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 the 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 summer 2013 (April, June, and July 2013) by Geodynamics. For this evaluation, the spring/summer 2013 survey was compared with the spring 2012 (March and April 2012) 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 2012 and 2013 survey profiles including;

Key statistics for individual reaches along Bogue Banks were as follows:

The Bogue Banks oceanfront MHW shoreline has advanced seaward over the past year, with the largest advancement at Emerald Isle – East due to the recent nourishment project completed, which placed the most amount of sand within this reach. The County Project experienced more accretion at MHW because the Atlantic Beach reach, which did not receive nourishment, was not included. The volumetric calculations indicate that along the entire oceanfront, the beach has gained sand above MHW, above -5 ft NAVD88, above -12 ft NAVD88, above -20 ft NAVD88, and -30 ft NAVD88. Of most importance is the storm protection approximated by the volume of sand above -12 ft NAVD88. Approximately 1.51 million cy of material was gained above -12 ft NAVD88 along the oceanfront, with 1.43 million cy of that being gained within the County Project area. The recent Post-Irene Renourishment project within the Emerald Isle and Pine Knoll Shores reaches accounts for the majority of this volume gain. However, since 965,011 cy was placed during the Post-Irene Renourishment Project, significant natural recovery has also taken place on the order of approximately 469,250 cy within the County Project and 540,667 cy along the entire island. Please note that approximately 1.4 Mcy was lost above -12 ft NAVD88 within the County Project area during Hurricane Irene.

The Post-Irene Renourishment Project performance was also analyzed by comparing the 2013 data with post-fill surveys taken at the time of the project. It is apparent that some material was lost from the upper elevations of the profile. However, this material has been captured between -12 ft NAVD88 and -16 ft NAVD88 and is still within the system. The profiles adjacent to the nourishment areas were also investigated and it was determined that in most cases, the profile equilibration had already caused material to travel 2-3 transects updrift and downdrift of the placement areas.

Bear Island appears to have minor losses above MHW and above -5 ft NAVD88, and larger losses above -12 ft NAVD88, -20 ft NAVD88, and -30 ft NAVD88. Most importantly, there was a loss of approximately 92,357 cy of sand at -12 ft NAVD88. Profile plots show a majority of this loss of material was accounted for at Transect 1, which is adjacent to Bogue Inlet. Shackelford Banks experienced significant losses above MHW, -5 ft NAVD88, -12 ft NAVD88, -20 ft NAVD88, and -30 ft NAVD88. There was a loss of 559,552 cy of sand above -12 ft NAVD88. Profile plots show that the majority of this loss occurred between Transects 22 and 23, which is adjacent to Beaufort Inlet.

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 components of the Bogue Banks Beach Restoration Project (County Project). It was determined that the Phase I, Phase II, and Phase III project reaches contain more sand than was originally in place after the earlier baseline projects with 131%, 126%, and 216% remaining in each reach, respectively. Within the Phase II project there has been a hotspot which, historically, has shifted back and forth between Transect 32 in Emerald Isle Central and Transect 44 in Emerald Isle East. Of the two subreaches within the Phase II project, Emerald Isle East contains the least amount of original fill material at 84%; however, currently contains sufficient reserve material. While there is evidence of the hotpost drifting into Emerald Isle Central, that reach currently contains sufficient reserve material (165%) as well.

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1.0 Objective

The Bogue Banks Beach and Nearshore Mapping Program (BBBNMP) is sponsored by Carteret County and formally 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 or County 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 the spring/summer timeframe. In addition, Bogue Banks is also surveyed after large storm events to quantify shoreline and volume changes and to augment the municipalities' FEMA reimbursement request for beach nourishment. The most recent regular survey was completed during spring and summer of 2013 (April, June, and July 2013) by Geodynamics LLC (Geodynamics). This report documents the data sources, methods, and results of a survey evaluation performed to compare the spring/summer 2013 survey with a previous survey performed in spring 2012 as well as a comparison of the spring/summer 2013 survey with a post-fill survey after the Post-Irene Renourishment Project to determine how much of the nourishment material is still in the system.

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 (Note: UNC-IMS completed the 2003 work). Each year, comparisons along Bogue Banks were made to an initial survey performed in 1999, providing for 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 were compared to the initial surveys in 2004 and 2005 to provide other 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 (Previous Studies)

	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 (Previous Studies)

	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 Shackleford Banks, Bear Island, and Bogue Banks in April, June, and July 2013. 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 2013 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.

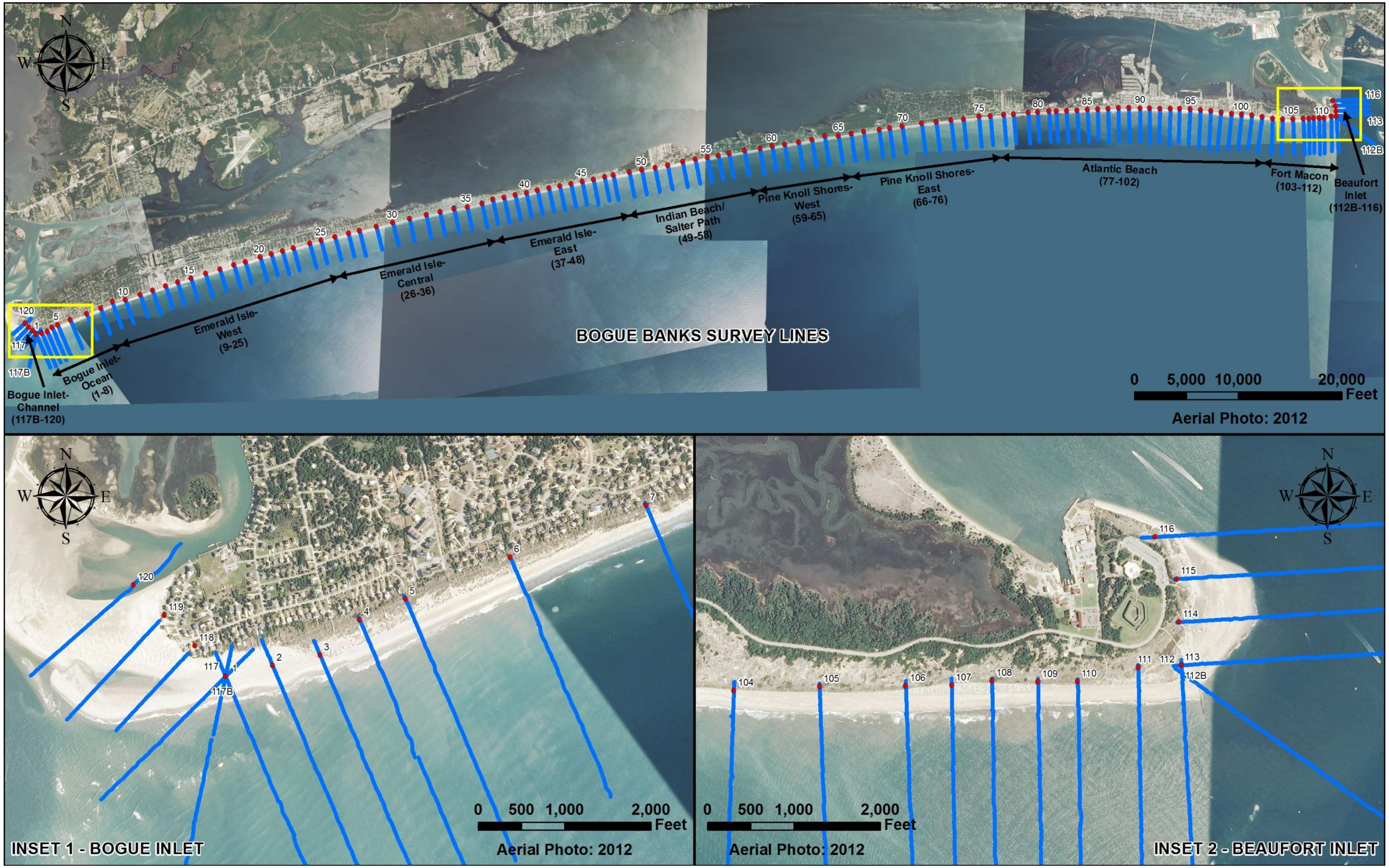

Figure 1. BBBNMP Profile Line Locations – Bogue Banks

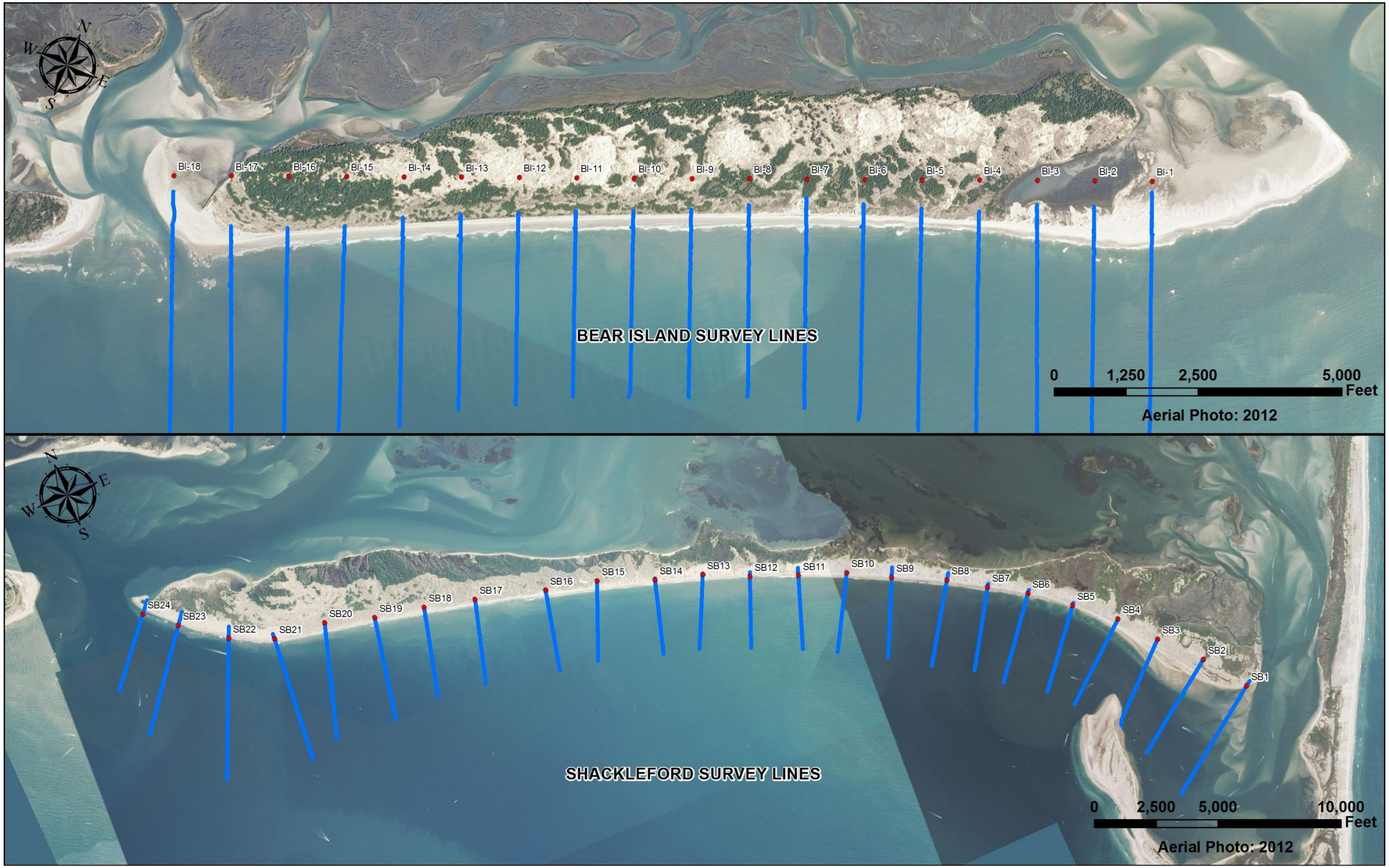

Figure 2. BBBNMP Profile Line Locations – Bear Island and Shackleford Banks

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 Echo served as the survey platform for singlebeam data acquisition (**Figure 3**). The R/V Echo is designed to be a vessel of opportunity for shallow water inshore and coastal ocean mapping. The R/V Echo is a 21 ft Cape Fear Catamaran with through-hull and pole-mount singlebeam sonar capability. The vessel is powered by a 140 hp four-stroke engine mounted on a jack plate to enable ultra shallow water data collection. Data acquisition computers are housed within the water-tight console and are powered through an onboard battery bank. This vessel represents the state-of-the-art in modern hydrographic surveying. The hardware systems inventory for the R/V Echo is shown in **Table 3**.

Figure 3. The R/V Echo 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	2012
	POSView	3.4
Data Processing	HYPACK	2012
	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

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 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**).

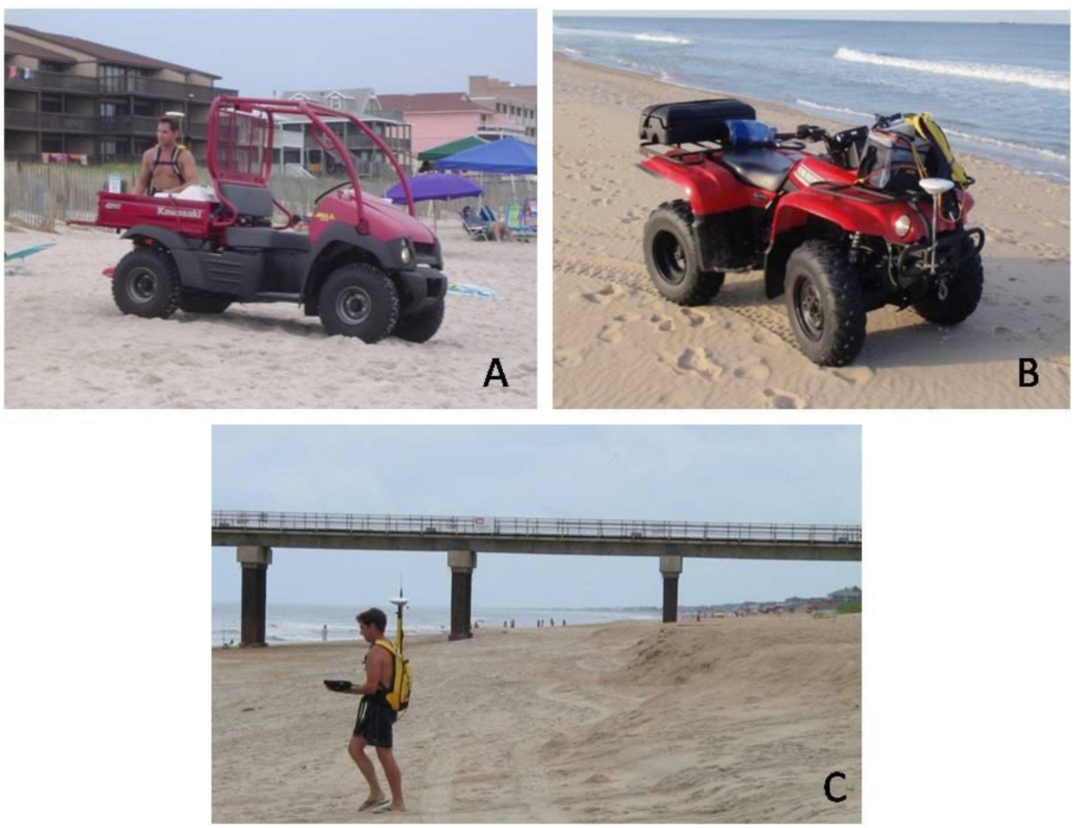

Figure 4. The (A) Kawasaki Mule, (B) Yamaha ATV, and (C)Trimble 5700 RTK-GPS Rover Backpack

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	2012
	GNSS Internet Radio	1.4.11
	VZAccess Manager (Verizon/Quick link)	6.9.0
Data	HYPACK	2012

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 2010 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.

