FINAL REPORT

Bogue Banks Beach

and Nearshore Mapping Program

October 2010

moffatt & nichol

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 program in October 2004 and Shackleford Banks was added in May 2005. Currently, surveys are performed annually during each spring/summer timeframe 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 during spring and summer 2010 (April and June 2010) by Geodynamics. For this evaluation, the spring/summer 2010 survey was compared with the summer 2009 (June, July, and August 2009) 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), -20 ft NAVD88, and -30 ft NAVD88.

Key statistics were computed for defined regions along the Bogue Banks shoreline, Bear Island, and Shackleford Banks between the 2009 and 2010 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	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Banks Oceanfront (1-112)	128,393	-4.9	0.4	52,473	-4.0	-519,972	-6.3	-811,170	5.5	710,238	10.0	1,288,351
Bogue Banks County Project (9-76)	88,094	-2.1	0.9	75,840	-3.4	-301,689	-7.6	-670,028	6.9	604,988	9.5	834,091
Bear Island (1-18)	16,500	-43.8	-5.2	-85,990	-8.6	-142,070	-9.3	-152,990	10.7	175,984	17.0	280,671
Shackleford Banks (1-24)	46,001	-13.7	-1.9	-86,156	-5.3	-242,629	-8.1	-372,572	-6.1	-282,375	5.7	260,886

Based on the calculations, the Bogue Banks oceanfront shoreline has experienced recession at MHW over the past year, with the largest landward movements occurring near the inlets in the Fort Macon and Bogue Inlet-Ocean regions. The volumetric numbers indicate that along the oceanfront, the beach has been accretional above MHW, erosional above -5 ft NAVD88 and above -12 ft NAVD88, and accretional above -20 ft NAVD88 and above -30 ft NAVD88. Upon examination of the individual profiles, it appears that the shoreline recession at MHW coupled with volumetric accretion above MHW is due to material around MHW being pushed onshore around the berm height (approximately +7 ft NAVD88), possibly resulting from winter storm events. In addition, uncertainty in hydrographic survey measurements may account for the majority of the offshore accretion seen above -20 ft NAVD88 and -30 ft NAVD88, with a slight upward shift of the 2010 offshore profile visible in many of the profile plots. Nevertheless, of most importance is the storm protection which is approximated by the volume of sand above -12 ft NAVD88. All reaches, with the exception of Bogue Inlet, saw considerable losses above this elevation, totaling -811,170 cy along the Bogue Banks oceanfront and -670,000 cy within the County Project.

Bear Island and Shackleford Banks showed similar trends to Bogue Banks with erosion above higher elevations and accretion offshore. Again, the offshore accretion is likely attributed to survey uncertainty which caused a slight shift in the offshore profiles between 2009 and 2010. Bear Island saw a large amount of shoreline recession at MHW, averaging almost -44 ft across the island. Examination of individual profiles shows significant beachface erosion

between 0 ft NAVD88 and +5 ft NAVD88. It should be noted that Bear Island was surveyed in April 2010 and the shoreline may not have recovered from winter storm events. Also of importance is the volumetric accretion seen at the eastern end of Bear Island, possibly caused by the ebb shoal welding to the shore while the remainder of the island saw some erosion. Shackleford Banks, which was also surveyed in April 2010 and may not have fully recovered from winter storm events, saw significant recession at MHW as well, averaging -14 ft across the island. Erosion of the beachface between 0 ft NAVD88 and +5 ft NAVD88 with large offshore bar changes, especially near Beaufort Inlet, is visible in many of the profiles on Shackleford Banks.

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 Phase I (Indian Beach/Salter Path and Pine Knoll Shores) and Phase III (Emerald Isle West and Bogue Inlet) reaches all currently contain more sand than was present after the earlier baseline projects were completed and are significantly above thresholds established in each community's FEMA monitoring and maintenance plan. However, The Emerald Isle East reach (Phase II) only contains 48% of the original fill, which is the lowest of any subunit in the County Project area. Emerald Isle East and Emerald Isle Central comprise the entire Phase II management reach for FEMA monitoring and maintenance which contains just under 100% of the original fill volume. This year's monitoring confirms the need for the potential hotspot project for Emerald Isle East being planned, possibly, for the next year.

Table of Contents

Appendices

List of Figures

List of Tables

1.0 Objective

The Bogue Banks Beach and Nearshore Mapping Program (BBBNMP), sponsored by Carteret County, formally began in June 2004 (Note: UNC-IMS completed the 2003 work) 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 annually during each spring/summer timeframe. 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 during spring and summer 2010 (April and June 2010) by Geodynamics LLC (Geodynamics). This report documents the data sources, methods, and results of a survey evaluation performed to compare the spring/summer 2010 survey with a previous survey performed in summer 2009.

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

3.0 Survey Methods and Data Sources

Most recently, Geodynamics conducted a survey of Bear Island and Shackleford Banks in April 2010 and Bogue Banks in June 2010. The profile lines and origins used in previous studies were also used for the most recent survey for ease of comparison. **Figure 1** and **Figure 2** show the location of the profile lines and origins applied by Geodynamics for the surveying. Two transects were added near Beaufort Inlet (112B) and Bogue Inlet (117B) in 2008 to better track sand movement near the inlets. 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. The spring/summer 2010 survey represents a continuation of previous surveys conducted for the Carteret County Shore Protection Office using high-density singlebeam sonar and topographic survey of Bogue Banks. This survey meets the requirements specified in the NOS (National Ocean Service) Hydrographic Surveys Specifications and Deliverables (April, 2007), the OCS (Office of Coast Survey) Field Procedures Manual for Hydrographic Surveying (June 2008) and the criteria for Navigation and Dredging Support Hydrographic Surveys as outlined in the U.S. Army Corps of Engineers Hydrographic Surveying Manual, EM 1110-2-1003 (EM 1110-2-1003 January 2002). The following sections will discuss the singlebeam (bathymetric) and topographic data acquisition including its associated equipment, quality control procedures, and data processing.

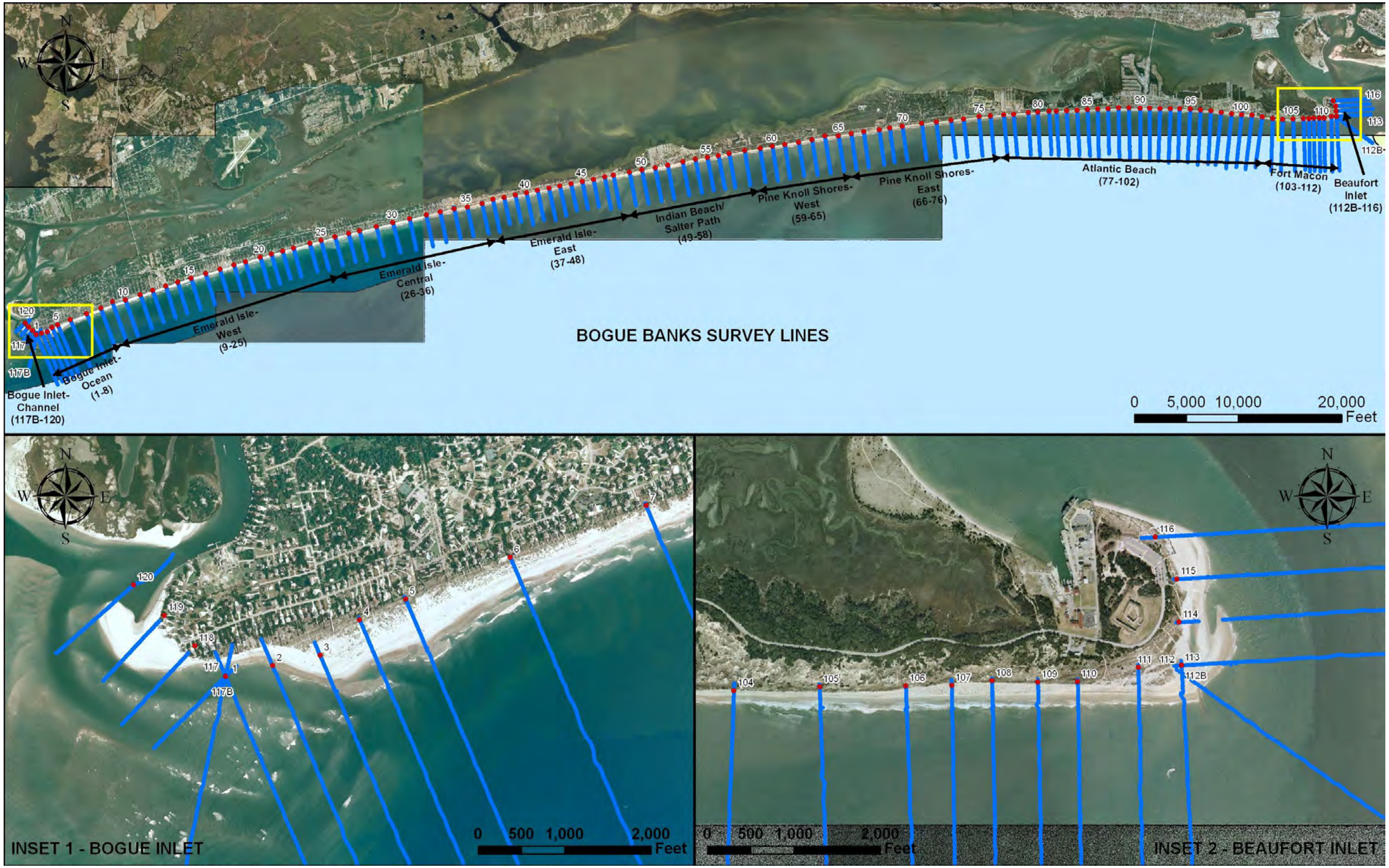

Figure 1. BBBNMP Profile Line Locations – Bogue Banks

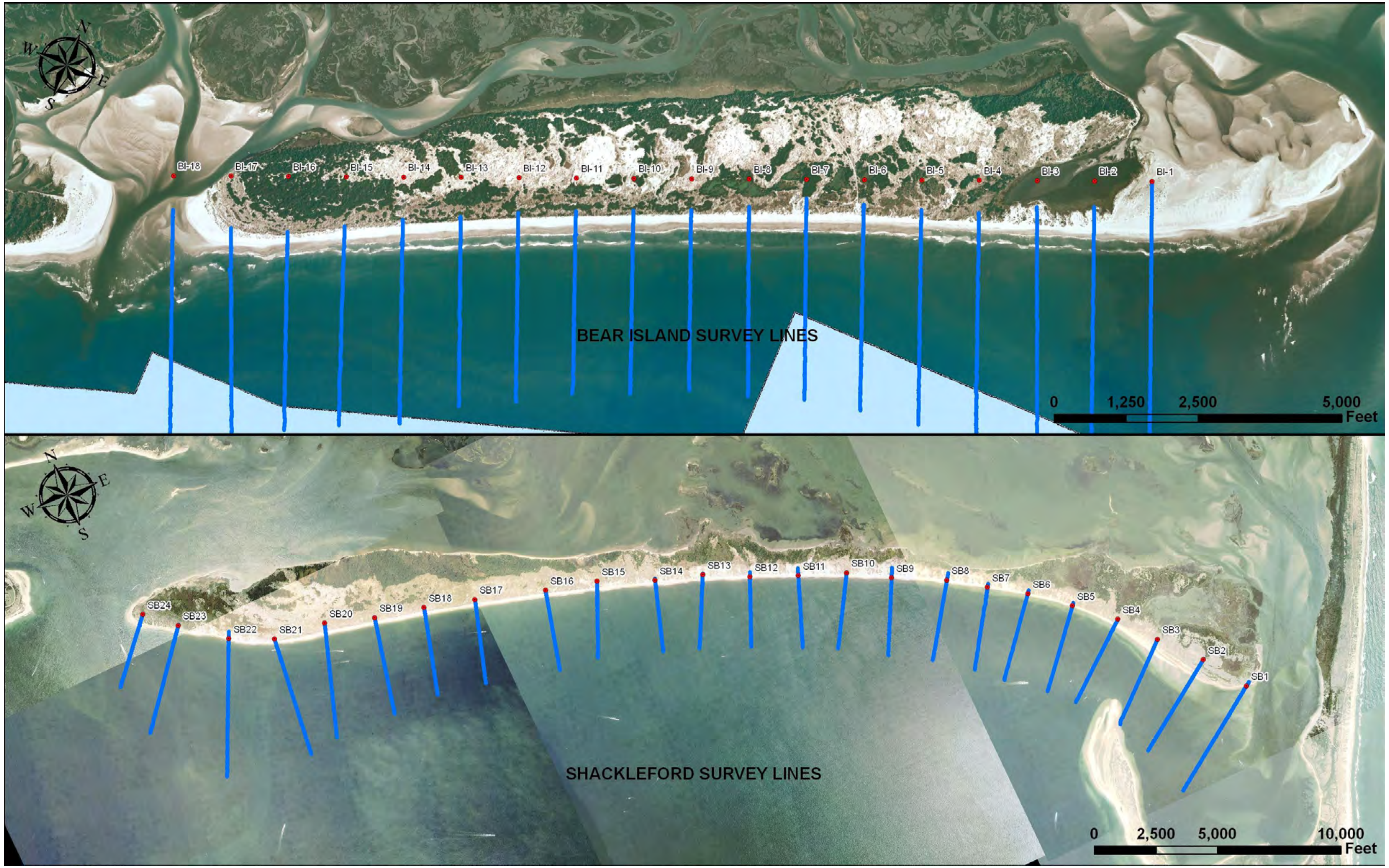

Figure 2. BBBNMP Profile Line Locations – Bear Island and Shackleford Banks

3.1. Singlebeam (Bathymetric) Data Acquisition and Processing

The following sections discuss the equipment, quality controls, sounding corrections, and data processing associated with the singlebeam data acquisition.

