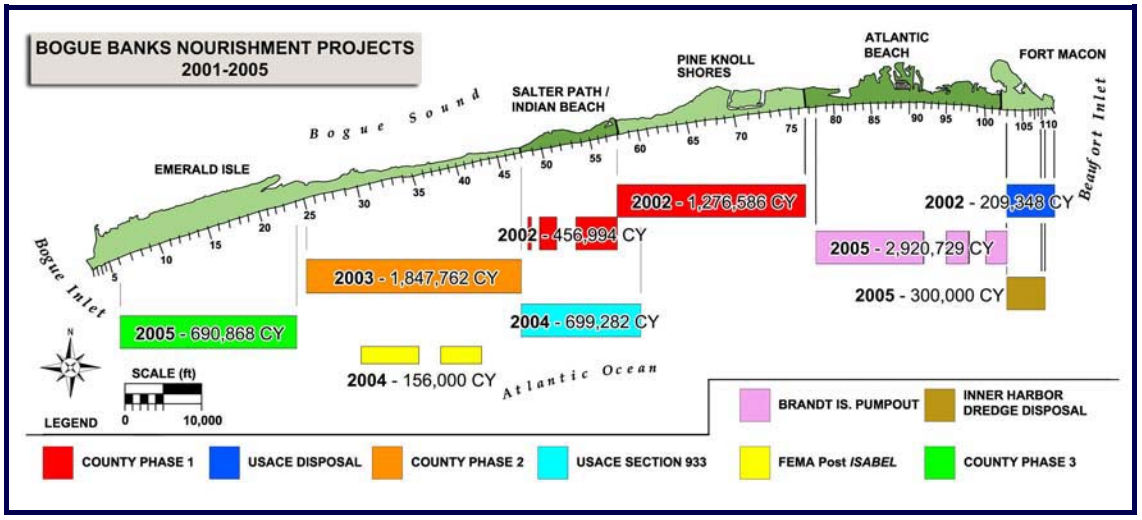
Survey Report 2005

Bogue Banks North Carolina



Prepared for:

Carteret County North Carolina

SURVEY REPORT 2005

Bogue Banks
North Carolina

Prepared for:

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[CSE SR 2132-03]
NOVEMBER 2005

COVER GRAPHICS

Upper left: Indian Beach after nourishment
Upper right: Same area in 2005 after nourishment
Lower: Nourishment projects total ~8.6 million cubic yards

EXECUTIVE SUMMARY

This report provides results of beach monitoring surveys covering the period June 1999 through May 2005, completed as part of the Bogue Banks Beach and Nearshore Mapping Program (BBBNMP) sponsored by Carteret County, North Carolina. The report documents changes in the condition of the beach over a six-year period which encompassed the following major events:

- Hurricanes *Dennis* and *Floyd* (September 1999)
- Phase 1 beach restoration project (Pine Knoll Shores and Indian Beach, December 2001–April 2002)
- Morehead City navigation project inner harbor material (nourishment disposal) to Fort Macon State Park (February 2002)
- Phase 2 beach restoration project (Emerald Isle, January–March 2003)
- US Army Corps of Engineers (USACE) Section 933 beach nourishment (Indian Beach and western Pine Knoll Shores, February to March 2003)
- Hurricane *Isabel* (September 2003)
- Post-*Isabel* FEMA beach renourishment (Emerald Isle, March 2004)
- Phase 3 beach restoration (Emerald Isle, February–April 2005)
- New inlet dredging at Bogue Inlet (January–April 2005)
- Hurricane *Ophelia* (September 2005)
- Brandt Island pumpout and disposal along Atlantic Beach and Fort Macon State Park (November 2004–February 2005)
- USACE Morehead City Harbor dredge disposal along Atlantic Beach and Fort Macon State Park (February–April 2005)

Surveys referenced herein were obtained using state-of-the-art technology as well as less sophisticated, but reliable, methods in earlier years. Up to ten sets of surveys are available for certain reaches and dates in connection with beach nourishment projects and storm events. The report describes the data collection methodology and analysis techniques. The majority of comparisons are made using volumetric measures whereby the quantity of sand contained between the foredune and a designated offshore contour(s) are compared over time. The results are compiled by town and for the island overall. Island-wide trends are given first, then separate sections of the report summarize results by community.

Between June 1999 and May 2005, Bogue Banks was impacted by Hurricane *Dennis* (1999), *Floyd* (1999), and *Isabel* (2003). Beach nourishment totaling ~8,558,000 cubic yards (cy) (Fig A) was placed along:

• Pine Knoll Shores	2001–2002
• Indian Beach/Salter Path	2002
• Fort Macon State Park	2002
• Eastern and central Emerald Isle	2003
• Indian Beach and western Pine Knoll Shores	2004
• Eastern Emerald Isle	2004
• Western Emerald Isle	2005
• Atlantic Beach	2004–2005
• Fort Macon State Park	2005

The surveys comparing June 1999 conditions with May 2005 conditions showed a net gain of ~8,267,000 cy (island-wide measured to the outer bar at depths of –11 ft NGVD). This means that the measured change over six years equals about 96.6 percent of the total volume of sand added to Bogue Banks by nourishment.

Nourishment volumes are nearly fully accounted for by the survey data when combined over the length of the island. However, from town to town, there were some differences between the nourishment volume and the surveyed volume. These differences are, in effect, the background erosion (or accretion) rates for the six-year period. The worst erosion (after nourishment is factored out) occurred along Atlantic Beach and Fort Macon State Park (~5–6 cy/ft/yr erosion). Eastern Emerald Isle and Pine Knoll Shores have eroded ~0.2 and ~1.8 cy/ft/yr (respectively) after the effect of nourishment is removed. When nourishment is included, Emerald Isle, Indian Beach, Pine Knoll Shores, and Atlantic Beach have gained an average of over 65 cy/ft. This is equivalent to an extra 85–85 ft beach width added to the four communities between June 1999 and May 2005. Higher erosion rates along Atlantic Beach are attributed to fill adjustment and loss of fine-grained sediments pumped from the Brandt Island disposal area in winter 2005 (G. Rudolph, pers comm, June 2005).

In June 1999, CSE Stroud (1999) determined that the central and western two-thirds of Bogue Banks had a sand deficit and inadequate beach width compared with Atlantic Beach. By May 2005, all of Bogue Banks contained a sand surplus compared with the target minimum beach volume (see main text). CSE's recommended target minimum dune/beach volume along the oceanfront is 225 cy/ft (measured to the outer bar at approximately –11 ft NGVD). In May 2005, the island-wide profile volume was ~279 cy/ft.

The presence of extra sand on the beach reduced damages to properties during Hurricane *Ophelia* (September 2005). Post-*Ophelia* surveys indicated that ~1,500,000 cy were lost between the foredune and the outer bar from western Atlantic Beach to Bogue Inlet. However, the storm caused negligible dune recession and almost no damage to walkovers or dune vegetation. The worst structural damage along the oceanfront was loss of the Sheraton Hotel pier.

The data herein support the finding that Bogue Banks has a relatively low, natural erosion rate and that nourishment is an effective means of mitigating erosion. Annual monitoring should be continued to track the performance of nourishment and to establish trigger points for future beach restoration.

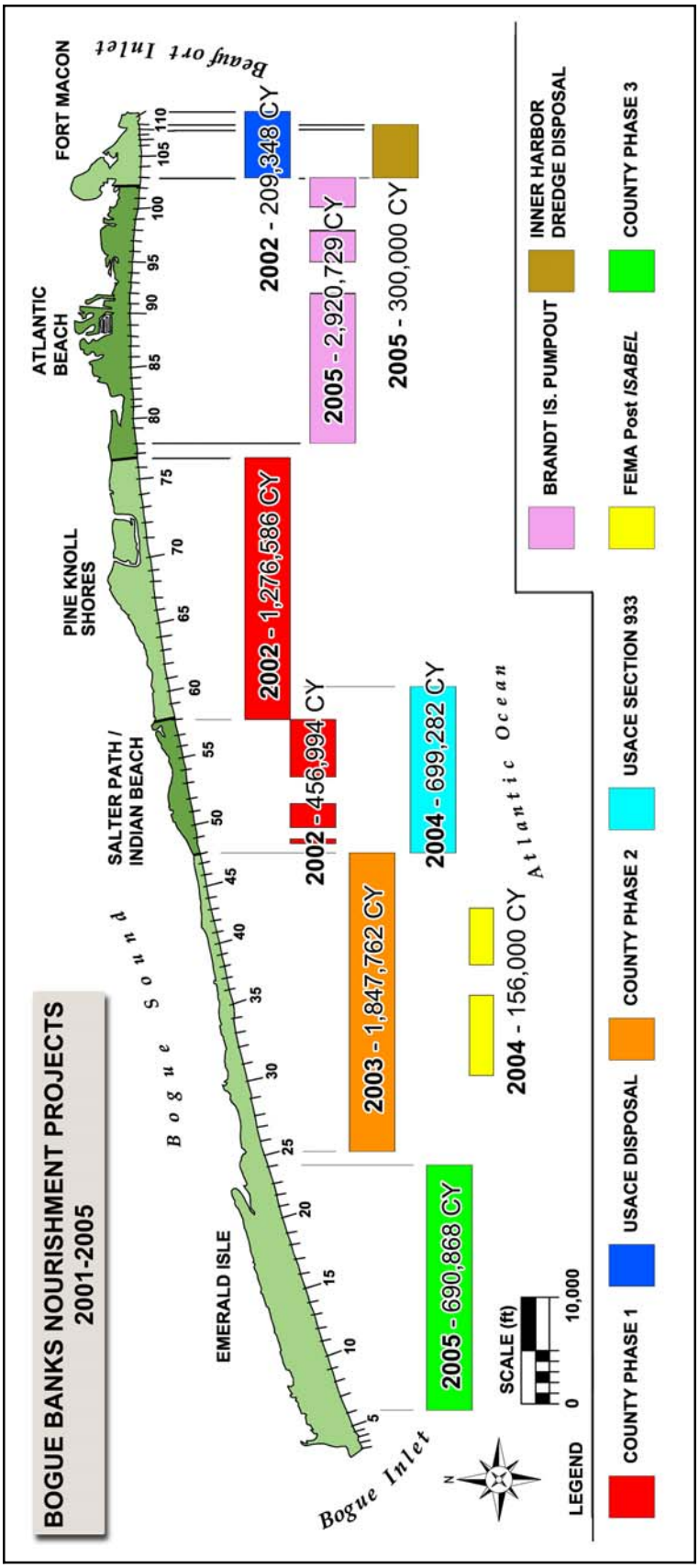

FIGURE A. Nourishment projects along Bogue Banks (2001–2005).

ACKNOWLEDGMENTS

This report was prepared under a contract between Carteret County and Coastal Science & Engineering (CSE). We thank the Carteret County Beach Commission for sponsoring and coordinating the work, including present commissioners:

William Donnelly	Atlantic Beach
Tom Doe III	Atlantic Beach
Joan Lamson	Pine Knoll Shores
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Vincent Oliveri	Emerald Isle
Buck Fugate	Indian Beach
James N Willis III	Bogue Banks Resident
Jim Stephenson	At-Large
Pat McElraft	Commissioner
Jack Goldstein	TDA

We especially thank Greg "Rudi" Rudolph, Carteret County Shore Protection Manager, for his support and contributions to the study.

CSE's work was directed by Dr. Timothy Kana. Philip McKee conducted the surveys with assistance by Brooke Fassnidge, Doug Dusini, and Justin McKee. The report was prepared by Doug Dusini with assistance by Tim Kana, Diana Sangster, Trey Hair, Libby Marcum, and Anna Terlizzi.

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INTRODUCTION

This report summarizes Year 2 (2004-2005) of the Bogue Banks Beach and Nearshore Mapping Program (BBBNMP) which is sponsored by Carteret County, North Carolina. The BBBNMP is a continuation of beach monitoring initiated by the county in 1999 (CSE-Stroud 1999, CSE 2000, Freeman et al 2003) and supplemented by surveys in connection with town-sponsored beach nourishment projects along Pine Knoll Shores, Indian Beach, and Emerald Isle (CSE-Stroud 2001, Kana et al 2002, CSE 2003a,b, 2004).

The primary purpose of beach monitoring is to:

- Determine the condition of the beach.
- Measure volumetric rates of erosion and accretion.
- Confirm sediment volumes added by nourishment.
- Track the movement of sand in the longshore and cross-shore directions by comparative surveys.
- Compare beach conditions from one reach to another for purposes of prioritizing beach nourishment or other restoration efforts.

The present monitoring report builds on previous results and includes comparisons of the 2005 conditions with those of 2004. In addition to site comparison from previous reports, CSE has included survey data and comparisons for Bear Island and Shackleford Banks in the present study. Bogue Banks comparisons are made on a June 2004 to May 2005 basis. Bear Island was surveyed in October 2004 and in May 2005. The comparison for Bear Island is based on these dates. Shackleford Banks was surveyed by CSE for the first time in May 2005; the initial survey data are presented in this report.

The past year has presented some significant events for Bogue Banks including:

- Phase 3 beach restoration (Emerald Isle, February–April 2005)
- New inlet dredging at Bogue Inlet (January–April 2005)
- Hurricane *Ophelia* (September 2005)
- Brandt Island pumpout and disposal along Atlantic Beach (November 2004–February 2005)
- USACE Morehead City Harbor dredge disposal along Atlantic Beach and Fort Macon State Park (February–April 2005)

The USACE pumped out the Brandt Island dredge disposal area and placed upward of 2.9 million cubic yards of sand along Atlantic Beach. This was the third pumpout of the spoil

area with prior projects in 1986 and 1994. The material in Brandt Island included considerable percentages of fines during the initial stages of the project so the resulting profile along the eastern end of Atlantic Beach where the disposal began was exceedingly wide and gently sloping (G Rudolph, pers comm, Feb 2005). It is believed that a considerable part of the initial fill dispersed offshore well seaward of the fill template. As construction progressed westward, the Brandt Island sediments became coarser with reportedly lower volume losses.

Beach surveys since June 2004 capture the Phase 3 nourishment project as well as the effects of Hurricane *Isabel*. Effects of Hurricane *Ophelia* were measured in September 2005 and are included in this report.

The focus of this report is on island-wide beach changes since June 2004. As in the previous report, the emphasis is on the volume of sand gained or lost within the littoral zone and an accounting of beach nourishment volumes. Following an overview of the entire project, the summaries of the findings for each town, including Bear Island and Shackelford Banks, are provided.

METHODOLOGY

Field Data Collection

Over the past 40 years, the methodology and approach for beach surveys has evolved from fairly crude methods (eg, Emery 1961) to highly sophisticated data collection systems involving global positioning system (GPS) satellite navigation in three dimensions (coordinates and elevations with respect to common horizontal and vertical datums). Prior to the past few years, CSE favored rod-and-level, theodolite, or sled surveys through the surf zone because they were the most accurate, consistent, and cost-effective method of data collection. This follows recommendations of the National Academy of Science (NRC 1995). No corrections are required for water depth by these methods because the measurements involve placement of a rod or prism directly on the bottom. Reliable land survey techniques are simply extended offshore by this method. CSE and the majority of professional organizations favored this method over boat surveys using fathometers because the latter require uncertain corrections for tide, waves, boat motion, and acoustic drift. Many of the problems associated with historical surveys can be traced to these imprecisions (NRC 1995). In the past few years with the availability of real-time-kinematic (RTK) GPS x–y–z positioning (post 1999), it is now possible to reduce (but not completely eliminate) the errors associated with boat surveys.

The present standard of practice for beach monitoring, and one that is consistent with nearly all historical profile surveys, is single-beam bathymetric surveys using a linked RTK-GPS receiver. This methodology conforms with the standards and requirements of the BBBNMP. Following is a brief description of CSE's methods of data collection and analysis for the present report.

On Bogue Banks, CSE mobilized survey crews and re-established 111 control points near the shoreline. Generally, each control point consists of a monument or survey nail in concrete placed 50–300 feet (ft) landward of the foredune. Spacing of points is generally around 1,000–1,600 ft and varies to accommodate existing development. Control points are spaced ~500 ft apart near the inlets. Many control points are at road intersections and/or fixed/recoverable structures. Each point was surveyed to standard North Carolina state plane coordinates (NAD'83) and vertical datum (NGVD'29) using a Trimble Model 4700 or 5800 RTK-GPS or a total station, transiting from known control points. Stationing is numbered consecutively from west to east. Appendix I lists the control points, coordinates, and vertical elevation for each station, as well as a detailed map of Bogue Banks profile lines. For Year 1 of the BBBNMP, CSE established eight additional control points and nine additional profiles for purposes of monitoring Bogue Inlet and Beaufort Inlet. Figure 1 shows the general location of all 120 beach profile lines on Bogue Banks along with approximate town boundaries.

