FINAL REPORT

carteret county Shore protection office
protectthebeach.com

Bogue Banks Beach
and Nearshore Mapping Program

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geodynamics
COMPLEX COASTAL CHANGE MADE CLEAR

Executive Summary

Comprehensive surveying of the Bogue Banks shoreline began in 1999 to develop the Bogue Banks Beach Restoration Project. In Spring 2004, the Bogue Banks Beach and Nearshore Mapping Program was initiated to assess beach conditions and form strategies for future beach nourishment projects. Bear Island was added to the project in October 2004 and Shackleford Banks was added in May 2005. Currently, surveys are performed each spring along all three islands. In addition, after large storm events surveying is performed along Bogue Banks to assess damages. The most recent regular survey was completed in June/July 2008 by Geodynamics. For this evaluation, the 2008 survey was compared with the 2007 survey. The survey data was used to compute shoreline change at +1.1 ft NAVD88 which is designated as Mean High Water (MHW) and volume change above MHW, -5 ft NAVD88 (wading depth), -12 ft NAVD88 (outer bar), and -20 ft NAVD88 (depth of closure).

Key statistics were computed for defined regions along the Bogue Banks shoreline, Bear Island, and Shackleford Banks between the 2007 and 2008 survey profiles including;

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Banks Oceanfront (1-112)	128,393	12.71	3.96	516,329	-2.79	-384,489	-4.41	-492,480	-13.58	-1,567,258
Bogue Banks County Project (9-76)	88,094	6.36	3.69	330,423	-4.09	-356,719	-1.78	-163,806	-10.19	-903,972
Bear Island (1-18)	17,000	42.53	7.79	129,249	3.85	57,942	5.98	96,090	9.39	155,938
Shackleford Banks (1-24)	46,001	5.80	-1.79	-73,540	-4.38	-201,919	-5.85	-247,192	-13.66	-597,556

Based on the calculations, a large amount of apparent erosion occurred along the Bogue Banks oceanfront from May 2007 to July 2008, approximately 1,600,000 cy above the depth of closure. The County Project had slightly less loss of approximately 900,000 cy. Bear Island experienced accretion while mostly erosion occurred along Shackleford Banks. The trend along Bogue Banks was that of accretion above MHW as a calmer storm season pushed sand onto the beach and overall erosion to the depth of closure as the offshore bar shifted and also sand was lost from the nearshore littoral system. It should be noted that the datum conversion required for the 2007 data from NGVD to NAVD may have introduced some error into these results.

In addition, calculations were performed to estimate the amount of material remaining on the beach in excess of the baseline nourishment condition established by the Phase I, Phase II, and Phase III Bogue Banks Beach Restoration Projects. It was determined that all reaches within the County Project currently contain more sand than was present after the baseline projects were completed.

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1.0 Objective

The Bogue Banks Beach and Nearshore Mapping Program (BBBNMP), sponsored by Carteret County, began in June 2004 as a continuation of a monitoring program initiated in 1999 for assessing beach conditions and forming strategies for the Bogue Banks Beach Restoration Project (Phases I, II, and III). Bear Island was first surveyed and added to the BBBNMP in October 2004 while Shackleford Banks was added in May 2005. Since May 2005, surveys along Bogue Banks, Bear Island, and Shackleford Banks have been performed each spring. In addition, Bogue Banks is also surveyed after large storm events to quantify damage done to the beach and augment the municipalities' FEMA reimbursement for beach nourishment. The most recent regular survey was completed in June/July 2008 by Geodynamics LLC (Geodynamics). This report documents the data sources, methods, and results of a survey evaluation performed to compare the June/July 2008 survey with a previous survey performed in May 2007.

2.0 Summary of Previous Work

Previous beach monitoring studies, performed by Coastal Science & Engineering (CSE) between 2004 and 2007, were reviewed to gain an understanding of previous survey methods, associated coastal analysis, and observed trends. This work is summarized below. Each year, comparisons along Bogue Banks were made to an initial survey performed in 1999, providing some long-term analysis. Bear Island and Shackleford Banks were added to the monitoring effort in 2004 and 2005 respectively. Each year, surveys for these regions are compared to the initial surveys in 2004 and 2005 to provide long-term analysis results. In addition, at Bogue Banks, Bear Island, and Shackleford Banks, comparisons were made each year to the previous year's survey, providing insight into sand movement within a single year. **Table 1** and **Table 2** show the long-term and short-term volume changes over the various reaches of shoreline included in the BBBNMP.

Table 1. Long-term Volume Change

	Dune to -4' NGVD				Dune to -11' NGVD				Dune to -15' NGVD			
	June 1999-June 2004	June 1999-May 2005	June 1999-May 2006	June 1999-May 2007	June 1999-June 2004	June 1999-May 2005	June 1999-May 2006	June 1999-May 2007	June 1999-June 2004	June 1999-May 2005	June 2004-May 2006	June 2004-May 2007
Reach	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy
Bogue Inlet-Channel	-	-	-	-	-	-	-	-	-	-	115,528	-
Bogue Inlet-Ocean	185,872	250,657	-25,335	33,023	-268,237	395,676	99,426	147,797	-	-	-	-
Emerald Isle-West	420,971	963,253	739,518	899,412	723,052	1,321,780	1,072,208	1,185,131	-	-	685,012	1,783,395
Emerald Isle-Central	604,558	675,135	586,251	661,490	874,031	1,002,184	742,535	781,223	-	-	-11,291	1,194,915
Emerald Isle-East	700,213	670,766	640,656	685,168	965,114	963,911	803,382	946,483	-	-	-20,827	1,335,655
Indian Beach/Salter Path	856,179	829,318	681,474	783,473	1,361,192	1,290,983	1,035,738	1,155,522	-	-	-178,053	1,744,153
Pine Knoll Shores-West	329,308	305,689	226,660	403,726	398,891	526,330	357,306	680,649	-	-	87,624	1,135,995
Pine Knoll Shores-East	500,958	392,759	315,186	781,720	650,158	576,150	399,946	1,072,778	-	-	-190,587	1,796,876
Atlantic Beach	-10,721	931,032	661,520	558,278	136,193	1,902,206	1,305,619	1,194,947	-	-	1,661,386	2,358,100
Fort Macon	-196,301	15,679	23,930	36,932	-184,943	287,847	179,302	221,169	-	-	695,424	558,157
Beaufort Inlet	-	-	-	-	-	-	-	-	-	-	-	-
County Project	3,412,182	3,836,920	3,189,745	4,214,989	4,972,437	5,681,337	4,411,116	5,821,785	-	-	371,879	8,990,990
Entire Oceanfront	3,390,495	5,034,288	3,849,860	4,843,223	4,655,450	8,267,067	5,995,463	7,385,699	-	-	2,728,689	11,907,247
Bear Island	-	-	-	-	-	-	-	-	-	-	-	-
Shackleford Banks	-	-	-	-	-	-	-	-	-	-	-	-

Table 2. Short-term Volume Change

	Dune to -4' NGVD				Dune to -11' NGVD				Dune to -15' NGVD			
	Dec 2003-June 2004	June 2004-May 2005	May 2005-May 2006	May 2006-May 2007	Dec 2003-June 2004	June 2004-May 2005	May 2005-May 2006	May 2006-May 2007	Dec 2003-June 2004	June 2004-May 2005	May 2005-May 2006	May 2006-May 2007
Reach	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy
Bogue Inlet-Channel	-9,809	10,792	42,160	-26,182	-24,465	20,639	131,171	-7,147	-17,943	18,389	-	103,996
Bogue Inlet-Ocean	46,594	13,918	-204,216	58,358	-8,041	626,020	-299,980	48,372	-	-	-235,915	-52,942
Emerald Isle-West	54,586	542,282	-223,735	159,894	153,489	598,728	-249,571	112,922	147,494	807,600	-122,588	82,591
Emerald Isle-Central	11,253	70,577	-88,885	75,240	80,919	128,154	-259,649	38,688	70,888	238,146	-249,437	50,782
Emerald Isle-East	35,498	-29,447	-41,418	44,512	60,434	-1,204	-177,539	143,100	37,466	86,866	-127,967	130,604
Indian Beach/Salter Path	350,295	-43,495	-128,931	101,999	651,819	-85,523	-234,853	119,783	649,217	6,703	-184,756	103,996
Pine Knoll Shores-West	45,812	-8,333	-66,901	177,066	39,306	146,225	-149,924	323,343	26,129	233,908	-146,284	400,836
Pine Knoll Shores-East	45,904	-83,525	-97,553	466,534	67,286	-59,354	-197,027	672,831	11,741	-44,338	-146,248	563,500
Atlantic Beach	123,250	942,289	-269,512	-103,242	65,826	1,766,014	-596,587	-110,672	-63,325	2,189,434	-528,048	-274,554
Fort Macon	8,783	255,147	-13,739	17,087	-42,921	473,780	-84,893	33,818	-94,922	792,583	-14,647	151,211
Beaufort Inlet	41,514	85,619	-22,410	-11,428	85,574	448,098	-56,020	-4,905	103,219	1,035,861	-	-
County Project	543,349	448,059	-647,422	1,025,245	1,053,253	727,025	-1,268,564	1,410,668	942,935	1,328,884	-977,280	1,332,309
Entire Oceanfront	721,977	1,659,414	-1,134,889	997,448	1,068,117	3,592,840	-2,250,025	1,382,186	784,689	4,310,901	-1,755,890	1,156,024
Bear Island	-	-29,705	-162,365	-105,930	-	-135,310	-139,170	-343,295	-	11,980	-64,820	-471,975
Shackleford Banks	-	-	-450,401	-74,356	-	-	-686,685	55,122	-	-	-665,033	270,338

The Bogue Banks area has also undergone extensive beach nourishment throughout the duration of the monitoring effort as part of the Bogue Banks Beach Restoration Project, the USACE Section 933 Project, USACE Dredge Disposal Projects, and some post-storm FEMA work. **Table 3** and **Table 4** summarize the recent nourishment projects in the study area. Atlantic Beach has received the most nourishment followed by Emerald Isle and Pine Knoll Shores.

Table 3. Nourishment Volumes by Project

Project	Reach	Year	In-Place Volume (cy)
County Phase 1	Pine Knoll Shores-East & West	2002	1,276,586
County Phase 1	Indian Beach/Salter Path	2002	456,994
USACE Disposal	Fort Macon	2002	209,348
County Phase 2	Emerald Isle-East & Central	2003	1,746,413
County Phase 2	Emerald Isle-East & West (dune)	2003	101,349
USACE Section 933	Indian Beach/Salter Path & Pine Knoll Shores-West	2004	699,282
FEMA Post Isabel	Emerald Isle-East & Central	2004	156,000
Brandt Island Pump Out	Atlantic Beach	2005	2,920,729
Inner Harbor Dredging Disposal	Fort Macon	2005	300,000
County Phase 3	Emerald Isle-West	2005	690,868
USACE Section 933	Pine Knoll Shores-East & West	2007	507,939
FEMA Post Ophelia	Emerald Isle, Pine Knoll Shores, & Indian Beach/Salter Path	2007	1,229,836
USACE Disposal	Fort Macon	2007	211,000
		Total	**10,506,344**

Table 4. Nourishment Volumes by Reach

Reach	Nourishment Volume
Bogue Inlet-Ocean	59,272
Emerald Isle-West	935,633
Emerlad Isle East & Central	2,348,172
Indian Beach/Salter Path	1,358,842
Pine Knoll Shores	2,163,348
Atlantic Beach	2,920,729
Fort Macon	720,348
Total	**10,506,344**

3.0 Survey Methods and Data Sources

Most recently, Geodynamics conducted a survey of Bear Island, Bogue Banks, and Shackleford Banks in June/July 2008. The profile lines and origins used in previous studies by CSE were also used for the most recent survey for ease of comparison. **Figure 1** shows the location of the profile lines and origins applied by Geodynamics for the surveying. Two transects were added near Beaufort Inlet (112a) and Bogue Inlet (117a) to better track sand movement near the inlet. Comparisons at these transects will be available starting with future reports since no survey data previously existed at these locations. The established profile lines and origins will be used in all future survey periods. As shown, lines were stationed from west to east along Bogue Banks and east to west along Bear Island and Shackleford Banks. The survey data was provided in ASCII (xyz), Excel (xyz), Shapefile (GIS), and ISRP (BMAP) formats allowing for compatibility with multiple programs. The survey was referenced in NAD 1983 State Plane North Carolina (feet) with a vertical datum of NAVD 1988. Several steps were taken by Geodynamics to ensure the most accurate survey data.