3.1.1. Singlebeam Survey Equipment, Hardware, and Software

The R/V Shoals served as the survey platform for singlebeam data acquisition (**Figure 3**). The R/V Shoals is designed to be a vessel of opportunity for shallow water inshore and coastal ocean mapping. The R/V Shoals is equipped with an over-the-side pole mount that serves as a transducer mount, inertial / tightly coupled navigation for positioning and elevation, sound velocity sensors and customized computer systems. This vessel represents the state-of-the-art in modern hydrographic surveying. The hardware systems inventory for the R/V Shoals is shown in **Table 3**.

Figure 3. The R/V Shoals Hydrographic Survey Platform Setup

Table 3. Singlebeam Hardware Systems Inventory

	R/V Shoals		
	Hardware	**Manufacturer**	**Model**
Horizontal Control	RTK Radio Modem	Pacific Crest	PDL LPB
	RTK Radio Antenna	Pacific Crest	n/a
	GPS Antenna	Trimble	Zephyr
	Cellular Internet Card	UT Starcom	UT 175
	GPS Receiver	Trimble	5700
	POS MV	Applanix	Wavemaster
Vertical Control	RTK Radio Modem	Pacific Crest	PDL LPB
	RTK Radio Antenna	Pacific Crest	n/a
	GPS Antenna	Trimble	Zephyr
	Cellular Internet Card	UT Starcom	UT 175
	GPS Receiver	Trimble	5700
	POS MV	Applanix	Wavemaster
Echo Sounding	2 Transducers	Airmar	SMSW200-4a
	ODOM CV100	ODOM	CV100
	Operator Station	CCS-inc	FPC-6920
Attitude Positioning	Inertial Motion Unit (IMU)	Applanix	Wavemaster
	Position Compute System (PCS)	Applanix	Wavemaster
	Primary GPS Antenna (port)	Trimble	Zephyr
	Secondary GPS Antenna	Trimble	Zephyr
Sound Velocity	Sound Profile Velocimeter	AML Oceanographic	Minos X SV&P

The vertical control for singlebeam data acquisition was provided by three basestations and a combination of VRS and RTK-GPS. They are: the North Carolina Geodetic Surveys' Virtual Reference Station "NCBE" located on Pivers Island, NC, "IMS Base" located at the UNC-IMS building in Morehead City, NC, and benchmark "Westport" located in Emerald Isle, NC. A repeater was also used to extend radio corrections. Station NCBE utilizes a Trimble NETR5 GNSS (Global Navigation Satellite System) receiver to collect and broadcast corrections to roving users via an internet connection.

Horizontal positioning and vessel attitude for singlebeam data was provided by the Applanix Positioning for Marine Vessels (POS/MV Wavemaster) systems and was corrected using Inertially-Aided Real-Time Kinematic (IARTK) technology. This system provides roll and pitch accuracy to 0.01°, heading to 0.02° (with a 2 m antenna baseline), heave accuracy to 5 cm or 5% (whichever is greater).

The AML Oceanographic Minos X SV&P sound velocimeter was used during the survey in order to obtain accurate sound velocity profiles throughout the survey area. Unlike traditional Conductivity, Temperature, and Depth (CTD) sensors, velocimeters measure sound speed directly using "time of flight" technology, automatically compensating for pressure, salinity, and temperature. The system comprises a sound velocity probe attached to the data collector where the survey technician logs the sound velocity profile data as the probe is deployed.

An Odom CV100 singlebeam sonar system was used to acquire singlebeam bathymetry data during the survey. The CV100 system operates at frequencies in the 200 kHz band; ideal for shallow depths (<40 m). The transducer forms a 4 degree beam. With an operational depth range from <30 cm to 600 m and a ping rate up to 20 Hz, the CV100 is ideal for shallow water surveys.

The software systems inventory for singlebeam data acquisition and processing is presented in **Table 4**.

Table 4. Singlebeam Software Systems Inventory

	Software	Version
Data Acquisition	HYPACK	2010
	POSView	3.4
Data Processing	HYPACK	2010
	POSPac MMS	5.2

The HYPACK software suite was used during survey preparation in order to create profile lines plans. The initial line plan was created in accordance with the Carteret County Shore Protection Office beach profile monitoring stations established in 1999. Survey lines were extended to a length of 5000 ft from the baseline as per the official SOW. HYPACK was also used during the survey to collect singlebeam bathymetric data and topographic data.

The POSView software by Applanix was used with the POS MV system. The software provides a tightly-coupled integration of the attitude measurements recorded by the IMU and the position measurements recorded by the GPS. POSView allowed the survey technician to monitor the attitude and positioning accuracy throughout the survey. POSView logged a POSPac True Heave file which contains the Kalman filtered heave for further post-mission attitude processing.

HYPACK was subsequently used to manipulate and process both singlebeam bathymetric data and topographic data once it was collected. The Singlebeam Editor in HYPACK was used to import, clean, and thin the data. Upon cleaning, the *Export* module was used to export the data into a specific format. The post-processed POSPac file was integrated with the singlebeam data in HYPACK single beam editor.

The POSPac MMS (mobile mapping solution) software by Applanix was used to post-process attitude and navigation data collected in POSView. By post-processing the attitude and navigation data stored in the POSPac data file with a logged GPS observable file from the basestation, common artifacts of RTK-GPS can most often be eliminated and the overall accuracy of the attitude and navigation can be increased.

3.1.2. Singlebeam Quality Control

All survey line planning was completed in HYPACK. Survey line spacing was based on previous surveys of Bogue Banks with extensions per USACE specification. Survey lines were extended to reach a 5000 ft distance offshore from the start of the profile or baseline.

At the start of each survey day, a series of pre-survey protocols were run to aide in quality control and to determine any possible errors/issues prior to surveying. A temporary benchmark located at Geodynamics headquarters in Morehead City, NC was checked daily. The GAMS parameters and POS/MV installation parameters located under the installation settings of the POS/MV were all checked each day prior to enabling Ethernet logging of POSPac data.

All singlebeam and topographic data acquisition were completed using HYPACK *Survey* software. Data acquisition was performed at vessel speeds of approximately 3 - 7 knots. The HYPACK data acquisition software produced a constantly-updated OTF (On-The-Fly) data matrix, which allowed for real-time monitoring of the data coverage. Data displays in HYPACK *Survey* were used to monitor all survey parameters and the quality of data being recorded.

Sound velocity profiles were acquired routinely and when the survey vessel moved to a different location within the survey area. Each successive sound velocity cast was assessed and used to determine the need for additional casts.

3.1.3. Corrections to Echo Soundings

Mobilization of the R/V Shoals occurred on 05/19/2010. The vessel offsets were measured with respect to the ship's reference point, located at the top center of the Inertial Motion Unit (IMU). The vessel offsets were then entered into POSView to ensure an accurate merging of the IMU data with the singlebeam data.

The Applanix POS/MV unit was setup to receive phase-differential RTK position offsets from the GPS base station at NCBE Pivers Island. This configuration allowed the POS/MV to integrate sub-meter positional solutions with highly-accurate vessel attitude positions obtained from the IMU. When the GPS Azimuth Measurement Subsystem (GAMS) was online, positional solutions were being received from 5 or more satellite fixes with a Positional Dilution of Precision (PDOP) equal to or less than 3. When these conditions were not satisfied, the GAMS solution becomes dormant. GAMS continues to track satellites while in this state, but does not process the phase-differential corrections. A calibration of the GAMS system was conducted at the start of survey on 05/21/2010 off Bogue Banks, NC following the auto-start procedure laid out in the POS/MV V4 Installation and Operation Guide. The GAMS parameters in the setup menu were initially set to zero, with the exception of the heading calibration threshold which was set to 0.500°. The vessel then made aggressive figure-8 maneuvers until the GAMS solution came online and the values in the parameter setup menu were automatically updated.

Dynamic draft is the summation of the static draft and settlement and squat corrections, and is a required corrector for the echo soundings. Dynamic draft was accounted for in the echo soundings by using RTK-GPS. The ellipsoid-based vertical corrections received from the VRS network provided the survey vessel with an accurate real-time elevation based on the vessels position in the water. This worked to factor out the static draft, settlement, and squat of the survey vessel.

Sound speed profiles were taken at the start of each survey day, and again throughout the day as warranted by the survey area and water mass properties. Sound velocity profiles were acquired routinely and when the survey vessel moved to a different location in the survey area. Each successive sound velocity cast was assessed and used to determine the need for additional casts. A total of 28 sound velocity profiles where taken during the survey which greatly exceeds the standard set forth in the USACE Hydrographic Manual. A comparison of the sound velocity profiles was conducted in order to determine sound speed variations in different parts of the survey area.

RTK-based tidal measurements were continuously recorded throughout the survey by HYPACK Survey. The GPS height determined by the POS/MV was integrated into the raw singlebeam sonar data in the HYPACK data acquisition software by integrating the post-processed POSPac Smoothed Best Estimate of Trajectory (SBET) file. After importing the raw singlebeam data in HYPACK, the GPS tide was merged with the heave such to provide accurate tidal corrections and remove heave.

3.2. Topographic Data Acquisition and Processing

The following sections discuss the equipment, quality controls, sounding corrections, and data processing associated with the topographic data acquisition.

3.2.1. Topographic Survey Equipment, Hardware, and Software

A Trimble 5700 RTK-GPS rover backpack system was used to acquire topographic data during the survey. The Trimble 5700 RTK-GPS receiver integrates GPS observables with real-time VRS network corrections to provide a centimeter-level position and elevation. The RTK-GPS data is output from the 5700 receiver at 10 Hz to the Panasonic Toughbook U1 data acquisition tablet PC. A Kawasaki Mule and a Yamaha ATV is used to transport personnel between profiles (**Figure 4**).

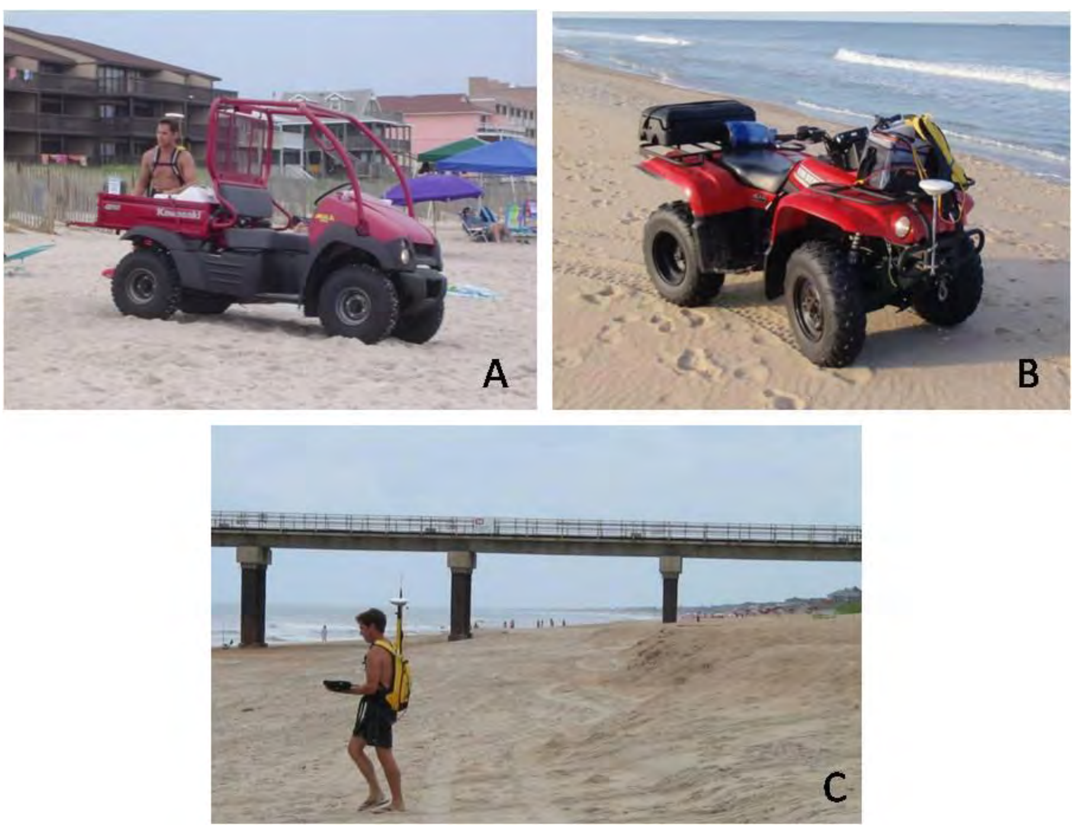

Figure 4. The (A) Kawasaki Mule, (B) Yamaha ATV, and (C)Trimble 5700 RTK-GPS Rover Backpack

The hardware systems inventory for topographic data collection is presented in **Table 5**.