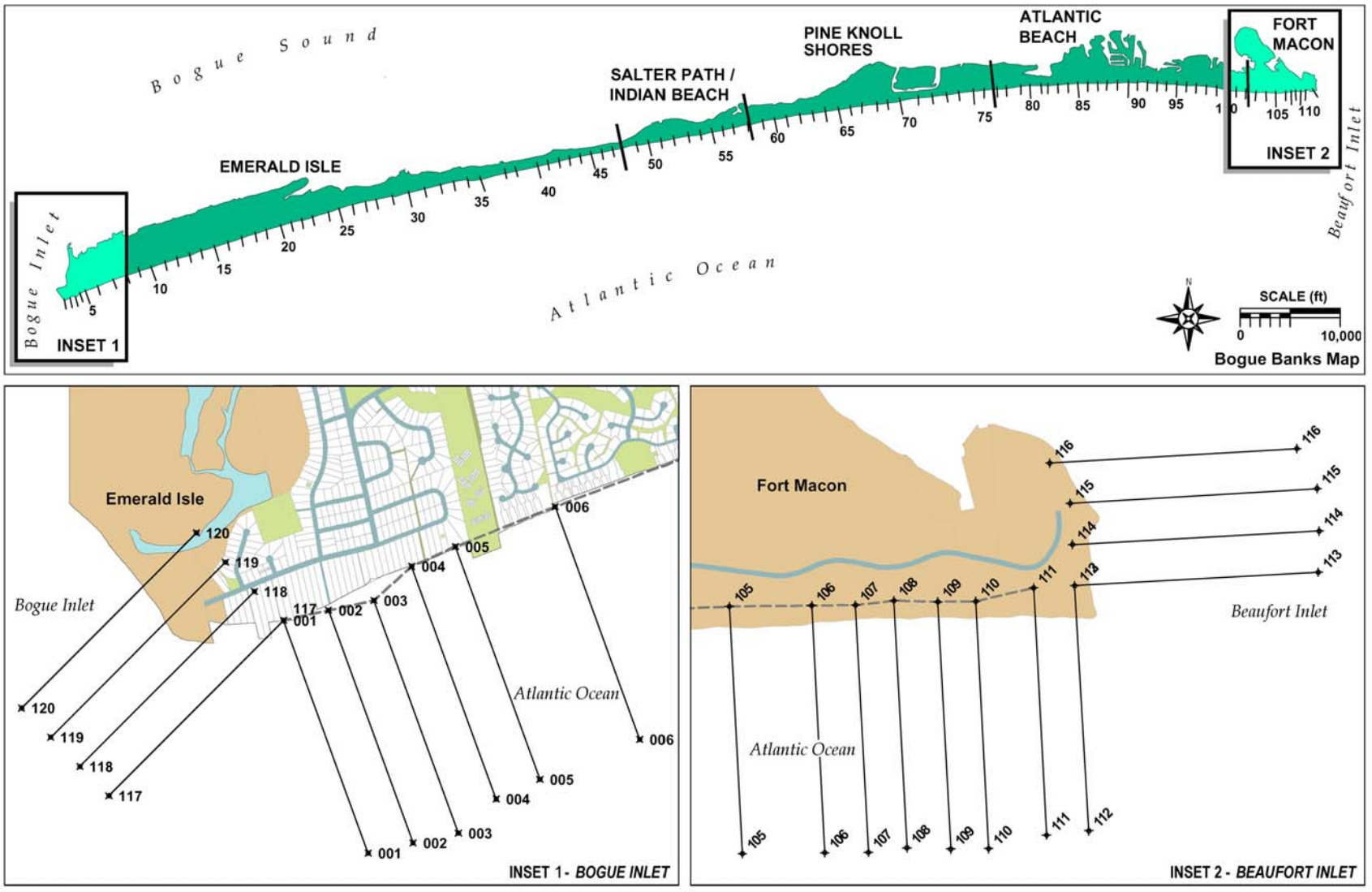


FIGURE 1. General location map of beach profile lines established in 1999 and resurveyed in December 2003, June 2004, and May 2005 under the present BBBNMP project. Lines 112 through 120 were established in December 2003.

In October 2004, CSE established 18 lines on Bear Island at 1,000-ft spacing. The general locations of the Bear Island profiles are shown in Figure 2 (upper). CSE re-acquired 24 control points on Shackleford Banks (Fig 2, lower) in May 2005 to establish profile lines at this location. These stations are spaced roughly 2,000 ft apart.

Profiles were first surveyed (1999) perpendicular to the local shoreline azimuth from the control points to the outer bar by a combination of methods, including differential GPS for backshore work, and rod and level for inshore work. The inshore work extended 500–1,000 ft offshore, crossing the low-tide terrace, inner runnel (trough), and outer bar. Discrete points were surveyed at breaks in slope and at key morphological features such that a representative "profile" was obtained. The outer depth limit was typically around –10 ft to –12 ft NGVD* along the seaward face of the outer bar.

[*NGVD: National Geodetic Vertical Datum of 1929, which is approximately 0.5 ft below present mean sea level.]

By 2002, CSE switched to a two-part survey system involving over-ground surveys by RTK–GPS between the foredune and low-tide wading depth with over-water work by RTK–GPS combined with a precision echo sounder mounted on a shallow-draft boat. Working around the tidal cycle, data collected on land is extended into shallow depths in the surf zone at low tide. Then data are collected from the boat at high tide such that overlap of the two surveys occurs close to shore.

Figure 3 illustrates the data collection equipment that CSE used on Bogue Banks for the present survey. The system requires a base station (Fig 3, upper left) calibrated to known reference points. It receives signals from up to 12 satellites and communicates with a rover unit(s) to provide horizontal and vertical coordinates (georeferenced position and elevation). The rover unit includes a data logger for recording x-y-z data at each point occupied. On the dunes, around critical habitat, or in shallow water, shot points must be occupied on foot (Fig 3, upper right and lower).

For offshore data collection, CSE used a shallow-draft C-Dory™ (*RV Irie*), which provides a fully enclosed cabin for the electronics (Fig 4, upper left). The GPS receiver was mounted near the transom over the transducer to minimize boat motion for the echo sounder. CSE used a SonarLite™ (Ohmex Ltd) precision echo sounder for depth measurements. The sampling rates for GPS and sounder were 10 Hz. Field tests for latency showed a 2.4 second difference between signals from the GPS and signals from the sounder. Data were corrected to eliminate the latency and provide x–y–z coordinates and elevations in real time.

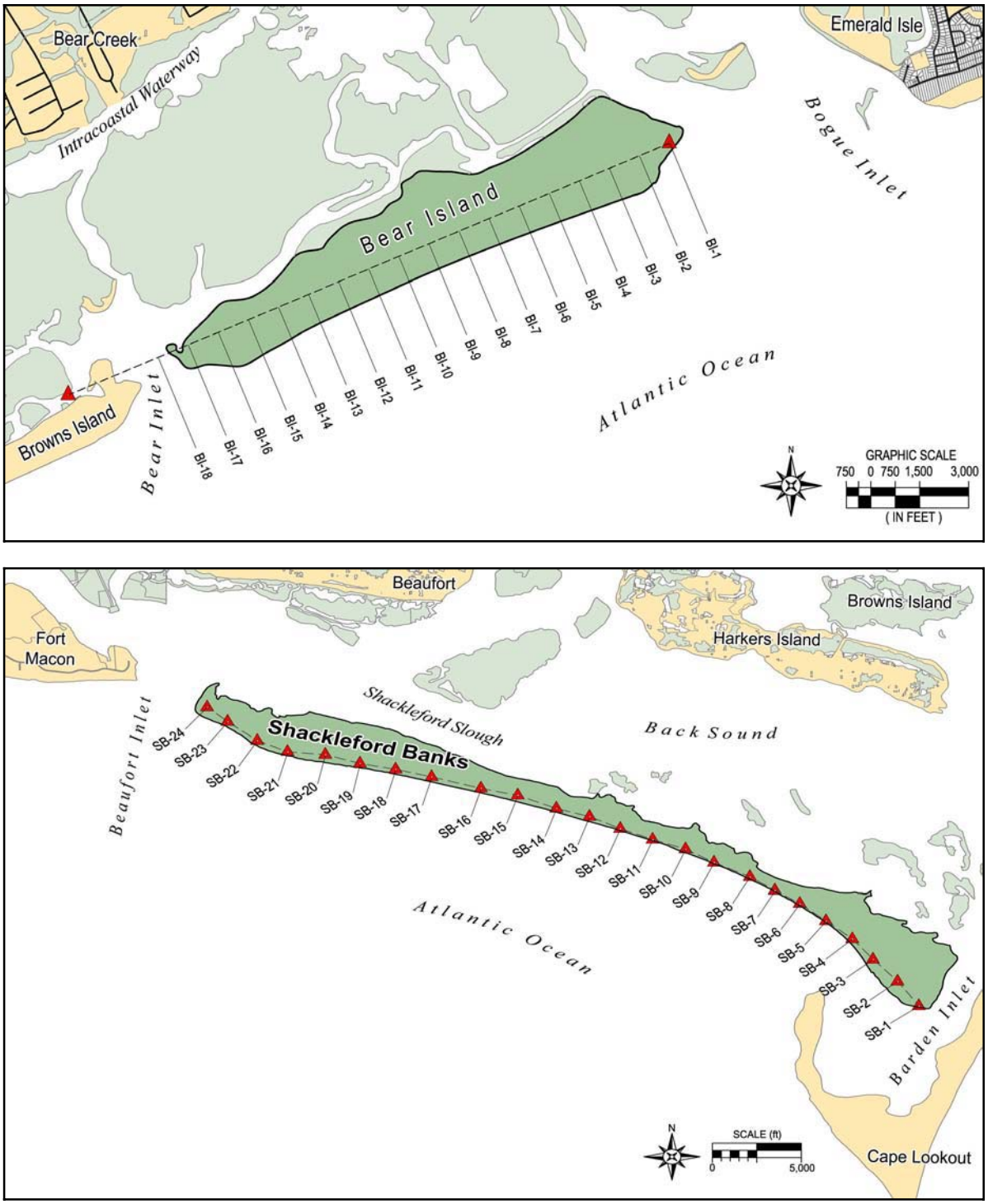


FIGURE 2. General location map of beach profile lines for Bear Island (upper) and Shackleford Banks (lower).

FIGURE 3. [**UPPER LEFT**] RTK-GPS base station receiver and radio link to rover unit. [**UPPER RIGHT**] Rover unit and data logger for close work in the dunes. [**LOWER LEFT**] Measurements around sensitive habitat (seabeach amaranth). [**LOWER RIGHT**] Measurements in the surf zone.

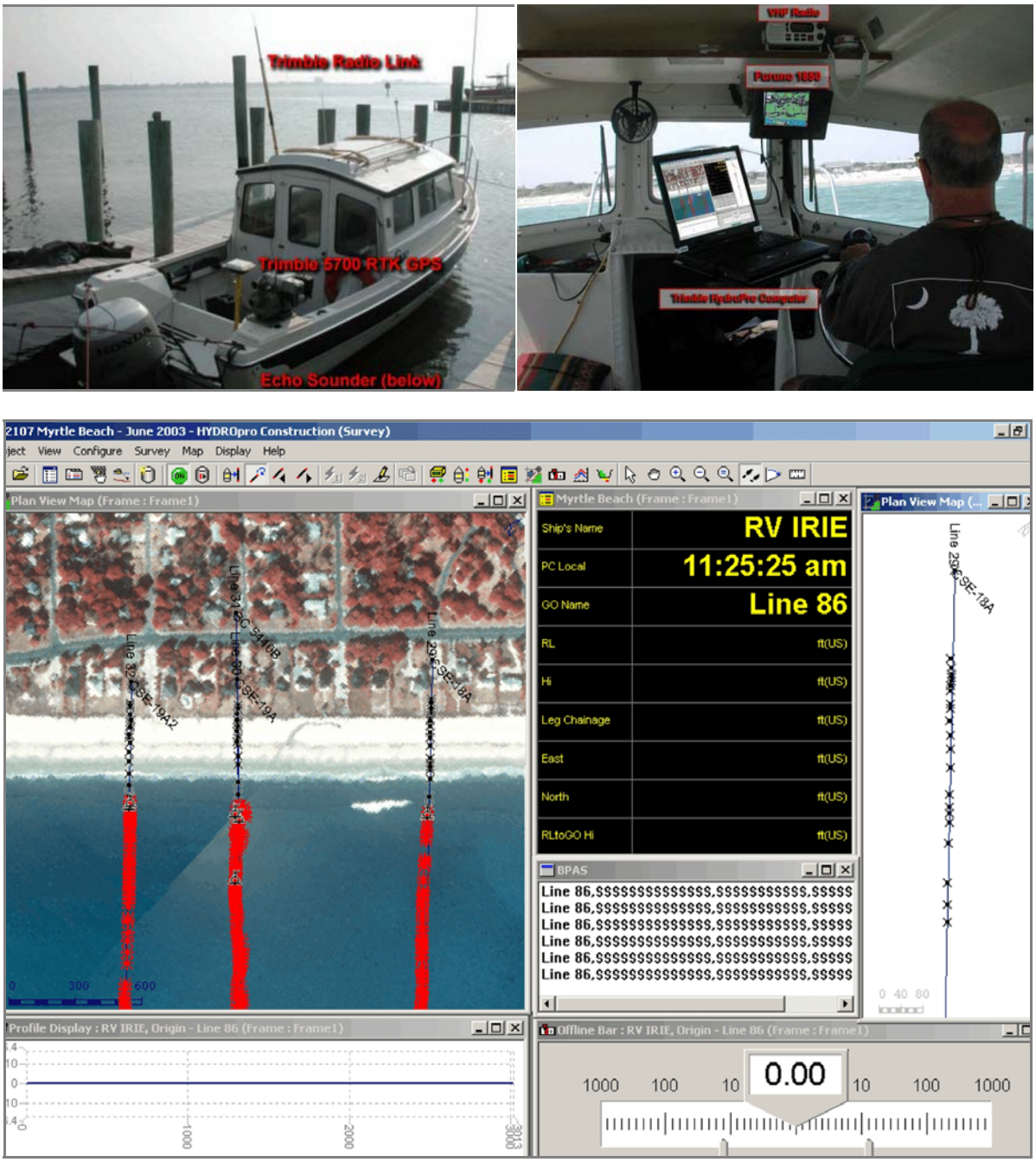


FIGURE 4. CSE's offshore equipment and survey vessel for use in shallow water.
[**UPPER LEFT**] 22-ft C-Dory™ with 7-inch draft and enclosed cabin.
[**UPPER RIGHT**] Navigation and data logging console.
[**CENTER**] HydroPro™ data logging and processing software showing track lines and overlap in real time with shore-based portion of the survey.
[**LOWER LEFT**] The vessel turns out at the landward end of the line and proceeds to the seaward end of the next line.

The navigation console and data-logging computer are shown in Figure 4 (upper right). Pre-set navigation lines matching the desired profile tracks were programmed into Trimble-HydroPro™ for guidance. This facilitated navigation by establishing a course and way-points so that profiles conformed to the required azimuth. The survey data were logged using Trimble-HydroPro™ software (Fig 4, center), which was set up with photo images over the area. As Figure 4 (center) illustrates, this allowed the boat operator to determine when the land-based section of a line had been crossed. CSE generally ran lines from seaward to landward, because the resulting profile tends to be smoother (less motion moving the same direction as incident waves) and it is easier to control the vessel through the surf zone. At the end of the line, the vessel turned out and proceeded to the seaward end of the next line (Fig 4, lower left).

Data Reduction and Analyses

Raw data (x–y–z format) were logged with the aid of Trimble-HydroPro™ software. The software module, NAVEDIT, was used for batch processing and organizing files as data were collected. It is common for soundings by fathometer to include spurious data because of reflections of sound waves off entrained bubbles, drifting objects, fish, etc. Such spikes were filtered using preset parameters (Fig 5, upper) and automatically deleted from the data set. Post-process filtering further reduced spikes as well as averaged adjacent points to provide a more realistic surface (Fig 5, lower).

CSE used in-house custom software, Beach Profile Analysis System (BPAS), for profile archiving and analysis. BPAS evolved from U.S. Army Corp of Engineers' algorithms dating back to the early 1980s. BPAS has been used by the State of South Carolina for more than a decade to archive and analyze beach profile data. The software facilitates data entry, archiving in x–y format (imported from Trimble-HydroPro™ x–y–z format and automatically converted to distance-elevation pairs consistent with the majority of historical profiles), plotting, and updating distances and elevations where monuments or datums change over time. BPAS was used for calculating the unit-width volume, unit-volume change, and contour position and movement for user-selected elevation intervals.

For the present project, CSE used the "profile volume method" of beach erosion analysis and nourishment design (cf, Kana 1993) following the empirical approach of Dutch coastal engineers (CUR 1987, Verhagan 1992). The profile volume approach was adopted by the State of South Carolina to help establish lines of jurisdiction for coastal development under the state's 1988/1990 Beachfront Management Act. The profile volume method offers a more quantitative and objective way of determining where the foredune exists in the absence of structures. It also allows quantification of the condition of a particular section of beach with respect to an ideal or desired condition.

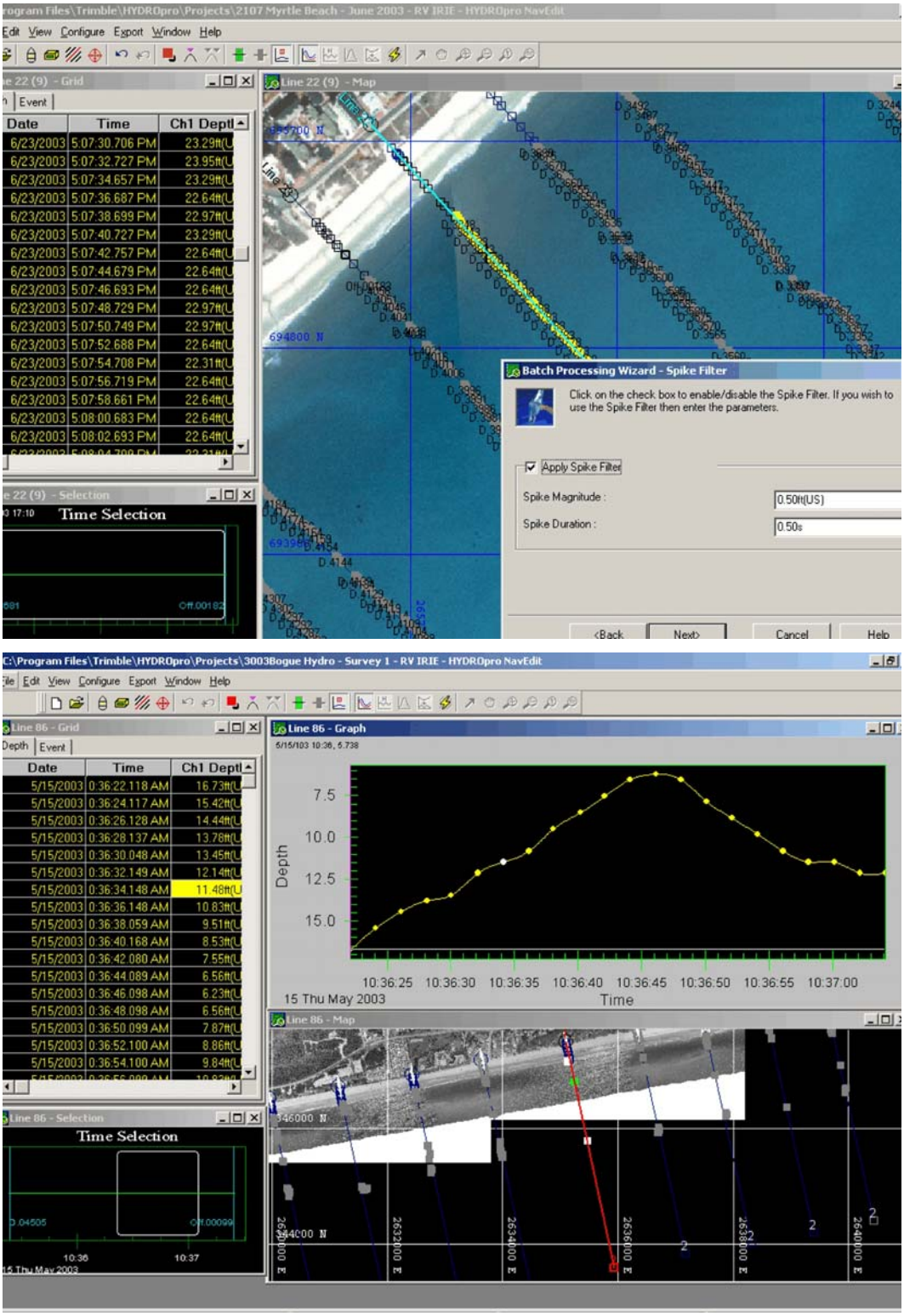


FIGURE 5. Trimble-HydroPro™ software was used by CSE to allow batch processing and editing of large files (data sampling rate used by CSE in Bogue Banks was 10 Hz). Software was used to filter spikes (upper) and provide floating point averages to yield smoother, more realistic profiles such as the one shown over the bar (lower).

