EDISTO BEACH
COASTAL STORM DAMAGE REDUCTION
GENERAL INVESTIGATION STUDY

APPENDIX D
GEOTECHNICAL ENGINEERING

Appendix D: Geotechnical Analyses

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1.0 INTRODUCTION

In order to provide a suitable amount of beach quality sand for the Edisto Beach Coastal Storm Damage Reduction Project, a Geotechnical analysis of potential borrow sources was performed. Based on a preliminary estimate, between 10 million cubic yards and 20 million cubic yards of beach quality sand was required to meet the 50 year needs for this project.

A contract was executed with HDR Engineering, Inc of the Carolinas (HDR) to perform the geotechnical investigations and analyses. Coastal Science & Engineering (CSE) was hired by HDR due to the extensive knowledge of the area and previous investigations performed in the Edisto Beach area. The work was to be done in 3 phases.

Phase 1 work included:

• Delineation of a sand search area based on previous experience with nourishment projects at Edisto Beach (CSE 2003, 2006).

• Collection of 38 initial borings on a coarse grid, with four additional boring sites visited and characterized. Core recovery was attempted but not successful at the four sites.

• Logging and sampling of all cores using standard methodology.

• A low-resolution bathymetric survey of the sand search area.

• Collection of native beach samples for native sediment quality analysis.

Phase 1 work was focused on locating and delineating offshore area(s) that may provide at least 20 million cubic yards of beach-quality sediment meeting or exceeding federal criteria for sediment compatibility. Phase 2 used results from Phase 1 to achieve higher resolution data and to refine the potential borrow area(s). Out of 40 boring locations occupied and attempted, an additional 39 borings were obtained in Phase 2. The results from Phase 1 and Phase 2, including:

• Location of the sand search area and the 77 borings obtained in both phases.

• Sediment descriptions for all cores collected.

• Grain-size distributions and statistical parameters for sediment samples using graphical and moment measures.

• Core photos and logs recorded by an SC-registered professional geologist.

• Bathymetric cross-sections showing the location and depth of recovery of cores along the transect.

• Isopach maps of mean grain size, mud content, and shell content.

• High-resolution bathymetric model of sand search area based on a detailed bathymetric survey with 200-foot (ft) line spacing.

• Native beach sediment descriptions and statistics.

• Overfill factors (RA) for sediment-compatibility analyses using two native beach sediment-size distributions (scenarios).

• Isopach maps of sediment recovery depth and sediment compatibility estimates using the overfill factor (RA).

• Alternate borrow area delineations and estimated volumes available for various sediment-compatibility scenarios.

Phase 3 was performed to better delineate the bathometry of the ocean bottom in the vicinity of Edisto Beach and to locate potential sources of beach quality sand and to determine future boring locations if additional beach quality sand is necessary. Phase 3 work included:

• Perform a bathymetric survey from roughly the North Edisto River and Seabrook Island in the north to the South Fork Edisto River and Pine Island in the south. This area measures approximately 52.5 square miles in size.

• Designate proposed locations of additional borings in the offshore area when may yield additional sources of beach quality sand that will be drilled in the future if additional volume is necessary.

2.0 GEOLOGIC SETTING

The Edisto Beach borrow survey area is located offshore the modern South Edisto River, South Carolina; one of several tide dominated drainage channels and passages between barrier islands in the center of a large, curved, embayment called the Georgia Bight that stretches from Myrtle Beach, South Carolina in the north to St. Marys River, Florida in the south. To the west, along the coast, are a series of drumstick barrier islands, and their marsh land lagoons that first formed about 40,000 years ago with higher sea levels and then again over the last 6,000years with Holocene sea level rise and continental shelf transgression (Booth et al. 1999). The survey area is 1.2 to 2.7 statute miles (1.9 to 4.3 kilometers) offshore in 3 to 15 feet of water (1to 3 meters), on the “inner” shelf. To the east and extending offshore, a large expanse of continental shelf gradually slopes to the shelf break located 75 statute miles (120 kilometers) offshore, where coastlines were at full glacial times.

The Georgia Bight is referred to as a “passive” continental margin meaning that it is not tectonic or isostatically influenced, although evidence for isostasy farther from the ice margins than expected seems to be gaining consensus—even as far south as the

Project Area in South Carolina(Baldwin et al. 2006; Colquhoun et al 1995;6). The Georgia Bight is the result of "paleooceanographic processes" (Garrison et al. 2012:109) which is to say regression and transgressionover several cycles of glaciation and deglaciation; exposing, then flooding, and creatingpatterned paleolandscape settings formed from reworking and development of marine derivedand terrestrially derived sediments. These glacial-interglacial "couplets"—11 over the past 2.8 million years—are caused by Earth orbit parameters (Emiliani et al. 1975), but it is only the last,"Flandrian," latest Pleistocene-early Holocene melting of huge expanses of glaciers andconcomitant transgression of the continental shelves by rising sea levels that is of concern forthis Project Area. This is because the earliest vestiges of human occupation of the region,outlined below, are constrained to these times. Basically, glacial melting started globally about17,000 calibrated years before present (calYBP), slowed substantially by 6,000 calYBP, and has fluctuated in relatively minor ways (geologically) since. Sea levels for this project are discussed in more detail below. The continental shelf of the Georgia Bight is covered with a significant amount of transgressive lag deposits in the form of a marine sediment bed drape. Ravinement (erosion) is dominant during transgression, meaning that terrestrial deposits are truncated and redeposited into marine dominated sediments with sea level rise.

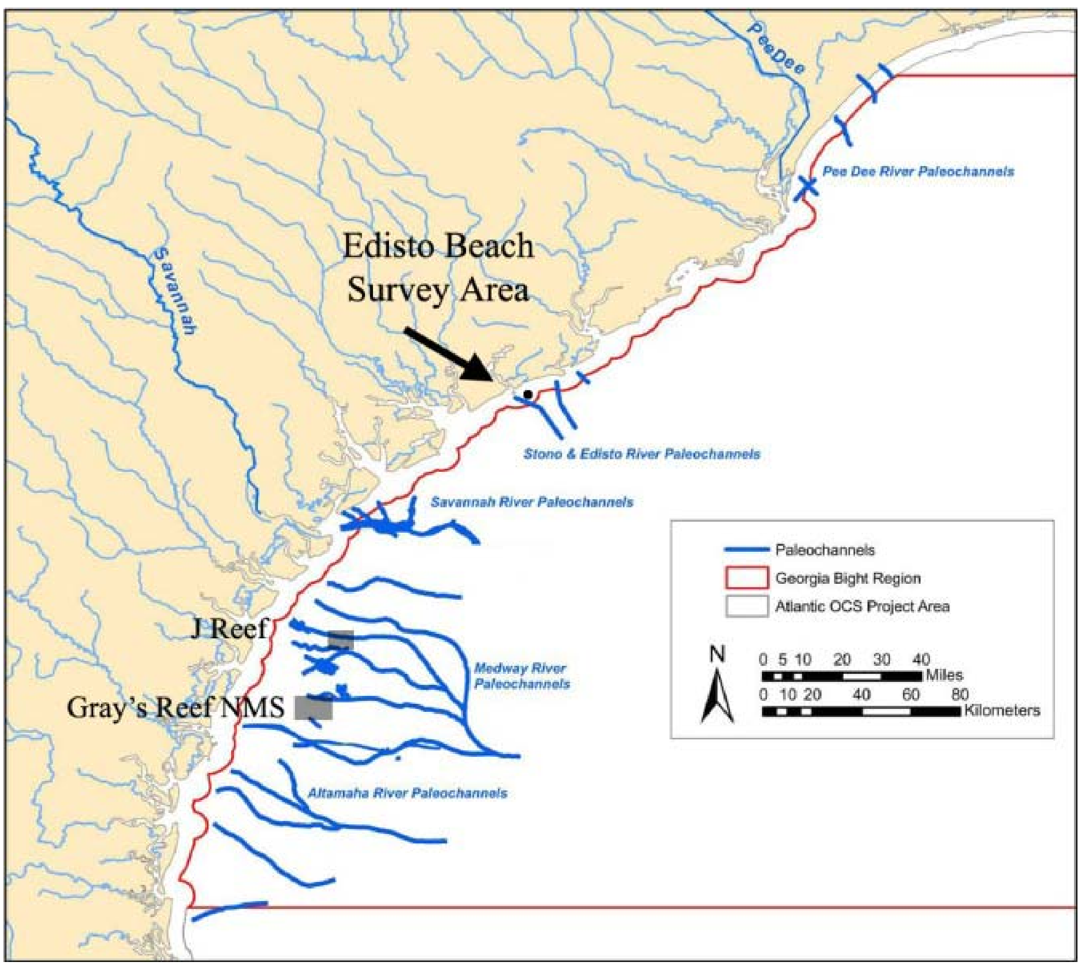


Figure D.1. A portion of the Georgia Bight's known Paleochannels, J Reef and Gray's Reef and the location of the Edisto Beach survey area.

Much of the Georgia Bight is covered with a 1- to 2-meter (thin) veneer of sandy sediments (Harris et al. 2005; Garrison et al. 2012). These are the "… eroded relicts of earlier subaerial coastal landforms characterized by dunes, wetlands, coastal rivers and forest much like today" (Garrison et al. 2012:109). These sediments have been reworked within the sand and shell marine dominated sediments that form the "palimpsest sand sheet" that blankets the continental shelf. This sand sheet is also reworked and moved by bottom currents generated by storms, tides, and wind depending.