Table 5. Topographic Hardware Systems Inventory

Hardware	Manufacturer	Model
Acquisition PC	Panasonic	Atom CF-U1
GPS Receiver	Trimble	5700
GPS Antenna	Trimble	Zephyr
Internet Con. (imbedded Gobi)	Qualcomm	HS-USB 250D

The vertical and horizontal control for topographic data acquisition was provided by three basestations and a combination of VRS and RTK-GPS. They are the North Carolina Geodetic Surveys' Virtual Reference Station "NCBE" located on Pivers Island, NC, "IMS Base" located at the UNC-IMS building in Morehead City, NC, and benchmark "Westport" located in Emerald Isle, NC. A repeater was also used to extend radio corrections. Station NCBE utilizes a Trimble NETR5 GNSS (Global Navigation Satellite System) receiver to collect and broadcast corrections to roving users via an internet connection.

Horizontal and vertical positioning for topographic data was acquired by a Trimble 5700 RTK-GPS system. The topographic rover received and integrated the differential corrections from the VRS station and RTK-GPS for centimeter-level positioning.

The software systems inventory for topographic data collection is presented in **Table 6**.

Table 6. Topographic Software Systems Inventory

	Software	Version
Data Acquisition	HYPACK	2010
	GNSS Internet Radio	1.4.11
	VZAccess Manager (Verizon/Quick link)	6.9.0
Data	HYPACK	2010

The HYPACK software suite was used during survey preparation in order to create profile lines plans. The initial line plan was created in accordance with the Carteret County Shore Protection Office beach profile survey lines. Survey lines were extended to a length of 5000 ft offshore from the baseline as per the official SOW. HYPACK was also used during the survey to collect topographic data. Phase-differential RTK corrections from NCBE were received by using an imbedded Gobi card accompanied with Verizon Access Manager and GNSS Internet Radio.

HYPACK was subsequently used to manipulate and process the topographic data. The Singlebeam Editor in HYPACK was used to import, clean, and thin the data.

3.2.2. Topographic Quality Control

All survey line planning was completed in HYPACK. The planned survey line spacing was dictated by the Carteret County Shore Protection Office Beach Profile Project. Survey lines were typically oriented parallel to the shoreline (note: lines were changed from Coastal Science and Engineering's 1999-2007 azimuths due to inconsistent data acquisition in 2008). Each topographic mapping system was tested prior to each survey day. Surveyors verified line files, data acquisition rates, masking angles, and software / hardware setup.

At the start of each survey day, a series of pre-survey protocols were run to aide in quality control and to determine any possible errors/issues prior to surveying. Benchmarks located at the Geodynamics office were checked and quality assessed prior to surveying each day. Each surveyor's rod and backpack antenna draft ware checked and input in the survey software.

All topographic data acquisition was completed using the HYPACK Survey software. Data acquisition was performed by walking as upright as possible while following the planned survey line. The surveyor constantly monitored the GPS status, off-line value, distance from baseline, and overall morphology along the profile. The HYPACK data acquisition software produced a constantly updated OTF data matrix, which allowed for real-time monitoring of the data coverage as well. To ensure ample topographic data overlap with the hydrographic data, the surveyor would plot the targets acquired during the surfzone hydrographic survey. These targets indicated how far the surveyor needed to go down the profile and into the surfzone. Upon completion of a survey day, all data was thoroughly reviewed and various profiles overlaid on the 2008 and 2009 profile data for a quick in-field QA-QC check.

3.3. Vertical and Horizontal Control

The vertical datum for this survey is the North American Vertical Datum of 1988 (NAVD88). Soundings were reduced to NAVD88 from ellipsoid heights in HYPACK by integrating the local Geoid 2003 model.

The horizontal datum for the final data product is the North Carolina State Plane Zone 3200, Feet. Horizontal control was derived using Real Time Kinematic (RTK) or VRS-RTK positioning. The North Carolina Geodetic Surveys' Virtual Reference Station "NCBE" located on Pivers Island, NC provided position and elevation as well as the multiple RTK-GPS basestations.

3.4. Merging Topographic and Bathymetric Data

Upon processing the individual hydrographic and topographic data sets in HYPACK, the datasets are merged, resulting in one edited HYPACK file per profile line. Each profile line is then thoroughly inspected for topo/bathy overlap, landward and seaward data extents, and consistency with previous profile data.

Rigorous QA-QC assessments are performed on the final topo-bathy profiles in order to ensure the highest quality data. Topographic data, in the less variable dune areas, is overlaid with the previous years' data and the horizontal and vertical alignment is evaluated. The topo-bathy profiles are examined one-by-one to review the overlap of topographic and hydrographic data to guarantee reliable surfzone data (**Figure 5**). The entire topo-bathy profile is then compared to the same profile from a previous years' dataset to assess the overall quality and consistency of the profile data.

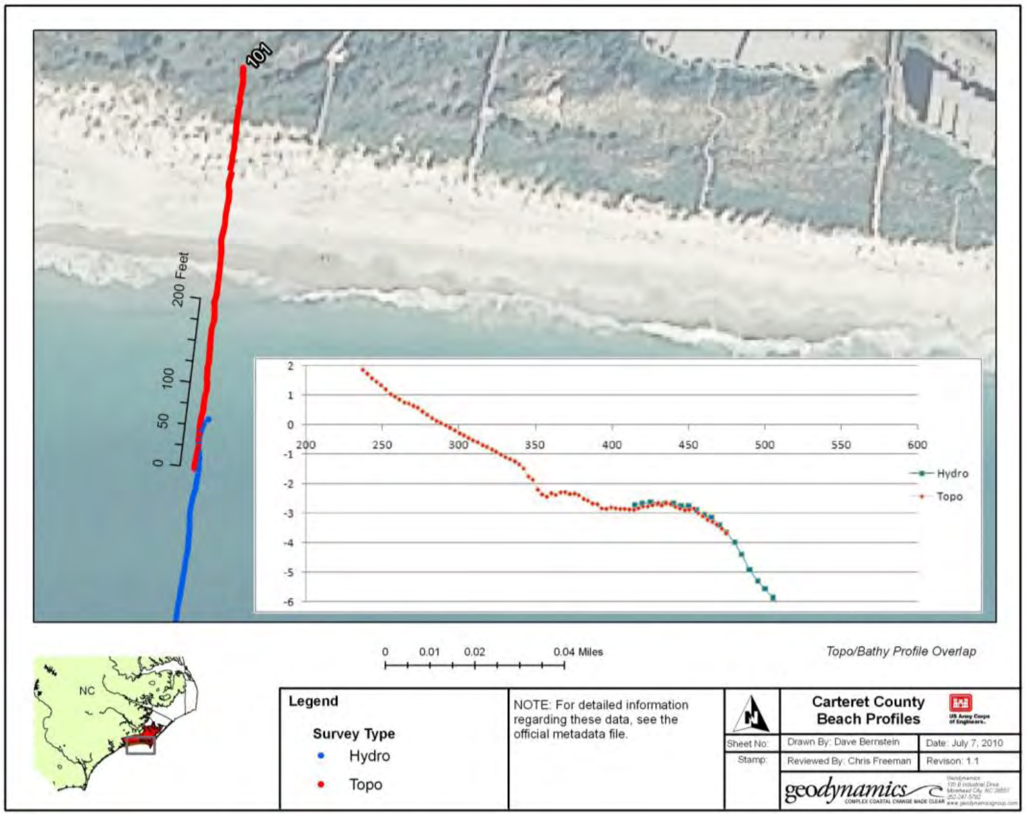

Figure 5. Example of Topographic and Bathymetric Data Overlap in Surfzone

3.5. Survey Data Acquisition Timeline

The most recent survey data was collected by Geodynamics during April and June of 2010. The Shackleford Banks survey was done on April 12, 2010 and April 13, 2010. For this report, April 13, 2010 was used as the survey date for all profile lines on Shackleford Banks. Bear Island surveys were performed on April 19, 2010 through April 29, 2010. For this report, April 29, 2010 was used as the survey date for all profile lines on Bear Island. The Bogue Banks survey, due to weather, was performed over a longer range of dates. The majority of the survey was performed from June 7, 2010 to June 15, 2010, with a few measurements taken in March and May 2010. Since the majority of the survey for the Bogue Banks transects was completed in June 2010, the date used for the Bogue Banks profiles for this report is June 15, 2010.

The previous set of survey data, used for comparison in this report, was also collected by Geodynamics during June, July, and August 2009. The Bear Island and Shackleford Banks surveys were performed from August 14, 2009 to August 18, 2009. For this report, August 15, 2009 was used as the survey date for all profile lines on Shackleford Banks while August 18, 2009 was used for all profile lines on Bear Island. The Bogue Banks survey, due to weather, was performed over a longer period from June 22, 2009 to August 18, 2009. June 23, 2009 was used as the survey date for comparison in this report since the majority of transects were surveyed from June 22 - June 24, 2009.

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 summer 2009 and spring/summer 2010 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 summer 2009 and spring/summer 2010 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 summer 2009 and spring/summer 2010. Volume changes were calculated for five 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-equivalent to -4 ft NGVD29), above -12 ft NAVD88 (outer bar-equivalent to -11 ft NGVD29), above -20 ft NAVD88, and above -30 ft NAVD88. Upon inspection of recent survey data, it appears the depth of closure is somewhere between -20 ft NAVD88 and -30 ft NAVD88 (likely closer to -20 ft NAVD88). For those profiles which did not extend to -30 ft NAVD88, volume calculations were performed above -30 ft out to the extent of the shortest survey. 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. It should be noted that the uncertainty in the hydrographic portion of the survey is approximately 0.11 ft. If this uncertainty is applied along the portion of the profile between the seaward side of the outer bar (approximately 1300 ft offshore) and a depth of -30 ft NAVD88 (approximately 2850 ft offshore) along all 128,393 ft of oceanfront shoreline, this lends itself to an uncertainty of approximately ±811,000 cy.

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 and are ultimately used in decision making for future beach nourishment projects. Volume comparisons above -20 ft NAVD88 allow for the tracking of sand movement offshore while reducing the amount of uncertainty associated with the survey data by eliminating changes beyond this depth related to the vertical margin of uncertainty in the hydrographic survey data. Finally, volume comparisons above -30 ft NAVD88 allow the complete tracking of sand movement offshore. However, hydrographic survey measurement accuracy may impact these calculations. 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.

Finally, FEMA beach maintenance calculations were done based on a baseline nourishment condition consisting of the post-nourishment surveys from Phase I (2002), Phase II (2003), and Phase III (2005) of the Bogue Banks Beach Restoration Project. Profile volumes above -12 ft NAVD88 (equal to previously utilized elevation of -11 ft NGVD29) from spring/summer 2010 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 and 2010.

For visual reference, a Digital Elevation Model (DEM) was created using Surfer, a 3D surface mapping software package, for both the summer 2009 and spring/summer 2010 profile data. The MHW shoreline position contour was extracted from the summer 2009 and spring/summer 2010 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 summer 2009 and spring/summer 2010 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

The Bogue Banks area has 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 7** and **Table 8** summarize the recent nourishment projects in the study area. Emerald Isle has received the most nourishment followed by Atlantic Beach and Pine Knoll Shores.

Table 7. 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 8. 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**

Most recently in January – March 2007, 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 Shores also received 507,939 cy of sand as part of the USACE Section 933 project dredging of Beaufort Inlet. In addition, 211,000 cy of material was placed on Fort Macon during late 2007. No nourishment projects were performed between 2007 and the most recent survey (2010).

5.2. Background Erosion Rates

Due to the numerous nourishment projects which have taken place along Bogue Banks since 2002, it is important to determine a background erosion rate without nourishment from which to compare the performance of the various projects. Nourishment volumes were subtracted from total volume changes above -12 ft NAVD88 between a baseline survey taken in 1999 and the spring/summer 2010 survey. **Table 9** shows the average annual background erosion rates for each reach of the Bogue Banks oceanfront. The average background erosion rate for the entire Bogue Banks shoreline is approximately -3 cy/ft/yr. This result compares favorably with similar calculations completed in previous years.

