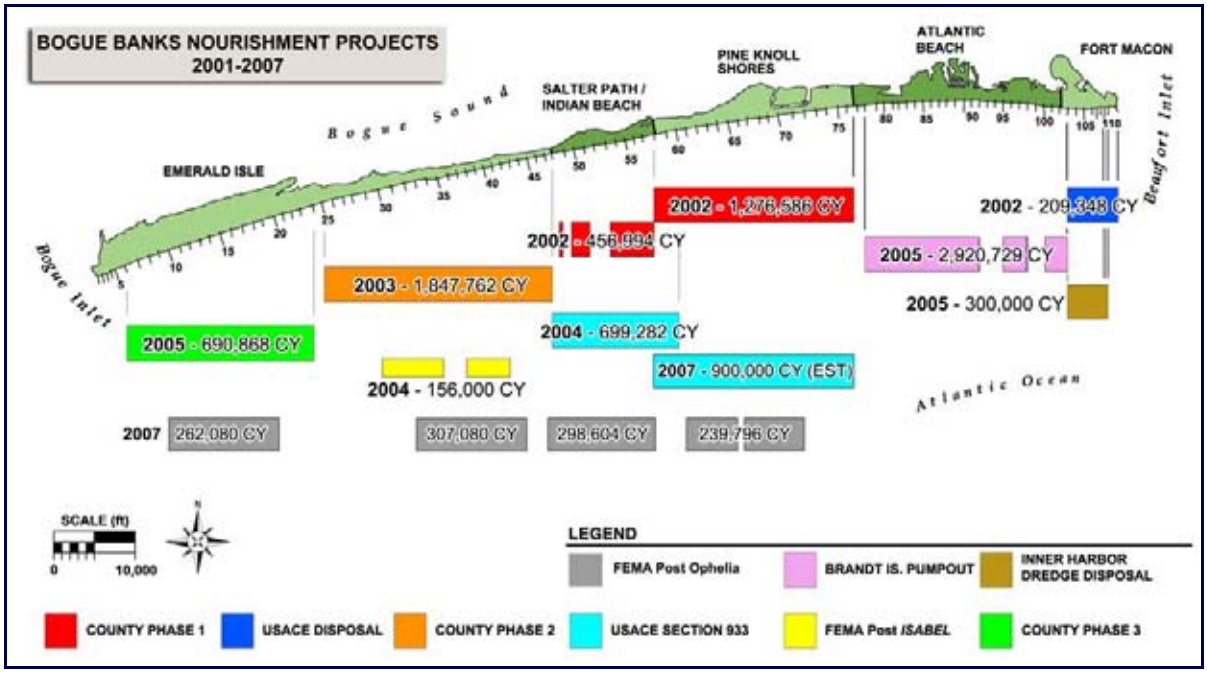
Survey Report 2006

Bogue Banks North Carolina



Prepared for:

Carteret County North Carolina

SURVEY REPORT 2006

Bogue Banks
North Carolina

Prepared for:

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[CSE SR2132-04]
NOVEMBER 2006

COVER GRAPHICS	Upper left:	Emerald Isle near Shell Drive immediately after Hurricane Ophelia (September 2005)
	Upper right:	Same location in May 2006
	Lower:	Postnourishment projects total ~8.6 million cubic yards – 2007 projects pending – total contracted volume estimate ~2.0 million cubic yards

EXECUTIVE SUMMARY

This report provides results of beach monitoring surveys covering the period June 1999 through May 2006, 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 seven-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).
- Hurricane *Isabel* (September 2003).
- US Army Corps of Engineers (USACE) Section 933 beach nourishment (Indian Beach and western Pine Knoll Shores, February to March 2004).
- Post-*Isabel* FEMA beach renourishment (Emerald Isle, March 2004).
- Phase 3 beach restoration (Emerald Isle, February–April 2005).
- New inlet dredging at Bogue Inlet (January–April 2005).
- Hurricane *Ophelia* (September 2005).
- Brandt Island pumpout and disposal along Atlantic Beach and Fort Macon State Park (November 2004–February 2005).
- USACE Morehead City inner harbor dredge disposal along Atlantic Beach and Fort Macon State Park (February–April 2005).

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

wide trends are given first, then separate sections of the report summarize results by community.

Between June 1999 and May 2006, Bogue Banks was impacted by Hurricanes *Dennis* (1999), *Floyd* (1999), *Isabel* (2003), and *Ophelia* (2005). Beach nourishment totaling 8,557,569 cubic yards (cy) (Fig A) was placed along:

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

Several reference depths are used in the report for purposes of computing volume erosion and accretion rates. The primary standard is –11 ft NGVD which encompasses the visible beach and inner littoral zone including the outer bar. This depth was used as a reference in the initial planning for the Carteret County nourishment project (CSE-Stroud 1999) because it was the limit of available profiles. Prenourishment and postnourishment profiles since then, as well as the annual survey for the BBBNMP, extend into deep water, generally well beyond closure depth.

In May 2005, CSE's island-wide survey indicated a net gain of 8,267,067 cy to –11 ft NGVD since June 1999. This represents nearly 97 percent of the nourishment volumes added to Bogue Banks between 2002 and 2005. The present survey (May 2006) yielded a net gain of 5,995,463 cy within the same calculation limits (to –11 ft NGVD). This means ~2,271,504 cy eroded between May 2005 and May 2006. Further analyses using deeper calculation depths show a net gain in volume of this same order of magnitude seaward of the outer bar during the past year. The offshore shift of sand is largely attributable to Hurricane *Ophelia* (14-15 September 2005) based on CSE's survey immediately after the storm.

While nearly all nourishment volumes can be accounted for island-wide and offshore to approximate closure depth (~15–20 ft NGVD), there were differences by reach between nourishment volumes placed and remaining sand within a particular reach (community).

The differences are, in effect, the background erosion rate. Using the results to the –11 ft contour, the highest seven-year erosion rates (1999–2006) have occurred along Atlantic Beach (–8.9 cy/ft/yr), Fort Macon State Park (–6.6 cy/ft/yr) and Pine Knoll Shores (–3.8 cy/ft/yr). By comparison, Indian Beach and Emerald Isle showed negligible net losses over a seven-year period. Most of the volume lost (about –11 ft NGVD) over the past seven years can be attributed to high erosion rates of the Atlantic Beach fill placed in early 2005 as part of the Brandt Island pumpout. Fine-grained sediments washed seaward soon after placement. The other factor accounting for losses in the past year was Hurricane *Ophelia*. Through natural erosional and accretional processes, 70 percent of the nourishment placed since June 1999 can be accounted for above –11 ft NGVD.

Despite erosion since May 2005, when nourishment is included — Emerald Isle, Indian Beach, Pine Knoll Shores, and Atlantic Beach have gained an average of over 51 cy/ft (measured to –11 ft). This seven-year net gain produced an average beach-width increase of ~74 ft to mean high water since June 1999 in the four communities.

In June 1999, CSE-Stroud (1999) determined that the central and western two-thirds of Bogue Banks had a sand deficit and inadequate beach width compared with Atlantic Beach. By May 2005, all of Bogue Banks contained a sand surplus compared with the target minimum beach volume. Between May 2005 and May 2006, all of the reaches on Bogue Banks as well as Bear Island and Shackleford Banks lost sand volume. Despite high loss rates during the past year, only Pine Knoll Shores (east) fell below the target minimum beach volume. CSE's recommended target minimum dune/beach volume along the oceanfront is 225 cy/ft (measured to the outer bar at approximately –11 ft NGVD). In May 2006, the island-wide profile volume averaged 261 cy/ft.

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

FEMA determined in fall 2005 that portions of Bogue Banks are eligible for renourishment under Category G public assistance funds. Pine Knoll Shores, Indian Beach, and Emerald Isle qualified for direct grants under this category because of sand losses due to *Ophelia* and the fact that the Phases 1, 2, and 3 (county) projects were accomplished entirely with local funds. Renourishment totaling 1,107,560 cy is scheduled to begin in January 2007 and be completed by 31 March (dates set by special conditions imposed by federal and

state permits). Atlantic Beach and Fort Macon State Park do not qualify for FEMA restoration funds.

Pine Knoll Shores is also scheduled to be renourished in winter 2007 under the Section 933 program, whereby the community is taking advantage of the Morehead City Harbor Federal Navigation Project and paying the differential cost for beach disposal. Up to 900,000 cy are expected to be added to Pine Knoll Shores under the 2007 Section 933 project. This will bring planned renourishment in 2007 to ~2 million cubic yards along Bogue Banks, largely making up sand losses since May 2005.

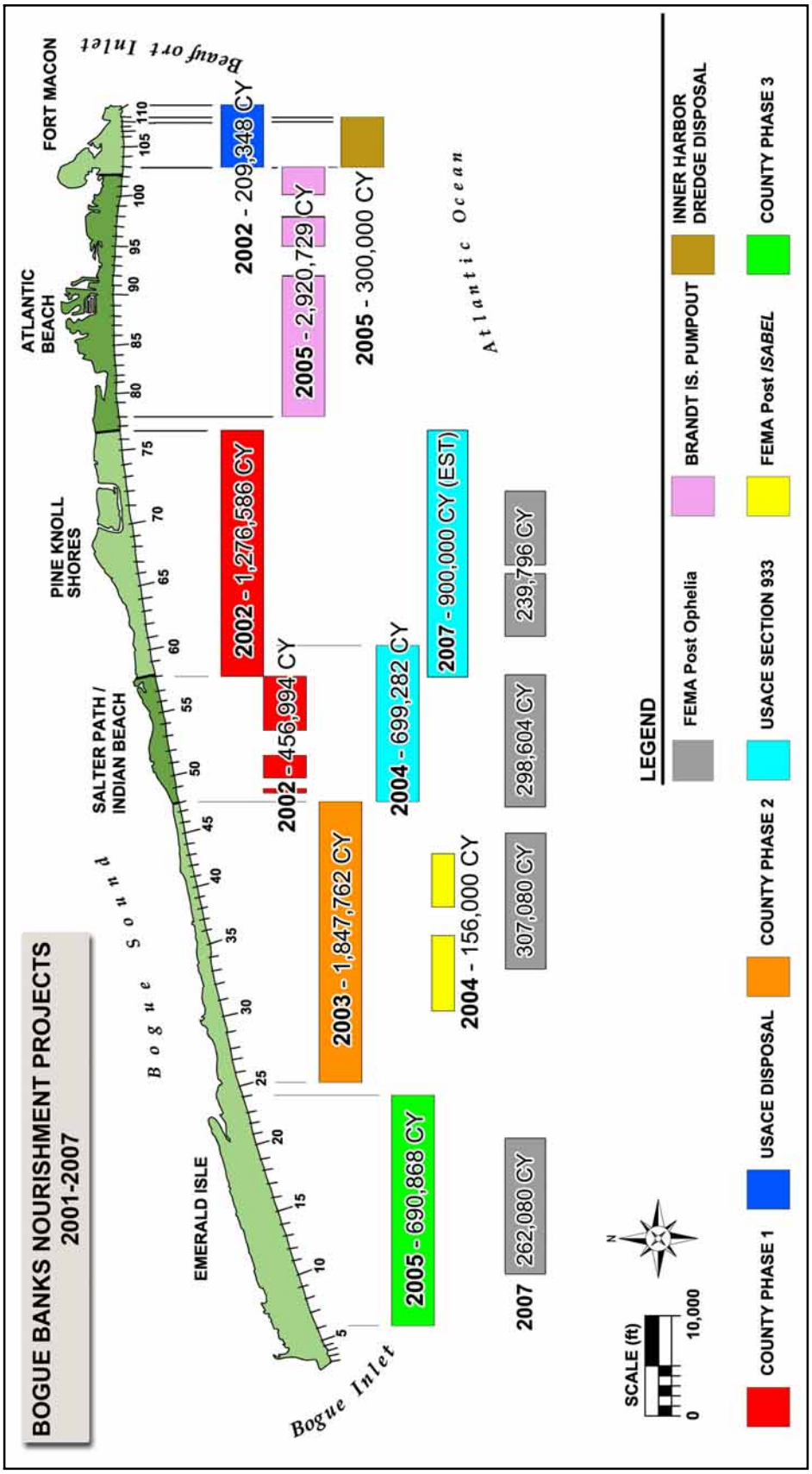

FIGURE A. Nourishment projects along Bogue Banks (2002–2005) and pending project for 2007.

ACKNOWLEDGMENTS

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William Donnelly (vice chair)	Atlantic Beach
Eddie Dawkins	Atlantic Beach
Joan Lamson	Pine Knoll Shores
Ted Lindblad	Pine Knoll Shores
Jerry Huml	Emerald Isle
Buck Fugate (chair)	Emerald Isle
Stewart Pickett	Indian Beach
James N Willis III	Bogue Banks Resident
Jim Stephenson	At-Large
Pat McElraft	Commissioner
Jack Goldstein	TDA

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

CSE’s work was directed by Dr. Timothy Kana. Philip McKee conducted the surveys with assistance by Andrew Giles, Alan Mehrzad, and Jeremy Ganey. The report was prepared by Doug Dusini and Tim Kana, with assistance by Diana Sangster, Trey Hair, Libby Marcum, and Kim Baker.

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1.0 INTRODUCTION

This report summarizes Year 3 (2005-2006) of the Bogue Banks Beach and Nearshore Mapping Program (BBBNMP) which is sponsored by Carteret County, North Carolina. The BBBNMP is a continuation of beach monitoring initiated by the County in 1999 (CSE-Stroud 1999, CSE 2000, Freeman et al 2003) and supplemented by surveys in connection with town-sponsored beach nourishment projects along Pine Knoll Shores, Indian Beach, and Emerald Isle (CSE-Stroud 2001, Kana et al 2002, CSE 2003a,b, 2004, 2005a).

The primary purpose of beach monitoring is to:

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

The present monitoring report builds on previous results and includes comparisons of the May 2006 conditions with those of June 1999 and May 2005. In addition to site comparisons from previous reports, CSE has included survey data and comparisons for Bear Island and Shackleford Banks in the present study. Bogue Banks, Bear Island, and Shackleford Banks comparisons are made on a May 2005 to May 2006 basis. Bear Island was first surveyed by CSE in October 2004 and has been included in the regular scope of work since then. Shackleford Banks was surveyed by CSE for the first time in May 2005.

Hurricane *Ophelia* impacted Bogue Banks in September 2005. The storm waves associated with the hurricane removed over 1.5 million cubic yards of sand from the beach (top of dune to –11 ft NGVD) (CSE 2005b). Emerald Isle and Indian Beach/Salter Path lost an average of ~14 cy/ft each. Pine Knoll Shores and Atlantic Beach fared slightly better, reporting losses of 10.99 cy/ft and 10.1 cy/ft (respectively). Plans to renourish losses caused by Hurricane *Ophelia* have been established. Beach construction to replace ~1.1 million cubic yards is set to begin in January 2007.

Beach survey data since June 2004 show the net effect of the Phase 3 nourishment project, which added 690,868 cy of sand to the western end of Emerald Isle, as well as the effects of Hurricane *Ophelia* in September 2005.

The focus of this report is on island-wide beach changes since June 1999 and May 2005 with emphases on the change in volume of sand within the littoral zone and on the accounting of beach nourishment volumes. Following an overview of the entire Bogue Banks, the report provides summaries of the findings for each community, including Bear Island and Shackleford Banks.

2.0 METHODOLOGY

2.1 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 followed recommendations of the National Academy of Science (NRC 1995). No corrections are required for water depth by these methods because the measurements involve placement of a rod or prism directly on the bottom. Reliable land survey techniques are simply extended offshore by this method. CSE and the majority of professional organizations favored this method over boat surveys using fathometers because the latter require uncertain corrections for tide, waves, boat motion, and acoustic drift. Many of the problems associated with historical surveys can be traced to these imprecisions (NRC 1995). In the past few years with the availability of real-time-kinematic (RTK) GPS x–y–z positioning (post 1999), it is now possible to reduce (but not completely eliminate) the errors associated with boat surveys.

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

On Bogue Banks, CSE mobilized survey crews and re-established 118 control points near the shoreline. Generally, each control point consists of a monument or survey nail in concrete placed 50–300 feet (ft) landward of the foredune. Spacing of points is generally around 1,000–1,600 ft and varies to accommodate existing development. Control points are spaced ~500 ft apart near the inlets. Many control points are at road intersections and/or fixed/recoverable structures. Each point was surveyed to standard North Carolina state plane coordinates (NAD'83) and vertical datum (NGVD'29) using a Trimble Model 5700 RTK-GPS, transiting from known control points. Stationing is numbered consecutively from west to east. Appendix I lists the control points, coordinates, and vertical elevation for each station, as well as a detailed map of Bogue Banks profile lines. For Year 1 of the BBBNMP, CSE established eight additional control points and nine additional profiles for purposes of monitoring Bogue Inlet and Beaufort Inlet. Figure 2.1 shows the general location of all 120 beach profile lines on Bogue Banks along with approximate town boundaries.

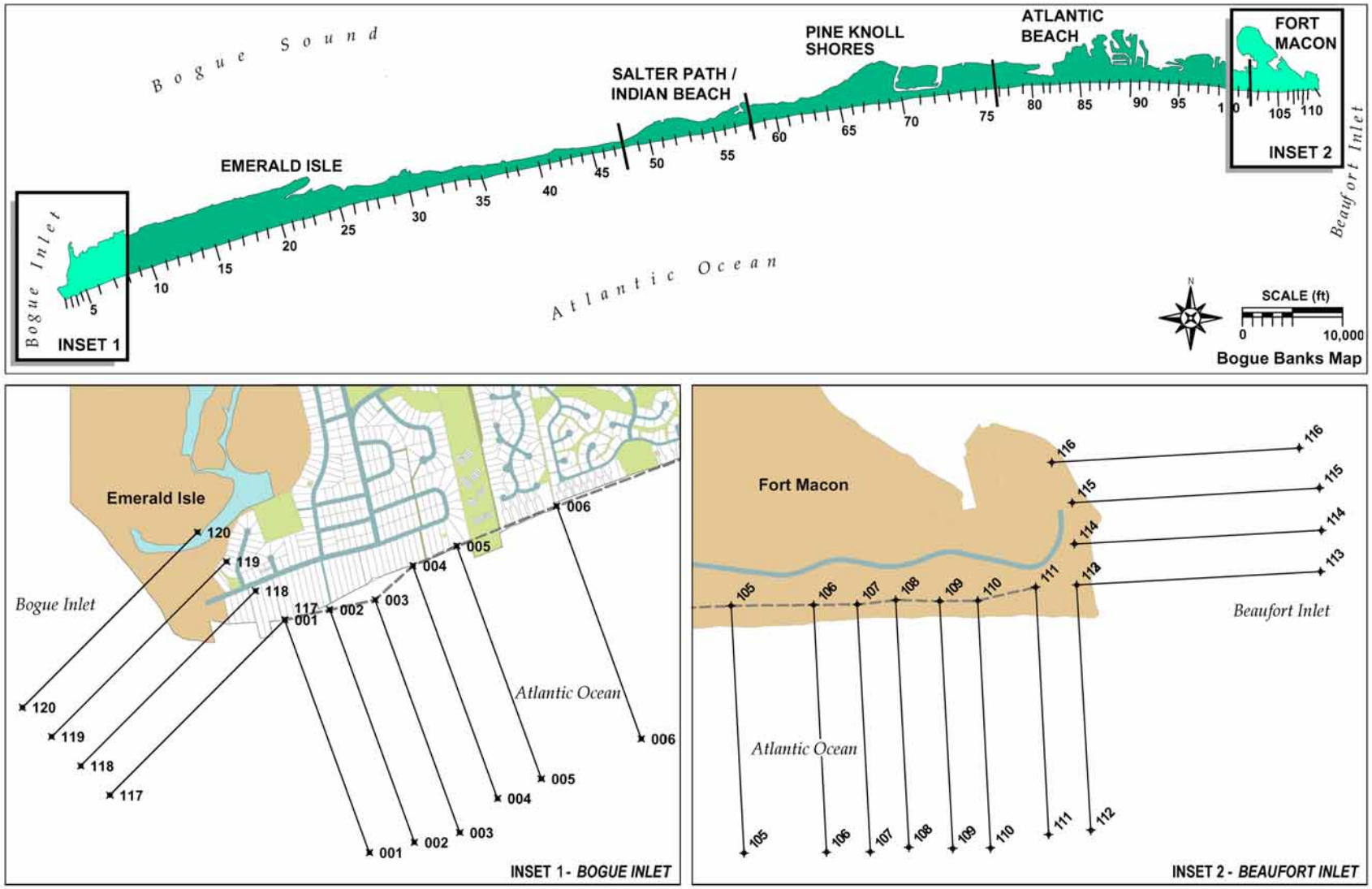


FIGURE 2.1. General location map of beach profile lines established in 1999 and resurveyed in December 2003, June 2004, May 2005, and May 2006 under the present BBBNMP project. Profile lines 112 through 120 were established in December 2003.

In October 2004, CSE established 18 lines on Bear Island at 1,000-ft spacing. The general locations of the Bear Island profiles are shown in Figure 2.2 (upper). CSE re-acquired the USACE baseline and 24 control points on Shackleford Banks (Fig 2.2, lower) in May 2005 to establish profile lines at this location. These stations are spaced roughly 2,000 ft apart.

Profiles along Bogue Banks 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 2.3 illustrates the data collection equipment that CSE used on Bogue Banks for the present survey. The system requires a base station (Fig 2.3, upper left) calibrated to known reference points. It receives signals from up to 12 satellites and communicates with a rover unit(s) to provide horizontal and vertical coordinates (georeferenced position and elevation). The rover unit includes a data logger for recording x-y-z data at each point occupied. On the dunes, around critical habitat, or in shallow water, shot points must be occupied on foot (Fig 2.3, upper right and lower).

For offshore data collection, CSE used a shallow-draft C-Dory™ (*RV Irie*), which provides a fully enclosed cabin for the electronics (Fig 2.4, upper left). The GPS receiver was mounted near the transom over the transducer to minimize boat motion for the echo sounder. CSE used a Odom Hydrotrac™ HT-100 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 2.4 (upper right). Pre-set navigation lines matching the desired profile tracks were programmed into Trimble HydroPro™ for guidance. This facilitated navigation by establishing a course and way-points so that profiles conformed to the required azimuth. The survey data were logged using Trimble-HydroPro™ software (Fig 2.4, center), which was set up with photo images over the area. As Figure 2.4 (center) illustrates, this allowed the boat operator to determine when the land-based section of a line had been crossed. CSE generally ran lines from seaward to landward, because the resulting profile tends to be smoother (less motion moving the same direction as incident waves) and it is easier to control the vessel through the surf zone. At the end of the line, the vessel turned out and proceeded to the seaward end of the next line (Fig 2.4, lower left).

2.2 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 2.5, upper) and automatically deleted from the data set. Post-process filtering further reduced spikes as well as averaged adjacent points to provide a more realistic surface (Fig 2.5, lower).

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

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

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 2.6 illustrates the profile volume reference points and contours used in the present report. The selection of contours (vertical boundaries) was arbitrary and can be easily adjusted in BPAS. The contours chosen were based on previous analyses dating to 1999 and on experience at other sites, because they represent a useful division of the beach in the cross-shore dimension. Unit-volume* calculations (cf, Fig 2.7) distinguish the quantity of sediment in the dunes, on the dry beach, in the intertidal zone to wading depth, and in the remaining area offshore to the approximate limit of profile change. In 1999, it was assumed the limit of measurable change was in depths of (~)–15 ft NGVD.

[*Figure 2.7 illustrates the concept of unit beach volume between reference contours applied over one linear foot of shoreline. When common boundaries are used from profile to profile or survey to survey, the relative as well as absolute variation in beach condition can be determined. In the example, the "eroded" beach profile contains half as much sand volume to low tide wading depth as the "normal" beach profile.]

For budgeting and other reasons, the 1999 survey terminated between the –10 ft and –15 ft contours, seaward of the outer bar. While it is accepted engineering practice to extrapolate the seaward ends of profiles along the natural slope, CSE prefers to avoid this uncertainty. In 1999, CSE–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 performed volume change calculations in the present report using various depths between –15 ft and –20 ft NGVD. Depths between –15 ft and –20 ft NGVD off Bogue Banks are now believed to capture nearly all of the sand moving in the cross-shore direction from year to year at decadal scales (cf, CSE 2000, CSE-Stroud 2001).

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

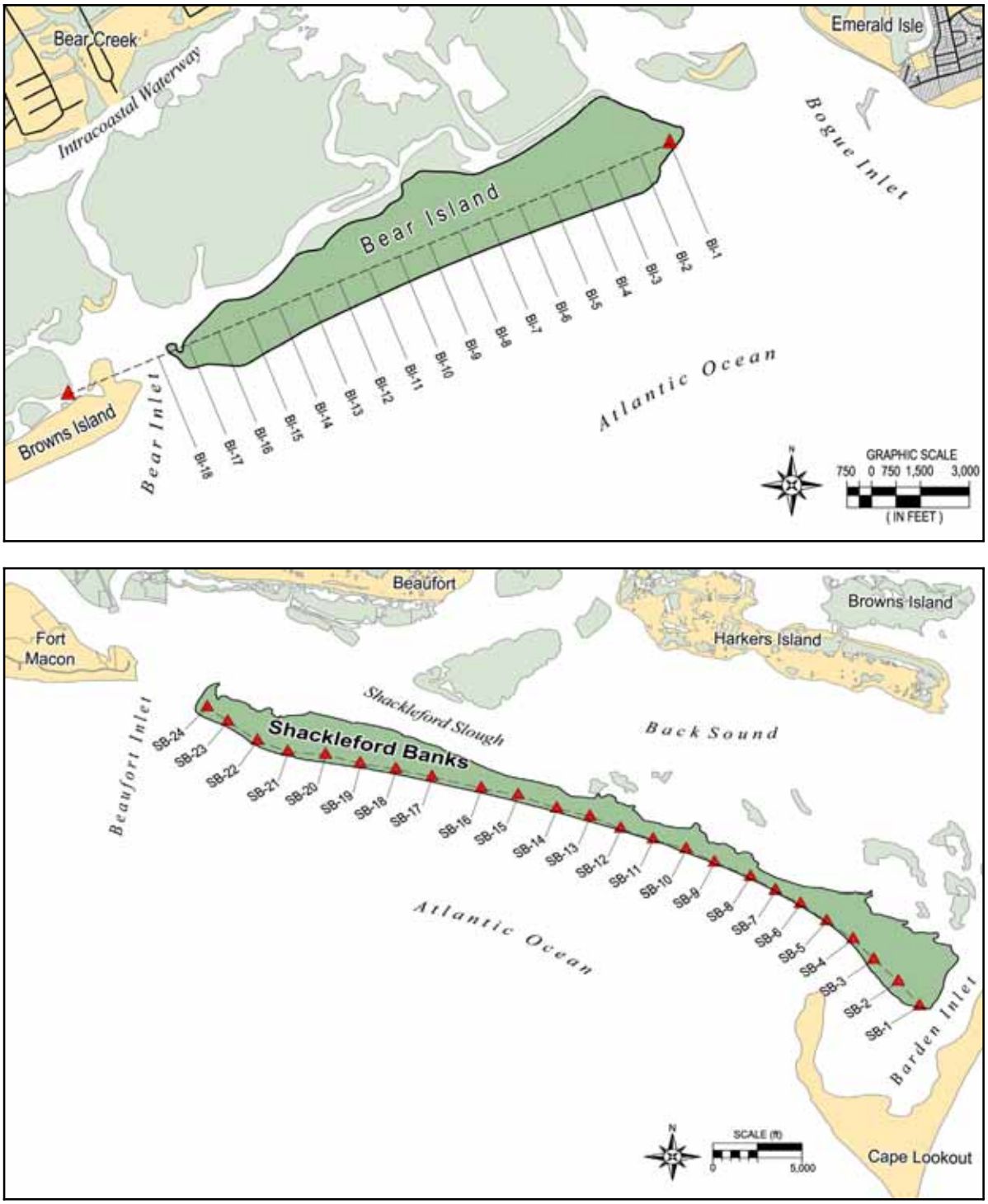


FIGURE 2.2. General location map of beach profile lines for Bear Island (upper) and Shackleford Banks (lower).

FIGURE 2.3. [UPPER LEFT] RTK-GPS base station receiver and radio link to rover unit. [UPPER RIGHT] Rover unit and data logger for close work in the dunes. [LOWER LEFT] Measurements around sensitive habitat (seabeach amaranth). [LOWER RIGHT] Measurements in the surf zone.

