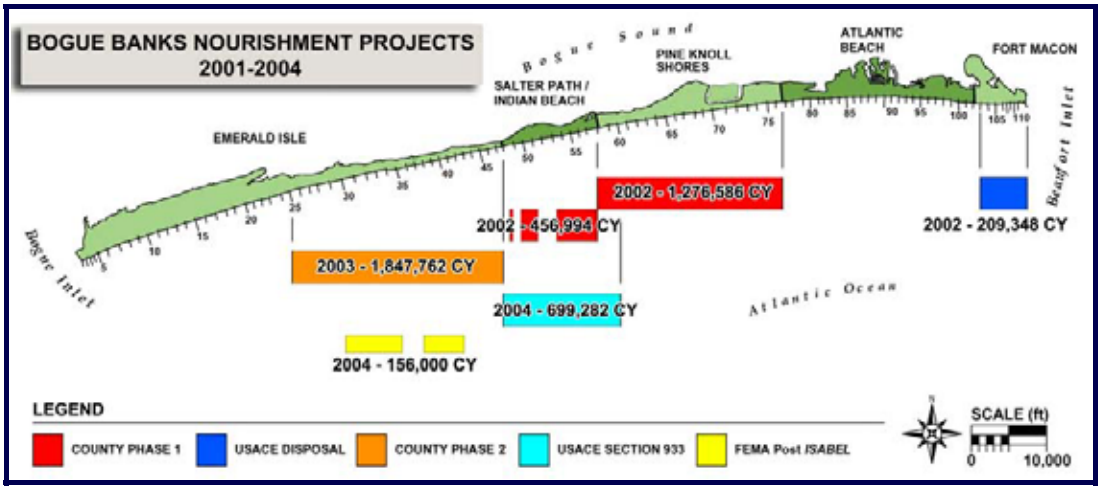
Survey Report 2004

Bogue Banks North Carolina



Prepared for:

Carteret County North Carolina

COASTAL SCIENCE & ENGINEERING

SURVEY REPORT 2004

Bogue Banks
North Carolina

Prepared for:

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[CSE SR2132]
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COVER GRAPHICS

Upper left:	Pine Knoll Shores after Hurricane *Floyd*
Upper right:	Same area after February 2002 Phase 1 nourishment
Lower:	Nourishment projects total ~4.6 million cubic yards

[Photos by TW Kana and PA McKee]

EXECUTIVE SUMMARY

This report provides results of beach monitoring surveys covering the period June 1999 through June 2004, 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 five-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 2004)
- Post-*Isabel* FEMA beach renourishment (Emerald Isle, March 2004)

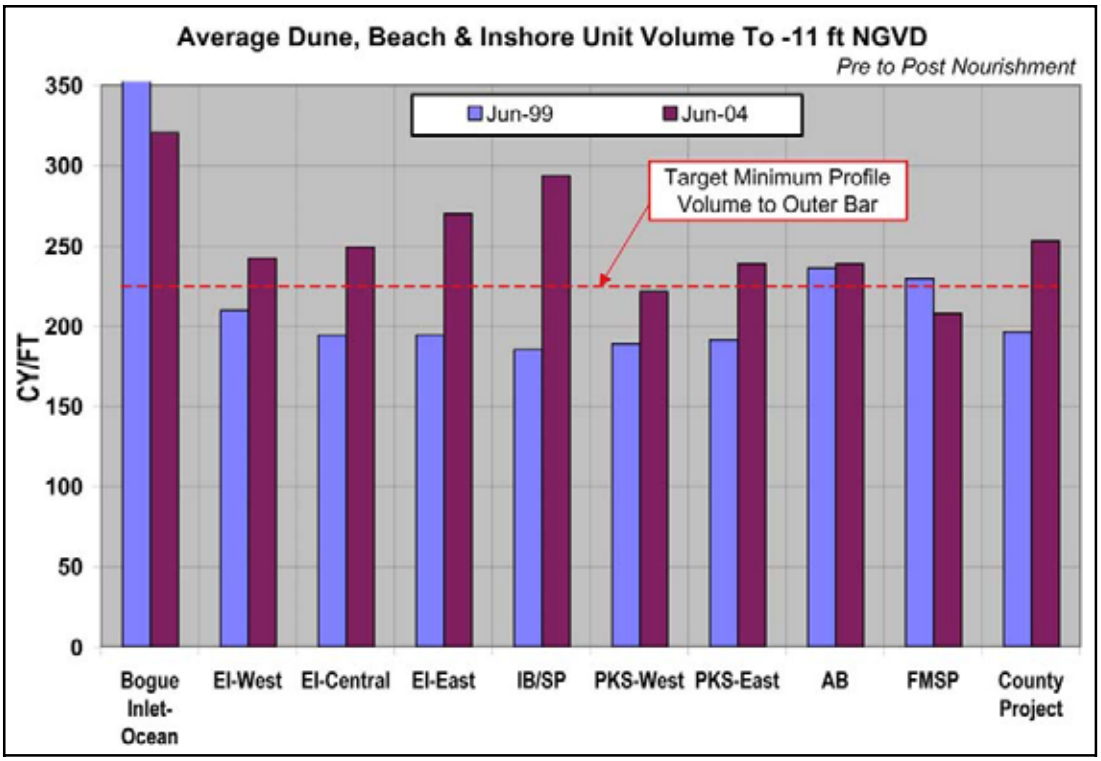
Surveys referenced herein were obtained using state-of-the-art technology as well as less sophisticated, but reliable, methods in earlier years. Up to ten sets of surveys are available for certain reaches and dates in connection with beach nourishment projects and storm events. The report describes the 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 town.

Between June 1999 and June 2004, Bogue Banks was impacted by Hurricane *Dennis* (1999), *Floyd* (1999), and *Isabel* (2003). Beach nourishment totaling ~4,650,000 cubic yards (cy) 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), and eastern Emerald Isle (2004). The surveys comparing June 1999 conditions with June 2004 conditions showed a net gain of ~4,500,000 cy (island-wide measured to the outer bar at depths of –11 ft NGVD). This means that the measured change over five years was almost identical to the volume of sand added to Bogue Banks by nourishment.

Nourishment volumes are 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 five-year period. The worst erosion (after nourishment is factored out) occurred near Bogue Inlet (~8 cy/ft/yr erosion) and along Fort Macon State Park (~11 cy/ft/yr erosion). Eastern Emerald Isle and Pine Knoll Shores eroded ~1.1 and ~2.5 cy/ft/yr (respectively) after the effect of nourishment is removed. When nourishment is included, Emerald Isle, Indian Beach, and Pine Knoll Shores gained an average of over 56 cy/ft. This is equivalent to an extra 75-ft beach width added to the three communities between June 1999 and June 2004.

In June 1999, CSE Baird-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 June 2004, most of Bogue Banks contained a sand surplus compared with Atlantic Beach. Presently, the worst erosion is occurring along Fort Macon State Park (where there is a deficit) and near Bogue Inlet (where there is still a surplus). Losses along Fort Macon State Park have shifted toward Beaufort Inlet and have built a spit along the channel as documented herein. Oceanfront losses near Bogue Inlet, by contrast, have not built up the shoreline along the inlet channel, where erosion continues to undermine houses.

The data herein support the finding that Bogue Banks has a relatively low, natural erosion rate. This means that nourishment can be effective and relatively long-lived in mitigating erosion. Annual monitoring should be continued to track the performance of nourishment and to establish trigger points for future beach restoration. As the graph in Figure A shows, there is considerably more sand on most of the beach today than there was in June 1999. Monitoring will determine how much sand shifts from community to community over time and will identify the most vulnerable sections of Bogue Banks.



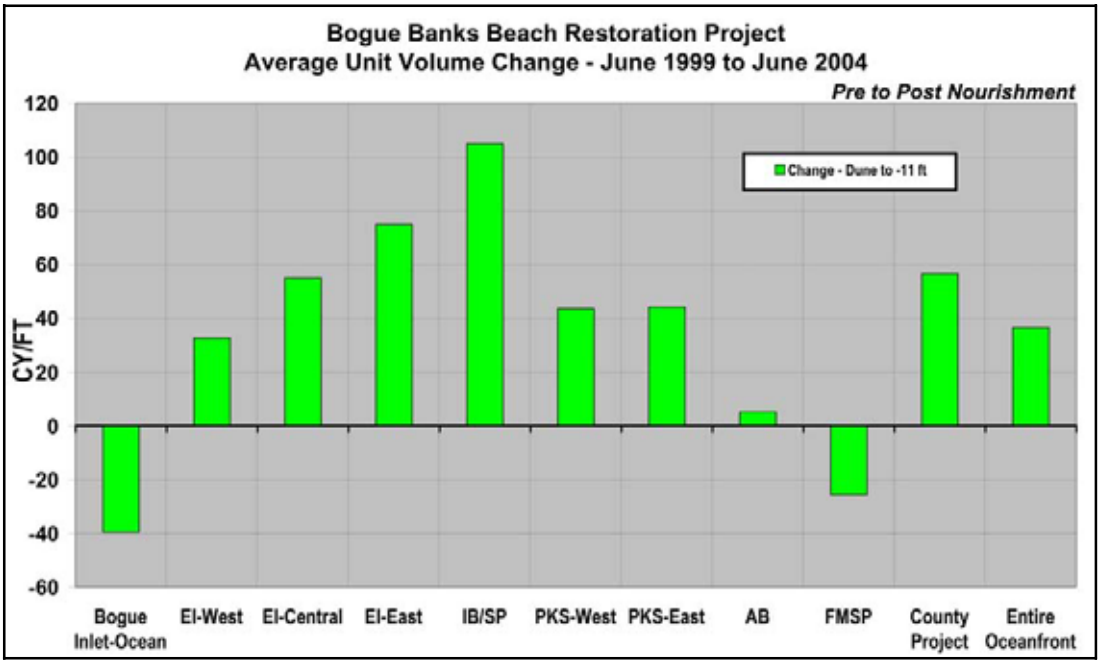


FIGURE A. Average change in sand volume by reach between 1999 and 2004. (Note: 50 cy/ft is equivalent to about 75 ft of beach width in this setting.)

ACKNOWLEDGMENTS

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Buck Fugate, Chairman, Indian Beach
Doug Brady, Carteret County
William Donnelly, Atlantic Beach
Jack Goldstein, TDA
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Ted Lindblad, Pine Knoll Shores
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Capt James Willis, Bogue Banks Resident

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 Chris Mack, Trey Hair, Andre Webb, Jim Prehn, and Tim Kana. The report was prepared by Tim Kana, Diana Sangster, Trey Hair, and Philip McKee.

TABLE OF CONTENTS

PAGE

EXECUTIVE SUMMARY i

ACKNOWLEDGMENTS v

TABLE OF CONTENTS vii

INTRODUCTION 1

METHODOLOGY 3
- Field Data Collection 3
- Data Reduction and Analyses 8
- Sediment Sampling and Testing 13

RESULTS 15
- Island-Wide Trends 15
- Comparison with Nourishment Volumes 26
- Emerald Isle 30
- Indian Beach/Salter Path 35
- Pine Knoll Shores 40
- Atlantic Beach 46
- Fort Macon State Park 52

BEACH SEDIMENTS 59

DISCUSSION AND RECOMMENDATIONS 65

REFERENCES 71

APPENDIX I Control Points
APPENDIX II Profiles
APPENDIX III Profile Volumes
APPENDIX IV FEMA Beach Maintenance Calculations

INTRODUCTION

This report summarizes results of Year 1 (2003-2004) of the Bogue Banks Beach and Nearshore Mapping Program (BBBNMP) sponsored by Carteret County, North Carolina. The BBBNMP is a continuation of beach monitoring initiated by the county in 1999 (CSE Baird–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).

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, and 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 with 1999 (prenourishment) conditions, although the actual survey work for Year 1 under the present agreement covers only semi-annual surveys in December 2003 and July 2004. For this first survey year under the BBBNMP, CSE merged selected sets of historical data such that changes over the past five years (June 1999 through June 2004) as well as December 2003 to June 2004 could be determined.

The past five years has included several extraordinary events for Bogue Banks including:

- 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 2004)
- Post-*Isabel* FEMA beach renourishment (Emerald Isle, March 2004)

Phases 1 and 2, and Section 933 projects were county-initiated and involved close coordination with the Beach Preservation Task Force and Carteret County Beach Commission. Prior to 1999, the only significant nourishment* along Bogue Banks consisted of two-USACE pump-outs of the Brandt Island upland disposal basin and placement along

Atlantic Beach and Fort Macon State Park in 1986 and 1994 (USACE 1993, 1999). Projects since 1999 have involved an additional ~13 miles of shoreline (out of Bogue Banks' 25-mile length). When combined with projects at Atlantic Beach and the state park, nearly 80 percent of Bogue Banks has received some form of beach nourishment since 1986. No island-wide beach surveys are available for the period 1980 to 1998.

> [*Note: At least one small project involving disposal of ~278,000 cy Atlantic Intracoastal Waterway sediments from Bogue Sound was placed along Pine Knoll Shores oceanfront in 1990 (Peterson et al 2000). Also, western Emerald Isle has received ~350,000 cy of sand from the AICWW since 1984 (G Rudolph, pers comm, August 2004).]

Beach surveys since June 1999 capture the majority of beach nourishment projects but miss impacts of the 1986 and 1994 projects, as well as the impacts of Hurricanes *Bertha* (June 1996), *Fran* (September 1996), and *Bonnie* (August 1998). A number of surveys have been conducted by CSE and others for limited reaches in connection with various beach fills. Readers are directed to CSE (2003a,b) for project-specific information and to www.protectthebeach.com for an overview of beach nourishment projects executed or planned for Bogue Banks.

The focus of this report is on island-wide beach changes since June 1999. 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 island, summaries are provided for each town. Source data (on which, for the most part, our results and findings are based) are found on CD/Rom (provided to Carteret County Shore Protection Office).

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-kinetic (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 the CSE's methods of data collection and analysis for the present report.

CSE mobilized survey crews in June 1999 and June 2000 and established 111 control points near the shoreline. Generally, each control point consists of a monument or survey nail in concrete placed 50 to 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.

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. Approximate town boundaries are also shown on Figure 1.

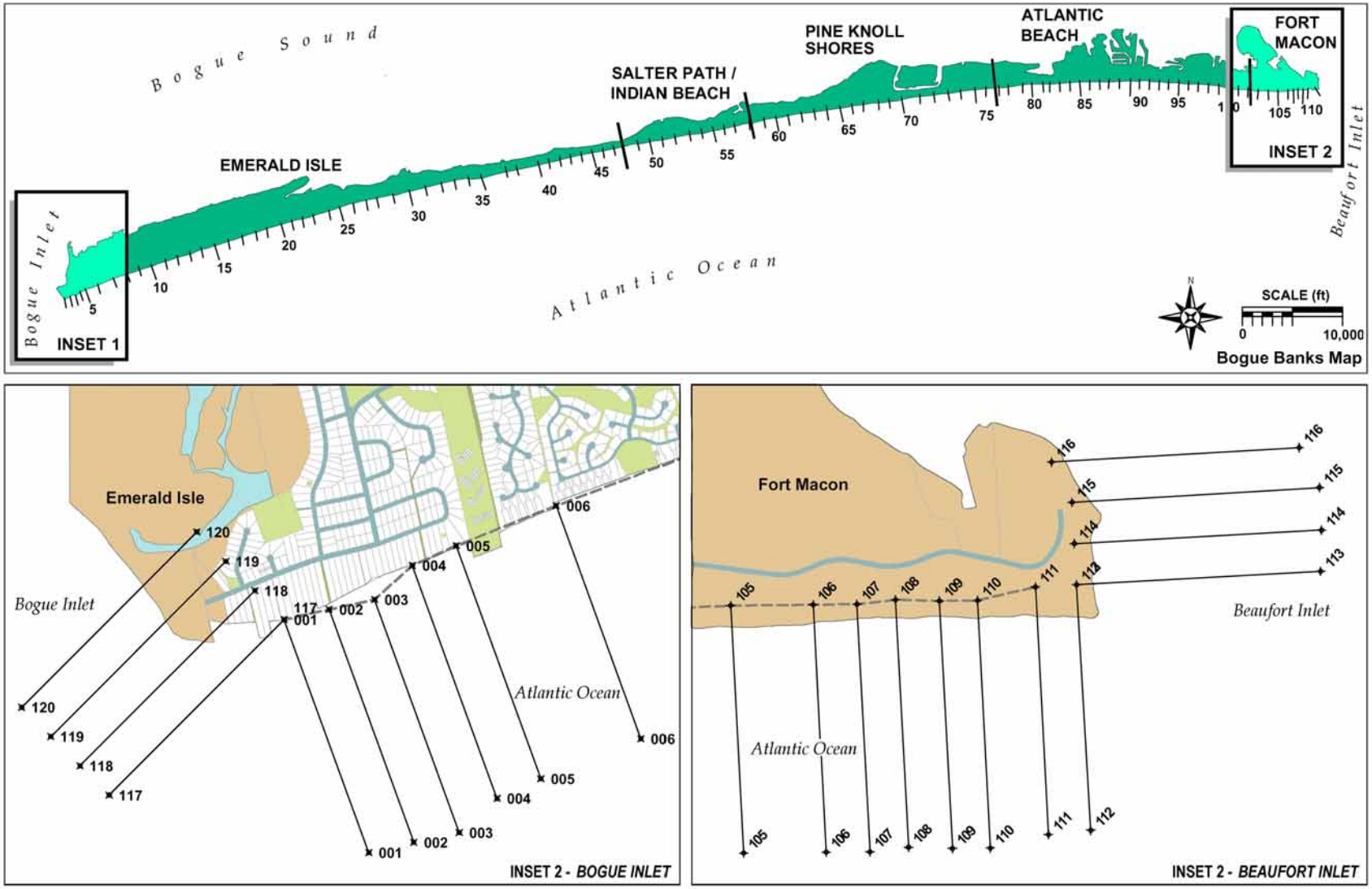


FIGURE 1. General location map of beach profile lines established in 1999 and resurveyed in December 2003 and June 2004 under the present BBBNMP project. Lines 112 through 120 were established in December 2003.

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 2 illustrates the data collection equipment that CSE used on Bogue Banks for the present survey. The system requires a base station (Fig 2, 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 2, 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 3, 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. The navigation console and data-logging computer are shown in Figure 3 (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 3, center), which was set up with photo images over the area. As Figure 3 (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 3, lower left).

FIGURE 2. [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.

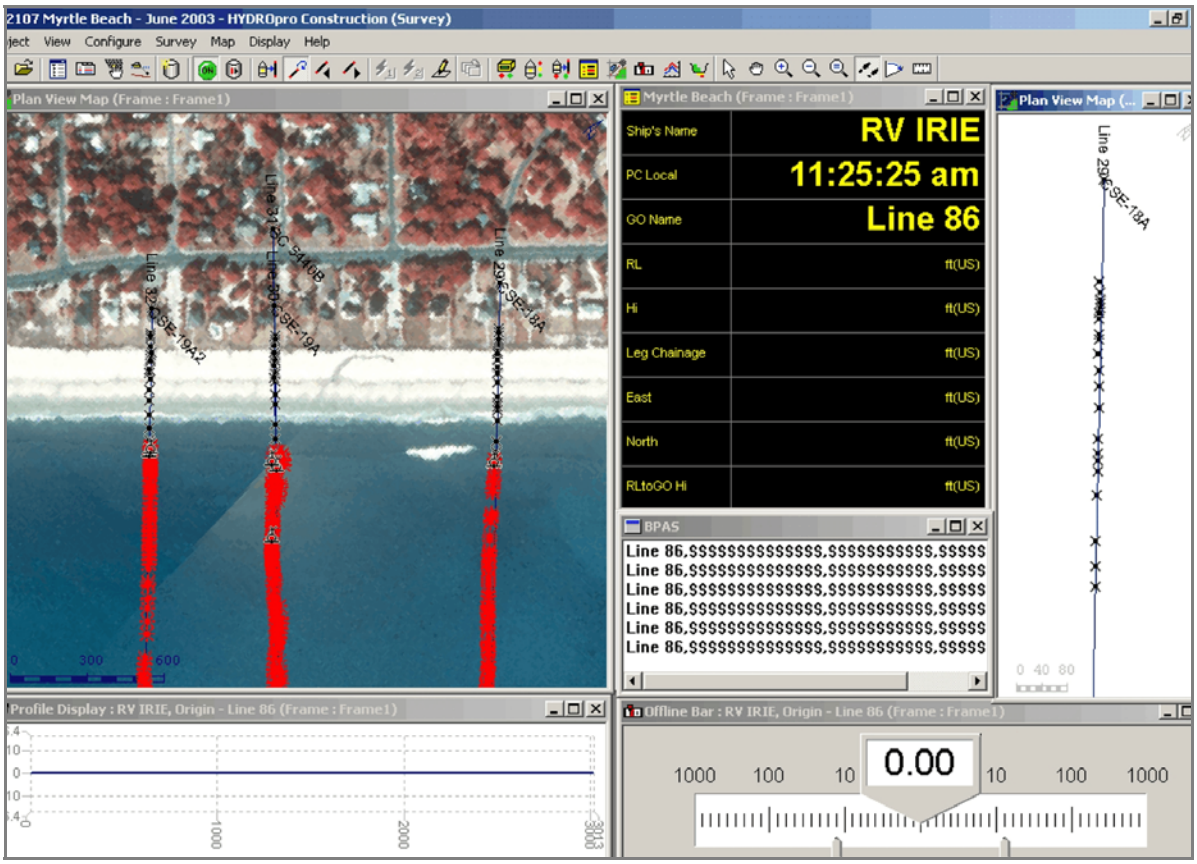


FIGURE 3. CSE's offshore equipment and survey vessel for use in shallow water.
[UPPER LEFT] 22-ft C-Dory™ with 7-inch draft and enclosed cabin.
[UPPER RIGHT] Navigation and data logging console.
[CENTER] HydroPro™ data logging and processing software showing track lines and overlap in real time with 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.

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 4, upper) and automatically deleted from the data set. Other filtering was applied which averaged adjacent points to provide a more realistic surface (Fig 4, 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– Delft Hydraulics Laboratory 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. 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.

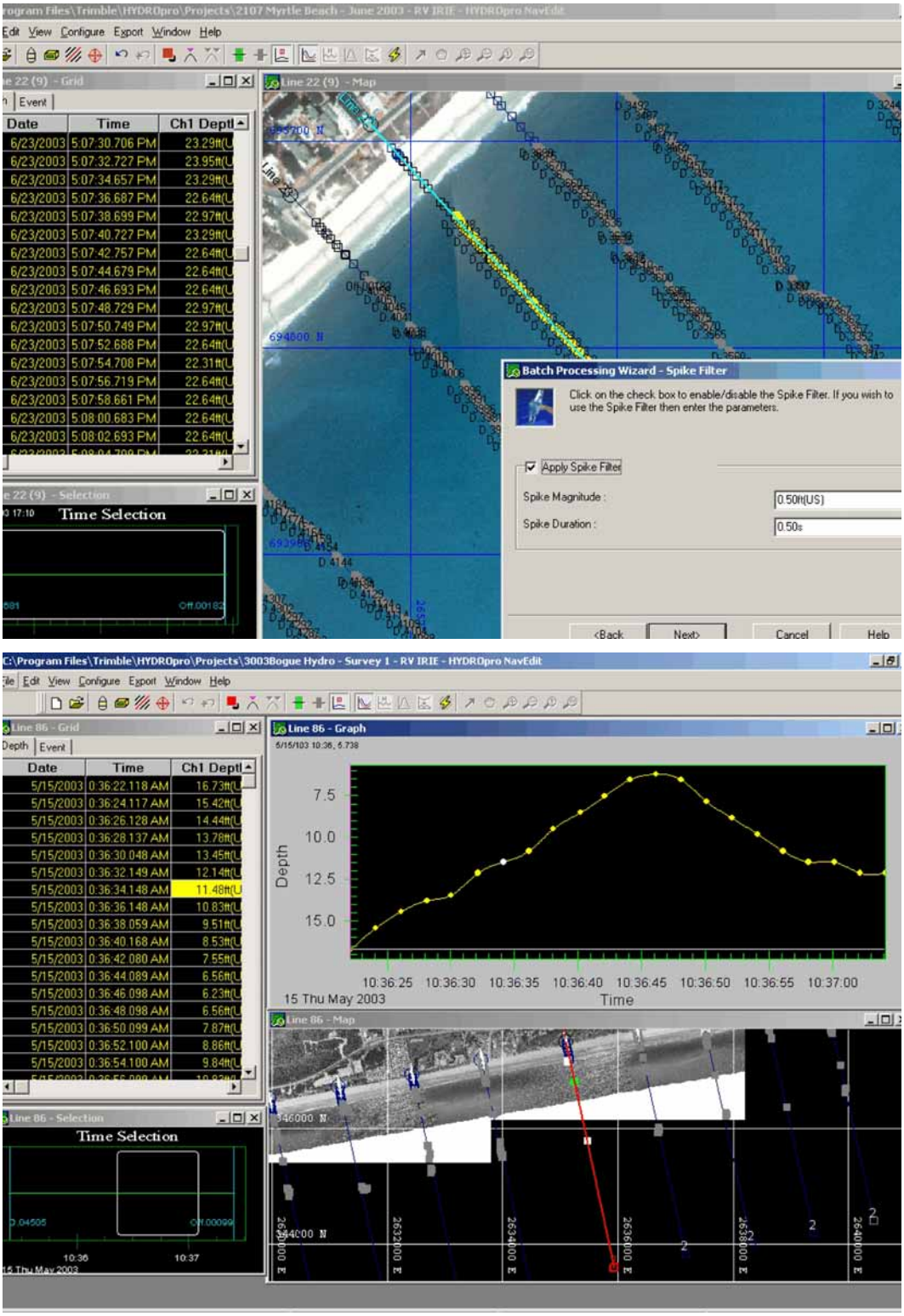
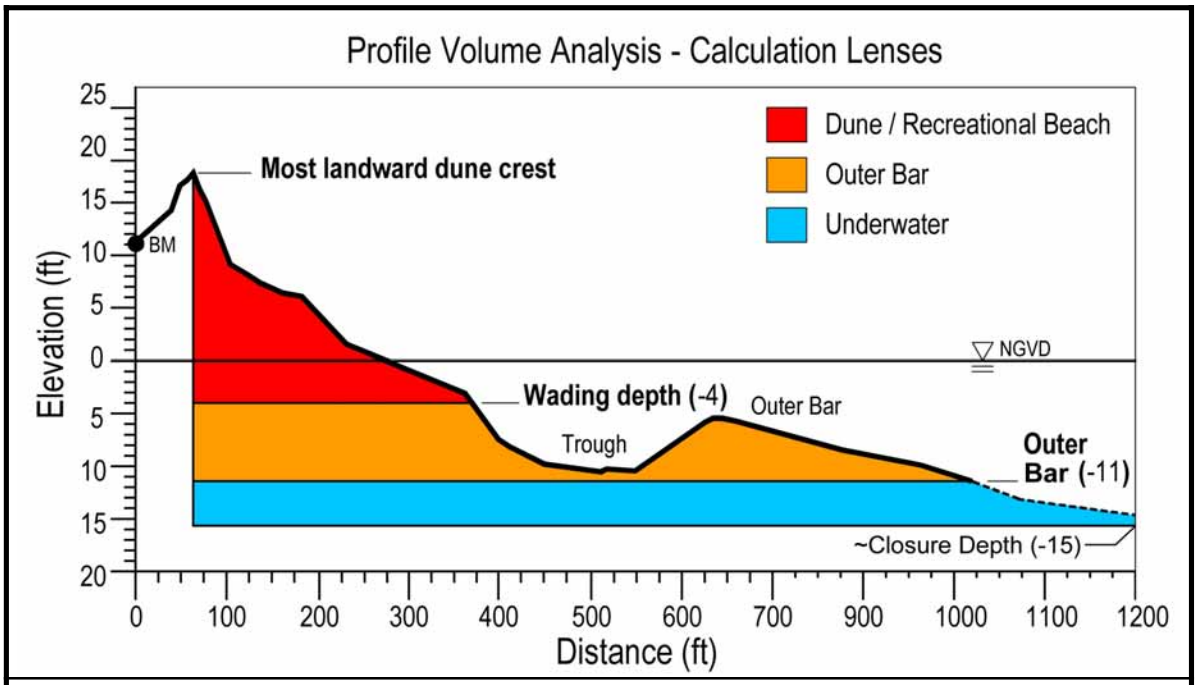


FIGURE 4. Trimble-HydroPro™ software was used by CSE to allow batch processing and editing of large files (data sampling rate used by CSE in Bogue Banks was 10 Hz). Software was used to filter spikes (upper) and provide floating point averages to yield smoother, more realistic profiles such as the one shown over the bar (lower).