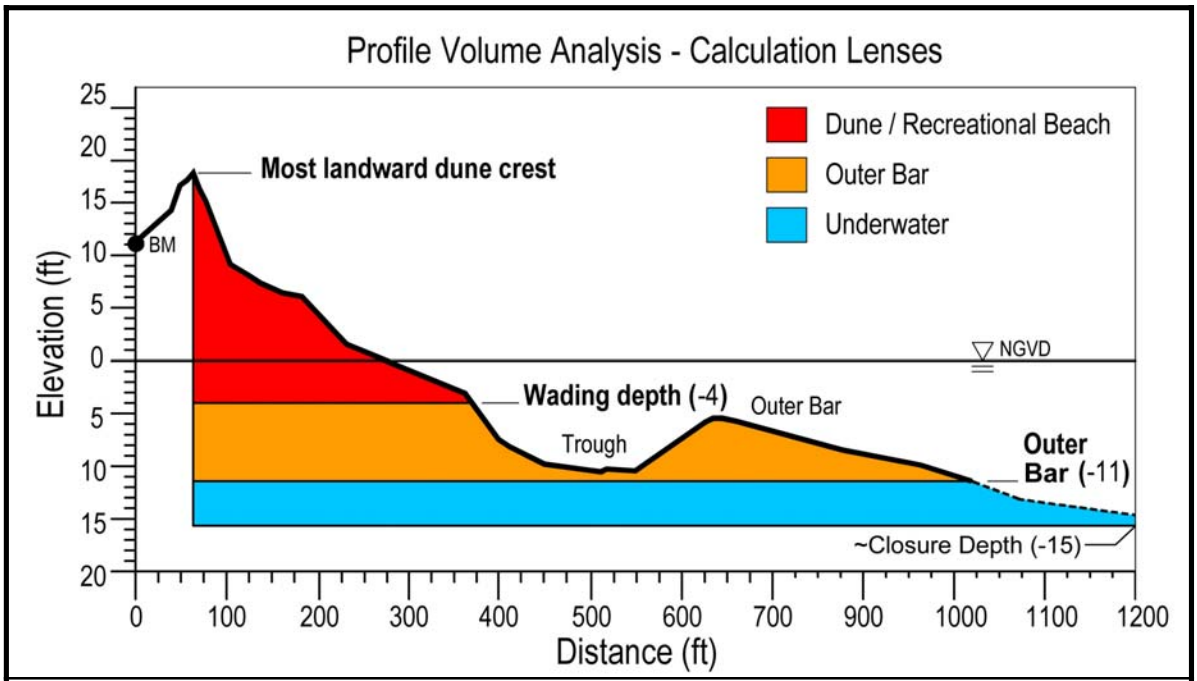
CSE used this methodology because it is linked directly to measurements of the beach zone as opposed to simulated models of profiles or topography. In some places because of the lack of field data, modeled shoreline data have been used for engineering purposes. Such data are necessarily extrapolated from limited measurements such as analyses of shoreline change using aerial photos. However, where repetitive controlled surveys exist, such as along Bogue Banks, there is less need to rely on modeled profile data.

Figure 6 illustrates the profile volume reference points and contours used in the present report. The selection of contours (vertical boundaries) was arbitrary and can be easily adjusted in BPAS. The contours chosen were based on previous analyses dating to 1999 and on experience at other sites, because they represent a useful division of the beach in the cross-shore dimension. Unit-volume* calculations (cf, Fig 7) distinguish the quantity of sediment in the dunes, on the dry beach, in the intertidal zone to wading depth, and in the remaining area offshore to the approximate limit of profile change. In 1999, it was assumed the limit of measurable change was in depths of approximately –15 ft NGVD.

[*Figure 7 illustrates the concept of unit beach volume between reference contours applied over one linear foot of shoreline. When common boundaries are used from profile to profile or survey to survey, the relative as well as absolute variation in beach condition can be determined. In the example, the "eroded" beach profile contains half as much sand volume to low tide wading depth as the "normal" beach profile.]

For budgeting and other reasons, the 1999 survey terminated between the –10 ft and –15 ft contours, seaward of the outer bar. While it is accepted engineering practice to extrapolate the seaward ends of profiles along the natural slope, CSE prefers to avoid this uncertainty. In 1999, CSE Baird–Stroud chose –11 ft as the reference minimum calculation depth because nearly all profiles in the 1999 data set achieved that limit. For the present project, –11 ft is retained as a primary reference boundary. CSE has also added a boundary at –15 ft in 2004, which is used for the present analysis. Depths around –15 ft NGVD off Bogue Banks are believed to capture nearly all of the sand moving in the cross-shore direction from year to year (CSE 2000, CSE-Stroud 2001).

Carteret County sponsored surveys by CSE in 1999, 2000, 2004, and the present project. Table 1 summarizes the number of usable profiles for island-wide comparisons to selected features offshore. For the present report, CSE also utilized selected project profiles collected in conjunction with nourishment projects in 2005. Appendix II contains profile plots for representative dates. A more comprehensive data set with computer files of each profile has been provided to Carteret County Shore Protection Office (CCSPO).



Dune/Recreational Beach — Defined as the cross-section (unit volume) from the most landward foredune crest (among available surveys) to +9 ft NGVD. This area incorporates the active dune, dry beach, and wet beach out to low-tide wading depth.

Outer Bar — Defined as the section between −4 ft and −11 ft NGVD. The lower datum was selected based on the typical limits of earlier data sets. It generally encompasses the outer bar (which varies from about −5 ft to −10 ft NGVD at its crest).

Underwater — This lens extends the profile closer to the seaward limit of yearly profile change ("Closure Depth") based on observations of Bogue Banks' historical profiles.

FIGURE 6. Three reference zones used for calculation of sand volume changes along Bogue Banks 2004–2005 (present report). Integrating all three lenses yields volumes that encompass nearly 100 percent of the sediment volume moving in the littoral zone from year to year.

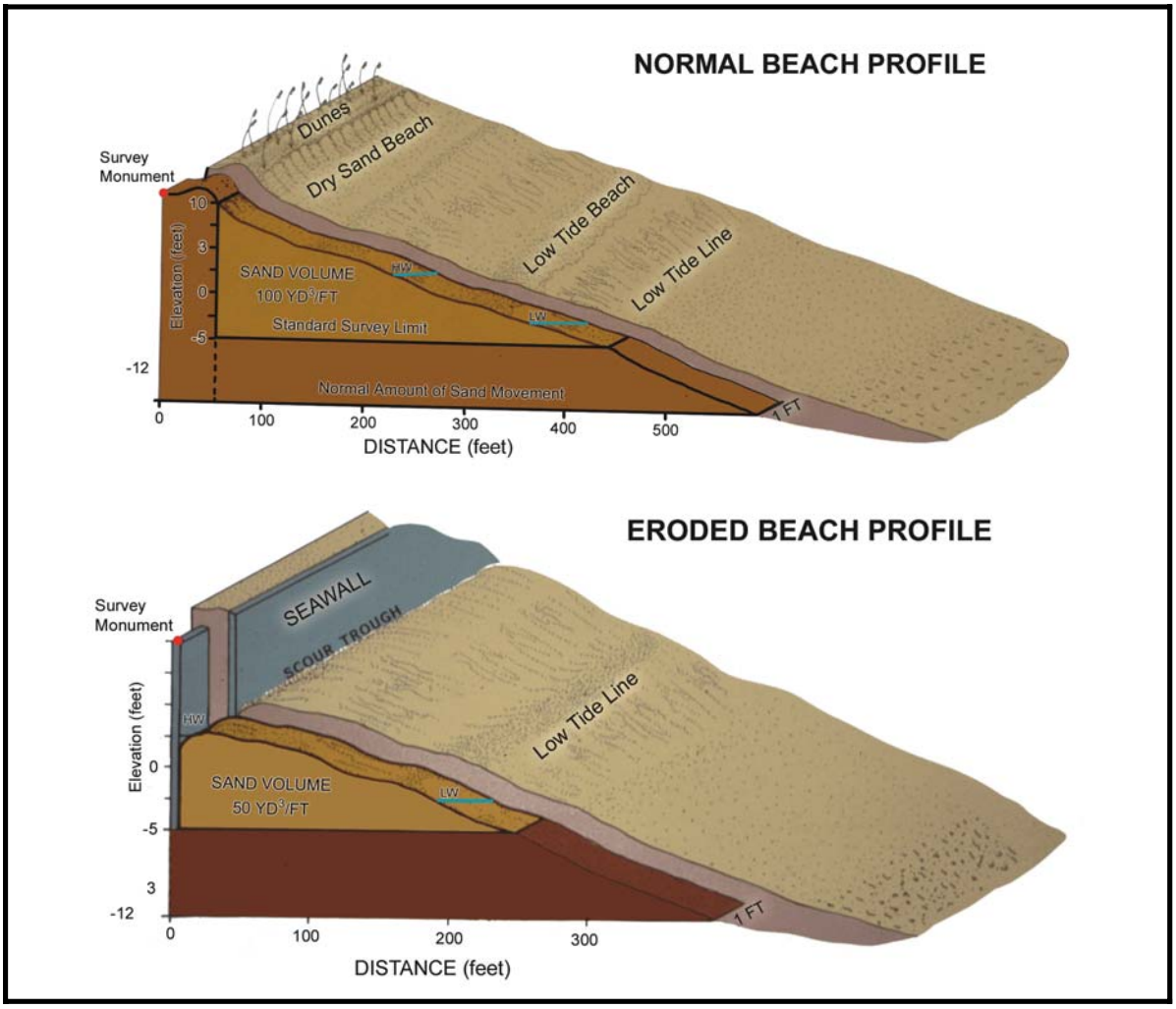


FIGURE 7. The concept of unit sand volume along the beach, which provides a quantitative measure of beach condition and changes before and after nourishment. The yearly limit of measurable sand movement ("profile closure depth") along Bogue Banks is thought to occur at depths of about 15 ft (±5 ft) (CSE-Stroud 2001, Appendix G). CSE's 1999 surveys ended around the outer bar in depths of ~12 ft about 800-1,000 ft from the foredune. Therefore, the early data encompassed the majority, but not all, of the active littoral zone. The present project (Year 2 of BBBNMP) involved profiling to –30 ft or deeper. [Diagram after Kana 1990]

TABLE 1. Bogue Banks shoreline reaches and numbers of profiles available for analysis for June 1999, September 1999, June 2000, December 2003, June 2004, and May 2005. [Reach lengths updated and revised slightly from CSE -Stroud (1999). *Profiles at reach boundaries are applicable to adjacent reaches.]

Reach	Reach Length (ft)	*Applicable Profile Numbers	Number of Usable Profiles by Date (Jun'99 / Sep'99 / Jun'00 / Dec'03 / Jun'04 / May'05)	
			@ low tide	@ outer bar
Bogue Inlet	6,772	1-8	6 / 0 / 8 / 8 /8/ 8	5 / 0 / 6 / 8 / 8 / 8
Emerald Isle-West	22,303	8-25	17 / 3 / 17 / 17 / 17 / 17	17 / 3 / 17 / 17 / 17 / 17
Emerald Isle-Central	15,945	25-36	11 / 2 / 11 / 11 / 11 / 11	11 / 1 / 11 / 11 / 11 / 11
Emerald Isle-East	12,900	36-48	12 / 2 / 12 / 12 / 12 / 12	12 / 2 / 12 / 12 / 12 / 12
Indian Beach-Salter Path	12,986	48-58+	9 / 2 / 10 / 10 / 10 / 10	9 / 1 / 10 / 10 / 10 / 10
Pine Knoll Shores West	9,182	59-65	6 / 2 / 7 / 7 / 7 / 7	6 / 1 / 7 / 7 / 7 / 7
Pine Knoll Shores East	14,785	65-76	10 / 2 / 11 / 11 / 11 / 11	10 / 2 / 11 / 11 / 11 / 11
Atlantic Beach	26,322	76-102	26 / 5 / 26 / 26 / 26 / 26	24 / 5 / 26 / 26 / 26 / 26
Fort Macon State Park	7,199	102-112	9 / 0 / 9 / 9 / 10 / 10	9 / 0 / 9 / 9 / 10 / 10
	128,392 (24.32 miles)			

Sediment Sampling and Testing

Although not specifically required under the present scope of services for Year 2, CSE obtained beach sediment samples at ~1 mile spacing along Bogue Banks, Bear Island, and Shackleford Banks. In prior sampling years, samples consisted of physical composites of multiple samples spaced 50 ft apart between the toe of the foredune and low-tide wading depth. A 15-centimeter (cm) by 15-cm corer was used to obtain equal-volume, random samples to ~15-cm depth. Samples at one transect were combined and mixed. Then an ~100-gram subsample was obtained for analysis. Grain-size distributions at 0.25-phi intervals (sand-size range) were determined by mechanical sieving after washing, drying and re-weighing each sample. Sample splits were converted to percentages and graphed as frequency and cumulative frequency distributions. Standard statistical measures were computed. CSE also subsampled and analyzed for shell content (percent calcium carbonate) and gravel content (percent >2-mm diameter). For the present survey, samples were collected into deeper water following draft protocols of the NC Coastal Resources Commission. These are being tested in the lab as discrete samples rather than physical composites of transect samples. Because of the large number of samples, Year 2 data are not yet available for inclusion in the present report.

RESULTS

Island-Wide Trends

Appendices II and III contain plotted profiles and unit volumes by station and reach (political jurisdiction) for 2004–2005 (respectively). Appendix III-A provides calculations from the foredune crest to –11 ft and –15 ft NGVD that include results from 2004–2005. Appendix III-B contains similar data measured to –4 ft NGVD (low-tide wading depth) for previous surveys, including the 2005 survey results. Appendix III-C provides the 1999–2005 results measured to –11 ft NGVD (outer bar). The bottom of each table in Appendix III (A–C) contains averages and totals by reach. Reference starting points and, in several cases, seaward calculation cutoff distances are given in the first few columns of each table. Unit-volume changes for selected dates are given in later columns. The net change between profiles is computed using the average-end-area method which applies the results for adjacent stations over the indicated shoreline distance ("Distance from Last") between profiles.

Table 2 summarizes the beach volume results by reach for June 2004 through May 2005. Eleven reaches are referenced along Bogue Banks. Nine reaches match the original ones established by CSE-Stroud (1999). Two new ones, Bogue Inlet Channel and Beaufort Inlet, extend the limits of the survey. [Note: These reaches are not included in the "oceanfront" totals.] Station 112 was added at the eastern end of Fort Macon State Park (FMSP) in 2003 (see Fig 1). It was surveyed on two azimuths (as indicated on the figure) with the Beaufort channel line referenced as station 113. This increased the reach length for FSMP and the overall (oceanfront) length to 128,392 ft (24.32 miles) for computation purposes. Since 1999, CSE has referred to the six reaches encompassing most of Emerald Isle (EI–West, EI–Central, EI–East), Indian Beach/Salter Path (IB/SP), and Pine Knoll Shores (PKS–West, PKS–East) as the "county project" because they incorporate planned nourishment. This ~17-mile subsection of the island is represented by profiles 8 through 76.

In general, the reach limits in Table 2 fall close to political boundaries. However, to simplify the analysis and retain consistency with prior studies, the effective reach boundaries fall on a particular profile line. Thus, the length of Indian Beach/Salter Path (IB/SP) computes at 12,986 ft, but is not precisely that length measured along the oceanfront. (The actual distance is closer to 12,905 ft as measured near the present foredune). In Table 2, unit-width volumes by reach for particular survey dates are weighted average unit volumes calculated from the profile unit volume data in Appendix III (A–C) and allow for direct calculation of weighted-average, unit-volume changes from one year to another.

TABLE 2. Beach volume changes by reach for Bogue Banks (NC) – June 1999 to May 2005. Volume calculations for Bear Island are for October 2004 to May 2005. Shackleford Banks data are presented for May 2005.