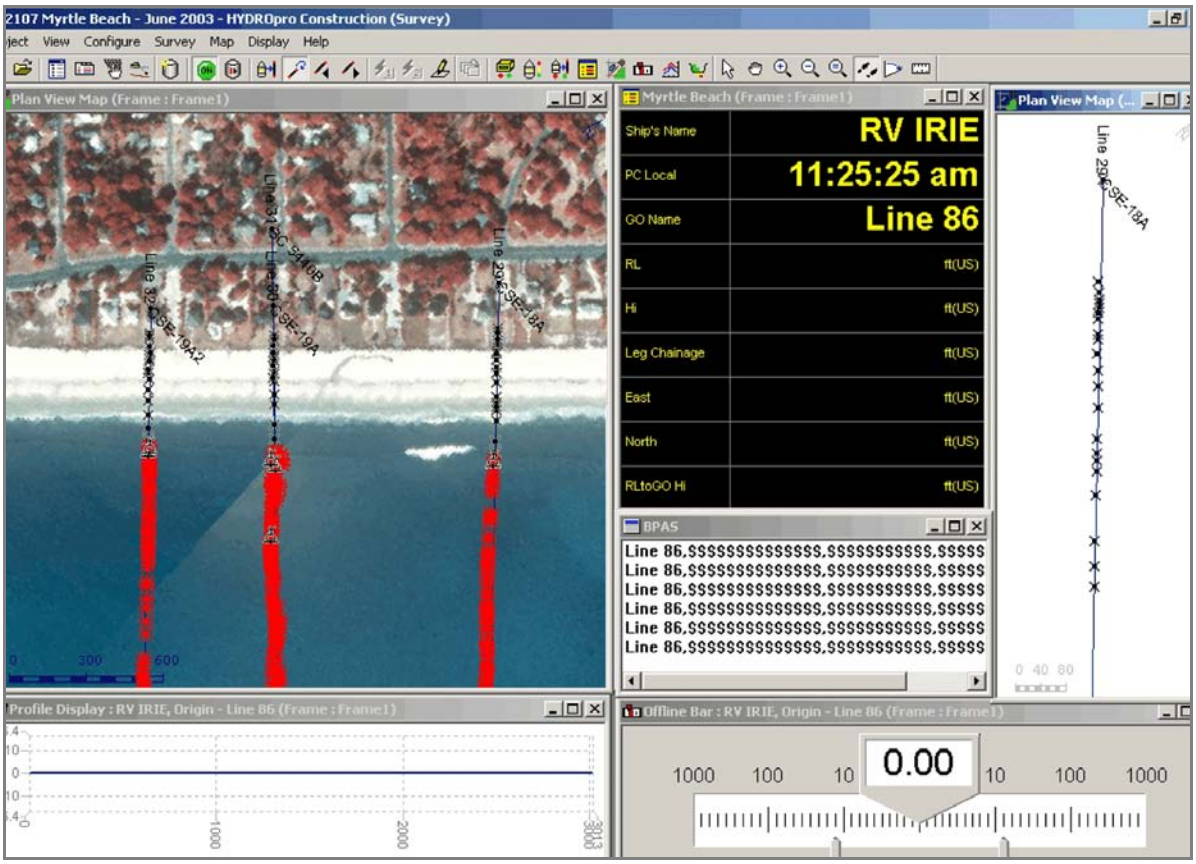


FIGURE 2.4. CSE's offshore equipment and survey vessel for use in shallow water.
[UPPER LEFT] 22-ft C-Dory™ with 7-inch draft and enclosed cabin.
[UPPER RIGHT] Navigation and data logging console.
[CENTER] HydroPro™ data logging and processing software showing track lines and overlap in real time with shore-based portion of the survey.
[LOWER LEFT] The vessel turns out at the landward end of the line and proceeds to the seaward end of the next line.

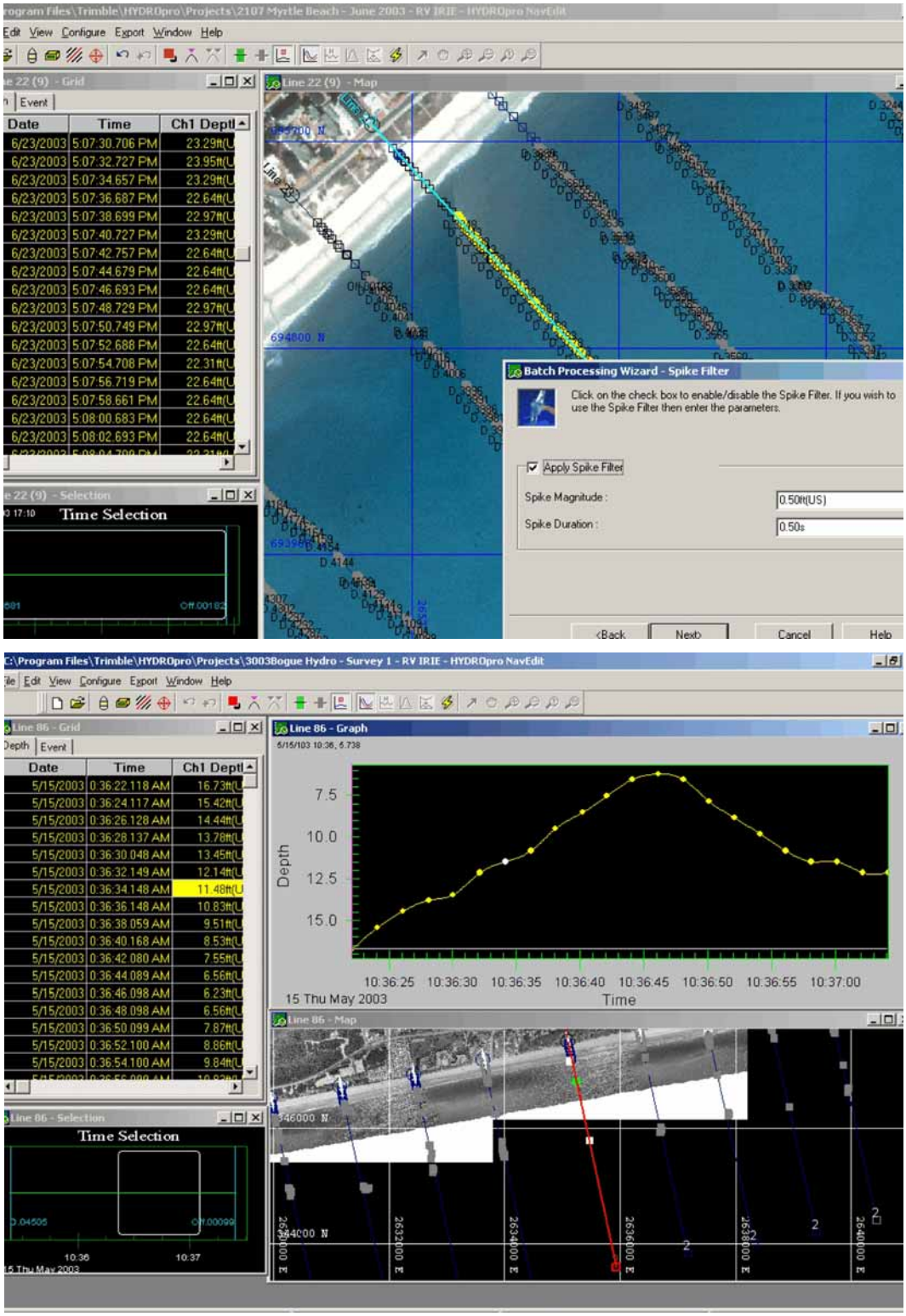
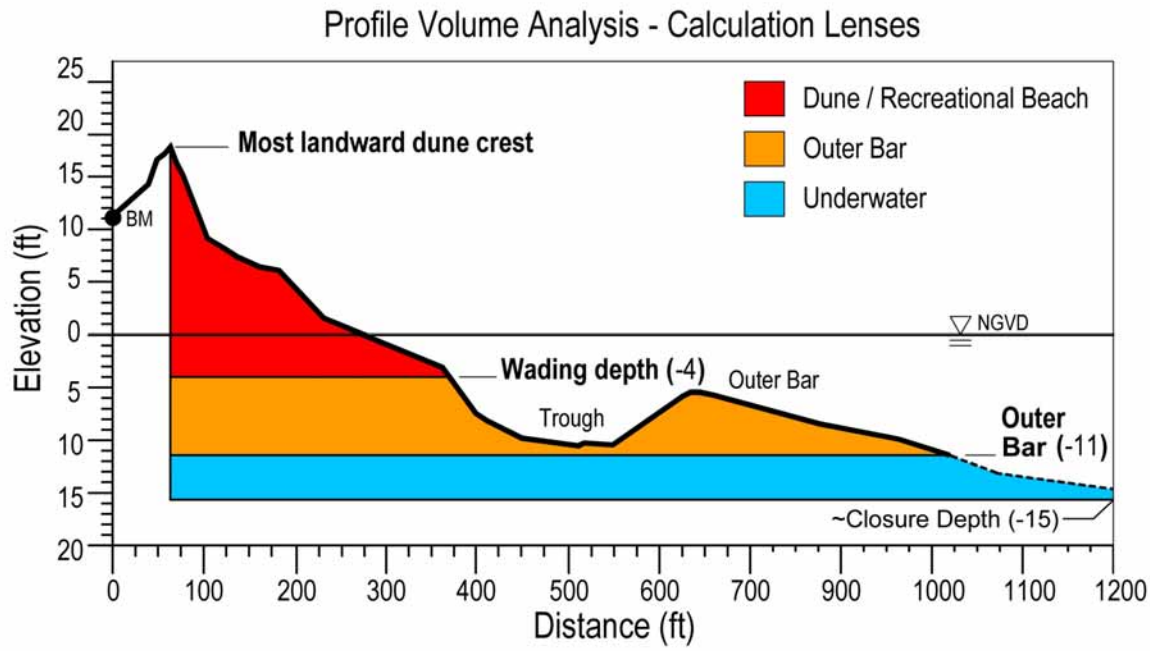


FIGURE 2.5. Trimble-HydroPro™ software was used by CSE to allow batch processing and editing of large files (data sampling rate used by CSE in Bogue Banks was 10 Hz). Software was used to filter spikes (upper) and provide floating point averages to yield smoother, more realistic profiles such as the one shown over the bar (lower).



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 2.6. Three reference zones used for calculation of sand volume changes along Bogue Banks 2005–2006 (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. NOTE: Limited calculations were also made for some reaches using deeper depths based on evidence of profile closure in the range –15 ft to –20 ft NGVD — detailed in a later section of the report.

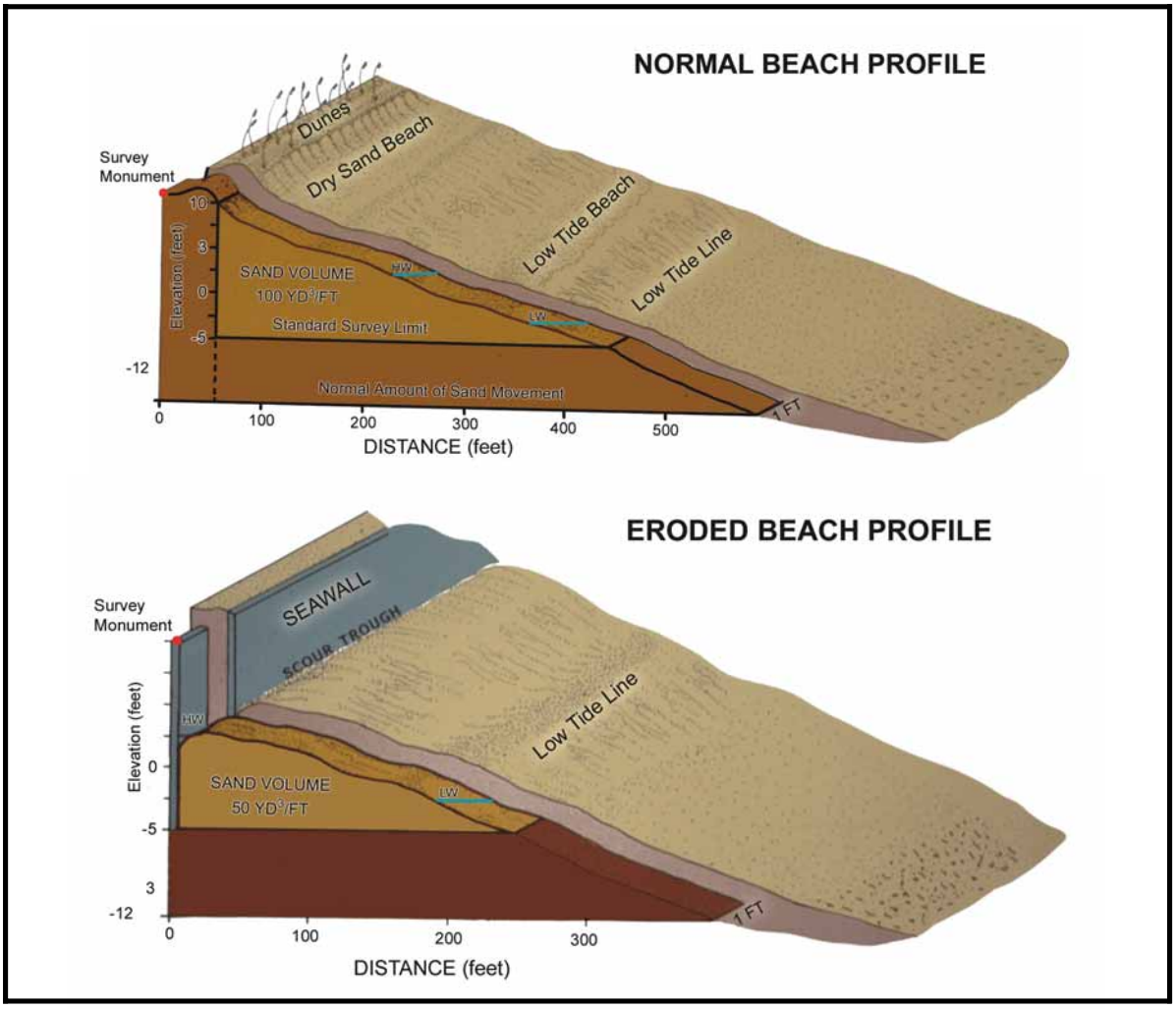


FIGURE 2.7. The concept of unit sand volume along the beach, which provides a quantitative measure of beach condition and changes before and after nourishment. The <u>yearly</u> limit of measurable sand movement ("profile closure depth") along Bogue Banks is thought to occur at depths of about 15 ft (±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 3 of BBBNMP) involved profiling to –30 ft or deeper. Post-*Ophelia* profiles (September 2005) indicate a range of closure depths from –15 ft to –20 ft NGVD for the present data set. [Diagram after Kana 1990]

TABLE 1. Bogue Banks shoreline reaches and numbers of profiles available for analysis for June 1999, September 1999, June 2000, December 2003, June 2004, May 2005, and May 2006. [Reach lengths updated and revised slightly from CSE -Stroud (1999). *Profiles at reach boundaries are applicable to adjacent reaches.]

Reach	Reach Length (ft)	*Applicable Profile Numbers	Number of Usable Profiles by Date (Jun'99 / Sep'99 / Jun'00 / Dec'03 / Jun'04 / May'05 / May'06)	
			@ low tide	@ outer bar
Bogue Inlet	6,772	1-8	6 / 0 / 8 / 8 /8/ 8 / 8	5 / 0 / 6 / 8 / 8 / 8 / 8
Emerald Isle-West	22,303	8-25	17 / 3 / 17 / 17 / 17 / 17 / 17	17 / 3 / 17 / 17 / 17 / 17 / 17
Emerald Isle-Central	15,945	25-36	11 / 2 / 11 / 11 / 11 / 11 / 11	11 / 1 / 11 / 11 / 11 / 11 / 11
Emerald Isle-East	12,900	36-48	12 / 2 / 12 / 12 / 12 / 12 / 12	12 / 2 / 12 / 12 / 12 / 12 / 12
Indian Beach-Salter Path	12,986	48-58+	9 / 2 / 10 / 10 / 10 / 10 / 10	9 / 1 / 10 / 10 / 10 / 10 / 10
Pine Knoll Shores West	9,182	59-65	6 / 2 / 7 / 7 / 7 / 7 / 7	6 / 1 / 7 / 7 / 7 / 7 / 7
Pine Knoll Shores East	14,785	65-76	10 / 2 / 11 / 11 / 11 / 11 / 11	10 / 2 / 11 / 11 / 11 / 11 / 11
Atlantic Beach	26,322	76-102	26 / 5 / 26 / 26 / 26 / 26 / 26	24 / 5 / 26 / 26 / 26 / 26 / 26
Fort Macon State Park	7,199	102-112	9 / 0 / 9 / 9 / 10 / 10 / 10	9 / 0 / 9 / 9 / 10 / 10 / 10
	128,392	(24.32 miles)		

3.0 RESULTS

3.1 Island-Wide Trends

Appendices II and III contain plotted profile lines and unit volumes by station and reach (political jurisdiction) for May 2005–May 2006. Appendix III-A provides calculations from the foredune crest to –4 ft NGVD (low-tide wading depth). Appendix III-B contains similar data measured to –11 ft NGVD (outer bar) for previous surveys, including the 2006 survey results. Appendix III-C provides the 1999–2006 results measured to –15 ft NGVD. The bottom of each table in Appendix III (A–C) contains averages and totals by reach. Reference starting points and, in several cases, seaward calculation cutoff distances are given in the first few columns of each table. Unit-volume changes for selected dates are given in later columns. The net change between profiles is computed using the average-end-area method which applies the results for adjacent stations over the indicated shoreline distance ("Distance from Last") between profiles.

Table 2 summarizes the beach volume results by reach for June 1999 to May 2006 and for May 2005 through May 2006. Along Bogue Banks, 11 reaches are referenced: nine reaches match those originally established by CSE-Stroud (1999); two new reaches (Bogue Inlet Channel and Beaufort Inlet) extend the limits of the survey. [Note: These reaches are not included in the "oceanfront" totals.] Station 112 was added at the eastern end of Fort Macon State Park (FMSP) in 2003 (see Fig 2.1). 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 profile lines 8 through 76.

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

TABLE 2. Beach volume changes by reach for Bogue Banks (NC) – June 1999 to May 2006. Volume calculations for Bear Island are for October 2004 to May 2006. Shackleford Banks data are presented for May 2005 and May 2006.

Dune to -4 ft NGVD													
Summary By Reach - Beach Volumes			Weighted Avg (cy/ft)							June 1999 — May 2006		May 2005 — May 2006	
Reach	Profiles	Reach Length (ft)	Jun-99	Jun-00	Apr-03	Dec-03	Jun-04	May-05	May-06	Wtd Avg (cy/ft)	Net (cy)	Wtd Avg (cy/ft)	Net (cy)
Bogue Inlet-Channel	117-120	1,900	-	-	-	44.0	38.8	44.4	66.6	-	-	22.2	42,160
Bogue Inlet-Ocean	1-8	6,772	147.4	156.7	162.8	164.9	171.8	173.8	143.7	-3.7	-25,335	-30.2	-204,216
El-West	8-25	22,303	76.7	80.1	87.8	93.2	95.6	119.9	109.9	33.2	739,518	-10.0	-223,735
El-Central	25-36	15,945	74.2	79.6	112.9	111.4	112.1	116.6	111.0	36.8	586,251	-5.6	-88,885
El-East	36-48	12,900	72.1	72.5	134.3	123.6	126.4	124.1	121.7	49.7	640,656	-3.2	-41,418
IB/SP	48-58+	12,986	69.2	72.6	101.8	107.9	134.9	131.6	121.6	52.5	681,474	-9.9	-128,931
PKS-West	58-65	9,182	72.7	66.2	102.6	99.8	100.5	100.6	94.0	24.7	226,660	-7.3	-66,901
PKS-East	65-76	14,785	66.4	64.0	99.4	96.8	99.9	94.3	87.7	21.3	315,186	-6.6	-97,553
AB	76-102	26,322	93.3	91.2	93.1	88.2	92.8	128.6	118.4	25.1	661,520	-10.2	-269,512
FMSP	102-112	7,199	98.3	90.5	82.9	72.9	74.1	104.8	102.9	3.3	23,930	-1.9	-13,739
Beaufort Inlet	112-116	2,250	-	-	-	126.6	145.0	160.5	144.4	-	-	-10.0	-22,410
County Project	**8-76**	**88,099**	**72.2**	**73.7**	**104.5**	**104.3**	**110.5**	**115.6**	**108.4**	**36.2**	**3,189,745**	**-7.3**	**-647,422**
Entire Oceanfront	**1-112**	**128,392**	**81.9**	**82.6**	**104.1**	**102.5**	**108.1**	**121.0**	**112.0**	**30.0**	**3,849,860**	**-8.8**	**-1,134,889**
			Weighted Avg (cy/ft)									May 2005 — May 2006	
							Oct-04	May-05	May-06			Wtd Avg (cy/ft)	Net (cy)
Bear Island	1-18	17,000					107.6	105.9	96.3			-9.6	-162,365
Shackleford	1-24	46,001						114.7	104.9			-9.8	-450,401

Dune to -11 ft NGVD													
Summary By Reach - Beach Volumes			Weighted Avg (cy/ft)							June 1999 — May 2006		May 2005 — May 2006	
Reach	Profiles	Reach Length (ft)	Jun-99	Jun-00	Apr-03	Dec-03	Jun-04	May-05	May-06	Wtd Avg (cy/ft)	Net (cy)	Wtd Avg (cy/ft)	Net (cy)
Bogue Inlet-Channel	117-120	1,900	-	-	-	101.7	88.9	98.9	167.9	-	-	69.0	131,171
Bogue Inlet-Ocean	1-8	6,772	363.2	375.5	323.0	330.9	329.7	422.1	377.8	14.7	99,426	-44.3	-299,980
El-West	8-25	22,303	208.1	211.5	228.3	233.6	240.5	267.3	264.3	48.1	1,072,208	-11.2	-249,571
El-Central	25-36	15,945	194.2	201.4	247.9	243.9	249.0	257.0	240.8	46.6	742,535	-16.3	-259,649
El-East	36-48	12,900	193.3	191.7	281.0	263.4	268.1	268.0	255.6	62.3	803,382	-13.8	-177,539
IB/SP	48-58+	12,986	188.5	195.3	244.6	242.8	293.0	286.4	268.3	79.8	1,035,738	-18.1	-234,853
PKS-West	58-65	9,182	189.6	183.5	237.5	222.6	219.3	239.9	225.6	38.9	357,306	-16.3	-149,924
PKS-East	65-76	14,785	192.9	188.5	245.7	232.7	237.3	233.2	219.9	27.1	399,946	-13.3	-197,027
AB	76-102	26,322	234.5	230.6	245.4	237.1	239.6	306.7	284.1	49.6	1,305,619	-22.7	-596,587
FMSP	102-112	7,199	228.1	226.4	218.2	208.1	202.1	267.9	256.1	24.9	179,302	-11.8	-84,893
Beaufort Inlet	112-116	2,250	-	-	-	310.9	348.9	417.0	368.0	-	-	-24.9	-56,020
County Project	**8-76**	**88,099**	**195.9**	**197.9**	**245.8**	**240.0**	**251.9**	**260.2**	**246.0**	**50.1**	**4,411,116**	**-14.4**	**-1,268,564**
Entire Oceanfront	**1-112**	**128,392**	**214.4**	**215.6**	**248.3**	**242.4**	**250.7**	**278.7**	**261.3**	**46.7**	**5,995,463**	**-17.5**	**-2,250,025**
			Weighted Avg (cy/ft)									May 2005 — May 2006	
							Oct-04	May-05	May-06			Wtd Avg (cy/ft)	Net (cy)
Bear Island	1-18	17,000					298.6	290.7	282.5			-8.2	-139,170
Shackleford	1-24	46,001						261.1	246.2			-14.9	-686,685

Dune to -15 ft NGVD													
Summary By Reach - Beach Volumes			Weighted Avg (cy/ft)							June 2004 — May 2006		May 2005 — May 2006	
Reach	Profiles	Reach Length (ft)	Jun-99	Jun-00	Apr-03	Dec-03	Jun-04	May-05	May-06	Wtd Avg (cy/ft)	Net (cy)	Wtd Avg (cy/ft)	Net (cy)
Bogue Inlet-Channel	117-120	1,900					86.4	150.0	234.7	60.8	115,528	-	-
Bogue Inlet-Ocean	1-8	6,772					-	627.2	592.4	-	-	-34.8	-235,915
El-West	8-25	22,303					374.6	410.8	405.3	30.7	685,012	-5.5	-122,588
El-Central	25-36	15,945					387.9	402.9	387.2	-0.7	-11,291	-15.6	-249,437
El-East	36-48	12,900					409.2	415.9	407.5	-1.6	-20,827	-9.9	-127,967
IB/SP	48-58+	12,986					436.1	436.7	422.4	-13.7	-178,053	-14.2	-184,756
PKS-West	59-65	9,182					356.6	387.2	372.0	9.5	87,624	-15.9	-146,284
PKS-East	65-76	14,785					387.5	384.5	374.6	-12.9	-190,587	-9.9	-146,248
AB	76-102	26,322					398.0	481.2	461.1	63.1	1,661,386	-20.1	-528,048
FMSP	102-112	7,199					345.9	456.0	442.5	96.6	695,424	-2.0	-14,647
Beaufort Inlet	112-116	2,250					483.6	603.1	500.7	-	-	-	-
County Project	**8-76**	**88,099**					**392.4**	**407.4**	**396.6**	**4.2**	**371,879**	**-11.1**	**-977,280**
Entire Oceanfront	**1-112**	**128,392**					**390.8**	**436.9**	**422.7**	**21.3**	**2,728,689**	**-13.7**	**-1,755,890**
			Weighted Avg (cy/ft)									May 2005 — May 2006	
							Oct-04	May-05	May-06			Wtd Avg (cy/ft)	Net (cy)
Bear Island	1-18	17,000					463.6	464.3	460.5			-3.8	-64,820
Shackleford	1-24	46,001						412.1	397.7			-14.5	-665,033

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

1) There has been an ~6.0 million cubic yard net increase in beach volume along Bogue Banks between June 1999 and May 2006. This equates to a weighted average gain of 46.7 cy/ft within the primary computation boundaries to –11 ft NGVD.

2) Bogue Banks lost 2.25 million cubic yards (17.5 cy/ft) between May 2005 and May 2006 from the foredune to the outer bar (-11 ft NGVD).

3) The 17-mile county project reach (designated by profile lines 8 to 76) lost 1.27 million cubic yards (14.4 cy/ft) of sand over the past year (to -11 ft NGVD). Atlantic Beach lost ~600,000 cy between May 2005 and May 2006.

4) The island-wide and county project volume losses to low-tide wading depth (–4 ft NGVD) for 2005–2006 were 1.13 million cubic yards (8.8 cy/ft) and 647,422 cy (7.3 cy/ft) (respectively) (Table 2). The island-wide and county volume losses to –11 ft were 2.25 million cubic yards and 1.27 million cubic yards (respectively). This means that 50 percent of the net loss can be accounted for in the upper beach island-wide. For the 17-mile-long county project, 51 percent of the volume losses are accounted for in the upper beach. In simple terms, much of the loss in sand volume was split evenly between the recreational beach and the beach offshore to the outer bar.

Figure 3.1-1 show the trends in unit beach volumes and unit beach volume changes by reach and island-wide for June 1999 and May 2006. Figure 3.1-1 (upper) compares 1999, 2004, 2005 and 2006 unit volumes to the outer bar. Also shown is a reference line for the "Target Minimum Profile Volume" similar to a criteria used by CSE–Stroud (1999) for the initial project planning.* The calculation boundaries are from the approximate dune crest to –11 ft NGVD. Figure 3.1-1 (lower) shows the changes in unit volumes between May 2005 and May 2006.

The largest changes in unit sand volume between May 2005 and May 2006 occurred at the Bogue Inlet–Ocean reach (profile lines 1-8). Bogue Inlet–Ocean lost 44.3 cy/ft in sand volume to -11 ft NGVD. Incidentally, this highly dynamic part of Bogue Banks had the highest increase in sand volume during the previous survey year (June 2004-May 2005) at 92.4 cy/ft. All of the reaches on Bogue Banks have experienced losses in sand volume since May 2005 except for the Bogue Inlet–Channel reach (profile lines 117-120) where there was a net gain in sand volume of 69.0 cy/ft. Average unit losses of 22.7 cy/ft have occurred at Atlantic Beach since May 2005. The Emerald Isle–West reach realized sand volume reduction of 11.2 cy/ft, which was the lowest rate of loss on the oceanfront. The

average net decrease in sand volume measured to the outer bar was 17.5 cy/ft over the entire oceanfront (Table 2).