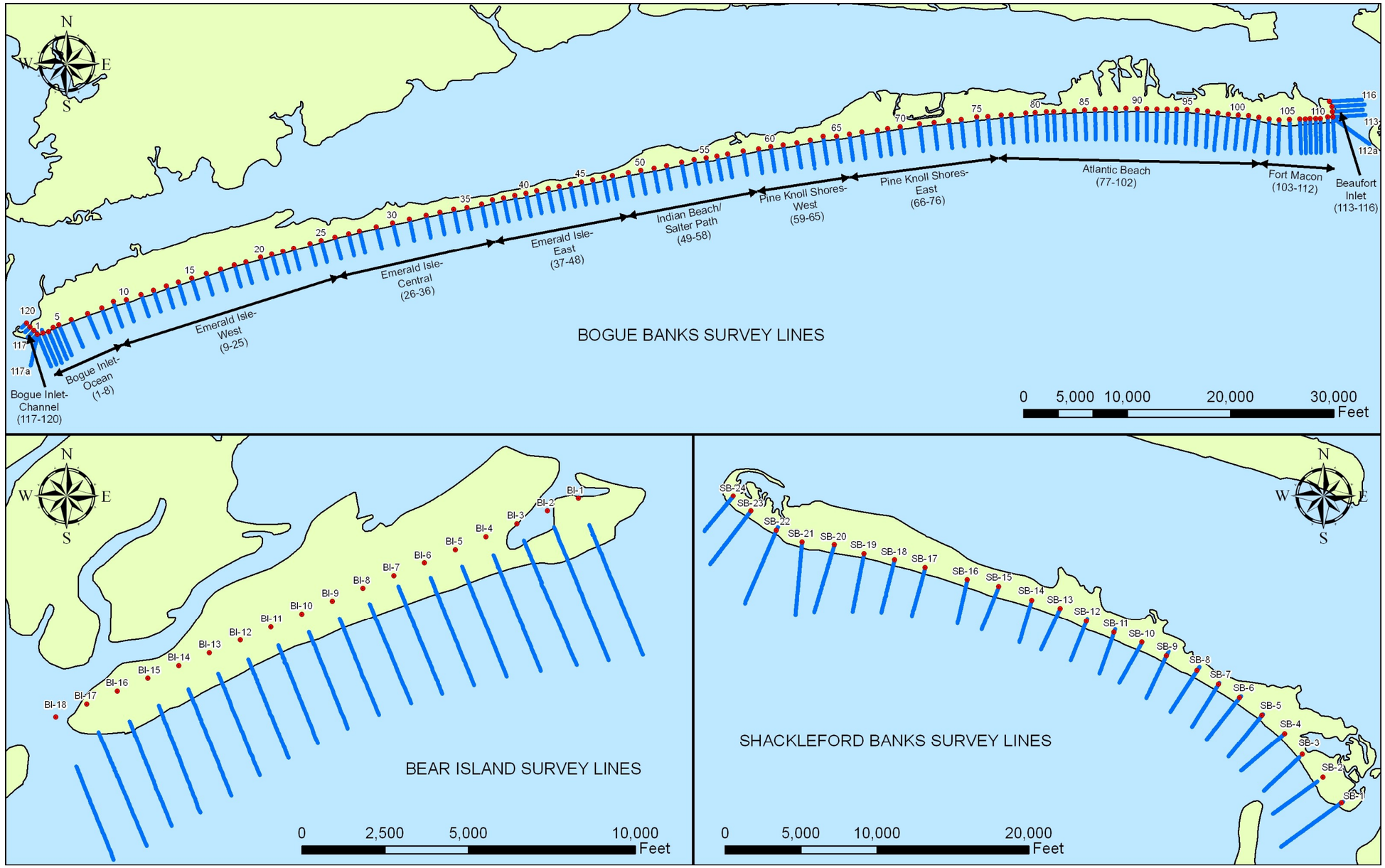

Figure 1. BBBNMP Profile Line Locations

3.1. Topographic and Bathymetric Data Acquisition

There are many environmental and operator-based influences that affect the accuracy of RTK/VRS-GPS systems and the resultant baseline solutions, as well as the soundings collected through multibeam and singlebeam sonar. In this section QA/QC checks for both topographic and bathymetric "on the fly" VRS-GPS solution accuracies through site calibration procedures, daily benchmark/draft checks and cross check analysis are detailed. Hydrographic sounder and motion referencing QA/QC parameters start with pre-project draft checks, motion sensor leveling and aiding and finally the acquisition of multiple sound velocity casts spatially across the project boundary. Finally, several QA/QC routines are run in the final stages of processing to ensure the highest level of data quality that conforms to both the USACE and International Hydrographic Organization (IHO) Standards.

3.1.1. Calibration

A detailed geodetic GPS site calibration was performed prior to the start of data acquisition since it is the common positioning system for both topographic and hydrographic surveys (note: this is important for accurately merging topo/bathy data). The site calibration is used to determine the virtual reference station (VRS) GPS basestation quality and to analyze any potential spatial separations between the local geoid heights (GEOID 03) and ellipsoidal values (WGS-84) that may influence the resultant orthometric elevations. The calibration entails selecting the best control to be used for the VRS-GPS basestation receiver and checking at least 3 known geodetic benchmarks of exceptional horizontal and vertical quality within and even outside the survey boundaries. The benchmarks are occupied in "site calibration mode" over 300 epochs or approximately 3 to 5 minutes. Final data generated from the NC Geodetic Survey Virtual Reference Station site calibration illustrate the accuracy of the mark used for broadcasting corrections and the maximum baseline length that can be used to achieve both horizontal and vertical precisions within the Standards.

A number of hydrographic calibration procedures are consistently performed, including the collection of sound velocity profiles spatially across the survey area, crosscheck error analysis and daily bar checks of the singlebeam. The bar check is a standard singlebeam calibration procedure in which the sonar depth measurement is adjusted to read that of a calibrated bar placed under the sonar transducer. To go a step further, a singlebeam calibration technique for the *R/V Shoals* (**Figure 2**) was developed that uses a direct seafloor elevation measurement derived from a VRS-GPS rover. The sonar is held steady in approximately 0.5 ft to 2 ft of water with a flat sandy bottom. A rod man takes a measurement directly under the transducer to get an accurate seafloor elevation to within three decimal places. If necessary, the sonar system "index" is then adjusted to read the measured elevation. This procedure is similar to the bar check but without the inherent limitations of that procedure. Sound velocity is collected at a minimum of two casts per day in accordance with the USACE Standard; however, if noticeable differences in surface waters appear a profile is immediately collected in the event that the speed of sound calculation is different than surrounding waters.

Another important step in accurately measuring the seafloor elevation with sonar-based techniques is the use of a factory calibrated Motion Reference Unit (MRU). The MRU measures

complex vessel motion such as heave, pitch, roll and yaw. However, traditional gyroscopic-based singlebeam motion sensors are notoriously slow to "settle" after turns in excess of 200°/second which provide a "false" heave measurement. This becomes a problem when surveying in the surfzone since hard turns are necessary to achieve maximum overlap and to avoid breaking waves. To combat this scenario the output rate of the sensor is bumped to 38400 bytes/second and the sensor is also "aided" with the external VRS-GPS heading at the same update frequency. By aiding the MRU with GPS data settling times on the turns is drastically reduced.

Figure 2. R/V Shoals Hydrographic Survey Platform Setup

3.1.2. Data Acquisition

Once the GPS site calibration and all the various singlebeam calibrations were performed the data acquisition phase began. The most important aspect of beach profiling is the collection of data within the surfzone to overlap with the topographic portion of the survey. Sandbars within the surfzone can contain as much or even more sand than the dry beachface and it is imperative to capture these data since most of the active changes occur in this zone and is a key component to monitoring volumetric change along a particular littoral zone. To achieve accurate overlap requires a sea-state of 1' or less such that a shallow draft vessel can get into the surfzone safely and that no bubbles from breaking waves influence the sonar readings. In addition, it is critical to "work" the tides such that at low water the topo crew gets as many short profiles from the berm crest to approximately waist deep water then at high tide collects from the berm crest to the highest possible location along the dune ridge. Conversely, at low tide, the hydro crew collects data from approximately -10' out to the furthest extent offshore and then at high tide "works" the -10' contour to as far into the surfzone as possible to achieve maximum overlap.

Typically the topographic profiling is started a day prior to the start of any hydrographic data acquisition. This allows the hydro crew to input the previous days topo data in the onboard computer each evening to assess the overlap and to know when overlap can no longer be achieved due to falling tide. In general, along the Carteret County coastline, there are about 3 to possibly 4 hours to "work" both the low (topo) and high (bathy) tides to accomplish complete overlap between the topography and bathymetry. Since surveying in this manner takes a lot longer than just ignoring the surfzone and overlap, only the amount of beach that can be covered within the predicted weather window is surveyed. For example, the USACE stipulates that "the timing of topo and hydro overlapping of the survey shall be scheduled so as not to exceed a

maximum of 3 days between overlapping segments". Since an attempt is made to limit topo/bathy overlap to either the same day or at a maximum of 1 day, it is imperative that the topo crew (which typically takes less time than the hydro) not get ahead of the hydro work so that if a wind or swell event were to arise that too many beach profiles have not been collected that would ultimately taint the final results or overlap accuracy.

As part of daily and periodic QA/QC protocol an attempt is made to check at least one mark prior to starting the day's survey operations (**Figure 3**). This ensures that the basestation has been setup properly and there have been no transcription errors to the coordinates programmed into the base receiver; however, the use of VRS-GPS has virtually eliminated all operator error in basestation setup. Also, topographic draft measurements are periodically verified on both the ATV and backpack system to account for daily variations in operator weight and clothing configurations.

Figure 3. Daily Benchmark and Geodetic Draft Checks

3.1.3. Bathymetric Data Processing

A typical singlebeam survey design will consist of a series of cross sectional profiles used to describe the two-dimensional morphology at a single point. These profile data are processed in the Hypack Max v 6.2b Singlebeam Editor. To meet the updated accuracy and resolution standards for Navigation and Dredging Support Surveys for soft bottom sediments specified in the USACE Hydrographic Surveying Manual (EM 1110-2-1003, 2002 revision) the measured echosounder depths are corrected for all departures from true depths attributable to the method of sounding or to faults in the measuring apparatus. These corrections are subdivided into four categories, and are listed below in the sequence in which they were applied to the data.

