Survey Report 2007

Bogue Banks North Carolina

Prepared for:

Carteret County North Carolina

SURVEY REPORT 2007

Bogue Banks
North Carolina

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COVER GRAPHICS	*Upper left:*	The beach near the Old Iron Steamer in May 2006 shows a lot of erosion. Note the escarpment at the berm crest. [Photo by P McKee]
	Upper right:	Same location in May 2007 after nourishment. The beach increased in width by ~100 ft more than May 2006 beach width. [Photo by P McKee]
	Lower:	Construction in early 2007 near the Old Iron Steamer. Pine Knoll Shores was renourished with over 770,000 cy in 2007. [Image courtesy of CCSPO, www.protectthebeach.com]

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1.0 INTRODUCTION

This report summarizes Year 4 (2006-2007) 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, 2006).

The primary purposes of beach monitoring are 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 using 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 2007 conditions with those of June 1999 and May 2006. Comparison with the June 1999 baseline conditions provides net volume change and beach condition information between the present condition and the condition of the beach prior to the county nourishment project (Phase 1) in 2002. The comparison with the May 2006 conditions provide net change information over a one-year period. 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. Bear Island was first surveyed by CSE in October 2004 and has since been included in the scope of work. Shackleford Banks has been included in annual monitoring efforts since May 2005.

In September 2005, storm waves associated with Hurricane *Ophelia* removed over 1.5 million cubic yards (cy) of sand from the beach (top of dune to –11 ft NGVD) (CSE 2005b).

Renourishment plans to replace the lost sand with FEMA funding began in January 2007 and ended in March 2007. Renourishment sand in excess of 1.2 million cubic yards was placed in five reaches in Emerald Isle, Indian Beach/Salter Path, and Pine Knoll Shores. Additionally, over 500,000 cy of sand from the Morehead City harbor federal navigation project were placed in Pine Knoll Shores over the course of the FEMA renourishment construction.

Between the May 2006 and May 2007 surveys, three storms impacted the North Carolina coast. On 14 June 2006, tropical storm *Alberto* weakened to a tropical depression off the mid-Atlantic coast. Tropical storm *Beryl* formed into a tropical depression about 290 miles east-southeast of Wilmington (NC) on 18 July 2006. The most damage came from Hurricane *Ernesto*, which made landfall at Oak Island (NC) on 1 September 2006 as a strong tropical storm with maximum-sustained winds exceeding 70 mph. Little damage was reported following *Alberto* and *Beryl*. *Ernesto* caused over $500 million in damage with over $104 million reported in Virginia.

[Source: National Weather Service TPC/National Hurricane Center, Miami, FL, 1 Dec 2006. ftp://ftp.met.fsu.edu/pub/weather/tropical/monthly/2006120114.ABNT30]

The focus of this report is on island-wide beach changes between June 1999 and May 2007 as well as changes resulting from the recent nourishment projects between May 2006 and May 2007.

2.0 METHODOLOGY

2.1 Field Data Collection

Over the past 45 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. The 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. 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 waypoints 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).

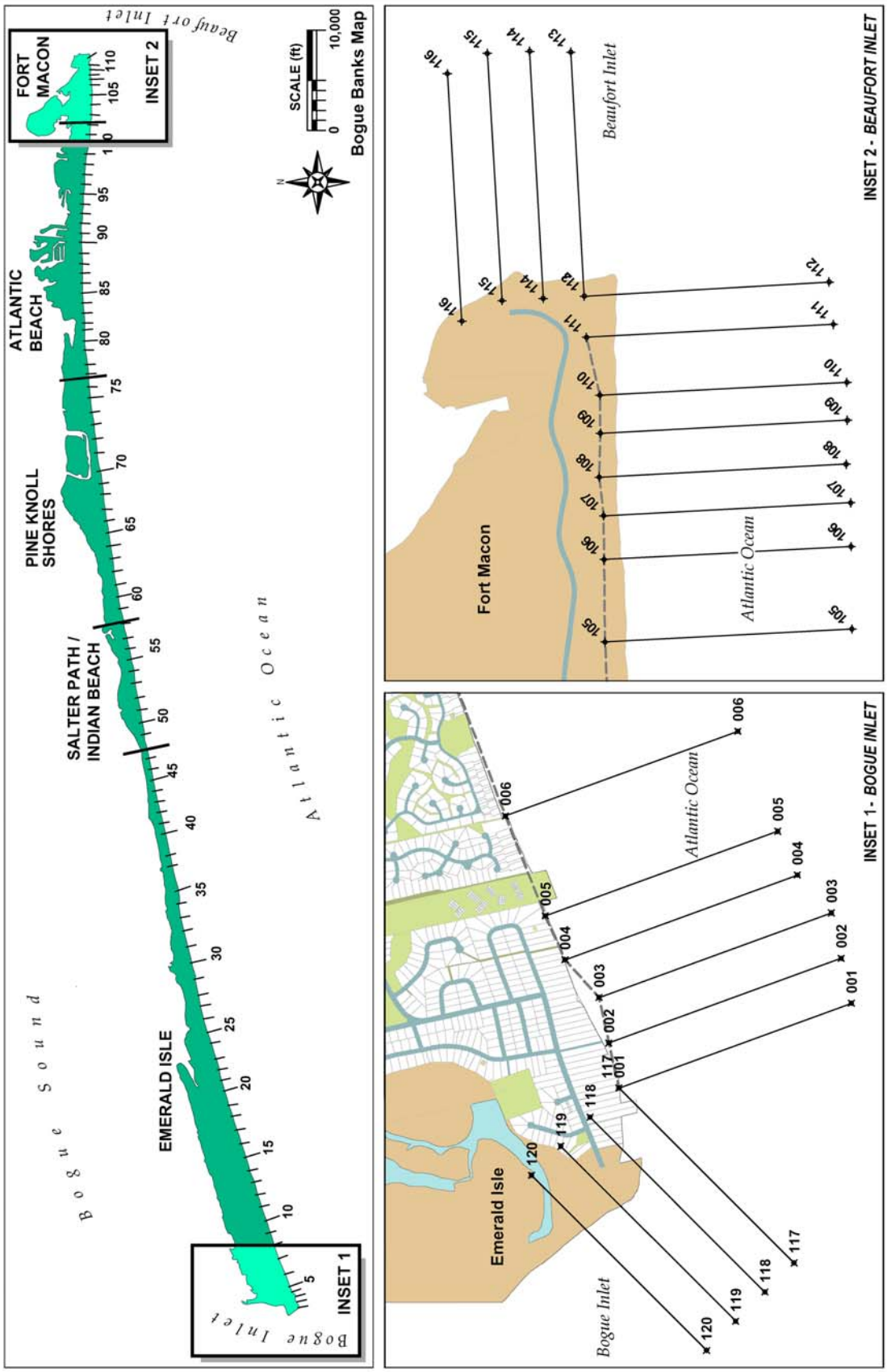


FIGURE 2.1. General location map of beach profile lines established in 1999 and resurveyed in December 2003, June 2004, May 2005, and May 2006 under the present BBBNMP project. Profile lines 112 through 120 were established in December 2003.

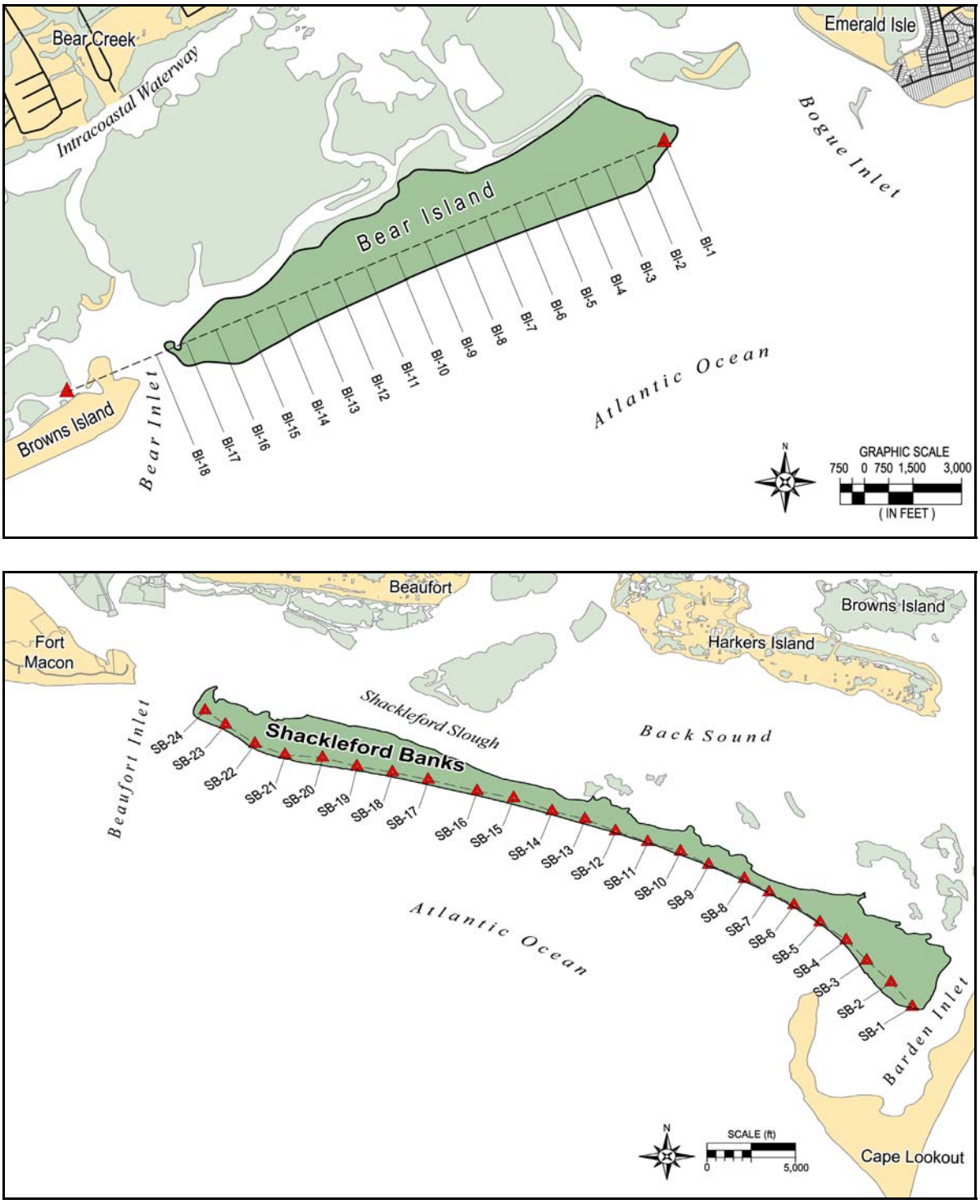


FIGURE 2.2. General location map of beach profile lines for Bear Island (upper) and Shackleford Banks (lower).

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.

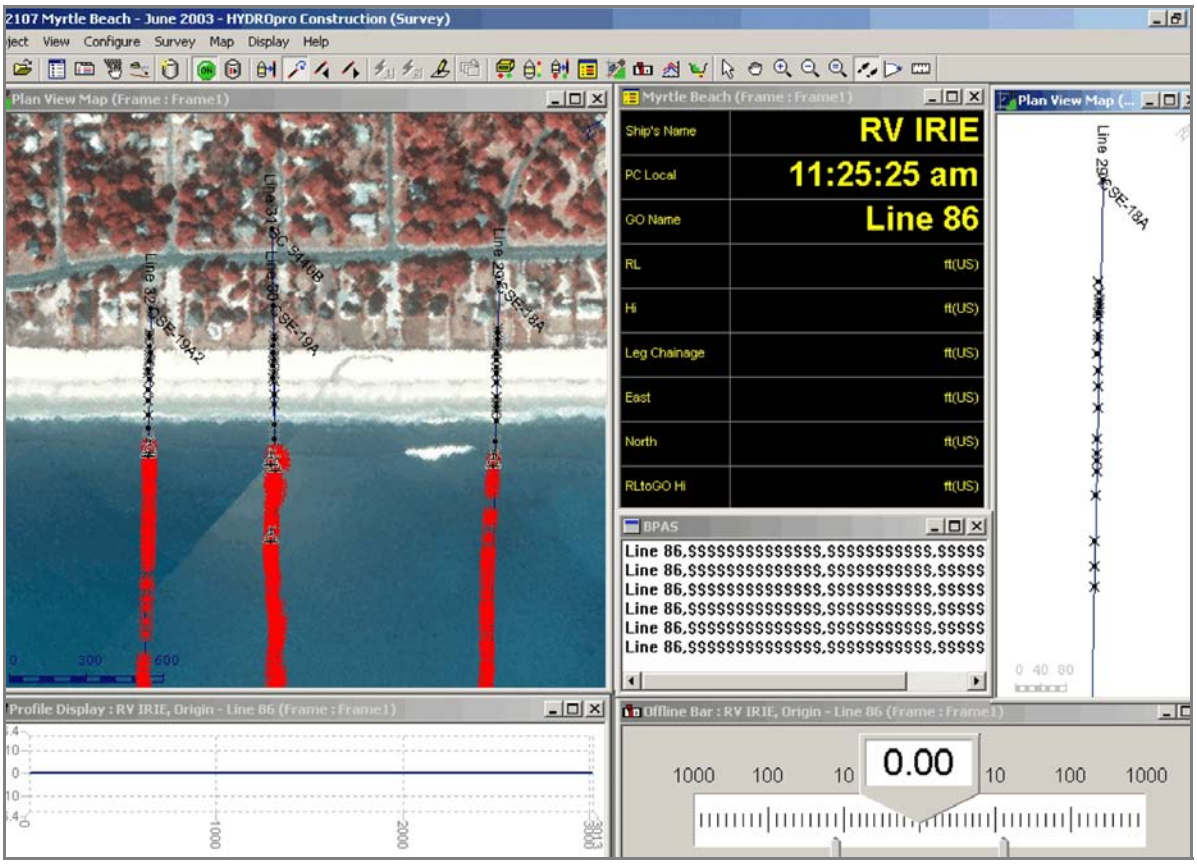


FIGURE 2.4. CSE's offshore equipment and survey vessel for use in shallow water.
[UPPER LEFT] 22-ft C-Dory™ with 7-inch draft and enclosed cabin.
[UPPER RIGHT] Navigation and data logging console.
[CENTER] HydroPro™ data logging and processing software showing track lines and overlap in real time with 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.

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.

