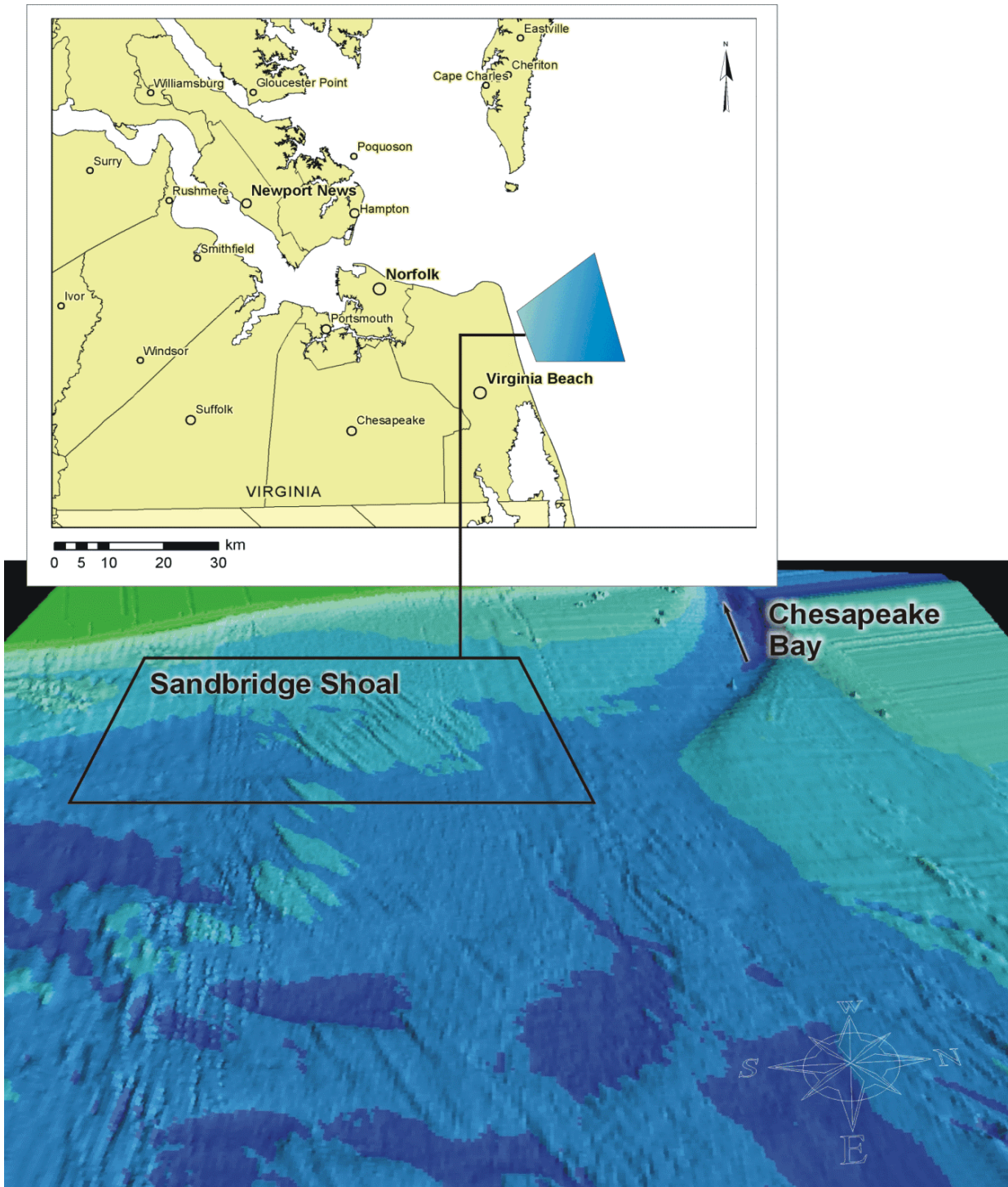
- 40 million cubic yards

*Other Comments*

- Connectivity to the coast is suggested by depth and profile
- Sediment type suggests that sites are not connected to the coast
- May be influenced by processes within Chesapeake Bay

*References*

- Hardaway et al. (1998)



**Figure 2.5.** Bathymetry offshore of Southern Virginia.

**Table 2.4.** North Carolina OCS borrow sites (see Figure 2.6).

*Location*

- 7 to 15 km offshore of Kitty Hawk
- North of Oregon Inlet
- Offshore Dare County

*Description*

- 4 sites

*Area Between Shore and Borrow Site*

- May be silt/clay

*Water Depth at Deposit*

- 15 to 25 m deep

*Estimated Reserves*

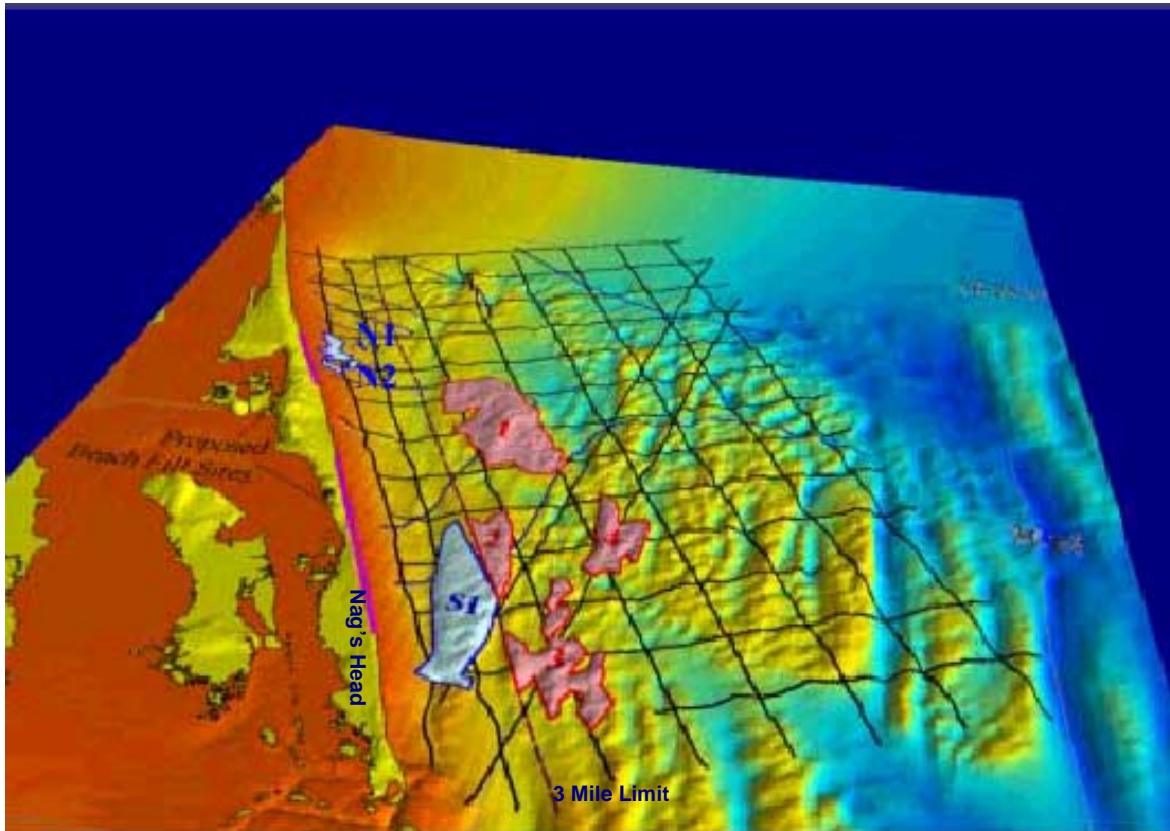
- 306 million cubic yards

*Other Comments*

- Not enough physical information to assess connectivity between each other and the coast
- May be influenced by processes in Oregon Inlet

*References*

- Continental Shelf Associates (2000)
- Boss and Hoffman (2001)



**Figure 2.6.** Perspective view showing inner shelf of proposed borrow deposits inshore and offshore of the three-mile limit, Dare County, NC.

**Table 2.5.** South Carolina OCS borrow sites (see Figure 2.7).

*Location*

- Offshore south of Myrtle Beach (and others)

*Estimated Reserves*

- 560 000 cubic yards (offshore Myrtle Beach only)

*Other Comments*

- Straddles 3 mile limit
- Biological studies by Van Dolah (1992; 1994)
- Bury and Van Dolah (1995)

**Table 2.6.** East Florida (see Figure 2.8).

*Location*

- 13 km offshore of Jacksonville Beach
- 11 km SE of St. John's Inlet
- Offshore Brevard, Indian River, St. Lucie and Martin Counties

*Water Depth at Deposit*

- Approximately 15 m – 20 m deep

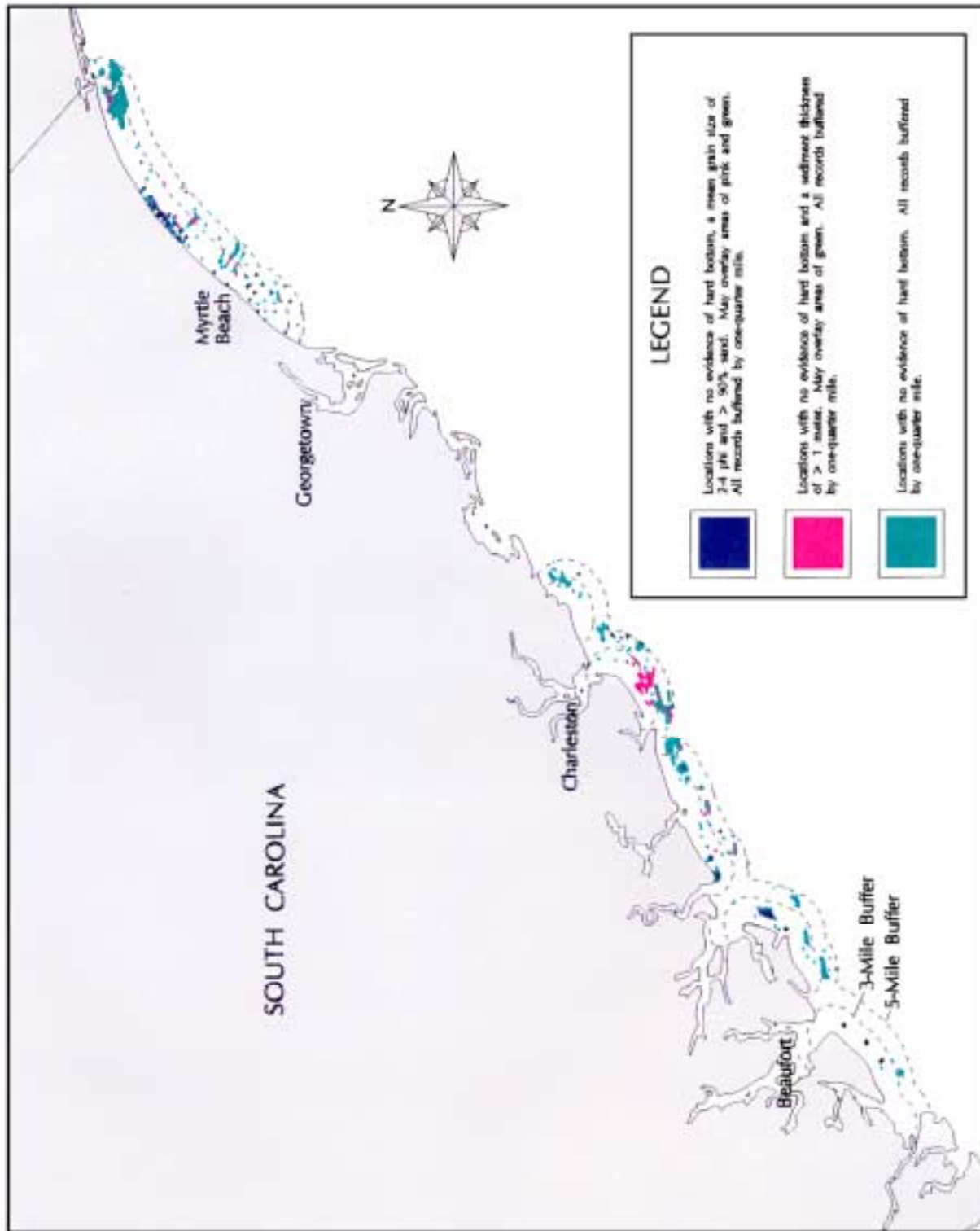
*Other Comments*

- Completed pre- and post-dredging assessment of benthic fauna and sediment
- For central Florida the Florida Geological Survey completed geophysical and vibracore investigations in cooperative work with MMS

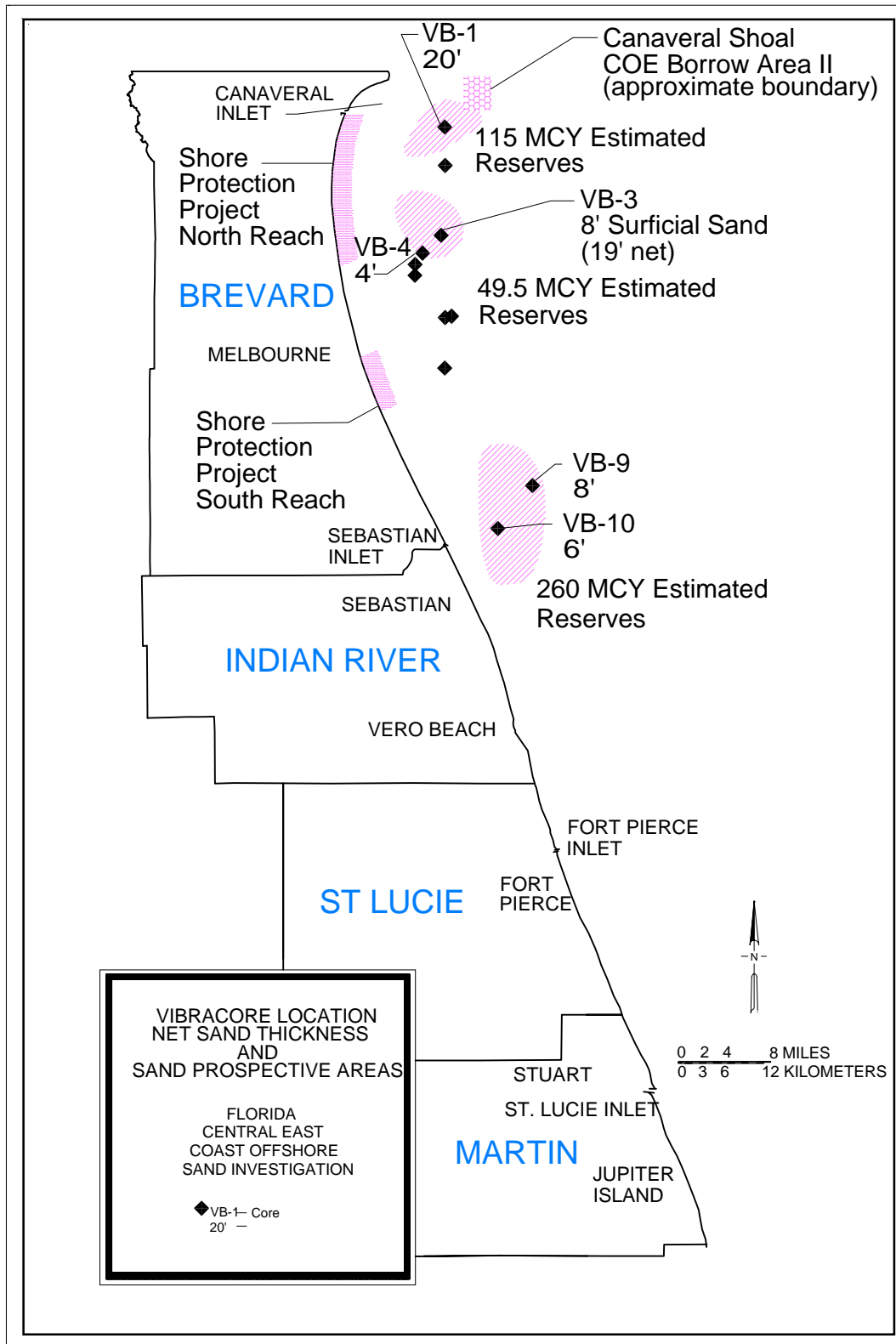
*References*

- Lotspeich et al. (1997)
- Freedenberg and Hoenstine (1999)





**Figure 2.7.** Analyses of records within three and five miles of erosional beaches that met certain criteria on bottom-type sediment composition and sediment thickness, offshore South Carolina (Bury and Van Dolah, 1995).



**Figure 2.8.** Possible Federal reserves offshore East-Central Florida (from Freedenberg and Hoenstine, 1999).

**Table 2.7.** Alabama OCS borrow sites (see Figure 2.9).

*Location*

- 7 to 15 km offshore

*Description*

- Three potential resource areas

*Water Depth at Deposit*

- 12 to 20 m deep

*Estimated Reserves*

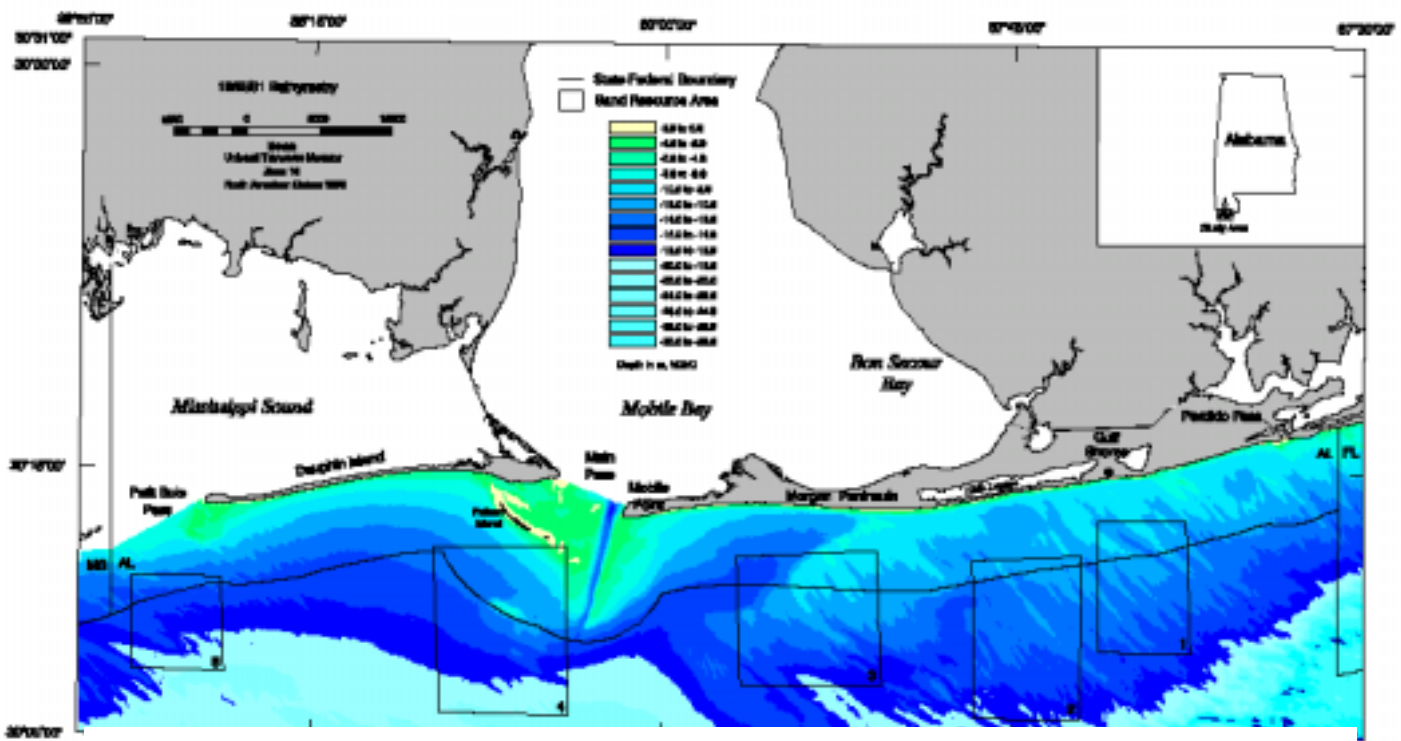
- 15.5 million cubic yards

*Other Comments*

- May be influenced by processes within Mobile Bay (central area is part of ebb shoal)
- May be a bypassing shoal

*References*

- OCS Study MMS 99-0052, Aubrey Consulting (1999)





**Table 2.8.** Louisiana OCS borrow sites (see Figure 2.10).

*Location*

- 13 to 17 km offshore of Isles Dernieres

*Description*

- Single shoal

*Area Between Shore and Borrow Site*

- 8 to 10 m deep

*Water Depth at Deposit*

- Approximately 4 m deep

*Estimated Reserves*

- 1.6 billion cubic yards

*Other Comments*

- Probably not linked to coast by sediment transport pathway
- Close to Terrebonne Bay

*References*

- Stone and Xu (1996), Stone (2000)



**Figure 2.10.** Location of the Ship Shoal deposit offshore Louisiana.

## 2.2 Summary

All identified OCS borrow sites share some common features. They are all in relatively shallow water, generally between 5 m and 15 m deep. The sites are mostly disconnected from coasts with respect to sediment transport paths. The sites also fall into three morphologic categories: isolated shoals/ridges, ebb shoals, and shelves.

### **3.0 PROJECT APPROACH**

To have an effective and successful monitoring program design, it is essential that the program designers have a clear understanding of the ecological changes or effects to be monitored and the ultimate goal of the program, i.e., how are the monitoring program data or information going to be used. To accomplish this, the project team identified three key initial actions to the project:

- In coordination with MMS/ INTERMAR project staff, identify the role of the OCS sand mining monitoring program in their management and environmental stewardship of this resource;
- Review available literature to clearly identify the geophysical processes and biological ecosystems that would be affected by OCS sand mining for beach replenishment; and
- Based on the information obtained from the two actions above, develop a series of broad scientific questions around which the monitoring program would be designed.

#### **3.1 Resource Management and Stewardship Goals**

##### **3.1.1 Goals**

Concurrent with the review of available literature, the project team developed a set of overall project goals around which the monitoring program would be designed. This effort was conducted with the assistance of MMS project personnel. These goals were to:

- 1) Better understand the physical and ecological effects of sand dredging, and
- 2) Obtain data or information relating to resource management decisions.

##### **3.1.2 Questions**

The resource management questions proposed by the team and MMS personnel were:

- Is there a threshold above which continuous mining results in unacceptable damage/impairment to marine ecosystems?
- Are there operational methods that can be changed to reduce/eliminate negative impacts to physical or biological conditions?
- Does sand dredging result in predicted impacts?
- Are there impacts that were not predicted or anticipated?
- Do the predicted impacts occur and recover as expected?

##### **3.1.3 Assumptions**

During these initial team discussions with the MMS, it was determined that certain types of dredging (aggregate mining with open ocean sorting) and sensitive habitats would not be considered in the design of the monitoring program. Other "core design assumptions" to the program were:

- Only beach replenishment type mining would be considered. In this process only a small fraction of the material dredged is returned to the sea during dredging (less than 10 to 20% of what is taken on board). Aggregate mining where the dredged material is graded offshore and only the desired grain size is retained would not be part of this project. In aggregate mining, the screening process results in a significant fraction of material taken on board that is returned to the sea during the dredging process.
- Contaminated and cultural resource sites would be avoided as potential sand borrow locations.
- Hard substrate areas (rocky reefs, coral reefs, artificial reefs, etc.) would be protected by both exclusion zones and buffer zones to prevent or avoid possible negative impacts, particularly those associated with the sedimentation footprint from the dredge plume.
- Avoidable physical and biological impacts would be avoided. Therefore, critical habitat/locations and critical time periods would be avoided by implementing operational constraints to prevent these types of impacts.
- The monitoring program would focus on only physical changes to habitat and community structure. Concerns about possible re-suspension of chemical contaminants would not be considered since all contaminated sites would be prohibited as possible sand borrow sites.

### **3.2 Literature Review**

To identify environmental parameters that need to be considered in the design of the long-term monitoring program for OCS sand mining sites, the project team reviewed the available literature. The literature review included pertinent technical papers on open ocean dredging and sand mining, environmental assessment reports, and biological baseline and monitoring studies of past dredging activities along the US coastlines and of potential OCS sand borrow sites. Most of these studies and reports were funded by MMS, for both the East and Gulf coasts of the United States as well as in the North Sea, where extensive offshore sand and gravel dredging is conducted.

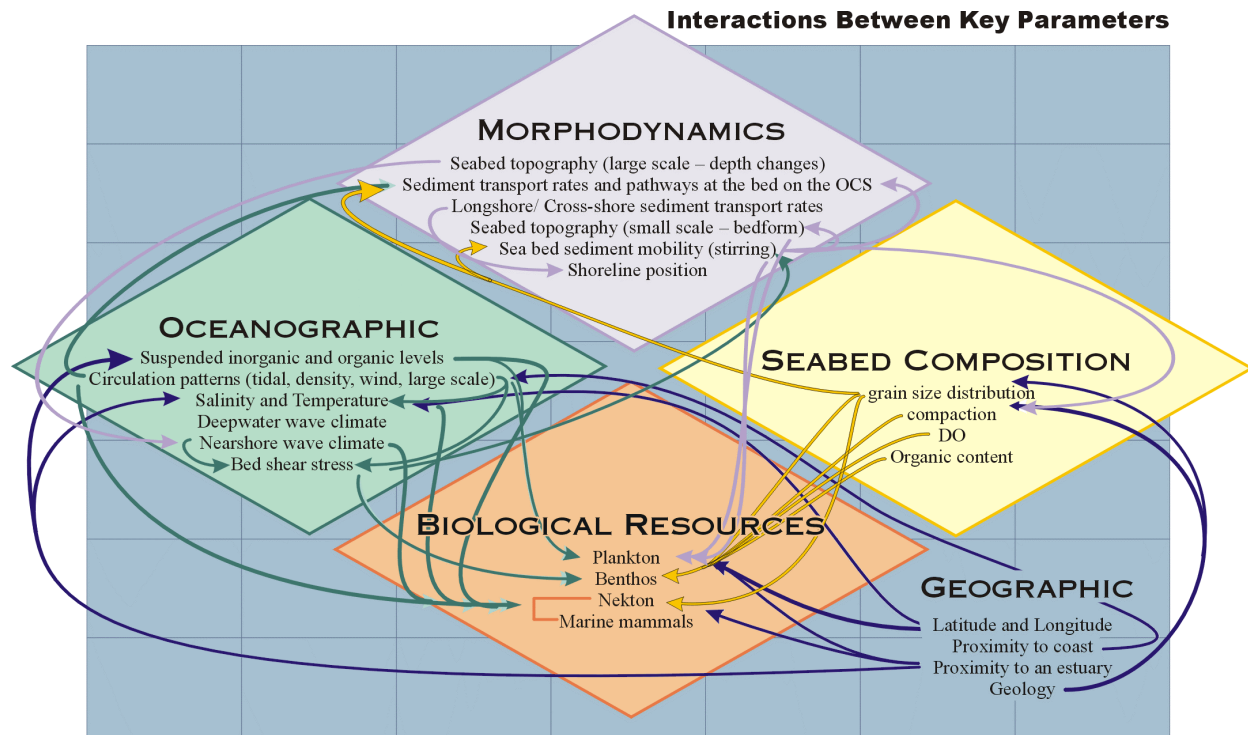
In addition, studies conducted by the states of South Carolina and Florida were reviewed, and the project team also conducted independent literature searches to obtain information on offshore sand ridge ecology and dynamics. Section 9 provides a listing of the references reviewed by the project team.

### **3.3 Ecological Issues of Concern**

Following the completion of the literature review, the project team identified those ecological resources (physical and biological) that would have the greatest potential for being affected by offshore sand mining, both directly and indirectly. Impacts occurring as a one-time dredging event at a given location or as repeated dredging of an area over some time period were included. All physical and biological processes were initially considered.

Figure 3.1 shows the relationships between key physical and biological parameters that were identified during the literature review. The parameters are divided among one biological and three physical components, as well as geographic influences. In addition, Table 3.1 presents

the specific physical processes and biological communities potentially affected by OCS sand dredging, as identified during the literature review.



**Figure 3.1** Interactions between key physical and biological parameters for OCS sand mining.

For the purposes of this project, impacts have been defined as follows:

- **Direct:** Changes that occur as a primary response to the dredging process, without an intervening process (e.g., removal of infauna). They generally extend from the area of extraction to the edge of the plume sedimentation footprint and/or extent of the plume itself in the water column.
- **Indirect:** Changes that occur as a result of a secondary response to dredging activities (e.g., change in fish populations because of the removal of infauna, changing the prey base), both within and outside the dredged area.