1. Instrument error corrections: account for the sources of error related to the sounding equipment itself. Draft and geodetic bar checks are performed and corrected prior to the commencement of each survey.

2. Vessel offsets: are added to the observed soundings to account for the sensor and antenna locations. A detailed sensor offset survey will be performed prior to the start of data acquisition with a digital laser level and other precise measuring apparatus.

3. Velocity of sound correctors: are applied to the soundings to compensate for the fact that echosounders may only display depths based on an assumed sound velocity profile while the true velocity may vary in time and space. Sound velocity is measured prior to the start of survey, in areas with "differing" water properties and at the end of each survey day. A minimum of two sound velocity profiles are taken per day at the survey boundaries.

4. Tide: is integrated with soundings from VRS-GPS to commonly reference data in a vertical datum. The VRS tide file is merged with the heave record in Hypack to totally filter the record for sea state. Alternatively, the VRS tide may be averaged to remove heave in circumstances where the heave record contains errors and is unusable (i.e. turns).

Singlebeam Data Processing in Hypack Max 6.2b then occurs using the following steps:

1. Data is imported into singlebeam processing module
2. All files are imported as soundings
3. Sound velocity is applied
4. File information and offsets are visually inspected and verified
5. Tidal elevations and positioning is filtered to include only VRS-fixed solutions
6. Data is filtered based on time or sample if needed
7. Larger spikes and echosounder freezes are removed if needed
8. VRS-tide is applied
9. Data is exported in a Hypack edited format (or ASCII XYZ) to be merged with topo data.

3.1.4. Topographic Data Processing

Topographic profile data collected in Hypack are also processed in the Hypack Max v 6.2b Singlebeam Editor using the following steps:

1. Data is imported into singlebeam processing module
2. All files are imported as elevations
3. File information and offsets are visually inspected and verified
4. VRS-GPS elevations and positioning is filtered to include only VRS-fixed solutions
5. Larger spikes are removed if needed
6. VRS-tide (elevation data) is applied
7. Data is exported in a Hypack edited format
8. Data is converted to Hypack XYZ format

3.1.5. Merging Topographic and Bathymetric Data

Upon processing individual bathymetric and topographic profile data in Hypack, the data is then merged into one continuous profile. Profiles are merged in the Hypack Max v 6.2b MergeXYZ program using the following steps:

1. Hypack log file is created for each bathy profile
2. The bathy profile log is selected in MergeXYZ
3. The respective topo profile XYZ file is selected
4. Data are inverted so that elevations are represented as positives and soundings are represented as negatives

5. File name for the merged profile is specified and the merged profile is created as a Hypack edited *.MRG file
6. Each *.MRG file is then exported with the Hypack Max v 6.2b Export to CAD program with user defined data fields as indicated in the official SOW.

Merged profiles are then imported into Microsoft Excel. In Excel, each profile is adjusted to NAVD88 and data fields are formatted. Each profile is graphed and inspected for errors as well.

3.1.6. Cross Check Analysis: Topographic to Hydrographic

In order to assess the accuracy in profile data merged from bathymetric data and topographic data that overlap in the surfzone, final profiles are analyzed for overlap accuracy and overlap length. **Figure 4** presents and example of overlap check in the surfzone for a profile on Shackleford Banks.

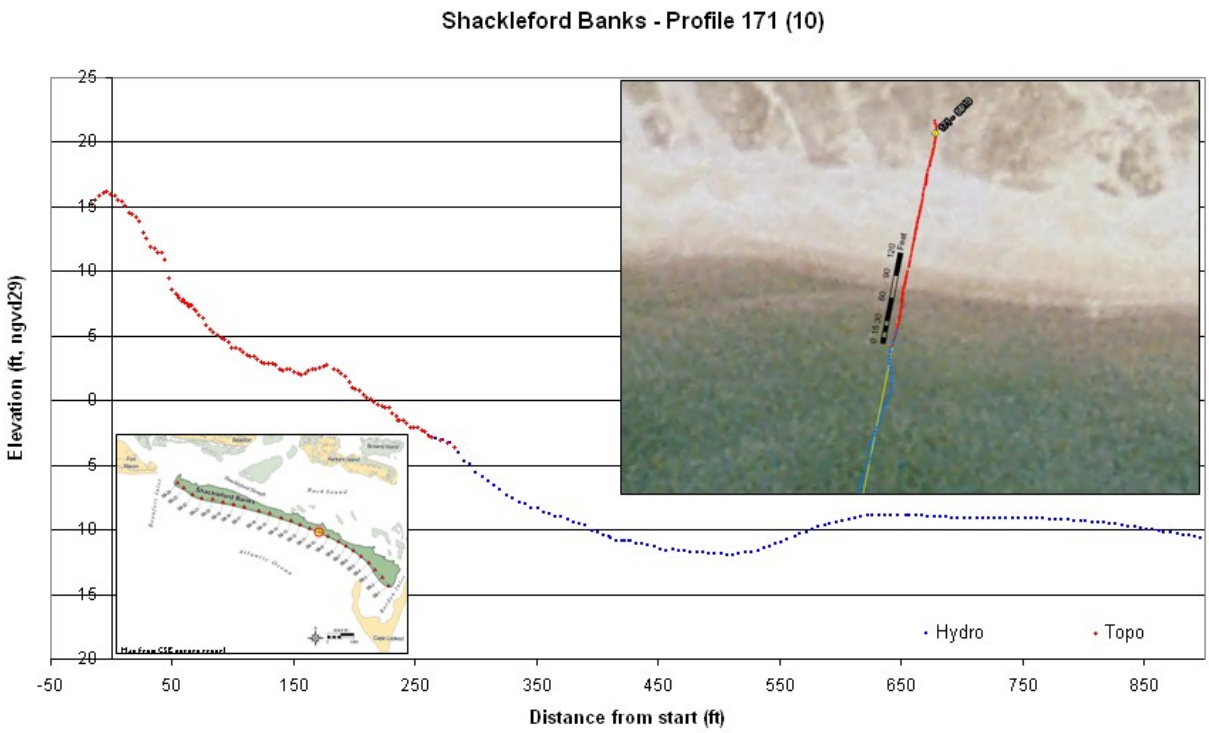

Figure 4. Example of Topographic and Bathymetric Data Overlap in Surfzone

3.2. 2007 Survey Data

The 2007 profiles used for comparison in this study were comprised of survey data provided by CSE and supplemented with post-nourishment survey data from both the FEMA post-Ophelia nourishment and the USACE Section 933 nourishment, which both took place in 2007. The FEMA post-Ophelia nourishment survey data was provided by Great Lakes Dredge & Dock (GLDD) while the USACE Section 933 post-nourishment data was provided by the Coastal, Hydrology, & Hydraulics Section of the Wilmington District of the USACE. The CSE data was available in both Easting/Northing/Elevation (ENZ) and Distance to Baseline/Elevation (XZ) formats in Excel. The GLDD data was provided in Easting/Northing/Elevation (ENZ) formatted text files and converted to Distance to Baseline/Elevation (XZ) format using transect origin

points and azimuths. The USACE Section 933 data was available in Distance to Baseline/Elevation (XZ) format in Regional Morphology Analysis Package (RMAP) and converted to Easting/Northing/Elevation (ENZ) using transect origin points and azimuths. All sets of survey data were performed in NAD 1983 State Plane North Carolina (feet) with a vertical datum of NGVD 1929. Since the vertical datum of these surveys were different than the 2008 survey performed by Geodynamics, the May 2007 survey data was converted from NGVD 1929 to NAVD 1988 using Corpscon v6.0.1.

4.0 Survey Evaluation Methods

Survey comparisons and respective analysis were performed using Beach Morphology Analysis Package (BMAP). BMAP is a program developed by the USACE to analyze morphologic and dynamic properties of beach profiles.

All survey data sources were imported into ArcGIS, in xyz format, and displayed to compare the coverage of each set of data. Excel files containing the May 2007 and June/July 2008 beach profiles being used for the comparison were then formatted and imported into Beach Morphology Analysis Package (BMAP). Using BMAP, two indicators of shoreline change were calculated for each transect.

First, change in shoreline position at mean high water (MHW), which was defined as +1.1 ft NAVD88 (based on NOAA tidal benchmark at Morehead City-equivalent to previously computed elevation of +2.1 ft NGVD29), was calculated at each transect between the May 2007 and June/July 2008 profiles. The resulting value represents the shoreline change (ft) over the time period between surveys. The shoreline change rate (ft/yr) was then calculated by dividing by the amount of time between survey dates in order to better compare changes between different time periods.

Then, representative volume changes were calculated at each transect between May 2007 and June/July 2008. Volume changes were calculated for four different extents in order to better understand the processes occurring onshore and offshore of the Bogue Banks beach area. Calculations included volume change above MHW (+1.1 ft NAVD88-equivalent to +2.1 ft NGVD29), above -5 ft NAVD88 (wading depth/recreational beach-equivilant to -4 ft NGVD29), above -12 ft NAVD88 (outer bar-equivalent to -11 ft NGVD29), and above -20 ft NAVD88 (approximate depth of closure). Upon inspection of profiles, the depth of closure was changed to -20 ft NAVD88 from -15 ft NGVD29 as used in previous reports. As with the shoreline change, the results represent volume change (cy/ft) over the period of time between surveys. The volume change rate (cy/ft/yr) was then calculated by dividing by the amount of time between survey dates in order to better compare changes between different time periods. In addition, the volume changes were converted to cumulative changes over the entire shoreline. This was done by applying the average end area method to the unit volume changes (cy/ft) and unit volume change rates (cy/ft/yr) computed at each transect and summing the total volume changes over the entire shoreline. The resulting value indicated the total loss or gain of material between survey periods based on the applicable profile extents.

Volume changes calculated for portions of the profiles above MHW are representative of changes in the amount of material in the dune system and on the subaerial beach. These areas

are highly influenced by the impact of storm activity. Volume comparisons for portions of the profiles above -5 ft NAVD88, which is an approximate wading depth, are representative of changes in the portion of the beach used for recreation. Volume comparisons above -12 ft NAVD88 help to track sand movement to and from the outer sand bar. Finally, volume comparisons above -20 ft NAVD88 allow for the tracking of sand movement offshore while reducing the amount of error associated with the survey data by eliminating changes beyond this depth related to the vertical margin of error in the hydrographic survey data. This is a comprehensive way to assess the impact of storm activity on the subaerial beach and dune system as well as track the movement of sand offshore and quantify total gains and losses in the entire system.

It should be noted that the Bear Island and Shackleford Banks surveys were performed from June 11, 2008 to June 18, 2008. For this report, June 15, 2008 was used as the survey date for all profile lines on those islands. The Bogue Banks survey, due to weather, was performed over a longer period from June 27, 2008 to August 12, 2008. July 15, 2008 was used as the survey date for comparison in this report.

Finally, FEMA beach maintenance calculations were done based on a baseline nourishment condition consisting of the post-nourishment surveys from Phase I, Phase II, and Phase III of the Bogue Banks Beach Restoration Project. Profile volumes above -12 ft NAVD88 (equal to previously utilized elevation of -11 ft NGVD29) from July 2008 were compared to profile volumes above -12 ft NAVD88 from the post-fill surveys. The amount of remaining fill was computed by subtracting the amount of fill placed in the restoration project from the volume change calculated between the post-nourishment surveys (2002, 2003, and 2005) and 2008.

