U.S. ARMY CORPS OF ENGINEERS

Alabama Beach Nourishment Borrow Area Study

Meghan Alesce and Michael FitzHarris
with assistance from Mark Byrnes, PhD., and Rose Dopsovic, Spatial Analyst

2/7/2012

Table of Contents

Figures

Tables

Executive Summary

Mobile District was asked by the Alabama Department of Conservation and Natural Resources to identify offshore sand resources in state waters for nourishing Dauphin Island beaches. The end product of this study is a report and borrow area map of the offshore region of western Alabama showing potential borrow areas and a database listing the material type, median grain size, estimated quantities, and dredging cost estimate for each identified borrow area. Study boundaries include Petit Bois Pass to the west, the western end of Morgan Peninsula to the east, and the state and federal boundary to the south. Dauphin Island and the Morgan Peninsula define the northern boundary. Other useable sand sources have been extensively studied and identified east of Mobile Pass. However, dredging/hauling expenses have made them less desirable for use on western Alabama beaches, and therefore, this area was not a focus for this study.

Through use of geographic information system (GIS) database modeling, available grab sample and vibracore logs, previous studies by the Geological Survey of Alabama (GSA) and others, and consultations with subject matter experts, this study determined that there are at least four suitable borrow areas with sand of sufficient quality and quantity to be economically feasible for use on Dauphin Island. The following table documents estimated quantity of material, estimated median grain diameter, average travel distance to Dauphin Island, and the estimated cost per cubic yard for each borrow site. Figure 20 illustrates mapped borrow site locations.

Table 1. Summary of Alabama Beach Nourishment Borrow Area Characteristics

Characteristics	**East Channel Margin Borrow Area**	**West Lobe Borrow Area**	**Petit Bois East Borrow Area**	**Petit Bois West Borrow Area**
[1]**Bathymetric Survey Volume (cy)**	21,930,000	8,917,000	NA	NA
[2]**Borings with Bathymetric Survey Volume (cy)**	2,907,000	7,031,000	11,400,000	4,300,000
[3]**Borings-only Volume (cy)**	14,897,000	12,713,000	17,514,000	10,070,000
Median (D50) Grain Size (mm)	0.26	0.22	0.33	0.30
[4]**Average one-way trip distance (miles)**	7.5	7.3	10.7	13.2
[4]**Average cost per yard for 1-mil cubic yards**	$ 7.93	$ 7.88	$ 8.60	$ 9.08
[4]**Average Cost per yard for 4-mil cubic yards**	$ 6.55	$ 6.53	$ 7.23	$ 7.78

[1] Volumes based on hydrographic surveys of sediment deposition (see Section III. D. Refinement of Results)
[2] Volumes based on hydrographic surveys of sediment deposition and Boring data (see Section III. D. Refinement of Results)
[3] Volumes based on Available Boring data (see Section III. D. Refinement of Results).
[4] Cost Estimation based on general placement locations (see Section III E. Cost Estimation).

Due to limited boring data, additional boring samples should be taken to further refine the boundaries and sand quality of potential borrow areas. Although minimal impact is expected from material removal at all four areas, a wave and current modeling analysis should be conducted for the eastern borrow area to determine the potential impacts of offshore sand excavation on wave propagation and hydrodynamic flow.

I. Introduction.

Erosion is a problem along the beaches and barrier islands of Alabama. Because of the tourism industry, beach-quality sand is a valuable resource. One of the most common engineering solutions for beach erosion is sand nourishment. This solution involves placement of beach-quality sand along the shoreline to backfill eroded areas. Beach fill can have a design life as long as other forms of protection if adequate sand supply is identified for nourishment (Godsey, 2012). Typically, the most economical approach to accomplish beach nourishment is to use sand from either near shore or offshore borrow sources that can be dredged and pumped onto an eroded beach. The focus for this study is identifying potentially useful sand deposits off the coast of Alabama, in State waters, for use in beach nourishment west of Mobile Pass. Study boundaries include Petit Bois Pass to the west, the western end of Morgan Peninsula to the east, and State/Federal boundary to the south. Dauphin Island and Morgan Peninsula define the northern boundary (Figure 1). The deliverable for this study is a report and map for offshore western Alabama showing potential borrow areas, including a database listing the material type, average grain size, and estimated quantities available for each area. A cost estimate is also provided for each location.

Littoral sediment is supplied to Alabama outer coast beaches primarily from beach and near shore environments along the Panhandle of western Florida (Stone et al., 2004). This transport process is primarily due to a net westward longshore current driven by dominant waves from the southeast. Wave action in the northern Gulf of Mexico (GOM) predominantly follows a southeast to northwest direction as evidenced by the orientation of offshore shoals which generally follow the same direction as predominant wave propagation. Sand transport processes result in varying beach sand characteristics because of superposition and gravity. Coarse-grained sediment falls out of suspension before finer-grained material, creating coarser grained beaches closer to the sand source (east) compared with generally finer-grained MS and LA beaches which are influenced by Mississippi River Delta deposits. Variability in grain size creates grain size constraints for sand placement on beaches. As such, borrow sand sources coarser or finer than native beach sand may have limited value for restoring beaches to natural conditions. Grain size should be as close to native as possible to ensure beach stability and minimize environmental impacts due to changes in beach characteristics (Godsey, 2012).

Through use of geographic information system (GIS) tools, available grab sample and vibracore logs, previous studies, and consultations with subject matter experts, this study determined that there are at least four suitable sources of sand with sufficient quality and quantity to be economically feasible for nourishing Dauphin Island beaches.

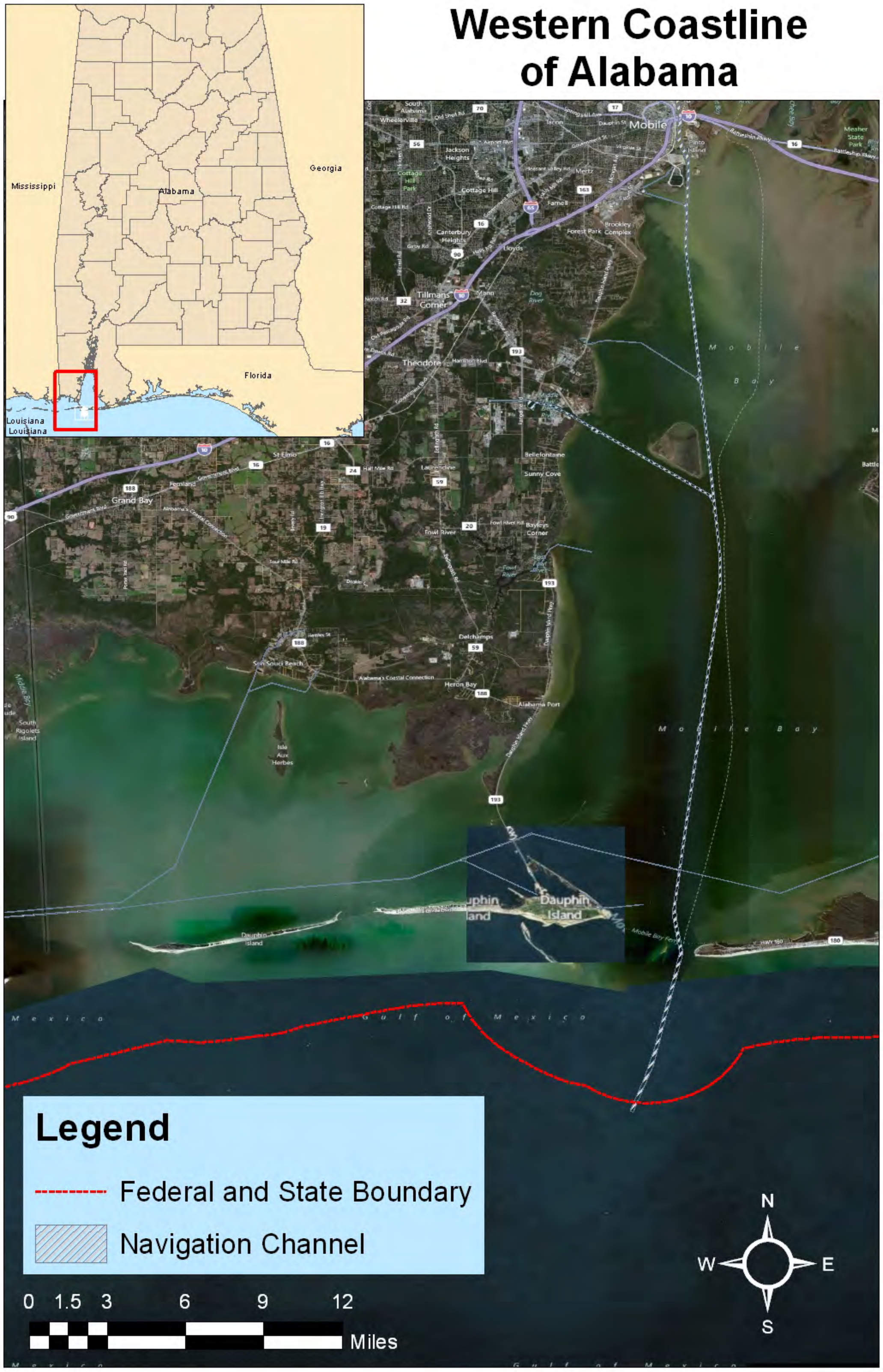


Figure 1. Map of western Alabama coastline with State inset map.

II. Background.

A. Geology. During the late Pleistocene era, sea level was approximately 120 m below present-day levels (Fairbanks, 1982; Flocks, 2010). This created fluvial environments where rivers and deltas prograded southward along the modern shelf edge causing numerous incised valleys. The Holocene era brought rapid sea-level rise causing back-stepping of bay-head deposits and infilling of river systems. When sea level rise slowed approximately 3,500 years ago, water level changes allowed barrier system development on the present-day mid-shelf and redistribution of sediments from reworked Pleistocene fluvial features. Oscillating sea levels also caused reworking of bayhead and shoreface deposits, creating shoals as sea-level rose (Flocks, 2010). Pleistocene fluvial features were destroyed by waves and currents during Holocene transgression. Much of the shelf offshore eastern Alabama is composed of sand from these features (Byrnes et al., 2010), while inner shelf deposits west of Mobile Pass are influenced by fine-grained sediment from Mobile Bay. Shelf deposits offshore Dauphin Island illustrate sediment textural variability, where sand can change rapidly to mud within a distance of several meters due to fine-grained discharge from Mobile Bay (Parker et al., 1992; Byrnes et al., 2010).

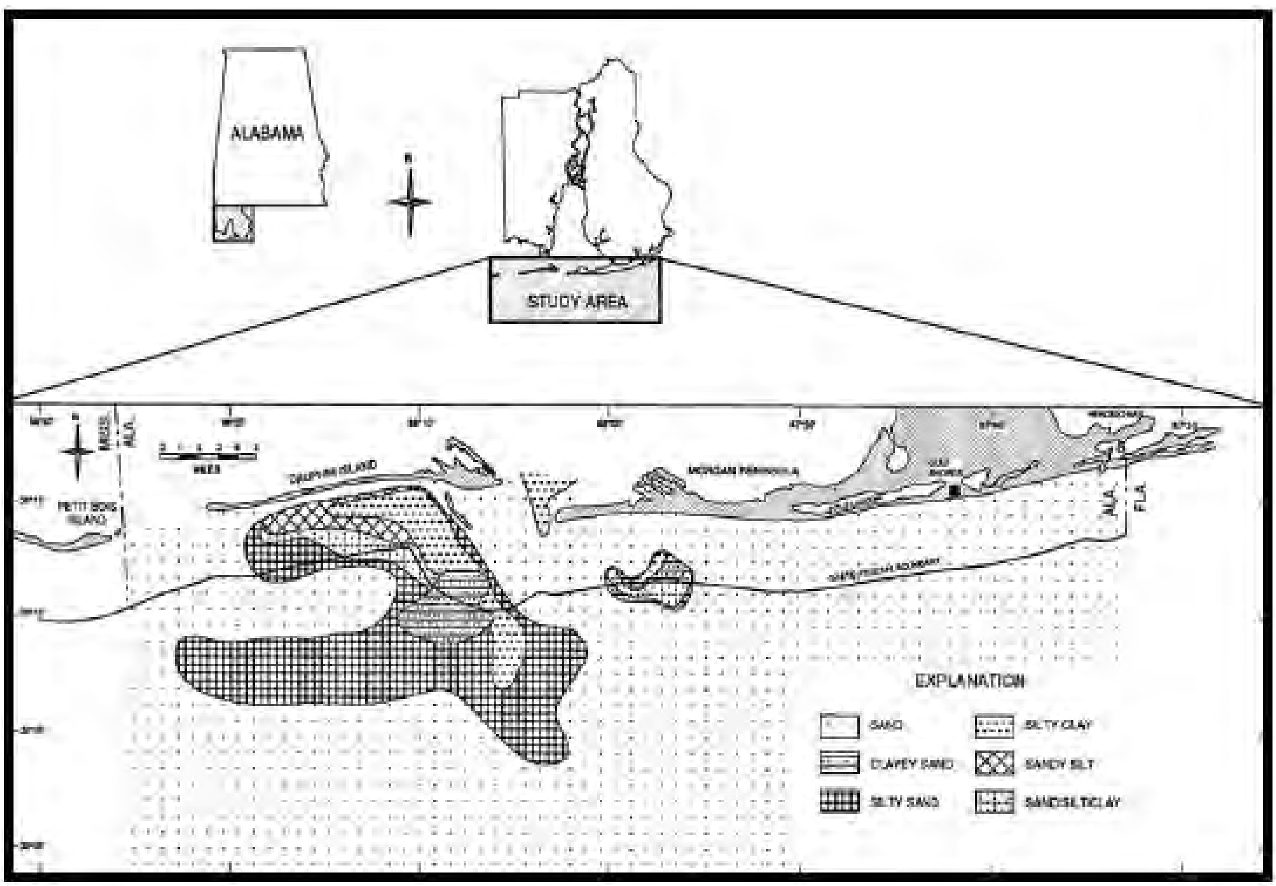


Figure 2. Surface sediment texture map for offshore Alabama (from USACE, 1984).

Bathymetry offshore central Dauphin Island generally is featureless with straight and parallel contours, a relatively steep near shore profile, and an absence of offshore shoals (Parker et al., 1992; Byrnes et al., 2010). Fine-grained sediment from Mobile Bay contributes approximately 337,000 to 420,000 cy/yr seaward and west of the ebb-tidal delta (Hardin et al., 1976; Isphording et al., 1996; Byrnes et al., 2010). These factors make the central Dauphin Island seafloor a less desirable borrow area for beach-quality sand. However, shoals are present within Petit Bois Pass at the western end of Dauphin Island in response to the interaction between wave and current processes at the entrance. Many shoals in this area are within the active littoral zone and sand extraction from these deposits may have a negative impact on the littoral sediment budget. Therefore, active shoals within the littoral zone are not recommended as potential sand borrow sources.

The Alabama outer coast is separated at Mobile Pass by a large ebb-tidal shoal. The shoal extends 6 miles offshore, is approximately 10 miles wide, and is composed of two large sediment lobes separated by a natural tidal channel that runs north to south and by a dredged navigation channel at the southern end of the shoal (Parker et al., 1997). The western portion of the shoal consists of Pelican Island and an ephemeral shoal, Sand Island, located southeast of Pelican Island (Figure 3; Byrnes et al., 2010). In addition, numerous shoals, shoreface sand ridges, and swales are present on the eastern Alabama shelf, including the eastern lobe of the ebb-tidal shoal. Shoreface ridges are identified as pre-Holocene paleotopography overlayed with Holocene sand (Parker et. al, 1997).

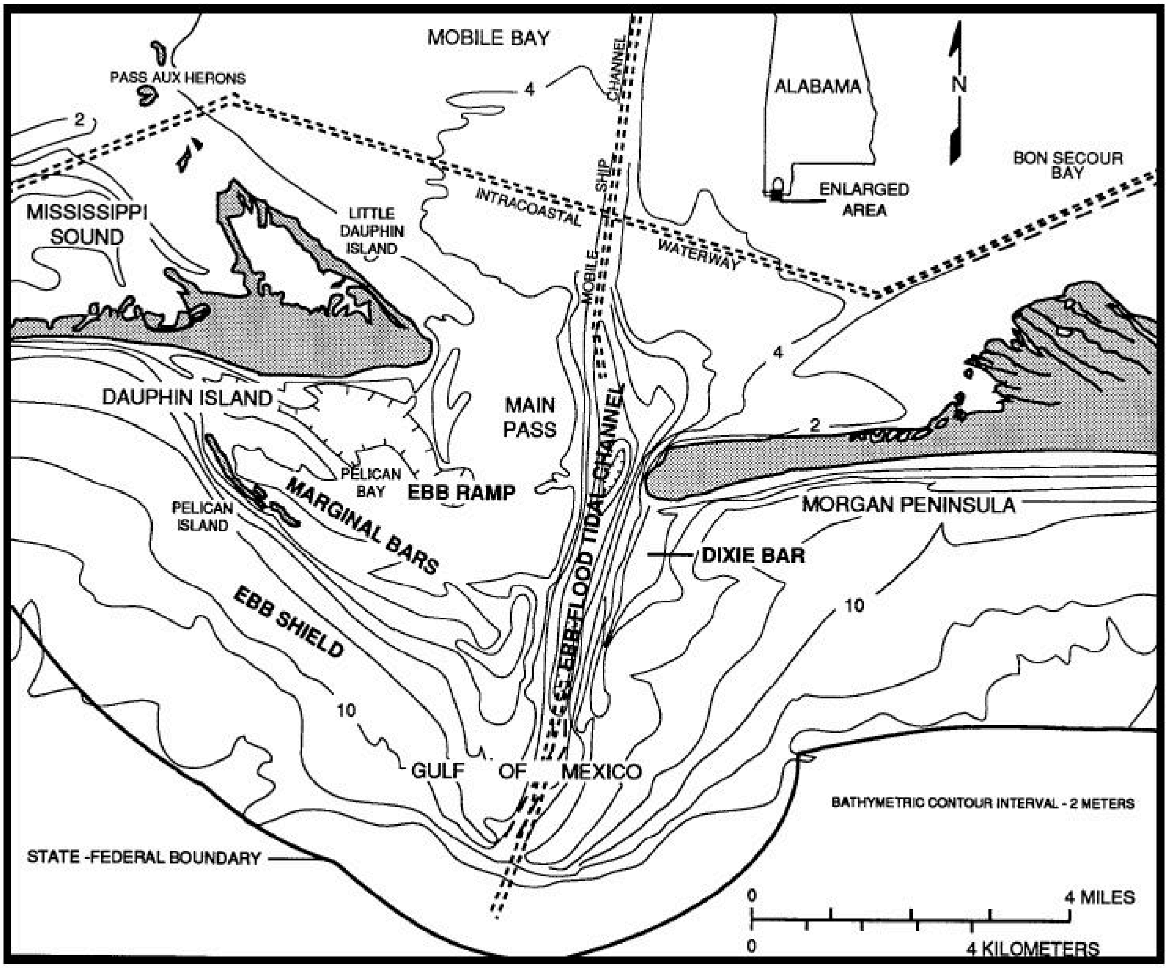


Figure 3. Geomorphology of the ebb-tidal shoal seaward of Mobile Bay entrance (from Hummell, 1996).

Longshore sediment transport from western Florida provides sediment to Gulf beaches in Alabama. Generally, sediment travels east to west along the shoreline until it encounters tidal currents at Mobile Pass. As sediment is transported west and encounters currents exiting Mobile Bay via the channel, littoral sediment infills the natural and engineered channel along the eastern channel margin and bar channel before it is dredged and placed on the west lobe of the ebb shoal. Figure 4 from Byrnes et al. (2010) illustrates areas of deposition and erosion occurring along the Alabama coastline for the period 1917/20 to 1982/2002.

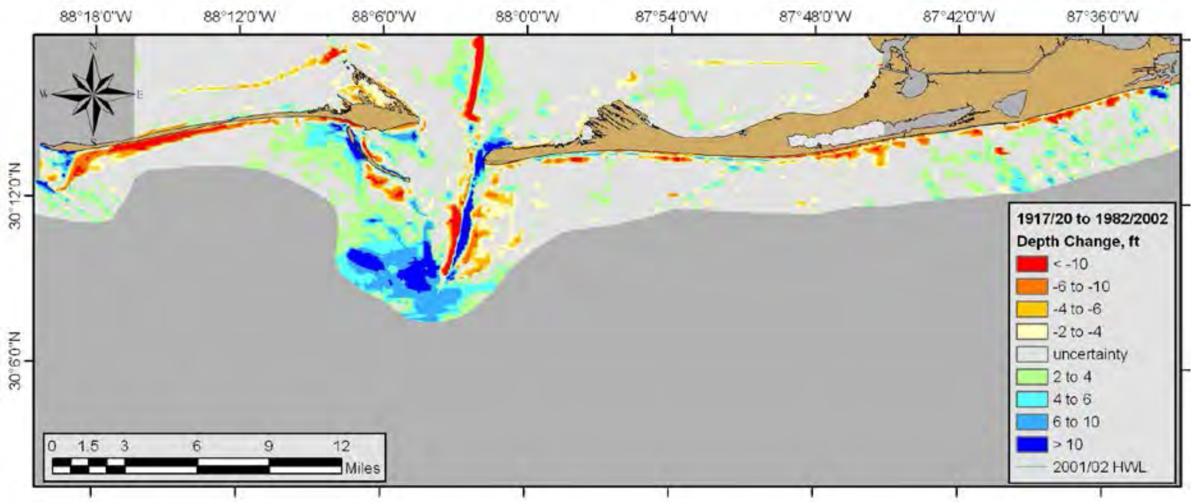


Figure 4. Bathymetric change between 1917/20 and 1982/2002 for the Alabama coastal zone. Hot colors represent erosion (yellow to red), and cool colors represent deposition (green to blue) (Byrnes et al., 2010).

Based on Figure 4, it is evident that erosion is occurring along the southeast coast and along the western side of the navigation channel as it migrates westward with time. Sand deposition is occurring on the eastern side of the channel and on the southwestern lobe of the ebb shoal. The western side of the channel is primarily erosional, and littoral zone currents transport sediment from the channel toward the western lobe of the ebb shoal. As a result of natural transport and deposition along the east side of the channel, the eastern lobe (includes Dixie Bar) of the ebb shoal becomes net depositional as the old channel location fills with south-directed littoral sediment from the Fort Morgan Peninsula (Figure 5). Further details regarding nearshore sediment transport and the sediment budget for Alabama coastline can be found in Byrnes et al. (2010).