DUNE TO -4 FT NGVD			Weighted Avg (cy/ft)						Jun-99 to May-05		Jun-04 to May-05	
Reach	**Profiles**	**Reach Length (ft)**	**Jun-99**	**Jun-00**	**Apr-05**	**Dec-05**	**Jun-05**	**May-05**	**Wtd Avg (cy/ft)**	**Net (cy)**	**Wtd Avg (cy/ft)**	**Net (cy)**
Bogue Inlet-Channel	117-120	1,900	-	-	-	44.0	38.8	44.4	-	-	5.7	10,792
Bogue Inlet-Ocean	1-8	6,772	209.3	156.7	162.8	164.9	171.8	173.8	37.0	250,657	2.1	13,918
EI-West	8-25	22,303	163.6	80.1	87.8	93.2	95.6	119.9	43.2	963,253	24.3	542,282
EI-Central	25-36	15,945	159.8	79.6	112.9	111.4	112.1	116.6	42.3	675,135	4.4	70,577
EI-East	36-48	12,900	175.7	72.5	134.3	123.6	126.4	124.1	52.0	670,766	-2.3	-29,447
IB/SP	48-58+	12,986	196.0	72.6	101.8	107.9	134.9	131.6	63.9	829,318	-3.3	-43,495
PKS-West	59-65	9,182	133.6	66.2	102.6	99.8	100.5	100.6	33.3	305,689	-0.9	-8,333
PKS-East	65-76	14,785	121.4	64.0	99.4	96.8	99.9	94.3	26.6	392,759	-5.6	-83,525
AB	76-102	26,322	164.4	91.2	93.1	88.2	92.8	128.6	35.4	931,032	35.8	942,289
FMSP	102-112	7,199	119.7	90.5	82.9	72.9	74.1	109.5	2.2	15,679	35.4	255,147
Beaufort Inlet	112-116	2,250	-	-	-	126.6	145.0	183.1	-	-	38.1	85,619
County Project	**8-76**	**88,099**	**72.0**	**73.7**	**104.5**	**104.3**	**110.5**	**115.6**	**43.6**	**3,836,920**	**5.1**	**448,059**
Entire Oceanfront	**1-112**	**128,392**	**81.8**	**82.6**	**104.1**	**102.5**	**108.1**	**121.0**	**39.2**	**5,034,288**	**12.9**	**1,659,414**
			Weighted Avg (cy/ft)								Oct-04 to May-05	
							Oct-04	May-05			Wtd Avg (cy/ft)	Net (cy)
Bear Island	1-18	17,000					107.6	105.9			-1.7	-29,705
Shackleford	1-24	23,000						114.7				

DUNE TO -11 FT NGVD			Weighted Avg (cy/ft)						Jun-99 to May-05		Jun-04 to May-05	
Reach	**Profiles**	**Reach Length (ft)**	**Jun-99**	**Jun-00**	**Apr-05**	**Dec-05**	**Jun-05**	**May-05**	**Wtd Avg (cy/ft)**	**Net (cy)**	**Wtd Avg (cy/ft)**	**Net (cy)**
Bogue Inlet-Channel	117-120	1,900	-	-	-	79.4	69.9	77.9	-	-	10.0	20,639
Bogue Inlet-Ocean	1-8	6,772	363.7	375.5	323.0	319.8	320.1	457.7	58.4	395,676	92.4	626,020
EI-West	8-25	22,303	208.1	211.5	228.3	236.0	242.1	268.0	59.3	1,321,780	26.8	598,728
EI-Central	25-36	15,945	194.2	201.4	247.9	244.6	249.1	258.0	62.9	1,002,184	8.0	128,154
EI-East	36-48	12,900	193.3	191.7	281.0	264.5	270.0	268.3	74.7	963,911	-0.1	-1,204
IB/SP	48-58+	12,986	187.0	195.3	244.6	240.1	293.3	287.3	99.4	1,290,983	-6.6	-85,523
PKS-West	59-65	9,182	186.3	183.5	237.5	222.8	221.4	238.2	57.3	526,330	15.9	146,225
PKS-East	65-76	14,785	194.3	188.5	245.7	233.3	238.6	234.2	39.0	576,150	-4.0	-59,354
AB	76-102	26,322	234.5	230.6	245.4	236.2	238.6	308.2	72.3	1,902,206	67.1	1,766,014
FMSP	102-112	7,199	227.9	217.5	209.9	216.2	207.7	274.4	40.0	287,847	65.8	473,780
Beaufort Inlet	112-116	2,250	-	-	-	312.6	359.3	407.9	-	-	68.1	448,098
County Project	**8-76**	**88,099**	**195.7**	**197.9**	**245.8**	**240.0**	**251.9**	**260.2**	**64.5**	**5,681,337**	**8.3**	**727,025**
Entire Oceanfront	**1-112**	**128,392**	**214.3**	**215.1**	**247.8**	**242.4**	**250.7**	**278.7**	**64.4**	**8,267,067**	**28.0**	**3,592,840**
			Weighted Avg (cy/ft)								Oct-04 to May-05	
							Oct-04	May-05			Wtd Avg (cy/ft)	Net (cy)
Bear Island	1-18	17,000					298.6	290.7			-8.0	-135,310
Shackleford	1-24	23,000						261.1				

DUNE TO -15 FT NGVD			Weighted Avg (cy/ft)								Jun-04 to May-05	
Reach	**Profiles**	**Reach Length (ft)**	**Jun-99**	**Jun-00**	**Apr-05**	**Dec-05**	**Jun-05**	**May-05**	**Wtd Avg (cy/ft)**	**Net (cy)**	**Wtd Avg (cy/ft)**	**Net (cy)**
Bogue Inlet-Channel	117-120	1,900				89.6	77.7	89.9			9.7	18,389
Bogue Inlet-Ocean	1-8	6,772				-	-	627.2			nd	-
EI-West	8-25	22,303				368.0	374.6	410.8			36.2	807,600
EI-Central	25-36	15,945				383.5	387.9	402.9			14.9	238,146
EI-East	36-48	12,900				406.2	409.2	415.9			6.7	86,866
IB/SP	48-58+	12,986				386.1	436.1	436.7			0.5	6,703
PKS-West	59-65	9,182				362.7	365.5	391.0			25.5	233,908
PKS-East	65-76	14,785				386.7	387.5	384.5			-3.0	-44,338
AB	76-102	26,322				400.4	398.0	481.2			83.2	2,189,434
FMSP	102-112	7,199				359.1	345.9	456.0			110.1	792,583
Beaufort Inlet	112-116	2,250				437.7	483.6	943.9			460.4	1,035,861
County Project	**8-76**	**88,099**				**381.7**	**392.4**	**407.4**			**15.1**	**1,328,884**
Entire Oceanfront	**1-112**	**128,392**				**384.4**	**390.8**	**426.3**			**33.6**	**4,310,901**
			Weighted Avg (cy/ft)								Oct-04 to May-05	
							Oct-04	May-05			Wtd Avg (cy/ft)	Net (cy)
Bear Island	1-18	17,000					463.6	464.3			0.7	11,980
Shackleford	1-24	23,000						412.1				

With respect to island-wide trends, Table 2 indicates the following:

1) There has been an ~8.3 million cubic yard net increase in beach volume along Bogue Banks between 1999 and 2005. This equates to a weighted average gain of 64.4 cy/ft within the primary computation boundaries to –11 ft NGVD.

2) Bogue Banks gained 3.6 million cubic yards (28.0 cy/ft) between June 2004 and May 2005 between the foredune and outer bar (-11 ft NGVD).

3) The 17-mile county project reach (designated by profile 8 to profile 76) gained 727,025 cy (8.3 cy/ft) of sand over the past year (to -11 ft NGVD). Atlantic Beach and Fort Macon State Park gained ~1,765,000 cy and 475,000 cy (respectively) between June 2004 and May 2005.

4) The island-wide and county project totals to low-tide wading depth (–4 ft NGVD) for 2004–2005 were 1.66 million cubic yards (12.9 cy/ft) and 448,059 cy (5.1 cy/ft) (respectively) (Table 2). The island-wide and county project totals to –11 ft were 727,025 cy and 3,592,839 cy (respectively). This means that 46 percent of the net increase can be accounted for in the upper beach island-wide. This figure is 62 percent for the county project. In simple terms, much of the increase in sand volume was split evenly between the recreational beach and the beach offshore to the outer bar.

Figure 8 show the trends in unit beach volumes and unit beach volume changes by reach and island-wide for June 2004 and May 2005. Comparisons for Bear Island use October 2004 and May 2005. Shackleford Banks uses data from 2005 only. Figure 8 (upper) compares 2004 and 2005 unit volumes to the outer bar. Also shown is a reference line for the "Target Minimum Profile Volume" similar to a criteria used by CSE–Stroud (1999) for the initial project planning.* The calculation boundaries are from the approximate dune crest to –11 ft NGVD. Figure 8 (lower) shows the changes in unit volumes between June 2004 and May 2005. The largest changes occurred along the Bogue Inlet Ocean reach (profiles 1-8), Emerald Isle–West (profiles 8-25), Atlantic Beach (profiles 76-102) and Fort Macon State Park (profiles 102-112). All of these reaches were directly nourished in 2004-2005. When averaged over the length of Bogue Banks, there was a net gain of ~28 cy/ft between June 2004 and May 2005.

[*The 1999 target-minimum volume for Bogue Banks was 175 cy/ft based on the average unit volume along Atlantic Beach measured from the **base** of the foredune. The target minimum shown herein (~225 cy/ft) takes into account dune volumes not included in the 1999 analysis.]

Previous studies (eg, CSE-Stroud 1999) have shown that the typical rate of beach change along Bogue Banks is of the order 2 cy/ft/yr. Only PKS–East and the eastern end of Emerald Isle show changes of this order for the 2004–2005 period. The majority of the island gained sand at rates of 25–90 cy/ft. This, of course, reflects the impact of nourishment. The eastern reach of Pine Knoll Shores lost about 4.4 cy/ft/yr in beach volume for the period June 2004 to May 2005. The eastern end of Emerald Isle had nearly zero net gain. As Table 2 indicates, the average gain for the entire oceanfront was 28.0 cy/ft (dune to –11 ft). As previously described, nearly all the gain occurred in the county project nourishment reaches of Atlantic Beach, FMSP, Bogue Inlet, Beaufort Inlet, and Emerald Isle–West.

Figure 8 illustrates why it is useful to consider the absolute volume of sand in the profile (unit-width volumes in Figure 8, upper) as well as the volume change between surveys. The largest sand gains between 2004 and 2005 occurred along the Bogue Inlet–Ocean reach (~92 cy/ft accretion). [Incidentally, for the five years prior to 1994, Bogue Inlet–Ocean experienced the greatest losses (CSE 2004).] FMSP gained ~65 cy/ft. Therefore, the erosion rates along the ends of the island (oceanfront) were well above the historical rate for the island.

Gains in the nourished reaches of Bogue Inlet–Ocean, Emerald Isle–West, Atlantic Beach, and FMSP have enabled the entire island to exceed the target minimum volume.

A review of the average unit volumes for 2004–2005 to the outer bar shows that:

- The largest increase in unit volume occurred at the Bogue Inlet–Ocean reach, reflecting in part Phase 3 nourishment volumes in January to April 2005.

- Other large increases occurred at Atlantic Beach and FMSP. Increases here are also reflective of nourishment volumes added during the 2004–2005 study period.

- Decreases in reach unit volumes are seen at Emerald Isle–East (–0.1 cy/ft), Indian Beach/Salter Path (–6.6 cy/ft), and Pine Knoll Shores–East (–4.0 cy/ft).

- With the exception of Bogue Inlet–Channel, all reaches exceeded the target minimum profile volume of 225 cy/ft in May 2005.

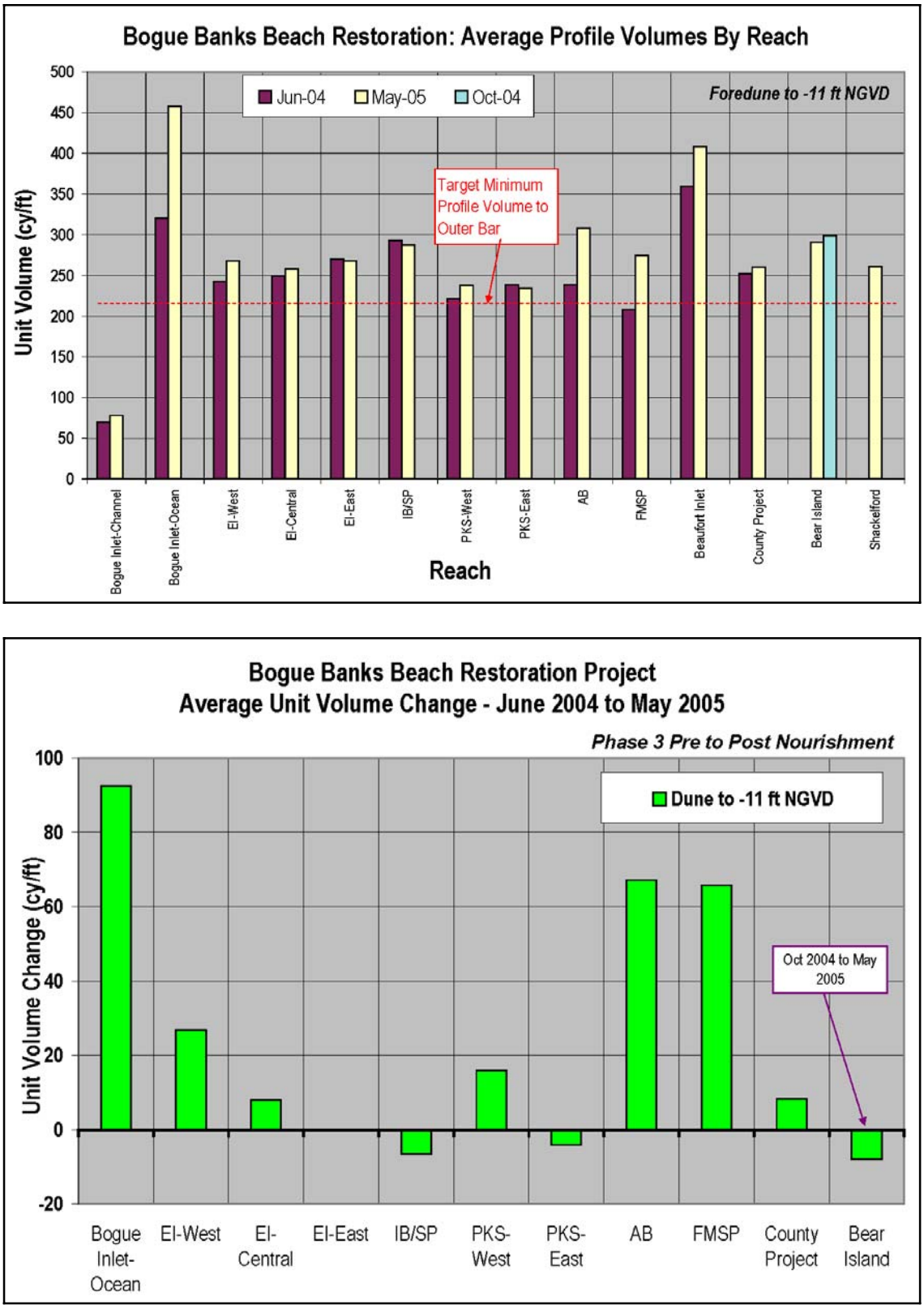


FIGURE 8. Trends (by reach) in average dune, beach, and inshore sand volume measured to –11 ft (including outer bar) between June 2004 and May 2005 (upper). Lower graph illustrates the change by reach for the one-year period.

Comparison with Nourishment Volumes

A total of *3,911,597 cy of sand was used to nourish beaches on Bogue Banks between February 2005 and April 2005 (*estimated in-place volume, CCSPO 2005). This brings the total nourishment volume to ~8,558,000 cy since November 2001 (Fig 9, Table 3). In 2005, the Brandt Island pumpout supplied ~2.9 million cubic yards to Atlantic Beach.

Inner harbor dredging disposal added ~300,000* cy to Fort Macon State Park, and Phase 3 of the county project added ~691,000 cy of sand to the western end of Emerald Isle (*estimated in-place volume, CCSPO 2005). The surveyed sand volume increase between June 1999 and May 2005 accounts for 96 percent of the total nourishment volume added. An estimated volume of 309,280 cy has eroded, allowing for an annual background erosion rate of 0.38 cy/ft/yr over the last six years.

Estimates of background erosion (summarized by reach) are listed in Table 4. Some adjacent reaches are combined to facilitate interpretation of the results. In reaches where nourishment volume exceeds the surveyed volume change, background erosion is evident. Where the surveyed volume change exceeds the nourishment volume added, there is a net accretion of sand. The nourishment and natural beach volume changes are shown in Figure 10 (upper). Atlantic Beach has received the most total nourishment volume of any reach and has experienced the most loss in volumes. Higher than usual loss rates are thought to be the result of high proportions of fine sediment in the Brandt Island spoil as well as erosive natural conditions.

Along the eastern reaches, erosion has averaged ~5–6 cy/ft/yr since 1999. Nourishment volumes exceed estimated beach volumes to –11 ft NGVD, resulting in a net erosion condition. Along the western reaches, nourishment volumes tend to be less than the estimated beach volume changes, which leads to a net accretion condition from June 1999 to May 2005. The Emerald Isle–East and Central combined reaches seem to go against this trend, but the eroded volume is very small compared to other reaches.

Volume losses and gains are directly reflected in the annual background erosion rates of each community (Fig 10, lower). The eastern reaches have experienced a high rate of erosion while the western reaches (with the exception of EI–East and EI–Central) have experienced a high rate of accretion over the last six years. The central reaches have volumetric accretion/erosion rates that are more typical of beaches in this region (CSE-Stroud 1999).