The following sections discuss in greater detail the effects of sand dredging on the physical environment and processes and biological communities and processes.

### 3.3.1 Geophysical Environment and Processes

There are three primary components of the physical environment:

- **Morphodynamics.** This group describes fluctuations and trends in changes to the elevation of the seabed and land surface extending from the vicinity of the borrow deposit to the furthest onshore extent of the dynamic beach zone. These changes are a result of

**Table 3.1.** Summary of potential physical and biological effects of OCS sand mining for beach replenishment.

<b>Physical or Biological Change</b>		<b>Effects/Impacts</b>
<i>Morphodynamics</i>		
<i>Direct</i>	Creation of depressions and furrows (possibly $\geq 0.3$ meters) from removal of substrate	Could result in changes to dredge site and shoreline geomorphology Potential change to benthos
<i>Indirect</i>	Change to seabed topography beyond immediate dredge area through induced erosion/deposition (created by changes to sediment transport processes and pathways)	Could result in impact (long-term) to shoreline geomorphology or the unraveling of a shoal/ridge feature Potential change to benthos
	Change to sea bed mobility due to change in depth and in waves/currents (driving forces)	No known or identified physical impacts. Potential change to benthos
	Change to shoreline evolution	Altered shoreline dynamics
<i>Seabed Composition</i>		
<i>Direct</i>	Removal (and disturbance) of substrate and exposure of underlying layer with different characteristics (grain size, DO, compaction and organic content). In some cases this may result in a positive impact where preferred substrates are exposed.	No known or identified physical impacts. Potential change to benthos and indirectly to nekton and marine wildlife
	Change in grain size due to settling and deposition of sediment in overspill plume (inside and outside dredged area)	No known or identified physical impacts. Potential change to benthos (smothering and altered habitat)
<i>Indirect</i>	Changes in grain size, compaction, organic content and DO induced by indirect erosion/deposition	No known or identified physical impacts. Potential change to benthos and fish (altered habitat)
<i>Oceanography</i>		
<i>Direct</i>	Elevated levels of suspended inorganic and organic solids in the overspill and benthic plumes	Temporarily increased water column turbidity Minimal effect to plankton, marine mammals, marine wildlife and nekton
<i>Indirect</i>	Changes to wave climate over and outside of the borrow area	Could result in changes to shoreline geomorphology (long-term) to or the unraveling of a shoal/ridge feature Potential change to benthos
	Changes to shear stresses related to alterations to the wave climate	No known or identified physical impacts.
	Changes to near bed current velocities associated with tidal, density driven and large scale circulation	Could result in shoreline geomorphology impact (long-term)

**Table 3.1. Cont.**

<b><i>Geography (location of the borrow deposit)</i></b>		
<i>Direct</i>	None	No known or identified physical impacts
<i>Indirect</i>	None	No known or identified physical impacts
<b><i>Plankton</i></b>		
<i>Direct</i>	Short-term Increased turbidity from cutter head or dredge barge overspill	Limited reductions in primary and secondary productivity
<b><i>Benthos</i></b>		
<i>Direct (Soft Bottom)</i>	Loss or reduced suitability of habitat	Total removal/loss of infauna and epifauna at borrow site with recolonization by benthic organisms occurring within 1-5 years (possibly longer) to a community with comparable pre-disturbance abundance, diversity and biomass but different species composition and community structure
	Changes in nearfield habitat condition resulting from altered sediment particle size composition from cutter-head discharge or altered ridge morphology	Changes in community structure (species present, diversity, abundance and biomass) in nearfield areas
<i>Direct (Hard Bottom)</i>	Increased deposition of advected suspended sediments, increased fluxes of suspended sediments during dredging	Burial of near-bottom organisms, fouling of feeding and respiratory surfaces
<i>Indirect (Soft Bottom)</i>	Recolonization by an altered biological community	Altered productivity and energy transfer effects on the food chain; altered species composition of fish prey base
<i>Indirect (Hard Bottom)</i>	Recolonization by an altered biological community	Altered productivity and energy transfer effects on the food chain; altered species composition of fish prey base
<b><i>Nekton</i></b>		
<i>Direct</i>	Loss or reduced suitability of habitat	Removal of infauna and epifauna: 1) Loss of foraging habitat; 2) Loss of spawning habitat; 3) Loss over overwintering habitat
	Increased turbidity and sedimentation	Gill clogging and burial
<i>Indirect</i>	Recolonization by an altered benthic biological community	Altered foraging efficiency with resultant effects on individual size, weight, and fecundity
<b><i>Marine Mammals &amp; Wildlife</i></b>		
<i>Direct</i>	Collisions during dredging operations and some noise disorientation.	Injury or death of animal; potential disorientation
	Loss or reduced suitability of habitat	Removal of infauna and epifauna: Change in foraging area and food
<i>Indirect</i>	Nearfield habitat changes	Removal of infauna and epifauna: Change in foraging area and food
	Increased turbidity and sedimentation	Reduced visibility resulting in reduced foraging efficiency and injury for visual predators

sediment transport processes. These process and related changes may occur across a wide spatial scale, extending from individual sand grains, to bedform, to large-scale erosion and accretion, including shoreline change.

- Seabed Characteristics. This group addresses the temporal and spatial (three-dimensional) variability of the characteristics of the seabed including but not limited to grain-size distribution, dissolved oxygen, compaction, and organic content. There are interrelationships between morphodynamics and seabed characteristics as the movement of sediment results in disturbance and change to the bed conditions and the sediment and larval deposition environment of the seafloor.
- Oceanographic Conditions. This group includes a wide range of processes and properties associated with the water column including waves, currents (with a wide range of forcing functions), suspended sediment levels, water temperature, salinity and others.

The most apparent direct physical impact is the removal of substrate and the reduction in the elevation of the seabed. This may result in the creation of furrows or a pit or the removal of a bathymetric high such as the top of a shoal. Indirect morphodynamic impacts include subsequent changes to the seabed topography, seabed mobility, and shoreline change.

From a purely physical perspective, the only change of consequence is the potential impact of dredging on shoreline change. For example, an increase in depth at a given location is not of direct importance to human activities – nor is a temporary sediment plume located in Federal waters some distance from shore. Theoretically the shoreline change can occur in one of two ways: 1) through alterations to the wave transformation pattern, changing the waves that reach the shore, in turn modifying the sand transport related processes and ultimately changing erosion and accretion patterns; and 2) by interrupting or modifying a sand supply pathway from or through the borrow area to the shore. A review of the currently identified OCS borrow deposits suggests that most of them are immune from the second impact because they are isolated from the sediment budget of the littoral system by large distances and muddy areas (the latter indicating the absence of a sand transport pathway). Nevertheless, this will not always be the case. Careful consideration must be given on a site-specific basis to the possibility of interrupting a sediment supply pathway to the shoreline.

All other physical changes and impacts caused by dredging are important only if they result in a biological impact, either directly or indirectly. From a morphodynamic perspective, the direct impacts consist of the depressions, furrows, and pits left by the dredging operations. Clearly, these can have an important impact on the benthic community. The indirect biological impacts derived from a change to morphodynamics may include long-term changes to depths within and beyond the dredge area, changing the mobility of the sediment at a given location due to a change in depth and/or wave conditions at a given location. Probably the biggest concern is the potential for ridge and shoal type features to “unravel” or be smoothed out where borrow deposits are accessed on an ongoing basis. This outcome could lead to large-scale impacts to biological communities that rely on the structure of these features and to possible shoreline impacts.

Direct impacts to seabed characteristics include removal and disturbance of the substrate and exposure of an underlying layer with different characteristics (i.e., grain size, reduced dissolved oxygen levels, and compaction), and changes in grain size of surficial sediments due to settling of fines from overspill plumes or sediment reworking. Indirect impacts include changes related to erosion and deposition. These changes will only be significant where they result in biological impacts.

The primary direct impact to the oceanographic conditions would be the elevated levels of suspended inorganic and organic solids in the overspill (at the point of discharge from the hopper dredge) and benthic (at the drag head) plumes. Indirect impacts include changes to the waves within and beyond the borrow area, changes to bed shear stresses and related seabed mobility due to changes to waves, and changes to near bed current velocities driven by tides, wind, and large-scale phenomenon. Recent UK studies as described by Newell et al. (1998) have found that the only detectable plume impact from a biological perspective is the direct sedimentation footprint and that this footprint is relatively limited in spatial extent (300 to 500 m from the borrow deposit). The investigations reported and referenced by Newell et al. (1998) pertain to heavily screened hopper dredge operations where there is a very significant overspill of sediment. Most sand dredging operations on the OCS will be non-screened (at least initially for beach nourishment borrow deposits) and the plume impact will be even less important than observed by Newell et al. (1998).

### **3.3.2 Biological Ecosystems**

For marine biota, the biological communities and associated habitats that were determined as being potentially affected by OCS sand dredging include:

- Plankton
- Soft substrate benthic communities
- Hard substrate benthic communities
- Nekton
- Marine mammals and wildlife.

As indicated in section 3.2, hard substrate areas will be avoided by dredging activities or be surrounded by sufficient buffer zones to prevent dredge discharges from having effects. In addition, since no sorting of dredged material will occur during beach replenishment dredging operations, the sediment plumes created by the dredge operations will be small and very temporary. Therefore, any effects to plankton should be minimal and of short duration (Hardaway et al., 1998; Hammer, 1993).

Of the original five groups of marine organisms potentially affected by sand dredging activities in the OCS, only soft bottom benthos, nekton, and marine mammals and wildlife have any serious potential to be affected directly or indirectly. The principal impacts to soft bottom benthos result directly from removal of sand and entrained benthos. Other impacts may be due to increased turbidity during dredging, potential burial of the seafloor during dredging, and



long-term changes in sediment properties resulting from alterations in geophysical and oceanographic dynamics as discussed in section 3.3.1.

Although short-term loss and changes in benthic community structure have been documented to occur following sand dredging (Blake et. al, 1996, Van Dolah et al., 1992), the ecological significance to the benthic community is uncertain. Studies investigating the recovery of benthic communities following dredging (Blake et. al., 1996; Newell et al, 1998; Van Dolah et al., 1992) have indicated that communities of comparable total abundance and diversity can be expected to re-colonize dredge sites within several years. However, even though these re-colonized communities may be similar in terms of total abundance and species diversity, their taxonomic composition, in terms of dominant species and species abundance, is often very different from pre- to post-dredging.

The key ecological question that remains to be answered is: Do the new benthic communities fill the same trophic function and provide the same energy transfer to higher trophic levels, as did the original communities? If they do not, then the potential long-term and cumulative ecological impacts of sand dredging may be far greater than predicted to date, a condition that may be unacceptable as more sites along the coast are dredged and others are dredged on a regular basis.

The potential effects to fisheries from sand dredging are unknown, having been identified in most of the environmental impact assessments prepared for OCS sand dredging to be minimal or non-existent (Hammer, 1993; Louis Berger Group, 1999). This assessment was based on the determination that most of the fish inhabiting the potential dredge areas were characterized as wide-foraging or migratory, spending only part of their life cycle in the dredge borrow area. In addition, the ridge/shoal and shelf features identified as potential sand borrow areas are very large in geographic extent, extending over kilometers of seafloor and the potential borrow area for each dredging event is relatively small. Therefore the lost or altered habitat area, overall, would probably be minimal.

The literature review effort conducted by the project team into the ecological utilization of ridge/shoal features by fish species indicated that little is known or has been published on the subject. Whether these features provide critical habitat for spawning, overwintering, or foraging area is relatively unknown. This information gap has been identified by the project team as an area requiring further study, and the results from such a study could result in the modification of the proposed monitoring program.

Excluding the potential effects of lost essential habitat as a result of dredging, the greatest potential effect to the fish community utilizing a dredge borrow area is an alteration in trophic energy transfer from the benthos to the fish population. As indicated above, if the amount of energy being transferred to the fish population from the benthos is less than what is currently being provided by the area before dredging, then the potential long-term and cumulative ecological impacts of sand dredging may be far greater than predicted to date, a condition that may be unacceptable as more sites along the coast are dredged and others are dredged on a regular basis.

In consideration of marine mammals and other marine wildlife such as sea turtles and birds, of the identified direct and indirect impacts, the greatest potential for serious effect is associated with direct collision with the dredge vessel or entrainment in the suction dredge.

### **3.4 Geophysical and Biological Parameters Addressed by the Monitoring Program**

#### **3.4.1 Physical Monitoring Program**

Recognizing the fact that most physical impacts only have the potential to become significant when they result in a biological impact or affect the shoreline dynamics, the monitoring program must be developed to consider the biophysical interactions of impacts – particularly the indirect type. The review of possible physical impacts points to the following focus for monitoring and modeling of physical parameters:

- Changes to bathymetry;
- Changes to waves and possible related shoreline changes; and
- Changes to the seabed characteristics that may result in biological impacts.

As discussed in Section 3.3.1, there are only two possible substantive physical impacts of concern: 1) those that result directly or indirectly in an unacceptable biological impact; and/or 2) those that lead to changes to the shoreline dynamics inshore of the borrow deposit. Four physical monitoring and modeling protocols have been developed to address these issues as listed below:

1. Bathymetric and Substrate Surveys
2. Sediment Sampling and Analysis
3. Wave Monitoring and Modeling
4. Shoreline Monitoring and Modeling

The first two protocols primarily address the potential for biological impacts that may result from physical impacts. They essentially focus on tracking geomorphic changes to the borrow area and the surrounding sea bed. For many of the currently identified OCS deposits (see Section 2.1), the potential impacts to the form of ridge and shoal features will be closely monitored. The Bathymetric and Substrate Surveys Protocol also provides a description of the form of the borrow deposit (and any indirect changes on adjacent sea bed elevations) that is required as input to the Wave Modeling, the third protocol listed above.

The third and fourth protocols listed above address the potential for shoreline impacts that may be directly related to changes to the sea bed elevations in the vicinity of the borrow deposit, in turn influencing the waves that reach the shore inshore of the borrow deposit, and in turn changing longshore and cross-shore sand transport rates and the resulting shoreline dynamics. Because there are many other factors that may result in changes to shoreline dynamics, the Wave and Shoreline Protocols include two key distinct features: 1) the need simply to document (or ensure documentation by others) of the waves (that cause changes to the shore) and shoreline change itself as a record of conditions; and 2) the need for modeling (in addition to monitoring) to attempt to isolate the direct influence of the changed bathymetry in

and around the borrow area on waves and shoreline dynamics (i.e. from all the other possible factors that may influence these processes). It is recognized that numerical modeling of these complex processes has many limitations, but nevertheless, these techniques provide at least some insight into the processes and the potential for dredging to lead to shoreline changes. Taken together with the field data derived from the monitoring and an understanding of the geomorphology of the area, the numerical model results provide the basis for evaluating the potential impacts of dredged borrow deposits on shoreline dynamics.

A summary of the four physical monitoring protocols is presented in Table 3.2. This table provides the key potential impact, the objectives, the monitoring and modeling requirements and approximate cost of each of the protocols. This table is provided as an overview only and the information is insufficient to provide a guideline for the monitoring requirements. Please refer to the full description of the protocols in Section 4 for implementation.

Detailed monitoring of the plumes generated during dredging operations at the overspill point and the draghead has not been included as a requirement (or addressed with a protocol) owing to the fact that the primary concern is the extent of the sedimentation footprint, not the impact of the temporary plume itself. The extent of the sedimentation footprint will be documented by the sediment sampling program. *A priori* knowledge of the extent of the footprint would be useful to develop the spatial boundaries for the monitoring programs, and this is the focus of a Plume Model development and testing project currently being undertaken by Baird & Associates for MMS in FY02.

**Table 3.2.** Summary of requirements of the physical monitoring protocols (NOTE: this table provided as an overview only for implementation refer to the full protocols in Section 4).

Protocol	Potential Impact	Objectives	Requirements		Cost/Year
			Monitoring	Modeling	
Bathymetry and Substrate	Changes to the morphology and substrate characteristics of the borrow deposit and surrounding area (particularly for ridges and shoals) and potential physical (waves and shoreline change) and biological impacts.	<ol style="list-style-type: none"> <li>1. Determine the location and quantity of sand removed and change to bathymetry caused by dredging operations.</li> <li>2. Quantify subsequent changes to bathymetry in the immediate vicinity of the borrow area.</li> <li>3. Quantify potential changes to the overall borrow deposit feature (e.g. ridge or shoal if one exists)</li> </ol>	<ol style="list-style-type: none"> <li>1. Hydrographic Survey (single beam acoustic) plus Side Scan Sonar: or,</li> <li>2. Hydrographic Survey with Multibeam technique; or,</li> <li>3. LIDAR/SHOALS or other methods that are able to achieve specifications and requirements of the Protocol.</li> </ol>		\$77,500-130,000
Sediment	Changes in sediment texture and total organic content and subsequent biological impacts.	<ol style="list-style-type: none"> <li>1. Define changes to texture caused by removal, sedimentation and indirect erosion/deposition processes.</li> <li>2. Potential changes may serve the assessment of changes to morphology of features at the borrow deposit (e.g. ridges and shoals).</li> <li>3. Determine changes in TOC to assess potential impact to benthic communities.</li> </ol>	Collect sand samples at the location of benthic samples and test for grain size distribution (both sieve and hydrometer test or equivalent) and TOC method based on high temperature combustion.		In biological protocol costs

**Table 3.2. Cont.**

Protocol	Potential Impact	Objectives	Requirements		Cost/Year
			Monitoring	Modeling	
Waves	Change to wave transformation patterns over the dredged area with possible ultimate impact of shoreline change	<ol style="list-style-type: none"> <li>1. Develop a continuous record of wave conditions starting from first access of borrow deposit.</li> <li>2. Assess influence of initial changes to bathymetry.</li> <li>3. Assess influence of subsequent (direct and indirect) changes to bathymetry.</li> </ol>	Deepwater wave data through combination of measured directional data and non-directional data and available hindcast data.	Complete nearshore wave transformation modeling to transfer deepwater waves to the borrow deposit, over the borrow deposit and into shore (ultimately for input to the shoreline change model).	\$113,000-154,000
Shoreline	Shoreline erosion directly attributable to dredging at the borrow deposit.	<ol style="list-style-type: none"> <li>1. Document actual shoreline change (regardless of cause).</li> <li>2. Assess the impact of dredging at the borrow deposit.</li> </ol>	<ol style="list-style-type: none"> <li>1. Beach and Nearshore Profile Surveys twice per year every 300 m.</li> <li>2. Georegistered aerial photographs and digitized shoreline twice per year.</li> </ol>	Apply GENESIS model or equivalent to assess longshore sand transport and related shoreline change with and without project prior to and after dredging commences (comparing to measured change in latter case).	\$28,000-51,000

### 3.4.2 Biological Monitoring Program

The biological monitoring elements of the MMS OCS sand mining monitoring program focus on:

- Benthic communities and their trophic relationships to fish, and
- Marine mammal and wildlife interactions during dredging.

Probably the most obvious biological effect of sand dredging operations is the complete removal of soft bottom habitat along with resident benthic organisms within the dredge area. Such removal affects not only the benthic communities, but also the fish assemblages that rely on the benthos for food. In addition, the potential small- and large-scale changes to seafloor geomorphology (e.g., substrate type and composition, surface texture, water circulation, nutrient distribution) due to altered wave patterns and sediment transport in the vicinity of the dredging operation may also affect benthic community structure and trophic energy flow.

Therefore, the recommended approach for monitoring biological change involves measuring trophic energy transfer between the benthos and representative species of the fish population. This approach will facilitate the monitoring of changes over a very wide area of potential impact and changes resulting from the sand dredging operations regardless of the origin of the habitat change, e.g., direct removal of sand or potential changes in habitat sediment composition following geomorphological changes in the ridge and shoal or shelf structure resulting from the sand dredging. In addition to the measuring of trophic energy transfer effects, community structure and composition information should be gathered on the benthos as well as limited community structure and composition information on fish.

In addition to monitoring trophic effects, it is suggested that the potential physical interactions and impacts to marine mammals and wildlife should also be monitored. This element of the monitoring program will be addressed as an operational control and monitoring component, that will occur during dredging operations.

The recommended biological monitoring protocols have been designed with two principal objectives in mind: 1) the monitoring effort should be scientifically rigorous, and 2) the program costs should be affordable. Scientific rigor has been incorporated through several approaches. First, sampling sites are distributed among strata based on environmental variables known to influence communities to reduce within-treatment variation and improve statistical power. Second, we have specified a sampling design that utilizes statistical tests and interpretive criteria to minimize misidentification of dredging impacts. This design is amenable to comparisons of variation within and between treatments through analysis of variance (ANOVA). Using ANOVA, dredging effects will be ascribed to significant time x treatment interactions that coincide with a divergence between dredged and undredged areas at the time of dredging. Recovery will be ascribed to a reconvergence between dredged and undredged areas over time. Third, numbers of replicate samples are based upon the various characteristics of the biological communities to ensure representative abundance estimates and description of the communities.

The proposed biological monitoring protocols do not include components specifically designed to evaluate differences in dredging strategies (e.g., removal of sand in different spatial patterns that retain undisturbed patches to facilitate recovery). In particular, samples will not be distributed within strata according to dredged and undredged patches of seabed. To evaluate the effects of different spatial patterns of sand removal, the differences in benthic communities between dredged and undredged samples within a stratum will simply contribute to the within-stratum variation. The dredging pattern will provide an independent variable for use in general linear model procedures to determine what variables affect rate of recovery (see the Data Analysis and Synthesis section of the benthos and fishes monitoring protocol.) If retention of undredged patches increases recovery rates, the effect will be evident without the added expense of full replication and separate analysis for dredged and undredged samples within strata.

Several aspects of the biological monitoring programs are assumed and will not be described in detail in subsequent sections. These include the use of precision navigation, such as differential GPS, to ensure that all samples are collected from the proper locations. Another is operational safety, such as wearing personal floatation devices at all times while working on the deck of the sampling vessel.

Furthermore, it was determined that the biological monitoring program design would focus on:

- Long-term rather than short-term impacts; and
- Ridge and shoal type ecosystems, because of their greater micro-habitat and geomorphological complexity, and they represent the predominant morphology of the currently identified OCS sand borrow sites along the eastern seaboard of the U.S. However, it should be noted that the proposed protocols and monitoring program design is equally applicable to flat, shelf-type ecosystems.

A summary of the two biological monitoring protocols is presented in Table 3.3. This table provides the key potential impact, the objectives, the monitoring and analysis requirements and approximate cost of each of the protocols. This table is provided as an overview only and the information is insufficient to provide a guideline for the monitoring requirements. Please refer to the full description of the protocols in Section 4 for implementation.

**Table 3.3.** Summary of requirements of the biological monitoring protocols (NOTE: this table is provided as an overview only. For implementation, refer to the full Protocols in Section 4)

Protocol	Potential Impact	Objectives & Justifications	Requirements		Cost/Year
			Monitoring	Analysis	
Benthos and Fishes; Trophic Transfer	<ol style="list-style-type: none"> <li>Total removal/loss of infauna and epifauna at borrow site with recolonization by benthic organisms occurring within 1-5 years (possibly longer) to a community with comparable pre-disturbance abundance, diversity and biomass but different species composition and community structure</li> <li>Altered foraging efficiency with resultant effects on individual size and weight.</li> <li>Altered species composition of fish prey base; altered productivity and energy transfer effects on the food chain</li> </ol>	<ul style="list-style-type: none"> <li>To determine the effects of dredging activities on benthic communities and the transfer of energy from benthic communities to fishes. While overall abundances of benthic organisms have been shown to return to pre-dredging levels in some cases within a year or two after dredging, species composition may be different and the ability of fishes to utilize such altered assemblages for prey is uncertain</li> </ul>	<ol style="list-style-type: none"> <li>Collect 0.10 m<sup>2</sup> benthic infauna samples from multiple strata at both impact and reference locations prior to dredging and in years 1, 3, 5 and 7 following dredging.</li> <li>Collect stomachs from numerically dominant or recreationally important species from multiple strata at both impact and reference locations prior to dredging and in years 1, 3,5 and 6 following dredging.</li> </ol>	<ol style="list-style-type: none"> <li>Infauna taxonomy for comparison with fish gut contents analysis and for determining secondary productivity values.</li> <li>Biomass measurements for determining secondary productivity values.</li> <li>Carbon and Nitrogen stable isotope measurements of key benthic prey species for fish.</li> </ol> <ol style="list-style-type: none"> <li>Fish gut analysis for comparison with infauna taxonomy.2.b. Carbon and nitrogen stable isotope measurements of fish muscle tissue.</li> </ol>	<ol style="list-style-type: none"> <li>\$110,000-\$169,900</li> <li>\$105,460-\$147,900</li> </ol>



**Table 3.3. Cont.**

Protocol	Potential Impact	Objectives & Justifications	Requirements		Cost/Year
			Monitoring	Analysis	
Marine Mammals & Wildlife	Injury or death of animal; potential disorientation	<ol style="list-style-type: none"> <li>1. To obtain site-specific marine wildlife observation and behavior data during OCS dredging events. This information will assist state and federal regulatory agencies in assessing the appropriateness of imposed marine mammal and wildlife protection mitigation requirements and guide any necessary revisions of future mitigation requirements.</li> <li>2. To obtain and assess marine wildlife stranding data for potential relationships between stranded animals and animals observed during OCS dredging. This information will assist state and federal regulatory agencies in assessing whether there exist any obvious relationships between post-dredging marine wildlife strandings and the OCS dredging event</li> <li>3. To provide a means for implementing environmental mitigation requirements designed to minimize potential hazardous interactions with marine mammals and protected wildlife during dredging events. (This is the only "operational control" monitoring program element included in the OCS sand dredging protocols.)</li> </ol>	<ol style="list-style-type: none"> <li>1. Collect observation and behavior data on marine mammals and wildlife during OCS dredging events.</li> <li>2. Collect marine mammal and wildlife stranding data for a 60-day period following dredging operations.</li> <li>3. Implement imposed environmental mitigation requirements designed to minimize collisions or harmful interactions between marine wildlife and dredging equipment.</li> </ol>	<ol style="list-style-type: none"> <li>1. Compare observation data with stranded animal data and document marine wildlife behavior during dredging events.</li> <li>2. Compare marine wildlife data with observation data collected during the dredging event as well as with stranding data recorded for comparable time periods during non-dredging years.</li> </ol>	No cost estimated

## **4.0 MONITORING PROTOCOLS**

This section includes the monitoring protocols for the six elements that were identified in Section 3 as core components of the monitoring plan. They are formatted as stand-alone templates. The six protocols are:

- Benthic Communities and Their Trophic Relationships to Fish
- Marine Mammals and Wildlife
- Sediment Sampling and Analysis
- Wave Monitoring and Modeling
- Bathymetric and Substrate Surveys
- Shoreline Monitoring and Modeling

The three biological protocols have a more extensive introduction that describes some of the basic design considerations that apply to all of the biological protocols.

### **4.1. Biological Protocol Approach**

The recommended biological monitoring approach emphasizes estimates of changes in the transfer of energy from benthic organisms to higher trophic levels, especially fish, resulting from dredging operations. It is recommended that benthic communities be sampled for organism densities. Fishes also should be sampled and numerically dominant and recreationally and commercially important species should receive additional investigation. These species should be analyzed for stomach contents to determine their utilization of benthic organisms. The utilized benthic species should be analyzed for their estimated secondary production using models that have developed over the past 20 years (Maslin, 1981; Morin, 1992; Tumbiolo, 1994). The amount of benthic production that is transferred to fishes should be estimated using accepted trophic transfer efficiencies.

The sampling design involves collection of samples before and after each dredging operation over multiple dates in areas that were physically similar before dredging. Stratification is an important strategy for sample allocation that improves the ability to detect impacts. Strata are identified based upon factors that are known to affect the distribution and abundance of organisms in the target communities. Pre-dredging samples are collected from within strata (i.e., areas) that are as physically homogeneous as possible. Impacts and recovery are inferred by changes in biological similarity through time between dredged and control areas within strata.

It is possible to design a monitoring program to detect a given amount of change in the parameter(s) being measured. Such an approach requires acceptance by the regulatory and scientific communities of a criterion for ecological significance. Once the maximum amount of acceptable change is established, the monitoring protocols can be designed to detect that amount of change, mainly through inclusion of sufficient numbers of replicates. When using this approach for designing a monitoring program, it is necessary to know the amount of variation in the parameters being measured, which requires site-specific data. Because we have neither consensus on appropriate levels of ecological significance nor site-specific data on trophic transfer, our approach for designing the biological monitoring protocols focus instead on

obtaining the most efficiently estimates of population means for measured parameters. This approach involves collecting the number of replicates that achieves the greatest decrease in standard error for measured parameters.

Each of the following sections presents detailed monitoring guidelines for benthic communities and fish assemblages. In some cases, differences are required between baseline (i.e., before dredging) monitoring and monitoring that occurs after the dredging. These differences are discussed in the appropriate technical sections.