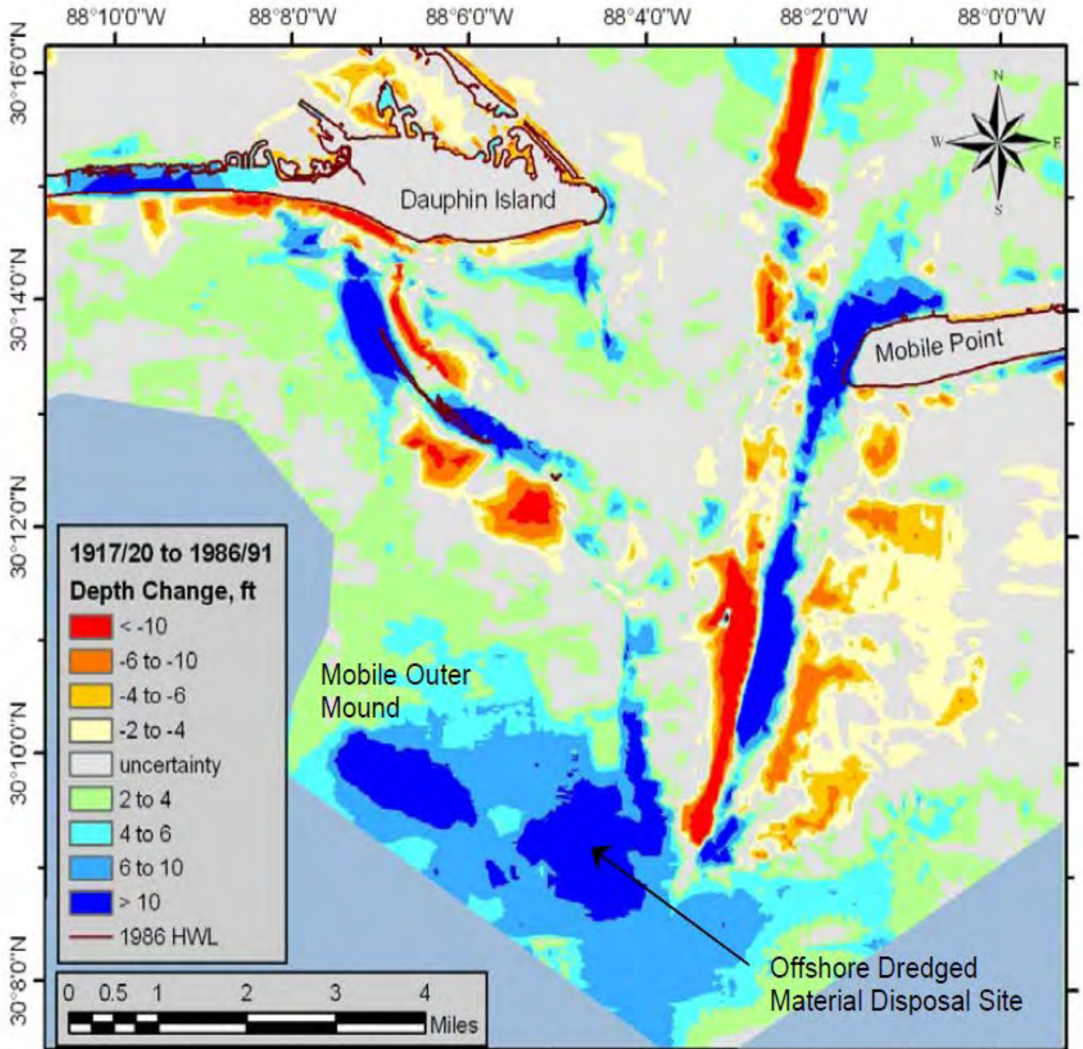


Figure 5. Location of offshore dredged material disposal site and the Mobile Outer Mound relative to deposition on the ebb-tidal shoal. Hot colors represent erosion (yellow to red), and cool colors represent deposition (green to blue). This figure is from Byrnes et al. (2010).

Estimated natural infilling for the eastern margin of the navigation channel has been calculated at approximately 250,000 cubic yards annually. Calculating infilling for the southeastern portion of the western lobe of the ebb shoal includes natural deposition and dredged material disposal. Based on sediment accumulation in this area, the infilling rate is approximately 110,000 cubic yards per year.

B. Dredging. Because sediment does shoal the bar channel, dredging is required to keep it navigable for shipping into the Port of Mobile. Dredging operations for the Mobile Pass Bar Channel began in 1904. From May 1917 through July 2002, approximately 287,000 cubic yards of maintenance have been dredged annually from the channel (Byrnes et al., 2010). Despite this channel maintenance material dredging quantity, approximately 262,000 cubic yards per year deposited on the west lobe of the ebb shoal and 40,000 cubic yards per year was supplied to the western two thirds of Dauphin Island (Byrnes et al., 2010). A steady supply of sediment from the west lobe of the ebb shoal to Dauphin Island has been able to maintain the island despite hurricane breaching along the central portion of the island and lateral growth along the western end of the island (Byrnes et al., 2010). As a result, it was concluded that channel dredging at Mobile Pass has had no measurable impact on the littoral sediment budget that maintains Dauphin Island (Byrnes et al., 2010). This is due in large part to the placement of historical and modern maintenance dredging material within the active littoral zone west of the navigation channel. Currently, the Sand Island Beneficial Use Area (SIBUA), located on the southeastern portion of the west lobe of the ebb shoal, is the main disposal area for sandy material from the navigation channel. Approximately 250,000 to 300,000 cubic yards of material are dredged from the channel annually and disposed of in the SIBUA. It contains beach-quality sand from the coast and offshore areas of southeastern Alabama that has been transported to the channel and mixed with finer material (fine sand, silts, and clays) from Mobile Bay. Because of the location of SIBUA, dredged sand is available for littoral zone currents to transport to Pelican and Dauphin Islands. Manual transport (dredging and placement) of this sand on Dauphin Island accelerates existing natural transport processes. Continued maintenance dredging of the channel ensures that the SIBUA is being refilled annually with presumably suitable material.

III. Methodology. The present study was conducted in five phases: Data Collection, Database Compilation, Spatial Analysis, Refinement of Results, and Cost Estimation.

A. Data Collection. The Geological Survey of Alabama (GSA) completed several studies in the past, tasked by the Minerals Management Service (MMS), presently the Bureau of Ocean Energy Management (BOEM), to develop a better understanding of State offshore sand resources. The culminating product was development of the Offshore Alabama Sand Information System (OASIS) (Jones, 2009). OASIS is a web-based GIS database that uses historical data, modern surveying techniques, and modeling to ultimately identify potential sand borrow sites offshore Alabama in State and Federal waters. The GSA provided Mobile District with shapefiles, reports, and raster files (see Database References), in addition to answering questions pertaining to their reports and use of the OASIS website. The GIS files GSA provided served as the technical foundation for this study.

Sand quality characteristics such as grain size, percent fines, and color are considered when determining potential borrow sites for beach nourishment projects. As such, sediment classification is extremely important for identifying suitable material. USACE typically uses the Unified Soil Classification System (USCS) for classifying sediment. Because the northern GOM beaches contain a predominantly quartz sand composite, the ideal beach nourishment material is a poorly graded quartz sand (SP) with minimal fine material (silts and clays) and trace to no gravel-sized material, and a color and grain size closely matching native beach sediment. The following USCS classifications were considered suitable material for this study: SP, SW, SW-SM, and SP-SM. Sediments with clay content (SP-SC, SC, CH, and CL) were not considered suitable. SM was not considered suitable material because of the range in fine material (>12% to 49%) possible for this sand classification. USACE typically uses D50 (median grain size) as its preferred indicator of sediment grain size. Not all lab reports contained a specified D50 value, but reports usually contained a mean or median grain size. Color classification for samples is a highly subjective process and most logs within the study did not have a Munsell color classification. As such, color was not used as a determining factor for suitable material.

B. Database Compilation. The Spatial Data Branch, U.S. Army Corps of Engineers, Mobile District, used ArcGIS to calculate and create maps from GIS files provided by the GSA. In addition to GSA files, current data from various studies also were analyzed. Boring log data and grab samples were entered into spreadsheets and compiled into a geodatabase. Specifically, each boring and grab sample had to contain grid coordinates, the method of sampling (vibracore or grab sample), stratigraphy, water depths (if available), and grain size (if available). Lab descriptions also were entered when available. Figure 6 illustrates the distribution of borings (white dots) and grab-samples (gray dots) with data available for this study (see Appendix A for larger images of the maps from this section).

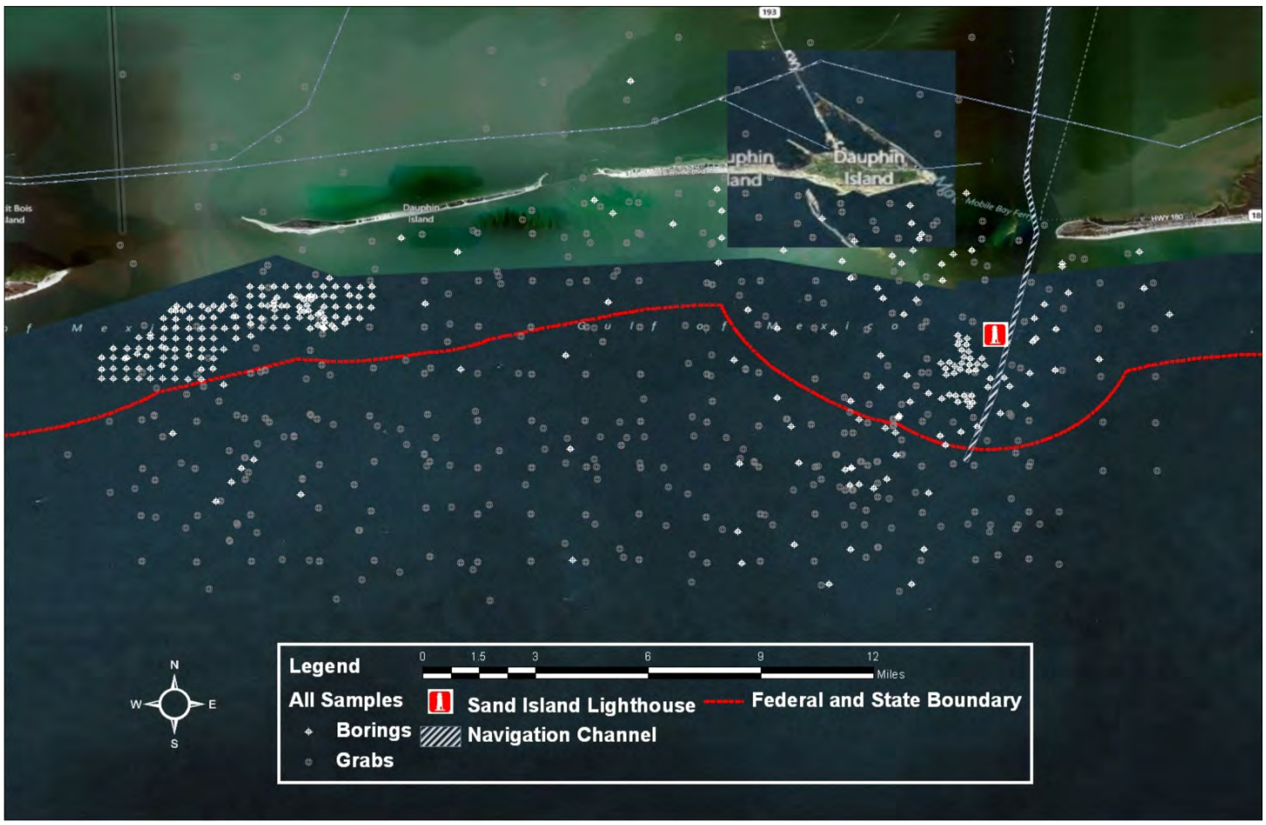


Figure 6. Borings and grab samples collected from various agencies and compiled into a single geodatabase.

1. Data Density. Data density for the study area affects accuracy of the model performing interpolation over the entire study area. The density of grab samples in the GOM is much higher than vibracore samples. Unfortunately, grab samples are surficial (less than a foot deep) and do not always represent the quality and quantity of sediment truly available in an area. For example, clean sand may exist six inches below a surface layer of silt, but a grab sample may only record the silt. This skews the mapping of grab samples and adds uncertainty to any interpolation completed by an algorithm. Borings provide a better representation of available material and depths, but there are fewer borings to provide an accurate coverage of the entire study area.

2. Sediment Classification. The majority of logs available used Folk classifications, or other non-USCS descriptions, for describing sediments. Converting Folk classifications to USCS using either verbal descriptions of material or lab percentages of grain size creates inaccuracies. Caution was taken to be more conservative while performing this conversion, making some classifications appear to contain greater fines. When lab data were available, the Grain Size Ternary Plot (Folk, 1954; 1980) was used as a guide for what sediment percentages comprised each Folk classification. When lab data were not available, the following conversions were made from descriptions (Table 2).

Table 2. Conversion used for sediment classification pertaining to the grab and vibracore samples used to create the geodatabase for this study. Folk classification was converted to Unified Soil Classification System (USCS).

Folk Symbol	Folk description	USCS Symbol	USCS Description
S	Sand	SP or SW	Poorly-Graded Sand, Well-Graded Sand
(g)S	gravelly Sand	SP or SW	Poorly-Graded Sand, Well-Graded Sand
(g)mS	slightly gravelly, muddy Sand	SM	Silty Sand
Gms	gravelly, muddy Sand	SM	Silty Sand
gS	gravelly Sand	SP	Poorly Graded Sand
sG	sandy Gravel	GP or GW	Poorly-graded Gravel, well-graded Gravel
MsG	muddy sandy Gravel	GM	Silty Gravel
mG	muddy Gravel	GM	Silty Gravel
G	Gravel	GP or GW	Poorly-graded Gravel, well-graded Gravel
M	Mud	ML	Silt
(g)M	slightly gravelly Mud	ML	Silt
(g)sM	slightly gravelly sandy Mud	ML	Silt
gM	gravelly Mud	ML	Silt

The gravel descriptor was disregarded for the Sand USCS descriptions because most lab data indicated the percentage of gravel was not significant to discount the sample as being suitable material. If a discrepancy existed between a field classification and a lab classification, the lab classification was used for this study.

3. Sampling.

Historical Data. The date that samples were obtained affects the accuracy of the available data. For instance, major storm events can cause a significant change in the amount of fine material deposited in an area. If a grab sample or boring is collected from an area following a hurricane or tropical storm, it may have a disproportionate amount of fines than it normally would contain. Ocean processes, such as tides and currents, also affect sediment distribution on the seafloor. As such, gaps in the dates of collection can potentially affect samples taken in the same location. Past samples may not reflect current in situ conditions.

Technology. Methods used for determining position on the open ocean have also changed through the years. GPS is far more accurate for determining boring locations than charts used in the past. Survey accuracy also has been improved by the use of SONAR and other methods. Improved sampling techniques, such as vibracoring, also have increased the quality of nearly undisturbed sediment sampling and classification.

Anthropogenic Errors. Error is introduced into data collection when non-automated techniques are used. Field sampling and classification of sediments are not always an exact science. Human error is introduced during sampling events. Representative samples are not always "representative" of the total thickness of strata indicated on the log. Lab testing is normally run after sampling events to confirm field classifications of sediment. Differences between field log classifications and more accurate lab classifications create potential uncertainty. For the purposes of this study, if a conflict existed between the field and the lab classifications, the lab classification was used. Data entry is also a potential source of anthropogenic error, especially for database compilation.

4. Grain Size. The engineering compatibility between borrow material and the native beach is dependent on sediment characteristics of the fill material. The grain size distribution of borrow material will affect beach slope, the rate that fill material will erode, and how the fill responds to storms (CEM 2003). D50 grain size is generally accepted as the preferred unit of measure for comparing borrow and native material grain size at the placement site. D50 was used for each boring or grab sample, if available. Unfortunately, different agencies use different statistical measurements for grain size. The majority of boring logs and lab data for this study did not use D50, but instead provided mean grain size. For this study, D50 and mean were used interchangeably, and phi units were converted to millimeters using the following formula: $D\ (mm) = 2^{-\phi}$. ArcGIS calculated weighted average median grain size for each boring based on data for individual stratigraphic units within the boring. This introduces potential uncertainty for final average median grain size for the entire borrow area.

C. Spatial Analysis

Spatial analysis was an important part of this study. Surface maps and volumetric calculations were derived using ArcGIS. In addition to producing numerous maps, three different methods were used to calculate sediment volumes for proposed borrow areas. The intent of calculating three volumes per area was to determine a range of estimated volumes that reflects uncertainty in each method.

Interpolation is used to model sediment location on the sea floor based on known data points. Interpolation takes known discrete data points, estimates missing values between these known points, and mathematically creates a continuous surface. Different algorithms can be used to perform the interpolation function. As such, different algorithms may produce different results given the same input data. For this study, the Nearest Neighbor algorithm was applied because it is commonly used for interpolating surfaces of this size and range. The result for Nearest Neighbor interpolation for surface sediment distribution is illustrated in Figure 7.

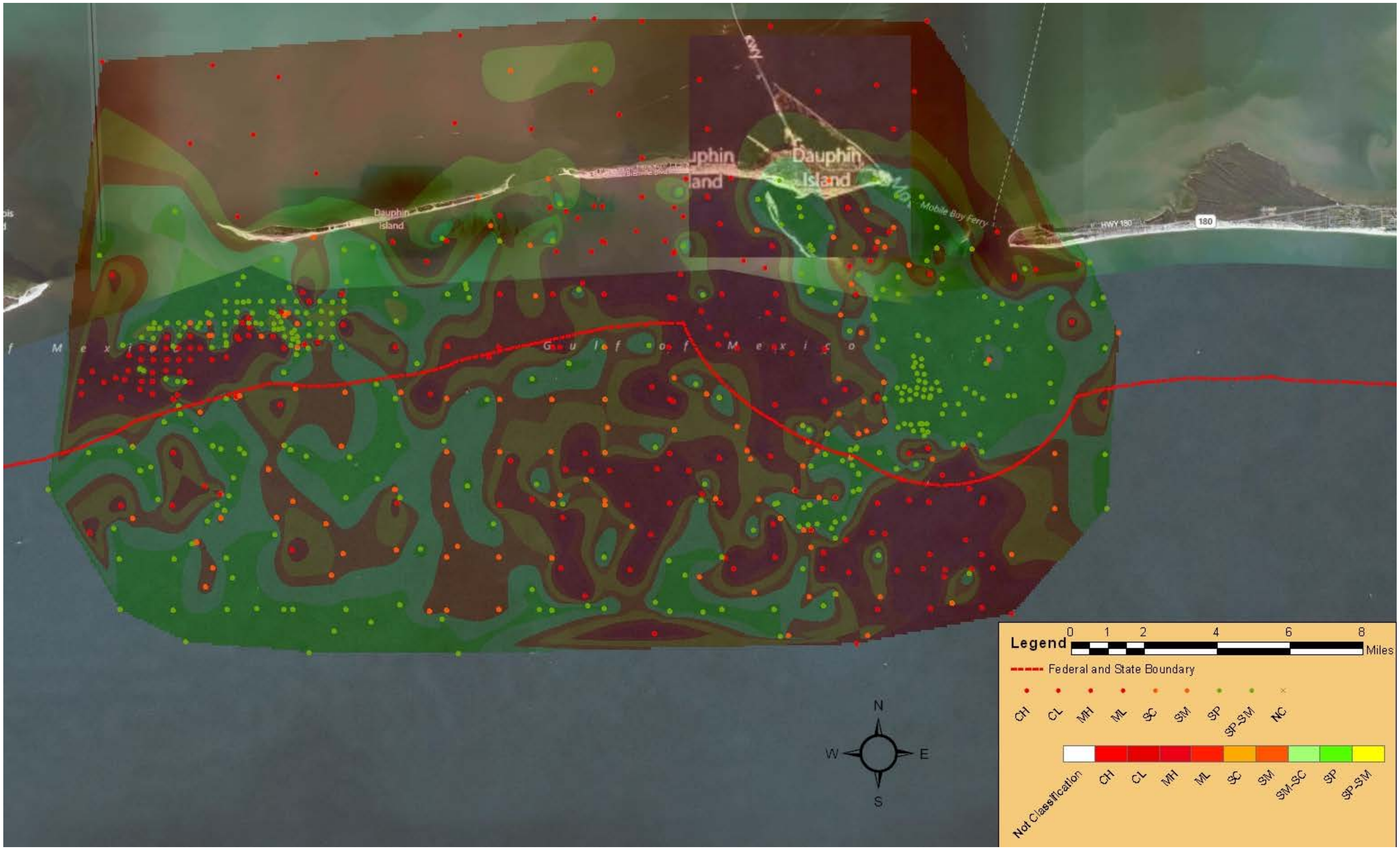


Figure 7. Surface sediment classification map for the offshore area of Dauphin Island, AL. The map depicts offshore sediment distribution relative to samples used in this study. Poor quality, fine-grained sediments (CH, CL, MH, ML, SC, SM) not suitable for beach nourishment are shown in red to orange colors, while suitable material (SM-SC, SP, SP-SM) is shown in green and yellow.

Throughout the mapping process, an iterative approach was used to determine the best representation of interpolated data. If data points (borings) were separated by large distances, a less accurate surface was created. Therefore, longer distances between points introduce more uncertainty. Modified boundaries for the study area were drawn to reduce data gaps in the area south of central Dauphin Island. Grab samples also were omitted to reduce uncertainty caused by surficial sediments (Figure 8).

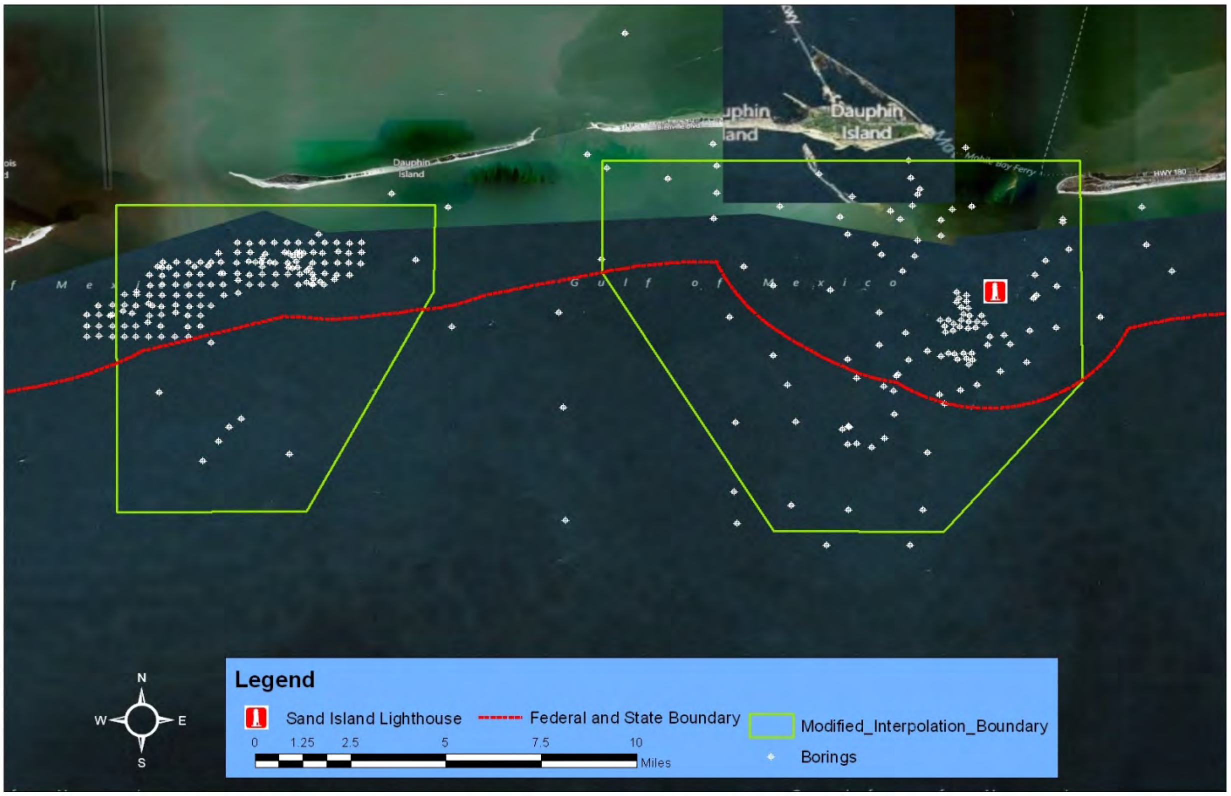


Figure 8. Modified Interpolation boundary with all borings plotted.

