FILL SUITABILITY CHARACTERIZATION OF A COMPLEX COASTAL AREA: DARE COUNTY, NORTH CAROLINA

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ABSTRACT

As part of the design and pre-project monitoring for a beach nourishment project, the native beach sediment needs to be characterized and compared with sediments from a borrow area to see if they are suitable for use. In preparation for a beach nourishment project along two sections of the Dare County, North Carolina coast, a total of 670 sediment samples were collected. Ten samples were collected along each of 67 profile lines along a stretch of coast from Southern Shores, NC to the northern side of Oregon Inlet in May 2006 as part of the pre-fill monitoring. Surface grab samples were collected by hand at the toe of the dune, berm crest, mean high water line, mean sea level line, and at the mean low water line. In the nearshore, samples were collected with a Ponar dredge from -6, -12, -18, -24 and -30 ft depths. This large number of native beach sediment samples has allowed for a detailed study of both cross shore and alongshore variability. The area features complex geology with variability in the morphology of the nearshore area. Several hot spots have been identified where erosion exceeds the average rate and their location can be tied to the morphology differences. The complex sediment data is related to this varied morphology and is characterized to provide data for design and monitoring of a stable beach nourishment project. The fill design can be adjusted in the future during the operations and maintenance of the project based on the results of this pre-fill monitoring.

INTRODUCTION

To assess fill suitability and document the composition of the natural beach, pre-fill beach sediment needs to be characterized and compared with sediments from a borrow area. The ideal situation would be for sediment in the borrow area to have the same grain size distribution and composition of the existing beach where the fill is to be placed. When the native beach and/or the borrow area have high variability in the distribution of grain sizes or composition of sediment, a more involved analysis procedure is needed to correctly characterize the beach and determine the amount of material needed to provide for a stable fill. This paper will provide techniques used to characterize the grain size of a native beach in an area that has a complex sediment distribution and to understand the reasons behind the associated complicated shoreline morphology. The goal is to provide the best analysis for monitoring a beach nourishment project that will provide the desired level of shore protection and damage reduction. A compatible fill will extend the interval between renourishments and reduce the overall cost of the project.

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DARE COUNTY PROJECT

Dare County, North Carolina is located in the northeast part of the state along the Atlantic Ocean. Portions of the beachfront are experiencing erosion with loss of beachfront homes and commercial structures from storm activity. The study area covers 44 km (27 miles) from Southern Shores in the north to Oregon Inlet in the south (Figure 1). The monitoring plan has divided the study area into a *North of Project* area, where no fill will be placed. The *Project Area* includes two areas (*North Fill* and *South Fill*) that will receive fill, separated by a gap of approximately 3 km (1.9 miles) between the fills where the shoreline has been stable and no fill will be placed. The monitoring continues in the *South of Project* area through the Cape Hatteras National Seashore to Oregon Inlet. No fill will be placed in this area, but it is downdrift of the net longshore transport and will be monitored to document any gain in sand on the National Seashore beach and Oregon Inlet ebb shoal from the fill placement.

DATA SAMPLING SCHEME

The physical monitoring program includes the surveying of 144 beach profiles spaced approx. 305 m (1,000 ft) apart. Profiles originate from a known benchmark landward of the primary dune and continue offshore to the -10 m (-32 ft) depth contour. Real Time Kinematic Global Positioning Satellite system (RTK GPS) is used to obtain position and elevation data with horizontal and vertical accuracies between 2-6 cm (0.05–0.20 ft). The dune and dry beach are surveyed with a backpack mounted RTK GPS system. The bathymetric data is collected with an Army Lighter Amphibious Resupply Cargo (LARC)

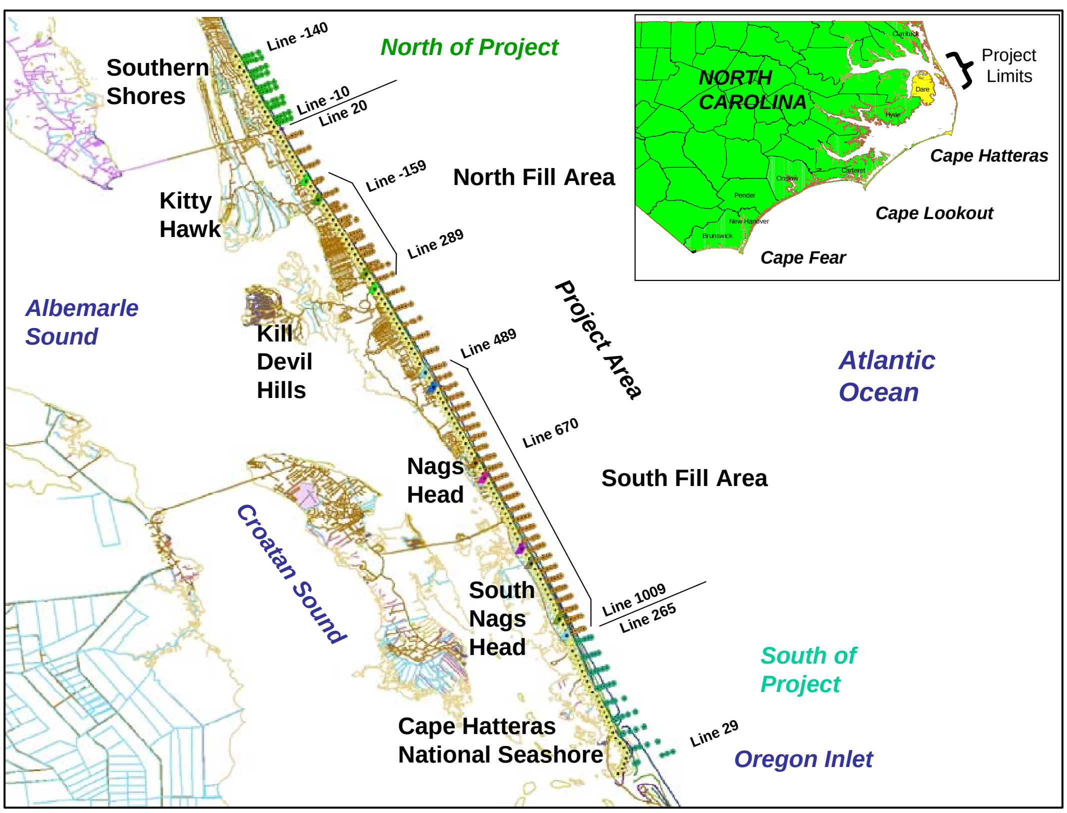

Figure 1. Location map and sampling scheme for the Dare County Project

vessel equipped with RTK GPS, echosounder, and motion reference unit measuring heave pitch and roll. The speed of sound through the water column was determined from measurements of conductivity, temperature, and salinity (CTD). The LARC has the advantage of being able to survey continuously from the base of the dune through the surf zone to the seaward limit of the profile. The backpack obtained portion of the profile was combined with the overlapping LARC beach portion of the profile to obtain a continuous profile from the landward side of the dune out to the seaward limit of the profile. The profile lines used in this study were collected during April 2006.

Sediment samples were collected along 67 of the profile lines (locations shown on Figure 1) during May 2006. Ten samples were collected along each profile with a total of 670 samples collected for grain size analysis.