## **4.2 Temporal Sampling Requirements**

To effectively assess both the short-term and long-term changes in benthic community composition and trophic dynamics in the dredge borrow site and adjacent near-field areas, sampling will need to be conducted at varying intervals over several years. The first survey should be conducted shortly before dredging to describe pre-dredging conditions. Because initial successional processes may affect the rate and process of long-term recovery in dredged areas, the first post-dredging survey should be conducted one year following dredging, and surveys should be conducted every two years after that, until year seven. In addition to the pre-dredge survey, a baseline survey may also be required if sufficient data are not available for strata delineation.

The purpose of the baseline survey would be to obtain sufficient information about the borrow site and adjacent areas to effectively delineate benthic habitats and associated benthic communities. This can be accomplished using Sediment Profile Imaging (SPI) equipment (VIMS, 2000) or benthic grabs. The effort can be combined with baseline geophysical data gathering efforts. At a typical ridge/shoal feature, this would include delineating the seaward flank of the feature, the landward flank and the ridge top, at a minimum, at both dredge and control locations. For a shelf feature, depth stratification may be more important.

As far as possible, sampling should be conducted in the same season for both pre-dredging and post-dredging sampling. Benthic communities exhibit strong seasonal patterns (Ott, 1977; Sarda, 1999; Vallet, 1999) and maintaining seasonal consistency of sampling reduces the effects of season on detection of long-term trends and recovery from dredging. It is suggested that summer is the best time to conduct sampling (Alden, 1997). Benthic sampling can be done concurrently with fish sampling or during a separate survey leg.

### 1.0 OBJECTIVES AND JUSTIFICATION

- To determine the effects of dredging activities on benthic communities and the transfer of energy from benthic communities to fishes. While overall abundances of benthic organisms have been shown to return to pre-dredging levels in some cases within a year or two after dredging, species composition may be different and the ability of fishes to utilize such altered assemblages for prey is uncertain.

### 2.0 SAMPLING DESIGN

#### 2.1 Stratification

Several factors are known to affect the distribution of benthic species and these should be considered in determining the pre-dredging strata. Sediment grain size and organic content are among the most important factors controlling the distribution of benthic organisms (Brown et al., 2000; Grove et al., 1999; Mancinelli et al., 1998; McLachlan, 1996; Pearson et al., 1987; Rosenberg, 1995). These factors, which vary with depth, also can be affected by bottom topography and water motion (Tanaka and Dang, 1996). The selection of strata for benthic sampling should be based on site-specific evaluations of these factors, as well as the morphology of the sand deposit to be dredged. Sand ridges, which form the dominant sand deposits along the East Coast, should be divided into strata of offshore ridge slope, ridge crest, nearshore ridge slope, and swale bottom, at a minimum. If the ridge is large enough or nearby seabed features are near enough and large enough to affect lengthwise heterogeneity in the sediment grain size and organic content, then additional strata should be designated. If sufficient data to designate strata are not available prior to the pre-dredging sampling, then additional sampling will be necessary to obtain these data. Although fish are more mobile than benthic organisms and may move between strata, they should be sampled within the same strata defined for the benthos. Maintaining consistent strata for benthic communities and fish assemblages will improve the ability to correlate benthic organisms with fish.

To provide a balanced statistical design, defined strata should be present in both the dredged area and the control areas. The control area should be near the dredged area to ensure similarity of factors such as depth and wave regime, but removed far enough to minimize dredging effects. The ideal proximity between dredged and control areas will depend on site-specific conditions, such as depth and the amount of area being dredged. Delineation of strata and subsequent sampling should ensure the same sample density in both dredged and control areas. To satisfy this requirement, the areas of sampling strata in dredged and reference areas should be approximately equal.

It is recognized that natural topographic and bathymetric variation may make it difficult to define identical strata at dredged and reference sites. The ability to detect changes caused by dredging may be reduced if there are large pre-dredging differences between dredged and reference sites. Delineation of strata is very important, so it must be done with care. The surest way to minimize the effects of natural variation between dredged and control sites is to employ the Beyond BACI design (Roberts, et al 1998; Underwood 1992), that uses multiple control sites to reduce the likelihood that differences in temporal patterns (e.g., changes that occur after dredging at the dredging site but not at the control site) are due to natural differences between sites. Unfortunately, a requirement for multiple reference sites would further complicate the potential difficulties of locating very similar dredging and control sites and also would substantially increase the cost of the monitoring program. It is suggested that the best solution to natural variation between dredging and control sites will include efforts to maximize similarity between them and then consider the remaining uncontrolled variation during data interpretation.

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After strata have been delineated, sampling locations should be randomly distributed within each stratum. Stratum boundaries should be established and sampling locations determined before beginning sampling. In the field, use of differential GPS will ensure that samples are collected in the correct locations.

### **2.2 Sampler Selection**

#### **2.2.1 Benthic Communities**

The selection of a sampler for benthic communities requires achieving a balance between consistent penetration and sample volume and ease of use. Important considerations are sediment texture, water depth, and sea state. Coarse or hard-packed sediments in deeper water may require a sampler that triggers on bottom contact to ensure deep enough penetration and prevent pre-tripping of the sampler during descent. Larger box corers, such as the USNEL corer (Somerfield and Clark, 1997), obtain consistent samples under most conditions, although they require heavy winches and large vessels for safe operation. Smaller box corers, such as the clamshell box corer (Diener et al., 1997), may be operated safely from smaller vessels. The Van Veen grab also satisfies the requirements of sample consistency and ease of use, and its many variations have been widely used (Dalto and Albuquerque, 2000; Kuehne and Rachor, 1996; Long and Lewis, 1987; McCabe et al., 1998; Muniz and Pires, 1999; Service, 1993; Southern California Coastal Water Research Project, 1977; Yi et al., 1988). While uniformity of samplers among all monitoring programs conducted under the auspices of MMS will enhance the comparability of results among regions, site-specific conditions may require the use of different samplers.

Regardless of the benthic sampler selected, a uniform sampler area is necessary. Species richness and other community parameters have been shown to be area-dependent in a variety of environments (Boudouresque and Belsher, 1979; Eckmann, 1995; Pastor et al., 1996; Underwood and Skilleter, 1996; Watters, 1992; Weinberg, 1978). As the sampler area increases, the number of species collected increases. A sampler area of 0.1 m<sup>2</sup> is commonly used (Grove et al., 1999; Muniz et al., 1999; Rosenberg et al., 2000; Service, 1993) and should be employed in sand dredging monitoring.

The quality of benthic grab samples should be ensured by requiring each sample to satisfy a set of criteria concerning the depth of penetration and disturbance of the sediment within the grab. In this way, all samples will contain comparable volumes of sediment within the area of the grab jaws. Samples will be rejected for the following conditions:

- A rock or shell fragment is wedged between the jaws of the grab allowing the sample to wash out.
- The surface of the sample is significantly disturbed.
- The sample is uneven from side to side, indicating that the grab was tilted when it penetrated the sediment.
- The surface of the sample is in contact with the top doors of the grab, indicating over-penetration of the grab and possible loss of material around the doors.

Weight can be added to the grab to improve penetration in harder-packed sediments and a shoe can be added to the bottom of the sampler's frame to minimize over-penetration in softer sediments.

#### **2.2.2 Fish Assemblages**

A sampler for fishes and demersal invertebrates should be chosen from among types of trawls. Consistency of trawl type is even more important than consistency of benthic grabs because configuration differences can have large effects on the fishing characteristics and catching efficiency of the gear

(Frecher, 2000; Halliday et al., 1999; Stokesbury et al., 1999). There are two main types of trawls, beam trawls and otter trawls. Within each type of trawl, there are numerous possible configurations involving differences in opening width, net mesh size, and net mesh configuration (i.e., diamond or square). Beam trawls have been commonly used to conduct fish population studies, as the beam insures that the width of the net remains constant, thus enabling calculations of population indices based on distance trawled. However, beam trawls are typically small in comparison with otter trawls, as the beam and thus the net opening are typically 3/4 of the width of the vessels transom. Otter trawls are more commonly utilized in fisheries investigations due to this limitation of beam trawls. The National Marine Fisheries Service (NMFS) uses otter trawls in its long-term fisheries survey of the eastern seaboard on North America, from Cape Hatteras, North Carolina, to Nova Scotia, Canada. This survey provides an index of abundance for numerous fish species, as well as other parameters such as scales, otoliths, and stomach content samples. Different types of otter trawls are used in this survey based on season and water depth. For spring and autumn inshore trawling, a 3/4 size #36 Yankee otter trawl is used. This net has a Horizontal Sweep (wingspread) of 8.6m and a Vertical Opening (headrope) of 1.4 m, and utilizes all steel doors. The cod end is lined with 1.3 cm stretch mesh to enable retention of juvenile and small fishes as well as large fish. The exact specifications of this net are on file at the NMFS Laboratory in Woods Hole, MA.

In addition to consistency of sampling gear, consistency of trawling speed is also important. If trawling speed is too slow, fish in the trawl's path may be able to escape. If trawl speed is too great, the gear may not stay on the bottom during the entire trawl. The optimum trawling speed is 3.5 knots, particularly if the 3/4 #36 Yankee trawl is used, as NMFS has determined this to be the optimum trawl speed for this net. The bottom of the doors and the footrope of the net should be observed after every trawl to check that they are being polished by contact with the bottom. Lack of polish indicates that the net was not riding on the bottom, thus allowing increased escapement of fish. There is no net that is 100% efficient (i.e., there is no net that captures all of the fish in a towed area). Many fish are able to swim faster than the net is being towed, are able to avoid the net by swimming above it, are able to burrow into the sea floor, or are too small and are able to escape through the meshes of the net. For these reasons, it is crucial that the same type of net and vessels of similar length and horsepower are used throughout the monitoring effort, and, ideally, the same net and vessel would be used for the study's duration. Use of sophisticated sonar and/or video equipment could be utilized to continually assess the net's sampling ability, to document fish escapement and the species escaping, the exact dimensions of the net's opening, and the length of each trawl.

### **2.3 Sample Replication**

#### **2.3.1 Benthic Communities**

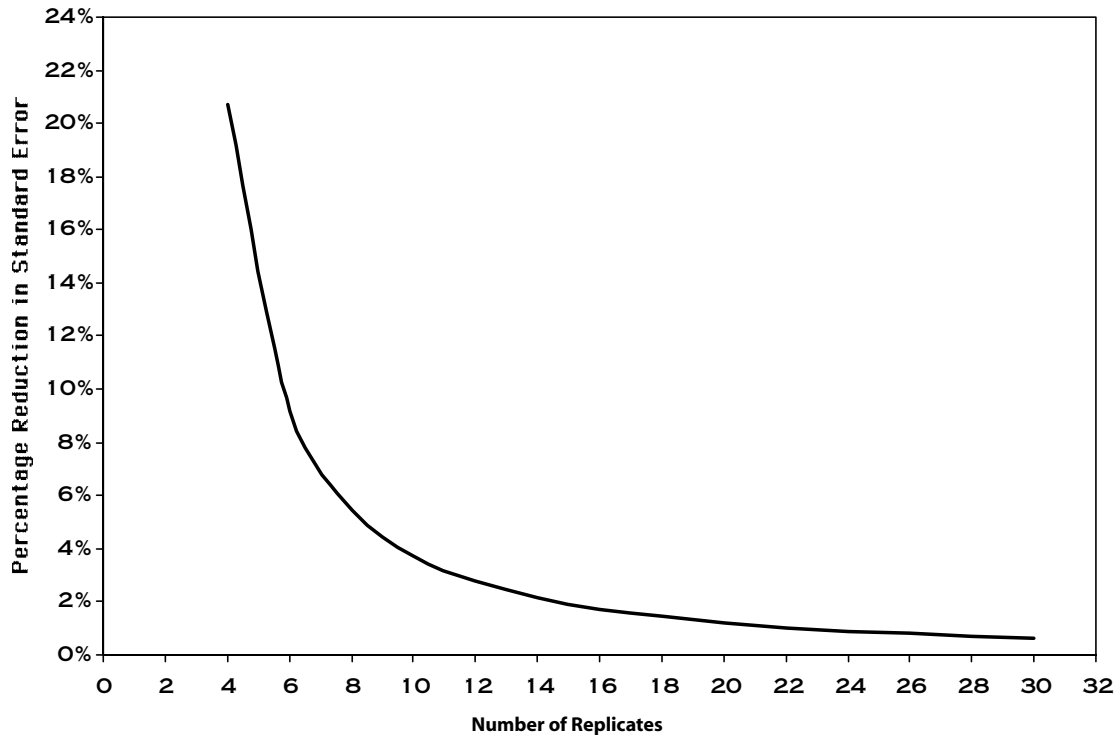
The number of replicates to be collected from within each stratum should be determined from analysis of the benthic community made as part of the baseline or pre-impact survey. Several methods are available for determining the optimum number of sample replicates. One common method involves determining the statistical power provided by a given number of replicates (Sokal and Rohlf, 1995). As the number of replicates increases, the statistical power increases. The number of replicates may be determined by arbitrarily setting the amount of difference to be detected between sets of samples and solving the equation for the number of replicates. This approach can be used on data for species abundances or community parameters. The relationship between statistical power and number of replicates varies according to the variability in the data, which is species specific. This means that using this approach for determining the number of replicates requires choices to be made regarding which species should provide the benchmark. Instead, a method that integrates the entire benthic community by relying on the relationship between standard error and number of replicates is suggested. The standard error is an estimate of how much a mean estimated from a given number of replicates varies from the true population mean. If a larger number of samples is used to estimate the mean, then the estimate will more

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accurately reflect the true mean and the standard error will be smaller. Using this method, the number of samples can be specified to provide the most efficient reduction in standard error per number of samples. As replicates are added, a diminishing percentage reduction in the standard error is encountered in each successive replicate. A curve of the relationship between percentage reductions in standard error and number of replicates is shown in Figure 4.1. Proportionally smaller decreases are achieved with each additional replicate above 10, and it is suggested that this should be the minimum number analyzed from each stratum. Because this program will focus on measurements of benthic secondary production and trophic transfer to fishes, the metric that should be used for establishing the necessary number of replicates is total biomass.

A separate sample should be collected from each stratum specifically for the analysis of stable isotopes. The handling and preservation of samples for stable isotope analysis differs from those required for analysis of benthic communities (Bosley and Wainright, 1999). One sample per stratum will provide information on the possible cause of any changes in stable isotope concentrations of fishes.



**Figure 4.1.** Curve that indicates more than approximately 10 replicates would provide smaller reductions in standard error for each additional replicate.

### 2.3.2 Fish Assemblages

The purpose of this monitoring program element is to assess the trophic transfer of energy to the resident fish population, rather than to assess changes in the resident fish community. The primary criterion for defining the adequacy of sampling for fishes is the collection of enough stomachs with prey from the numerically dominant or commercially or recreationally important fish species to adequately

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describe their diets, in keeping with the focus on the effects of dredging on secondary production and trophic transfer to fishes.

Determining the adequacy of replication will require some sample processing in the field. It is anticipated that a minimum of 30 stomachs with prey will need to be obtained to characterize the prey that each target fish species may be consuming, and more might be needed (Brown et al., 1992; Keats, 1990; McKenna, 1991; Rachlin and Warkentine, 1988) if a rarefaction curve of cumulative prey items indicates that the asymptote is not approached. Moreover, prey selection varies with the age of the fish (Toepfer and Fleeger, 1995; Wyche et al., 1986), and sufficient stomachs to include the range of prey items are needed from each size class of a species to thoroughly describe how changes in benthic communities might affect trophic transfer to that species. Feeding activity of fishes may also vary between the day and night (Auster et al., 1995; Haight et al., 1993). Consequently, samples should be collected in both the day and night. A minimum of three day and three night trawls should be made in each stratum. Each trawl should be conducted along the long axis of the stratum, with beginning and ending points established to ensure that the trawl does not sample outside the stratum. Different locations should be used for successive trawls to minimize resampling the same area of seafloor. Trawls should be made following the collection of benthic samples to prevent trawl disturbances from biasing the benthic data. As trawls are being collected in the field, fishes should be examined to determine whether they have prey in their stomachs to ensure that sufficient samples are obtained for the gut-content analysis.

### **2.4 Sample Processing**

#### **2.4.1 Benthic Communities**

Initial processing of benthic samples should begin immediately when the samples are brought onboard the vessel. Initially, subsamples of sediment are removed for laboratory analysis of grain size and total organic carbon. Processing of benthic samples should follow traditional procedures (Swartz, 1978). These involve sieving through 0.5-mm mesh screens, using filtered seawater to separate the organisms from the sediment. Organisms should be hand picked from the sieves using forceps and placed into jars that have been labeled according to project, site, coordinates, and date. Organisms should be narcotized by placing them into isotonic  $MgCl_2$  or propylene phenoxylol for several hours before they are preserved with buffered 10% formalin in seawater. After several days in formalin, the samples should be transferred to 75% ethanol. Rose bengal may be added at this time to facilitate sorting organisms from debris under dissecting microscopes.

Consistent taxonomy is necessary to ensure that trends in benthic organisms are not confounded by differences in identifications. While identifying organisms to the lowest practical taxon is often performed in benthic studies, it requires much more effort without providing a concomitant increase in information compared to identifying organisms to higher taxonomic levels (e.g., family) (Clarke et al., 1998; Clarke et al., 1999; Warwick et al., 1998). Identifications of fish gut contents should be made to a similar taxonomic level.

Biomass measurements are necessary to estimate secondary production of benthic organisms. Blotted wet weight should be measured for each taxon (e.g., family). Because dry weight data are needed for calculation of secondary production, appropriate conversion factors should be applied to each taxon (Ricciardi and Bourget, 1998). Calculations of secondary productivity also require dry weight measurement for the largest individual of each taxon (see Section 3.1). For larger organisms, this can be estimated by converting wet weight to dry weight. For smaller organisms, this can be estimated by dividing the total wet weight by the number of individuals and applying an appropriate factor to account for differences in sizes of individuals. To facilitate identification of important prey species found in fish gut samples, identification of benthic taxa should be conducted concurrent with the fish gut analysis. In



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addition, benthic species should be separated into important prey groupings as determined during the fish gut analysis after the taxonomic identification work.

The sample collected from each stratum for stable isotope analysis should be gently elutriated to remove the organisms from the sediment. An elutriation device that provides adjustable rates of flow-through water and deposits organisms into submerged mesh bags is preferred. When sample elutriation is completed, the removed organisms should be placed into a container of ambient seawater for approximately 24 hours to allow purging of their gut contents. Care should be taken to ensure adequate oxygenation and temperature control so that the organisms do not die. After their guts have purged, the organisms can be separated into taxonomic groups and frozen in sample bags or jars. Once the samples are ashore, they should be freeze-dried to preserve them for analysis of stable isotopes, with care being taken to prevent sample contamination by oil from the vacuum pump.

### **2.4.2 Fish Assemblages**

Processing of trawl samples begins when they are brought on deck. Fishes should be sorted into species, counted, measured for standard length, sex and sexual maturity determined and weighed. If very high numbers of a species are caught, random subsampling is acceptable for length and weight measurements. Following the initial separation of each trawl catch into species, and the selection of the numerically dominant and/or commercially/recreationally important, those species being analyzed for gut contents should be processed immediately to minimize continued degradation of the gut contents. A tally should be kept of the number of stomachs that appear to have prey in them. The three fish species that have been selected for analysis of gut contents and at least the next two most abundant or commercially or recreationally important species should be preserved in the field in buffered 10% formalin. Juvenile fishes may be especially valuable for analysis because their small size makes it more likely that differences in feeding strategies will be reflected in their stable isotope ratios. For large species, injection of formalin into the stomach (or removal and separate fixation of the stomach) may be required to ensure adequate preservation of gut contents. Preservation of more than the three most abundant species protects against loss of data if the most abundant species are not consistently collected in subsequent surveys.

Muscle tissues for stable isotope analysis should be dissected from the fish using pre-cleaned stainless steel scalpels and a pre-cleaned teflon cutting board. Dissected muscle tissue should be wrapped in teflon sheets or aluminum foil, placed into sealable sample bags, and then frozen while on-board the survey vessel. As soon as possible, the tissue samples should be freeze-dried for storage and shipment to the analytical laboratory, again avoiding contamination with oil from the vacuum pump. Large samples are not necessary, but the analytical laboratory selected for analysis should be consulted as to the sample size required, and any other specific sampling requirements. Lipid removal may be considered to minimize the effects of reproduction on stable isotope concentrations.

## **3.0 DATA ANALYSIS**

### **3.1 Benthic Community and Secondary Production Analysis**

The abundance of each benthic taxon should be determined by counting the number of individuals. The density and biomass of each taxon then can be extrapolated to  $m^2$  and to the entire stratum by multiplying these numbers by the ratio between the sampler area and the total area of the stratum. Sediment grain size and total organic carbon samples should be analyzed to provide data for later use as independent variables in analysis of recovery processes and rates in benthic communities.

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Several investigators have proposed ways of estimating secondary production using static measurements (Brey, 1990; Tumbiolo et al., 1994). Biomass, temperature, and depth provide inputs for a recent method of estimating secondary production (Tumbiolo and Downing, 1994), according to the following equation:

$$\text{Log } P = 0.24 + 0.96\text{Log } B - 0.21\text{Log } W_m + 0.03T_s - 0.16\text{Log } (Z+1)$$

where  $P$  is annual productivity in grams dry weight/m<sup>2</sup>,  $B$  is the average biomass in grams dry weight/m<sup>2</sup>,  $W_m$  is the maximum individual body mass in milligrams dry weight,  $T_s$  is the annual mean water temperature at the bottom in C°, and  $Z$  is bottom depth in meters. The secondary production for each stratum should be calculated by multiplying the production for each m<sup>2</sup> times the total area of the stratum.

### 3.2 Fish Assemblage Biomass and Gut Content Analysis

The abundance of each fish species should be determined by counting the number of individuals. The number and weight of each species then can be extrapolated to densities and biomass per m<sup>2</sup> and to the entire stratum by multiplying these numbers by the ratio between the sampled area and the total area of the stratum.

In the laboratory, gut contents should be washed in freshwater and placed in jars with 70% isopropyl alcohol. Stomachs should then be emptied, the contents sieved with a 0.5-mm sieve, sorted, identified to the lowest practical taxonomic level, and counted. Percent volume, percent number, and percent frequency of occurrence of each type of prey item should be calculated for each fish species using means of all the stomachs from that species. These parameters can then be used to determine the Index of Relative Importance (IRI) (Pinkas et al., 1971). The IRI data should be normalized to percentage of the total IRI for a species, to enable comparisons based upon stomachs of varying fullness (Barry et al., 1996; Carrasson et al., 1992; Cortes, 1997; Cortes et al., 1996).

Consistent taxonomy of gut contents is necessary to ensure that trends in prey utilization are not confounded by differences in identifications. Prey items should be identified to the lowest practical taxon. Consistency of identifications will be affected not only by taxonomic expertise but also by the degree of digestion and the adequacy of preservation of gut contents.

### 3.3 Stable Isotope Analysis

Stable isotope ratios of organisms provide valuable clues to the carbon sources of their diets. Carbon stable isotope ratios change only slightly with transfer between trophic levels, so changes in primary producers that fix carbon could be detected. Nitrogen isotopes show larger changes with each trophic transfer, and they have been used to establish trophic level.

Disturbed communities often host transitory or opportunistic species that may alter the dynamics of carbon and nitrogen flow to bottom-feeding fish or facilitate the transfer of an altered organic matter source term (Spies et. al., 1989). While detecting a population-level effect of a disturbed benthic invertebrate community on bottom-foraging fishes would likely require a large affected area and significant disturbance using standard methods of population assessment, stable isotope shifts might detect altered organic matter and energy transfer on less than a population level. Therefore, it may be possible to detect changes in the invertebrate prey of fish, post-dredging.

Incorporating a carbon and nitrogen stable-isotope monitoring component into the long-term OCS sand mining monitoring program could provide the program with an additional source of data and perspective with which to understand what long-term ecological changes (if any) may be occurring. The data would be complimentary to the trophic energy transfer data. However, it should be understood that

before incorporating any such measures into a long-term monitoring program, it would be appropriate to either carry out a pilot project on an existing sand mining area to see if such changes do occur or to carefully monitor the data from a long-term program and evaluate the results and contribution to the overall program on a regular basis.

Measurements should be made of carbon and nitrogen isotopes in benthic species that constitute important prey items for fishes. Because stable isotopes from food items are incorporated into the bodies of consumers with only small changes, the isotopic signatures of consumers reflect the food they have consumed. This allows stable isotope data to be used to describe trophic pathways (Cabana and Rasmussen, 1996; Fry, 1999; Hansson et al., 1997; Keough et al., 1996; Peterson, 1999; Pinnegar and Polunin, 2000; Vander Zanden et al., 1999). These measurements should be made in pooled samples of specimens for important species from within each stratum for both dredged and control areas.

As with benthic organisms, measurements should be made of carbon and nitrogen isotopes in important fish species. These measurements should be made in pooled samples of dorsal muscle for the selected species from within each stratum for both dredged and control areas. Because fishes can be very opportunistic in their prey selection (Derrick and Kennedy, 1997; Manderson et al., 1999), stable isotope measurements are an important adjunct to analysis of gut contents because they integrate more of the feeding history of the fish than does examination of the current contents of the gut.

### 3.4 Data Synthesis and Analysis

Data synthesis and statistical analysis should focus on describing the rate and process of recovery of dredged sites. Data synthesis should involve interpretation of data for benthic communities, fish assemblages, fish gut contents, and stable isotopes. Three hypothetical outcomes illustrate how the data from each component could be used.

#### *Outcome 1*

Species composition and organism densities within all strata of the dredged and control benthic assemblages become very similar five years following dredging. Nevertheless, biomass and estimated secondary production for key fish benthic prey species remain low and analysis of gut contents and stable isotopes suggest that fishes are feeding at a lower trophic level in the dredged area, compared to the control area. While the benthic communities appear to be recovered, dredging effects on fishes remain.

#### *Outcome 2*

Five years following dredging, the species composition in all strata of dredged and control areas remains very different, and gives no indication of converging. Nevertheless, overall organism densities and estimated secondary production of benthic communities have become similar at the dredged and control sites. Analysis of fish gut contents and stable isotopes suggest that utilization of benthic organisms for prey by fishes is the same at dredged and control sites. While benthic communities have not recovered, dredging effects on availability of benthic prey to fish assemblages are not apparent.

#### *Outcome 3*

Five years following dredging, the offshore ridge slope strata have become very similar between dredged and control areas in benthic community composition and secondary production. Nevertheless, benthic communities in ridge crest and shoreward ridge slope strata remain very different between dredged and control sites. It appears that the entire dredged area (i.e., all strata) has become physically and biologically homogeneous, similar to the pre-dredging offshore ridge slope. Perhaps because of fish mobility, there are no differences in either fish gut contents or stable isotopes between dredged and control sites, in any stratum. While the benthic communities exhibit only partial recovery, dredging effects on fish assemblages are not detectable.

The endpoint for recovery should be established before post-dredging sampling. We suggest a return to the within-control 95% confidence interval for mean values at the dredged site. Metrics for determining recovery of the benthos might be species abundances, total biomass, and estimated secondary production. Consistent with the major objective of this protocol to determine the effects of sand dredging on trophic transfer from the benthos to fishes, we suggest biomass and secondary production should be emphasized. High within-strata variation at the control site will make it relatively easier to establish recovery. Because natural, non-dredging factors may cause control sites to change over time, determination of recovery should be based on comparisons between contemporaneous conditions at dredged and control areas. Rates of recovery can be estimated by computing the rates at which means from dredged and control areas converge.

Step-wise multiple regressions also can be useful in these biological monitoring activities. Step-wise multiple regressions determine the significance of effects of several independent variables on dependent variables and allow estimation of the amount of variation in the dependent variable that is accounted for by the independent variables. In the case of sand mining, depth, water temperature, sediment grain size, total organic carbon, density of fishes, initial within-site similarities, and densities of early colonizers are examples of possible independent variables. Examples of dependent variables are rates of recovery or times to recovery.