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

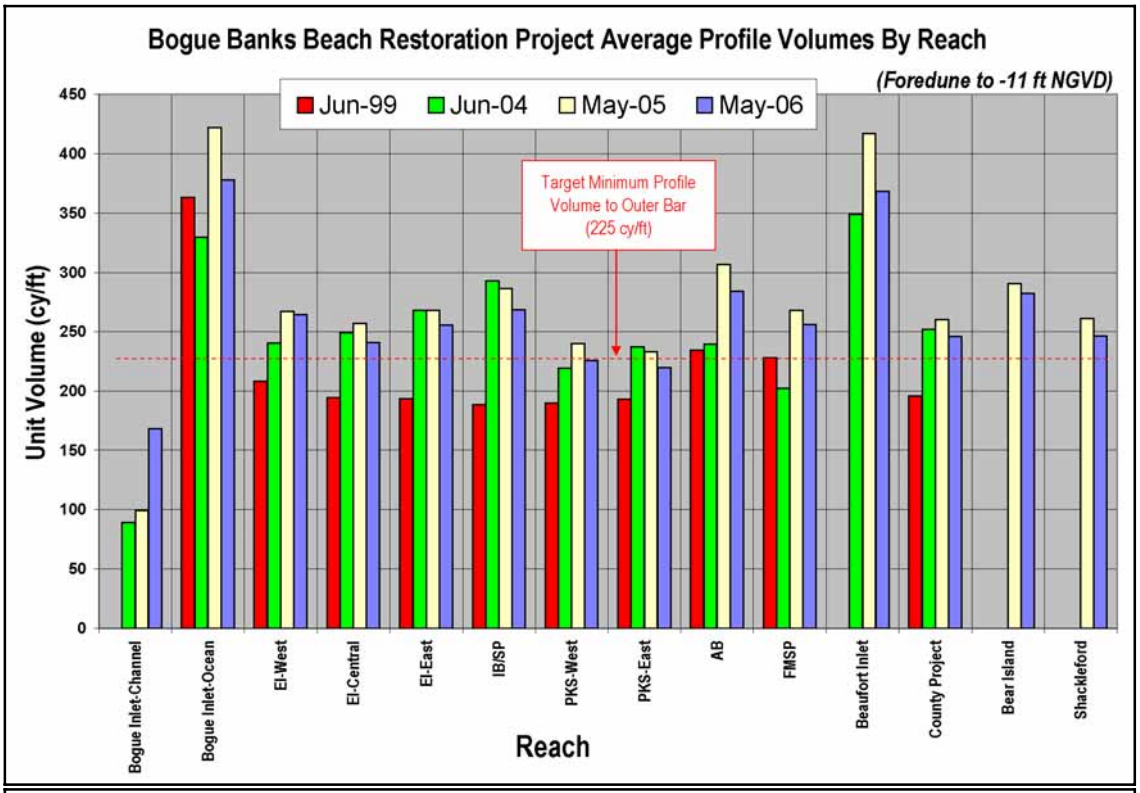
Previous studies (eg, CSE-Stroud 1999) have shown that the typical rate of beach change along Bogue Banks is of the order 2 cy/ft/yr. During the past survey year (May 2005 – May 2006), the majority of the island lost sand at rates of 10–20 cy/ft. These losses are a direct reflection of the impact of Hurricane *Ophelia* in September 2005. A posthurricane survey by CSE in September 2005 reported total average sand volume losses of 13.3 cy/ft between profile lines 1 and 112 (CSE 2005b). An additional ~4.2 cy/ft have been lost (to –11 ft) since September 2005.

Figure 3.1-1 illustrates why it is useful to consider the absolute volume of sand in the profile (unit-width volumes in Figure 3.1-1, upper) as well as the volume change between surveys. The largest sand gains between 2004 and 2005 occurred along the Bogue Inlet–Ocean reach (~92 cy/ft accretion), leaving it with much more sand than other reaches. Since May 2005, the reach has lost nearly 45 cy/ft, yet it still retains more sand than is typical for Bogue Banks. Much of the surplus sand volume is associated with the updrift swash platform of Bogue Inlet that fronts much of this reach.

Gains, as a result of nourishment in early 2005, in the nourished reaches of Bogue Inlet–Ocean, Emerald Isle–West, Atlantic Beach, and Fort Macon State Park have enabled nearly the entire island to exceed the target minimum volume.

A review of the average unit volumes for 2005–2006 to the outer bar shows that:

- The largest decrease in unit volume occurred at the Bogue Inlet–Ocean reach.
- Other large decreases occurred at Atlantic Beach.
- Decreases in reach unit volumes are seen at all reaches along the Bogue Banks oceanfront.
- With the exception of Pine Knoll Shores–East, all oceanfront reaches exceeded the target minimum profile volume of 225 cy/ft in May 2006 (measured to –11 ft NGVD).



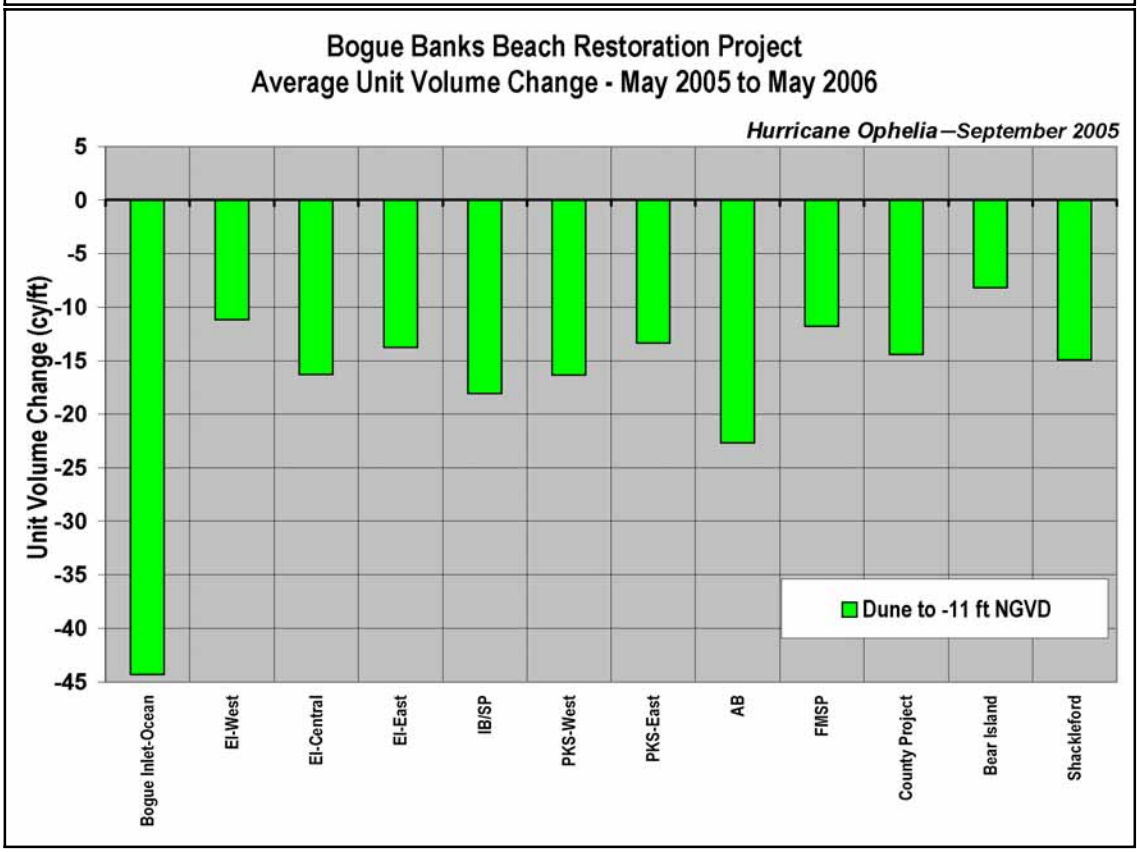


FIGURE 3.1-1. Trends (by reach) in average dune, beach, and inshore sand volume measured to –11 ft (including outer bar) between May 2005 and May 2006 (upper). Lower graph illustrates the change by reach for the one-year period.

3.2 Comparison with Nourishment Volumes

Between 2002 and 2005, a total of 8,557,569 cy of sand were placed along the Bogue Banks oceanfront in eight separate nourishment projects (Fig 3.2-1, Table 3). The most recent projects supplied 3,911,597 cy of sand (estimated in place volume, CCSPO 2005) to the western end of Emerald Isle, Atlantic Beach, and Fort Macon State Park between February and April 2005. There were no nourishment project along Bogue Banks between May 2005 and May 2006.

Island-wide surveys from 1999 and 2006 were used to compare net volume changes with nourishment volumes added. The difference represents an estimate of background erosion (or accretion) rates for various reaches.

Estimates of background erosion (summarized by reach) are listed in Table 4. Some adjacent reaches are combined to facilitate interpretation of the results. In reaches where nourishment volume exceeds the surveyed volume change, background erosion is evident. Where the surveyed volume change exceeds the nourishment volume added, there is a net accretion of sand. The nourishment and natural beach volume changes are shown in Figure 3.2-2 (upper). Atlantic Beach has received the most total nourishment volume of any reach and has experienced the most loss in volumes. Higher than usual loss rates are thought to be the result of high proportions of fine sediment in the Brandt Island spoil as well as the impact of Hurricane *Ophelia*.

The average annual background erosion rate for the Bogue Banks–Oceanfront is 2.9 cy/ft/yr since June 1999 (measured to –11 ft). Along Atlantic Beach and Fort Macon State Park at the eastern end of Bogue Banks, erosion rates have averaged 8.4 cy/ft/yr since June 1999. This is sharply contrasted by the accretional western end of Bogue Banks where the Bogue Inlet–Ocean reach and Emerald Isle–West have gained an average of 2.4 cy/ft/yr since June 1999. This includes an average annual volume gain of 2.9 cy/ft/yr in the Emerald Isle–West reach.

Volume losses and gains (factoring out nourishment) are shown for each community in Figure 3.2-2 (lower). The eastern reaches have generally experienced high rates of erosion while the western reaches (with the exception of EI–East and EI–Central) have experienced significant accretion over the last seven years. The central reaches (PKS to EI–Central) have volumetric accretion/erosion rates that are more typical of beaches in this region (CSE-Stroud 1999). The background erosion rate estimates for the seven-year period (1999–2006) are much higher than the results for 1999 to 2005 (CSE 2005a) due to the impact of Hurricane *Ophelia*.*

[*Hurricane *Ophelia* caused an estimated 1.53 million cubic yards of erosion on Bogue Banks to the outer bar. Annualized over the last seven years, the additional erosion rate due to *Ophelia* is 1.71 cy/ft/yr. The background rate of erosion for Bogue Banks without the effect of *Ophelia* is 1.2 cy/ft/yr, which is more in line with beaches in this region. This figure assumes that there was not significant volume change between the May 2005 survey and the post-*Ophelia* survey.]

Calculations of remaining nourishment volume for Phases 1, 2, and 3 of the county project are shown in Appendix III-D. Plans are underway to renourish Pine Knoll Shores, Indian Beach/Salter Path, and Emerald Isle in two projects scheduled for winter 2007. FEMA funding will be used to accomplish ~1.1 million cubic yards and restore sand losses due to Hurricane *Ophelia* (along EI, IB/SP, and PKS). A second project totaling up to 900,000 cy will be implemented at Pine Knoll Shores under the federal Section 933 program. As a result of these planned projects, certain project surveys will be performed upon completion by CSE (project engineer for the FEMA-sponsored work). CSE recommends that the postnourishment project surveys be scheduled in May 2007 to coincide with the annual monitoring schedule under the BBBNMP, which will reduce the scope of field data collection and monitoring expense for 2007. CSE suggests that the BBBNMP field data collection in May 2007 can be limited to resurvey of Atlantic Beach, Fort Macon State Park, Bear Island, and Shackleford Banks. These data could then be combined with the post nourishment surveys along PKS, IBSP and EI to perform the island wide analysis of changes, consistent with recent monitoring reports.

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

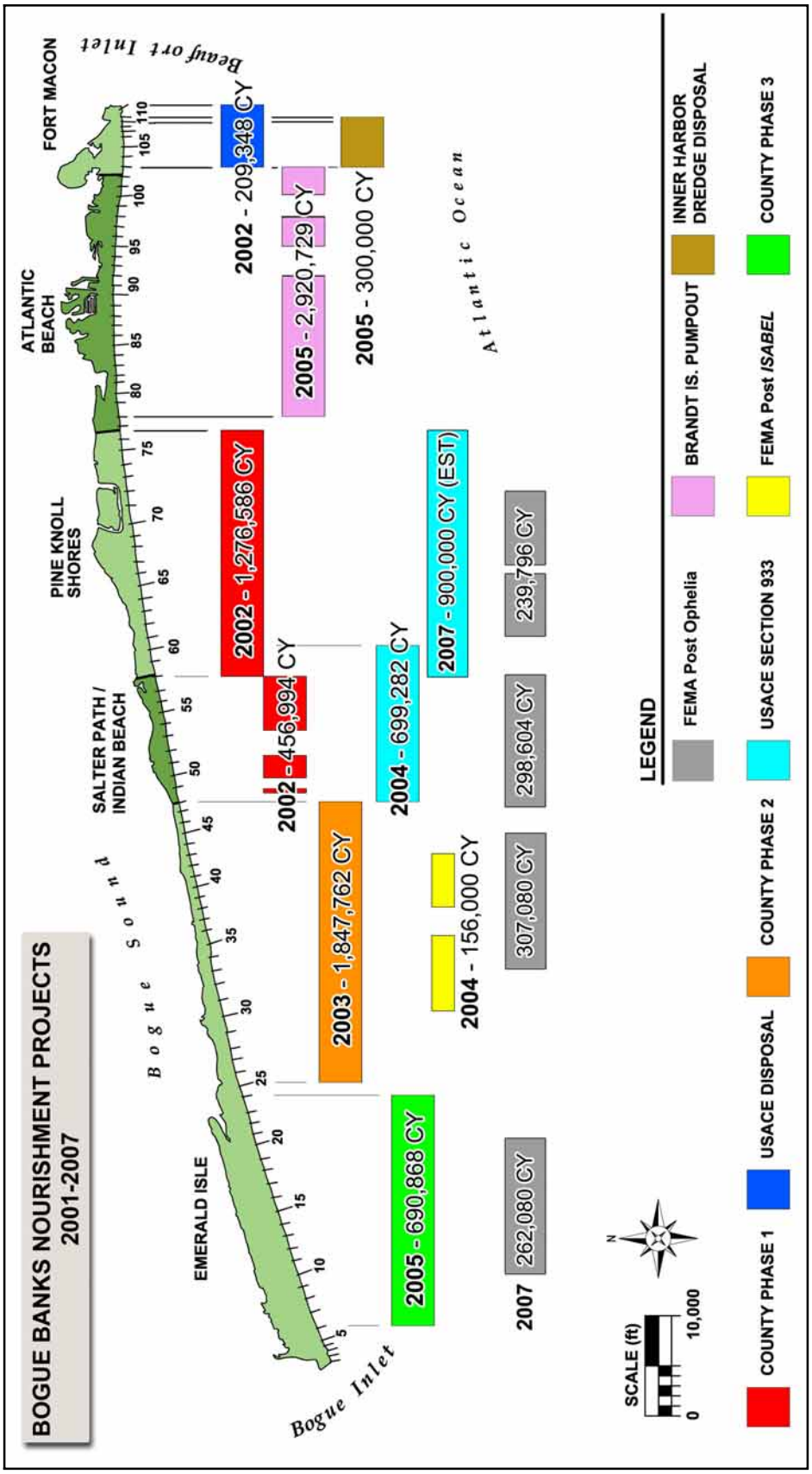


FIGURE 3.2-1. Nourishment projects along Bogue Banks (2002–2005) and pending projects for 2007.

TABLE 3. Bogue Banks nourishment volumes (2002–2005). Sources: CSE (2003a,b), Weeks Marine Inc, Great Lakes Dredge & Dock Company, and CCSPO (2004, 2005).

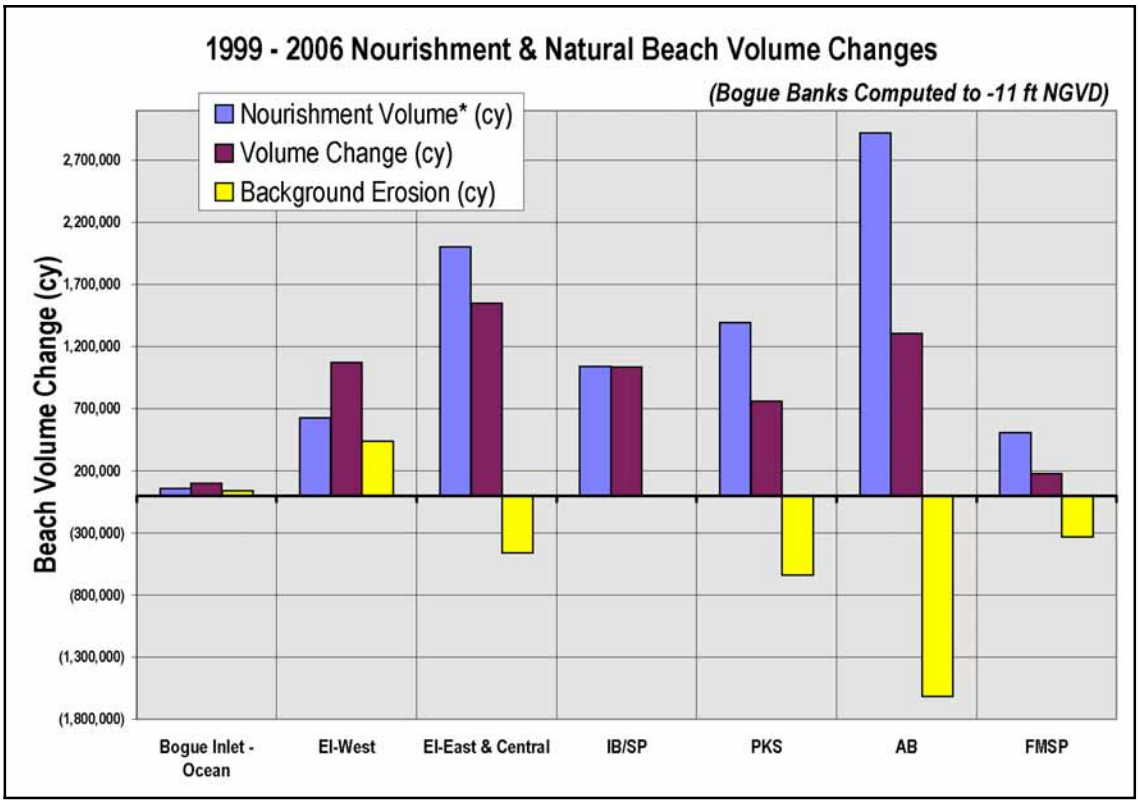
*Contracted volumes vary from "in-place" volumes for different reasons depending on the project. Turtle takes during County Project Phase 1 (PKS and IB/SP) caused a premature shutdown of the project before all contracted work could be completed. County Project Phase 2 was modified during construction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

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

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

TABLE 4. Bogue Banks nourishment volumes (2002–2005) and estimated background erosion rate (1999–2006) without nourishment. Calculations to –11 ft NGVD. [*Volume of Section 933 prorated between PKS–West and IB/SP. Volume of EI–West Phase 3 prorated between Bogue Inlet–Ocean and EI–West.]

Reach	Length (ft)	Nourishment Volume* (cy)	Jun 1999 to May 2006 Volume Change (cy)	Background Erosion (cy)	Average Annual Background Erosion Rate (cy/ft/yr)
Bogue Inlet–Ocean	6,772	59,272	99,426	40,154	0.86
EI-West	22,303	631,596	1,072,208	440,612	2.86
EI-East & Central	28,844	2,003,762	1,545,917	(457,845)	-2.29
IB/SP	12,986	1,039,729	1,035,738	(3,991)	-0.04
PKS	23,967	1,393,133	757,252	(635,881)	-3.84
AB	26,322	2,920,729	1,305,619	(1,615,110)	-8.87
FMSP	7,199	509,348	179,302	(330,046)	-6.63
Bogue Banks Total	128,392	8,557,569	5,995,462	(2,562,107)	-2.89



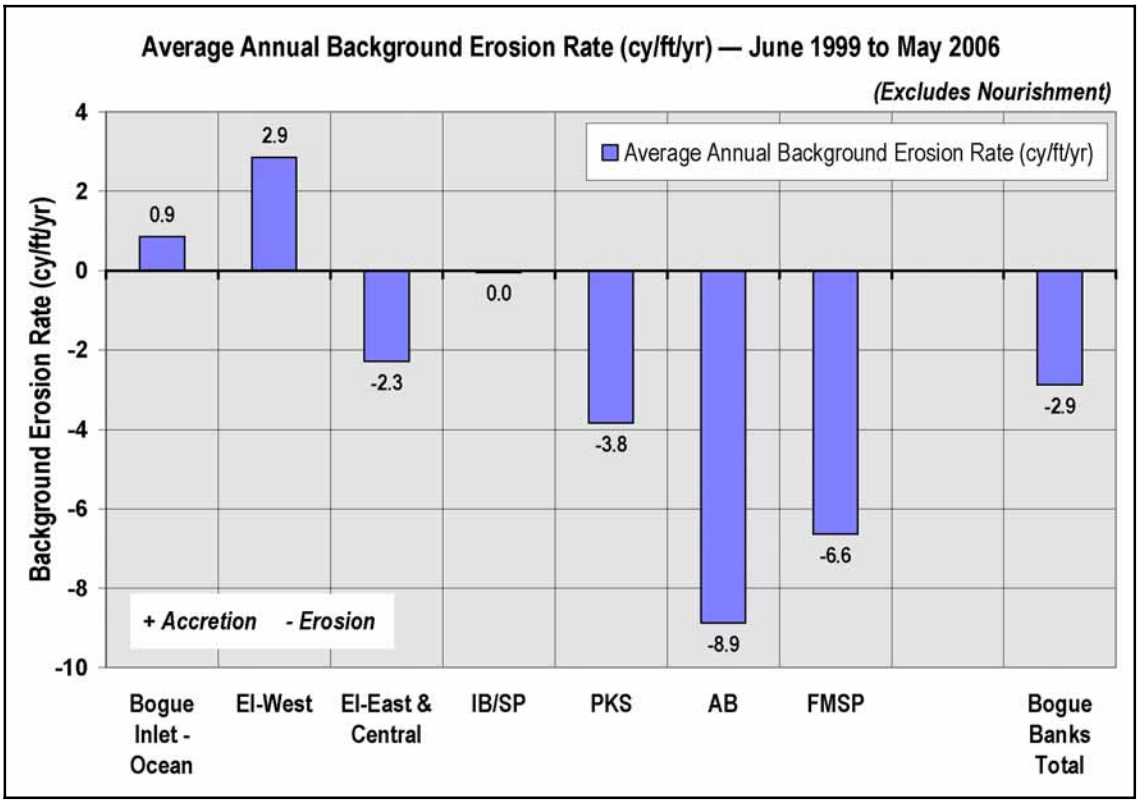


FIGURE 3.2-2. [UPPER] Total nourishment volumes and surveyed volume changes by reach for June 1999 to May 2006. The difference between the two quantities is the "background" erosion rate. [LOWER] Average, annual, background erosion rate after factoring out nourishment.

3.3 Emerald Isle

Emerald Isle (EI) is part of the Carteret County beach restoration project initiated in 1999. Reaches EI–East, EI–Central, and EI–West comprise 51,148 ft between stations 8 and 48. An additional 6,772 ft (stations 1–8) make up the Bogue Inlet–Ocean reach along western Emerald Isle. A total nourishment volume of 2,536,630 cy was placed in Emerald Isle as part of the County's Phases 2 and 3 nourishment projects in 2003 and 2005. Phase 2 nourishment affected EI–Central and EI–East; Phase 3 nourishment sand was placed in EI–West and Bogue Inlet–Ocean.

The net change in sand volume (from May 2005 to May 2006) along Emerald Isle (EI–East, EI–Central, and EI–West) was a loss of 686,760 cy (to –11 ft NGVD). The average volume loss for these three reaches was 13.4 cy/ft. Losses in the recreational beach to wading depth accounted for 52 percent of the volume decrease from May 2005 to May 2006 (Table 2, Appendix IV). Losses documented after Hurricane *Ophelia* in September 2005 account for 606,477 cy in Emerald Isle, while the remaining 80,283 cy eroded between September 2005 and May 2006 through natural processes. EI–West lost 11.2 cy/ft of sand over the monitoring period; EI–Central lost 16.3 cy/ft, and EI–East lost 13.8 cy/ft.

While most of Emerald Isle experienced erosion over the last year, some localities were net accretional to –11 ft. Emerald Isle–West showed areas of accretion near Lee Avenue as well as near profile lines 11 and 12. Emerald Isle–Central gained sand between Santa Maria and Periwinkle Drive.

Figure 3.3-1 shows the unit volume changes by station from May 2005 to May 2006. High erosion to the outer bar occurred at:

- Profile lines 13, 16, 21, 23 (Bluewater Drive) in the west reach.
- Profile line 27 (Surfview Road) and profile line 29 (Paxon Drive) in the central reach.
- Profile line 37 (21st–23rd Streets) in the east reach.

Since June 1999, Emerald Isle (stations 1–48) has gained 2.72 million cubic yards between the foredune and the outer bar. This equates to an average gain of 46.9 cy/ft. Discounting the nourishment totals, natural accretion has allowed a net gain of 22,921 cy since June 1999 (0.40 cy/ft). Natural accretion and erosion have nearly balanced between June 1999 and May 2006, which is evident given the low annual background erosion rate over the last seven years in Emerald Isle.

In May 2005, the average annual (6-year) background volume change rate estimate was accretional at 2.9 cy/ft/yr, meaning that Emerald Isle had been (on average) gaining 2.9

cy/ft of sand since June 1999. Much of the decrease in the annual change rate over the previous year's estimate is due to the impact of Hurricane *Ophelia* on 13–14 September 2005. Limited survey results after the storm indicated that Emerald Isle lost about 600,000 cy from the foredune to the outer bar during *Ophelia*. The loss during the storm accounts for 62 percent of the total net loss (May 2005 to May 2006). Based on this estimate, Emerald Isle retains at least 2.7 million cubic yards more sand along the beach compared with 1999 conditions.

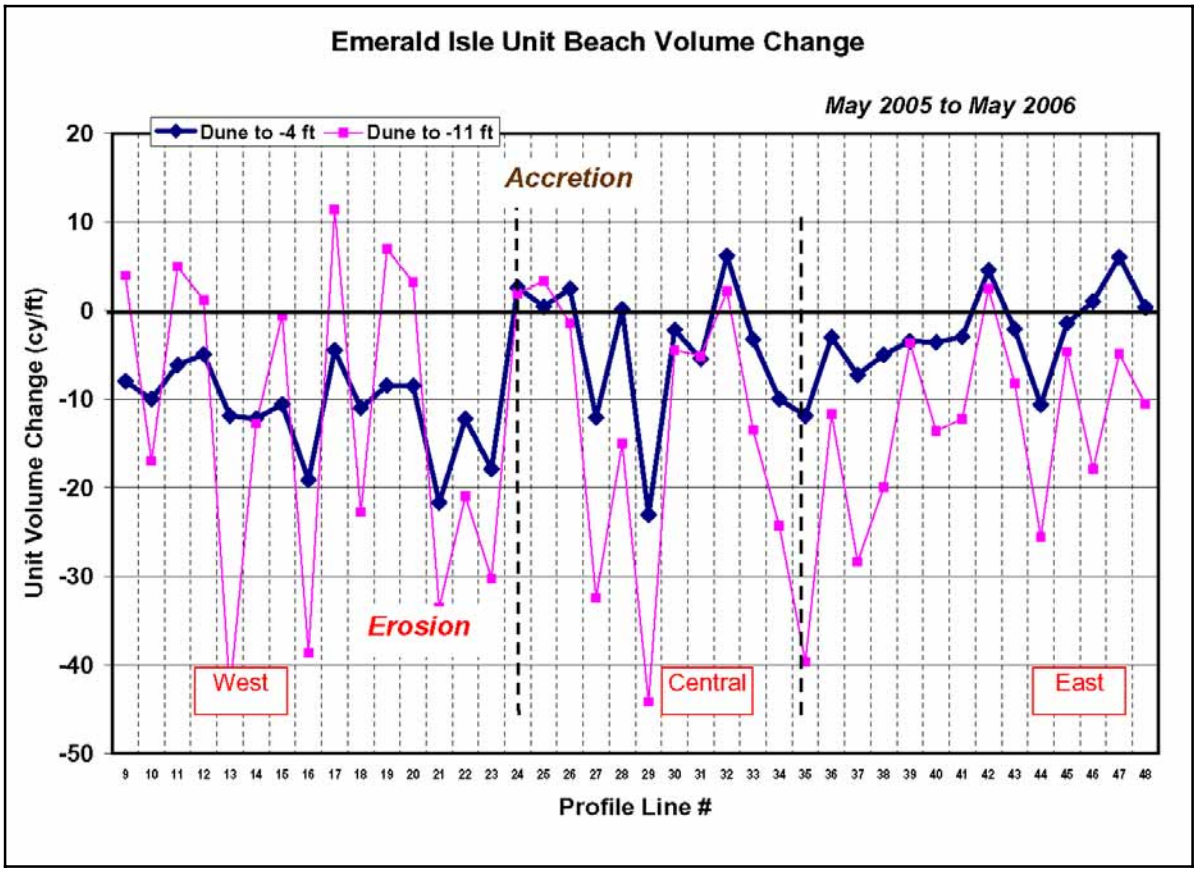


FIGURE 3.3-1. The net change by station to –4 ft and –11 ft calculation depths at all stations from May 2005 to May 2006. September 2005 photo is post-*Ophelia*. (Photos – D Dusini, P McKee)

3.4 Indian Beach/Salter Path

Indian Beach/Salter Path (IB/SP) is part of Phase 1 of the county nourishment project initiated in 1999 and the Section 933 nourishment project completed under the direction of the CCSPO in winter 2004. The 2.5-mile shoreline of this reach includes profile lines 48 to 58. Since 2002, nourishment projects have added 1,039,729 cy to the beach. Most recently, the 2004 Section 933 project added 699,282 cy split between the western reach of Pine Knoll Shores and Indian Beach/Salter Path. IB/SP received 582,735 cy of the in-place total.