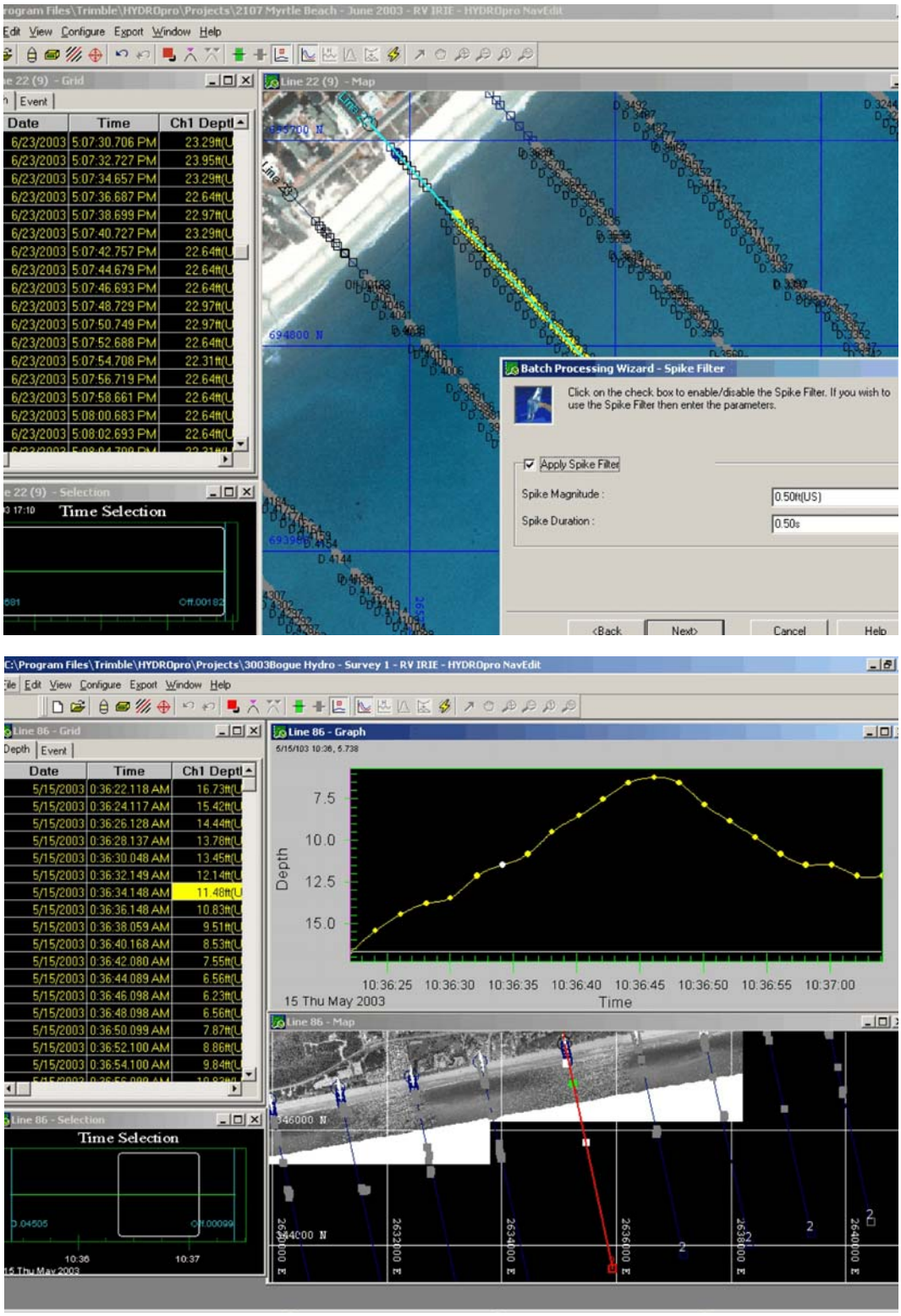


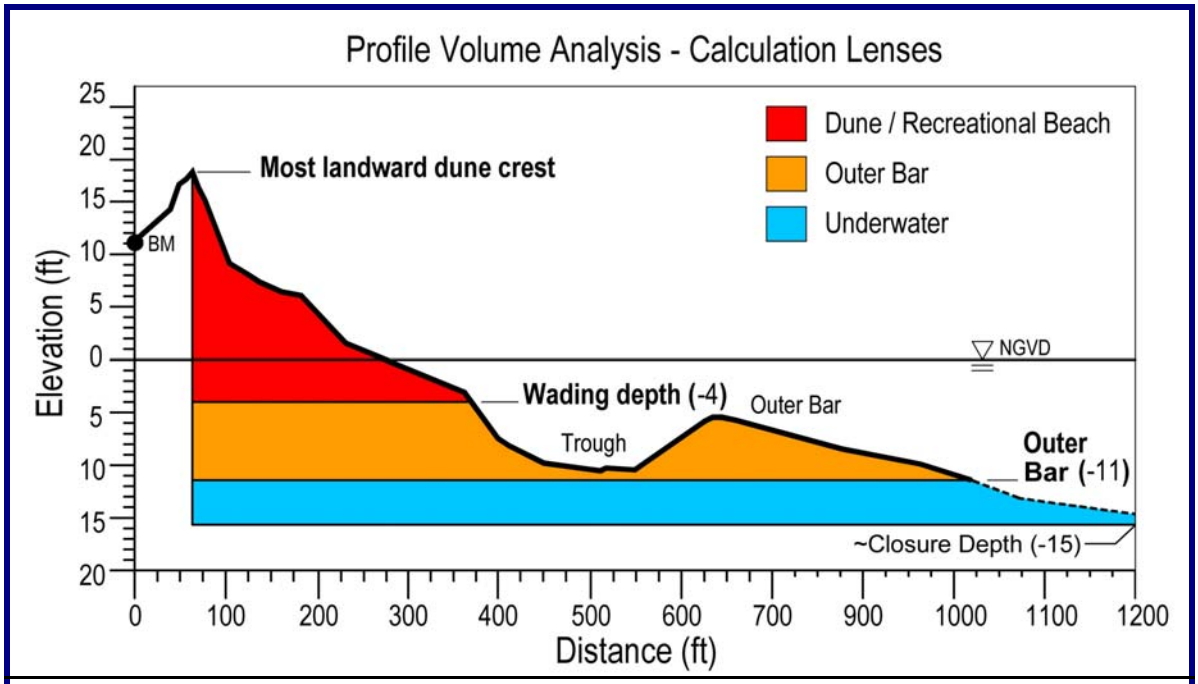
FIGURE 2.5. Trimble-HydroPro™ software was used by CSE to allow batch processing and editing of large files (data sampling rate used by CSE in Bogue Banks was 10 Hz). Software was used to filter spikes (upper) and provide floating point averages to yield smoother, more realistic profiles such as the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

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 performed by CSE in 1999, 2000, 2004, 2005, 2006, and the present project. Table 1 summarizes the number of usable profiles for island-wide comparisons to selected offshore features. For the present report, CSE also utilized selected project profiles collected in conjunction with nourishment projects which were implemented in 2005. Appendix II contains profile plots for representative dates. A more comprehensive data set (with computer files of each profile) has been provided to Carteret County Shore Protection Office (CCSPO).



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

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

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

FIGURE 2.6. Three reference zones used for calculation of sand volume changes along Bogue Banks 2006–2007 (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.

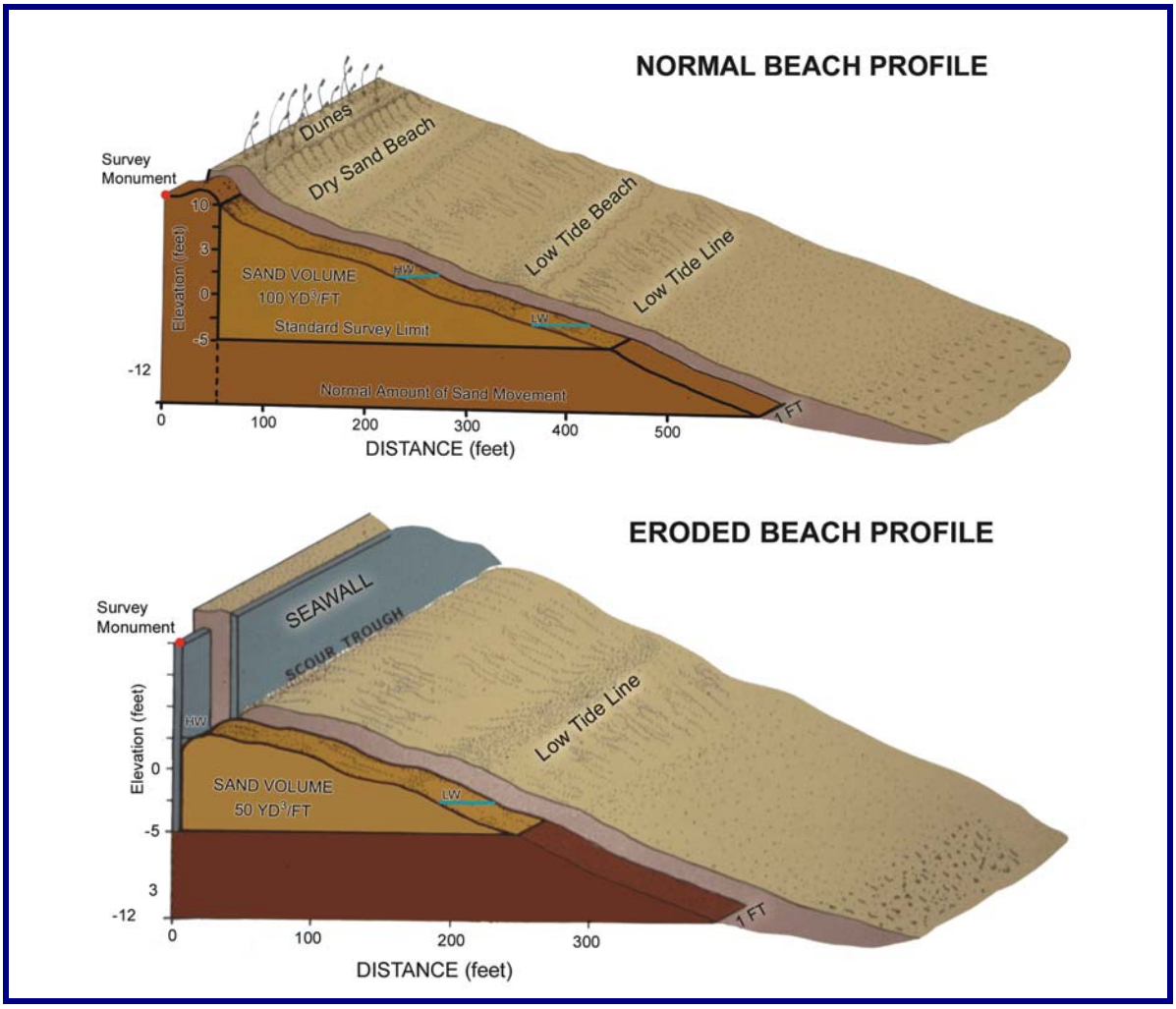


FIGURE 2.7. The concept of unit sand volume along the beach, which provides a quantitative measure of beach condition and changes before and after nourishment. The <u>yearly</u> limit of measurable sand movement ("profile closure depth") along Bogue Banks is thought to occur at depths of about 15 ft (±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 4 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, May 2006, and May 2007. [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 / May'07)															
			@ low tide								@ outer bar							
Bogue Inlet	6,772	1-8	6	0	8	8	8	8	8	8	5	0	6	8	8	8	8	8
Emerald Isle-West	22,303	8-25	17	3	17	17	17	17	17	17	17	3	17	17	17	17	17	17
Emerald Isle-Central	15,945	25-36	11	2	11	11	11	11	11	11	11	1	11	11	11	11	11	11
Emerald Isle-East	12,900	36-48	12	2	12	12	12	12	12	12	12	2	12	12	12	12	12	12
Indian Beach-Salter Path	12,986	48-58+	9	2	10	10	10	10	10	10	9	1	10	10	10	10	10	10
Pine Knoll Shores West	9,182	59-65	6	2	7	7	7	7	7	7	6	1	7	7	7	7	7	7
Pine Knoll Shores East	14,785	65-76	10	2	11	11	11	11	11	11	10	2	11	11	11	11	11	11
Atlantic Beach	26,322	76-102	26	5	26	26	26	26	26	26	26	5	26	26	26	26	26	26
Fort Macon State Park	7,199	102-112	9	0	9	9	10	10	10	10	9	0	9	9	10	10	10	10
	128,392	(24.32 miles)																

3.0 RESULTS

3.1 Island-Wide Trends

Eleven reaches are referenced along Bogue Banks. Nine of these 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 survey's "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 with the Beaufort channel line referenced as station 113. The addition of profile 113 effectively increased the reach length for FMSP and the overall (oceanfront) length to 128,392 ft (24.32 miles) for sand volume computation purposes. Since 1999, CSE has referred to the six reaches that make up most of Emerald Isle (EI-West, EI-Central, and EI-East), Indian Beach/Salter Path (IB/SP), and Pine Knoll Shores (PKS-West, and PKS-East) as the "county project" because they incorporate planned nourishment projects. 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 coincide with profile lines. Thus, the length of Indian Beach/Salter Path (IB/SP) computes to 12,986 ft, but is not precisely that length measured along the oceanfront. The actual distances from the eastern boundary are closer to 12,905 ft as measured along the foredune. The unit-width volumes by reach listed in Table 2 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.

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

1) There has been a 7.7 million cubic yard increase in sand volume along the entire oceanfront between June 1999 and May 2007. This volume was measured to –11 ft NGVD.

2) Nearly 1.36 million cubic yards of the increase occurred between May 2006 and May 2007.

3) The county project, which does not include the highly variable section of oceanfront beach at the western end of Emerald Isle, has gained 5.82 million cubic yards of sand (66.1 cy/ft) since June 1999.

TABLE 2. Beach volume changes by reach for Bogue Banks (NC) – June 1999 to May 2007. Volume calculations for Bear Island are for October 2004 to May 2007. Shackleford Banks data are presented for May 2005 to May 2007.

Dune to -4 ft NGVD

Summary By Reach - Beach Volumes			Weighted Avg (cy/ft)								June 1999 — May 2007		May 2006 — May 2007	
Reach	Profiles	Reach Length (ft)	Jun-99	Jun-00	Apr-03	Dec-03	Jun-04	May-05	May-06	May-07	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	52.9	-	-	-13.8	-26,182
Bogue Inlet-Ocean	1-8	6,772	147.4	156.7	162.8	164.9	171.8	173.8	143.7	152.3	4.9	33,023	8.6	58,358
El-West	8-25	22,303	76.7	80.1	87.8	93.2	95.6	119.9	109.9	117.1	40.3	899,412	7.2	159,894
El-Central	25-36	15,945	74.2	79.6	112.9	111.4	112.1	116.6	111.0	115.7	41.5	661,490	4.7	75,240
El-East	36-48	12,900	72.1	72.5	134.3	123.6	126.4	124.1	121.7	125.2	53.1	685,168	3.5	44,512
IB/SP	48-58+	12,986	69.2	72.6	101.8	107.9	134.9	131.6	121.6	129.5	60.3	783,473	7.9	101,999
PKS-West	58-65	9,182	72.7	66.2	102.6	99.8	100.5	100.6	94.0	116.8	44.0	403,726	19.3	177,066
PKS-East	65-76	14,785	66.4	64.0	99.4	96.8	99.9	94.3	87.7	119.2	52.9	781,720	31.6	466,534
AB	76-102	26,322	93.3	91.2	93.1	88.2	92.8	128.6	118.4	114.5	21.2	558,278	-3.9	-103,242
FMSP	102-112	7,199	98.3	90.5	82.9	72.9	74.1	104.8	102.9	105.3	5.1	36,932	2.4	17,087
Beaufort Inlet	112-116	2,250	-	-	-	126.6	145.0	160.5	144.4	144.5	-	-	-5.1	-11,428
County Project	**8-76**	**88,099**	**72.2**	**73.7**	**104.5**	**104.3**	**110.5**	**115.6**	**108.4**	**120.0**	**47.8**	**4,214,989**	**11.6**	**1,025,245**
Entire Oceanfront	**1-112**	**128,392**	**81.9**	**82.6**	**104.1**	**102.5**	**108.1**	**121.0**	**112.0**	**119.8**	**37.7**	**4,843,223**	**7.8**	**997,448**
			Weighted Avg (cy/ft)										May 2006 — May 2007	
							Oct-04	May-05	May-06	May-07			Wtd Avg (cy/ft)	Net (cy)
Bear Island	1-18	17,000					107.6	105.9	96.3	90.1			-6.2	-105,930
Shackleford	1-24	46,001						114.7	104.9	103.3			-1.6	-74,356

Dune to -11 ft NGVD

Summary By Reach - Beach Volumes			Weighted Avg (cy/ft)								June 1999 — May 2007		May 2006 — May 2007	
Reach	Profiles	Reach Length (ft)	Jun-99	Jun-00	Apr-03	Dec-03	Jun-04	May-05	May-06	May-07	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	164.2	-	-	-3.8	-7,147
Bogue Inlet-Ocean	1-8	6,772	363.2	375.5	323.0	330.9	329.7	422.1	377.8	385.0	21.8	147,797	7.1	48,372
El-West	8-25	22,303	208.1	211.5	228.3	233.6	240.5	267.3	256.1	261.2	53.1	1,185,131	5.1	112,922
El-Central	25-36	15,945	194.2	201.4	247.9	243.9	249.0	257.0	240.8	243.2	49.0	781,223	2.4	38,688
El-East	36-48	12,900	193.3	191.7	281.0	263.4	268.1	268.0	255.6	266.7	73.4	946,483	11.1	143,100
IB/SP	48-58+	12,986	188.5	195.3	244.6	242.8	293.0	286.4	268.3	277.5	89.0	1,155,522	9.2	119,783
PKS-West	58-65	9,182	189.6	183.5	237.5	222.6	219.3	239.9	225.6	264.2	74.1	680,649	35.2	323,343
PKS-East	65-76	14,785	192.9	188.5	245.7	232.7	237.3	233.2	219.9	265.4	72.6	1,072,778	45.5	672,831
AB	76-102	26,322	234.5	230.6	245.4	237.1	239.6	306.7	284.1	279.9	45.4	1,194,947	-4.2	-110,672
FMSP	102-112	7,199	228.1	226.4	218.2	208.1	202.1	267.9	252.6	253.5	30.7	221,169	4.7	33,818
Beaufort Inlet	112-116	2,250	-	-	-	310.9	348.9	417.0	351.1	358.1	-	-	-2.2	-4,905
County Project	**8-76**	**88,099**	**195.9**	**197.9**	**245.8**	**240.0**	**251.9**	**260.2**	**246.0**	**262.0**	**66.1**	**5,821,785**	**16.0**	**1,410,668**
Entire Oceanfront	**1-112**	**128,392**	**214.4**	**215.6**	**248.3**	**242.4**	**250.7**	**278.7**	**261.1**	**271.7**	**57.5**	**7,385,699**	**10.8**	**1,382,186**
			Weighted Avg (cy/ft)										May 2006 — May 2007	
							Oct-04	May-05	May-06	May-07			Wtd Avg (cy/ft)	Net (cy)
Bear Island	1-18	17,000					298.6	290.7	282.5	262.3			-20.2	-343,295
Shackleford	1-24	46,001						261.1	246.2	247.4			1.2	55,122