#### 4.0 DATA SPECIFICATIONS

- Include benthic species identified to a consistent taxonomic level (e.g., family)
- Include benthic species abundances as both raw data and normalized to density per m<sup>2</sup>
- For benthic species include numbers of individuals and total biomass per taxon and total individuals, biomass, and number of taxa per sample
- Include species identification, standard length, sexual maturity, and weight for each fish from each trawl
- Include trawl area (i.e., width x length) for each trawl sample
- Include volume, number of individuals for each taxon of fish prey, and percent fullness for each fish stomach
- Include fish stomach content data reported for each trawl
- Include benthic and fish stable isotope data for each sample or trawl
- Include benthic and fish data reported separately for each stratum
- Include geographic coordinates for each sample
- Include time and date that sample was collected
- Submit the information in digital (commercial spreadsheet format) and hard copy

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# Protocols for Monitoring Marine Mammals and Wildlife

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## 1.0 OBJECTIVE AND JUSTIFICATION

- To obtain site-specific marine wildlife observation and behavior data during OCS dredging operations. This information will assist state and federal regulatory agencies in assessing the appropriateness of imposed marine mammal and wildlife protection mitigation requirements.
- To obtain and assess marine wildlife stranding data for potential similarities between stranded animals and animals observed during OCS dredging operations. This information will assist state and federal regulatory agencies in assessing whether there exist any obvious relationships between post-dredging marine wildlife strandings and OCS dredging operations.
- To provide a means for the implementation of environmental mitigation requirements imposed to prevent or reduce potential hazardous interactions with marine mammals and protected wildlife during dredging operations. (This is the only "operational control" monitoring program element included in the OCS sand dredging protocols.)

## 2.0 SHIPBOARD PROTOCOL

During shipboard dredging activities, marine wildlife observers should be placed aboard the dredge vessel or an ancillary craft to:

- Observe for the presence of marine wildlife in the dredge area,
- Document the behavior of marine wildlife to the dredging activities, and
- Document any collisions or other negative interactions between the dredge vessel and support craft with marine wildlife.

Prior to the commencement of any shipboard observations, a detailed observation plan should be prepared and approved by the local office of the National Marine Fisheries Service (NMFS) and the Minerals Management Service (MMS). This plan should identify the personnel who will be involved in the observation effort, the specific procedures and equipment that will be used to conduct the observations, the geographic location of the observations, the procedures for avoiding negative interactions between the dredging operation and marine wildlife, and how observations and stranding data will be analyzed and reported. The following are basic guidelines and protocols that should be followed in the drafting of a more project-specific observation plan.

At least two trained marine wildlife observers need to be present aboard the dredge vessel watching for marine mammals, sea turtles, and other protected marine wildlife. Depending on the time of year, geographic location and total duration of the dredging operations (both hours per day and total days), four or more observers may be required. The observers should stand alternate watches to ensure that at least one or more observers is continuously watching for the presence and movement of marine wildlife during the dredging operations. It is critical that the observers position themselves aboard the dredging vessel at appropriate locations so they can observe the surrounding sea in all directions. Use of an ancillary vessel for conducting marine observations maybe preferable. To facilitate observations, each monitor should be equipped with conventional marine binoculars, range-finding binoculars, and night-vision binoculars. Use of mounted binoculars is encouraged, but their temporary mounting and safe use aboard the observation vessel should be discussed with the dredging contractor prior to commencement of field observations.

Observations should be recorded on data sheets that include:

- The date, vessel name and observer's name,



## **Protocols for Monitoring Marine Mammals and Wildlife**

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- The time and position of each sighting. (Positions can be obtained from the vessel's Global Position System (GPS) or by a handheld GPS system, if the vessel's system is not available to the monitor.),
- The genus and species of each protected animal observed, along with the number of animals present and any associated wildlife,
- The behavior (e.g., feeding, diving, slow travel) and unique markings of any animal(s) in each sighting (photographs of animals should also be made),
- Photograph number for a particular sighting, and
- Any suspected or observed adverse effects from the dredging operation, along with the steps the observer and the vessel took to avoid such impacts.

Photographic and video equipment should be capable of clearly documenting animals at a distance of 200-300 meters. Although 35-mm SLR cameras equipped with telephoto lenses are the most commonly employed photodocumentation tool, use of digital video and still image equipment should be considered if resolution comparable to high quality 35-mm images can be obtained.

### **3.0 COLLISIONS WITH MARINE MAMMALS AND WILDLIFE**

As indicated in the goals and objectives for the Marine Mammal and Wildlife Protocols, it is anticipated that permit or environmental mitigation requirements will be imposed on OCS dredging operations with the intent to prevent the collision or negative interaction with protected or sensitive marine mammals and wildlife (principally sea turtles). To this purpose, the project-specific marine mammal and wildlife observation plan should contain procedures for dealing with potential collisions or equipment interactions with marine wildlife. This plan should include project permit or environmental mitigation requirements for cessation of operations, agency notifications and emergency response for recovery and treatment of injured animals.

At a minimum, the plan should consider the temporary cessation of dredging activities if an animal approaches the dredging vessel closer than 300-meters. If the vessel is underway and heading in the direction of the animal, a greater distance may be appropriate. If a collision or near-miss occurs between the dredging operations and a protected species, the on-site observer should record all pertinent information on the incident, and the animal affected and report immediately to the appropriate personnel at the regional NMFS and MMS offices. Photographs or video of the incident and animal should be collected, if possible. On-board marine wildlife observers should be used as third-party monitors to ensure the effective implementation of any imposed environmental mitigation requirements imposed to prevent collision or negative interactions with sensitive or protected marine wildlife species.

### **4.0 POST-DREDGING STRANDING CENSUS**

Concurrent with the sand dredging operations and for a period of 60 days after completion of sand dredging, marine wildlife observers should be in communication with federal, state and local agencies responsible for documenting marine wildlife strandings. Every reported stranding that occurs along the coastline adjacent to the dredging operations should be checked for possible correlation with animals observed during the dredging operation (species, size, unique body markings, etc.) and for possible new markings on the body that would suggest a collision with the dredging equipment.

### **5.0 DATA MANAGEMENT, ANALYSIS AND REPORTING**

Unless there has been a documented collision or impact between the dredging operation and marine wildlife, it is unlikely that the monitoring program will be able to clearly attribute a particular

## **Protocols for Monitoring Marine Mammals and Wildlife**

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stranding to the dredging operation. Assessing stranding data for specific individuals that have been observed by the on-board observers in the stranding data may provide important anecdotal information. After multiple years of collecting field observation data during OCS dredging activities, and assessing stranding data for dredging and non-dredging years, the program should look for any trends that would indicate whether OCS sand dredging has a negative effect on marine wildlife. Repeated increased wildlife strandings following OCS dredging events for similar periods and seasons in non-dredging years could be indicative of some unobservable effect resulting from the dredging operation.

Following the completion of a dredging operation and the elapse of the 60-day stranding period, a report should be prepared detailing the procedures employed for observing marine mammals and wildlife, details on all sighting and stranding data and any discussion of the data. All observation and stranding data should be provided in digital format for inclusion in the monitoring program database.

### 1.0 OBJECTIVES AND JUSTIFICATION

- To determine the change in sediment texture (as defined by a grain or particle size distribution) resulting from dredging within and adjacent to the borrow deposit. Changes may result from removal of sediment (within the area dredged), sedimentation within the zone of the sedimentation footprint that results from the fallout of the overspill and drag head plumes generated by the hopper dredge, and indirect impacts to erosion and deposition processes outside of the immediate dredge area.
- The change in grain size is primarily important with respect to the possible impacts to benthic communities.
- For borrow sites with distinct and active morphologic features (such as ridges and shoals) the baseline and future monitoring data derived from this protocol may also be useful for assessing and interpreting long-term changes to the form of the feature.
- To determine the change in total organic carbon (TOC) content of sediment resulting from dredging within and adjacent to the borrow deposit. Changes will result from sediment removal (within the area dredged) and from sedimentation within the zone of the sedimentation footprint that results from fallout of the overspill and drag head plumes generated by the hopper dredge.
- The change in TOC is primarily important with respect to the possible impacts to benthic communities.

Many of the requirements related to sampling are covered under the protocol for Benthos and Fishes as sediment samples will be collected as part of the benthic sampling program. Sediment samples will only be collected at locations where benthic samples are retrieved as changes to grain size are primarily “important” as they may relate to a biological impact. It is also noted that the Bathymetry and Substrate Protocol specifies surveys that will provide information from acoustic techniques related to the nature of the substrate in the vicinity of the planned borrow deposit. The information from this Sediment Sampling and Analysis Protocol provides ground-truth data for the more spatially comprehensive information collected under the Bathymetry and Substrate Protocol.

### 2.0 SAMPLING LAYOUT

The sampling layout requirements of the Benthos and Fishes Protocol are applicable. Tests of grain size distribution and TOC should be completed for all benthic samples, including samples collected for benthic analysis and archiving.

### 3.0 TEMPORAL SAMPLING REQUIREMENTS

The temporal sampling requirements of the benthic communities are applicable.

### 4.0 METHODS AND SPECIFICATIONS

The sampling requirements of the benthic communities are applicable.

Sand-sized samples are usually analyzed with the use of stack of sieves ordered from largest wire cloth mesh on top to finest on the bottom with a pan at the base. The stack of sieves is shaken for approximately 15 minutes. The range of sieve openings must span the range of sediment sizes in the sample. A minimum of 6 full height or 13 half height sieves are required. A minimum sample size of 40 g is required for each test. The analysis of silt and clay sized particles must be completed through a hydrometer analysis (see Das, 1998).

## **Protocols For Sediment Sampling and Analysis**

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All of the requirements of ASTM Standard D422-63 (Reapproved in 1990) on particle size analysis are applicable to this Protocol. The application of D422 requires sample preparation as described in ASTM Standard D421-85 (Reapproved 1993). The applicable ASTM reference is the 1994 version of Volume 4.08. All of the relevant requirements of this reference are applicable.

The TOC method should be based on high-temperature combustion. Inorganic carbon (e.g., carbonates) can be a substantial proportion of the total carbon in some samples, so treatment with acid is necessary to remove the inorganic carbon prior to TOC analysis (Plumb, 1981).

### **5.0 DATA DELIVERABLES**

The data grain size distribution for each sediment sample retrieved will be delivered as follows:

- Plotting in semilog format
- Include both grain size in both Phi and mm units
- Include both Modified Wentworth Classification and Unified Soils Classification descriptions
- Include geographic coordinates for each sample
- Include time and date that sample was collected
- Provide estimates of  $D_{10}$  (grain size where 10% by weight of the sample is finer) and  $D_{50}$  (also known as the median grain diameter)
- Submit the information in digital (commercial spreadsheet format with both semilog plot and raw data) and hard copy

The data on TOC content for each sediment sample retrieved will be delivered as follows:

- Include both percent organic carbon and percent inorganic carbon
- Include geographic coordinates for each sample
- Include time and date that sample was collected
- Submit the information in digital (commercial spreadsheet format) and hard copy

Locations for all grain size and TOC samples shall be reported to both NAD27 and NAD83 horizontal datums (depths) and in UTM projection.

### **6.0 REFERENCES FOR SEDIMENT SAMPLING AND ANALYSIS PROTOCOL**

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- Das, Braja M. 1998. Principles of Geotechnical Engineering, Fourth Edition. Boston, MA: PWS Publishing Company. 712 pp.
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# Protocols for Wave Monitoring and Modeling

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## 1.0 OBJECTIVES AND JUSTIFICATION

- To develop a continuous record of the wave conditions that the borrow deposit (and areas inshore) is exposed to after the initial dredging operation. The data will provide the necessary information to evaluate any possible direct or indirect impacts of the dredging on the waves and associated physical and biological parameters.
- To assess the influence of changes to bathymetry (due to the direct impact of dredging) on waves in the immediate vicinity of the borrow site, inshore of the borrow site, and in the adjacent nearshore zone. This information is required to determine whether there are any direct or indirect physical or biological impacts resulting from changes to the waves based on the modified bathymetry immediately following the dredging operation.
- To assess the influence of possible subsequent changes to bathymetry (as an indirect impact of dredging) on waves in the immediate vicinity of the borrow site, inshore of the borrow site, and in the adjacent nearshore zone. In turn, any changes to the waves will be assessed with respect to resulting physical or biological impacts.

## 2.0 DEEPWATER WAVE CLIMATE

### 2.1 Temporal Requirements

It is essential that all borrow sites have a near continuous record of wave conditions at the site from the start of dredging operations (i.e. from the time the site is first dredged) to the cessation of the required long-term monitoring for the site (see Section 3.2 of this Protocol for a definition of the long-term requirements). In addition to this, there must also be wave data sufficient to define the long-term wave climate prior to any dredging.

The long-term wave climate considered during the permitting phase will consist of one year of recorded directional wave data plus one of the following:

- An additional four years of directional wave data (for a total of five years)
- A five-year record of non-directional wave data, which is used to validate the WIS wave hindcast (WIS data prior to 1976 should not be considered) for the site. The time period of the non-directional data and the hindcast must correspond, and validation should be carried out based on summary statistics (e.g., wave height and period frequency by season) and time series. The error between WIS and the measured data must be such that it would not influence the assessment of potential impact to nearshore waves and shoreline dynamics (for the latter – see the Shoreline Monitoring and Modeling Protocol). If a hindcast other than the WIS hindcast is to be used, approval will be made on a case-by-case basis.

### 2.2 Spatial Requirements

The spatial requirements for the wave climate pertain to the proximity of the wave data to the site under consideration. Where data from an active directional wave buoy at an upwave location are not available sufficiently close to the site to allow for a reliable transformation of these wave data to the borrow site location (i.e., using a wave transformation model), an instrument or device for determining directional waves must be deployed. The decision on whether a new instrument must be deployed will be determined on a case-by-case basis. It is recommended that during and after dredging, a directional buoy be located in very close proximity to the site (as close as possible to the site without risk to the instrumentation due to marine operations).

## Protocols for Wave Monitoring and Modeling

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### 2.3 Instrumentation Guidelines

Directional wave measurement that is either required to be installed at the site, or may be considered acceptable if it is already in operation, must meet the following criteria:

- Measurements made at an interval of less than 3 hours (preferably one or two hours) with a minimum sampling duration of 20 minutes;
- Wave periods ranging from 4 to 20 seconds should be adequately resolved;
- Directional spectra must be available in addition to the summary statistics that are typically reported ( $H_{m0}$ , peak period, mean wave direction, etc.).

It is recommended that a directional wave buoy be used for wave measurement. ADCP may be acceptable if it can be shown that the wave measurements are of similar or better accuracy obtained from wave buoys. Conventional single point “PUV” gauges are not recommended due to their inability to produce a full directional spectra and poor directional resolution in the presence of strong background currents.

### 3.0 MODELING REQUIREMENTS

#### 3.1 Spatial Boundaries

##### *Offshore*

The offshore modeling is carried out to transform the measured wave climate to a location immediately offshore from the borrow site. Two factors may control the size of the offshore modeling region:

- The distance from the nearest active directional wave buoy to a location in the vicinity of the borrow site;
- The distance from a “deep water” location where the wave climate is defined to a location in the vicinity of the borrow site. In this case, “deep water” is defined as a depth greater than one half of the wavelength of a wave with the longest peak wave period present in the wave climate.

In instances where a directional wave buoy is located very close to the site, the offshore modeling region may encompass a small area of perhaps a few miles or less. For instances where the buoy is located some distance from the site, or where waves from a more distant buoy must be transformed over a significant distance of transitional water depths, the offshore region may be very large. Modeling of the offshore region may also have to consider “backtransforming” waves measured at a buoy in intermediate water depths, to deep water, and then to the borrow region. “Backtransforming” waves is only acceptable where the buoy is located in water depths greater than 50 m and/or such procedures are appropriate given the bathymetry offshore of the buoy (i.e., the bathymetry is not overly complex).

##### *Borrow Region*

The borrow region model domain addresses the area in the immediate vicinity of the borrow site and will encompass the full extent of a distinguishable sand body (e.g. a ridge or shoal) if one exists. The purpose of the borrow region modeling is to determine how changes to the bathymetry may influence the form of the sand body, if one exists, and to assess the change to the wave climate in the immediate vicinity of the borrow site, and particularly on the shoreward side of the feature.

## Protocols for Wave Monitoring and Modeling

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### *Nearshore Region*

The nearshore region, which may vary greatly in size, encompasses the area from the nearshore side of the borrow site to the shoreline. The purpose of modeling this region is to assess how changes to the wave climate on the shoreward side of the borrow region will influence the wave conditions in the shoreline region, and ultimately shoreline change.

Depending on the site conditions, the selected model and the type of assessment being completed, the offshore region, borrow region and nearshore region models may be related in the following manners:

- The borrow region model will derive its boundary from the offshore region model;
- The nearshore region model will derive its boundary from the borrow region model.

Alternatively, if the processes that must be modeled in different regions are similar, the regions may be modeled in the following manner:

- All three regions may be simulated with the same grid resolution and model type;
- The offshore region and the borrow region may be simulated with the same grid resolution and model type, and data from this model defines the nearshore model inputs;
- The borrow region and the nearshore region may be simulated with the same grid resolution and model type, and are driven by data from the offshore model.

Note that the requirement for the nearshore region's offshore boundary to be defined by the results of the borrow region will likely require that the domain size of the borrow region model extend far beyond the limits of the borrow deposit itself. This makes it more practical to combine the borrow region and the nearshore region into the same model.

When defining the model boundary of the borrow region or nearshore region based on results from a model further offshore, it is often desirable to define a spatially varying boundary condition according to the output from the model providing the boundary, rather than making the assumption that the wave conditions are uniform along the boundary. This is very important when there is a large variation that occurs along the boundary in either wave height or direction, and may influence the choice of model that may be used due to this boundary requirement.

The alongshore extent of the nearshore (and borrow) region(s) must also be compatible with the alongshore extent of the shoreline change model (refer to the Shoreline Protocol). The wave transformation model provides the required boundary condition input to the shoreline change model.

### **3.2 Temporal Modeling Requirements**

Numerical model assessments of possible borrow region wave transformation impacts should be performed in the following cases:

- Prior to initial dredging of the site in those cases where previous wave transformation modeling meeting the requirements of this Protocol has not been performed;
- In the event that the sand body (where one exists) has been determined to have changed significantly based on a review of long term monitoring bathymetric survey comparisons.

Numerical model assessments of possible nearshore wave transformation impacts should be performed in the following cases:

## Protocols for Wave Monitoring and Modeling

- Prior to initial dredging of the site in those cases where previous wave transformation modeling meeting the requirements of this Protocol has not been performed (either with respect to specifications of the model requirements or with respect to geographic coverage);
- In the event that the sand body (where one exists) has been determined to have changed significantly based on a review of long term monitoring bathymetric surveys;
- Prior to each new dredging operation, nearshore wave climate for the period dating back to the previous dredging operation shall be determined (so as to provide a continuous history of nearshore conditions).

Modeling requirements may be terminated once shoreline change monitoring is no longer required (see the Shoreline Protocol).

### 4.0 MODEL SPECIFICATIONS

#### 4.1 Suggested Models and Applicability

There is a wide range of models (not to mention versions of individual models) available for wave transformation, and only a subset of these models will be applicable to the specific conditions at the borrow site of interest. This section specifies the processes and methods that must be considered and followed, as well as examples of the capabilities of several models that are currently available. Table 4.1 specifies the processes that must be considered for the borrow region model, and for the offshore and nearshore model domains.

The primary additional factor that is recommended for consideration in the borrow region model is diffraction. However, in many locations it will not be necessary to consider diffraction effects. Tests were completed for the group of shoals offshore of the Maryland-Delaware border and it was determined that not considering diffraction resulted in changes of less than 10% to the wave heights compared along a line inshore of the shoals. The requirement to include shoaling and depth-induced breaking will depend on the local characteristics. It will be necessary to justify to MMS using physical process arguments that diffraction effects can be ignored, otherwise they must be considered.

**Table 4.1.** Processes to be considered for various model domains.

	<b>Offshore Region</b>	<b>Borrow Region</b>	<b>Nearshore Region</b>
<b>Shoaling</b>	unlikely	possibly	yes
<b>Refraction</b>	yes	yes	yes
<b>Depth-induced Breaking</b>	unlikely	possibly	yes
<b>Diffraction</b>	unlikely	possibly	possibly
<b>Bottom Friction</b>	unlikely	no	possibly
<b>Wind Generation</b>	yes*	no	yes
<b>Wave-wave Interactions</b>	possibly	no	no
<b>Reflection</b>	no	no	unlikely
<b>Current Interaction</b>	no	possibly	possibly
<b>Multi-Frequency</b>	yes		
<b>Multi-directional</b>	yes	yes	yes

\* - only if fetches in the model domain exceed 10 km.



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The main distinction of the offshore model is the need to consider wind generation and possibly wave-wave interaction, because the transformation distance from the nearest directional wave measurement station may be long. Shoaling and breaking need only be considered from the borrow deposit into the shoreline and then only if the borrow deposit is shallow and waves are required in or near the surfzone (the latter may not be the case if a package such as GENESIS is applied to address the shoreline impacts – see the Shoreline Protocol).

It is imperative that all regions that are modeled are done so with models capable of representing both the frequency spectrum (i.e. random waves) and directional spectrum (i.e., directional waves). For example, it is not acceptable to apply the unidirectional version of REF/DIF; instead, REF/DIF S must be applied.

Tables 4.2 and 4.3 summarize the capabilities of models that are typically used for wave transformation. It is important to note that the capabilities summarized in these two tables are not definitive, and the capabilities of the models change with time and release of new version, thus the model developer's recommendations will take precedence over these tables. Table 4.2 summarizes some of the more common spectral models, while Table 4.3 provides a list of functionality for phase resolving (i.e., Boussinesq or Mild Slope) models. It is evident from the tables that there is no ideal model for all situations and that in some cases it may not be possible to fulfill all the requirements at a given site. The purpose of Tables 4.1-4.3 is to assist in defining the best possible model for the particular application.

**Table 4.2.** Capabilities of spectral wave transformation models. ♦ *Indicates the process is included in the model.*

	SWAN	MIKE21 NSW	STWAVE	GHOST
<b>Shoaling</b>	♦	♦	♦	♦
<b>Refraction</b>	♦	♦	♦	♦
<b>Depth-induced Breaking</b>	♦	♦	♦	♦
<b>Diffraction</b>				♦
<b>Bottom Friction</b>	♦	♦	♦	♦
<b>Wind Generation</b>	♦	♦	♦	
<b>Wave-wave Interactions</b>	♦	♦	♦	♦
<b>Reflection</b>				
<b>Current Interaction</b>	♦	♦	♦	♦
<b>Angular Limitations</b>	no	yes	yes	some
<b>Multiple grids needed?</b>	usually not	yes	yes	usually not
<b>Computational Speed</b>	fair	fast	fast	fast

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**Table 4.3.** Capabilities of phase-resolving wave transformation models. ♦ *Indicates the process is included in the model.*

	MIKE21 BW	FUNWAVE	REF/DIF S	MIKE21 PMS
<b>Shoaling</b>	♦	♦	♦	♦
<b>Refraction</b>	♦	♦	♦	♦
<b>Depth-induced Breaking</b>	♦	♦	♦	♦
<b>Diffraction</b>	♦	♦	♦	♦
<b>Bottom Friction</b>		♦	♦	♦
<b>Wind Generation</b>				
<b>Wave-wave Interactions</b>	♦	♦		
<b>Reflection</b>	♦	♦		
<b>Current Interaction</b>	♦	♦	♦	♦
<b>Angular limitations</b>	no	no	yes	yes
<b>Multiple grids needed?</b>	no	no	yes	yes
<b>Computational speed</b>	slow	slow	fair	fair

## 4.2 Modeling Methodology

The following general guidelines are provided for applying the wave transformation models, but are not intended to replace the models' user manuals and a thorough understanding of the model's suitability for any given problem.

### 4.2.1 Grid Specifications

- Be aware of angle limitations. Most models require at least two or three different grids with different orientations to address a directional window of 60 to 90 degrees at the outer boundary of the model domain. Different versions of the same model may have different angle limitations so it is not possible to specify these limitations for each model here;
- Some models (such as MIKE21 NSW) require grid cells that are much longer in the y-direction than the x-direction. For these models, the grid cell spacing will typically refer to the longest grid dimension;
- Most of the phase-resolving models have grid-size limitations whereby a minimum of (for example) seven grid cells are required per wavelength. This can cause computation meshes to be extremely large, resulting in long simulation times;
- The grid spacing must be sufficiently small to resolve the bathymetry of the area being dredged and important surrounding features. Justification for a selected grid spacing may be demonstrated by showing that halving the grid cell size (and defining elevations in the higher resolution mesh with the appropriate bathymetric data) results in essentially the same wave field. The contour lines from the plotted mesh should also clearly show the difference due to dredging;
- For models with an x-y- $\theta$  grid (different computational direction bins), a directional spacing of not more than 5° to 6° should be used. There should also be enough directional bins such that the wave angle is not limited by the number of directional bins (instead the computational scheme will limit the permissible wave angles);

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- For models that require user-defined frequencies to create a wave spectrum, a minimum of eight (and preferably more) logically selected frequencies should be used.

### 4.2.2 Wave Climate Resolution

Two techniques may be employed to create a nearshore wave history:

- A. The entire offshore time series may be transformed to the nearshore, with a simulation for each time step; and
- B. A matrix of different heights, periods, and directions may be simulated and a transfer function may be developed that will allow the measured range of wave conditions to be transformed to a selected location for each transfer function.

If method (B) is used, the following guidelines will apply:

- If the location(s) of interest is outside the surf zone and breaking is not important throughout the model domain, then a simulation of a single wave height may be scaled to represent different wave heights;
- To create a transfer function from a series of simulations, it is likely that 60 to 200 simulations will need to be carried out. This will depend on the possible range of direction and period, and whether or not multiple wave heights need to be simulated;
- Directional spreading parameters for the various model simulations should be determined based on the measured wave data. It is often appropriate to use different directional spreading values for steeper (locally generated) versus less-steep (generated at a distance) waves.

## 5.0 DATA SPECIFICATIONS

### 5.1 Geo-referencing

All data locations, model grids and other spatial data must be defined in latitude and longitude using NAD 83 and NAD27 (both are required). In addition, it is also desirable to define these items in a projected coordinate system such as UTM. Associated metadata files should be completed in FGDC compliant formats.

### 5.2 Data Formats

Data formats for input and output data must be clearly documented, and may consist of either ASCII or binary files. Subroutines for reading the data in either FORTRAN or C must also be provided.

### 5.3 Wave Climate Summary

The offshore wave climate at the site (either in deep water or at the borrow location) should be provided in the form of frequency tables of height and period combinations in a digital file, and as hard copy in the report. Selected time series should be plotted for a number of the larger storm events. A digital time series of the summary statistics (height period and direction) should be provided in the format described above. If available, two-dimensional wave spectra should also be provided in a suitable digital format.

### 5.4 Model Input Data

Model input data and model version information should be provided so others can repeat the modeling exercise at a later date. Where possible the executable version of the model used should also be submitted (i.e., where the model is not proprietary). All model input data, including the bathymetric grid (geo-referenced), the input wave conditions, and any other model control parameters (numerical scheme options, winds etc.) should be supplied for each simulation. These data should be provided in digital format, as specified above.

### 5.5 Model Output Data

Due to the possibly large amount of data generated in modeling tasks, the following output is required:

- Plots of not less than 20 different wave simulations, showing contours of wave height and vectors indicating directions. Plots should include typical and more extreme wave conditions that are contained in the wave climate. Digital graphical formats are required in addition to hard copies;
- The transfer function (if used) that transforms the waves from deep water to the study location;
- A summary of the nearshore wave climate in the form of frequency tables for each of the scenarios simulated; and
- A summary of the difference in the wave climate in the form of frequency tables for each of the scenarios simulated.

# Protocols For Bathymetric and Substrate Surveys

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## 1.0 OBJECTIVES AND JUSTIFICATION

- To determine the location and quantity of sand removed and the associated change in bathymetry immediately after completion of dredging operations, thus providing a record of the short term and direct impact of the dredging project.
- To quantify any subsequent changes to the bathymetry and substrate within the immediate vicinity of the borrow area to help in the assessment of biological impacts.
- To quantify any subsequent changes to the bathymetry and substrate for the overall sand body feature or pit feature for those sites where such a feature is distinguishable (e.g. ridges and shoals or shallow pits). Long-term changes to the bathymetry could impact the distribution of benthic communities and also could impact shoreline erosion/accretion processes (by modifying wave refraction/diffraction processes).

It is noted that the changes to substrate will be assessed through a consideration of the findings of the acoustic survey techniques specified in this protocol together with the grain-size distribution analysis for the samples specified in the Sediment Sampling and Analysis Protocol.

## 2.0 SPATIAL BOUNDARIES REQUIREMENTS

The spatial extent of the survey will depend on the size of the borrow area and the local seabed conditions, including sediment type, seabed stability, current direction and speed, and the overall sensitivity of the area.

The area of the survey will be defined as the borrow area and a buffer zone around the dredged area. The survey area shall not be less than three times the borrow area for the specified dredging project. For example, the buffer zone around a 1 km<sup>2</sup> borrow area would be 370 meters and 520 meters for a 2 km<sup>2</sup> borrow area.