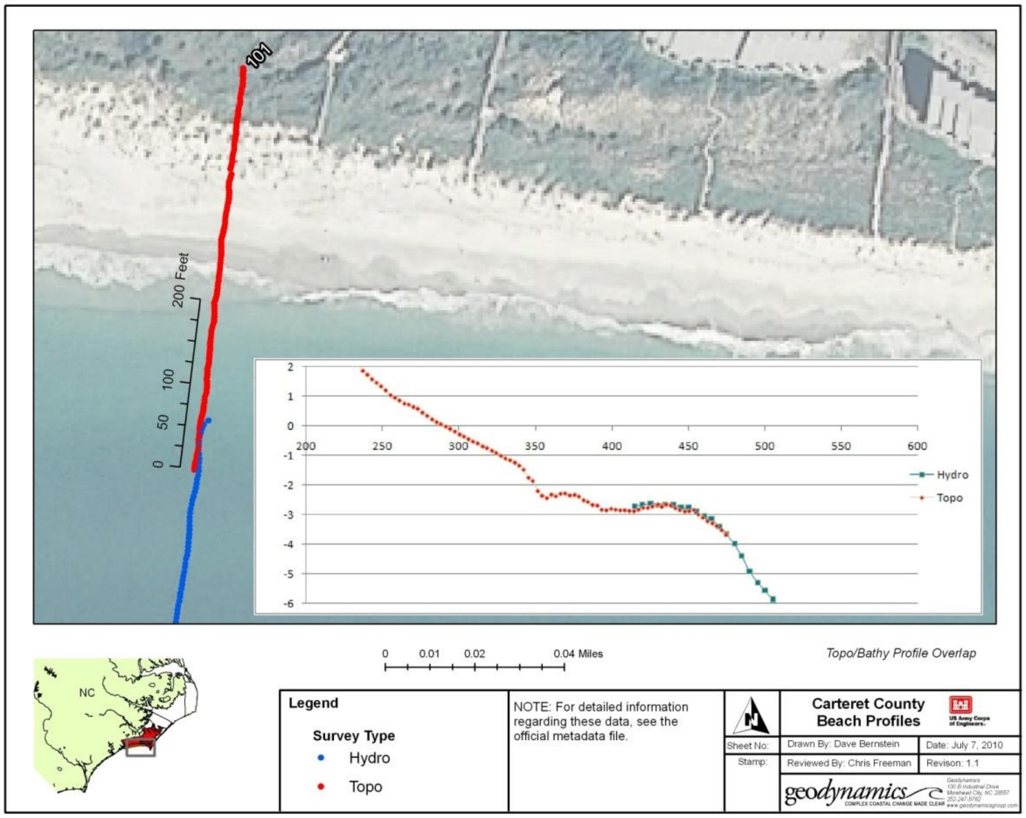

Figure 5. Example of Topographic and Bathymetric Data Overlap in Surfzone

3.5 Survey Data Acquisition Timeline

The most recent survey data was collected by Geodynamics during April July of 2013. The Shackleford Banks survey was done on April 25, 2013 through April 26, 2013. For this report, April 26, 2013 was used as the survey date for all profile lines on Shackleford Banks. Bear Island surveys were performed on July 17, 2013 and July 18, 2013. For this report, July 18, 2013 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 from March 20, 2013 to July 18, 2013. The date used for the Bogue Banks profiles for this report is June 21, 2013 when a majority of the data was collected.

The previous set of regular survey data, used for comparison in this report, was also collected by Geodynamics during March and April of 2012. The Shackleford Banks survey was done on March 19, 2012 through March 20, 2012. For this report, March 20, 2012 was used as the survey date for all profile lines on Shackleford Banks. Bear Island surveys were performed on March 29, 2012 and April 3, 2012. For this report, April 3, 2012 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 from March 23, 2012 to April 13, 2012. The date used for the Bogue Banks profiles for this report is April 11, 2012 when a majority of the data was collected.

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 spring 2012 and spring/summer 2013 beach profiles being used for the comparison were then formatted and imported into 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 spring 2012 and spring/summer 2013 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 spring 2012 and spring/summer 2013. 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. **Figure 6** presents a graphic showing the various calculation lenses.

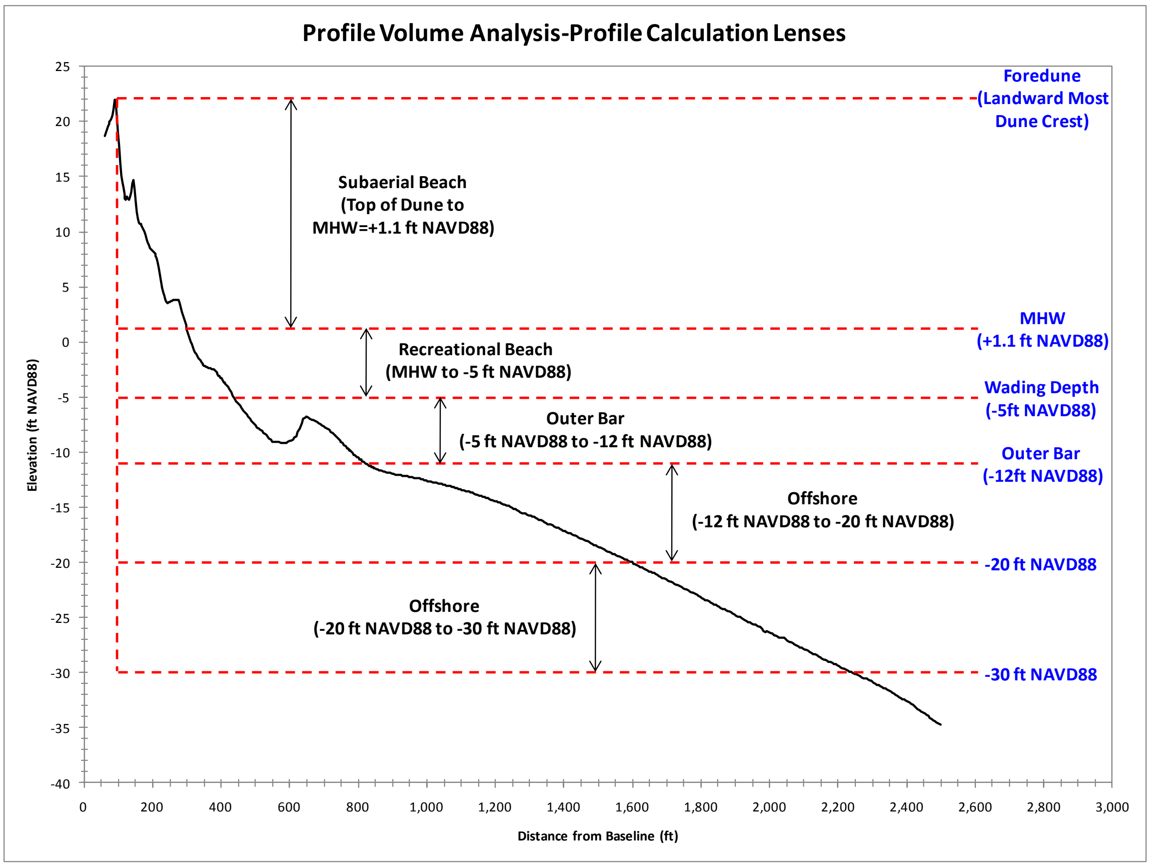

Figure 6. Profile Volume Calculation Lenses

Finally, FEMA beach maintenance calculations were done based on a baseline nourishment condition consisting of the post-nourishment surveys from the County Project. Profile volumes above -12 ft NAVD88 (equal to previously utilized elevation of -11 ft NGVD29) from spring 2012 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 2013.

For visual reference, a Digital Elevation Model (DEM) was created by Geodynamics using Surfer, a 3D surface mapping software package, for both the spring 2012 and spring/summer

2013 profile data. The MHW shoreline position contour was extracted from the spring 2012 and spring/summer 2013 DEMs and plotted on aerials. These figures are presented in **Appendix A**.

5.0 Discussion of Periodic Surveying Evaluation

This section will discuss long-term background erosion rates, recent events (i.e. nourishment projects, storms, etc.), overall shoreline trends, regional shoreline trends, and beach maintenance analysis. Plots of the shoreline and volume changes from spring 2012 and spring/summer 2013, 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 spring 2012, spring/summer 2013, and post-fill where applicable 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**. FEMA beach maintenance calculations for comparison to the original County Project are presented in **Appendix E**.

5.1 Determination of Background Erosion Rate for Bogue Banks

Due to the numerous nourishment projects which have taken place along Bogue Banks since the monitoring program was initiated in 1999, it is important to determine a background erosion rate without nourishment from which to compare the performance of the various projects and to develop long-term trends in volume losses/gains. Therefore, the historical volume changes above -12 ft NAVD88 and beach nourishment volumes were documented. The Bogue Banks area has undergone extensive beach nourishment throughout the duration of the monitoring effort as part of the County Project, the USACE Section 933 Project, USACE Dredge Disposal Projects, and post-storm FEMA work. **Table 7** and **Table 8** summarize the nourishment projects in the study area since the monitoring program was initiated. It should be noted that these tables differ slightly from previous reports due to in depth research regarding the Bogue Banks nourishment history which revealed a few discrepancies, mostly due to discrepancies in reported excavated versus in-place nourishment volumes.

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 (berm)	2003	1,743,788
County Phase 2	Emerald Isle - East & Central (dune)	2003	123,938
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	2,390,000
USACE Disposal	Fort Macon	2005	530,729
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	184,828
AIWW Tangent B Disposal	Pine Knoll Shores East	2008	148,393
USACE Disposal	Atlantic Beach	2011	799,504
USACE Disposal	Fort Macon	2011	547,196
FEMA Post Irene	Pine Knoll Shores & Emerald Isle	2013	965,011
		Total	**12,660,240**

Table 8. Nourishment Volumes by Reach

Reach	Nourishment Volume (cy)
Bogue Inlet - Ocean	59,272
Emerald Isle - West	1,133,823
Emerald Isle - Central & East	2,819,736
Indian Beach/Salter Path	1,358,842
Pine Knoll Shores	2,626,962
Atlantic Beach	3,189,504
Fort Macon	1,472,101
Total	**12,660,240**

To calculate the background erosion rate, nourishment volumes were subtracted from total volume changes above -12 ft NAVD88 between a baseline survey taken in 1999 and the spring 2013 survey. The volume changes were established by adding the yearly volume changes calculated by M&N since 2008 to the volume changes from 1999-2007 calculated in the 2007 monitoring report (CSE 2007). **Table 9** shows the computed volume change (including nourishments) above -12 ft NAVD88 from 1999-2013 for the defined reaches.

Table 9. Volume Change by Reach Above -12 ft NAVD88

Reach	Volume Change (cy) (1999-2007)	Volume Change (cy) (2007-2008)	Volume Change (cy) (2008-2009)	Volume Change (cy) (2009-2010)	Volume Change (cy) (2010-2011)	Volume Change (cy) (2011-2012)	Volume Change (cy) (2012-2013)	Volume Change (cy) (1999-2013)
Bogue Inlet-Ocean	147,797	-218,444	169,134	-82,982	-28,440	-199,903	91,493	-121,346
Emerald Isle West	1,185,131	-107,631	75,690	-107,529	30,257	-264,467	408,863	1,220,313
Emerald Isle Central & East	1,727,705	117,522	-96,085	-281,475	57,244	-293,600	684,367	1,915,678
Indian Beach/ Salter Path	1,155,522	-116,245	-118,761	-118,078	55,234	-163,958	-44,355	649,359
Pine Knoll Shores	1,753,427	-57,453	-53,514	-162,946	-81,597	-313,077	385,385	1,470,225
Atlantic Beach	1,194,947	27,172	-106,720	-11,803	750,462	-530,856	59,686	1,382,887
Fort Macon State Park	221,169	-137,402	-151,048	-46,357	595,792	-167,964	-79,760	234,430
Total	**7,385,698**	**-492,481**	**-281,305**	**-811,170**	**1,378,951**	**-1,933,825**	**1,505,678**	**6,751,547**

Table 10 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 -3.3 cy/ft/yr. This result is slightly lower than last year and more in line with calculations from previous years likely due to natural recovery from Hurricane Irene in August 2011 as well as the effects of the Post-Irene Renourishment Project.

Table 10. Average Annual Background Erosion Rates (1999-2013)

Reach	Length (ft)	Volume Change Above -12 ft NAVD88 (cy) (1999-2013)	Nourishment Volume (cy)	Background Erosion (cy)	Average Annual Background Erosion Rates (cy/ft/yr)
Bogue Inlet-Ocean	7,432	-121,346	59,272	-180,618	-1.74
Emerald Isle West	22,344	1,220,313	1,133,823	86,490	0.28
Emerald Isle Central & East	29,022	1,915,678	2,819,736	-904,058	-2.23
Indian Beach/Salter Path	12,850	649,359	1,358,842	-709,483	-3.94
Pine Knoll Shores	23,878	1,470,225	2,626,962	-1,156,737	-3.46
Atlantic Beach	26,176	1,382,887	3,189,504	-1,806,617	-4.93
Fort Macon State Park	6,691	234,430	1,472,101	-1,237,671	-13.21
Total	**128,393**	**6,751,547**	**12,660,240**	**-5,908,693**	**-3.29**

5.2 Key Events During the Reporting Period

Beach changes are greatly influenced by natural and engineering processes. This section describes key events that occurred during the reporting period that likely had an impact on shoreline change as well as profile volume gains and losses.

5.2.1 Storm Events

The 2012 hurricane season was mild with only one hurricane of significance (Sandy) passing approximately 280 miles east of Cape Hatteras, North Carolina. Hurricane Sandy’s closest position to Bogue Banks was 350 miles east of the island. Sandy was a category one hurricane as it passed North Carolina and generated waves above 14 feet for a duration of 30 hours.

The nor’easter season was slightly more active as compared to the previous year. Wave data indicates seven instances where offshore wave heights reached 12 feet. This is relatively calm compared to other years which have seen some larger nor’easter events where offshore wave heights reached as high as 25 feet, with multiple events of waves over 16 feet.

5.2.2 Nourishment Events

During the 2011-2012 monitoring cycle, Hurricane Irene impacted Carteret County, in particular Bogue Banks. Based on pre- and post-storm monitoring efforts, Moffatt & Nichol determined that Bogue Banks lost approximately 1.4 million cubic yards (cy) of material as a result of the storm. The Federal Emergency Management Agency’s (FEMA’s) Public Assistance Program and the N.C. Division of Emergency Management will reimburse communities for the replacement of sand lost during a federally-declared disaster event provided an original beach nourishment project was predominantly non-federally funded, and project sponsors have developed and adhered to a beach maintenance and monitoring program. Carteret County qualified for this assistance and FEMA approved a reimbursement package to pay for the mobilization/demobilization for the project as well as replace 269,628 cy of sand lost during the Irene storm event across the shorelines of Pine Knoll Shores (PKS) and Emerald Isle (EI) – 112,555 cy and 157,073 cy, respectively. To fully leverage/maximize the high mobilization/demobilization costs associated with beach nourishment projects; the communities of PKS and EI, in cooperation with the County’s Beach Commission/Shore Protection Office, elected to pursue a “delta” component of the project whereby additional funding was provided by the local governments to place an additional 643,537 cy of sand in the three reaches of Pine Knoll Shores, Emerald Isle East, and Emerald Isle West for a total of 913,165 cy. The borrow source for this nourishment effort was the Offshore Dredged Material Disposal Site (ODMDS) associated with Morehead City Federal Navigation Project. This dump site is essentially a repository for dredged material historically extracted from the Outer Harbor reach of the navigation channel. Figure 7 shows the extents of the nourishment project preliminary plan.