In the five years following the June 1999 beach survey, this reach gained more sand per foot of beach than any other along Bogue Banks (CSE 2004). The average sand volume from the top of the dunes to the outer bar in June 2004 for IB/SP was 293 cy/ft, an average **annual** increase of 20.9 cy/ft. Since June 2004, IB/SP lost 320,754 cy of sand, of which 235,047 cy were lost after May 2005 (see Table 2).

Even though IB/SP lost beach volume between May 2005 and May 2006, it still has 1,035,938 cy more sand now than it did in June 1999. When nourishment volume is factored out, the IB/SP reach had a net loss of sand of only 3,991 cy over the last seven years. The average annual (background) erosion rate over seven years is nearly zero (–0.04 cy/ft/yr). The low background erosion rate reflects a near balance between erosion and accretion.

IB/SP lost sand at eight of its ten profile lines between May 2005 and May 2006. High erosion areas include profile lines 50, 54, and 58. The beach at profile lines 53 and 56 had a net gain in sand volume over last year (Fig 3.4-1) for results to –11 ft NGVD.

Hurricane *Ophelia* had more of an impact at IB/SP than the other reaches along Bogue Banks with respect to average volume lost per foot of beach. IB/SP lost 298,606 cy of sand during the storm (to –11 ft NGVD) which resulted in an average net loss of 23 cy/ft. Some of this loss was recovered between September 2005 and May 2006 based on ~64,000 cy more detected on the beach in May 2006. Caution should be taken when comparing hurricane survey data (September 2005) and the present monitoring data (May 2006) as the September 2005 survey was performed using coarser longshore stationing than the May 2006 data.

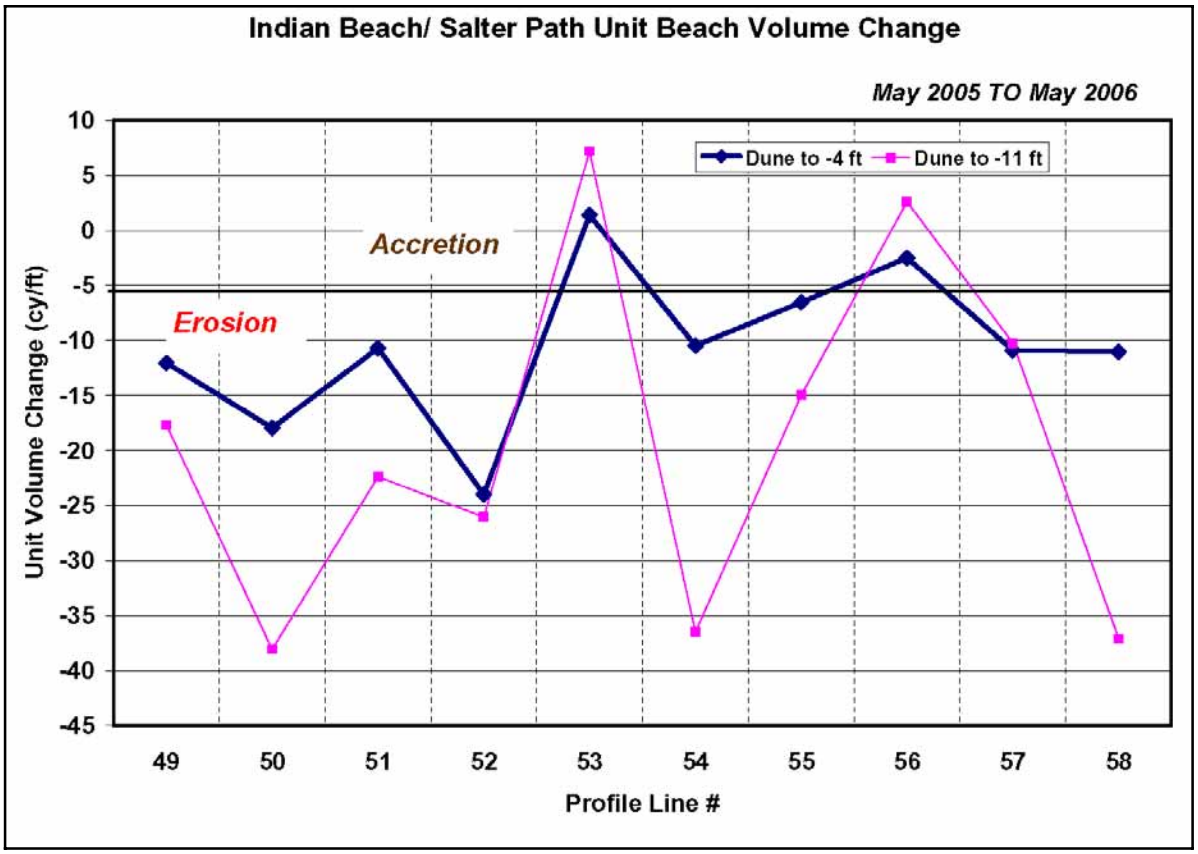


FIGURE 3.4-1. The net change by station to –4 ft and –11 ft calculation depths at all stations from May 2005 to May 2006. September 2005 photo is post *Ophelia*. (Photos – D Dusini, P McKee)

3.5 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 project completed under the direction of the CCSPO in winter 2004. Its 4.5-mile shoreline includes profile lines 58 to 76. The PKS reach is divided into two sub reaches: PKS–West (profile lines 58–65) and PKS–East (profile lines 65–76). Nourishment projects added 1,393,133 cy of sand to Pine Knoll Shores in 2002 and 2004 (see Table 2). Since June 1999, PKS has gained 757,252 cy of sand based on May 2006 survey data. When the effects of nourishment are removed, the net decrease in volume to the outer bar is 635,881 cy or a loss of 3.8 cy/ft/yr over the last seven years. The east reach and the west reach combined for a total volume loss of 346,951 cy between May 2005 and May 2006 (to –11 ft NGVD). PKS–West averaged a unit volume loss of 16.3 cy/ft and PKS–East averaged a loss of 13.3 cy/ft over the last year. The losses at PKS–West for 2005–2006 may be overestimated due to an anomaly in the 2005 survey data at profile 61. When compared against the 2004 survey, the net change at profile 61 was +15.1 cy/ft, similar in magnitude to adjacent stations.

PKS is erosional at nearly all surveyed lines between May 2005 and May 2006 (Fig 3.5-1). A notable exception is profile 69 in PKS–East where there is a net gain of 15 cy/ft over this time period. The limited data collected immediately after Hurricane *Ophelia* suggest that Pine Knoll Shores lost 239,793 cy of sand due to the storm. The comparison of hurricane losses with 2006 data suggest that PKS lost an additional ~107,000 cy due to natural erosion processes between September 2005 and May 2006.

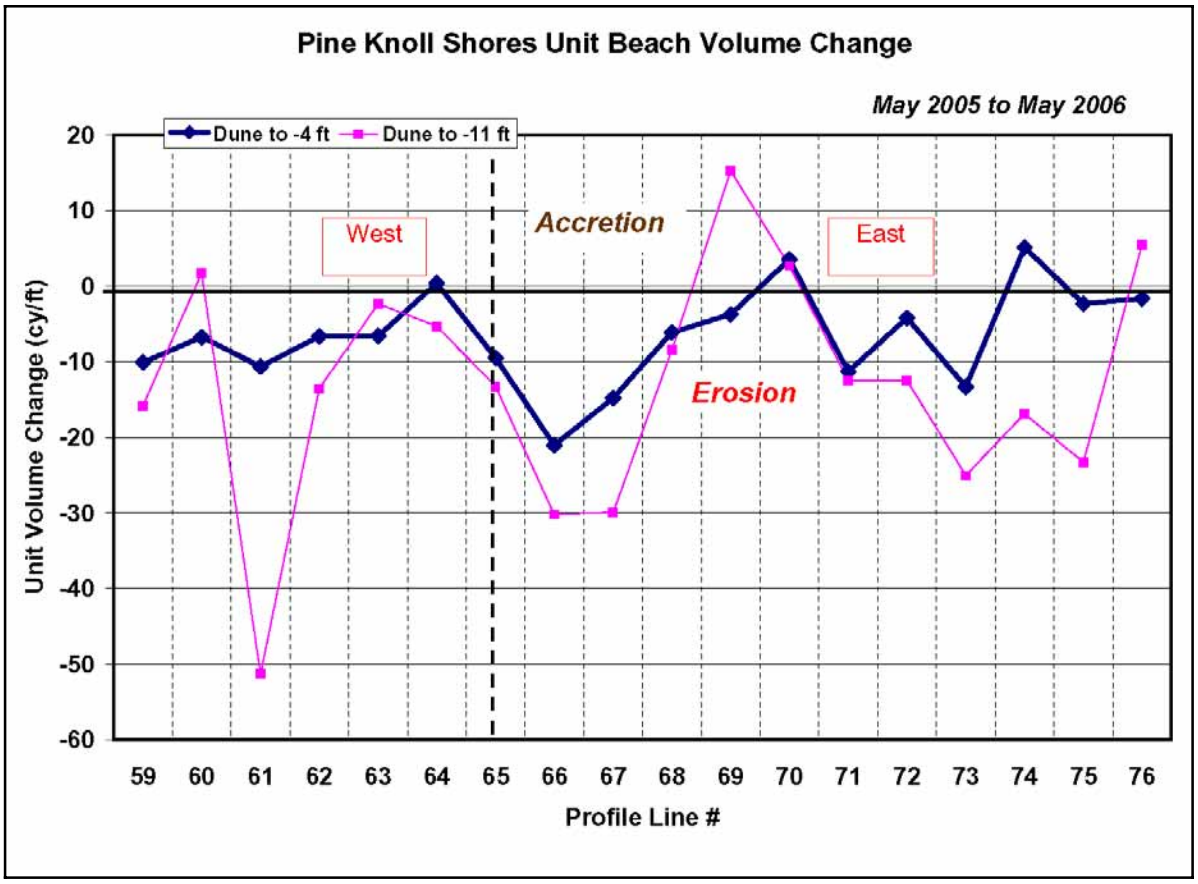


FIGURE 3.5-1 The net change by station to –4 ft and –11 ft calculation depths at all stations from May 2005 to May 2006. Hurricane *Ophelia* exposed protective sand bags at Pine Knoll Townes condominiums in September 2005, but otherwise caused negligible dune recession or damage to walkovers. In May 2006, a 2-3 ft escarpment is at the backbeach in front of the dunes. (Photos – D Dusini, P McKee)

3.6 Atlantic Beach

Atlantic Beach (AB) was nourished in 1986, 1994, and again in 2005 in conjunction with disposal of the Brandt Island upland spoil basin. [The Brandt Island disposal project added 2,920,729 cy to Atlantic Beach in 2005.] It remains part of the USACE plan for periodic disposal of harbor sediments. The 5.0-mile-long AB shoreline is between profile lines 76 and 102.

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

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

While Atlantic Beach still had more sand after the May 2006 survey than the other communities on Bogue Banks (284.1 cy/ft to –11 ft NGVD), it was the loss leader in average unit volume (–22.7 cy/ft) compared with other reaches over the last year. In 2006, Atlantic Beach was marked by sand volume losses at every profile with the exception of profile 79, which had a near zero net gain. High losses were evident in the areas that were nourished by Brandt Island sediments at the beginning of 2005 (Fig 3.6-1). This is indicative of the quality of sand used in the renourishment. The finer sediments are more easily eroded to deep water than typical beach-quality sand.

Under the hurricane conditions of September 2005, CSE estimated losses to –11 ft NGVD of 342,246 cy (13 cy/ft). Of the 596,587 cy of sand volume lost between May 2005 and May 2006, 57 percent of the losses are accounted for by Hurricane *Ophelia*. Volume gains between June 1999 and May 2006 total 1,305,619 cy in Atlantic Beach. When total nourishment volumes gained over the last seven years are removed from the total change, Atlantic Beach has a background erosion rate of 8.9 cy/ft/yr for the last seven years, the highest along Bogue Banks.

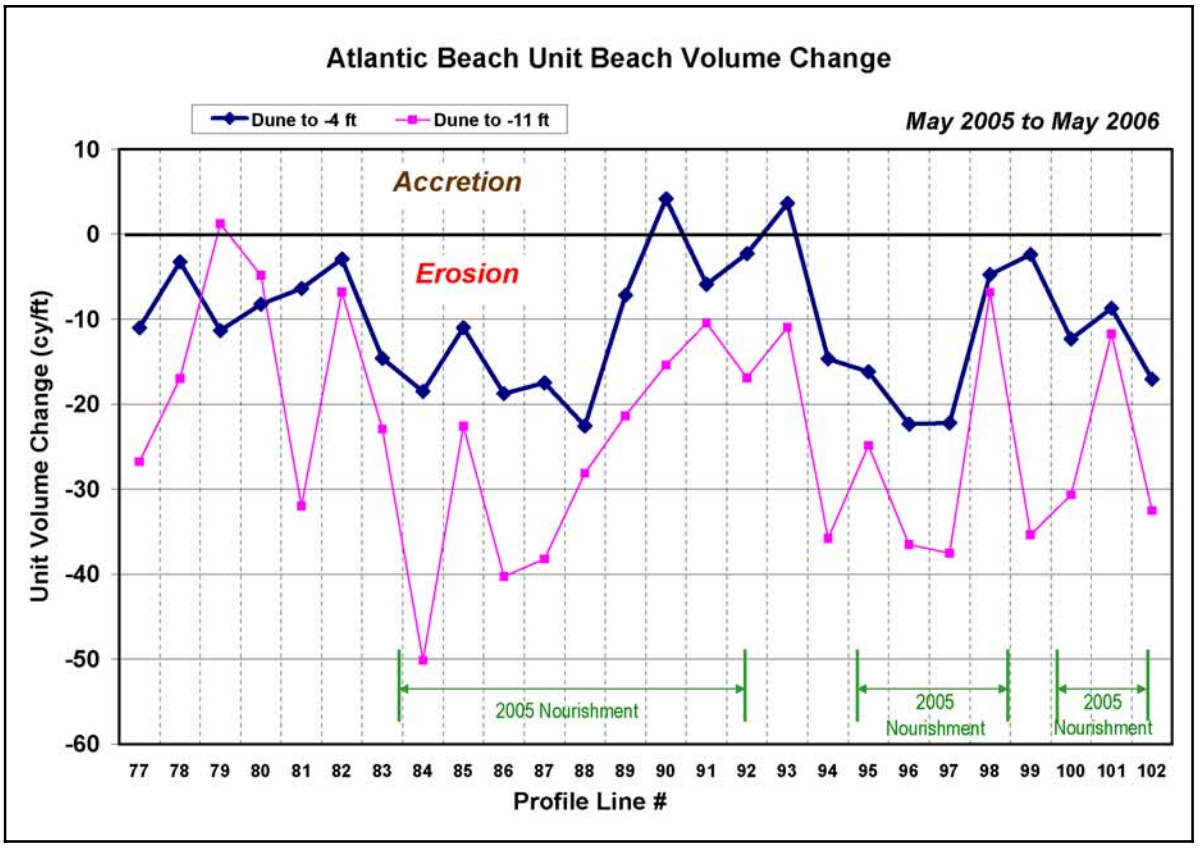


FIGURE 3.6-1. The net change by station to –4 ft and –11 ft calculation depths at all stations from May 2005 to May 2006. Note escarpment at front of berm in 2006. (Photos – D Dusini, P McKee)

3.7 Fort Macon State Park

Fort Macon State Park (FMSP) occupies the eastern end of Bogue Banks. The 1.4-mile coastline lies between profile lines 102 and 112. The 2,250-ft reach adjacent to Beaufort Inlet (profile lines 113–116) was established by CSE in December 2003 and is analyzed separately from the FMSP reach. Fort Macon State Park was nourished in 2002 and 2005 in conjunction with disposal of inner harbor dredge material associated with the Morehead City federal navigation project. It remains part of the plan for periodic disposal of harbor sediments (USACE 1993).

Fort Macon State Park lost 11.8 cy/ft of sand between May 2005 and May 2006 (see Table 2). The eastern half of the reach was accretional to –11 ft NGVD, while the western half was erosional (Fig 3.7-1). The upper beach to –4 ft NGVD was slightly erosional overall at –1.9 cy/ft. The high erosion rates along the eastern part of the beach along with the high losses at profile line 112 near Beaufort Inlet worsen the overall erosional rate. Post-*Ophelia* survey data do not adequately detail losses to the outer bar for FMSP. Survey data of the upper beach (dune to +2 ft NGVD) indicate that FMSP lost 5.48 cy/ft of recreational beach, higher than the island-wide average of 4.0 cy/ft of erosion.

The Fort Macon State Park beach was less affected by Hurricane *Ophelia* in September 2005 than the other communities along Bogue Banks. Fort Macon lost an average of 5.5 cy/ft of sand due to the storm. The background erosion rate over the past seven years is 6.6 cy/ft/yr when the 509,348 cy of nourishment sand is not included.

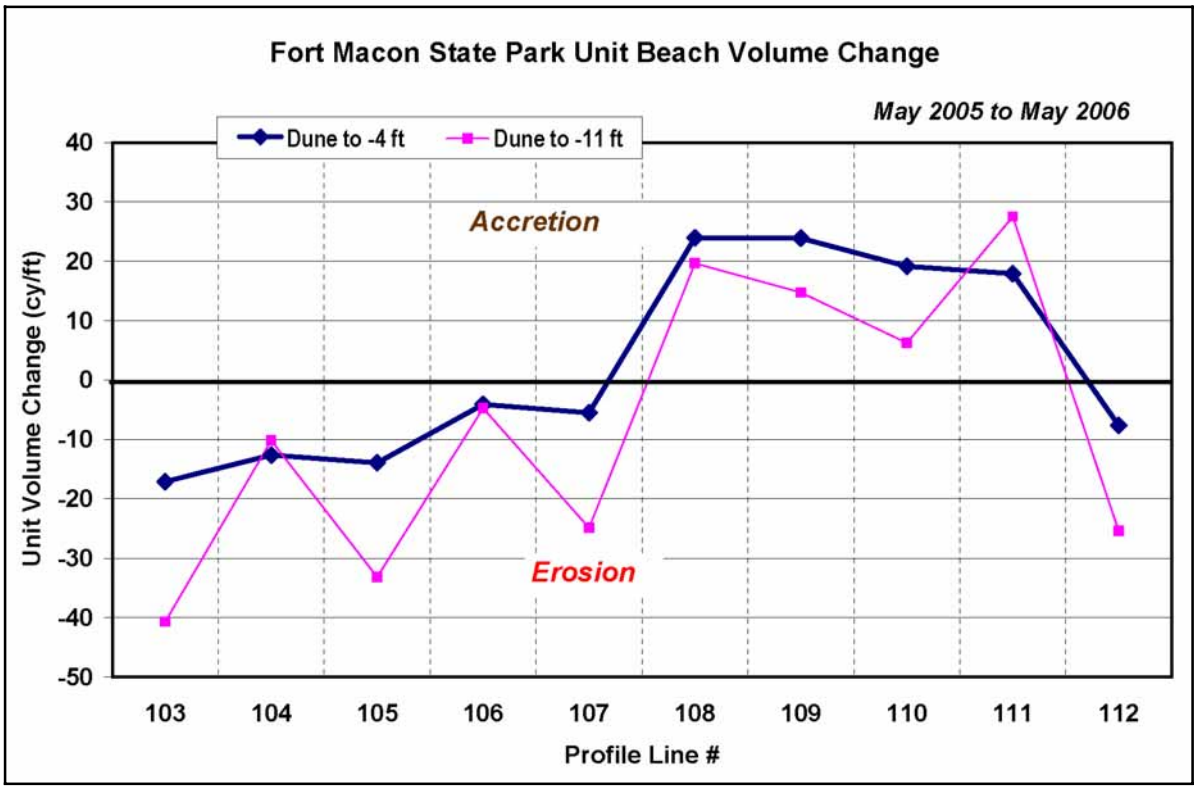


FIGURE 3.7-1. The net change by station to –4 ft and –11 ft calculation depths at all stations from May 2005 to May 2006. Nourishment in early 2005 buried the groin near the park access (profile 103). *Ophelia* subsequently uncovered part of the groin. (Photos – P McKee, D Dusini)

3.8 Bogue Inlet Changes

Two reaches are monitored around Bogue Inlet at The Point:

- Bogue Inlet–Ocean encompasses ~6,772 ft between profiles 1 and 8.
- Bogue Inlet–Channel encompasses ~1,500 ft between profiles 117 and 120.

During the past year (May 2005 to May 2006), Bogue Inlet–Ocean lost nearly 300,000 cy (measured to –11 ft NGVD). Severe erosion occurred inshore with beach recession upward of 200 ft in places (Fig 3.8-1). Despite the losses, the reach maintains a broad platform extending offshore, which is the updrift portion of the ebb-tidal delta of old Bogue Inlet.

Losses along the oceanfront near Bogue Inlet were counter-balanced by large gains along the abandoned channel at The Point. During the past year, ~343,000 cy accreted around The Point along this ~1,500-ft reach (profile lines 117–120). Approximately 70,000 cy of this total represents sand that was dredged from the Bogue Inlet access channel and placed along The Point in spring 2006 (G Rudolph, CCSPO, pers comm, Nov 2006). The average rate of accretion (measured across the old channel) averaged ~230 cy/ft (Table 5). Figures 3.8-2 through 3.8-6 show dramatic changes during the past year. Four principal events contributed to the observed changes:

- Construction of a new channel for Bogue Inlet in spring 2005 (Phase 3 of the County nourishment project).
- Hurricane *Ophelia* on 13-14 September 2005.
- Breach of the “Coast Guard” channel during *Ophelia*.
- Sand disposal at The Point from channel maintenance dredging near the Atlantic IntraCoastal Waterway.

A sequence of aerial photos from the Carteret County Shore Protection Office (Fig 3.8-2) shows rapid buildup of a spit at The Point. This is the type of change that was expected to occur after the new Bogue Inlet channel was constructed in spring 2005. Spit growth at The Point was not immediate because the old channel remained open. Ebb flows in the old channel (monitored in June 2005) remained sufficient to flush sand offshore and retard spit growth in our opinion. This condition changed when the “Coast Guard” channel breached the spit just north of The Point on 14 September 2005. Ebb flows through the breach channel then redirected the discharge in the old channel away from the sand-bagged area. This modification of tidal circulation probably accelerated spit growth at The Point (Fig 3.8-2).

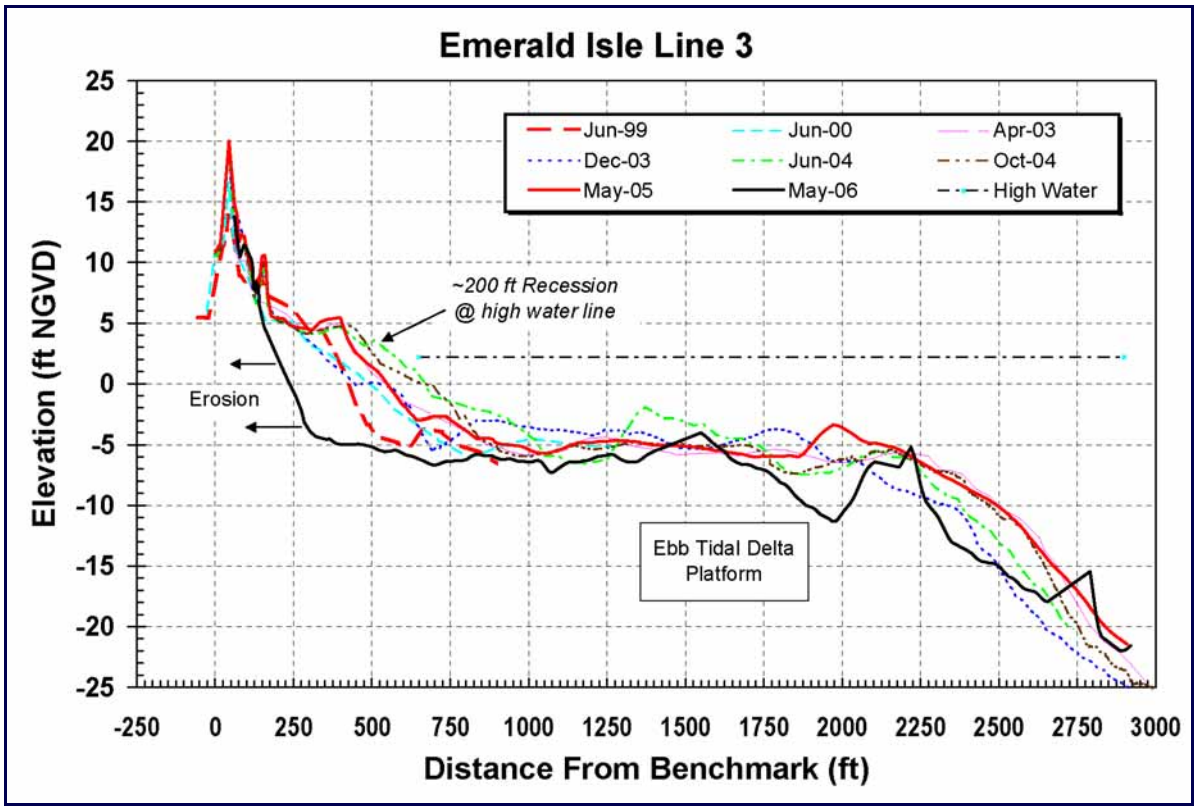


FIGURE 3.8-1. Comparative profiles for profile line 3 in the Bogue Inlet–Ocean reach. Note nearly 200 ft of shoreline recession since May 2005. Despite this loss, much of the reach retains a broad platform, part of the ebb-tidal delta of old Bogue Inlet.

TABLE 5. Bogue Inlet and Beaufort Inlet profile volumes and volume changes. Calculation limits are generally the centerline (CL) of the adjacent channel.

		Start Dis	Cutoff						Jun'04-May'06	May'05-May'06		Jun'04-May'06	May'05-May'06
		Baseline	Distance	Distance	Dec-03	Jun-04	May-05	May-06	Unit Vol	Unit Vol		Net Vol	Net Vol
Area	Station	Offset	~Channel CL	To Next	Unit Vol	Unit Vol	Unit Vol	Unit Vol	Change	Change		Change	Change
		(ft)	(ft)	(ft)	(cy/ft)	(cy/ft)	(cy/ft)	(cy/ft)	(cy/ft)	(cy/ft)		To Next (cy)	To Next (cy)
					Dune to -60	*Dune to -60*	*Dune to -60*	*Dune to -60*					
Beaufort	113	0	1750	500	2960.27	3015.26	3222.85	3192.74	177.48	-30.11		100,848	10,485
Inlet	114	0	1700	500	2754.84	2887.97	3041.83	3113.88	225.91	72.05		101,660	28,828
	115	0	1500	550	2271.59	2355.24	2492.71	2535.97	180.73	43.26		3,710	6,218
	116	0	1400	-	1901.61	1924.78	1778.19	1757.54	-167.24	-20.65		-	-
					Dune to Channel bottom (-20 to -35 ft variable)								
Bogue	117	-175	875	500	426.71	421.93	429.01	735.47	313.54	306.46		182,355	176,713
Inlet	118	105	750	500	237.10	236.39	251.88	652.27	415.88	400.39		139,925	140,358
	119	135	550	500	251.77	231.78	214.56	375.60	143.82	161.04		34,990	25,668
	120	135	500	-	58.37	78.15	132.66	74.29	-3.86	-58.37		-	-
Summary By Area - Average Volumes and Volume Changes									Jun'04-May'06	May'05-May'06		Jun'04-May'06	May'05-May'06
	Profiles			Reach Length	Dec-03	Jun-04	May-05	May-06	*Wtd Avg (cy/ft)*	*Wtd Avg (cy/ft)*		Net (cy)	Net (cy)
Beaufort	113-116			1,550	2,472.1	2,545.8	2,633.9	2,650.0	**133.0**	**29.4**		**206,217**	**45,530**
Inlet													
Bogue	117-120			1,500	243.5	242.1	257.0	459.4	**238.2**	**228.5**		**357,270**	**342,738**
Inlet													

FIGURE 3.8-2(a–c).

Oblique aerial photos of The Point showing spit development between September 2005 and October 2006.

[Upper] September 2005
[Middle] March 2006
[Lower] October 2006

Note the “Coast Guard” breach channel is at the upper right corner of each image.