Figure 5 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 6) 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. 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 for the 2003–2004 data analyses. 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).

[*Figure 6 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.]

Carteret County sponsored surveys by CSE in 1999 and 2000, as well as 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 2001 through 2004. 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.



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 5. Three reference zones used for calculation of sand volume changes along Bogue Banks 1999–2003 (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.

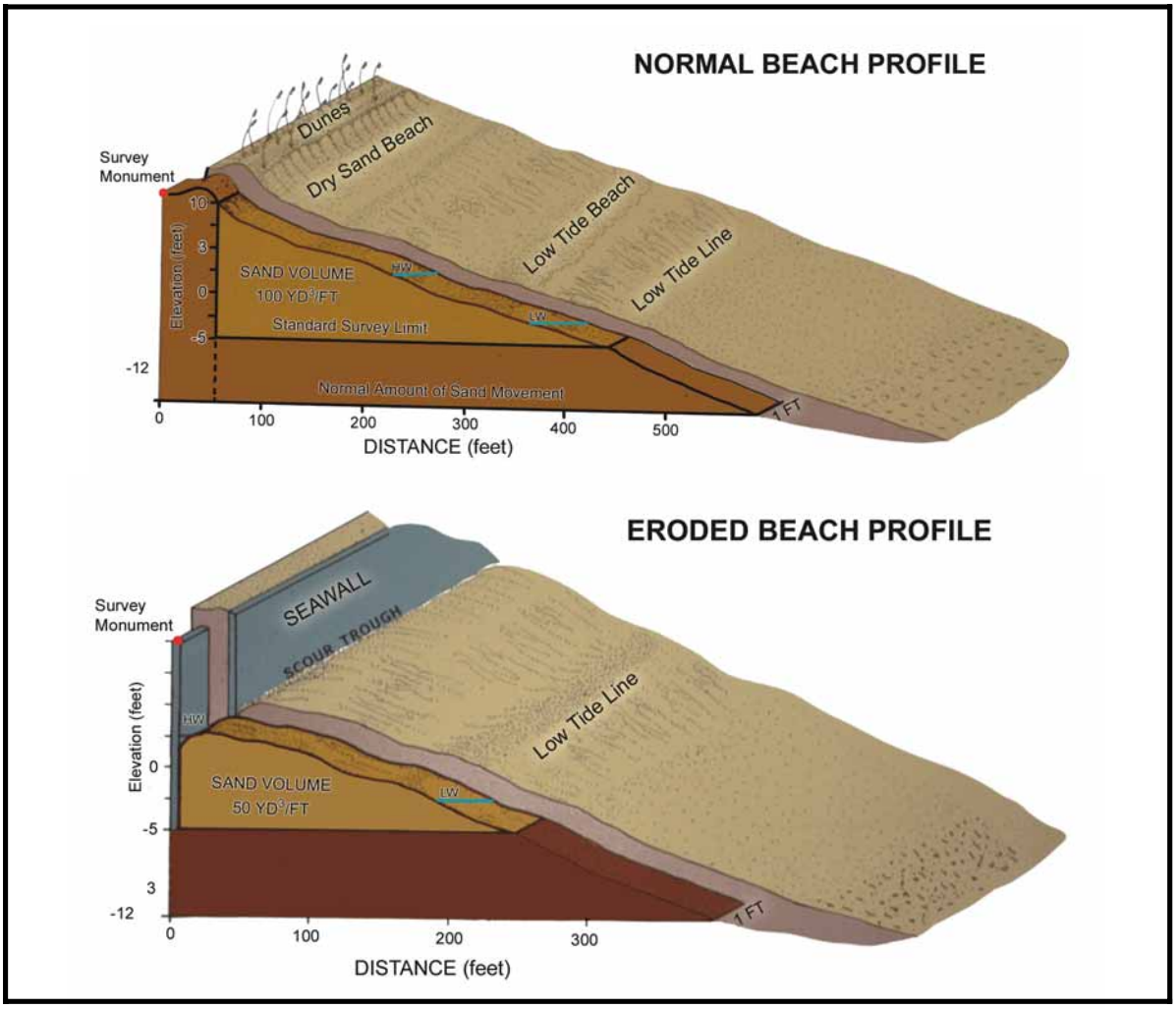


FIGURE 6. The concept of unit sand volume along the beach, which provides a quantitative measure of beach condition and changes before and after nourishment. The yearly limit of measurable sand movement ("profile closure depth") along Bogue Banks is thought to occur at depths of about 15 ft (±5 ft) (CSE-Stroud 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 1 of BBBNMP) involved profiling to –25 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, and June 2004. [Reach lengths updated and revised slightly from CSE Baird-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)	
			@ low tide	@ outer bar
Bogue Inlet	6,772	1-8	6 / 0 / 8 / 8 /8	5 / 0 / 6 / 8 / 8
Emerald Isle-West	22,303	8-25	17 / 3 / 17 / 17 / 17	17 / 3 / 17 / 17 / 17
Emerald Isle-Central	15,945	25-36	11 / 2 / 11 / 11 / 11	11 / 1 / 11 / 11 / 11
Emerald Isle-East	12,900	36-48	12 / 2 / 12 / 12 / 12	12 / 2 / 12 / 12 / 12
Indian Beach-Salter Path	12,986	48-58+	9 / 2 / 10 / 10 / 10	9 / 1 / 10 / 10 / 10
Pine Knoll Shores West	9,182	59-65	6 / 2 / 7 / 7 / 7	6 / 1 / 7 / 7 / 7
Pine Knoll Shores East	14,785	65-76	10 / 2 / 11 / 11 / 11	10 / 2 / 11 / 11 / 11
Atlantic Beach	26,322	76-102	26 / 5 / 26 / 26 / 26	24 / 5 / 26 / 26 / 26
Fort Macon State Park	7,199	102-112	9 / 0 / 9 / 9 / 10	9 / 0 / 9 / 9 / 10
	128,392 (24.32 miles)			

Sediment Sampling and Testing

Although not specifically required under the present scope of services for Year 1, CSE obtained and analyzed beach sediment samples in the primary nourishment areas of Pine Knoll Shores, Indian Beach, and eastern Emerald Isle. Samples analyzed consisted of physical composites collected at approximate 1-mile spacing. Each composite involved collection of a "transect" of samples spaced 50 feet 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). The results were compared with prenourishment and construction samples and are summarized in a later section of the report.

RESULTS

Island-Wide Trends

Appendixes II and III contain plotted profiles and profile volumes by station and reach (political jurisdiction) for 1999–2004 (respectively). Appendix III-A provides calculations from the foredune crest to –11 ft and –15 ft NGVD for April 2003 (non-county-sponsored survey by CSE), December 2003, and June 2004. Appendix III-B contains similar data measured to –4 ft NGVD (low-tide wading depth) for June 1999, June 2000, and the three most recent survey dates. Appendix III-C provides the 1999–2004 results measured to –11 ft NGVD (outer bar). The bottom of each table in Appendix III 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 spreadsheet. 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 1999 through June 2004. Eleven reaches are referenced along Bogue Banks. Nine reaches match the original ones established by CSE Baird-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) (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).

TABLE 2. Beach Volume Changes by Reach - Bogue Banks NC June 1999-June 2004

Change - Dune to -4 ft

Summary By Reach - Beach Volumes						Arith Avg (cy/ft)		Jun99 to Jun04		*Dec03 to Jun04*		
	Profiles	Reach Length	Jun-99	Jun-00	Apr-03	Dec-03	Jun-04	*Wtd Avg (cy/ft)*	Net (cy)	*Wtd Avg (cy/ft)*	*Net (cy)*	Reach
Bogue Inlet-Channel	117-120	1,900	nd	nd	nd	37.6	32.7	nd	nd	*-5.2*	*-9,809*	Bogue Inlet-Chan
Bogue Inlet-Ocean	1-8	6,772	172.1	173.8	167.8	163.9	175.6	27.4	185,872	*6.9*	*46,594*	Bogue Inlet-Ocean
EI-West	8-25	22,303	77.6	81.6	89.5	94.9	96.9	18.9	420,971	*2.4*	*54,586*	EI-West
EI-Central	25-36	15,945	74.2	79.9	114.2	112.3	112.8	37.9	604,558	*0.7*	*11,253*	EI-Central
EI-East	36-48	12,900	72.5	72.2	133.6	123.2	126.6	54.3	700,213	*2.8*	*35,498*	EI-East
IB/SP	48-58+	12,986	68.6	72.4	100.7	107.0	135.3	65.9	856,179	*27.0*	*350,295*	IB/SP
PKS-West	59-65	9,182	70.2	66.5	101.4	98.7	100.9	35.9	329,308	*5.0*	*45,812*	PKS-West
PKS-East	65-76	14,785	65.2	63.2	99.5	97.0	100.7	33.9	500,958	*3.1*	*45,904*	PKS-East
AB	76-102	26,322	93.9	91.9	92.2	87.1	91.8	-0.4	-10,721	*4.7*	*123,250*	AB
FMSP	102-112	7,199	106.9	101.5	92.5	78.7	80.8	-27.3	-196,301	*1.2*	*8,783*	FMSP
Beaufort Inlet	112-116	2,250	nd	nd	nd	133.0	154.1	nd	nd	*18.5*	*41,514*	Beaufort Inlet
County Project	8-76	88,099	**72.3**	**73.9**	**105.6**	**105.1**	**111.2**	**38.7**	**3,412,182**	***6.2***	***543,349***	**County Project**
Entire Oceanfront	1-112	128,392	**86.1**	**86.7**	**105.3**	**102.2**	**108.0**	**26.4**	**3,390,495**	**5.6**	**721,977**	**Entire Oceanfront**

Change - Dune to -11 ft

Summary By Reach - Beach Volumes						Arith Avg (cy/ft)		Jun99 to Jun04		*Dec03 to Jun04*		
	Profiles	Reach Length	Jun-99	Jun-00	Apr-03	Dec-03	Jun-04	*Wtd Avg (cy/ft)*	Net (cy)	*Wtd Avg (cy/ft)*	*Net (cy)*	Reach
Bogue Inlet-Channel	117-120	1,900	nd	nd	nd	79.4	69.9	nd	nd	*-12.9*	*-24,465*	Bogue Inlet-Chan
Bogue Inlet-Ocean	1-8	6,772	426.0	432.5	309.6	319.8	320.1	-39.6	-268,237	*-1.2*	*-8,041*	Bogue Inlet-Ocean
EI-West	8-25	22,303	209.4	213.4	231.0	236.0	242.1	32.4	723,052	*6.9*	*153,489*	EI-West
EI-Central	25-36	15,945	194.1	202.6	249.1	244.6	249.1	54.8	874,031	*5.1*	*80,919*	EI-Central
EI-East	36-48	12,900	194.3	190.9	281.3	264.5	270.0	74.8	965,114	*4.7*	*60,434*	EI-East
IB/SP	48-58+	12,986	185.1	195.6	241.6	240.1	293.3	104.8	1,361,192	*50.2*	*651,819*	IB/SP
PKS-West	59-65	9,182	188.8	184.5	237.3	222.8	221.4	43.4	398,891	*4.3*	*39,306*	PKS-West
PKS-East	65-76	14,785	191.2	187.3	246.5	233.3	238.6	44.0	650,158	*4.6*	*67,286*	PKS-East
AB	76-102	26,322	235.8	232.2	244.1	236.2	238.6	5.2	136,193	*2.5*	*65,826*	AB
FMSP	102-112	7,199	229.4	230.6	223.3	216.2	207.7	-25.7	-184,943	*-6.0*	*-42,921*	FMSP
Beaufort Inlet	112-116	2,250	nd	nd	nd	312.6	359.3	nd	nd	*38.0*	*85,574*	Beaufort Inlet
County Project	8-76	88,099	**196.2**	**198.1**	**247.3**	**241.1**	**252.8**	**56.4**	**4,972,437**	***12.0***	***1,053,253***	**County Project**
Entire Oceanfront	1-112	128,392	**219.5**	**223.5**	**248.5**	**242.7**	**249.7**	**36.3**	**4,655,450**	***8.3***	***1,068,117***	**Entire Oceanfront**

Change - Dune to -15 ft

								Dec03 to Jun04				
	Profiles	Reach Length				Dec-03	Jun-04	cy	*cy/ft*	Reach		
Bogue Inlet-Channel	117-120	1,900				110.4	95.6	-17,943	-9.4	Bogue Inlet-Chan		
Bogue Inlet-Ocean	1-8	6,772				nd	nd	nd	nd	Bogue Inlet-Ocean		
EI-West	8-25	22,303				370.9	376.7	147,494	6.6	EI-West		
EI-Central	25-36	15,945				384.3	388.2	70,888	4.4	EI-Central		
EI-East	36-48	12,900				407.6	411.0	37,466	2.9	EI-East		
IB/SP	48-58+	12,986				383.2	436.6	649,217	50.0	IB/SP		
PKS-West	59-65	9,182				362.2	359.0	26,129	2.8	PKS-West		
PKS-East	65-76	14,785				387.9	389.2	11,741	0.8	PKS-East		
AB	76-102	26,322				399.3	396.8	-63,325	-2.4	AB		
FMSP	102-112	7,199				366.0	350.2	-94,922	-13.2	FMSP		
Beaufort Inlet	112-116	2,250				434.2	490.0	103,219	45.9	Beaufort Inlet		
County Project	8-76	88,099				383.0	393.4	**942,935**	**10.7**	**County Project**		
Entire Oceanfront	1-112	128,392				385.4	386.5	**784,689**	**6.1**	**Entire Oceanfront**		

In Table 2, unit-width volumes by reach for particular survey dates are arithmetic averages of the data in Appendix III. The net change allows simple calculation of weighted-average, unit-volume changes. Thus, the weighted averages given herein generally vary slightly from the arithmetic averages. As an example, the weighted unit-volume change for the County Project (dune to –4 ft) for 1999 to 2004 is 38.7 cy/ft (Table 2). The difference between June 1999 and June 2004 arithmetic average unit volumes (72.3 and 111.2) is 38.9 cy/ft. Minor differences such as this between arithmetic and weighted averages should be kept in mind as the results are reviewed. With respect to island-wide trends, Table 2 indicates the following:

1) There has been a ~4.7 million cubic yard net increase in beach volume along Bogue Banks between 1999 and 2004. This equates to a weighted average gain of 36.3 cy/ft within the primary computation boundaries to –11 ft NGVD.

2) The 17-mile County Project reach gained nearly 5.0 million cubic yards (56.4 cy/ft) between June 1999 and June 2004. This accounts for more than the net island-wide gain, meaning Atlantic Beach (AB), FMSP, and Bogue Inlet's ocean shoreline (combined) lost sand.

3) The island-wide and County Project totals to low-tide wading depth (–4 ft NGVD) for 1999–2004 were ~3.39 million cubic yards (26.4 cy/ft) and ~3.41 million cubic yards (38.7 cy/ft) (respectively) (Table 2, upper). This means that calculations to wading depth account for ~70 percent of the volume gained to the outer bar. In simple terms, most of the beach-volume gain was in the recreational portion of the beach.

4) The results for December 2003 to June 2004 (present survey year) show the island gained ~1.1 million cubic yards in the past six months, nearly all of which is accounted for in the County Project reach (measured to –11 ft NGVD). This equates to an average gain of 12.0 cy/ft (County Project) and 8.3 cy/ft (island-wide).

5) The December 2003 to June 2004 data show lower net change when measured to –15 ft NGVD (beyond outer bar), suggesting that gains on the bar offset losses in deeper water. Another way of interpreting this result is to say that some sediment from offshore (beyond –15-ft depth) migrated shoreward during the December–June period. This period also included the "Section 933" nourishment along Indian Beach (discussed in a later section of the report).

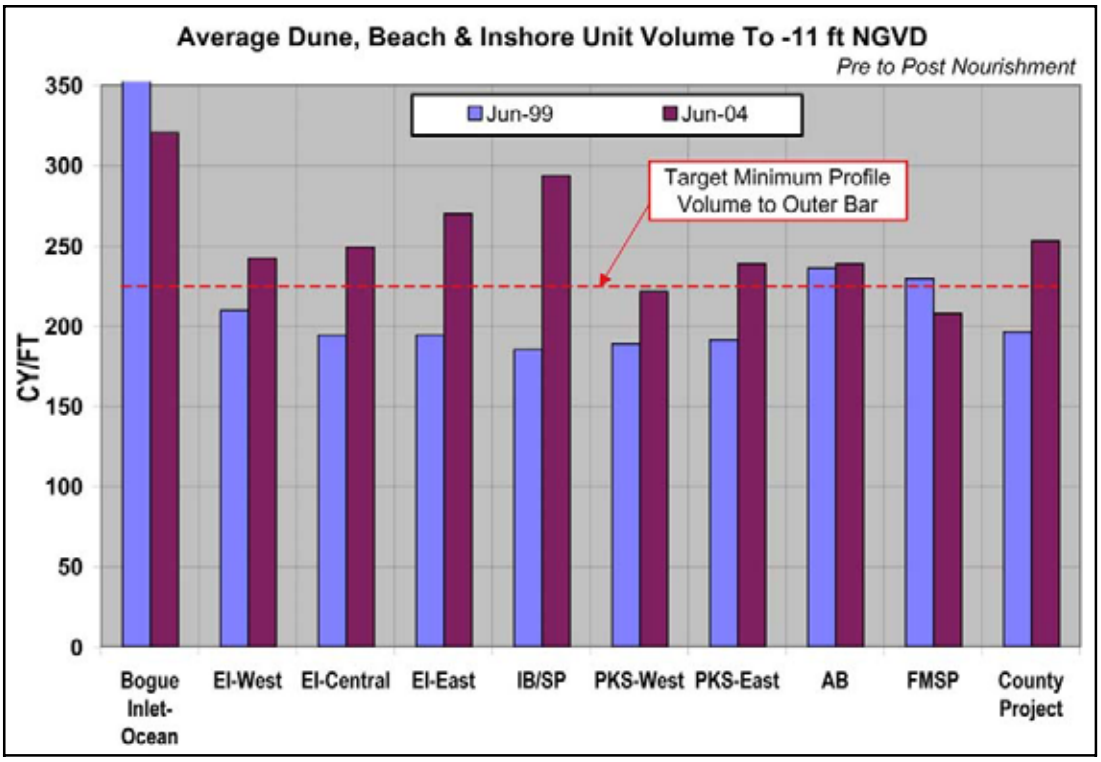
Figures 7–9 show the trends in unit beach volumes and unit beach volume changes by reach and island-wide for 1999–2004 and December 2003–June 2004. Figure 7 (upper) compares 1999 and 2004 unit volumes to the outer bar. Also shown is a reference line for the "Target Minimum Profile Volume" similar to a criteria used by CSE Baird–Stroud (1999) for the initial project planning.* The calculation boundaries are from the approximate dune crest to –11 ft NGVD. Figure 7 (lower) shows the changes in unit volumes over the past five years. The results are striking compared with historical trends along Bogue Banks.

[*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 Baird-Stroud 1999) have shown that the typical rate of beach change along Bogue Banks is of the order 2 cy/ft/yr. Thus, changes of ~10 cy/ft would be expected over a five-year period. Only Atlantic Beach and FMSP show changes of this order for the 1999–2004 period. The majority of the island gained sand at rates of 30–100 cy/ft. This, of course, reflects the impact of nourishment. Atlantic Beach experienced only ~1 cy/ft/yr change in beach volume for the period. FMSP lost about 25 cy/ft over the past five years. As Table 2 indicates, the average gain for the entire oceanfront was 36.3 cy/ft (dune to –11 ft). As previously described, nearly all the gain occurred in the County Project nourishment reaches of Emerald Isle, Indian Beach, and Pine Knoll Shores.

Figure 7 illustrates why it is useful to consider the absolute volume of sand in the profile (unit-width volumes in Figure 7, upper) as well as the volume change between surveys. The largest sand losses between 1999 and 2004 occurred along the Bogue Inlet–Ocean reach (~40 cy/ft erosion). FMSP lost ~25 cy/ft. These rates equate to 8 cy/ft/yr and 5 cy/ft/yr (respectively). Therefore, the erosion rates along the ends of the island (oceanfront) were about five times and two times (respectively) the historical rate for the island. In the case of the Bogue Inlet–Ocean shoreline reach, the loss was significant, but there is still much more sand in the profile compared with other reaches (Fig 7, upper). By contrast, losses along FMSP have dropped the beach volume below the target minimum for the island.

Of the nourished reaches, all but PKS–West exceed the target minimum volume (to –11 ft) following nourishment projects in 2001 through 2004. PKS-West gained ~43.4 cy/ft, restoring the profile deficit to nearly the target minimum volume.



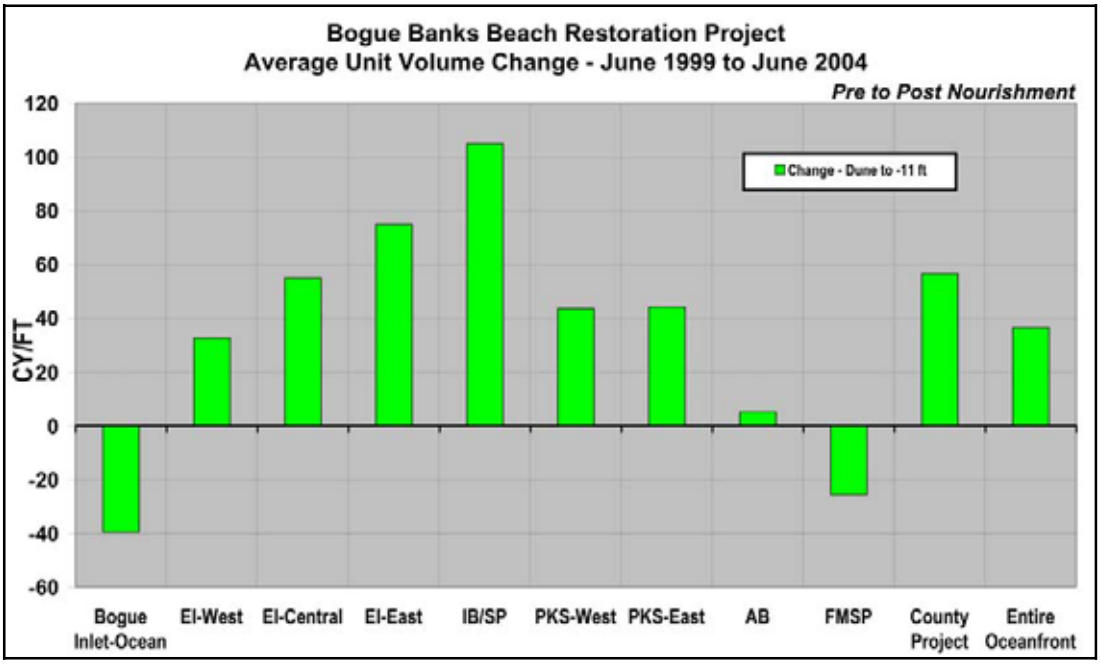


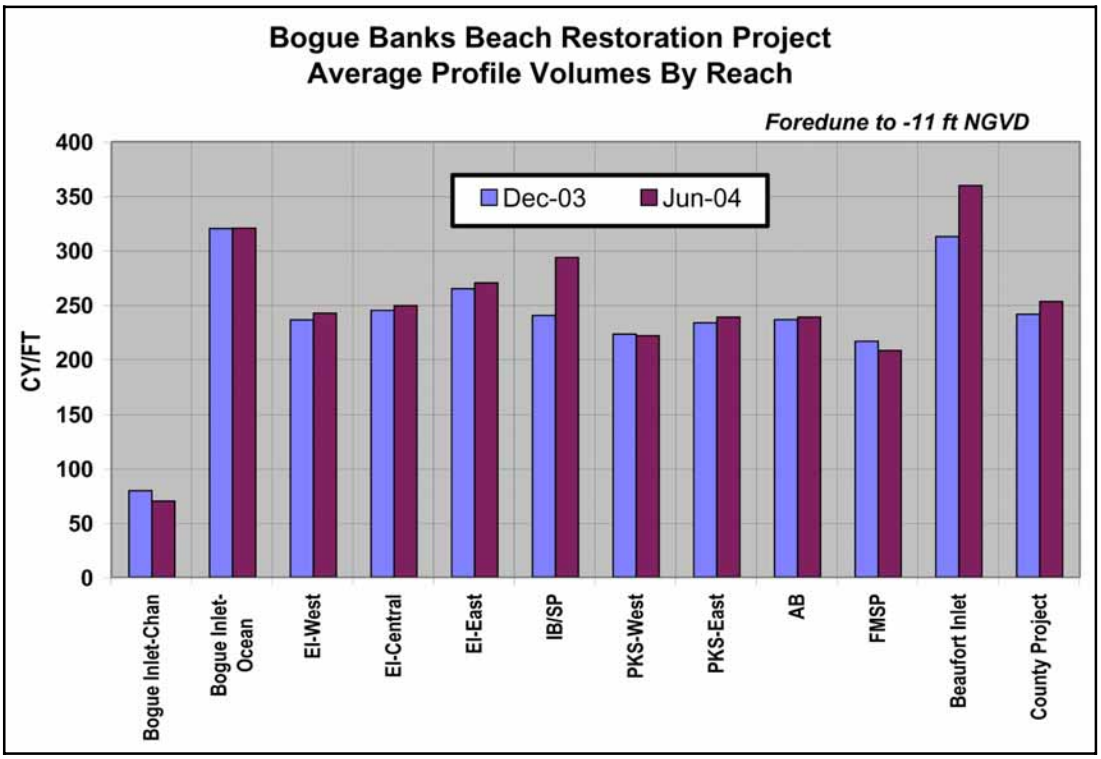
FIGURE 7. Trends (by reach) in average dune, beach, and inshore sand volume measured to –11 ft (including outer bar) between June 1999 and June 2004 (upper). Lower graph illustrates the change by reach for the five-year period.

The largest increase in beach volume to –11 ft (~105 cy/ft) occurred in the IB/SP reach (Fig 7, lower). This reach was nourished twice between 1999 and 2004 with the Section 933 project constructed two years after the County Project (Phase 1).

Figure 8 compares unit volumes by reach to –11 ft (outer bar) and to –15 ft NGVD for the six-month period, December 2003 to June 2004. The latter depth limit was used because, upon inspection of the suite of profiles, some changes between –11 ft and –15 ft were detectable. Nevertheless, the overall trends are similar for both calculation limits. Differences are shown in Figure 9. Note that pairs of bars having the same length mean there is no difference in net volume change between the calculations to –11 ft and to –15 ft. In other words, the calculation to the shallower depth accounts for all the change.