Dune to -15 ft NGVD

Summary By Reach - Beach Volumes			Weighted Avg (cy/ft)								June 2004 — May 2007		May 2006 — May 2007	
Reach	Profiles	Reach Length (ft)	Jun-99	Jun-00	Apr-03	Dec-03	Jun-04	May-05	May-06	May-07	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	237.9	-	-	8.0	103,996
Bogue Inlet-Ocean	1-8	6,772					-	627.2	592.8	585.0	-	-	-7.8	-52,942
El-West	8-25	22,303					374.6	410.8	406.2	409.9	80.0	1,783,395	3.7	82,591
El-Central	25-36	15,945					387.9	402.9	391.9	395.1	74.9	1,194,915	3.2	50,782
El-East	36-48	12,900					409.2	415.9	407.6	417.7	103.5	1,335,655	10.1	130,604
IB/SP	48-58+	12,986					436.1	436.7	425.2	433.2	134.3	1,744,153	8.0	103,996
PKS-West	59-65	9,182					356.6	387.2	369.1	417.2	123.7	1,135,995	43.7	400,836
PKS-East	65-76	14,785					387.5	384.5	375.8	414.0	121.5	1,796,876	38.1	563,500
AB	76-102	26,322					398.0	481.2	461.5	451.1	89.6	2,358,100	-10.4	-274,554
FMSP	102-112	7,199					345.9	456.0	396.9	417.9	77.5	558,157	21.0	151,211
Beaufort Inlet	112-116	2,250					483.6	603.1	500.7	506.8	-	-	-	-
County Project	**8-76**	**88,099**					**392.4**	**407.4**	**398.1**	**413.2**	**102.1**	**8,990,990**	**15.1**	**1,332,309**
Entire Oceanfront	**1-112**	**128,392**					**390.8**	**436.9**	**421.3**	**430.3**	**92.7**	**11,907,247**	**9.0**	**1,156,024**
			Weighted Avg (cy/ft)										May 2006 — May 2007	
							Oct-04	May-05	May-06	May-07			Wtd Avg (cy/ft)	Net (cy)
Bear Island	1-18	17,000					463.6	464.3	460.5	432.7			-27.8	-471,975
Shackleford	1-24	46,001						412.1	397.7	403.6			5.9	270,338

4) The rest of the oceanfront outside of the "county project" has gained 1.55 million cubic yards (38.4 cy/ft) over the same time period.

5) Over the past monitoring period between May 2006 and May 2007, the "county project" has gained 1.41 million cubic yards of sand (16.0 cy/ft) but the rest of the oceanfront not included in the county project has lost nearly 56,000 cy over a 40,293 ft ("entire oceanfront" minus "county project") length of beach (approximately –1.38 cy/ft). These volumes are measured to –11 ft NGVD.

6) Seventy-two percent of the gain in sand volume in the "county project" reaches is on the recreational beach above low-tide wading depth (–4 ft NGVD). Along the rest of the island outside the "county project" reaches, only 40 percent of the sand volume measured to –11 ft is above low-tide wading depth.

All reaches have increased in sand volume above –11 ft except Atlantic Beach and the two inlets – Bogue Inlet at the western end of the island, and Beaufort Inlet at the eastern end. Atlantic Beach lost 110,672 cy of sand to –11 ft over 26,322 ft of beach. More than 90 percent of the loss was above the –4 ft contour. The channel reaches are very dynamic by nature. The Bogue Inlet channel reach lost 26,182 cy of sand (–13.8 cy/ft) close to the –4 ft contour but gained 19,000 cy of sand between the –4 ft and –11 ft elevations for a net loss of 7,147 cy to –11 ft. Beaufort Inlet experienced a similar change, losing 11,428 cy of sand above the –4 ft elevation but gaining 6,500 cy between –4 ft and –11 ft for a net loss of 4,905 cy to –11 ft.

Figure 3.1-1 shows the trends in unit beach volumes and unit beach volume changes by reach and island-wide. Figure 3.1-1 (upper) compares 1999, 2004, 2005, 2006, and 2007 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 2006 and May 2007.

[*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.]

The largest changes in unit volumes to between May 2006 and May 2007 were in Pine Knoll Shores. Two nourishment projects (the FEMA sand replacement and the federal Section 933 navigation dredge disposal) were responsible for high volume sand gains:

- +35.2 cy/ft in the Pine Knoll Shores-West reach.
- +45.5 cy/ft in the Pine Knoll Shores-East reach.

The remaining reaches in the “county project” also showed significant gains in average sand volume over the length of the reach, but well below the Pine Knoll Shores averages. The Emerald Isle-East reach gained an average of 11.1 cy/ft. Emerald Isle gained 5.8 cy/ft over its entire length. In the western and central reaches of Emerald Isle, nourishment sand helped increase the average sand volume to 6.1 cy/ft over the 38,248 ft total length of the reaches above –4 ft. Loss of sand below the –4 ft elevation resulted in a total net increase in sand volume of 4.0 cy/ft to –11 ft for these two reaches. Indian Beach/Salter Path increased in sand volume by 119,783 cy to the outer bar. Most of the gain was found above wading depth where 86 percent of the volume change was gained above –4 ft.

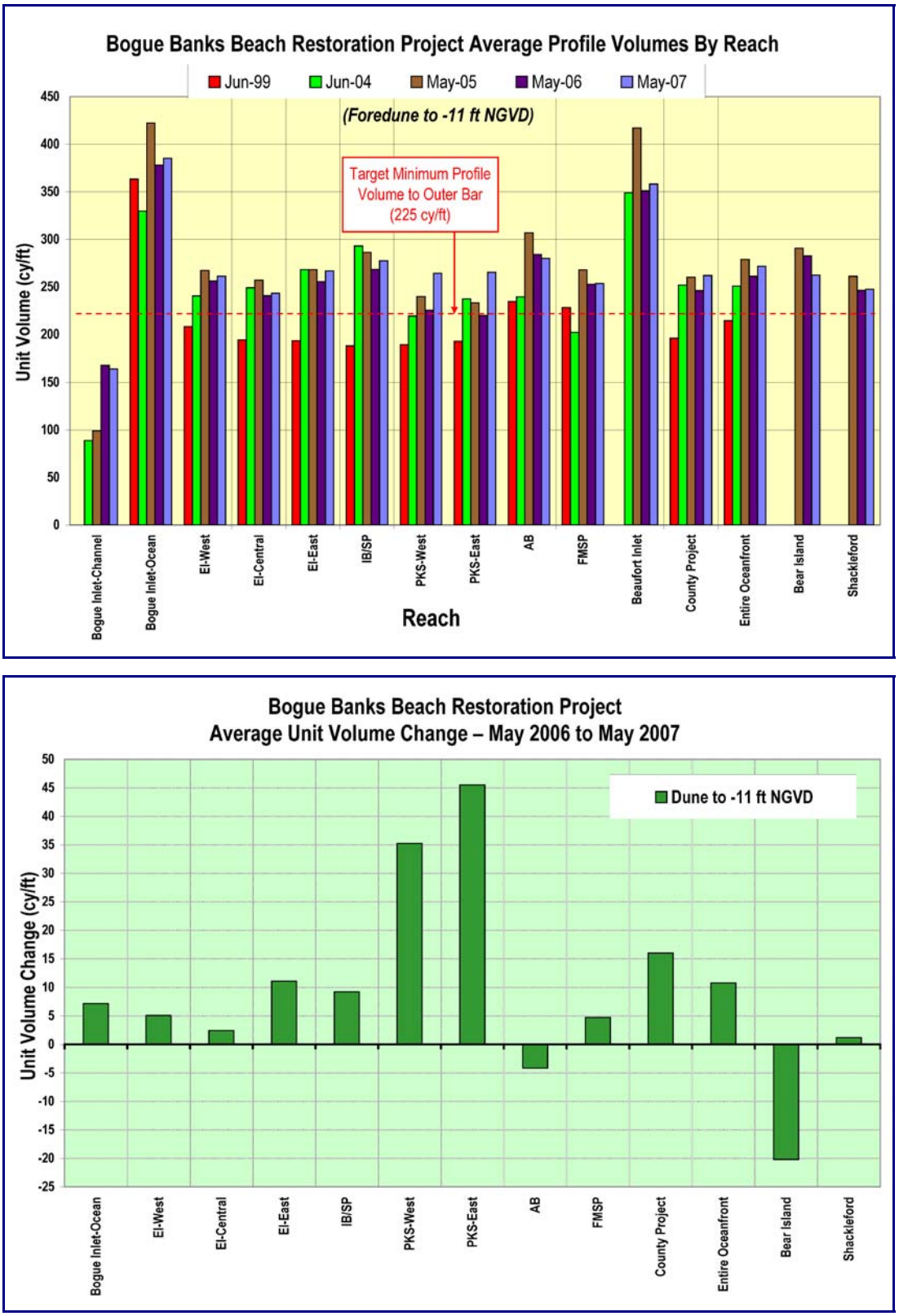


FIGURE 3.1-1. Trends (by reach) in average dune, beach, and inshore sand volume measured to –11 ft (including outer bar) between 1999 and 2007 (upper). Lower graph illustrates the change by reach for the one-year period.

3.2 Comparison with Nourishment Volumes

Following a year without nourishment between May 2005 and May 2006, Bogue Banks received sand from two major projects in 2007. The two projects supplied 1,737,775 cy of sand to Emerald Isle, Indian Beach/Salter Path, and Pine Knoll Shores between the end of December 2006 and the end of May 2007 (Table 3). The primary nourishment project of 2007 was a FEMA-funded sand replacement project to replenish Bogue Banks with sand lost to Hurricane *Ophelia* in September 2005. CSE (2005) estimated sand losses at 1.53 million cubic yards (13.1 cy/ft) over the entire oceanfront to –11 ft NGVD. The construction project added 1,229,836 cy of sand to the "county project" beaches over five separate nourishment reaches.

"County project" reaches lost an estimated total of ~1.1 million cubic yards (74 percent of the "oceanfront total") during Hurricane *Ophelia*. The subsequent FEMA sand replacement project added 1,229,836 cy of sand to the beach. Losses during Hurricane *Ophelia* and renourishment gains by reach are:

> Town of Emerald Isle lost 569,160 cy. Replacement sand totaled 648,447 cy in two reaches from profile lines 10 to 20 and from lines 33 to 45 (~27,500 linear feet).
>
> Town of Indian Beach lost 298,604 cy. Replacement sand totaled 319,113 cy over one reach between profile lines 48 and 58 (~13,400 linear feet).
>
> Town of Pine Knoll Shores lost 239,796 cy. Replacement sand totaled 262,276 cy in two reaches between profile lines 62 and 65 and between profile lines 66 and 73 (~13,600 linear feet).

Pine Knoll Shores also received 507,939 cy as part of a federal navigation maintenance dredging project in Beaufort Inlet. The Section 933 dredged materials were placed in two reaches over 21,599 linear feet of beach (4.09 miles) (G Rudolph, pers comm, May 2007).

TABLE 3. Bogue Banks nourishment volumes (2002–2007). Sources: CSE (2003a,b), Weeks Marine Inc, Great Lakes Dredge & Dock Company, and CCSPO (2004, 2005, 2007).

*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
10	USACE Section 933 PKS–E and PKS–W	2007	682,561	507,939
11	FEMA Sand Replacement Project EI, PKS, & IB/SP	2007	1,107,560	1,229,836
	Totals		11,001,414	10,295,344

NOTE: Approximately 75,000 cy were placed along the beaches of the Bogue Inlet channel reach in June and July 2006. This was a dredged material disposal project associated with the Atlantic Intracoastal Waterway.

Island-wide surveys from 1999 to 2007 were used to compare net volume changes with total added renourishment volumes. The difference between the net volume change and the total renourishment volume is the background erosion rate over the specified time period. Estimates of background erosion rates for each reach are listed in Table 4. Some adjacent reaches are combined to facilitate interpretation of results. In reaches where nourishment volume exceeds the surveyed volume change, background erosion is evident. Where the surveyed volume exceeds the nourishment volume added, the difference is a net accretion of sand. All reaches had a net negative (erosion) background erosion rate except for the Bogue Inlet-Ocean reach (profile lines 1 through 8) and Emerald Isle-West.

TABLE 4. Bogue Banks nourishment volumes and estimated background erosion rate without nourishment (May 2006 to June 2007). 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)	Volume Change (cy)	Background Erosion (cy)	Average Annual Background Erosion Rate (cy/ft/yr)
Bogue Inlet–Ocean	6,772	59,272	147,797	88,526	1.65
EI–West	22,303	935,633	1,185,131	249,497	1.41
EI-East & Central	28,844	2,348,172	1,727,705	(620,467)	-2.72
IB/SP	12,986	1,358,842	1,155,522	(203,320)	-1.98
PKS	23,967	2,163,348	1,753,427	(409,921)	-2.16
AB	26,322	2,920,729	1,194,947	(1,725,782)	-8.28
FMSP	7,199	509,348	221,169	(288,179)	-5.06
Bogue Banks Total	128,392	10,295,344	7,385,698	(2,909,646)	-2.86

Between June 1999 and May 2007, a total of 10,295,344 cy of sand was placed on Bogue Banks in 11 separate projects as noted in Table 3 (Fig 3.2-1). During that time, the beach volume was measured to have increased by 7,369,677 cy. The difference between the total volume of nourishment added and the net volume change is –2,909,646 cy for a background erosion rate of –2.86 cy/ft of beach per year between June 1999 and May 2007 (nearly eight years).

To date, Atlantic Beach has received the most total sand from nourishment projects –2,920,729 cy from one project (the 2005 Brandt Island pumpout). Atlantic Beach also has the highest background erosion rate (-8.28 cy/ft/yr) between June 1999 and May 2007. This high rate of erosion is presumed to be due to the loss of a high proportion of fine-grained sediments formerly stored in the upland disposal facility of Brandt Island as well as Hurricane *Ophelia* impacts. Outside of Atlantic Beach, the rest of the oceanfront (Bogue Inlet-Ocean to Fort Macon State Park) has a net background erosion rate of –1.5 cy/ft/yr. This includes an annual net accretion rate of 1.41 cy/ft/yr along the Emerald Isle-West reach and 1.65 cy/ft/yr along the Bogue Inlet-Ocean reach. Fort Macon State Park on the eastern end and Atlantic Beach has lost 5.34 cy/ft/yr and 8.28 cy/ft/yr (respectively).