These large areas of sand offshore are interspersed with rocky outcrops of "harbottom" (Garrison et al. 2012:111) that are Miocene- and Pliocene-aged limestones scattered as erosional remnants, ledges, and "ramps." Some of these features indicate weathering in subaerial (exposed) conditions, including evidence for stream erosion and karst formation (Garrison et al. 2012:111). Notches in the Pliocene-aged Raysor Formation at the 20-meter isobath, indicate a still stand, but its age of formation is unknown. These limestone outcrops are the main geomorphic features that occur in the Georgia Bight, some having live bottoms like Gray's Reef and J Reef shown in Figure D.1, indicating sustained exposure of the outcrop.

Other geomorphic features more relevant to the Edisto Beach study area include Pleistocene - and Holocene-aged shoal complexes made up of silt to gravel-sized sediments of terrigenous origin, abundant shell, and areas of dispersed peat (Sexton et al. 1992). The seaward relief of these features can be steep, with the near-coastal portions less of a slope. The shoal complex seaward of the Santee/PeeDee Delta is the largest—a deltaic deposit with shore parallel scarps that are evidence of pause or still stand during Holocene sea level rise. The islands are supposed to be migrating along with sea level rise, but abandoned examples could be expected given the magnitude and rapidity of some sea level rise estimates.

Sources of terrigenous sediments are the rivers draining the coastal plain, including reworking from previous high stand materials as parent materials for subaerial pedogenesis and landforms, with reworking again with Holocene transgression. Sediment packages build up in the lagoon on the lee side of the islands, and if those were preserved offshore, they could be expected to retain stratigraphic integrity and be at or near locations of human activities and refuse.

Drowned coastal stream and river paleochannels occur, but most are truncated and buried under the sand sheet drape such that they are not usually apparent on the surface in the bathymetry. Therefore, they cannot be adequately remotely sensed with bathymetric or sidescan sonar devices; rather, they need be remotely sensed with seismic subbottom profiler devices (Baldwin et al. 2006). Studies by Garrison et al. (2008) and others (Baldwin et al. 2006; Harris et al. 2005) confirm that these paleochannels are buried, albeit shallowly, under the reworked marine sediment drape cover (Garrison et al. 2012). Baldwin et al. (2006) used a dense pattern of subbottom profiler lines over great space to reconstruct and offer ages for the paleochannels offshore South Carolina.

Figure D.1 above shows the Garrison et al. (2012) compilation of Geographic Information System (GIS) data for the Paleo-Altamaha, Paleo-Savannah, and Paleo-Meway rivers offshore Georgia, and the Stono-Edisto and Pee Dee paleochannels offshore South Carolina. Several generations of the ancestral Pee Dee River system have been mapped beneath and along the coast and inner continental shelf revealing a complex pattern of paleochannels of different ages (Baldwin et al. 2006). Figure D.1 also shows the location of the Edisto Beach study area. The Investigative Findings chapter of this document reports another channel segment vestige or segment.

During sea level low stands, drainage valleys are shallowly incised into the continental shelf andbackfilled with various sediment types, depending on local conditions and sea level rise and fall rates. Paleovalleys have backfilled during cyclic changes in sea level with sediment types ranging from estuarine muds to clean shelly sands (Harris et al. 2005 in Garrison et al. 2012:116). Quaternary paleochannels tend to be filled with muds, sandy muds, and muddy sands; whereas, tidally scoured paleochannels general contain clean shelly sands (Harris et al. 2005:511). Prior to 7,000 years ago, the islands would have been part of the mainland, hill-like ridges with valleys in between with tributary gullies cutting into the hills. The marshes surrounding the Project Area would have been drier swales. In a similar way, Garrison and Tribble (1981) model the paleolandscape of the marshland during the late Pliestocene-Early Holocene as grassland and savannas with non-tidal perched streams and possible spring connections. If these spring locations could be identified, there may be archaeological remains around them.

The age of a peat bed marking coastal marsh at Cracker Tom Marsh on St. Catherine's Island, Georgia was around 6,800 calYBP (Booth and Rich 1999; Rich and Booth 2011:134). But in the coastal plain s of the Project Area, archaeological sites are lacking in the middle Holocene (and earlier) age frame (Turck et al. 2011). Sites earlier than calYBP are either missing or possibly lovated in buried stratigraphic units buried by later Holocene transgression and sedimentary processes, or in the areas offshore that have been submerged. An exposed paleolandscape setting 28 feet below the river water level found in a St Augustine River study area confirms the potentials of this kind of buried archaeology. The radioactive age of an inplace stump there was 8,100 calYBP (7300 +/- 40 YBP ; Beta 36234: James, et al. 2012).

The earliest Holocene salt marsh in this newly submerged area, recently discovered at a location along the wouthwestern edge of St. Catherine's Island, has been radiocarbon dated to 4,060 plus or minus 50 YBP shell, United States Geological Survey (USGS) #WW1262. This provides the best available indication of when the island became isolated from the mainland (Booth et al. 1999:84) and probably the age at which the Edisto Beach study area was completely submerged.

The configuration of the survey area appears to be a paleobarrier feature transgressed by late Holocene sea level rise. Paleochannel margins, of late Pleistocene early

Holocene age, are prime locations for submerged pre-Contact archaeological sites and barrier-marsh coastal systems are likely draws to humans for a variety of resources.

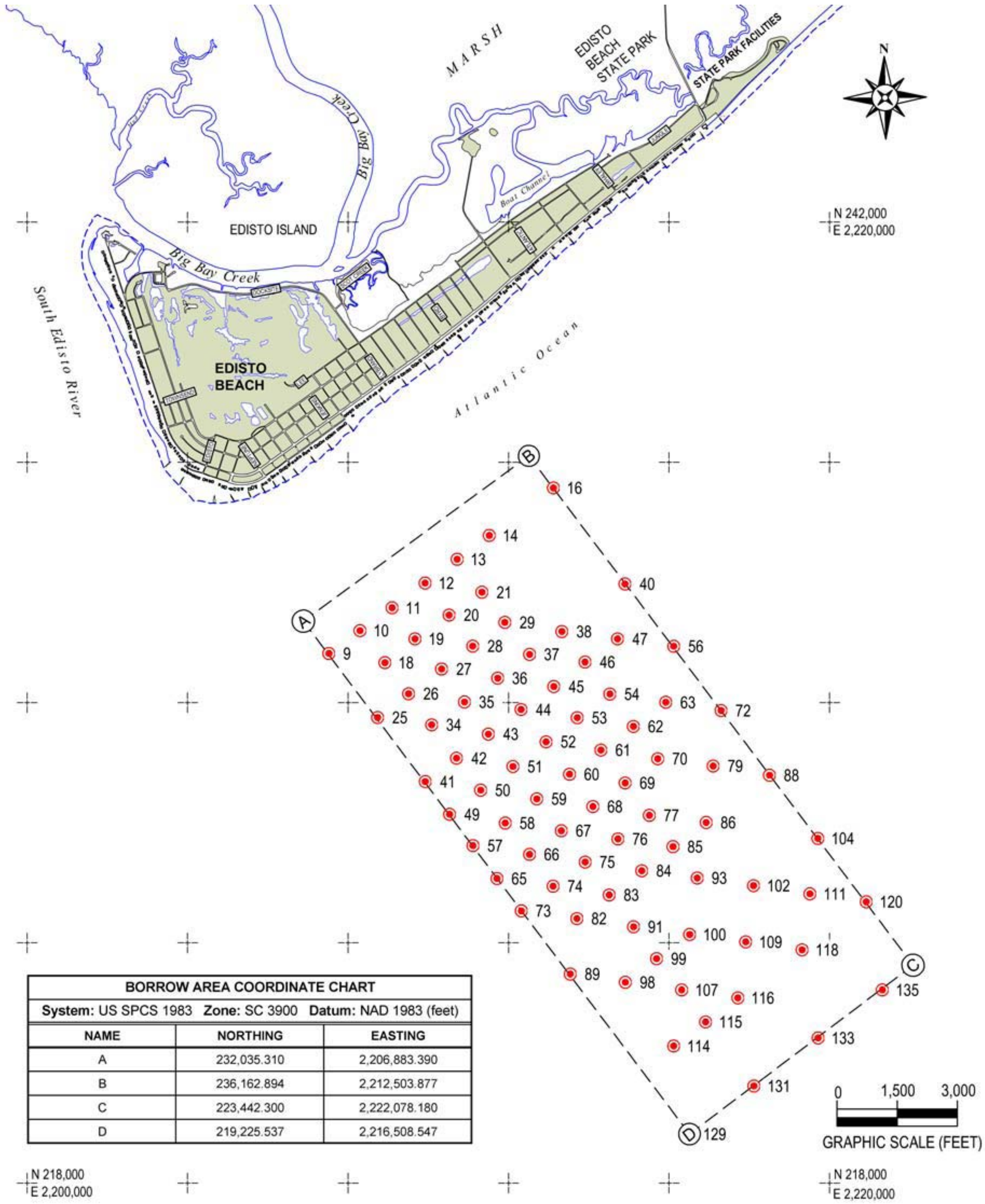
3.0 FIELD LABORATORY METHODS

CSE delineated an initial sampling grid on roughly 2,000-ft spacing based on previous sand search experience at Edisto Beach (CSE 1990, 1992; CSE-Baird 1996; CSE 2003, 2004, 2006). The sand search area targeted the seaward shoal of South Edisto River Inlet at the southern end of Edisto Beach. The shoal is part of the ebb-tidal delta of St Helena Sound and is known to contain mixed sand and shell sediments that are similar to the native beach (CSE 2006). The search area encompassed an area 7,000 ft by 16,000 ft (~4 square miles) paralleling the north side of the main channel of South Edisto River Inlet. Figure D.2 shows the location of the search area relative to Edisto Beach.