Table 9. Average Annual Background Erosion Rates (1999-2010)

Reach	Length (ft)	Volume Change Above -12 ft NAVD88 (cy) (1999-2010)	Nourishment Volume (cy)	Background Erosion (cy)	Average Annual Background Erosion Rates (cy/ft/yr)
Bogue Inlet-Ocean	7,432	15,505	59,272	-43,767	-0.54
Emerald Isle West	22,344	1,045,661	935,633	110,028	0.45
Emerald Isle Central & East	29,022	1,467,666	2,348,172	-880,506	-2.76
Indian Beach/ Salter Path	12,850	802,438	1,358,842	-556,404	-3.94
Pine Knoll Shores	23,878	1,479,514	2,163,348	-683,834	-2.60
Atlantic Beach	26,176	1,103,596	2,920,729	-1,817,133	-6.31
Fort Macon State Park	6,691	-113,638	720,348	-833,986	-11.33
Total	**128,393**	**5,800,742**	**10,506,344**	**-4,705,602**	**-3.33**

5.3. *Regional 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 summer 2009 to spring/summer 2010 comparison are presented in **Table 10** through **Table 12**. 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, above -20 ft NAVD88, and above -30 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 10. Bogue Banks Regional Shoreline and Volume Change Statistics (Summer 2009 – Summer 2010 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	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Inlet-Ocean (1-8)	7,432	-10.8	-1.3	-9,356	-3.6	-26,915	-11.2	-82,982	-15.3	-113,534	-14.5	-108,059
Emerald Isle-West (9-25)	22,344	0.1	-0.8	-18,936	-1.5	-33,736	-4.8	-107,529	9.6	213,446	11.5	256,130
Emerald Isle-Central (26-36)	15,802	-2.0	0.2	3,873	-2.1	-33,249	-10.2	-161,290	3.8	59,271	6.1	96,582
Emerald Isle-East (37-48)	13,220	-0.9	0.4	5,541	-5.0	-66,438	-9.1	-120,185	4.2	55,085	4.3	56,701
Indian Beach-Salter Path (49-58)	12,850	-2.8	3.3	42,844	-2.3	-29,370	-9.2	-118,078	4.8	62,224	6.3	80,902
Pine Knoll Shores-West (59-65)	9,063	-5.8	1.5	13,455	-6.5	-58,859	-7.0	-63,649	10.0	90,337	14.8	134,479
Pine Knoll Shores-East (66-76)	14,815	-3.9	2.0	29,063	-5.4	-80,036	-6.7	-99,297	8.4	124,625	14.1	209,297
Atlantic Beach (77-102)	26,176	-7.3	0.4	9,928	-4.7	-121,903	-0.5	-11,803	6.2	162,027	14.7	383,683
Fort Macon State Park (103-112)	6,691	-25.1	-3.6	-23,939	-10.4	-69,465	-6.9	-46,357	8.5	56,756	26.7	178,637
Beaufort Inlet (113-116)	2,000	3.7	1.7	3,390	18.3	36,548	37.1	74,157	45.9	91,719	47.5	94,961
Bogue Inlet-Channel (117-120)*	2,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Reach Length	Weighted Avg	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total
County Project (9-76)	88,094	-2.1	0.9	75,840	-3.4	-301,689	-7.6	-670,028	6.9	604,988	9.5	834,091
Oceanfront (1-112)	128,393	-4.9	0.4	52,473	-4.0	-519,972	-6.3	-811,170	5.5	710,238	10.0	1,288,351

*Note: Due to the dynamic nature of Bogue Inlet, shoreline and volume calculations were not performed

Table 11. Bear Island Shoreline and Volume Change Statistics (Summer 2009 – Spring 2010 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	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bear Island (1-18)	16,500	-43.8	-5.2	-85,990	-8.6	-142,070	-9.3	-152,990	10.7	175,984	17.0	280,671

Table 12. Shackleford Banks Shoreline and Volume Change Statistics (Summer 2009 – Spring 2010 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	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Shackleford Banks (1-24)	46,001	-13.7	-1.9	-86,156	-5.3	-242,629	-8.1	-372,572	-6.1	-282,375	5.7	260,886

According to **Table 10**, the Bogue Banks oceanfront shoreline has experienced recession at MHW over the past year, with the largest landward movement occurring near the inlets in the Fort Macon and Bogue Inlet-Ocean regions. The volumetric numbers indicate that along the oceanfront, the beach has been accretional above MHW, erosional above -5 ft NAVD88 and above -12 ft NAVD88, and accretional above -20 ft NAVD88 and above -30 ft NAVD88. Upon examination of profiles in **Appendix C**, it appears that the shoreline recession at MHW coupled with volumetric accretion above MHW is due to material around MHW being pushed onshore around the berm (approximately +7 ft NAVD88), possibly resulting from winter storm events. This is most noticeable in the Indian Beach/Salter Path and Pine Knoll Shores regions, which show the highest volumetric accretion above MHW. In addition, the hydrographic survey uncertainty previously mentioned (see **Section 4.0**) may be responsible for a majority of the apparent offshore accretion. Profile plots in **Appendix C** show a slight upward shift of the offshore survey data from 2009 to 2010, most noticeably in the Pine Knoll Shores and Atlantic Beach regions which show some of the highest offshore accretion numbers. Therefore, while calculations show that the Bogue Banks oceanfront gained approximately 1,288,350 cy of sand above -30 ft NAVD88 between summer 2009 and summer 2010 and the County Project area gained approximately 834,000 cy of material during the same time period, much of this likely due to survey uncertainty. Nevertheless, of most importance is the storm protection which is approximated by the volume of sand above -12 ft NAVD88. All reaches, with the exception of Bogue Inlet, saw considerable losses above this elevation, totaling -811,170 cy along the Bogue Banks oceanfront and -670,000 cy within the County Project. It should be noted that while average shoreline changes at MHW are rather large in some areas, the average unit volume changes (cy/ft) are much smaller, indicating that material which is eroding from the beach face is often just being moved onshore or offshore but remaining within the littoral system.

Bear Island and Shackleford Banks showed similar trends to Bogue Banks with erosion above higher elevations and accretion offshore. Again, the offshore accretion is likely attributed to survey uncertainty which caused a shift in the offshore profiles between 2009 and 2010 (see **Appendix C**). According to **Table 11,** Bear Island saw a large amount of shoreline recession at MHW (approximately -44 ft) which was the result of beachface erosion between 0 ft NAVD88 and +5 ft NAVD88, possibly due to winter storm events which closely preceded the April 2010 survey. Upon inspection of profiles in **Appendix C**, it also appears that the eastern end of Bear Island showed some volumetric accretion, possibly caused by the ebb shoal welding to the shore while the remainder of the island saw some erosion. **Table 12** indicates that Shackleford Banks also saw significant recession at MHW (approximately -14 ft), possibly due to winter storm events which closely preceded the April 2010 survey. **Appendix C** shows erosion of the beachface between 0 ft NAVD88 and +5 ft NAVD88 with large offshore bar changes, especially near Beaufort Inlet, on many profiles.

Figure 6 and **Figure 7** display the trends seen in **Table 10** through **Table 12** with bar plots of the average unit volume changes and cumulative volume changes at each reach.

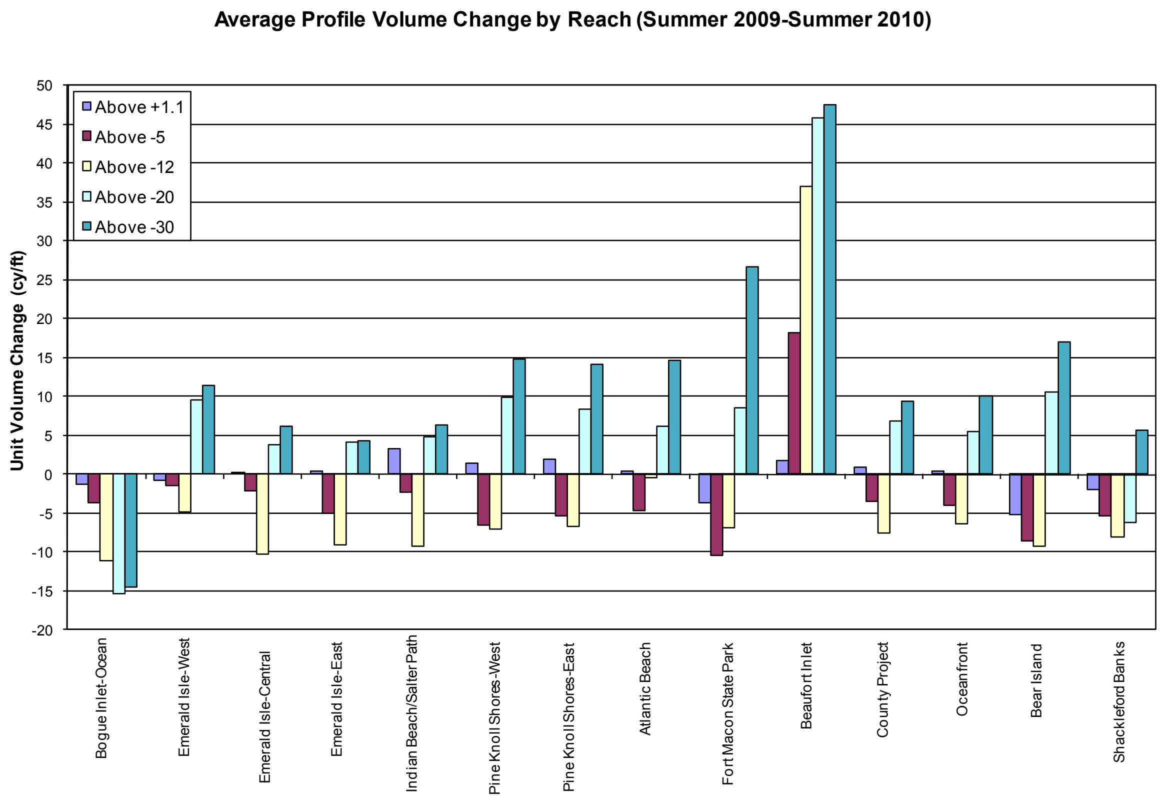

Figure 6. Average Unit Volume Change by Reach

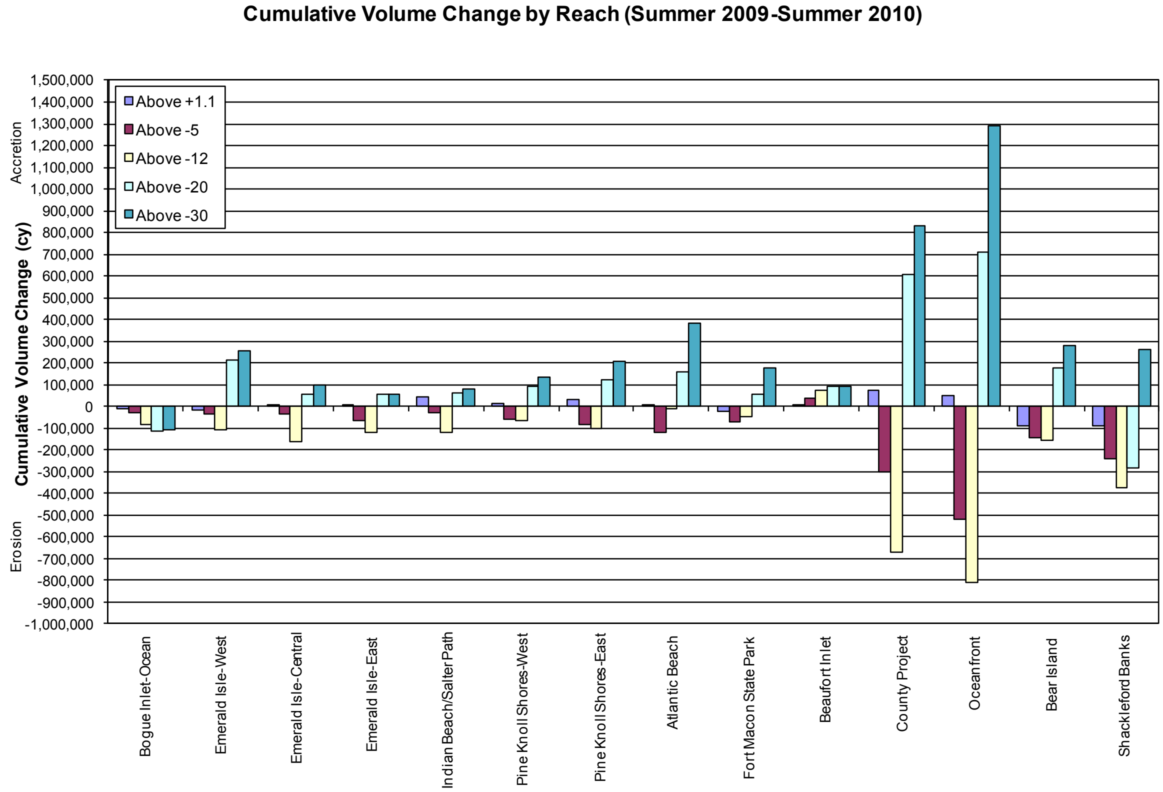

Figure 7. Cumulative Volume Change by Reach

Apparent from these figures is the movement of sand from the Fort Macon region eastward to Beaufort Inlet. These results give credence to the arguments that this area is likely influenced by Beaufort Inlet and may require additional nourishment volumes when projects are completed in the future. **Figure 6** and **Figure 7** also show the fact that nearly all of Bogue Banks has suffered volume losses above -12 ft NAVD88 which approximates the volume of sand available for storm protection. As mentioned previously, apparent gains above -20 ft NAVD88 and -30 ft NAVD88 are most likely due to the uncertainty associated with the hydrographic survey.