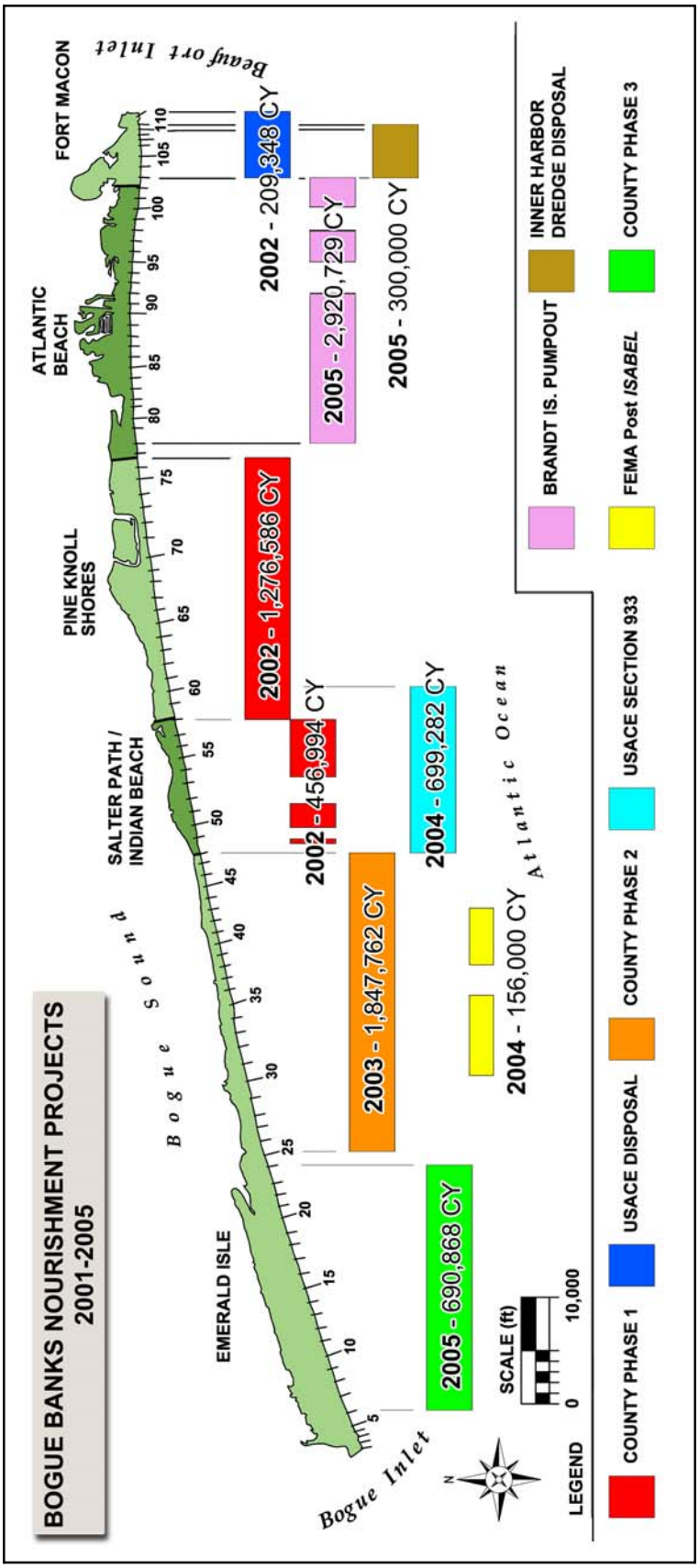


FIGURE 9. Nourishment projects along Bogue Banks (2001–2005).

TABLE 3. Bogue Banks nourishment volumes (2001–2005). Sources: CSE (2003a,b), Weeks Marine Inc, Great Lakes Dredge & Dock Company, and CCSPO (2004, 2005).

*Contracted volumes vary from "in-place" volumes for different reasons depending on the project. Turtle takes during County Project Phase 1 (PKS and IB/SP) caused a premature shutdown of the project before all contracted work could be completed. County Project Phase 2 was modified during construction such that a more continuous foredune could be reestablished. The USACE Section 933 project (a) provided for a maximum of 900,000 cy to be removed from the Beaufort Inlet channel, (b) yielded ~800,000 cy removed (on which hopper pay volume was based), and (c) produced ~700,000 cy surveyed in-place on the beach.

**In-place volumes are generally based on detailed project surveys immediately before and after fill placement. For the majority of projects, in-place volumes serve as the basis for payment to contractors. Post-*Isabel* FEMA project volume is based on ~90 percent hopper bin volume of 172,555 cy.

	Project - Reach	Year	Contracted* Volume (cy)	In-Place** Volume (cy)
1	County Phase 1 PKS–East & West	2002	1,402,983	**1,276,586**
2	County Phase 1 IB/SP	2002	770,233	**456,994**
3	USACE Disposal - FMSP	2002	209,348	**209,348**
4a	County Phase 2 EI–East & Central	2003	1,810,000	**1,746,413**
4b	County Phase 2 EI–E&W - Dune	2003	60,000	**101,349**
5	USACE Section 933 IB/SP & PKS–W	2004	900,000	**699,282**
6	FEMA Post *Isabel* - EI–East & Central	2004	128,000	**156,000**
7	Brandt Island Pump Out - AB	2005	2,920,729	**2,920,729**
8	Inner Harbor Dredging Disposal - FMSP	2005	300,000	**300,000**
9	County Phase 3 EI–West	2005	710,000	**690,868**
	Totals		9,211,293	**8,557,569**

TABLE 4. Bogue Banks nourishment volumes (2001–2005) and estimated background erosion rate without nourishment. Calculations to –11 ft NGVD. [*Volume of Section 933 prorated between PKS–West and IB/SP. Volume of EI–West Phase 3 prorated between Bogue Inlet–Ocean and EI–West.]

Reach	Length (ft)	Nourishment Volume* (cy)	Jun 1999 to May 2005 Volume Change (cy)	Background Erosion (cy)	Average Annual Background Erosion Rate (cy/ft/yr)
Bogue Inlet - Ocean	6,772	46,540	395,676	349,136	8.71
EI-West	22,303	644,328	1,321,780	677,452	5.13
EI-East & Central	28,844	2,003,762	1,966,095	(37,667)	-0.22
IB/SP	12,986	1,039,729	1,290,983	251,254	3.27
PKS	23,967	1,393,133	1,102,480	(290,653)	-2.05
AB	26,322	2,920,729.00	1,902,206	(1,018,523)	-6.54
FMSP	7,199	509,348	288,837	(220,511)	-5.18
Bogue Banks Total	**128,392**	**8,557,569**	**8,268,057**	**(289,512)**	**-0.38**

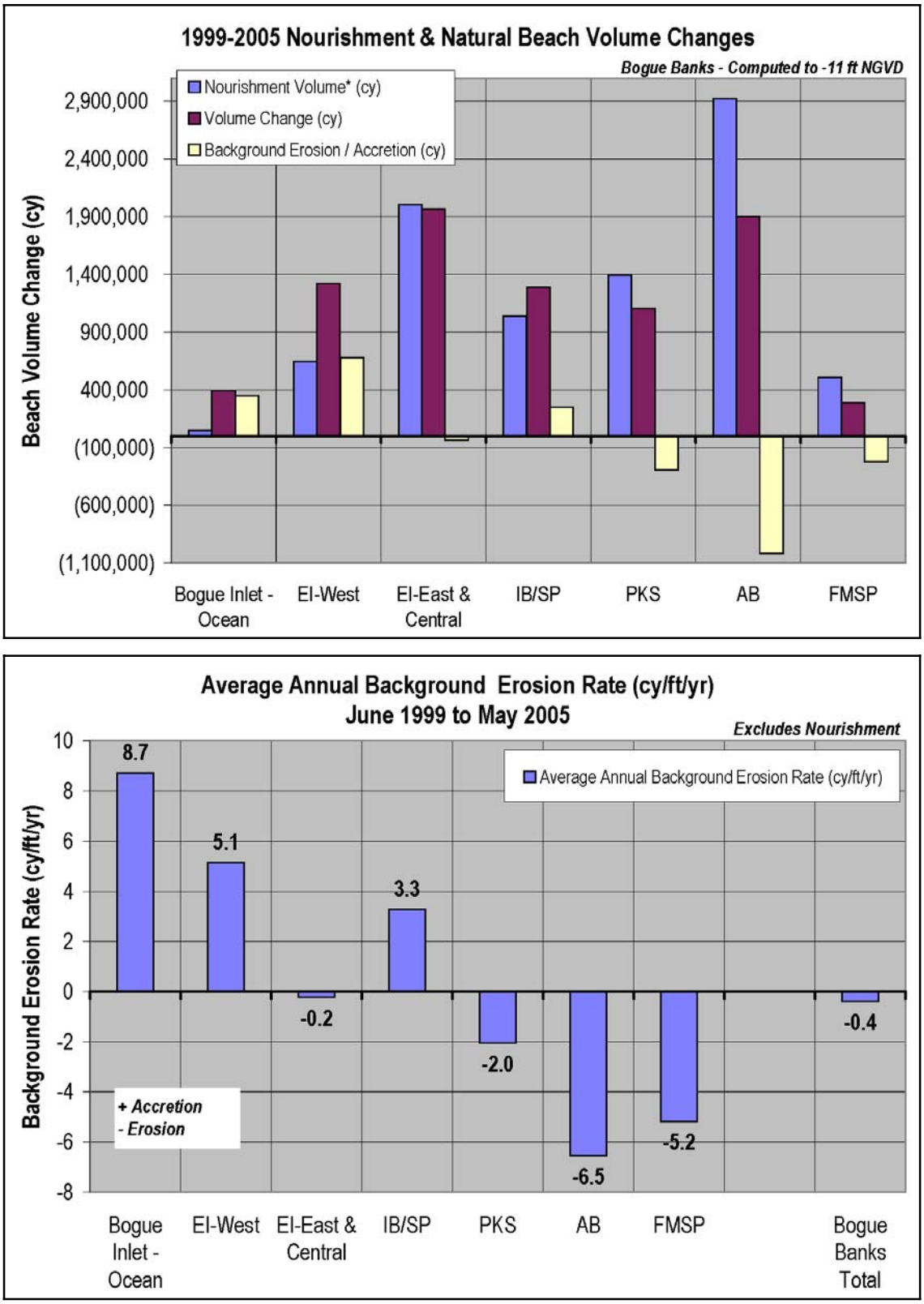


FIGURE 10. **[UPPER]** Total nourishment volumes and surveyed volume changes by reach for June 1999 to June 2005. The difference between the two quantities is the "background" erosion rate. **[LOWER]** Average, annual, background erosion rate after factoring out nourishment.

The rate of erosion for all of Bogue Banks was 0.38 cy/ft/yr, suggesting that net losses were only slightly more than the net gains in sand volume over the last six years. Given the limitations of the surveys, these results confirm the long-standing notion that Bogue Banks is one of the more stable barrier islands on the North Carolina coast (Pilkey et al 1975, 1982).

Calculations of remaining nourishment volume for the county project Phase 1 and Phase 2 beach renourishment are shown in Appendix III-D.

The next sections describe community-by-community results with data for individual communities included in Appendix V.

Emerald Isle

Emerald Isle (EI) is part of the county project which was initiated in 1999. Reaches EI–East, EI–Central, and EI–West comprise 51,148 ft lying between stations 8 and 48. An additional 6,772 ft (stations 1–8) make up the Bogue Inlet–Ocean reach along western Emerald Isle. Nourishment totaling 690,868 cy of sediment dredged from Bogue Inlet was placed on the western part of Emerald Isle between February and April 2005 (Bogue Banks restoration project Phase 3). The nourishment sand was placed between stations 6 and 24. Of the 690,868 cy placed, ~644,328 cy were placed in Emerald Isle (western reach, between stations 8 and 24), and the remaining 46,540 cy were placed between stations 6 and 8 of the Bogue Inlet–Ocean reach (CPE 2005).

The net change in sand volume along Emerald Isle (EI–East, EI–Central, and EI–West) was a gain of 725,678 cy (to –11 ft NGVD) between June 2004 and May 2005. The average volume gain for these three reaches was 14.2 cy/ft. Gains in the recreational beach to wading depth accounted for 80 percent of the volume increase from June 2004 to May 2005 (Table 2, Appendix IV). Nourishment accounts for 87 percent of the gain along Emerald Isle with nearly all of it concentrated along EI–West. Through nourishment and natural processes, EI–West captured 26.8 cy/ft of sand over the last year. The central reach captured 8.0 cy/ft; and the eastern reach was virtually stable (change = 0.10 cy/ft) over the same time period.

The unit volume changes by station from June 2004 to May 2005 are shown in Figure 11. EI–West typically experienced high increases in unit volume, while the eastern and central reaches were marked by highly variable changes from station to station. High erosion to the outer bar occurred at profiles 27 and 43, whereas high accretion occurred at profiles 33 and 95. Gains and losses to –4 ft were less variant and more moderate than they were to –11 ft NGVD.

Since June 1999, Emerald Isle (stations 1–48) has gained nearly 3.7 million cubic yards between the foredune and the outer bar. This equates to an average gain of ~6.36 cy/ft or an approximately 80–85 ft wider dry beach. Nourishment accounts for ~2.7 million cubic yards. Therefore, natural accretion has totaled upward of 1 million cubic yards (~2.9 cy/ft/yr) between June 1999 and May 2005, leaving Emerald Isle's beach much healthier. Some of the gain is attributed to the westerly movement of sand from Indian Beach and Pine Knoll Shores. Hurricane *Ophelia* struck Emerald Isle on 13–14 September 2005, after the Year 2 survey. Limited survey results (given at the end of this report) indicate that Emerald Isle lost about 580,000 cy during the storm. Based on this estimate, Emerald Isle retains at least 3.1 million cubic yards more sand along the beach compared with 1999 conditions.

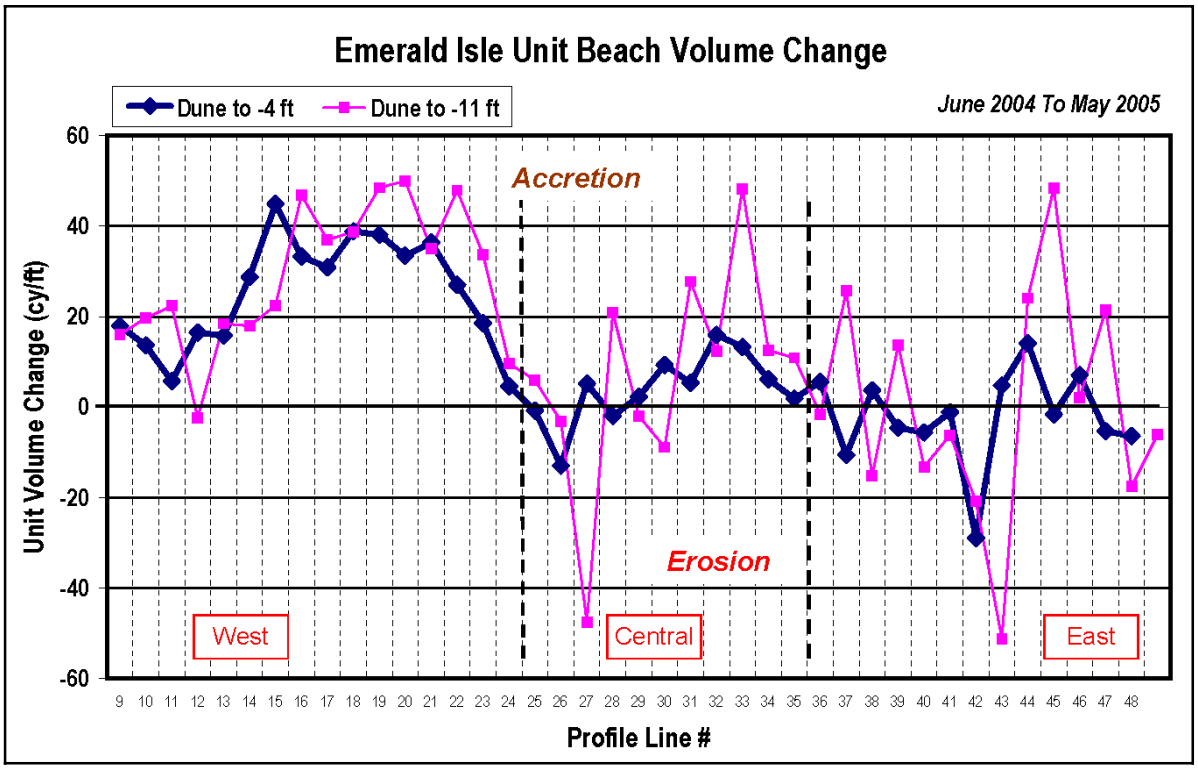


FIGURE 11. The net change by station to –4 ft and –11 ft calculation depths at all stations from June 2004 to May 2005.

Indian Beach/Salter Path

Indian Beach/Salter Path (IB/SP) is part of Phase 1 of the county nourishment project initiated in 1999 and the Section 933 nourishment project completed under the direction of the CCSPO in winter 2004. The 2.5-mile shoreline of this reach lies between profile lines 48 and 58. Survey data indicate that IB/SP lost 85,523 cy of sand from June 2004 to May 2005 due to erosion (to –11 ft NGVD). The average unit volume change in this reach during the past year was –6.59 cy/ft. Interestingly, IB/SP gained more sand per foot of beach than any other reach along Bogue Banks in the five years prior to the present analysis (CSE 2004).

Nourishment projects have added 1,039,729 cy (Table 4), but the surveyed volume change from 1999 to 2004 was 1,361,192 cy (measured to –11 ft). The corresponding surveyed volume change between 1999 and 2005 was 1,290,983 cy. Therefore, Indian Beach has gained ~80 cy/ft via nourishment and ~19.3 cy/ft via natural accretion since 1999. This is the equivalent of an ~120–130 ft wider beach on average compared with conditions in June 1999.

The unit volume changes by station between June 2004 and May 2005 are shown in Fig 12 for results to 4 ft and 11 ft NGVD. The beach lost sand at half the profiles, resulting in a unit volume decrease of 3.3 cy ft (to –4 ft). To –11 ft, IB/SP lost sand at four out of six profiles, which resulted in a loss of 6.59 cy/ft for the entire reach. Converging lines are indicative of sand accumulation in the outer bar while diverging lines indicate sand accumulation above the –4 ft contour.