Phase 1 core locations were selected generally following a 2,000-ft grid within the search area. To maximize the number of cores containing beach-quality sediments, minor modifications to the grid were made when areas with incompatible sediments were found.

CSE occupied 42 boring locations within the search area during the Phase 1 scope of work. Four of these sites contained very coarse, shell lag deposits and coring was not possible with the equipment used. Grab samples were obtained from two of these sites for reference.

Phase 2 aimed to confirm potential beach quality sand in the vicinity of the shoal and to define boundaries between acceptable and unacceptable material. Combined with Phase 1, Phase 2 generally produced a 1,000-ft grid of borings covering the majority of the shoal adjacent to the South Edisto River Inlet. CSE occupied 40 locations in Phase 2, obtaining 39 borings and 1 grab sample (Fig D.2).



BORROW AREA COORDINATE CHART		
System: US SPCS 1983	Zone: SC 3900	Datum: NAD 1983 (feet)
NAME	NORTHING	EASTING
A	232,035.310	2,206,883.390
B	236,162.894	2,212,503.877
C	223,442.300	2,222,078.180
D	219,225.537	2,216,508.547

Figure D.2. Sand search grid over the shoals of South Edisto River Inlet beginning ~4,000 ft offshore of the south tip of Edisto Beach.

4.0 FIELD DATA AQUISITION

CSE used a custom designed coring system operated by personnel from the 22-ft research vessel R/V *Irie* during Phase 1 and from CSE's new shallow-draft research vessel R/V *Congaree River* for Phase 2 (Fig 3). This proprietary system (developed by CSE) uses a hydraulic pump, manifold, and three-inch aluminum core barrels to obtain relatively undisturbed cores up to 12-ft long in water depths from ~10 ft to 60 ft. Depending on the particular requirements of the project, the CSE coring system can be combined with a conventional vibracore device to aid in the collection of cores. CSE navigated to the coordinates of each preselected core site, anchored, and then lowered coring equipment over the side. Navigation and soundings were via Furuno Model 1850DF. Water depth, time, and personnel were recorded in a field notebook. Final elevations (top of core) were based on modeled bathymetry using data from a May 2008, high-resolution bathymetric survey (36 lines 15,000 ft long at 200-ft spacing for a total of ~102 miles of track lines, Fig 4). The Phase 1 low-resolution bathymetry involved a limited number of vessel track lines that ran the sample grid (1,000-ft spacing). Both bathymetric surveys were conducted using a Trimble R8 GNSS RTK-GPS combined with an ODOM HydroTrac™ precision echo-sounder mounted on the research vessel. Survey lines overlapped core locations; therefore, "modeled" elevations from the survey closely match true elevations

Upon completion of coring, the coring device was removed from the barrel, and the core barrel was cut 1 ft above the substrate. Cores were capped at the top, removed from the sea floor, then capped or sealed at the bottom before being hauled on board. Core recovery length was measured and recorded on board after removing the top cap and inserting a measuring rod to the top surface of the sediment. The topmost section of the core barrel was recut slightly above the top layer of sediment, then sealed for transport to the lab. Cores were stored in an upright position or inclined upward for transit. Sediment samples were collected in December 2007 along the native beach at 1,000-ft intervals from Big Bay Creek to Edingsville Beach. At each location, four samples were taken along the width of beach profile (transect) covering the toe of the dune, berm, beach face, and low-tide terrace (low-tide swash zone). Samples were recovered from the top ~20 centimeters (cm) of sand and analyzed for grain-size distributions and shell content. Mud content was considered insignificant (trace) and was not analyzed for the beach samples. Samples for transects 32-34 were located on Edingsville Beach.

5.0 LOGGING AND SAMPLE TESTING

At CSE's lab, each core was split, logged, and sampled by a registered professional geologist and technical staff. For this project, one half of each core was preserved intact, sealed in clear plastic sleeves, and stored at CSE for eventual transfer to the US Army Corps of Engineers. The other half of each core was further divided into samples representing the typical lithology for the section and used for detailed sediment testing. Typically, two or three samples were taken from each core. CSE's procedure was to take the entire section for analysis, mixing each unit well, then extract about 100-500 grams for analysis. Where significant fines were visible, one fraction of raw sample was reserved for determination of silt/clay percentage. Similarly, a fraction was reserved for determination of percent shell material (calcium carbonate percentage). The principal fraction was used for dry sieving. Standard laboratory procedures were followed, including:

• Drying unwashed samples.

• Weighing to 0.01 grams.

• Disaggregating clays and wet-sieving one fraction for the percent mud determination using a 230 sieve [0.0625-millimeter (mm) mesh].

• Redrying and reweighing one wet-sieved (saved) fraction (one ~20-gram fraction reserved for percent shell analysis).

• Dry sieving at 0.25 phi (φ) intervals (sand size range).

• Dry sieving at 0.5 φ to 1.0 φ intervals between -4.0 φ and -1.0 φ for selected samples having a significant coarse fraction (granule to medium pebble size range).

• Weighing each saved fraction on the sieves.

• Recording weights and analyzing grain-size distributions by standard method of moments and graphic techniques using custom software.

Sediment statistics were obtained through graphical and moment measures. Folk (1974) gives graphical measures of mean, standard deviation, skewness, and kurtosis, which use cumulative percentage values (the grain size at which a given percentage of the total sample is coarser) to calculate grain-size statistics.

Table D.1. Folk graphical method taken from Blott and Pye (2001)

Mean	Standard deviation	Skewness	Kurtosis
$M_Z = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$	$\sigma_I = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6{\cdot}6}$	$Sk_I = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_5 + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - \phi_5)}$	$K_G = \frac{\phi_{95} - \phi_5}{2{\cdot}44(\phi_{75} - \phi_{25})}$

Sorting (σ_1)		Skewness (Sk_1)		Kurtosis (K_G)	
Very well sorted	<0·35	Very fine skewed	$^+$0·3 to $^+$1·0	Very platykurtic	<0·67
Well sorted	0·35–0·50	Fine skewed	$^+$0·1 to $^+$0·3	Platykurtic	0·67–0·90
Moderately well sorted	0·50–0·70	Symmetrical	$^+$0·1 to $^-$0·1	Mesokurtic	0·90–1·11
Moderately sorted	0·70–1·00	Coarse skewed	$^-$0·1 to $^-$0·3	Leptokurtic	1·11–1·50
Poorly sorted	1·00–2·00	Very coarse skewed	$^-$0·3 to $^-$1·0	Very leptokurtic	1·50–3·00
Very poorly sorted	2·00–4·00			Extremely leptokurtic	>3·00
Extremely poorly sorted	>4·00				

The graphical method provides an easy calculation of parameters; however, it is not as representative as the method of moments. The moment method is a mathematical measure of the above-listed parameters which more accurately describes the sediment sample because it uses all values from the size distribution, whereas the graphical measures only use a few interpolated values. By standard convention, computations of size frequency use the midpoint size between each sieve used in the laboratory analysis.

Table D.2. Method of moments taken from Blott and Pye (2001)

Mean	Standard deviation	Skewness	Kurtosis
$\bar{x}_\phi = \frac{\Sigma f m_\phi}{100}$	$\sigma_\phi = \sqrt{\frac{\Sigma f (m_\phi - \bar{x}_\phi)^2}{100}}$	$Sk_\phi = \frac{\Sigma f (m_\phi - \bar{x}_\phi)^3}{100 {\sigma_\phi}^3}$	$K_\phi = \frac{\Sigma f (m_\phi - \bar{x}_\phi)^4}{100 \sigma_\phi^4}$

Sorting (σ_ϕ)		Skewness (Sk_ϕ)		Kurtosis (K_ϕ)	
Very well sorted	<0·35	Very fine skewed	>+1·30	Very platykurtic	<1·70
Well sorted	0·35–0·50	Fine skewed	+0·43 to +1·30	Platykurtic	1·70–2·55
Moderately well sorted	0·50–0·70	Symmetrical	−0·43 to +0·43	Mesokurtic	2·55–3·70
Moderately sorted	0·70–1·00	Coarse skewed	−0·43 to −1·30	Leptokurtic	3·70–7·40
Poorly sorted	1·00–2·00	Very coarse skewed	<−1·30	Very leptokurtic	>7·40
Very poorly sorted	2·00–4·00				
Extremely poorly sorted	>4·00				

Sediment grain sizes are presented on data sheets that incorporate the raw data, percentages by size, standard moment and graphical measures, and graphs of cumulative and frequency distributions. The overall sediment classification is also provided for each sample using both Wentworth classification and the Unified Soil Classification System (USCS). Class limits distinguishing sand sizes differ between the two systems (Table 1). The Wentworth system provides measures of sorting, skewness, and kurtosis, which provide details about the shape of the frequency distribution. The USCS system classifies sediment based on two letters, the first of which represents the size of the dominant grain (all samples in this study tested as “S” for sand) and the second representing either the grading of the sediment [either poorly graded (P) or well graded (W)] or the plasticity of the sediment [either low (M) or high (C)], depending on the amount of fine-grained material in the sample. An example of a USCS classification for poorly graded sand is SP. If >12 percent of the sample (calculated by combining the percent mud with the percent retained on a No. 230 sieve) passes a No. 200 sieve, the classification would be SM for low plasticity silty sand, and SC for high plasticity clayey sand. If the percentage passing a No. 200 sieve is between 5 and 12 percent, the sample requires a duel symbol (i.e., SP-SM). Results from the sediment analysis were compiled in the software, MATLAB, to produce composite statistics for individual cores. MATLAB was also used to create colored contour maps of composite grain size, percent mud, and percent shell using linear interpolation. Grain-size statistics from Phase 1 are modified from those previously reported to include the finest fraction in the moment calculations (>4.0 φ); generally the change in mean grain size was <0.010 mm.