Surface grab samples were collected by hand at specific elevations based on the NAVD88 tidal datum. Sample locations included the Dune Toe (+3.96 m, +13 ft), Berm Crest (+2.13 m, +7 ft), mean high water line (MHW) (+0.76 m, +2.5 ft), mean sea level line (MSL) (+0.15 m, +0.5 ft), and at the mean low water line (MLW) (-0.3 m, -1.0 ft). In the nearshore, samples were collected with a Ponar dredge off the LARC at -1.83, -3.66, -5.49, -7.32 and -9.14 m (-6, -12, -18, -24 and -30 ft) depths (Figure 2). GPS was used to obtain positions of the sediment samples and they were entered into a Geographic Information System (GIS). With this large number of native beach sediment samples, a detailed study of cross shore and alongshore variability in the native beach grain size distributions could be completed.

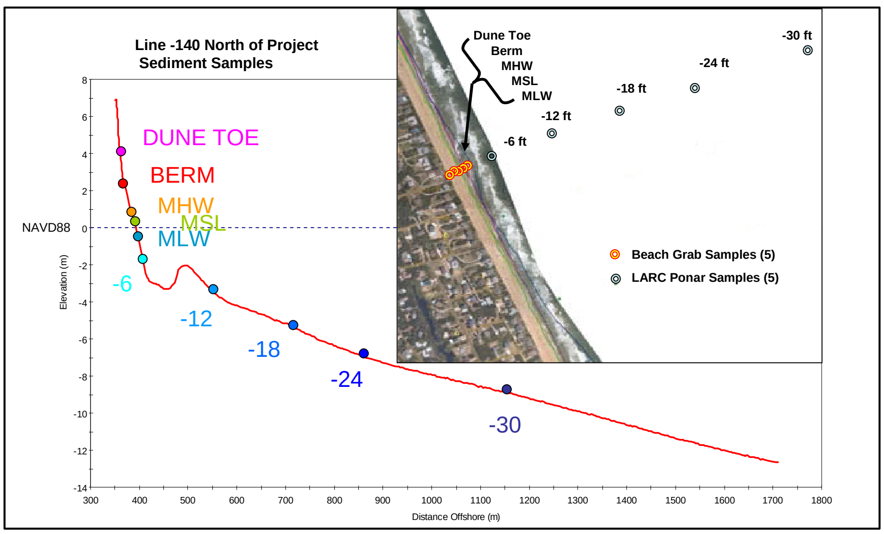

Figure 2. Sediment sample locations across profile

GRAIN SIZE ANALYSIS

All 670 sediment samples were washed and sieved at ½ phi intervals from -2.5 phi (5.66 mm) to 4.0 phi (0.0625 mm) at the Coastal and Hydraulics Sedimentation Research Laboratory. About 10% of the samples were also run through the Coulter LS100 laser particle counter to analyze for silt size material. Sediment statistics including mean grain size and sorting were calculated by method of moments.

The grain size distributions were highly variable in both the cross shore and long-shore directions. Figure 3 shows representative frequency curves across four profiles from the a) North of Project, b) North Fill, c) South Fill and d) South of Project areas. The nearshore samples all had similar curves showing a fine grained, well sorted sand. The beach samples showed the variability with coarser, more poorly sorted sands on the northern portion of the study and finer, more-well sorted sands to the south. The distribution of the mean grain size across the profile, using all 670 samples shows that the most variability and coarsest material are in the MHW, MSL, MLW and -6 ft samples (Figure 4). The means became slightly finer toward the dune toe but still had a wide spread. The nearshore samples from -3.66 to -9.14 m (-12 to -30 ft) were all fine sands with much less mean grain size variability. This spatial distribution of mean grain sizes was found on other ocean beaches. This difference in the grain size distribution as one proceeds from the dune base, across the beach and continues offshore was described by Bascom (1959). The coarsest grains are usually found in an area just seaward of the backwash/surf interaction zone, at the shore break plunge point, an area of high turbulence (Bascom, 1959; Zarillo, et al, 1985; Stauble, 1992; Stauble and Bass, 1999). The berm crest area also contains significant coarse material due to runup sediment transport dynamics. Finer, better-sorted material is found in the dune area owing predominantly to wind transport processes. Seaward of the nearshore bar, sediments become more uniform, with a narrow range of fine grain sizes (well sorted), between the -3.66 to -9.14 m (-12 to -30 ft) samples. This extends to depth of closure (the seaward limit of significant depth change) on most of the profiles (Birkemeier et al, 2007).