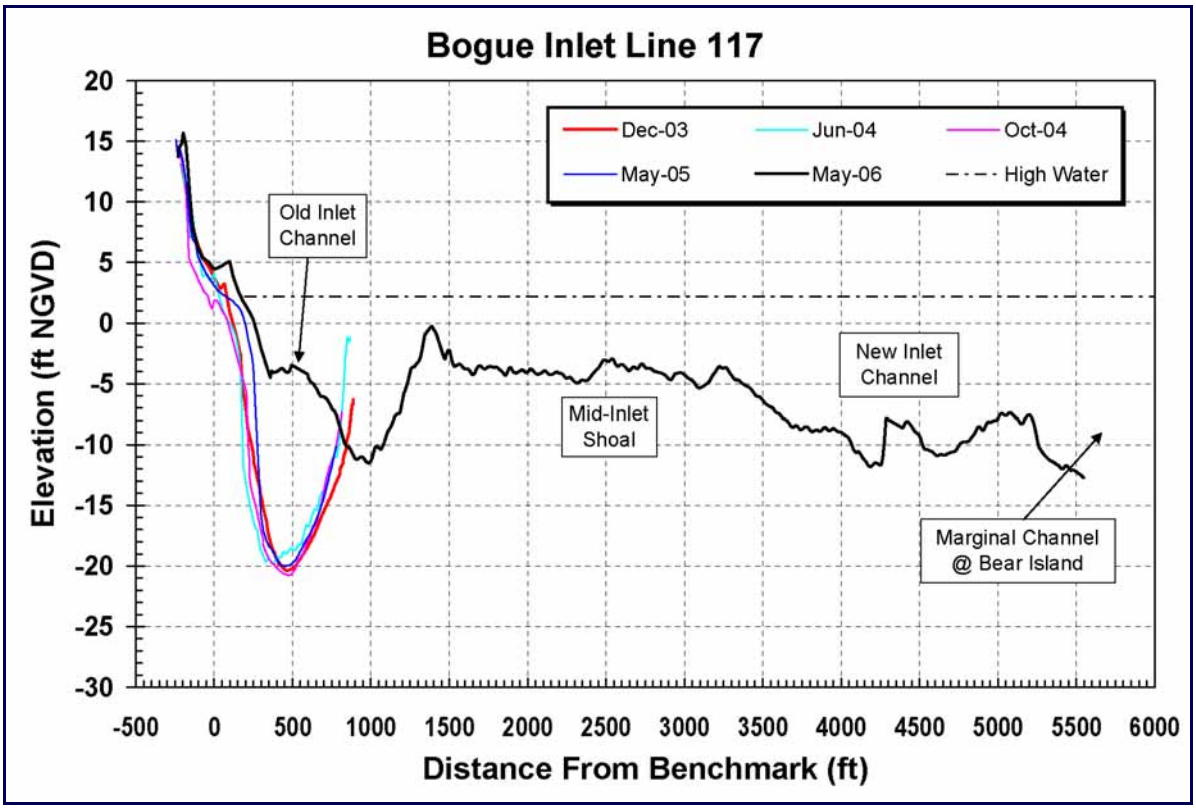
Images courtesy of CCSPO

FIGURE 3.8-2(d). Aerial photo of Bogue Inlet in October 2006 showing the new channel (note boat wake at lower center) and the Coast Guard channel adjacent to The Point. (Image courtesy of CCSPO)

It is important to emphasize that recovery of The Point was aided by the breach channel, but would not have occurred as rapidly without construction of the new channel. Inlet realignment in spring 2005 captured at least half the discharge exiting Bogue Inlet (CSE 2005c). This reduced the flow velocities in the old channel and allowed discharge through the breach channel (after *Ophelia*) to redirect ebb currents away from the sand bags at The Point. This, in turn, made flood currents and wave-generated transport along the beach relatively stronger than ebb flows at The Point, so that sand transport into the old channel accelerated.

Comparative profiles show extensive infilling of the old channel around The Point (Figs 3.8-3 to 3.8-6). Changes at the seaward-most profile lines (117 and 118) ranged from 300–400 cy/ft between May 2005 and May 2006. The rate of change at profile 119 was ~160 cy/ft. Profile 120 shows erosion for the period because it is situated in the breach channel. As profile 118 illustrates (Fig 3.8-4), spit growth has nearly infilled the old channel. The discharge through the Coast Guard channel has created a new channel (or more properly, displaced the old channel) about 500–800 ft seaward of The Point (Fig 3.8-4, lower).

While further flow studies are needed to confirm this, the morphological changes at The Point suggest the possibility that the new spit will eventually merge with subaerial portions of the mid-inlet shoal (see Fig 3.8-2, lower). If this occurs, the discharge through the Coast Guard channel will be deflected to the west toward the new inlet. If the spit does not merge with the mid-inlet shoal, the Coast Guard channel will continue to exit east of the new channel, in effect, maintaining a dual channel system for Bogue Inlet (cf, Fig 3.8-2d). In either case, the erosion pressure at The Point will continue to diminish. The Point area and Bogue Inlet compartment should be monitored carefully over the next few years. Rapid spit growth in one area usually reflects rapid erosion in nearby updrift reaches. This has certainly been the case during the past year (Table 5).



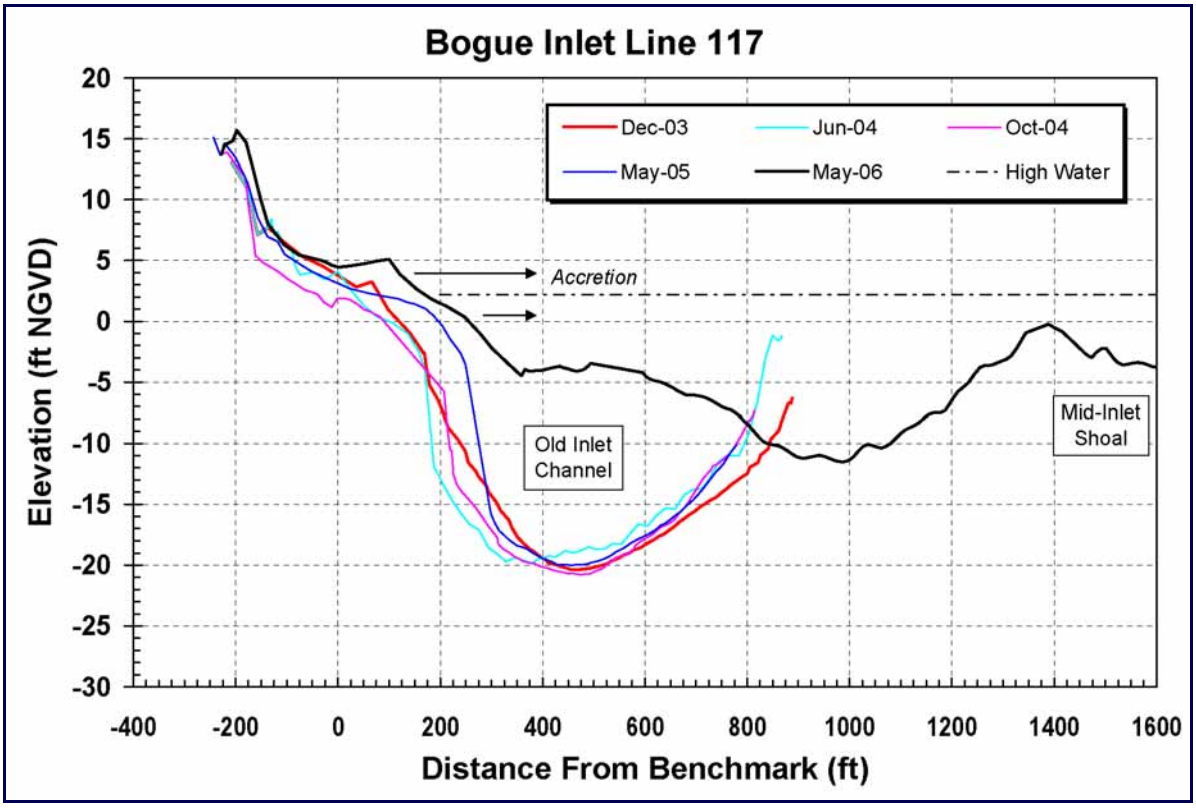
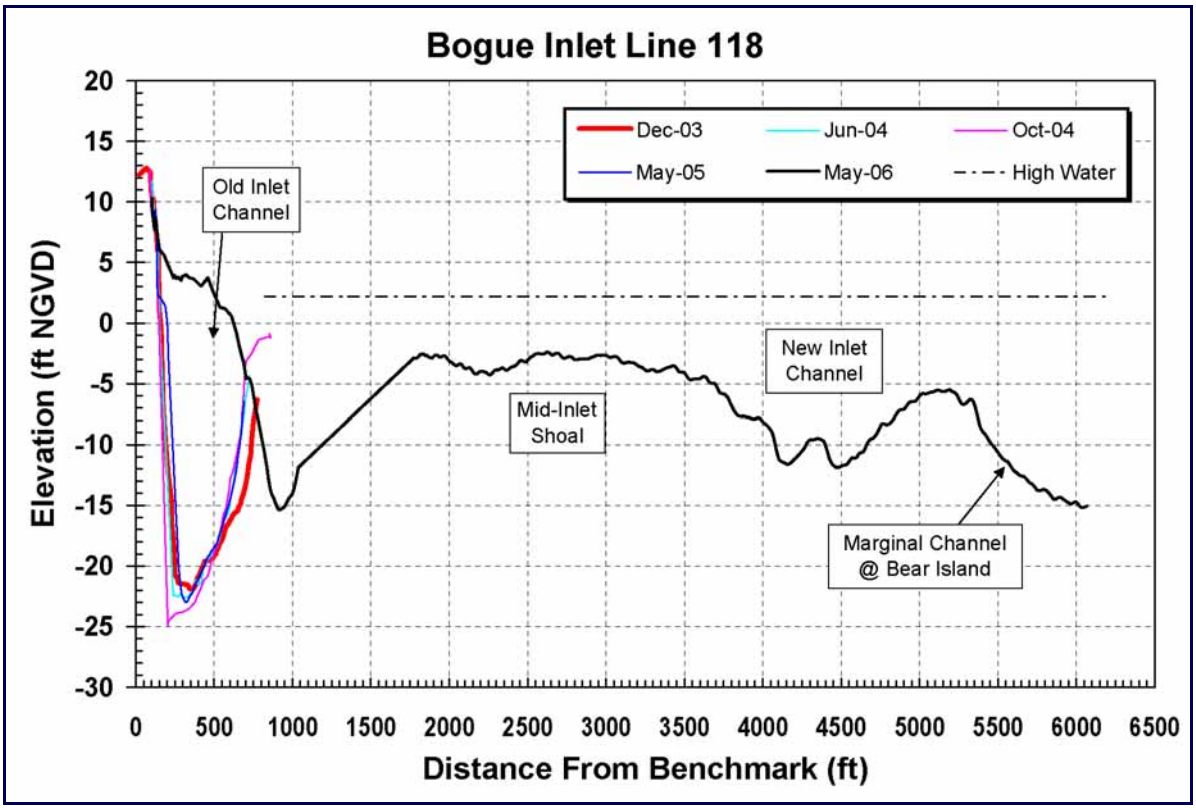


FIGURE 3.8-3. Comparative profiles along Bogue Inlet at The Point. Note major changes between May 2005 and May 2006 associated with construction of new Bogue Inlet (spring 2005), Hurricane *Ophelia* (September 2005), and the breach of the "Coast Guard" channel during *Ophelia*.



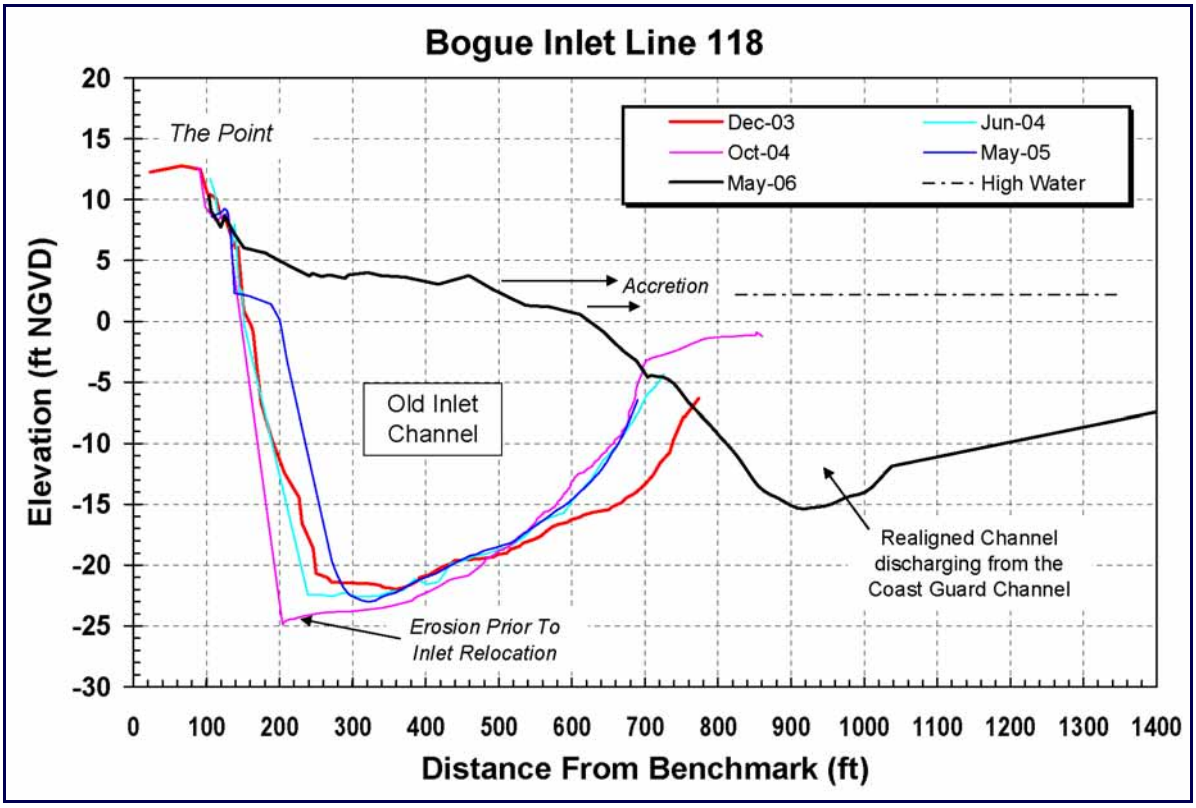
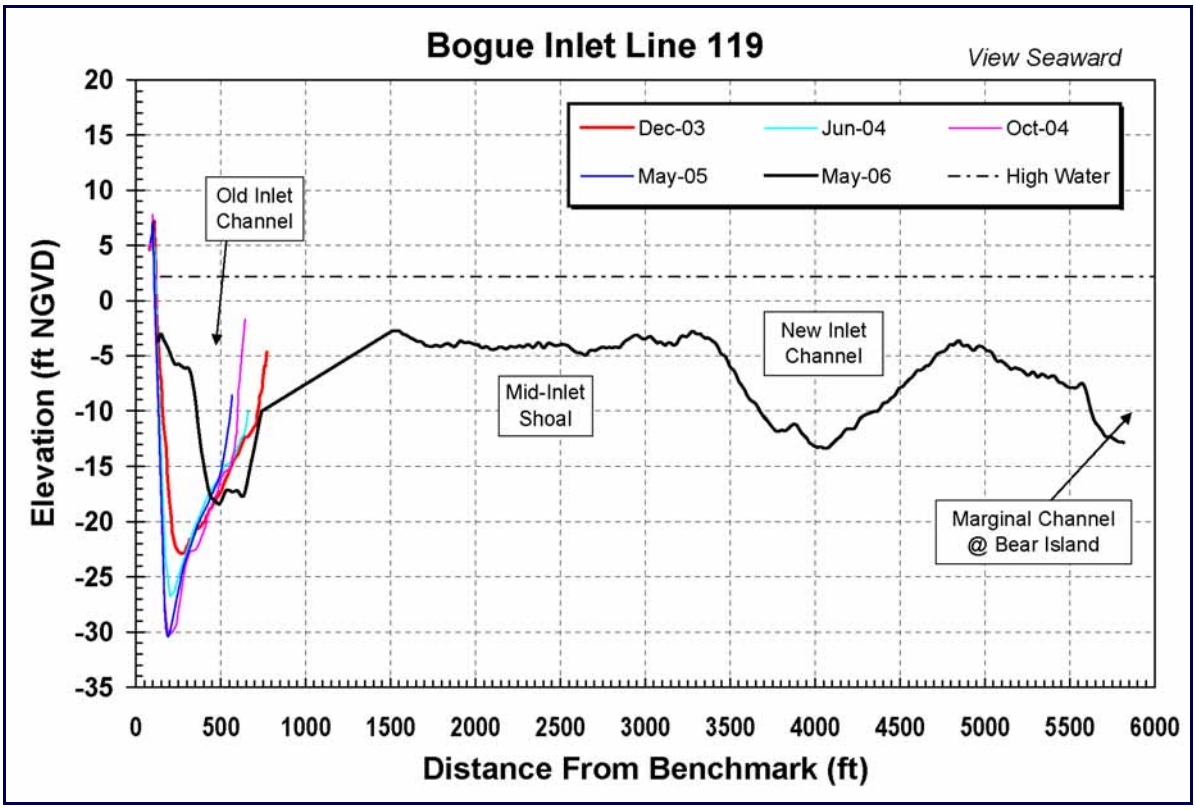


FIGURE 3.8-4. Comparative profiles along Bogue Inlet at The Point. Note major changes between May 2005 and May 2006 associated with construction of new Bogue Inlet (spring 2005), Hurricane *Ophelia* (September 2005), and the breach of the "Coast Guard" channel during *Ophelia*.



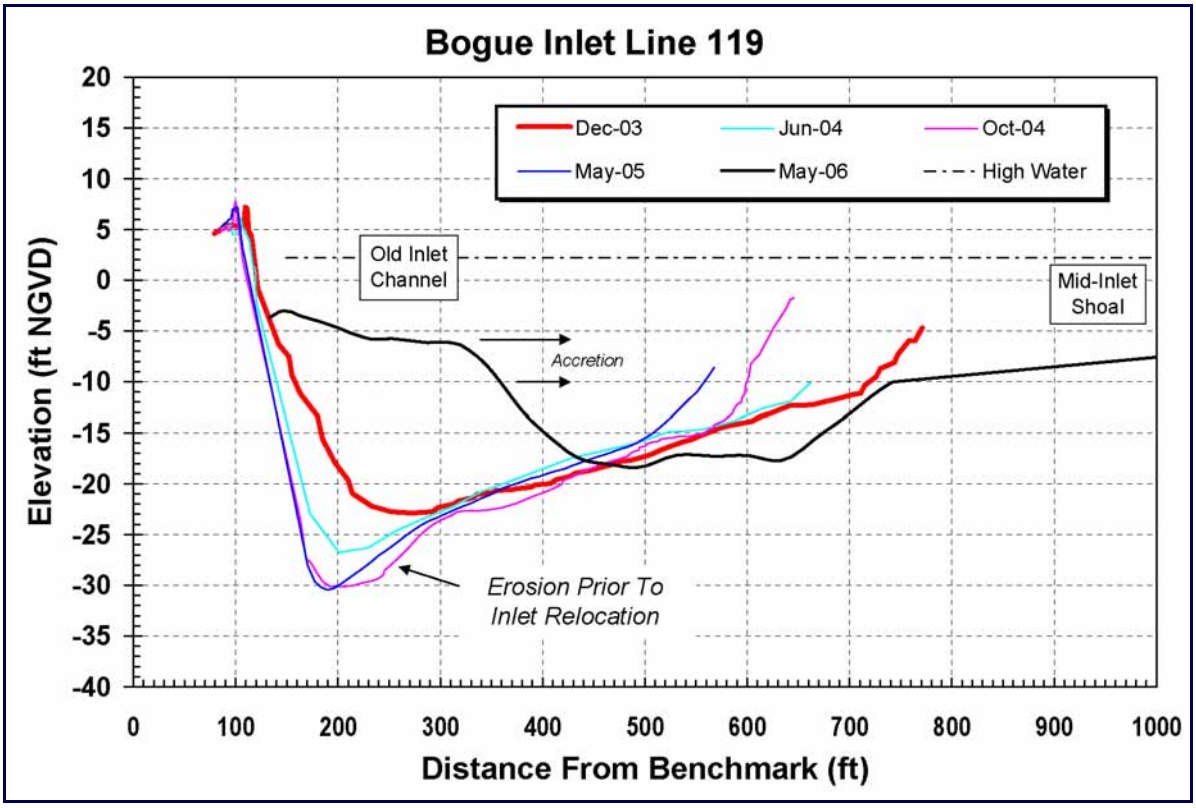


FIGURE 3.8-5. Comparative profiles along Bogue Inlet at The Point. Note major changes between May 2005 and May 2006 associated with construction of new Bogue Inlet (spring 2005), Hurricane *Ophelia* (September 2005), and the breach of the "Coast Guard" channel during *Ophelia*.

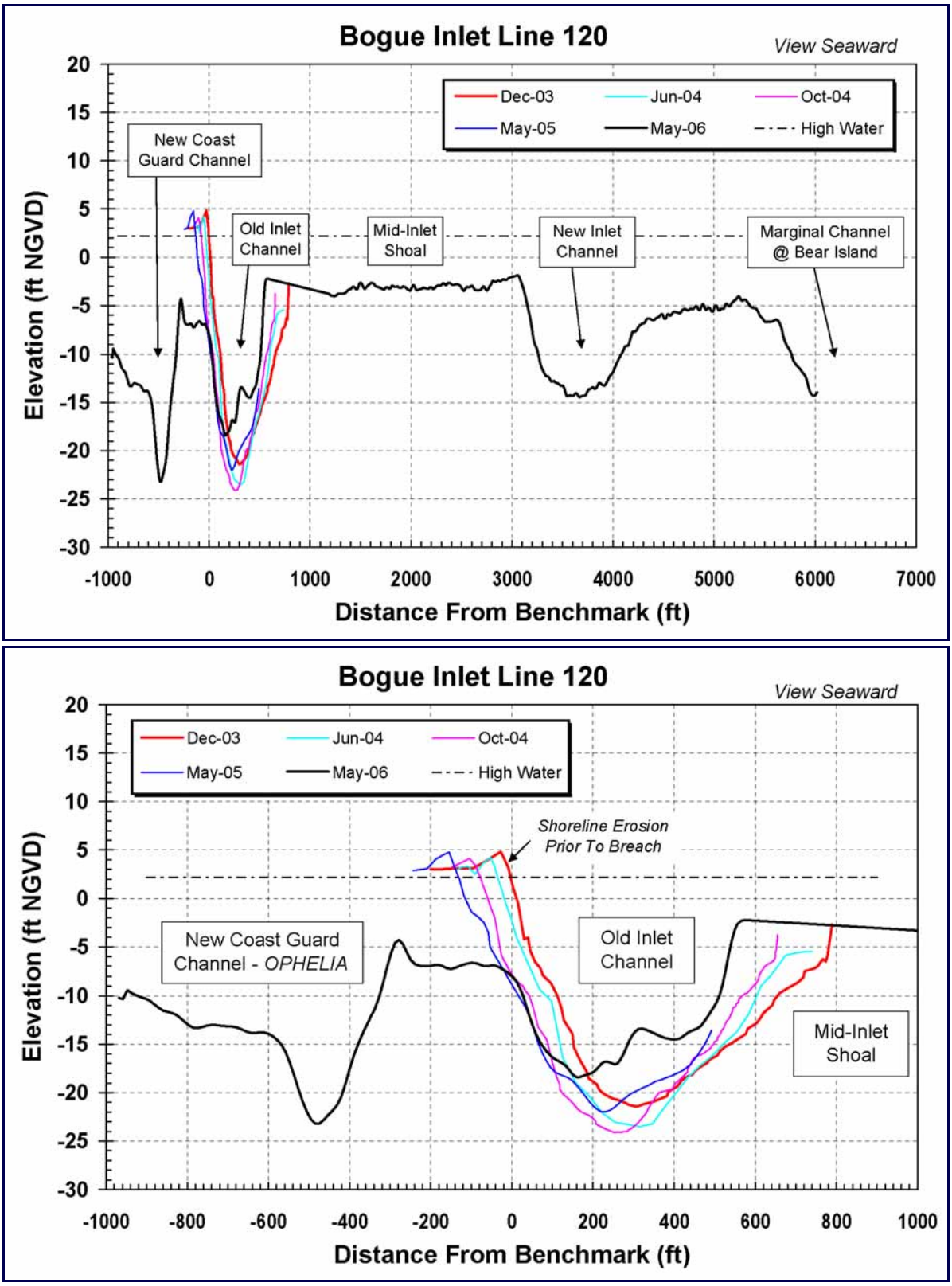
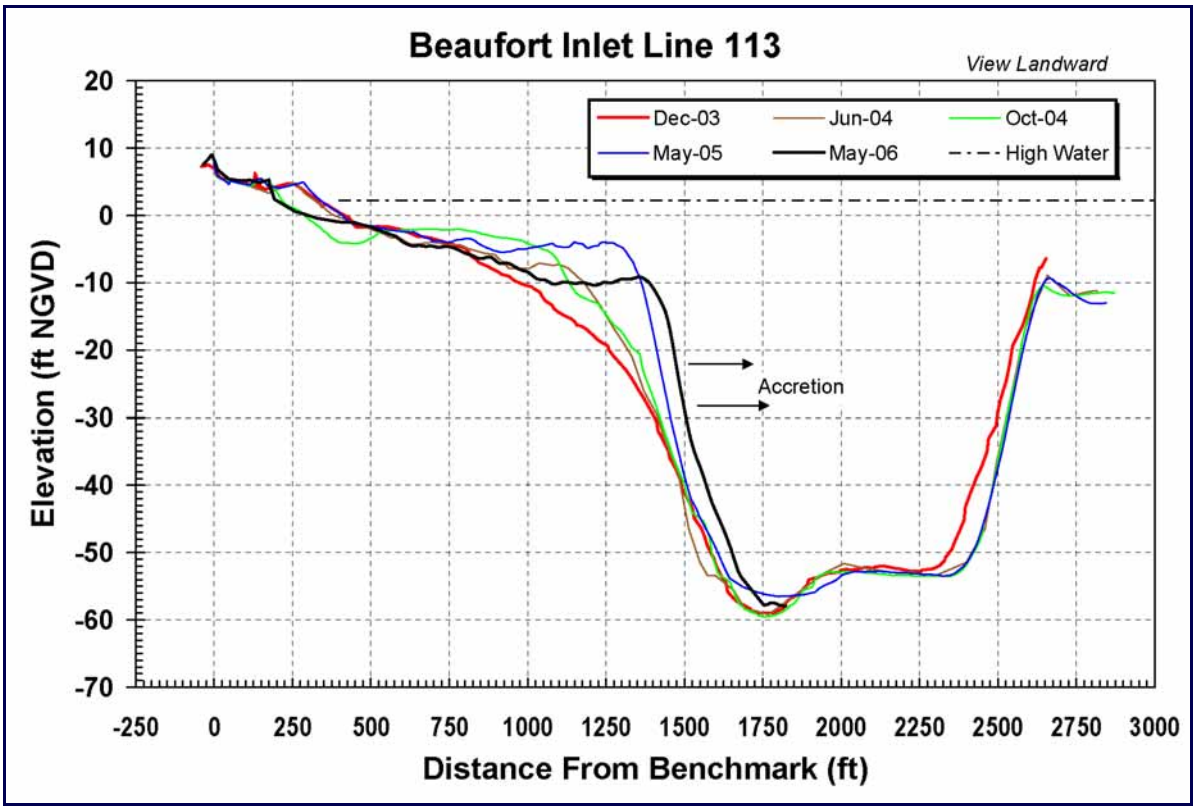


FIGURE 3.8-6. Comparative profiles along Bogue Inlet at The Point. Note major changes between May 2005 and May 2006 associated with construction of new Bogue Inlet (spring 2005), Hurricane *Ophelia* (September 2005), and the breach of the "Coast Guard" channel during *Ophelia*.

3.9 Beaufort Inlet Changes

At the opposite end of Bogue Banks, profiles along Beaufort Inlet also show significant spit accretion. Profile lines 113 to 116 gained a weighted average of ~30 cy/ft during the past year (measured to –60 ft NGVD — center of channel). This gain is additional to the ~100 cy/ft accreted between June 2004 and May 2005 (Table 5). Comparative profiles (Figs 3.9-1 and 3.9-2) show substantial accretion along the upper portion of the profile (to –10 ft) and the flank of the entrance channel. The shoreline at profile 114, for example, has accreted nearly 250 ft since December 2003. From June 2004 to May 2006, an estimated 206,000 cy have accumulated along the 1,550-ft Beaufort Inlet reach. According to normal inlet sand circulation patterns, the principal source of sand for this accretion was the oceanfront along Fort Macon State Park (FMSP). Nourishment projects (ie, federal dredge disposal projects) in 2002 and 2005 added over 500,000 cy to the FMSP reach. CSE believes this extra sand accounts of much of the observed buildup along the Beaufort Inlet reach.