For visual reference, a Digital Elevation Model (DEM) was created in ArcGIS for both the May 2007 and June/July 2008 profile data. The MHW shoreline position contour was extracted from the May 2007 and June/July 2008 DEMs and plotted on aerials. These figures are presented in **Appendix A**.

5.0 Discussion of Periodic Surveying Evaluation

This section will discuss recent nourishment projects, overall shoreline trends, regional shoreline trends, and beach maintenance analysis. Plots of the shoreline and volume changes at each transect for Bogue Banks, Bear Island, and Shackleford Banks are presented in **Appendix B**. Profile comparison plots for individual transects, which include the May 2007 and June/July 2008 profiles, are presented in **Appendix C**. The computed shoreline changes and volume changes at each individual transect for the time periods being covered are tabulated in **Appendix D**.

5.1. Nourishment Projects

As a result of Hurricane Ophelia, which impacted the Bogue Banks area in 2005, FEMA funding was acquired to place sand on the beach, replenishing what had been removed by the storm. A total of 1,229,836 cy of material was placed on the beach on various stretches of Emerald Isle (648,447 cy), Indian Beach/Salter Path (319,113 cy), and Pine Knoll Shores (262,276 cy). Pine Knoll shore also received 507,939 cy of sand as part of the USACE Section 933 project dredging

of Beaufort Inlet. This report will show the remaining impacts of the 2007 nourishment projects by calculating volume change over the past year and total volume of profiles above the outer bar.

5.2. General Shoreline Trends

Key statistics were calculated to describe the average shoreline and volume changes over the entire shoreline as well as for each region of the shoreline. The computed statistics include average shoreline change, average volume change, and cumulative volume change (e.g. total volume of material lost or gained along a section of shoreline). A summary of the resulting statistics for the May 2007 to June/July 2008 comparison are presented in **Table 5** through **Table 7**. Evaluation of the computed statistics will take into account volume changes computed for portions of the profile above MHW (+1.1 ft NAVD88), above -5 ft NAVD 88, above -12 ft NAVD88, and above -20 ft NAVD88 in order to better understand onshore and offshore processes. Since each reach consists of a different length of shoreline, a weighted average for unit shoreline change (ft) and unit volume change (cy/ft) at each transect was calculated for the Bogue Banks Oceanfront and County Project based on the length of each reach.

Table 5. Bogue Banks Regional Shoreline and Volume Change Statistics (May 2007 - July 2008 Comparison)

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Inlet-Ocean (1-8)	7,432	70.7	5.5	42,022	8.8	47,519	-46.2	-218,444	-73.5	-322,442
Emerald Isle-West (9-25)	22,344	14.9	6.4	138,826	-2.0	-48,298	-4.4	-107,631	-12.5	-288,205
Emerald Isle-Central (26-36)	15,802	8.2	8.6	139,696	-3.0	-48,648	9.2	136,125	4.2	57,277
Emerald Isle-East (37-48)	13,220	20.4	3.1	40,542	0.6	7,738	-1.4	-18,603	-14.3	-187,491
Indian Beach-Salter Path (49-58)	12,850	2.6	1.6	24,137	-8.7	-107,520	-9.6	-116,245	-18.8	-235,865
Pine Knoll Shores-West (59-65)	9,063	-1.8	1.1	10,750	-7.5	-65,975	4.7	46,793	1.9	20,955
Pine Knoll Shores-East (66-76)	14,815	-12.9	-1.7	-23,529	-6.4	-94,017	-7.0	-104,246	-18.3	-270,644
Atlantic Beach (77-102)	26,176	24.2	6.4	166,141	-0.1	-5,549	1.1	27,172	-5.2	-139,970
Fort Macon State Park (103-112)	6,691	-13.3	-3.9	-22,257	-8.9	-69,740	-14.1	-137,402	-24.5	-200,874
Beaufort Inlet (113-116)	1,500	-20.7	-3.2	-3,247	-2.8	4,470	-3.9	5,419	-2.7	2,636
Bogue Inlet-Channel (117-120)	1,500	-172.5	-33.0	-32,991	-67.6	-67,577	-107.7	-107,708	-107.7	-107,708
	Reach Length	Weighted Avg	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total
County Project (9-76)	88,094	6.36	3.69	330,423	-4.09	-356,719	-1.78	-163,806	-10.19	-903,972
Oceanfront (1-112)	128,393	12.71	3.96	516,329	-2.79	-384,489	-4.41	-492,480	-13.58	-1,567,258

Table 6. Bear Island Shoreline and Volume Change Statistics (May 2007 - June 2008 Comparison)

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bear Island (1-18)	17,000	42.5	7.8	129,249	3.8	57,942	6.0	96,090	9.4	155,938

Table 7. Shackleford Banks Shoreline and Volume Change Statistics (May 2007 - June 2008 Comparison)

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Shackleford Banks (1-24)	46,001	5.8	-1.8	-73,540	-4.4	-201,919	-5.8	-247,192	-13.7	-597,556

According to **Table 5**, the Bogue Banks oceanfront shoreline has experienced accretion at MHW over the past year, mostly occurring on the western portion of the island. The numbers indicate that along the oceanfront, the beach has been accretional above MHW and erosional above -5 ft NAVD88, above -12 ftNAVD88, and above closure (-20 ft NAVD88). Accretion above MHW is most likely due to calm summer waves pushing sand up onto the beach. Erosion above the other elevations is largely due to equilibration of nourished portions of the beach and large movements of the offshore bar. **Table 6** indicates that Bear Island has been slightly accretional over the past year. Transport of nourishment sediment from Bogue Banks westward to Bear Island could have attributed to some of this. **Table 7** indicates that Shackleford Banks has been erosional over the past year. This is expected given no nourishment has been performed and the location of Shackleford Banks makes it unlikely that sediment would be transported to this area. **Figure 5** displays the trends seen in **Table 5** through **Table 7** with a bar plot of the cumulative volume changes at each reach. Accretion above MHW and erosion below is apparent at a majority of reaches. The Bogue Banks oceanfront lost approximately 1,567,000 cy of sand between May 2007 and July 2008. The County Project area lost approximately 900,000 cy of material. It is very possible that a significant portion of these large calculated losses may be due to conversion of the 2007 data to a different datum as well as differences in surveying equipment and methods utilized by CSE versus Geodynamics. A small difference over a large distance can account for significant loss or gain. Shackleford Banks lost approximately 600,000 cy of material while Bear Island saw a gain in volume of approximately 156,000 cy.

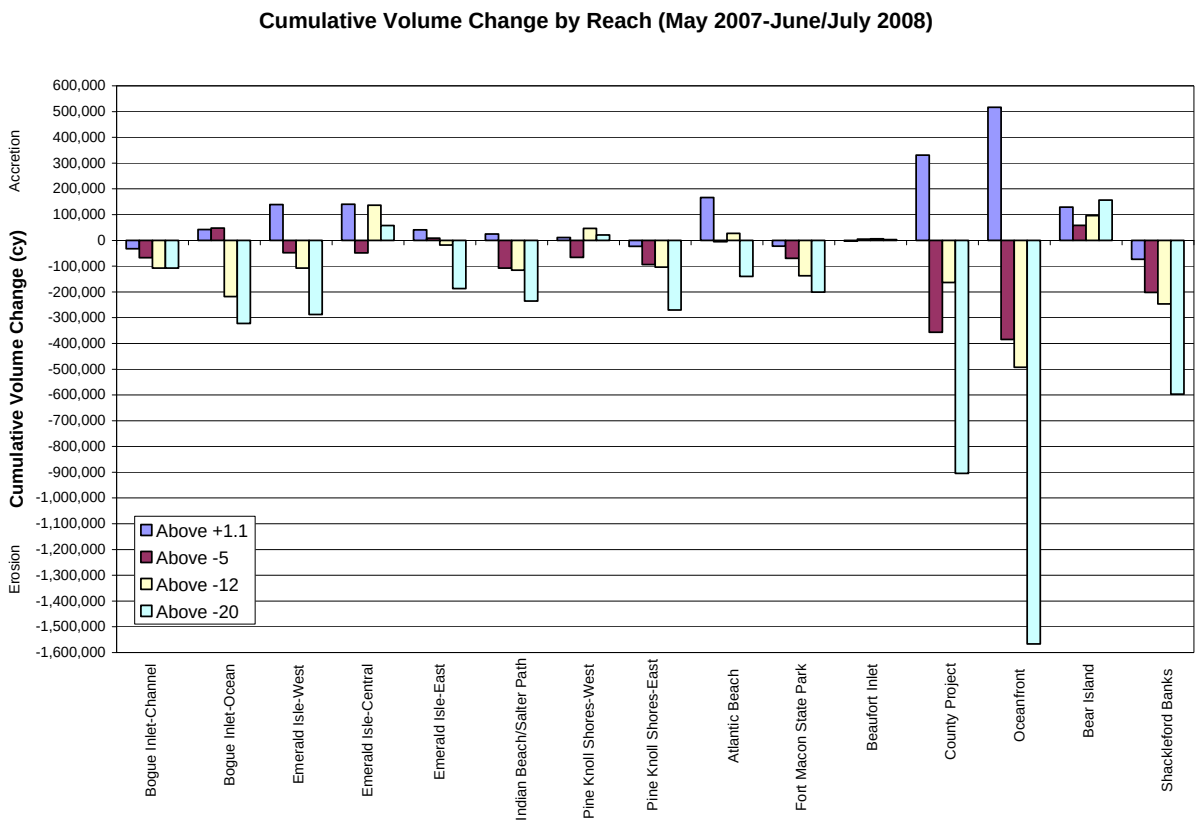

Figure 5. Cumulative Volume Change by Reach

A target minimum volume for each profile to the outer bar (above -12 ft NAVD88) has been established at 225 cy/ft. Along the Bogue Banks, Bear Island, and Shackleford Banks shorelines, the average profile volume from the dune to the outer bar exceeds the 225 cy/ft deemed necessary for adequate protection. **Figure 6** displays the average profile volume to the outer bar per transect within each reach of shoreline for May 2007 and June/July 2008.