A review of Figure 9 shows the following trends for December 2003 to June 2004 (relative to –11 ft):

- Largest change (~50 cy/ft) is along the IB/SP reach, reflecting construction of the “Section 933" nourishment project in January to March 2004.
- Second largest change (~38 cy/ft) is along the new Beaufort Inlet reach (see Fig 1).
- Emerald Isle gained sand (5–7 cy/ft) partly because of a small FEMA-sponsored renourishment after Hurricane *Isabel* (September 2003), which was completed in March 2004.
- FMSP eroded ~6 cy/ft.
- The new reach along Bogue Inlet (see Fig 1) lost about 13 cy/ft, despite the protection by large sand bags along much of this reach.
- The island-wide and County Project totals to low-tide wading depth (–4 ft) for December 2003 to June 2004 were 0.72 million cubic yards and 0.54 million cubic yards (respectively). This means that ~50–70 percent of the increase in material was gained in the recreational portion of the beach (compared to the –11 ft result).
- Pine Knoll Shores (east and west) and Atlantic Beach gained ~4.5 cy/ft and 2.5 cy/ft (respectively) during the December 2003 to June 2004 monitoring period.



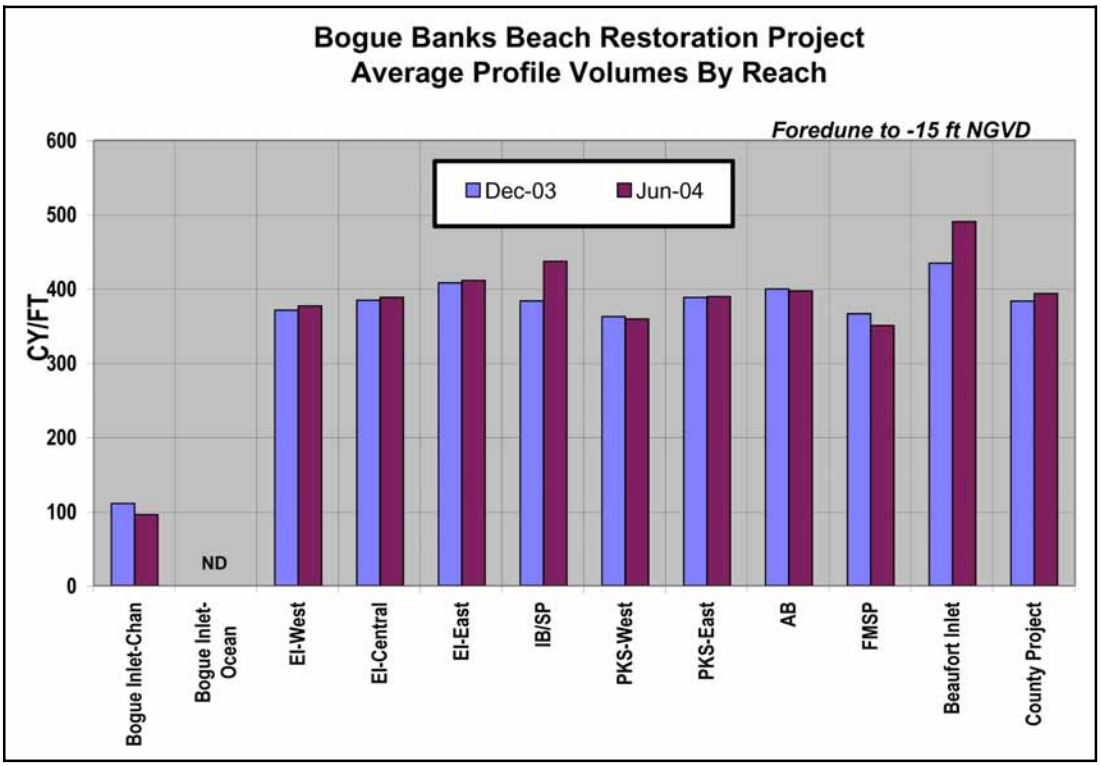


FIGURE 8. Trend in unit volumes by reach for December 2003 and June 2004 for calculation limits of –11 ft NGVD (upper) and –15 ft NGVD (lower).

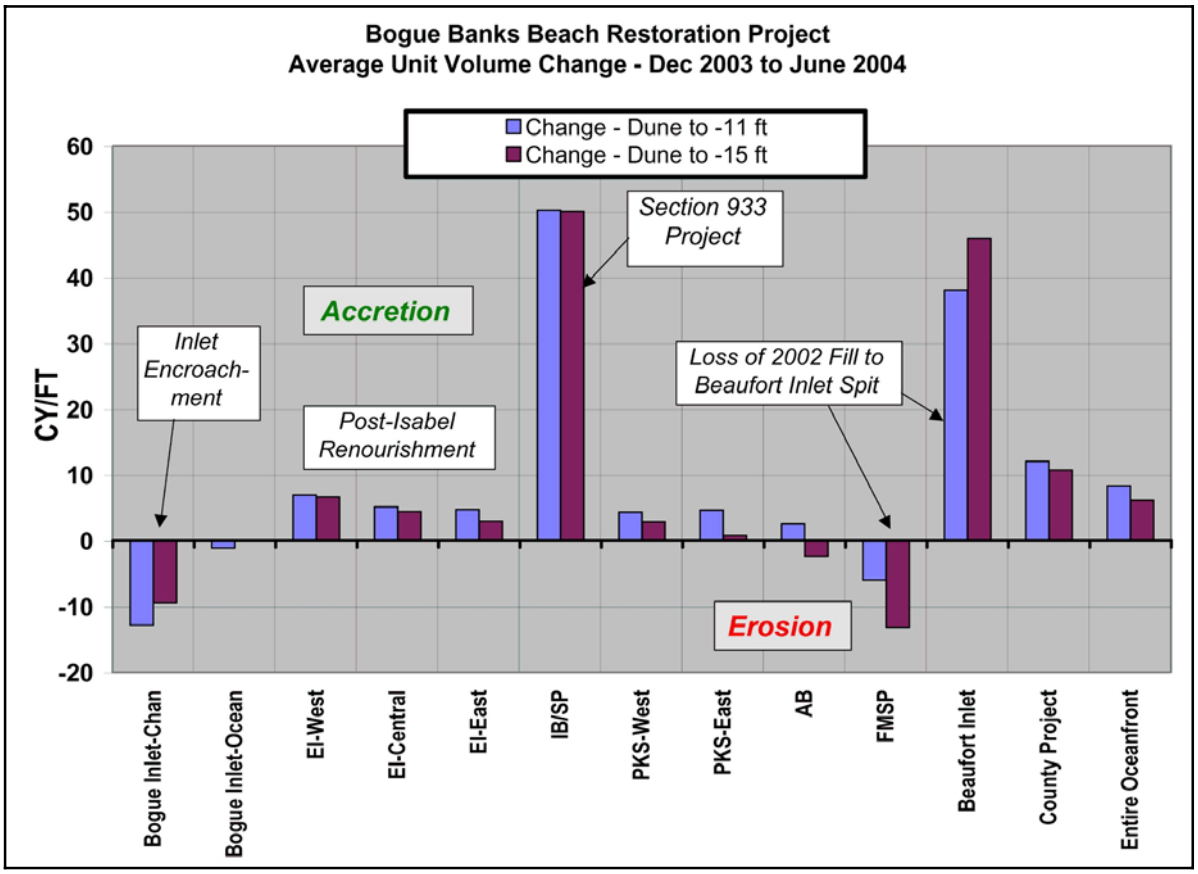


FIGURE 9. Changes in unit beach volume by reach for the period December 2003 to June 2004, showing differences between –11 ft and –15 ft calculation depths. Equal-length bar pairs mean the shallower depth limit accounts for the net volume change. The inlet reaches exhibit changes in deeper water in relation to the depth of the channel.

Figure 9 has been annotated to show relevant events affecting each reach. Nourishment is an obvious event because it involves direct placement of fill into a given reach. The trends at the inlets are less obvious, but can be inferred from other observations and morphological indicators. For example, a large spit has developed along the margin of Beaufort Inlet. Comparative profiles, as well as the appearance of a large bar close to shore, confirm that the beach has grown over the past six months about 38 cy/ft (Fig 10). At the same time, FMSP has lost around 6 cy/ft. Most of FMSP's loss is along the beach face and foredune, leaving a narrow profile and steep dune scarp. (See profiles 103–112 in Appendix II.)

Net sand transport is inferred from FMSP to Beaufort Inlet spit by observed morphological changes as well as the natural circulation patterns at inlets (Fitzgerald et al 1976, Hayes 1980, Kana et al 1999). Flanking the main channel of Beaufort Inlet is a marginal channel, which directs flood tides along the beach. This augments wave-generated transport and carries sand to the spit. The reason the rates of change differ between FMSP and Beau-

fort Inlet spit is their shoreline lengths. The FMSP reach is much longer. An incremental amount of erosion contributed from a long reach becomes a large amount of accretion along a short reach, such as Beaufort Inlet spit. This simply reflects the tendency for sand to accumulate in natural traps at the ends of littoral cells. Keep in mind, this is a localized trend and does **not** mean net transport for all of Bogue Banks is from west to east.

The net volume change for December 2003 to June 2004 provides additional insight into the sediment-transport trend around Beaufort Inlet. Calculations to the outer bar (–11 ft) show accretion along Atlantic Beach (net ~66,000 cy, or 2.5 cy/ft), erosion along FMSP (net –43,000 cy, or –6.0 cy/ft), and accretion along Beaufort Inlet (net ~85,000 cy or 38.0 cy/ft). When the calculations are taken to –15 ft NGVD, the trend reverses at Atlantic Beach to erosion (net ~63,000 cy or –2.4 cy/ft). The erosion rate along FMSP increases to ~95,000 cy (–13.2 cy/ft), and accretion along Beaufort Inlet spit increases to ~103,000 cy (46 cy/ft). Coincidently, the net erosion along FMSP for the past six months nearly equals the accretion along Beaufort Inlet. Note that this comparison is not precise because portions of the spit north of profile 116 are excluded, and the underwater slope of the spit below –15 ft NGVD to the channel center line is excluded. (See Figure 10, lower.) Still, there is ample evidence that a large portion of FMSP's erosion contributed to spit growth along Beaufort Inlet between December 2003 and June 2004.

The situation along Atlantic Beach is less clear. Its gain above –11 ft can be the result of sand transfer from deeper water (ie, losses between –11 ft and –15 ft), as well as long-shore transport from FMSP. Some of its gain is likely due to spreading of Phase 1 nourishment sand from PKS–East. The data are not sufficiently detailed to distinguish among these three transport sources.

The situation at Bogue Inlet is different. During the first six months of 2004, the ocean-front reach of the inlet (Bogue Inlet–Ocean) was relatively stable with accretion of ~7 cy/ft along the recreational beach (measured to –4 ft NGVD) and minor erosion of ~1.2 cy/ft measured further offshore (–11 ft NGVD). The oceanfront reach contributed relatively little sand to the new inlet channel reach. This, of course, exacerbated erosion along the inlet. Continued encroachment by Bogue Inlet channel resulted in losses of the order 13 cy/ft (to –11 ft) in the Bogue Inlet–Channel reach between December 2003 and June 2004 (Fig 11). Profiles 117 to 120 (Appendix II) confirm the continuing process of channel encroachment along that reach. (Note: Compare Bogue Inlet profiles with Beaufort Inlet profiles 113 to 116; Beaufort Inlet's channel was positionally stable for the period.)

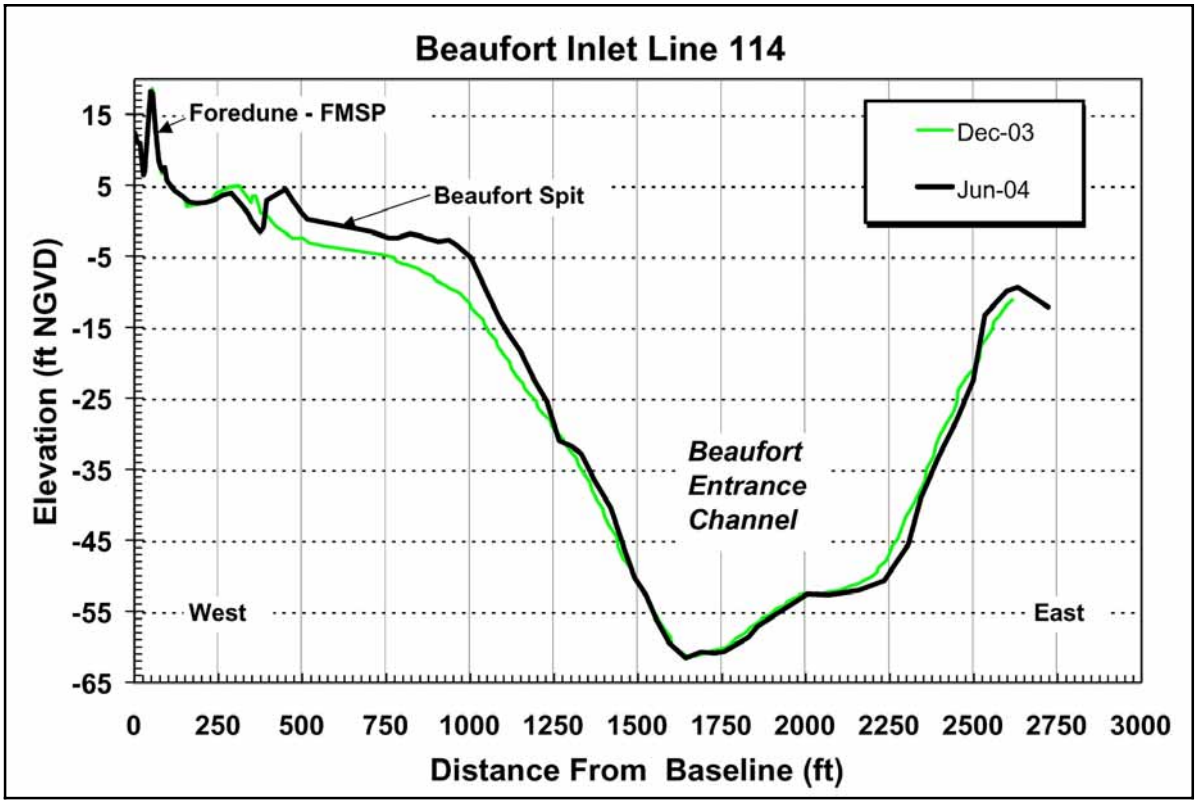
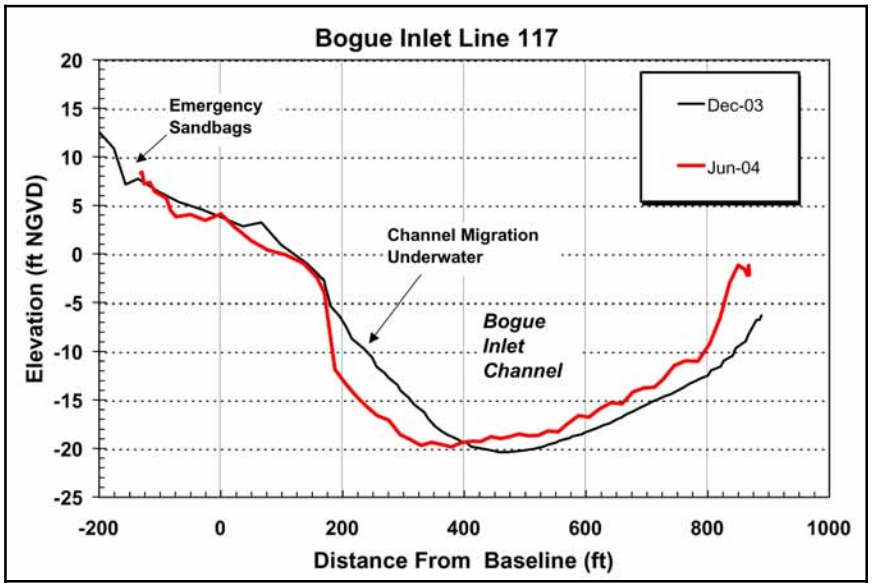


FIGURE 10. Beaufort Inlet spit has grown rapidly during the past year (upper). Its growth extends underwater as shown in the profiles (lower).



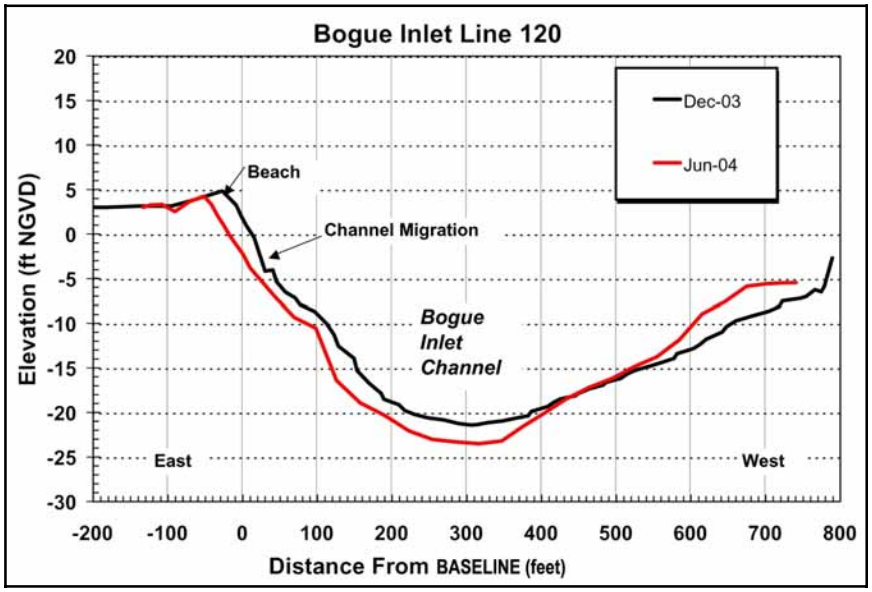


FIGURE 11. Bogue Inlet changes (December 2003 to June 2004) showing continued encroachment by the channel and undermining of emergency sand bags (upper). Channel migration was upward of 75 ft at profile 117 and 50 ft at profile 120 during the six-month period (lower).

Comparison with Nourishment Volumes

Between November 2001 and March 2004, nearly 4,650,000 cy were added to Bogue Banks by nourishment projects (Fig 12, Table 3). This total is remarkably close to the measured volume change (to –11 ft NGVD) for the entire oceanfront for the period, June 1999 to June 2004. In fact, the difference is less than 0.1 percent.

Table 4 provides estimates of the differences between nourishment volumes and surveyed volumes by reach. In this case, some reaches are combined to facilitate interpretation of the results. Figure 13 (upper) graphs the differences. Note that for some reaches such as Emerald Isle and Pine Knoll Shores, the nourishment volume exceeds the surveyed volume. The difference is the background erosion volume for the five-year period. Figure 13 (lower) normalizes the data by reach length and annualizes it over five years to provide estimates of average annual (background) erosion rates by community. The results show EI–West, IB/SP, and AB reaches were accretional, whereas EI–Central, EI–East, PKS, and FMSP were erosional.

When averaged over the entire oceanfront, the net change rate was virtually 0.0 cy/ft/yr. This suggests there was no loss (or gain) due to natural processes along Bogue Banks between 1999 and 2004. While this should not be accepted as a precise result, given the limitations of all field surveys, it does 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). Ironically, the reach that received the most nourishment (per foot), Indian Beach/ Salter Path, also experienced a high background accretion rate of 5 cy/ft/yr. Erosion rates along most of Emerald Isle and Pine Knoll Shores were ~1.1 and ~2.5 cy/ft/yr (respectively). Both ends of the island had high background erosion rates, even after factoring out nourishment at FMSP. EI–West accreted partly because of the Phase 2 nourishment project (EI–Central and EI–East).

The next sections describe community-by-community results.

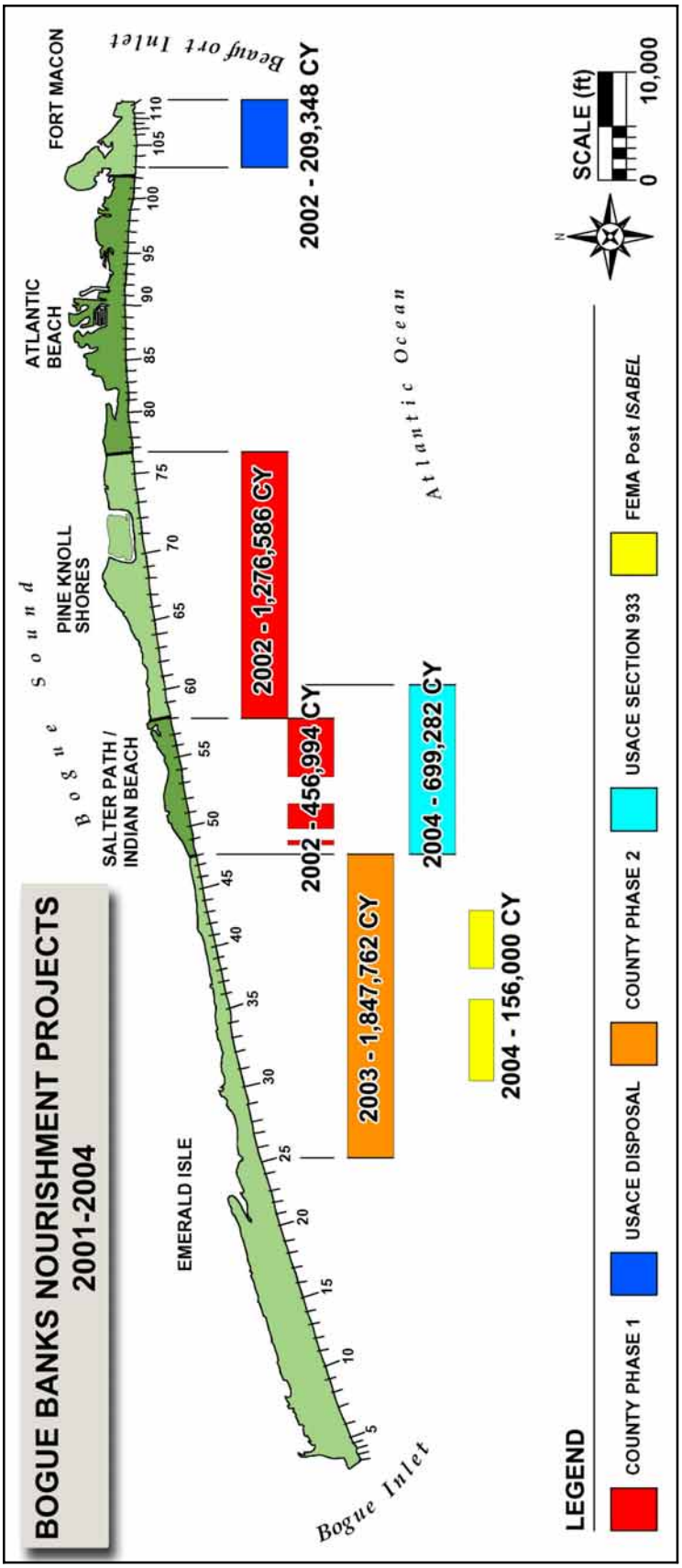


FIGURE 12. Nourishment projects along Bogue Banks (2001–2004).

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

*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 and PKS–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 and EI–Central	2003	1,810,000	1,746,413
4b	County Phase 2 EI–East and EI–Central – Dune	2003	60,000	101,349
5	USACE Section 933 IB/SP and PKS-West	2004	900,000	699,282
6	FEMA Post-*Isabel* – EI–East and EI–Central	2004	128,000	156,000
	Totals		5,280,564	4,645,972

TABLE 4. Bogue Banks nourishment volumes (2001–2004) and estimated background erosion rate without nourishment. Calculations to –11 ft NGVD. *Volume of Section 933 (surveyed in place before and after construction) totaled 630,094 cy along IB/SP and 69,188 cy along PKS–West.

Reach	Length	Nourishment Volume*	Jun 1999 to Jun 2004 Volume Change (cy)	Background Erosion Volume Change (cy)	Average Annual Background Erosion Rate (cy/ft/yr)
Bogue Inlet - Ocean	6,772	0.00	(268,237)	(268,237)	-7.92
EI-West	22,302	0.00	723,052	723,052	6.48
EI-East & Central	28,844	2,003,762	1,839,145	(164,617)	-1.14
IB/SP	12,986	1,087,088	1,361,192	274,104	4.22
PKS	23,967	1,345,774	1,049,049	(296,725)	-2.48
AB	26,322	0.00	136,193	136,193	1.03
FMSP	7,199	209,348	(184,943)	(394,291)	-10.95
Bogue Banks Total	128,392	4,645,972	4,655,451	9,479	0.01

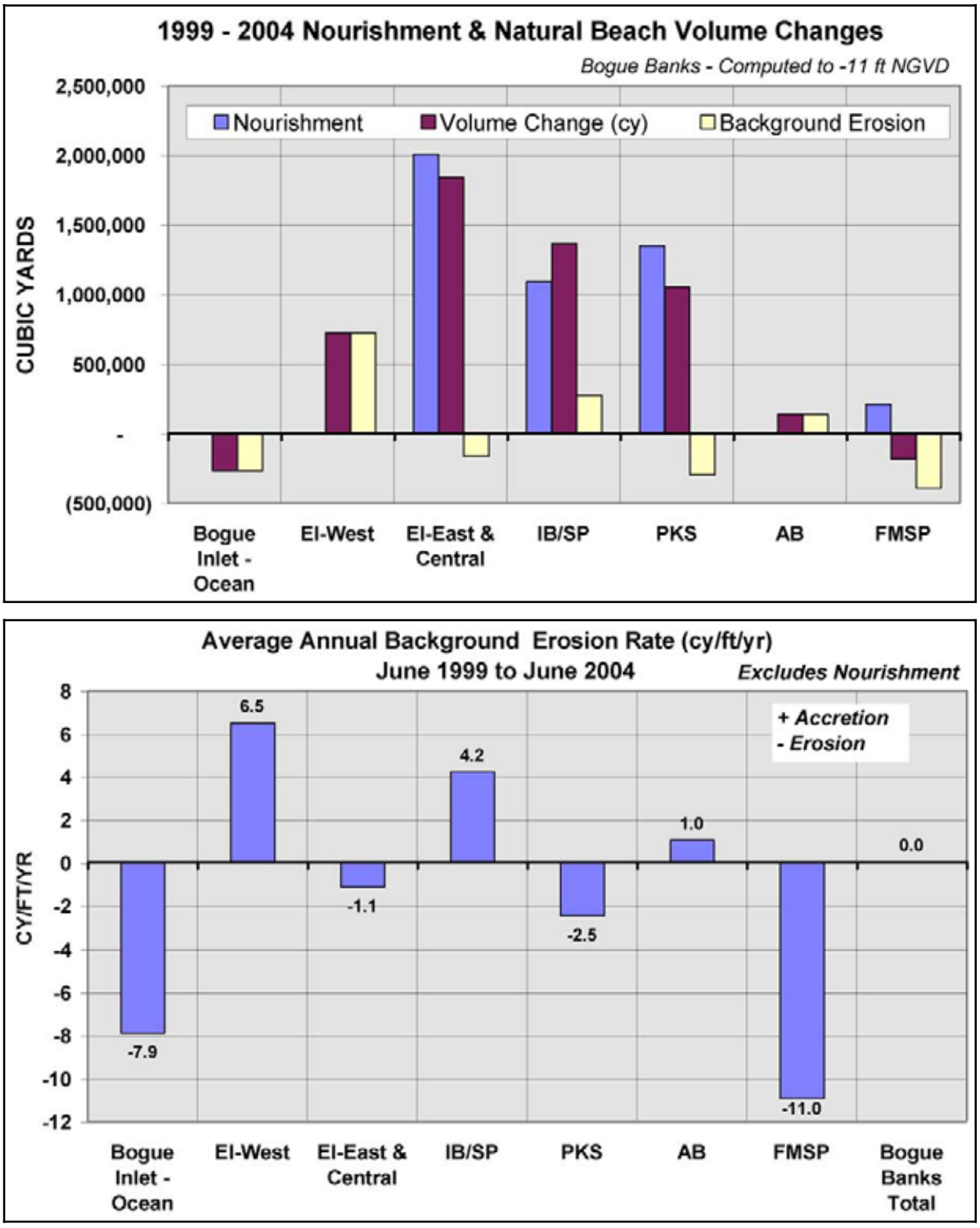


FIGURE 13. [UPPER] Total nourishment volumes and surveyed volume changes by reach for June 1999 to June 2004. The difference between the two quantities is the "background" erosion rate. [LOWER] Average, annual, background erosion rate after factoring out nourishment.