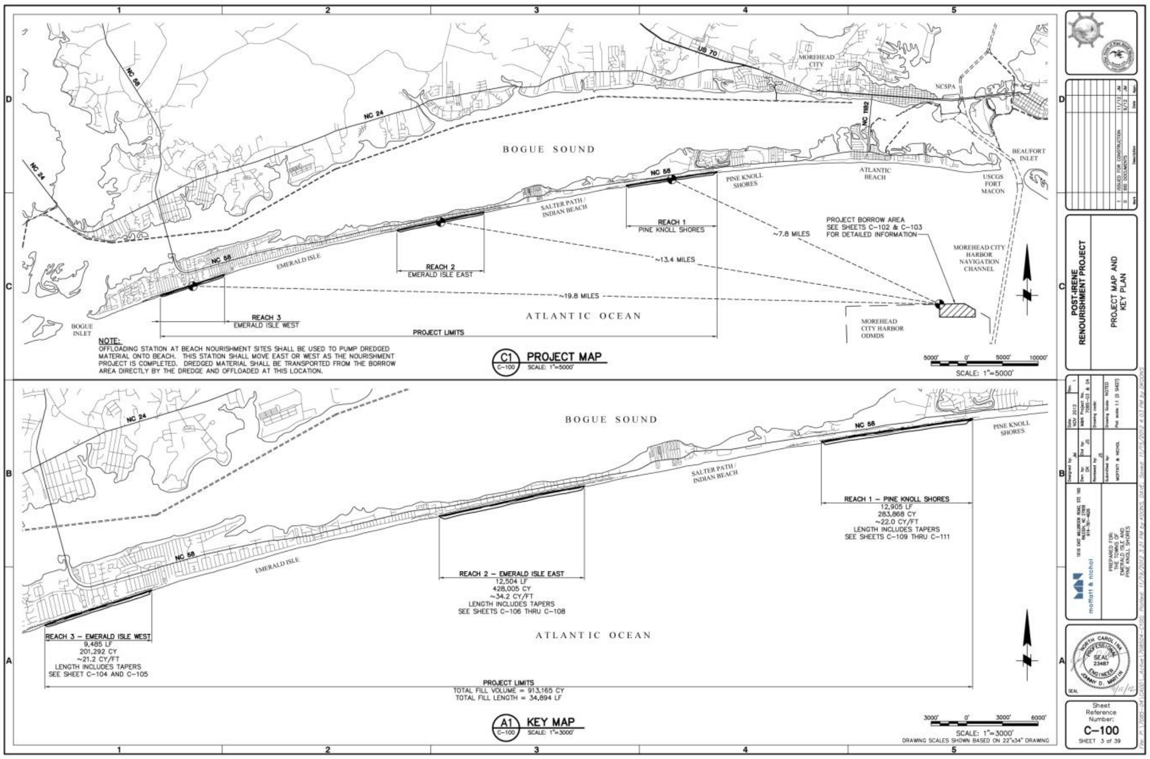

Figure 7. Project Map and Preliminary Plan

The entire project took just under seven weeks and 965,011 cy of material was placed along the three reaches of Bogue Banks. Pine Knoll Shores (Reach 1) received a total of 315,221 cy of material over 12,905 ft of beach for an average of 24.4 cy/ft. Emerald Isle East (Reach 2) received approximately 451,600 cy of material over 12,504 ft of beach for an average of 36.1 cy/ft. Emerald Isle West (Reach 3) received approximately 198,190 cy of material over 9,485 ft of beach for an average of 20.9 cy/ft.

5.3 Regional Shoreline and Volume Trends

Key statistics were calculated to quantify average shoreline and volume changes for each individual shoreline reach as well as the entire 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 reporting period comparison are presented in **Table 11** through **Table 13**. 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 11. Bogue Banks Regional Shoreline and Volume Change Statistics (Spring 2012 – Summer 2013 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	0.3	0.7	5,253	4.1	30,534	12.3	91,493	-7.9	-58,617	-17.3	-128,254
Emerald Isle-West (9-25)	22,344	25.7	6.1	135,315	9.9	221,266	18.3	408,863	19.7	440,559	14.6	326,826
Emerald Isle-Central (26-36)	15,802	23.9	2.7	42,816	5.4	85,715	15.1	238,243	22.2	350,341	14.8	233,761
Emerald Isle-East (37-48)	13,220	36.2	7.7	101,933	18.5	244,190	33.7	446,124	35.7	471,700	30.3	399,929
Indian Beach-Salter Path (49-58)	12,850	15.5	-0.7	-8,959	-2.4	-30,470	-3.5	-44,355	-2.8	-36,464	-13.9	-178,762
Pine Knoll Shores-West (59-65)	9,063	34.7	1.9	17,151	7.7	70,218	9.3	84,184	13.1	118,512	-1.7	-15,830
Pine Knoll Shores-East (66-76)	14,815	35.7	1.8	26,242	10.7	157,819	20.3	301,201	26.0	385,232	17.4	258,264
Atlantic Beach (77-102)	26,176	6.5	0.1	2,384	0.2	6,427	2.3	59,686	2.4	61,779	3.7	96,080
Fort Macon State Park (103-112)	6,691	-28.8	-1.9	-12,695	-4.9	-32,638	-11.9	-79,760	17.3	115,664	19.0	127,038
Beaufort Inlet (113-116)	2,000	67.3	9.8	19,645	24.9	49,849	39.8	79,579	46.4	92,878	50.2	100,387
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	28.1	3.6	314,498	8.5	748,738	16.3	1,434,260	19.6	1,729,881	11.6	1,024,187
Oceanfront (1-112)	128,393	19.1	2.4	309,441	5.9	753,061	11.7	1,505,678	14.4	1,848,706	8.7	1,119,052

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

Table 12. Bear Island Shoreline and Volume Change Statistics (Spring 2012 – Summer 2013 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	-8.6	-1.7	-27,380	-2.1	-34,711	-5.6	-92,357	-8.8	-144,505	-19.8	-326,718

Table 13. Shackleford Banks Shoreline and Volume Change Statistics (Spring 2012 – Spring 2013 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	-31.7	-6.6	-304,088	-11.6	-534,930	-12.2	-559,552	-24.7	-1,136,854	-32.4	-1,488,781

It is apparent from **Table 11** that the Bogue Banks shoreline has experienced advancement at MHW over the past year, primarily due to the impact of the Post-Irene Renourishment project. The volumetric numbers also indicate a gain of sand along the oceanfront above MHW, above -5 ft NAVD88, above -12 ft NAVD88, above -20 ft NAVD88, and above -30 ft NAVD88. Of importance is the storm protection estimated by the volume of sand above -12 ft NAVD88 along the oceanfront. Approximately 1.51 million cy of material was gained above -12 ft NAVD88. The recent nourishment project at Emerald Isle East, Emerald Isle West, and Pine Knoll Shores accounts for the majority of this gain (965,011 cy), but it is also apparent that some delayed recovery after Hurricane Irene has also taken place. Within the County Project, there were large gains in material above MHW, -5 ft NAVD88, and -12 ft NAVD88, which qualifies as storm protection.

Bear Island appears to have experienced a moderate amount of shoreline recession and volume loss over the past year as shown in **Table 12**. After examining the volume change plots in **Appendix B** and profile plots in **Appendix C**, it is apparent that the majority of the losses were located at the transect adjacent to Bogue Inlet below -5 ft NAVD88.

Shackleford Banks appears to have experienced a significant amount of shoreline recession and volume loss, as shown in **Table 13**. The volume change plots in **Appendix B** and profile plots in **Appendix C** indicate that the majority of the volume loss was located adjacent to Beaufort Inlet, including major losses to the dunes. Losses to the beachface and down to the elevation of the outer bar are apparent as well.

Figure 8 and **Figure 9** display the trends seen in **Table 11** through **Table 13** with bar plots of the average unit volume changes and cumulative volume changes at each reach. Apparent from these figures is the significant volume gains seen throughout Emerald Isle and Pine Knoll Shores due to the nourishment project. The Beaufort Inlet reach also experienced volume gains over the past year. This was most likely due to the longshore transport around the terminal groin at Fort Macon.

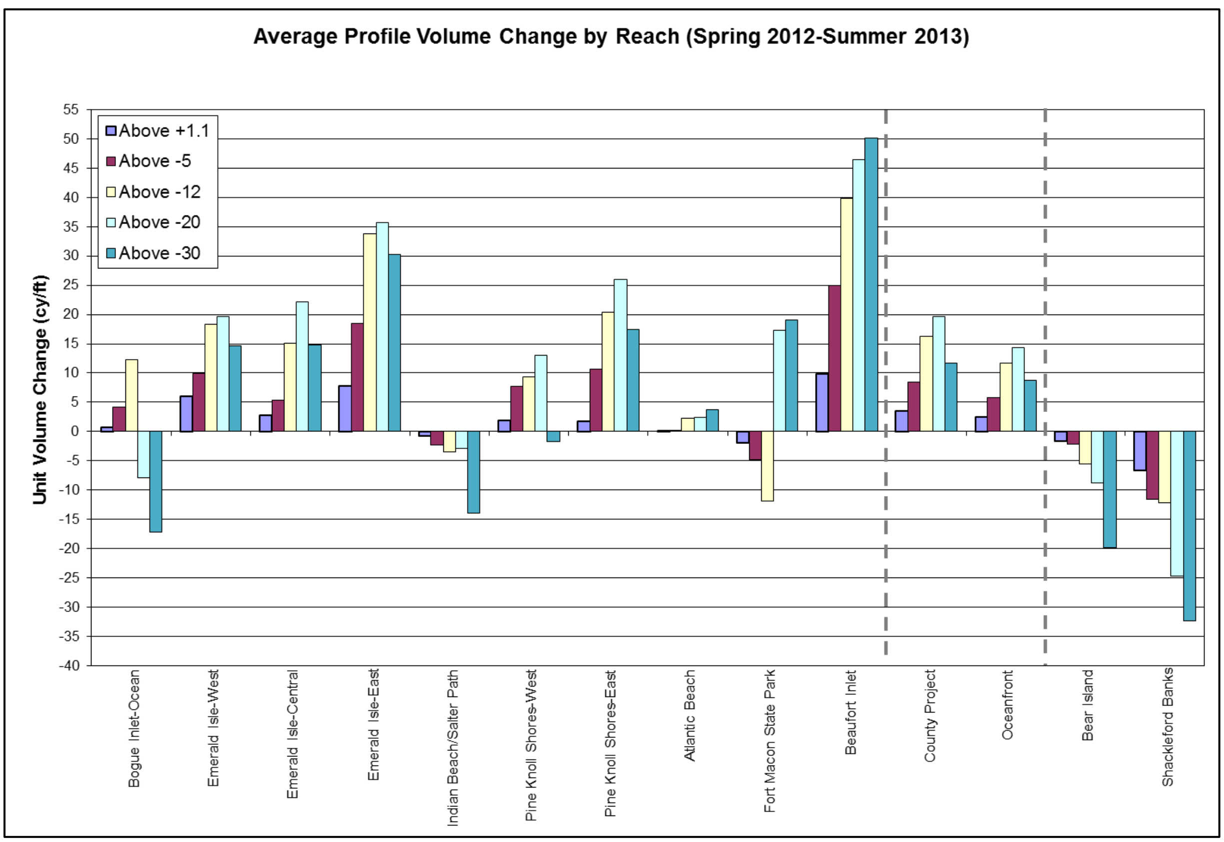

Figure 8. Average Unit Volume Change by Reach

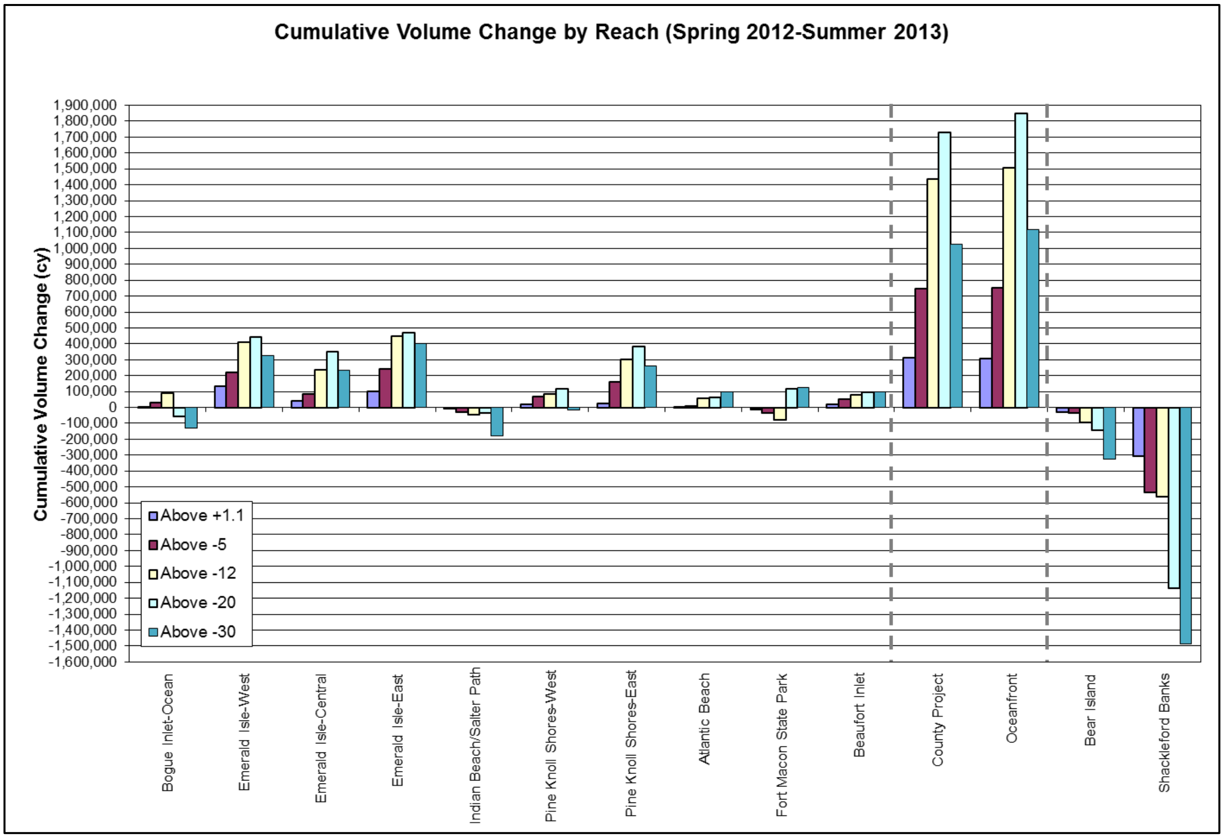

Figure 9. Cumulative Volume Change by Reach

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 County Project. **Figure 10** displays the average profile volume to the outer bar per transect within each reach of shoreline for 2008 - 2013. Values displayed in the graph are tabulated in **Table 14**.

As shown in **Figure 10**, there are currently no reaches along Bogue Banks that are close to the minimum target of 225 cy/ft. The three Emerald Isle reaches currently have the most protection in their respective reaches since 2008.