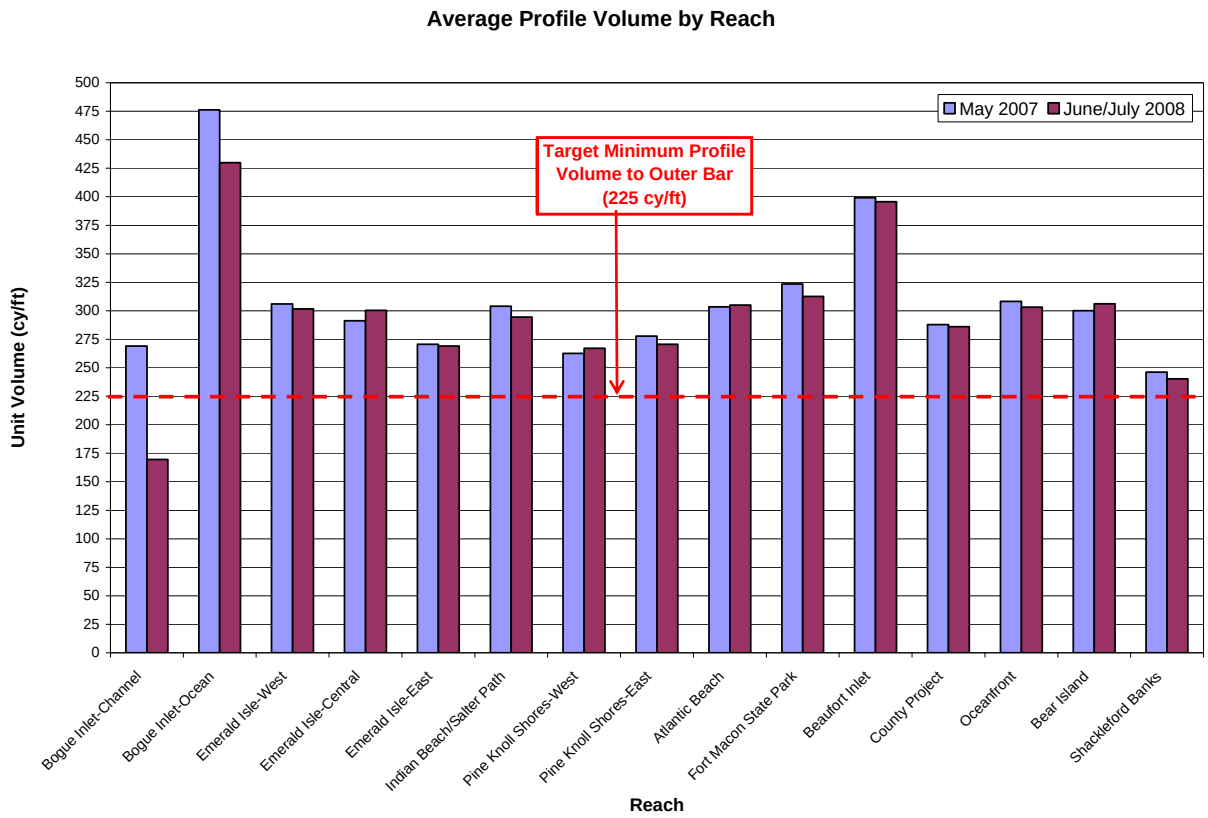

Figure 6. Average Profile Volume to Outer Bar

5.3. Regional Shoreline Trends

Regional shoreline trends are discussed below for the defined regions of Bogue Banks as well as Bear Island and Shackleford Banks (**Figure 1**). A summary of the information in **Table 5** through **Table 7** and **Appendix B** has been created for each region of study.

5.3.1. Emerald Isle

The Emerald Isle region covers transects 9 through 48 (Sta 80+91 to Sta 580+13). Portions of all three sections of Emerald Isle received nourishment from the 2007 post-Ophelia nourishment efforts. A summary of average shoreline and volume changes between May 2007 and June/July 2008 for the Emerald Isle region are presented in **Table 8**.

Table 8. Average Shoreline and Volume Change for Emerald Isle

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Emerald Isle-West (9-25)	22,344	14.9	6.4	138,826	-2.0	-48,298	-4.4	-107,631	-12.5	-288,205
Emerald Isle-Central (26-36)	15,802	8.2	8.6	139,696	-3.0	-48,648	9.2	136,125	4.2	57,277
Emerald Isle-East (37-48)	13,220	20.4	3.1	40,542	0.6	7,738	-1.4	-18,603	-14.3	-187,491

Table 8 indicates that even with the adjustment of the profiles to include the post-Ophelia GLDD surveys and USACE Section 933 surveys, the area is showing accretion between the May 2007 and July 2008 surveys above MHW. Even with some accretion above the depth of closure in Emerald Isle Central, the Emerald Isle region as a whole lost approximately 418,000 cy of material above -20 ft NAVD88. **Figure 7** displays the unit volume change at each transect above the four elevations that were analyzed.

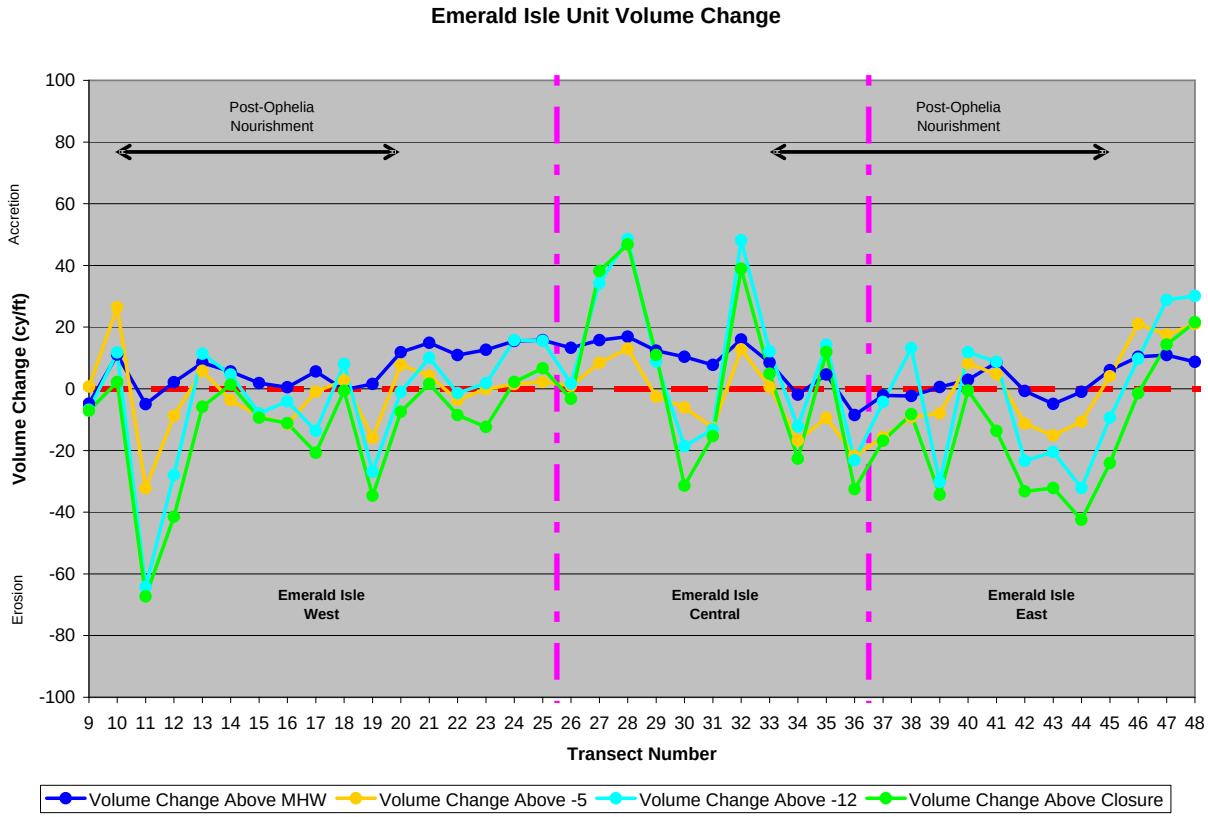

Figure 7. Emerald Isle Unit Volume Change (May 2007-July 2008)

5.3.2. Indian Beach/Salter Path

The Indian Beach region covers transects 49 through 58 (Sta 595+84 to Sta 709+05). This region received nourishment from the 2007 post-Ophelia nourishment efforts. A summary of average shoreline and volume changes between May 2007 and June/July 2008 for the Indian Beach/Salter Path region are presented in **Table 9**.

Table 9. Average Shoreline and Volume Change for Indian Beach/Salter Path

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Indian Beach-Salter Path (49-58)	12,850	2.6	1.6	24,137	-8.7	-107,520	-9.6	-116,245	-18.8	-235,865

Table 9 indicates that even with the adjustment of the profiles to include the post-Ophelia GLDD surveys and USACE Section 933 surveys, the area is showing accretion between the May 2007 and July 2008 surveys above MHW. On the contrary, approximately 236,000 cy of material was lost above the depth of closure. Calculations above remaining elevations all show erosion. **Figure 8** displays the unit volume change at each transect for the Indian Beach/Salter path region.

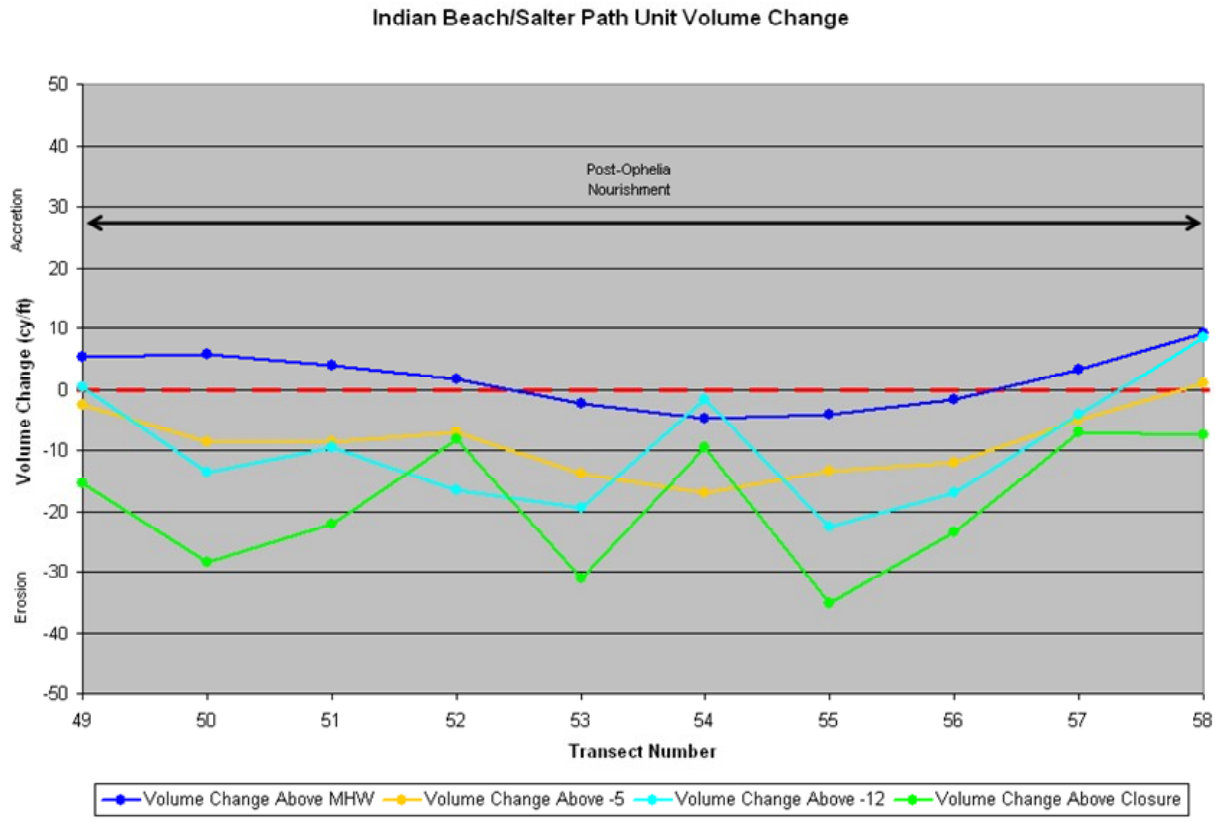

Figure 8. Indian Beach/Salter Path Unit Volume Change (May 2007-July 2008)

5.3.3. Pine Knoll Shores

The Pine Knoll Shores region covers transects 59 through 76 (Sta 723+93 to Sta 948+81). The majority of Pine Knoll Shores East and a small Portion of Pine Knoll Shores West received nourishment from the post-Ophelia FEMA efforts. Pine Knoll Shores also received nourishment as part of the USACE Section 933 project. A summary of average shoreline and volume changes between May 2007 and June/July 2008 for the Pine Knoll Shores region are presented in **Table 10**.