Emerald Isle

Emerald Isle is part of the County Project which was initiated in 1999. It is represented by profile lines 8–48. Nourishment totaling 1,847,762 cy was completed along the eastern and central reaches between January and March 2003 (Bogue Banks beach restoration project Phase 2). Of this total, 101,349 cy were placed in a new foredune for purposes of rebuilding the dune that was washed out by Hurricane *Floyd* (September 1999). An additional ~156,000 cy were placed in March 2004 as part of the post-*Isabel* restoration program sponsored by FEMA. Emerald Isle qualified for emergency funds after the hurricane because of its investment in the Phase 2 project.

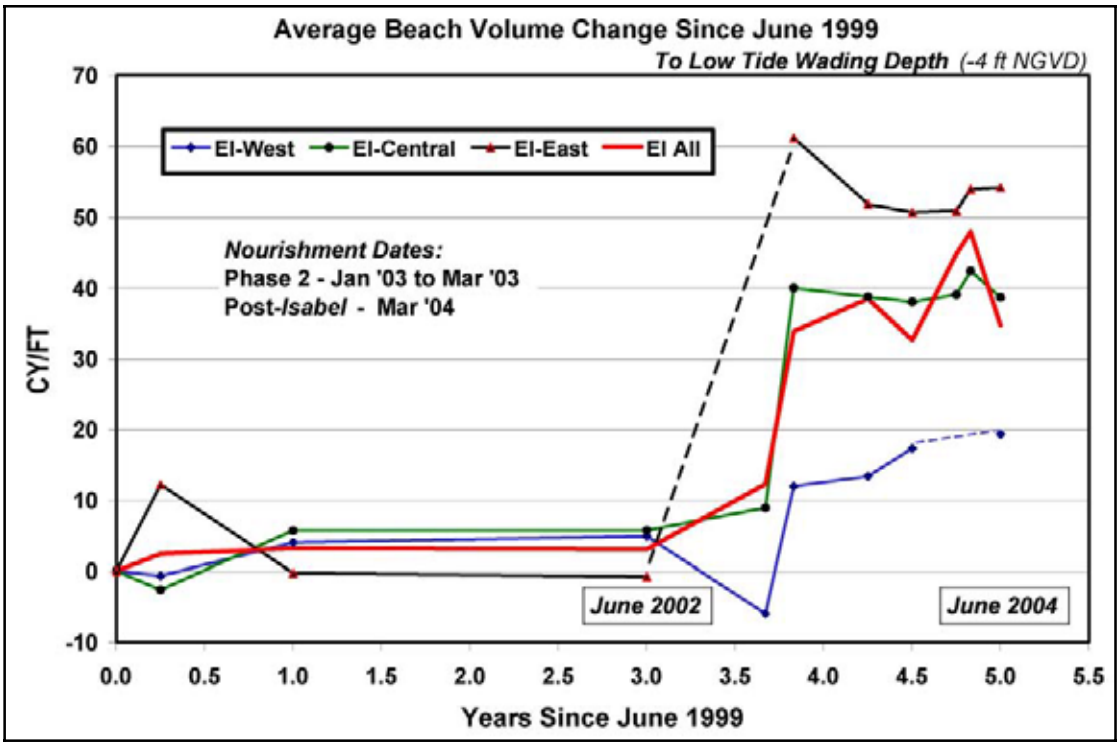
The net change along Emerald Isle (including EI–West) was a gain of 2,562,197 cy (to –11 ft). Thus, nourishment accounts for ~80 percent of the new sand. The net gain averages 50 cy/ft for the three reaches.

Figure 14 (upper) illustrates the change in average beach volume by reach between June 1999 and June 2004. (Note: This graph tracks changes on the recreational part of the beach to low tide wading depth and excludes volumes in the bar.) Additional surveys are available in connection with the Phase 2 nourishment project and some of the results are included here. Figure 14 shows little change in volume between 1999 and 2002 (Years 0–3 on the graph). The totals increase dramatically between Years 3 and 4 in conjunction with nourishment. Some of the zigzags in the graphs reflect seasonal changes in the recreational beach. Storms and heavy surf periods shift sand seaward beyond the –4 ft contour. Fair weather or low-wave periods shift sand back into the recreation zone of the beach.

The five-year changes by station are given in Figure 14 (lower). Results to –11 ft as well as –4 ft are shown. All profile lines gained sand. However, there was some rhythm to the gains. Where the two lines match means all the volume change at that station is accounted for above low-tide wading depth. Variations between the two lines are attributed to differences in the outer bar, including runnel outlets. Where the offshore zone is more uniform, the result for –11 ft will track parallel to, and above, the result for –4 ft.

Nourishment and natural accretion have advanced the shoreline about 75–100 ft and restored the beach well beyond the target minimum volume* to low-tide wading depth (Fig 15). Tables 5 and 6 provide volume calculations to –4 ft and –11 ft NGVD (respectively) for every station, reach, and available survey date for Emerald Isle.

[*Using the Atlantic Beach condition as the principal criteria for minimum acceptable beach volume, consistent with the approach used by CSE Baird–Stroud (1999) in the original planning for the County Project.]



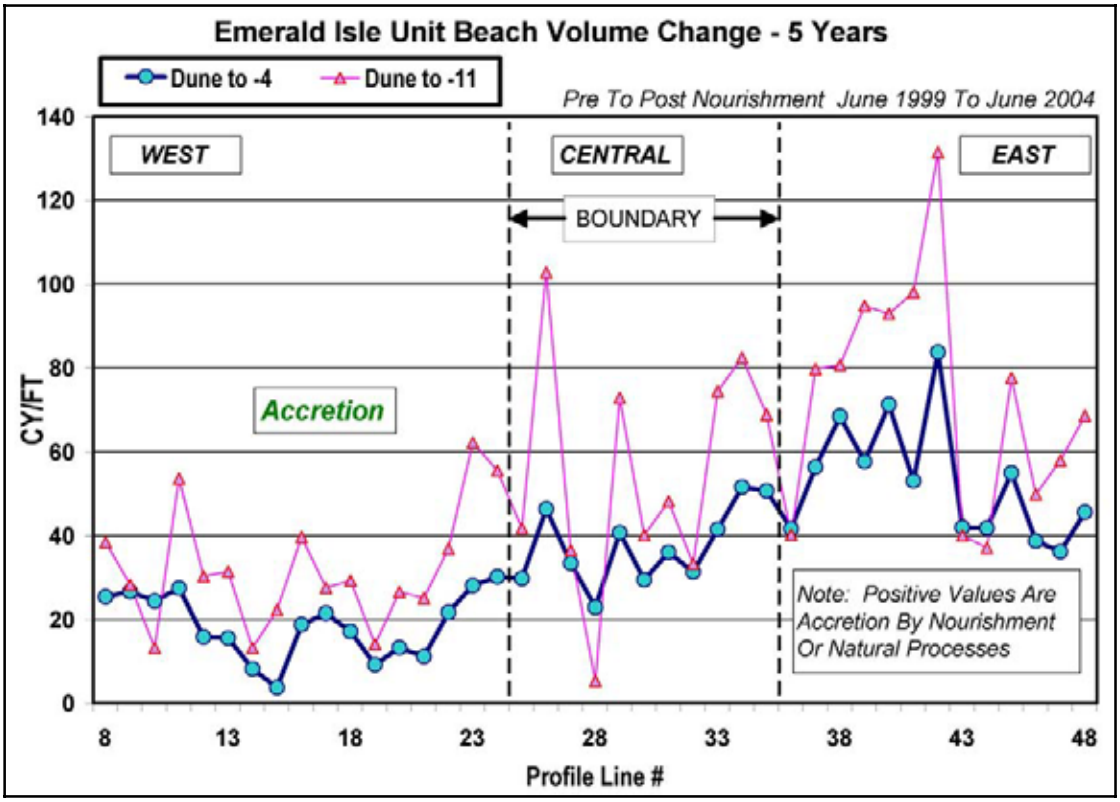


FIGURE 14. [UPPER] Trend in average, beach volume change by reach for the five-year period, June 1999 to June 2004, measured between the foredune and low-tide wading depth. [LOWER] The net five-year change by station to –4 ft and –11 ft calculation depths showing accretion by nourishment or natural processes at all stations.

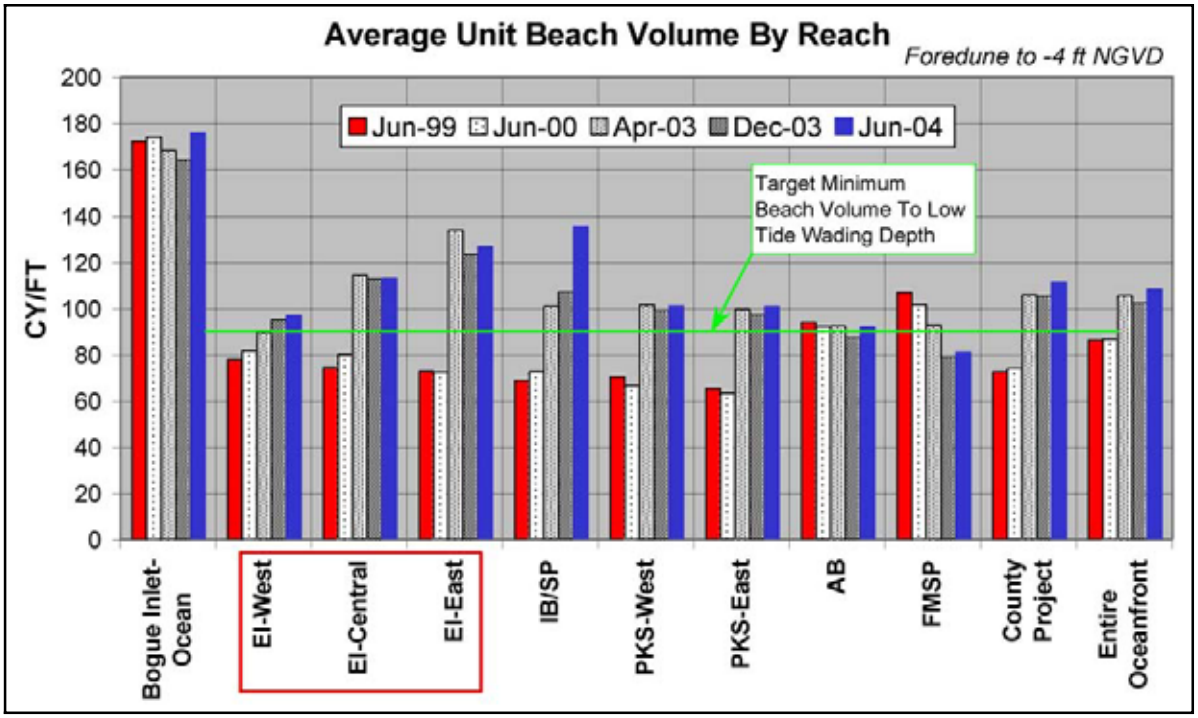


FIGURE 15. Average beach volume to low-tide wading depth by reach for representative survey dates. Target minimum beach volume (~90 cy/ft) is based on conditions along Atlantic Beach to the same calculation limit. [Representative photos of Emerald Isle by P McKee.]

TABLE 5. Emerald Isle Profile Volumes for June 1999 to June 2004 - Foredune to -4 ft

Reach	Station	Baseline Offset (ft)	Cutoff (ft)	Distance from Last (ft)	Jun-99 Dune to -4 Unit Vol (cy/ft)	Sep-99 Dune to -4 Unit Vol (cy/ft)	Jun-00 Dune to -4 Unit Vol (cy/ft)	(Jul02) Jun-02 Dune to -4 Unit Vol (cy/ft)	(Jan03) Feb-03 Dune to -4 Unit Vol (cy/ft)	Apr-03 Dune to -4 Unit Vol (cy/ft)	Sep-03 Dune to -4 Unit Vol (cy/ft)	Dec-03 Dune to -4 Unit Vol (cy/ft)	Mar-04 Dune to -4 Unit Vol (cy/ft)	Apr-04 Dune to -4 Unit Vol (cy/ft)	Jun-04 Dune to -4 Unit Vol (cy/ft)	Jun99-Jun04 Unit Vol Change (cy/ft)	Jun99-Jun04 Net Vol Change (cy)
Emerald	8	0	None	1464	112.65		137.66			140.77		143.21			137.95	25.30	34,145
Isle	9	229	None	1317	88.83		109.82			111.03		110.87			115.39	26.56	31,773
West	10	-4	None	1249	76.64		72.80			90.35	95	100.83			100.97	24.33	39,274
	11	25	None	1519	76.89		83.94	94.15		92.80		89.37			104.27	27.38	27,214
	12	50	None	1260	66.11		69.38	71.16		76.19		80.92			81.93	15.82	21,077
	13	33	None	1343	85.51		81.24	87.20		95.63		96.09			101.08	15.57	14,350
	14	35	None	1206	74.32		71.33	80.42		76.10		87.28			82.55	8.23	8,046
	15	35	None	1349	61.05	72.79	64.90	69.75		70.96	74	69.32			64.75	3.70	16,449
	16	35	None	1463	67.98		62.81	71.93		73.17		76.82			86.77	18.79	29,054
	17	13	None	1444	87.82		92.86	101.04		95.80		106.99			109.28	21.46	27,611
	18	24	None	1431	87.69		92.70	103.26		104.24		109.55			104.83	17.14	14,971
	19	30	None	1136	70.34		71.21	86.39		78.39		78.87			79.55	9.21	16,981
	20	50	None	1513	66.72	79.81	71.12	73.76		74.99	82	76.00			79.96	13.24	13,565
	21	0	None	1112	91.79		98.44	93.57		94.65		102.95			102.95	11.16	18,123
	22	45	None	1105	64.88		69.12	69.37		63.58		79.35			86.53	21.65	27,403
	23	30	None	1104	72.37		74.68	nd		75.23		90.69			100.35	27.98	47,436
	24	35	None	1633	76.56		73.94	80.18	74.64	100.72		107.46			106.67	30.11	33,500
	25	45	None	1120	68.70	78.19	70.83	72.66	68.62	97.07	114	101.45			98.40	29.70	53,202
Emerald	26	50	None	1400	67.58		70.31	75.48	69.47	103.85		110.50			113.91	46.33	53,141
Isle	27	10	None	1335	84.76		99.34	99.76	94.45	125.81		126.84			118.06	33.30	30,874
Central	28	24	None	1099	81.65		89.19	83.26	83.05	111.41		102.84			104.54	22.89	53,035
	29	35	None	1670	80.55		89.49	93.63	94.47	126.98		125.51			121.19	40.64	57,470
	30	40	None	1642	71.68	77.73	78.50	74.56	74.29	105.15	121	100.70			101.04	29.36	54,175
	31	30	None	1658	76.78		85.01	81.93		110.58	113	111.83	116	113	112.77	35.99	55,229
	32	20	None	1642	71.86		76.79	83.71		111.65	120	106.41	103	105	103.14	31.28	49,636
	33	20	None	1364	73.87		74.68	81.78		114.24	104	107.80	112	117	115.36	41.49	64,995
	34	55	None	1396	75.82		74.60	77.83		119.53	100	111.98	121	130	127.42	51.60	65,422
	35	-5	None	1279	63.59	65.54	63.24	60.40		103.08	105	113.46	115	124	114.26	50.67	67,379
	36	0	None	1460	68.50		78.01	67.15		124.43	127	117.22	113	113	110.13	41.63	54,479
Emerald	37	155	None	1112	72.67		64.67	57.72		133.76		120.28	123	123	129.05	56.38	69,264
Isle	38	67	None	1110	75.64		81.10	79.41		154.87		145.09	147	144	144.06	68.42	69,555
East	39	87	None	1103	79.17		74.90	71.90		135.03	119	129.02	129	140	136.87	57.70	70,620
	40	37	None	1096	94.26	99.26	98.01	101.52		171.90	174	159.43	159	169	165.44	71.18	68,021
	41	91	None	1095	74.85		66.51	69.25		130.70	129	123.69	124	132	127.91	53.06	76,486
	42	66	None	1118	65.40		71.98	69.79		142.47	124	132.38	131	140	149.13	83.73	67,825
	43	100	None	1080	62.41		63.03	58.04		117.80	128	111.63	107	112	104.34	41.93	46,095
	44	66	None	1102	73.51		74.74	74.16	140.74	134.53		118.99	118	115	115.26	41.75	53,509
	45	80	None	1107	61.87	70.07	69.68	67.28		130.49	128	117.03	116	116	116.82	54.95	51,337
	46	80	None	1097	65.31		69.69	65.81		122.75	113	107.49	106	107	103.98	38.67	41,163
	47	102	None	1101	66.64		56.71	62.59		110.50	99	96.33	100	100	102.75	36.11	31,859
	48	103	None	780	78.13		75.33	83.62		118.86	104	116.86	121	119	123.69	45.56	-

Summary By Reach - Beach Volumes	Profiles			Reach Length	Jun-99	Sep-99	Jun-00	Jun-02	Feb-03	Apr-03	Sep-03	Dec-03	Mar-04	Apr-04	Jun-04	Jun'99-Jun'04 Change - Dune to -11 ft		Reach
													Arith Avg (cy/ft)			*Wtd Avg (cy/ft)*	Net (cy)	
El-West	8-25			22,303	77.6	76.9	81.6	82.5	71.6	89.5	91.0	94.9	nd	nd	96.9	**18.9**	**420,971**	El-West
El-Central	25-36			15,945	74.2	71.6	79.9	80.0	83.1	114.2	113.0	112.3	113.3	116.7	112.9	**37.9**	**604,558**	El-Central
El-East	36-48			12,900	72.5	84.7	72.2	71.8	nd	133.6	124.3	123.2	123.4	126.4	126.6	**54.3**	**700,213**	El-East
El All	8-48			51,147	75.2	77.6	78.4	78.3	87.5	109.1	113.7	107.8	120.0	123.2	109.9	**33.7**	**1,725,742**	El All
Volume Changes Since June 1999																		
El-West	8-25			22,303	0.0	-0.7	4.0	4.9	-6.0	11.9	13.4	17.3			19.3	**18.9**	**420,971**	El-West
El-Central	25-36			15,945	0.0	-2.6	5.7	5.7	8.9	40.0	38.8	38.0	39.1	42.4	38.7	**37.9**	**604,558**	El-Central
El-East	36-48			12,900	0.0	12.2	-0.3	-0.7		61.2	51.8	50.7	50.9	53.9	54.1	**54.3**	**700,213**	El-East
El All	8-48			51,147	0.0	2.4	3.2	3.1	12.3	33.9	38.5	32.6	44.8	48.0	34.7	**33.7**	**1,725,742**	El All
			Years Since June 1999		*0*	*0.25*	*1*	*3*	*3.67*	*3.83*	*4.25*	*4.5*	*4.75*	*4.83*	*5*			

TABLE 6. Emerald Isle Profile Volumes for June 1999 to June 2004 - Foredune to -11 ft

Note: Profiles for Some Dates Terminate in Trough and Exclude Outer Bar

Reach	Station	Baseline Offset (ft)	Cutoff (ft)	Distance from Last (ft)	Jun-99 Dune to -11 Unit Vol (cy/ft)	Sep-99 Dune to -11 Unit Vol (cy/ft)	Jun-00 Dune to -11 Unit Vol (cy/ft)	Jun-02 (Jul02) Dune to -11 Unit Vol (cy/ft)	Feb-03 (Jan03) Dune to -11 Unit Vol (cy/ft)	Apr-03 Dune to -11 Unit Vol (cy/ft)	Sep-03 Dune to -11 Unit Vol (cy/ft)	Dec-03 Dune to -11 Unit Vol (cy/ft)	Mar-04 Dune to -11 Unit Vol (cy/ft)	Apr-04 Dune to -11 Unit Vol (cy/ft)	Jun-04 Dune to -11 Unit Vol (cy/ft)	Jun99-Jun04 Unit Vol Change (cy/ft)	Jun99-Jun04 Net Vol Change (cy)
Emerald	8	0	None	1464	269.6		296.7			307.5		312.62			307.99	38.39	43,836
Isle	9	229	None	1317	243.9		260.9			260.5		257.90			272.06	28.19	25,886
West	10	-4	None	1249	236.0		211.0			231.6	252.1	259.18			249.26	13.27	50,833
	11	25	None	1519	206.6		213.2	237.2		235.1		226.43			260.22	53.66	52,815
	12	50	None	1260	182.7		195.5	195.3		208.3		222.53			212.83	30.18	41,328
	13	33	None	1343	221.8		218.9	222.6		248.8		240.80			253.12	31.37	26,904
	14	35	None	1206	213.5		206.3	213.3		215.6		238.27			226.75	13.25	23,894
	15	35	None	1349	179.5	192.9	186.7	204.5		210.1	213.3	197.69			201.66	22.18	45,193
	16	35	None	1463	192.0		191.9	204.8		201.4		199.45			231.57	39.61	48,436
	17	13	None	1444	226.5		230.5	250.5		237.6		258.80			253.97	27.49	40,522
	18	24	None	1431	223.9		226.7	252.3		249.7		262.31			253.08	29.16	24,590
	19	30	None	1136	192.4		194.9	223.9		214.4		213.19			206.55	14.12	30,710
	20	50	None	1513	190.2	195.2	192.8	211.5		210.7	225.5	214.35			216.68	26.48	28,620
	21	0	None	1112	218.5		241.1	232.8		231.4		247.30			243.46	25.00	34,157
	22	45	None	1105	193.0		197.8	199.7		193.7		200.83			229.79	36.84	54,718
	23	30	None	1104	193.6		197.3	nd		211.5		218.72			255.89	62.26	96,163
	24	35	None	1633	193.8		187.3	211.0	201.8	245.4		241.21			249.30	55.50	54,447
	25	45	None	1120	192.6	192.7	186.4	199.3	199.1	244.9	262.5	235.55			234.32	41.71	101,156
Emerald	26	50	None	1400	183.2		194.8	196.8	191.8	234.8		256.07			286.04	102.85	92,969
Isle	27	10	None	1335	209.0		229.4	226.7	227.2	261.8		264.02			245.43	36.46	22,951
Central	28	24	None	1099	227.1		226.4	211.5	196.6	234.0		237.23			232.38	5.31	65,198
	29	35	None	1670	198.4		214.2	225.4	212.9	280.1		261.88			271.20	72.79	92,642
	30	40	None	1642	188.0	163.9	199.4	195.9	189.7	228.5	265.4	221.62			228.03	40.05	73,126
	31	30	None	1658	196.9		206.1	206.1		245.6	249.7	249.95	228	236	245.04	48.16	66,821
	32	20	None	1642	184.8		198.3	218.5		244.4	260.0	230.70	208	220	218.06	33.23	73,387
	33	20	None	1364	194.4		197.4	206.3		255.3	239.3	238.83	226	256	268.74	74.36	109,450
	34	55	None	1396	190.5		180.2	201.1		249.2	236.0	248.61	233	267	272.93	82.40	96,755
	35	-5	None	1279	176.4	158.9	167.1	181.1		232.4	225.6	237.88	213	247	245.21	68.85	79,577
	36	0	None	1460	186.7		215.8	200.1		274.3	274.5	244.15	206	222	226.85	40.16	66,630
Emerald	37	155	None	1112	196.8		175.3	187.5		277.2		259.07	250	281	276.47	79.71	89,000
Isle	38	67	None	1110	197.4		200.3	214.9		301.0		289.40	267	268	278.00	80.65	96,750
East	39	87	None	1103	195.9		197.2	201.4		282.0	264.9	269.15	244	279	290.63	94.78	102,834
	40	37	None	1096	225.3	227.7	223.4	243.6		326.1	334.0	310.78	289	320	318.17	92.89	104,556
	41	91	None	1095	195.3		194.4	197.2		270.7	265.2	261.30	233	271	293.36	98.08	128,336
	42	66	None	1118	179.1		190.1	201.2		303.6	268.1	286.03	241	293	310.58	131.44	92,524
	43	100	None	1080	187.6		179.9	180.6		251.1	276.1	242.85	213	233	227.58	39.98	42,432
	44	66	None	1102	190.2		184.9	201.0		271.3		256.56	222	235	227.22	37.05	63,453
	45	80	None	1107	176.6	186.7	193.3	196.8		281.5	281.4	253.57	221	244	254.21	77.62	69,887
	46	80	None	1097	192.7		184.6	187.0		270.1	258.2	235.47	202	226	242.49	49.83	59,339
	47	102	None	1101	186.9		170.0	190.4		253.2	236.6	234.94	208	227	244.91	57.97	49,375
	48	103	None	780	207.4		199.8	211.8		288.1	264.3	274.93	242	269	276.01	68.60	-

Summary By Reach - Beach Volumes	Profiles	Reach Length	Jun-99	Sep-99	Jun-00	Jun-02	Feb-03	Apr-03	Sep-03	Dec-03	Mar-04 Arith Avg (cy/ft)	Apr-04	Jun-04 (Jun'99-Jun'04 Change - Dune to -11 ft)	Wtd Avg (cy/ft)	Net (cy)	Reach
El-West	8-25	22,303	209.4	193.6	213.1	218.5	200.5	231.0	238.3	236.0	nd	nd	242.1	32.4	723,052	El-West
El-Central	25-36	15,945	194.1	161.4	202.6	206.3	203.6	249.1	250.1	244.6	219.2	241.4	249.1	54.8	874,031	El-Central
El-East	36-48	12,900	194.3	207.2	191.1	201.1	nd	281.3	272.1	264.5	235.9	262.1	270.0	74.8	965,114	El-East
El All	8-48	51,147	200.9	188.3	203.9	209.2	202.7	250.6	257.6	246.6	230.3	255.2	252.1	50.1	2,562,197	El All

Volume Changes Since June 1999																
El-West	8-25	22,303	0.0	-15.9	3.7	9.0	-9.0	21.6	28.9	26.5			32.7	32.4	723,052	El-West
El-Central	25-36	15,945	0.0	-32.7	8.5	12.2	9.5	55.0	56.0	50.5	25.0	47.3	55.0	54.8	874,031	El-Central
El-East	36-48	12,900	0.0	12.9	-3.2	6.9		87.1	77.8	70.3	41.6	67.8	75.7	74.8	965,114	El-East
El All	8-48	51,147	0.0	-12.6	3.0	8.3	1.8	49.7	56.7	45.8	29.4	54.3	51.3	50.1	2,562,197	El All
		Years Since June 1999	*0*	*0.25*	*1*	*3*	*3.67*	*3.83*	*4.25*	*4.5*	*4.75*	*4.83*	*5*			

Indian Beach/Salter Path

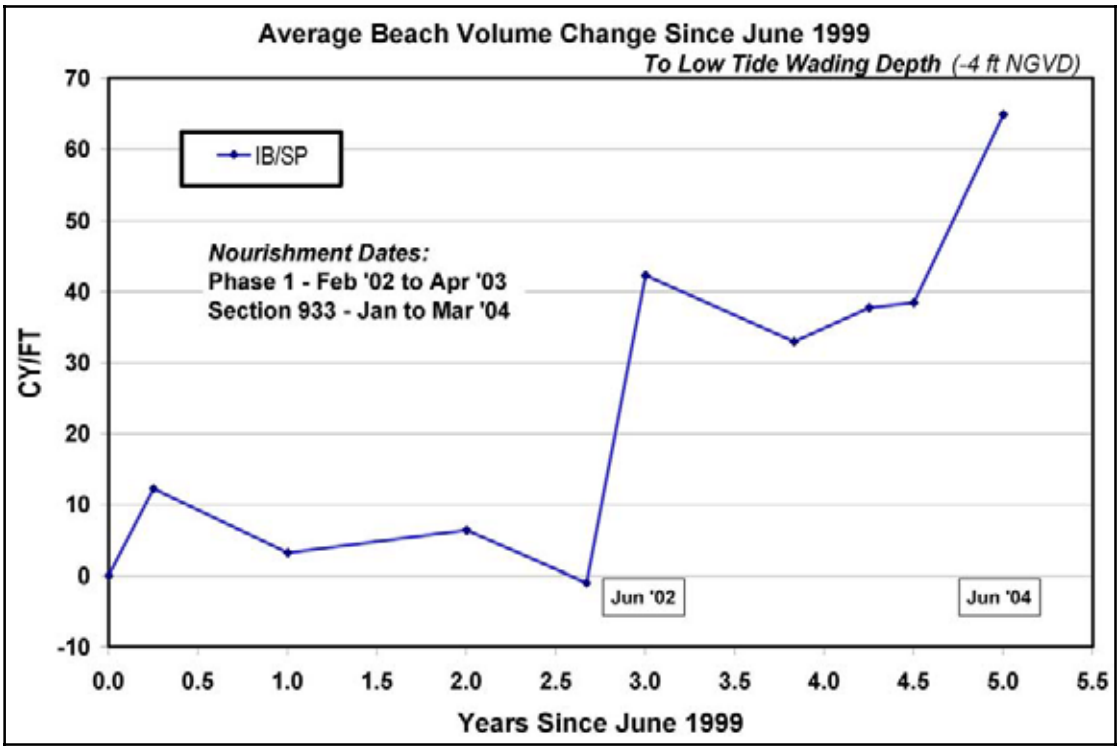
Indian Beach/Salter Path (IB/SP) is part of Phase 1 of the county nourishment project initiated in 1999 and the Section 933 nourishment completed under the direction of the Carteret County Shore Protection Office in winter 2004. Its ~2.5 mile shoreline is represented by profile lines 48–58. Nourishment totaling 456,994 cy in March–April 2002 and 630,094 cy in February–March 2004 provided an average nourishment addition of ~84 cy/ft in the past three years. Surveys from June 1999 to June 2004 indicate that IB/SP has actually gained over 1.36 million cubic yards (~105 cy/ft) in the past five years. This means natural accretion has also been significant, contributing ~20 percent of the buildup (measured to the outer bar at –11 ft NGVD depth). In fact, IB/SP acquired more sand per foot of beach than any other reach along Bogue Banks in the past several years.