Using ArcMap to query the geodatabase, sediment type was interpolated to create a surface for determining potential borrow areas. A map was created using modified study boundaries to illustrate the locations of beach quality sediment with a minimum thickness of 5 feet and starting no less than one foot below the seafloor. A minimum thickness of five feet was considered to obtain an economical quantity of suitable material. It should be noted, however, that thinner deposits may be suitable depending on the equipment used to extract them during dredging/placement. Areas with borings showing unsuitable material at the surface and extending more than one foot deep were avoided. If a boring indicated that a layer of unusable material, such as clay, greater than one foot thick was located in the first five feet of the boring, then that area was avoided. Figure 9 shows all borings with suitable material and associated thickness at the boring location within the modified boundaries.

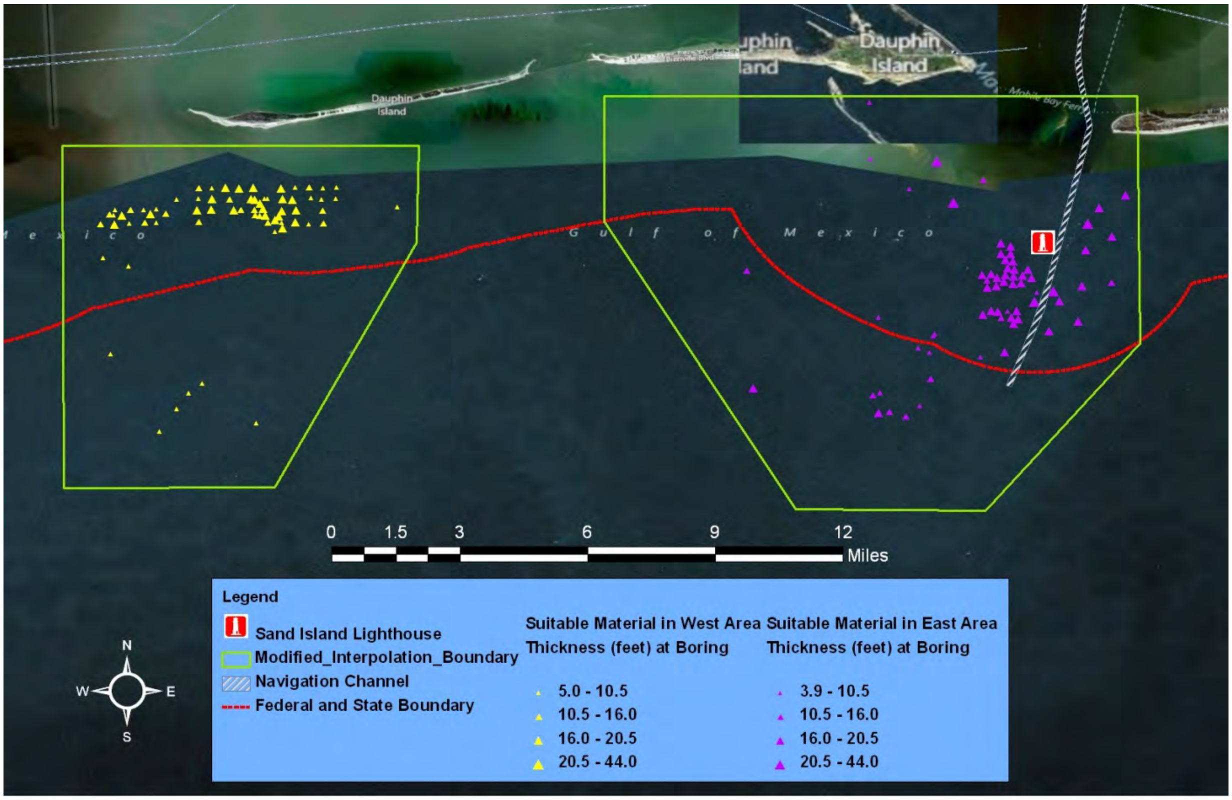


Figure 9. Borings that contain suitable material

Using the borings identified in Figure 9, a material thickness map was created using a volumetric calculator created by the USACE Mobile District Spatial Data Branch. Appendix A contains procedures used to create this map. Figure 10 shows the resulting interpolated surface. The colors represent thickness of suitable material surrounding the borings.

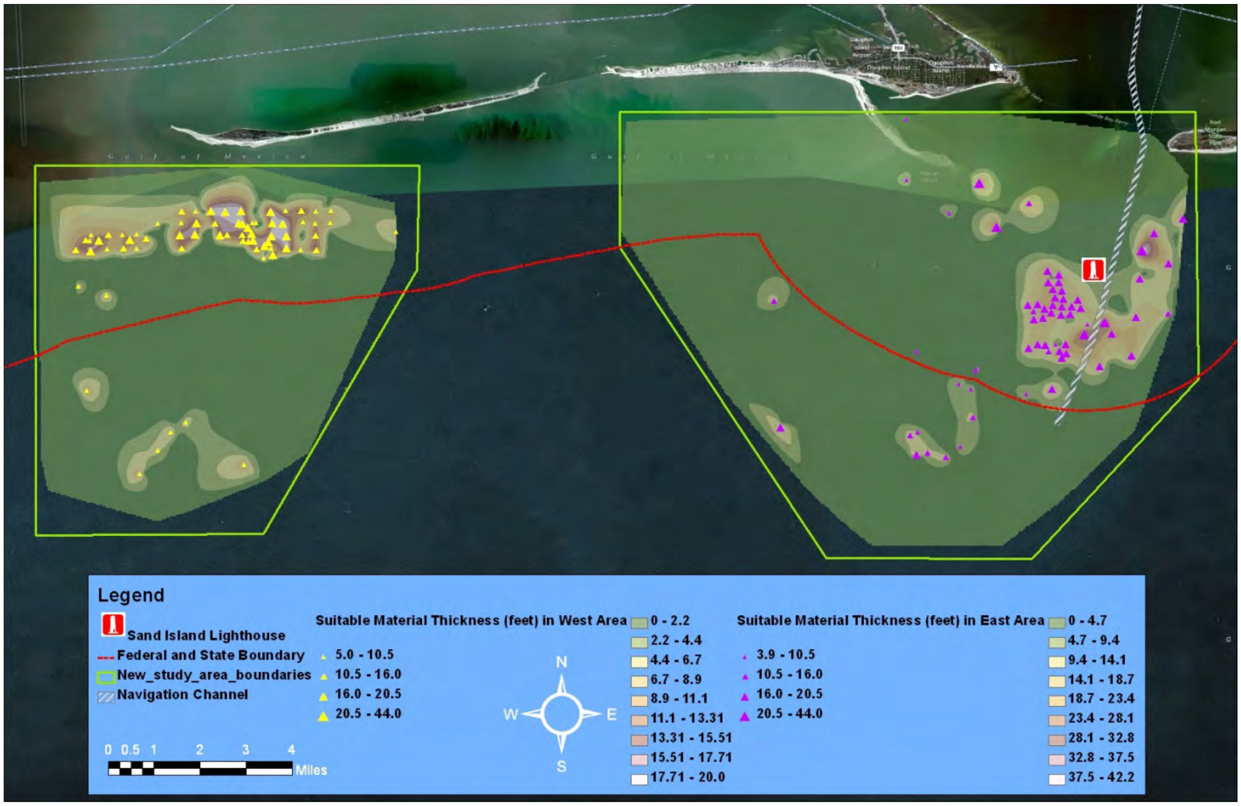


Figure 10. Sediment thickness map derived using boring data with beach quality material.

Following the interpolation and mapping process, potential borrow areas were identified based on distribution of sediment type, available thickness, and proximity to Dauphin Island and State/Federal offshore boundaries. Figure 11 illustrates potential borrow areas with suitable material in the western Alabama offshore area.

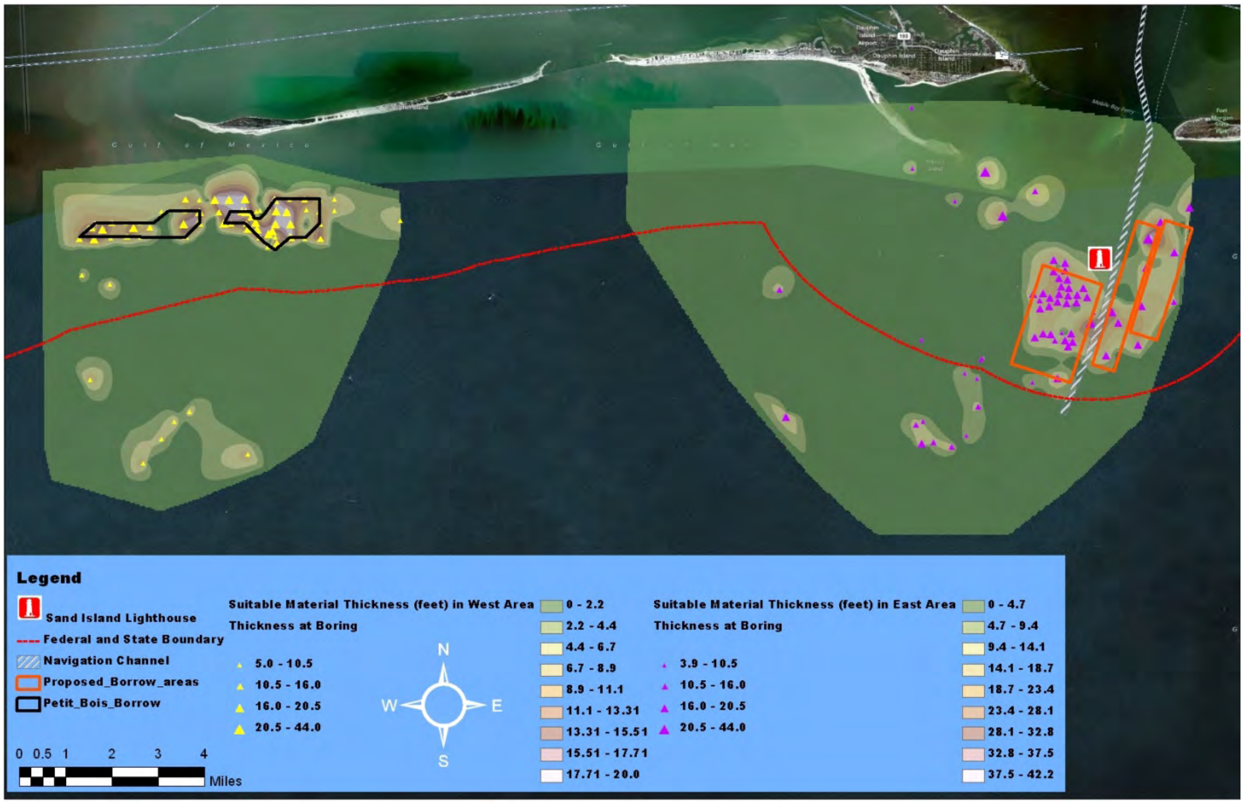


Figure 11. Locations of potential borrow area polygons drawn according to suitable material thickness and density.

The West Borrow Area boundaries were derived from USACE vibracore sampling conducted as part of a geotechnical investigation for identifying beach quality sand for the Mississippi Coastal Improvements Program (MsCIP). The MsCIP investigation identified suitable sand for the project, in Alabama State waters and outside of the littoral zone. Modeling potential impacts of borrow material excavation was conducted as part of the MsCIP investigation. Because extensive sampling was conducted, potential borrow area boundaries derived as part of MsCIP were used to delineate western borrow areas for this study. The interpolated surface indicates several potential areas with suitable material in Federal waters, but they were not investigated.

The map was reviewed to validate if the surfaces and interpolation processes were logical. Borrow area locations and polygons in the east were altered to better fit recommendations (Byrnes, 2012). As previously mentioned, the western borrow areas have already been studied and modeled extensively for the USACE MsCIP investigation. Therefore, no recommendations were made to alter the locations or shapes of the Petit Bois East and West borrow areas. Figure 12 illustrates the modified borrow areas in the east, overlaying original borrow areas.

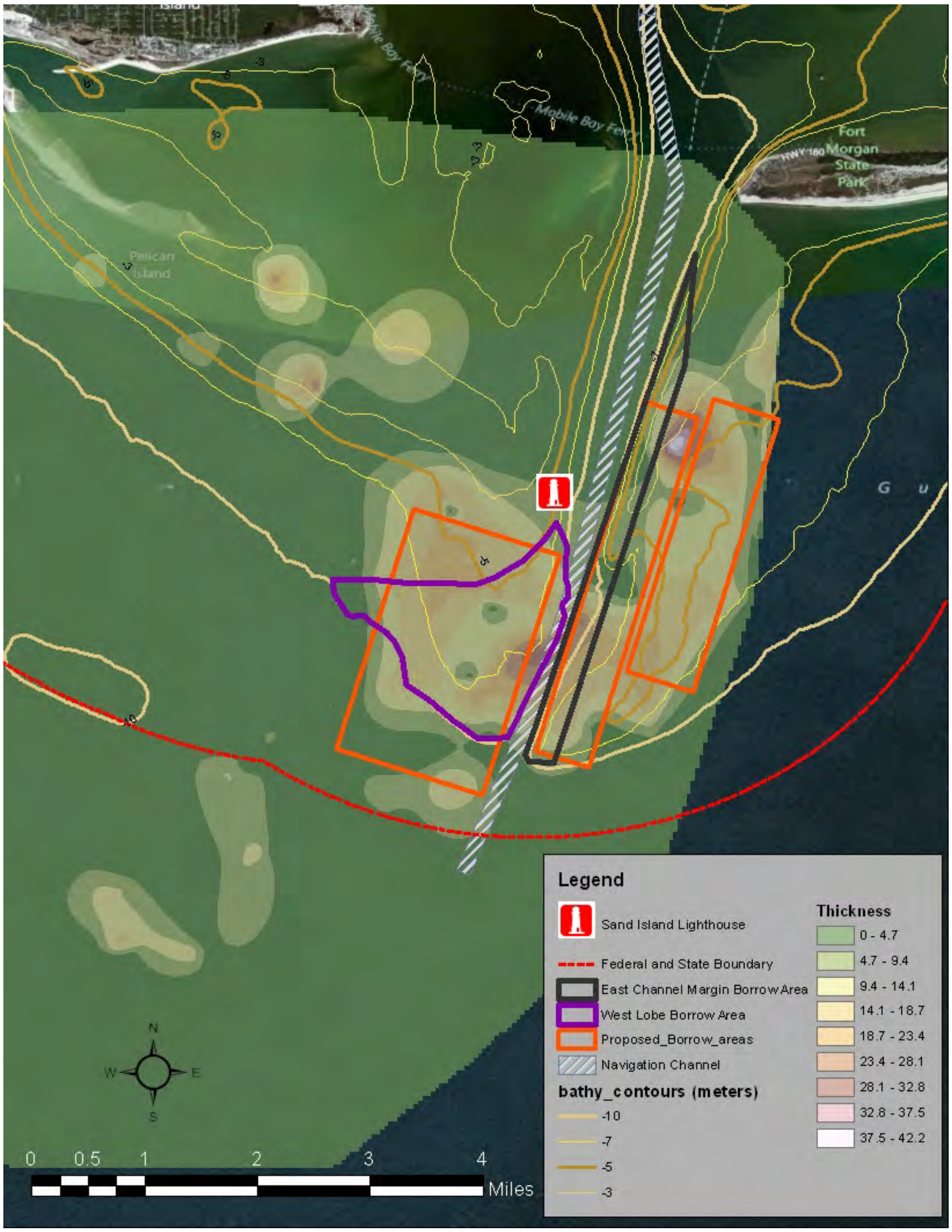


Figure 12. Initial east borrow area polygons overlain by modified East Channel Margin Shoal and West Lobe borrow area polygons based on conversations with Byrnes (2012).

Figure 13 shows this area without the original borrow areas illustrated. Modified polygons were drawn based on the channel boundaries and the 5-meter depth contour.

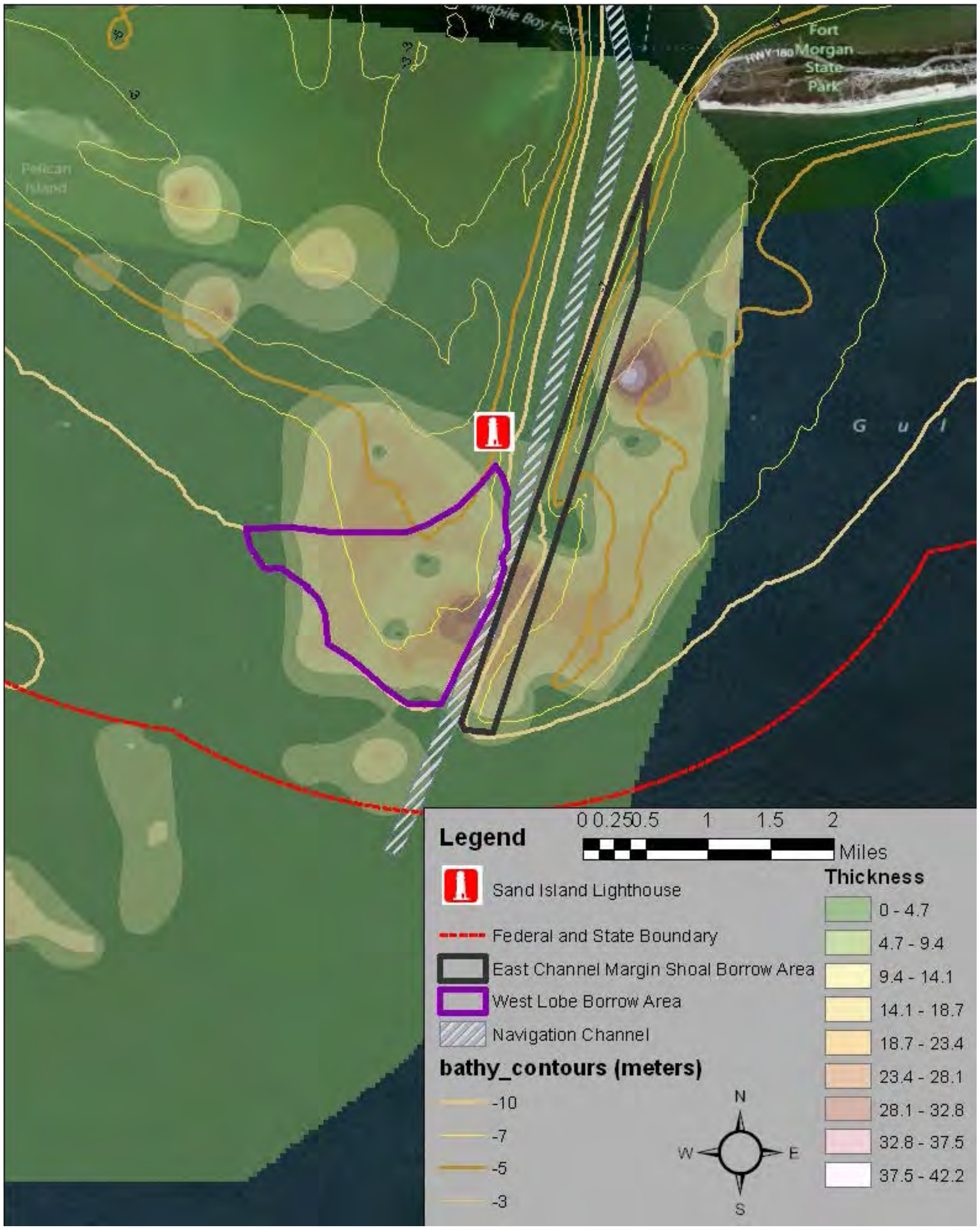


Figure 13. Modified East Channel Margin Shoal and West Lobe borrow area polygons without initial polygon overlays.

D. Refinement of Results. Updated borrow locations and polygons were reviewed for further refinement.

A previous study of the area highlighted the deposition rates for the East Channel Margin Shoal borrow area and the West Lobe borrow area (Byrnes et al., 2010). This study contains detailed deposition and erosion maps from 1917 to 2002. Adjustments to depth measurements were made to bring all data to a common plane of reference, NAVD88, prior to surface modeling and change calculations (Byrnes et al., 2010). See Figure 4 for a regional map of this deposition and Figure 5 for a study-specific map of the deposition. As mentioned in the Geology section, natural sand transport is from east to west along northern Gulf of Mexico beaches, and sand naturally traverses these potential borrow areas. As such, sediment deposited in the East Channel Margin Shoal and West Lobe areas is expected to be of fairly high quality beach sand that has migrated from the eastern Alabama beaches. The West Lobe is more affected by discharge from the Mobile Bay due to natural ocean processes and disposal of dredged channel sediment, resulting in more fine-grained sediment than identified in East Channel Margin Shoal area. Recommendations were made to use the limits of recently deposited material (1917 to 2002) as the boundary for the East Channel Margin Shoal borrow area (Byrnes, 2012). Natural deposition zones can be well-suited for borrow areas because a deposition rate can be calculated to estimate the amount of time required to infill the borrow area through natural processes (Byrnes, 2012). See Geology section for a discussion of infilling rates. As previously stated, three different methods were used to calculate sand deposit volumes.

<u>Volumes Calculated for Total Deposition via Bathymetric Survey Data</u>. Alterations to the borrow area shapes and locations were made to better fit the natural and man-made deposition areas in the eastern portion of the study area, as discussed in section IIA and illustrated in Figure 5 (Byrnes, 2012). Figure 14 illustrates overlays of both sets of modified borrow area shapes on Figure 5. ArcGIS 3-D Analyst was used to calculate an average thickness and volume for both borrow areas. The 1917/18 and 2002 historical hydrographic surveys for this area were transformed into a Triangulated Irregular Network (TIN) surface. These TIN surfaces served as the top and bottom boundaries of deposition between 1917 and 2002. Borrow area polygons were used to calculate the volume of sediment deposition between the two TIN surfaces. The resulting volume is the calculated amount of material deposited between these two time periods. The average thickness was calculated by dividing deposition volume by the borrow site surface area. For further explanation of the depositional study and procedures used to calculate volumes, see Byrnes et al. (2010). An assumption with this method of calculating borrow area volumes is that all material deposited between these time periods is beach quality sand. This assumption is reasonable given the type of material within the natural sediment transport system along the eastern Alabama coast (Byrnes, 2012). Boring data also tends to support this assumption, but is limited in coverage.