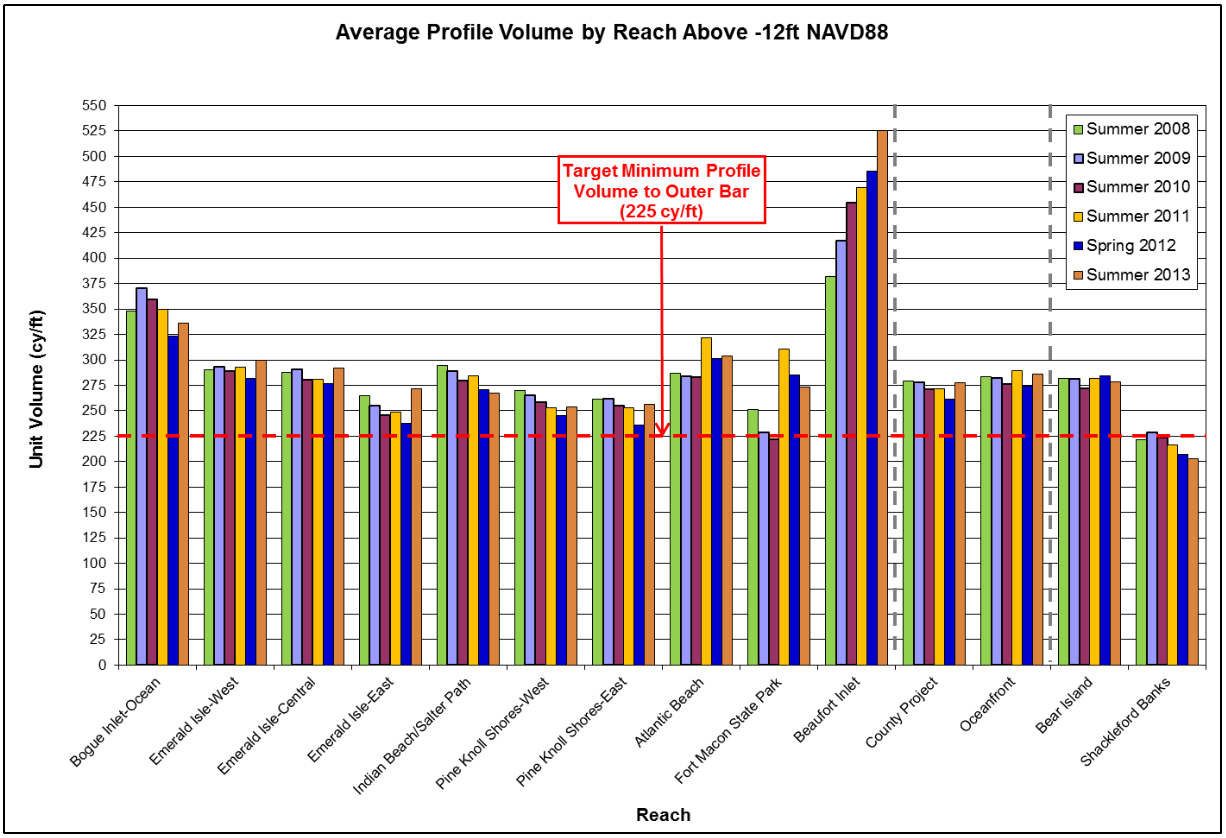

Figure 10. Average Profile Volume From Foredune to Outer Bar by Reach

Table 14. Average Profile Volume From Foredune to Outer Bar by Reach

Reach	July 2008	June 2009	June 2010	June 2011	April 2012	July 2013
Bogue Inlet-Channel (117-120)	N/A	N/A	N/A	N/A	N/A	N/A
Bogue Inlet-Ocean (1-8)	348	371	359	350	323	336
Emerald Isle-West (9-25)	290	294	289	293	282	300
Emerald Isle-Central (26-36)	288	291	280	281	277	292
Emerald Isle-East (37-48)	265	255	245	249	238	271
Indian Beach/Salter Path (49-58)	294	289	280	284	271	268
Pine Knoll Shores-West (59-65)	270	265	258	253	245	254
Pine Knoll Shores-East (66-76)	261	262	255	253	236	256
Atlantic Beach (77-102)	287	284	283	322	302	304
Fort Macon State Park (103-112)	251	229	222	311	286	274
Beaufort Inlet (113-116)	382	418	455	469	485	525
County Project	280	278	271	272	261	277
Oceanfront	284	282	276	289	274	286
Bear Island (1-18)	282	281	272	282	284	279
Shackleford Banks (1-24)	221	229	223	216	207	203

5.4 Local Shoreline and Volume Trends

Local shoreline trends are discussed below for the defined regions of Bogue Banks (**Figure 1**) as well as Bear Island and Shackleford Banks. A summary of the information in **Table 11** through **Table 13** and plots in **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 3.95 million cy of nourishment material as a result of the County Project and FEMA post-storm work (Isabel, Ophelia, and Irene). A summary of average shoreline and volume changes between 2012 and 2013 for the Emerald Isle region are presented in **Table 15**.

Table 15. Average Shoreline and Volume Change for Emerald Isle (2012-2013)

	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	25.7	6.1	135,315	9.9	221,266	18.3	408,863	19.7	440,559	14.6	326,826
Emerald Isle-Central (26-36)	15,802	23.9	2.7	42,816	5.4	85,715	15.1	238,243	22.2	350,341	14.8	233,761
Emerald Isle-East (37-48)	13,220	36.2	7.7	101,933	18.5	244,190	33.7	446,124	35.7	471,700	30.3	399,929

The Post-Irene Renourishment project included two reaches within Emerald Isle. The first reach was located within Emerald Isle West and included Transects 10 through 16. The average placement volume for this reach was 20.9 cy/ft with a total volume placed of 198,190 cy. The second reach was located in both Emerald Isle Central and Emerald Isle East and included Transects 35 through 45. The average placement volume for this reach was 36.1 cy/ft with a total volume placed of 451,600 cy. Shoreline change at MHW showed considerable seaward advancement at all reaches of Emerald Isle, most of which was due to the Post-Irene Renourishment project. Volumetrically, **Table 15** indicates that all reaches of Emerald Isle experienced a gain in sand above all elevations. Most importantly, the Emerald Isle region gained 1.1 million cy of material above -12 ft NAVD88. The largest gains came in Emerald Isle East, where the most material was placed during the Post-Irene project due to the hotspot located within this reach. However, since 649,790 cy was placed during the Post-Irene Renourishment Project, significant natural recovery has also taken place. Lastly, it is interesting to note that the profiles in **Appenidx C** show that the nourishment material has already migrated 2-3 profiles updrift and downdrift of the placement areas.

The hotspot in Emerald Isle historically has drifted between Transect 44 in Emerald Isle East and Transect 32 in Emerald Isle Central, shifting slightly westward over the past few years. The past survey evaluation indicated the hotspot had shifted back to Emerald Isle East between Transects 40 and 44. The current survey indicates some localized volume losses at Transect 21 and 28.

Figure 11 displays the unit volume change at each transect above the five elevations that were analyzed.

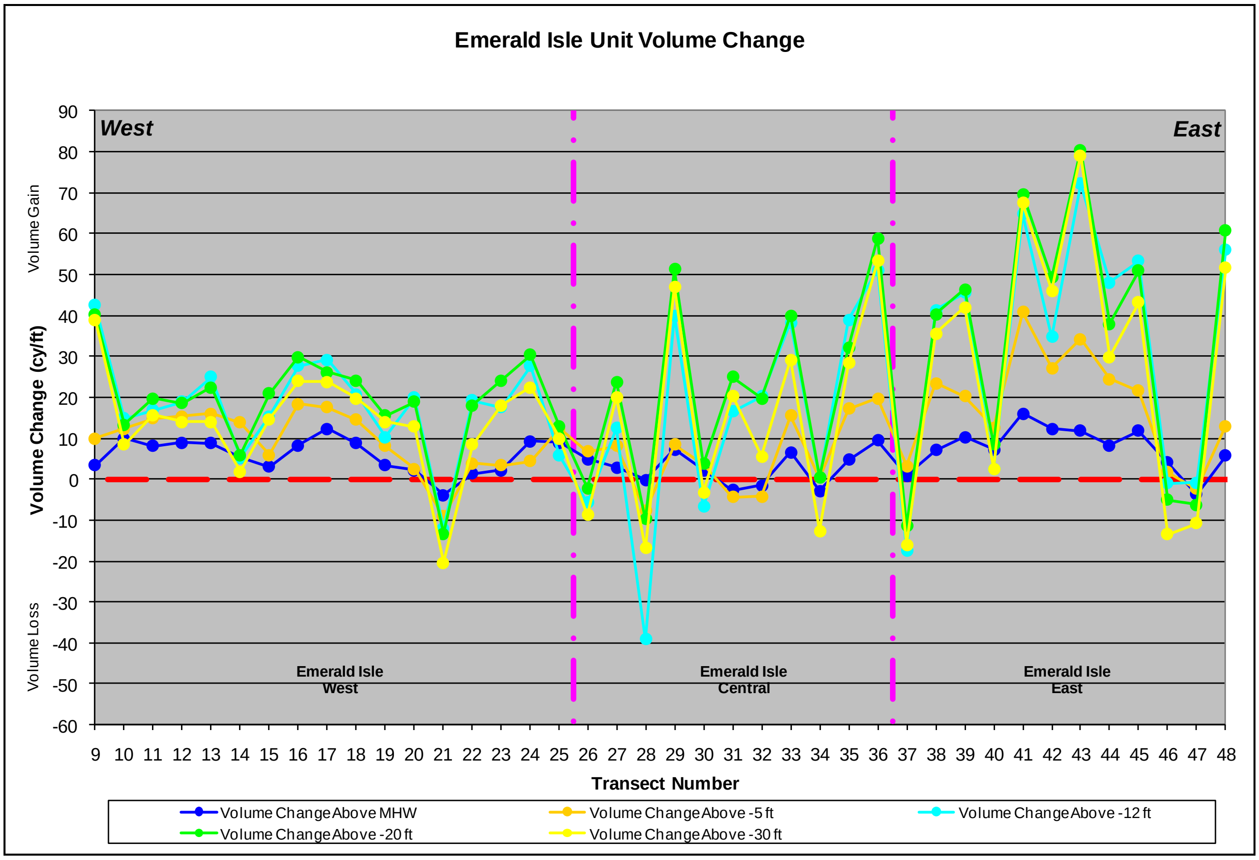

Figure 11. Emerald Isle Unit Volume Change (2012 - 2013)

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 County Project, USACE Section 933, and FEMA post-storm work (Ophelia). A summary of average shoreline and volume changes between 2012 and 2013 for the Indian Beach/Salter Path region are presented in **Table 16**.

Table 16. Average Shoreline and Volume Change for Indian Beach/Salter Path (2012-2013)

	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	15.5	-0.7	-8,959	-2.4	-30,470	-3.5	-44,355	-2.8	-36,464	-13.9	-178,762

As with Emerald Isle, shoreline change at MHW in the Indian Beach/Salter Path area showed seaward advancement of approximately 15.5 ft between the last two surveys. Profile plots in **Appendix C** show the bar in this area has been pushed farther offshore during the past year. Volumetrically, **Table 16** indicates that the Indian Beach/Salter Path area lost material above all elevations over the past year. **Figure 12** displays the unit volume change at each transect for the Indian Beach/Salter path region. The western end of this reach has experienced localized volume gain most likely due to the equilibration of the renourishment project from the Emerald Isle East reach. The eastern end of this reach is characterized by significant volume losses at the lower elevations.

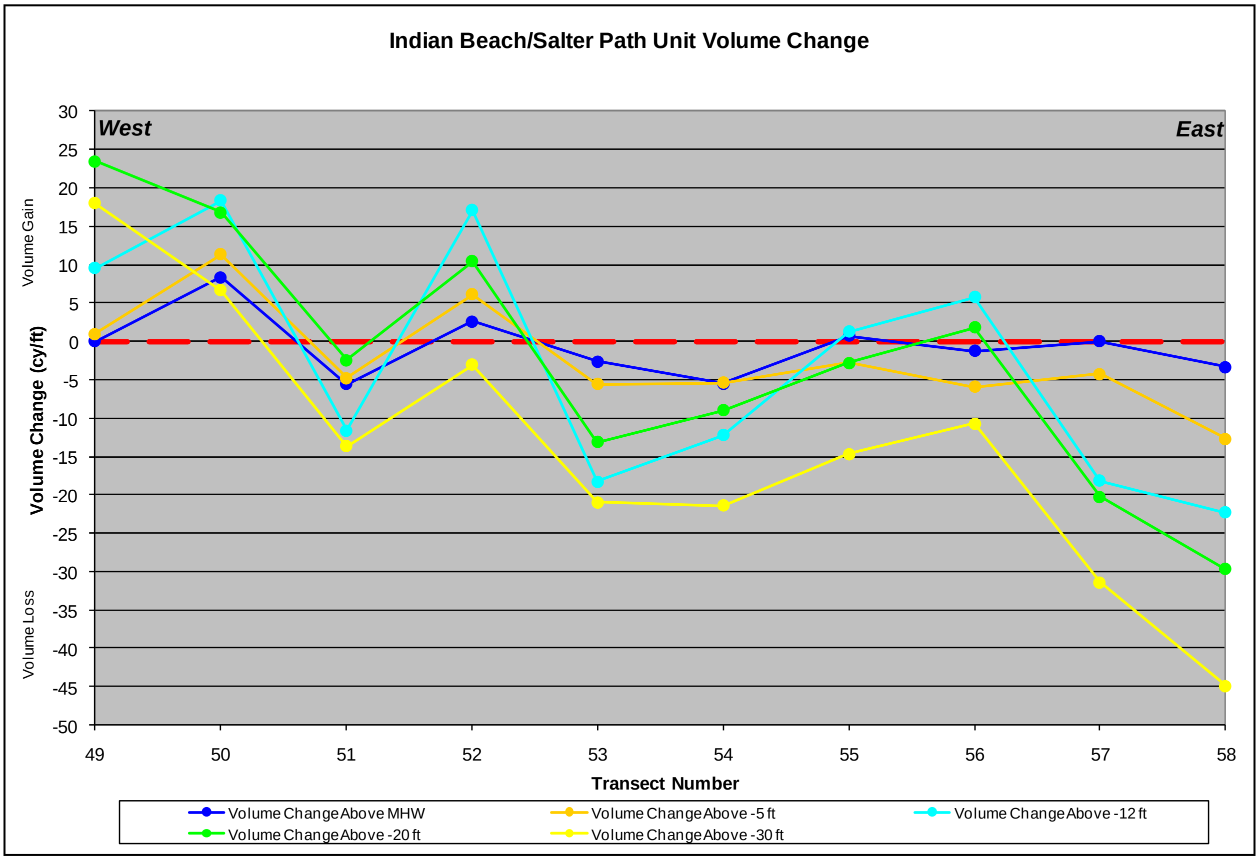

Figure 12. Indian Beach/Salter Path Unit Volume Change (2012 - 2013)

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 2.63 million cy of nourishment material as a result of the County Project, USACE Section 933, and FEMA post-storm work (Ophelia and Irene). A summary of average shoreline and volume changes between 2012 and 2013 for the Pine Knoll Shores region are presented in **Table 17**.

Table 17. Average Shoreline and Volume Change for Pine Knoll Shores (2012-2013)

	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	34.7	1.9	17,151	7.7	70,218	9.3	84,184	13.1	118,512	-1.7	-15,830
Pine Knoll Shores-East (66-76)	14,815	35.7	1.8	26,242	10.7	157,819	20.3	301,201	26.0	385,232	17.4	258,264

The Post-Irene Renourishment project included one reach that spanned between both Pine Knoll Shores West and East, which included Transects 62 through 71. The average placement volume for this reach was 24.4 cy/ft with a total volume placed of 315,221 cy.

Shoreline change at MHW showed considerable seaward advancement within each reach of Pine Knoll Shores, most of which was due to the Post-Irene Renourishment project. Volumetrically, **Table 17** indicates that Pine Knoll Shores West experienced an overall gain in sand above all elevations except above -30 ft NAVD88. Pine Knoll Shores East experienced an overall gain in sand above all elevations. Most importantly, the entire Pine Knoll Shores region gained 385,385 cy of material above -12 ft NAVD88. **Figure 13** displays the unit volume change at each transect for the Pine Knoll Shores region. The equilibration of the nourishment can be seen on this figure as well, with sediment moving outside of the nourishment extents. Transect 63 has experienced a significant amount of erosion which can be seen in **Figure 13** and confirmed by the profile plots in **Appendix C** (note that offshore bar is not as shallow or as nearshore as surrounding areas). A majority of the sediment at this location has most likely moved alongshore and caused the volume gains at Transect 61.