Figure 16 (upper) illustrates the change in average beach volume between June 1999 and June 2004. (Note: The graph tracks changes on the recreational part of the beach to low-tide wading depth and excludes volumes in the bar.) Additional surveys are available in connection with the Phase 1 nourishment project, and some of the results are included here. Figure 16 shows little change in volume between June 1999 and December 2001 (Years 0–2.5 on the graph). The total increases dramatically between Years 2.5 and 3.0 in conjunction with the Phase 1 nourishment. Totals then track with little change from Years 3 to 4.5 (June 2002–December 2003). The final increase in volume occurs after the Section 933 project, with a second jump on the graph between Years 4.5 and 5.0. Some of the zigzags in the graph reflect seasonal changes in the recreational beach. Storms and heavy surf periods shift sand seaward beyond the –4 ft contour. Fair weather or low-wave periods, shift sand back into the recreation zone of the beach.

The five-year changes by station are given in Figure 16 (lower). Results to –11 ft as well as –4 ft are shown. All profile lines gained sand, although there was some variation from station to station. Where the two lines approach each other means most of the volume change can be accounted for above the –4 ft contour. Divergence of the two lines means sand is also accumulating in the outer bar area. The more the lines parallel each other, the more uniform are the beach width and outer bar.

Nourishment and natural accretion have restored Indian Beach and Salter Path well beyond the target minimum volume* to low-tide wading depth (Fig 17). Tables 7 and 8 provide volume calculations to –4 ft and –11 ft (respectively) for every station, reach, and available survey date for Indian Beach/Salter Path.

[*Using the Atlantic Beach condition as the principal criteria for minimum acceptable beach volume, consistent with the approach used by CSE Baird–Stroud (1999) in the original planning for the County Project.]



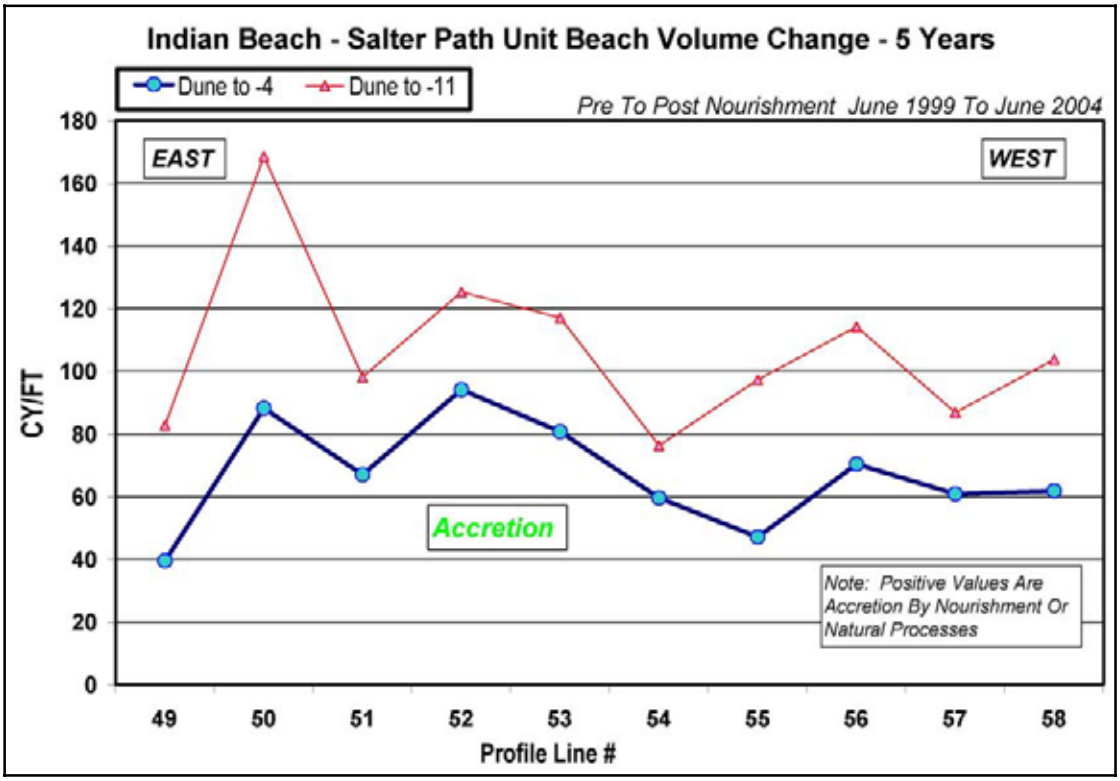


FIGURE 16. [UPPER] Trend in average, beach volume change by reach for the five-year period, June 1999 to June 2004, measured between the foredune and low-tide wading depth. [LOWER] The net five-year change by station to –4 ft and –11 ft calculation depths showing accretion by nourishment or natural processes at all stations.

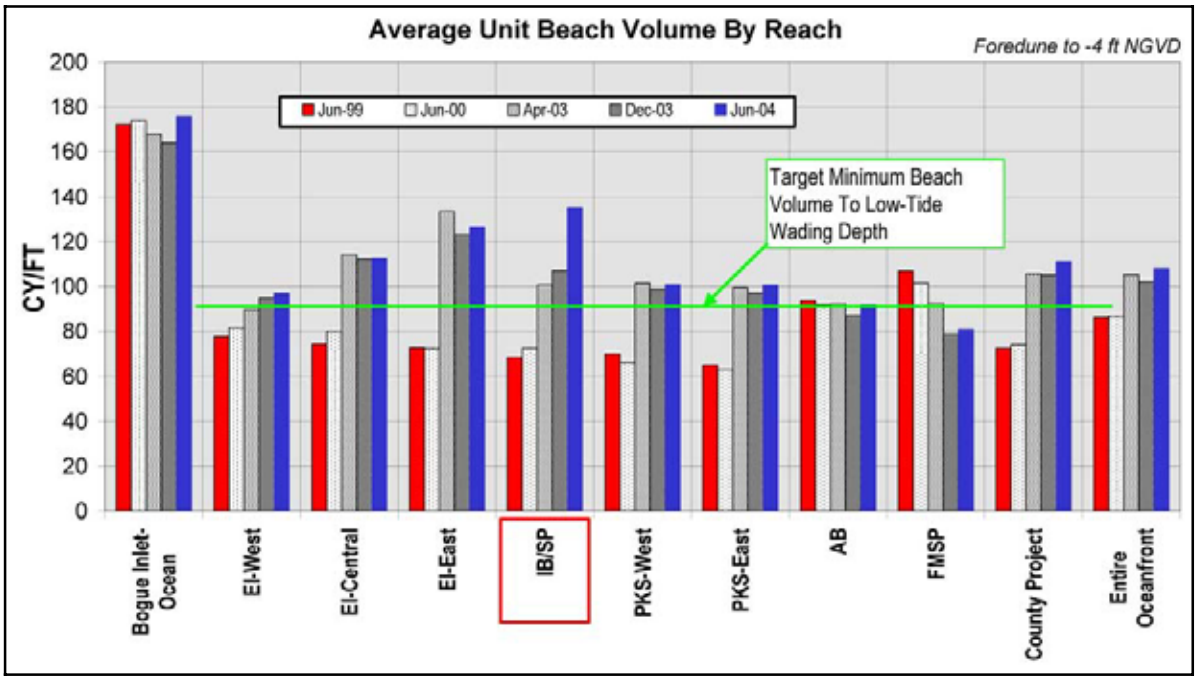


FIGURE 17. Average beach volume to low-tide wading depth by reach for representative survey dates. Target minimum beach volume (~90 cy/ft) is based on conditions along Atlantic Beach to the same calculation limit. [Representative photos of Indian Beach/Salter Path by P McKee.]

TABLE 7. Indian Beach/Salter Path Profile Volumes for June 1999 to June 2004 - Foredune to -4 ft

Reach	Station	Baseline Offset (ft)	Cutoff (ft)	Distance from Last (ft)	Jun-99 Dune to -4 Unit Vol (cy/ft)	Sep-99 Dune to -4 Unit Vol (cy/ft)	Jun-00 Dune to -4 Unit Vol (cy/ft)	Jun-01 Dune to -4 Unit Vol (cy/ft)	(Jan03) Feb-02 Dune to -4 Unit Vol (cy/ft)	(Jul02) Jun-02 Dune to -4 Unit Vol (cy/ft)	Apr-03 Dune to -4 Unit Vol (cy/ft)	Sep-03 Dune to -4 Unit Vol (cy/ft)	Dec-03 Dune to -4 Unit Vol (cy/ft)	Jun-04 Dune to -4 Unit Vol (cy/ft)	Jun99-Jun04 Unit Vol Change (cy/ft)	Jun99-Jun04 Net Vol Change (cy)
	48	103	None	780.2	78.13		75.33	78.01		83.61	118.86	103.56	116.86	123.69	45.56	66,738
Indian	49	103	None	1571	72.04		69.08	67.11		91.56	74.84		91.96	111.47	39.43	77,938
Beach/	50	24	None	1222	74.80	105.53	89.19	101.70		133.94	117.67	112.45	124.64	162.96	88.16	99,557
Salter	51	7	None	1283	62.72		69.96	74.24	72.99	110.47	91.80		100.53	129.73	67.01	99,981
Path	52	20	None	1241	52.39		67.36	82.41	71.30	108.36	104.93	105.37	111.55	146.51	94.12	129,891
	53	26	None	1486	nd		67.58	74.21	69.08	104.07	95.53		110.41	148.28	80.70	87,236
	54	20	None	1244	83.37		96.28	87.04	86.00	140.78	120.40		128.09	142.92	59.55	62,073
	55	29	None	1165	72.75	57.82	66.85	71.51	69.34	120.12	103.62	107.40	103.02	119.80	47.05	70,076
	56	16	None	1194	68.03		63.14	63.33	59.12	112.43	100.67		102.14	138.36	70.33	69,145
	57	32	None	1055	65.74		67.06	74.46	68.04	118.61	106.20		102.96	126.54	60.80	93,544
	58	53	None	1526	65.20		67.14	60.11	51.80	105.23	91.74		94.64	127.00	61.80	-
Summary By Reach - Beach Volumes					Arithmetic Averages cy/ft								Jun 1999 to Jun 2004		**Change - Dune to -4 ft**	
	Profiles			Reach Length	**Jun-99**	**Sep-99**	**Jun-00**	**Jun-01**	**Feb-02**	**Jun-02**	**Apr-03**	**Sep-03**	**Dec-03**	**Jun-04**	***Vtd Avg (cy/fi***	**Net (cy)**
IB/SP	48-58			12,986	69.5	81.7	72.6	75.8	68.5	111.7	102.4	107.2	107.9	134.3	**65.9**	**856,179**
Volume Changes Since June 1999																
IB/SP	48-58			12,986	0.0	12.2	3.1	6.3	-1.1	42.2	32.9	37.7	38.4	64.8	**65.9**	**856,179**
			Years Since June 1999		*0*	*0.25*	*1*	*2*	*2.67*	*3*	*3.83*	*4.25*	*4.5*	*5*		

TABLE 8. Indian Beach/Salter Path Profile Volumes for June 1999 to June 2004 - Foredune to -11 ft

Reach	Station	Baseline Offset (ft)	Cutoff (ft)	Distance from Last (ft)	Jun-99 Dune to -11 Unit Vol (cy/ft)	Sep-99 Dune to -11 Unit Vol (cy/ft)	Jun-00 Dune to -11 Unit Vol (cy/ft)	Jun-01 Dune to -11 Unit Vol (cy/ft)	(Jan03) Feb-02 Dune to -11 Unit Vol (cy/ft)	(Jul02) Jun-02 Dune to -11 Unit Vol (cy/ft)	Apr-03 Dune to -11 Unit Vol (cy/ft)	Sep-03 Dune to -11 Unit Vol (cy/ft)	Dec-03 Dune to -11 Unit Vol (cy/ft)	Jun-04 Dune to -11 Unit Vol (cy/ft)	Jun99-Jun04 Unit Vol Change (cy/ft)	Jun99-Jun04 Net Vol Change (cy)
	48	103	None	780	207.41		199.84	207.33		211.77	288.06		274.93	276.01	68.60	118,832
Indian	**49**	103	None	1571	197.18		192.01	177.93		221.19	206.42		225.08	279.91	82.73	153,549
Beach/	**50**	24	None	1222	172.89	190.75	207.26	238.11		275.43	264.69	258.99	270.84	341.53	168.64	171,140
Salter	**51**	7	None	1283	188.37		184.42	192.84	188.60	241.38	225.71		237.68	286.47	98.10	138,607
Path	**52**	20	None	1241	180.23		172.18	209.58	191.68	241.85	244.37	230.65	238.09	305.51	125.28	180,081
	53	26	None	1486	nd		196.95	205.52	196.58	238.56	264.08		248.35	314.04	117.09	120,276
	54	20	None	1244	217.79		239.31	227.01	215.77	286.87	269.17		273.99	294.07	76.28	101,070
	55	29	None	1165	155.87	141.83	189.08	204.65	183.85	254.67	233.86		225.11	253.16	97.29	126,260
	56	16	None	1194	187.18		197.64	181.86	177.12	242.00	237.06		231.17	301.38	114.20	105,987
	57	32	None	1055	189.98		177.13	202.36	185.90	247.48	240.31		228.39	276.78	86.80	145,390
	58	53	None	1526	176.04		200.07	173.51	167.82	234.71	230.10		222.02	279.79	103.75	-

Summary By Reach - Beach Volumes					Arithmetic Averages cy/ft								Jun 1999 to Jun 2004		**Change - Dune to -11 ft**	
	Profiles			Reach Length	**Jun-99**	**Sep-99**	**Jun-00**	**Jun-01**	**Feb-02**	**Jun-02**	**Apr-03**	**Sep-03**	**Dec-03**	**Jun-04**	***Wtd Avg (cy/ft)***	**Net (cy)**
IB/SP	48-58			12,986	185.1	166.3	195.6	201.3	188.4	248.4	241.6	244.8	240.1	293.3	**104.8**	**1,361,192**
Volume Changes Since June 1999																
IB/SP	48-58			12,986	0.0	-18.8	10.5	16.3	3.4	63.4	56.5	59.8	55.0	108.2	**104.8**	**1,361,192**
			Years Since June 1999		*0*	*0.25*	*1*	*2*	*2.67*	*3*	*3.83*	*4.25*	*4.5*	*5*		

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 completed under the direction of the Carteret County Shore Protection Office in winter 2004. Its ~4.5 mile shoreline is represented by profile lines 58–76. Nourishment totaling 1,276,586 cy in December 2001–March 2002 and 69,189 cy in February–March 2004 provided an average nourishment addition of ~56 cy/ft in the past three years. The 2004 fill volume is based on preconstruction and post-construction surveys of in-place volumes by the contractor. Surveys from June 1999 to June 2004 indicate that PKS has actually gained ~1.05 million cubic yards (~44 cy/ft) in the past five years. This means natural erosion also occurred, reducing the net buildup by ~22 percent (measured to the outer bar at –11 ft NGVD depth). PKS received about 30 percent more nourishment sand than IB/SP, but it was distributed over twice the shore length. Also, PKS lost portions of its fill to erosion while IB/SP gained additional sand by natural accretion. Thus, dry-beach width along PKS averages about one half that of Indian Beach at present.

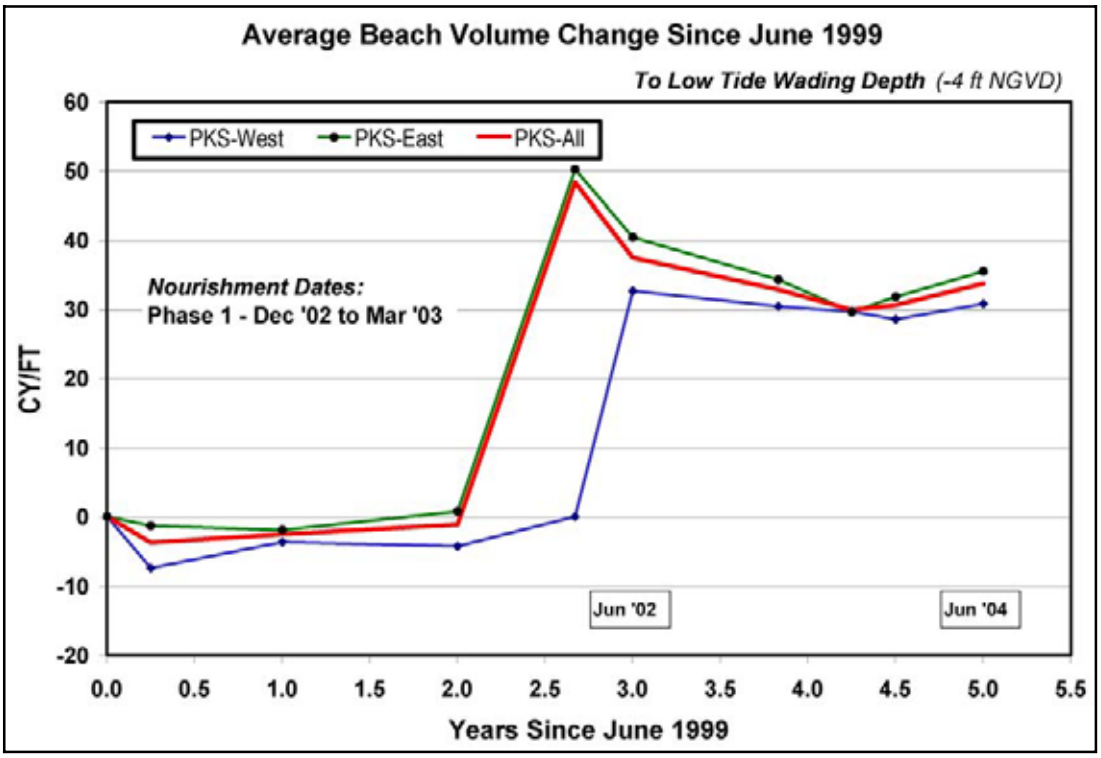
Figure 18 (upper) illustrates the change in average beach volume between June 1999 and June 2004. (Note: The graph tracks changes on the recreational part of the beach to low-tide wading depth and excludes volumes in the bar.) Additional surveys are available in connection with the Phase 1 nourishment project, and some of the results are included here. Figure 18 (upper) shows little change in volume between June 1999 and June 2001 (Years 0–2.0 on the graph). The total increases dramatically between Years 2.0 and 2.5 in conjunction with the Phase 1 nourishment. Totals then track with moderate erosion from Years 3 to 4.5 (June 2002–December 2003). The final increase in volume occurs after the Section 933 project, with a small rise on the graph between Years 4.5 and 5.0. The Section 933 increase is limited because only 10 percent of PKS was renourished. Some of the zigzags in the graph reflect seasonal changes in the recreational beach. Storms and heavy surf periods shift sand seaward beyond the –4 ft contour. Fair weather or low-wave periods, shift sand back into the recreation zone of the beach.

The five-year changes by station are given in Figure 18 (lower). Results to –11 ft as well as –4 ft are shown. All profile lines gained significant quantities of sand (to –4 ft), although there was variation from station to station (Table 9). Where the two lines approach each other means most of the volume change can be accounted for above the –4 ft contour. Divergence of the two lines means sand is also accumulating in the outer bar area. The more the lines parallel each other, the more uniform are the beach width and outer bar. The rhythmic variation in profile volumes from station to station tends to reflect rhythmic topography of the beach and outer bar. It can also be due to variations in dune condition, some of which result from poststorm sand scraping. Breaks in the bar

are reflected in lower volumes (measured to –11 ft). Healthy buildups on the recreational beach sometimes mimic buildups on the bar.

Nourishment and natural accretion have restored Pine Knoll Shores about 10 percent beyond the target minimum volume* to low-tide wading depth (Fig 19). Because of less buildup underwater, profile volumes to the outer bar average 2–3 percent less than the target minimum volume to –11 ft. Tables 9 and 10 provide volume calculations to –4 ft and –11 ft (respectively) for every station, reach, and available survey date for Pine Knoll Shores.

[*Using the Atlantic Beach condition as the principal criteria for minimum acceptable beach volume, consistent with the approach used by CSE Baird–Stroud (1999) in the original planning for the County Project.]



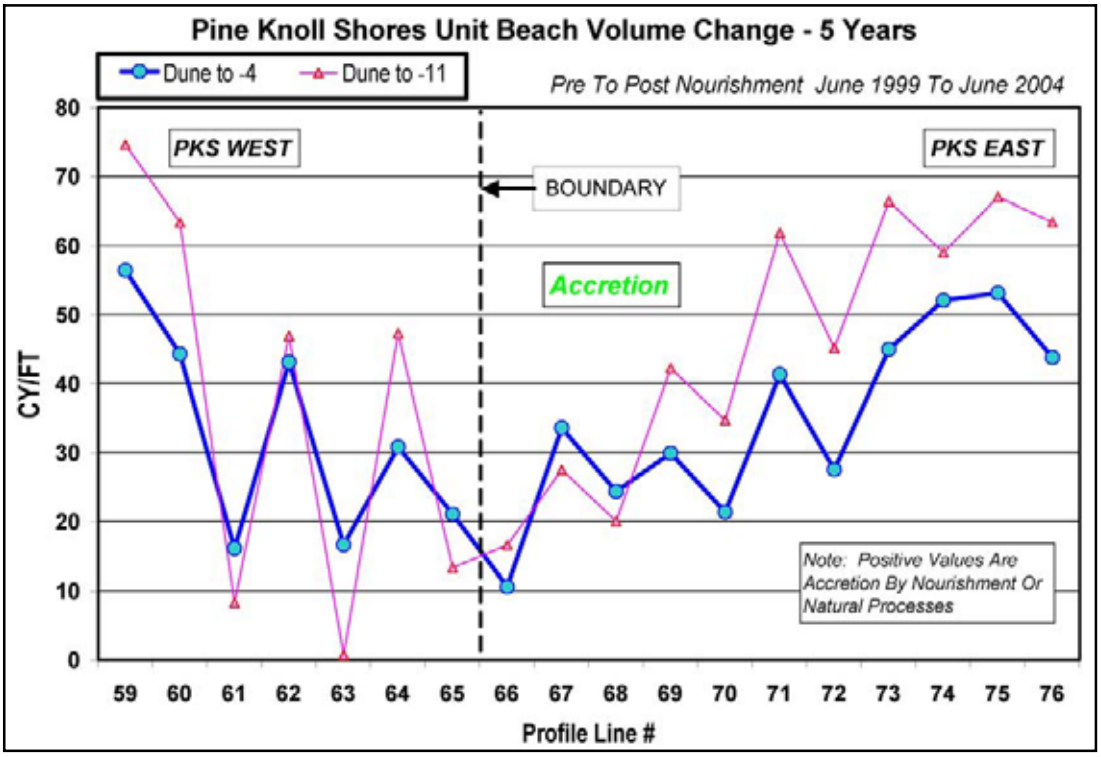


FIGURE 18. [UPPER] Trend in average, beach volume change by reach for the five-year period, June 1999 to June 2004, measured between the foredune and low-tide wading depth. [LOWER] The net five-year change by station to –4 ft and –11 ft calculation depths showing accretion by nourishment or natural processes at all stations.

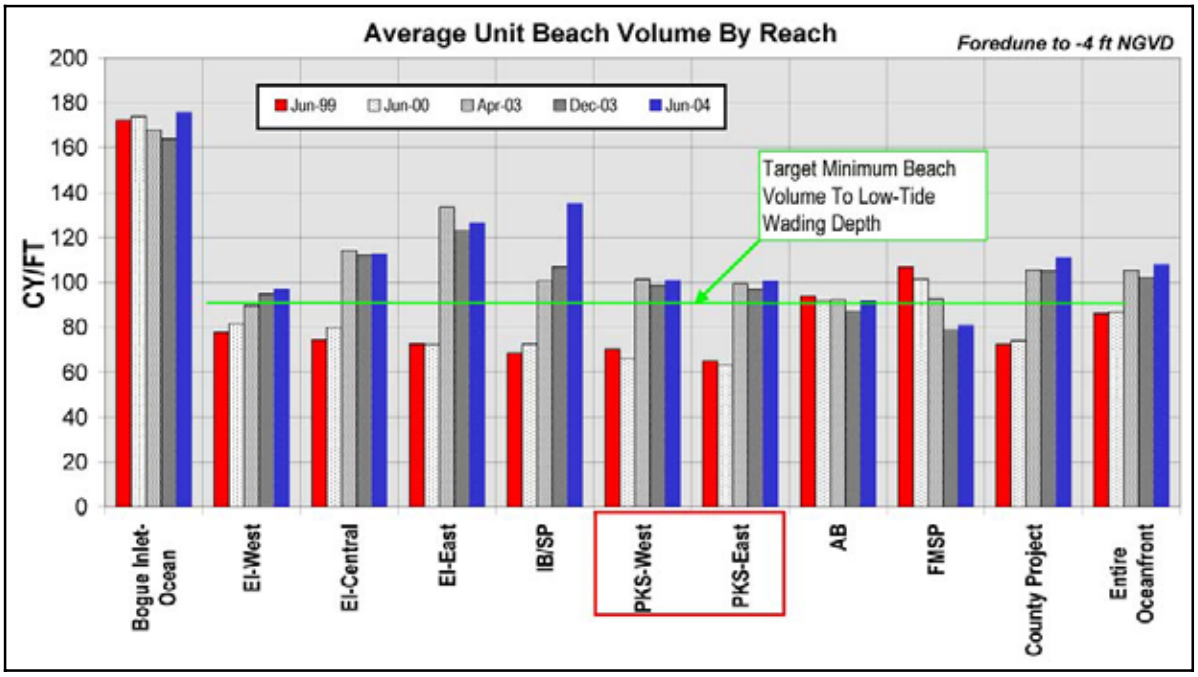


FIGURE 19. Average beach volume to low-tide wading depth by reach for representative survey dates. Nourishment has restored the recreational part of the beach (dune to low-tide wading depth) well beyond its 1999 condition. Target minimum beach volume (~90 cy/ft) is based on conditions along Atlantic Beach to the same calculation limit. [Representative photos of Pine Knoll Shores by P McKee.]