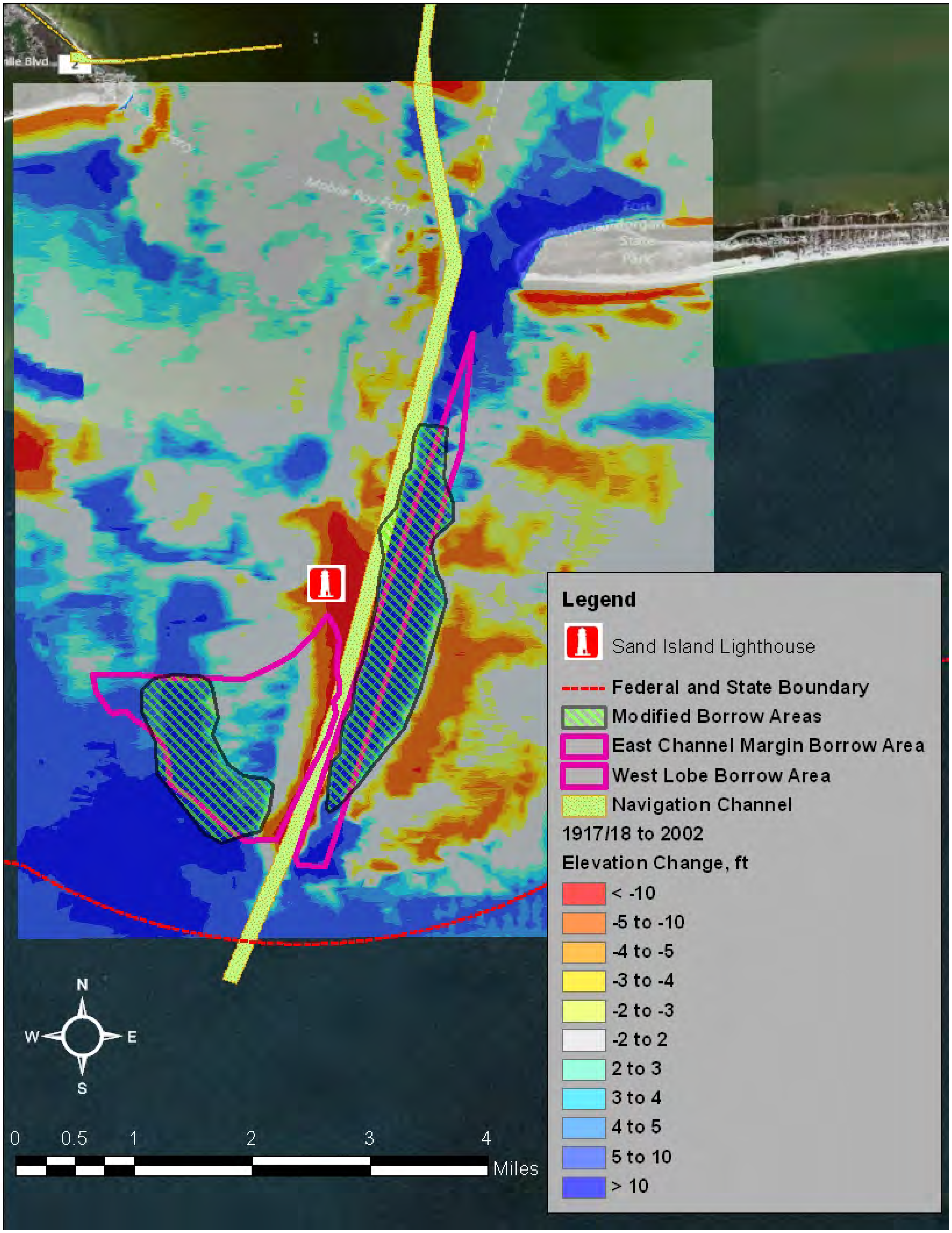


Figure 14. Modified potential borrow areas overlaying the bathymetric change surface for the period 1917/18 to 2002 (change surface from Byrnes et al., 2010).

Figure 15 shows the final eastern borrow area polygons, East Channel Margin Shoal and West Lobe, superimposed over the depositional areas modeled for 1917/18 to 2002.

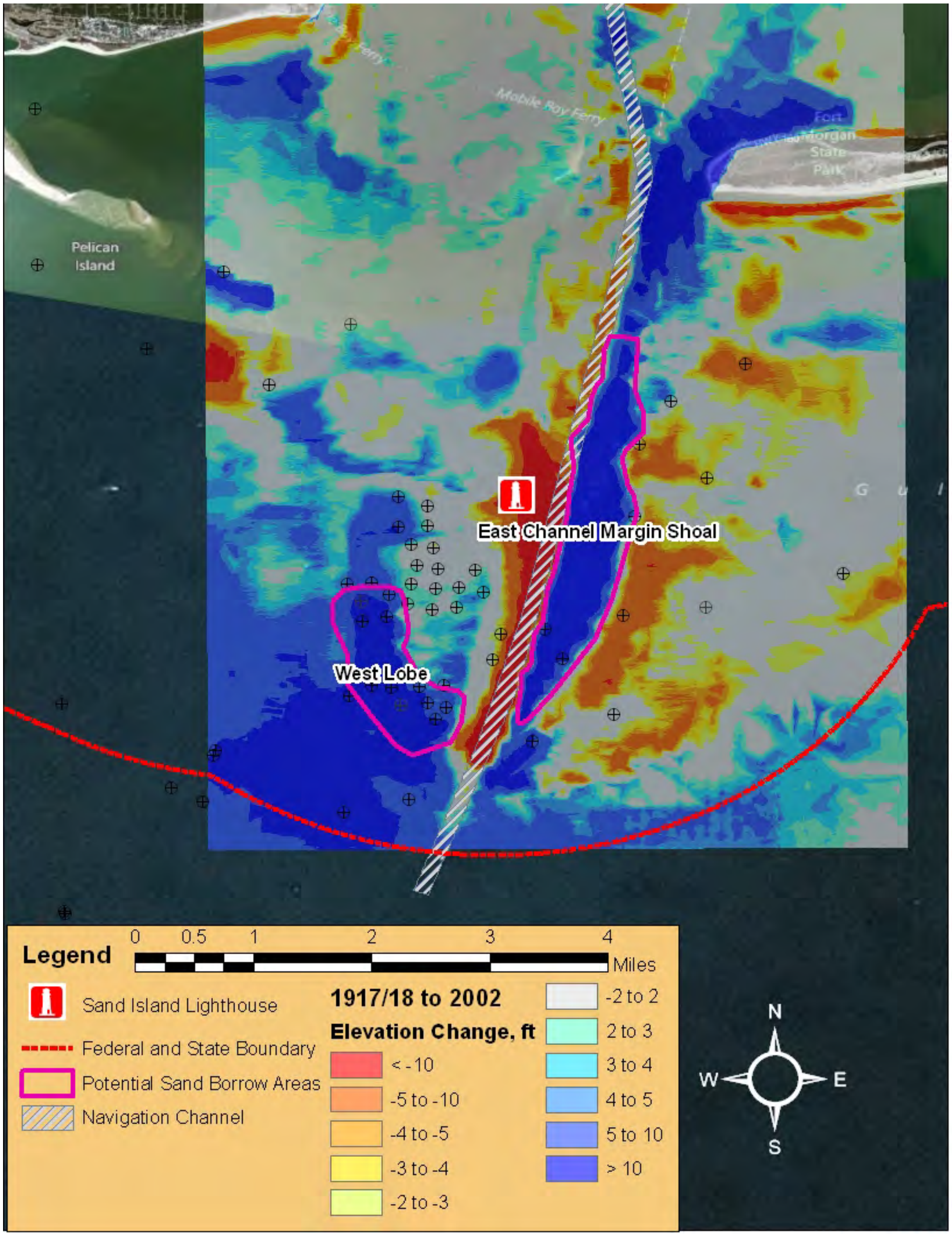


Figure 15. Final borrow area polygons superimposed over deposition from 1917/18 to 2002 (modified from Byrnes et al., 2010).

Figure 16 displays borrow areas and calculated volumes of material within the polygons. As previously stated, 3D Analyst was used to calculate the volumes. Volumes include all deposition, no material below the 1917/18 elevations, and do not take into account borings used in this study. Borings are only displayed to show sampling locations within the depositional/erosional areas.

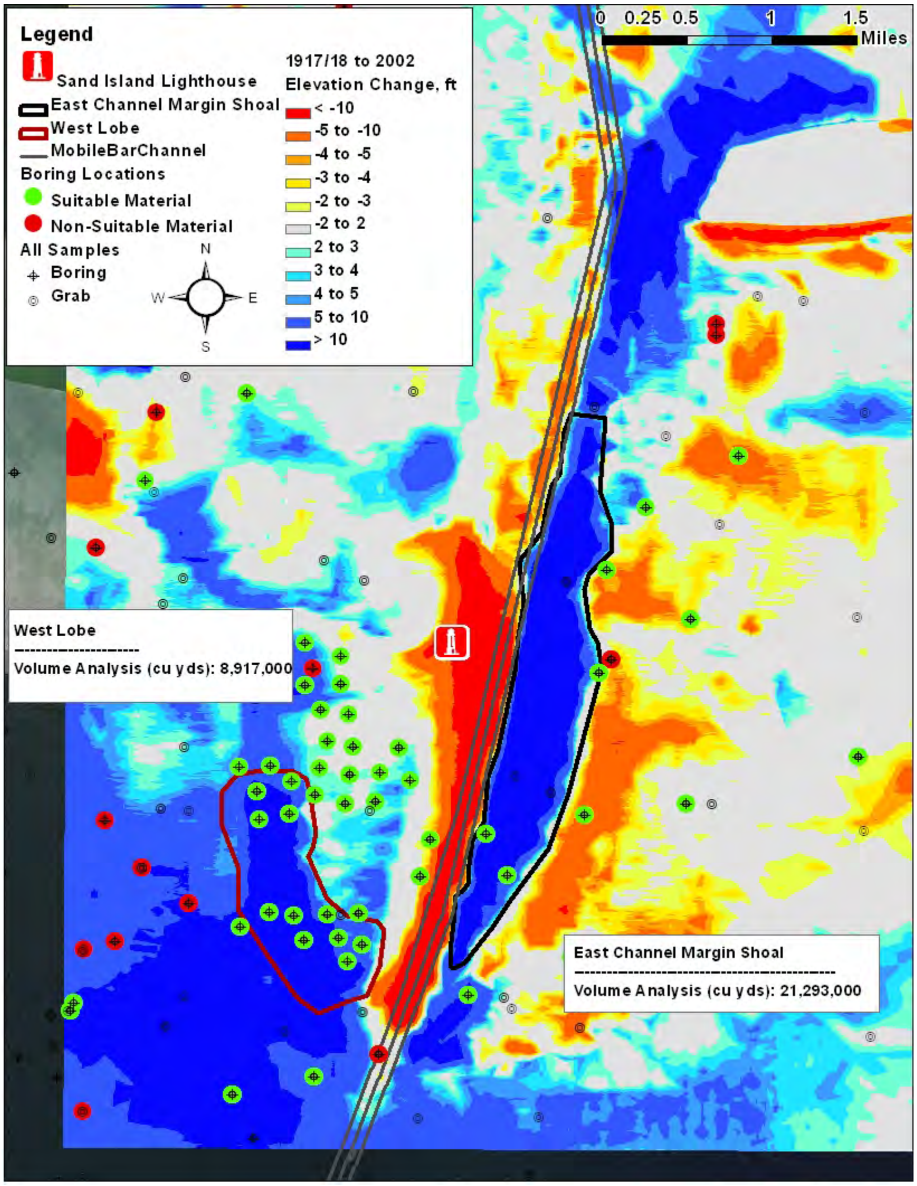


Figure 16. Volumes calculated for total deposition during period from 1917/18 to 2002 (modified from Byrnes et al., 2010).

Volumes Calculated via Boring and Bathymetric Survey Data. In addition to the volumes derived from bathymetric surveys (Byrnes, 2012), the Mobile District Spatial Data section created a suitable material thickness surface using boring data and the 1917/18 survey as the bottom elevation boundary (Figure 17). They then applied the modified borrow area polygons to the resulting surface and calculated volumes. Calculated sediment volume includes suitable material thickness taken from boring logs, rather than simply total deposition. Resulting sediment volume was expected to be lower than the quantity calculated from the total deposition because borings with non-suitable material within the borrow area were excluded during interpolation. Also, the 1917/18 survey boundary prevented boring data below this baseline elevation from being included in the calculation. Thus, borings with suitable material extending below the 1917/18 survey were truncated and deeper material was ignored. Assumptions were made in the volume computation of suitable material when comparing to the 1917/18 survey. The elevation values available in the 1917/18 surface were adjusted to the NAVD88 vertical datum; however complete metadata for the referenced borings is unknown. Considering the recent dates of the borings (mostly after 1990), NAVD88 was assumed as the vertical datum for the elevation values of the borings. If the origin of the vertical datum differs from this assumed datum, the input elevations for each sample may be up to four feet lower or higher than the input used in the calculation. For the East Channel Margin Shoal borrow area, approximately two-thirds of the polygon does not appear to have a thick suitable material layer. However, the borings with suitable material located on the eastern boundary of the polygon are located in net erosional (hot) areas (Figure 16). Therefore, they did not contribute significant quantities to the volume calculation. The lack of borings in the top two-thirds of the East Channel Margin Shoal polygon also affects the volume calculation because the interpolated thicknesses are less accurate with fewer known points.

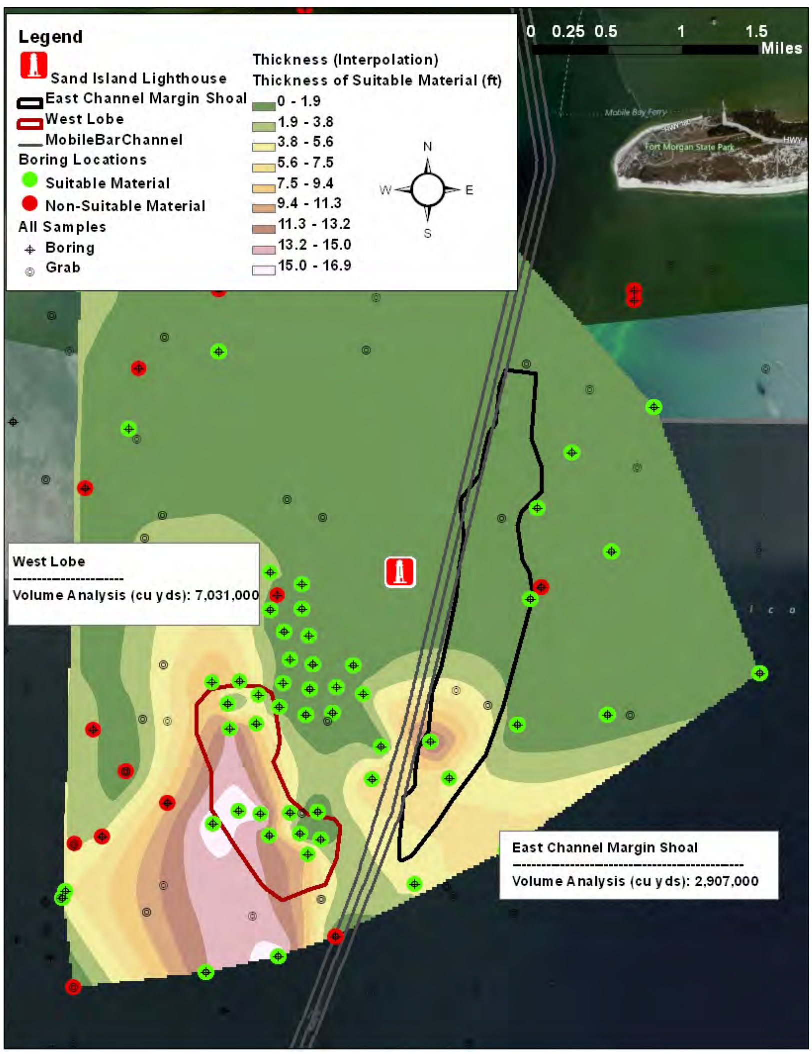


Figure 17. Volume analysis using borings with suitable material and the 1917/18 elevation survey as the bottom boundary.

Volumes calculated with Boring Data. A third volume was calculated using all available material in the suitable material borings without having the 1917/18 TIN surface as the lower elevation limit. As a result, suitable boring materials omitted in the previous volume calculation were included in this calculation. The change in available suitable material is quite considerable, nearly triple the previous amount. This indicates that suitable material is located deeper than the 1917/18 depositional layer. Figure 18 illustrates that the modeled suitable material quantities available outside borrow area polygons are significantly larger as well, but would require using more native material rather than historical deposition alone.

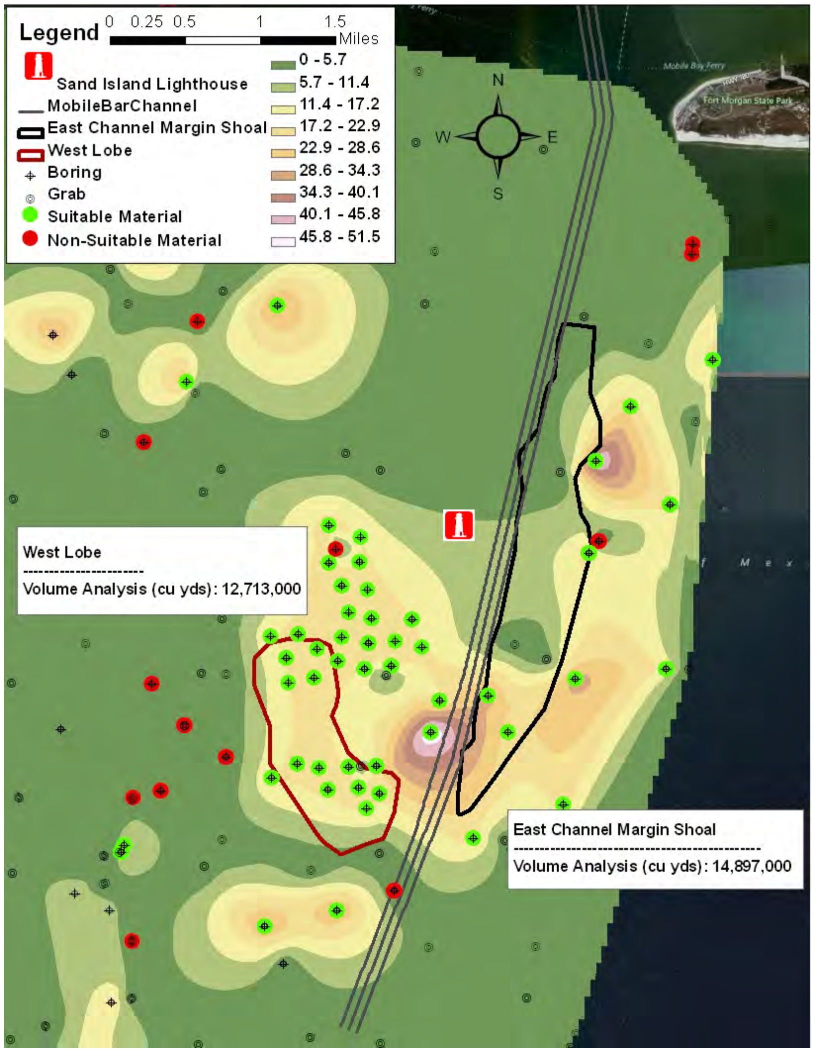


Figure 18. East Borrow areas with total volumes calculated from borings with suitable material only.

As stated previously, the density of borings in this area does have an impact on modeled surfaces. Denser boring grids should be used to verify model results. For further details on the database compilation and map creation process, please see Appendix A.

Calculated Volumes by Method. Table 3 shows volume calculation results for all three methods.

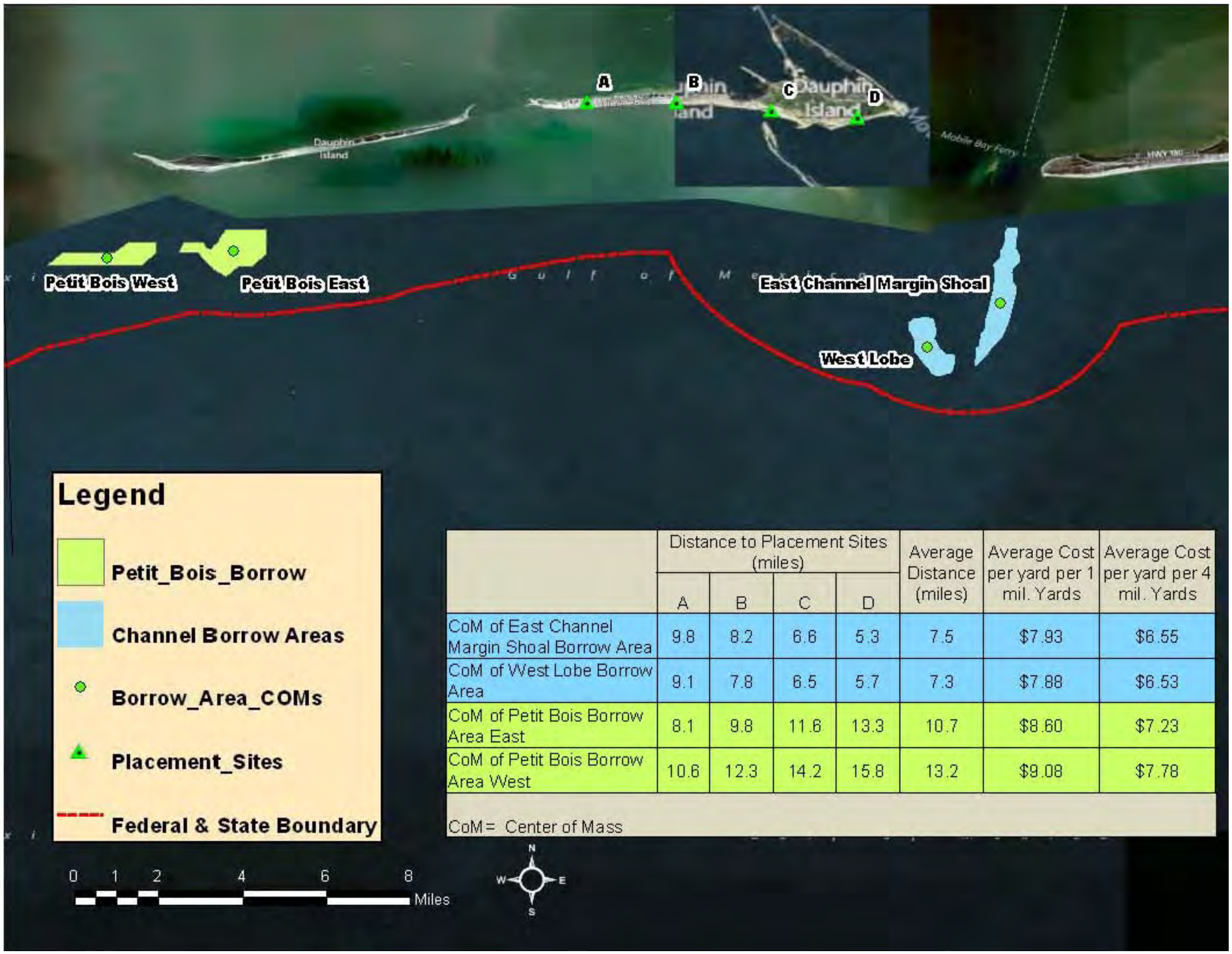
Table 3. Volumetric Calculations using three different modeling methods.