- Where the dredging takes place on a distinguishable ridge or shoal feature the survey will encompass the full extent of this feature, but not greater than 5 km<sup>2</sup>. Where the area of the feature is larger than 5 km<sup>2</sup>, the 5 km<sup>2</sup> survey area will be centered on the dredge site.
- Both pre- or post- dredge survey must be completed according to the applicable conditions.

The area covered by long-term monitoring surveys following the post-dredge survey may be reduced or expanded in size. A reduction or expansion of the survey area will be dependent on the impact to the seafloor surrounding the dredged area. If there is significant impact, then the size of the survey area should be expanded. It may be determined that future surveys need only cover the borrow area. This should be evaluated on a case-by-case basis from survey to survey.

## 3.0 TEMPORAL SAMPLING REQUIREMENTS

The following requirements must be achieved with respect to the timing of the surveys:

- The pre-dredge survey will be completed no more than 30 days prior to the start of dredging.
- The post-dredge survey should be completed immediately following the completion of dredging, and not more than 15 days after the completion of dredging.
- One survey should be completed following a storm event with a two-year return period (See the Waves Protocol).

## Protocols For Bathymetric and Substrate Surveys

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- Long-term monitoring surveys are required one, three, and seven years following the completion of dredging. The first year survey should be conducted in late spring early summer, coinciding as closely as possible with the timing of the benthic survey. The clock for long-term monitoring survey requirements is reset for each new dredging operation.
- If the impact on the seafloor is significant, then surveys should be conducted more frequently.
- If there is minimal impact on the seafloor, surveys should be conducted less frequently.

Repeated surveys at defined intervals will assist in the identification of the impacts and changes to the pit and surrounding areas, stability of the seabed, as well as changes in habitat.

### 4.0 SURVEY REQUIREMENTS

With the exception of the drawing, plotting, line spacing and point density specifications, all requirements outlined under “Contract Payment Survey Classification 1” in EM1110-2-1003 (1994) and EC1130-2-210 (1998) of the US Army Corps of Engineers or the Technical and Engineering Guide for Hydrographic Surveying by ASCE (1998) should apply. Revised accuracy standards and related technical guidance contained in EC1130-2-210 supersede applicable portions of EM1110-2-1003.

Methodology for the measurement of tides and water levels are well documented by USACE (EM1110-2-1003, 1994) and NOAA (1999). Traditional tide staffs/tide gauges or RTK DGPS systems are all acceptable methods for measuring tides. Data from NOS (National Ocean Service) National Water Level Observation Network tide stations are also available. The recommended vertical datum for offshore coastal surveys is mean lower low water (MLLW).

General survey criteria for coastal dredge sites in water depths <30 meters are summarized in Table 4.4. There are three possible acceptable systems to meet the requirements of this protocol, that are described in the following paragraphs:

- Single beam acoustic echosounding with side scan sonar
- Multi-beam echosounding
- LIDAR

### 4.1 System Specifications

The survey system should be capable of:

- Collecting bathymetry data to USACE specifications;
- Assessing sediment transport features;
- Assessing biological habitat.

Survey system specifications, methods and limitations are described below. Table 4.5 provides a summary of single beam, multibeam, LIDAR and side scan sonar systems.

#### 4.1.1 Single Beam Echosounding

Single beam echosounding works on the principle of transmitting a pulse of sound, measuring the time for echoes to be received from the seafloor, and then converting the measured travel time into a corresponding depth. Travel time is converted to depth by multiplying the travel time by the speed of sound in water and then dividing the result by two in order to account for the round trip of the sound pulse in the water column.

## Protocols For Bathymetric and Substrate Surveys

**Table 4.4.** Summarized general bathymetric survey criteria (water depth < 30 meters).

	Type of Survey			
	All Systems	Single Beam	Multi-beam	LIDAR
<b>Survey Positioning</b>				
<b>Horizontal Accuracy (95% Confidence Level)</b>	< 5 meters			
<b>Horizontal Datum</b>	NAD 83			
<b>Reference Grid System</b>	UTM (6 degree zones)			
<b>Vertical Accuracy</b>	0.06m (< 6m) / 0.15m (> 6m)			
<b>Vertical Datum</b>	MLLW			
<b>System Resolution</b>		1 cm (<100 m depth)	1 cm	15 cm
<b>Speed and Coverage</b>				
<b>Vessel Speed</b>		8 knots	10 knots	50 knots
<b>Survey Line Spacing</b>		25m	system/water depth dependent	
<b>Survey Cross Line Spacing</b>		100m		
<b>Survey Data Overlap</b>		n/a	10% minimum	10% minimum
<b>Quality Control</b>				
<b>Velocity profile</b>		> 2/day	> 2/day	n/a
<b>Bar calibration</b>		> 2/day	2/day	n/a
<b>Max-beam angle</b>			90-degrees	n/a
<b>Beam overlap</b>			10% minimum	at least 10%
<b>Alignment calibration</b>			as required	
<b>Patch test calibration</b>			periodic	
<b>Performance Test</b>			1/project	
<b>Position Calibration</b>	1/day			
<b>Acoustic Frequency</b>		>= 200 kHz	>= 200 kHz	n/a
<b>Volume Computation Method</b>	dtm/dem			

NOTE: System resolution is not the same as vertical accuracy

## Protocols For Bathymetric and Substrate Surveys

**Table 4.5.** Comparison of acceptable bathymetric survey systems.

	<b>Single Beam</b>	<b>Side scan sonar</b>	<b>Multibeam</b>	<b>LIDAR (SHOALS)</b>
<b>Recommended Frequency</b>	>= 200 kHz	>= 100 kHz	>= 200 kHz	n/a
<b>Minimum depth range</b>	0.5 - 1 m below transducer		1 - 3 m below transducer	1 - 1.5 m
<b>Maximum depth range</b>	150-300m	< 1000m	150-300m	~50m but typically 20 - 30m (2.5 x secchi depth)
<b>Survey speed</b>	5-10 knots	4-6 knots	10-16 knots	~50 m/sec (50 knots)
<b>Areal survey coverage</b>	< 1 sq. km/hour	1 - 2 sq. km/hour	1 - 6 sq. km/hour	8 sq. km/hour
<b>Survey Platform</b>	vessel	vessel	vessel	helicopter/aircraft
<b>Sounding Density</b>	1-3 meters along - track, across-track dependent on line spacing	n/a	1-3 meters	3 - 15 m spacing
<b>Sounding Rate</b>	depth dependent (up to 20/sec)	n/a	depth dependent (up to 25-30/sec)	200/sec
<b>Swath Width</b>	0.05 to 0.14 x water depth	variable (100m recommended)	2 to 7.8 x water depth	5-70% of altitude (100m)
<b>System Resolution</b>	1cm (water depth < 100m)	~10 cm	1-5cm	+/- 15 cm

The basic single beam echosounder system consists of an acoustic transducer, a transmitter, and a receiver. The transmitter applies an electric current to the acoustic transducer, which converts this current into a pressure wave directed at the seafloor. When the pressure wave contacts the seafloor, it is reflected back to the acoustic transducer where the pressure is converted to an electric current and sent to the receiver. The output from the receiver is usually sent to a display device or recorder for visual recognition and logged digitally to a hydrographic survey software package.

The density of soundings with a single beam system is dependent on the survey line spacing, vessel speed and the echosounder ping rate. The footprint of the single beam transducer is dependent on the beam angle and the water depth. Essentially the single beam transducer calculates the water depth directly beneath the survey vessel.

The limitation of a single beam system compared to multibeam is the sample density or seafloor coverage. Advantages include survey costs and multibeam coverage of the seafloor is significantly reduced in shallow water (< 5 m). A high frequency (200 kHz or greater) transducer is required for single beam echosounding.



## Protocols For Bathymetric and Substrate Surveys

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Single beam systems are widely used for bathymetry surveys and in combination with a side scan sonar system. The combination of these two systems provides for 100% seabed coverage on the surficial sediments, sediment transport features, and the impact of dredging on the seafloor.

### 4.1.2 Multibeam Echosounding

A multibeam echosounder works much like a single beam echosounder in that a pulse of sound is produced, reflected by the seafloor, and then received by an acoustic transducer. The main difference between the two systems is that the multibeam echosounder produces a number of separate beams (between 80-200 beams) forming a “fan” of acoustic energy in the water column. This fan of energy increases the swath, and therefore the coverage, of the multibeam survey as compared to the single-beam survey. Multibeam surveys can provide 100% coverage of a survey area. The location of the seafloor in a multibeam survey is computed by the angle and range measurements of the returning signals. The maximum vessel speed for this type of survey is higher than that of any other non-airborne survey at 10-16 knots.

The relative density of a multibeam sonar is a complicated function of the ship's speed, sounder repetition rate, along-track beam width, across-track beam width, mode of sonar operation (equiangular or equidistant), and the ability to compensate for ship motion.

The main advantage of the multibeam system is the ability to collect 100% bathymetry coverage as well as backscatter data that can be used to characterize the surficial sediment and sediment transport features. Compared to a side scan sonar, a multibeam system generates quantitative bathymetric data but the backscatter data is usually lower resolution. The costs compared to single beam surveys are significantly higher and swath width is significantly reduced in water depths less than 10 m. However, the total cost of single beam survey together with side scan sonar can be comparable to the cost of multibeam survey. The required frequency for a multibeam system is 200 kHz or higher and must be capable of collecting backscatter/side scan data.

### 4.1.3 LIDAR (Light Detection And Ranging)

LIDAR is a form of airborne hydrography that uses lasers to measure water depth. In the 1970's experimental laser based bathymetric profiling were developed in the U.S., Canada, Australia, and Sweden. Over time these have evolved into two primary systems; the SHOALS and HAWKEYE systems and the Australian LADS and LADS II systems. This system can either be attached to a fixed wing aircraft or a helicopter flying at an altitude of 200-1000 m, with a speed of 50-145 knots. The LIDAR system transmits two co-linear laser pulses, one infra-red and one green, towards the water surface where the infra-red beam is scattered at the water surface and the green beam penetrates the water and is scattered at the seafloor. The receiver onboard the survey aircraft detects returns from both beams and the time difference between the two is then used to calculate water depth.

LIDAR systems have a swath of approximately 100 m and can cover about 8-10 km<sup>2</sup> of survey area in one hour. The vertical accuracy of LIDAR can be as good as +/- 15 cm.

The swath width of the SHOALS LIDAR system ranges from 5 to 70% of the altitude and is on average 100 meters. The maximum penetration is 50 m water depth in ideal conditions but is typically 20 to 30 meters and the sounding density can range from 3 to 15 m spacing. The maximum water depth limit is dependent on vegetation and the amount of suspended solids.

## Protocols For Bathymetric and Substrate Surveys

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The main advantage of the LIDAR system is that the areal coverage per unit time is much greater than acoustic systems. The sample density for the most part is less than multibeam sonars in equivalent water depths and significantly greater than single beam systems. The main disadvantages are mobilization costs and, unlike multibeam and side scan sonars LIDAR is less suitable for characterizing the surficial sediments and sediment transport features. A LIDAR survey would only be economical if monitoring surveys were required over a number of sites and/or if it can be mobilized by the Corps of Engineers at little or no cost.

### 4.1.4 Side Scan Sonar

The basis of side scan sonar is that two acoustic transducers are turned on their sides in order to observe a series of echoes from the seafloor rather than just one echo from directly below the survey vessel. Side scan sonar uses a very narrow beam ( $0.1^{\circ}$ - $1.5^{\circ}$ ) to achieve a high-resolution image of the seafloor. This image is created by combining successive sonar scans as the system is towed through the water. In ideal conditions, the side scan sonar record can look like a photograph of the seafloor. The transducers in the side scan sonar system are contained in an assembly called the towfish. This towfish is towed behind the survey vessel at some depth below the sea surface in order to increase resolution and to limit noise effects cause by the vessel and the sea surface itself. A typical side scan sonar system will operate between 100-500 kHz with a variable swath, 50 to 100 meters swath is recommended for water depths 3 to 25 m.

Side scan sonar systems do not provide water depth measurements but they do provide 100% coverage of the seafloor and are ideal for mapping sediment types, sediment transport features, and bottom habitats. Where a single beam acoustic system is selected (i.e. in favor of Multi-Beam and LIDAR) it is required that a side scan sonar survey also be completed for the required Survey area.

### 4.1.5 Horizontal Positioning

Horizontal positioning requirements must meet USACE Class 1 guidelines of  $\pm 5$ m for soft material. In general, code phase, meter level US Coast Guard differential GPS radio beacons or satellite based differential corrections (Starfix, Skyfix, etc.) will provide sufficient accuracy for most survey locations. This will also ensure the data is referenced to the NAD 83 horizontal datum. In offshore coastal areas carrier phase kinematic DGPS (either real-time kinematic (RTK) or post-processed) may be required to enhance the vertical accuracy of the soundings. RTK provides a horizontal and vertical solution for the vessel thereby eliminating the need for water level measurements.

### 4.1.6 Motion Sensors

Motion sensors are recommended for single beam surveys and required for multibeam surveys. Heave sensors that meet IHO standards are acceptable for single beam surveys. These sensors are easily calibrated and interfaced with single beam systems. Multibeam systems are much more complicated as the swath of soundings must be corrected for the full motion of the vessel. In the past, heave/pitch/roll sensors along with survey grade gyros have been deployed. The most accurate is an inertial navigation system that incorporates a combination of DGPS, motion sensor and gyro to correct for vessel motion. Extensive calibration tests are required to effectively interface these systems to multibeam sonars.

## Protocols For Bathymetric and Substrate Surveys

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### 4.2 Survey Sounding Density Requirements

Sounding density will relate to the type of equipment utilized for these surveys. The factors that influence sounding density of each system have been presented in the previous section. One of the following two sampling density requirements will apply to all hydrographic surveys:

- For multibeam or LIDAR surveys, at least one sounding per 25 m<sup>2</sup>.
- For traditional single beam systems, survey lines will be spaced at 25 m intervals and cross lines will be completed every 100 m through the survey area.

For comparison purposes USACE and IHO specifications for single and multibeam surveys are as follows:

- The U.S. Army Corps of Engineers (USACE) recommends 100 ft or 30 m spaced longitudinal lines and 200 ft spacing on cross-sections for single beam Class 1 (Contract Payment) surveys (EC1130-2-210, 1998). For Class 1 multibeam surveys the USACE recommends a maximum beam angle of 90 to 120 degrees and 10 to 50% beam overlap.

According to IHO (International Hydrographic Organization) minimum standards for Order 1 hydrographic surveys the recommended maximum survey line spacing is 3 x average depth or 25 m, whichever is greater. This refers to the spacing of sounding lines for single beam echosounders, and distance between the outer limits of swaths for multibeam echosounder systems.

### 5.0 FINAL CONSIDERATIONS

Multibeam systems will provide high-resolution bathymetry maps of the seabed as well provide information on seabed sediment texture and bedform structures. The disadvantages associated with swath systems are their higher costs and the need to have highly skilled operators. In addition, the output often requires considerable post-processing time and expense to derive the best images. On the other hand single beam systems cost much less and are generally simple to operate. The main disadvantage of single beam echosounders is survey coverage. The lack of 100% coverage of the seafloor results in the need to undertake extensive spatial interpolation in order to provide full-coverage bathymetry maps of the seabed. A single beam echosounder in combination with a side scan sonar (as required under this protocol) will provide bathymetry as well as information of surficial sediment types and features.

The primary focus of monitoring the borrow area is to calculate a reliable sediment budget and secondly to assess changes in surficial sediments, sediment transport and habitat. As a result, either a single beam echosounder/side scan sonar combination survey or high-resolution shallow water multibeam echosounder survey must be performed. The multibeam system must be capable of collecting high-resolution backscatter/side scan data. The frequency of the single or multibeam transducer should be 200 kHz or greater. If very fine changes to the overall sediment budget are to be measured then a multibeam system is required. A LIDAR survey is acceptable where sea conditions and cost considerations permit.

### 6.0 DATA DELIVERABLES

Minimum deliverables include the following:

- Survey Operations Report and Hydrographic Sounding Chart of the area.

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The survey operations report should include the following:

- Description of the survey equipment as well as specifications
- Field notes
- Description of sounding system calibration
- Description of positioning system and calibration
- Methodology and equipment used to reduce soundings
- Description of monuments/reference stations

Sounding chart should include:

- Survey location name or reference number
- Name of survey agency and the date the survey was completed
- Horizontal Datum and Projection used, NAD27 and NAD83 horizontal datum (both required) and UTM projection are required
- UTM and geographic reference grids
- Vertical datum used, as well as the numbers and elevation values of all vertical control monuments used for water level reduction
- At least one reference station giving the latitude, longitude, northing, easting, and source
- Key map and scale bar
- List of survey equipment/software used
- Source of shoreline, if applicable

Required digital deliverables must include:

- Navigation and sounding data (to both NAD27 and NAD83 horizontal datum and UTM projection)
- Geo-referenced side scan sonar or backscatter images (to both NAD27 and NAD83 horizontal datum and UTM projection)
- Interpreted surficial sediment and sediment features GIS data layers
- Complete associated metadata in FGDC Content Standard for Digital Geospatial Metadata

Additional deliverables could include:

- Side scan sonar mosaic or backscatter map
- Interpreted surficial sediment and features map
- Digital data including navigation/sounding files, geo-referenced side scan sonar or backscatter images, and meta-data

Specific format of the digital data should meet USACE guidelines.

### **7.0 REFERENCES FOR THE BATHYMETRIC AND SUBSTRATE SURVEYS PROTOCOL**

ASCE, American Society of Civil Engineers. 1998. Hydrographic Surveying, Technical Engineering and Design Guides as Adapted from the US Army Corps of Engineers No 25.

CHS, Canadian Hydrographic Service. 1998. Standards for Hydrographic Surveys, Second Edition.

DETR, Department of the Environment, Transport and the Regions, 2001, Draft Marine Minerals Guidance on the Extraction by Dredging of Sand, Gravel, and Other Minerals from the English Seabed (Consultation paper), London.

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- Hughes Clarke, J.E; C. deMoustier, L. Mayer, and D. Wells. 2000. Y2K Coastal Multibeam Sonar Training Course Lecture Notes, Vols. 1 & 2, Burlington, Ontario.
- Hughes Clarke, J.E. 1999. Provisional Swath Sonar Survey Specifications, National Topographic and Hydrographic Authority, Land Information New Zealand, TH Technical Report #2.
- ICES, International Council for the Exploration of the Sea. 2000. Report of the Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem, Gdansk, Poland.
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- Miller, J., J.E. Hughes Clarke, and J. Patterson. 1997. How effectively have you covered your bottom?: *Hydrographic Journal* 83:3-10.
- NOAA, National Oceanic and Atmospheric Administration, April 23, 1999. NOS Hydrographic Surveys Specifications and Deliverables.
- USACE, United States Army Corps of Engineers. 1994. Engineering and Design, Hydrographic Surveying, EM1110-2-1003.
- USACE, United States Army Corps of Engineers. 1998. Project Operations, Hydrographic Surveying, EC1130-2-210.

### 1.0 OBJECTIVES AND JUSTIFICATION

- To document the change to the shoreline inshore of the borrow deposit during the period of active use of the deposit and thereafter until it is determined that there has been no significant impact. This objective is addressed through monitoring the shoreline, nearshore profiles, and nearshore bathymetry. By extracting sand from the sea bed, it is possible that the waves passing over the dredged area will be modified leading to possible changes in longshore and cross-shore sand transport patterns, and therefore, shoreline and nearshore morphodynamics. All shorelines and nearshore zones are dynamic, the purpose here is to determine whether these dynamics have been significantly altered by the dredging activities (and subsequent indirect impacts of dredging).
- To assess the role of changes to wave transformation patterns over the borrow deposit on shoreline change and nearshore morphodynamics. This second objective requires the application of numerical models to assess whether there has been or will be any impact of changes to bathymetry at the borrow site on the sand transport and morphodynamic processes in the nearshore zone and at the shore.

It is recognized that both shoreline monitoring and shoreline modeling also fall under the jurisdiction and mandate of other agencies. For example, shoreline monitoring programs are usually administered by agencies within each State as part of a Coastal Zone Management Program. Shoreline modeling may also be completed by the State or at least by the proponents or sponsors of coastal projects (such as the Corps of Engineers District offices) that require sand from the borrow deposits under MMS jurisdiction. Therefore, it is necessary that this Protocol be applied in a manner that is consistent with these activities by others and in such a way to avoid duplication of effort.

### 2.0 MONITORING AND MODELING

Shoreline monitoring is performed in most States through a combination of profile surveys repeated at some frequency (e.g. twice a year, once a year or once every two or more years) in addition to the use of aerial photos to document shoreline change (or the change of some other related distinguishable feature such as a vegetation line). The purpose of the shoreline monitoring is to document change or lack thereof. Another key piece of information to assess shoreline change is the deepwater and nearshore wave climate (both prior to and after the initial use of a borrow site) – see the Waves Protocol. Documentation of the shoreline change and the driving forces for change in the form of the wave climate on their own are not sufficient to provide an explanation for observed changes and to discern whether these changes may be attributable to dredging at an offshore borrow site. The reason for this is that the wave climate (and the associated sand transport and shoreline change) for one year or even a period of several years is not stationary or well represented by an average set of conditions. Furthermore, the influence of other external factors that affect shoreline change such as the impact of coastal structures, beach nourishment projects, other impacts to sand supply or sea level rise are not stationary with time (i.e. they also vary from period to period).

Therefore, in order to determine the influence of one factor independent of the variation of other factors it is necessary that modeling be performed. Modeling provides a means of creating a common basis for comparison. For example, shoreline change for a five-year period after a dredging project could be simulated using wave models coupled to shoreline change models with measured wave data as input. The simulation could be calibrated and verified against documented shoreline change for that period. Then the model could be run again with the original bathymetry prior to the dredging project to determine whether any changes were directly attributable to direct and indirect impacts of dredging on the borrow deposit. This same approach should be (and in many cases has been) undertaken prior to the initiation of dredging on a borrow deposit. However, often there is insufficient local wave data or reliable and sufficiently accurate shoreline change data to complete this assessment in a pre-project “hindcast” mode.

## **Protocols for Shoreline Monitoring and Modeling**

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Furthermore, completing this assessment after the fact provides a different perspective and an additional test of the model predictions. In the pre-project assessment the shoreline change without the dredging project is known, whereas in the monitoring assessment (after the initial dredging event) the shoreline change with the project is known.

It is worth mentioning that there are different views on meaningfulness of shoreline change modeling in the literature. It is important to recognize that the recommendation to perform modeling as part of this protocol is related to the possible changes nearshore wave conditions related to changes to distinct offshore features such as shoals or ridges. Numerical models of wave transformation have been shown to accurately reproduce measurements from physical models in laboratory experiments and from full scale measurements. It would be impossible to assess such complex changes without the application of numerical model.

There are two possible contributing factors to shoreline change associated with dredging of deposits in Federal waters:

1. Changes to nearshore wave conditions, longshore sand transport and therefore shoreline change; and
2. Interruption or cut off of pathways of sand to shore (where they may exist).

Methods for determination of deepwater and nearshore wave conditions and the influence of a dredging project on the latter are specified in the Waves Protocol. The focus of this Shoreline Protocol is:

- The collection of the necessary information to document shoreline change, and
- The specification of methods to simulate shoreline change with models.

The remainder of this document will address the requirements of both monitoring and modeling necessary to discern the role of dredging projects in Federal waters on shoreline change, if any.

### **3.0 SPATIAL BOUNDARIES**

#### **3.1 Monitoring**

In most States the monitoring program covers the entire length of the open coast. This is the preferred spatial coverage.

Basco et al. (1999) determined that the area of measurable impact to waves that reach the shoreline in response to a hypothetical removal of a large part of the Sandbridge shoal offshore Virginia was at least three times the lateral extent of the borrow area. Impacts to shoreline change will extend well beyond the immediate area of impact to waves and sand transport (just as impacts of inlet structures extend many times the length of the structure in the downdrift direction).

Therefore, in those States where monitoring is not being performed along the entire coast, for the purposes of assessing the impact of dredging in Federal waters, the area of monitoring must extend:

- A total of five times the shoreline projected alongshore extent of the borrow area (including all past borrow areas in the same vicinity) in both the updrift and downdrift direction for a total length of monitored shoreline of ten times the shoreline projected alongshore extent of the borrow deposit(s).

## **Protocols for Shoreline Monitoring and Modeling**

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The spatial coverage of the required shoreline monitoring should be reassessed and expanded or reduced depending on the findings of the monitoring and modeling.

### **3.2 Modeling and Analysis**

As noted in Section 2, for the shoreline change assessment it will be necessary to have an adequate record of deepwater waves for the monitoring period and to transfer these waves inshore using wave transformation models. The requirements (including the spatial boundaries) for the deepwater and nearshore wave climates are described in the Waves Protocol. It will be necessary that the alongshore coverage of the nearshore wave transformation model matches that of the shoreline change model (i.e. with the ten times the shoreline projected alongshore extent of the borrow deposit(s)).

## **4.0 TEMPORAL REQUIREMENTS**

### **4.1 Monitoring**

Beach and nearshore profiles and shoreline position should be surveyed twice per year, once in the late spring and once in early fall. The two sets of surveys must be completed every year following the initiation of dredging at the borrow deposit.

Termination of shoreline monitoring for the purpose of determining possible impacts of dredging in Federal waters may only occur when the interpretation of the monitoring and modeling efforts clearly demonstrates there has been no impact to shoreline change and no further dredging of a borrow area is planned. In any event the termination of monitoring shall not occur before ten years after the cessation of dredging in a given borrow area.

### **4.2 Modeling**

Numerical model assessments of possible shoreline change impacts should be performed as follows:

- Prior to initial dredging of the site in those cases where previous shoreline change modeling meeting the requirements of this Protocol has not been performed.
- Once every five years following the initiation of dredging for a given borrow deposit area.
- In the event that the sand body (where one exists) has been determined to have changed significantly based on a review of long term monitoring bathymetric survey comparisons.

Termination of shoreline modeling for the purpose of determining possible impacts of dredging in Federal waters may only occur when the interpretation of the monitoring and modeling efforts clearly demonstrates there has been no impact to shoreline change and no further dredging of a borrow area is planned. In any event the termination of modeling shall not occur before ten years after the cessation of dredging in a given borrow area.

## **5.0 METHODS AND SPECIFICATIONS**

The monitoring and modeling of shoreline change is usually performed at two primary levels of detail:

1. Assessment of the change in the shoreline position, in which case this variable is considered to be representative of the change to the entire littoral zone inshore of the closure depth; and
2. Consideration of the change to the sea bed and beach surface (a greater level of detail).



## Protocols for Shoreline Monitoring and Modeling

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For monitoring, the first level of assessment is completed through topographic surveys of a representative shoreline feature (e.g. high water mark, vegetation line or toe of foredune line) or more commonly the interpretation aerial surveys to define similar features. Modeling at this level of detail is completed through the application of a one-line shoreline change model, the most widely used being the Corps of Engineers GENESIS model (Hanson and Kraus, 1989). Obviously, this level of assessment provides a quantitative estimate of shoreline change (which is most important in the assessment of possible land side impacts of induced changes). However, it assumes that any erosion or deposition is occurring at the same rate across the beach and nearshore profile.

Monitoring at the second level of detail ideally includes a combination of hydrographic and topographic surveys extending from the inshore toe of the primary dune out to the depth of closure. As topographic and hydrographic LIDAR surveys become more widely applied, this approach will provide for a comprehensive assessment of the total gain or loss of sediment from any given control volume. This level of detail would allow for a full assessment of the sediment budget (i.e., the evaluation of total net gain or loss of sediment from the active littoral zone). However, at present beach and nearshore profiles (usually at something in the range of 300 m spacing) are surveyed to provide some indication of the three dimensional nature of the changes. Unfortunately, there are no commonly accepted and applied numerical models for estimating the three-dimensional changes to the beach and littoral zone (at research or site specific level these types of models have been developed, tested and applied with varying degrees of success). This level of assessment provides a more comprehensive indication of changes that may be caused by external influences (such as offshore dredging). For example, dredging may lead to erosion in the nearshore zone and profile steepening with only limited shoreline change initially. Profile or hydrographic surveys would capture this level of change whereas shoreline surveys would not. Ultimately, changes to the shoreline will be observed. Therefore, the hydrographic survey information provides an early warning of changes to the nearshore that ultimately may lead to shoreline change.

It is important note that it may be necessary to extend the bathymetry survey beyond the closure depth in instances where there may be a sediment transport supply pathway from an offshore deposit. Therefore, the offshore extent of the bathymetry survey must be considered on a site-specific basis and account for the possibility of more far-reaching sand transport processes.

### 5.1 Monitoring

Topographic and hydrographic profile surveys should be conducted of the beach and nearshore zone within the spatial boundaries identified in Section 3. Where State Coastal Zone Program requirements do not exist, profile surveys should be conducted at approximately 300 m spacing along an azimuth perpendicular to the shoreline. Where previous survey lines exist, these should be re-occupied. The hydrographic surveys should extend to a depth of closure or a minimum of 1,000 m seaward of mean high water, whichever is farther. Additional profile surveys should be conducted at intermediate stations adjacent to coastal protection structures or within localized areas of accelerated erosion.