TABLE 9. Pine Knoll Shores Profile Volumes for June 1999 to June 2004 - Foredune to -4 ft

Reach	Station	Baseline Offset (ft)	Cutoff (ft)	Distance from Last (ft)	Jun-99 Dune to -4 Unit Vol (cy/ft)	Sep-99 Dune to -4 Unit Vol (cy/ft)	Jun-00 Dune to -4 Unit Vol (cy/ft)	Jun-01 Dune to -4 Unit Vol (cy/ft)	(Mar03) Feb-02 Dune to -4 Unit Vol (cy/ft)	Jun-02 Dune to -4 Unit Vol (cy/ft)	Apr-03 Dune to -4 Unit Vol (cy/ft)	Sep-03 Dune to -4 Unit Vol (cy/ft)	Dec-03 Dune to -4 Unit Vol (cy/ft)	Jun-04 Dune to -4 Unit Vol (cy/ft)	(Jun00-Jun04) Jun99-Jun04 Unit Vol Change (cy/ft)	Jun99-Jun04 Net Vol Change (cy)
	58	53	None	1526	65.20		67.14	60.11		105.23	91.74		94.64	127.00	61.80	87,933
Pine	59	27	None	1488	62.48		73.88	69.22		102.36	93.37		97.63	118.87	56.39	60,755
Knoll	60	34	None	1208	60.77	56.98	56.09	55.53		94.01	86.29	86.69	96.74	105.01	44.24	36,370
Shores	61	-34	None	1206	82.06		77.37	85.83		122.97	111.17		111.22	98.16	16.10	40,643
West	62	0	None	1374	nd		57.21	59.25		101.82	94.18		99.50	100.27	43.06	38,626
	63	7	None	1294	73.72		66.15	63.8		88.64	106.21	107.89	96.00	90.36	16.64	30,482
	64	158	None	1284	77.26		72.67	67.89		112.68	114.79		102.71	108.10	30.84	34,498
	65	13	None	1329	64.72	68.44	61.86	59.53		97.23	97.84	104.83	87.02	85.78	21.06	19,658
Pine	66	0	None	1242	91.9		82.34	76.81		100.80	98.59		97.61	102.50	10.60	26,631
Knoll	67	49	None	1205	nd		72.91	68.33		116.37	112.61		104.34	106.51	33.60	43,847
Shores	68	0	None	1513	56.85		56.51	55.94		79.87	86.01	80.33	78.65	81.21	24.36	27,916
East	69	26	None	1029	57.93		60.31	75.8		85.34	81.70		80.01	87.85	29.92	31,888
	70	0	None	1244	74.3	69.22	65.91	64.89	88.23	93.62	99.29	98.81	94.35	95.66	21.36	59,389
	71	32	None	1896	62.98		81.15	75.41	113.1	97.51	104.95		103.04	104.28	41.30	48,188
	72	22	None	1400	72.69		57.18	58.86	121.29	115.77	93.82		101.08	100.23	27.54	51,787
	73	14	None	1429	62.23		53.55	56.5	123.29	114.68	101.86	102.75	101.27	107.17	44.94	59,006
	74	18	None	1217	64.79		60.59	71.4	129.19	131.24	113.39		114.85	116.82	52.03	78,848
	75	108	None	1500	43.91	58.48	50.00	45.01	104.82	107.27	94.36	97.23	90.73	97.01	53.10	53,795
	76	23	None	1111	64.35		55.07	76.51	127.61	119.00	107.52		100.89	108.10	43.75	-

Summary By Reach - Beach Volumes	Profiles	Reach Length	Jun-99	Sep-99	Jun-00	Jun-01	Feb-02	Jun-02	Apr-03	Sep-03	Dec-03	Jun-04	Vtd Avg (cy/fi	Net (cy)
			Arithmetic Averages cy/ft								Jun 1999 - Dec 2003		Change - Dune to -4 ft	
PKS-West	59-65	9,182	70.2	62.7	66.5	65.9	nd	102.8	100.6	99.8	98.7	100.9	**35.9**	**329,308**
PKS-East	66-76	14,785	65.2	63.9	63.2	66.0	115.4	105.6	99.5	94.8	97.0	100.7	**33.9**	**500,953**
PKS-All	59-76	23,967	67.1	63.3	64.5	65.9	115.4	104.5	99.9	96.9	97.6	100.8	**34.6**	**830,260**
Volume Changes Since June 1999														
PKS-West	59-65	9,182	0.0	-7.5	-3.7	-4.3	nd	32.6	30.4	29.6	28.5	30.8	**35.9**	**329,308**
PKS-East	66-76	14,785	0.0	-1.3	-2.0	0.8	50.2	40.4	34.3	29.6	31.8	35.5	**33.9**	**500,953**
PKS-All	59-76	23,967	0.0	-3.8	-2.6	-1.1	48.3	37.5	32.8	29.9	30.6	33.7	**34.6**	**830,260**
		Years Since June 1999	*0*	*0.25*	*1*	*2*	*2.67*	*3*	*3.83*	*4.25*	*4.5*	*5*		

TABLE 10. Pine Knoll Shores Profile Volumes for June 1999 to June 2004 - Foredune to -11 ft

Reach	Station	Baseline Offset (ft)	Cutoff (ft)	Distance from Last (ft)	Jun-99 Dune to -11 Unit Vol (cy/ft)	Sep-99 Dune to -11 Unit Vol (cy/ft)	Jun-00 Dune to -11 Unit Vol (cy/ft)	Jun-01 Dune to -11 Unit Vol (cy/ft)	(Mar03) Feb-02 Dune to -11 Unit Vol (cy/ft)	Jun-02 Dune to -11 Unit Vol (cy/ft)	Apr-03 Dune to -11 Unit Vol (cy/ft)	Sep-03 Dune to -11 Unit Vol (cy/ft)	Dec-03 Dune to -11 Unit Vol (cy/ft)	Jun-04 Dune to -11 Unit Vol (cy/ft)	(Jun00-Jun04) Jun99-Jun04 Unit Vol Change (cy/ft)	Jun99-Jun04 Net Vol Change (cy)
	58	53	None	1526	176.04		200.07	173.51		234.71	230.10		222.02	279.79	103.75	132,678
Pine	**59**	27	None	1488	187.87		202.05	193.92		236.68	240.97		233.64	262.45	74.58	83,269
Knoll	**60**	34	None	1208	184.54	146.51	170.06	154.5		221.32	221.98	210.90	222.74	247.88	63.34	43,187
Shores	**61**	-34	None	1206	199.07		197.32	215.1		262.60	257.85		239.34	207.38	8.31	37,916
West	**62**	0	None	1374	nd		162.29	174.61		224.36	220.40		216.43	209.17	46.88	30,804
	63	7	None	1294	182.8		170.82	184.44		197.20	236.66	225.34	205.55	183.53	0.73	30,797
	64	158	None	1284	194.3		209.81	189.94		245.34	251.13		228.36	241.54	47.24	40,241
	65	13	None	1329	184.28	204.17	179.31	166.95		232.28	232.08	247.76	213.78	197.58	13.30	18,552
Pine	**66**	0	None	1242	221.31		213.96	203.58		238.68	239.17		230.85	237.89	16.58	26,558
Knoll	**67**	49	None	1205	nd		209.17	213.97		265.92	272.05		247.01	236.67	27.50	35,987
Shores	**68**	0	None	1513	183.68		177.58	183.29		215.73	221.00	206.52	196.70	203.75	20.07	32,025
East	**69**	26	None	1029	180.66		190.1	199.35		235.43	216.37		209.61	222.86	42.20	47,826
	70	0	None	1244	210.56	198.3	199.71	201.52	229.24	247.62	244.44	234.68	233.15	245.27	34.71	91,491
	71	32	None	1896	190.74		222.57	204.83	259.91	250.90	254.27		240.48	252.56	61.82	74,837
	72	22	None	1400	198.39		162.57	187.09	260.14	265.27	245.97		239.20	243.48	45.09	79,660
	73	14	None	1429	186.16		178.26	166.97	260.73	257.42	249.59	246.59	240.13	252.56	66.40	76,312
	74	18	None	1217	199.38		181.32	206.88	273.35	303.08	261.42		258.08	258.39	59.01	94,500
	75	108	None	1500	156.75	182.18	153.71	176.88	243.79	258.57	242.51	240.53	227.83	223.74	66.99	72,408
	76	23	None	1111	184.22		171.06	224.73	282.14	291.46	265.23		243.52	247.59	63.37	-

Summary By Reach - Beach Volumes					Arithmetic Averages cy/ft								Jun 1999 - Dec 2003		**Change - Dune to -11 ft**	
	Profiles			Reach Length	**Jun-99**	**Sep-99**	**Jun-00**	**Jun-01**	**Feb-02**	**Jun-02**	**Apr-03**	**Sep-03**	**Dec-03**	**Jun-04**	***Wtd Avg (cy/ft)***	**Net (cy)**
PKS-West	59-65			9,182	188.8	175.3	184.5	182.8	nd	231.4	237.3	228.0	222.8	221.4	**43.4**	**398,891**
PKS-East	66-76			14,785	191.2	190.2	187.3	197.2	258.5	257.3	246.5	232.1	233.3	238.6	**44.0**	**650,158**
PKS-All	59-76			23,967	190.3	182.8	186.2	191.6	258.5	247.2	242.9	230.3	229.2	231.9	**43.8**	**1,049,048**

Atlantic Beach

Atlantic Beach (AB) was nourished in 1986 and 1994 in conjunction with disposal of the Brandt Island upland spoil basin. It remains part of the USACE plan for periodic disposal of harbor sediments (USACE 1993). However, during the past five years (June 1999–June 2004), there was no renourishment along Atlantic Beach. Its ~5.0-mile shoreline is represented by profile lines 76–102. Surveys from June 1999 to June 2004 indicated that Atlantic Beach gained ~136,000 cy (5.2 cy/ft) over the past five years (measured to the outer bar at a reference depth of –11 ft NGVD). However, measured to low-tide wading depth (–4 ft NGVD), Atlantic Beach lost ~11,000 cy between 1999 and 2004.

Figure 20 (upper) illustrates the change in average beach volume to low-tide wading depth. No surveys are available for 2001 and 2002 (Years 2.0 and 3.0 on the graph). Note that Figure 20 (upper) tracks mainly the visible beach and excludes volumes in the bar. Surveys in 2003 and 2004 show seasonal changes in the sand volume on the recreational beach. [Note zigzags in the graph (Fig 20, upper) for Years 4.0 to 5.0.] Storms and heavy-surf periods shift sand seaward beyond the –4 ft contour (values decline on the graph). Fair weather, or low-wave periods, shift sand back into the recreational zone (values increase on the graph). As illustrated in Figure 20 (upper), the net change over five years has been exceedingly small along Atlantic Beach. The average volume change to low-tide wading depth is ~2 cy/ft (or ~0.4 cy/ft/yr).

The five year changes by station are illustrated in Figure 20 (lower). Results to –11 ft as well as –4 ft are shown. Where the two lines approach each other means most of the change can be accounted for above the –4-ft contour. Divergence of the two lines means sand is either accumulating (–11-ft line is *above* the –4-ft line) or is being lost at a higher rate (–11-ft line is *below* the –4-ft line) in the outer bar area. The more the lines parallel each other, the more uniform are the beach width and outer bar in the alongshore direction.

The rhythmic variation in profile volume changes (and volumes) from station to station tends to reflect rhythmic topography of the beach and outer bar. Breaks in the bar are reflected in lower volumes. Healthy buildups on the recreational beach sometimes mimic buildups on the bar. As Figure 20 (lower) shows, most of the western end and the central portion of Atlantic Beach were stable between June 1999 and June 2004. The eastern end sustained the most erosion.

Some of the variations in profile volumes are due to irregularities in the dune crest. For example, there is no foredune at station 90 (pavilion area). Calculations begin at the seawall, which is lower than the adjacent dunes. However, the seawall is set landward of the

starting point for profiles 89 and 91, giving profile 90 a wider beach and, therefore, higher sand volume than adjacent stations. The western end of Atlantic Beach (profiles 77–79) show accretion during the past five years because a portion of the Phase I nourishment has likely spread eastward into Atlantic Beach.

Figure 21 shows the average beach volume along all of Bogue Banks. Atlantic Beach's volume served as the basis for nourishment planning along Emerald Isle, Pine Knoll Shores, and Indian Beach. Therefore, by definition it contains the 'target minimum beach volume."***** Figure 21 shows the average volume to low-tide wading depth along Atlantic Beach has remained nearly constant since June 1999. Note the county nourishment reaches (PKS–East to EI–Central) began with a sand deficit on the beach in 1999 and now exceed the target minimum volume. Fort Macon State Park (FMSP) began with a sand surplus in 1999 and now has a large deficit. Obviously, the healthier adjacent reaches are, the healthier Atlantic Beach will be. As Figure 21 shows, Fort Macon State Park and Atlantic Beach are now the least healthy sections of Bogue Banks (as measured by sand volume on the beach). In 1999, these two reaches had the most sand (Bogue Inlet–Ocean reach excluded).

Data, such as the present monitoring results, are intended to help establish priorities for beach nourishment. **By these measures, Atlantic Beach, FMSP, and Emerald Isle-West are considered to be the next candidates for beach nourishment.**

Tables 11 and 12 provide volume calculations to –4 ft and –11 ft NGVD (respectively) for every station, reach, and available survey data for Atlantic Beach.

[*Using the Atlantic Beach condition as the principal criteria for minimum acceptable beach volume, consistent with the approach used by CSE Baird–Stroud (1999) in the original planning for the County Project.]

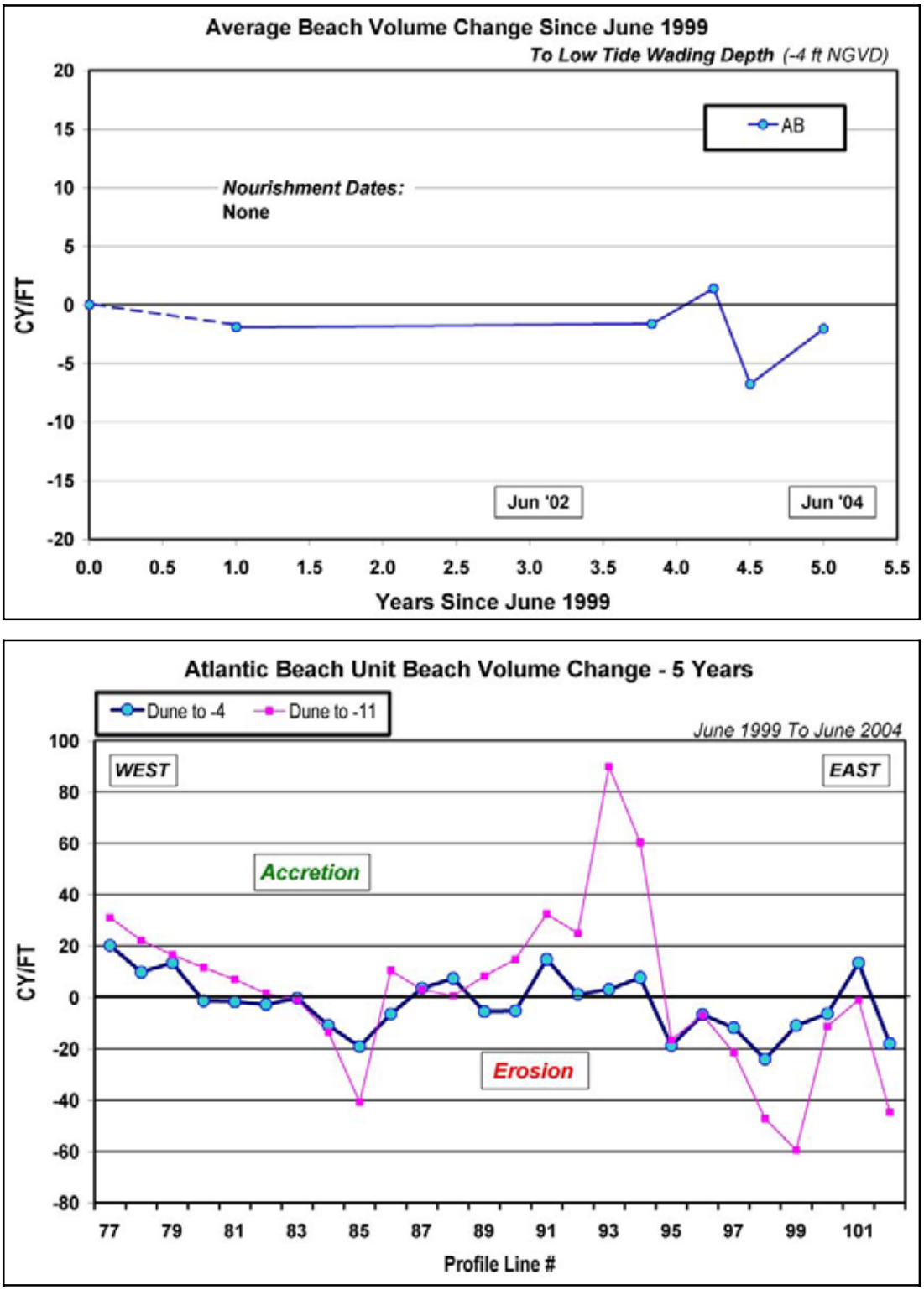


FIGURE 20. [UPPER] Trend in average, beach volume change by reach for the five-year period, June 1999 to June 2004, measured between the foredune and low-tide wading depth. [LOWER] The net five-year change by station to –4 ft and –11 ft calculation depths showing little change along much of the recreational beach (zero values for the dune to –4 ft line on the graph). The pavilion area is profile 90.

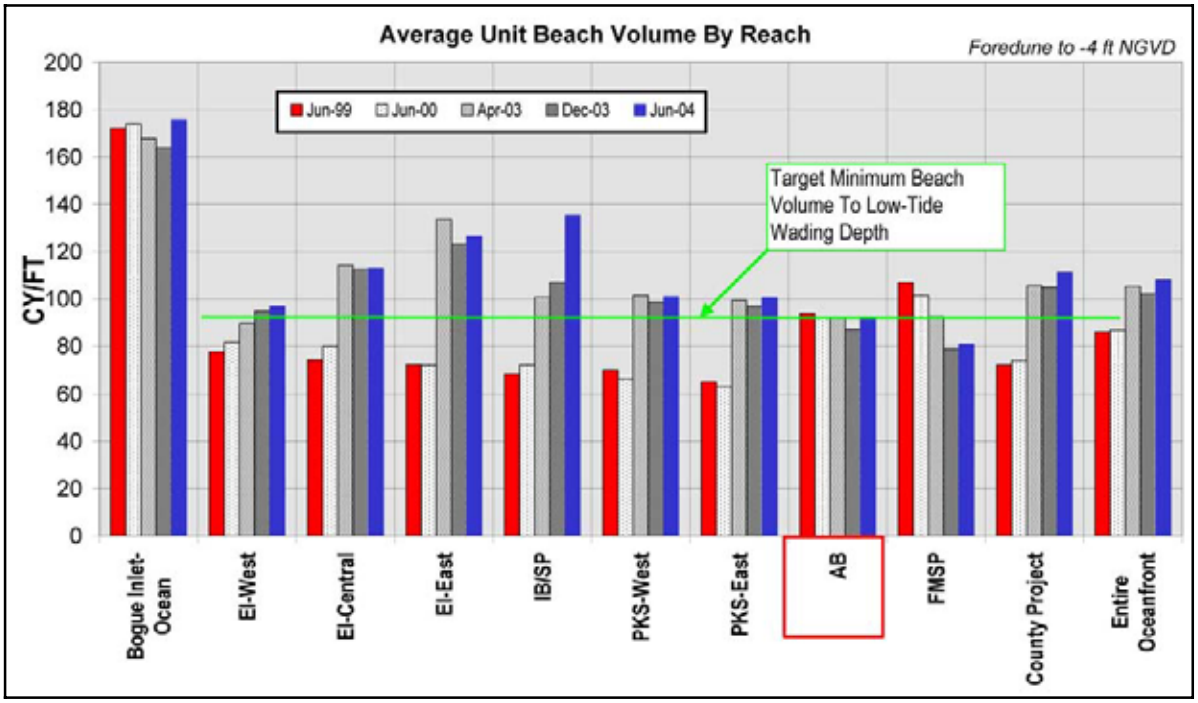


FIGURE 21. Average beach volume to low-tide wading depth by reach for representative survey dates. Target minimum beach volume (~90 cy/ft) is based on conditions along Atlantic Beach to the same calculation limit. [Representative photos of Atlantic Beach by P McKee.]

TABLE 11. Atlantic Beach Profile Volumes for June 1999 to June 2004 - Foredune to -4 ft

Reach	Station	Baseline Offset (ft)	Cutoff (ft)	Distance from Last (ft)	Jun-99 Dune to -4 Unit Vol (cy/ft)	Sep-99 Dune to -4 Unit Vol (cy/ft)	Jun-00 Dune to -4 Unit Vol (cy/ft)	Apr-03 Dune to -4 Unit Vol (cy/ft)	Sep-03 Dune to -4 Unit Vol (cy/ft)	Dec-03 Dune to -4 Unit Vol (cy/ft)	Jun-04 Dune to -4 Unit Vol (cy/ft)	Jun99-Jun04 Unit Vol Change (cy/ft)	Jun99-Jun04 Net Vol Change (cy)
	76	23	None	1111	64.35		55.07	107.52		100.89	108.10	43.75	41,241
Atlantic	**77**	36	None	1290	70.97		72.47	96.74	97.24	87.02	91.14	20.17	14,225
Beach	**78**	20	None	948	83.77		77.26	94.77		94.74	93.60	9.83	16,711
	79	48	None	1444	98.52		95.69	101.31		101.38	111.84	13.32	5,452
	80	0	None	900	116.24	114.07	113.20	119.75	118.49	114.80	115.04	-1.20	(1,531)
	81	15	None	1097	101.82		96.55	102.38		96.65	100.23	-1.59	(1,506)
	82	1	None	707	84.39		69.41	75.36		79.22	81.72	-2.67	(1,447)
	83	0	None	998	94.84		93.50	93.83		86.77	94.61	-0.23	(5,626)
	84	0	None	1012	107.51		107.86	99.16		89.02	96.62	-10.89	(14,959)
	85	-6	None	1000	114.63	110.11	107.34	98.25	99.52	98.24	95.59	-19.04	(12,713)
	86	0	None	1001	103.84		103.49	94.63		93.55	97.49	-6.35	(1,344)
	87	12	None	1000	110.73		117.14	117.84		108.63	114.39	3.66	5,509
	88	13	None	994	140.45		152.57	144.18		140.90	147.88	7.43	1,028
	89	95	None	1008	100.37		92.29	98.34		85.03	94.98	-5.39	(5,771)
	90	0	None	1099	122.60	120.89	115.40	128.06	115.46	110.94	117.49	-5.11	4,401
	91	50	None	912	92.66		92.26	95.55		91.10	107.42	14.76	8,014
	92	60	None	1000	97.16		89.82	93.54		87.09	98.43	1.27	2,224
	93	60	None	1000	80.12		80.69	73.19		78.95	83.30	3.18	4,867
	94	80	None	892	77.83		70.05	80.29		79.56	85.56	7.73	(5,614)
	95	100	None	1024	86.88	83.15	89.64	83.57	71.5	72.37	68.18	-18.70	(12,592)
	96	93	None	996	75.90		71.74	62.53		61.18	69.31	-6.59	(9,150)
	97	25	None	999	80.29		85.74	71.98		63.56	68.56	-11.73	(17,838)
	98	13	None	1000	78.95		85.84	66.97		53.21	55.00	-23.95	(17,876)
	99	-8	None	1025	75.69		70.47	61.84		62.34	64.76	-10.93	(8,334)
	100	0	None	973	74.99	92.16	66.43	68.75	69.30	77.16	68.79	-6.20	3,618
	101	31	None	1004	84.59		91.24	98.32		93.65	98.00	13.41	(2,247)
	102	10	None	1001	85.15		82.38	76.71		57.47	67.25	-17.90	-

Summary By Reach - Beach Volumes					Arithmetic Averages cy/ft					Jun 1999 to Jun 2004		**Change - Dune to -4 ft**	
	Profiles			Reach Length	**Jun-99**	**Sep-99**	**Jun-00**	**Apr-03**	**Sep-03**	**Dec-03**	**Jun-04**	***Wtd Avg (cy/ft)***	**Net (cy)**
AB	77-102			26,322	93.9	104.1	91.9	92.2	95.3	87.1	91.8	**-0.4**	**-11,258**
Volume Changes Since June 1999													
AB	77-102			26,322	0.0		-1.9	-1.7	1.4	-6.8	-2.1	**-0.4**	**-11,258**
			Years Since June 1999		*0*	*0.25*	*1*	*3.83*	*4.25*	*4.5*	*5*		

TABLE 12. Atlantic Beach Profile Volumes for June 1999 to June 2004 - Foredune to -11 ft

Reach	Station	Baseline Offset (ft)	Cutoff (ft)	Distance from Last (ft)	Jun-99 Dune to -11 Unit Vol (cy/ft)	Sep-99 Dune to -11 Unit Vol (cy/ft)	Jun-00 Dune to -11 Unit Vol (cy/ft)	Apr-03 Dune to -11 Unit Vol (cy/ft)	Sep-03 Dune to -11 Unit Vol (cy/ft)	Dec-03 Dune to -11 Unit Vol (cy/ft)	Jun-04 Dune to -11 Unit Vol (cy/ft)	Jun99-Jun04 Unit Vol Change (cy/ft)	Jun99-Jun04 Net Vol Change (cy)
	76	23	None	1111	184.22		171.96	265.23		243.52	247.59	63.37	60,946
Atlantic	**77**	36	None	1290	184.84		188.94	241.66	229.59	222.54	215.93	31.09	25,225
Beach	**78**	20	None	948	215.55		193.37	235.73		225.11	237.66	22.11	27,885
	79	48	None	1444	245.04		243.53	248.81		244.58	261.56	16.52	12,608
	80	0	None	900	257.80	233.22	271.06	274.73	266.46	266.25	269.31	11.51	10,215
	81	15	None	1097	244.35		228.72	258.26		248.37	251.46	7.11	3,090
	82	1	None	707	223.60		192.88	222.45		215.75	225.23	1.63	374
	83	0	None	998	236.73		224.78	246.32		237.31	235.85	-0.88	(7,250)
	84	0	None	1012	260.05		251.90	250.55		239.26	246.60	-13.45	(27,084)
	85	-6	None	1000	273.81	262.31	266.91	247.54	250.21	248.05	233.07	-40.74	(15,126)
	86	0	None	1001	243.07		243.00	253.07		244.71	253.60	10.53	6,812
	87	12	None	1000	258.79		256.19	279.69		265.20	261.89	3.10	1,898
	88	13	None	994	320.31		342.59	323.21		314.37	321.03	0.72	4,560
	89	95	None	1008	236.87		227.16	252.79		232.77	245.20	8.33	12,679
	90	0	None	1099	275.17	263.18	268.54	304.43	294.21	275.40	289.91	14.74	21,494
	91	50	None	912	232.38		235.23	261.43		244.25	264.77	32.39	28,662
	92	60	None	1000	227.91		200.52	246.56		244.33	252.85	24.94	57,413
	93	60	None	1000	147.53		150.69	220.35		243.17	237.45	89.92	67,049
	94	80	None	892	182.28		174.59	239.00		246.26	242.66	60.38	22,507
	95	100	None	1024	230.83	215.28	230.78	231.43	227.98	225.73	214.43	-16.40	(11,571)
	96	93	None	996	215.47		207.96	202.04		207.18	208.63	-6.84	(14,114)
	97	25	None	999	235.87		236.49	212.45		208.16	214.45	-21.42	(34,262)
	98	13	None	1000	227.07		256.05	210.35		188.18	179.96	-47.11	(54,617)
	99	-8	None	1025	253.36		237.33	193.93		187.63	193.90	-59.46	(34,357)
	100	0	None	973	222.49	253.06	223.98	225.65	231.91	232.96	211.33	-11.16	(6,047)
	101	31	None	1004	239.25		244.98	255.88		242.32	238.36	-0.89	(22,793)
	102	10	None	1001	240.98		237.78	208.11		190.92	196.32	-44.66	-

Summary By Reach - Beach Volumes					Arithmetic Averages cy/ft				Jun 1999 to Jun 2004			**Change - Dune to -11 ft**	
	Profiles			Reach Length	**Jun-99**	**Sep-99**	**Jun-00**	**Apr-03**	**Sep-03**	**Dec-03**	**Jun-04**	***Wtd Avg (cy/ft)***	**Net (cy)**
AB	77-102			26,322	235.8	245.4	232.2	244.1	250.1	236.2	238.6	**5.2**	**136,193**
Volume Changes Since June 1999													
AB	77-102			26,322	0.0		-3.7	8.3	14.2	0.4	2.8	**5.2**	**136,193**
			Years Since June 1999		*0*	*0.25*	*1*	*3.83*	*4.25*	*4.5*	*5*		

Fort Macon State Park

Fort Macon State Park (FMSP) was nourished in February 2002 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). Its ~1.4-mile ocean shoreline is represented by profile lines 102–112. Beaufort Inlet lines 113–116 were established in December 2003 and are now part of the new Beaufort Inlet cell. Surveys from June 1999 to June 2004 indicated that FMSP lost ~185,000 cy (–25.7 cy/ft) over the past five years (measured to the outer bar at a reference depth of –11 ft NGVD). Measured to low-tide wading depth (–4 ft NGVD), FMSP lost ~196,000 cy between 1999 and 2004. In other words, virtually all of the beach erosion along FMSP occurred in the recreational zone of the beach.