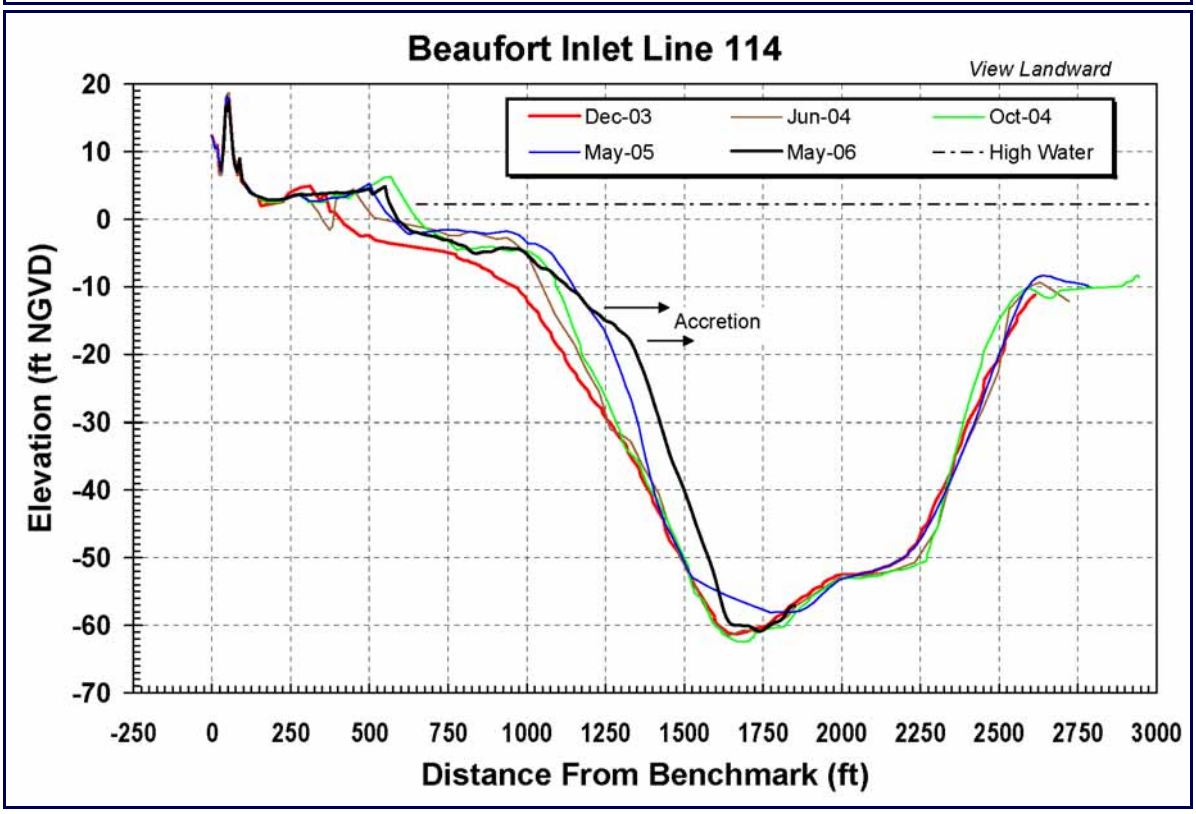
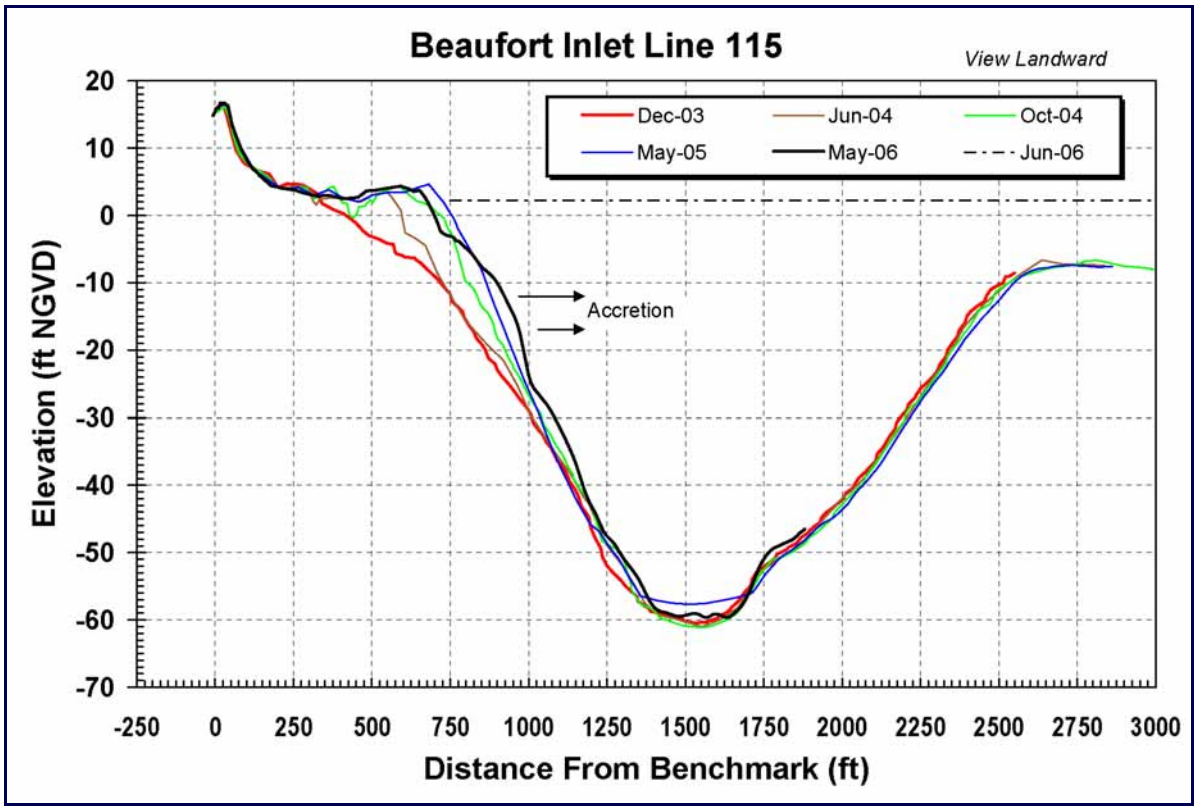


FIGURE 3.9-1. Comparative profiles along Beaufort Inlet. Note significant spit growth since 2003, likely the result of nourishment sand shifting from the Fort Macon State Park reach.



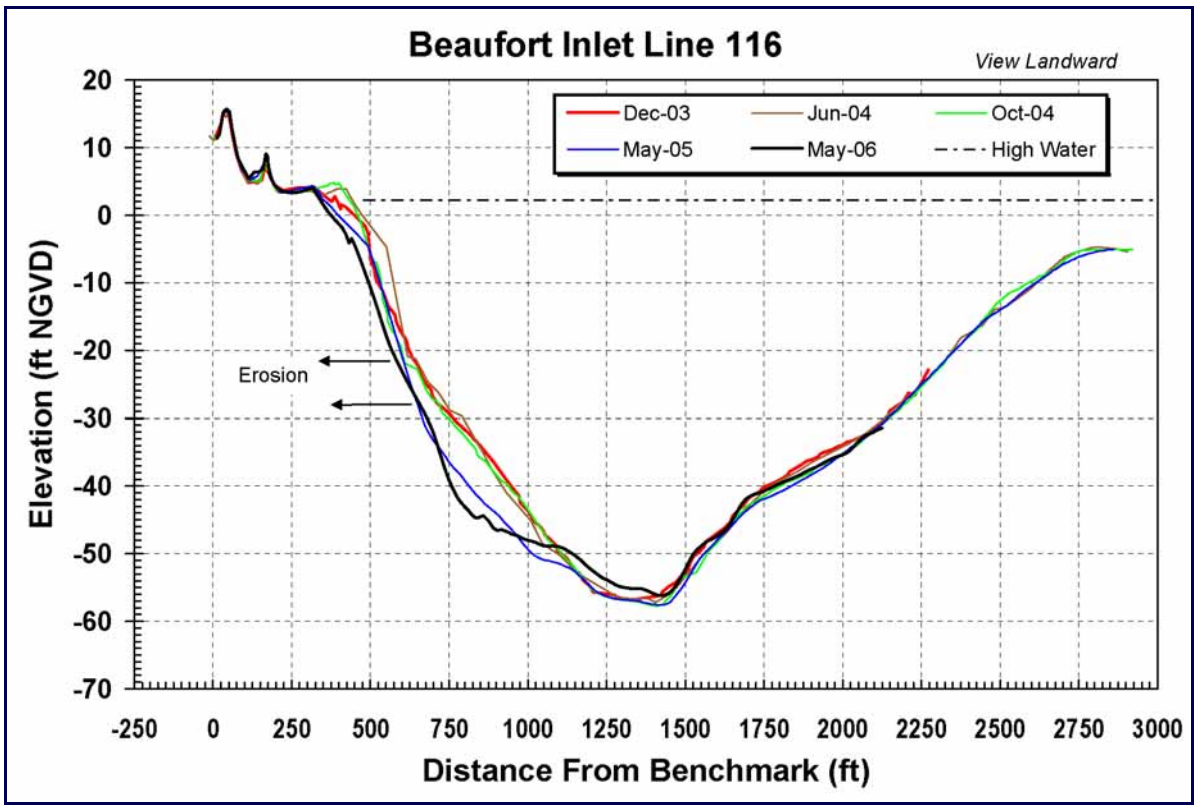


FIGURE 3.9-2. Comparative profiles along Beaufort Inlet. Note significant spit growth since 2003 at profile 115, likely the result of nourishment sand shifting from the Fort Macon State Park reach. The most landward profile (116) has eroded since 2003.

3.10 Bear Island

Bear Island lies west of Bogue Inlet from Emerald Isle. The Atlantic coastline of Bear Island was first surveyed by CSE in October 2004 and again in conjunction with the BBBNMP Year 2 monitoring project in May 2005. CSE established 18 profile lines at 1000-ft spacing. The 17,000-ft Bear Island reach had a net loss of 139,170 cy of sand between May 2005 and May 2006, which amounts to an average unit volume change of –8.2 cy/ft (to –11 ft NGVD).

The majority of the erosion occurred above –4 ft NGVD where Bear Island lost 162,355 cy of sand, which means there was a net gain in sand volume between –4 ft NGVD and –11 ft NGVD of ~23,000 cy between 2005 and 2006. This gain in sand volume is evident in the station to station beach unit volume change comparisons (Fig 3.10-1). There was less sand loss (or more sand gain) in 11 of the 18 profile lines when measured to –11 ft NGVD than when measured to –4 ft NGVD.

Profile line 17 is characterized by a high loss of sand to –11 ft NGVD relative to the other profiles. Although Bear Island was net erosional over the last year, there are profiles at the east, central, and western ends that have gained sand volume. The eastern end of the island has gained over 60 cy/ft to the outer bar with one-third of the net increase appearing on the recreational beach.

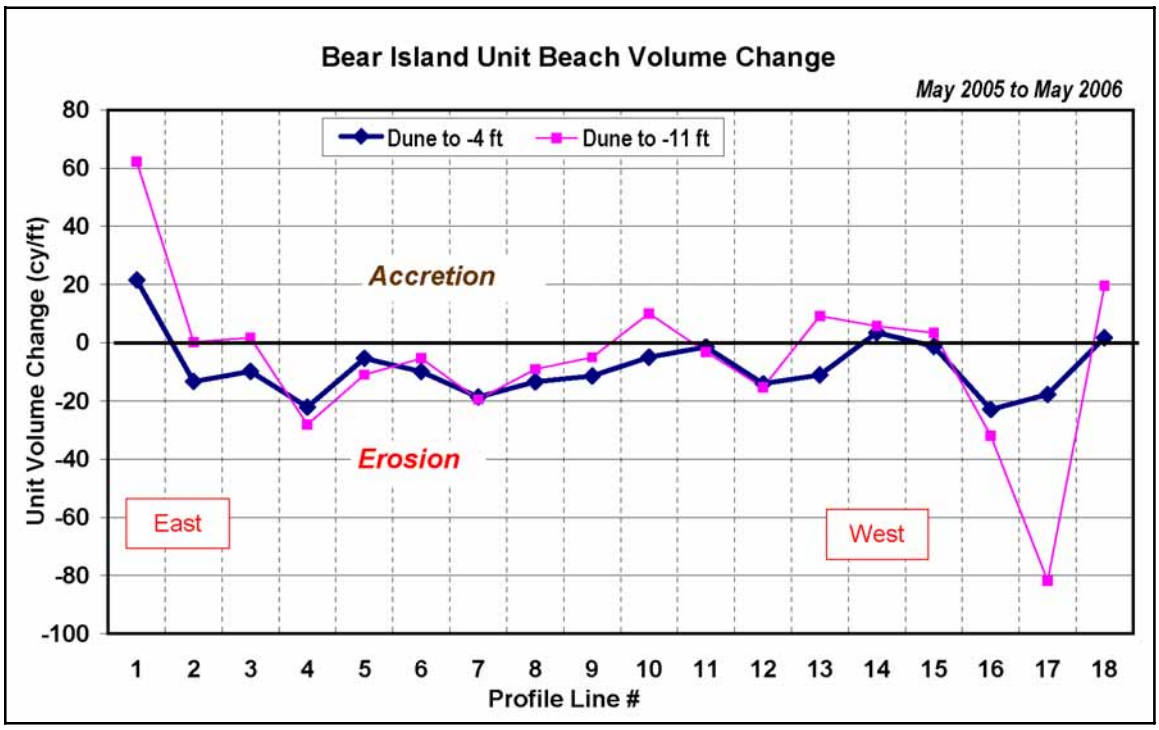


FIGURE 3.10-1. May 2005 to May 2006 beach volume changes – Bear Island.

3.11 Shackleford Banks

Shackleford Banks, located across Beaufort Inlet from Fort Macon State Park, is ~46,000 ft long. CSE first surveyed the island in May 2005. Between May 2005 and May 2006, Shackleford Banks lost 686,685 cy of sand (to –11 ft NGVD), averaging –14.9 cy/ft. This figure includes the high erosion at profile 1 near Barden Inlet. When this value is not included, the average unit volume change is –12.1 cy/ft. The average sand volume losses to –4 ft (9.8 cy/ft) are similar to those of Bear Island (9.6 cy/ft). However, the losses below –4 ft NGVD are much higher. Almost all of the losses are accounted for from the dune to the outer bar. There has been an estimated gain of 21,652 cy of sand between the outer bar and –15 ft NGVD (see Table 2).

The beach system at Shackleford is moderately stable and has nearly a zero net change in average sand volume on the eastern end of the island — with the exception of profile line 1, which was very erosional due to its location adjacent to the inlet. The central and western parts of the island show much less stability relative to the eastern end (Fig 3.11-1). Over the monitoring period, the central and western parts of the island were, on average, moderately erosional with high erosion spots at profile lines 9, 12, and 15 (dune to –11 ft NGVD) and moderate gains in sand volume at profile lines 14, 17, and 23.

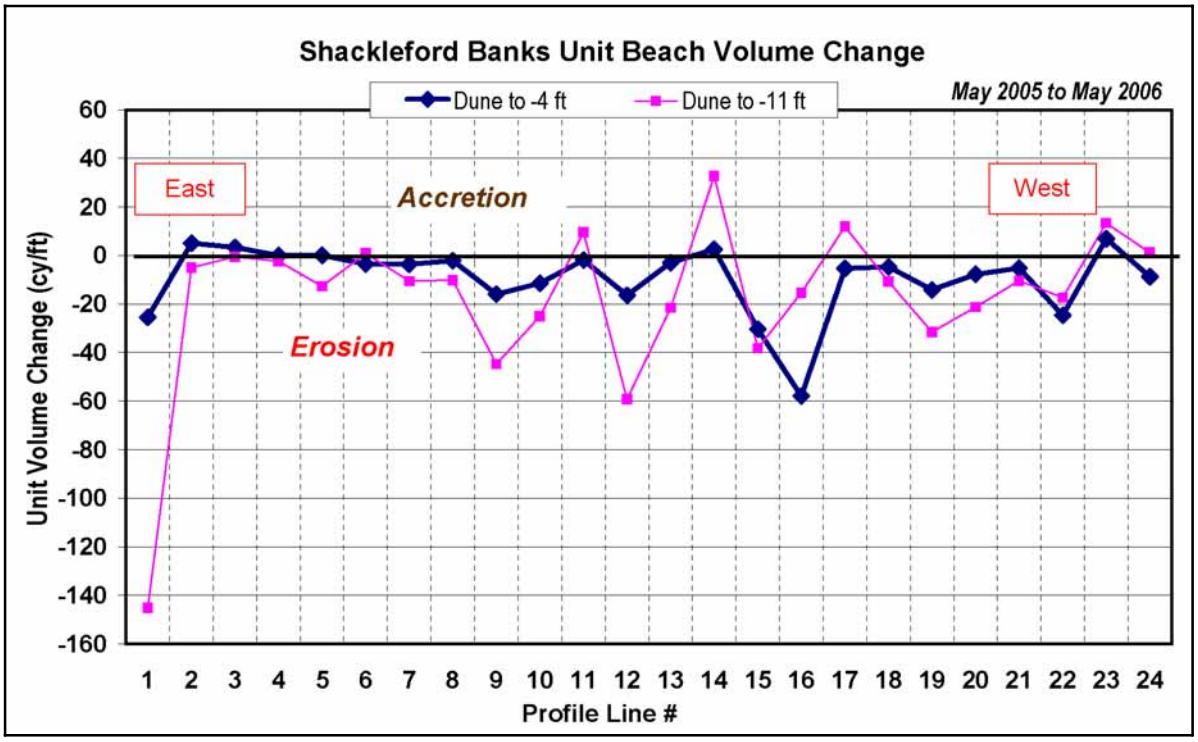


FIGURE 3.11-1. May 2005 to May 2006 – Shackleford Banks.

3.12 Post-*Ophelia* Response

CSE completed a post-Hurricane *Ophelia* assessment of Bogue Banks between 16 and 18 September 2005, following the storm's impact on the island on 13–14 September. By re-occupying 40 of the 112 survey lines on Bogue Banks, CSE was able to estimate hurricane losses and assess profile adjustment for most of the island (CSE 2005c). Selected stations and data are listed in Tables 6 and 7. These data from CSE's 2005 monitoring report are repeated in the present report because they apply to the May 2005–May 2006 period which is covered herein.

Table 7 summarizes the results by community and by calculation lens. Relatively little sand was lost in the foredunes throughout the island (Fig 3.12-1). The entire island lost ~1,500,000 cy of sand or 13.1 cy/ft of beach measured from the dune to –11 ft (to the outer bar, Fig 3.12-2). While sand losses on the beach were significant, accumulation of sand offshore to the outer bar (–18 ft NGVD) accounts for 90 percent of those losses. Changes in volume were more variable at the intertidal zone (wet beach) where there was an overall gain in sand of 1,466 cy (0.04 cy/ft). Erosion was highest from the low-tide elevation to the outer bar where the overall unit volume change was –9.2 cy/ft. Accretion was highest seaward of the bar to –18 ft NGVD where the overall unit volume change was 12.6 cy/ft between May 2005 and the post-*Ophelia* survey.

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

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

FEMA reviewed the condition of the beach and the results of post-storm surveys and concluded that the Towns of Emerald Isle, Indian Beach, and Pine Knoll Shores qualified for Category G community assistance funds to replace sand volumes lost due to *Ophelia*. Losses were calculated to the –11 ft NGVD contour, the depth standard on which the county nourishment project is based. FEMA project worksheets PW 38 (Emerald Isle), PW 39 (Pine Knoll Shores), and PW 40 (Indian Beach) defined the scope of restoration as follows:

A) Town of Emerald Isle: 569,160 cy (two reaches totaling ~27,500 linear feet between profile lines 10-20 and profile lines 33-45).

B) Town of Pine Knoll Shores: 239,796 cy (two reaches totaling ~13,600 linear feet between profile lines 62-65 and profiles lines 66-73).

C) Town of Indian Beach: 298,604 cy (one reach totaling ~13,400 linear feet between profile lines 48-58).

The project worksheets specify that beach restoration should be accomplished by 31 March 2007. As of this writing, bids for construction have been received and a contract awarded to Great Lake Dredge & Dock Company. Federal and state permits have been issued with construction estimated to start in early January 2007. Unit bid price for nourishment by the lowest responsible bidder was $9.89 per cubic yard utilizing sand from the Beaufort Entrance ODMDS. The FEMA estimate (PW 38, 39, 40) was $9.00 per cubic yard.

As the overall volume change analyses (presented at the beginning of this report) show, erosion losses to –11 ft NGVD have generally persisted over the past year. By May 2006, there had been little recovery of sand from deeper water. This suggests the planned renourishment remains an important component of the county's long-range strategy to maintain the beach. Post-*Ophelia* nourishment is expected to restore ~1.1 million cubic yards between Pine Knoll Shores and Emerald Isle.

An unrelated, but important additional beach restoration is planned for Pine Knoll Shores under the federal Section 933 project. Plans call for up to 900,000 cy to be dredged from the Morehead City Navigation Channel and placed on the beach. This is a continuation of Section 933 work begun at Indian Beach in 2004 (cf Fig 3.2-1). Thus, by summer 2007, Bogue Banks may receive up to 2 million cubic yards of additional sand on the beach.

Despite much higher erosion rates since May 2005, there was negligible damage to the foredune during the year. *Ophelia*'s surge reached the toe of the dune, but generally caused little scarping. This is in sharp contrast to dune erosion during Hurricane *Floyd*, which left hundreds of walkovers damaged or destroyed. Figures 3.12-3 through 3.12-8 show the post-*Ophelia* beach in several representative areas.

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

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

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

TOP OF DUNE TO +9 ft NGVD					
Reach	Length (ft)	May 2005 Unit Vol (cy/ft)	Sep 2005 Unit Vol (cy/ft)	May - Sep Unit Vol Change (cy/ft)	May - Sep Net Vol Change (cy)
Emerald Isle	57,919	15.94	16.02	0.08	4,686
Indian Beach/ Salter Pat	12,986	35.23	35.19	-0.04	-543
Pine Knoll Shores	23,968	16.76	16.06	-0.70	-16,771
Atlantic Beach	26,321	12.77	12.31	-0.46	-12,020
Fort Macon	7,199	16.87	16.97	0.10	709
	128,392	17.44	17.26	-0.19	-23,939

+9 FT TO +2 FT NGVD					
Reach	Length (ft)	May 2005 Unit Vol (cy/ft)	Sep 2005 Unit Vol (cy/ft)	May - Sep Unit Vol Change (cy/ft)	May - Sep Net Vol Change (cy)
Emerald Isle	57,919	47.32	45.13	-2.19	-126,719
Indian Beach/ Salter Pat	12,986	51.06	47.67	-3.39	-44,045
Pine Knoll Shores	23,968	34.71	27.83	-6.87	-167,541
Atlantic Beach	26,321	55.86	51.00	-4.87	-115,536
Fort Macon	7,199	41.61	36.02	-5.58	-40,178
	128,392	46.77	42.85	-3.92	-494,019

+2 FT TO -4 FT NGVD*					
Reach	Length (ft)	May 2005 Unit Vol (cy/ft)	Sep 2005 Unit Vol (cy/ft)	May - Sep Unit Vol Change (cy/ft)	May - Sep Net Vol Change (cy)
Emerald Isle	57,919	81.35	79.95	-1.40	-81,206
Indian Beach/ Salter Pat	12,986	83.99	83.24	-0.75	-9,691
Pine Knoll Shores	23,968	60.62	65.57	4.95	116,069
Atlantic Beach	14,496	82.52	80.87	-1.65	-23,706
Fort Macon	0	0.00	0.00	0.00	0
	109,368	77.28	77.31	0.04	1,466

-4 FT TO -11 FT NGVD*					
Reach	Length (ft)	May 2005 Unit Vol (cy/ft)	Sep 2005 Unit Vol (cy/ft)	May - Sep Unit Vol Change (cy/ft)	May - Sep Net Vol Change (cy)
Emerald Isle	57,919	157.37	150.41	-6.96	-403,238
Indian Beach/ Salter Pat	12,986	166.43	147.62	-18.82	-244,327
Pine Knoll Shores	23,968	140.35	133.45	-6.90	-171,551
Atlantic Beach	14,496	181.97	168.75	-13.22	-190,983
Fort Macon	0	0.00	0.00	0.00	0
	109,368	157.98	148.79	-9.19	-1,010,099

-11 FT TO -18 FT NGVD*					
Reach	Length (ft)	May 2005 Unit Vol (cy/ft)	Sep 2005 Unit Vol (cy/ft)	May - Sep Unit Vol Change (cy/ft)	May - Sep Net Vol Change (cy)
Emerald Isle	57,919	290.86	304.50	13.63	789,716
Indian Beach/ Salter Pat	12,986	291.39	305.22	13.83	179,553
Pine Knoll Shores	23,968	287.84	298.83	10.99	265,678
Atlantic Beach	14,496	340.64	350.73	10.10	150,806
Fort Macon	0	0.00	0.00	0.00	0
	109,368	296.86	309.47	12.61	1,385,753

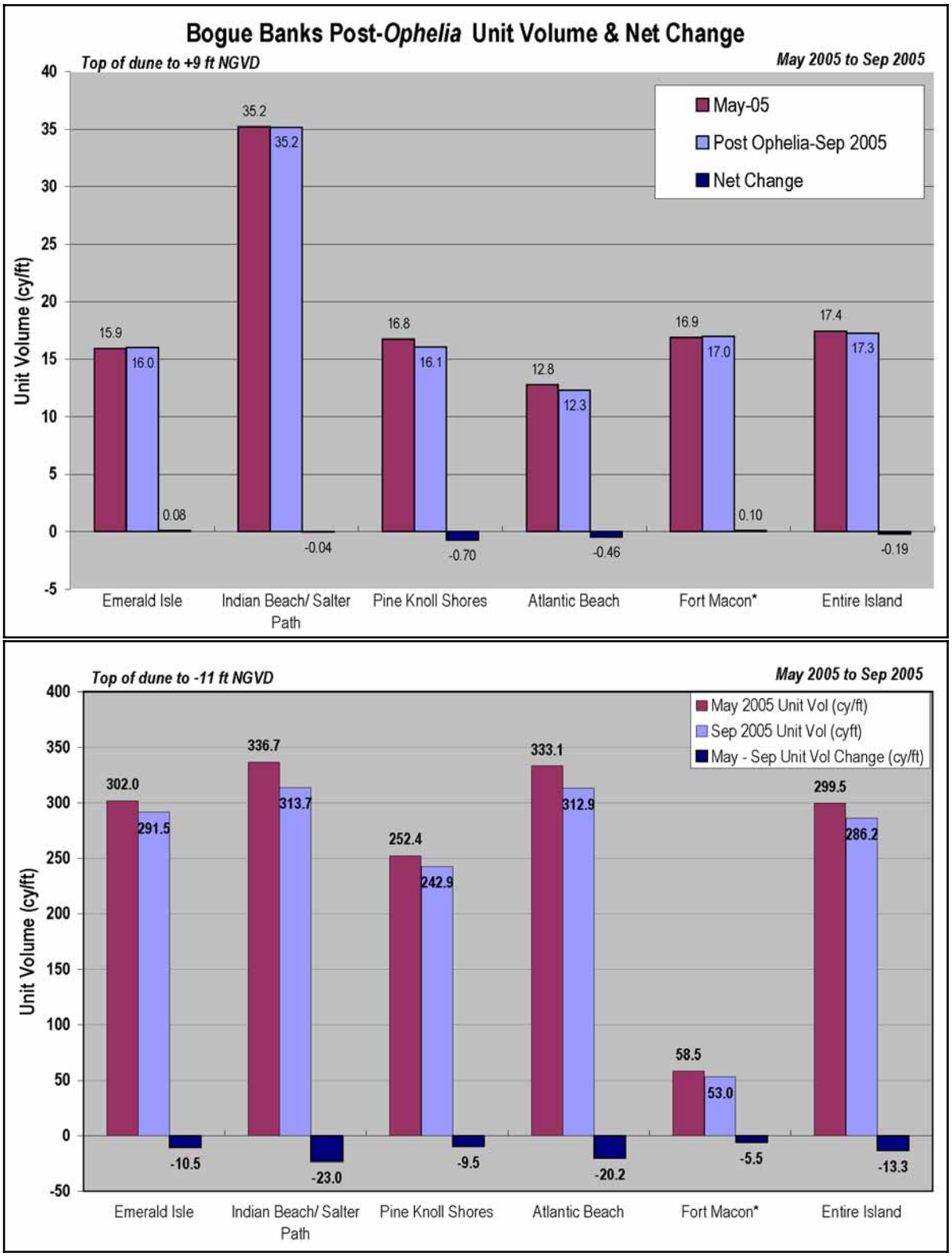


FIGURE 3.12-1. Net unit volume in the dunes (upper) and to the outer bar (lower) for each reach. Unit volume changes are calculated for the period May 2005 to September 2005.

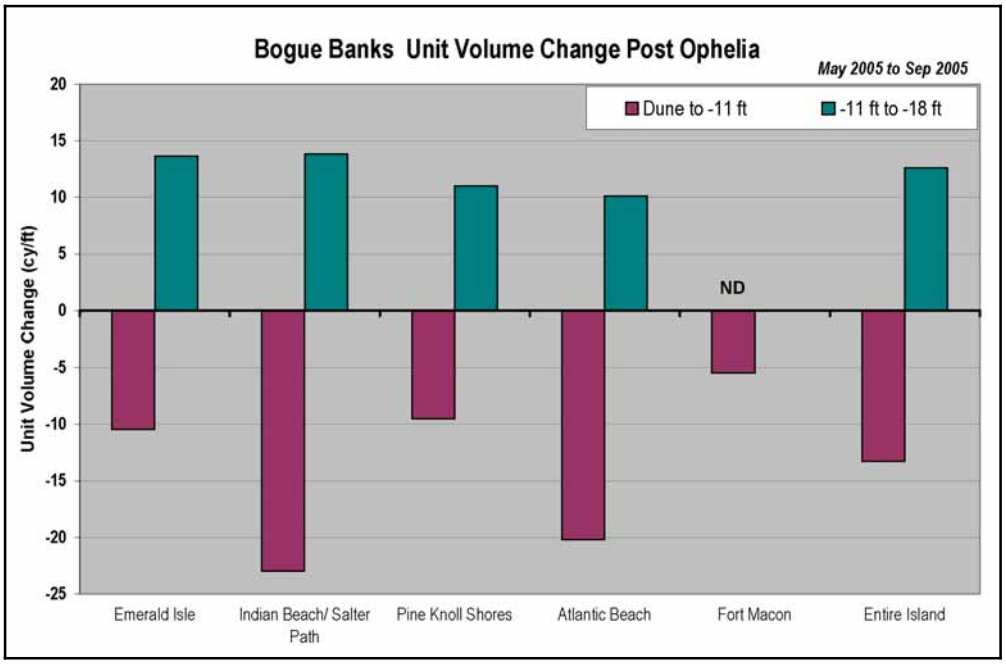


FIGURE 3.12-2. Volume losses on the beach to the outer bar are balanced by volume gains between the outer bar (–11 ft) and approximate closure depth (–18 ft).