Table D.3. Sediment size classifications. [Source: USACE (2002) Coastal Engineering Manual EM1110-2-1100, Part III, Table III-1-2, pg. III-1-8]

Table III-1-2
Sediment Particle Sizes

ASTM (Unified) Classification[1]	U.S. Std. Sieve[2]	Size in mm	Phi Size	Wentworth Classification[3]
Boulder		4096.	-12.0	
		1024.	-10.0	Boulder
	12 in. (300 mm)	256.	-8.0	
Cobble		128.	-7.0	Large Cobble
		107.64	-6.75	
		90.51	-6.5	Small Cobble
	3 in. (75 mm)	76.11	-6.25	
		64.00	-6.0	
		53.82	-5.75	
		45.26	-5.5	Very Large Pebble
Coarse Gravel		38.05	-5.25	
		32.00	-5.0	
		26.91	-4.75	
		22.63	-4.5	Large Pebble
	3/4 in. (19 mm)	19.03	-4.25	
		16.00	-4.0	
		13.45	-3.75	
		11.31	-3.5	Medium Pebble
		9.51	-3.25	
Fine Gravel	2.5	8.00	-3.0	
	3	6.73	-2.75	
	3.5	5.66	-2.5	Small Pebble
	4 (4.75 mm)	4.76	-2.25	
	5	4.00	-2.0	
Coarse Sand	6	3.36	-1.75	
	7	2.83	-1.5	Granule
	8	2.38	-1.25	
	10 (2.0 mm)	2.00	-1.0	
	12	1.68	-0.75	
	14	1.41	-0.5	Very Coarse Sand
	16	1.19	-0.25	
Medium Sand	18	1.00	0.0	
	20	0.84	0.25	
	25	0.71	0.5	Coarse Sand
	30	0.59	0.75	
	35	0.50	1.0	
	40 (0.425 mm)	0.420	1.25	
	45	0.354	1.5	Medium Sand
	50	0.297	1.75	
	60	0.250	2.0	
	70	0.210	2.25	
Fine Sand	80	0.177	2.5	Fine Sand
	100	0.149	2.75	
	120	0.125	3.0	
	140	0.105	3.25	
	170	0.088	3.5	Very Fine Sand
	200 (0.075 mm)	0.074	3.75	
Fine-grained Soil: Clay if PI ≥ 4 and plot of PI vs. LL is on or above "A" line and the presence of organic matter does not influence LL. Silt if PI < 4 and plot of PI vs. LL is below "A" line and the presence of organic matter does not influence LL. (PI = plasticity limit; LL = liquid limit)	230	0.0625	4.0	
	270	0.0526	4.25	
	325	0.0442	4.5	Coarse Silt
	400	0.0372	4.75	
		0.0312	5.0	
		0.0156	6.0	Medium Silt
		0.0078	7.0	Fine Silt
		0.0039	8.0	Very Fine Silt
		0.00195	9.0	Coarse Clay
		0.00098	10.0	Medium Clay
		0.00049	11.0	Fine Clay
		0.00024	12.0	
		0.00012	13.0	Colloids
		0.000061	14.0	

[1] ASTM Standard D 2487-92. This is the ASTM version of the Unified Soil Classification System. Both systems are similar (from ASTM (1994)).
[2] Note that British Standard, French, and German DIN mesh sizes and classifications are different.
[3] Wentworth sizes (in mm) cited in Krumbein and Sloss (1963).

6.0 OFFSHORE BORINGS

Collectively, CSE obtained 77 cores from 82 proposed locations in the search area during Phases 1 and 2. The five sites that were unsuccessful (9, 14, 16, 26, and 40) contained very coarse shell deposits near the sediment surface, hindering significant penetration by CSE's coring system. Phase 1 core locations generally followed a 2,000-ft grid, then began to fill in the grid to a 1,000-ft resolution. Phase 2 borings focused on bathymetric highs and areas of Phase 1 borings which appeared to contain sediment more suitable for beach nourishment purposes. The average recovery for the 77 obtained borings was 7.8 ft. There were 32, 22, and 7 cores longer than 8 ft, 9 ft, and 10 ft (respectively). Areas which showed poor recovery generally possessed a very coarse fraction at the bottom of the core, which prevented further penetration of the core tube (e.g., cores 25, 35, 36). From the 77 borings, 212 sediment samples were obtained and analyzed for grain size, silt/clay content, and shell content.

Results of the sediment sample analysis showed mean grain size ranged from 0.115 mm to 3.087 mm (0.404 standard deviation), and collectively averaged 0.406 mm. Ninety-eight (98) samples (46 percent) showed a mean grain size <0.250 mm, which classifies as fine sand under the Wentworth Classification system. Sixty-eight samples (32 percent) classified as medium sand (0.250–0.500 mm), and the remaining 46 samples (22 percent) classified as coarse sand or larger (0.500 mm). Under the USCS, 150 samples (71 percent) classified as fine sand (0.075–0.425 mm), 58 samples (27 percent) classified as medium sand (0.425–2.0 mm) and 4 samples (2 percent) classified as coarse sand (2 mm).

Samples were wet-sieved for silt/clay content using a No. 230 sieve (4.0 phi). Silt/clay content ranged from 0.3 percent to 30.8 percent, and averaged 3.0 percent. Of the 205 samples analyzed for silt/clay, 120 samples (59 percent) contained less than 2 percent silt/clay, while 34 samples (17 percent) contained more than 5 percent silt/clay.

Shell content (CaCO3) ranged from 1.9 to 75.5 percent, and averaged 18.8 percent for all samples. Shell content varied from fine shell hash (sand-sized shell fragments) to very coarse, large shells (e.g., oyster, scallop, etc). Lenses of coquina-like unconsolidated shells consisting of high concentrations of Donax sp (small, thin-walled surf zone clam) were also found in a number of samples. Overfill factors (aka overfill ratios), RA, were calculated using USACE Automated Coastal Engineering System (ACES) Version 1.07f. Overfill ratios are used to estimate the quantity of borrow material needed to perform like a given quantity of native beach material based on the mean grain size and sorting (standard deviation) of the native and fill material. The selection of "native" grain size and sorting is somewhat problematic where a broad spectrum of grain sizes exists across the littoral profile. For example, if the beach sampling plan emphasizes subaerial samples and omits offshore samples, the "native" size distribution is likely to be somewhat coarser. Addition of offshore samples tends to lower the mean grain size. If a beach has been nourished recently, the "native" sediment distribution is likely to reflect the quality of the borrow material.

The first scenario (RA1) represents a composite grain-size distribution of all 34 beach stations (136 samples) collected along Edisto Beach. The mean grain size and sorting for this scenario was 0.404 mm and 0.397 mm (respectively). The second scenario (RA2) uses a composite distribution from stations 1–8 and 30–34. These stations are outside of the 2006 project area and show less influence of the nourishment placed during that project. The mean grain size and sorting for this scenario is 0.336 mm and 0.350 mm (respectively). The two scenarios do not incorporate any offshore samples which, if available, would probably lower the overall mean grain size.

Overfill ratios for the 212 core samples vary from 1.00 to >10.0. Any RA values greater than 10.0 were given a value of 10.0. In general, RA values <1.50 are favored for nourishment purposes; however, these values are dependent on the selection of a native grain size. It is important to note that RA values do not directly address silt/clay or shell concentration, and low RA values may not always represent compatible material.

7.0 CORE COMPOSITE STATISTICS

Sample statistics were weighted by length and combined for each core. These statistics were used to produce isopach maps modeling the grain size, mud content, shell content, and RA values over the search area. Generally, very coarse material is present at the northern end (landward) of the borrow area, and finer material is present seaward and to the east of the shoal. High mud content is present in the eastern extreme of the search area. Shell content generally increases with mean grain size, with large shell fractions present in the northeastern portion of the search area. The southeast end of the search area shows very little shell content and mostly fine-grained material. Overfill ratios were calculated for each core based on the composite grain size distribution for each core’s entire length of recovery and for both native sediment scenarios. In general, lower overfill ratios are present in the northern and western regions of the search area, with high values in the southern and central-eastern areas. Due to the exponential nature of overfill ratios, distinguishing small differences between potentially compatible cores is difficult with an isopach map; however, it does provide a general idea of potential borrow areas. Four speculative borrow areas were evaluated to determine the potential availability of up to 20 million cubic yards of accessible compatible material. Each area was generally selected based on sediment compatibility, including overfill ratios, silt/clay, and shell content, as well as operational considerations. The theoretical borrow areas are shown in Figures D.3 and D.4. The composite grain-size distribution (weighted by core length) for all samples within each borrow area was used to calculate overfill ratios for each area.