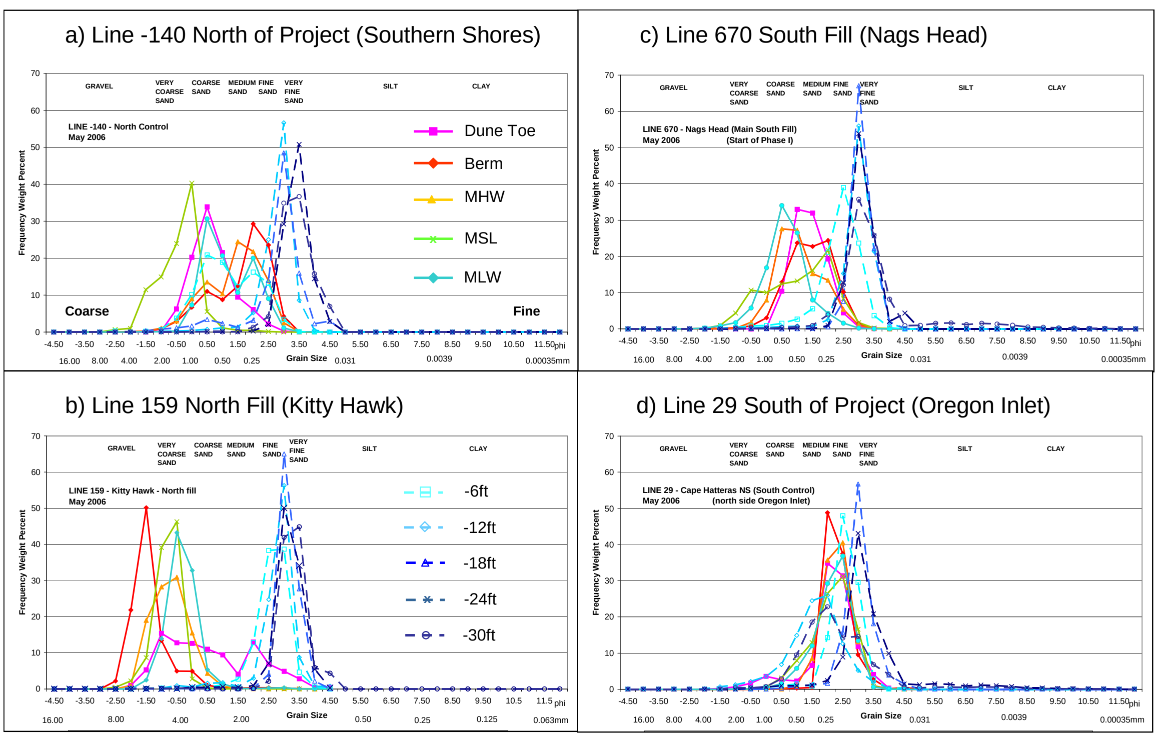

Figure 3. Variability in individual grain size distributions along study area

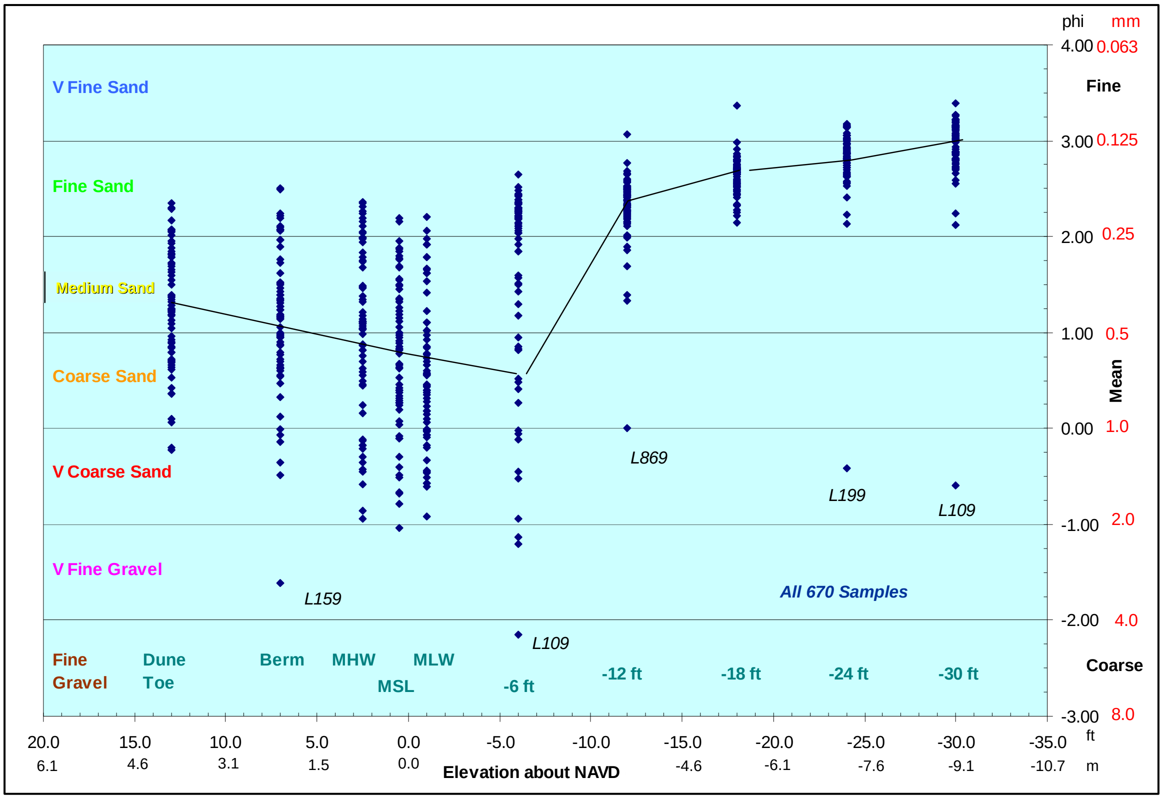

Figure 4. Mean vs. sorting plot of cross-shore trends

CHOOSING A COMPOSITE SAMPLE

To reduce some of the variability in grain size distributions, composite curves were constructed by mathematically combining the weight percents of each sieve size for several samples across the profile. The typical composite sample is the *Profile Composite* where all 10 samples (Figure 5a) were combined and averaged to produce a new composite frequency distribution curve (blue line in Figure 5d). Due to the abundance of fine well sorted nearshore samples, the composite curve is finer and more poorly sorted than the individual curves. This tended to make all the curves similar for each profile line and did not help in understanding the grain size distribution along the project. A *Foreshore Composite* is often used to represent the intertidal area of the beach profile where most fill sand will be placed during a project. This curve is a composite of the MHW, MSL and MLW samples (Figure 5b). This composite curve (green line in figure 5d) represents the combined grain size distributions of the intertidal area of the beach and eliminates the finer nearshore samples. Since there was high variability in the Berm Crest and -6 ft samples along the Dare County beaches, a *Beach Composite* was constructed that included the Berm Crest, MHW, MSL, MLW and -6 ft samples (Figure 5c). This curve (red line in Figure 5d) fell between the coarser foreshore composite and the finer profile composite. It was thought this curve best represented the sediment composition along each profile line and was used in the analysis for this paper.