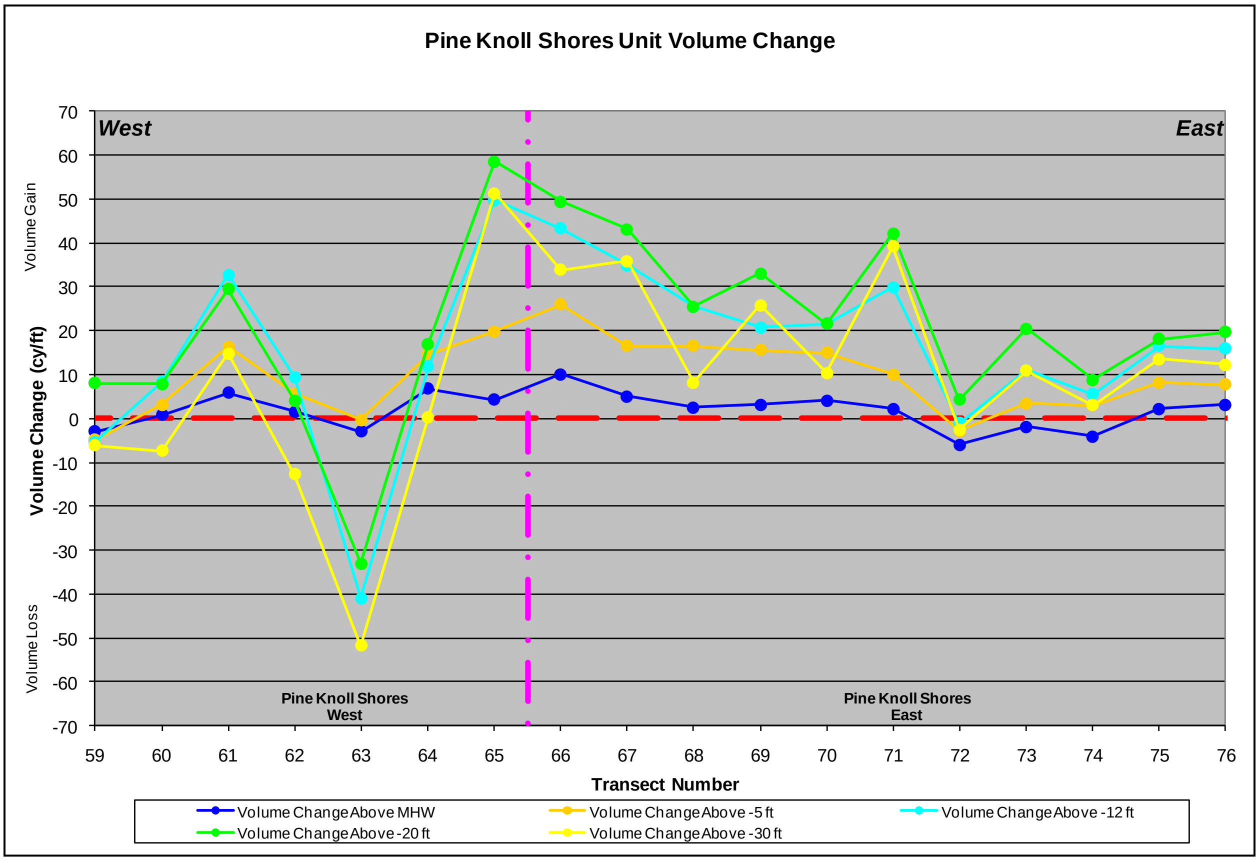

Figure 13. Pine Knoll Shores Unit Volume Change (2012 - 2013)

5.4.4 Atlantic Beach

The Atlantic Beach region covers Transects 77 through 102. Since monitoring began in 1999, the region has received 3.19 million cy of nourishment material from the Brandt Island Pump Out and USACE dredge disposal. Most recently, approximately 800,000 cy of material was placed on Atlantic Beach in winter 2010-2011 as Year 1 of the USACE Interim Operation Plan for the Morehead City Harbor Federal Navigation Project. A summary of average shoreline and volume changes between 2012 and 2013 for the Atlantic Beach region are presented in **Table 18**.

Table 18. Average Shoreline and Volume Change for Atlantic Beach (2012-2013)

	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	6.5	0.1	2,384	0.2	6,427	2.3	59,686	2.4	61,779	3.7	96,080

Atlantic Beach experienced a seaward shoreline advancement at MHW of 6.5 ft over the past year. Volumetrically, the reach had minor gains above each elevation between 2012 and 2013, and specifically gained 59,686 cy/ft of sand above -12 ft NAVD88. **Figure 14** displays the unit volume change for each transect in the Atlantic Beach region. The majority of the Atlantic Beach reach experienced volume gain; however, the most notable volume losses occurred between Transect 98 and 100 which is at the nodal point location estimated in past studies by both the USACE and Olsen Associates.

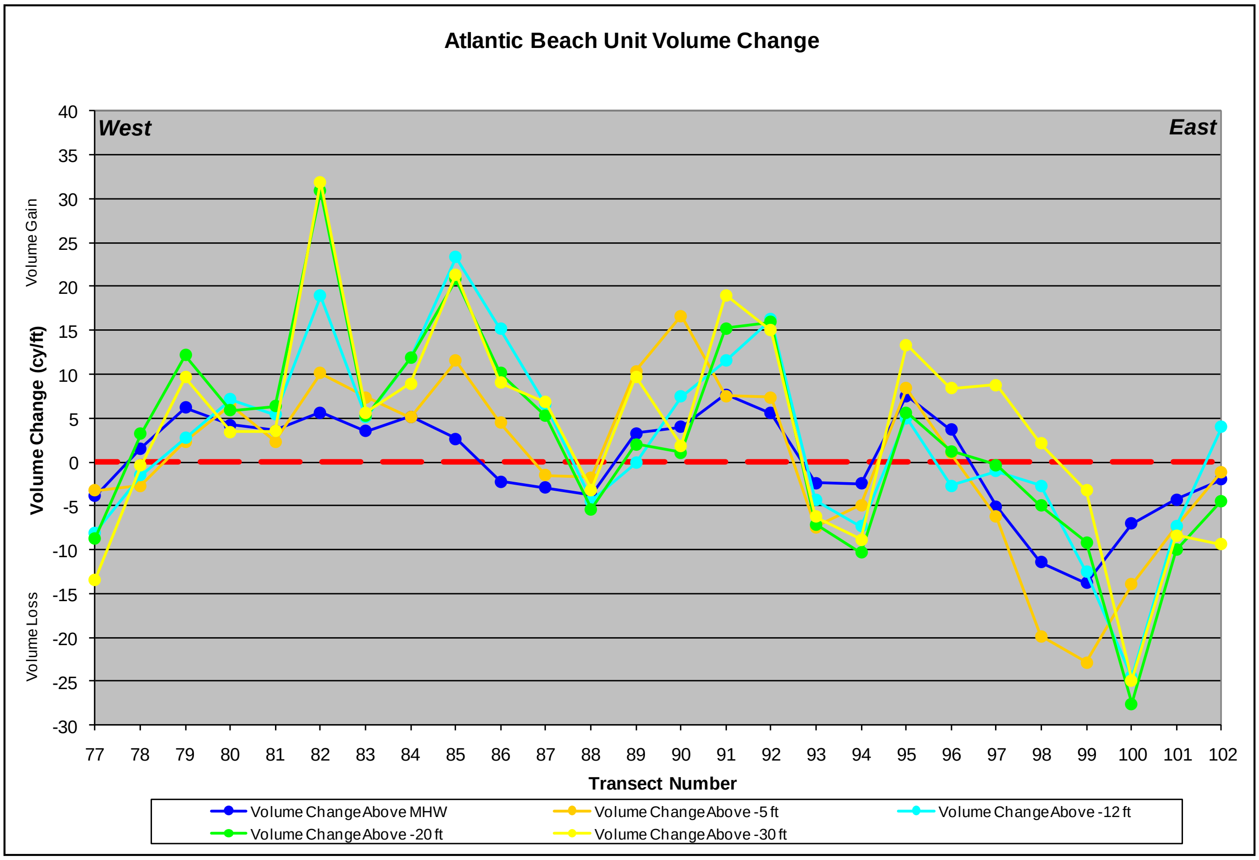

Figure 14. Atlantic Beach Unit Volume Change (2012 - 2013)

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 1.47 million cy of nourishment material from USACE Inner Harbor Dredging Disposal. Most recently, 547,000 cy of material was placed on Fort Macon from November 2010 to April 2011 as part of the Year 1 USACE Interim Operation Plan for the Morehead City Harbor Federal Navigation Project. A summary of average shoreline and volume changes between 2012 and 2013 for the Fort Macon State Park region are presented in **Table 19**.

Table 19. Average Shoreline and Volume Change for Fort Macon State Park (2012-2013)

	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
Fort Macon State Park (103-112)	6,691	-28.8	-1.9	-12,695	-4.9	-32,638	-11.9	-79,760	17.3	115,664	19.0	127,038

Fort Macon State Park experienced 28.8 ft of shoreline recession over the past year. Volumetrically, the reach had losses in material above upper elevations but gains in material at deeper elevations between 2012 and 2013. **Figure 15** displays the unit volume change at each transect in the Fort Macon State Park region. The eastern end of this reach is characterized by large volume gains at the lower elevations. Profile plots in **Appendix C** show that this gain was not from nearshore sand moving offshore but, most likely, came from the Beaufort Inlet complex.

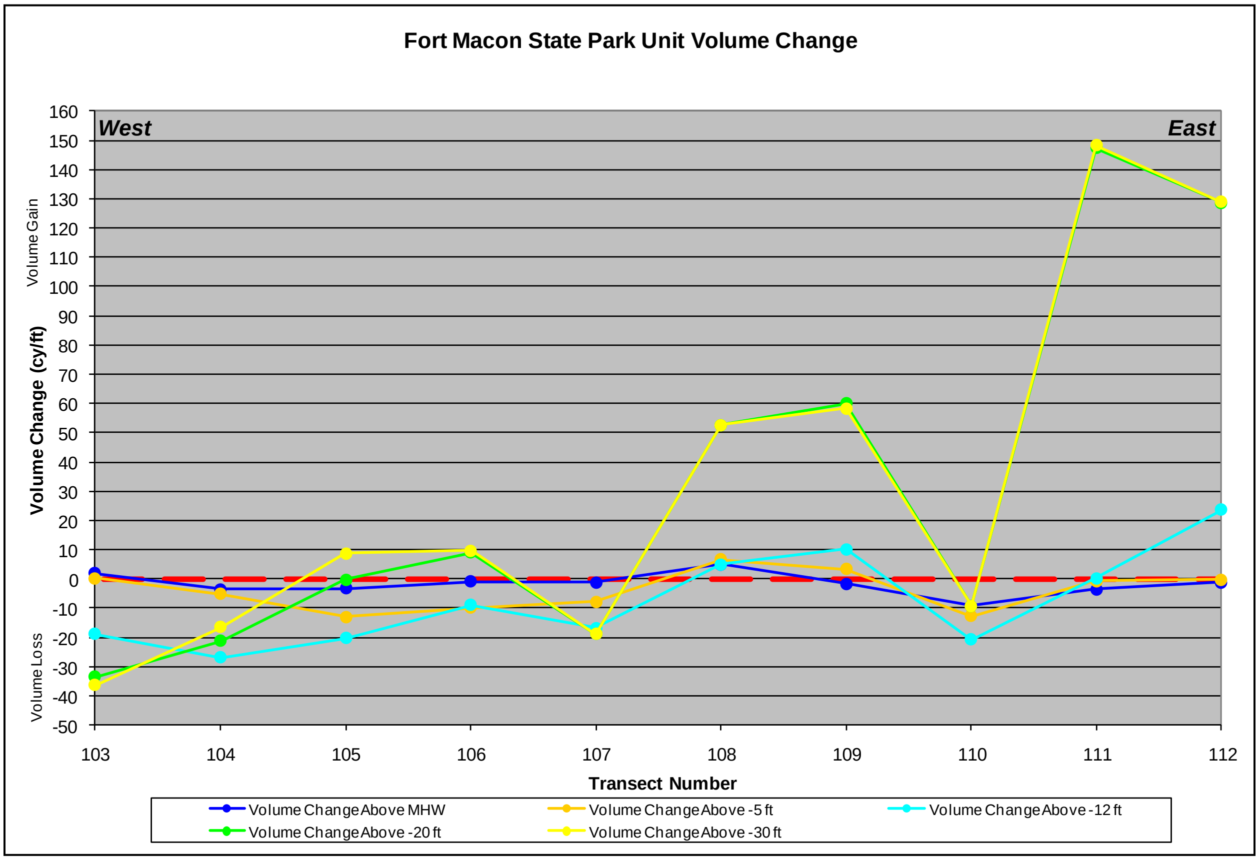

Figure 15. Fort Macon State Park Unit Volume Change (2012 - 2013)

5.4.6 Bogue Inlet

The Bogue Inlet region is comprised of an area along the western terminus of Bogue Banks 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 2012 and 2013 for the Bogue Inlet region are presented in **Table 20**.

Table 20. Average Shoreline and Volume Change for Bogue Inlet (2012-2013)

	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	0.3	0.7	5,253	4.1	30,534	12.3	91,493	-7.9	-58,617	-17.3	-128,254
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 MHW shoreline located along the Bogue Inlet-Channel region, analytical calculations were not performed at Transect 117 through 120. The location of dry land changes so frequently that profiles along Bogue Inlet often do not line up properly from year to year and due to the growth of the spit, the profiles only exist at shallow elevations, often barely reaching MHW. However, upon investigation of the profile plots in **Appendix C**, it appears that the area along the shoulder of the inlet (Transects 117 and 117B) has gained sand over the past year. Although also dynamic, calculations were able to be performed for the Bogue Inlet-Ocean region, which saw volumetric gains at the upper elevations. Most importantly, this region gained 91,493 cy/ft of sand above -12 ft NAVD88. **Figure 16** displays the unit volume change at each transect for the Bogue Inlet Ocean region. It can be seen that the majority of the volume gain within this region was located at Transect 1, which is highly influenced by Bogue Inlet.

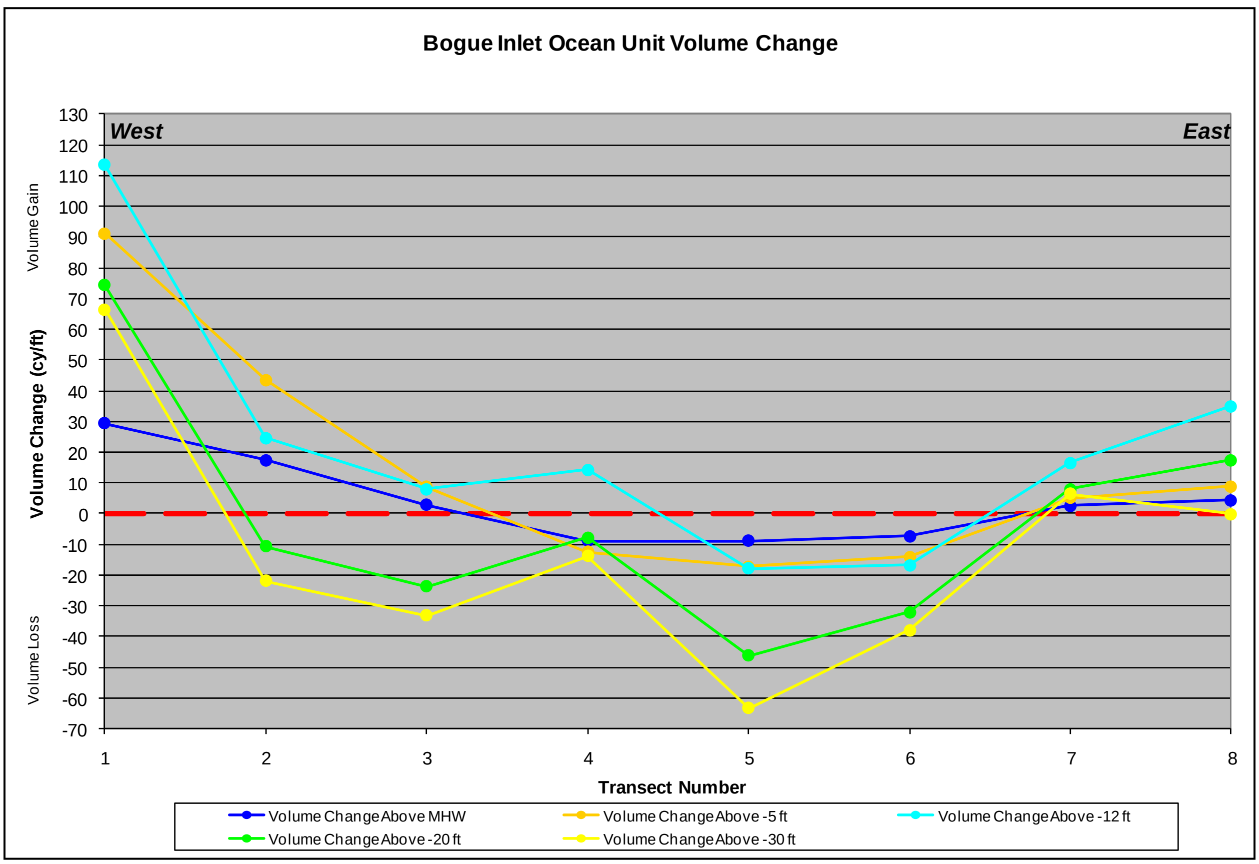

Figure 16. Bogue Inlet Ocean Unit Volume Change (2011 - 2012)

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 2012 and 2013 for the Beaufort Inlet region are presented in **Table 21**.