A target minimum volume for each profile from the foredune (landward most crest of the primary dune) to the outer bar (above -12 ft NAVD88) was established at 225 cy/ft during the formulation of the Bogue Banks Beach Restoration Project. 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 currently deemed necessary for adequate protection in all areas except Fort Macon and Shackleford Banks. **Figure 8** displays the average profile volume to the outer bar per transect within each reach of shoreline for summer 2008, summer 2009, and spring/summer 2010. Values displayed in the graph are tabulated in **Table 13**.

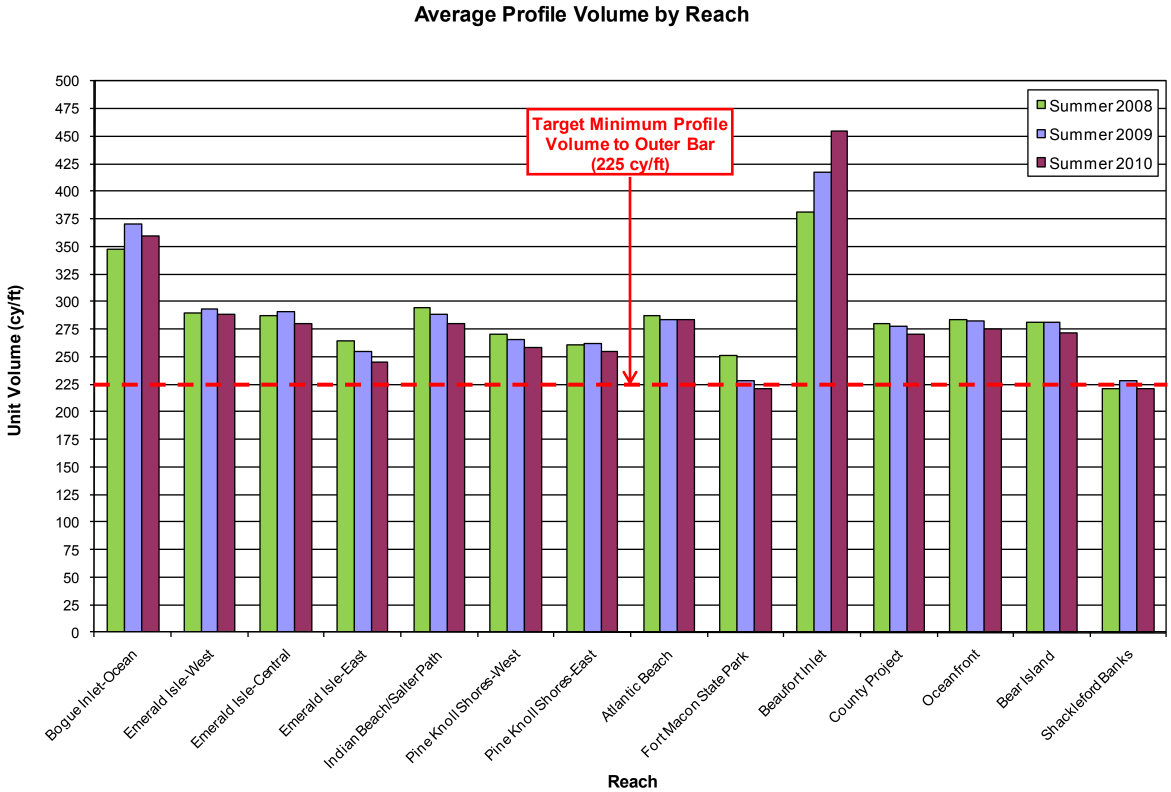

Figure 8. Average Profile Volume From Foredune to Outer Bar by Reach

Table 13. Average Profile Volume From Foredune to Outer Bar by Reach

Reach	July 2008	June 2009	June 2010
Bogue Inlet-Channel	N/A	N/A	N/A
Bogue Inlet-Ocean	348	371	359
Emerald Isle-West	290	294	289
Emerald Isle-Central	288	291	280
Emerald Isle-East	265	255	246
Indian Beach/Salter Path	294	289	280
Pine Knoll Shores-West	270	265	258
Pine Knoll Shores-East	261	262	255
Atlantic Beach	287	284	283
Fort Macon State Park	251	229	222
Beaufort Inlet	382	418	455
County Project	280	278	271
Oceanfront	284	282	276
Bear Island	282	281	272
Shackleford Banks	221	229	221

As shown in **Figure 8**, areas closest to the minimum target (Emerald Isle East, Fort Macon, and Shackleford Banks) of 225 cy/ft all experienced a significant loss in volume from summer 2009 to spring/summer 2010, placing Fort Macon and Shackleford below the target, with Emerald Isle East being the next lowest. The issues at Fort Macon should be addressed very soon with the upcoming USACE project this winter which currently plans to place sand within Atlantic Beach and Fort Macon (Transects 90-107). The Phase II project area (Emerald Isle Central and Emerald Isle East) may require nourishment in the future as well (due to the Emerald Isle East region behavior). This is also apparent in the FEMA beach maintenance calculations presented in **Section 5.5**. The County and the Town of Emerald Isle are currently in the planning stages of a hotspot project to utilize next year's planned USACE hopper project to place sand in this area.

5.4. Local 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 10** through **Table 12** and **Appendix B** has been created for each region of study.

5.4.1. Emerald Isle

The Emerald Isle region covers transects 9 through 48. Since monitoring began in 1999, Emerald Isle has received a total of 3.28 million cy of nourishment material as a result of the Bogue Banks Beach Restoration Project and FEMA post-storm work (Isabel and Ophelia). A summary of average shoreline and volume changes between summer 2009 and summer 2010 for the Emerald Isle region are presented in **Table 14**.

Table 14. 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	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Emerald Isle-West (9-25)	22,344	0.1	-0.8	-18,936	-1.5	-33,736	-4.8	-107,529	9.6	213,446	11.5	256,130
Emerald Isle-Central (26-36)	15,802	-2.0	0.2	3,873	-2.1	-33,249	-10.2	-161,290	3.8	59,271	6.1	96,582
Emerald Isle-East (37-48)	13,220	-0.9	0.4	5,541	-5.0	-66,438	-9.1	-120,185	4.2	55,085	4.3	56,701

Shoreline change at MHW showed slight recession in Emerald Isle Central and Emerald Isle East, with slight seaward movement in Emerald Isle West, possibly due to transport of material from the central and east regions to the west. Volumetrically, **Table 14** indicates that Emerald Isle West experienced erosion above MHW while the remaining portions of Emerald Isle were fairly stable above MHW. The profile plots in **Appendix C** indicate that the majority of the erosion above MHW in Emerald Isle West took place on the beach face between 0 and +7 ft NAVD88. All three regions of Emerald Isle showed a loss in volume above -5 ft NAVD88 and -12 ft NAVD88. The profile plots in **Appendix C** indicate the volume being lost below MHW to -12 ft NAVD88 is being pulled offshore to the seaward side of the ocean bar which has some extreme changes in size and position between the most recent surveys. As is the trend along the majority of the shoreline, all three regions of Emerald Isle experienced accretion above -20 ft NAVD88 and -30 ft NAVD88. Much of this appears to be due to sand being pulled offshore, seaward of the ocean bar, in addition to uncertainty in the hydrographic survey measurements. Most importantly, the Emerald Isle region lost -389,000 cy of material above -12 ft NAVD88, a considerable amount of storm protection.

As mentioned previously, the Emerald Isle East portion of the Phase II project may be in need of nourishment within the next few years. Historically, the area between 10^{th} street (Transect 43) and 20^{th} Street (Transect 38) has been an erosion hotspot. The 2008 periodic survey evaluation indicated erosion between Transects 42 and 44 (12^{th} Street to 8^{th} Street) between 2007 and 2008. The 2009 periodic survey evaluation indicated further erosion between Transects 40 and 43 (16^{th}

Street to 10th Street) between 2008 and 2009. The current survey evaluation indicates the erosion in this area has shifted slightly westward and is occurring between Transect 34 in Emerald Isle Central and Transect 42 in Emerald Isle East. Trends still indicate that the material being lost from Emerald Isle East is likely being transported west to the remaining regions of Emerald Isle.

Figure 9 displays the unit volume change at each transect above the five elevations that were analyzed.

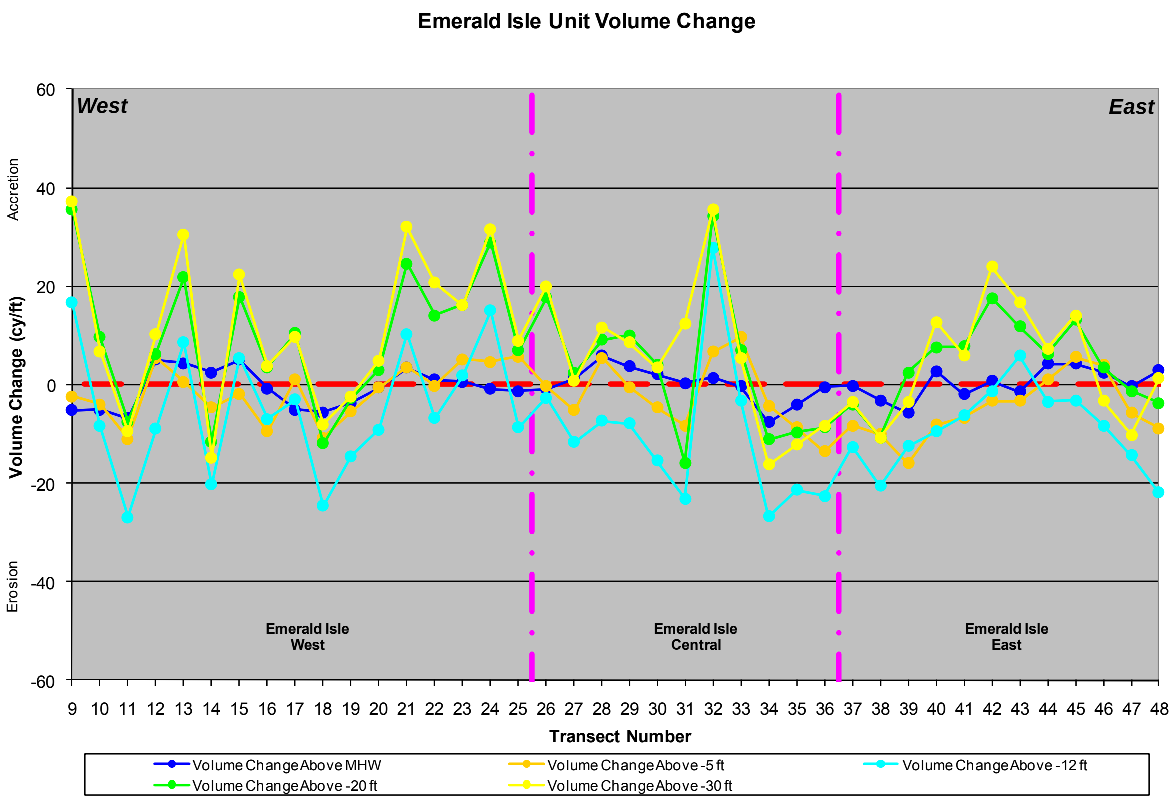

Figure 9. Emerald Isle Unit Volume Change (Summer 2009 - Summer 2010)

5.4.2. Indian Beach/Salter Path

The Indian Beach region covers transects 49 through 58. Since monitoring efforts began in 1999, this region has received 1.36 million cy of nourishment material from the Bogue Banks Beach Restoration Project, USACE Section 933, and FEMA post-storm work (Ophelia). A summary of average shoreline and volume changes between summer 2009 and summer 2010 for the Indian Beach/Salter Path region are presented in **Table 15**.

Table 15. 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	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Indian Beach-Salter Path (49-58)	12,850	-2.8	3.3	42,844	-2.3	-29,370	-9.2	-118,078	4.8	62,224	6.3	80,902

Shoreline change in the Indian Beach/Salter Path area showed a recession of approximately -3 ft between the last two surveys. Profile plots in **Appendix C** show that at transects where recession occurred at MHW, material appears to have been pushed to higher elevations around the berm height (approximately +7 ft NAVD88), possibly resulting from winter storm events. Volumetrically, **Table 15** indicates that the area followed the island wide trend of accretion above MHW, losses above -5 ft NAVD88 and -12 ft NAVD88, and gains above -20 ft NAVD88 and -30 ft NAVD88. The profile plots in **Appendix C** indicate that most of the erosion occurred between 0 and -5 ft NAVD88 and again around -10 ft NAVD88 where the previously muted bar from the 2009 survey has redeveloped and moved slightly seaward, creating a trough approximately 700 ft offshore. **Figure 10** displays the unit volume change at each transect for the Indian Beach/Salter path region. As can be seen, the erosion is slightly worse in the eastern portion of the region.