Table 10. Average Shoreline and Volume Change for Pine Knoll Shores

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Pine Knoll Shores-West (59-65)	9,063	-1.8	1.1	10,750	-7.5	-65,975	4.7	46,793	1.9	20,955
Pine Knoll Shores-East (66-76)	14,815	-12.9	-1.7	-23,529	-6.4	-94,017	-7.0	-104,246	-18.3	-270,644

Pine Knoll Shores West showed mostly accretion between May 2007 and July 2008 while Pine Knoll Shores East was erosional. The Pine Knoll Shores region as a whole lost approximately 250,000 cy of material above the depth of closure. **Figure 9** displays the unit volume change at each transect for the Pine Knoll Shores region.

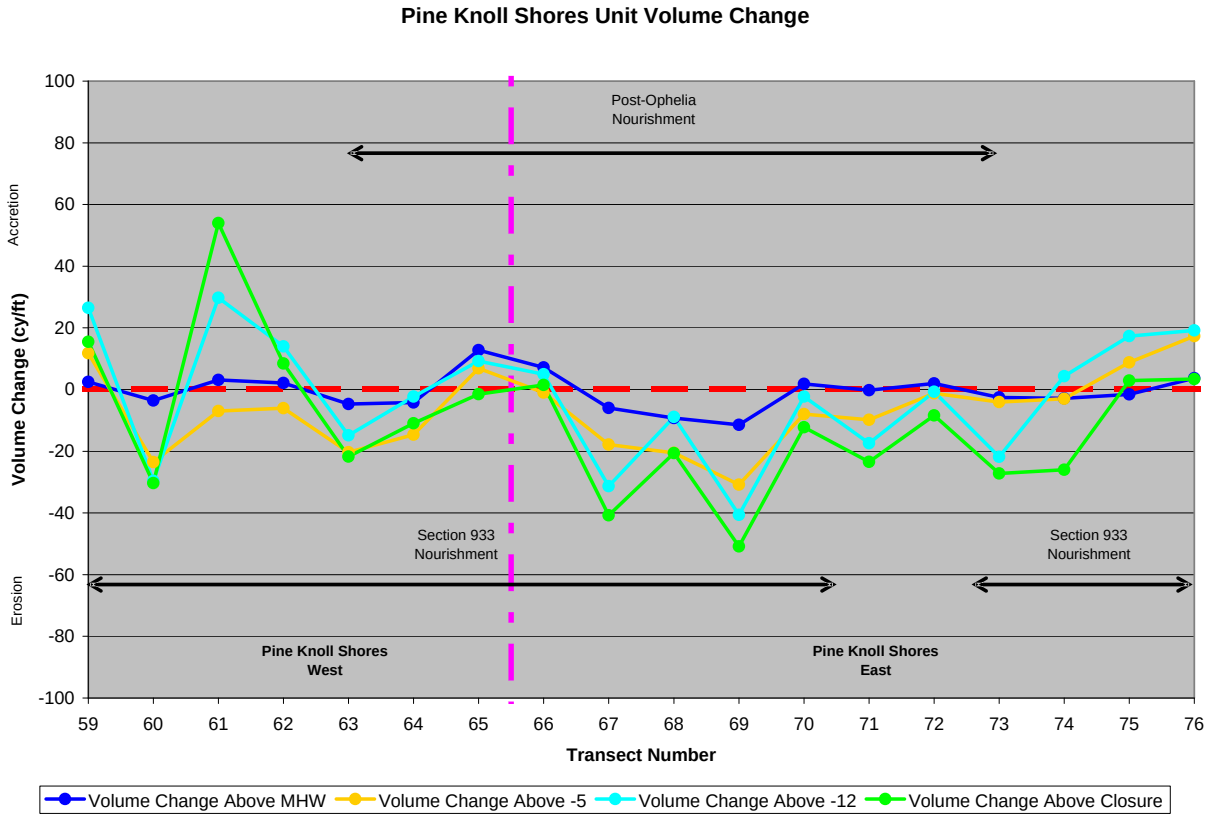

Figure 9. Pine Knoll Shores Unit Volume Change (May 2007-July 2008)

5.3.4. Atlantic Beach

The Atlantic Beach region covers transects 77 through 102 (Sta 961+72 to Sta 1211+94). This region did not receive any post-Ophelia FEMA nourishment. A summary of average shoreline and volume changes between May 2007 and June/July 2008 for the Atlantic Beach region are presented in **Table 11**.

Table 11. Average Shoreline and Volume Change for Atlantic Beach

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Atlantic Beach (77-102)	26,176	24.2	6.4	166,141	-0.1	-5,549	1.1	27,172	-5.2	-139,970

This region showed varying accretion and erosion above the various elevations chosen for comparison. The region lost a total of approximately 140,000 cy of material above the depth of closure. **Figure 10** displays the unit volume change for each transect in the Atlantic Beach region.

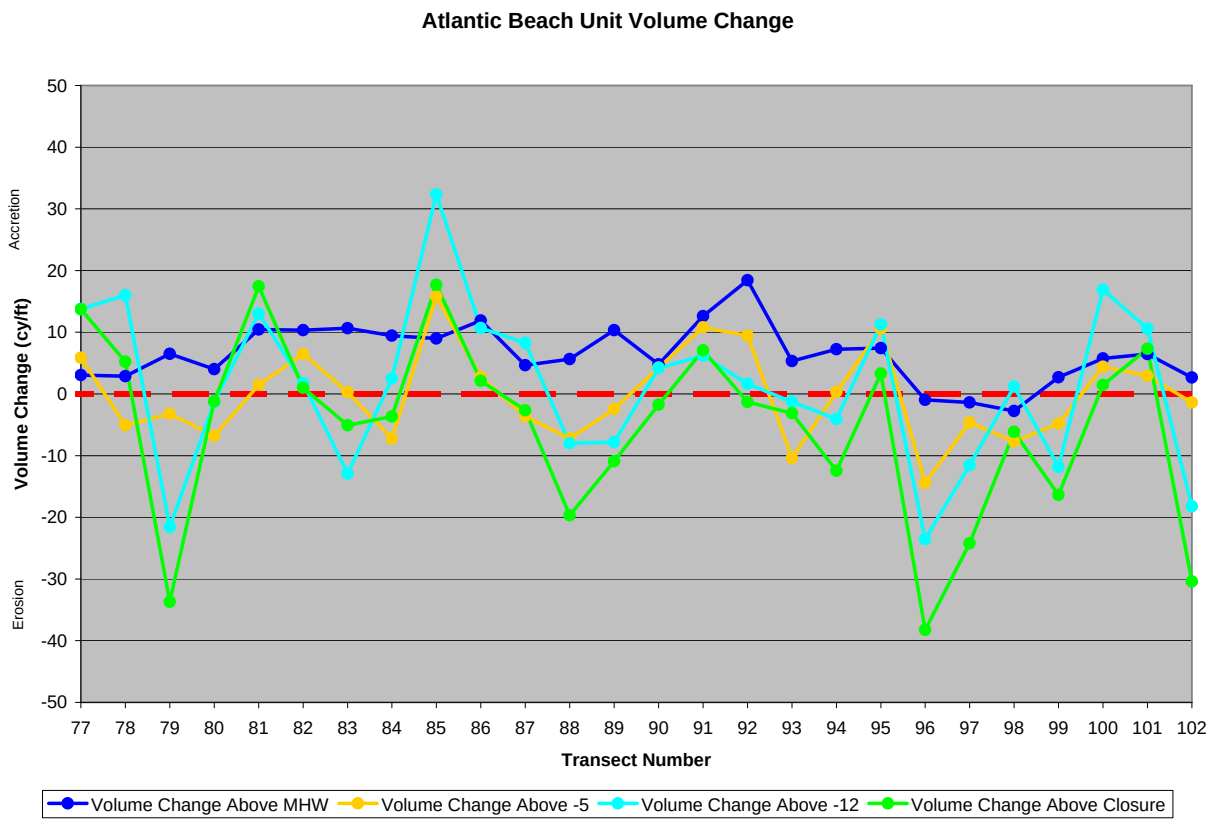

Figure 10. Atlantic Beach Unit Volume Change (May 2007-July 2008)

5.3.5. Fort Macon State Park

The Fort Macon State Park region covers transects 103 through 112 (Sta 1222+11 to Sta 1283+93). This region received approximately 211,000 cy of sand from USACE harbor dredging. A summary of average shoreline and volume changes between May 2007 and June/July 2008 for the Fort Macon State Park region are presented in **Table 12**.

Table 12. Average Shoreline and Volume Change for Fort Macon State Park

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Fort Macon State Park (103-112)	6,691	-13.3	-3.9	-22,257	-8.9	-69,740	-14.1	-137,402	-24.5	-200,874

Fort Macon State Park showed erosion above all elevations considered in the analysis. **Figure 11** displays the unit volume change at each transect in the Fort Macon State Park region.

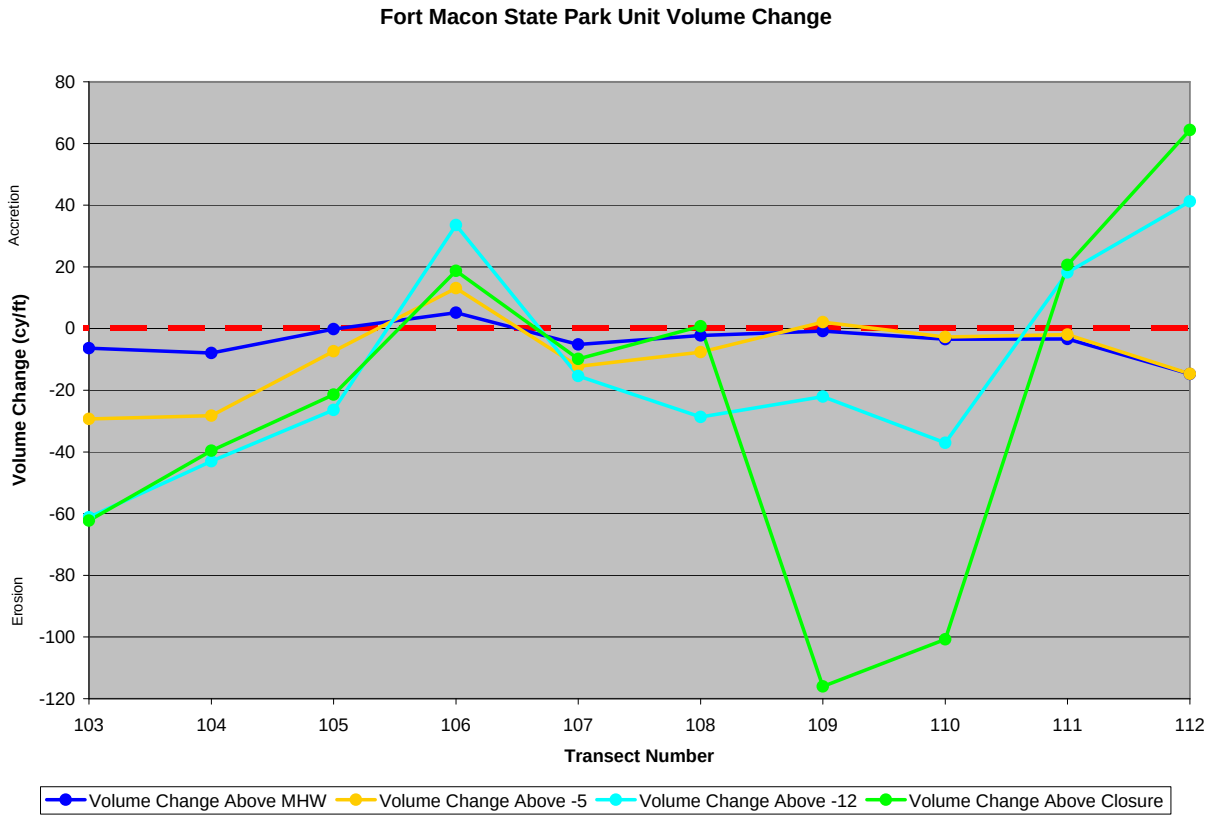

Figure 11. Fort Macon State Park Unit Volume Change (May 2007-July 2008)

5.3.6. Bogue Inlet

The Bogue Inlet region is comprised of an area along the oceanfront which covers transects 1 through 8 (Sta 0+00 to Sta 67+74) and an area along the eastern side of Bogue inlet covering transects 117 through 120. A summary of average shoreline and volume changes between May 2007 and June/July 2008 for the Bogue Inlet region are presented in **Table 13**.