TABLE 8. Summary of volume changes by reach.

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

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

FIGURE 3.12-3.

Post-*Ophelia* beach at profile line 35 (2700 block) of Emerald Isle. Note lack of escarpment although some sand washed out around the sand fencing. [All photos by P McKee]

FIGURE 3.12-4.

Post-*Ophelia* beach at profile line 42 (Emerald Isle–East) where sand fencing was washed out by *Ophelia*. Dune recession was minor and localized.

FIGURE 3.12-5.

Post-*Ophelia* beach at profile line 56 (Indian Beach) showing damaged sand fencing but no dune recession.

FIGURE 3.12-6.

Post-*Ophelia* beach at profile line 70 (Pine Knoll Shores) showing upper beach erosion and exposure of large sand bags at Pine Knoll Townes condominiums. There was no structural damage in contrast to much worse conditions after Hurricane *Floyd*.

FIGURE 3.12-7.

Post-*Ophelia* beach at profile line 85 (Atlantic Beach) showing damage to sand fencing but no poststorm escarpment.

FIGURE 3.12-8.

Post-*Ophelia* beach at profile line 103 (Fort Macon State Park) showing minor dune erosion near the visitors center.

3.13 Profile Analyses — Prenourishment to Postnourishment

This section provides a simplified analysis of profiles by reach for purposes of illustrating typical conditions before and after nourishment. Given the large number of profiles in the Bogue Banks data set, it is useful to develop composites that represent average conditions. This tends to smooth irregularities and make interpretation of changes easier to visualize.

CSE followed a multi-step procedure to develop composite profiles (Fig 3.13-1):

- Select applicable profile lines and dates by reach.
- Select a common contour to match the cross-shore alignment of profiles.
- Determine the elevation at regular intervals along each profile.
- Compute the average elevation at each interval from the suite of profiles.
- Plot distance-average elevation pairs to represent the "composite" average profile for the reach.

Figure 3.13-1 illustrates some of the steps for the June 2002 prenourishment survey at Emerald Isle–East; 13 profile lines (36–48) are applicable. Figure 3.13-1 (upper) shows them overlain as surveyed (ie, plotted relative to the survey baseline control points). The middle graphic shows the same raw profiles matched at the +9-ft NGVD contour. Note the general consistency of shape reflecting similarity of the profiles within the reach. The lower graphic shows the average elevation (as well as maximum and minimum observed values) as calculated every 5 ft along the profile.

CSE similarly determined the average profile for the suite of postnourishment and May 2006 profiles at each reach. This yielded three comparative profiles for each reach referenced to the +9-ft contour. Figure 3.13-2 shows results for Atlantic Beach and Emerald Isle–West. The change in cross-section under each profile, measured to the approximate depth of closure, was calculated and converted to unit-width volume change (in cy/ft). The "Pre to Post" result yields an estimate of the average gain in volume due to nourishment. Note that because nourishment was performed in phases, the "Pre to Post" dates vary by reach. The profiles also give the net average change between prenourishment and May 2006 (most recent survey). Obviously, if the "Pre to May 06" volume change is less than the "Pre to Post" volume change, there has been erosion of the nourishment.

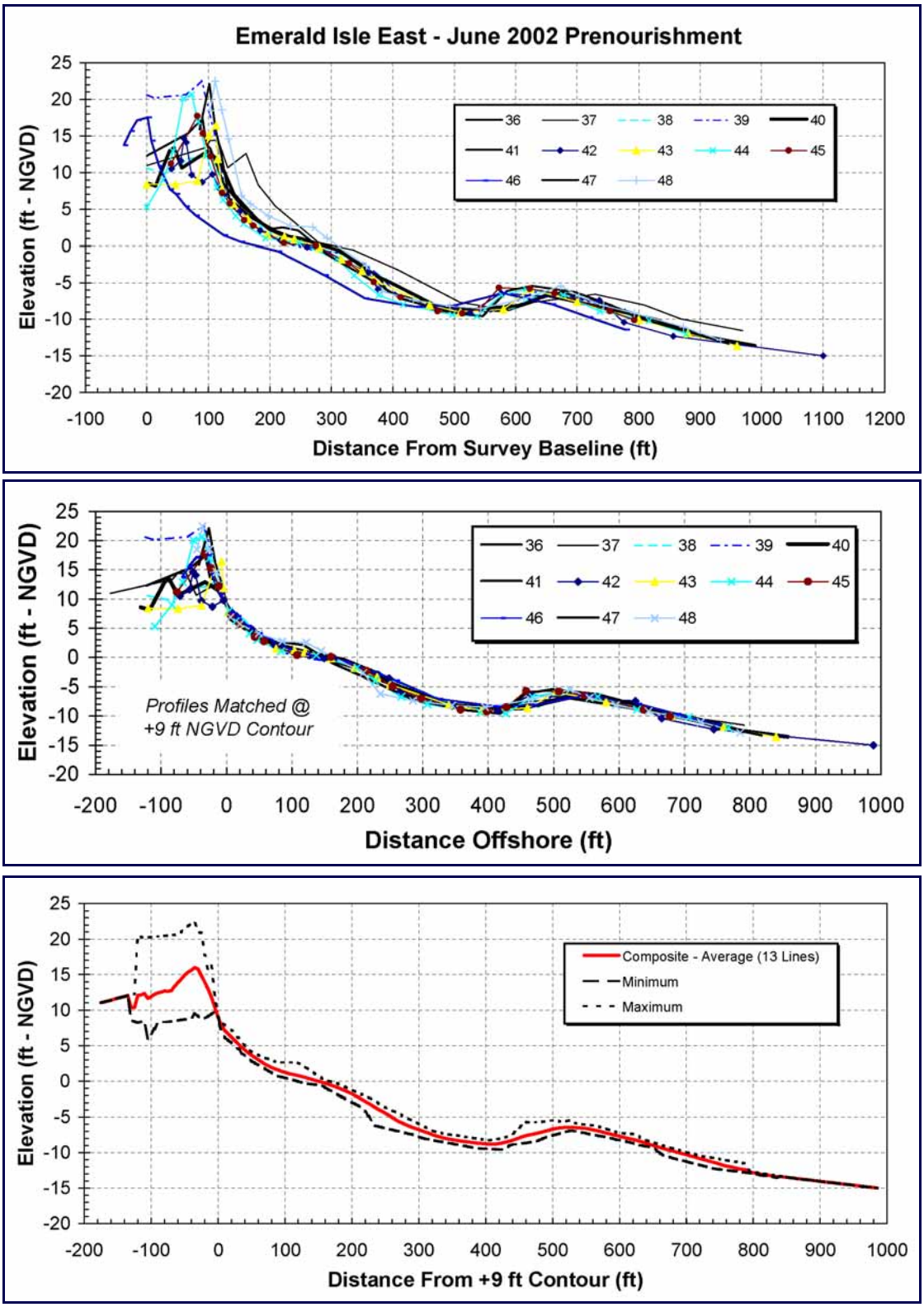
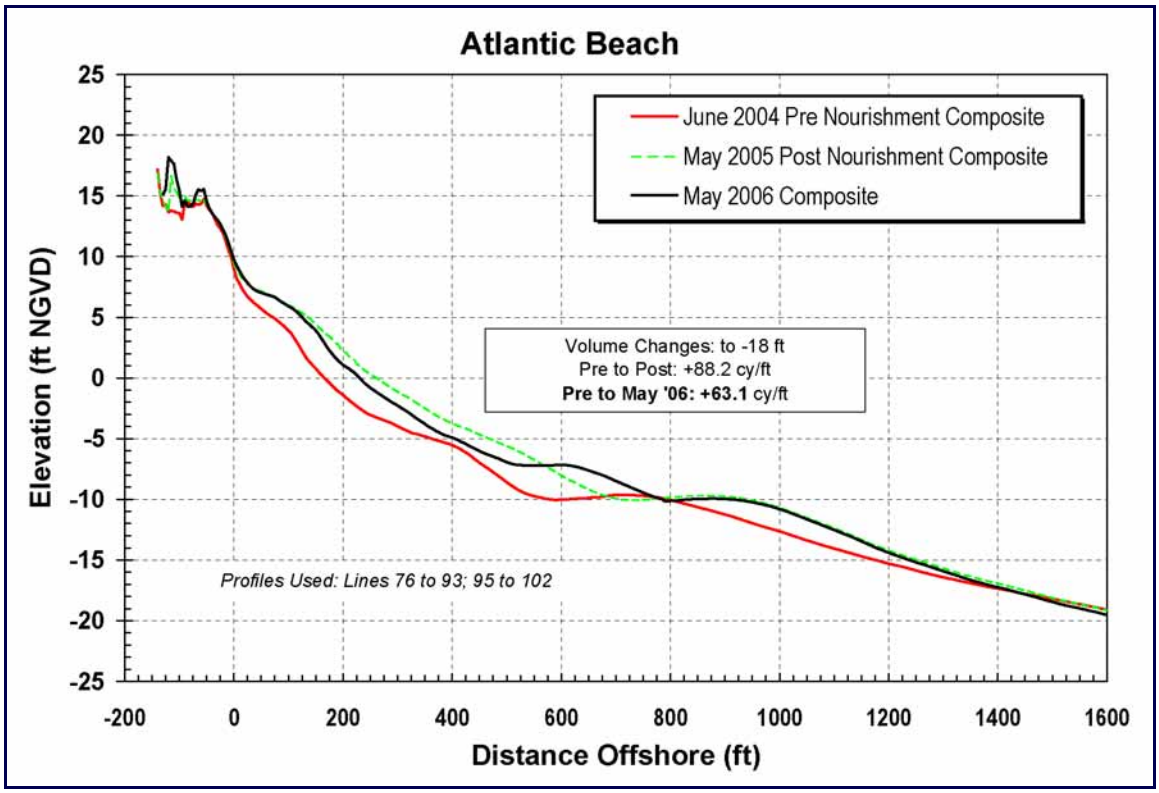


FIGURE 3.13-1. Example procedure for calculating an average (composite) profile by reach using (upper) applicable profile lines – raw data, (middle) matching each profile at the +9-ft NGVD contour to juxtapose relative to a common morphological feature such as the toe of dune, (lower) then calculating the average elevation at set distances offshore. Average profiles before nourishment (pre) and after nourishment (post), as well as May 2006 were developed for most reaches along Bogue Banks.



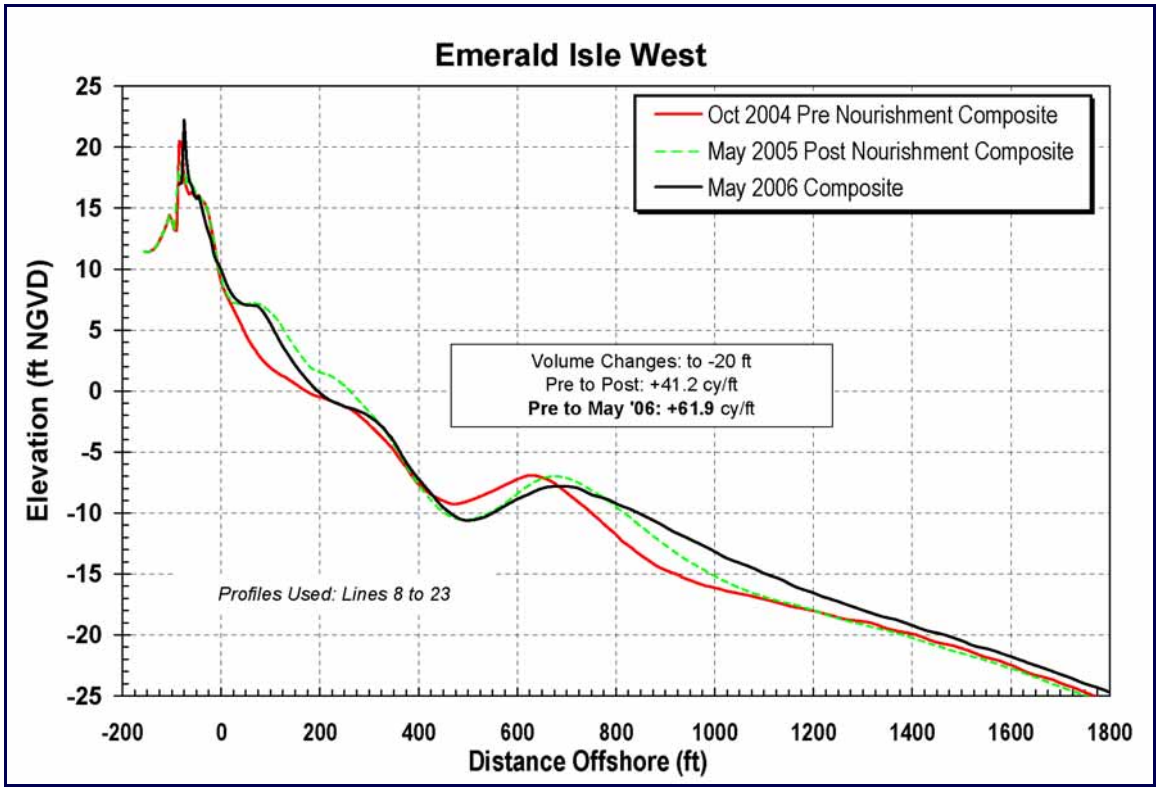


FIGURE 3.13-2. Composite average profiles for Atlantic Beach and Emerald Isle–West before and after nourishment showing the typical seaward displacement of the profile and average gain in volume to a reference depth (near closure depth).

In most reaches, this “Pre to May 06” volume change is greater, reflecting some combination of (1) additional accretion in the reach or (2) additional nourishment. Indian Beach, for example, was nourished in 2002 under Phase 1 of the county project. Then it received additional nourishment in 2004 under the Section 933 project. “Pre to Post” in the case of IB/SP compares February 2002 and June 2002 (ie, county project). “Pre to May 06” incorporates the impact of the spring 2004 Section 933 project.

Figure 3.13-2 (upper) for Atlantic Beach shows a typical nourishment volume of 88.2 cy/ft (federal Brandt Island pumpout in spring 2005). The net change by May 2006 was 63.1 cy/ft, indicating about 25 cy/ft eroded between May 2005 (postnourishment) and May 2006. By contrast, Emerald Isle–West (Fig 3.13-2, lower) received an average of ~41.2 cy/ft in the county Phase 3 nourishment in spring 2005, then gained an additional ~20.7 cy/ft between May 2005 and May 2006 (measured to **–20 ft** NGVD).

Table 9 provides a rough estimate of net volume change along Bogue Banks to closure depth based on the composite profiles. In this case, the average unit volume change by reach (prenourishment to May 2006) is applied over the corresponding length of each reach. No data are available for the end compartments because they are biased by inlet volumes associated with the ebb-tidal delta. Nevertheless, an estimate can be made for remaining reaches, then extrapolated to the ends of the island as shown in Table 9. The results account for 7.9 to 8.9 million cubic yards which are certainly comparable to the total volume of nourishment between 2002 and 2005 (~8.6 million cubic yards). This result suggests that surveys to depths ranging from –15 ft to –20 ft NGVD account for all the sand added along Bogue Banks in the past five years. Comparing with the results to –11 ft NGVD, Table 9 indicates the 2.5 million cubic yards lost between the foredune and outer bar since 2005 are now situated between –11 ft and –20 ft NGVD.

TABLE 9. Estimated net volume change to approximate closure depth — prenourishment to May 2006 based on composite (average) profile volume changes to the indicated depth.

Reach	Length (ft)	Calculation Depth (ft-NGVD)	Unit Volume Change (cy/ft)	Net Change (ft)
Fort Macon State Park	7199		ND	
Atlantic Beach	26,322	-18	63.1	1,660,918
Pine Knoll Shores - East	14,785	-16	17.4	257,259
Pine Knoll Shores - West	9,182	-15	73.8	677,632
Indian Beach/Salter Path	12,986	-15	104.4	1,355,738
Emerald Isle - East	12,900	-18	110.6	1,426,740
Emerald Isle - Central	15,945	-18	72.7	1,159,202
Emerald Isle - West	22,303	-20	61.9	1,380,556
Bogue Inlet - Ocean	6,772		ND	
Totals - AB to EI-West	114,423		69.2	7,918,044
Totals - FMSP to BI-Ocean	128,394	**via Extrapolation*	69.2	~8,900,000

Profile Shape Changes

The composite profiles were also used to evaluate shape changes. A comprehensive statistical analysis is outside the time available for the present study. Nevertheless, some simple procedures can be applied to visualize how similar the postnourishment profile shape is compared with the prenourishment shape. CSE-Stroud (2001) recommended certain offshore borrow areas because they contain a similar broad spectrum of sediment grain sizes as the native beach. If nourishment sediments match the native size distribution, the resulting profile should be similar in form. CSE-Stroud (2001) emphasized that broad sediment size distributions are necessary to maintain bar-trough profiles in this setting. If nourishment sediments were uniform fine sand, for example, the resulting beach slope would be gentler and the bar-trough topography would be less developed.

CSE's procedure for comparing the degree of similarity in profile shape involved the following steps:

- Extract the portion of the profile in the active littoral zone (ie, approximate upper beach face to the outer bar).
- Match pre, post and May 2006 composites at the high water contour.

- Normalize the prenourishment profile and plot as a percentage (ie, plots as a straight line at 100 percent).

- Normalize the post and May 2006 profiles against the normalized prenourishment profile and plot as a percentage.

The degree of similarity in shape of the postnourishment and prenourishment profiles is reflected by differences in elevation at each calculation point along the profile. The differences are plotted as a percentage, but in this case, percentage is similar in magnitude to an absolute measure in feet.

Figure 3.13-3 shows the result for PKS–West. The upper graph shows the composite prenourishment and postnourishment profiles matched at the +9-ft contour. The middle graph has extracted the active littoral zone portion of each profile and matched them at the high-water contour. (Note: The elevation has been increased by an arbitrary +100 ft to facilitate visualization of the data.) The resulting overlay illustrates the similarity and differences in shape with distance offshore. Note, in this case, the June 2002 postnourishment profile does not match the prenourishment profile very well. Its trough and outer bar are centered ~150 ft landward (relative distance) of the prenourishment profile. However, by May 2006 (four years postnourishment), the profiles are in fairly close alignment in both shape and relative elevation.

Figure 3.13-3 (lower) shows the percentage variation in relative elevation for postnourishment profiles versus the prenourishment profile. Note the June 2002 profile shape varied about ±4 percent (ie, approx ±4 ft) from the prenourishment profile. By contrast, the May 2006 profile shape only varies about 1–2 percent (~1–2 ft) from the prenourishment profile. Keep in mind, the postnourishment profiles for PKS-West reflect gains of ~53-74 cy/ft. The data in Figure 3.13-3 suggest that, on average, PKS–West's profile shape today is very similar to its prenourishment shape. This has important implications because if the profile shape after nourishment is similar, wave-breaking and sediment-transport processes should remain similar, even with the new profile displaced seaward.

Figures 3.13.4 through 3.13.7 show representative results for other reaches. In the case of PKS–East (Fig 3.13-4) the prenourishment and postnourishment profiles generally differ in relative elevation and shape by 2 percent or less. Only the outer bar area in May 2006

varies by more than ~2 percent. Its present elevation is (~)–9.5 ft, whereas the prenourishment elevation averaged (~)–7.5 ft.

IB/SP postnourishment profiles varied as much as 5 percent from the normalized prenourishment profile. But by May 2006, the degree of similarity had improved all the way to the outer bar (Fig 3.13-5). Note how closely the May 2006 profile matches the prenourishment profile in the inshore zone (relative distances 0–300 ft offshore).

EI–East and EI–Central (Figs 3.13-6, 3.13-7) showed similar trends in prenourishment and postnourishment shapes.

As a means of evaluating the sensitivity of profile shape before and after nourishment, CSE performed a similar normalization procedure on all prenourishment profiles. IB/SP was selected as the reference profile, and all other composites (except Atlantic Beach) were normalized against that one. Figure 3.13-8 (upper) shows an overlay of the portion for each profile used in the analysis. Composite profiles by reach have been matched at the high-water contour. (Note: 100 ft have been added to all elevations to facilitate normalization.) Figure 3.13-8 (lower) shows the variation in elevation relative to IB/SP. Note the typical percentage difference in relative elevation at any point along the active profile is (~)±2 percent. In other words, prenourishment profiles from reach to reach along Bogue Banks show a range of shape differences very similar in magnitude to the normalized postnourishment profiles. An ideal data set would be expected to show no difference in shape. These data reflect the inherent variability of the littoral zone. The key point here is that the postnourishment variations in profile geometry are essentially of the same magnitude as the prenourishment variations from Pine Knoll Shores to Emerald Isle. To the casual observer, then, such variations should not be noticed when using the nourished beach.

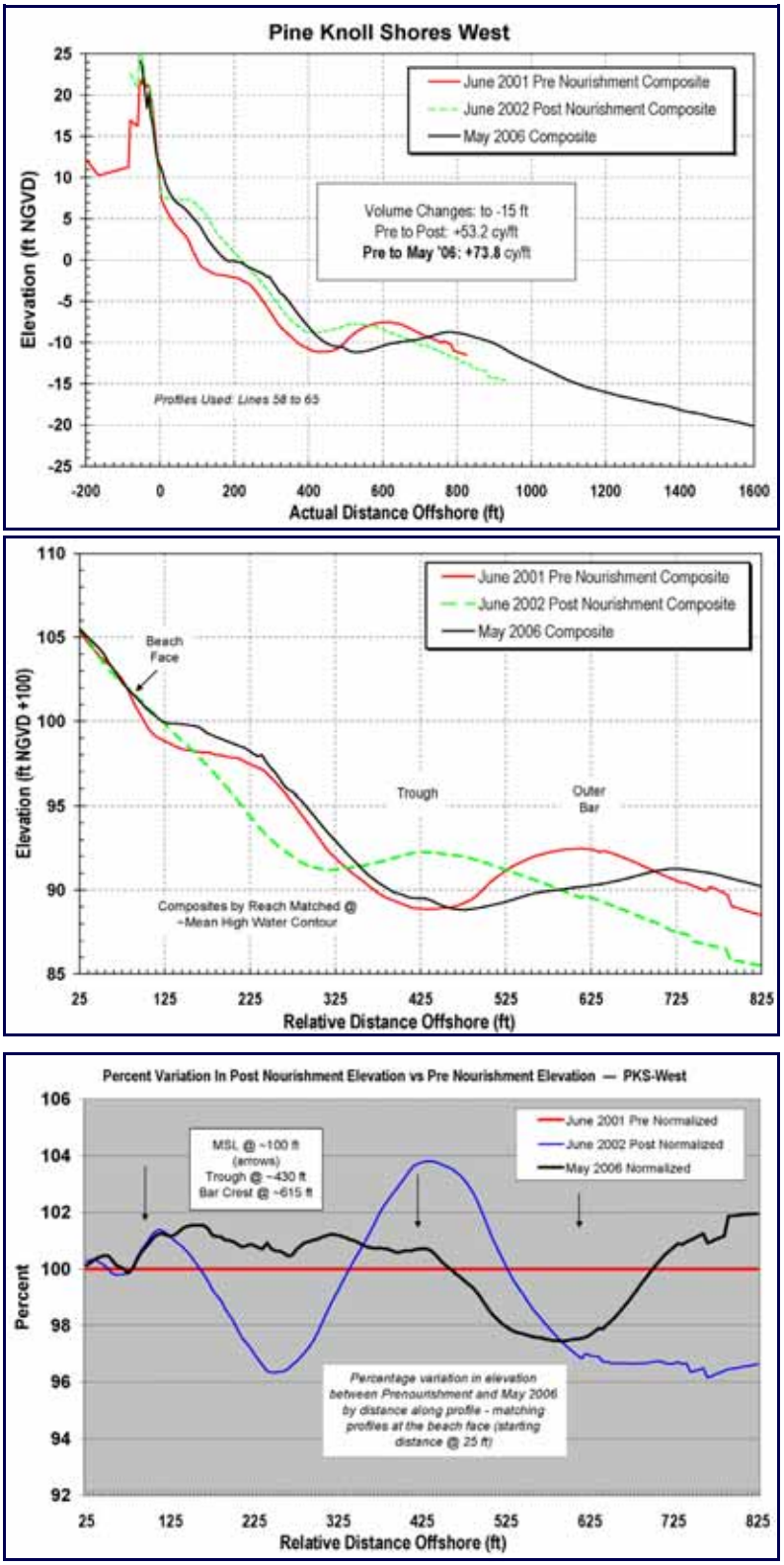
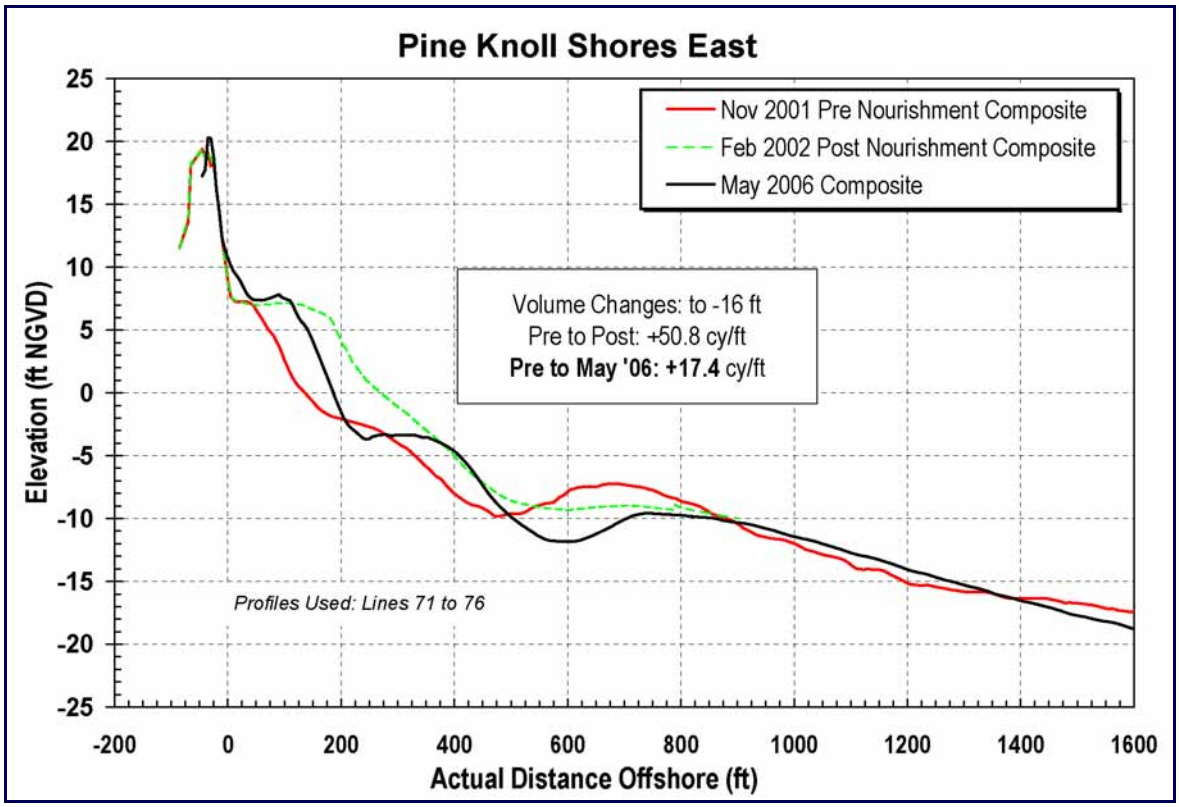


FIGURE 3.13-3. Average pre and postnourishment profiles for PKS–West (upper). The seaward displacement of post-nourishment profiles reflects the average impact of nourishment. A portion of each profile was extracted and overlain by matching the high water contour (middle). Then the data were normalized against the pre nourishment profile (lower). The percentages above or below 100 indicate the degree of similarity between postnourishment and prenourishment profile shapes. A perfect match would plot as a straight line at 100 percent.