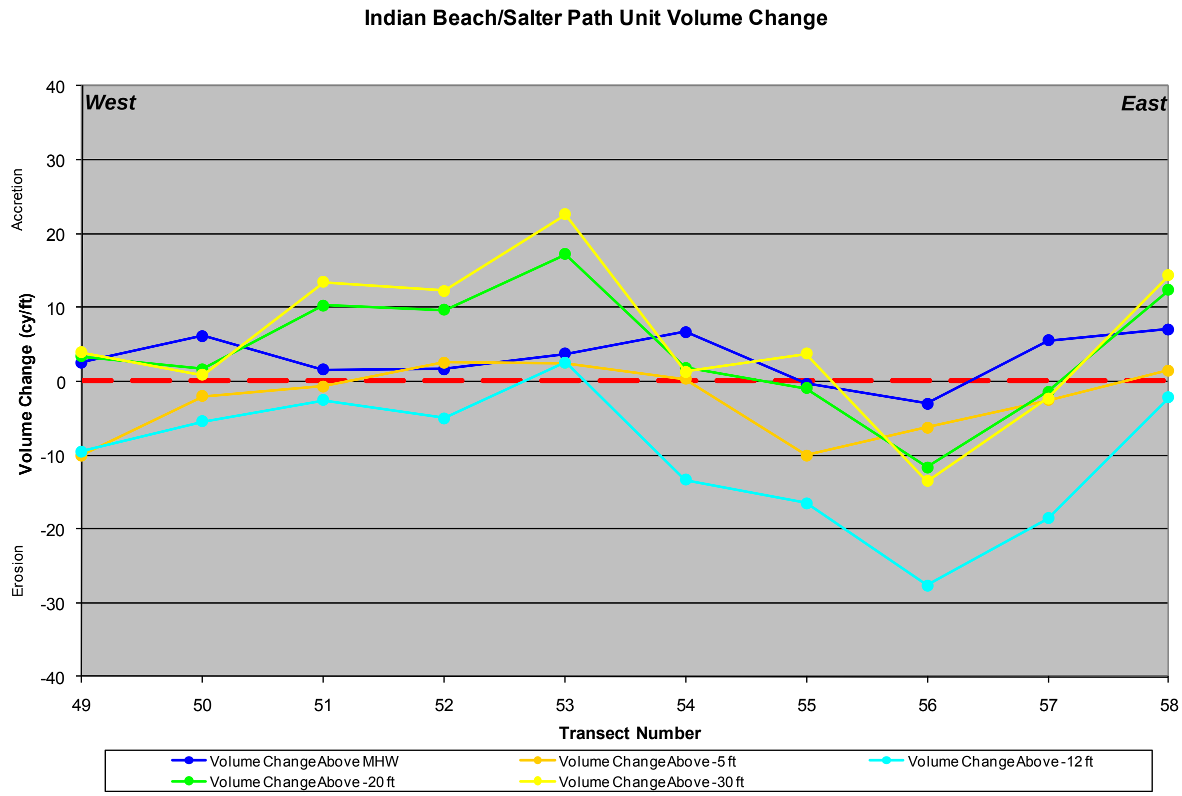

Figure 10. Indian Beach/Salter Path Unit Volume Change (Summer 2009 - Summer 2010)

5.4.3. Pine Knoll Shores

The Pine Knoll Shores region covers transects 59 through 76. Since monitoring efforts began in 1999, the Pine Knoll Shores region has received 2.16 million cy of nourishment material as a result of the Bogue Banks Beach Restoration Project, USACE Section 933, and FEMA post-storm work (Ophelia). A summary of average shoreline and volume changes between summer 2009 and summer 2010 for the Pine Knoll Shores region are presented in **Table 16**.

Table 16. 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	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Pine Knoll Shores-West (59-65)	9,063	-5.8	1.5	13,455	-6.5	-58,859	-7.0	-63,649	10.0	90,337	14.8	134,479
Pine Knoll Shores-East (66-76)	14,815	-3.9	2.0	29,063	-5.4	-80,036	-6.7	-99,297	8.4	124,625	14.1	209,297

The Pine Knoll Shores shoreline showed increased recession between the last two surveys. Profile plots in **Appendix C** show that at transects where recession occurred at MHW, material appears to have been pushed to higher elevations around the berm height (approximately +7 ft NAVD88), possibly resulting from winter storm events. Volumetrically, **Table 16** indicates that the area followed the island wide trend of accretion above MHW, losses above -5 ft NAVD88 and -12 ft NAVD88, and gains above -20 ft NAVD88 and -30 ft NAVD88. The Pine Knoll Shores region as a whole lost approximately -163,000 cy of material above -12 ft NAVD88. **Figure 11** displays the unit volume change at each transect for the Pine Knoll Shores region. Trends appear to be consistent over the entire region, with slightly more erosion at the ends. The profile plots in **Appendix C** show the erosion below 0 ft NAVD88 and seaward movement of the ocean bar as was seen in Indian Beach/Salter Path.

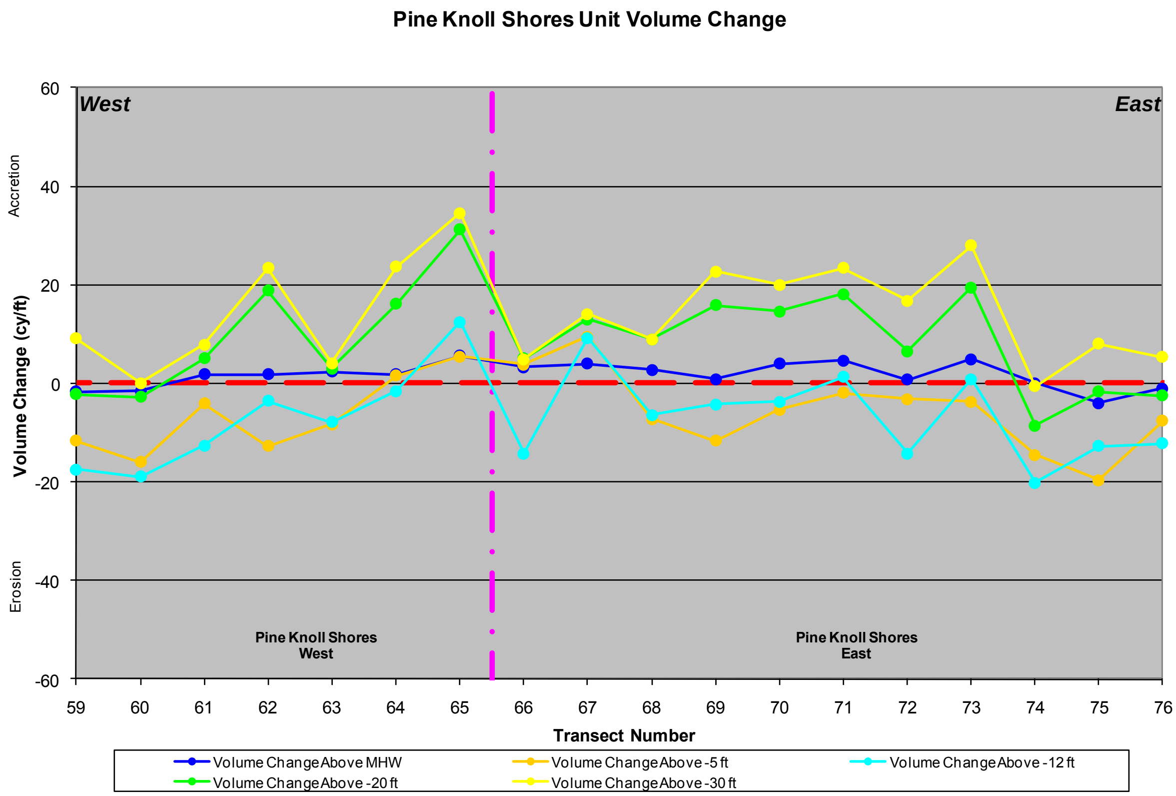

Figure 11. Pine Knoll Shores Unit Volume Change (Summer 2009 - Summer 2010)

5.4.4. Atlantic Beach

The Atlantic Beach region covers transects 77 through 102. Since monitoring began in 1999, the region has received 2.92 million cy of nourishment material from the Brandt Island Pump Out. A summary of average shoreline and volume changes between summer 2009 and summer 2010 for the Atlantic Beach region are presented in **Table 17**.

Table 17. 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	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Atlantic Beach (77-102)	26,176	-7.3	0.4	9,928	-4.7	-121,903	-0.5	-11,803	6.2	162,027	14.7	383,683

Atlantic Beach saw a large landward movement of the shoreline position at MHW between the last two surveys, mostly due to erosion of the beach face below the berm (see **Appendix C**). Volumetrically, **Table 17** indicates that the area followed the island wide trend of accretion above MHW, losses above -5 ft NAVD88 and -12 ft NAVD88, and gains above -20 ft NAVD88 and -30 ft NAVD88. The largest losses in this region occurred above -5 ft NAVD88 (-121,900 cy), with relatively small losses above -12 ft NAVD88 as compared to other regions which saw their largest losses above -12 ft NAVD88. However, this region showed widely varying accretion and erosion along the shoreline. **Figure 12** displays the unit volume change for each transect in the Atlantic Beach region. Highly localized erosion and accretion patterns are present across the entire region with noticeable erosional areas being seen at Transects 84-87, 92-94, and west of Transect 97.

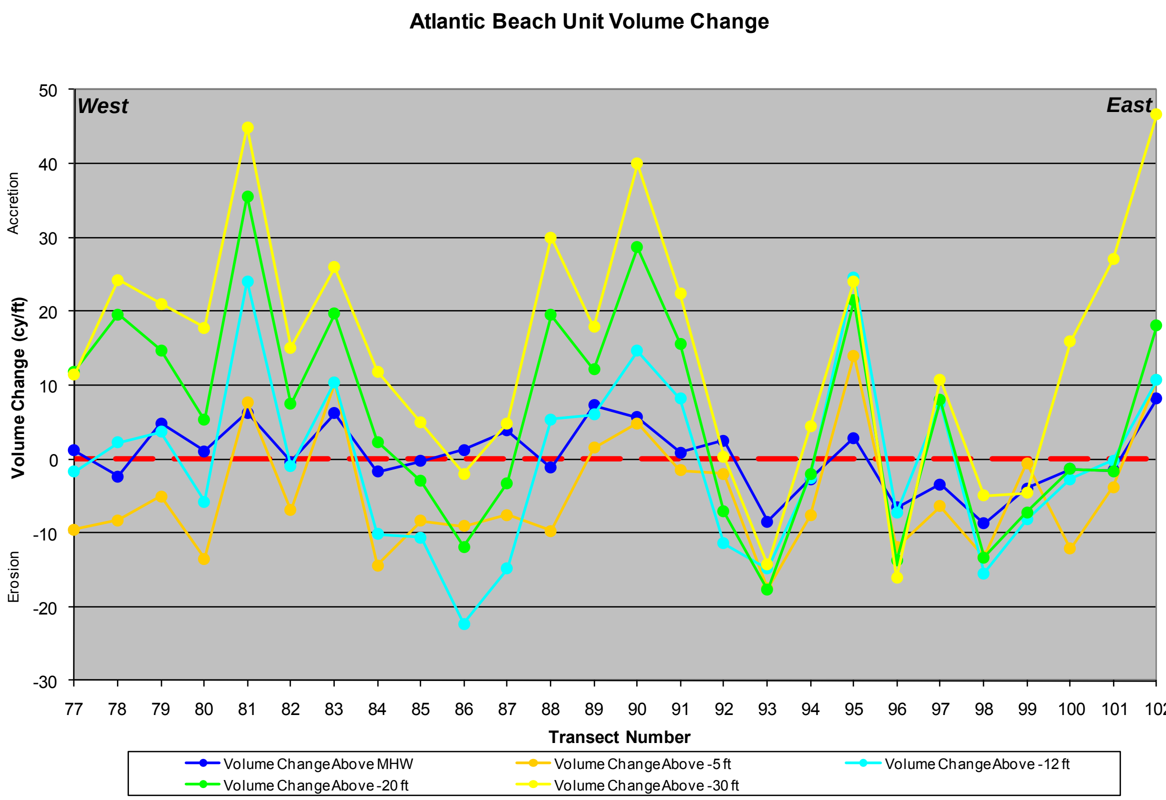

Figure 12. Atlantic Beach Unit Volume Change (Summer 2009 - Summer 2010)

5.4.5. Fort Macon State Park

The Fort Macon State Park region covers transects 103 through 112. Since monitoring began in 1999, this region has received 0.72 million cy of nourishment material from USACE Inner

Harbor Dredging Disposal. A summary of average shoreline and volume changes between summer 2009 and summer 2010 for the Fort Macon State Park region are presented in **Table 18**.

Table 18. 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	avg volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft
Fort Macon State Park (103-112)	6,691	-25.1	-3.6	-23,939	-10.4	-69,465	-6.9	-46,357	8.5	56,756	26.7

Shoreline recession at MHW was the highest at Fort Macon, eroding approximately 25 ft between the last two surveys, which can be attributed to large losses in material below the berm (see **Appendix C**). Volumetrically, Fort Macon State Park showed a similar trend to the western end of the island (Bogue Inlet-Ocean) of erosion above MHW, -5 ft NAVD88, and -12 ft NAVD88 and accretion above -20 ft NAVD88 and -30 ft NAVD88. The profile plots in **Appendix C** show erosion occurring from +5 ft NAVD88 to -10 ft NAVD88 along with drastic changes in the offshore bar. **Figure 13** displays the unit volume change at each transect in the Fort Macon State Park region.