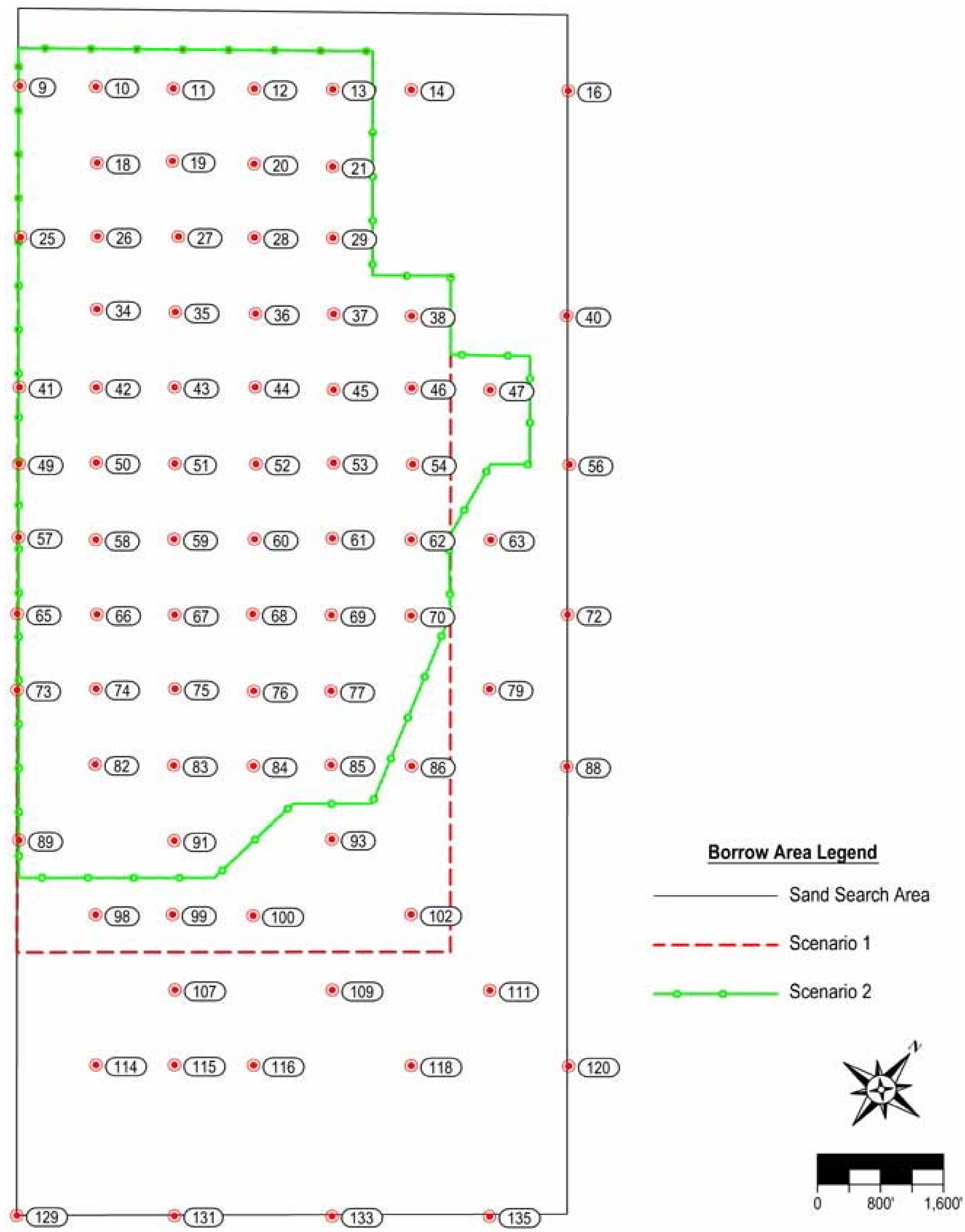


Figure D.3. Two scenario borrow area delineations within the sand search area.

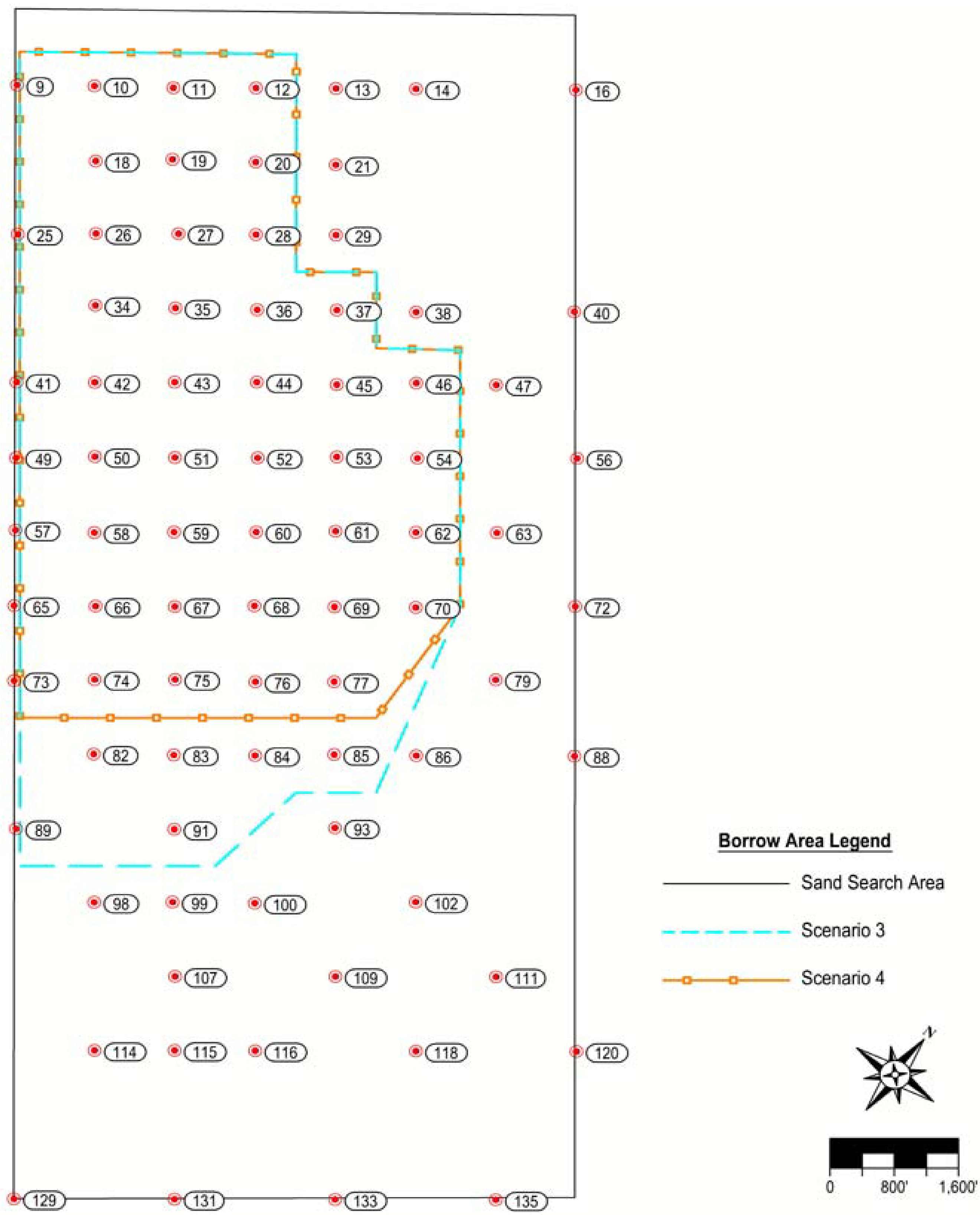


Figure D.4. Two scenario borrow area delineations within the sand search area.

This method acts to combine all samples within an area to produce one grain-size distribution from which an overfill ratio is calculated. Grain-size distributions from each sample within an area were multiplied by the length of core for which that sample represents. The weighted distributions from all samples within the area were then added by class and divided by the total length of all samples within the area to produce a single composite, grain-size distribution. This method acts to treat the entire area up to the depth of core recovery as one sample. For the presented borrow area scenarios, this method produces a lower RA value than a linear average of the core composite overfill ratios. The results are shown in Table 2. The composite overfill ratio for the entire sand search area is 1.34 and 1.13 for native beach scenarios RA1 and RA2 (respectively). The lower RA values for scenario RA2 reflect the finer native mean grain size used for the “native” beach. RA values for the four speculative borrow areas ranged from 1.17 to 1.34 for the RA1 scenario and 1.03 to 1.05 for the RA2 scenario. The linear average overfill ratios calculated from the core composite RA2 scenario ranged from 2.44 to 3.02. The overfill ratios decreased with the exclusion of cores in the southern portions of the search area which contained material finer than what is presently on the subaerial beach. Overfill ratios also decreased with the inclusion of cores in the northeastern portions of the borrow area which contained coarse material, usually containing a significant shell portion. The potential volume of borrow material under the four scenarios ranges from ~12 million cubic yards to ~18 million cubic yards (Table 2). The entire sand search area contains potentially almost 30 million cy if excavated to an average of ~7.7 ft. An isopach map of compatible sediment thickness is shown in Figure 15. The criteria for determining compatible material was an RA value of ~1.20 or less, with mud content <5.0 percent and without very coarse shell material. In certain situations, samples with RA values greater than 1.20 were included if the composite grain-size distribution for the core appeared compatible. Data are reported in Table 2.