Table 13. Average Shoreline and Volume Change for Bogue Inlet

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Inlet-Ocean (1-8)	7,432	70.7	5.5	42,022	8.8	47,519	-46.2	-218,444	-73.5	-322,442
Bogue Inlet-Channel (117-120)	1,500	-172.5	-33.0	-32,991	-67.6	-67,577	-107.7	-107,708	-107.7	-107,708

This region is highly dynamic due to the inlet. This can be seen in the survey evaluation plots in **Appendix B** and the profiles presented in **Appendix C**. **Figure 12** displays the unit volume change at each transect for the Bogue Inlet Ocean region. Changes become less noticeable as you move east along the shoreline, away from the inlet.

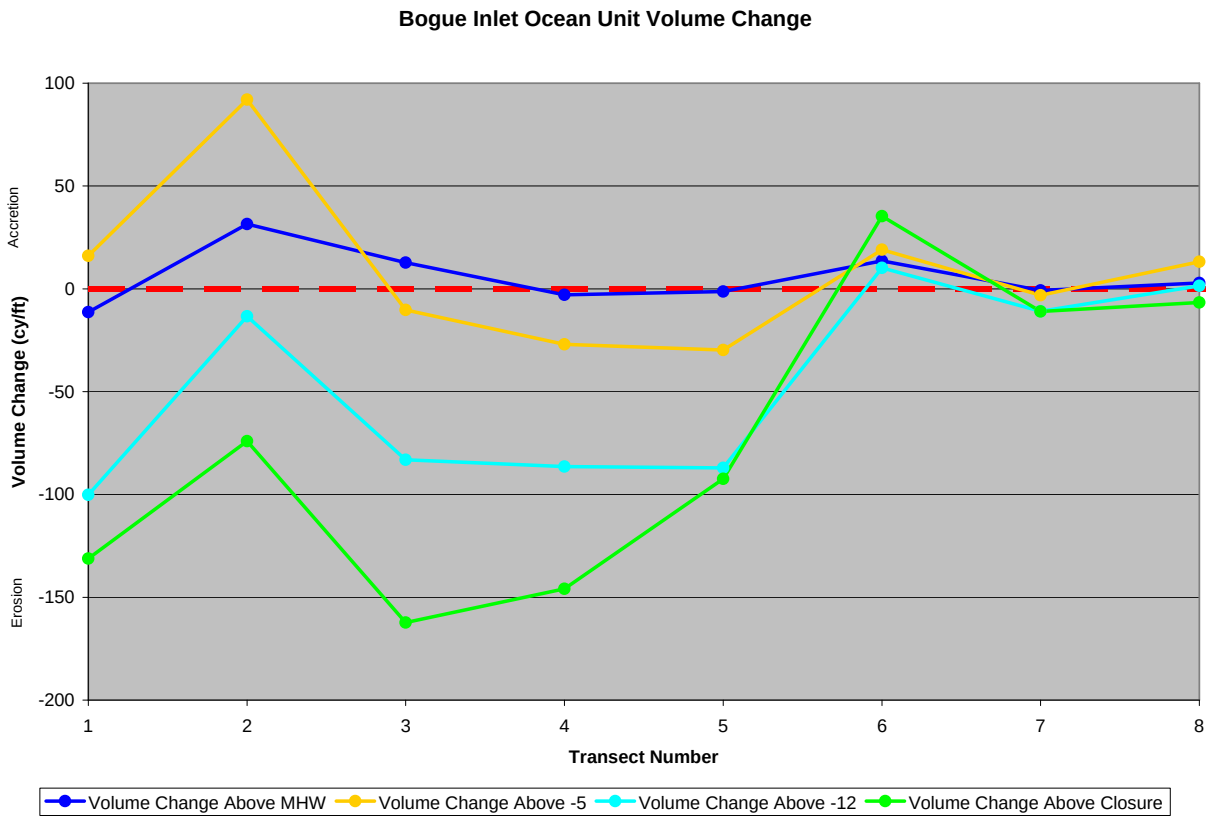

Figure 12. Bogue Inlet Ocean Unit Volume Change (May 2007-July 2008)

Profiles in the Bogue Inlet channel region varied widely and calculations could only be performed at transects 118 and 119 (see **Table 13**). Profile at transect 117 did not go below -5 ft NAVD88 while profiles at transect 120 did not go above MHW.

5.3.7. Beaufort Inlet

The Beaufort Inlet region is comprised of an area along the western side of Beaufort Inlet which covers transects 113 through 116. A summary of average shoreline and volume changes between May 2007 and June/July 2008 for the Beaufort Inlet region are presented in **Table 14**.

Table 14. Average Shoreline and Volume Change for Beaufort Inlet

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Beaufort Inlet (113-116)	1,500	-20.7	-3.2	-3,247	-2.8	4,470	-3.9	5,419	-2.7	2,636

Volume changes at Beaufort Inlet were very mild. Profiles for this region can be seen in **Appendix C. Figure 13** displays the unit volume change at each transect in the Beaufort Inlet region.

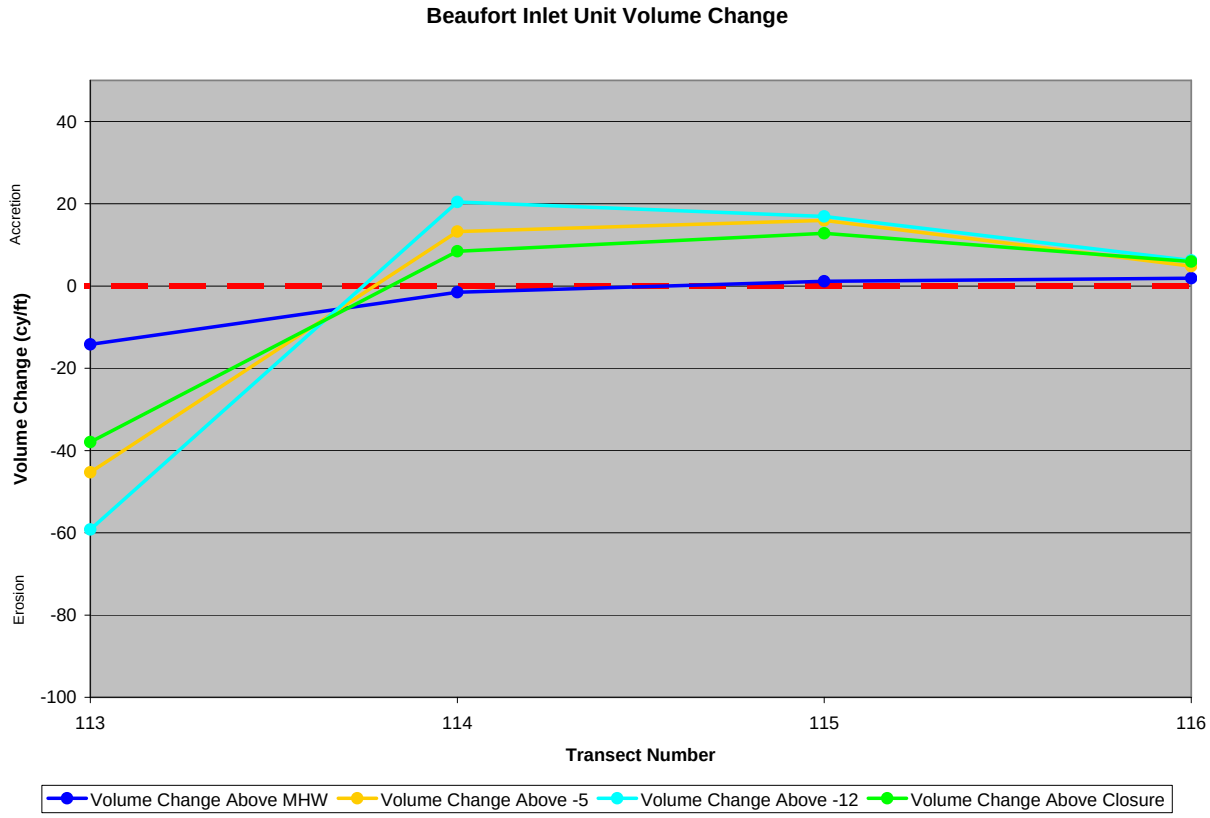

Figure 13. Beaufort Inlet Unit Volume Change (May 2007-July 2008)

5.3.8. Bear Island

Bear Island contains 18 transects spaced 1000 ft apart. A summary of average shoreline and volume changes between May 2007 and June/July 2008 for the Beaufort Inlet region are presented in **Table 15**.

Table 15. Average Shoreline and Volume Change for Bear Island

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bear Island (1-18)	17,000	42.5	7.8	129,249	3.8	57,942	6.0	96,090	9.4	155,938

Bear Island experienced accretion between the May 2007 and June/July 2008. This could be in part due to littoral drift of nourishment material from the 2007 Bogue Banks nourishment project. **Figure 14** displays the unit volume change at each transect on Bear Island. Profiles from transect 18 only contained elevations below -5 ft NAVD88 and therefore were not included in the analysis.