	Total Deposition via Bathymetric Survey (cy)	Borings with Bathymetric Survey (cy)	Borings (cy)
East Channel Margin Shoal	21,293,000	2,907,000	14,897,000
West Lobe	8,917,000	7,031,000	12,713,000

E. Cost Estimation. Dredging costs are a major factor in choosing a borrow area. Transportation of dredged material can add significant costs. Therefore, borrow areas closer to the placement site are preferred. Cost estimates for dredging, transportation, and placement were made by the Mobile District Cost Estimation section for each potential borrow area. To estimate the distances from each borrow area to Dauphin Island, the residential portion of the island was divided into quarters with one placement site per quarter. The one-way transport distance was measured from the center of mass of each borrow area to all four placement sites. This mileage was used to calculate a per cubic yard cost estimate for one million and four million cubic yards per placement site for all four borrow areas. The cost breakdown is included in Appendix B along with a map illustrating the borrow areas and the four placement sites (Figure 19 and Appendix B). The western, uninhabited portion of the island was not factored into the unit costs of this analysis. Table 4 shows the average cost per cubic yard for one million and four million cubic yards per borrow area:

Table 4. Dredging Cost Analysis table depicting the average cost for each borrow site per average distance to all 4 placement sites from each potential borrow area. An average distance was calculated to allow for an average cost. Further details of the cost analysis breakdown is found in Appendix B.

Borrow Area	Average one-way trip distance (miles)	Average cost per yard for 1-mil cubic yards	Average Cost per yard for 4-mil cubic yards
East Channel Margin Shoal	7.5	$ 7.93	$ 6.55
West Lobe	7.3	$ 7.88	$ 6.53
Petit Bois East Borrow Area	10.7	$ 8.60	$ 7.23
Petit Bois West Borrow Area	13.2	$ 9.08	$ 7.78



	Distance to Placement Sites (miles)				Average Distance (miles)	Average Cost per yard per 1 mil. Yards	Average Cost per yard per 4 mil. Yards
	A	B	C	D			
CoM of East Channel Margin Shoal Borrow Area	9.8	8.2	6.6	5.3	7.5	$7.93	$6.55
CoM of West Lobe Borrow Area	9.1	7.8	6.5	5.7	7.3	$7.88	$6.53
CoM of Petit Bois Borrow Area East	8.1	9.8	11.6	13.3	10.7	$8.60	$7.23
CoM of Petit Bois Borrow Area West	10.6	12.3	14.2	15.8	13.2	$9.08	$7.78
CoM= Center of Mass							

Figure 19. Dredging Cost Estimate. Green dots are centers of mass for the borrow areas and the green triangles are estimated placement sites. Distances are measured from each center of mass to each placement site.

IV. Summary

This study investigated the availability of offshore borrow areas containing suitable beach-quality sand in Alabama State waters within the Gulf of Mexico. Median grain size along the Gulf coast of Alabama, from Fort Morgan in the east (0.34 mm) (Kopaska-Merkel, 2002) to Dauphin Island in the west (0.29 mm), is variable. The variability continues into Mississippi with Petit Bois Island (0.36 mm) and Horn Island (0.28 mm) (USACE 2009, 2010). This report focused on locations in State waters south and west of Morgan Peninsula and extending to Petit Bois Pass west of Dauphin Island.

Dauphin Island was considered the case study for placement of the sand identified in this report. Mean grain size of sediment on the eastern portion of the island is 0.27 mm on the west end and 0.28 mm on the east end (Forrest-Vandera, 2011).

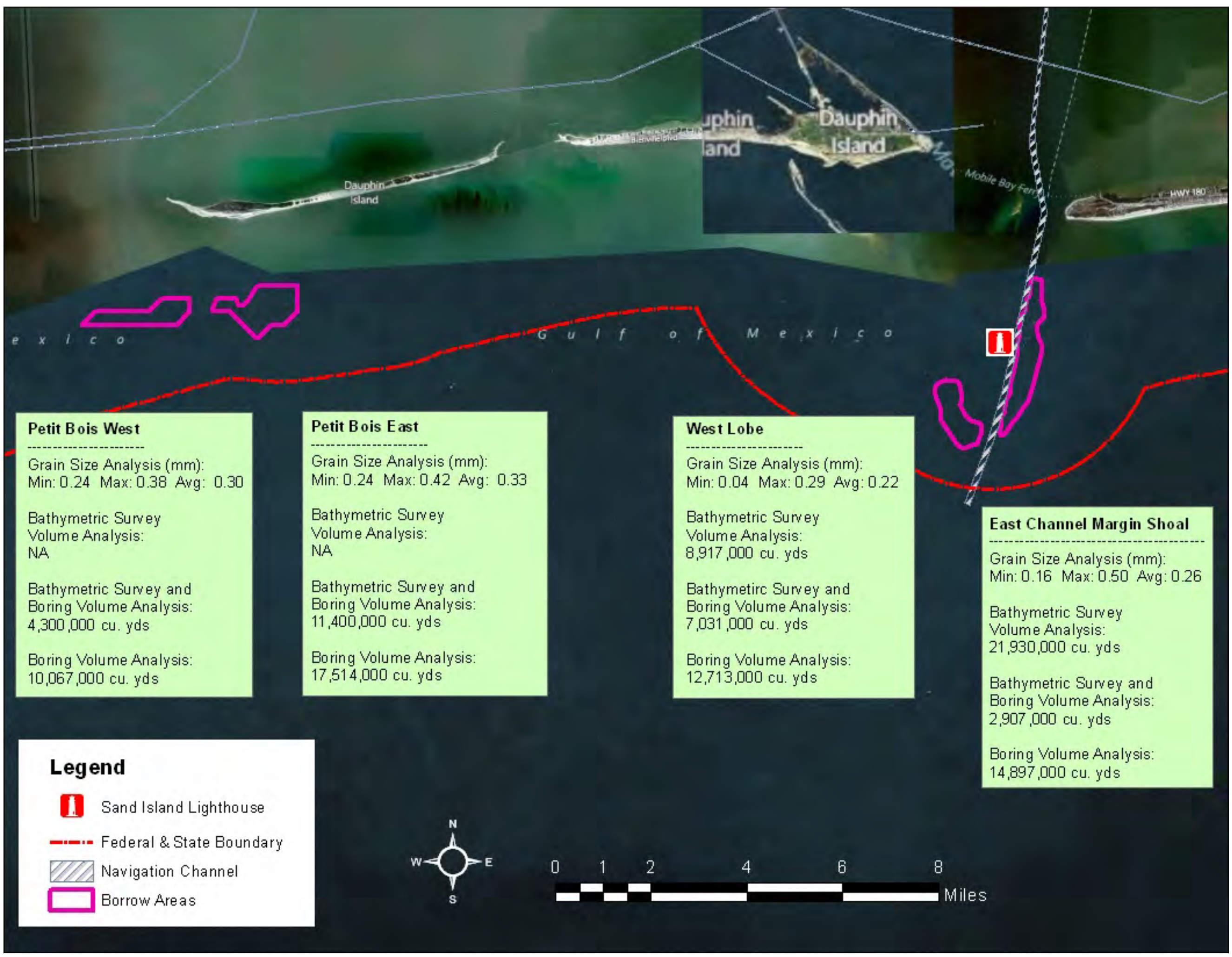


Figure 20. Aerial imagery of Dauphin Island, AL and surrounding areas. Potential borrow areas are displayed in pink. Average grain size and calculated volumes of suitable material from the three different methods.

Using information from previous and ongoing studies and sample logs, two areas in the west and two areas in the east were identified as potential borrow areas.

Western Borrow Areas (Petit Bois East and West) - The areas in the west, Petit Bois East and Petit Bois West, contained suitable quantities of sand and had a median grain size ranging from 0.30 to 0.33 mm. This grain size is coarser than the native material on the nearest beach, Dauphin Island.

The cost for dredging sand from these areas has a higher unit price (per cubic yard) due to the longer transportation distance to potential placement sites on Dauphin Island. Modeling of the wave and current flow for both areas has indicated that borrowing material from this area will have a negligible impact on the western end of Dauphin Island. The infilling rate for these western sites is expected to be slower than for the eastern sites. Borrow locations are outside the littoral zone and have no effect on the littoral sediment budget. As a result, these areas are not expected to be as rapidly replenished as the borrow areas identified in the eastern study area.

Eastern Borrow Areas (East Channel Margin Shoal and West Lobe) - The East Channel Margin Shoal and West Lobe of the Mobile Pass ebb shoal contain suitable quantities of beach-quality sand for beach nourishment. The East Channel Margin Shoal is expected to have greater quantities than the West Lobe borrow area. Median grain size for both sites is 0.26 and 0.22 mm, respectively. Grain size is slightly finer than the native material on Dauphin Island. More fine material is expected in the West Lobe borrow area because it is comprised partly of dredged material from the bar channel. The cost for dredging/hauling the sand from these two areas is less than the western areas because of the close proximity to potential placement sites. The natural infilling rate for the East Channel Margin Shoal area is expected to be faster than for the West Lobe area. Modeling the impacts on current flow and wave action needs to be conducted prior to material removal.

Currently, the Town of Dauphin Island has identified two offshore borrow areas in the vicinity of the West Lobe borrow area and is in the permitting process to use these for a Dauphin Island shoreline nourishment project (Forrest-Vandera, 2011). The northern borrow area is estimated at 5,303,000 cubic yards and the southern borrow area is estimated at 2,541,500 cubic yards. These figures are based on cut depths and not total material available. As such, if these areas are used, they are not expected to exhaust the supply of suitable material on the West Lobe. Figure 21 shows the layout of these proposed borrow areas in relation to borrow areas identified in this study.

Figure 21. Polygons labeled North and South Borrow Areas are current borrow source locations for a Dauphin Island nourishment project. Borrow area shapes are approximate. Borrow area designs with proposed shapes are included in the report (Forrest-Vandera, 2011). The West Lobe and East Channel Margin Shoal areas are illustrated.

Based on the results of this investigation, both western and eastern borrow areas are suitable sources of beach-quality sand. However, further hydrodynamic modeling should be conducted on the eastern sites to determine sand excavation effects on wave and current flow through the area and to refine borrow area designs. Core sampling with a denser grid of sample sites should be conducted to better refine the boundaries and validate the quality of sand.

Bibliography

(2006). Appendix A: Vibracore Logs. In *Phase I Deepwater Sand Search, Baldwin County, Alabama* (p. 60). Jacksonville, FL, Alabama, U.S.A: Olsen Associates, Inc submitted to Gulf State Park and Gulf Shores.

(1999). *Appenidx East Alabama Shore: Geological and ecomonic characterization and near-term potential of sand resources of the east Alabama inner continental shelf offshore of Morgan Peninsula, Alabama.* Alabama Geological Survey Report for MMS Cooperative Agreement No. 145-01-98-CA-30935.

Byrnes, M. R., & Hammer, R. M. (1999). *Final Report: Environmental Survey of Identified Sand Resource Areas Offshore Alabama; OCS Study MMS 99-0052.* Applied Coastal Research and Engineering, Inc.

Byrnes, M. R., Griffee, S. F., & Olser, M. S. (2010). *ERDC/CHL TR 10-8: Channel Dredging and Geomorphic Response at and Adjacent to Mobile Pass, Alabama.* Coastal and Hyrdraulics Laboratory.

Byrnes, M. R., Griffee, S. F., & Olser, M. S. (2008). *Final Report: Evaluation of Channel Dredging on Shoreline Response at and Adjacent to Mobile Pass, Alabama.* Applied Coastal Research and Engineering, Inc. prepared for the U.S. Army Corps of Engineers.

Byrnes, M., & Hammer, R. M. (1999). *Executive Summary: Environmental Survey of Identified Sand Resourse Areas Offshore Alabama; OCS Study MMS 99-0052.* Applied Coastal Research and Engineering, Inc.

Flocks, J. G., Sanford, J. M., & Smith, J. L. (2009). *USGS Open-File Report: Sediment Distribution on the Mississippi-Alabama Shelf, Northern Gulf of Mexico.* currently unpublished.

Forrest-Vandera, B. M., Larenas, M., & Andrews, J. L. (2011). *Appendix J: Dauphin Island Coastline Restoration: Sand Search Investigation.* Coastal Planning and Engineering, Inc., and South Coast Engineers, LLC.

Hummell, R. L. (1997). *Hydrographic numerical model investifation and analysis of an offshore sand resource site for use in beach nourishment projects on Dauphin Island, Alabama.* Alabama Geological Survey Report for MMS Cooperative Agreement No. 14-35-0001-30781.

Hummell, R. L., & Smith, W. E. (1995). *Geologic and Environmental Characterization and near-term lease potential of an offshore sand resource site for use in beach nourishment projects on Dauphin Island, Alabama; MMS Cooperative Agreement No. 14-35-0001-30725.* Alabama Geological Survey Report for MMS Cooperative Agreement No. 14-35-0001-30725.

Hummell, R. L., & Smith, W. E. (1996). *Geologic Resource Delineation and Hydrographix Characterization of an Offshore Sand Resource site for use in Beach Nourishment Projects on Dauphin Island, Alabama.* Alabama Geological Survey Report for MMS Cooperative Agreement No. 14-35-0001-30781.

Jones, S. C., Darby, S. B., & Tidwell, D. K. (2009). *The Development of an Offshore Alabama Sand Information Systems.* Alabama Geological Survey Report for MMS Cooperative Agreement No. M07AC12488.

Kopaska-Merkel, D. C., & Rindsberg, A. K. (2002). *Progress Report on analysis of Alabama beach sediment characteristics.* Alabama Geological Survey Open-File Report for MMS Cooperative Agreement No. 1435-01-98-CA-30935.

Kopaska-Merkel, D. C., & Rindsberg, A. K. (2005). *Sand-Quality Characteristics of Alabama Beach Sediment, Environmental Conditions, and Comparison to Offshore Sand Resources.* Alabama Geological Survey Open-File Report 0508.

Parker, S. J., Davies, D. J., & Smith, W. E. (1993). *Geological, economic, and environmental characterization of selected near-term leasable offshore sand deposits and competing onshore sources for beach nourishment.* Alabama Geological Survey Open-File Report for MMS Cooperative Agreement No. 14-35-0001-30630.

Rindsberg, A. K., & Kopaska-Merkel, D. C. (2006). *Sand-Quality Characteristics of Alabama Beach Sediment, Environmental Conditions, and Comparison to Offshore Sand Resources: Annual Report 2.* Alabama Geological Survey Open-File Report 0607: Geological Investigations Program.

Stone, G. W., Liu, B., Pepper, D. A., & Wang, P. (2004). The importance of extratropical and tropical cyclones on the short-term evolution of barrier islands along the northern Gulf of Mexico, U.S.A. *Marine Geology, 210* , 63-78.

USACE. (2008, August). Coastal Engineering Manual. *EM-1110-2-1100* .

Database References

*Subscript applies to Report reference in Bibliography

-Data provided by the Geological Survey of Alabama (GSA), United States Army Corps of Engineers (USACE), and Coastal Planning and Engineering, Inc. (CPE)

Western Study Area Borings			Eastern Study Area Borings		
Source	**Sample Type**	**Layer Name**	**Source**	**Sample Type**	**Layer Name**
GSA	Grab Samples	AL_sand_data_Byrnes1[2, 6]	GSA	Grab Samples	ByrnesSurvey1E[2, 6]
GSA	Grab Samples	AL_sand_data_Byrnes2 [2, 6]	GSA	Grab Samples	ByrnesSurvey2E[2, 6]
GSA	Borings and Grab Samples	AL_sand_data_gsa_mms[4, 5, 6]	GSA	Borings and Grab Samples	GSA_MMSe [4, 5, 6]
GSA	Borings and Grab Samples	AL_sand_data_deck41[6]	GSA	Borings and Grab Samples	Deck41E[6]
GSA	Grab Samples	AL_sand_data_Grabsamples[6]	GSA	Grab Samples	GrabSamplesE[6]
GSA	Borings and Grab Samples	Extracted_AL_sand_data[6]	GSA	Borings and Grab Samples	usSEABED_extractedE[6]
GSA	Borings	gsa_usgs_AL_sand_data[4, 6]	GSA	Borings	GSA_UsgsE[4, 6]
GSA	Grab Samples	Nos_sed_AL_sand_data[6]	GSA	Grab Samples	nosSedE[6]
GSA	Borings and Grab Samples	Parsed_AL_sand_data[6]	GSA	Borings and Grab Samples	usSEABED_parsedE[6]
USACE	Borings	X006_borehole_AL_sand_data	CPE	Borings	Douglass_2010[3]
			CPE	Borings	Douglass_2011[3]
			GSA	Borings	Olsen2006E[1]
			GSA	Borings	ExxonE[4, 5]

Appendix A: Material Identification Geoprocessing

Section 1: ArcGIS Technical Database Construction and Queries

Material Identification Geoprocessing

CESAM-OPJGIS provided template Microsoft Excel spreadsheets to standardize data entry. This data entry template is compliant with the schema used by a Sediment Sampling tool, developed by CESAM-OPJGIS, for assistance with data analysis of sediment data within ArcGIS software. For purposes of this project, all non-spatial data tables were stored in a temporary Access database (tables noted below). Final results will be imported into CESAM's enterprise GIS (EGIS) database.

1. Microsoft Excel Data Preparation
    a. Merge supplied, completed, spreadsheets into a single Excel workbook
        i. Minimum data entry per site includes:
            1. Sample Name/Log ID
            2. Coordinates (in Decimal Degrees)
        ii. *Type (Boring or Grab)*Details for stratigraphy available at each Location
            1. Top of Layer Depth
            2. Bottom of Layer Depth
            3. Material Type, Description, Remarks
            4. Top/Bottom of Hole Elevation
    b. Add REF_SAMPLE_ID (auto-generated numeric ID) to locations (TBL_SAMPLE_LOCATIONS) (MS Excel)
    c. Assign XREF_SAMPLE_ID to associated stratigraphy (TBL_SAMPLE_STRATIGRAPHY) (MS Excel)
2. Microsoft Access Data Filtering
    3. Import LOCATIONS and STRATIGRAPHY tables/tabs into Access database
    4. Calculate Thickness in TBL_SAMPLE_STRATIGRAPHY Table:
        a. Expression: [ENTRY_SAMPLE_BOTTOM_DEPTH] –[ENTRY_SAMPLE_TOP_DEPTH]
    5. Isolate sites where ***suitable*** materials ARE available at 0-1 ft. cut depth
        a. Query Stratigraphy Table:
            i. ENTRY_SAMPLE_TOP_DEPTH <=1 AND
            ii. ENTRY_MATERIAL_CODE = "SP" Or "SW" Or "SW-SM" Or "SP-SM"
        b. Get Distinct List of Sites (to obtain single location of suitable materials)
        c. Output Queries:
            i. 1QrySuitableSamplesNearTop
            ii. 1QrySuitableSitesAllDetail
    6. Isolate suitable materials with thickness

   a. Find all sites where suitable materials (via **1QrySuitableSamplesNearTop**) are ***not*** found in the entire core.
      i. ENTRY_MATERIAL_CODE <>"SP" And <>"SW" And <>"SW-SM" And <>"SP-SM
      ii. Output Query : **2QrySuitableSamplesNearTopMixed**
   b. Find all sites where suitable materials are not mixed with other material in the entire core.
      i. SELECT [QryDistinctSuitableSites<1].FILENAME
         FROM [QryDistinctSuitableSites<1] LEFT JOIN
         2QrySuitableSamplesNearTopMixed ON
         [QryDistinctSuitableSites<1].XREF_SAMPLE_ID =
         2QrySuitableSamplesNearTopMixed.XREF_SAMPLE_ID
         WHERE (((2QrySuitableSamplesNearTopMixed.FILENAME) Is Null));
      ii. Output Queries/Table
         1. **3QryDistinctSamplesNearTopNoMix** (Distinct sites that only include suitable material)
         2. **3QryDistinctMixed** (Distinct sites)
            3. These sites were provided to the customer. Per each site, a thickness was calculated for *continuous* thickness of suitable material. Customer identified those questionable sites to be included in the “acceptable” (> 5 feet) thickness parameter.
         4. These sites were uploaded as new table (**MixedSitesWithThickness**) into the database.
            a. The value for **Viable Thickness** is not an auto-generated calculation. Thickness for the questionable samples we manually added together based on their proximity within the core sample.
            b. Query all points where no material designation exists. These points will not be including top of sample layer.
   c. Create a make table query to extract those additional sites to include as suitable locations for material.
      i. Output Table: **AllSuitableSites_ThicknessPerPoint**
            1. Key Fields: X, Y, Viable Thickness, Avg D50, Sample Name
            2. This table also includes all sites where suitable material was identified 0-1 feet, entire core sample was of suitable material, and thickness was > 5 feet (**4Qry>5Thickness_NoMix**).
      ii. Output Query: **5QryThickness_Mixed**
7. Find suitable thickness at defined cut depths (no cut, 5, 10, 15, and 20 ft). Cut depth is being derived by depth value supplied per top of stratigraphy layer.
   a. 5Qry5ftCut_SuitableSamples_TopDepth, 5Qry10ftCut_SuitableSamples_Top, 5Qry15ftCut_SuitableSamples_Top, 5Qry20ftCut_SuitableSamples_Top
      i. TBL_SAMPLE_STRATIGRAPHY.ENTRY_SAMPLE_TOP_DEPTH >=5
      ii. TBL_SAMPLE_STRATIGRAPHY.ENTRY_SAMPLE_TOP_DEPTH >=10
      iii. TBL_SAMPLE_STRATIGRAPHY.ENTRY_SAMPLE_TOP_DEPTH >=15

        iv. TBL_SAMPLE_STRATIGRAPHY.ENTRY_SAMPLE_TOP_DEPTH >=20
        v. **5QryNoCut_SuitableSamples_Top** (No Filter)
            1. Example: If SP material was identified within a stratigraphy layer that started at a top depth of 3 feet and continued to 7 feet, thickness for a 5 foot cut depth = 4 (7 minus 3)

    b. Find the sum of the thickness per site. Group all records by site and sum the calculated thickness at the specified cut depth.
        i. 6QryNoCut_SuitableSample_SumThickness_TopDepth
        ii. 6Qry20ftCut_SuitableSample_SumThickness_TopDepth
        iii. 6Qry15ftCut_SuitableSample_SumThickness_TopDepth
        iv. 6Qry10ftCut_SuitableSample_SumThickness_TopDepth
        v. 6Qry5ftCut_SuitableSample_SumThickness_TopDepth
    c. Create a 'Make Table' query and append all records from the SumThickness query (one table per cut depth)
        i. Initial append will include all records where sum of thickness is >5 feet and is available at noted cut depth.
        ii. Create an 'Append' query and add all sites that are not already available in the table.
            1. INSERT INTO 15ftCutSuitableMaterial_TopDepth (XREF_SAMPLE_ID, X_DD, Y_DD, FILENAME)
               SELECT TBL_SAMPLE_LOCATIONS.REF_UID, TBL_SAMPLE_LOCATIONS.X_DD, TBL_SAMPLE_LOCATIONS.Y_DD, TBL_SAMPLE_LOCATIONS.REF_SAMPLE_ID
               FROM 6Qry15ftCut_SuitableSample_SumThickness_TopDepth RIGHT JOIN TBL_SAMPLE_LOCATIONS ON 6Qry15ftCut_SuitableSample_SumThickness_TopDepth].XREF_SAMPLE_ID = TBL_SAMPLE_LOCATIONS.REF_UID
               WHERE ((([6Qry15ftCut_SuitableSample_SumThickness_TopDepth].FILENAME) Is Null));
            2. Set the Thickness (Update query) to 0 (zero). This will decrease the amount of interpolation, but including ALL SITES. If the material is not suitable or does not contain the necessary thickness (<5 feet), the cell value in the interpolation will be zero.
                a. Output Tables: **NoCutSuitableMaterial_TopDepth, 5ftCutSuitableMaterial_TopDepth, 10ftCutSuitableMaterial_TopDepth, 15ftCutSuitableMaterial_TopDepth, 20ftCutSuitableMaterial_TopDepth**