Figure 22 (upper) illustrates the change in average beach volume to low-tide wading depth. No surveys are available for 2001 and 2002 (Years 2.0 and 3.0 on the graph). Note that Figure 22 (upper) tracks mainly the visible beach and excludes volumes in the bar. Surveys in 2003 and 2004 show a very rapid decline in the sand volume. Storms and heavy-surf periods shift sand seaward beyond the –4 ft contour (values decline on the graph). Fair weather, or low-wave periods, shift sand back into the recreational zone (values increase on the graph). As illustrated in Figure 22 (upper), the net change over five years has been exceedingly large along FMSP. The average volume change to low-tide wading depth is ~26 cy/ft (or ~5.2 cy/ft/yr). This rate is close to three times the historical average volume lost along Bogue Banks.

Figure 22 (upper) does not show the short-term impact of beach nourishment in February 2002 because no surveys are available herein. Addition of ~210,000 cy in early 2002 would be expected to add at least 20 cy/ft to the recreational beach (above –4 ft NGVD). This would show as a sharp increase in average beach volume on the graph. The fact that the beach volume in April 2003 is ~10 cy/ft **lower** than the beach volume in June 2000 suggests that the impact of the 2002 nourishment was exceedingly short-lived. There are three possible reasons for this:

1) The length of the project was small (several thousand feet) and nourishment longevity is proportional to the square of the project length (NRC 1995).

2) The sediments in the inner harbor tend to be finer than the sediments on Bogue Banks, making them less stable (CSE Baird–Stroud 1999).

3) Nourishment close to Beaufort Inlet becomes subject to strong tidal currents that tend to cause accelerated transport toward the inlet.

While there are no surveys to confirm five-year changes along Beaufort Inlet , the present monitoring project has documented a six-month gain of over 85,000 cy on the spit (north

of the short groins). It is reasonable to assume much of the loss along FMSP's oceanfront has resulted in gains on the spit.

The five year changes by station are illustrated in Figure 22 (lower). Results to –11 ft as well as –4 ft are shown. Where the two lines approach each other means most of the change can be accounted for above the –4-ft contour. Divergence of the two lines means sand is either accumulating (–11-ft line is *above* the –4-ft line) or is being lost at a higher rate (–11-ft line is *below* the –4-ft line) in the outer bar area. The more the lines parallel each other, the more uniform are the beach width and outer bar in the alongshore direction. Large divergences and irregularities of the lines are expected around tidal inlets because of the formation of shoals associated with inlet deltas. Irregular sand bars migrate on and off the beach, producing large variations in profile volumes.

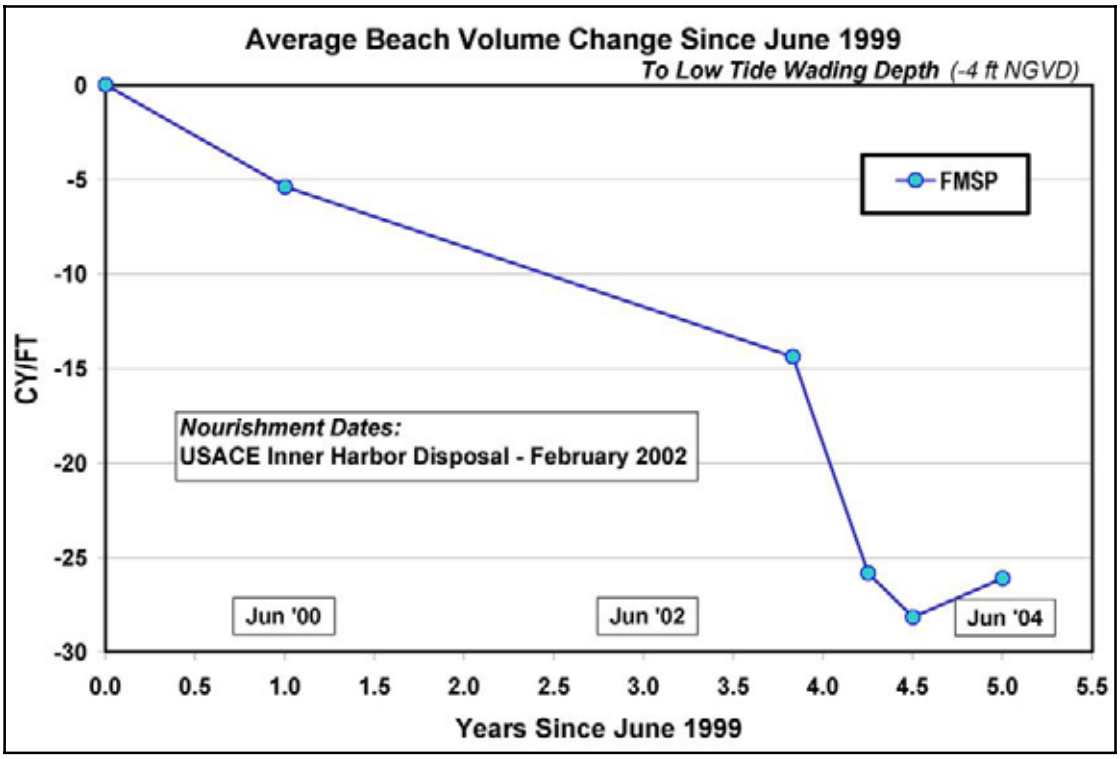
The rhythmic variation in profile volume changes (and volumes) from station to station, at small scales, reflects rhythmic topography of the beach. Breaks in offshore bars are reflected in lower volumes. Healthy buildups on the recreational beach sometimes mimic buildups on the bars. Some of the variations in profile volumes are due to irregularities in the dune crest, heights of dunes, and heights of the dry beach. For example, nourishment in the past has left higher berms (dry beach). The eastern end of FMSP (profiles 108–110) show less erosion during the past five years, probably because of the inner harbor disposal event.

Figure 23 shows the average beach volume along all of Bogue Banks. Atlantic Beach's volume served as the basis for nourishment planning along Emerald Isle, Pine Knoll Shores, and Indian Beach. Therefore, by definition it contains the 'target minimum beach volume."***** Figure 23 illustrates the average volume to low-tide wading depth along FMSP has declined significantly since June 1999. Note the county nourishment reaches (PKS–East to EI–Central) began with a sand deficit on the beach in 1999 and now exceed the target minimum volume. Fort Macon State Park began with a sand surplus in 1999 and now has a deficit. As Figure 23 shows, Fort Macon State Park is now the least healthy section of Bogue Banks (as measured by sand volume on the beach). In 1999, this reach along the western end of the island (Bogue Inlet–Ocean) had the most sand.

Data, such as the present monitoring results, are intended to help establish priorities for beach nourishment. By these measures, FMSP, Atlantic Beach,and Emerald Isle-West are considered to be the next candidates for beach nourishment.

Tables 13 and 14 provide volume calculations to –4 ft and –11 ft NGVD (respectively) for every station, reach, and available survey data for Fort Macon State Park.

[*Using the Atlantic Beach condition as the principal criteria for minimum acceptable beach volume, consistent with the approach used by CSE Baird–Stroud (1999) in the original planning for the County Project.]



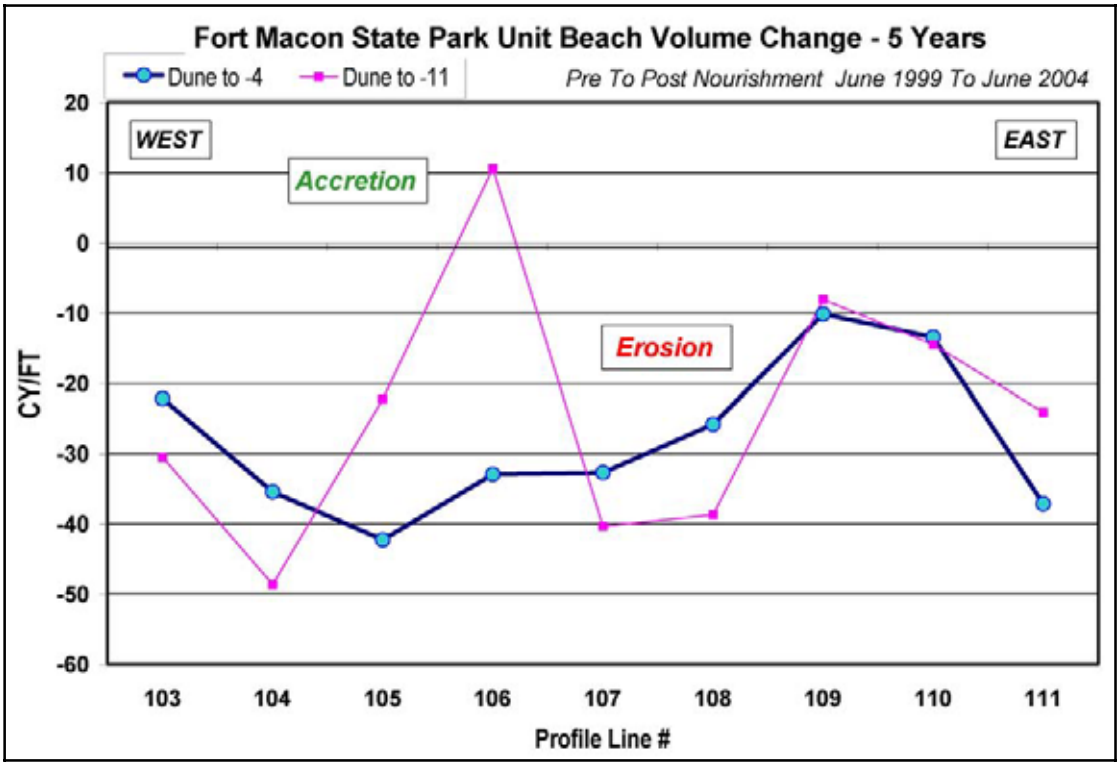


FIGURE 22. [UPPER] Trend in average, beach volume change by reach for the five-year period, June 1999 to June 2004, measured between the foredune and low-tide wading depth. [LOWER] The net five-year change by station to –4 ft and –11 ft calculation depths showing accretion by nourishment or natural processes at all stations.

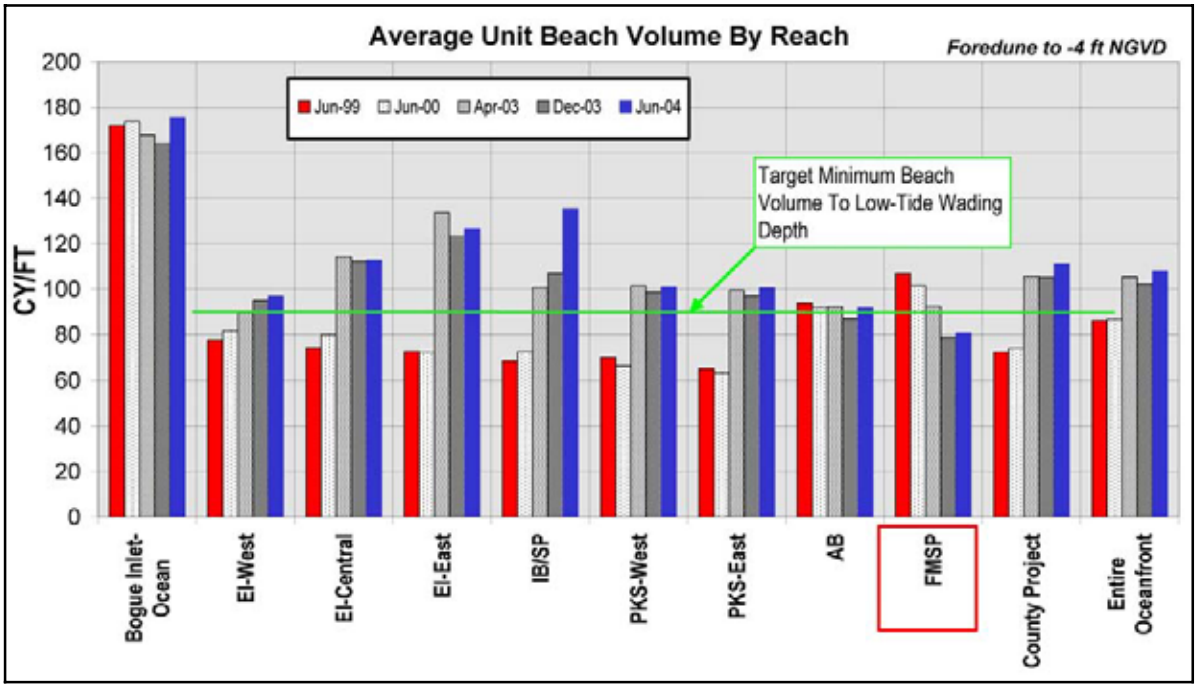


FIGURE 23. Average beach volume to low-tide wading depth by reach for representative survey dates. Target minimum beach volume (~90 cy/ft) is based on conditions along Atlantic Beach to the same calculation limit. [Representative photos of Fort Macon State Park by P McKee.]

TABLE 13. Fort Macon State Park Profile Volumes for June 1999 to June 2004 - Foredune to -4 ft

Reach	Station	Baseline Offset (ft)	Cutoff (ft)	Distance from Last (ft)	Jun-99 Dune to -4 Unit Vol (cy/ft)	Jun-00 Dune to -4 Unit Vol (cy/ft)	Apr-03 Dune to -4 Unit Vol (cy/ft)	Sep-03 Dune to -4 Unit Vol (cy/ft)	Dec-03 Dune to -4 Unit Vol (cy/ft)	Jun-04 Dune to -4 Unit Vol (cy/ft)	Jun99-Jun04 Unit Vol Change (cy/ft)	Jun99-Jun04 Net Vol Change (cy)
	102	10	None	1001	85.15	82.38	76.71		57.47	67.25	-17.90	(20,372)
Fort	**103**	-17	None	1016	74.00	65.33	50.62		43.35	51.81	-22.19	(28,111)
Macon	**104**	-40	None	975	96.07	74.88	77.41		72.79	60.62	-35.45	(38,613)
State	**105**	55	None	993	90.51	77.73	68.68	62.45	59.61	48.22	-42.29	(37,582)
Park	**106**	27	None	999	113.63	72.70	85.54		78.26	80.68	-32.95	(17,426)
	107	0	None	531	116.84	102.78	100.53		88.85	84.13	-32.71	(13,767)
	108	46	None	471	107.95	116.02	107.16		84.91	82.14	-25.81	(9,581)
	109	0	1250	533	114.44	133.01	117.96		95.60	104.28	-10.16	(5,433)
	110	11	None	460	118.15	142.56	121.92	99.64	93.16	104.68	-13.47	(18,241)
	111	190	None	721	130.37	128.37	102.43		81.10	93.22	-37.15	(7,175)
	112	155	1050	500	nd	nd	nd		89.51	97.96	8.45	*
Summary By Reach - Beach Volumes									Jun 1999 to Jun 2004		**Change - Dune to -4 ft**	
	Profiles			Reach Length	**Jun-99**	**Jun-00**	**Apr-03**	**Sep-03**	**Dec-03**	**Jun-04**	***Wtd Avg (cy/ft)***	**Net (cy)**
FMSP	102-112			7,199	106.9	101.5	92.5	81.0	78.7	80.8	**-27.3**	**-196,301**
Volume Changes Since June 1999												
FMSP	102-112			7,199	0.0	-5.4	-14.4	-25.8	-28.2	-26.1	**-27.3**	**-196,301**
			Years Since June 1999		*0*	*1*	*3.83*	*4.25*	*4.5*	*5*		

TABLE 14. Fort Macon State Park Profile Volumes for June 1999 to June 2004 - Foredune to -11 ft

Reach	Station	Baseline Offset (ft)	Cutoff (ft)	Distance from Last (ft)	Jun-99 Dune to -11 Unit Vol (cy/ft)	Jun-00 Dune to -11 Unit Vol (cy/ft)	Apr-03 Dune to -11 Unit Vol (cy/ft)	Sep-03 Dune to -11 Unit Vol (cy/ft)	Dec-03 Dune to -11 Unit Vol (cy/ft)	Jun-04 Dune to -11 Unit Vol (cy/ft)	Jun99-Jun04 Unit Vol Change (cy/ft)	Jun99-Jun04 Net Vol Change (cy)
	102	10	None	1001	240.98	237.78	208.11		190.92	196.32	-44.66	(38,208)
Fort	**103**	-17	None	1016	207.96	201.55	173.58		161.44	177.43	-30.53	(38,611)
Macon	**104**	-40	None	975	247.37	190.72	216.78		207.68	198.73	-48.64	(35,216)
State	**105**	55	None	993	190.61	224.88	206.24	208.41	197.44	168.35	-22.26	(5,829)
Park	**106**	27	None	999	221.44	188.81	221.35		215.30	232.03	10.59	(7,912)
	107	0	None	531	250.91	208.15	223.64		231.25	210.51	-40.40	(18,608)
	108	46	None	471	222.55	249.89	231.61		225.30	183.85	-38.70	(12,465)
	109	0	1250	533	234.87	267.72	250.00		235.63	226.77	-8.10	(5,196)
	110	11	None	460	238.30	287.48	247.71	232.42	228.92	223.80	-14.50	(13,913)
	111	190	None	721	250.52	255.83	239.13		218.29	226.41	-24.11	(8,985)
	112	155	1050	500	nd	nd	nd		240.86	229.03	-11.83	-
Summary By Reach - Beach Volumes									Jun 1999 to Jun 2004		**Change - Dune to -11 ft**	
	Profiles			Reach Length	**Jun-99**	**Jun-00**	**Apr-03**	**Sep-03**	**Dec-03**	**Jun-04**	***Wtd Avg (cy/ft)***	**Net (cy)**
FMSP	102-112			7,199	229.4	230.6	223.3	220.4	216.2	207.7	**-25.7**	**-184,943**
Volume Changes Since June 1999												
FMSP	102-112			7,199	0.0	1.2	-6.1	-9.0	-13.2	-21.7	**-25.7**	**-184,943**
			Years Since June 1999		*0*	*1*	*3.83*	*4.25*	*4.5*	*5*		

BEACH SEDIMENTS

CSE has collected beach sediment samples along Bogue Banks in connection with the Phase 1 and Phase 2 nourishment projects. Samples are available for representative profiles before, during, and after construction. The results are given in Tables 15 and 16.

Initial sampling in June 1999 and May 2001 showed the mean grain size between the foredune and low-tide terrace was 0.303 millimeter (mm) (CSE-Stroud 2001). This is classified as medium sand. Beaches along the northern Outer Banks of North Carolina tend to be coarser (~0.45 mm), whereas those in the southern part of the state tend to be finer (~0.25 mm) (Giles and Pilkey 1965, Kana and Ward 1980). Shells exist on the beach in varying concentrations adding to the quartz sand that dominates. Most shell material (calcium carbonate – $CaCO_3$) is finely crushed remains of *Donax* species, which are thin-shelled mollusks (~0.2–0.5 inches in diameter) that thrive in the surf zone. Other gastropods and bivalves produce large shell fragments. Samples of the "native beach" before nourishment indicated shells made up ~15 percent of the sediment on the beach (Tables 15 and 16).

Phases 1 and 2 nourishment sediment was obtained from offshore borrow areas close to the project site. The Section 933 nourishment (winter 2004) obtained sand from the Beaufort Inlet outer harbor channel. Each borrow area contained coarser and more shelly material.

Samples during construction of Phase 1 (PKS and IB/SP – see upper section of Table 15) tested an average grain size of ~0.350-mm diameter and an average shell content of ~32 percent. Postproject samples 0.25 years and 1.4 years after construction tested 0.388 mm and 0.342 mm (respectively), suggesting a slight fining of sediments on the beach compared with the borrow sediment size. Shell content decreased from 32 percent to 19 percent during the first 1.4 years (lower part of Table 15). The most recent sampling of Phase 1 (June 2004) showed an increase in mean grain size to 0.40 mm and an increase in shell content to ~26 percent. The mean size for Pine Knoll Shores 2.2 years after the Phase 1 nourishment was ~0.38 mm. Mean grain size along Indian Beach (stations 48–58) increased to 0.44 mm in June 2004 (0.3 years after the Section 933 nourishment).

Emerald Isle was nourished in winter 2003 (Phase 2). During construction, mean grain size increased to 0.414 mm and shell content increased to 42 percent (upper section of Table 16). Postproject samples in June 2004 (1.2 years after nourishment) showed a slight decrease in mean grain size to 0.396 mm and a decrease in shell content to ~25 percent (lower section of Table 16).

The average trends in grain size and shell content for the Phases 1 and 2 project areas are illustrated in Figure 24. The data confirm the expected trend of fining of the borrow material after the nourishment sand begins sorting on the beach. Variations in sediment size are expected to persist from reach to reach as the morphology of the beach evolves. Seasonal changes in the profile can expose heavy shell concentrations, then bury them with fine sand migrating shoreward from the bar. Each of the results reported in Tables 15 and 16 are actually composites of many samples collected along profile lines.

No rigorous measurements of sediment color are available. However, it has been widely reported that the nourishment sand for Phases 1 and 2 was medium grey in appearance compared with the tannish white color of the native beach and fresh shell material. Over time, the sand on the beach is washed and abraded by waves, and bleached by the sun. Figure 25 provides examples of the transformation in color of the nourished areas. The Section 933 project involved lighter colored sands that had not been deposited as long as the Phases 1 and 2 borrow material. As a result, the Section 933 project looked much more natural soon after placement along Indian Beach and western Pine Knoll Shores.

Table 15. Phase 1 - Pine Knoll Shores & Indian Beach - Pre-Project, Construction & Post-Project Beach Sediment Samples

Bogue Banks Beach Nourishment Project - Phase 1 *See Notes Bottom of Table 16*

Pre-Project Samples - July 1999 and May 2001

Station Location	Profile #'s	CSE Mile #	Sample Location**	Mean Grain Size (mm)	Std Dev (mm)	Skewness	Shell Content Percent CaCo3	Sediment Type
Island	10,30,50,70,90		D-B-BF-LTT	0.302	0.585	-0.648	15.0%	MS,mws,c-s
PKS/IB/SP	48,52,56,60,64,68,72,76		D-B-BF-LTT	0.303	0.614	-0.704	12.90%	MS,mws,c-s
Phase 1 Averages				**0.303**	**0.600**	**-0.676**	**14.0%**	MS,mws,c-s

During Construction Samples - February - March 2002

Station	Profile #	CSE Mile #	Date	Mean (mm)	Std Dev (mm)	Skewness	Shell Content % CaCO3	Type
25+00	75	7	22-Feb-02	0.27	0.37	-0.661	18.5	FS,ms,sc-s
50+00	74	6.5	22-Feb-02	0.31	0.40	-0.574	27.6	MS,ps,sc-s
75+00	72	6	22-Feb-02	0.34	0.42	-0.43	30.4	MS,ps,sc-s
100+00	70	5.5	22-Feb-02	0.33	0.42	-0.455	31.5	MS,ps,sc-s
125+00	68	5	22-Feb-02	0.29	0.47	-0.642	18.8	MS,ps,sc-s
150+00	66	4.5	22-Feb-02	0.32	0.42	-0.496	30.9	MS,ps,sc-s
175+00	64	4	28-Feb-02	0.37	0.50	-0.45	30.0	MS,ps,cs
187+00	63	3.75	28-Feb-02	0.36	0.48	-0.459	28.6	MS,ps,cs
199+00	62	3.5	28-Feb-02	0.40	0.43	-0.408	32.4	MS,ps,sc-s
210+00	61	3.35	14-Mar-02	0.37	0.43	-0.409	32.1	MS,ps,sc-s
220+00	61	3.2	14-Mar-02	0.39	0.40	-0.36	39.1	MS,ps,sc-s
230+00	60	3	21-Mar-02	0.37	0.41	-0.378	45.3	MS,ps,sc-s
260+00	58	2.5	21-Mar-02	0.43	0.38	-0.271	50.8	MS,ps,sc-s
Phase 1 Averages		*Miles east from IB town line*		**0.350**	**0.425**	**-0.461**	**32.0**	MS, ps, sc-s
(Non-wt'd.)								