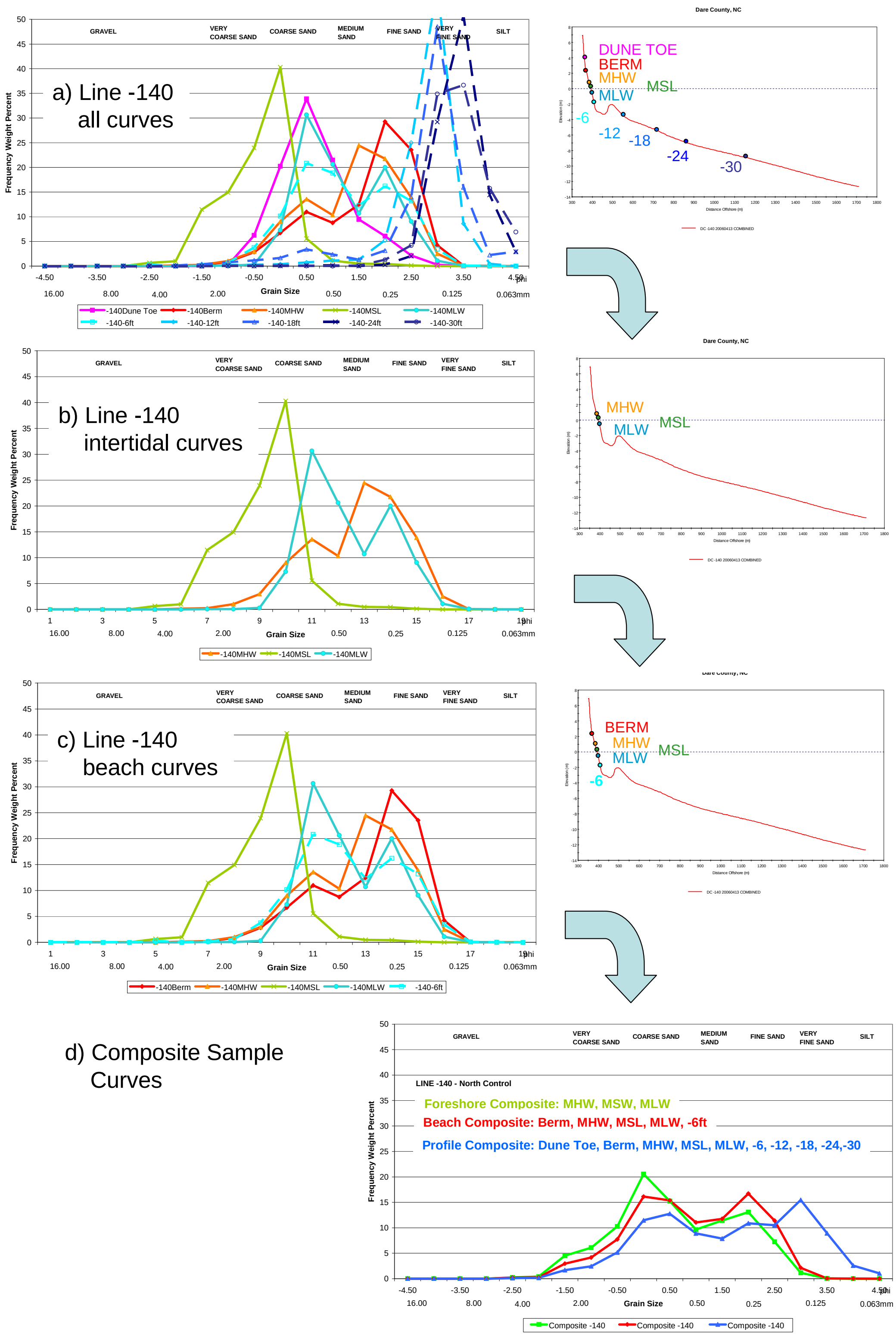

Figure 5. Composite sample types examined for study

SEDIMENT DISTRIBUTIONS AND PROFILE CHARACTERISTICS

Due to the high variability in the individual sediment samples along each profile line, the *Beach Composite* was constructed for each profile. To identify spatial patterns on this project, the analysis of the composite grain size curves was divided into the four zones of the project.

North of Project Area

The North of Project area included profile lines -140 to -10. The 10 composite samples in this zone are shown in Figure 6. Even with the use of composites there is still a high degree of variability and no discernable pattern in the grain size distributions in this zone. There are three peaks in the grain size distributions showing a predominance of very coarse sand on profile lines -110, -70 and -20 (lines w/red tones). A second group of samples had a peak of coarse to medium sand on lines -130, -100, -80 and -50 (lines w/blue tones). A third group had a peak in the fine sand range on lines -140, -40, and -10 (lines w/green tones). All of these samples were poorly sorted indicating a wide range of grain sizes found on the beach between the Berm Crest and the -6ft sample. The profile lines are shown in an insert on Figure 6 and show that the profiles are all uniform in shape in this area, with a dune, steep foreshore slope (indicative of the coarser sediments) and a single nearshore bar. The nearshore slope is uniform seaward of the bar.

North Fill Area

Fill material will be placed south of the vicinity of profile line 109 and extend to the vicinity of profile line 329. Eight composite samples from profile lines 20 to 189 are shown in Figure 7 that covers the area in Kitty Hawk. As in the North of Project area, the sediments are highly variable, with very coarse to coarse composites at lines 109, 138 and 159. Coarse to medium sands are located at lines 20, 50 and 189, while lines 80 and 169 are medium to fine sands. In Kill Devil Hills the sediment composites become a little finer, but there is still a high variability in grain sizes distributions (Figure 8). Profile line 260 is composed of coarse sand and profile line 289 is bi-modal with predominately medium sand but has a coarse component. Profile lines 199, 219, 249, 279 and 309 are predominately medium sands and line 229 has a fine grain peak. This zone exhibits complex 3D nearshore bathymetry with ridges and swales or “moguls” running obliquely to the beach as shown in the two figures in both plan views and in profile. Generally, the coarser beach composites are along the profile lines that transect the swales and the finer beach composites are along the lines that transect the ridges, but there are some exceptions. As will be shown later, this area is associated with the subsurface trace of the ancestral Albemarle River channel (Snyder, 1997).

South Fill Area

The gap between the North and South Fill area is represented by the beach composites on profiles 340 to 460 (Figure 9). These composites are either predominately coarse grained as in lines 369 and 400 or predominately medium sands as in lines 340, 429, and 460. The profiles along this section show a smoother nearshore with a single nearshore bar/trough configuration but still contain complex sediment grain size distributions.