8. Find Average Grain Size per Suitable Sites
    a. For all sites where grain size data is available (size > 0), calculate average size per site.

    b. Output : **QryAllSitesAvgGrainSize**
9. Export Tables and Import into ArcMap
3. ArcMap Layers
    a. Thickness Analysis (created from each *_TopDepth tables)
        i. Create an Event layer using the X_DD and Y_DD fields
        ii. Create feature class (per cut depth)
        iii. Using customer defined Area of Interest polygons (east and west), extract all points that are contained in each of the polygons into separate feature classes.
            1. *Note: Using a concentrated area of interest reduces the error introduced during the interpolation step.*
            2. Use Select by Location Query
            3. Export as separate point feature class
        iv. Using the Spatial Analysis extension, interpolate a Thickness surface, using the Thickness attribute as the Z value class per each cut depth feature.
            1. *Natural Neighbor interpolation* method
            2. Defaults accepted for the cell size
    b. Grain Size (created from QryAllSitesAvgGrainSize)
        i. Create an Event layer using the X_DD and Y_DD fields
        ii. Create feature class.
        iii. Using the Spatial Analysis extension, interpolate Average Grain Size surface, using the AvgD50 attribute as the Z value class per each cut depth feature.
            1. *Natural Neighbor interpolation* method
            2. Defaults accepted for the cell size
        iv. Using the Spatial Analysis extension, use the *Zonal Statistics as Table* tool to calculate the minimum, maximum, and average grain size per supplied borrow area locations.
            1. Use the newly create AvgD50 surface as the input
            2. Accept the default cell size.
        v. Using the *Contour* module under Spatial Analyst's Surface tools, create contours for the grain size surface.
    c. Volume Differences
        i. Using CE-Tools: Depth Difference calculator, compare a "zero" surface for each proposed borrow area polygons with the derived cut depth surfaces.
            1. The "Zero" surface was created by using the Raster Calculator (Spatial Analyst) and subtracting the Cut surface from itself.
                a. Environment Settings (in ArcToolbox) were changed for the raster analysis mask. Per each zero surface, the mask was set to the boundary of the each borrow area.
            2. A selected feature (individual borrow area boundary) was used for the boundary of volume analysis for each cut depth.

Comparing Volumes to 1917-1918 Surface

The following data extraction was performed to limit the bottom depth of the boring for use in comparison to the volumes calculated using available bathymetric data. Boring data was truncated based the base elevation in 1917. For all sites (149 sites) that intersect the 1917 layer, assign 1917 elevations

1. Get elevation from 1917/20 surface for each point in Event Layer.
    a. Using *Extract Values to Points* tool in Spatial Analyst.
2. Export into table, import **_Sampleswith1917Elev**
3. Check how many sites with an available 1917 elev also have a top and bottom of bottom of stratigraphy elevation.
    a. Output Query: **Qry1917SiteWithBoringElev - 74 remaining sites.**
4. Compare to Suitable Sites (**AllSuitableSites_ThicknessPerPoint) – 52 suitable sites.**
    a. Make Table query - **Qry1917SiteWithBoringElevDistinct**
        i. Output Table - **1917SitesWithBoringElev_Suitable**
        ii. Add individual thickness of layers using Make Table query
            1. Output Query: **QrySampleswith1917ElevStrat**
    b. New Table Output -**_Sampleswith1917ElevStrat**
        i. Add ModifedThickness Column
        ii. Set ModifedThickness to 0 for not suitable sites.
        iii. Set ModifedThickness to 0 for stratigraphy layers for top elevation (of stratigraphy layer) is deeper than the 1917 elevation
        iv. Calculate ModifedThickness where stratigraphy layer top and bottom elevation are shallower than 1917 elevation.
            1. ModifedThickness = Bottom – Top elevation
        v. Calculate ModifedThickness where stratigraphy layer top is more shallow than 1917 and layer bottom is deeper than 1917 layer. ModifedThickness = 1917 elevation – Top elevation of stratigraphy layer.
        vi. Sum all modified thickness per site with suitable material.
            1. "SP" Or "SW" Or "SW-SM" Or "SP-SM"
            2. Output Query: **QryAllModifiedThicknessSites**
        vii. Import query results into ArcMap.
        viii. Plot as event layer.
        ix. Export as feature class.
        x. Use Natural Neighbor interpolation method on the ModifiedThickness value.
        xi. Compare a zero (base) layer to the derived modified thickness layer to compute the volume of suitable material.
            1. Use a "zero layer" (based on borrow area boundary) instead of the 1917 bathymetry, since the 1917 elevations were taken into consideration producing the modified thicknesses.
            2. The CE-Tools: Surface Area-Volume tool was used to compute volume.
            3. Results:

a. **Dixie Bar: 2,906,878 cu yards**
b. **West Lobe: 7,030,567 cu yards**

Complete Boring Analysis

1. Data Prep – using points: **NoCutSuitableMaterial_TopDepth** (Access table)
    a. Create Event layer
    b. Converted to State Plane (Alabama West) coordinate system.
    c. Interpolated (Natural Neighbor)
    d. Crop surface on each borrow area
        i. Raster Calculator
        ii. Analysis Mask set to borrow area layer
2. Statistics (using CE-Tools: Depth Difference Calculator) on each cropped surface
    a. Dixie Bar – 14,896,774 cu yards
        i. Min - 0.3 feet
        ii. Max - 35.3 feet
        iii. Avg – 11.4 feet (Used Zonal Statistics for borrow area boundary)
    b. West Lobe – 12,712,972 cu yards
        i. Min – 2.0 feet
        ii. Max – 26.29 feet
        iii. Avg – 16.3 feet (Used Zonal Statistics for borrow area boundary)

Section 2: <u>Procedures for compiling hydrographic surveys into surfaces for 3D Analyst volume calculations</u>

"Seafloor elevation measurements, compiled from historical hydrographic surveys, were used to identify seafloor morphology and change to quantify sediment transport pathways and rates relative to natural processes and engineering activities. Nine bathymetry data sets were compiled to document seafloor changes between 1847/51 and 2002. Eight of these data sets were compiled from hydrographic surveys completed by the USC&GS in 1847/51, 1892, 1908, 1917/20, 1941, 1960/61, 1970, and 1982/92, and one was compiled from digital beach profile and hydrographic survey data collected between April and July 2002 by the USACE, Mobile District (Table 3-1). Regional comparisons were made between 1847/51, 1917/20, and 1982/2002 to observe historical seafloor change; recent bathymetric changes were documented by comparing the 1982/92 and 2002 surfaces

Furthermore, bathymetric comparisons were made for the ebb-tidal delta and adjacent shores for time periods where survey coverage was limited (1847/48 to 1892, 1892 to 1908, 1908 to 1917/20, 1917/20 to 1941, 1941 to 1960/61, 1960/61 to 1970, 1970 to 1986, and 1986 to 2002). Regional data extend from the east side of Petit Bois Island to about 5 miles east of Perdido Pass and offshore to about the 70-ft depth contour (about 15 miles) for 1847/51, 1917/20, and 1982/2002 bathymetry data extend offshore to about the 30-ft contour (about 2.5 to 4 miles).

Digitized soundings and shorelines were used to create digital elevation models of the seafloor for the period 1847/51 to 1982/2002. The Triangulated Irregular Network (TIN) method was used in this study to form a surface of continuous connected triangular planes based on irregular points (Petrie, 1991). The elevation of each point in the model is determined by solving equations for its horizontal location on the triangulated surface. Therefore, only points existing in the original data sources are used to create the surface model, as opposed to grid models which interpolate evenly spaced points from original data. TIN model surfaces were used for all calculations of bathymetric volumes and change; however, grid surfaces were generated for graphic display purposes.

TIN polygon volume is determined by summing calculated volumes for each triangle, or portion thereof, relative to a specified reference height and polygon boundary. Triangle volumes above and/or below the reference height are calculated for a defined polygon to compute net differences between surfaces. To calculate volume differences across two TIN surfaces, every data point from the primary surface is projected onto the secondary surface and the *z*-value of the secondary surface is subtracted from the *z*-value of the original point (Petrie, 1991). Likewise, every data point from the secondary surface is projected onto the primary surface and the *z*-values subtracted. The resultant difference TIN contains zero contours that represent the intersection between the two original TIN surfaces. The zero contours are added as breaklines to the difference TIN, and the resulting triangles are classified as above, below, or equal to zero. Volume change is calculated by summing the volume of each triangle region….

…Changes in erosion and deposition on the ebb-tidal delta were quantified to isolate trends that may have evolved as the result of channel dredging through the outer bar. Similar to the sand volume analysis completed for the east and west lobes of the ebb-tidal delta (see Table 3-4), bathymetric change results for pre- and post-dredging time periods were quantified for both areas as well. However, polygon boundaries for defining calculation limits were based on erosion and accretion boundaries in the channel, the approximate location of the 30-ft depth contour for the most recent surface where deposition occurred and the older surface where erosion was identified, and the landward boundary where sand deposition or erosion is associated with shoal migration or sand bypassing to the beach…” (from Byrnes et al., 2010)

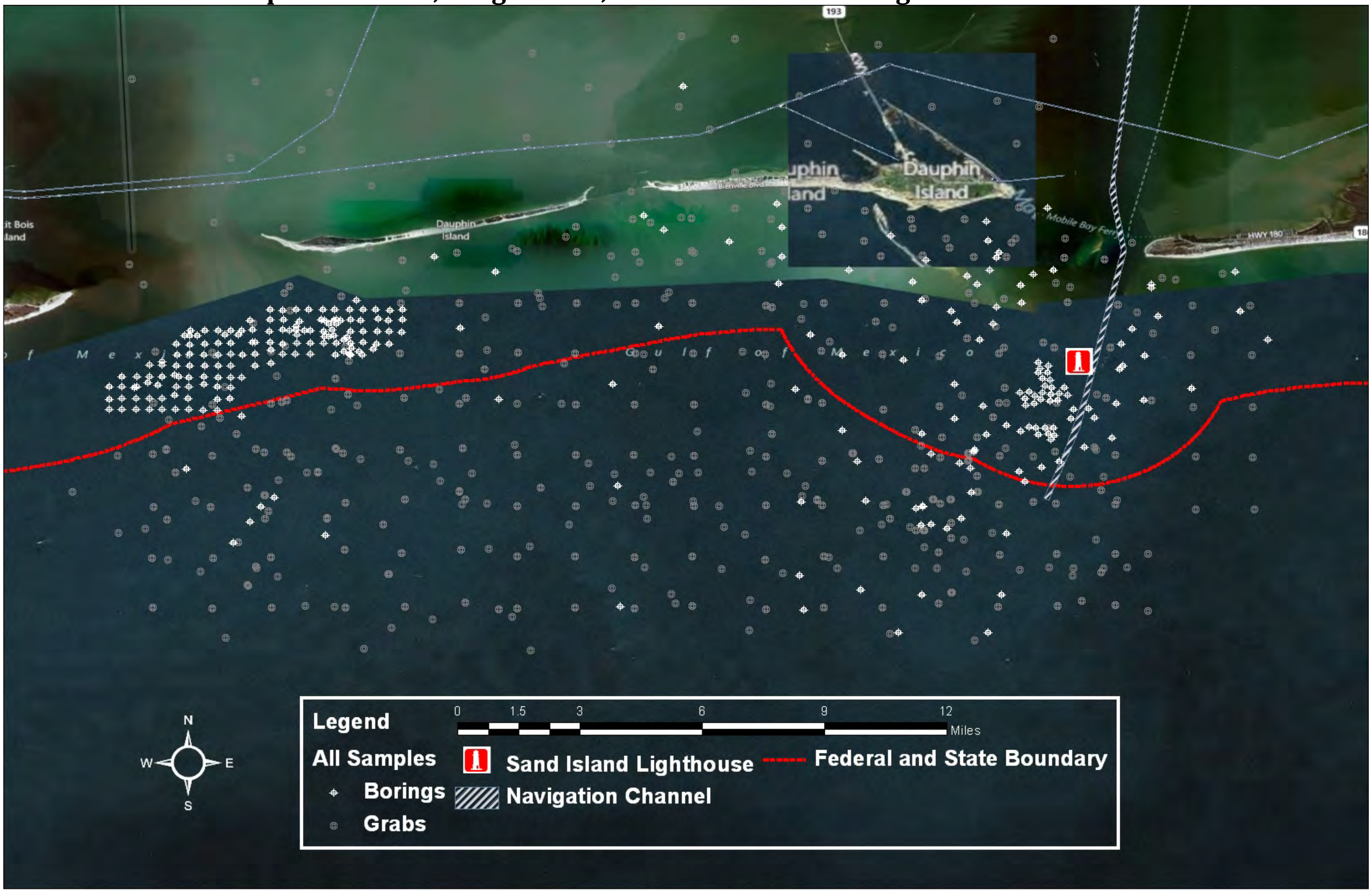


Figure 22. Borings and grab samples collected from various agencies and compiled into a single geodatabase.

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

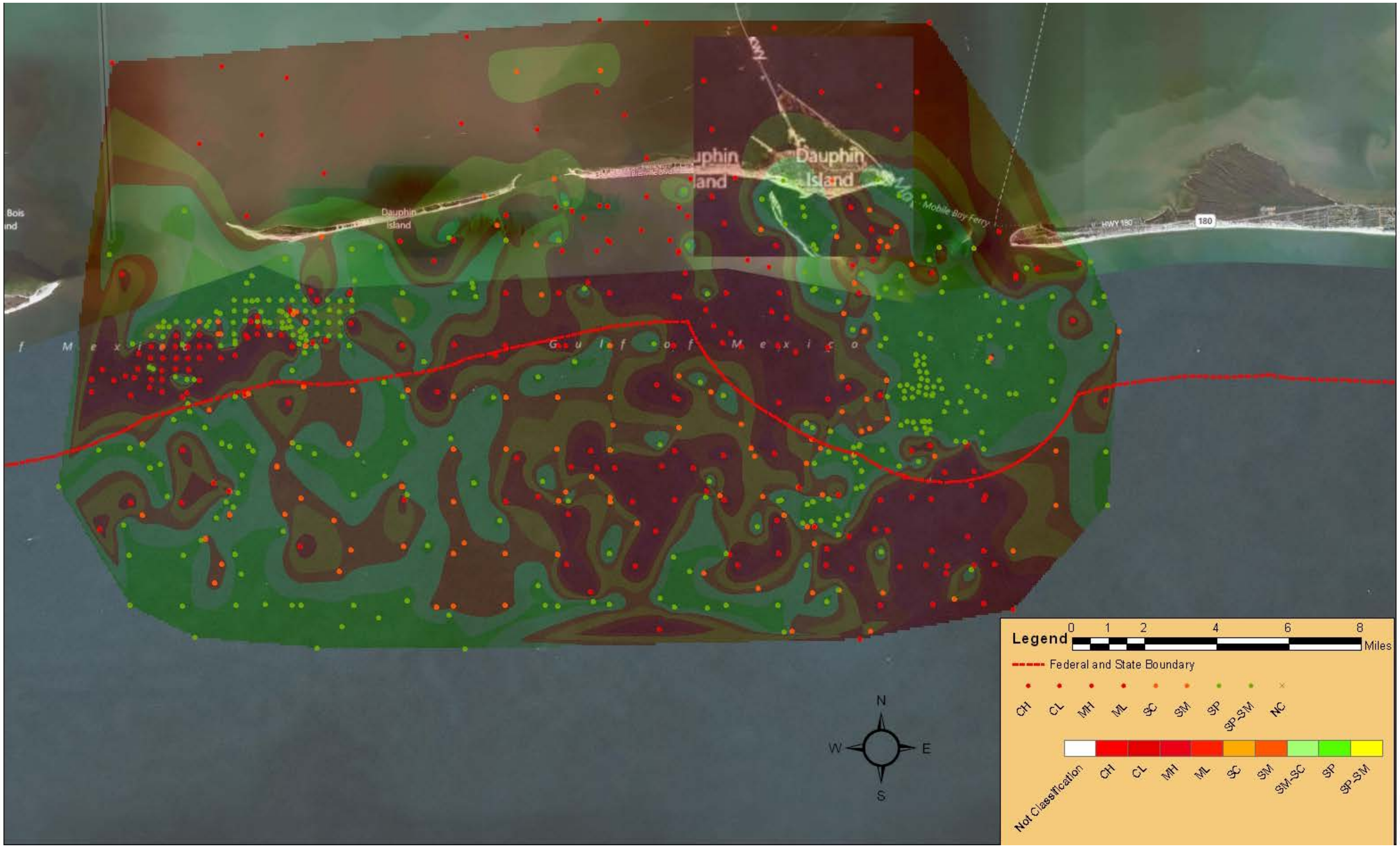


Figure 23. Surface sediment classification map for the offshore area of Dauphin Island, AL. The map depicts offshore sediment distribution relative to samples used in this study. Poor quality, fine-grained sediments (CH, CL, MH, ML, SC, SM) not suitable for beach nourishment are shown in red to orange colors, while suitable material (SM-SC, SP, SP-SM) is shown in green and yellow.

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

Figure 24. Modified Interpolation boundary with all borings plotted.