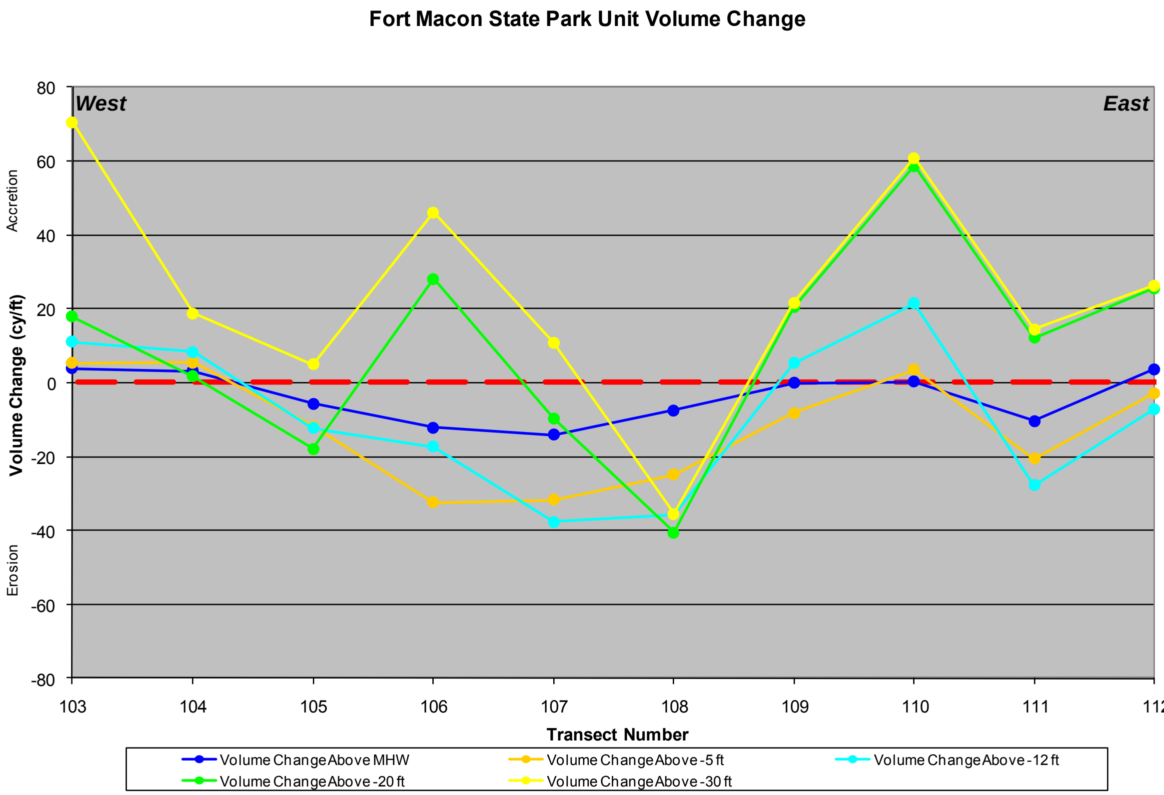

Figure 13. Fort Macon State Park Unit Volume Change (Summer 2009 - Summer 2010)

As noted previously, it appears that the material being lost from the Fort Macon region is moving eastward to Beaufort Inlet. In addition, it is fortuitous that Fort Macon is scheduled for nourishment this winter from the Morehead City Harbor maintenance dredging project.

5.4.6. Bogue Inlet

The Bogue Inlet region is comprised of an area along the oceanfront which covers transects 1 through 8 and an area along the eastern side of Bogue Inlet covering transects 117 through 120. A summary of average shoreline and volume changes between summer 2009 and summer 2010 for the Bogue Inlet region are presented in **Table 19**.

Table 19. 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	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Inlet-Ocean (1-8)	7,432	-10.8	-1.3	-9,356	-3.6	-26,915	-11.2	-82,982	-15.3	-113,534	-14.5	-108,059
Bogue Inlet-Channel (117-120)*	2,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

*Note: Due to the dynamic nature of Bogue Inlet, shoreline and volume calculations were not performed

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**. Due to the quickly changing seaward extents of the shoreline located along the Bogue Inlet Channel region, calculations were not performed at transect 117 through 120. The location of dry land changes so frequently that profiles along Bogue Inlet do not line up appropriately from year to year. However, upon investigation of the profile plots in **Appendix C**, it appears that this area has experienced accretion between +5 ft NAVD88 and -5 ft NAVD88. Although also dynamic, calculations were able to be performed for the Bogue Inlet Ocean region, which saw erosion above all elevations used in the calculations. Slight accretion at the western end is in accordance with the accretion seen on the inlet side of the survey (transects 117-120). Also noticeable is the erosion occurring between Transects 2-4, which could be the source of accretion in the inlet. Profile plots in **Appendix C** show large losses between +5 ft NAVD88 and -10 ft NAVD88. **Figure 14** displays the unit volume change at each transect for the Bogue Inlet Ocean region.

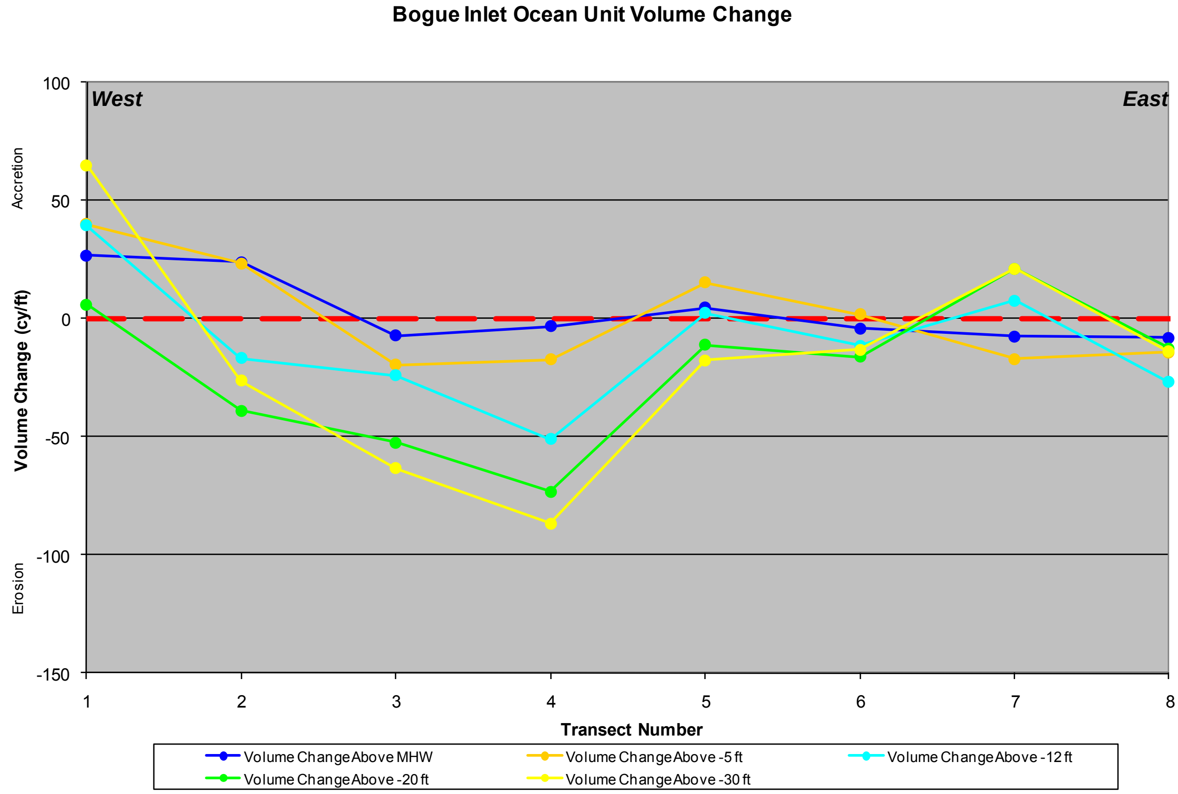

Figure 14. Bogue Inlet Ocean Unit Volume Change (Summer 2009 - Summer 2010)

5.4.7. 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 summer 2009 and summer 2010 for the Beaufort Inlet region are presented in **Table 20**.

Table 20. 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	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Beaufort Inlet (113-116)	2,000	3.7	1.7	3,390	18.3	36,548	37.1	74,157	45.9	91,719	47.5	94,961

Shoreline and volume changes at Beaufort Inlet showed accretion over the past year above all elevations, a different trend than the majority of the island. As mentioned previously, it is likely that material from Fort Macon has been transported eastward to Beaufort Inlet. The region gained approximately 74,000 cy of material above -12 ft NAVD88, a majority of the offshore accretion. Profiles for this region can be seen in **Appendix C**. The shoreline configuration in this area is highly dynamic due to the inlet. **Figure 15** displays the unit volume change at each transect in the Beaufort Inlet region.

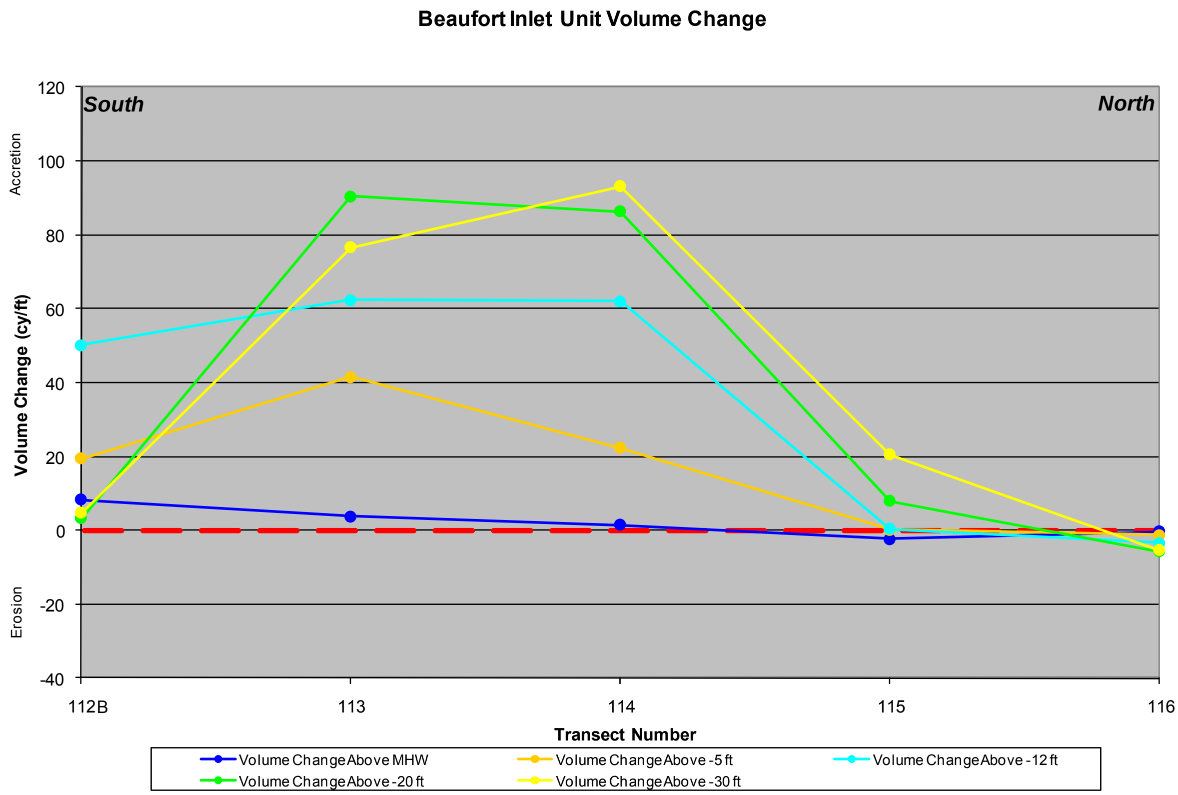

Figure 15. Beaufort Inlet Unit Volume Change (Summer 2009 - Summer 2010)

5.4.8. Bear Island

Bear Island contains 18 transects spaced 1000 ft apart. A summary of average shoreline and volume changes between summer 2009 and spring 2010 for the Bear Island region are presented in **Table 21**.

Table 21. 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	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bear Island (1-18)	16,500	-43.8	-5.2	-85,990	-8.6	-142,070	-9.3	-152,990	10.7	175,984	17.0	280,671

Bear Island experienced similar trends to Bogue Banks with erosion above the upper elevations and accretion above the lower elevations. However, Bear Island experienced the largest amount of recession of the shoreline at MHW, possibly due to the proximity in time of the survey and winter storm events, not allowing for recovery of the shoreline. Profile plots in **Appendix C** show erosion of the beach face between 0 ft NAVD88 and +5 ft NAVD88. Volume change patterns appear fairly stable over most of the island with the exception of the eastern end near Bogue Inlet. This end showed large amounts of accretion offshore which can be seen in the profile plots in **Appendix C**. Accretion near Bogue Inlet was also evident in the previous survey evaluation. It is possible that the dynamic movements of Bogue Inlet are responsible for the accretion seen at the eastern end of Bear Island. It is thought that the channel has been naturally realigning to the east of its current position, causing the ebb shoal material to weld to the eastern end of Bear Island. **Figure 16** 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.