Table 21. Average Shoreline and Volume Change for Beaufort Inlet (2012-2013)

	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	67.3	9.8	19,645	24.9	49,849	39.8	79,579	46.4	92,878	50.2	100,387

Shoreline changes at MHW showed a large seaward advancement of approximately 67.3 ft and volume changes at Beaufort Inlet showed volume gain over the past year above all elevations. It is likely that material from Fort Macon has been transported alongshore to supply these gains. Profiles for this region can be seen in **Appendix C**. The shoreline configuration in this area is highly dynamic due to the inlet. **Figure 17** displays the unit volume change at each transect in the Beaufort Inlet region.

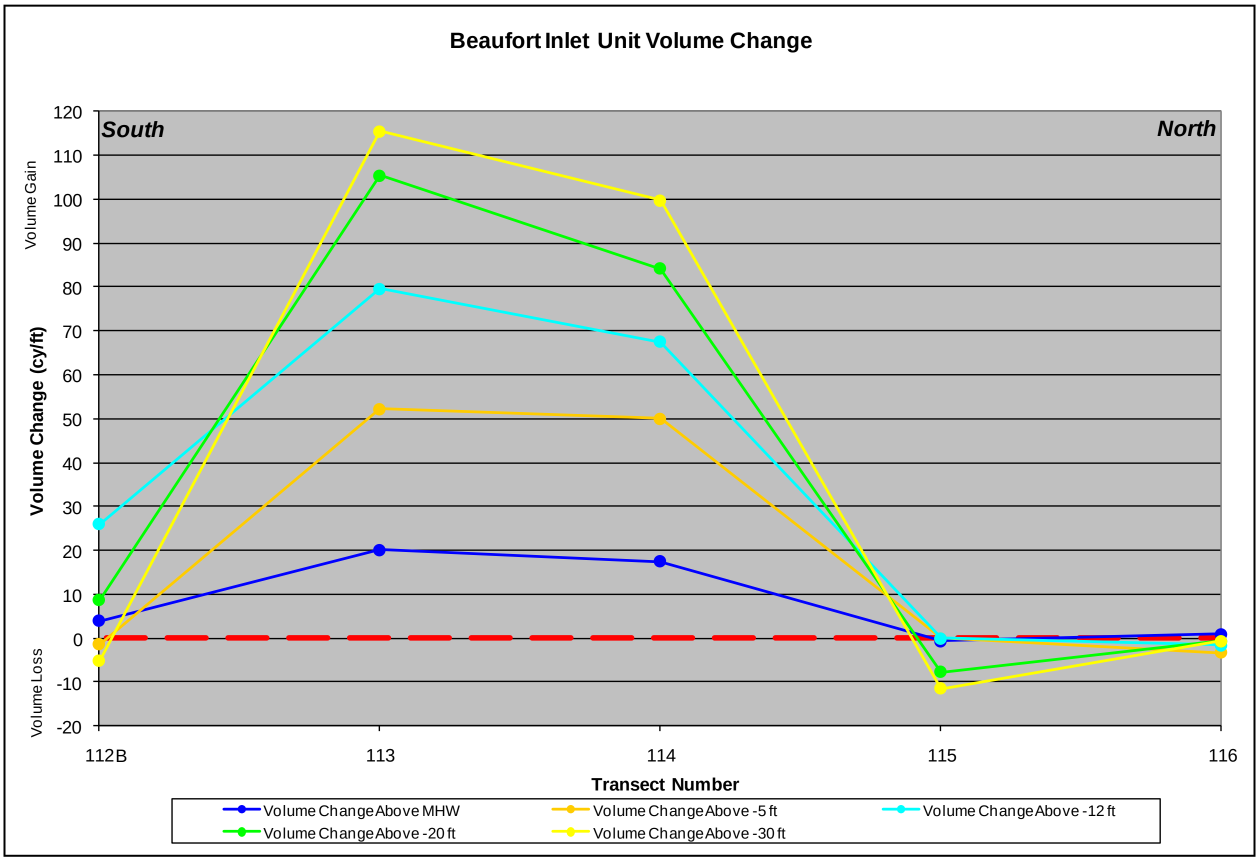

Figure 17. Beaufort Inlet Unit Volume Change (2012 - 2013)

5.4.8 Bear Island

Bear Island contains 18 transects spaced 1000 ft apart. A summary of average shoreline and volume changes between spring 2012 and summer 2013 for the Bear Island region are presented in **Table 22**.

Table 22. Average Shoreline and Volume Change for Bear Island (2012-2013)

	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	-8.6	-1.7	-27,380	-2.1	-34,711	-5.6	-92,357	-8.8	-144,505	-19.8	-326,718

Bear Island appears to have experienced a recession of the shoreline position and overall losses in the volume of sand at all elevations. Upon looking at the volume change plots in **Appendix B** and profile plots in **Appendix C**, it is apparent that the majority of profiles saw loss of material along the beachface. There is a pattern of consistent erosion along eastern and central portions of the island at the lower elevations. It may be that the active nor'easter season had an effect on this island. Volume gain near Bogue Inlet at Transects 1-3 was evident in the previous survey evaluation. It is possible that the dynamic movements of Bogue Inlet are responsible for the large change seen at the eastern end of Bear Island. Previously, it appeared that the channel had 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 18** displays the unit volume change at each transect on Bear Island. Profiles from Transect 18 were not included in the analysis.

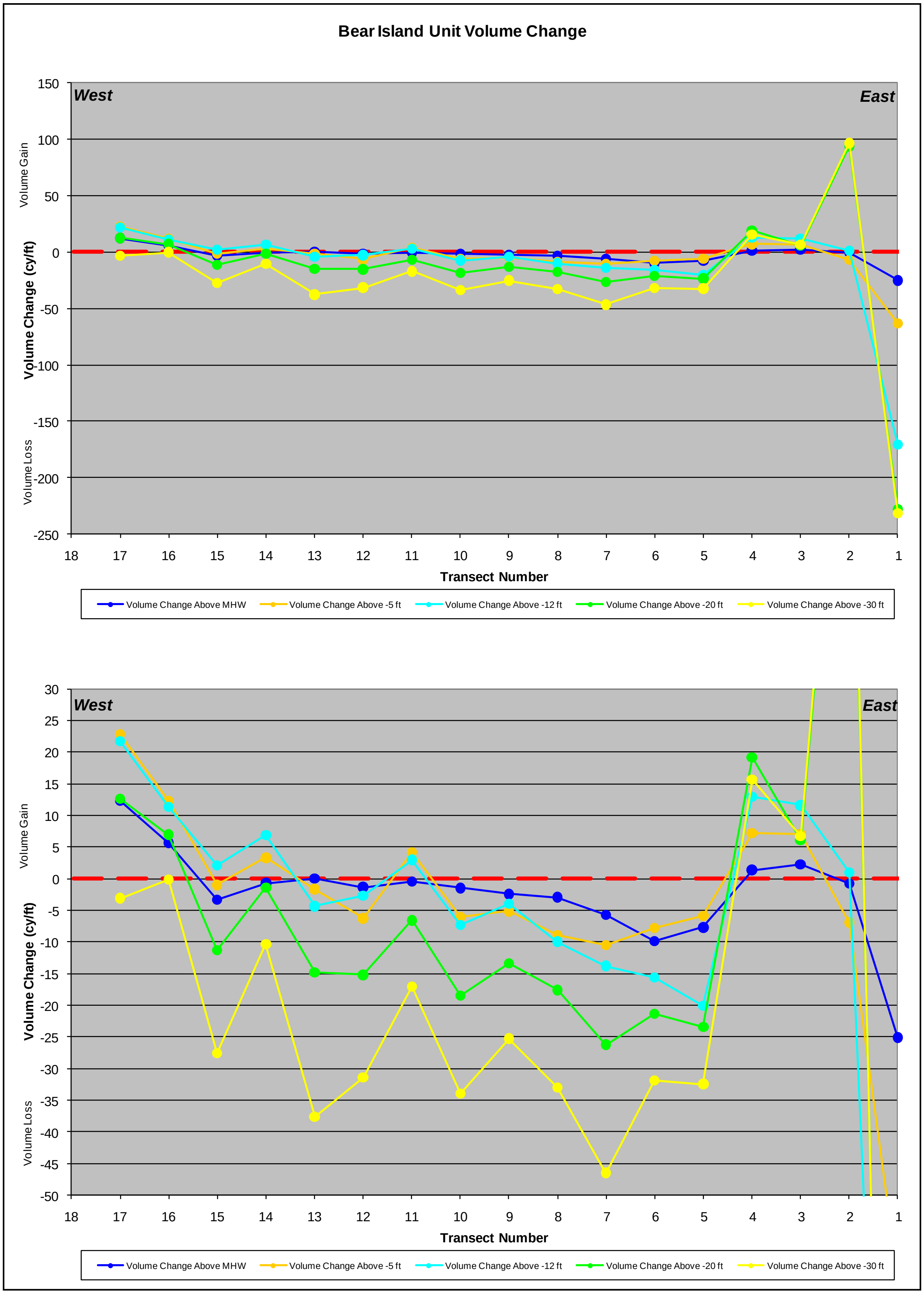

Figure 18. Bear Island Unit Volume Change (2012 - 2013)

5.4.9 Shackleford Banks

Shackleford Banks is comprised of 24 transects and is a natural shoreline, receiving no nourishment. As a result, varying accretion and erosion occurs along the island. A summary of average shoreline and volume changes between 2012 and 2013 for the Shackleford Banks region are presented in **Table 23**.

Table 23. Average Shoreline and Volume Change for Shackleford Banks (2012-2013)

	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	-31.7	-6.6	-304,088	-11.6	-534,930	-12.2	-559,552	-24.7	-1,136,854	-32.4	-1,488,781

Shackleford Banks showed significant shoreline recession at MHW along with large volumetric losses above all elevations considered. Upon looking at the volume change plots in **Appendix B** and profile plots in **Appendix C**, it is evident the many of the dunes were impacted possibly by the active nor'easter season as Bear Island was. This area has seen significant volume losses to the dunes over the past few years starting with Hurricane Irene in 2011. This loss in protection is likely causing increased losses even during quiescent periods. **Figure 19** displays the unit volume change at each transect on Shackleford Banks. It is evident from this figure that the majority of the loss on Shackleford Banks was located at Transects 22 and 23, adjacent to Beaufort Inlet.

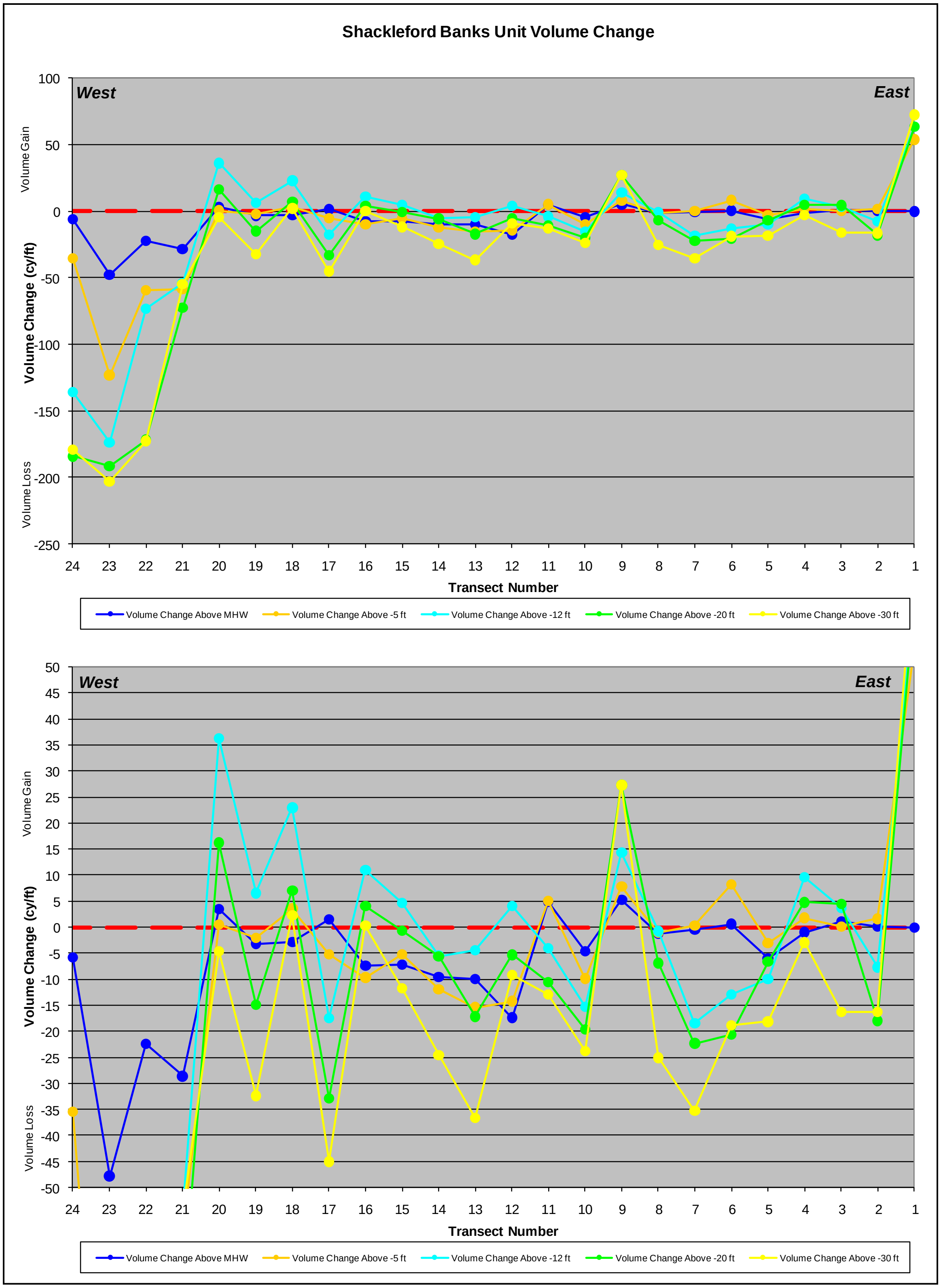

Figure 19. Shackleford Banks Unit Volume Change (2012 – 2013)

5.5 Post-Irene Project Analysis

This section provides an overall analysis of the performance of the Post-Irene Renourishment at each of the three reaches along Bogue Banks. Volume change between the spring 2012 and the spring/summer 2013 profiles was compared to the volume change between the before dredge (BD) survey and the after dredge (AD) survey above elevations +1.1 ft NAVD88 (MHW), -5 ft NAVD88, -12 ft NAVD88, and -16 ft NAVD88. The cumulative volumes found for the BD to AD survey above elevations of +1.1 ft NAVD88 and -5 ft NAVD88 were calculated based on the Bogue Banks transects (1000 ft spacing). The cumulative volume found for the BD to AD survey above elevation -12 NAVD88 was the total amount placed based on the Post-Irene Renourishment Project (using transects at 100 ft spacing).