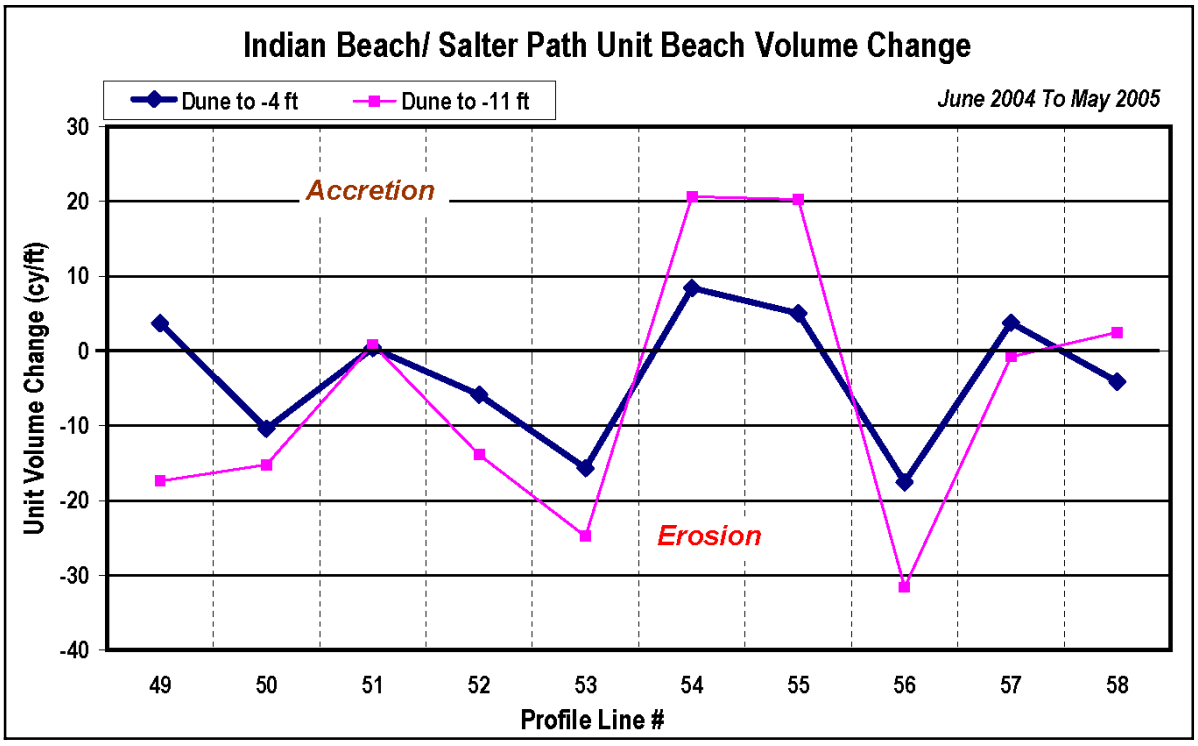


FIGURE 12. The net change by station to –4 ft and –11 ft calculation depths at all stations from June 2004 to May 2005.

Pine Knoll Shores

Pine Knoll Shores (PKS) is part of Phase 1 of the county nourishment project initiated in 1999 and the Section 933 nourishment project completed under the direction of the CCSPO in winter 2004. Its 4.5 mile shoreline lies between profile lines 58 and 76. The PKS reach is divided into two sub reaches: PKS-East (lines 58 to 65) and PKS-West (lines 65-76). Survey data indicate that PKS had a net gain of sand due to natural processes of 86,871 cy to –11 ft NGVD. PKS-West gained 146,225 cy (15.92 cy/ft) from June 2004 to May 2005, while PKS-East lost 59,354 cy (–4.01 cy/ft) during the same time period. The average change in volume for the entire reach was 3.62 cy/ft. All of the losses at Pine Knoll Shores can be accounted for above the –4 ft elevation. Losses in volume to –4 ft NGVD were nearly –1 cy/ft at PKS–West and –5.6 cy/ft at PKS–East (–3.8 cy/ft overall). The high increase in sand volume between low tide and the outer bar along the western reach accounts for the net gain in volume for the entire reach in the past year.

Nourishment projects have added 1,393,133 cy to Pine Knoll Shores, but the surveyed volume change from 1999 to 2005 is 1,102,480 cy (Table 2). The difference (290,653 cy) provides an estimate of the net erosion losses during the past six years. Averaged annually over the length of PKS, the background erosion rate has been ~2.1 cy/ft/yr, which is close to historic averages estimated before nourishment (CSE-Stroud 1999). Pine Knoll Shores is scheduled to receive nourishment during the next 933 project subject to federal funding and project implementation (G Rudolph, CCSPO, pers comm, August 2005).

Figure 13 shows the unit volume changes at each station to –4 ft and –11 ft elevations. Accumulation of sand to the outer bar at the western end of PKS is somewhat dramatic. Accumulation at more moderate levels is seen to the –4 ft elevation in this part of the reach. The eastern end of PKS is marked by losses at just about every position.

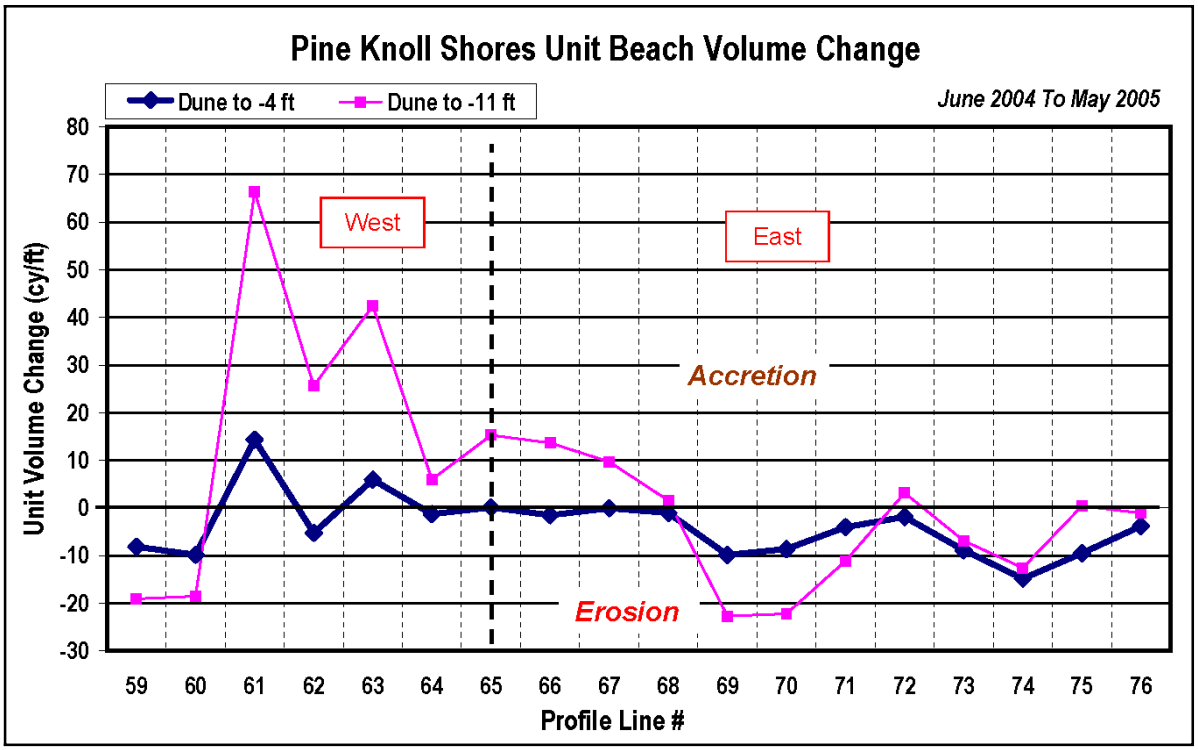


FIGURE 13. The net change by station to –4 ft and –11 ft calculation depths at all stations from June 2004 to May 2005.

Atlantic Beach

Atlantic Beach (AB) was nourished in 1986, 1994, and most recently in 2005 in conjunction with disposal of the Brandt Island upland spoil basin. It remains part of the USACE plan for periodic disposal of harbor sediments. The 5.0-mile-long AB shoreline lies between profile lines 76 and 102. Survey data indicate that Atlantic Beach gained over 1.76 million cubic yards of sand between June 2004 and May 2005 (measured to –11 ft NGVD).

Atlantic Beach served as a model for the rest of Bogue Banks in 1999 based on its relatively healthy beach after the 1986 and 1994 dredge disposal projects. CSE Baird-Stroud (1999) based the target minimum volumes for other communities on the condition of Atlantic Beach. This criteria was tested during Hurricane *Floyd* (September 1999). While Emerald Isle, Indian Beach, Salter Path, and Pine Knoll Shores sustained extensive damage to shore-front structures, AB lost few walkovers and retained a viable dune system.

Between 1999 and June 2004, Atlantic Beach remained fairly stable with only minor sand losses (~0.4 cy/ft/yr) to low-tide wading depth. Nourishment by way of Brandt Island spoil disposal in winter 2005 increased the unit volumes along Atlantic Beach well beyond the target minimum volume or the volumes in other communities. In May 2005, AB's typical volume to the outer bar was ~307 cy/ft versus ~265 cy/ft along Emerald Isle, 285 cy/ft along Indian Beach, and ~240 cy/ft along Pine Knoll Shores. In short, Atlantic Beach, once again, has more sand along the beach than any other Bogue Banks community.

Atlantic Beach is marked by high unit volume gains reflected in accumulation to the outer bar as well as accumulation to –4 ft elevation. This is indicative of the beach nourishment supplied at the beginning of 2005. The sinusoidal nature of the graph in Figure 14 probably reflects variation in the rate of fill placement. According to the CCSPO (see protectthebeach.com), the initial fill (lines 95 to 100 along eastern AB) contained high proportions of fines, which resulted in large volumes shifting offshore before the dry beach width was accomplished. Adjustments were made for more westerly sections to reduce the unit volumes placed. The sediment quality also improved for the second half of the project, leading to more stable sections (profiles 84–88). Brandt Island pumpout sand was not placed in the vicinity of Sportsman Pier and Oceanana Pier (profiles 92–95) or in the vicinity of Triple S Pier (profiles ~98–100). Leaving these areas unnourished has enhanced the sinusoidal shape of the unit volume change curve at this locations.

Unlike the neighboring PKS–East reach, the beach to –4 ft along Atlantic Beach has seen high accretion volumes over the entire reach (35.8 cy/ft). The gain in sand is also evident to the outer bar (67.1 cy/ft). All the volume gain from June 2004 to May 2005 can be attributed directly to the nourishment project in 2005. However, out of an estimated 2.9

million cubic yards placed, upward of 1.15 million cubic yards were lost (presumably into deeper water) because of the presence of mud and very fine sand in the spoil.

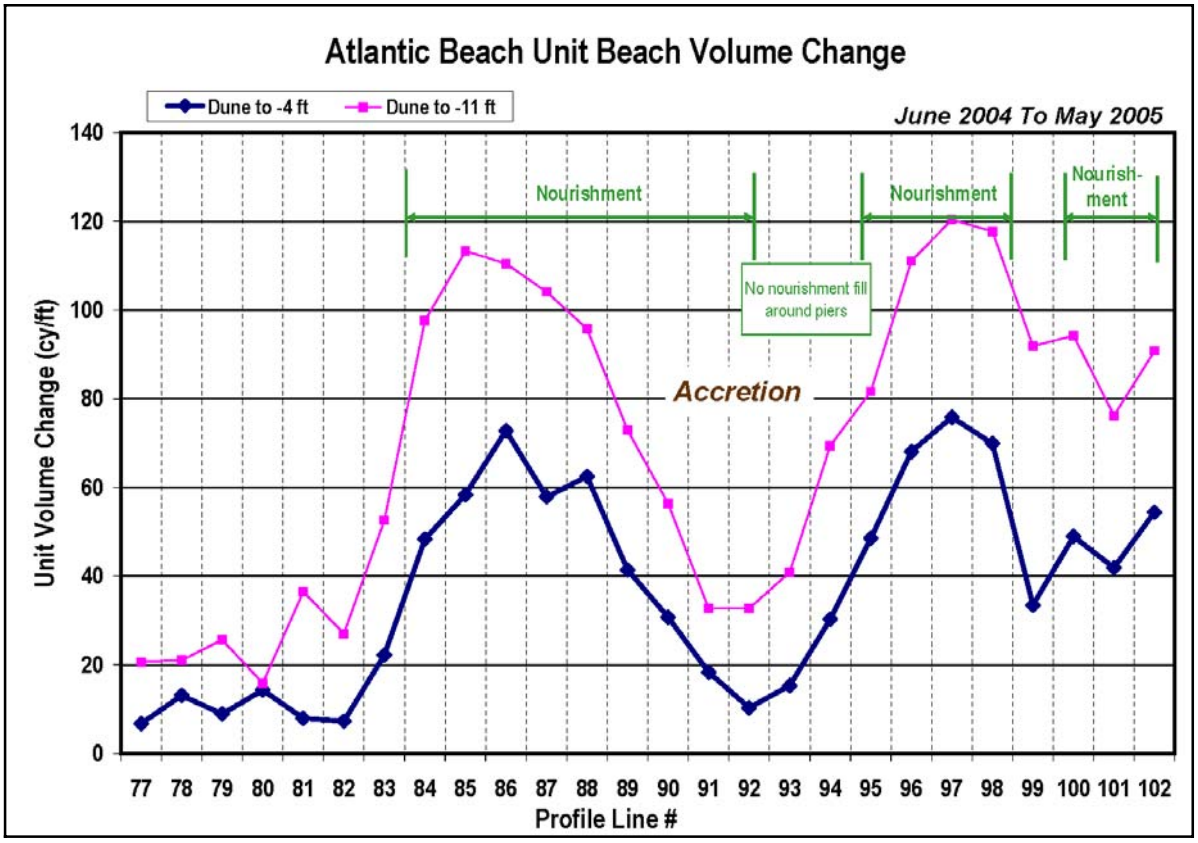


FIGURE 14. The net change by station to –4 ft and –11 ft calculation depths at all stations from June 2004 to May 2005.

Fort Macon State Park

Fort Macon State Park (FMSP) was nourished in 2002 and again in 2005 in conjunction with disposal of the inner harbor dredged material associated with the Morehead City federal navigation project. It remains part of the USACE plan for periodic disposal of harbor sediments (USACE 1993). The 1.4-mile Atlantic coastline length of Fort Macon State Park lies between profile lines 102 and 112. The 2,250-ft reach adjacent to Beaufort Inlet (lines 112–116) was established by CSE in December 2003 and is analyzed separately from the FMSP reach. Survey data indicated that FMSP had a net gain of 473,780 cy of sand between June 2004 and May 2005. Of this gain, 300,000 cy were gained from nourishment.

Fort Macon State Park, like Atlantic Beach, benefitted from nourishment at the beginning of 2005. The increase in sand volume per foot of beach width is very close to that of Atlantic Beach and like Atlantic Beach, FMSP gained volume to the –4 ft elevation as well as to the outer bar. On the recreational beach to –4 ft NGVD, the unit volume gain is 35.4 cy/ft. To the outer bar, the unit volume gain is 65.8 cy/ft. Less accumulation is seen to the east of profile 109, where the nourishment was initiated and continued westward (Fig 15). Volume has increased greatly at profile 112 near the terminal groin at the eastern end of the island.

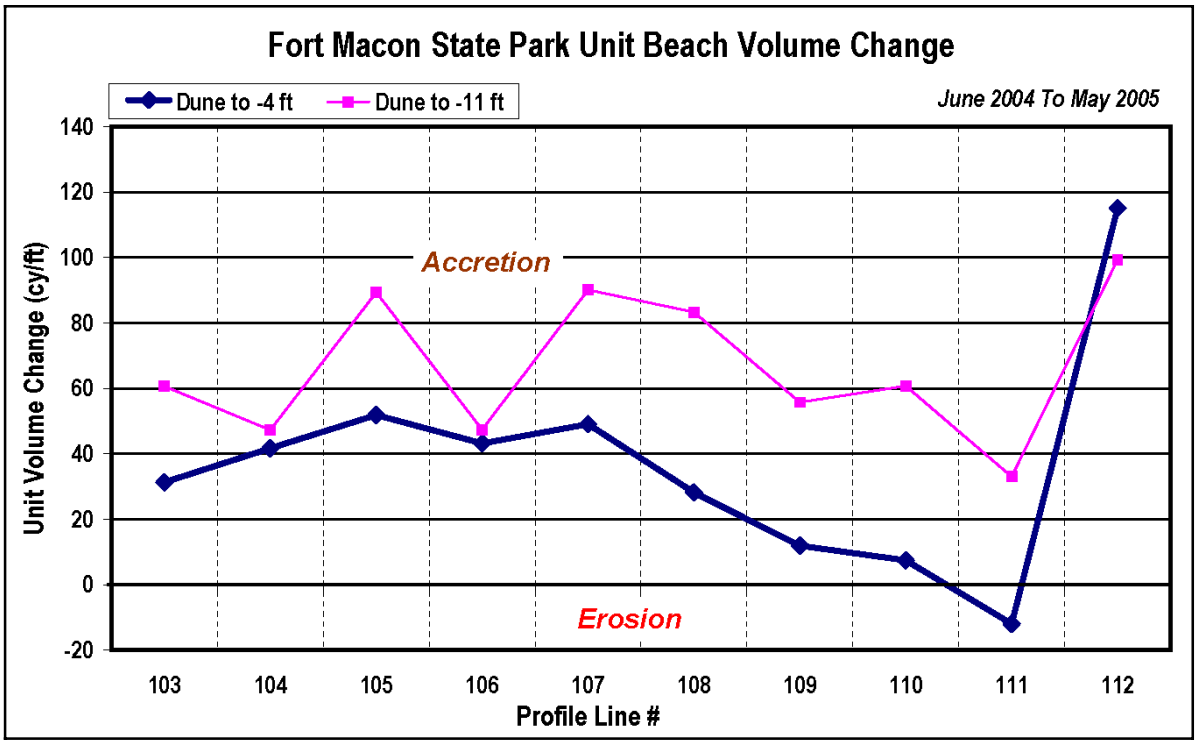


FIGURE 15. The net change by station to –4 ft and –11 ft calculation depths at all stations from June 2004 to May 2005.