Table D.4. Potential borrow areas (scenarios), respective volumes, and composite RA's for applicable cores (two native grain-size scenarios.

Edisto Beach Sand Search Area Core Overfill Ratios									
	R_{A1}: Un = 1.308 φ, Sn = 1.334 φ				R_{A2}: Un = 1.575 φ, Sn = 1.515 φ				
Potential Area (number of cores within area)	Cores Representing Potential Borrow Area	Area (acres)	Average Recovery Depth (ft)	Volume (cy) Area x Average Recovery	U_b (phi)	S_b (phi)	R_{AL}	R_{A1}	R_{A2}
Entire Search Area	All obtained cores	2,410	7.7	29,938,627	1.774	1.660	4.02	1.34	**1.13**
Scenario 1 (58)	10 11 12 13 18 19 20 21 25 26 27 28 29 34 35 36 37 38 41 42 43 44 45 46 49 50 51 52 53 54 57 58 59 60 61 62 65 66 67 68 69 70 73 74 75 76 77 82 83 84 85 86 89 91 93 98 99 100 102	1,443	7.7	17,925,908	1.523	1.722	3.02	1.21	**1.05**
Scenario 2 (53)	10 11 12 13 18 19 20 21 25 26 27 28 29 34 35 36 37 38 41 42 43 44 45 46 47 49 50 51 52 53 54 57 58 59 60 61 62 65 66 67 68 69 70 73 74 75 76 77 82 83 84 85 89 91	1,269	7.6	15,559,632	1.418	1.733	2.65	1.17	**1.04**
Scenario 3 (48)	10 11 12 18 19 20 25 26 27 28 34 35 36 37 41 42 43 44 45 46 49 50 51 52 53 54 57 58 59 60 61 62 65 66 67 68 69 70 73 74 75 76 77 82 83 84 85 89 91	1,138	7.8	14,320,592	1.516	1.662	2.82	1.19	**1.03**
Scenario 4 (42)	10 11 12 18 19 20 25 26 27 28 34 35 36 37 41 42 43 44 45 46 49 50 51 52 53 54 57 58 59 60 61 62 65 66 67 68 69 70 73 74 75 76 77	955	7.8	12,017,720	1.473	1.679	2.44	1.17	**1.03**

8.0 BEACH SAMPLES

Beach samples collected at 34 stations along Edisto Beach (Fig 4) were used to determine the existing condition of the beach and to compare sediment quality with the offshore sediments in the sand search area. The samples along the beach reflect conditions after the 2006 renourishment between Edisto Beach State Park and groin 27 at the southernmost tip of the island (CSE 2006). Each station involved four grab samples – one each from the toe of the dune, berm, beach face, and low tide swash zone. A total of 136 samples were collected in December 2007 and analyzed in a similar manner as the core samples (without measuring mud content). Table 8 lists sediment statistics and descriptions for the beach samples.

The composite mean grain size of all samples was 0.404 mm (medium sand). Mean grain size along the beach profile is often a function of energy, with coarsest sediments found in the most energetic environments. In the case of typical South Carolina beaches, the beach face is subject to the most wave energy, and grain size is greater than at the dune, top of berm, and low-tide terrace. The composite grain sizes by profile location for all samples were:

- 0.373 mm for the toe of the dune.
- 0.420 mm for the berm.
- 0.462 mm for the beach face.
- 0.367 mm for the low-tide terrace.

Shell content for beach samples ranged from 2.9 percent to 78.1 percent, with an average of 24.8 percent. Typically, shell material present in the beach samples was relatively fine, with little shell >2 mm (average of 6.6 percent by weight for all samples). A few samples contained greater portions of large shells. Generally, shell content was greater at the beach face and low-tide terrace than at the dune and berm.

The results of the beach samples are consistent with previous sediment data for Edisto Beach (CSE 1992, 2003, 2006). Edisto Beach tends to have more shell and is coarser than most South Carolina beaches because of several factors (CSE 2006):

• Updrift sediment supply is derived from eroding marsh deposits along Edingsville Beach which yield high concentrations of oyster shells and mud.

• The first nourishment project in 1954 excavated marsh deposits in the lagoon on the landward side of the island. Muddy sediments eroded rapidly, leaving a lag of shells derived from the marsh.

• Groin construction in the 1950s, 1960s and 1970s created groin cells, which trapped and retained fillets of coarse sediment, including high concentrations of oyster shells and shell hash.

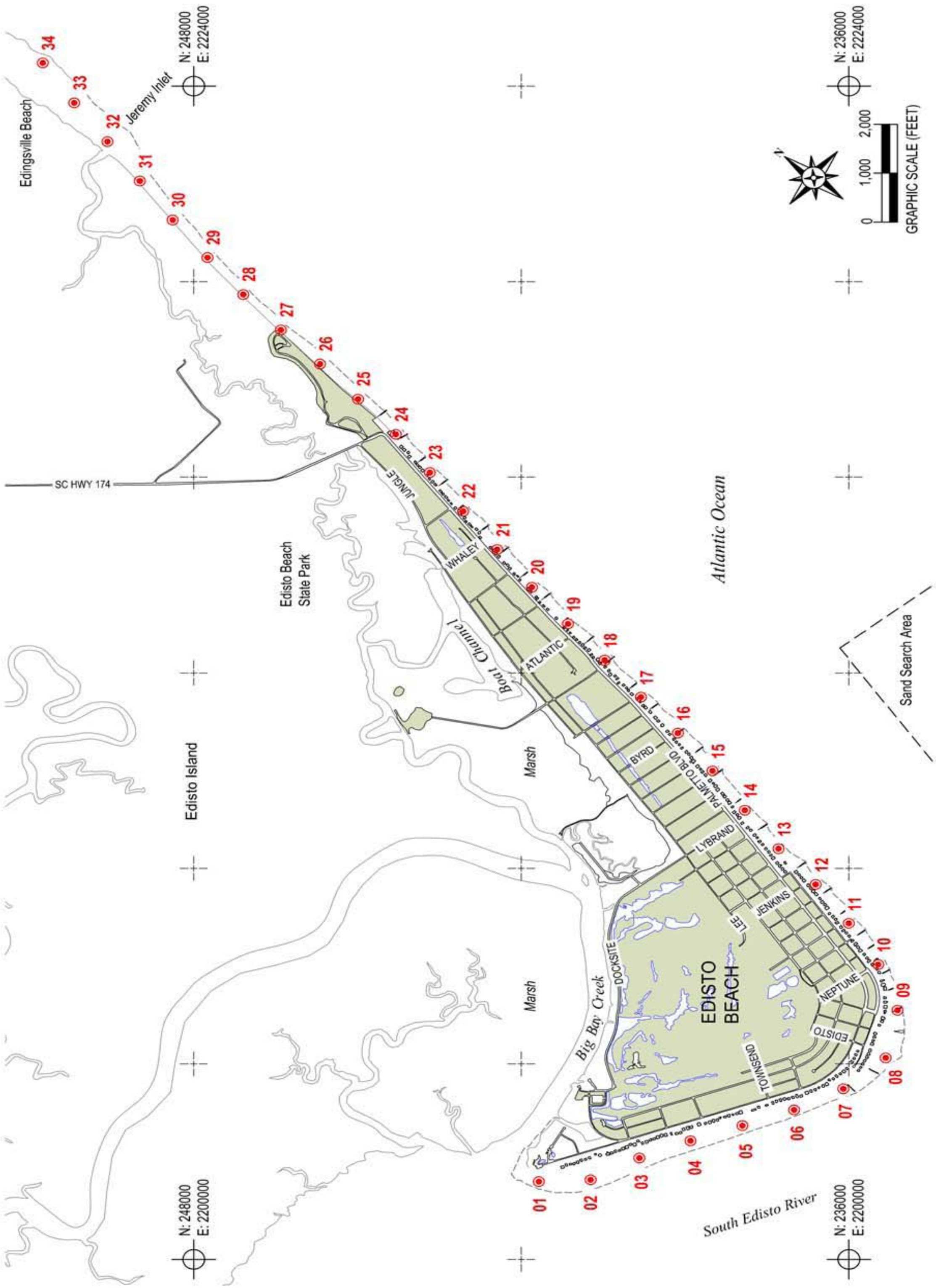


Figure D.5. Locations of beach samples obtained in December 2007. At each location, four samples were taken along the width of the profile covering the toe of the dune, berm, beach face, and low-tide terrace.