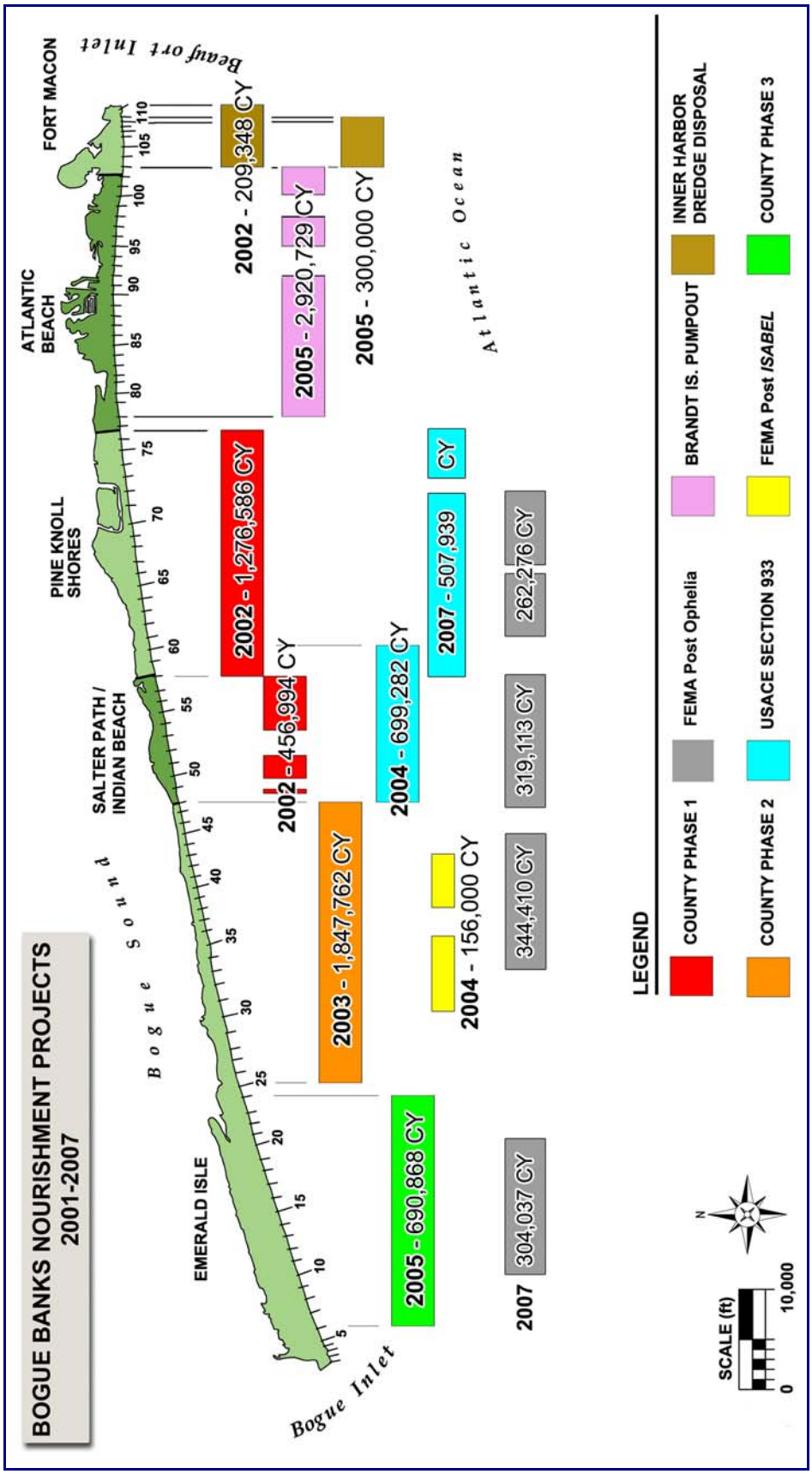
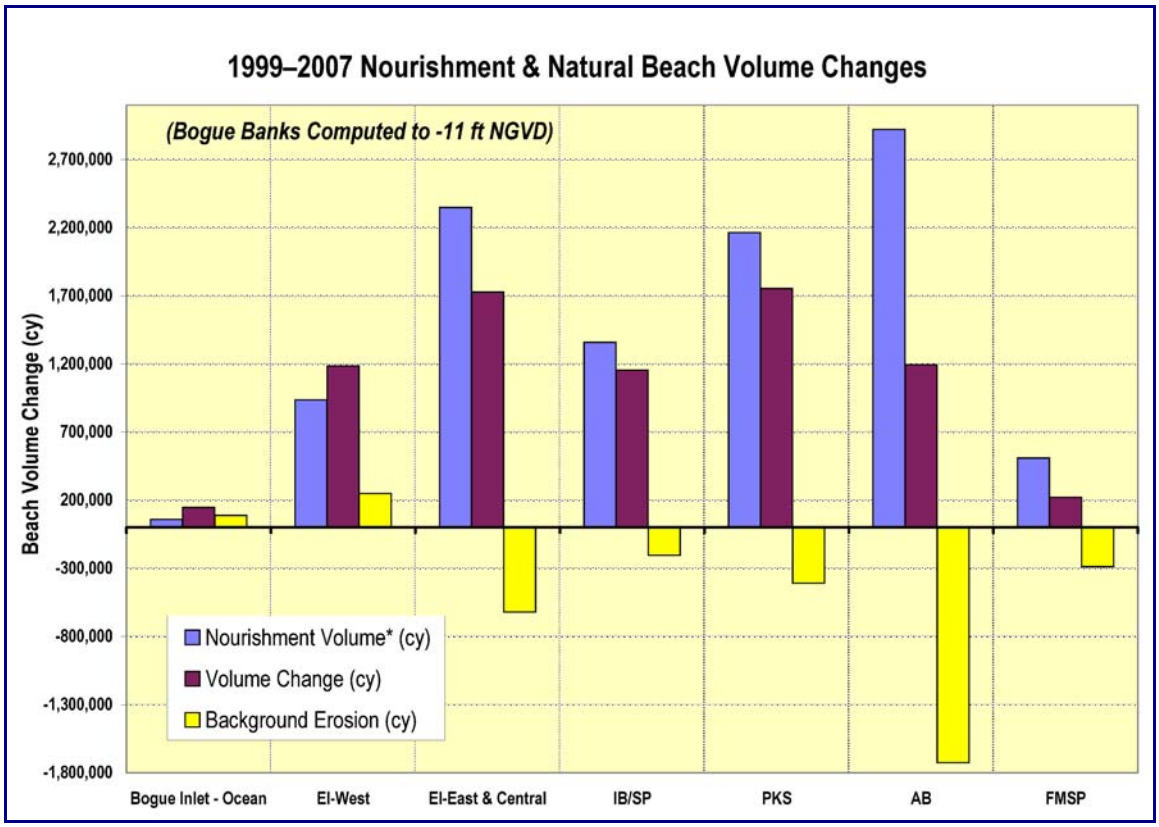


FIGURE 3.2-1. Nourishment projects along Bogue Banks (2002–2007).

Figure 3.2-2 shows the volume changes (upper) and volume change rates (lower) for each community. The eastern reaches of Bogue Banks have generally experienced higher rates of erosion than the western reaches. The central reaches of Pine Knoll Shores, Indian Beach, and the Emerald Island-West and Emerald Isle-Central reaches tend to have annual erosion rates typical of beaches in this region (CSE-Stroud 1999). The eight-year background erosion rate (2.86 cy/ft/yr – June 1999 to May 2007) was nearly the same as the seven-year rate (2.89 cy/ft/yr – June 1999 to May 2006 – CSE 2006). The low change in the annual erosion rate indicates that the recent erosion has been balanced with the recent nourishment and natural accretion.

Hurricane *Ophelia* caused an estimated loss of 1.53 million cubic yards on Bogue Banks to the outer bar. Assuming no volume losses between May 2005 and the September 2005 post-*Ophelia* survey and annualized over the past eight years, the additional erosion rate due to *Ophelia* is 1.50 cy/ft/yr. Without this additional loss, the background erosion rate for Bogue Banks is 1.36 cy/ft/yr (June 2999 to May 2007), which is more typical of beaches in the same region.

The annual background erosion rate between May 2006 and May 2007 along the Bogue Banks oceanfront was 0.47 cy/ft/yr (Table 5). Indian Beach/Salter Path saw the highest rate of erosion among the communities. Indian Beach/Salter Path received 319,113 cy of FEMA replacement sand in 2007. The net gain in sand volume to –11 ft was 119,783 cy between May 2006 and May 2007. The resulting one-year background erosion rate was 15.35 cy/ft. In contrast to Indian Beach's erosion rate is the net accretion rate in Pine Knoll Shores (9.43 cy/ft). Pine Knoll Shores gained 770,215 cy in nourishment in 2007 and an additional 225,959 cy from natural sediment transport processes.



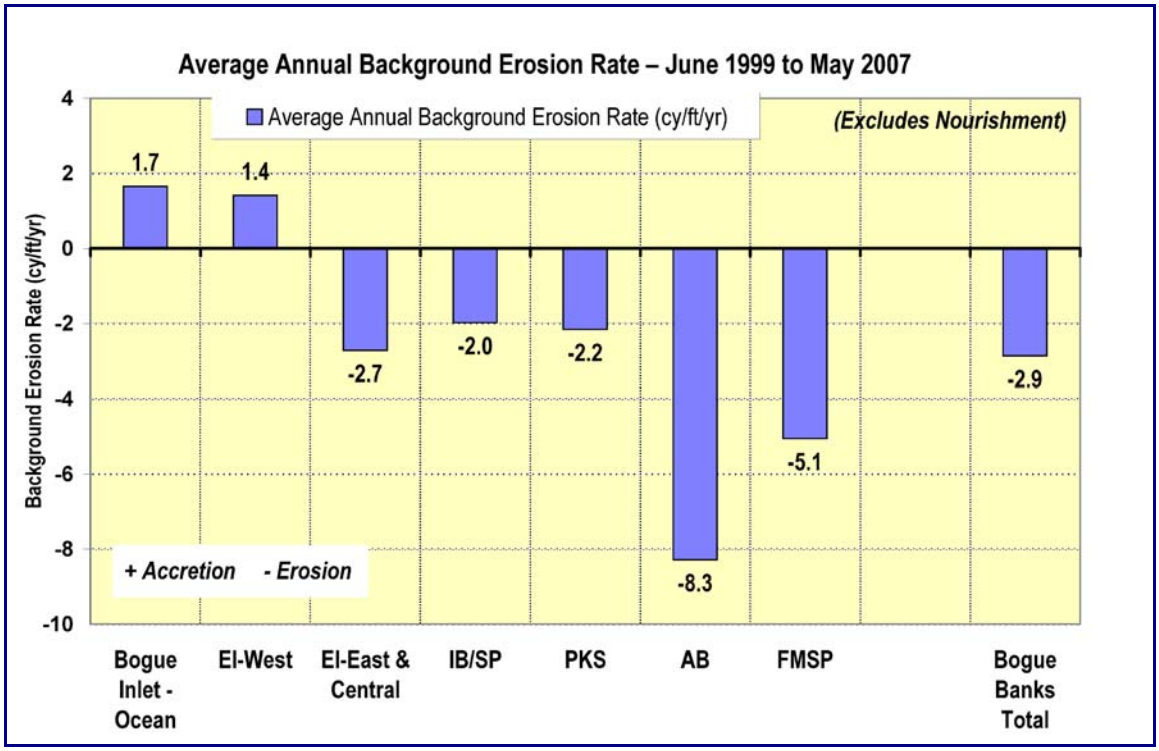


FIGURE 3.2-2. [UPPER] Total nourishment volumes and surveyed volume changes by reach for June 1999 to May 2007. The difference between the two quantities is the "background" erosion rate. [LOWER] Average, annual, background erosion rate after factoring out nourishment.

TABLE 5. Bogue Banks nourishment volumes (May 2006 to May 2007) and estimated background erosion rate without nourishment. Calculations to –11 ft NGVD.

Reach	Length (ft)	Nourishment Volume* (cy)	Volume Change (cy)	Background Erosion (cy)	Average Annual Background Erosion Rate (cy/ft/yr)
Bogue Inlet–Ocean	6,772		48,372	48,372	7.14
EI-West	22,303	304,037	112,922	(191,115)	-8.57
EI-East & Central	28,844	344,410	181,788	(162,622)	-5.64
IB/SP	12,986	319,113	119,783	(199,330)	-15.35
PKS	23,967	770,215	996,174	225,959	9.43
AB	26,322		(110,672)	(110,672)	-4.20
FMSP	7,199		33,818	33,818	4.70
Bogue Banks Total	128,392	1,737,775	1,382,186	(355,589)	-0.47

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

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 of the total 88,099 ft of "county project" beachfront. An additional 6,772 ft (stations 1-8) make up the Bogue Inlet-Ocean reach along the western Emerald Isle oceanfront. A total nourishment volume of 3,283,805 cy has been placed in Emerald Isle as part of the three projects:

- 2003 – County-Phase 2 (total 1,847,762 cy).
- 2004 – FEMA post-*Isabel* sand replacement (156,000 cy).
- 2005 – County-Phase 3 (690,868 cy).
- 2007 – most recent FEMA post-*Ophelia* sand replacement (589,175 cy).

The County's Phase 2 project placed sand in EI-East and EI-Central primarily and in the dunes in EI-East and EI-Central as well. Phase 3 nourishment sand was placed in EI-West as well as the Bogue Inlet-Ocean reach. The FEMA post-*Isabel* project placed sand in the EI-East and Central reaches and the post-*Ophelia* project placed sand in all three reaches of Emerald Isle (East, Central, and West).

The net change in sand volume from May 2006 to May 2007 along Emerald Isle was a gain of 294,710 cy of sand from profile volumes measured to the outer bar. The total volume over the length of Emerald Isle amounts to a net gain of 5.76 cy/ft over the last year. Nearly 95 percent of the increase over 2006 was measured on the recreational beach to low-tide wading depth (–4 ft NGVD). The high relative distribution of the sand on the recreational beach is a direct result of the recent nourishment project.

The highest gains in individual profile volumes, to no surprise, were found within the post-*Ophelia* nourishment project reaches. The volume at 16th Street (profile line 40) increased by 33.2 cy/ft over last year's measured volume. Similarly high volume changes (to –11 ft) were measured at Janell Drive (lines 13 and 14) and at the regional beach access at Diane Street (line 35). See Appendix IV-2 for individual profile volume measurements. The highest losses in Emerald Isle were found at the junction of the EI-West and EI-Central reaches (at Periwinkle Drive and the Sea Crest Court access). Losses there were measured between –20.8 cy/ft and –25.2 cy/ft over the past monitoring year to -11 ft.

Figure 3.3-1 shows the Emerald Isle unit volume change is generally higher in the eastern and western reaches and lower in the central reach. The trend is consistent with the placement of post-*Ophelia* nourishment sand mostly in the east and west reaches. While losses tend to be higher in the central reach, profiles 28 and 29 (at Hurst Road and Paxon Drive) still show an increase in sand volume atypical for the reach at over 15 cy/ft.

Since June 1999, Emerald Isle has gained 2,912,836 cy in sand volume (57.0 cy/ft) between the foredune and the outer bar. Discounting the nourishment totals, natural processes have eroded ~371,000 cy of sand (or 7.25 cy/ft) over the 9.7 miles of Emerald Isle. The net annual erosion rate for Emerald Isle is 0.92 cy/ft/yr, below the estimated average of 2 cy/ft/yr.

The profile at 16th Street had not only the largest increase in volume over the past year but also the largest increase in unit volume for the reach since June 1999. To the outer bar, the unit volume was measured to be 331.6 cy/ft, which is an increase of 106.3 cy/ft over the past eight years. The smallest increase in unit volume over the past eight years was at profile 28 (Hurst Road) in the central reach (4.1 cy/ft). All Emerald Isle profiles were net accretional for the June 1999 to May 2007 period.

The net gain in sand volume due to Hurricane *Ophelia* [nourishment volume gain (589,175 cy) – estimated losses due to the hurricane (569,160cy)] is 20,015 cy. By discounting the hurricane losses and hurricane nourishment gain, the net change in sand volume between May 2006 and May 2007 is 274,695 cy (or 5.4 cy/ft) to the outer bar. The additional nourishment (above the hurricane losses) supplied an additional 0.4 cy/ft averaged over the length of Emerald Isle.

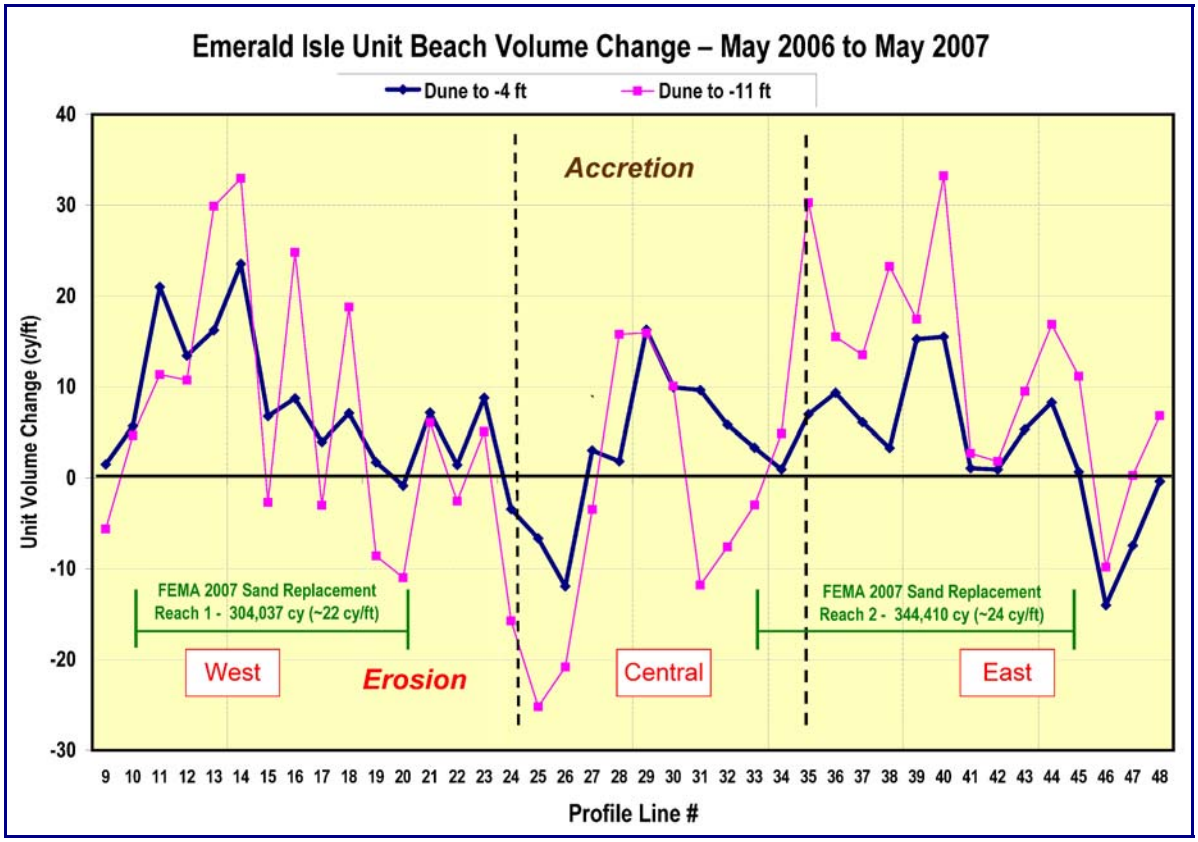


FIGURE 3.3-1. The net change by station to –4 ft and –11 ft calculation depths at all stations (May 2006 to May 2007). Between May 2006 and May 2007, Emerald Isle gained ~5 cy/ft on the visible beach and 17 ft of beach width at mean high water at CSE line 43. (Photos – P McKee)

3.4 Indian Beach/Salter Path

Indian Beach/Salter Path (IB/SP) is part of the Carteret County beach restoration project initiated in 1999. Since 2002, Indian Beach has received 1.36 million cubic yards of nourishment from three separate projects. County-Phase 1 supplied 456,994 cy of sand in 2002. The federal Section 933 waterway maintenance dredging supplied 582,735 cy in 2004, and the FEMA post-*Ophelia* project replaced 319,113 cy in 2007.