Bogue Inlet and Beaufort Inlet

At Bogue Inlet, the oceanfront reach (Bogue Inlet–Ocean, profiles 1–8) was relatively stable overall with an average net gain in unit volume of ~2 cy/ft on the recreational beach (to –4 ft NGVD) and an average net gain of 92.4 cy/ft further offshore to –11 ft NGVD. On the channel side (Bogue Inlet–Channel, profiles 117–120), erosion at profiles 119 and 120 were balanced by accretion at profiles 117 and 118. Near the inlet channel, accretion has allowed for channel migration by as much as 90 ft at profile 117 where net gain in profile volume was ~42 cy/ft between June 2004 and May 2005 (to –11 ft NGVD) (Fig 16, upper). However, water moving around the point continues to erode the beach further up the channel. At profile 120, erosion caused up to 90 ft of recession between June 2004 and May 2005 (Fig 16, lower). The net loss in unit volume at this profile was roughly 28 cy/ft. The Bogue Inlet–Channel reach gained nearly 10 cy/ft overall.

The change in unit volume between June 2004 and May 2005 at the Beaufort Inlet reach (profiles 113–116) matched those of the nourished reaches of Atlantic Beach and Fort Macon State Park. The net average gain at the Beaufort Inlet reach was ~68 cy/ft while at Atlantic Beach and FMSP, the gains were ~67 cy/ft and ~66 cy/ft (respectively). The hydraulic conditions at Beaufort Inlet promote a more stable shoreline on the inlet reach, although the channel has migrated up to 100 ft offshore (Fig 17). With the exception of erosion at profile 116, the reach has gained sand volume and has been more positionally stable than at Bogue Inlet.

Bogue Inlet–Ocean received 59,272 cy of nourishment as part of Phase 3 of the county project in which 690,868 cy were added to the western end of Emerald Isle. Not including this nourishment volume, the background volumetric rate of change was the highest of the reaches examined. The rate of accretion was 8.4 cy/ft/yr from June 1999 to May 2005.

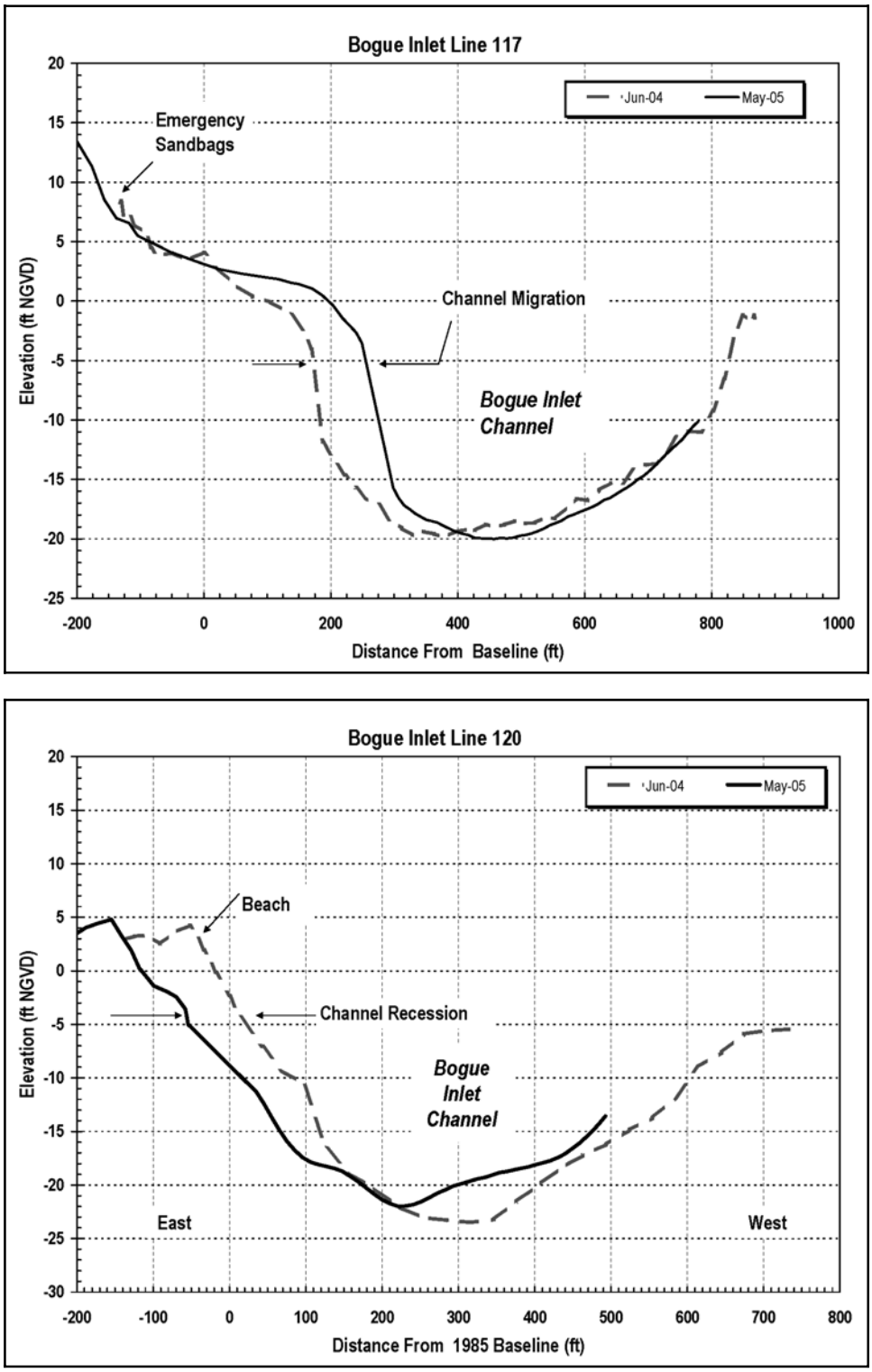


FIGURE 16. Bogue Inlet shows very different changes between the channel entrance at profile 117 (upper) and profile 120 (lower), just 1,500 ft further up the channel. The eastern channel wall has migrated offshore at the channel entrance while it has eroded further upstream.

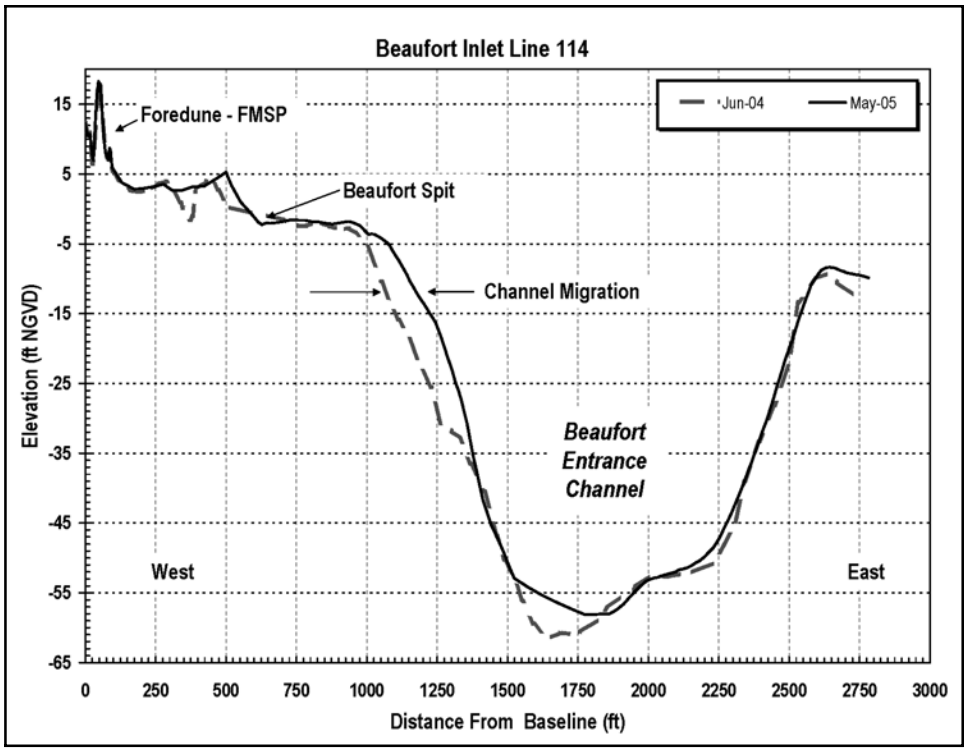


FIGURE 17. Beaufort Inlet spit has been positionally stable from June 2004 to May 2005. Channel area has decreased somewhat due to the migration of the channel wall on the west side of the inlet at this location.

Bear Island

Bear Island lies west of Bogue Inlet from Emerald Isle. The Atlantic coastline of Bear Island was first surveyed by CSE in October 2004 and most recently in conjunction with the BBBNMP Year 2 monitoring project in May 2005. CSE established 18 profiles lines at 1000-ft spacing. The 17,000-ft Bear Island reach had a net loss of 135,310 cy of sand between October 2004 and May 2005, which amounts to an average unit volume change of –8.0 cy/ft (to –11 ft NGVD). Bear Island, however, had a net gain of 11,980 cy when measured to –15 ft NGVD (0.7 cy/ft).

Between October 2004 and May 2005, the stations at the east end of Bear Island have seen moderate gains along with some losses in unit volume to –4 ft elevations. Losses in unit volume to the outer bar at the eastern end are somewhat balanced by the modest gains above the –4 ft contour for this time period. Figure 18 shows that the majority of the stations at the western end of Bear Island have experienced a loss in unit volume at – 4 ft and to the outer bar area. Exceptions include profiles at stations 11,13, and 16.

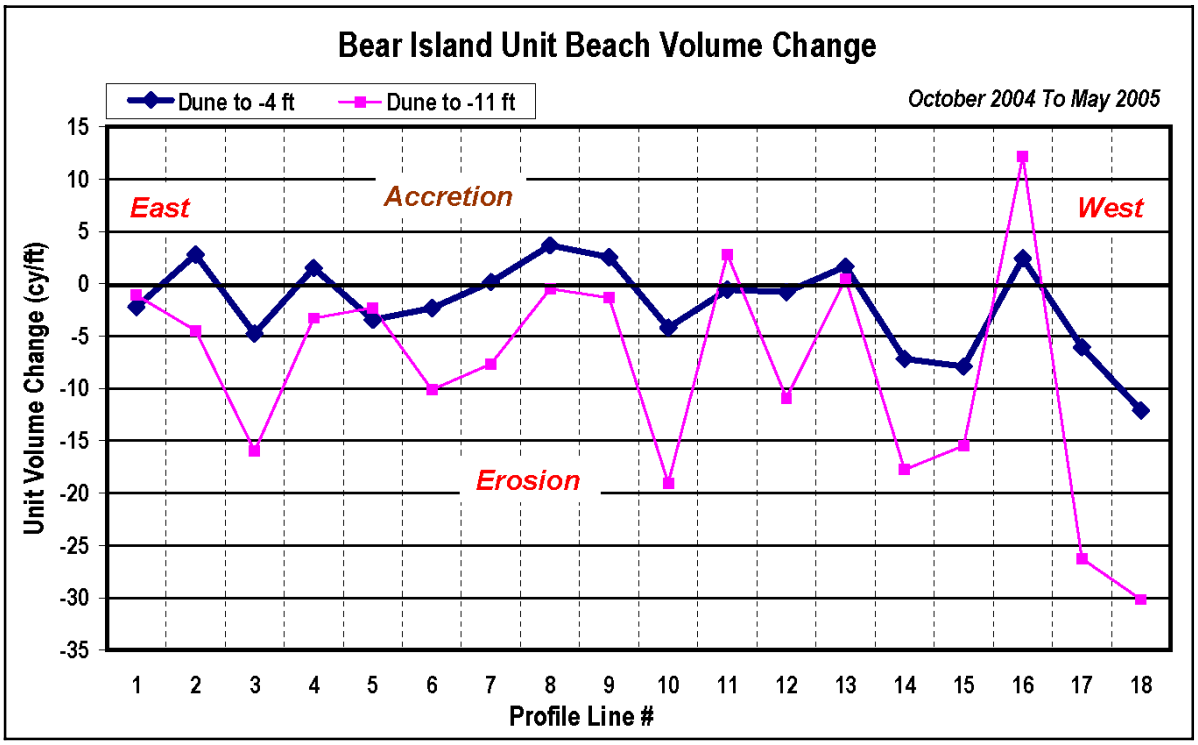


FIGURE 18. October 2004 to May 2005 – Bear Island.

Shackleford Banks

Shackleford Banks is located across Beaufort Inlet from Fort Macon State Park. It was first surveyed by CSE in May 2005. The present analysis indicates that the Atlantic Ocean coastal zone of Shackleford Banks contains roughly 12 million cubic yards of sand over 46,000 ft of beach (to –11 ft NGVD). The entire Atlantic coastline of Shackleford Banks averaged over 261 cy/ft of sand from the dune to –11 ft and 114 ft/cy from the dune to –4 ft elevation in May 2005 (Table 5). These volumes on average are consistent with a minimally healthy beach for this region. However, some stations have little sand in the profile. Low volumes at stations 4 and 5 reflect the presence of a flushing channel (Barden Inlet, Fig 2), which encroaches on the beach. Several other stations have less than the target minimum beach volume to –11 ft (ie, <225 cy/ft). The result is chronic dune escarpments, little dry beach, and poor turtle nesting habitat in some places. (See plotted profiles for stations 7, 14, 18, 21, and 22.)

TABLE 5. Shackleford Banks profile volumes for May 2005 (foredune to -11 ft – preliminary).

Station	Baseline Offset (ft)	Cutoff (ft)	Distance from Last (ft)	May-05 Dune to -11 ft Unit Vol (cy/ft)
1	-125	3,000	0	912.04
2	450		2051	574.07
3	230		2029	402.28
4	525		1801	60.78
5	275		1918	44.53
6	-90		1877	205.48
7	-100		1653	196.08
8	-70		1672	234.85
9	-195		2245	270.19
10	-55		1833	250.03
11	-210		1964	235.59
12	-165		1964	264.57
13	35		1914	215.42
14	-15		1942	202.76
15	155		2352	245.34
16	30		2123	229.64
17	-13		2880	332.64
18	128		2089	209.65
19	-15		2046	346.57
20	255		2038	260.38
21	25		2134	213.40
22	-50		1859	147.44
23	75		2107	210.40
24	310		1508	270.01

Summary- Beach Volumes			May-05	Oct-04 to May-05	
Profiles		Reach Length		*Wtd Avg (cy/ft)*	Net (cy)
1-24		46,001	261.1	**0.0**	**0**
Volume Changes Since October 2004					
1-24		46,001	12,011,775	**0.0**	**0**
Years: Oct 2004 to May 2005		0.63			

Post-*Ophelia* Response

CSE completed a post-Hurricane *Ophelia* assessment of Bogue Banks between 16 and 18 September, following the storm's impact on the island on 13–14 September 2005. By re-occupying 40 of the 112 survey lines on Bogue Banks, CSE was able to estimate hurricane losses and assess profile adjustment for most of the island. Selected stations and data are listed in Table 6. [See CSE (2005) for detailed data summary.]

Table 7 summarizes the results by community and by calculation lens. Relatively little sand was lost in the foredunes throughout the island (Fig 19). The entire island lost ~1,500,000 cy of sand or 13.1 cy/ft of beach measured from the dune to –11 ft (to the outer bar, Fig 20). While sand losses on the beach were significant, accumulation of sand offshore to the outer bar (–18 ft NGVD) accounts for 90 percent of those losses. Changes in volume were more variable at the intertidal zone (wet beach) where there was an overall gain in sand of 1,466 cy (0.04 cy/ft). Erosion was highest from the low-tide elevation to the outer bar where the overall unit volume change was –9.19 cy/ft. Accretion was highest seaward of the bar to –18 ft NGVD where the overall unit volume change was 12.61 cy/ft between May 2005 and the post-*Ophelia* survey.

Table 8 provides a breakdown of volume changes by reach. Due to lack of data at Fort Macon State Park and the eastern end of Atlantic Beach, these communities are not included. All communities along Bogue Banks lost sand from the beach (dune to –4 ft NGVD) as well as from the dune to the outer bar (–11 ft NGVD).

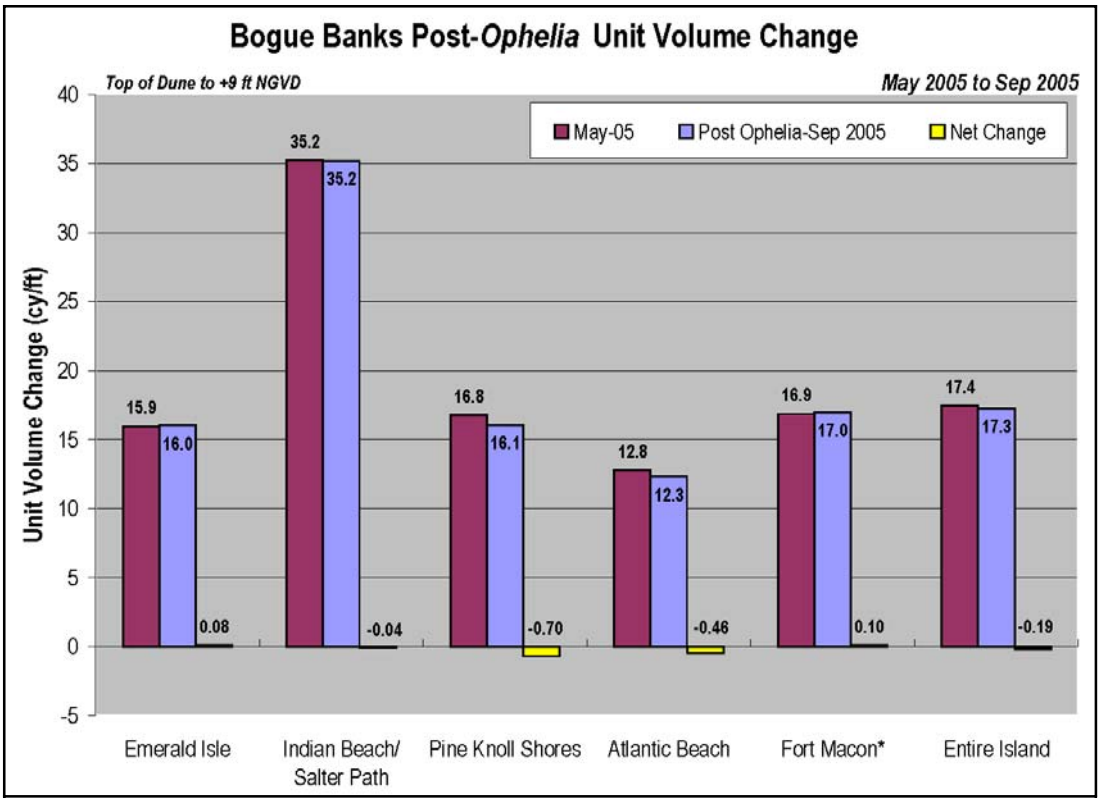
Losses to –11 ft were nearly balanced by gains offshore of the outer bar (totaling ~1.4 million cubic yards). The net changes from the foredune to –18 ft between Bogue Inlet and Atlantic Beach West were low at 0.4 cy/ft. Atlantic Beach West had the greatest loss in sand volume from the dune to –18 ft NGVD (~155,000 cy or 10.7 cy/ft). Indian Beach/Salter Path lost ~119,000 cy (9.2 cy/ft) and Emerald Isle–East lost ~74,000 cy (6.3 cy/ft).