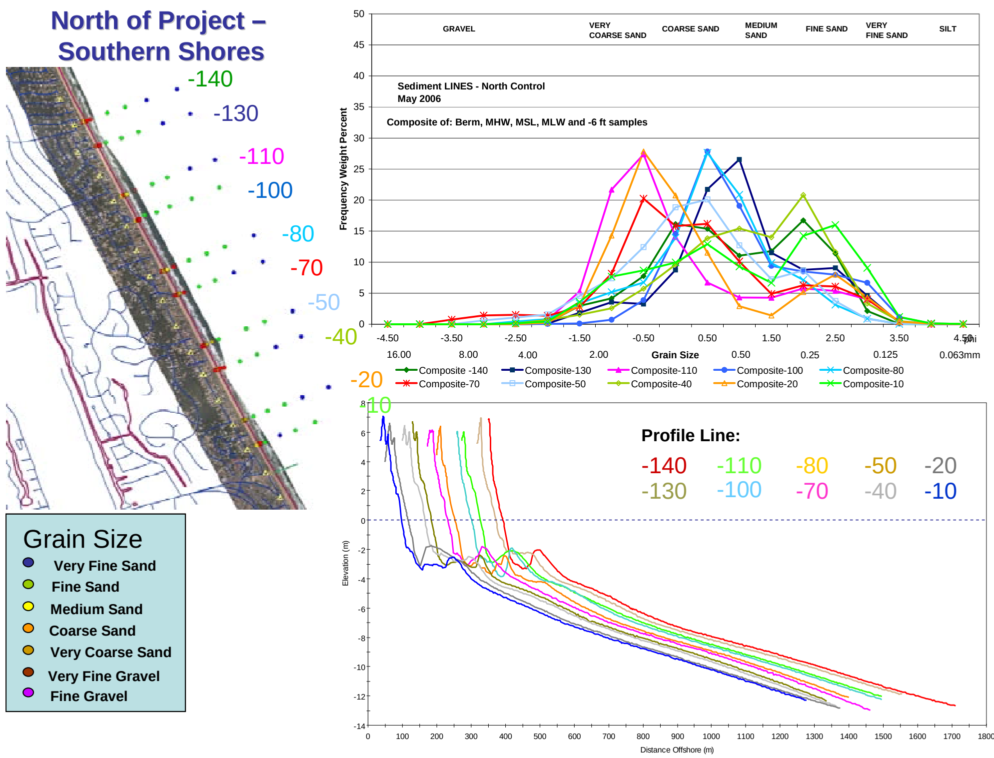

Figure 6. North of Project beach composite variation and related beach profiles

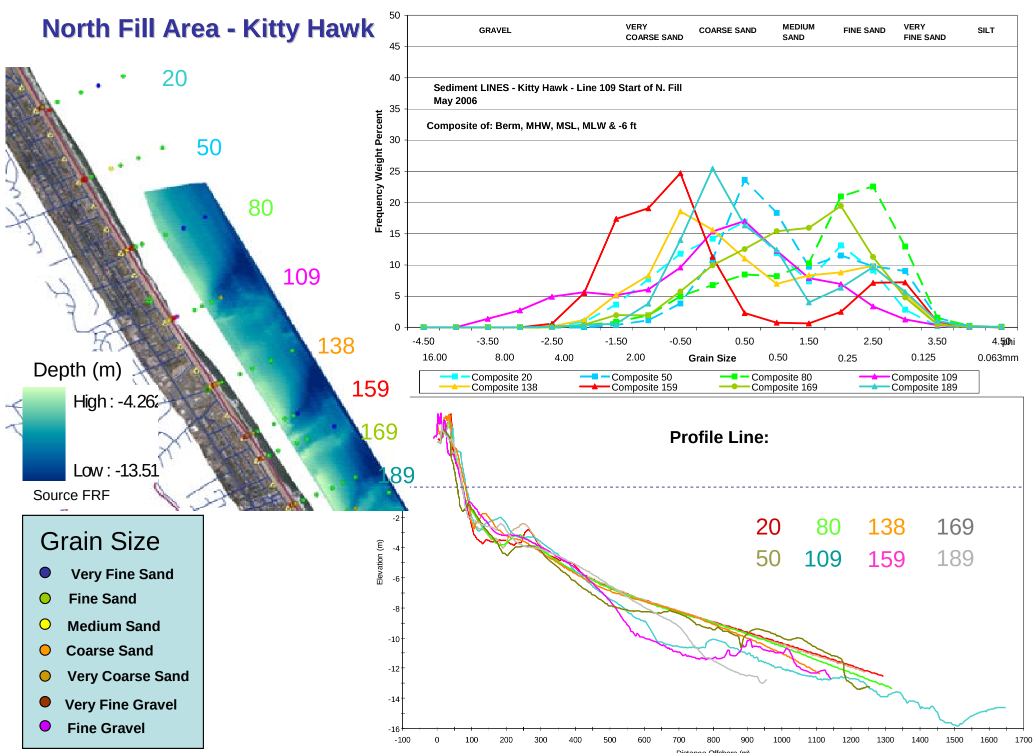

Figure 7. North Fill (Kitty Hawk) beach composite variation and "mogul" bathymetry

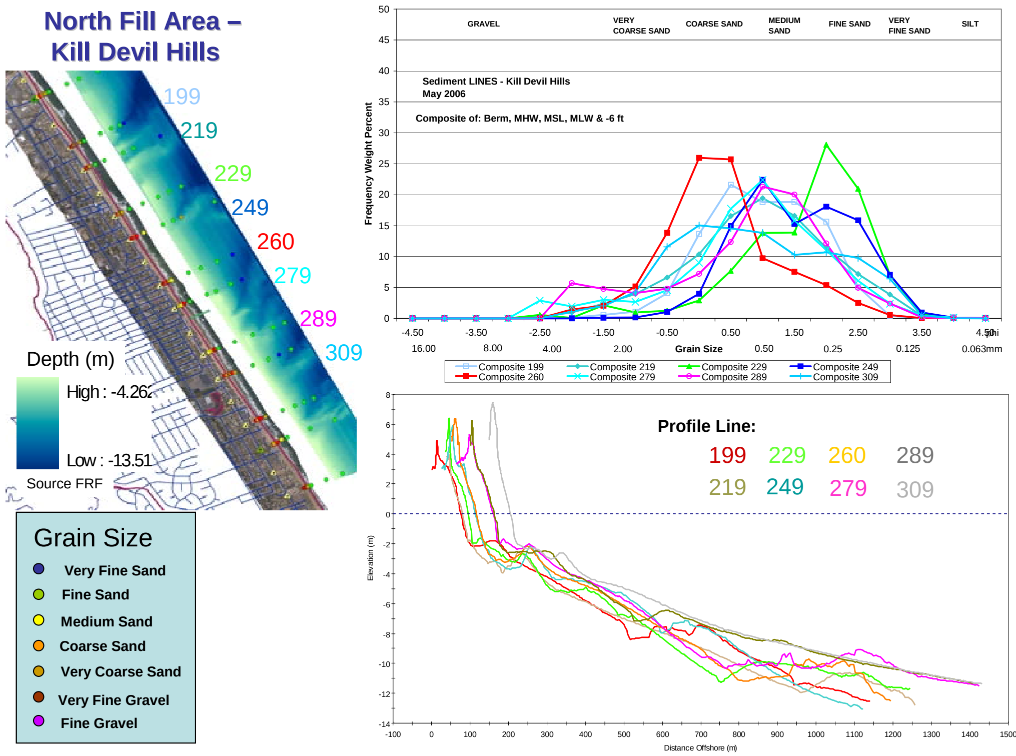

Figure 8. North Fill (Kill Devil Hills) beach composite variation and "moguls"

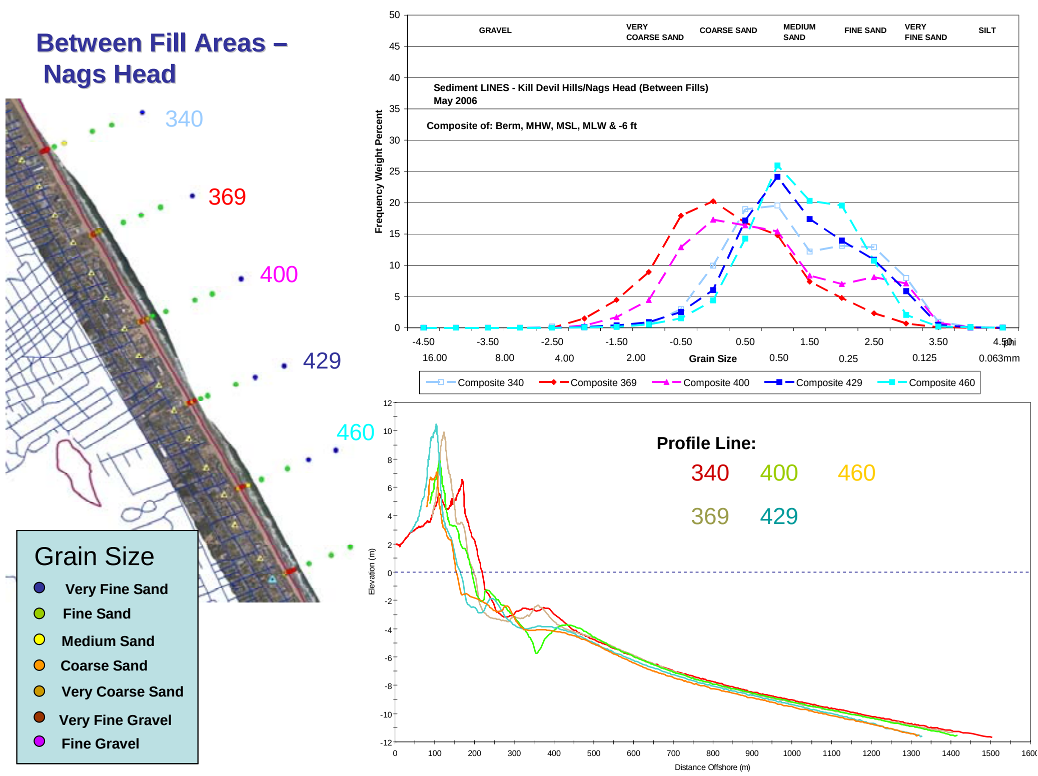

Figure 9. Area between Fills beach composite variation and related beach profiles

The South Fill will start in the vicinity of profile line 489 and extend to near profile line 1020 in the Town of Nags Head. The native beach composite grain size distributions in this zone are more skewed to medium to fine sand sizes. In the north end of the South Fill, only lines 489, 549 and 609 of the nine profiles had peaks in the coarse size range (Figure 10). The rest of the samples are predominately medium to fine sands. The beach profile shapes in this northern part of the South Fill have a more complex nearshore bar/trough configuration, with the trough width varying along each profile. The central section of the South Fill area also has a similar beach composite set, with only one very coarse sample at line 829 (Figure 11). There are a few coarse to medium samples at lines 670, 709, and 729. The other five composites are skewed to the finer grain size distributions. The profiles in this central South Fill area showed a smooth nearshore and single nearshore bar/trough shape. Line 829 is the northernmost line to show the shore-attached shoal at the seaward end of the profile. The remaining composites along the profiles in the southern section of the South Fill are shown in Figure 12. The composites are all composed of predominately fine grained material and show better sorting of grain sizes. This set of composites, containing no coarse material, is distinctly different from the composites in the north part of the study area. The profiles have the characteristic bar/trough configuration in the nearshore, but the slope of the nearshore is variable and the seaward end of the profiles show the edge of Pratt Shoals.