Over the past year (May 2006 to May 2007), Indian Beach has gained 9.2 cy/ft over the 12,986 linear feet of beach measured to the outer bar (–11 ft NGVD). The FEMA sand replacement project, which placed sand over the entire length of Indian Beach/Salter Path, is largely responsible for the positive net change as well as the distribution of ~86 percent of the sand volume to the outer bar above the low-tide wading depth elevation (–4 ft NGVD). When the FEMA post-*Ophelia* nourishment volume is factored out, IB/SP has a net loss of sand volume 199,330 cy (–15 cy/ft). The background erosion rate over the past year is about eight times greater than its eight-year average of 1.98 cy/ft/yr, which is a typical historical rate for beaches in this region.

Figure 3.4-1 shows that Indian Beach/Salter Path has been accretive for nearly all of its profiles (to –11 ft). The few profiles that have eroded over the past year have shown only minor losses. Profile 52 (near Summer Winds beach access) and profile 57 (at Sea Isle Plantation) were net erosive over the past year at –0.42 cy/ft and -1.80 cy/ft (respectively). All other profiles saw a net gain in volume to –11 ft. The highest gains were at profiles 49 and 50 at the western end of Indian Beach. See Appendix IV individual profile volumes to –4 ft, –11 ft, and –15 ft.

The volume change in Indian Beach from June 1999 to May 2007 was 1,115,146 cy (85.9 cy/ft). The average unit volume gain for that time period is the largest among the communities of Bogue Banks. Volume gains along Indian Beach over the eight-year period range from 58.8 cy/ft (westernmost profile 48) to 108.8 cy/ft at (profile 55 near the western entrance to Hoffman Beach Road).

Hurricane *Ophelia* removed more sand along Indian Beach/Salter Path than the other Bogue Banks communities (CSE 2005, 2006). IB/SP lost 23 cy/ft of sand along the beach due to the storm (to –11 ft NGVD). The sand volumes rebounded to 277.5 cy/ft with the addition of an average of 24.6 cy/ft along Indian Beach from the 2007 FEMA project but remain below the May 2005 average unit volume of 286.4 cy/ft.

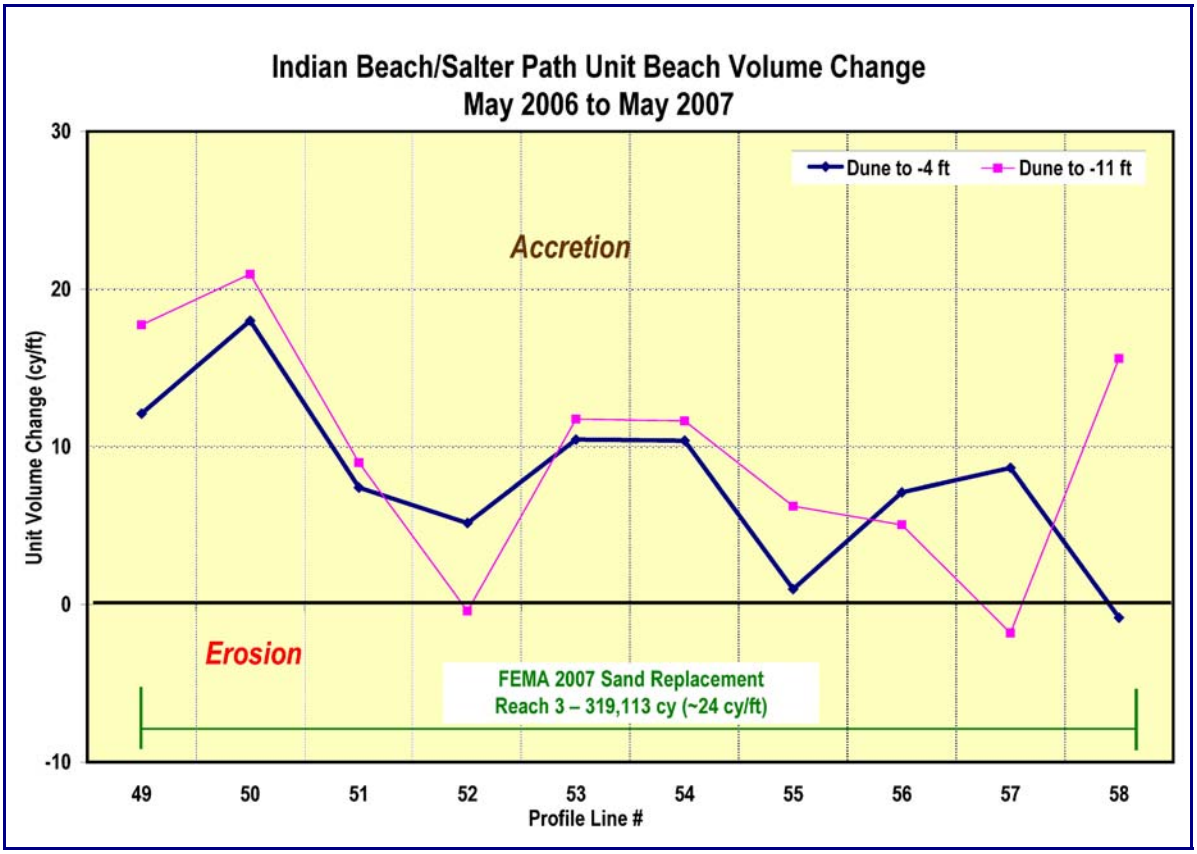


FIGURE 3.4-1. The net change by station to –4 ft and –11 ft calculation depths at all stations (May 2006 to May 2007). Between May 2006 and May 2007, Indian Beach gained ~10.5 cy/ft on the visible beach and 9 ft of beach width at CSE line 53. (Photos – P McKee)

3.5 Pine Knoll Shores

Pine Knoll Shores (PKS) is part of the Carteret County nourishment project initiated in 1999, and for purposes of analysis, is divided into two reaches: PKS-West (profiles 59 to 65) and PKS-East (profiles 66-76).

PKS has received 2,163,348 cy in four separate nourishments between June 1999 and May 2007. PKS-East and PKS-West received 1,276,586 cy during the County-Phase 1 project in 2002. PKS-West 's share of the 2004 Section 933 project was 116,547 cy. PKS was supplied 507,939 cy from the 2007 federal Section 933 project over both the east and west reaches. Also in 2007, the FEMA-funded post-*Ophelia* project replaced 262,276 cy collectively in both reaches.

Betweeen May 2006 and May 2007, the net volume change in PKS was a gain of 996,174 cy. PKS-West volumes increased by an average of 35.2 cy/ft (to –11 ft NGVD), and PKS-East volumes increased by an average of 45.5 cy/ft. The average increase over the entire length (23,967 ft) of PKS was 41.6 cy/ft. Over the past monitoring period, all 18 profiles gained sand. The largest increases in profile volumes were at profile 65 (junction of PKS-West and PKS-East) and at profile 68 (Pine Knoll Town condominiums). The volume gains at these profiles were 70.9 cy/ft and 73.2 cy/ft (respectively). These sections of the beach were nourished by both the FEMA and the Section 933 projects in 2007. Every part of PKS was enhanced by at least one of the two projects (Fig 3.5-1). The profiles with the lowest gains in sand volume to the outer bar were at either end of PKS. Profile 59 (west end) gained a relatively low 18.9 cy/ft, and profile 76 (east end) gained just 8.3 cy/ft. Profile 72 was nourished by the FEMA project in 2007 but not by the Section 933 project. It also had a relatively low profile volume increase of 20 cy/ft. See Appendix IV for individual profile volumes.

The overall change in volume between June 1999 and May 2007 along Pine Knoll Shores was 1,741,538 cy measured to the outer bar. The distribution of sand was divided nearly evenly between PKS-West (71.6 cy/ft) and PKS-East (73.3 cy/ft) for a net increase of 72.7 cy/ft over the June 1999 volume. Like the other Bogue Banks reaches that received nourishment in 2007, the cross-shore distribution of sand is skewed by the effects of the sand placement. However, where the sand above the low-tide wading depth accounted for 93 percent of the total volume of sand measured to the outer bar in Emerald Isle and Indian Beach, only 65 percent of that sand is above low-tide wading depth in Pine Knoll Shores, which indicates that more sand may have been placed below the waterline in PKS than in the other project reaches.

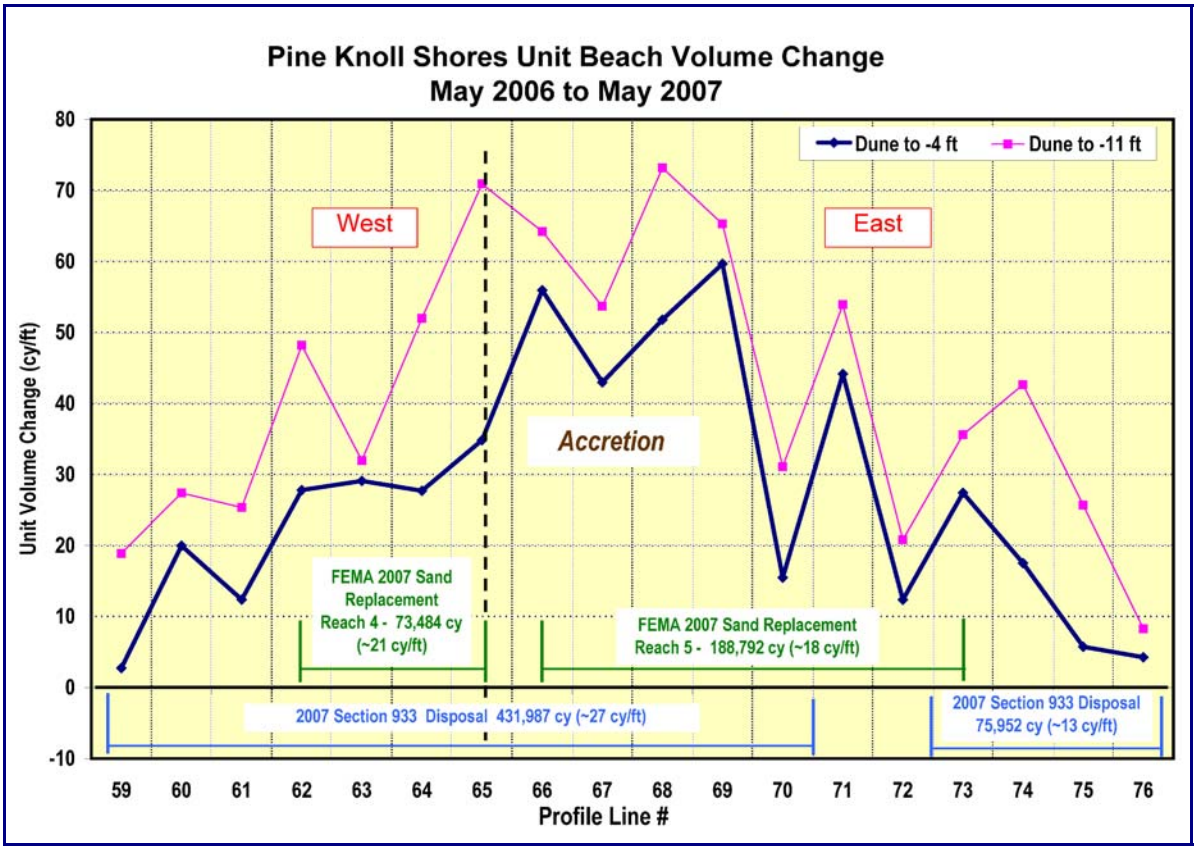


FIGURE 3.5-1 The net change by station to –4 ft and –11 ft calculation depths at all stations (May 2006 to May 2007). Between May 2006 and May 2007, Pine Knoll Shores gained ~51 cy/ft on the visible beach and 97 ft of beach width at CSE line 68. (Photos – P McKee)

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. Since 1999, AB has received 2,920,729 cy of sand (from the 2005 Brandt Island disposal project). It remains part of the USACE plan for periodic renourishment by the dredged harbor sediments disposal.

Atlantic Beach served as a model for Bogue Banks in 1999 because of 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* in September 1999. While the communities to the west (Emerald Isle, Indian Beach, Salter Path, and Pine Knoll Shores) each 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. The Brandt Island spoil disposal nourishment in winter 2005 helped to increase the unit volumes along AB well beyond the target minimum volume or the volumes in other communities. In May 2005, AB's typical volume to the outer bar (–11 ft NGVD) 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. Atlantic Beach once again had more sand along the beach than any other community on Bogue Banks.

Between May 2005 and May 2006, Atlantic Beach had the highest losses among the Bogue Banks communities, losing 22.7 cy/ft. In 2006, AB's profile line 79 (near the western town limit) had nearly zero net gain over the 2005 profile volume. Between May 2006 and May 2007, the profile lost 40.3 cy/ft, the largest loss among the AB profiles. Atlantic Beach is the only Bogue Banks community to have a net **loss** of sand compared to the May 2006 unit volumes. Eleven of the 27 profiles experienced a loss of volume over the past year (May 2006 to May 2007) (Fig 3.6-1). With the exception of profile 79, the trend indicates that AB had become more erosive from west to east. The highest profile volume gain was at profile 77 (43 cy/ft). See Appendix IV for individual profile volumes.

While Atlantic Beach volumes have decreased over the past two years, the beach has been net accretive between June 1999 and May 2007 (1,194,947 cy or 45.4 cy/ft) over the length of the beach. The highest eight-year change occurred at profile 92 (Money Island Drive). The eight-year increase at this profile was 112.2 cy/ft with a loss of 7.7 cy/ft between May 2006 and May 2007.