The nourishment extents within the Emerald Isle West reach include Transects 10 through 16. **Table 24** presents the difference in cumulative volume change between the 2012 to 2013 surveys, the BD to AD surveys, and finally the AD to 2013 surveys. These multiple calculations were required due to the fact that the AD surveys did not extend far enough offshore to capture the offshore movement of sand. It is important to note that the loss attributed to each elevation does not solely represent the loss of sand from the nourishment because there was a loss of sediment prior to commencement of the project. Also, after placement, the project will equilibrate, transporting sand alongshore outside of the reach extents as well as cross-shore along the profile.

Table 24. Emerald Isle – West Project Performance

Elevation (ft NAVD88)	Cumulative Volume Change 2012 - 2013 (cy)	Cumulative Volume Change BD - AD (cy)	Difference in Cumulative Volume 2012 - 2013 (cy)	Percent Difference 2012 - 2013	Difference in Cumulative Volume Change AD - 2013 (cy)	Percent Difference AD - 2013
1.1	58,414	111,365	-52,951	-47.5%	-31,377	-28.2%
-5	109,490	152,899	-43,408	-28.4%	-43,807	-28.7%
-12	139,564	198,190	-58,626	-29.6%	-22,577	-11.4%
-16	231,665	198,190	33,475	16.9%	NA	NA

The nourishment extents within the Emerald Isle East reach include Transects 35 through 45. **Table 25** presents the difference in cumulative volume change between the 2012 to 2013 surveys, the BD to AD surveys, and the AD to 2013 surveys.

Table 25. Emerald Isle - East Project Performance

Elevation (ft NAVD88)	Cumulative Volume Change 2012 - 2013 (cy)	Cumulative Volume Change BD - AD (cy)	Difference in Cumulative Volume 2012 - 2013 (cy)	Percent Difference 2012 - 2013	Difference in Cumulative Volume Change AD - 2013 (cy)	Percent Difference AD - 2013
1.1	103,203	169,748	-66,545	-39.2%	-40,266	-23.7%
-5	254,829	330,050	-75,221	-22.8%	-70,220	-21.3%
-12	324,518	451,600	-127,082	-28.1%	21,032	4.7%
-16	613,642	451,600	162,042	35.9%	NA	NA

The nourishment extents within the Pine Knoll Shores reach include Transects 62 through 71. **Table 25** presents the difference in cumulative volume change between the 2012 to 2013 surveys, and the BD to AD surveys, and the AD to 2013 surveys.

Table 26. Pine Knoll Shores Project Performance

Elevation (ft NAVD88)	Cumulative Volume Change 2012 - 2013 (cy)	Cumulative Volume Change BD - AD (cy)	Difference in Cumulative Volume 2012 - 2013 (cy)	Percent Difference 2012 - 2013	Difference in Cumulative Volume Change AD - 2013 (cy)	Percent Difference AD - 2013
1.1	46,150	152,123	-105,972	-69.7%	-57,390	-37.7%
-5	173,911	258,562	-84,651	-32.7%	-66,987	-25.9%
-12	206,338	315,221	-108,883	-34.5%	3,176	1.0%
-16	384,907	315,221	69,686	22.1%	NA	NA

Based on the calculations comparing the BD – AD survey with the 2012 – 2013, it is apparent that the material which has been lost from upper elevations of the profile has been captured between -12 ft NAVD88 and -16 ft NAVD88. To quantify how much of this loss occurred post nourishment placement, the AD – 2013 volumes were calculated for the upper elevations of +1.1 ft NAVD88, -5 ft NAVD88, and -12 ft NAVD88, as shown in **Table 24** through **Table 26**. Again, the volume above -16 ft NAVD for the AD – 2013 comparison could not be used because the AD survey does not extend down to that depth. The losses found from the AD – 2013 survey above +1.1 ft NAVD88 and -5 ft NAVD88 range between 20% and 30%. The majority of sediment has remained above -12 ft NAVD88 in all reaches. Given the above results, the adjacent profiles to the nourishment areas were also investigated. **It was determined that in most cases, the material had equilibrated and traveled 2-3 transects updrift and downdrift of the placement areas. Therefore, M&N is confident that all of the material placed from the Post-Irene Renourishment Project has remained within the system.**

5.6 Statistical Analysis of Recent Volume Change Trends

Using the six most recent high quality survey datasets (2008-2013), statistical analyses were performed to determine if any long-term trends in the Bogue Banks oceanfront behavior are beginning to appear. The average volume change per year was calculated using the volume changes from the current monitoring report along with the four previous reports (M&N 2009 2010, 2011, and 2012). The recent nourishment (February/March 2013) in Emerald Isle East, Emerald Isle West, and Pine Knoll Shores was subtracted out at each transect based on an average cubic yard per foot placed along each reach of beach in order to determine the background erosion rate. Therefore, these numbers are subject to some uncertainty since the same amount of nourishment was likely not placed at each transect. **Figure 20** shows the mean volume change with nourishment and **Figure 21** shows the mean volume change with the nourishment subtracted out. The hotspots and Emerald Isle and Pine Knoll Shore are still visible.

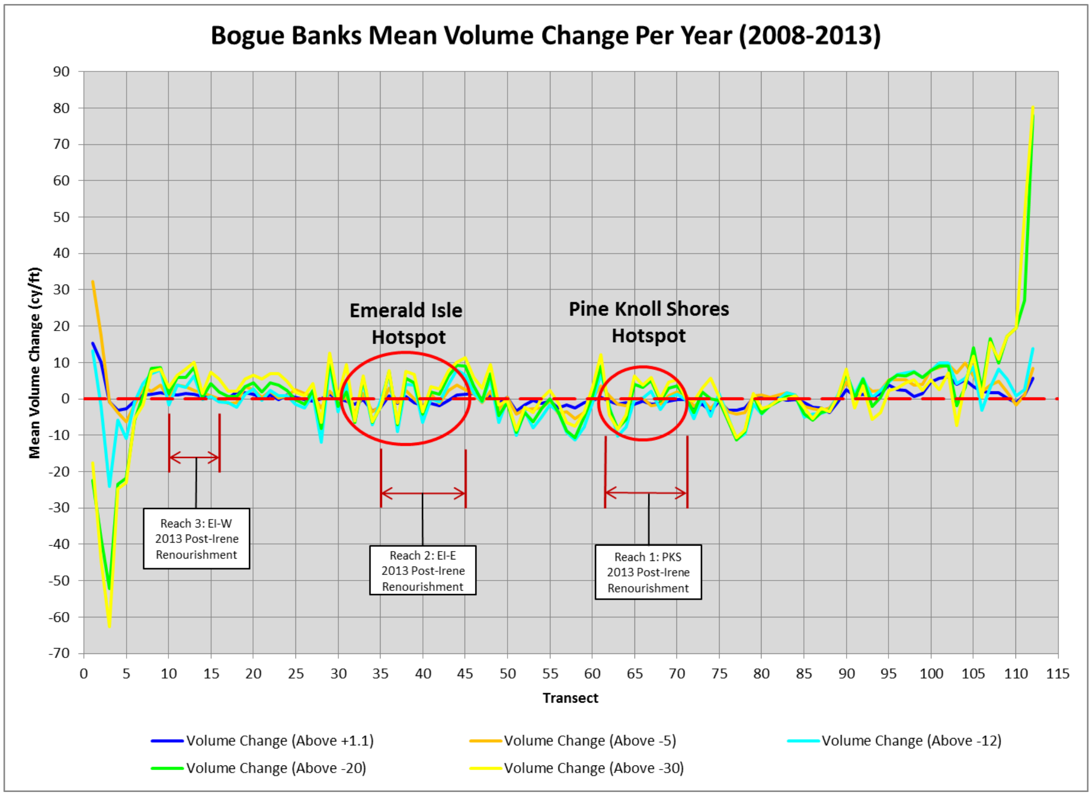

Figure 20. Bogue Banks Mean Volume Change (With Nourishment)

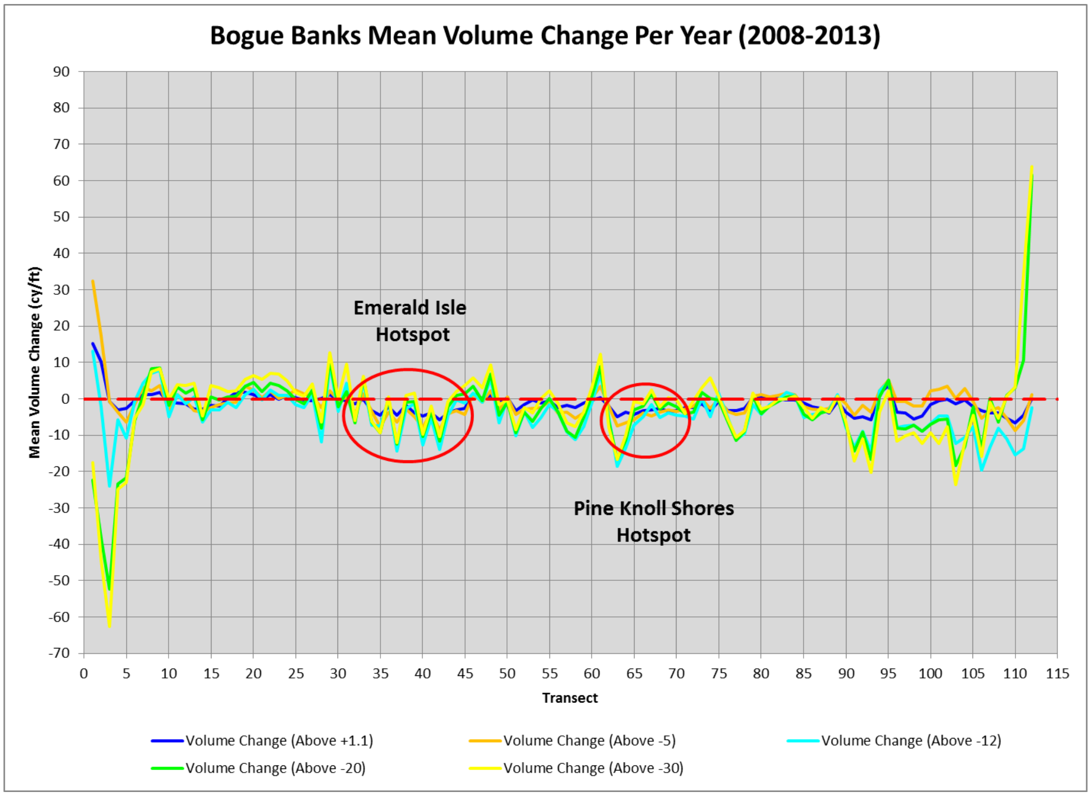

Figure 21. Bogue Banks Mean Volume Change (Without Nourishment)

The standard deviation of the mean volume change per year were also calculated. **Figure 22** through **Figure 26** shows the mean volume change per year with standard deviation bars at plus or minus one standard deviation for each of the elevations above which volume change was calculated.