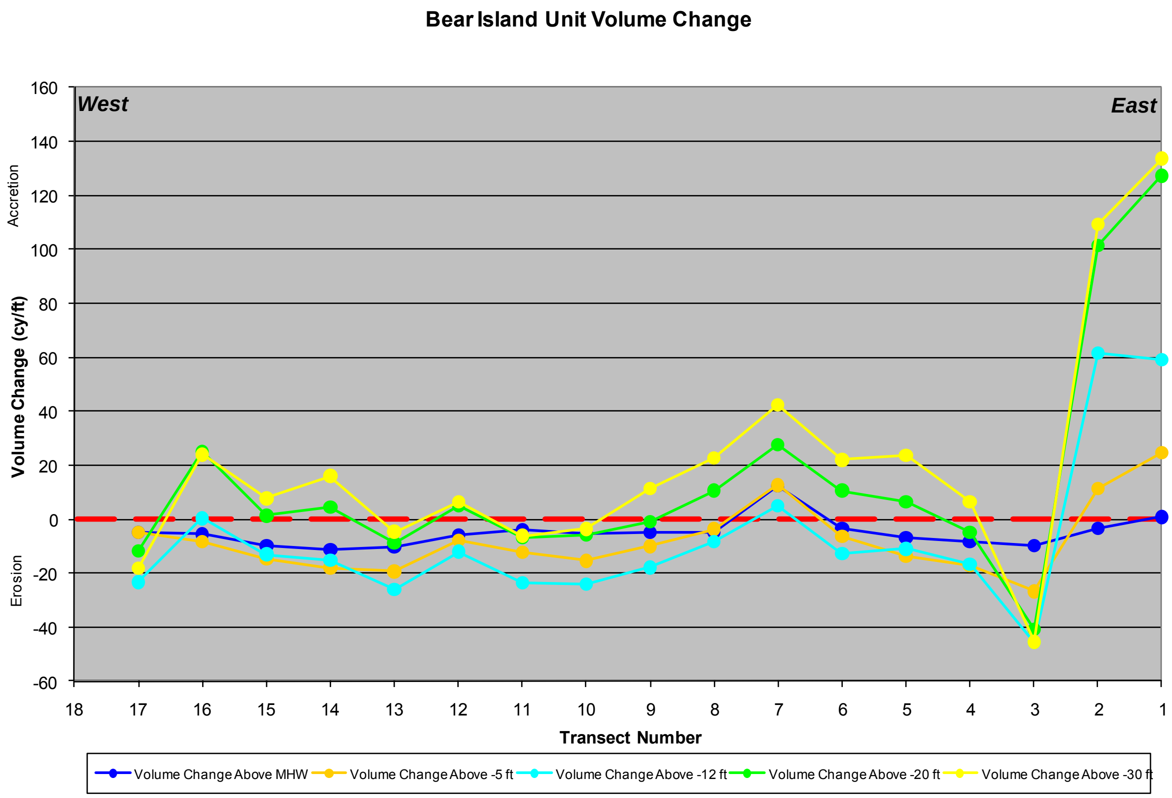

Figure 16. Bear Island Unit Volume Change (Summer 2009 - Spring 2010)

5.4.9. Shackleford Banks

Shackleford Banks is comprised of 24 transects. Shackleford 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 summer 2009 and spring 2010 for the Shackleford Banks region are presented in **Table 22**.

Table 22. 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	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Shackleford Banks (1-24)	46,001	-13.7	-1.9	-86,156	-5.3	-242,629	-8.1	-372,572	-6.1	-282,375	5.7	260,886

Overall, Shackleford Banks experienced shoreline recession and volumetric erosion over the last year. The large amount of shoreline erosion is possibly due to the proximity in time of the survey and winter storm events, not allowing for recovery of the shoreline. The accretion seen in **Table 22** above -30 ft NAVD88 is largely due to one transect (Transect 22) which showed major gains offshore, likely due to inlet influences. **Figure 17** displays the unit volume change at each transect on Shackleford Banks. Patterns are fairly stable along the island as natural erosion processes are at work.

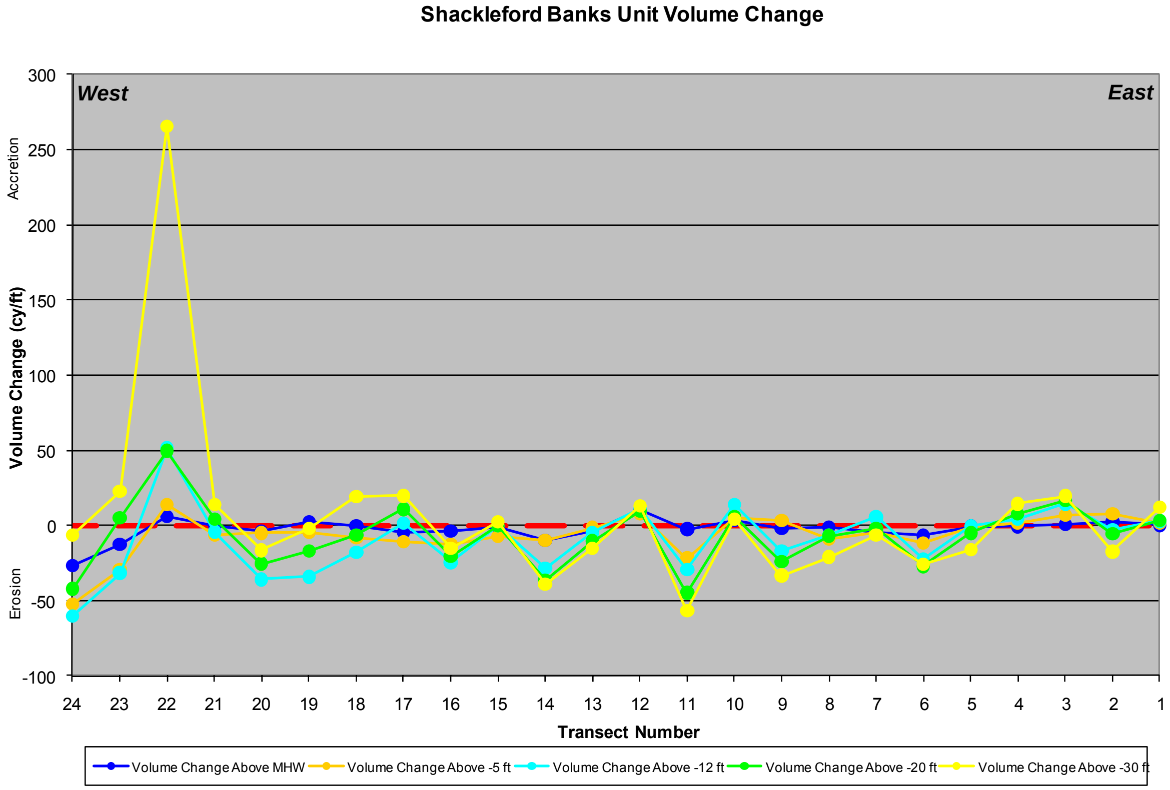

Figure 17. Shackleford Banks Unit Volume Change (Summer 2009 – Spring 2010)

5.5. 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 above -12 ft NAVD88 between the Phase I, Phase II, and Phase III post-nourishment surveys and the summer 2010 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 23** presents the results of the beach maintenance analysis.

Table 23. Percent Fill Remaining from Base Nourishment

Reach	Percent Fill Remaining	
Indian Beach/Salter Path	**193.6**	
Pine Knoll Shores West	*150.0*	**119.0**
Pine Knoll Shores East	*99.7*	
PHASE I	**138.6**	
Emerald Isle Central	*147.3*	**99.8**
Emerald Isle East	*48.0*	
PHASE 2	**99.8**	
Emerald Isle West	**177.1**	
Bogue Inlet	**137.8**	
PHASE 3	**174.5**	

The Emerald Isle East reach only contains 48% of the original fill, which is the lowest of any subunit in the County Project area. However, Emerald Isle East and Emerald Isle Central comprise the entire Phase II management reach for FEMA monitoring and maintenance which contains just under 100% of the original fill volume. This year's monitoring confirms the need for the potential hotspot project for Emerald Isle East being planned, possibly, for the next year.

6.0 Summary

Comprehensive surveying of the Bogue Banks shoreline began in 1999 as a way to formulate 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 annually during each spring/summer timeframe 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 during spring/summer 2010 (April and June 2010) by Geodynamics. For this evaluation, the summer 2009 survey was compared with the spring/summer 2010 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), -20 ft NAVD88 (approximate closure), and -30 ft NAVD88.

Key statistics were computed for defined regions along the Bogue Banks shoreline, Bear Island, and Shackleford Banks between the 2009 and 2010 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	avg volume change above -30 ft NAVD	cumulative volume change above -30 ft NAVD
Reach (Profiles)	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Banks Oceanfront (1-112)	128,393	-4.9	0.4	52,473	-4.0	-519,972	-6.3	-811,170	5.5	710,238	10.0	1,288,351
Bogue Banks County Project (9-76)	88,094	-2.1	0.9	75,840	-3.4	-301,689	-7.6	-670,028	6.9	604,988	9.5	834,091
Bear Island (1-18)	16,500	-43.8	-5.2	-85,990	-8.6	-142,070	-9.3	-152,990	10.7	175,984	17.0	280,671
Shackleford Banks (1-24)	46,001	-13.7	-1.9	-86,156	-5.3	-242,629	-8.1	-372,572	-6.1	-282,375	5.7	260,886

Based on the calculations, the Bogue Banks oceanfront shoreline has experienced recession at MHW over the past year, with the largest landward movements occurring near the inlets in the Fort Macon and Bogue Inlet-Ocean regions. The volumetric numbers indicate that along the oceanfront, the beach has been accretional above MHW, erosional above -5 ft NAVD88 and above -12 ft NAVD88, and accretional above -20 ft NAVD88 and above -30 ft NAVD88. Upon examination of the individual profiles, it appears that the shoreline recession at MHW coupled with volumetric accretion above MHW is due to material around MHW being pushed onshore around the berm height (approximately +7 ft NAVD88), possibly resulting from winter storm events. In addition, uncertainty in hydrographic survey measurements may account for the majority of the offshore accretion seen above -20 ft NAVD88 and -30 ft NAVD88, with a slight upward shift of the 2010 offshore profile visible in many of the profile plots. Nevertheless, of most importance is the storm protection which is approximated by the volume of sand above -12 ft NAVD88. All reaches, with the exception of Bogue Inlet, saw considerable losses above this elevation, totaling -811,170 cy along the Bogue Banks oceanfront and -670,000 cy within the County Project.

Bear Island and Shackleford Banks showed similar trends to Bogue Banks with erosion above higher elevations and accretion offshore. Again, the offshore accretion is likely attributed to survey uncertainty which caused a slight shift in the offshore profiles between 2009 and 2010. Bear Island saw a large amount of shoreline recession at MHW, averaging almost -44 ft across the island. Examination of individual profiles shows significant beachface erosion between 0 ft NAVD88 and +5 ft NAVD88. It should be noted that Bear Island was surveyed in April 2010 and the shoreline may not have recovered from winter storm events. Also of importance is the volumetric accretion seen at the eastern end of Bear Island, possibly caused by the ebb shoal welding to the shore while the remainder of the island saw some erosion. Shackleford Banks, which was also surveyed in April 2010 and maynot have fully recovered from winter storm events, saw significant recession at MHW as well, averaging -14 ft across the island. Erosion of the beachface between 0 ft NAVD88 and +5 ft NAVD88 with large offshore bar changes, especially near Beaufort Inlet, is visible in many of the profiles on Shackleford Banks.

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 reaches within the Phase I and Phase III projects contain more sand than was originally in place after the earlier baseline projects while the Phase II reach contains just under 100% of the sand in place after earlier projects.** Within the Phase II project, Emerald Isle East is in need of nourishment due to a hotspot between Transect 35 (Eastern Ocean Regional Access) and Transect 49 (1,600 ft east of the Emerald Isle border in Indian Beach). While there is evidence of some erosion extending westward into Emerald Isle Central, that reach currently contains sufficient reserve material and is eroding at a slower rate.

As noted, there are inevitable margins of uncertainty associated with hydrographic survey data that may reduce the accuracy of volumetric change analyses. The current estimate of uncertainty in the hydrographic portion of the survey is approximately ±0.11 ft. This results in a variability along the entire Bogue Banks shoreline of roughly ±811,000 cy when taking into account the portion of the profile seaward of the outer bar (approximately 1300 ft offshore) out to a depth of

-30 ft NAVD88 (approximately 2850 ft offshore). 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.