With the exception of the drawing, plotting, line spacing or point density specifications, all requirements outlined under for Class II hydrographic surveys in EM1110-2-1003 (1994) and EC1130-2-210 (1998) of the US Army Corps of Engineers or the Technical and Engineering Guide for Hydrographic Surveying by ASCE (1998) shall apply. Revised accuracy standards and related technical guidance contained in EC1130-2-210 supersede applicable portions of EM1110-2-1003.

Where aerial survey requirements are not specified as part of a State Coastal Zone Management Program, shoreline delineation can be derived from stereo photogrammetry (either black & white or color) using tide-coordinated aerial photography controlled by kinematic Global Positioning Systems

## **Protocols for Shoreline Monitoring and Modeling**

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(GPS) techniques. The derived mapping scale should be a common ratio such as 1:12,000 or 1:24,000 scale vertical air photos. The specifications and standards as outlined in the American Society for Photogrammetry & Remote Sensing (ASPRS) Standards for Aerial Photography shall apply. The imagery should be suitable for digital orthoimagery production.

### **5.2 Modeling**

Shoreline modeling shall be performed with the GENESIS model (or an acceptable equivalent). The input wave data for the GENESIS model shall be derived from an acceptable wave transformation model as defined in the Waves Protocol. It is noted that the Corps of Engineers NEMOS package includes direct links between the STWave model and GENESIS together with pre- and post-processing software.

The GENESIS model domain must comply with the spatial coverage outlined in Section 3. Application of the GENESIS model should follow the guidance of the Users Manual.

The model must be calibrated for a hindcast period where concurrent wave and shoreline change data are available. Once calibrated, the model should be verified against an independent wave and shoreline change data set. Once these two steps are complete the model should be applied to determine the with and without project shoreline position at one year intervals for the next five years using five years of average annual wave conditions as input. The “without” project condition shall consist of the original pre-dredge configuration of the shoal. The “with” project condition shall be based on the most recent survey of the nearshore conditions in the vicinity of the borrow deposit.

### **6.0 DATA DELIVERABLES**

Nearshore profile survey results will be delivered in digital format (BPAS or EXCEL) with georeference information, and cross-reference to profile surveys at the same location.

All aerial photos and derived shoreline position data files must be delivered in one or more georeferenced digital formats. The aerial photos should be differentially rectified to produce digital orthophotos, and cropped in such a manner to provide a manageable orthophoto mosaic and alignment with quad sheet boundaries. The orthoimages should follow the guidelines as defined in the most recent version of the Federal Geographic Data Committee (FGDC) Content Standard for Digital Orthoimagery. The recommended delivery format is GeoTIFF and TIFF with an accompanying TFW georeferencing world file. The shoreline position should be delivered as a line feature data set with an appropriate attribute table including fields that identify the shorelines' mean high water (MHW) and mean lower low water (MLLW) location and shore interface type. The recommended delivery format is SDTS, Arc Export (E00) or ArcView shapefile. All geospatial data should be submitted in the following datum and coordinate systems: North American Datum 1927 and 1983 (both NAD27 and NAD83 are required), and Universal Transverse Mercator (UTM) grid. All digital geospatial data products are to be accompanied by complete metadata documentation in the FGDC Content Standard for Digital Geospatial Metadata (CSDGM) format.

For the wave modeling work the required deliverables are described in the Waves Protocol. For the GENESIS modeling, all input and output files must be submitted in digital format. Also, key results files including the calibration run, the verification run and predicted shoreline change with and without the dredging project must be supplied in digital format. Georeference information must be provided for the GENESIS grid. A report describing the calibration, verification and application of GENESIS must also be provided.

### 7.0 REFERENCES

- ASCE, American Society of Civil Engineers. 1998. Hydrographic Surveying, Technical Engineering and Design Guides as Adapted from the US Army Corps of Engineers No 25.
- Hanson, H. and Kraus, K. 1989. GENESIS: Generalized Model for Simulating Shoreline Change. Report 1. Technical Reference, Tech. Rept. CERC-89-19.
- USACE, United States Army Corps of Engineers. 1994. Engineering and Design, Hydrographic Surveying, EM1110-2-1003.
- USACE, United States Army Corps of Engineers. 1998. Project Operations, Hydrographic Surveying, EC1130-2-210.

## 5.0 ADAPTIVE MANAGEMENT

A key component of any long-term scientific study or monitoring program is the need to adapt the original study design and approach to reflect information and understanding gained from on-going studies during the execution of the program. For this reason it is the recommendation and assumption that the MMS will establish a permanent scientific review/advisory board to oversee the implementation and evolution of the OCS sand monitoring program and advise the MMS on the program components. Another key role of the scientific advisory board is to ensure the scientific validity and integrity of the monitoring programs and their findings.

The scientific advisory board should include a benthic ecologist, physical oceanographer or specialist in sediment transport and movement, a bio-statistician, and a marine fisheries specialist.

Some of the areas that the project team envisions requiring input and recommendations by the advisory board to the MMS include:

- Duration and frequency of sampling: The monitoring program design recommends collecting data at specific frequencies after a dredging event. Based upon the monitoring results to-date, it may be determined that monitoring may be required for a longer or shorter period or at more frequent intervals, for each program element.
- Inclusion of new or dropping of existing monitoring elements: The scientific advisory board should monitor program results carefully to validate the scientific value of each program element. If program results suggest that biological communities or geomorphological processes are being affected which are not part of the implemented monitoring program, then these elements will need to be added. Conversely, if a program element is not undergoing the expected change or not showing any effect or change as a result of dredging activities, then that element should be dropped from the program.
- Adapting the program to new locations: The current monitoring program was designed within the framework of the known OCS borrow locations and current dredging regimes. The program has been designed to measure the same core group of ecological parameters at each location. However, as new OCS sand borrow locations are identified or new dredging techniques are developed, it will be important for the scientific advisory board to ensure that the monitoring program, as implemented at each site, is conducted in a scientifically valid manner and that any critical adaptations necessary to ensure accomplishment of the original goals are included.
- Data synthesis and interpretation: The proposed monitoring program has the potential to generate data for multiple years at the same site as well as data for multiple years at multiple sites. It is important that the scientific advisory board ensures accurate and meaningful interpretation of these individual and cumulative data sets so that the MMS obtains the information it needs to assist it in resolving identified program resource management questions.

- Detecting regional differences: One of the scientific questions that the proposed monitoring program has been designed to attempt to answer is whether there are any regional differences in recovery or impact from OCS dredging activities. It will be important that the scientific advisory board ensures that any differences in recovery or impact in different regions are detected and reported.

In addition to the above items, within the actual protocols there are items where a decision may need to be made by the scientific advisory board concerning a specific program element.

## **6.0 COST ANALYSIS**

In developing a cost estimate for the designed monitoring program, basic assumptions about the dredging operations needed to be made by the project team, such as the location of the borrow site, the potential size of the dredging operation, and distance of the borrow site from shore. To this end, the project team elected to select one of the MMS identified Regions of Interest (ROI) located along the Atlantic coast as a hypothetical project site, and to develop a cost estimate for the designed monitoring program for that location. The selected site was the Fenwick Shoal, Isle of Wight Shoal, and Weaver Shoal Regions of Interest located offshore the coast of Maryland and Delaware.

General program assumptions include:

- Potential dredged area size is one kilometer (km) square by one meter (m) depth.
- Dredging would be along the top of the ridge feature.
- Dredging would occur using either a trailing suction hopper dredge or a cutter head suction dredge.
- The dredge site is relatively close to shore and ship transit time from a nearby port is minimal.
- Survey vessel size and design are such that 24-hour operations are possible, and all but the most inclement weather would prevent survey work from occurring.
- Because of differences in regional labor costs, a range for labor rates is used.
- No estimate of travel costs or equipment shipping costs is included in the cost estimate.
- All cost estimates are in 2001 dollars and may need to be adjusted for inflation and technological/commercial advances in future years.

In addition to the assumption for the overall program, specific assumptions for each monitoring program element were made. These assumptions are detailed below along in the cost estimates for each program element.

### **6.1 Physical Program Elements**

The monitoring/modeling program targeted at the physical processes includes the following elements:

- Hydrographic surveys;
- Definition of deepwater and nearshore wave climate;
- Monitoring and modeling of shoreline change; and
- Grain-size analysis for sediment samples.

Cost estimates for each survey and/or assessment are provided in the following sub-sections.

### 6.1.1 Hydrographic Surveys

#### Assumptions:

- According to the required buffer area the total survey area for this example (1 km<sup>2</sup> dredge area) is 3 km<sup>2</sup>.
- Three possible alternatives to completing the hydrographic surveys are acceptable: 1) single beam acoustic with side scan sonar survey; 2) multibeam acoustic survey; and 3) Airborne LIDAR, such as the Corps' SHOALS system.
- Cost estimates are for a single survey. No time has been allotted for weather downtime.
- The single beam/side scan sonar survey estimates are based on utilizing a vessel of opportunity in the nearest port and the multibeam estimate is based on a dedicated 60-foot survey vessel.
- It is noted that the initial two surveys prior to and immediately following dredging are required for payment under the dredging contract. It is recommended that the surveying for contract payment follow the Bathymetry Protocol to avoid duplication of effort.

#### Cost Estimate:

##### *Single Beam/Side Scan Sonar Survey*

- Survey scope (determined from protocol) is 25 m spaced survey lines with 100 m cross lines for a total of 134 single beam survey line kilometers and 20 km of side scan sonar survey line.
- Equipment and personnel included: survey vessel and personnel; surveyor; side scan sonar operator; DGPS and hydrographic survey software; single beam echosounder system; motion sensor; tide gage; and side scan sonar system.
- The estimated survey time is two days for mobilization/demobilization and two days of survey time at a day rate of \$3,900/day.
- The total estimated cost including survey costs, processing operations report, bathymetry map and side scan sonar mosaic is in the range of \$35,000 to \$45,000.
- The additional cost for difference mapping and a report detailing changes to the seabed (compared to previous surveys) is estimated to be \$7,500.

##### *Multibeam Survey*

- Line spacing for a multibeam survey will vary according to system and water depth. A water depth of 7.5 m has been assumed for this site with 3.5x water depth swath width and 10 percent beam over lap.
- Equipment and personnel include: dedicated multibeam survey vessel and personnel; surveyor; multibeam operator; multibeam acquisition system; MVP-30 velocity profiler, navigation software; and tide gage.

- The estimated survey time is two days for mobilization/demobilization and one day surveying at an estimated day rate of \$8,800/day.
- The total estimated cost including survey costs, processing operations report, bathymetry map and backscatter mosaic is in the range of \$48,000 to \$60,000.
- Additional cost for difference mapping and report detailing changes to the seabed is estimated to be \$10,000.

#### *LIDAR Survey with Corps of Engineers SHOALS System*

- If the Corps of Engineers were mobilized in the area for other purposes (i.e., the mobilization cost was covered by others) the survey cost would be in the range of \$10,000 to \$15,000.
- Mobilization cost would be on the order of \$75,000 if the Corps were not operating in the area when the survey is required. However, it is unlikely such a small project would be scheduled with priority.
- It is expected that by 2004 the SHOALS approach will be commercialized and more widely available.
- Additional cost for difference mapping and report detailing changes to the seabed is estimated to be \$10,000.

#### **6.1.2 Wave Monitoring and Modeling**

##### **Assumptions:**

- There is a directional wave buoy (NBDC44009) located approximately 19 km directly offshore of the hypothetical borrow site at Fenwick Shoal (offshore of the Maryland-Delaware border). This buoy is close enough and provides sufficient temporal data coverage that a site specific buoy would not be required. Nevertheless, for the purposes of providing cost information we have assumed that a buoy will be deployed at the location of the existing buoy.
- It is possible that where a new buoy is required, that NOAA may cover part of the purchase and deployment cost. This has not been considered in our cost estimate.
- Wave transformation costs have been determined to cover the offshore, borrow and nearshore regions as described in the Waves Protocol.
- The costs are for an assessment of the wave transformation for two cases considering the bathymetry before and after dredging. This will be required in the initial assessment prior to each dredging project. It is possible some interim assessments may only require one transformation case and a reduction in the overall cost for this situation is presented.

##### **Cost Estimate:**

- The cost of purchasing and deploying a directional wave buoy with the capacity to transmit real-time data to shore is in the range of \$60,000 to \$80,000.



- The annual maintenance cost including both data management and physical maintenance of the buoy and moorings is estimated to be in the range of \$10,000 to \$20,000 per year.
- Preparation of the deepwater wave climate for transformation to shore is estimated to cost \$5,000 to \$7,000.
- Offshore Region wave transformation to develop the wave climate at the site is estimated to cost \$8,000 to \$12,000. Note that this is the initial cost. Once the grid is available for future assessments, the cost of this task will be reduced by 50 percent.
- Borrow Region wave modeling is estimated to cost \$18,000 to \$24,000 for an assessment of two bathymetry cases. The cost would be reduced by \$10,000 for a single bathymetry case assessment.
- Nearshore Region wave modeling is estimated to cost \$12,000 to \$16,000 for an assessment of two different wave climates (i.e., for the different bathymetry grids evaluated under the Borrow Region modeling). Two assessments will always be required for the Nearshore Region to evaluate shoreline changes with and without the bathymetry changes in the borrow region.
- Reporting and preparation of data for delivery in the required format is estimated to cost \$10,000 to \$15,000.

### **6.1.3 Shoreline Monitoring and Modeling**

#### **Assumptions:**

- Most states have some form of shoreline monitoring program in place that collects nearshore profiles and aerial photos. Therefore, only a very rough estimate of costs to collect and process this information has been provided.
- It has been assumed that the shoreline modeling is performed with the U.S. Army Corps of Engineers GENESIS model within the NEMOS software that is part of the CEDAS package. This is by far the most widely applied shoreline change model.
- The estimates are based on the application of the model to a 10 km reach of shoreline centered on the hypothetical borrow deposit based on the application of the Shoreline Protocol requirements for a 1 km long borrow area.
- There will be two main steps to the shoreline change modeling as outlined in the Shoreline Protocol: 1) calibration and verification; and 2) prediction of shoreline change with and without dredging project wave climates.

#### **Cost Estimate:**

- The cost of surveying and processing data for 20 or more nearshore profiles would be in the range of \$1,800 to \$2,400 per profile. The cost for 10 km reach of shore with 300 m spacing on the profiles and two surveys per year would be \$120,000 to \$160,000.
- The cost of taking aerial photos and registering these images for a 10 km reach of shoreline would be \$20,000 to \$40,000.

- The cost of calibration and verification of the GENESIS model within the NEMOS package is estimated to be in the range of \$5,000 to \$10,000. This calibration only needs to be completed for the initial assessment.
- The cost of completing GENESIS model runs with and without the proposed dredging project is estimated to be in the range of \$3,000 to \$6,000.
- It is estimated that the cost of preparing a report that presents and interprets the results of the monitoring and modeling would be in the range of \$10,000 to \$15,000.

#### **6.1.4 Grain Size Analysis**

The cost of retrieving and analyzing the samples for grain size testing (including hydrometer analysis) has been included under the Benthic Field Sampling program costs. The cost of grain size analysis for individual samples is approximately \$100 per sample.

### **6.2 Biological Program Elements**

The biological monitoring program is based on the following general assumptions:

- Each monitored dredge site would have both impact and one control sampling locations.
- Each monitored dredge site would have a minimum of four strata at the control and impact sampling locations. These strata correspond to the ridge top (dredge site), steep sloped ridge face, shallow sloped ridge face, and low valley or plain located at the base of the steep slope ridge face. For broad shelf borrow areas the fourth strata is eliminated, and the steep sloped and shallow slope ridge features are replaced by leading edge and trailing edge areas of the seafloor adjacent to the dredge borrow site and oriented along the predominant wave and seafloor sediment movement.
- Cost estimates are per a single survey (pre-impact, year 1, year 3, year 5 or year 7).
- No cost estimates are made for marine mammal and wildlife monitoring since there are too many unknown parameters (number of observers required, number of days of dredging, project-specific environmental mitigation requirements to avoid collisions and harmful interactions with marine wildlife, etc). It was also assumed that, because of the expected imposition of environmental mitigation requirements to prevent collisions or harmful interactions with marine wildlife, the cost of this component of the monitoring program would be born by the dredging operation.

#### **6.2.1 Benthic Field Sampling and Analysis**

##### **Assumptions:**

- Because of different manning and equipment requirements, the benthic and fish data collection efforts could be combined and conducted at the same time or split into separate survey legs or phases. For the purposes of cost estimating, it was assumed that these sampling efforts would be done on separate survey legs.

- For the purposes of establishing a budget estimate and based on the study design and data collected by previous MMS surveys of OCS sand borrow areas, it is estimated ten benthic grabs will be collected at each of four strata at both the dredge and control sites, for a total of 80 benthic grab samples. The actual number of samples collected at each strata will need to be determined from samples collected during the pre-dredging baseline survey in accordance with the procedures outlined in the sampling protocols.
- The benthic sampling field leg will require three scientific personnel and will be conducted during daylight hours.
- Once on site, the time required to collect the grab, initiate sample processing and move to the next location is one hour.
- Three to four days will be required to collect all of the requisite samples. No time has been allotted for weather downtime.
- Transit to and from the survey site requires less than one day total.
- A vessel of sufficient size and capacity will be used that will allow staying on-site during each leg of the field effort.
- Grain size analysis and Total Organic Carbon (TOC) analysis will be performed on sub-samples from all benthic grabs. A total 80 samples will be analyzed.

**Cost Estimate:**

- Costs for the survey vessel (including crew) is estimated to be \$2,500 to \$3,500/day. Total vessel cost for four days of surveying and two additional days of mobilization/demobilization and transit is estimated to be \$15,000 to \$21,000.
- Labor rates for the scientific personnel will be \$650/day to \$800/day (12 hour days), depending on experience and qualification. Total scientific labor cost will range between \$11,750 and \$14,400.
- Incidental costs associated with local travel of personnel, field sample equipment, and miscellaneous sampling supplies are estimated to be \$2,500 to \$3,000.
- Analysis of benthic infauna will be \$750 to \$1,250 per sample, depending on the complexity and species diversity of the benthic infaunal community. Total estimated cost will range between \$60,000 and \$100,000, depending on the total number of samples collected and the actual cost of the analysis.
- Grain size and TOC analysis will be \$125-\$175 per sample (\$75-\$100/sample for grain size and \$50-\$75/sample for TOC). Total estimated cost is \$10,000-\$14,000.

**6.2.2 Fish Field Sampling and Analysis**

**Assumptions:**

- Because of different manning and equipment requirements, the benthic and fish data collection efforts could be combined and conducted at the same time or split into separate survey legs or phases. For the purposes of cost estimating, it was assumed these sampling efforts would be done on separate survey legs.

- Two to five bottom trawls will be required at each of the four strata at the control and dredge sites (12-30 trawls total) to collect sufficient fish samples for gut contents and to identify the dominant resident fish species. Trawls will be conducted both during daylight hours and at night.
- All fish trawls will be conducted within four days with an additional two days of mobilization/demobilization and transiting to the survey site.
- The fish sampling field leg will require six scientific personnel to accommodate day and night sampling (three per half day). The number of personnel is based on the assumption that for each crew shift, two of the scientists will be responsible for collecting information on each fish sample and remove the fish guts and muscle tissue samples. The third scientist will be responsible for recording data and ensuring all samples are properly labeled and processed.
- Each trawl will be analyzed in the field. Fish muscle tissue samples and fish gut contents samples will be collected, properly preserved, and shipped to the laboratory for analysis.
- For the purposes of establishing a budget estimate, it has been assumed that approximately 30 gut-content samples per each of three species will be collected from each of the four sampled strata at both the dredge site and control site, for a total of 720 fish-gut content samples. The actual number of samples collected at each strata will need to be determined from samples collected during the pre-dredging baseline survey in accordance with the procedures outlined in the sampling protocols.

#### **Cost Estimate:**

- The survey vessel (including crew) is estimated to cost \$3,500 to \$4,500/day, to accommodate 24-hour operations. Total vessel cost for four days of surveying and two additional days of mobilization/demobilization and transit is estimated to be \$21,000 to \$27,000.
- Labor rates for the scientific personnel will range between \$650/day and \$800/day (12 hour days), depending on experience and qualification. Total scientific labor cost will range between \$23,400 and \$28,800.
- Incidental costs associated with travel of personnel, field sample equipment, sample jars, preservative, etc. are estimated to be \$2,500 to \$3,000.
- Fish gut contents analysis is estimated to cost \$55 to \$85 per sample. Total analytical costs will be \$39,600 to \$61,200.

#### **6.2.3 Stable Isotope Analysis**

##### **Assumptions:**

- Samples will be collected either during field sampling (fish muscle tissue) or during laboratory analysis (benthic infauna).
- A total of 120 benthic infaunal stable isotope samples will be analyzed [3 replicates x 5 benthic species/faunal group x 4 strata x 2 sites (control and impact)].

- A total of 72 fish stable isotope samples will be analyzed (3 replicates x 3 fish species x 4 strata per site x 2 sites (control and impact)).

**Cost Estimate:**

- Stable isotope samples are estimated to cost \$50 to \$75/sample.
- Benthic infauna stable isotope sample analysis is estimated to cost \$6,000 to \$9,000.
- Fish muscle tissue stable isotope sample analysis is estimated to cost \$3,960 to \$5,400.

**6.2.4 Data Analysis and Reporting**

**Assumptions:**

- Minimal data analysis and interpretation would occur following the baseline survey. More detailed data analysis and interpretation would occur following each post-impact survey (years 1, 3, 5 and 7).
- As the number of surveys increases, data comparison with previous years surveys increases and may require additional effort.

**Cost Estimate:**

- Estimated cost for data analysis, interpretation and preparation of a report is \$30,000 to \$45,000.

**6.3 Summary of Estimated Costs**

The low and high range cost estimates for the designed OCS sand dredging monitoring program are summarized in Table 6.1. At most locations (i.e., the State is already surveying nearshore profiles and taking aerial photographs and where a wave buoy is not required) for most surveys (i.e., other than the initial survey and for cases where a site is accessed for sand removal on a frequent basis), the cost of implementing the monitoring protocols will be in the \$349,110 to \$541,750 range (i.e., Total 4). In cases where a site is only accessed once, Total 3 would be the monitoring costs. It is also noted that at least part of the hydrographic survey component of this cost (\$70,000 to \$120,000) is required for payment on the dredging contract (i.e., would be completed regardless of the Protocols).

In the event that the monitoring program is required for a full seven years, totals for a variety of possible outcomes have been determined and are presented in Table 6.2. In all cases it has been assumed that bathymetry as changed to the extent that wave transformation modeling (Item 1.4 in Table 6.1) is required. It is likely that for many locations other agencies will cover the costs of nearshore profile monitoring and aerial photographs and that a dedicated wave buoy will not be required. Also, the estimates in Table 6.2 assume that the site is dredged only once at Year 0.

**Table 6.1.** Low and high cost estimates for the designed monitoring program, for pre-dredging, immediate post-dredging, and Year 1 shoreline monitoring activities plus estimates for seven years of monitoring.

Physical Parameters	Program Element	Low \$ Estimate	High \$ Estimate
1.1	Hydrographic survey with single beam & side scan sonar or multibeam (includes 1 pre-dredging and 1 post-dredging surveys) survey	\$70,000	\$120,000
1.2	Report on seabed change	\$7,500	\$10,000
1.3	Wave buoy (if necessary) (does not include \$10,000-20,000 annual maintenance cost)	\$60,000	\$80,000
1.4	Wave transformation modeling (cost will be reduced by \$20,000 after initial assessment)	\$43,000	\$59,000
1.5	Report and data delivery - Waves	\$10,000	\$15,000
1.6	Nearshore Profiles (if necessary) 2 surveys in the first year post-dredging	\$120,000	\$160,000
1.7	Aerial photography and registration	\$10,000	\$20,000
1.8	GENESIS calibration/verification (initial assessment only)	\$5,000	\$10,000
1.9	GENESIS model tests with and without project	\$3,000	\$6,000
1.10	Interpretation and reporting on shoreline change for Year 1	\$10,000	\$15,000
	<b>Sub-total</b>	\$338,500	\$495,000
Biological Parameters	Program Element	Low \$ Estimate	High \$ Estimate
2.1	Benthic and Sediment Field Sampling Effort	\$26,700	\$35,400
2.2	Fisheries Field Sampling Effort	\$44,400	\$55,800
2.3	Benthic Infauna Sample Analysis	\$60,000	\$100,000
2.4	Incidental Field costs	\$5,000	\$6,000
2.5	Fish-Gut Contents Analysis	\$39,600	\$61,200
2.6	Grain Size and TOC Analysis	\$10,000	\$14,000
2.6	Infauna Stable Isotope Analysis	\$6,000	\$9,000
2.7	Fish Stable Isotope Analysis	\$3,960	\$5,400
2.8	Data Analysis & Reporting	\$30,000	\$45,000
	Sub-Total	\$166,450	\$291,750
<b>TOTAL 1</b>	All Items - Year 1	\$564,160	\$826,800
<b>TOTAL 2</b>	Without Wave Buoy (Item 1.3) – Year 1	\$504,160	\$746,800
<b>TOTAL 3</b>	Without Wave Buoy (Item 1.3), Nearshore Profiles (1.6) or Aerial Photography (1.7) – Year 1	\$374,160	\$571,800

**Table 6.2** Low and high cost estimates over seven years for different scenarios (note: totals are not discounted for time to present day dollars).

<b>Scenario</b>	<b>Low \$ Estimate</b>	<b>High \$ Estimate</b>
1. Full Requirements	\$2,164,800	\$3,429,000
2. No Wave Buoy Required	\$2,034,800	\$3,244,000
3. Nearshore Profile and Air Photo Surveys by Others (with buoy)	\$1,324,800	\$2,309,000
4. Nearshore Profile and Air Photo Surveys by Others (without buoy)	\$1,194,800	\$2,124,000

## 7.0 INFORMATION GAPS

In conjunction with the monitoring program design and assessment of each program element, the project team identified information gaps that will need to be addressed either prior to the implementation of the monitoring program or concurrent with its implementation. These gaps include:

- Are there procedures to dredge shoal and ridge features that will minimize ecological impacts and/or speed recovery, such as dredging completely one specific shoal or ridge and leave adjacent features un-touched vs. dredging a small amount of sand from each shoal or ridge feature, or dredging in strips leaving undisturbed areas that act as local sources of recruitment and allow recruitment from older life stages, as supported by the work conducted by Whitlatch et al. (1998).
- Are there gaps in baseline data, both biological and geomorphological, at each candidate OCS dredging site? Although some site characterization data have been gathered at some locations, the data and information are such that they will not suffice for establishing an accurate "before impact" data set.
- What is the use and role of sand ridges and shoals as potential "essential fish habitat" by migrating or resident fish? Many researchers suggest that these topographic features perform some critical function in supporting fish stocks, either during migration or as habitat for spawning/juvenile fish. However, there are limited data to confirm or disprove this belief.
- Are there benthic biological differences that run longitudinally along the ridge and shoal features that may affect the proposed sampling design and require further stratification?
- Can the relationship of carbon and nitrogen stable isotopes and trophic level improve the scientific knowledge of how the alteration of organic matter and benthic invertebrate communities affect the population of bottom feeding fish in an anthropogenically disturbed and recovering area of the ocean?
- Is there a preferred manner to remove sand from a shoal/ridge feature to maximize their use and maintain the integrity of the feature? For example, there are currently concerns that certain dredging practices results in the accumulation of fine-grained sediments in the burrow areas, making the site unsuitable for re-use. Also, there are questions about where on ridges is it best to dredge to speed recovery and reduce long-term impacts.

Several of the key questions related to data gaps are concerned with the nature and characteristics of ridge and shoal features. As a result, and considering that the majority of deposits that have been identified thus far fall into this category, a preliminary review of the literature was completed to assemble what is know about physical and biological processes associated with these features. Section 7.1 presents a summary of this review.