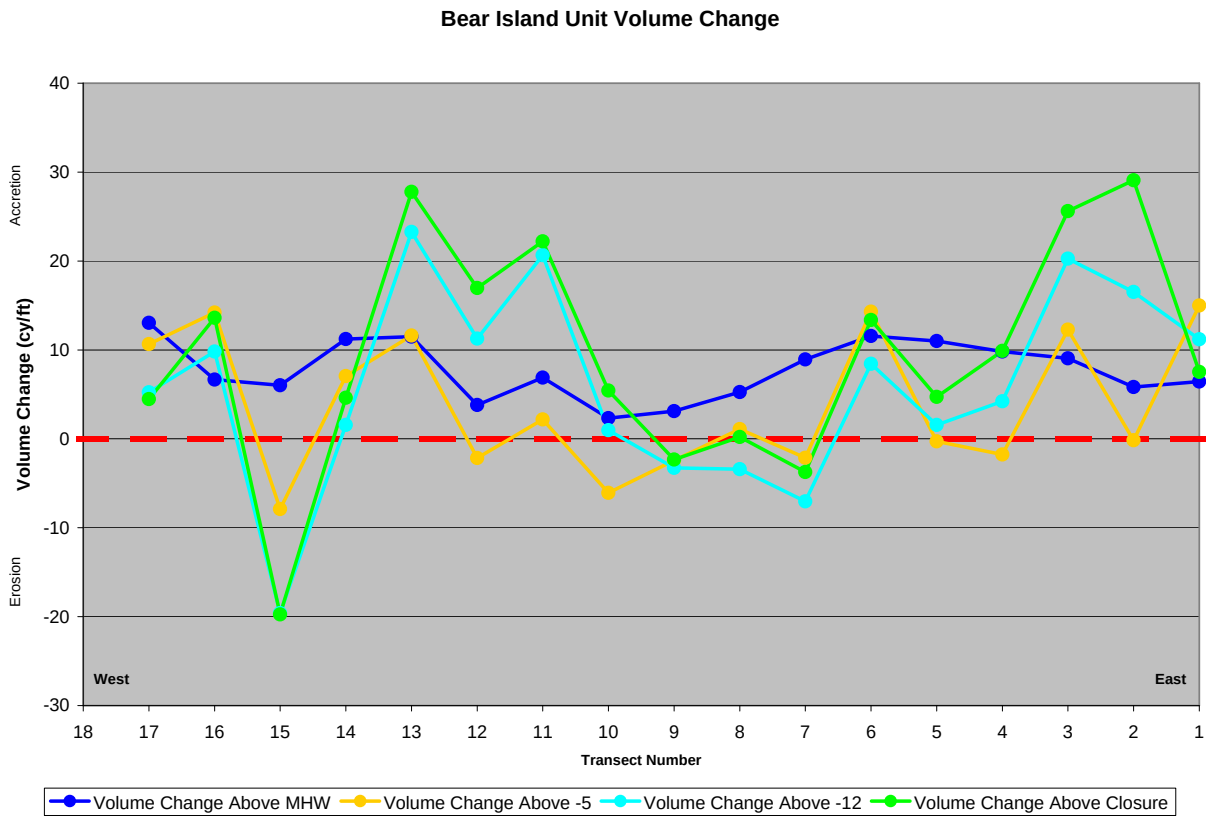

Figure 14. Bear Island Unit Volume Change (May 2007-June 2008)

5.3.9. Shackleford Banks

Shackleford Banks is comprised of 24 transects. Shackelford Banks is a natural shoreline, receiving no nourishment. As a result, varying accretion and erosion occurs along the shoreline. A summary of average shoreline and volume changes between May 2007 and June/July 2008 for the Beaufort Inlet region are presented in **Table 16**.

Table 16. Average Shoreline and Volume Change for Shackleford Banks

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Shackleford Banks (1-24)	46,001	5.8	-1.8	-73,540	-4.4	-201,919	-5.8	-247,192	-13.7	-597,556

Figure 15 displays the unit volume change at each transect on Shackleford Banks. The most drastic changes occur around the inlets on either side of Shackleford Banks. Transect 1 had a different alignment in the June 2008 survey than the May 2007 survey and was therefore not included in this analysis.

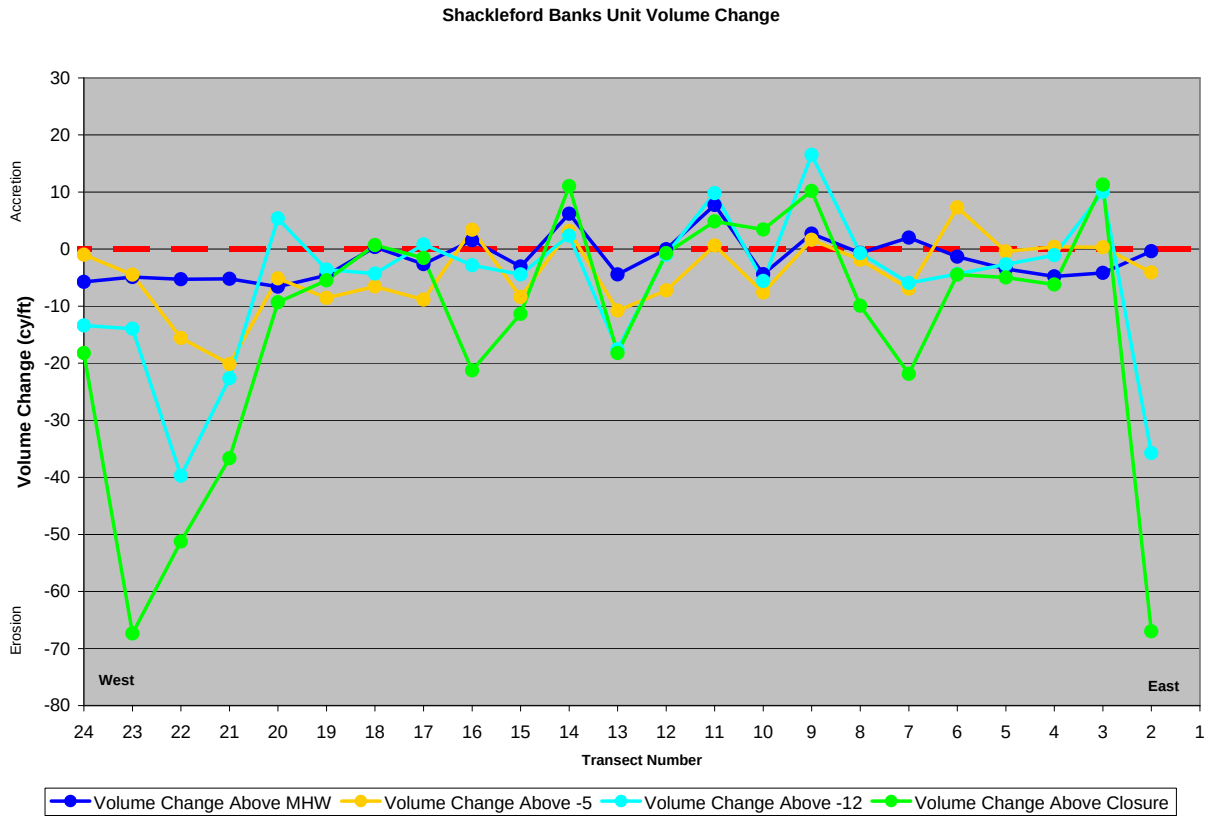

Figure 15. Shackleford Banks Unit Volume Change (May 2007-June 2008)

5.4. FEMA Beach Maintenance Analysis

Based on nourishment performed as part of Phase I, Phase II, and Phase III of the Bogue Banks Beach Restoration Project, analysis was performed to calculate the amount of fill remaining. Using the volume change between the Phase I, Phase II, and Phase III post-nourishment surveys and the July 2008 survey along with the amount of fill placed during Phase I, Phase II, and Phase III, the percentage of remaining fill was determined. If any reach falls below 50% of fill remaining, this area needs to be considered for nourishment. With the recent FEMA and USACE nourishment at Emerald Isle, Pine Knoll Shores, and Indian Beach/Salter path in 2007, the amount of remaining fill (compared to original base fill amount) in the County Project areas is all above the minimum level. FEMA beach maintenance calculations for applicable reaches are presented in **Appendix E**. **Table 17** presents the results of the beach maintenance analysis.

Table 17. Percent Fill Remaining from Base Nourishment

Reach	Percent Fill Remaining
Indian Beach/Salter Path	232.4
Pine Knoll Shores West	168.8
Pine Knoll Shores East	125.7
PHASE I	**166.0**
Emerald Isle Central	178.0
Emerald Isle East	84.8
PHASE 2	**133.5**
Emerald Isle West	224.7
Bogue Inlet	115.7
PHASE 3	**217.4**

6.0 Summary

Comprehensive surveying of the Bogue Banks shoreline began in 1999 as a way to monitor the Bogue Banks Beach Restoration Project. In Spring 2004, the Bogue Banks Beach and Nearshore Mapping Program was initiated to assess beach conditions and form strategies for future beach nourishment projects. Bear Island was added to the project in October 2004 and Shackleford Banks was added in May 2005. Surveys are performed each spring along all three stretches of shoreline. In addition, after large storm events, surveying is performed along Bogue Banks to assess damages. The most recent regular monitoring survey was completed in June/July 2008 by Geodynamics. For this evaluation, the 2008 survey was compared with the 2007 survey. The profile data were used to compute shoreline change at MHW (+1.1 ft NAVD88) and volume change above MHW, -5 ft NAVD88 (wading depth), -12 ft NAVD88 (outer bar), and -20 ft NAVD88 (closure).

Key statistics were computed for defined regions along the Bogue Banks shoreline, Bear Island, and Shackleford Banks between the 2007 and 2008 survey profiles including:

	Reach Length	avg shoreline change @ MHW	avg volume change above +1.1 ft NAVD	cumulative volume change above +1.1 ft NAVD	avg volume change above -5 ft NAVD	cumulative volume change above -5 ft NAVD	avg volume change above -12 ft NAVD	cumulative volume change above -12 ft NAVD	avg volume change above -20 ft NAVD	cumulative volume change above -20 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Banks Oceanfront (1-112)	128,393	12.71	3.96	516,329	-2.79	-384,489	-4.41	-492,480	-13.58	-1,567,258
Bogue Banks County Project (9-76)	88,094	6.36	3.69	330,423	-4.09	-356,719	-1.78	-163,806	-10.19	-903,972
Bear Island (1-18)	17,000	42.53	7.79	129,249	3.85	57,942	5.98	96,090	9.39	155,938
Shackleford Banks (1-24)	46,001	5.80	-1.79	-73,540	-4.38	-201,919	-5.85	-247,192	-13.66	-597,556

Based on the calculations, a large amount of apparent erosion occurred along the Bogue Banks oceanfront from May 2007 to July 2008, approximately 1,600,000 cy above the depth of closure. The County Project had slightly less loss of approximately 900,000 cy. Bear Island experienced accretion while mostly erosion occurred along Shackleford Banks. The trend along Bogue Banks was that of accretion above MHW as a calmer storm season pushed sand onto the beach and overall erosion to the depth of closure as the offshore bar shifted and also sand was lost from the nearshore littoral system. It should be noted that the datum conversion required for the 2007 data from NGVD to NAVD may have introduced some error into these results.

In addition, calculations were performed to estimate the amount of material remaining on the beach in excess of the baseline nourishment condition established by the Phase I, Phase II, and Phase III Bogue Banks Beach Restoration Projects. **It was determined that all reaches within the County Project currently contain more sand than was in place after the earlier baseline projects.**

As noted, there are inevitable margins of error associated with the different survey techniques used by CSE and Geodynamics that may reduce the accuracy of volumetric change analyses. The 2009 survey from Geodynamics will provide a consistent, high quality data set to compare with the 2008 survey yielding greater confidence in beach morphology changes. The addition of two transects at Bogue and Beaufort Inlets will hopefully improve quantification of sand movements in those highly dynamic regions. Therefore, it is essential to thoroughly review the beach and bathymetric profiles using various analytical techniques and general engineering judgment to assure that results are not falsely interpreted. Future periodic survey evaluations will continue to improve on analysis techniques so that the rich survey data sets are best utilized.