TABLE 6. Bogue Banks - Post-Ophelia: September 2005. Station numbers and distances.

STA	Distance to Next (ft)	STA	Distance to Next (ft)	STA	Distance to Next (ft)
Emerald Isle		*Indian Beach/ Salter Path*		*Atlantic Beach*	
1	2,321	48	2,792	76	2,238
5	5,768	50	2,524	78	2,343
9	1,249	52	3,895	80	4,814
10	1,519	55	3,775	85	5,101
11	1,260	58	0	90	4,827
12	2,549		12,986	95	1,995
14	1,349			97	2,998
15	6,986			100	2,005
20	6,074			102	0
25	7,145	*Pine Knoll Shores*			26,321
30	7,340	58	2,696		
35	2,572	60	6,487		
37	2,213	65	3,960		
39	1,096	68	2,272	*Fort Macon*	
40	2,213	70	1,896	102	1,016
42	3,288	71	2,829	103	1,969
45	1,097	73	2,717	105	2,993
46	1,881	75	1,111	110	1,221
48	0	76	0	112	0
	57,919		23,968		7,199

TABLE 7. Summary of results by community and by calculation lens. [*Volumes from +2 ft to –11 ft NGVD were calculated from lines 1 to 90 (EI, IB/SP, PKS, and 14,496 ft of 26,321 ft AB). Volumes to +2 ft NGVD were calculated for the entire project length.]

TOP OF DUNE TO +9 ft NGVD					
Reach	Length (ft)	May 2005 Unit Vol (cy/ft)	Sep 2005 Unit Vol (cyft)	May - Sep Unit Vol Change (cy/ft)	May - Sep Net Vol Change (cy)
Emerald Isle	57,919	15.94	16.02	0.08	4,686
Indian Beach/ Salter Path	12,986	35.23	35.19	-0.04	-543
Pine Knoll Shores	23,968	16.76	16.06	-0.70	-16,771
Atlantic Beach	26,321	12.77	12.31	-0.46	-12,020
Fort Macon	7,199	16.87	16.97	0.10	709
	128,392	17.44	17.26	-0.19	-23,939
+9 FT TO +2 FT NGVD					
Reach	Length (ft)	May 2005 Unit Vol (cy/ft)	Sep 2005 Unit Vol (cyft)	May - Sep Unit Vol Change (cy/ft)	May - Sep Net Vol Change (cy)
Emerald Isle	57,919	47.32	45.13	-2.19	-126,719
Indian Beach/ Salter Path	12,986	51.06	47.67	-3.39	-44,045
Pine Knoll Shores	23,968	34.71	27.83	-6.87	-167,541
Atlantic Beach	26,321	55.86	51.00	-4.87	-115,536
Fort Macon	7,199	41.61	36.02	-5.58	-40,178
	128,392	46.77	42.85	-3.92	-494,019
+2 FT TO -4 FT NGVD*					
Reach	Length (ft)	May 2005 Unit Vol (cy/ft)	Sep 2005 Unit Vol (cyft)	May - Sep Unit Vol Change (cy/ft)	May - Sep Net Vol Change (cy)
Emerald Isle	57,919	81.35	79.95	-1.40	-81,206
Indian Beach/ Salter Path	12,986	83.99	83.24	-0.75	-9,691
Pine Knoll Shores	23,968	60.62	65.57	4.95	116,069
Atlantic Beach	14,496	82.52	80.87	-1.65	-23,706
Fort Macon	0	0.00	0.00	0.00	0
	109,368	77.28	77.31	0.04	1,466
-4 FT TO -11 FT NGVD*					
Reach	Length (ft)	May 2005 Unit Vol (cy/ft)	Sep 2005 Unit Vol (cyft)	May - Sep Unit Vol Change (cy/ft)	May - Sep Net Vol Change (cy)
Emerald Isle	57,919	157.37	150.41	-6.96	-403,238
Indian Beach/ Salter Path	12,986	166.43	147.62	-18.82	-244,327
Pine Knoll Shores	23,968	140.35	133.45	-6.90	-171,551
Atlantic Beach	14,496	181.97	168.75	-13.22	-190,983
Fort Macon	0	0.00	0.00	0.00	0
	109,368	157.98	148.79	-9.19	-1,010,099
-11 FT TO -18 FT NGVD*					
Reach	Length (ft)	May 2005 Unit Vol (cy/ft)	Sep 2005 Unit Vol (cyft)	May - Sep Unit Vol Change (cy/ft)	May - Sep Net Vol Change (cy)
Emerald Isle	57,919	290.86	304.50	13.63	789,716
Indian Beach/ Salter Path	12,986	291.39	305.22	13.83	179,553
Pine Knoll Shores	23,968	287.84	298.83	10.99	265,678
Atlantic Beach	14,496	340.64	350.73	10.10	150,806
Fort Macon	0	0.00	0.00	0.00	0
	109,368	296.86	309.47	12.61	1,385,753



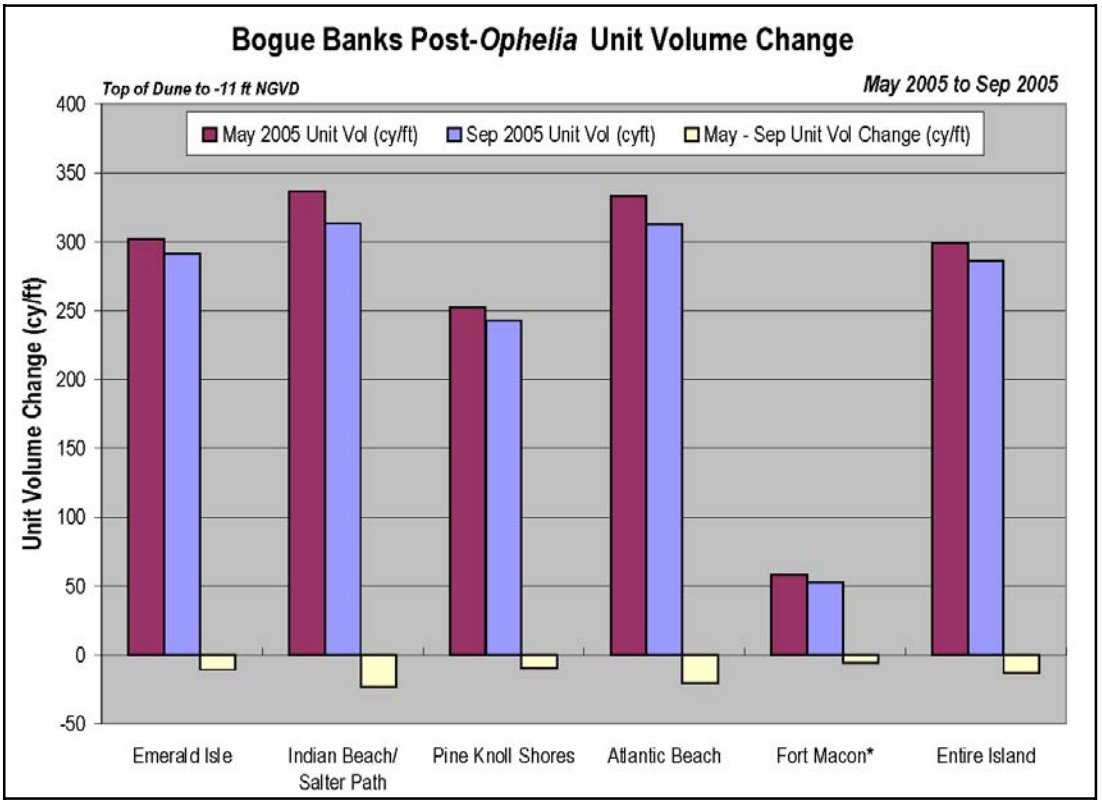


FIGURE 19. Net unit volume change in the dunes (upper) and to the outer bar (lower) for each reach. Unit volume changes are calculated for the period June 2004 to May 2005.

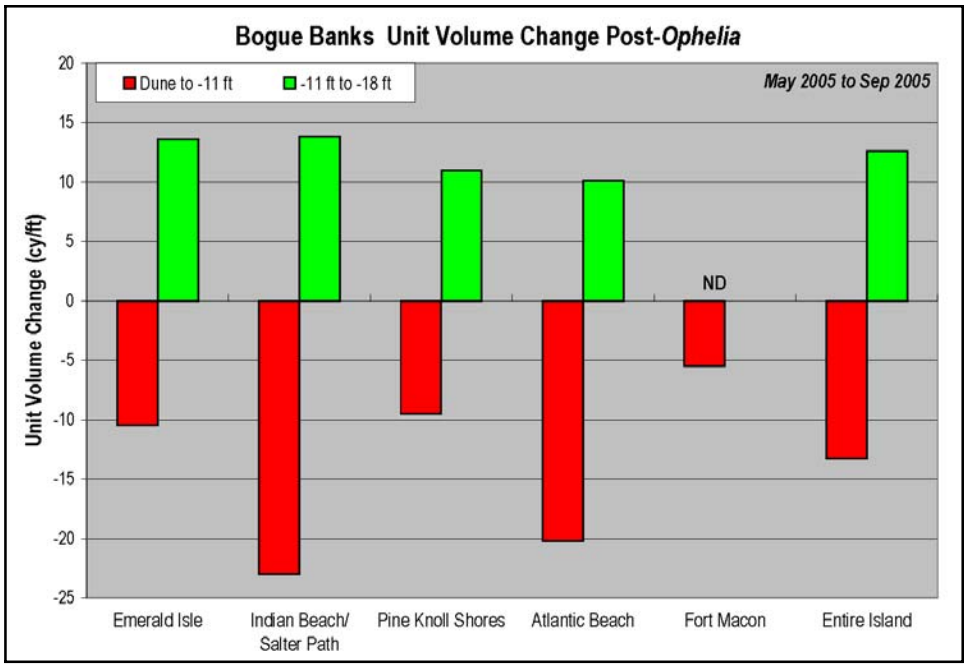


FIGURE 20. Volume losses on the beach to the outer bar are balanced by volume gains between the outer bar (–11 ft) and closure depth (–18 ft).

TABLE 8. Summary of volume changes by reach.

NOTES:
- The volume change boundaries match the limits used in the project design (CSE–Stroud 1999).
- PKS-E, PKS-W & IB/SP nourished in 2002 (county/town project Phase 1)
- FMSP nourished in 2002 (harbor maintenance disposal)
- EI–E, EI–C nourished in 2003 (county/town project Phase 2)
- IB/SP, PKS–W nourished in 2004 (Section 933 – harbor maintenance)
- EI–E, EI–C nourished in 2004 (FEMA post-*Isabel*)
- AB–E, AB–W nourished in spring 2005 (Brandt Island pumpout and harbor maintenance)
- EI–W nourished in spring 2005 – Bogue Inlet realignment (county/town project Phase 3)

			Estimated Volume Changes (cy)				*Total*	*Total*
	Applicable	Reach	Dune	Dry Beach	Wet Beach	UW to Bar	*To Wet Bch*	*To Outer Bar*
Reach	Profiles	Lgth (ft)	To +9 ft	+9 to +2 ft	+2 to -4 ft	-4 to -11 ft	*Dune to -4 ft*	*Dune to -11 ft*
BI	1-9	8,089	-1,067	-33,242	10,079	10,565	-24,230	-13,665
EI-W	9-25	20,986	-9,798	-41,384	-42,762	-153,516	-93,944	-247,460
EI-C	25-37	17,057	16,528	-31,533	-18,929	-86,894	-33,934	-120,828
EI-E	37-48	11,788	-976	-16,908	-9,593	-173,395	-27,477	-200,872
IB/SP	48-58	12,986	-543	-44,045	-9,691	-244,325	-54,279	-298,604
PKS-W	58-65	9,183	-4,741	-40,245	9,466	-22,838	-35,520	-58,358
PKS-E	65-76	14,785	-12,031	-127,296	106,602	-148,713	-32,725	-181,438
AB-W	76-90	14,496	-3,426	-88,046	-23,707	-190,984	-115,179	-306,163
SubTotals		109,370	**-16,054**	**-422,699**	**21,465**	**-1,010,100**	**-417,288**	**-1,427,388**
Wt'd Unit Vol Change (cy/ft)			*-0.1*	*-3.9*	*0.2*	*-9.2*	*-3.8*	*-13.1*
AB-E	90-102	11,825	-8,594	-27,490	ND	ND	-36,084	ND
FMSP	102-112	7,199	708	-40,178	ND	ND	-39,470	ND
Grand Total		128,394	-23,940	-490,371			-492,846	ND
Wt'd Unit Vol Change (cy/ft)			*-0.2*	*-3.8*			*-3.8*	

DISCUSSION AND RECOMMENDATIONS

The present survey documented changes between June 2004 and May 2005 for Bogue Banks as well as changes between October 2004 and May 2005 for Bear Island. Survey data were collected by CSE for the first time on Shackleford Banks as part of this study. CSE also looked at the volume comparisons between June 1999 and May 2005 in relation to nourishment volume added over that time period. For this time period, survey data accounted for 96 percent of nourishment volume.

The background erosion rate for Bogue Banks over the last six years was determined to be 0.43 cy/ft/yr (measured between the foredune and the outer bar). The western end of the island experienced relatively high accretion rates**:** 74.1 cy/ft/yr at Bogue Inlet–Ocean and 5.1 cy/ft/yr at EI–West. The eastern end of the island experienced relatively high background erosion rates**:** 6.54 cy/ft/yr at Atlantic Beach and 5.18 cy/ft/yr at FMSP. These rates are slightly higher than long-term (linear) averages for the island, but are skewed by placement and subsequent loss of fine-grained sediment associated with the Brandt Island pumpout. Erosion rates for the center of the island [where Indian Beach/ Salter Path experienced an average of 3.07 cy/ft/yr accretion for the last six years and where EI–East, EI–Central, and PKS experienced 0.22 cy/ft/yr and 1.81 cy/ft/yr (respectively)] are consistent with the long-term average erosion rates expected for the island.

The June 2004 and May 2005 surveys documented overall gains in sand volume for Bogue Banks. Some communities lost sand volume measured to the outer bar (Emerald Isle East, Indian Beach/Salter Path and Pine Knoll Shores East). However, all reaches in the present survey exceeded the target minimum profile volume (~225 cy/ft to –11 ft NGVD) in May 2005. FMSP (whose average profile volume was below the target level in June 2004) received nourishment from the inner harbor dredging disposal in 2005 and now has more sand on average than the target value. Atlantic Beach also benefitted from nourishment by the Brandt Island pumpout in 2005. Without this sand volume (in excess of 2.9 million cubic yards), Atlantic Beach would have failed to meet the target minimum profile volume.

Bear Island was first surveyed by CSE in October 2004 and again in May 2005. While comparative season analyses are not yet available, the data provide an initial estimate of erosion rates for Bear Island. Between October 2004 and May 2005, Bear Island lost an average of –8.0 cy/ft from the foredune to the –11 ft NGVD elevation. To the –15 ft elevation, however, the profiles gained 0.7 cy/ft. It has yet to be determined whether the –15 ft elevation is a better datum to use for Bear Island comparisons.

The focus of the present report was on changes in sand volume between the foredune and the outer bar over the period June 2004 to May 2005 on Bogue Banks. Many comparisons are available using various depth contours and reach boundaries. CSE believes the most interesting and relevant effect over the past year (as has been the case in the previous analysis) is that nourishment has improved the protection of the island during storms. There was negligible damage to the dunes or oceanfront structures during *Ophelia*. Further, the poststorm surveys indicate that only about 18 percent of the total nourishment volume placed since 2001 was lost during the storm (measured to –11 ft NGVD).

CSE's post-*Ophelia* survey suggests that the *Ophelia* losses can be accounted for between –11 ft and –18 ft NGVD. As additional data become available, CSE expects to be able refine estimates of closure depths for Bogue Banks, Bear Island, and Shackleford Banks. The post-*Ophelia* data indicate closure depths of the order –18 ft NGVD. Prior surveys suggested closure depths in the –11 ft to –17 ft NGVD range (CSE-Stroud 2001).

CSE's primary recommendations following this year's surveys are as follows:

- Continue annual or semi-annual surveys using common boundaries and datums such that all communities are kept informed of the overall beach condition and performance of individual projects. These data can be compared with prior conditions as well as the condition of adjacent communities.

- Continue annual or semi-annual surveys for Bear Island and Shackleford Banks to monitor erosion trends and sand volumes for these reaches.

- Use the data herein as a basis for planning and prioritizing future beach nourishment projects.

- Perform modified beach surveys immediately following destructive major storms to measure extent of beach loss.

- Continue to monitor the sediment quality and quantitatively compare sediments with prenourishment conditions.

- Provide updated annual erosion rate estimates and document the rate of nourishment loss by reach.

- Provide these data and results to the USACE for planning purposes in association with federal beach erosion and hurricane protection projects.

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