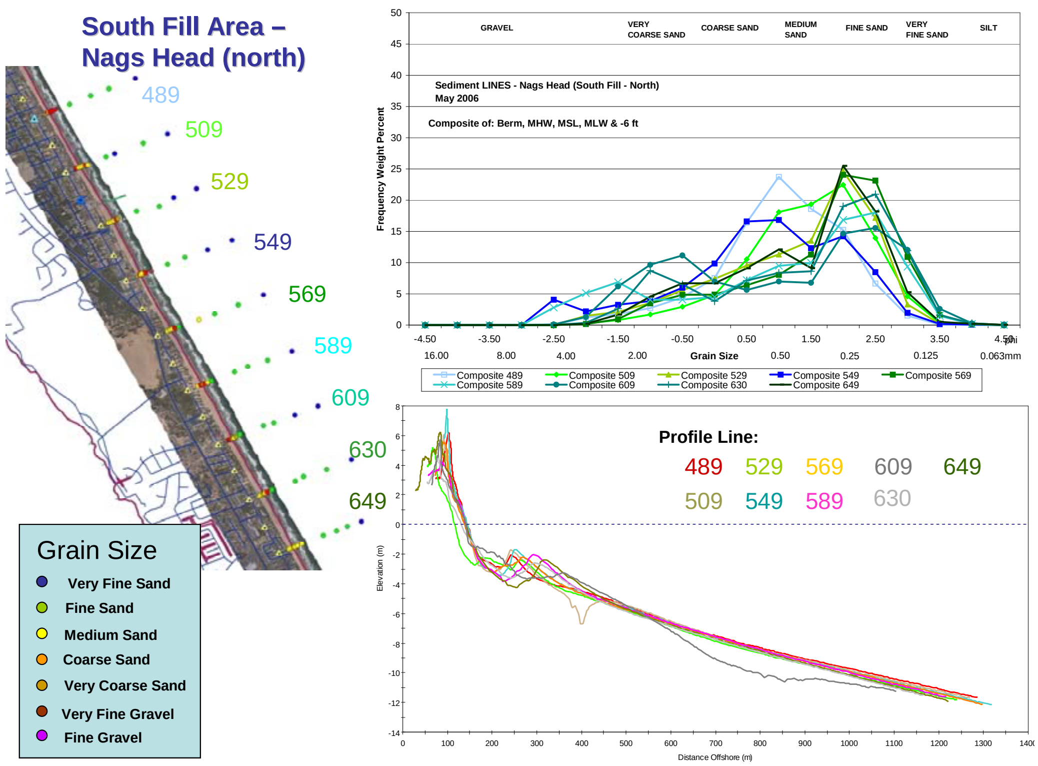

Figure 10. South Fill (north) beach composite variation and related beach profiles

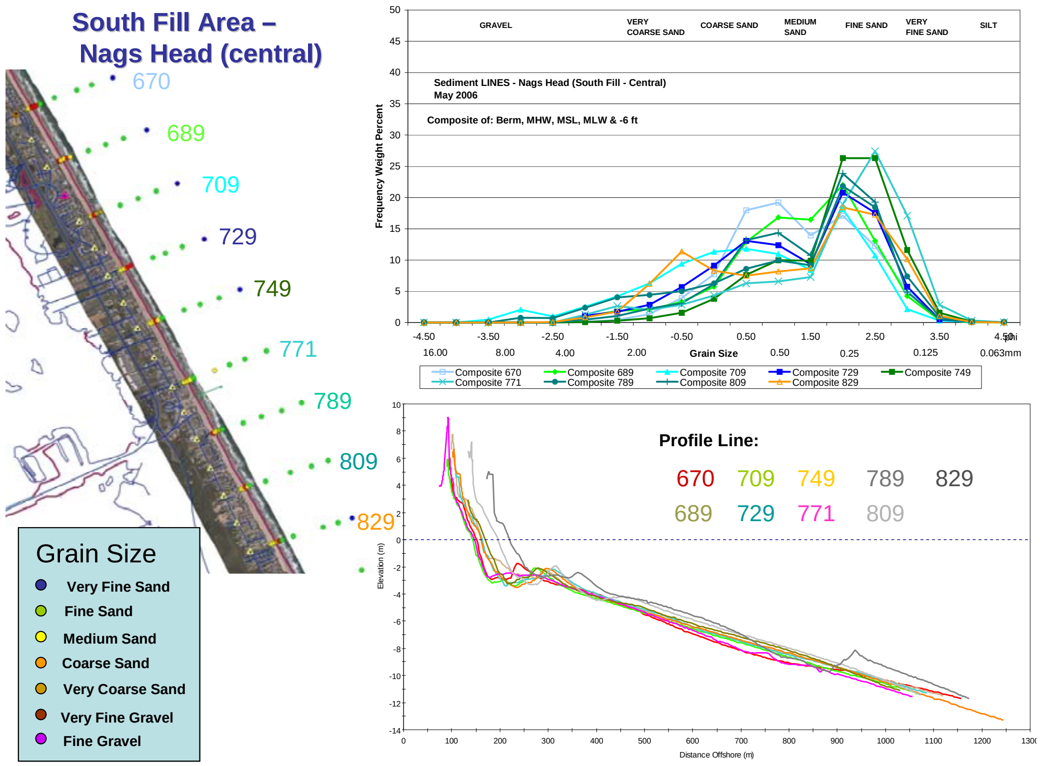

Figure 11. South Fill (central) beach composite variation and related beach profiles