9.0 OTHER POTENTIAL SAND REOURCES

As Phase 3 of this project, CSE performed bathymetric survey from roughly the North Edisto River and Seabrook Island in the north to the South Fork Edisto River and Pine Island in the south. This area measures approximately 52.5 square miles in size. Information from this survey and historic information researched by CSE was used to locate proposed future borings which may determine the location of additional sources to be used for possible borrow for beach nourishment. These areas will be used only if sand is required in addition to the material available in the designated borrow area. Possible boring locations are shown on Figure D.6.

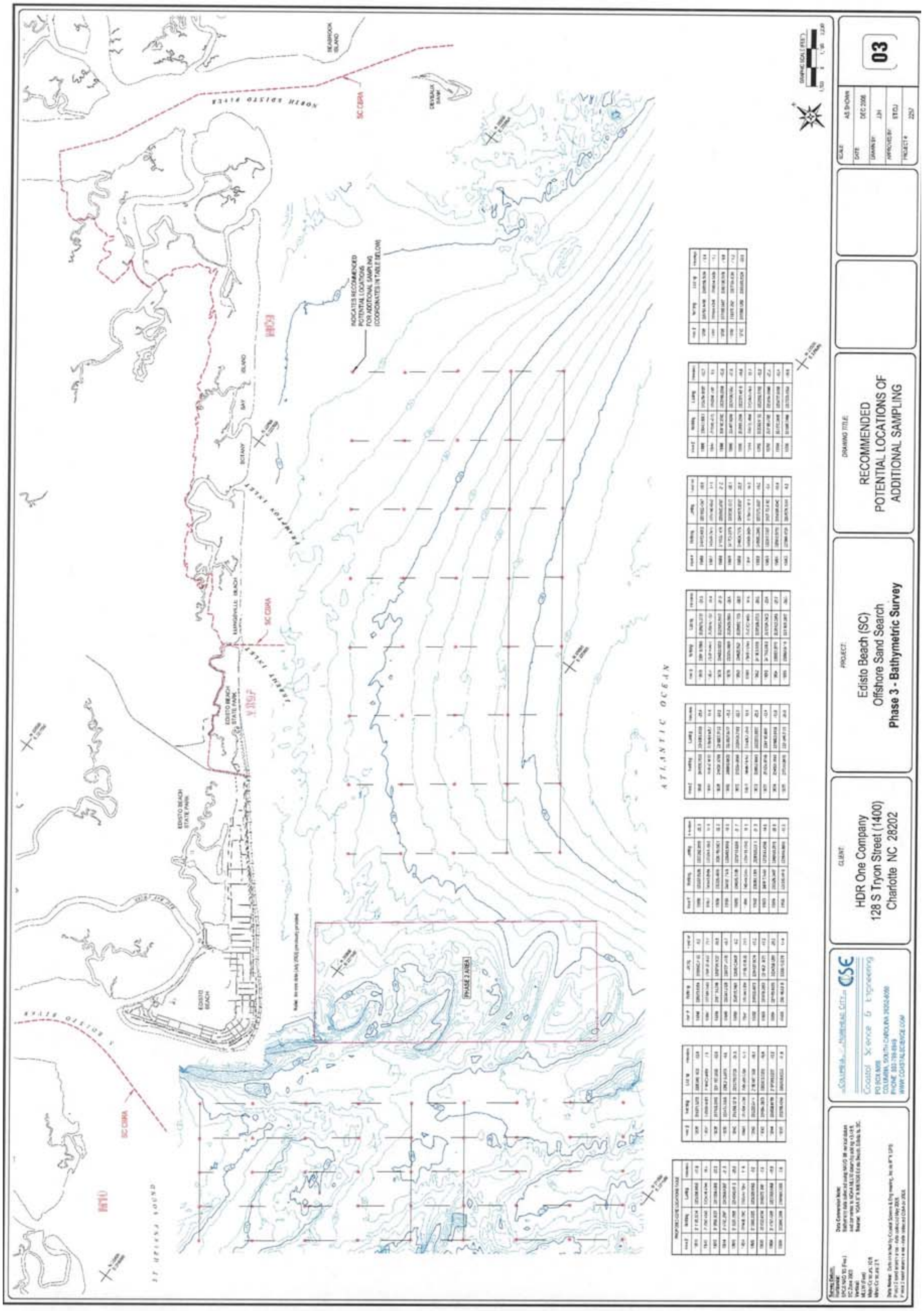


Figure D.6. Proposed future boring locations offshore of Edisto Beach.

10.0 VOLUME CALCULATION

The Surface-Water Modeling System (SMS) was used to estimate borrow volumes. Boreholes were used in identifying the vertical boundaries of the potential borrow sources. The composition and thickness of overburden were examined and borrow areas were identified based on depth of suitable material. Vertical buffers must be delineated between suitable and non suitable sediments, which cannot be included in the source's available volume. A one foot vertical buffer was adopted in the study. Isopach map of the deposit was prepared to determine the volume of the proposed borrow materials. An isopach map is a contour map showing the thickness of a deposit between two physical or arbitrary boundaries. SMS was used to define the upper boundary of the deposit by the surface of the sea bottom and the lower boundary was created by interpolating the scatter borehole data to a uniform grid with a resolution of 20 m. The removal depth followed the borehole surface created from the borehole scatter data set.

Due to the dredging process, it may not be practical to dredge the full depth of the borrow area. A vertical buffer of 1-foot was considered to accommodate the inaccuracies during dredging. The borrow area volumes were calculated for the full borrow depth and the borrow area with a 1-foot buffer. Based on previous experience with hopper dredges, the 1-foot buffer is reasonable to account for the dredging process. The 1-foot buffer was used to determine the quantities of borrow material available. The surface area and volumes of available material in each borrow area scenario with the vertical buffer are shown in table D..

Table D.5. Edisto Borrow Area Footprint and Volumes

Borrow Area	Average Depth (feet)	Footprint Area (acres)	Volume (mcy) 1' Buffer
Scenario A	6.9	650	7.2
Scenario B	6.8	500	5.5
Scenario C	6.3	485	4.9
Scenario D	6.7	395	4.3

11.0 COMPATIBILITY ANALYSIS

A compatibility analysis involves the comparison of the grain size distribution characteristics of the material existing on the active profile of the native or reference beach and the material available from the proposed borrow area. The native beach and borrow sediments were analyzed using standard sieving techniques. Based on the size distributions of the two materials, estimates can be made of the amount of over-filling required to construct a given design beach profile.

Wave action tends to distribute the material across this active beach profile in discrete size increments. The active beach profile is that portion of the profile regularly affected by wave action and generally extends from the crest of the beach berm seaward to water depths of approximately 24 feet. Samples of the native beach material are collected at uniform depth intervals from the crest of the beach berm seaward to water depths of about 30 feet and the size characteristics of each sample determined by standard sieve analyses. The size characteristics of the individual samples are mathematically mixed to determine composite mean and composite standard deviation of the material that is on the active beach profile.

12.0 COMPATIBILITY REQUIREMENT (CRITERIA)

The Charleston District guideline with regard to the percentage of fine-grained sediments is that borrow areas containing more than 10 percent fines are generally considered to be incompatible for placement on the beach due to potential problems with turbidity and siltation during placement.

13.0 NATIVE BEACH CALCULATIONS

The native beach composites were generated to reflect variations in sediment characteristics across the beach profile through varied energy zones, along the beach, at depths within the active profile. Surface samples were combined into one composite average grain-size distribution by summing the weights retained on each sieve interval and then dividing by the number of samples. The composite weight for a given size is:

$$w_{\text{composite}} = (w_{S1} + w_{S2} + w_{S3} + \ldots\ldots + w_{Sn})/n$$

where:

$w_{\text{composite}}$ = composite weight for a specific sieve
w_{Sn} = sediment weight retained on a specific sieve for each sample
n = number of samples

An analysis was performed with the grain size results of the samples taken to determine the native beach quality values. The values of key criteria was determined for the purpose of comparing potential sources of borrow material. The analysis determined the percent finer than then #4 sieve, the % finer than then #10 sieve, the percent finer than then #200 sieve, and the shell content.

14.0 OVERFILL RATIO

The suitability of the borrow material for placement on the beach is based on the overfill ratio. The overfill ratio is computed by numerically comparing the size distribution characteristics of the native beach sand with that in the borrow area and includes an adjustment for the percent of fines in the borrow area. The overfill ratio is primarily based on the assumption that the borrow material will undergo sorting and winnowing once exposed to waves and currents in the littoral zone, with the resulting sorted distribution approaching that of the native sand. Since borrow material will rarely match the native material exactly, the amount of borrow material needed to result in a net cubic yard of beach fill material will generally be greater than one cubic yard. The excess material needed to yield one net cubic yard of material in place on the beach profile is the overfill ratio. The overfill ratio is defined as the ratio of the volume of borrow material needed to yield one net cubic yard of fill material. For example, if 1.5 cubic yards of fill material is needed to yield one net yard in place, the overfill factor would equal 1.5.

The overfill criteria developed by James (1975) is the method used in the Automated Coastal Engineering System (ACES). The procedure is also described in the U.S. Army Coastal Engineering Manual EM-1110-2-1100 Part V (July 2003).

The equilibrium slope method by Pilarczyk, van Overeem and Bakker (1986) bases the recharged profile on the present native profile. However, if the grain size of the fill material is different from the native material, the profile steepness is altered.