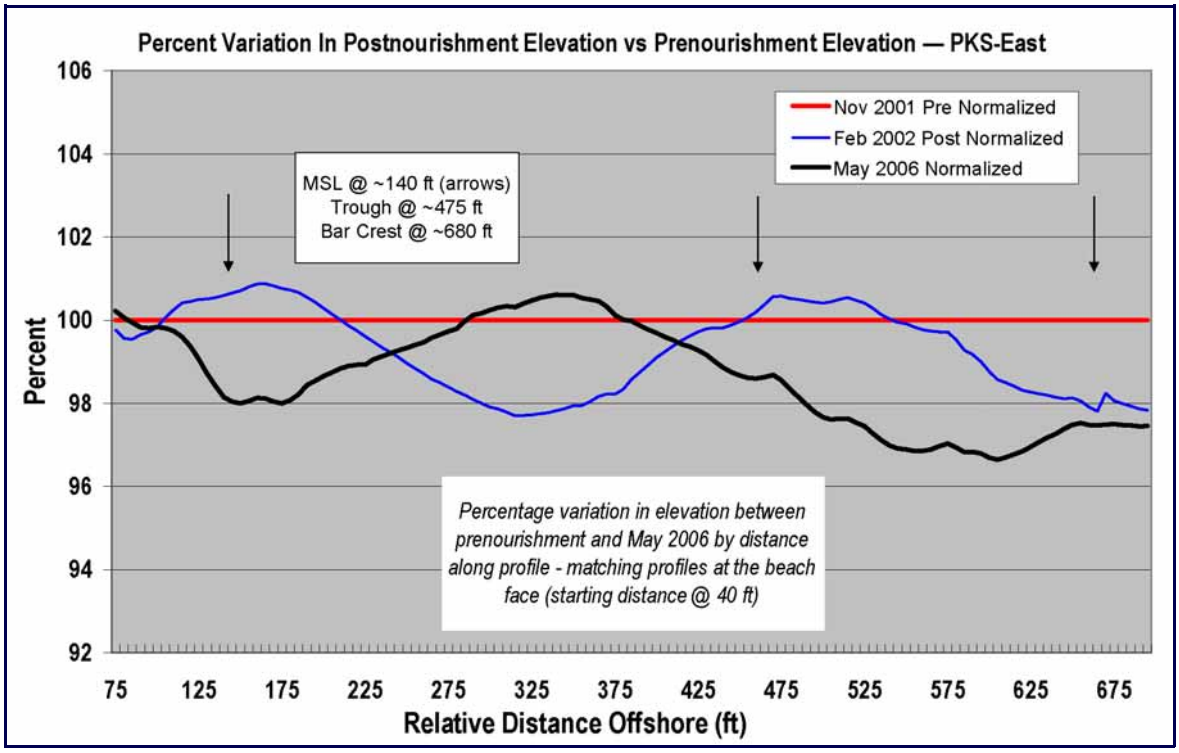


FIGURE 3.13-4. Average pre and postnourishment profiles for PKS–East (upper) and the normalized variation in relative elevation (shape) between prenourishment and postnourishment profiles (lower).

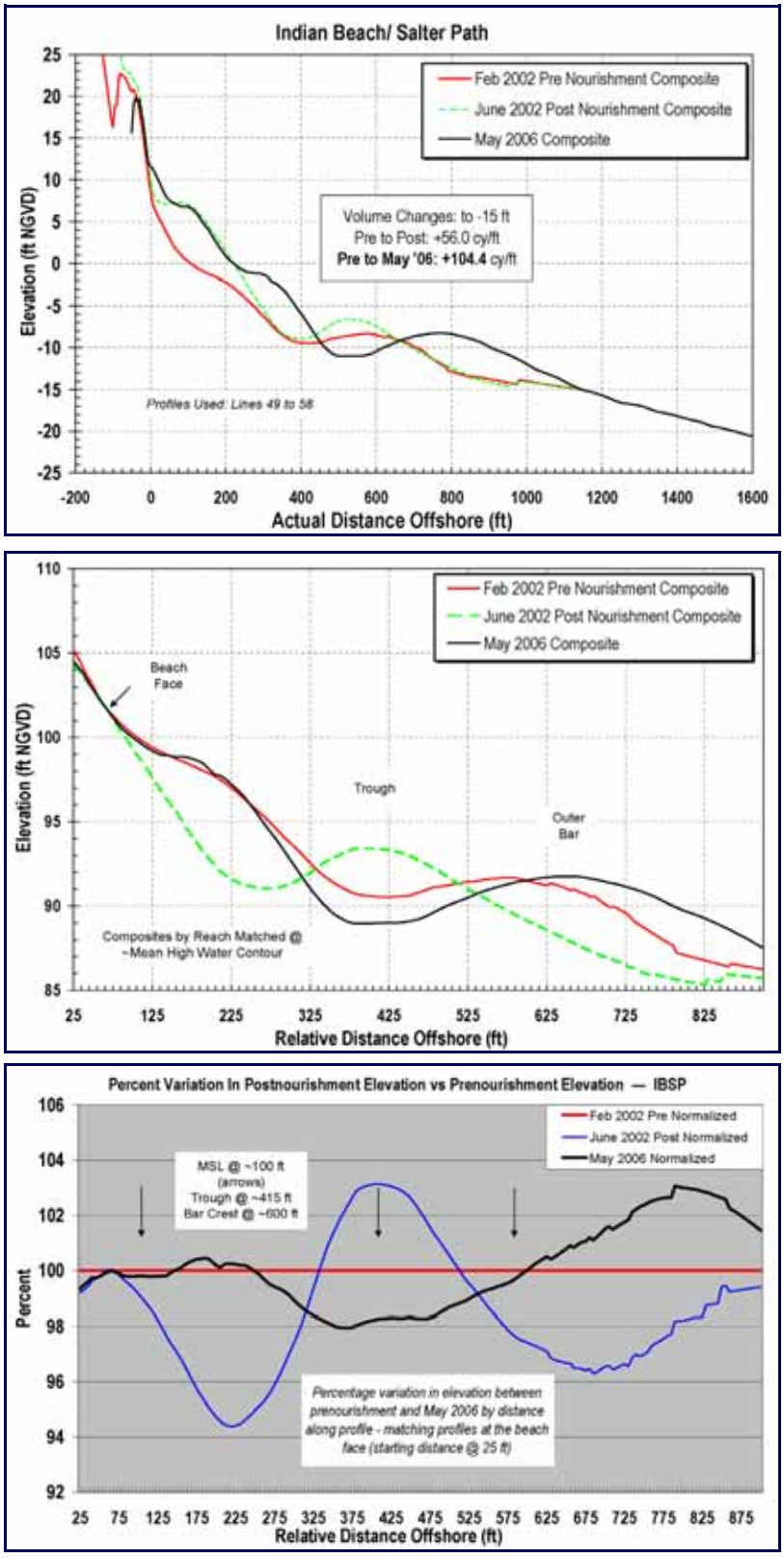


FIGURE 3.13-5. Average pre and postnourishment profiles for IB/SP (upper). Portion of IB/SP profiles extracted and overlain by matching the high water contour – adding 100 ft to elevation for normalization (middle). Then the data were normalized against the prenourishment profile (lower). The percentages above or below 100 indicate the degree of similarity between postnourishment and prenourishment profile shapes.

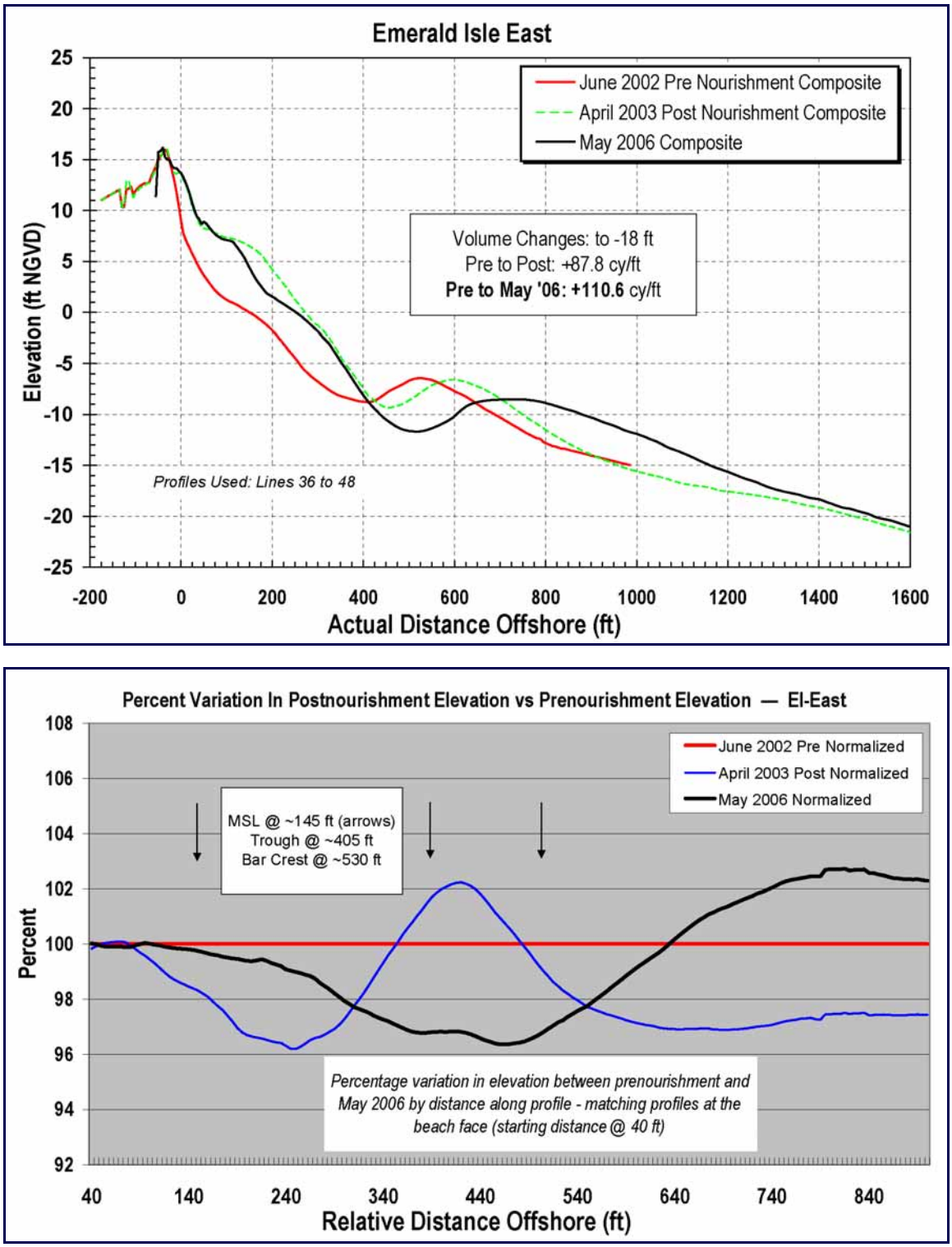


FIGURE 3.13-6. Average pre and postnourishment profiles for Emerald Isle–East (upper) and the normalized variation in relative elevation (shape) between prenourishment and postnourishment profiles (lower).

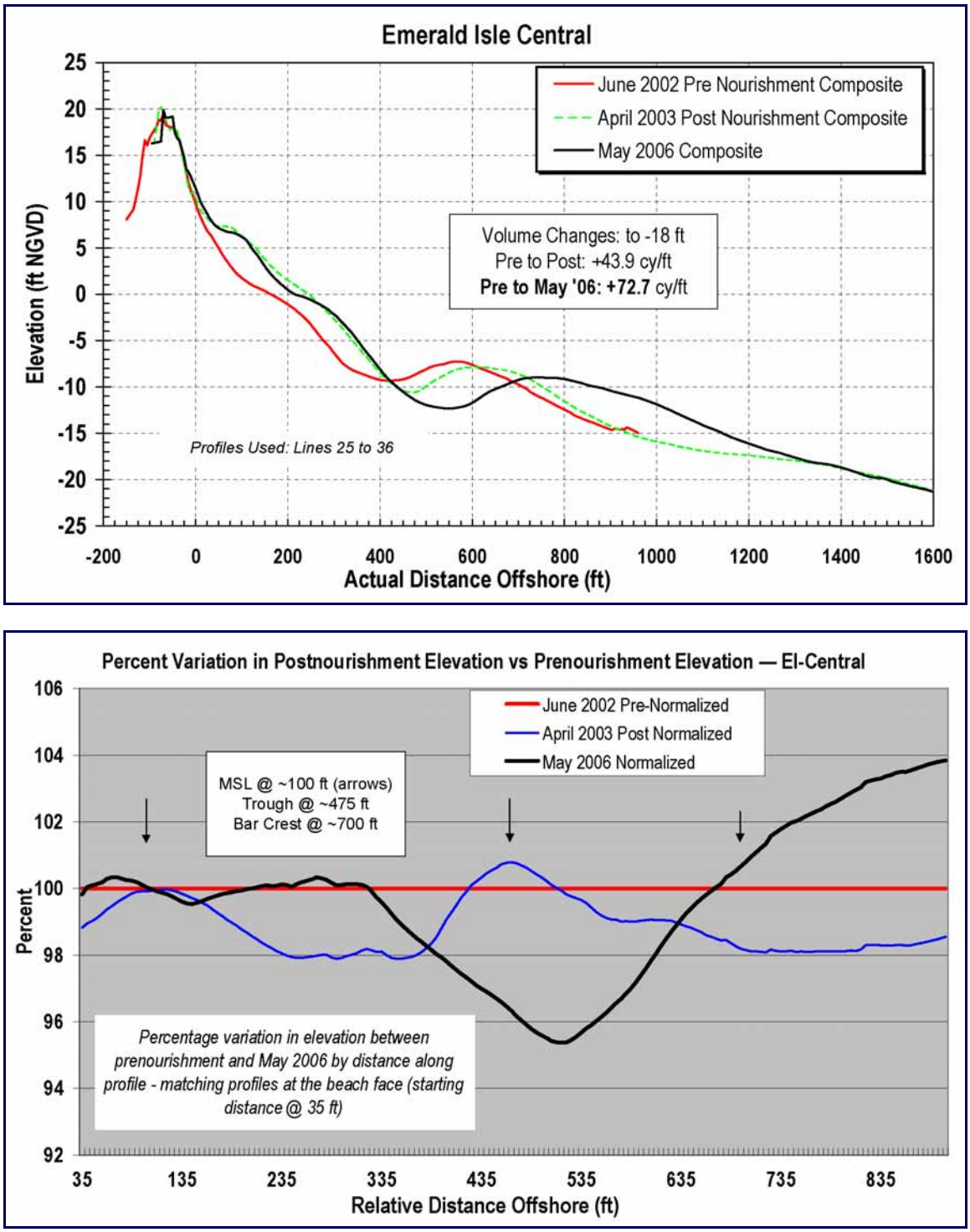
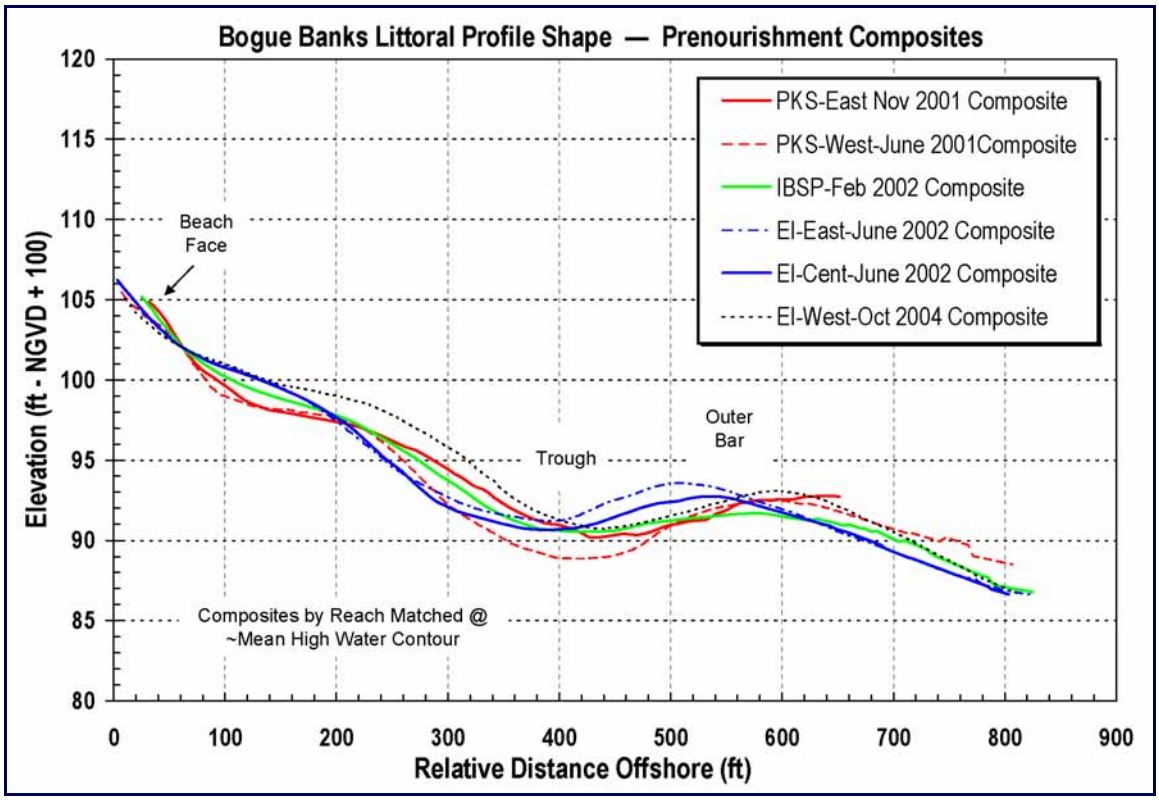


FIGURE 3.13-7. Average pre and postnourishment profiles for Emerald Isle–Central (upper) and the normalized variation in relative elevation (shape) between prenourishment and postnourishment profiles (lower).



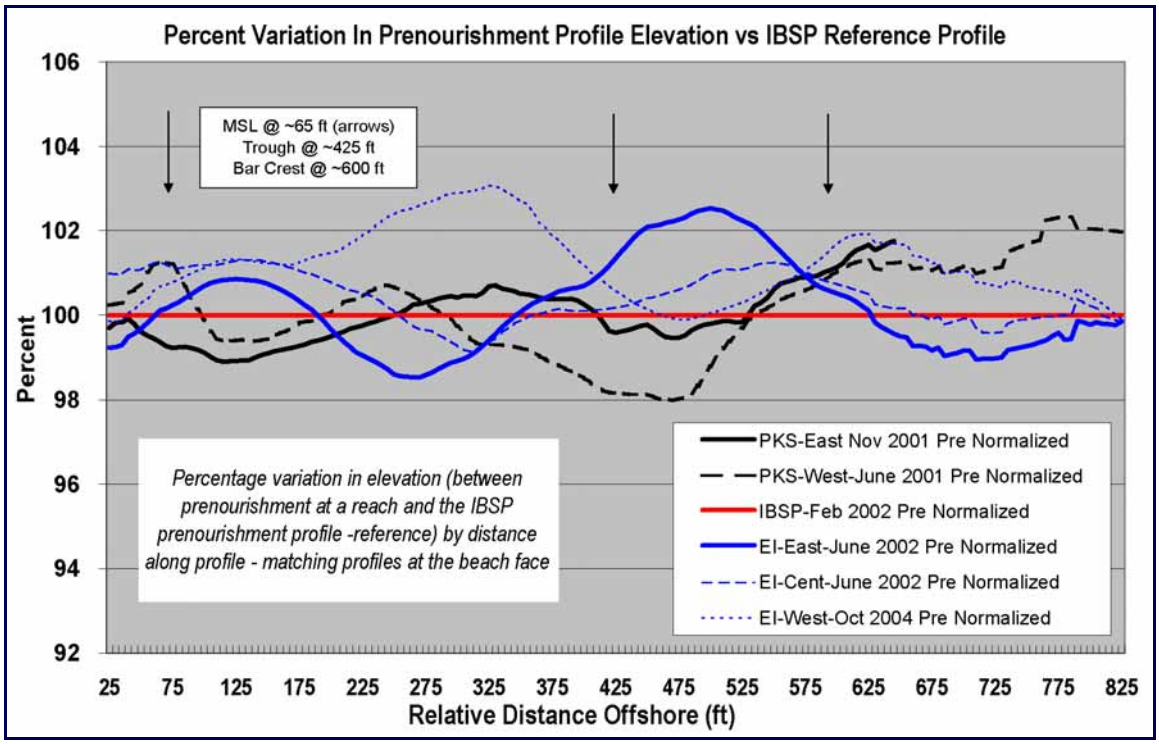


FIGURE 3.13-8. Prenourishment composite profiles by reach matched and overlain at the high water contour (upper). Elevations are increased by +100 ft to facilitate normalization. Lower graph shows variation in relative elevation (shape) compared with IB/SP. See text for further explanation.

3.14 Shoreline Changes

As part of the Year 3 analyses, the survey data of May 2006 were used to estimate the shoreline position on Bogue Banks and compare it with the shoreline position of June 1999. The mean high water line was used to define the position of the shoreline. In this case, CSE assumes mean high water based on a tidal benchmark at Morehead City Harbor (NC) of +2.1 ft NGVD.

Shoreline positions (MHW) are shown for all of Bogue Banks for June 1999 and May 2006. The May 2006 shoreline is seaward of the June 1999 shoreline at all positions between profile lines 8 and 111 (Figs 3.14-1 thru 3.14-11) with the exception of the western end of Fort Macon (Fig 3.14-11). The average net seaward change of the shoreline east of profile line 8 is 71 ft. The maximum net movement is in Salter Path at profile line 53 where the shoreline position moved seaward by 141 ft relative to the 1999 position. The minimum shoreline movement over the last seven years occurred at profile line 108 in Fort Macon State Park where the shoreline receded by 54 ft. The dynamic east and west ends of the Bogue Banks shoreline have experienced an overall average recession since 1999. This is especially the case at the west end of Emerald Isle where changes to Bogue Inlet have helped to change the hydrodynamic forces acting on that end of the island. The shoreline near Bogue Inlet has receded by nearly 400 ft over the last seven years. Average shoreline recession at the eastern end near Beaufort Inlet is not as pronounced.

Average beach-width change is listed in Table 10 along with the minimum and maximum beach-width changes for each reach. IB/SP had the highest average shoreline movement at 106 ft seaward. PKS-East had the least amount of average shoreline movement at 60 ft (with the exception of FMSP at 18 ft). Bogue Banks shoreline change appears to be somewhat correlated to the beach volume change over the past seven years to May 2006 in that the two reaches with the highest average seaward shoreline change also had the highest total change in average volume to -11 ft NGVD (IB/SP and EI-East). Conversely, the two reaches with the lowest average seaward shoreline movement also had the lowest total change in average unit volume (PKS-East and FMSP).

TABLE 10. Shoreline change (June 1999–May 2006) determined with beach-width change at the mean high water (MHW) elevation. At Bogue Banks, the MHW is (~)+2.1 ft NGVD. Volume change for each reach is also shown to compare the change in shoreline position with respect to the volume change. (*Bogue Inlet–Ocean reach is not used in this analysis.)

Shoreline Change (June 1999 — May 2006)			Observed Beach Width Change (ft) Seaward (+) Landward (-)			Shoreline Width Rank	Volume Change (1999 —2006) (cy/ft)	Volume Change Rank
Reach	Profiles	Reach Length (ft)	Minimum	Maximum	Average			
EI-West*	8-25	22,303	12	114	61	6	48.1	4
EI-Central	25-36	15,945	47	123	82	3	46.6	5
EI-East	36-48	12,900	79	120	100	**2**	62.3	**2**
IB/SP	48-58+	12,986	85	141	106	**1**	79.8	**1**
PKS-West	58-65	9,182	41	100	70	4	38.9	6
PKS-East	65-76	14,785	13	107	60	**7**	27.1	**7**
AB	76-102	26,322	1	134	61	5	49.6	3
FMSP	102-112	7,199	-54	56	18	**8**	24.9	**8**
Total Reach	**8-112**	**121,620**	**-54**	**141**	**71**			

FIGURE 3.14 [Panels 01–11, next 11 pages]. Approximate MHW elevation contours for June 1999 and May 2006 overlain on rectified orthophotographs by Independent Mapping Consultants (Mathews NC); 2004 rectified orthophotographs provided by Carteret County. MHW is (~)+2.1 ft NGVD and is based on observations at Morehead City Harbor channel. Profile line positions are shown. Note the coincidental position of the 2006 shoreline with the wetted beach line in panels 01–09 which were taken in July 2006. Compare the same shoreline estimation on the photos from 2004 in panels 09–11. The more recent photographs show the obvious shoreline movement seaward compared to the 2004 photographs.

4.0 DISCUSSION AND RECOMMENDATIONS

The present survey documented changes between May 2005 and May 2006 for Bogue Banks, Bear Island, and Shackleford Banks. CSE also analyzed volume changes from June 1999 to May 2006 on Bogue Banks in relation to nourishment volume added over that time period. In May 2006, survey data accounted for 70 percent of nourishment volume measured to –11 ft NGVD (outer bar). September 2005 survey data indicate that Hurricane *Ophelia* losses account for the majority of nourishment losses to date.

The May 2005 and May 2006 surveys documented overall sand volume losses along Bogue Banks. Every community and each reach lost sand volume to the outer bar from May 2005 to May 2006. Nevertheless, the entire oceanfront (on average) still retains profile volumes exceeding the 225 cy/ft minimum target profile volume. Individually, all reaches except for Pine Knoll Shores–East exceeded the target volume. PKS–East retains an average unit volume of 219.9 cy/ft. The Pine Knoll Shores–West reach just met the target profile volume at 225.6 cy/ft. There were no nourishment projects at Bogue Banks between May 2005 and May 2006, so all beach volume changes were driven by natural processes, most notably Hurricane *Ophelia* in September 2005.

The storm waves produced by Hurricane *Ophelia* caused a loss of over 1.5 million cubic yards along the oceanfront from the foredunes to the outer bar. The hurricane losses account for at least 60 percent of the total losses on Bogue Banks of ~2.5 million cubic yards between 2005 and 2006 (measured to –11 ft NGVD). Survey data between –11 ft and –20 ft NGVD indicate that most of the lost sand shifted seaward of the bar.

Despite a high rate of sand loss in the past year (measured to the outer bar), much more sand remains on the beach compared with prenourishment conditions. Average shoreline position has moved seaward by an average of 71 ft in the last seven years. Beach width and sand volume changes from June 1999 to May 2006 are somewhat correlated although the limited amount of data does not provide high confidence in the correlation. Survey data confirms that shoreline width change is positively related to volume average change. The largest gains over the past seven years have occurred along Atlantic Beach and Emerald Isle–East reaches. The smallest increases in beach width are on the east end of Bogue Banks, along Fort Macon State Park, and in Pine Knoll Shores–East.

There are a couple of ways to consider the amount of nourishment remaining. One is measured against just the base nourishment volumes in Phases 1, 2, and 3 (1,733,580 cy, 1,847,762 cy and 690,868 cy—respectively) and condition of the postnourishment beach, while the other also includes the Section 933 fill (699,282 cy to IBSP, and PKS-West), Post-*Isabel* renourishment (156,000 cy to Emerald Isle) and federal disposal projects along AB and FMSP (~3,430,000 cy). The results of the first method are given in Appendix III-D. This method is referenced as the FEMA beach maintenance calculation and serves as a measure against which a particular threshold (50 percent of base fill remaining in this case) is determined. As Appendix III-D shows, the percentage of base fill remaining (compared with postnourishment) within the county project area (to –11 ft) is as follows:

Phase 1 (PKS and IBSP)	84.3 percent
Phase 2 (EI–East and Central)	63.2 percent
Phase 3 (EI–West)	61.1 percent

There are large differences between certain reaches. For example, PKS-East and West retain 34.4 percent and 91.7 percent (respectively), while IBSP retains 162.6 percent of its base nourishment largely because of the positive impact of the Section 933 project.

The second method CSE used compares the net volume change between June 1999 and May 2006 with the total volumes placed. This latter method incorporates the impact of all fills within a reach and the impact of changes between June 1999 and the first date of nourishment. The island-wide net change is 5,955,462 cy through May 2006 which is 70.1 percent of all fill volumes placed during the period. The percentage of fill remaining by reach (based on Table 4) is as follows (1999 to 2006 comparison):

FMSP	35.2 percent
AB	44.7 percent
PKS	54.4 percent
IBSP	99.6 percent
EI–East and Central	77.2 percent
EI–West	169.8 percent

The 1999 to 2006 result for EI West (169.8 percent) appears anomalous compared with the FEMA beach maintenance calculation (61.3 percent). This reflects the different time

periods used in the methods. The "FEMA" method compares May 2006 conditions with May 2005 (immediate postnourishment survey). During the past year, ~40 percent of the fill eroded largely because of Hurricane *Ophelia*. However, when compared with the June 1999 condition, EI–West in May 2006 is much healthier with a net gain equivalent to 1.7 times the nourishment volume placed. This means EI–West gained a large volume by natural accretion before nourishment (eg, Table 3).

CSE's primary recommendations following the May 2006 surveys are as follows:

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

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

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

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

- Expand the network of lines at Bogue Inlet to better monitor changes in the vicinity of The Point and the Coast Guard channel.

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

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

As with this year's survey, CSE endeavors to maintain certain uniformity and consistency with the analyses from report to report, believing this makes it easier for the lay public to interpret changes and place them in context each year. At the same time, the large data set CSE has developed provides opportunities for additional or new analyses that may better explain the observed changes (eg, profile shape analysis). It is CSE's hope that as nourishment experience is gained along Bogue Banks, it will serve as a model for other projects in North Carolina.

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