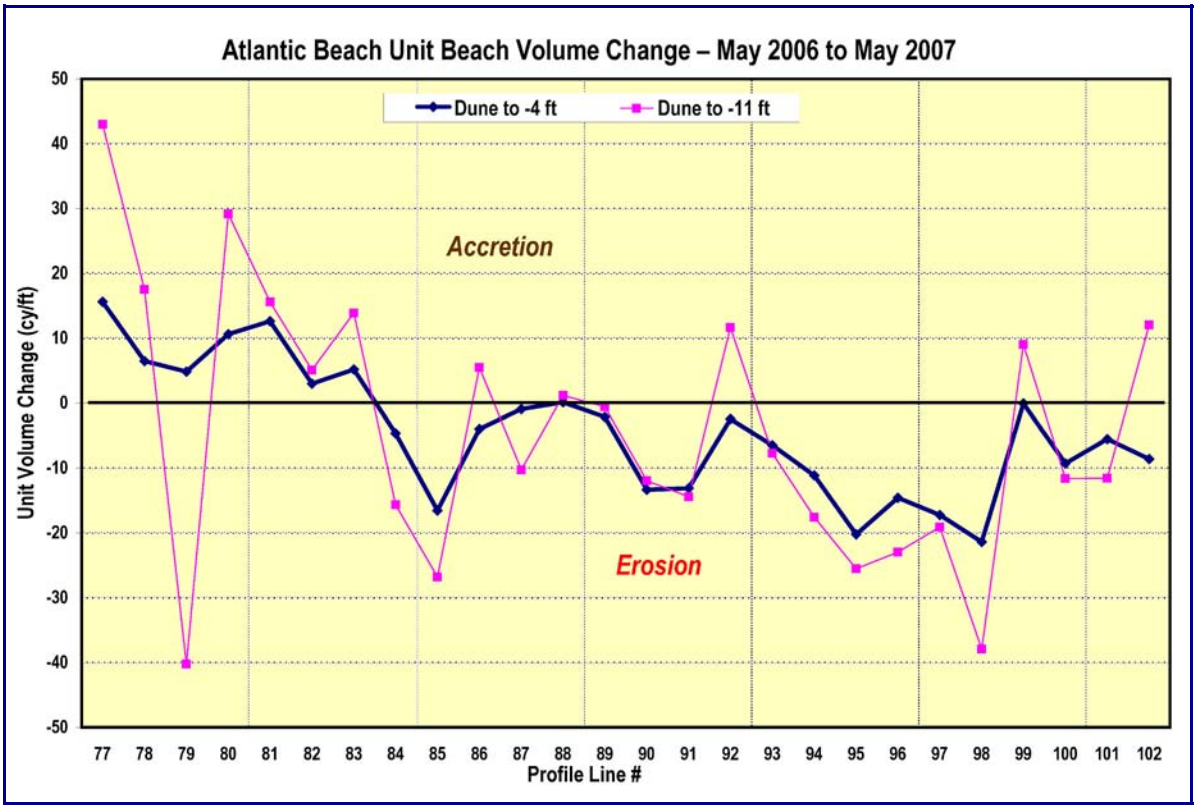


FIGURE 3.6-1. The net change by station to –4 ft and –11 ft calculation depths at all stations (May 2006 to May 2007). Between May 2006 and May 2007, Atlantic Beach lost 13 cy/ft on the visible beach and 91 ft of beach width at the Circle (CSE line 90). (Photos – P McKee)

3.7 Fort Macon State Park

Fort Macon State Park (FMSP) occupies the eastern end of Bogue Banks. The 1.4-mile coastline of FMSP was nourished in 2002 with 209,348 cy of dredged material in conjunction with the Morehead City federal navigation project. FMSP was most recently nourished in 2005 with ~300,000 cy under the same navigation project. It remains part of the plan for periodic disposal of harbor sediments (USACE 1993).

Fort Macon State Park gained 4.7 cy/ft of sand (to –11 ft NGVD) between May 2006 and May 2007 after having lost nearly 12 cy/ft over the course of the previous year (see Table 2). FMSP had a net gain of 2.4 cy/ft above low-tide wading depth. The majority of the profiles that had measured sand losses showed those losses above low-tide wading depth. This trend was noted in 2006 when the recreational beach was found to have lost –1.9 cy/ft above the low-tide wading depth (CSE 2006). The areas of the beach with losses to the outer bar were around profiles 105 and 111 (Fig 3.7-1). At profile 111, the high loss (–35.9 cy/ft) was evident between the lower beach face and the outer bar (compare May 2006 and May 2007 profiles for “Fort Macon Line 111" in Appendix II). The largest net gains in sand volume were measured at profiles 103, 107, and 110. These profiles gained between 17.4 cy/ft and 22.4 cy/ft between the foredune and the outer bar from May 2006 to May 2007. See Appendix IV for individual profile volumes.

Between June 1999 and May 2006, Fort Macon State Park had gained an average of 30.7 cy/ft to –11 ft NGVD. Like the Bogue Inlet-Ocean reach (profiles 1–8) at the western end of the island adjacent to Bogue Inlet, the net gain in unit volume is much less than the average gain for the entire island. The relatively low volume gain in FMSP is a result of lower than average nourishment volume gained since 1999 as well as erosion losses due to its proximity to Beaufort Inlet. [FMSP averaged 70.8 cy/ft and the rest of Bogue Banks gained 80.7 cy/ft in nourishment volumes between June 1999 and May 2006.]

Total volume losses tend to be higher near the eastern end of FMSP as the spit along Beaufort Inlet draws sand from the ocean beach. The net volume loss between profiles 110 and 112 (1,221 ft) was 14,688 cy (to the outer bar) between May 2006 and May 2007. The loss of 3,208 cy to –11 ft NGVD along the 1,986-ft length of beach between profiles 104 and 106 is due to the losses on the upper beach in this area. These same areas of erosion are notable because they are measurable in both the one-year monitoring period and in the longer eight-year period from June 1999 to May 2007.

The erosional nature of the east end of Fort Macon State Park is evident in the background erosion rate of 5.06 cy/ft/yr between June 1999 and May 2007.

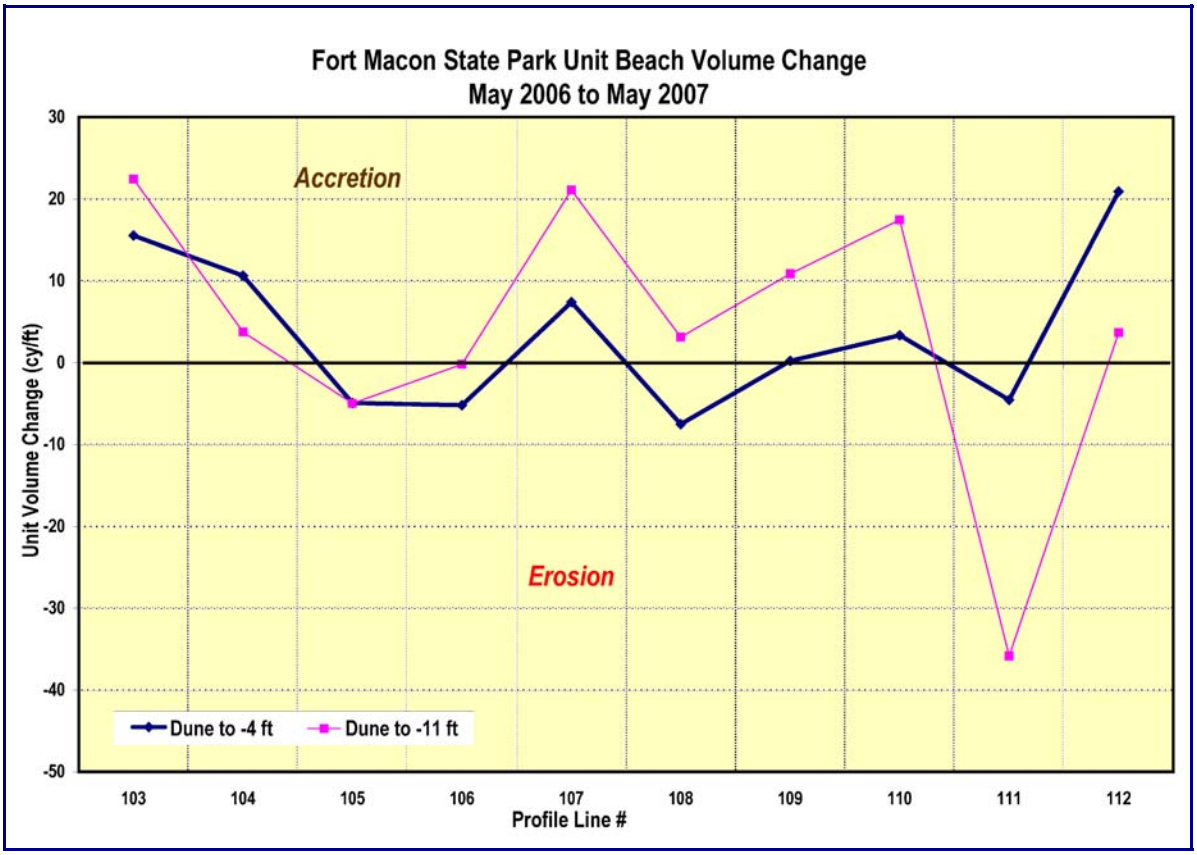


FIGURE 3.7-1.

The net change by station to –4 ft and –11 ft calculation depths at all stations (May 2006 to May 2006). Between May 2006 and May 2007, Fort Macon State Park lost 5 cy/ft and 21 ft of beach width at CSE line 105.

(Photo – P McKee)

3.8 Bogue Inlet

Bogue Inlet is monitored in two reaches at The Point in Emerald Isle:

- Bogue Inlet–Ocean encompasses ~6,772 ft between profiles 1 and 8.
- Bogue Inlet–Channel encompasses ~1,500 ft between profiles 117 and 120 along the Emerald Isle portion of the channel.

From May 2006 to May 2007, Bogue Inlet-Ocean gained 48,372 cy (measured to –11 ft NGVD). All of the gain in sand volume can be accounted for above the –4 ft NGVD contour where the reach gained a total of 58,358 cy, meaning that there was a net loss in volume between –4 ft and –11 ft NGVD of ~10,000 cy. Measured from –11 ft to –15 ft NGVD, the ocean reach lost an additional ~101,000 cy.

After three consecutive years of dramatic increases in sand volume along the channel reach, recession along the upper beach at profiles 117 and 120 caused a net volume loss of 3.8 cy/ft for the reach above the –11 ft contour. The high accretion rate at profile 119 resulted in an increase in beach width of over 500 ft at the high waterline (Fig 3.8-1) between May 2005 and May 2007. The lost sand volume above –11 ft NGVD was offset by gains of 4.2 cy/ft between –11 ft and –15 ft. See Appendix IV for individual profile volumes. The sand volume deficit above the –11 ft elevation (-3.8 cy/ft) is accounted for above the –4 ft NGVD elevation. The net one-year loss above low-tide wading depth is 13.8 ft. Net accretion below –4 ft NGVD allowed for a much smaller deficit to –11 ft. The accretion of 10 cy/ft between –4 ft and –11 ft resulted in a net loss of sand of 3.8 cy/ft to –11 ft NGVD.

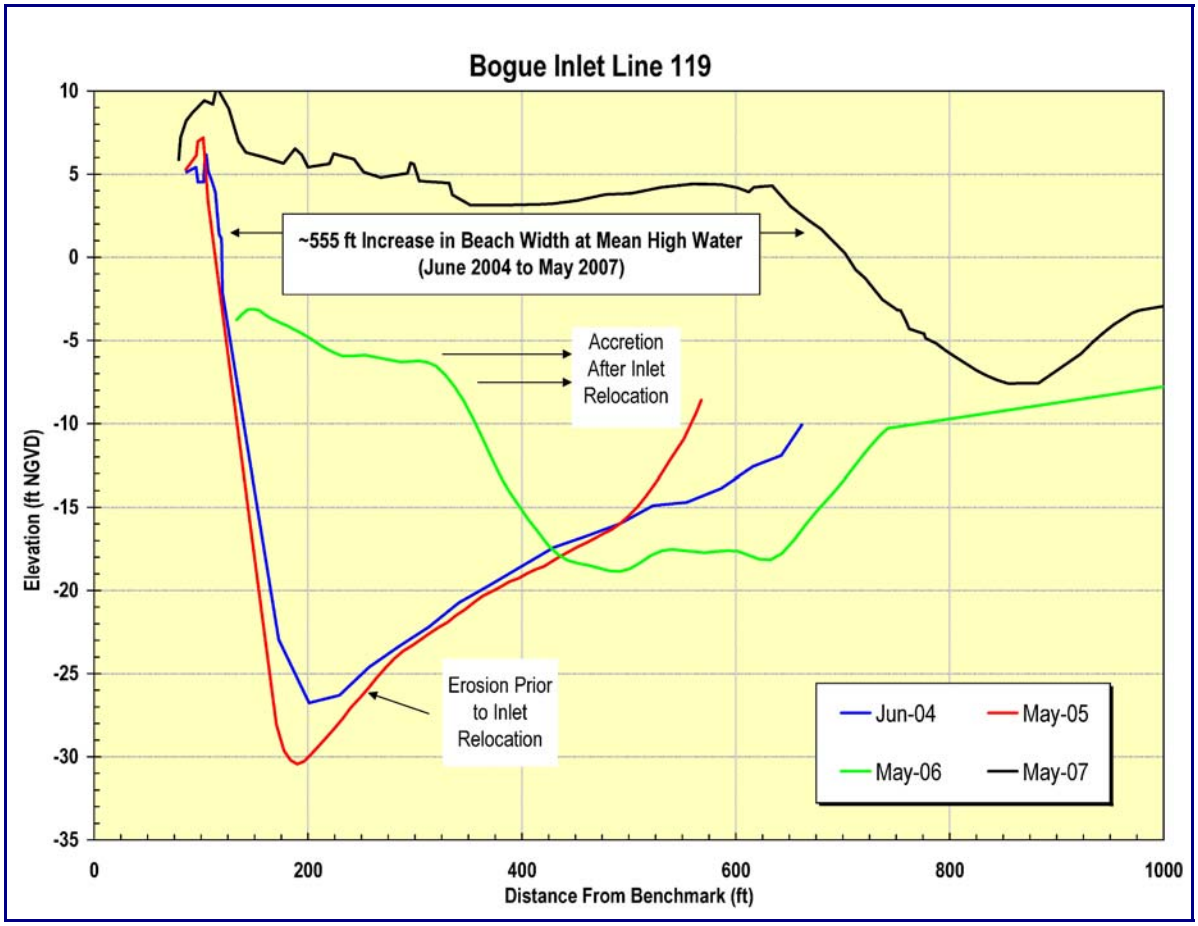


FIGURE 3.8-1. Comparative profile at Bogue Inlet–channel line 119. High accretion since the channel realignment in spring 2005 resulted in a wide beach by May 2007.

3.9 Beaufort Inlet

Beaufort Inlet (at the eastern end of Bogue Banks) showed minor erosion over the past monitoring period (May 2006 to May 2007). Measured to –4 ft NGVD, the area lost 11,428 cy of sand long the 2,250-ft reach between profiles 112 and 116. Beaufort Inlet had a net gain in sand volume of 2.9 cy/ft between the –4 ft and –11 ft elevations. Profiles 113 and 114 (nearest to the inlet entrance) have gained sand volume above low-tide wading depth (10.2 cy/ft and 5.3 cy/ft, respectively), but the high loss at profile 115 of 31 cy/ft to –4 ft NGVD accounts for the overall erosion of the reach (Fig 3.9-1). There have also been gains in sand for profiles 113 and 114 to the –11 ft NGVD contour (51.4 cy/ft and 10.7 cy/ft, respectively), which have overcome the deficits at the other two profiles, allowing the reach to be net accretive to –11 ft.

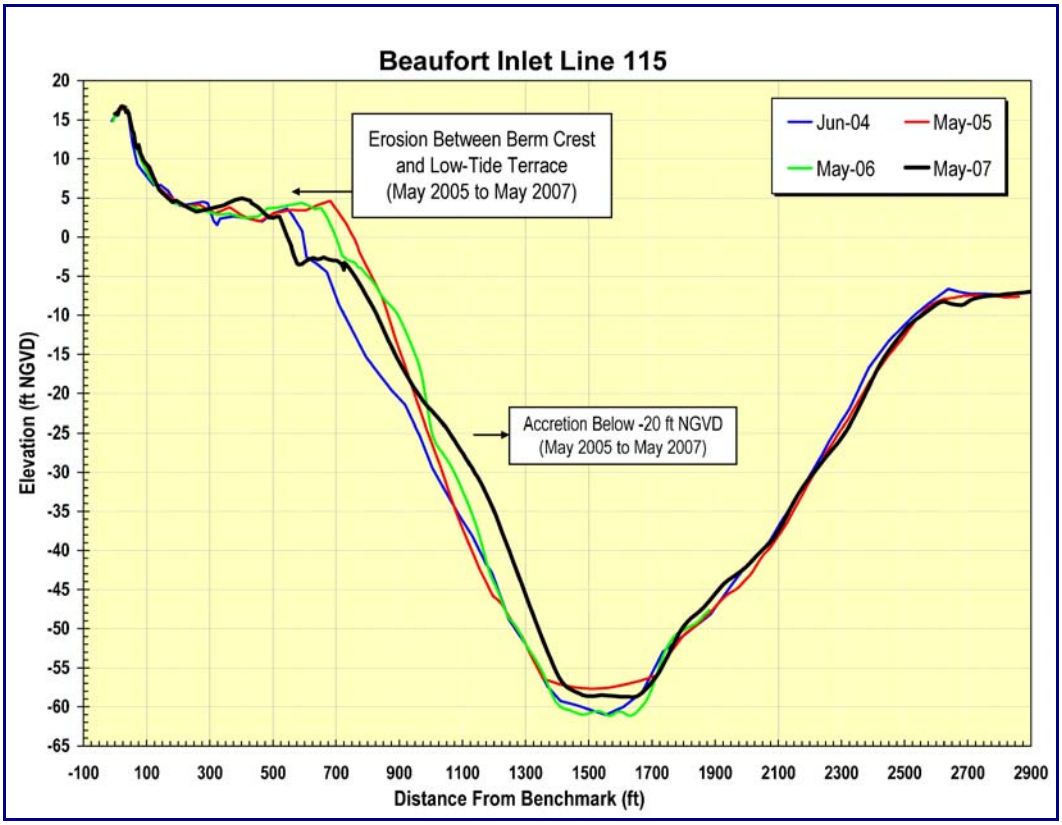


FIGURE 3.9-1. Erosion above the low-tide terrace at Beaufort Inlet line 115 between May 2005 and May 2006 and again from May 2006 to May 2007 contributed to the net sand loss in the reach since May 2005.