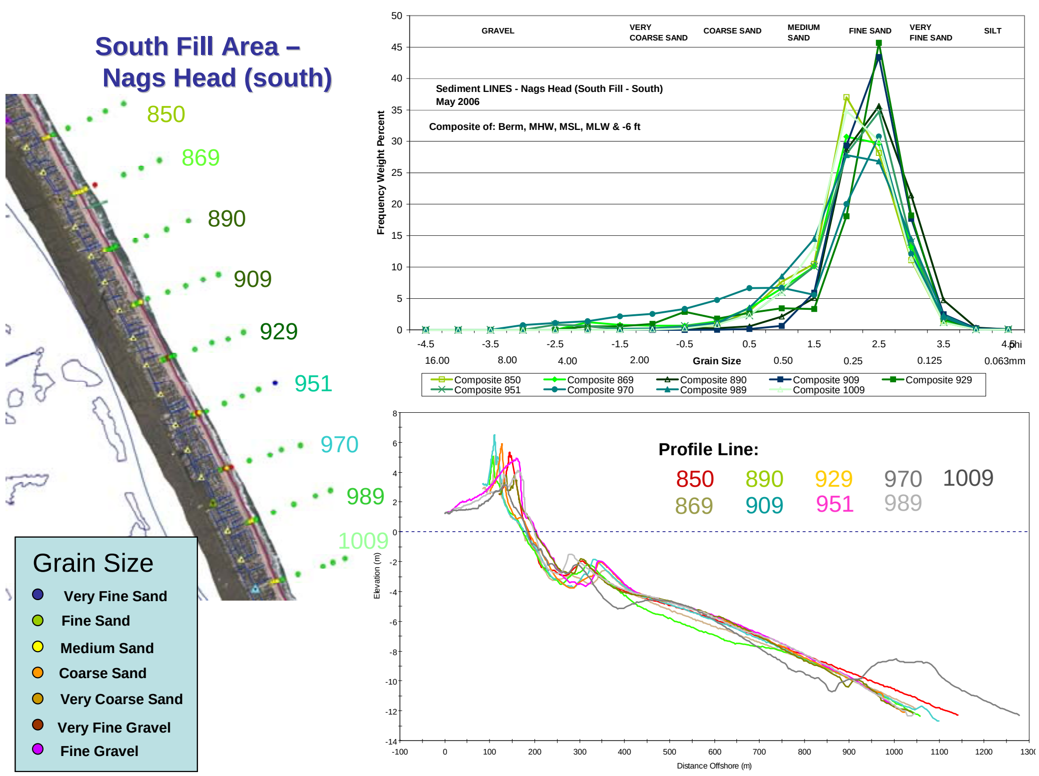

Figure 12. South Fill (south) beach composite variation and related beach profiles

South of Project Area

Sediment samples were collected along 9 profiles in the South of Project area within the Cape Hatteras National Seashore property. The beach composites show more variability than the south end of the southern fill, but are still predominately fine grained sand. Only lines 234, 204, and 174 have a small percentage of coarse sand (Figure 13). The profiles show the influence of the northern edge of the ebb shoal at Oregon Inlet with a high degree of variability of nearshore bar positions and slopes.

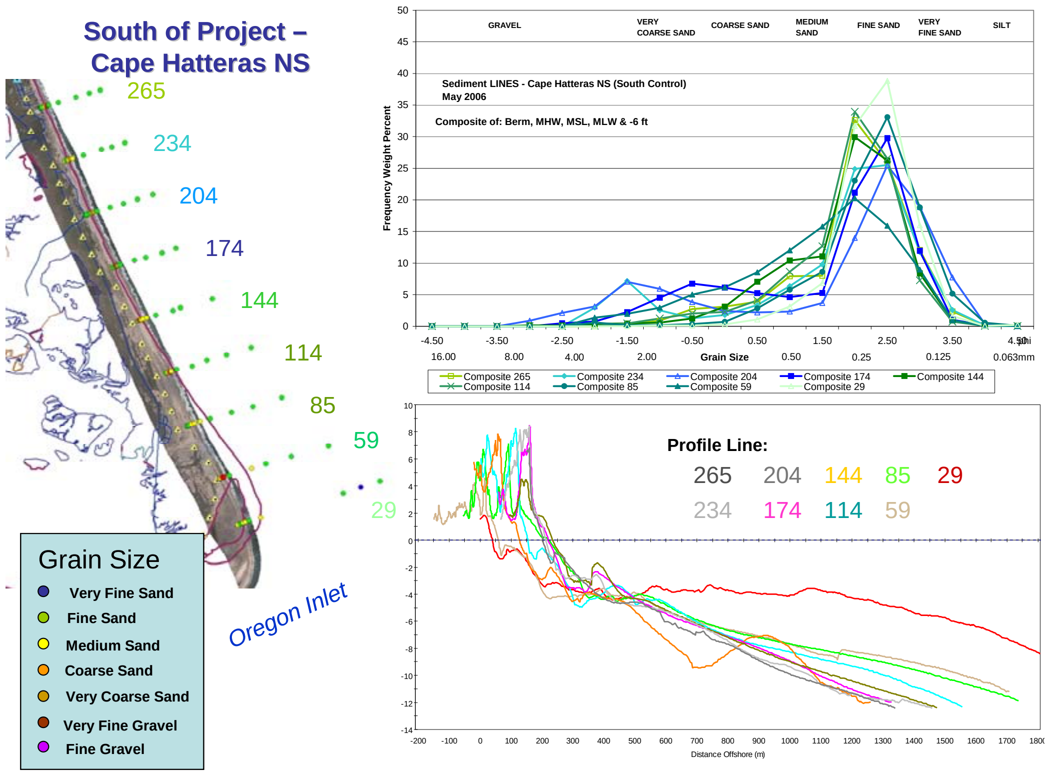

Figure 13. South of Project area beach composite variation and related beach profiles

HOT SPOTS

Hot spots along a beach are areas of the shoreline that erode higher than the background rate along a stretch of coast. Two hot spots have been identified along the Dare County coast within the project area. Figure 14 shows the location of the two hot spots on nearshore bathymetry surveyed by the United States Geological Survey (USGS). The irregular offshore bathymetry in the North Fill area is due to the ancestral Albemarle River channel (Browder and McNinch, 2006; McNinch, 2004). A USGS shoreline change study comparing the 1970 to 1997 shoreline also confirms a higher rate of erosion in this region (Morton and Miller, 2005). Rates of erosion between 2 and 4 m/yr (6 and 13 ft/yr) were measured in the mogul area. The underlying geology appears to control the highly variable bathymetry, which in turn affects the sediment distributions in this area. The second hot spot is associated with the shore-attached shoal at the southern end of the project. This hot spot may be the result of wave refraction over the shoal feature.