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

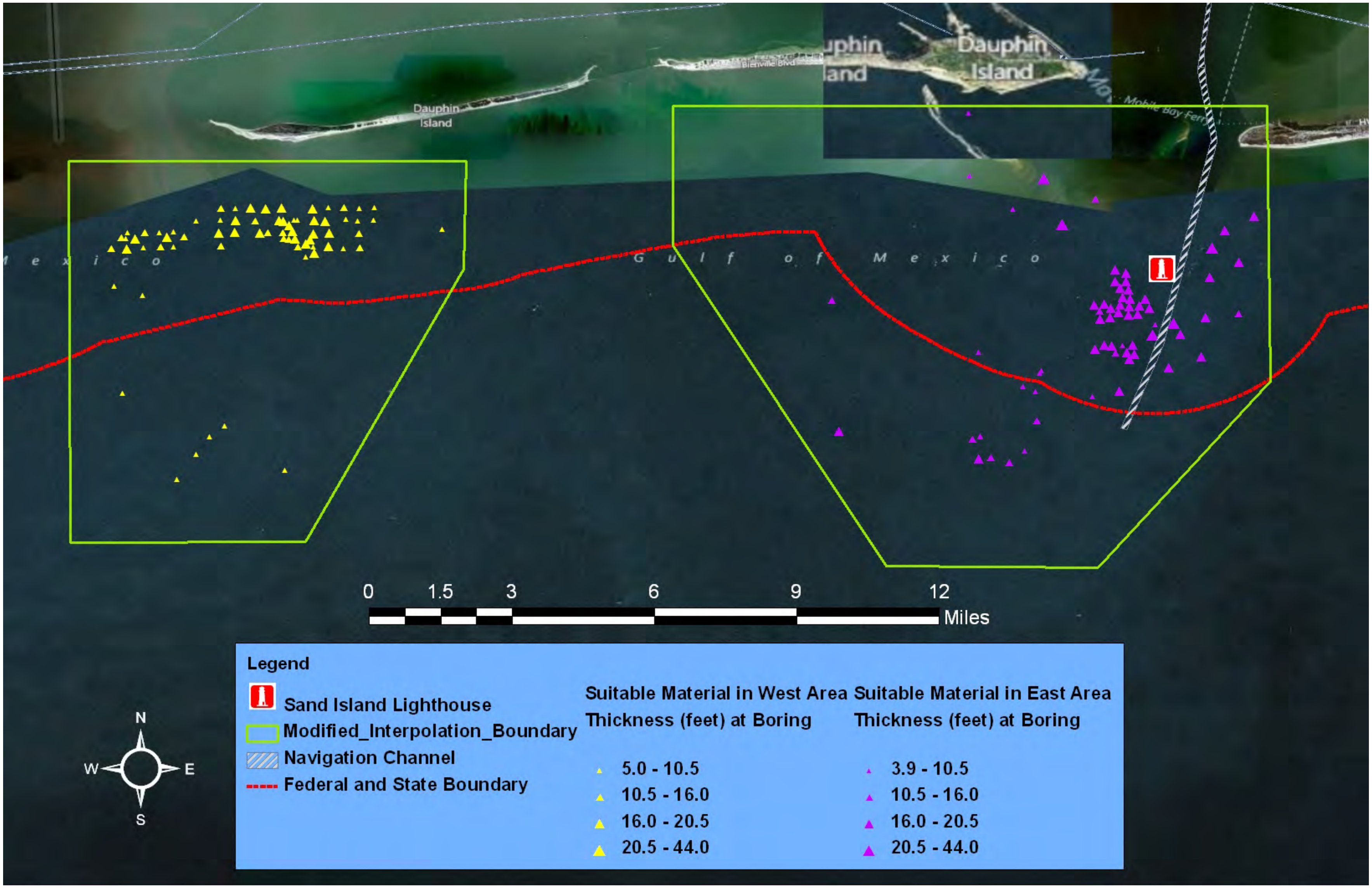


Figure 25. Borings with suitable material

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

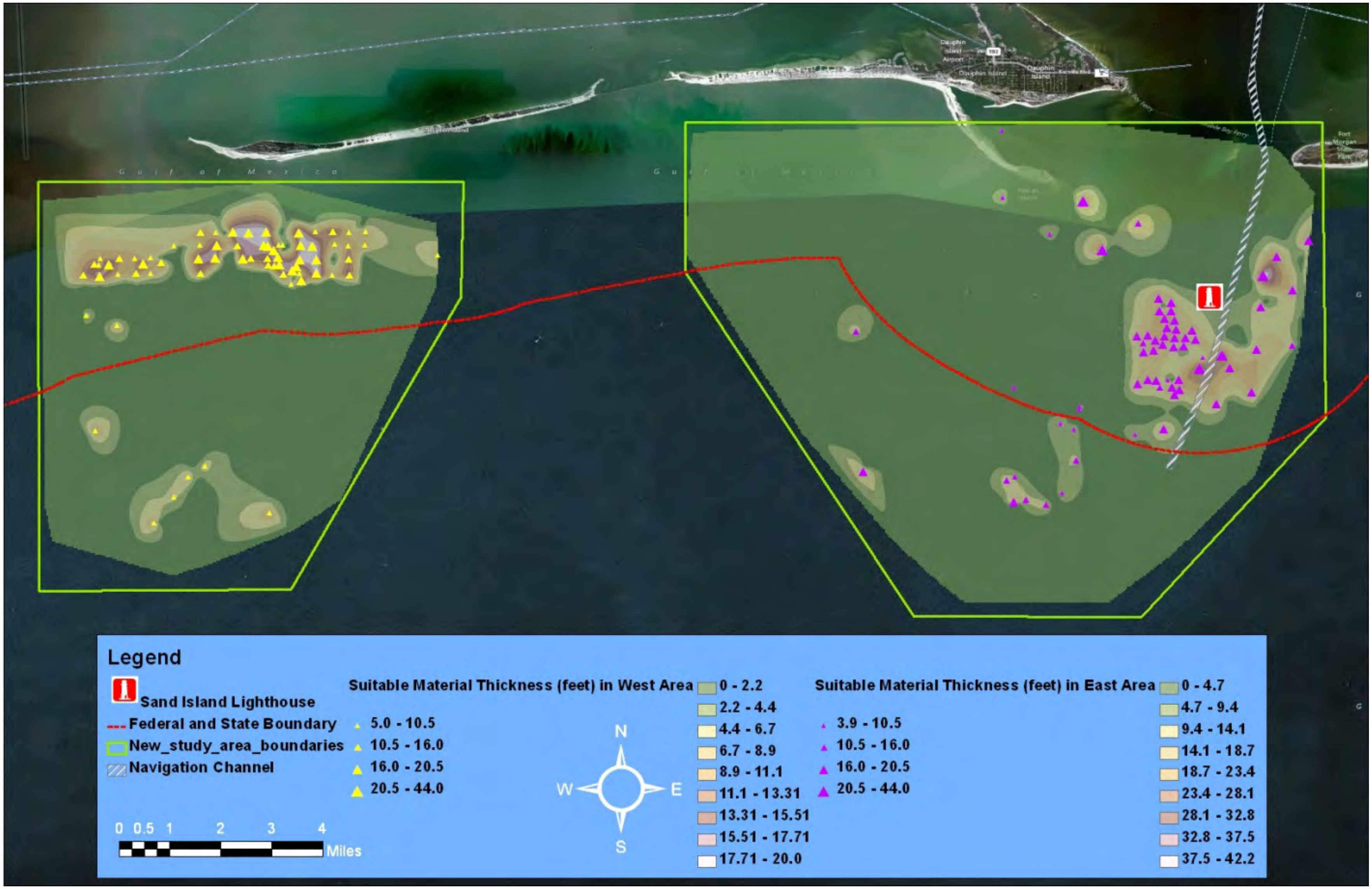


Figure 26. Suitable material thicknesses created through interpolation using borings with acceptable material and modified interpolation boundaries.

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

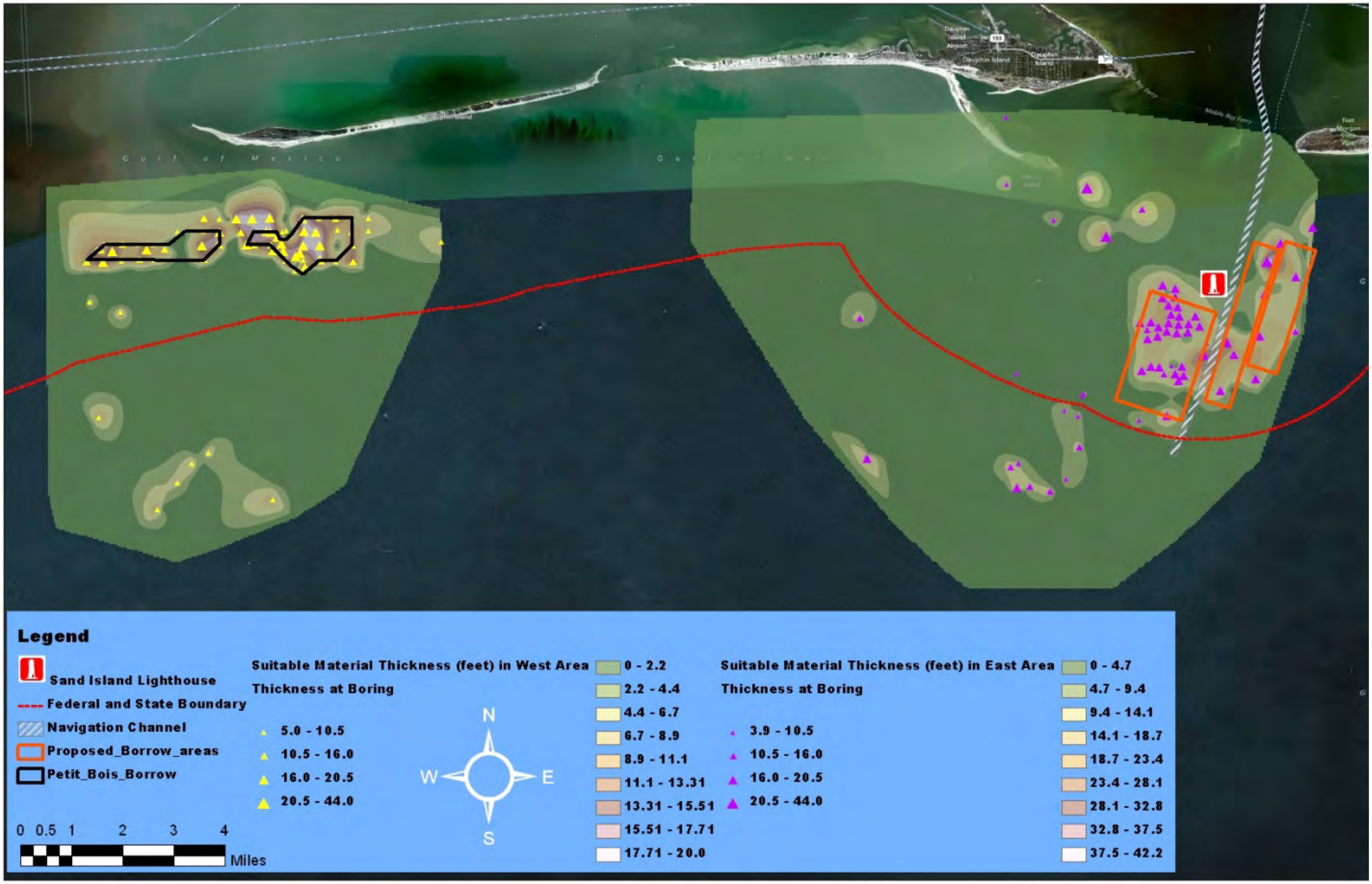


Figure 27. Locations of potential borrow area polygons drawn according to suitable material thickness and density of borings with suitable material.

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

Figure 28. Refined placement of eastern borrow areas based on interpolated thicknesses of suitable material.

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

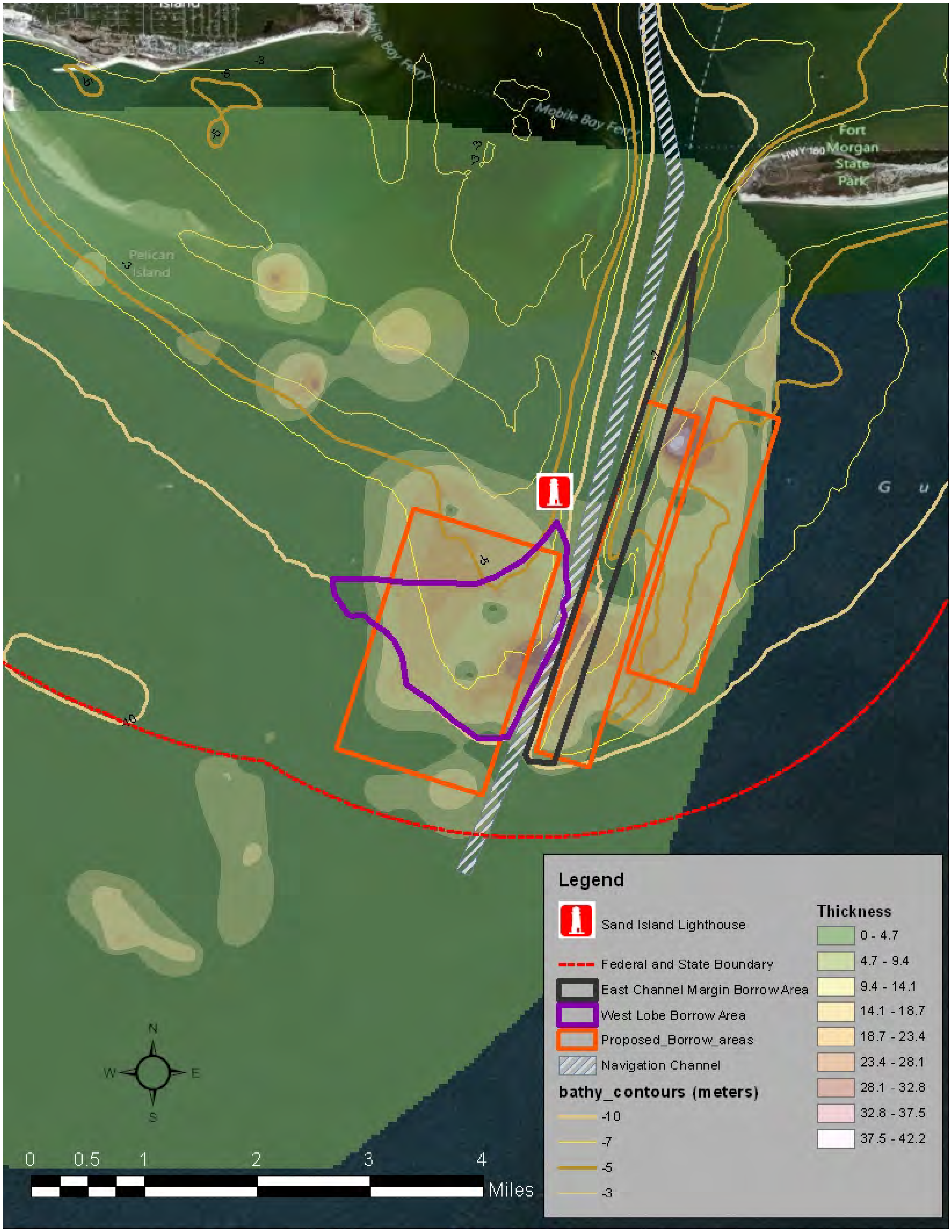


Figure 29. Initial east borrow area polygons overlain by modified East Channel Margin Shoal and West Lobe borrow area polygons based on conversations with Mark Byrnes.

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

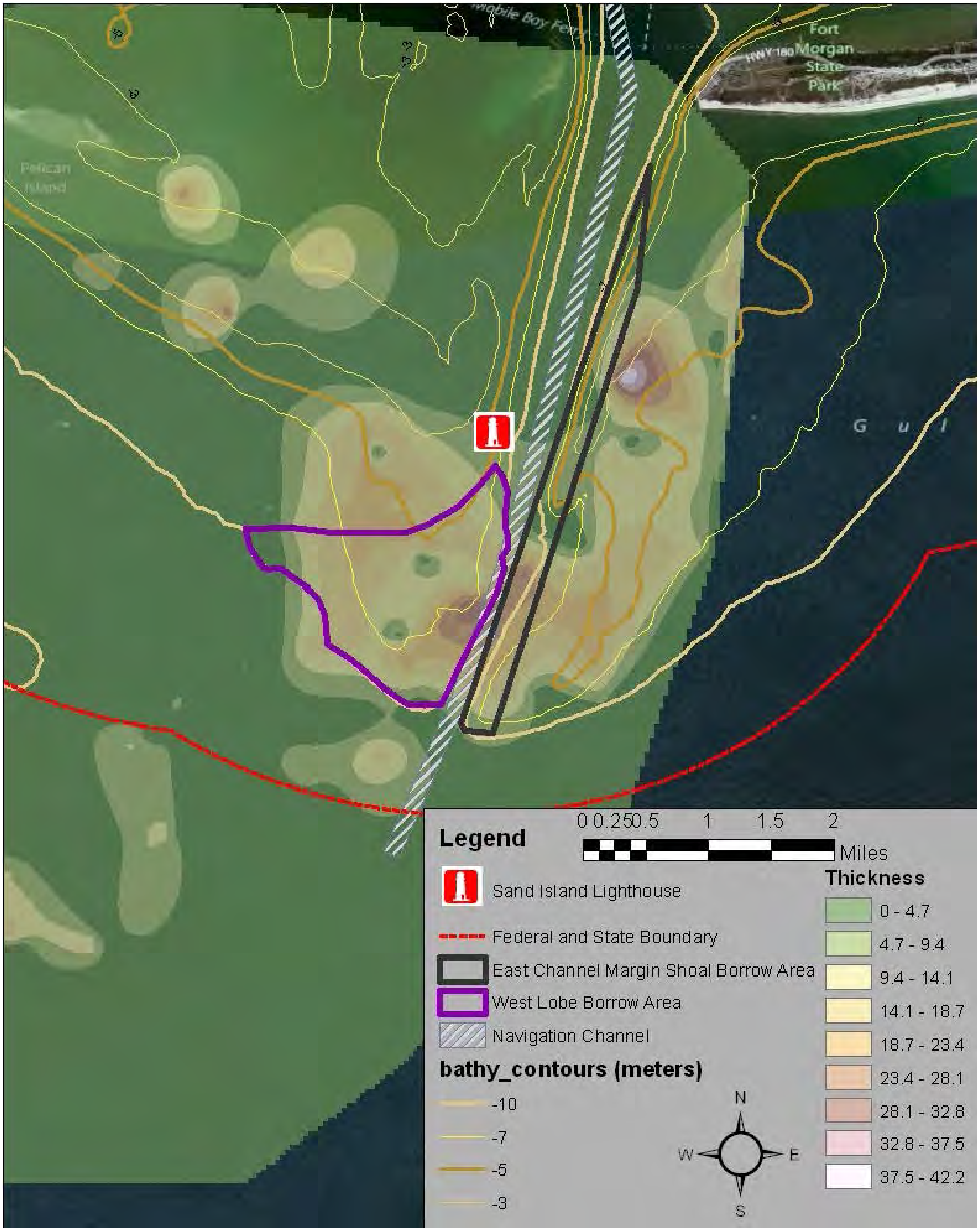


Figure 30. Modified East Channel Margin Shoal and west lobe borrow area polygons without initial polygon overlays.

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

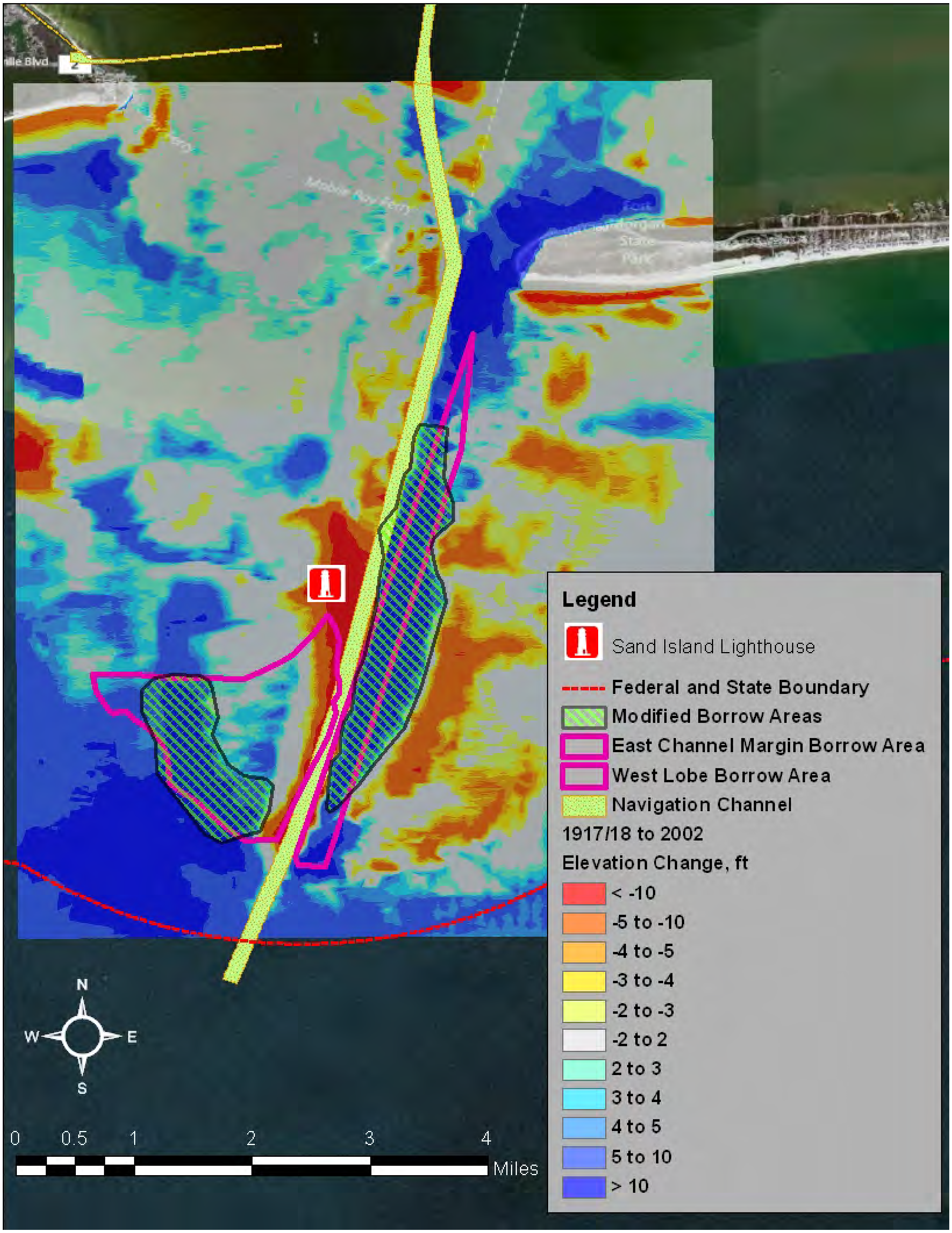


Figure 31. Modified from Byrnes et al. (2010) and Byrnes (2012).

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

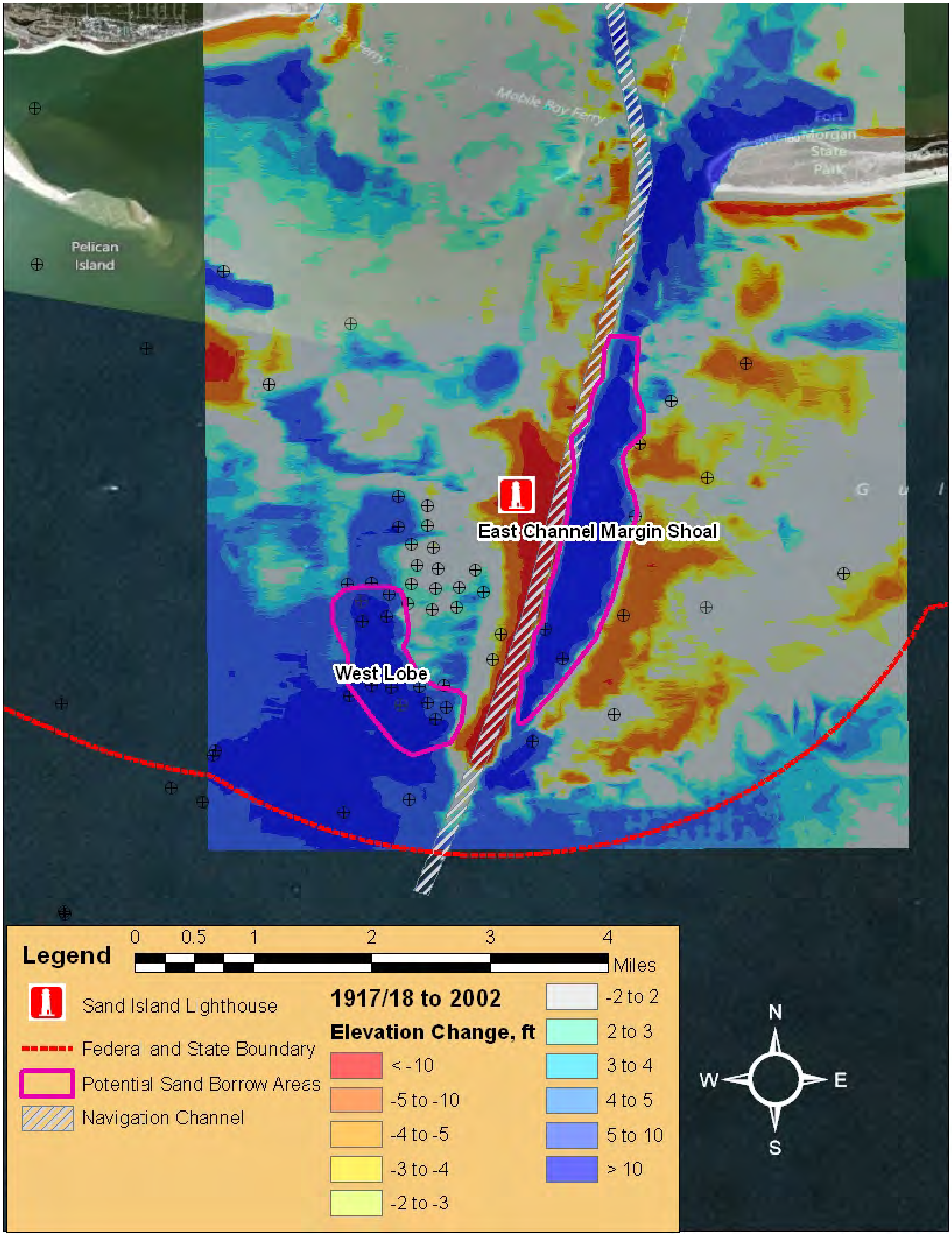


Figure 32. Final borrow area polygons superimposed over deposition from 1917/18 to 2002 (Modified from Byrnes, 2010).