3.10 Bear Island

Bear Island, west of Bogue Inlet from Emerald Isle, was first surveyed by CSE in October 2004 and was thereafter included in the normal scope of work in conjunction with the BBBNMP monitoring project. The reach is 17,000-ft long and includes Bear Island profiles 1–18. Profile 1 is adjacent to Bogue Inlet. Profile 18 is adjacent to Bear Inlet.

Bear Island was net erosive over the past monitoring period (May 2006 to May 2007). It lost 105,930 cy (6.2 cy/ft) above the low-tide wading depth and an additional ~238,000 cy (14 cy/ft) measured to the –11 ft contour. Nearly all profiles were erosional (Fig 3.10-1). Profile volume losses were measured between 2.7 cy/ft and 17 cy/ft (profiles 7 and 16, respectively) to the –4 ft NGVD contour. The findings were similar for volumes measured to –11 ft and –15 ft. Profile 12 showed a measured net gain in volume at each elevation, although the gain above –4 ft helped to offset the losses below -4 ft. At profile 12, the volume gained (to –4 ft NGVD) was 10.8 cy/ft. A loss of ~2.4 cy/ft between the –4 ft and –11 ft elevations and an additional loss of ~6 cy/ft continuing out to the –15 ft elevation were not enough to create a net deficit at the profile. At Bear Inlet, profile 18 was also measured to have a net gain in sand volume at the elevations of interest.

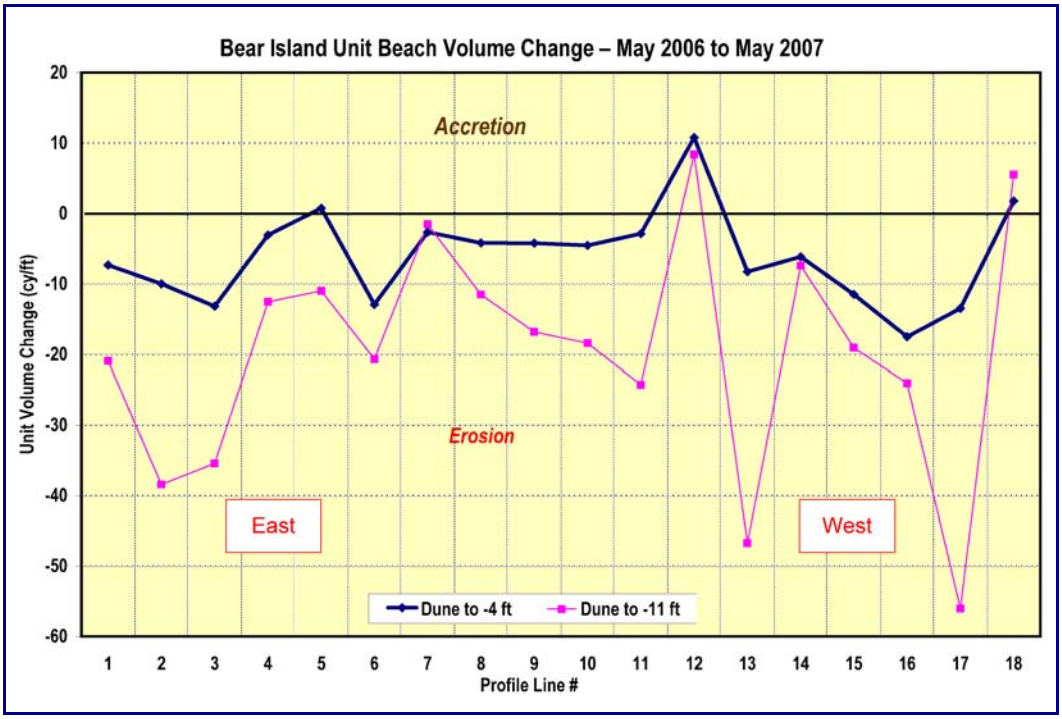


FIGURE 3.10-1. May 2006 to May 2007 beach volume changes – Bear Island.

3.11 Shackleford Banks

Shackleford Banks is an ~46,000-ft-long island situated between Bogue Banks and Cape Lookout. CSE first surveyed the island in May 2005, and it has been included in the regular monitoring effort since then. Twenty-four lines are profiled to analyze Shackleford Banks. Profile line 1 is adjacent to Barden Inlet between Cape Lookout and Shackleford Banks; line 24 is adjacent to Beaufort Inlet.

During the past year, Shackleford Banks gained 55,122 cy of sand (measured to –11 ft NGVD) averaging 1.2 cy/ft. The net gain includes the highly erosional profile 1 at Barden Inlet (Fig 3.11-1). When this profile is not included, Shackleford's island-wide average gain is increased to 2.8 cy/ft. The island actually lost 74,366 cy above –4 ft NGVD (visible beach) during the past year. But this erosion was offset by increases in sand volume between –4 ft and –11 ft NGVD of 129,478 cy and between –11 ft and –15 ft NGVD of 215,216 cy. The highest losses on Shackleford Banks were measured at profiles 11, 17, and 24 (along Beaufort Inlet) measured to –11 ft. The losses in these profiles are between 18.7 cy/ft and 20.5 cy/ft (Fig 3.11-1). The profiles that showed gains to –11 ft had an average increase of 14 cy/ft over the May 2006 profiles.

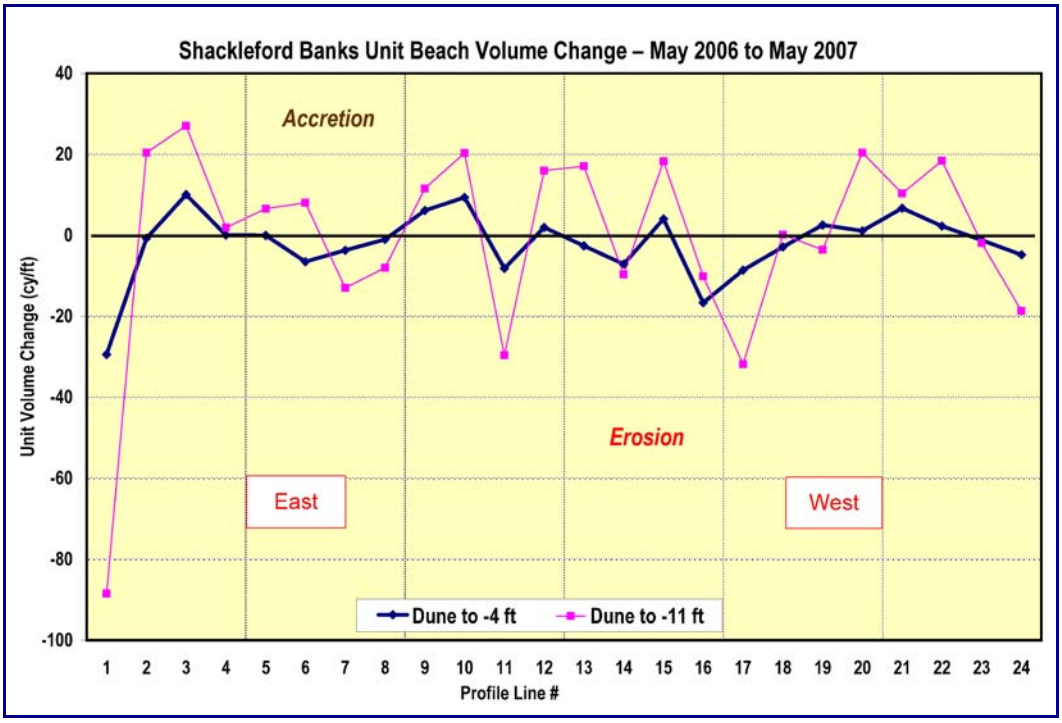


FIGURE 3.11-1. May 2006 to May 2007 – Shackleford Banks.

3.12 Nourishment Project Analysis

The May 2007 survey includes the impact of the FEMA sand replacement project which replenished Emerald Isle, Indian Beach/Salter Path, and Pine Knoll Shores with ~1.2 million cubic yards of sand that had been lost due to Hurricane *Ophelia* in September 2005.

The 2007 survey (detailed in previous sections) showed the gains in sand volume with respect to the May 2006 survey. A simplified beach elevation analysis is provided in this section as a way of evaluating the littoral beach condition before and after nourishment. The three nourished communities are divided into five reaches for analysis. The five reaches are the same as those used to analyze Bogue Banks. Composite changes for each reach are developed using average profiles that comprise the reach. [See CSE (2006) for method details.]

CSE computed composite profiles for each reach for both the prenourishment conditions (May 2006) and the postnourishment conditions (May 2007). The individual profiles are composited by matching them at the toe of the dune (+9 ft NGVD contour). The prenourishment and postnourishment composites are then plotted with respect to the postnourishment contour horizontal axis, so the postnourishment composite is plotted normally. When aligned as such, changes in slope and relative widths of various portions of the profile can be compared. The different between the two is simply the effect between the composites of the surveyed elevations.

The Emerald Isle composites [Figs 3.12-1,2,3 (upper)] show similarities in the distribution of the sand volume. A majority of the sand is shown to be placed on the lower beach below the berm with little change in beach elevation (ie, beach volume) above the berm crest. The postnourishment profiles also show that the change in volume increases until it reaches the outer bar of the May 2006 profile (~)+600 ft from the toe of the dune. The net change in volume quickly decreases once it reaches that point [Figs 3.12-1,2,3 (lower)].

The Indian Beach composite profiles show a more uniform slope between the toe of dune and low-water contour. Seaward of low water, slopes increase (before and after nourishment). The largest increase in the elevation variation occurs at about 410 ft seaward of the toe of the dune (Fig 3.12-4, lower). Similar to the Emerald Isle composite profiles, the sand volume decreases at about 600 ft seaward of the dune, which reflects a lowering of the outer bar.

The two Pine Knoll Shores composites (east and west) show greater change in elevation for 2006-2007 than the other nourished reaches. Pine Knoll Shores received 4.5 times as much sand (on a per foot average) as IB/SP and had over seven times as much as Emerald Isle. The profiles, however, reveal similar trends as the other nourished reaches in that most of the volume gain with respect to variation in elevation change is found between the lower beach and the outer bar. The PKS-East reach shows a significant increase in elevation along the upper beach and dune [Figs 3.12-5,6 (upper)]. In both cases, the variation in the 2007 profile elevation increases to the outer bar, then simply decreases over the bar [Fig 3.2-5,6 (lower)].

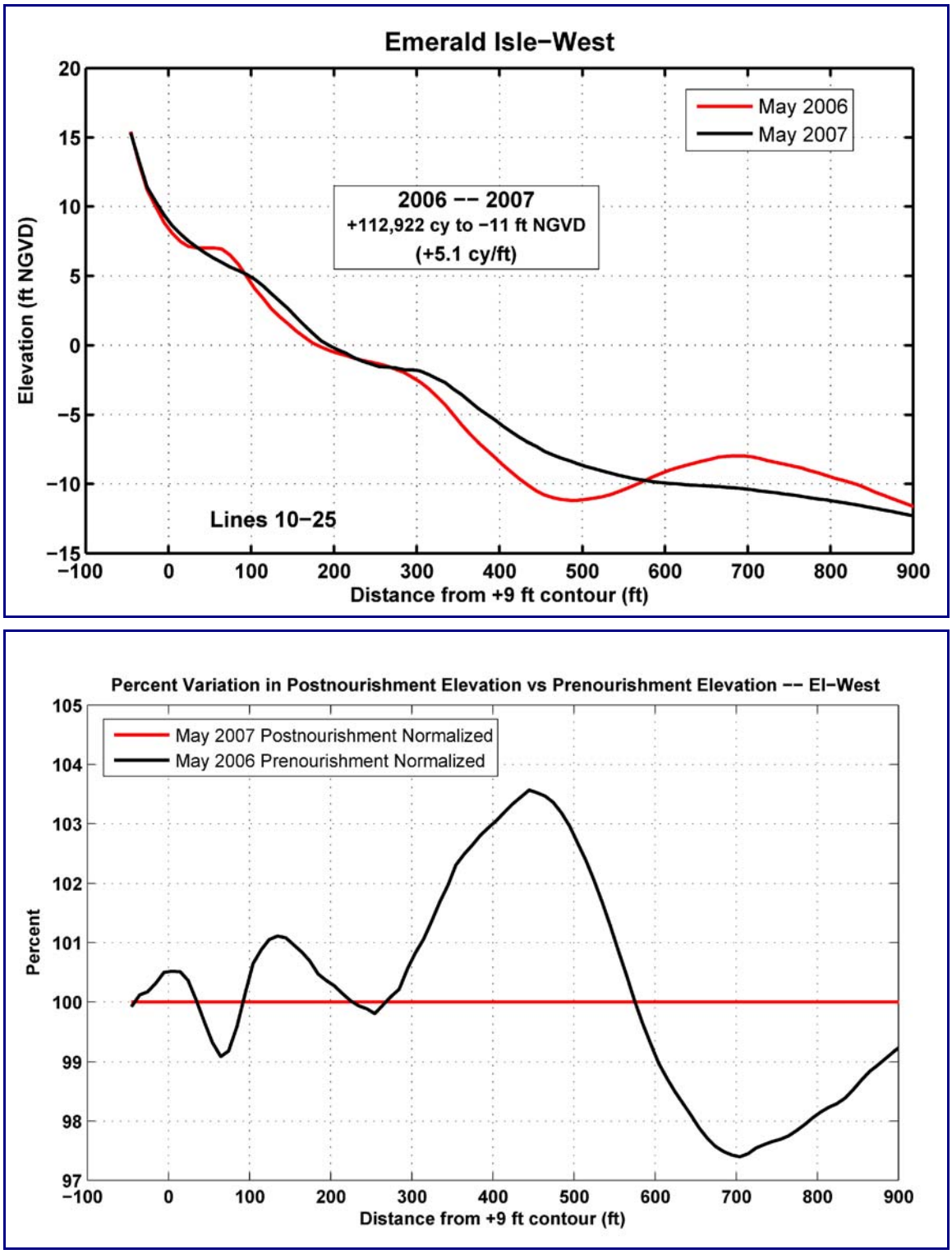


FIGURE 3.12-1. Composite profiles before and after nourishment juxtaposed at the postnourishment +9 ft contour. Note the similarity of slopes and elevations before and after nourishment above mean low water (approximately –2 ft). The prenourishment profile had a well-developed outer bar ~700 ft offshore.