The Dean's equilibrium method (Dean, 1991) determines the volume of recharged sand of a given grain size to increase the width of dry beach by a given amount. Dean proposed that beach profiles develop a characteristic parabolic equilibrium profile.

The Krumbein and James Method is only applicable if the native material is better sorted than the fill material. If the fill material is better sorted than the native material, this method simply does not apply. Secondly, the Krumbein and James Method assumes that the portion of the fill material retained on the beach after sorting by waves and current will have exactly the same size distribution of the native material. This implies that both the fine and coarse portion of the fill will be lost. This feature is not consistent with the knowledge of sediment transport process as the coarser portion of the fill will likely remain on the beach without being carried away by waves and currents (Dean, 1974; also Dean and Dalrymple, 2002). The overfill ratio by the Krumbein and James Method will tend to be overestimated. Dean (1974) addressed the above shortcomings by assuming that only the finer portion of the fill will be winnowed away by prevailing wave condition leaving the mean diameter of altered distribution of fill material to be at least as large as the mean diameter of native material. Dean defines the overfill ratio as the required replacement volume of fill material to obtain one unit of compatible beach material and uses the 'phi' unit to describe the size of sand particle.

The overfill ratio for the Native or Reference Beach was compared to the borrow area material was calculated by all 4 methods. The Equilibrium Slope Method (ESM) are considered to be the most accurate method base in the case of Edisto Beach. Based on these methods, the overfill ratio for is varied between 1.28 and 1.51. Any overfill ratio value of 1.5 or less with a fine content of less than 10% is considered acceptable for use as beach renourishment. The overfill ratio for each borrow area configuration is shown in Table D.6.

Table D.6. Edisto Beach Overfill Ratios.

			Silt Correction	Overfill Ratio Berm Height=7' Berm Width=50' Significant Wave Height=8'			
	MEAN (phi)	**STD DEV (phi)**	**Factor**	**Aces**	**EPM**	**ESM**	**Dean Method**
Native Beach	1.31	1.33	**NA**	**NA**	**NA**	**NA**	**NA**
All	1.85	1.12	1.012	2.26	2.29	1.35	1.20
Scenario 1	1.61	1.27	1.006	1.36	1.62	1.22	1.15
Scenario 2	1.50	1.32	1.005	1.19	1.37	1.17	1.10
Scenario 3	1.60	1.32	1.005	1.37	1.60	1.22	1.15
Scenario 4	1.57	1.29	1.004	1.29	1.52	1.20	1.10
Scenario A	1.73	1.31	1.004	1.51	1.93	1.28	1.20
Scenario B	1.71	1.33	1.004	1.16	1.88	1.27	1.20
Scenario C	1.67	1.29	1.004	1.43	1.77	1.25	1.15
Scenario D	1.71	1.25	1.004	1.549	1.88	1.27	1.20

ACES - Automated Coastal Engineering System

EPM - Equilibrium Profile Method

ESM - Equilibrium Slope Method

15.0 RESULTS

The borrow area scenarios with “letter” designations were selected to reduce the area surface area and the cost of environmental and archeological investigations. Based on the analysis of the overfill ratio and the grain size analysis borrow areas Scenario A was selected as the source of borrow material. The percent passing the #200 sieve is less than 10 percent for the proposed borrow area. The grain size distributions for the native beaches and the borrow areas are shown in Table D.7. A total of 7.2 million cubic yards of material is available within the proposed borrow area. The volume of available material and the footprint area of each borrow area is shown in Table D.7.

Table D.7. Edisto Grain Size Comparison.

	MEAN (phi)	STD DEV (phi)	% PASSING #5	%PASSING #10	% PASSING #200	% PASSING #230	% VISUAL SHELL
	-	-	-	-	-	-	-
Native Beach	**1.31**	**1.33**	**97.8**	**93.5**	**0.1**	**0.0**	**26.9**
	-	-					
All	**1.85**	**1.12**	**95.3**	**91.0**	**1.2**	**0.5**	**17.6**
Scenario 1	**1.61**	**1.27**	**94.3**	**89.3**	**0.6**	**0.2**	**20.1**
Scenario 2	**1.50**	**1.32**	**93.9**	**88.6**	**0.5**	**0.2**	**21.3**
Scenario 3	**1.60**	**1.27**	**94.7**	**89.9**	**0.5**	**0.2**	**19.7**
Scenario 4	**1.57**	**1.29**	**94.5**	**89.6**	**0.4**	**0.2**	**20.4**
Scenario A	**1.73**	**1.31**	**94.7**	**90.0**	**0.4**	**0.2**	**18.8**
Scenario B	**1.71**	**1.33**	**94.4**	**89.6**	**0.4**	**0.2**	**19.0**
Scenario C	**1.67**	**1.29**	**93.9**	**89.0**	**0.4**	**0.2**	**18.9**
Scenario D	**1.71**	**1.25**	**94.3**	**89.4**	**0.4**	**0.2**	**18.3**

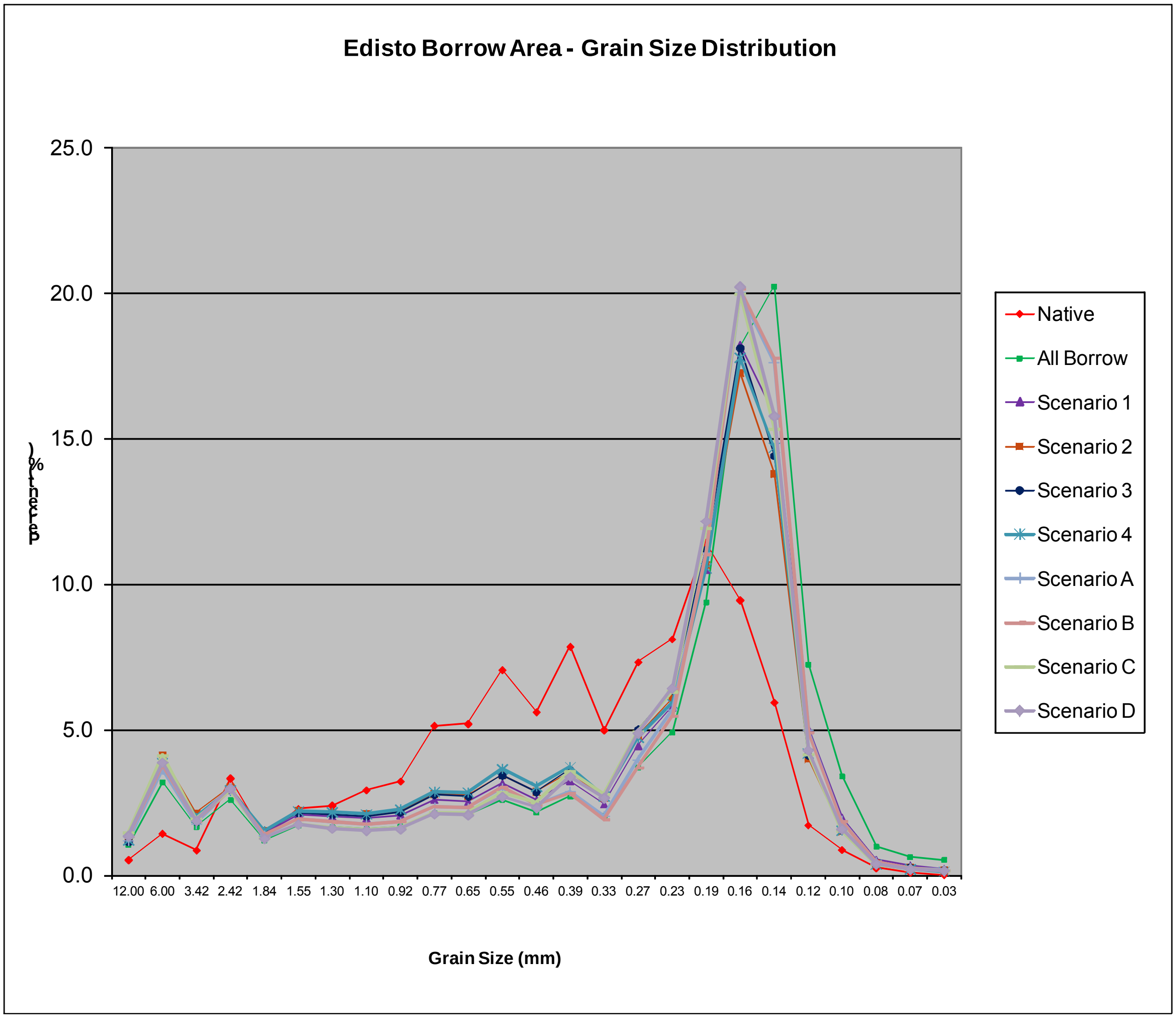


Figure D.7. Edisto Beach Grain Size Distribution for Borrow Area Scenarios and Native Beach.

16.0 CONCLUSION

Based on the total estimated volume in the borrow areas, including the 1-foot vertical buffer, there is an adequate quantity of suitable beach quality material to complete the full 50-year life of the project. There is approximately 7.2 million cubic yards of suitable borrow material available in the proposed borrow area, Scenario A. This volume does not include any recharge of these areas. The area to be used for borrow will be further defined during the Preconstruction, Engineering, and Design phase of this project. Additional borings and/or geophysical surveys will be performed as necessary to better delineate the borrow area boundaries and material types.

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