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

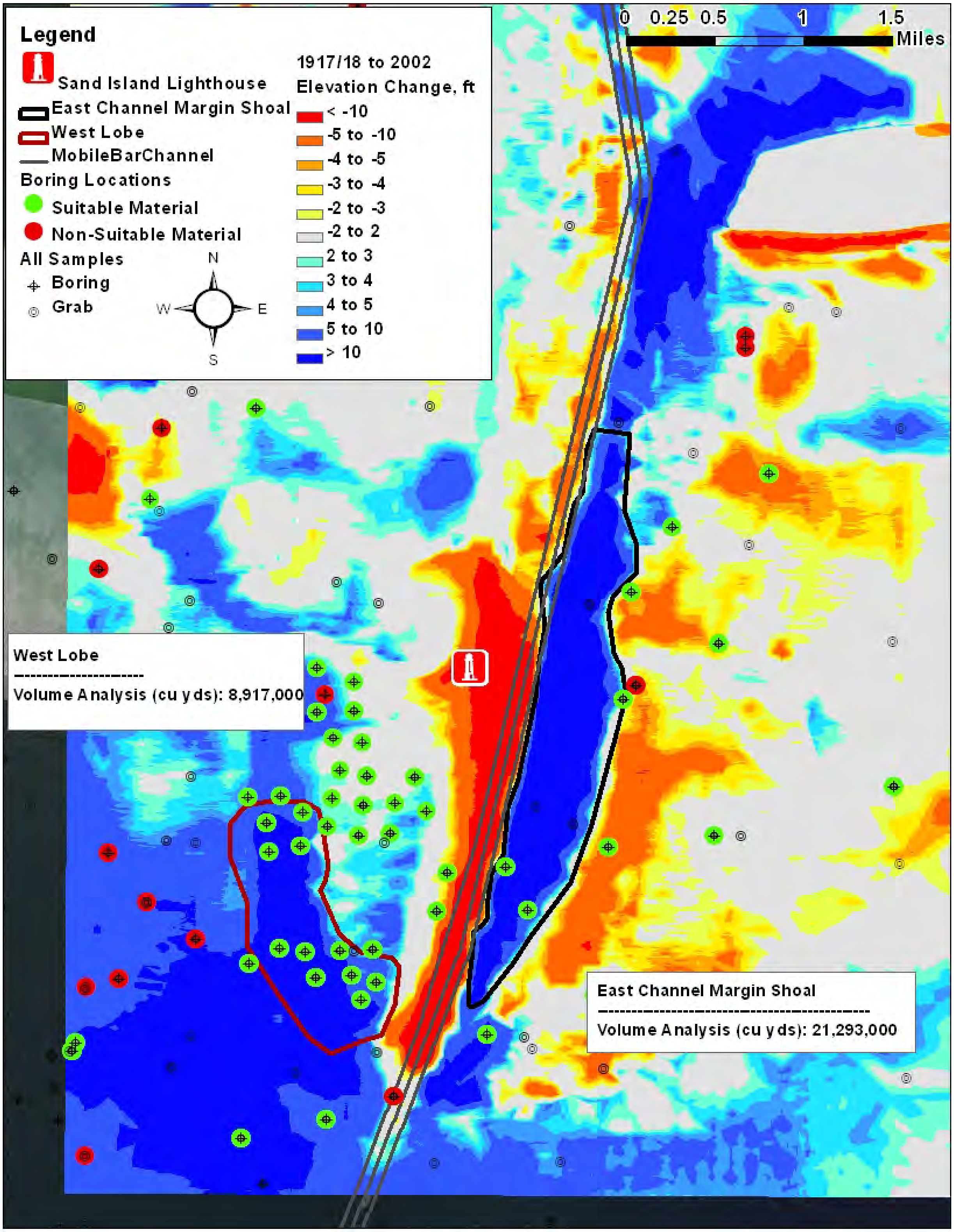


Figure 33. Volumes calculated for total deposition during period from 1917/18 to 2002 (Modified from Byrnes 2010).

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

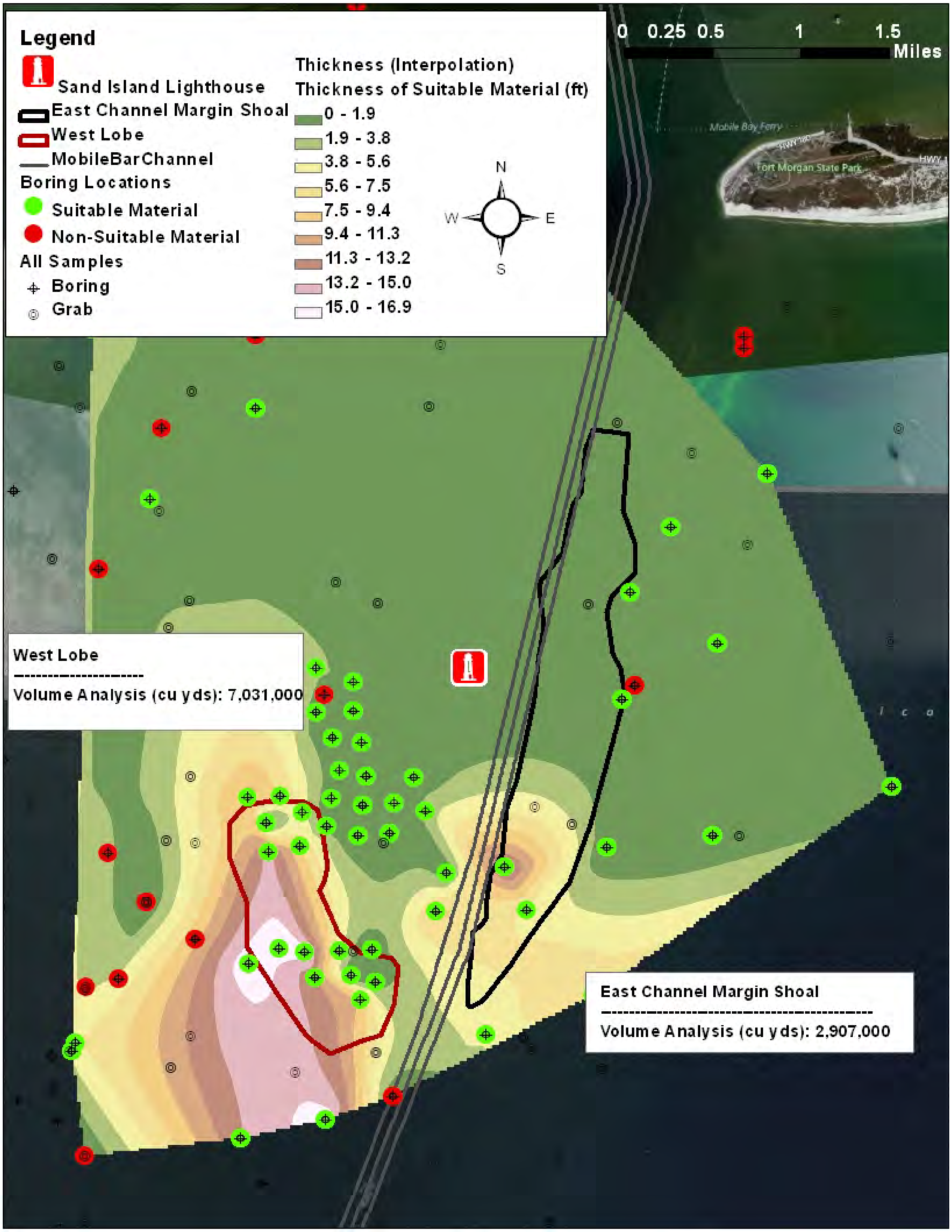


Figure 34. Volume analysis using borings with suitable material and the 1917/18 elevation survey as the bottom boundary.

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

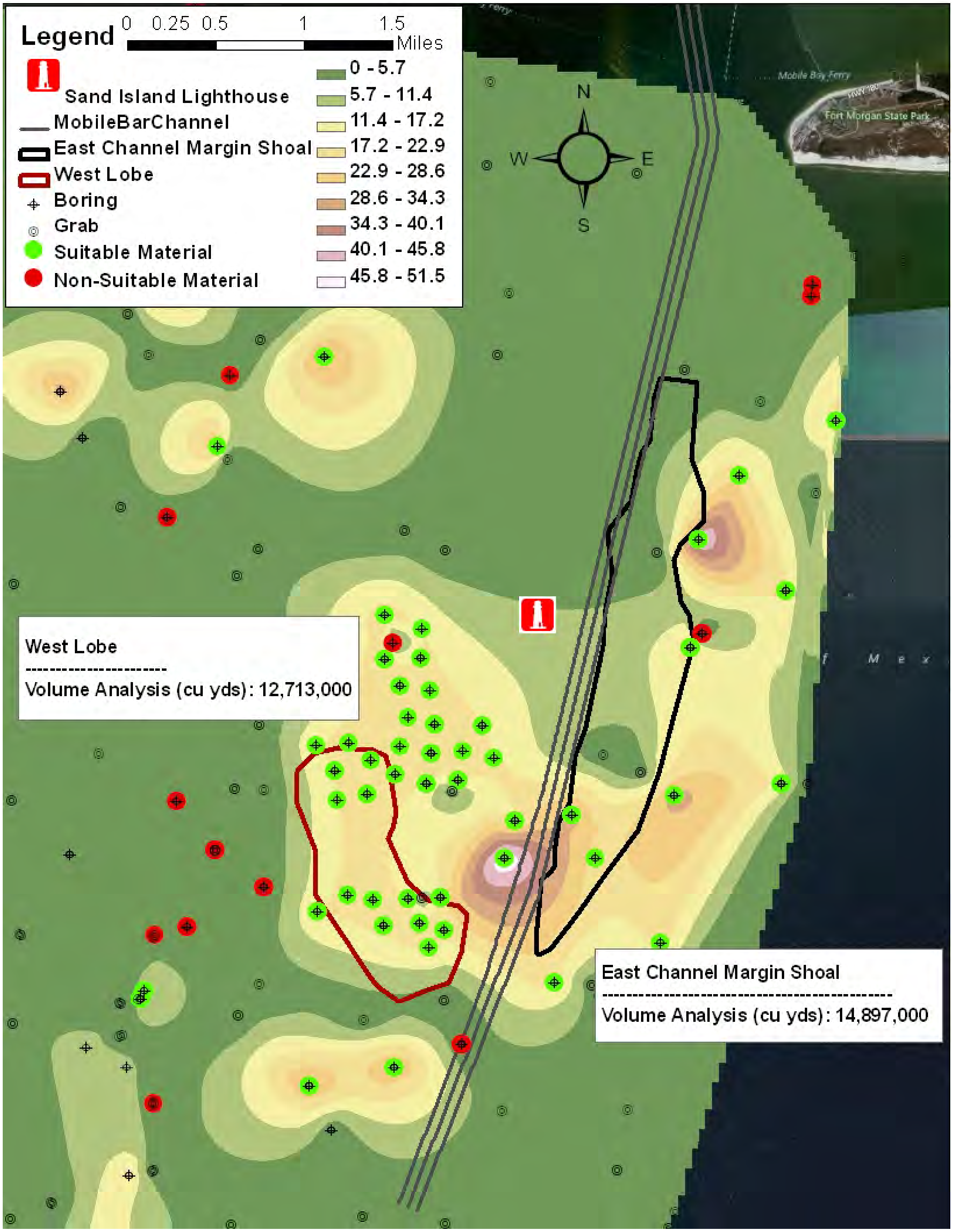


Figure 35. East Borrow areas with total volumes calculated from borings with suitable material only

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

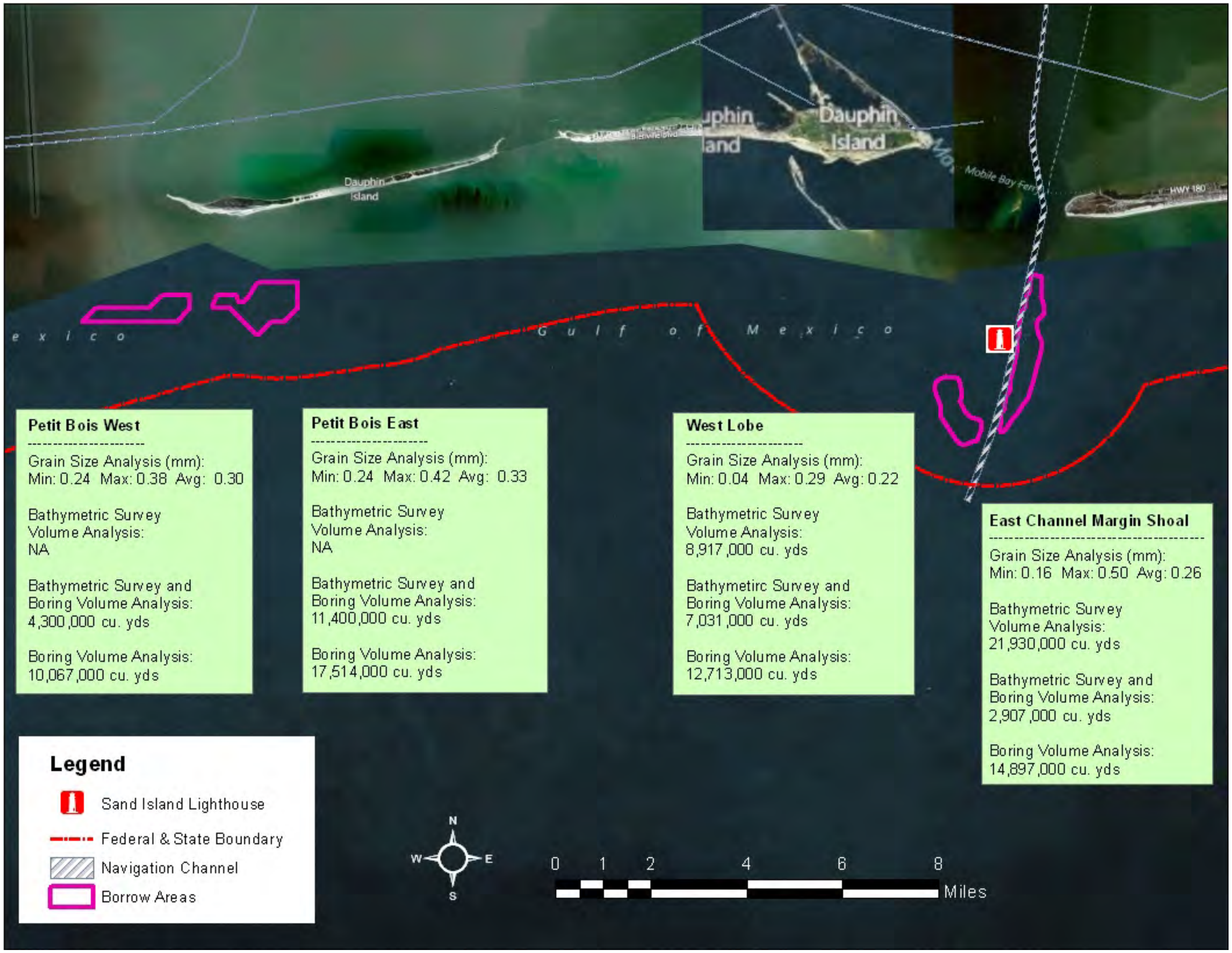


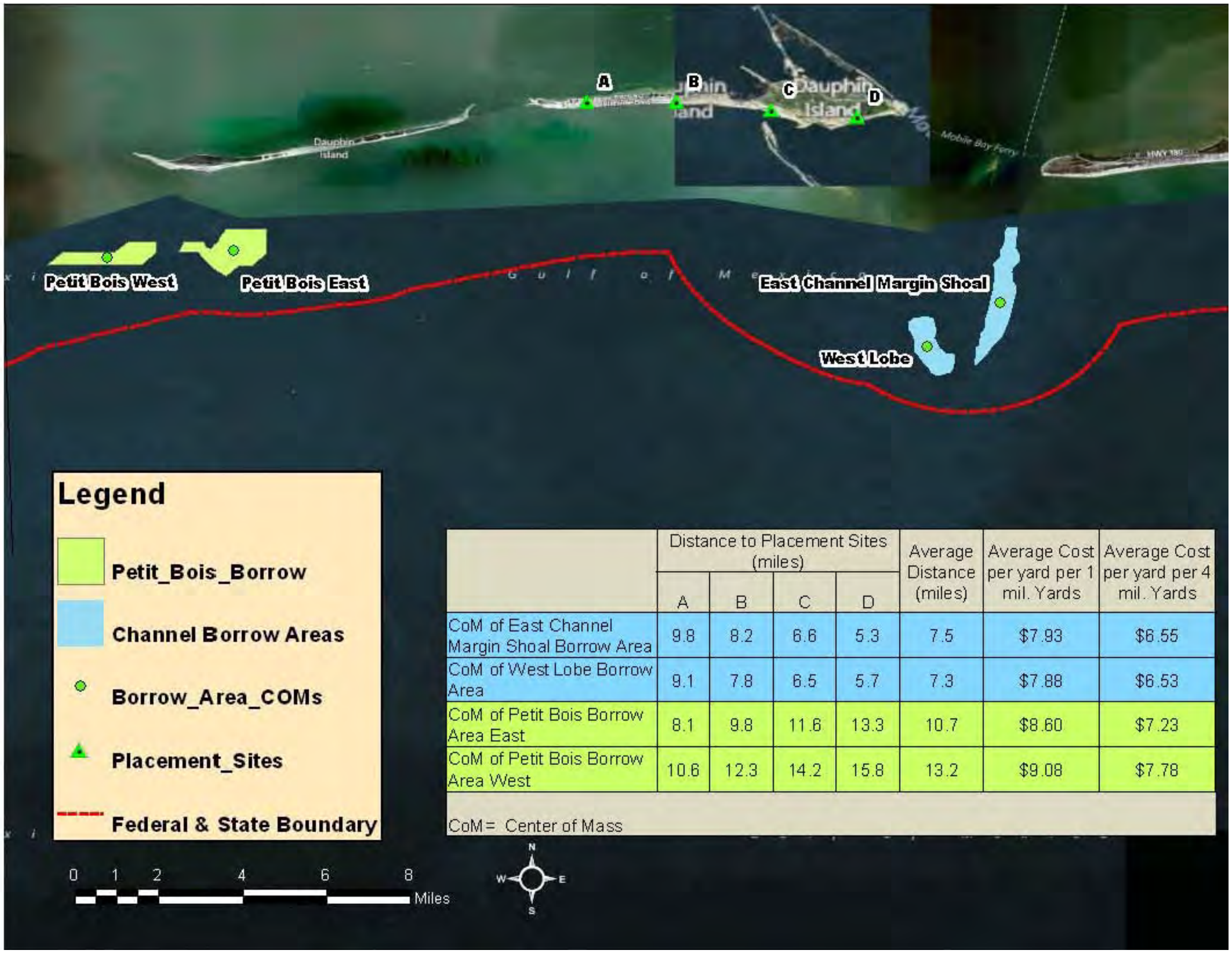
Figure 36. Aerial imagery of Dauphin Island, AL and surrounding areas. Potential borrow areas are displayed in pink. Average grain size and calculated volumes of suitable material from the three different methods.

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

Figure 37. Areas labeled North and South Borrow Areas are current borrow source locations for a Dauphin Island nourishment project (Forrest-Vandera, 2011). The West Lobe and Dixie Bar areas are overlayed these areas.

*Thicknesses and distributions displayed on maps are interpolations and estimates, and should be used for planning purposes only.

Appendix B: Cost Estimation



	Distance to Placement Sites (miles)				Average Distance (miles)	Average Cost per yard per 1 mil. Yards	Average Cost per yard per 4 mil. Yards
	A	B	C	D			
CoM of East Channel Margin Shoal Borrow Area	9.8	8.2	6.6	5.3	7.5	$7.93	$6.55
CoM of West Lobe Borrow Area	9.1	7.8	6.5	5.7	7.3	$7.88	$6.53
CoM of Petit Bois Borrow Area East	8.1	9.8	11.6	13.3	10.7	$8.60	$7.23
CoM of Petit Bois Borrow Area West	10.6	12.3	14.2	15.8	13.2	$9.08	$7.78

CoM= Center of Mass

Figure 38. Map of potential borrow areas with associated cost estimates for use on Dauphin Island.

*Summary of Cost**

Placement Site		One-Way Haul Distance	Estimated Borrow Range 1 mil-y's	4 mil-cy's
East Channel Margin Shoal Borrow Area	"A"	**9.8 miles**	**$8.40**	**$7.00**
East Channel Margin Shoal Borrow Area	"B"	**8.2 miles**	**$8.10**	**$6.70**
East Channel Margin Shoal Borrow Area	"C"	**6.6 miles**	**$7.70**	**$6.40**
East Channel Margin Shoal Borrow Area	"D"	**5.3 miles**	**$7.50**	**$6.10**
	Average	7.5 miles	$ 7.93	$ 6.55
West Lobe Borrow Area	"A"	**9.1 miles**	**$8.30**	**$6.90**
West Lobe Borrow Area	"B"	**7.8 miles**	**$8.00**	**$6.60**
West Lobe Borrow Area	"C"	**6.5 miles**	**$7.70**	**$6.40**
West Lobe Borrow Area	"D"	**5.7 miles**	**$7.50**	**$6.20**
	Average	7.3 miles	$ 7.88	$ 6.53
Petit Bois Borrow Area East	"A"	**8.1 miles**	**$8.10**	**$6.70**
Petit Bois Borrow Area East	"B"	**9.8 miles**	**$8.40**	**$7.00**
Petit Bois Borrow Area East	"C"	**11.6 miles**	**$8.80**	**$7.40**
Petit Bois Borrow Area East	"D"	**13.3 miles**	**$9.10**	**$7.80**
	Average	10.7 miles	$ 8.60	$ 7.23
Petit Bois Borrow Area West	"A"	**10.6 miles**	**$8.50**	**$7.20**
Petit Bois Borrow Area West	"B"	**12.3 miles**	**$8.90**	**$7.60**
Petit Bois Borrow Area West	"C"	**14.2 miles**	**$9.30**	**$8.00**
Petit Bois Borrow Area West	"D"	**15.8 miles**	**$9.60**	**$8.30**
	Average	13.2 miles	$ 9.08	$ 7.78

Table 5. Summary of estimated costs per cubic yard from each borrow area to placement sites on Dauphin Island.

*Disclaimer: This is only an estimate based on the following factors.

1. Project consists of Hopper Dredging, Transporting from Borrow Area 1, 2, & Petit Bois East/West to Dauphin Island with Direct Pumpoff
2. Costs are based on Jan 2012 Level. *** Estimated Quantities are for a range of 1 to 4 mil cy's ***
3. Design Scope and Estimated Quantities prepared by Michael S. FitzHarris & Justin S. McDonald
4. Estimated Costs are Current Contract Cost w/o Escalation, Contingency, Design, and/or Construction Management
5. Overflow of Hopper is allowed
6. Estimate includes all Borrow Area Activities
7. Silent Inspector Cost is included in estimate.
8. Sea Turtle / Gulf Sturgeon Observer required on hopper full time and is included under OTHER MONTHLY COSTS.
9. Effective Capacity is calculated at 60% of Volume of Hopper (60% of 3,800 =2,280 cy is based on historical data
10. Excavation Rate, Travel Speeds, Dumping Time, Cleanup, and effective work time is based on historical data