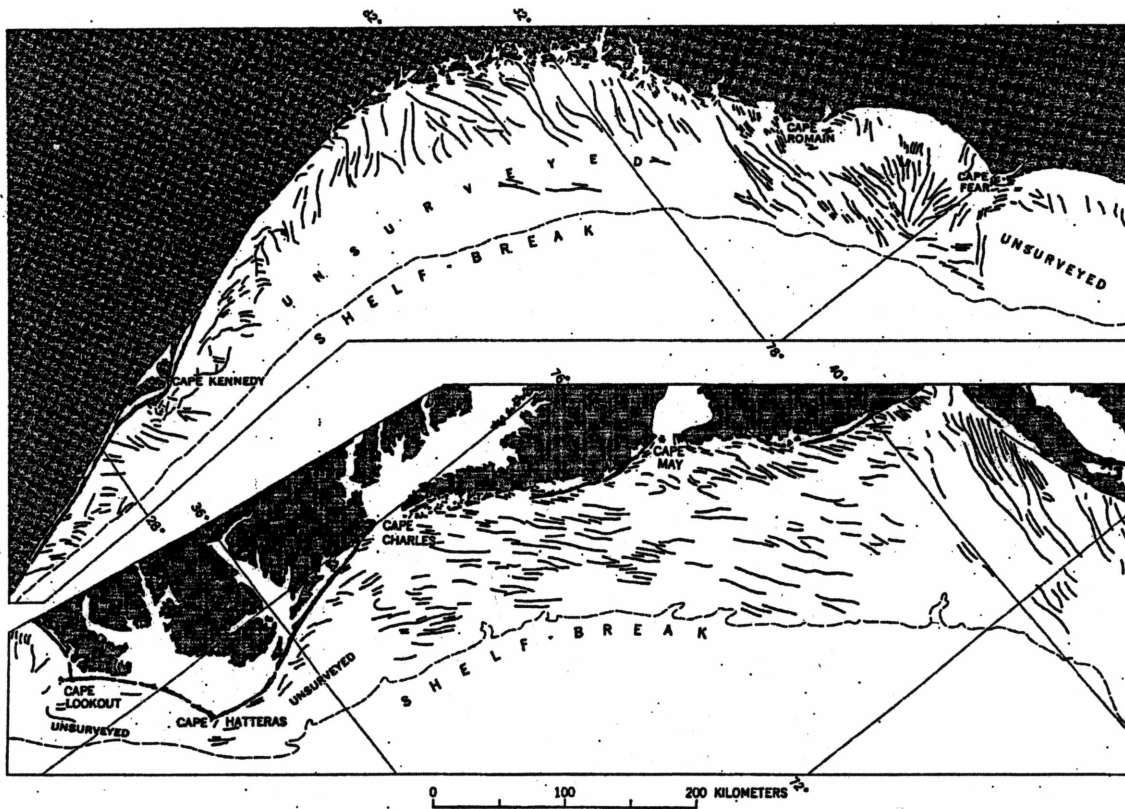


It is important to note that while the majority of potential OCS borrow deposits identified to date consist of ridges and shoals, in the future it is likely that the range of deposit types will be expanded to include paleo-channels, paleo-deltas, and other buried sand deposits. It has been postulated that while ridges and shoals are more readily (and less costly) to identify in the first place, it is likely that more economic (i.e., larger and closer to shore) and higher quality buried deposits will be discovered within federal waters.

## 7.1 Characteristics of OCS Shelf Sand Ridges and Shoals

### 7.1.1 Definition and Occurrence

There are several different kinds of sand bodies present on the continental shelf of the USA, but this discussion will focus primarily on sand ridges and swales that are located on the inner/upper continental shelf and oriented obliquely to the predominant/prevaling wave approach direction. One of the first comprehensive descriptions of these occurrences on the continental shelf off the east coast of the USA was by Uchupi (1968). His map, shown in Figure 7.1, illustrates the features he termed sand swells and described as follows:



**Figure 7.1.** Sand swells on continental shelf from New York to Cape Kennedy. Curved lines indicate crests of sand swells (from Uchupi, 1968).

- 1) Radiating clusters near the mouths of estuaries
- 2) Arcuate, seaward convex ridge systems near cusped forelands
- 3) Shoreface ridge and swale systems
- 4) Broadly spaced ridges and swales on open shelf

Types 3 and 4 will be emphasized in this discussion.

Other types of sand bodies preserved on the shelf that could provide sand for beach renourishment include; (1) overstepped barrier islands (e.g., Ship Shoal off the Mississippi Delta); (2) estuarine entrance shoals (both active and inactive; e.g., off St. Helena Sound, South Carolina); (3) large ebb-tidal deltas off major tidal inlets (e.g., off inlet to Mobile Bay), (4) delta lobes deposited at lower stands of sea level (common off Santee Delta, South Carolina); (5) features associated with low stand river valleys (present on shelf off Texas and North Carolina); (6) tidal sand ridges (off New England and Alaska); and possibly others.

The best examples of ridge and swale topography on the North American continental shelf occur in the following areas:

- 1) Mid-Atlantic Bight (Fig. 7.2)
- 2) Northeastern Gulf of Mexico (off coasts of Alabama and northwest Florida; Fig. 7.3)
- 3) Sable Island Bank, eastern Canada (Fig. 7.4)

Note that in every case, the ridges are oriented directly into the predominant/prevaling or storm wave direction. Waves approach from the northeast in mid-Atlantic Bight (during “nor’easters”), from the southeast off Alabama, and from the southwest on Sable Bank. This fact seems to imply a common process for the origin and maintenance of these features.

Table 7.1, summarized from the data for the Maryland shelf (slightly modified from Swift and Duane, 1981) and for global sand ridges (including tidal sand ridges) (from Snedden and Dalrymple, 1999), lists the general characteristics of sand ridges.

The grain size trends commonly observed on the sand ridges off Sable Island and New Jersey are illustrated in Figure 7.5. Coarsest sediments occur in the swales and on the updrift sides of the ridges (i.e., northwest side of New Jersey ridges and west side of Sable Island ridges). This pattern appears to be typical for ridges in <20 m depths. This observation implies that the coarser sediment is a lag-like deposit that acts to stabilize the ridge to some extent.

In any event, it seems clear from the numerous studies that have been conducted within the last two decades, that once formed, most ridges in depths <20 m are maintained and even enlarged by present-day hydrodynamics (Snedden and Dalrymple, 1999). It also seems clear that there is an evolutionary progression in an offshore direction as the influence of waves diminishes. The contrast of storm and fair-weather conditions on the ridges, in both nearshore and offshore areas, as envisioned by Snedden and Dalrymple (1999) is given in Figure 7.6. Measurements of currents during a storm imply that storm-generated currents do run obliquely offshore and across the crest of a shoreface attached-ridge in New Jersey (Fig. 7.7; from Snedden et al. 1994).

**Table 7.1.** General characteristics of sand ridges summarized from the data for the Maryland shelf (slightly modified from Swift and Duane, 1981) and for global sand ridges, including tidal sand ridges (from Snedden and Dalrymple, 1999).

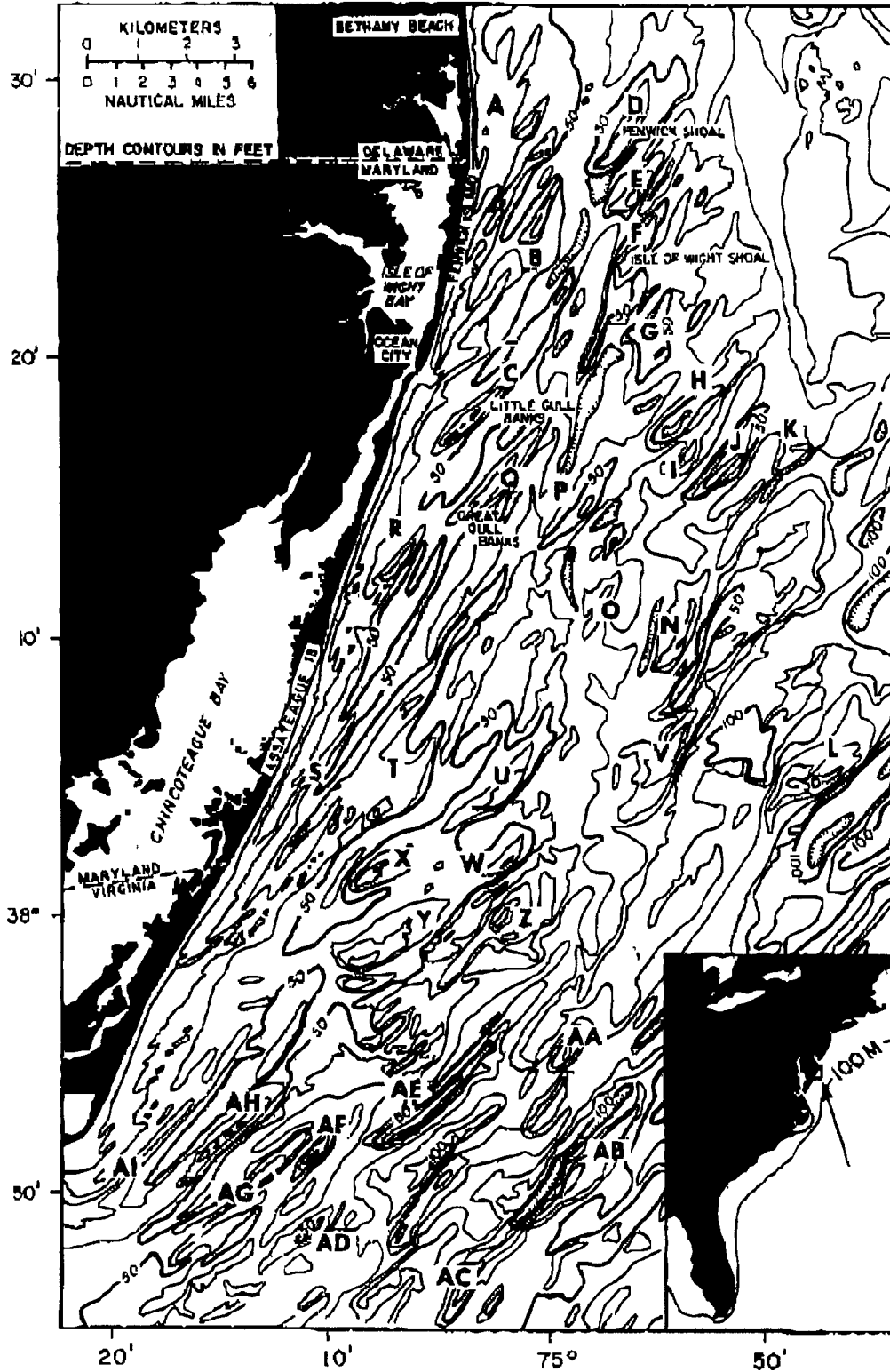
<u>Criteria</u>	<u>Maryland</u>	<u>Global</u>
orientation	perp. to wave approach	flow-oblique
symmetry	asymmetrical near shore	asymmetrical
relief	3-12 m	5-40 m
horizontal width	0.9-2.8 km	0.7-8 km
spacing	1.5-11.1 km	-
maximum side slopes	0.2-7 degrees	<1-7 degrees
grain size	fine to coarse sand	fine to coarse sand
lateral trends (grain size)	stoss side coarser than lee side	stoss side coarser
superimposed bedforms	ripples to sand waves	ripples/sand waves

Goff et al. (1999) state that “in depths >20 m, ridges have not continued to grow since transgression has brought them into the offshore hydrodynamic regime”. Many studies have concluded that there is reworking of the tops of the ridges located further offshore, but few imply that the ridges have been completely reformed.

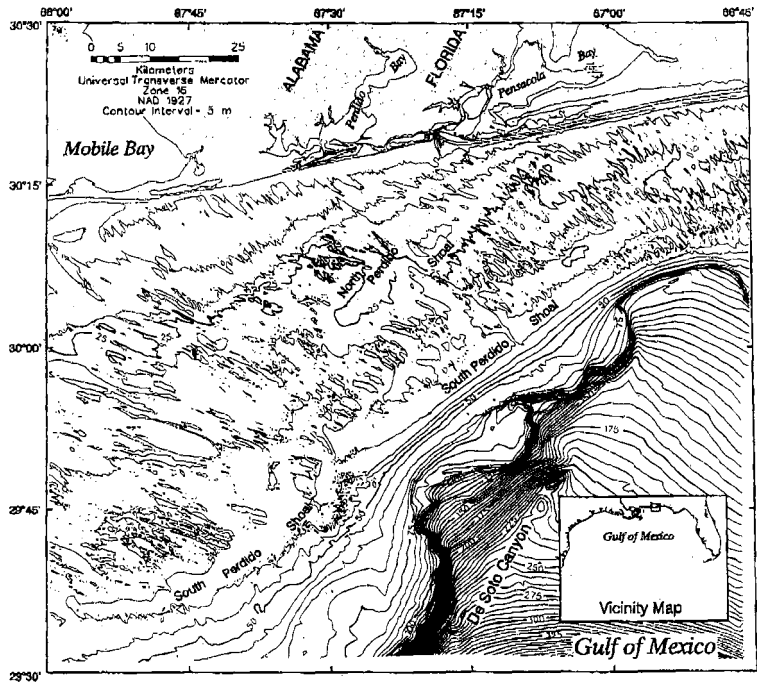
### 7.1.2 Theories for Origin

The Ship Shoal off the coast of Louisiana, which was treated in a comprehensive study by Penland et al. (1986), is discussed first. Their study included vibracoring, age dating, seismic profiling, fossil assemblage studies, etc. The shoal, located in 3-10 m water depths, has a 5 m thick core that was clearly defined as a barrier island deposit in that study. However, the shoal is asymmetric landward, implying some modification and reworking by waves. Preservation of a relict barrier island of this magnitude can only occur on shorelines that are sinking rapidly, which is certainly the case for the Mississippi delta lobe that the barrier island was associated with. That delta lobe was abandoned when the river mouth switched to a new position. On tectonically stable shelves, such as Maryland and Alabama, any such low-stand barrier islands that may have been present in those areas, owing to a stabilization of sea level for some period of time, were eroded away during the slow rise of the sea after formation of the islands. Some authors, such as Stubblefield et al. (1984) and others, do believe that remnants of relict barrier islands are still preserved on the middle continental shelf of the Mid-Atlantic Bight, but none have been proposed for depths as shallow as the Ship Shoal, at least not in the more recent literature.

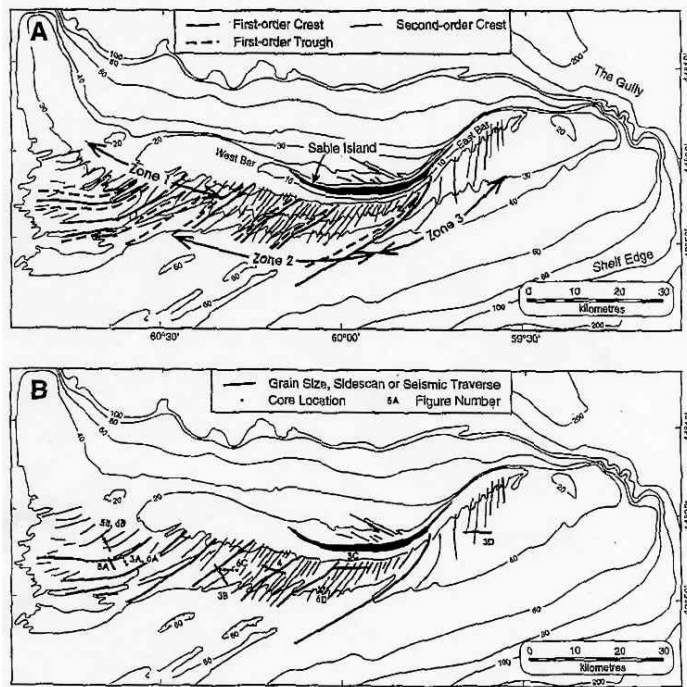
*Sand ridges, Maryland coast*



**Figure 7.2.** Bathymetry of the Assateague ridge field, contoured from National Ocean Survey smooth sheets. Ridges are designated by letters. Contour interval: 10 feet. (From Swift and Field, 1981).

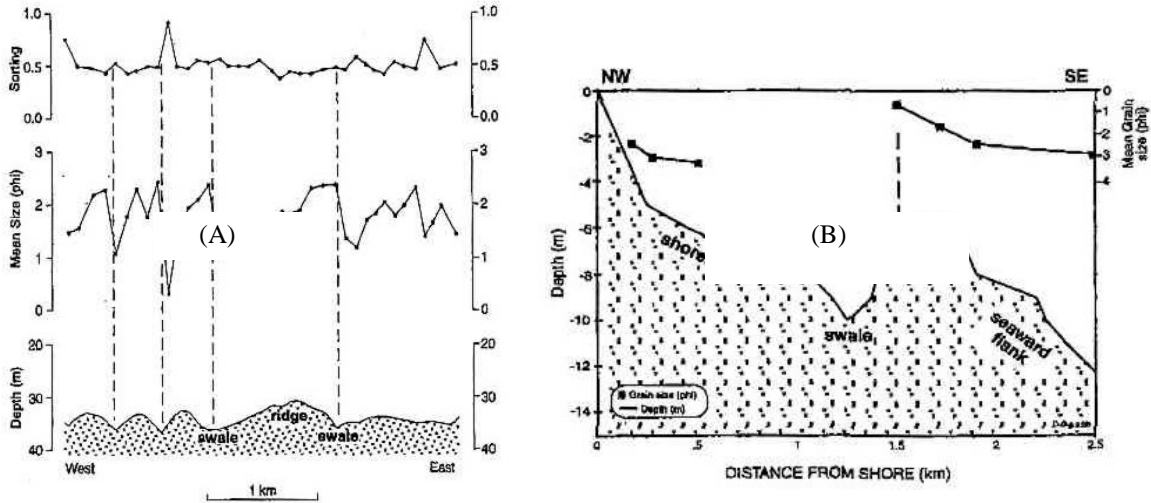


**Figure 7.3.** Study area in the northeastern Gulf of Mexico showing detailed bathymetry at 5 m contour intervals. Thicker contours are at 25 m intervals. North and South Perdido Shoals trend northeast - southwest on the mid-shelf area. From McBride et al. (1999).

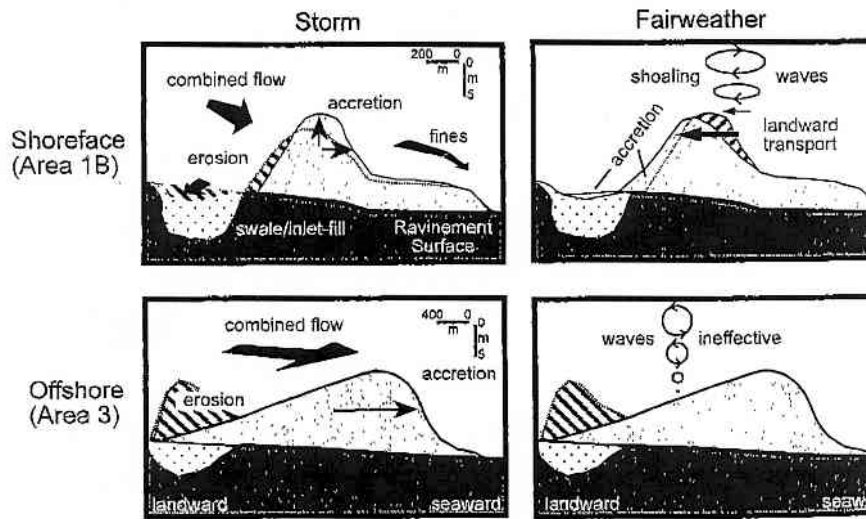


**Figure 7.4.** (a) Bathymetry (in metres) of the area surround Sable Island, with crestline positions of the shoreface-attached ridges and locations of morphological zones discussed in the text (B) Location of grain-size transects, sidescan and seismic profiles, and vibrocores shown in subsequent figures. From Hoogendoorn and Dalrymple (1986).

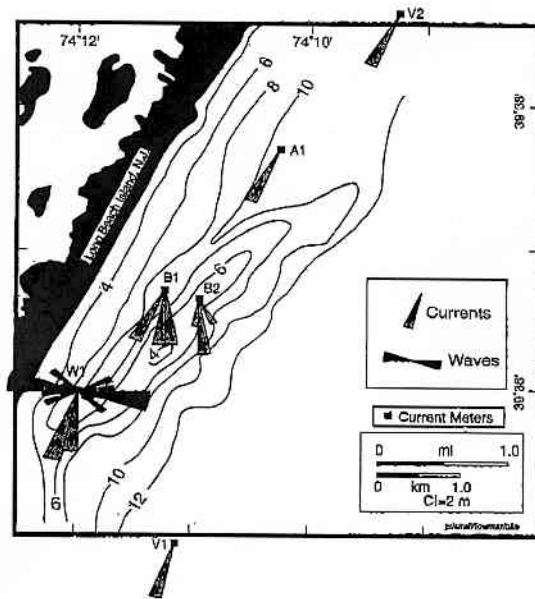




**Figure 7.5.** Trends in texture of surficial sediments over shoreface sand ridges. A) Sable Island, Nova Scotia. B) Peahala Ridge, New Jersey. Note offset between the bathymetric and grain-size profiles. From Snedden and Dalrymple (1999).



**Figure 7.6.** Storm and fair-weather dynamics and ridge migration in nearshore and offshore areas. Based on current meter reported in Snedden et al. (1994) and McClelland (1973b) and bathymetric surveys of McHone (1973). From Snedden et al. (1999).



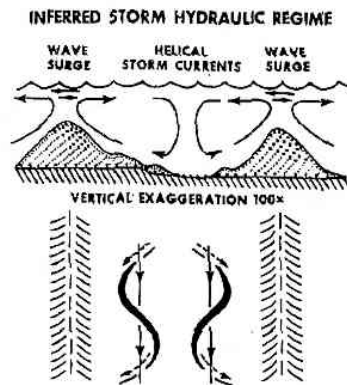
**Figure 7.7.** Orientation of near-bottom, peak storm current and wave motion 30-31 March 1985. Current meters V1 and V2, which are located outside map area, are shown for reference. From Snedden et al. (1994).

The development of ridge and swale topography of the type under discussion here seems to be favored by the following conditions:

- 1) A wide, sandy continental shelf with a moderately abundant sand supply, either from riverine sources, erosion of the shoreline as the sea level rises, or from sediment brought to the shelf during periods of glaciation and/or ice melt.
- 2) Rising sea level over a widening shelf.
- 3) Drowned bathymetric irregularities that act as nuclei for the ridges.

Ridges and swales do not occur on prograding delta fronts or other intensely prograding areas, especially those with high rates of mud deposition. Based on the limited literature search completed, they do not occur on macrotidal coasts, but apparently there are some off the mesotidal coast of Western Europe. The center of the Georgia Bight, which has the largest tides along the east coast of the USA south of Maine as well as an abundant muddy sediment source, does not have near the number of ridges as seen in the Mid-Atlantic Bight area.

Early studies on the Mid-Atlantic Bight recognized a need to explain the puzzling fact that the ridges were parallel to each other, seeming to mimic earlier ridges out on the shelf, and that they were oriented directly into the dominant northeasterly wave approach direction. Swift et al. (1973) and later authors of the same group concluded that the ridges were derived from the shoreface of barrier islands as they retreated across the continental shelf in response to rising sea level. Over time, these new shoals broke away from the barrier islands and retreated to the southwest as the barrier island continued to migrate landward. In order to explain how the ridges were maintained, these authors called on storm-generated helical secondary flow structure and storm wave surge, which resulted in converging bottom currents that aggraded the ridge crests. This model is illustrated in Figure 7.8.



**Figure 7.8.** Schematic diagram of secondary flow motions (helical flow structure) and storm wave surge believed to be associated with storm flow field. From Swift et al. (1973).

Numerous other theories have been proposed, none of which dispute the importance of rising sea level and an abundant sand supply. One of the more interesting ones is the theory of Boczar-Karakiewicz and Bona (1986), which states, “On wave-dominated shelves, a mechanism that may account for systems of sand ridges is associated with the development of infragravity waves”. These waves have periods ranging from 30 seconds to 5 minutes. This theory does seem to account for the number and parallelism of some of the ridges, but even the authors admit that issues such as how the sediment gets onto and is dispersed along the shelf and what mechanisms lead to the development of the ridges are unknown to them.

Another theory of formation has been prepared by Trowbridge (1995), who once again, discussing the ridges on the Mid-Atlantic Bight shelf, states that storm-driven southerly currents veer offshore over the ridge crests. This is apparently true, as the data of Snedden et al. (1984; see Fig. 7.7) clearly show. Trowbridge also states that the “exponential growth of shore-oblique features is a result of offshore deflection of storm-driven alongshore flows at ridge crests, which leads to convergence of sediment flux because the effective carrying capacity decreases with increasing distance offshore.”

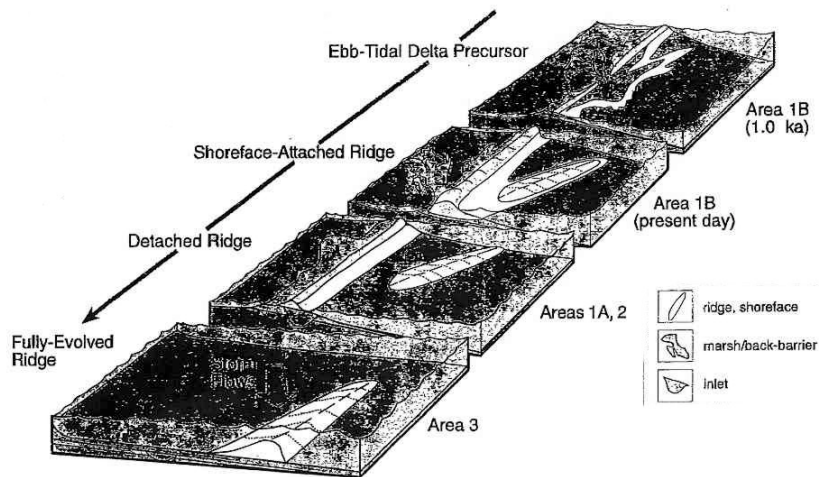
One of the more widely quoted theories is that of Huthnance (1982), even though it was originally proposed to explain the tidal sand ridges in the North Sea, which are clearly related to tidal activity. In any event, the Huthnance model has the following requirements:

- 1) Irregularities exist on a sandy bed
- 2) The current runs around and over these irregularities
- 3) Upcurrent side starts to accrete
- 4) Then upcurrent side eroded with sand being deposited on crest of new feature which causes it to grow upward and migrate down current
- 5) Maximum growth is oblique to flow direction
- 6) Grows until “equilibrium profile” is reached
- 7) No more active growth
- 8) Waves would erode the ridge but currents counteract wave action, maintaining the ridge



There are three major constraints that must be met in order for this theory to work: (1) a sufficient quantity of loose sand (no problem); (2) currents capable of moving the sand; and (3) a pre-existing irregularity.

In order to take issue three into account, many of the recent workers favor an idea presented by McBride and Moslow (1991), which is outlined in Figure 7.9. Under this theory, the “pre-existing irregularity” is the ebb-tidal delta of an inlet through the adjacent barrier island. The inlet migrates downdrift, leaving a piece of its ebb-tidal delta behind that becomes the core of the new sand ridge formed by the process outlined by Huthnance. The inlet continues to migrate until it eventually closes and a new inlet forms and the process starts all over again. Snedden and Dalrymple (1999), in an excellent paper on sand ridges, are strong proponents of this idea, and indicate that the migrating inlet somehow is responsible for the swale on the landward side of the new ridge. There are limitations and outstanding questions with all of these theories so the search for the universal precursor (initial irregularity) of sand ridges continues, to fulfill the Huthnance theory. There could be any number of possible initial irregularities, as suggested by Snedden and Dalrymple (e.g., submerged pieces of relict barrier islands).