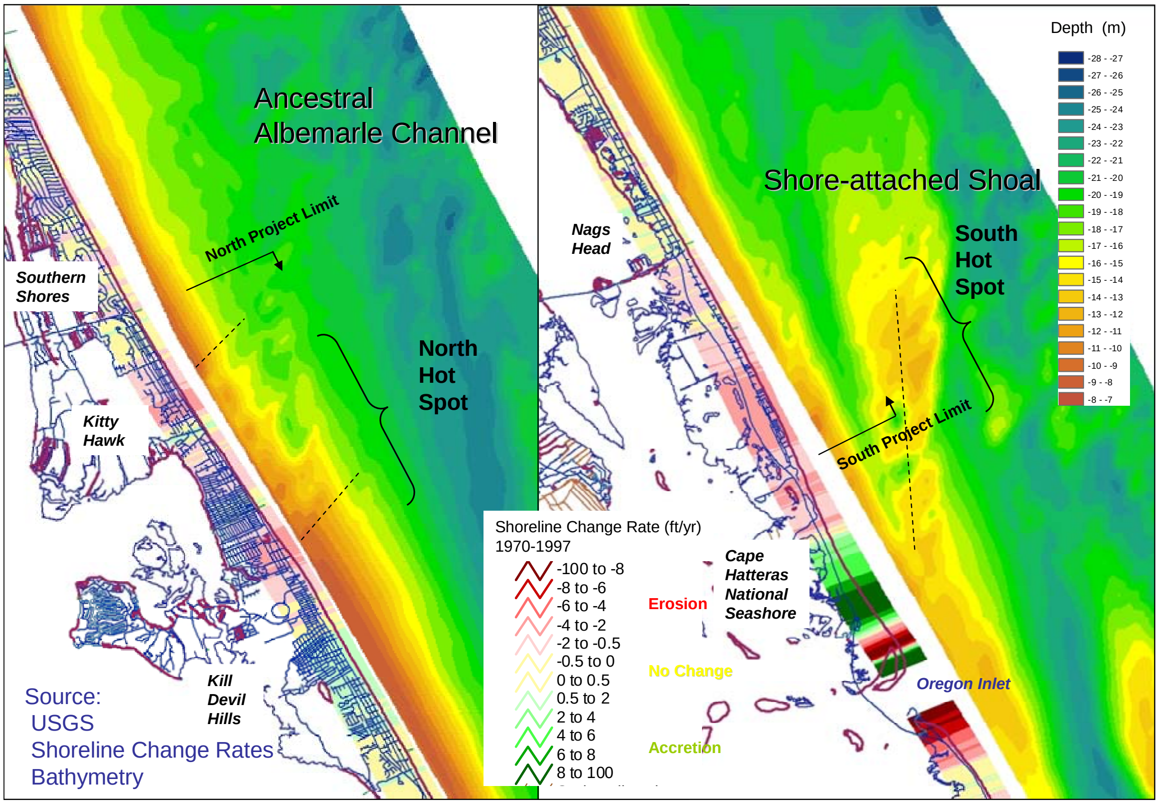

Figure 14. Location of hot spots related to bathymetry and shoreline erosion rates

Similar patterns were found at Ocean City, MD, where two separate shore-attached shoals were associated with two hot spots (Stauble and Bass, 1999). Shoreline erosion rates in this hot spot area were measured to range between 0.5 to 4 m/yr (1.6 to 13 ft/yr). The uniform sediment distributions do not reflect this southern hot spot, but there is a general fining trend toward the south from Southern Shores to Oregon Inlet. The finest sediment composites are found in the southern South Fill and South of Project areas.

FILL SUITABILITY

Typical fill suitability techniques use the mean and sorting of borrow and native sediments obtained from grain size analysis. The overfill ratio or fill factor methods use the single value of the mean and sorting values of both borrow and native grain size distributions. The Dare County sediment data provide an ideal opportunity to evaluate this approach since there is a wide variation in the grain sizes present ranging from gravels to fine silt. Use of the entire grain size distribution should improve both the accuracy in identifying compatible sediments, and the performance of nourishment projects in areas with complex and variable beach sediments.

A large number of cores have been collected and analyzed to identify suitable borrow areas. A complete analysis of the borrow area is beyond the scope of this paper. Figure 15 illustrates how this analysis could be done. A single composite core grain size distribution is shown which is achieved by mathematically combining several samples taken at selected depths in the core. This core composite is compared with two representative native beach composite samples to show how compatibility could be evaluated. A typical analysis would consist of assembling a borrow composite of several cores from a nearshore area that would be compared to multiple beach composites. A more extensive analysis of the borrow sediments can be found in U.S. Army (2000). Offshore borrow area core NDCS_01_v_16 (dashed light blue line) from the southern shoal area is compared with a representative beach composite sample from the coarser North Fill area (Line 609 green line), and a finer representative beach composite from the South Fill area (Line 909, dark blue line). Looking at the entire distribution of each composite, shows that this single borrow core composite has less coarse material than the single North Fill beach composite, but has more medium sand and less fines. The representative finer South Fill beach composite has more fine grained material than this borrow area core.

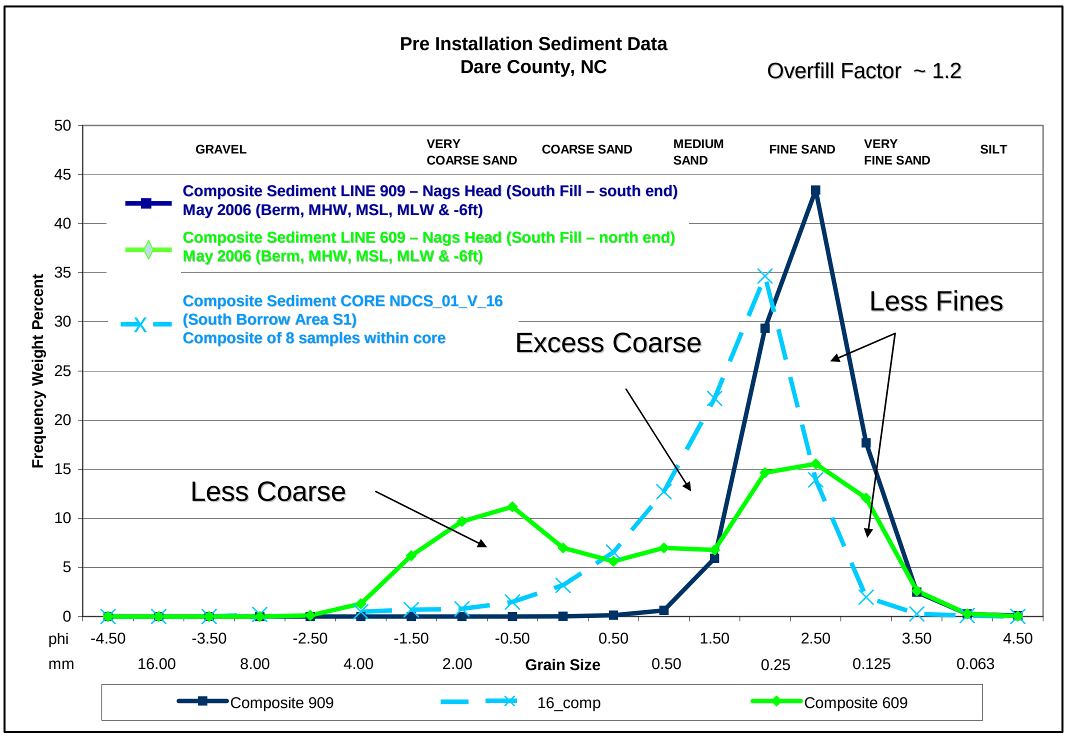

Figure 15. Example comparison of borrow core with beach composites

CONCLUSIONS

This study was able to characterize the pre-fill highly variable "native" conditions which appear to be related to the underlying geology of the area. This data established a pre-fill baseline to evaluate project performance when the project is constructed. The behavior of the fill can be compared to the native beach to identify renourishment requirements to maintain the design level of protection. It is anticipated that the fill will have a variable rate of loss as a function of the location of the hot spots. With the characterization of the native fill by profile, a measure of the fill stability can be done after fill placement. With the high variability in the native beach, the post-placement beach sediment distributions are suspected to also be complex. The ability to quantify storm protection and benefits realized along this highly variable beach could not be possible without first understanding the details of the native beach sediment variability. With this understanding of the details of sediment distribution and profile response, guidance on the management of complex fills, including erosional hot spots can be made with more certainty.

ACKNOWLEDGEMENTS

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