Post-Project Samples - June 2002

Phase 1 Station	Profile #	CSE Mile #	Sample Date	Mean (mm)	Std Dev (mm)	Skewness	Shell Content % CaCO3	Type
					0.25 years after Nourishment			
0+00	77	7.4	21-Jun-02	0.336	0.591	-0.735	10.9	MS,mws,c-s
45+07	74	6.5	21-Jun-02	0.506	0.545	-0.316	27.9	MS,ms,c-s
97+87	70	5.5	21-Jun-02	0.333	0.467	-0.568	24.4	MS,ps,sc-s
150+67	66	4.5	21-Jun-02	0.340	0.572	-0.492	15.3	MS,ms,c-s
176+47	64	4	21-Jun-02	0.374	0.478	-0.418	29.5	MS,ps,sc-s
229+27	60	3	21-Jun-02	0.289	0.525	-0.711	15.1	MS,ms,sc-s
282+07	56	2	21-Jun-02	0.431	0.414	-0.327	30.3	MS,ps,sc-s
334+87	52	1	21-Jun-02	0.569	0.423	-0.139	42.2	CS,ps,c-s
387+67	48	0	21-Jun-02	0.311	0.535	-0.692	18.9	MS,ms,sc-s
Phase 1 Averages				**0.388**	**0.506**	**-0.489**	**23.8**	MS, ms, sc-s

Post-Project Samples - August 2003

Phase 1 Station	Profile #	*CSE Mile #	Sample Date	Mean (mm)	Std Dev (mm)	Skewness	Shell Content % CaCO3	Type
					1.4 years after Nourishment			
0+00	77	7.4	13-Aug-03	0.380	0.553	-0.493	16.9	MS,ms,sc-s
18+99	76	7	13-Aug-03	0.357	0.604	-0.499	15.0	MS,mws,c-s
71+56	72	6	13-Aug-03	0.328	0.511	-0.670	14.6	MS,ms,sc-s
122+05	68	5	13-Aug-03	0.246	0.706	-0.232	6.6	FS,ws,sym
175+76	64	4	13-Aug-03	0.369	0.466	-0.436	30.1	MS,ps,sc-s
231+79	60	3	13-Aug-03	0.383	0.442	-0.422	22.3	MS,ps,sc-s
284+56	56	2	13-Aug-03	0.395	0.459	-0.384	27.5	MS,ps,sc-s
334+87	52	1	13-Aug-03	0.236	0.582	-0.740	10.5	FS,mws,sc-s
387+67	48	0	13-Aug-03	0.382	0.453	-0.352	28.3	MS,ps,sc-s
Phase 1 Averages			**PKS & IB**	**0.342**	**0.531**	**-0.470**	**19.1**	MS,ps,sc-s

Post-Project Samples - June 2004

Phase 1 Station	Profile #	CSE Mile #	Sample Date	Mean (mm)	Std Dev (mm)	Skewness	Shell Content % CaCO3	Type
					2.2 years after Nourishment			
					0.3 years after Section 933 Nourishment			
0+00	77	~7.5	30-Jun-04	0.319	0.597	-0.462	14.0	MS,ms,c-s
18+99	76	7	30-Jun-04	0.393	0.509	-0.231	27.5	MS,ps,sc-s
71+56	72	6	30-Jun-04	0.424	0.531	-0.205	20.9	MS,ps,sc-s
122+05	68	5	30-Jun-04	0.455	0.518	-0.103	29.7	CS,ps,sc-s
175+76	64	4	30-Jun-04	0.398	0.533	-0.259	29.8	MS,ps,sc-s
231+79	60	3	30-Jun-04	0.308	0.573	-0.402	20.0	MS,ms,c-s
284+56	56	2	30-Jun-04	0.363	0.534	-0.344	26.3	MS,ps,sc-s
334+87	52	1	30-Jun-04	0.594	0.508	0.236	45.8	VCS,vps,sc-s
387+67	48	0	30-Jun-04	0.374	0.558	-0.268	19.3	MS,ms,c-s
Phase 1 Averages			**PKS & IB**	**0.403**	**0.540**	**-0.226**	**25.9**	MS,ps,sc-s

Table 16. Phase 2 - Emerald Isle - Pre-Project, Construction & Post-Project Beach Sediment Samples

Bogue Banks Beach Nourishment Project - Phase 2

Pre-Project Samples - October 2002

Station Location	Profile #	CSE Mile #	Sample Location**	Mean Grain Size (mm)	Percent > 2mm	Percent Mud	Shell Content Percent CaCo3	Sediment Type
					Sample Date	10/04/02		
387+67	48	0	D-B-BF-LTT	0.372	6.40%	0.01%	23.1%	MS,ms,c-s
429+41	44	-0.8	D-B-BF-LTT	0.418	14.81%	0.01%	26.6%	CS,ms,c-s
473+36	40	-1.6	D-B-BF-LTT	0.254	0.35%	0.01%	6.4%	MS,ms,c-s
517+58	36	-2.5	D-B-BF-LTT	0.287	1.43%	0.01%	10.1%	MS,mws,c-s
572+58	32	-3.5	D-B-BF-LTT	0.270	1.82%	0.01%	11.8%	MS,ms,c-s
638+70	28	-4.8	D-B-BF-LTT	0.270	1.09%	0.02%	7.3%	MS,ms,c-s
688+23	24	-5.6	D-B-BF-LTT	0.316	2.18%	0.01%	10.4%	MS,ms,c-s
737+78	20	-6.6	D-B-BF-LTT	0.281	1.07%	0.01%	7.7%	MS,mws,c-s
Phase 2 Averages		*Miles west from IB town line*		**0.308**	**3.6%**	**0.01%**	**12.9%**	MS,ms,c-s
(Non-wt'd.)								

During Construction Samples - February - April 2003

Station	Profile #	CSE Mile #	Date	Mean (mm)	Std Dev (mm)	Skewness	Shell Content % CaCO3	Type
392+00	47	0	22-Feb-03	0.430	0.459	-0.070	41.1	MS,ps,sc-s
413+00	45	-0.5	09-Feb-03	0.452	0.432	0.134	51.9	CS,ps,sym
439+00	43	-1	04-Apr-03	0.352	0.500	-0.185	30.5	MS,ps,sc-s
469+00	40	-1.5	04-Apr-03	0.378	0.450	-0.157	40.2	MS,ps,sc-s
496+00	38	-2	13-Mar-03	0.669	0.503	0.426	62.4	CS,ps,sym
523+00	36	-2.5	04-Apr-03	0.339	0.436	-0.217	34.1	MS,ps,sc-s
546+00	34	-3	22-Mar-03	0.395	0.446	-0.099	38.7	MS,ps,sc-s
574+00	32	-3.5	09-Mar-03	0.409	0.464	-0.053	44	MS,ps,sc-s
600+00	30	-4	14-Apr-03	0.327	0.506	-0.297	31.8	MS,ps,sc-s
625+00	29	-4.5	25-Feb-03	0.390	0.459	-0.134	40.1	MS,ps,sc-s
651+00	27	-5	07-Feb-03	0.406	0.433	-0.041	44	MS,ps,c-s
677+00	25	-5.5	15-Feb-02	0.425	0.446	-0.027	42.2	MS,ps,c-s
Phase 2 Averages			**Emerald Isle**	**0.414**	**0.461**	**-0.060**	**41.8**	MS, ps, sc-s

Post-Project Samples - August 2003

Phase 2 Station	Profile #	CSE Mile #	Sample Date	Mean (mm)	Std Dev (mm)	Skewness	Shell Content % CaCO3	Type
					0.4 years after Nourishment			
387+67	48	0	13-Aug-03	0.382	0.453	-0.352	28.3	MS,ps,sc-s
440+43	43	-1	13-Aug-03	0.467	0.414	-0.225	32.7	MS,ps,sc-s
495+36	38	-2	13-Aug-03	0.745	0.432	0.104	68.5	CS,ps,sym
544+97	34	-3	13-Aug-03	0.357	0.415	-0.448	36.1	MS,ps,c-s
600+00	30	-4	13-Aug-03	0.399	0.465	-0.432	29.8	MS,ps,sc-s
649+69	27	-5	13-Aug-03	0.336	0.478	-0.505	25.8	MS,ps,sc-s
704+57	23	-6	13-Aug-03	0.22	0.598	-1.043	8.4	FS,mws,sc-s
Phase 2 Averages			**Emerald Isle**	**0.415**	**0.465**	**-0.414**	**32.8**	MS,ps,sc-s

Post-Project Samples - June 2004

Phase 2 Station	Profile #	CSE Mile #	Sample Date	Mean (mm)	Std Dev (mm)	Skewness	Shell Content % CaCO3	Type
					1.2 years after Nourishment			
387+67	48	0	30-Jun-04	0.374	0.558	-0.268	19.27	MS,ms,c-s
440+43	43	-1	30-Jun-04	0.655	0.522	0.358	49.09	VCS,vps,c-s
495+36	38	-2	30-Jun-04	0.427	0.487	-0.133	33.81	MS,ps,sc-s
544+97	34	-3	30-Jun-04	0.347	0.508	-0.331	19.02	MS,ps,sc-s
600+00	30	-4	30-Jun-04	0.305	0.582	-0.436	14.77	MS,ms,sc-s
649+69	27	-5	30-Jun-04	0.332	0.56	-0.364	17.44	MS,ms,sc-s
704+57	23	-6	30-Jun-04	0.331	0.497	-0.393	25.23	MS,ps,sc-s
Phase 2 Averages			**Emerald Isle**	**0.396**	**0.531**	**-0.224**	**25.5**	MS,ps,sc-s

Construction and Post-Project Sediment Samples - Fill Transects from Backbeach to Trough

**Positive east from Indian Beach/Emerald Isle town line. Negative to the west.*

Note: Physical composites of surficial samples at 50 ft spacing along each transect

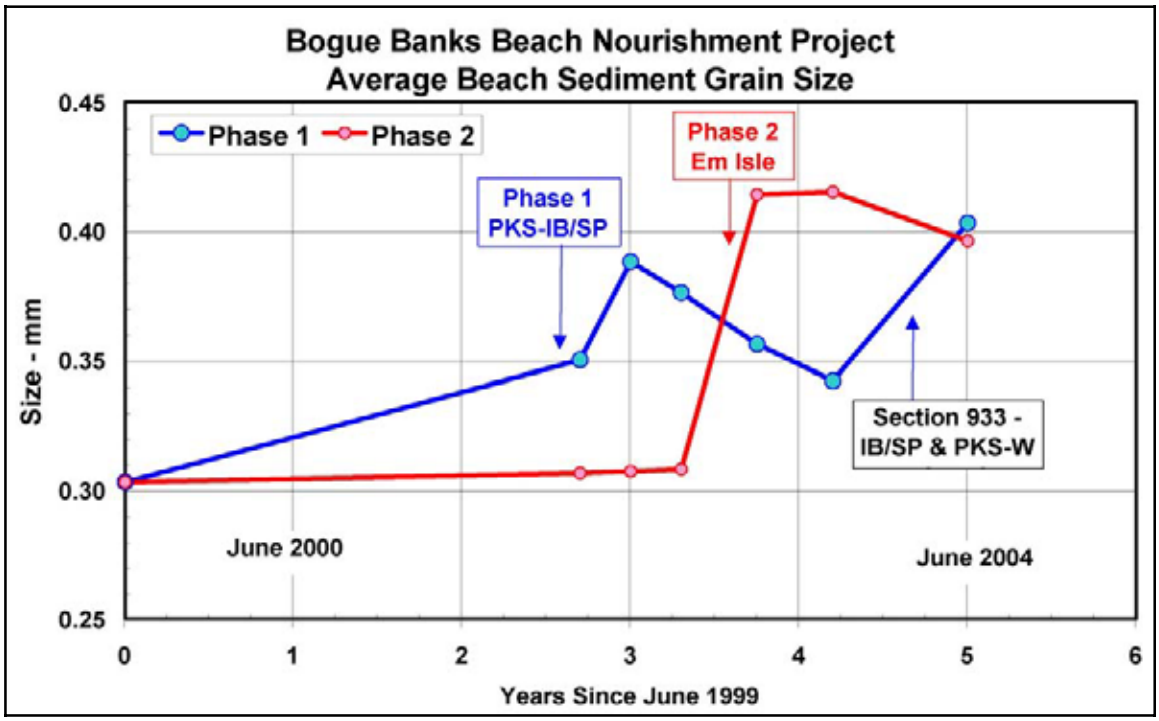
An equal volume of sediment was obtained at each point along the transect.

**VCS-Very Coarse Sand; CS-Coarse Sand; MS-Medium Sand; FS-fine sand*

ms-moderately sorted; mws-moderately well sorted; ws-well sorted; ps-poorly sorted

c-s coarse skewed; sc-s strongly coarse skewed; f-s fine skewed; sym - symmetrical size distribution

***D-Toe of Foredune; B-Berm; BF- Beachface; LTT-Low Tide Terrace*



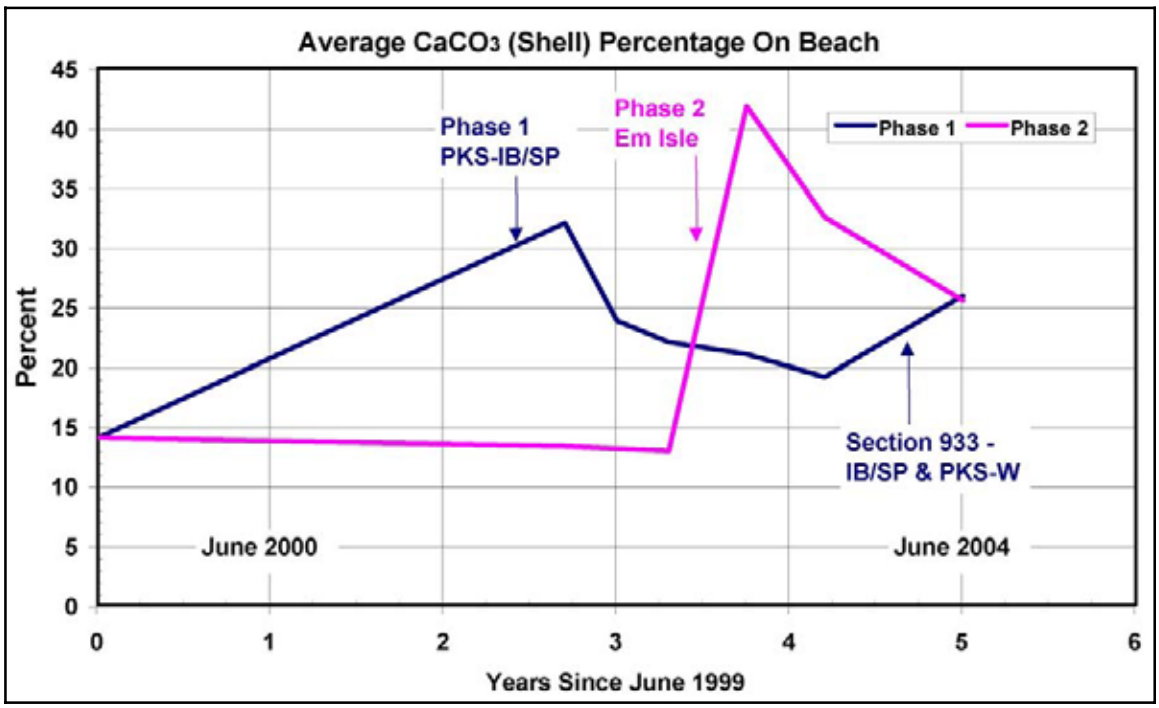


FIGURE 24. [UPPER] Trend in average sediment grain size for Phase 1 and Phase 2 project areas (construction times indicated by arrows. Note: Sand size is a classification that ranges from 0.0625 mm to 2 mm mean diameter. The indicated variation falls within a narrow range corresponding to medium sand (0.25–0.5 mm). [LOWER] Trend in shell content on the beach before and after nourishment.

FIGURE 25.

[UPPER]
Grayish nourishment sand at Pine Knoll Towns condominiums in October 2003, approximately 1.5 years after nourishment.

[CENTER]
The same area in June 2004, approximately 2.5 years after nourishment.

[LOWER]
Indian Beach in June 2004, 0.3 months after the Section 933 nourishment, showing light-colored sediments obtained from the outer harbor. Grain-size distribution and shell percentages were nearly identical for the Phase 1 and Section 933 projects.

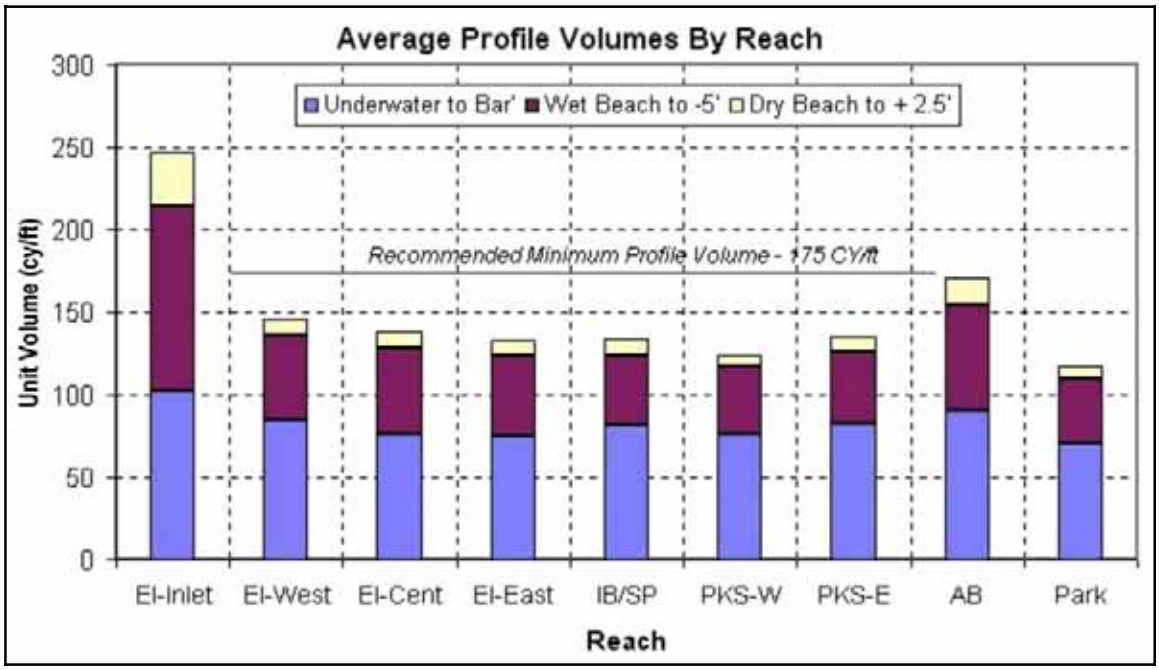
DISCUSSION AND RECOMMENDATIONS

A decade ago, Bogue Banks entered a period of unprecedented change, beginning with Hurricane *Bertha* in June 1996 and *Fran* in September 1996. More hurricanes followed with *Bonnie* in August 1998, *Dennis* in September 1999, and *Floyd* on 15 September 1999. Each storm caused dune erosion and prompted many oceanfront property owners to rebuild the dunes by scraping. Other poststorm expenses included debris cleanup and reconstruction of dune walkovers and repairs to houses. Particularly unsettling was the fact that storms occurred in quick succession compared with historical trends. Many repairs made in 1997 after *Bertha* and *Fran* had to be repeated in 1998 and 1999 after the next storms.

Bogue Banks has been quite stable compared with many barrier islands along the East Coast. NCDENR's official maps (Fig 26) show 50-year erosion rates in the range 2–3 ft per year for nearly all of the island. The maps are based on 1998 imagery. Yet by June 1999, much of Bogue Banks was severely eroded. Beach width was too narrow along eastern Emerald Isle, Indian Beach, Salter Path, and Pine Knoll Shores to sustain small storms without damage to the dunes.

Carteret County established a Beach Preservation Task Force in 1997 to assess alternatives for beach stabilization. With input from every town along the oceanfront and many community representatives and experts, a draft plan for beach restoration was developed in September 1999, just as *Dennis* and *Floyd* were impacting the coast. A key element of the plan was a systematic inventory of the beach. Profiles were established along the length of the island by CSE Baird–Stroud (1999) for purposes of comparing the condition of the beach from town to town. The concept of "target minimum profile volume" was introduced using 1999 conditions along Atlantic Beach as a model for other communities along Bogue Banks (Fig 27).

FIGURE 26. Section of NC DENR Long-Term Average Annual Shoreline Change Study (2003) showing 50-year erosion rates (2–3 ft/yr) for Bogue Banks.



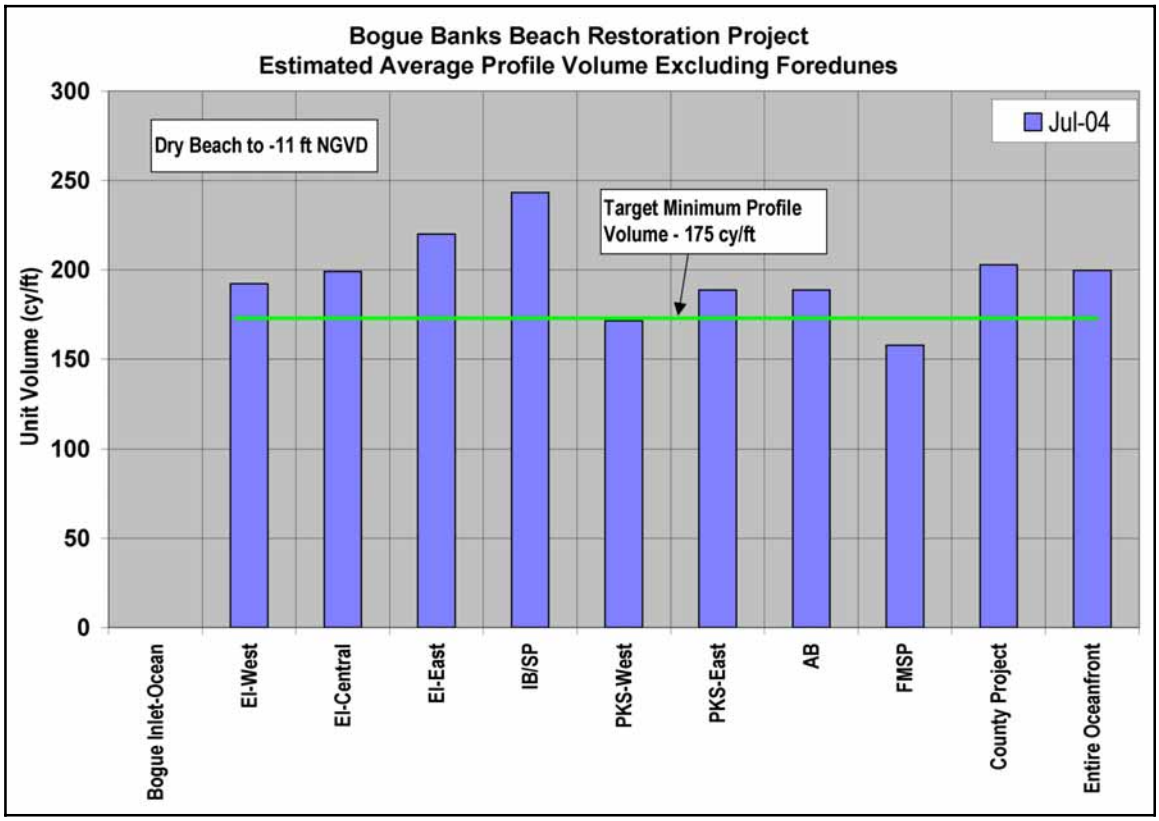


FIGURE 27. [UPPER] Average profile volumes by reach for June 1999 calculated between the base of the foredune and –11 ft NGVD contour (from CSE Baird-Stroud 1999). [LOWER] Estimated average profile volumes by reach for June 2004 after nourishment, using the results herein and factoring out the estimated volume contained within the foredune so the two graphs represent comparable calculation limits.

By 2001, additional beach surveys (eg, CSE 2000) had confirmed that Bogue Banks' background erosion rate is low. Surveys also demonstrated the onshore-offshore movement of sand between the outer bar and the beach.

Drawing on the nourishment experience at Atlantic Beach, Pine Knoll Shores, Indian Beach, and Emerald Isle implemented the "County Project" between December 2001 and March 2003. Phases 1 and 2 of the Bogue Banks beach restoration project added nearly 3.6 million cubic yards to the beach. This project directly impacted ~12.5 miles of shoreline, making it one of the longest and largest-volume nourishment projects in the United States. Its cost was approximately $23 million or (~)$6.50/cy (including engineering, permitting, and environmental monitoring). The County Project added an average of ~55 cy/ft to the eastern half of Emerald Isle, Pine Knoll Shores, and Indian Beach/Salter Path. Thus, the investment per oceanfront foot of beach was (~)$350/ft. This is equivalent to about $35,000 per oceanfront property on average. What truly sets the Bogue Banks project apart from most nourishment projects is the fact that it was paid for entirely with locally generated funds. More than 50 percent of the cost is being paid for by oceanfront property owners. Plans are continuing for Phase 3 of the County Project, pending permits, to realign Bogue Inlet and nourish the western end of Emerald Isle (CSE–Stroud 2001, CPE 2004).

In parallel with the County Project, the Carteret County Shore Protection Office has coordinated federal studies for a long-term beach restoration approach along Bogue Banks. This effort led to successful completion of a Section 933 project at Indian Beach and western Pine Knoll Shores, whereby dredged sediments from the Beaufort Harbor entrance channel were disposed on the beach instead of being dumped offshore. The American Shore & Beach Preservation Association (ASBPA) has named the Section 933 project one of its four winners for the "Top Restored Beach Awards" for 2004 (visit www.asbpa.org). While it was much smaller than the County Project, it had two distinct advantages. The Section 933 project was constructed using lighter colored sediments from the harbor entrance, and nearly 65 percent of the cost was paid by the federal government. Sediments were considered better mainly because of color. The data herein show the average grain-size distribution and shell content were nearly identical to the County Project. Unit construction costs for the Section 933 project were approximately $8/cy or about 25 percent higher than the County Project. This difference reflects the extra distance (transportation cost) between the borrow source and the project area.

Two other small nourishment projects in the past five years, detailed herein, bring the total nourishment volume to 4.65 million cy. Averaged the length of Bogue Banks, this is an addition of over 35 cy/ft. In simple terms, this equates to about 50 ft more beach width on

average. The total area represented by new dry beach is of the order 150 acres. If long-term erosion rates persist, it will take upward of 20 years for all of the new sand to erode out of the system. In actuality, the time will be longer because most of the nourishment went to the center of the island. Natural processes will tend to shift it gradually toward the ends of the island, prolonging the time before some reaches return to their prenourishment condition. It is uncertain what proportion will shift east from Pine Knoll Shores under the process of fill adjustment and what proportion will move west by longshore transport. The county has initiated studies to investigate that question (Carteret County Request for Proposal dated 12 Dec 2003).

The present survey documented changes between December 2003 and June 2004. However, for this Year 1 report of the BBBNMP, CSE elected to combine the present data with similar surveys dating back to June 1999. These data provide a five-year view of changes including all the nourishment during the period. Perhaps most striking about the results is the determination that after nourishment is omitted, the net change in sand volume along Bogue Banks was zero between June 1999 and June 2004. In other words, Bogue Banks neither gained sand nor lost sand on average (measured to the outer bar). Surveys account for nearly all the additions of fill. Certainly, this result is fortuitous to some degree because no survey technology yields 100 percent accuracy. Nevertheless, the result strongly suggests Bogue Banks' sediment budget was in near-balance over the past five years. Factoring out nourishment, CSE's surveys show Indian Beach gained an extra 4.2 cy/ft/yr by natural accretion. The background erosion rates for eastern and central Emerald Isle and Pine Knoll Shores were found to be ~1.1 and 2.5 cy/ft/yr (respectively). These rates are consistent with long-term (linear change) averages for the island.

The December 2003 and June 2004 surveys documented the large gain along Indian Beach and western Pine Knoll Shores as a result of the Section 933 project. They also detected some additional buildup due to shoreward movement between the –15 ft and –11 ft contours. Nourishment added ~855,000 cy in early 2004 to Indian Beach/Salter Path and Emerald Isle. The surveyed gain (island-wide) was about 1.07 million cubic yards measured to –11 ft and only 0.75 million cubic yards measured to –15 ft. The difference between these two quantities represents sand shifted landward (minus error in the surveys that become magnified with distance, depth, and changes in sediment type on the bottom).

Focus of the present report was on changes between the foredune and outer bar over the period June 1999 to June 2004. Numerous comparisons are possible using different depth contours and reach boundaries. However, CSE believes the most interesting and relevant story of the past five years is the nourishment and restoration of the beach. Having a similar set of surveys from June 1999, June 2000, and several other dates allowed

direct comparison with previous analyses. Along with common seasons for the first and last survey in the data set, this makes objective comparisons possible. This leads to our primary recommendations following this year's surveys:

- 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. (See Appendix IV.) These data can be compared with prior conditions as well as the condition of adjacent communities.

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

- Continue to monitor the sediment quality and compare it quantitatively with pre-nourishment conditions.

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

- Provide these data and results to the US Army Corps of Engineers for planning purposes in association with federal, beach-erosion and hurricane-protection projects.

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