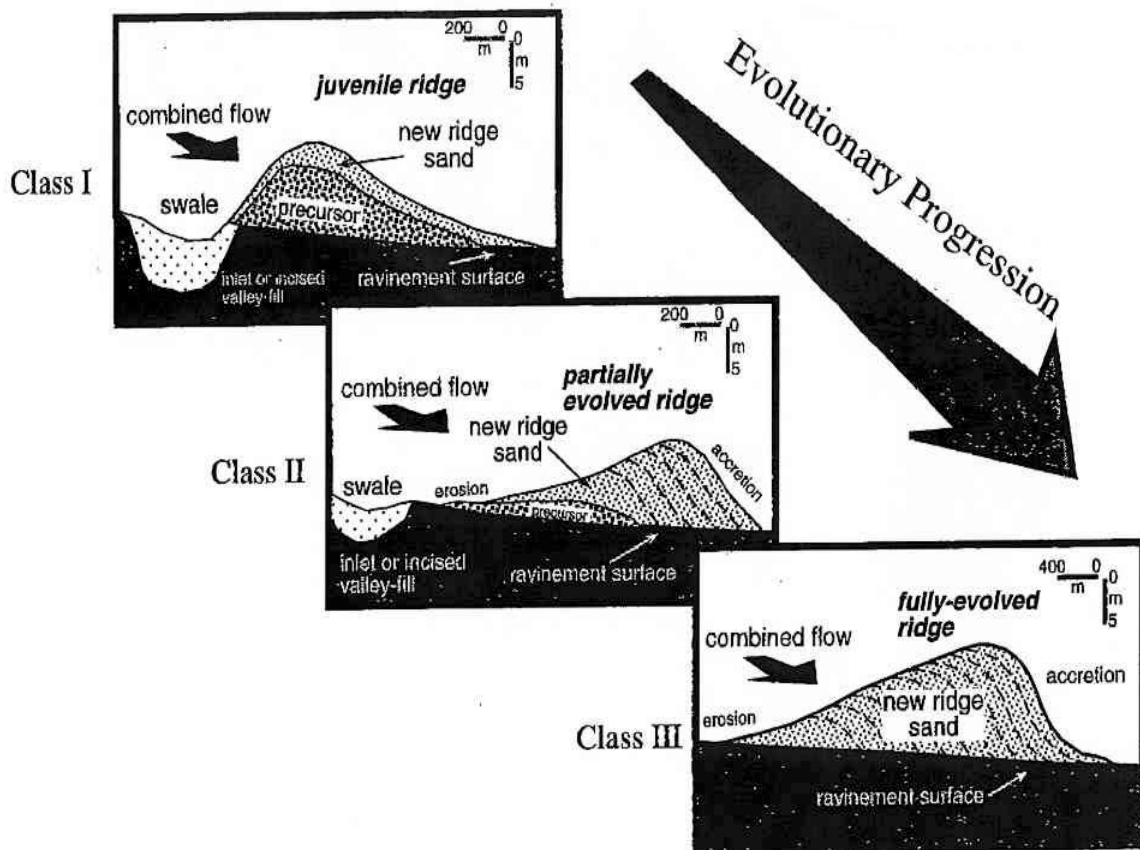


**Figure 7.9.** Evolution of ridges on the New Jersey Atlantic Shelf, USA. The first three evolutionary phases depicted here (ebb-tidal precursor, attached-ridge) are modified after McBride and Moslow (1991). From Snedden et al. (1999).

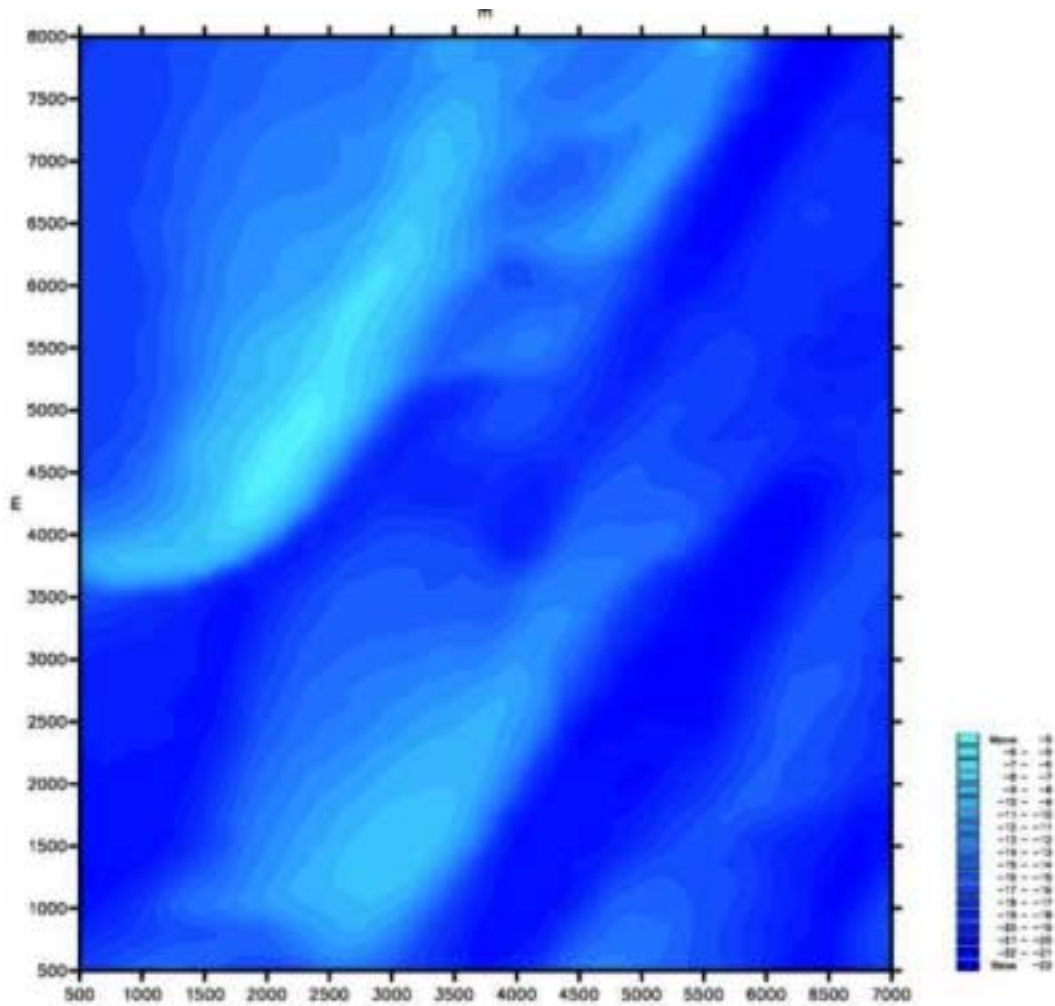
In the evolutionary progression for the sand ridges proposed by Snedden and Dalrymple (1999), the ebb-tidal delta precursor may eventually be either left behind or eroded away as the migrating ridge works its way offshore (illustrated in Fig. 7.10).

One process that has received little attention in the literature is the influence of wave action on these features. As part of this study, a Boussinesq wave model (phase resolving) was applied to assess the influence of waves on the group of shoals offshore Maryland/Delaware

(Fenwick, Weaver and Isle of Wight Shoals). The results for a 1-m, 16-s wave from the ENE are shown in Figures 7.11A-C. Figure 7.11C is a snapshot of an animation which clearly demonstrates together with Figure 11B that the waves converge over the crest of the shoal. Shoaling waves and the related orbital velocities in these water depths are non-linear and generally result in sand transport in the direction of wave attack. Therefore, over the crest of the shoal the converging waves would head to a convergence of sand transport. This process could explain how these features are maintained over time.

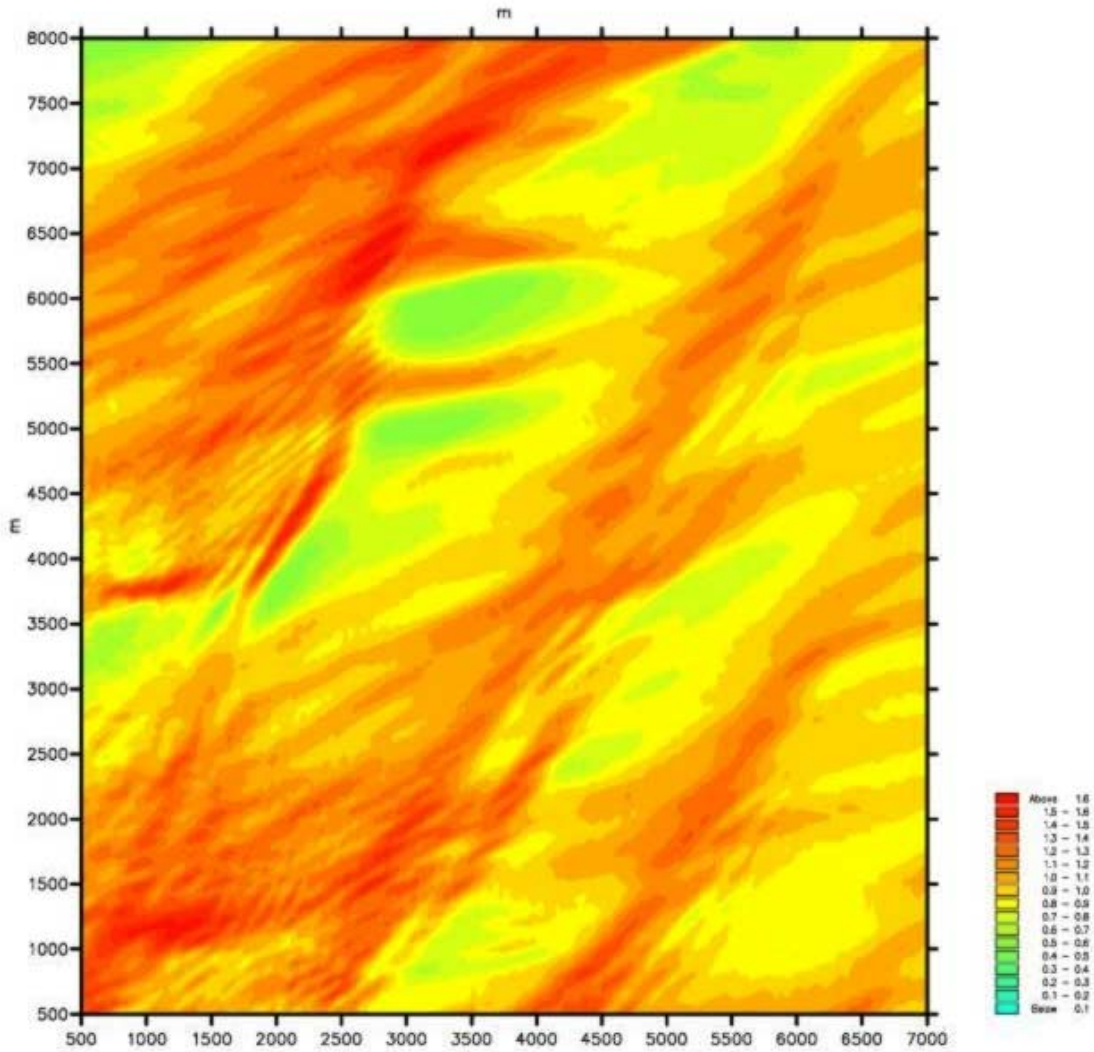


**Figure 7.10.** Schematic diagram of ridge classes. The precursor in the case of the Class I and II ridges is a pre-existing bathymetric feature, sometimes associated with a shoreline or inlet, which provides the nucleation point for the ridge via the Huthnance process. Subsequently, this precursor may be removed or reduced in size through current erosion and ridge migration. Accretion on the landward side of the juvenile ridge (Class I) is largely induced by fair-weather wave transport from the ridge crest and is not expected to occur in ridges developed in deeper water, as with Classes II and III. New ridge sand is primarily deposited in shelf waters by combined flows associated with storm passage. From Snedden and Dalrymple (1999).

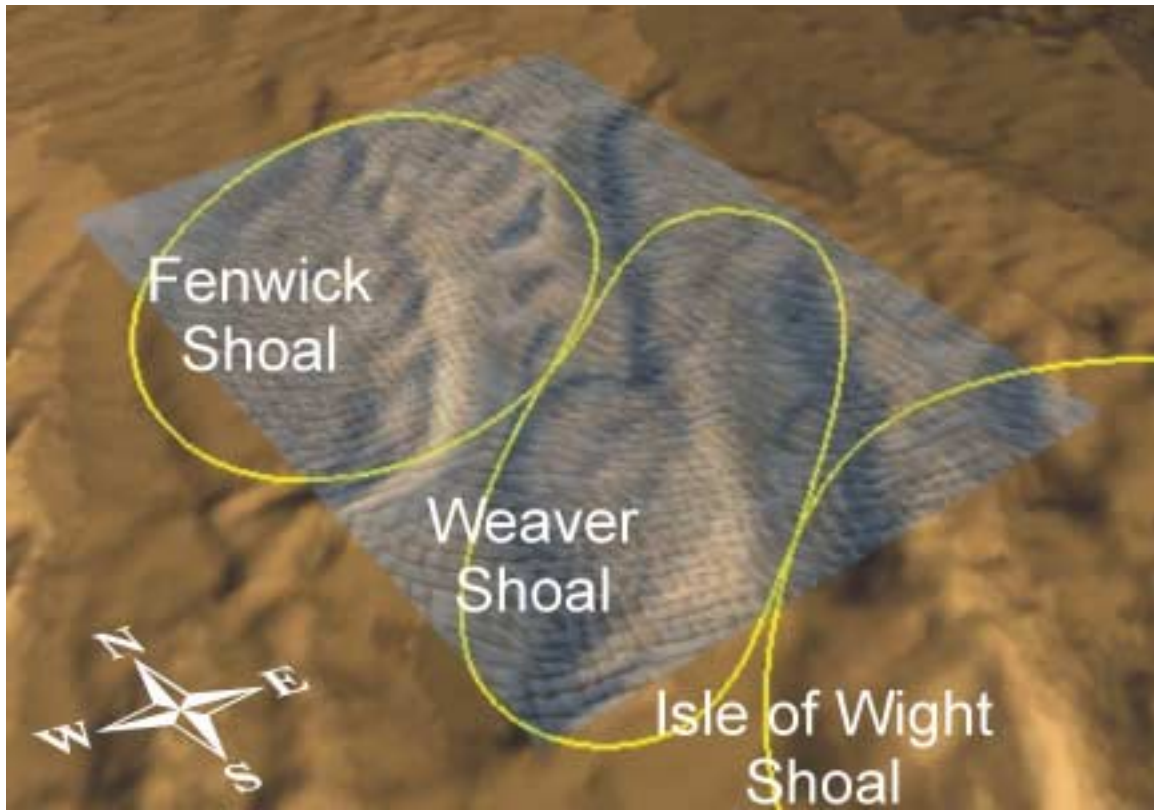


**Figure 7.11A.** Bathymetry of shoals offshore Maryland/Delaware border (depths and x-y axes in meters).

Another formation process or explanation of origin for ridge and shoal features relates to stratigraphically controlled features. These consist of sand deposited over Pleistocene sediment units and are particularly prevalent along the North Carolina coast (Stan Riggs, pers. comm.) The stratigraphy of such features has important implications to the size of sand reserves and the potential impacts of dredging.



**Figure 7.11B.** Wave heights predicted by a Boussinesq wave model for shoals offshore of the Maryland/Delaware border (incoming wave:  $H_s=1$  m,  $T_p=16$ s, ENE).



**Figure 7.11C.** 3D view of three shoals.



### **7.1.3 Future Formation and Mobility of the Ridge Features**

Sand ridges will continue to form in the future providing there is enough sand available for ridge formation. Ridge formation continues at the present time, as evidenced by the presence of numerous shoreface-attached ridges in the two study areas (Alabama and Mid-Atlantic Bight). Also, numerous studies have shown that wave-generated currents and storm-generated flows impact the ridges several times a year. But this must be a very long-term process and may not mitigate the loss of a ridge resulting from dredging activities.

An important issue is how fast are the ridges moving, which is an indirect way to infer how quickly they will be re-created. The following are some comments from the different papers on rates of migration and infill:

- 1) Ridges migrate fifty meters per year off Sable Island (Hoogendoorn and Dalrymple, 1986).
- 2) Quote from Alabama report Aubrey et al. (2000) – “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.” One dredged area refilled at 10,000 cubic meters per year. An even faster rate was reported where silt and clay were refilling the dredged area.
- 3) Numbers from Duane et al. (1972) - ridge moved 3600 m in 53 years (off Virginia coast); ridge moved 76 m during the Ash Wednesday storm of 1962 (off Delaware).

These numbers seem to indicate that re-creation or recovery is a possibility in some areas.

The part of the ridge the sediment comes from would also seem to be an issue. It is probable that some engineers would prefer to take the coarsest sand from the northwest side of the shoal (Mid-Atlantic Bight example). However, this might slow the rate of recovery of the ridge to its original shape and position, because it might be shifted further down current because of the absence of the coarse lag on the upcurrent side. If the ridge is located in depths >20 m, the possibility of reformation is probably quite remote. According to Goff et al. (1999), in depths >20 m, “ridges have not continued to grow since transgression has brought them into the offshore hydrodynamic regime”.

### **7.1.4 Impact of Dredging**

One of the primary concerns regarding the impact of dredging is whether the removal of sand from the shoal will somehow disrupt the process that maintains the shape of the shoals. For example, if convergence of waves over the crest is a contributing factor to maintaining the shape of the shoals as suggested in Section 7.1.2, there may be a limit where reduction in the crest height of the shoal would suppress this process. The concern would be that the shoal might deflate or unravel, losing its form with time.

At this time the state-of-the-art in modeling these processes is probably insufficient to confidently assess the impact. Therefore, the focus of the monitoring protocols for bathymetry is to track changes in the shape of the shoal, ridge, or swale features.

### **7.1.5 Biological Factors**

In support of this project, a fly-through of the bathymetry and some biological data collected by VIMS (2001) for the Maryland/Delaware shoals and presented in GIS was developed. Based on the fly-through, there appeared to be relationships between the topography of the shoals, sediment grain size composition, and some of the biological parameters characterizing the benthic and nekton communities. It was initially assumed by the project team and later confirmed by the fly through that these offshore ridge and shoal features represent very diverse and active physical systems with differing habitat conditions located throughout each feature. For example, the ridge tops represent a very high wave energy, intensely stirred and mixed coarse sediment with low organic material type habitat, whereas the trailing slope of the feature (up wave) is a habitat with a very gentle slope, decreasing energy and surface sediment mixing from wave action as it slopes into deeper water, and organically enriched sediments from deposition of fines. There are at least two other unique physical habitat areas on and surrounding the ridge features: 1) the leading (down wave) side of the ridge is steeper and is depositional in nature (many ridges will be slowly migrating in the direction of this side of the ridge); and 2) deep troughs between the ridges that are relatively sheltered from wave action (due to both depth and breaking of waves over the crest of the ridge) and feature fine muddy sediments. The benthic communities and fish populations associated with each of these habitats are very different, as indicated in the VIMS (2001) study. It can also be assumed that small micro-habitats will also exist within the shoal and ridge features. It may be inferred that if a shoal did deflate due to dredging impacts, these community structures would be significantly influenced.

Despite the prevalence of these features along the east coast of the United States, little is documented about the ecological relationships of these features and their associated biological communities. Several authors (Louis Berger Group, 1999; Hammer, 1993; Oakwood Environmental, 1998) speculate about the importance of offshore ridge and shoal features to fisheries migrations and as important habitat for fisheries growth and development. However, a literature review conducted by the project team failed to obtain any scientific evidence to support these relationships.

### **7.1.6 Summary**

There is no apparent consensus on the processes that work to maintain the shape of the ridge, swale, and shoal structures that represent the form of many of the identified OSC borrow sites. The role of wave action appears to have been entirely neglected in the literature. While there are no direct references in the literature, there is evidence that the form of these sand body features may have an important influence on the structure and distribution of biological communities inhabiting them. Monitoring for changes to the form of the shoal, grain-size characteristics, and the related biological communities is essential.

It is also recommended that research into the physical, biological and biophysical processes of these features be performed. Results from the monitoring program will be valuable for such investigations.

## 8.0 DATA MANAGEMENT

The various monitoring protocols that have been developed and are described in Section 4 each include a section on requirements for data deliverables. Each monitoring survey (triggered by a dredging event or a timing requirement) will result in the collection of large amounts of spatial data, most of which will be repeated in subsequent monitoring programs. These large data sets will be developed for each borrow deposit or regional group of borrow deposits. Over time, this temporal continuance will create an extremely large database of information that must be properly organized and documented with appropriate metadata.

For each sand borrow site, it will be necessary in the assessment of possible impacts to make inter-comparisons between different data layers for a given time period and over time. It is likely that these types of analysis will also reveal new understanding on the temporal and spatial relationships among the various key physical and biological parameters. As explained in Section 5.0, understanding these new relationships forms the cornerstone of Adaptive Management, guiding future refinements to the monitoring program.

A list of generic data types that will be collected is provided in Table 8.1. In addition to these parameters that are measured, many other parameters will be derived from this information. Some derived data set examples are provided.

**Table 8.1.** Data sets to be collected in the OCS sand dredging monitoring program.

<b>Protocol</b>	<b>Data Set Created</b>	<b>Derived Data Sets</b>
Bathymetry and Substrate	Digital Elevation Model of the Seabed, Seabed Texture	Maps of Seabed Change and Changes to Bedforms
Waves	Deepwater Wave Record, Wave Climate (Height, Period, Direction and spectral characteristics) in Offshore, Borrow and Nearshore Regions	Bed Shear Stresses, Sediment Mobility Characteristics
Shoreline	Aerial Photos, Nearshore Profiles, Measured (interpreted) and Predicted Shoreline Positions	Rates of Shoreline Change, Longshore Sand Transport Rates
Benthos	Species Presence, Species Abundance, Wet Weight and Dry Weight Measurement for Each Species	Species Density, Biomass, Secondary Productivity
Fish	Specimen Species Identification, Standard Length, Sex and Sexual Maturity, Wet Weight of Gut Contents by Taxon, Specimen Wet Weight	Species Abundance, Species Density, Species Biomass, Index of Relative Importance for Gut Contents
Grain Size	% Sand, Silt and Clay per Sample	Strata Characteristics, Combine with Seabed Texture from Bathymetry and Substrate Protocol
Stable Isotopes	Carbon and Nitrogen Isotope Values per strata for Benthos and Fish	Carbon and Nitrogen Isotope Ratios.



Therefore, it is evident that a well-planned data management program will be required. The program should achieve the following objectives:

- Retain the integrity of the original data quality (once collected it cannot be altered);
- Support easy and timely database update with newly collected data;
- Adhere to FGDC Metadata standards to permanently document data characteristics (date collected, data collection techniques, notes on limitations, etc.);
- Store data in common horizontal projection and vertical reference datum in GIS format;
- Be well organized under Protocol groupings and for individual borrow deposits or geographic groupings of deposits;
- Be searchable via keywords and map-based spatial queries;
- Be fully and easily accessible over the Internet with on-line mapping tools available to view the data in a variety of combinations;
- Be scalable to allow for an ever increasing growth in database size;
- Provide data download capability based on user access privileges; and
- Be adaptable to incorporate new or different data types as a result of refinements to the monitoring program.

In doing so, the data management program will provide the following benefits:

- The data will be widely used to assess possible impacts and support research into improved understanding of the physical, biological and biophysical processes associated with the borrow deposit environments;
- Efficient access to data will maximize the time available to interpret the data;
- Decision-making processes on impacts will be transparent; and
- Ensure timely access to information critical to the ongoing Adaptive Management program.

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## **Appendix A**

## **WORKSHOP SUMMARY**

### **Design of a Monitoring Protocol/Plan for Environmentally Sound Management and Development of Federal Offshore Borrow Areas Along the United States East and Gulf of Mexico Coasts**

In April 2000, the MMS awarded a contract to Research Planning, Inc. (RPI) of Columbia, South Carolina to design and develop biological and physical monitoring templates for the Outer Continental Shelf (OCS) sand resources. Baird and Associates, Inc. and Applied Marine Science are key sub-contractors on the project. The project consists of the following components:

- Development of field monitoring systems to evaluate the physical and biological effects of using Federal offshore borrow areas on a long-term basis;
- Examination of the feasibility, appropriateness, and desirability of putting these monitoring systems into place and identification of the need for collection of supplemental biological data or physical modeling information in the Federal borrow areas;
- Identification, review, and evaluation of environmental work or mechanisms (organizational, economic) that may be needed to offset any potential adverse impacts; and
- Identification of the need for and collection of any additional geological/geo-physical data to define available sand supplies for planned projects within the study areas.

An additional component of the project is to formulate options and recommendations for including Federal, State, and local governments in an overall planning process to manage the Federal offshore borrow sites in an environmentally responsible and cost-effective manner over a long-term period.

A workshop was held on 12 December at the Virginia Institute of Marine Science. The objective of the workshop was to have scientific review of the proposed monitoring protocols before preparation of the draft report. The workshop agenda and participants are listed below.

#### **Agenda**

- 8:30 Introductions of Participants
- 8:45 Overview of the Project
- 9:00 Characteristics of Known Federal OCS Borrow Sites
- 10:00 Monitoring Questions to be Addressed
- 10:30 Impacts Summary and Monitoring Objectives
- 11:00 Proposed Monitoring Approaches
- 12:00 Lunch
- 13:30 Open Discussion

16:30 Summary of Discussion, Future Directions

17:00 Adjourn

### **List of Participants**

#### USACE

Joan Pope, Corps of Engineers Coastal and Hydraulics Lab

Jerry Swean, Norfolk District

Chris Spaur, Baltimore District

#### VIMS

Woody Hobbs, Bob Diaz, Scott Hardaway, Jerome Maa, Lyle Varnell

David Basco, Old Dominion

Bob Van Dolah, S.C. Department of Natural Resources

Jeff Redidenauer, Louis Berger & Associates

Rich Hammer, Continental Shelf Associates

Mark Byrnes, Applied Coastal Research and Engineering, Inc.

Barry Vittor, Barry Vittor & Associates, Inc.

#### MMS

Barry Drucker, Beth Burkhard

#### Project Quality Review Board

Al Hine, University of South Florida

Stan Riggs, East Carolina University

#### Project Team

Jacqueline Michel, Research Planning, Inc.

Rob Nairn, Baird & Associates Ltd

Jay Johnson and Dane Hardin, Applied Marine Sciences, Inc.

## **Regional Sand Management Strategy Issues from the 12 December 2000 Workshop**

1. Identify critical endpoints, e.g.,
  - maximum removal depths or volumes
  - no pits (and definition of pit)
  - don't affect shape
  - don't affect wave patterns that lead to shoreline erosion/change
  - don't affect grain size that will affect future utility of the site prematurely
2. Talk with Bob Dean about CETAC guidelines for Florida
3. Consider sand transport processes, whole system functioning, in coordination with the ACOE
4. Fish issues to deal with: Essential fish habitat, fish utilization of topographic features for migration, spawning/juvenile habitat. Look at coming report by Diaz on fish probability model; check with fishers about local knowledge
5. Data gap: how to dredge shoals to maximize their use?
6. Funding for long-term monitoring from the lessee? Need justification; show that it is in their best long-term interest; that they will get better use of sites.
7. Shoreline change monitoring guidelines. Check with MD, DE, FL for programmatic guidelines.
8. Develop the concept of a Technical Review Committee at the regional level. Would have ability to review and change monitoring programs, using the Adaptive Management Approach. Determine resource utilization timeframes (volume available versus long-term needs) that would filter into monitoring plans.
9. The concept of a national Science Review Committee that would:
  - deal with multi-site issues,
  - develop nation-wide guidelines,
  - determine conformance of monitoring programs with the guidelines,
  - approve changes to monitoring programs recommended by the regional groups
  - be totally independent of work being done at the sites
10. Define levels of change in parameters that are acceptable. e.g., 80% of volume lost has been replaced, biological abundance/diversity to xx% of reference, etc.
11. Find out what chemical testing of borrow site materials is already being done by both the ACOE and by states working on projects without ACOE funding (e.g., Florida).



## Monitoring Protocol Issues from the 12 December 2000 Workshop

1. Make sure that all sand deposit categories are considered, Emphasis is currently on shoals, ridges and swales, because they are the primary targets.
2. Physical Impacts - add change in grain size that affects the future utility of the sites (where it might fill with mud and become unsuitable for re-use).
3. Data Gaps:
  - definition of pit, dimensions (use ACOE max side slopes, SCDNR example)
  - fish utilization of topographic features
  - where on ridges is it best to dredge
4. How to deal with the shoreline change issues? Rob Nairn to write up draft guidelines. May be two types of analysis: 1) at the placement site, and 2) associated with the borrow site.
5. Ecological succession model - applicability to shelf benthic invertebrates? We decided it was not and would remove references to it.
6. Physical monitoring ideas:
  - "recovery of volume lost" per Van Dolah
  - bathymetry - specify number of points
  - how to consider the passage of a major storm in the monitoring plan
  - to increase understanding of natural variability in physical parameters, check into the USGS bathymetry work; do not expand size of the monitoring
  - specify criteria versus technology, but suggest current technology that meets criteria
  - develop a grain size protocol
  - re-run the wave models for real post-dredging bathymetry
  - discuss requirements for deep water wave climate data and need for a buoy
  - plume monitoring requirements will be delayed until the results of the new study being conducted by MMS are available.
7. Be very clear about what need for specific data, to justify monitoring costs.
8. Biological monitoring:
  - for marine mammals and turtles during operations, refer to the NMFS trained observer guidelines; but do write protocols for increased stranding component
  - Fish protocols need more development; talk with Ken Able about juvenile fish issues.
  - benthos: yes, specify gear for grab sampler.
  - for benthos, generate a list of appropriate parameters for spatial and temporal comparisons, s
  - for determining number of sites to sample for benthos, use random/stratified design but need guidance on degree of uncertainty allowed, definition of strata, guidance on the minimum number of samples per strata, guidance on how they can modify density over time. AMS to consult with biostatistician on these issues
  - need definition of recovery, along the lines that were presented
  - we do not need chemical pollutant analyses; do not need archive sample splits