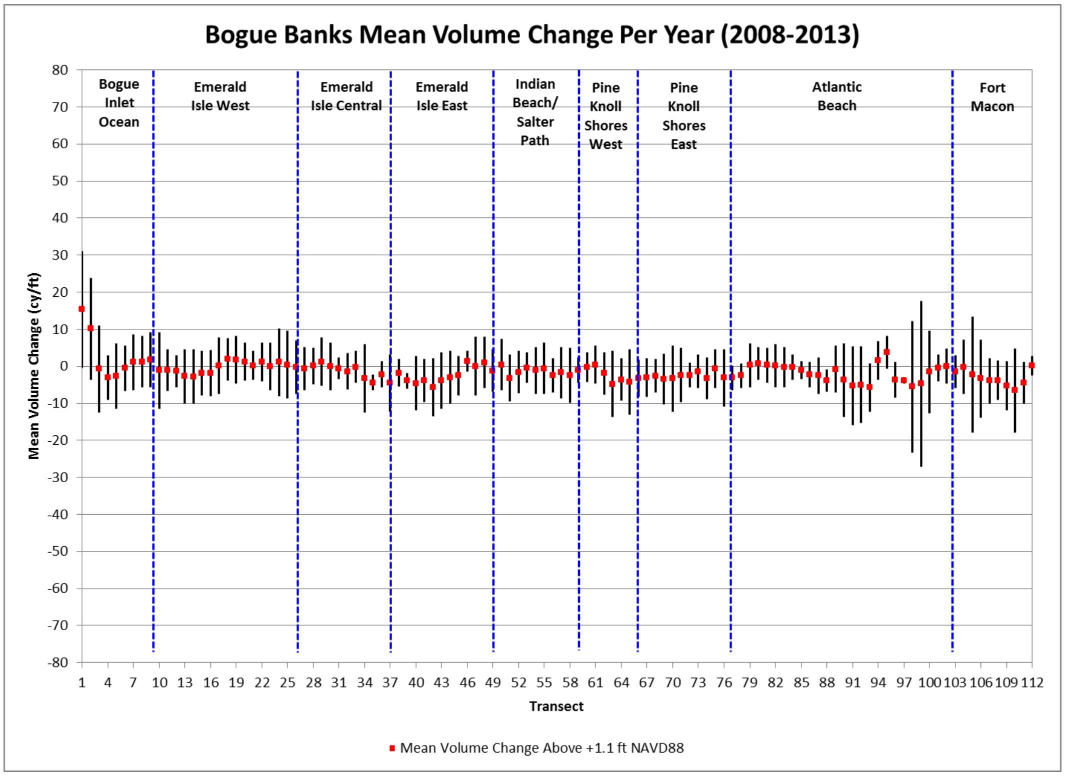

Figure 22. Statistical Analysis of Volume Change Above +1.1 ft NAVD88

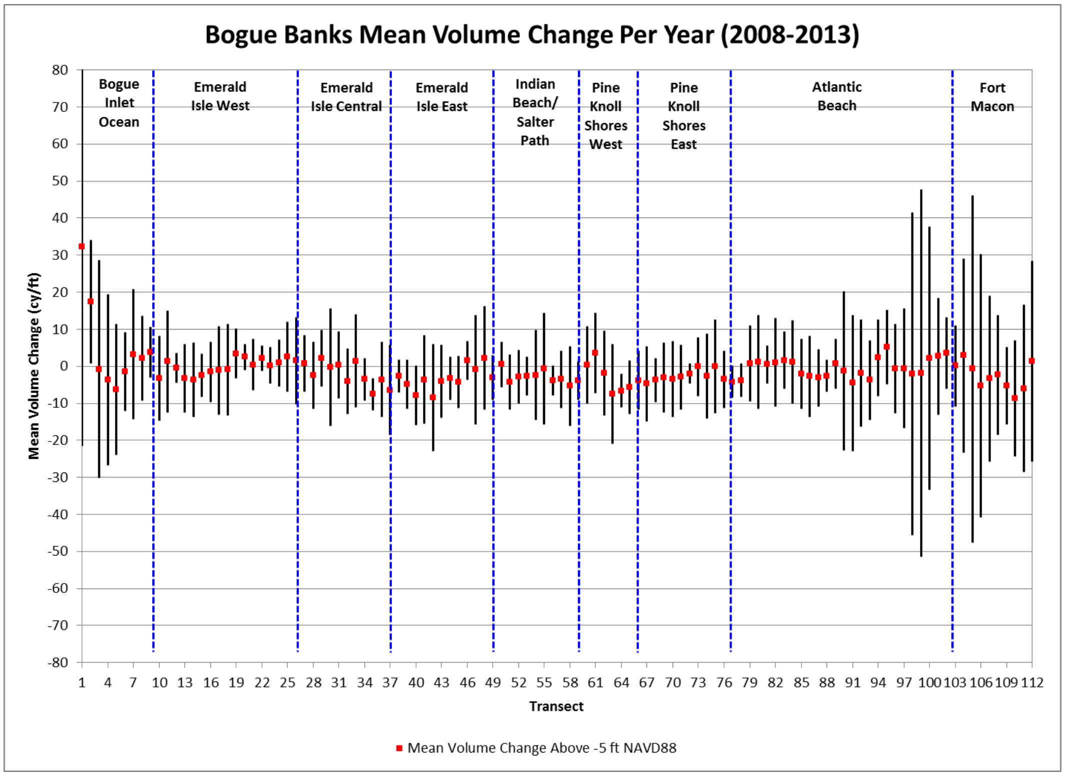

Figure 23. Statistical Analysis of Volume Change Above -5.0 ft NAVD88

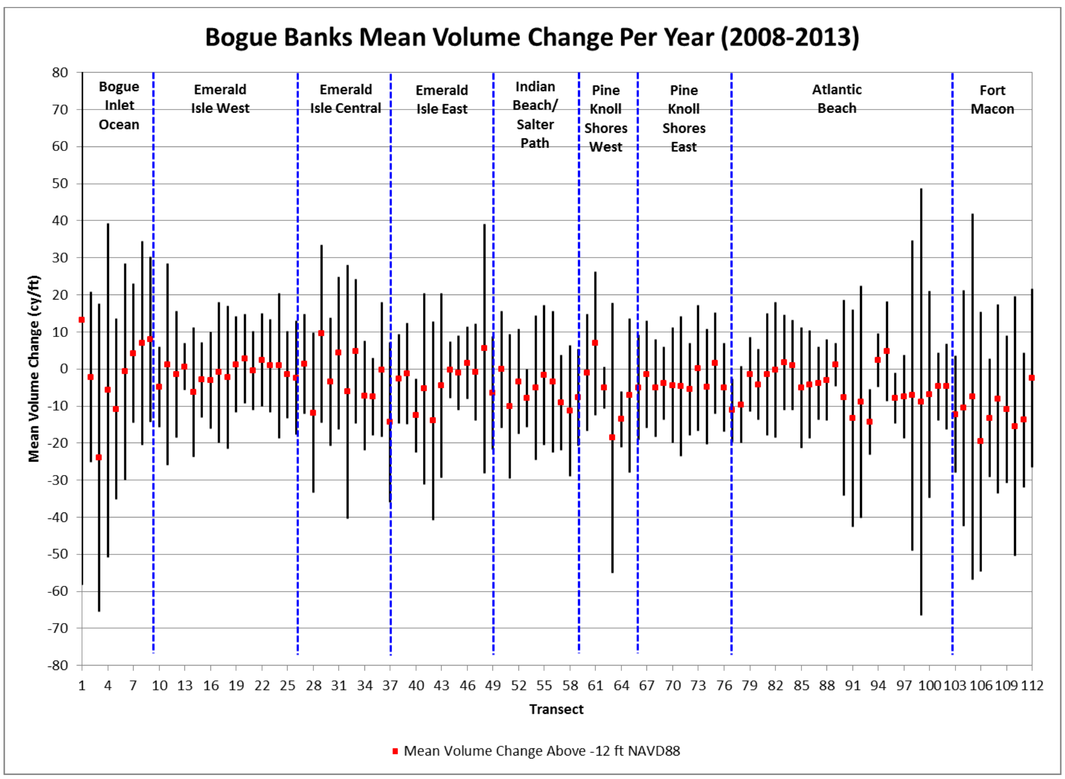

Figure 24. Statistical Analysis of Volume Change Above -12.0 ft NAVD88

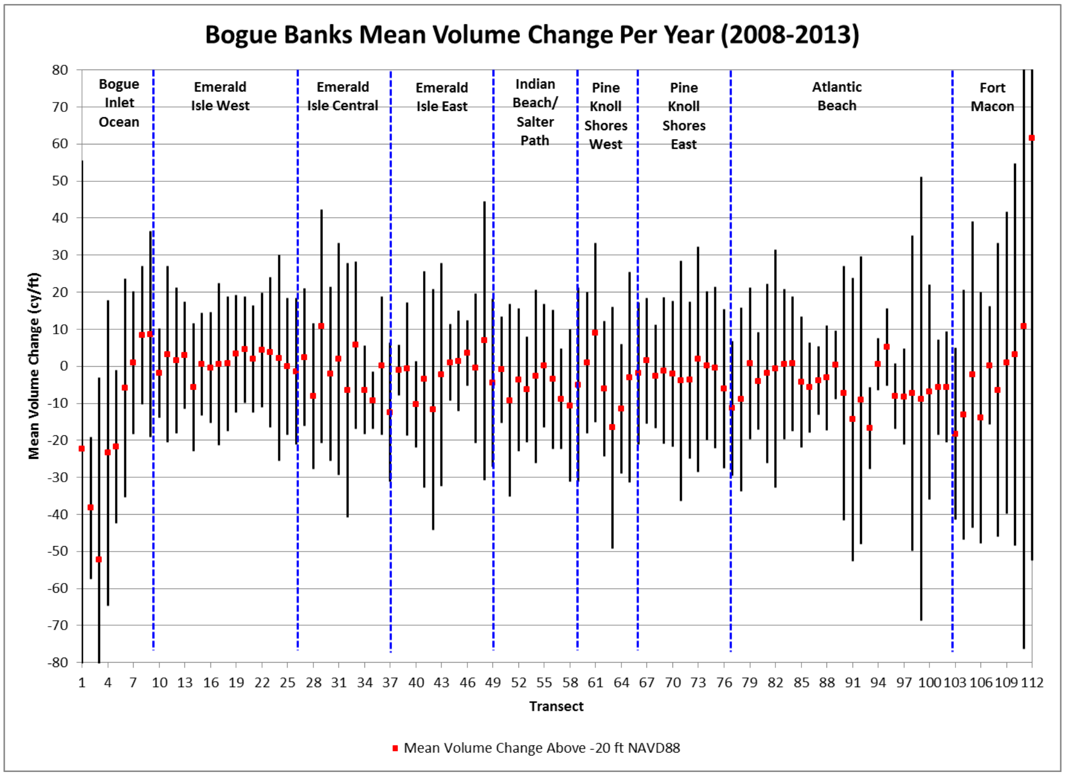

Figure 25. Statistical Analysis of Volume Change Above -20.0 ft NAVD88

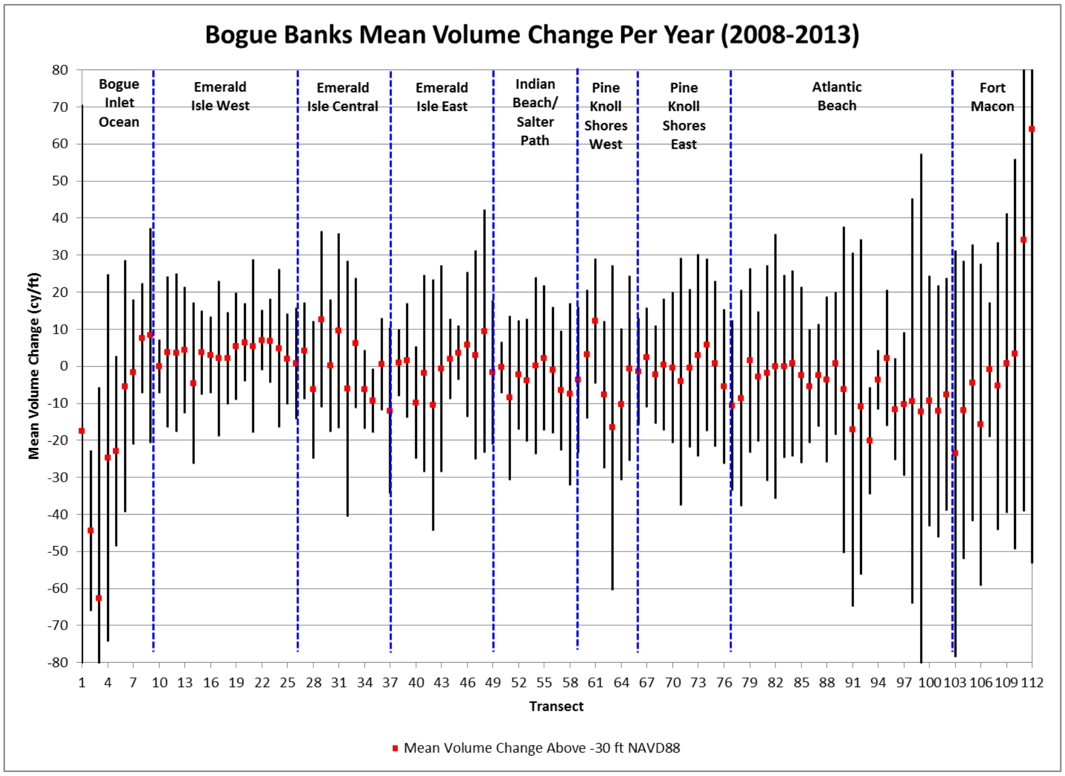

Figure 26. Statistical Analysis of Volume Change Above -30.0 ft NAVD88

The variability in volume change increases with depth especially above MHW, -5 ft NAVD88, and -12 ft NAVD88. This is intuitive based on the fact that the majority of sand movement historically happens in the subaerial beach with large fluctuations in the position of the offshore bar. The standard deviation of volume change above -20 ft NAVD88 and above -30 ft NAVD88 is not much higher than that values calculated for above -12 ft NAVD88. This implies that there is not a large amount of additional sand movement at these lower depths. Also important to note is the standard deviation is much larger on either end of the island, as would be expected given the drastic effect that the inlets have on the adjacent shoreline. Changes near the inlets often fluctuate significantly each year. As more datasets are collected, it is hoped that long-term trends will become apparent.

5.7 FEMA Beach Maintenance Analysis

Analysis was performed to calculate the amount of fill remaining from Phase I, Phase II, and Phase III of the County Project. Using the volume change above -12 ft NAVD88 between the Phase I, Phase II, and Phase III post-nourishment surveys and the spring 2012 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. FEMA beach maintenance calculations for applicable reaches are presented in **Appendix E.** **Table 27** presents the results of the 2012 and 2013 beach maintenance analysis for comparison. Due to the Post-Irene Renourishment project, the overall percent fill remaining has increased significantly.

Table 27. Comparison of Percent Fill Remaining from Base Nourishment

2013

Reach	Percent Fill Remaining	
Indian Beach/Salter Path	**174.1**	
Pine Knoll Shores West	*136.0*	**116.1**
Pine Knoll Shores East	*103.8*	
PHASE I	**131.4**	
Emerald Isle Central	*165.3*	**126.3**
Emerald Isle East	*83.6*	
PHASE 2	**126.3**	
Emerald Isle West	**218.9**	
Bogue Inlet	**168.0**	
PHASE 3	**215.5**	

2012

Reach	Percent Fill Remaining	
Indian Beach/Salter Path	**170.4**	
Pine Knoll Shores West	*128.5*	**89.1**
Pine Knoll Shores East	*64.7*	
PHASE I	**110.5**	
Emerald Isle Central	*135.1*	**87.4**
Emerald Isle East	*35.1*	
PHASE 2	**87.4**	
Emerald Isle West	**152.5**	
Bogue Inlet	**87.1**	
PHASE 3	**148.1**	

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 the 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 monitoring survey was completed during spring/summer 2013 (April, June, and July 2013) by Geodynamics. For this evaluation, the spring/summer 2013 survey was compared with the spring 2012 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 2012 and 2013 survey profiles including;

Key statistics for individual reaches along Bogue Banks were as follows:

The Bogue Banks oceanfront shoreline has advanced seaward at MHW over the past year, with the largest advancement at Emerald Isle – East due to the recent nourishment project completed, which placed the most amount of sand within this reach. The County Project experienced larger seaward advancement at MHW because the Atlantic Beach reach, which did not receive nourishment, was not included. The volumetric calculations indicate that along the entire oceanfront, the beach has gained sand above MHW, above -5 ft NAVD88, above -12 ft NAVD88, above -20 ft NAVD88, and -30 ft NAVD88. Of most importance is the storm protection approximated by the volume of sand above -12 ft NAVD88. Approximately 1.51 million cy of material was gained above -12 ft NAVD88 along the oceanfront, with 1.43 million cy of that being gained within the County Project area. The recent Post-Irene Renourishment project within the Emerald Isle and Pine Knoll Shores reaches accounts for the majority of this volume gain. However, since 965,011 cy was placed during the Post-Irene Renourishment Project, significant natural recovery has also taken place on the order of approximately 469,250 cy within the County Project and 540,667 cy along the entire island. Please note that approximately 1.4 Mcy was lost above -12 ft NAVD88 within the County Project area during Hurricane Irene.

Reach (Profiles)	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	av c abo
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	
Bogue Inlet-Ocean (1-8)	7,432	0.3	0.7	5,253	4.1	30,534	12.3	91,493	
Emerald Isle-West (9-25)	22,344	25.7	6.1	135,815	9.9	221,266	18.3	408,863	
Emerald Isle-Central (26-36)	15,802	23.9	2.7	42,816	5.4	85,715	15.1	238,243	
Emerald Isle-East (37-48)	13,220	36.2	7.7	101,933	18.5	244,190	33.7	446,124	
Indian Beach-Salter Path (49-58)	12,850	15.5	-0.7	-8,959	-2.4	-30,470	-3.5	-44,352	
Pine Knoll Shores-West (59-65)	9,063	34.7	1.9	17,151	7.7	70,218	9.3	84,184	
Pine Knoll Shores-East (66-76)	14,815	35.7	1.8	26,242	10.7	157,819	20.3	301,201	
Atlantic Beach (77-102)	28,173	6.5	0.1	2,384	0.2	5,407	2.3	59,686	
Fort Macon State Park (103-112)	8,691	-28.3	-1.0	-12,695	-4.9	-42,638	-11.9	-79,720	
Beaufort Inlet (113-116)	2,000	67.3	-9.8	-19,645	24.9	49,849	39.6	79,279	
Bogue Inlet Channel (117-120)*	2,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

Reach (Profiles)	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	av c abo
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	
Bogue Banks Oceanfront (1-112)	128,393	19.1	2.4	309,441	5.9	763,061	11.7	1,505,678	
Bogue Banks County Project (9-76)	88,094	23.1	3.6	314,495	8.5	742,738	16.3	1,434,200	
Bear Island (1-18)	16,500	-8.6	-1.7	-27,380	-2.1	-34,741	-5.6	-92,357	
Shackleford Banks (1-24)	46,001	-31.7	-6.6	-304,088	-11.6	-534,930	-12.2	-559,552	

The Post-Irene Renourishment Project performance to date was also analyzed by comparing the 2013 data with some post-fill surveys taken at the time of the project. It is apparent that some material was lost from the upper elevations of the profile. However, this material has been captured between -12 ft NAVD88 and -16 ft NAVD88 and is still within the system. The profiles adjacent to the nourishment areas were also investigated and it was determined that in most cases, the profile equilibration had already caused material to travel 2-3 transects updrift and downdrift of the placement areas.

Bear Island appears to have minor volume losses above MHW and above -5 ft NAVD88, and larger losses above -12 ft NAVD88, -20 ft NAVD88, and -30 ft NAVD88. Most importantly, there was a loss of approximately 92,357 cy of sand at -12 ft NAVD88. Profile plots show a majority of this loss of material was accounted for at Transect 1, which is adjacent to Bogue Inlet. Shackelford Banks experienced significant volume losses above MHW, -5 ft NAVD88, -12 ft NAVD88, -20 ft NAVD88, and -30 ft NAVD88. There was a loss of 559,552 cy of sand above -12 ft NAVD88. Profile plots show that the majority of this loss occurred between Transects 22 and 23, which is adjacent to Beaufort Inlet.

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 components of the County Project. It was determined that the Phase I, Phase II, and Phase III project reaches contained more sand than was originally in place after the earlier baseline projects with 131%, 126%, and 216% remaining, respectively. Within the Phase II project there has been a hotspot which, historically, has shifted back and forth between Transect 32 in Emerald Isle Central and Transect 44 in Emerald Isle East. Of the two subreaches within the Phase II project, Emerald Isle East contains the least amount of original fill material at 84%; however, currently contains sufficient reserve material. While there is evidence of the hotpost drifting into Emerald Isle Central, that reach currently contains sufficient reserve material (165%) as well.

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.