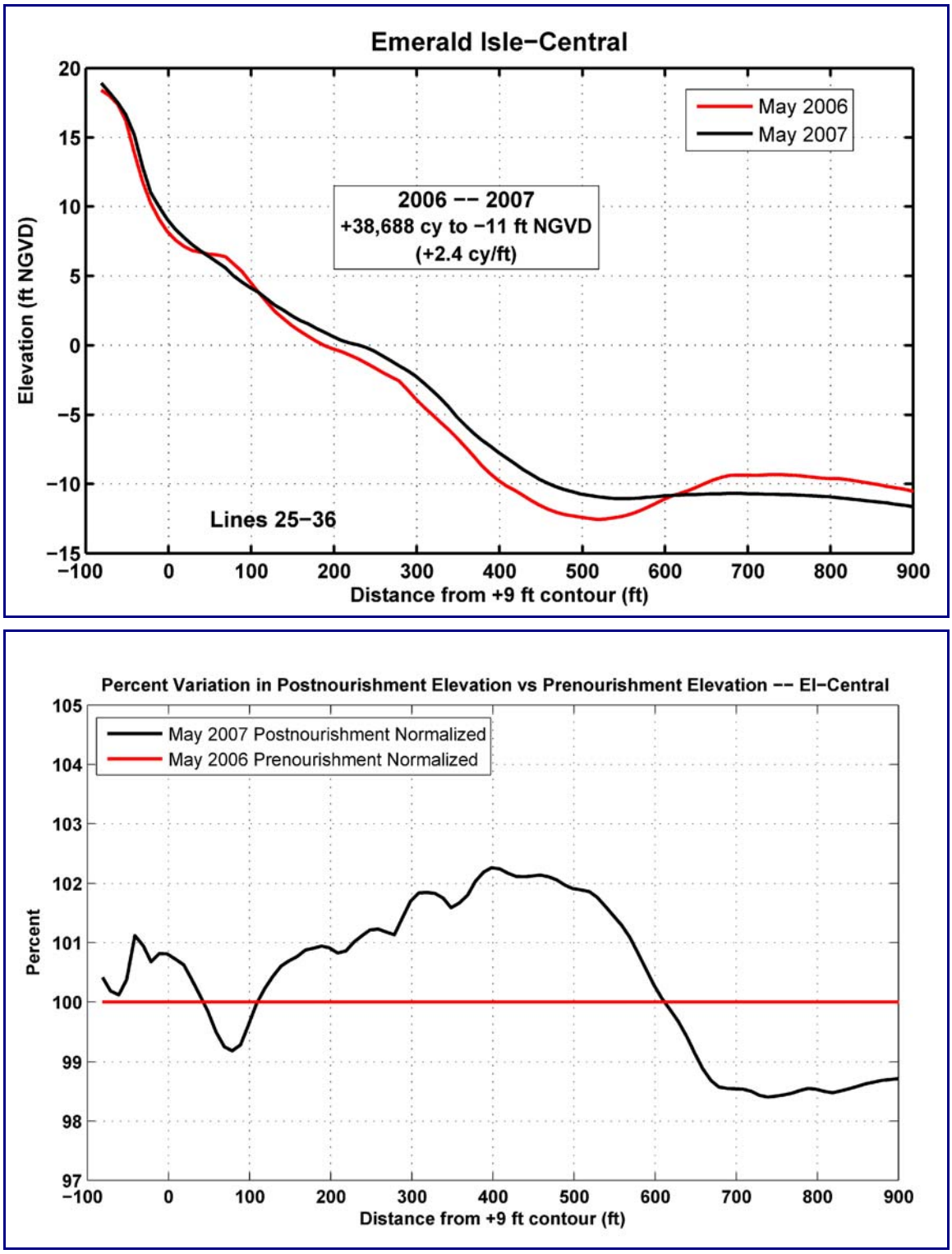


FIGURE 3.12-2. Composite profiles before and after nourishment juxtaposed at the postnourishment +9 ft contour. This reach received very little nourishment in 2007, but experienced significant accretion below mean sea level. Some of the gain was likely due to shoreward movement of the outer bar.

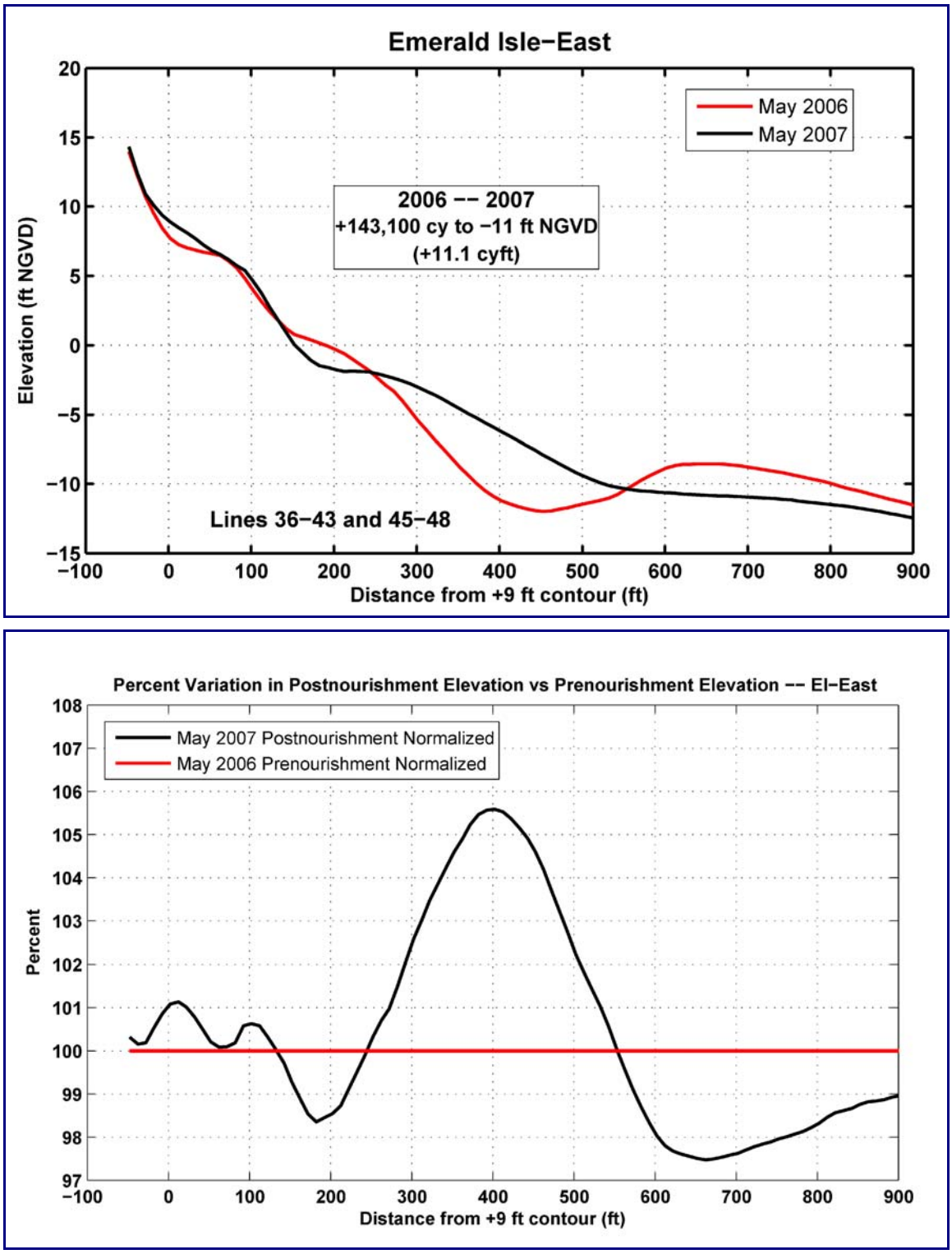


FIGURE 3.12-3. Composite profiles before and after nourishment juxtaposed at the postnourishment +9 ft contour. The large gain between mean low water and –10 ft reflects the impact of nourishment in 2007.

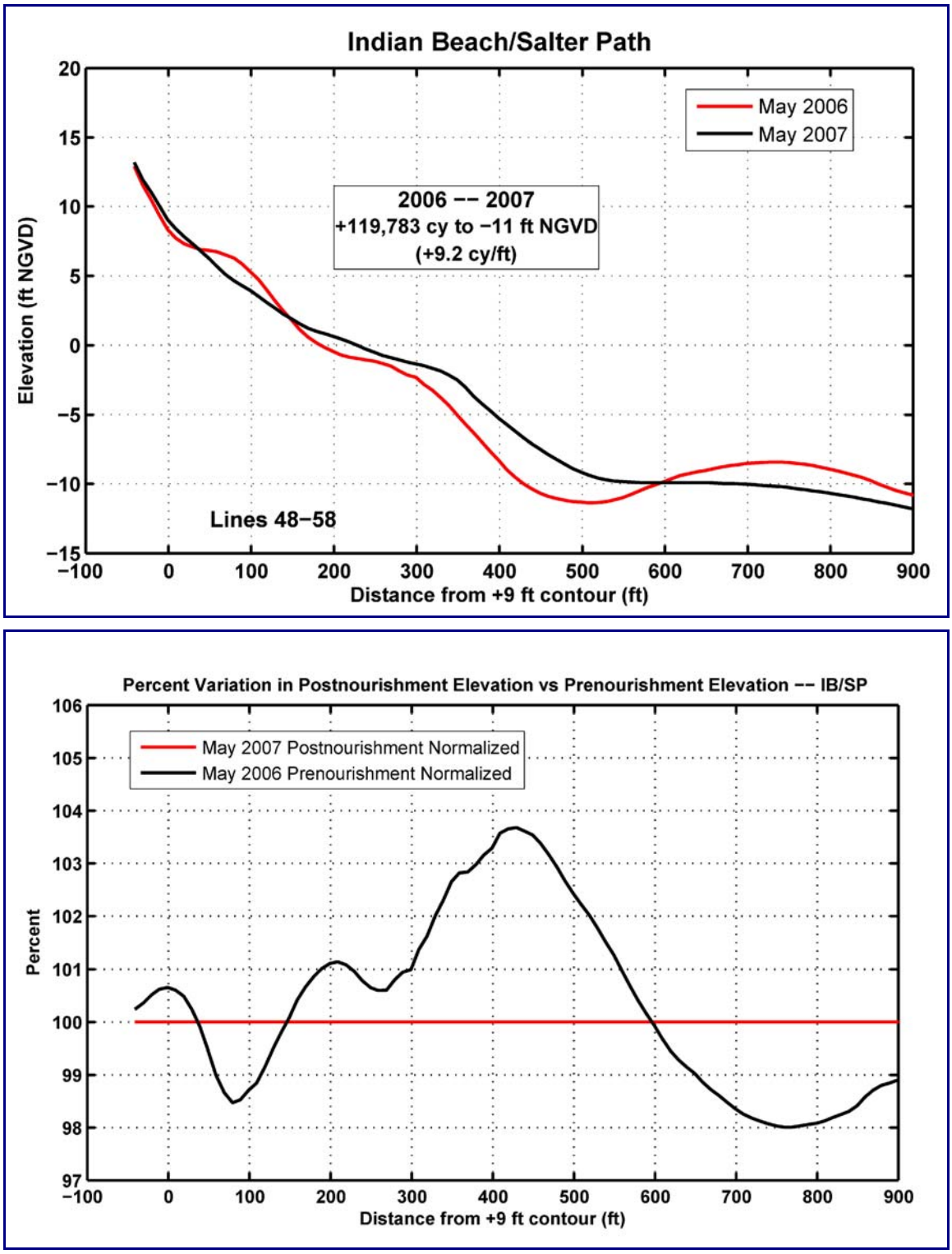


FIGURE 3.12-4. Composite profiles before and after nourishment juxtaposed at the postnourishment +9 ft contour. The postnourishment profile had lesser relief over the visible beach and gained volume between mean sea level and the outer bar.

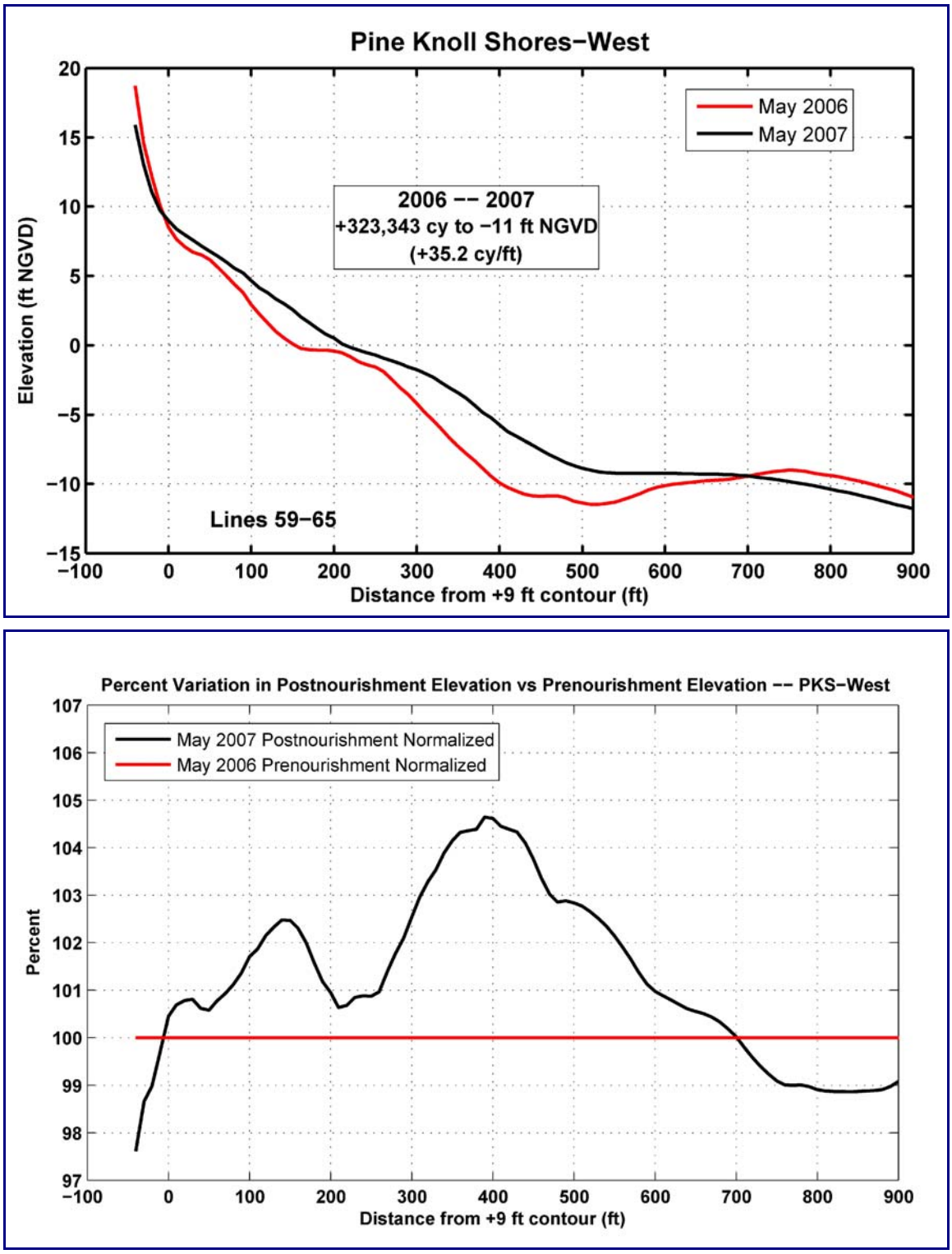
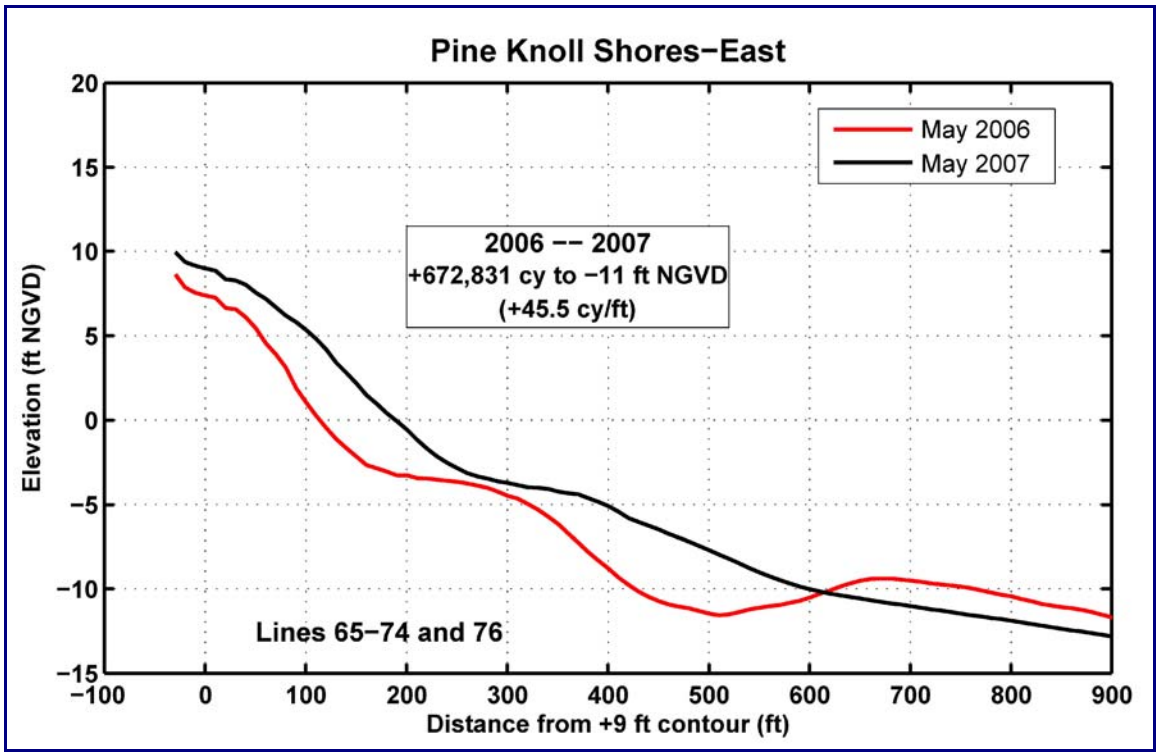


FIGURE 3.12-5. Composite profiles before and after nourishment juxtaposed at the postnourishment +9 ft contour. Nourishment in 2007 increased elevations from the toe of the dune to the outer bar.



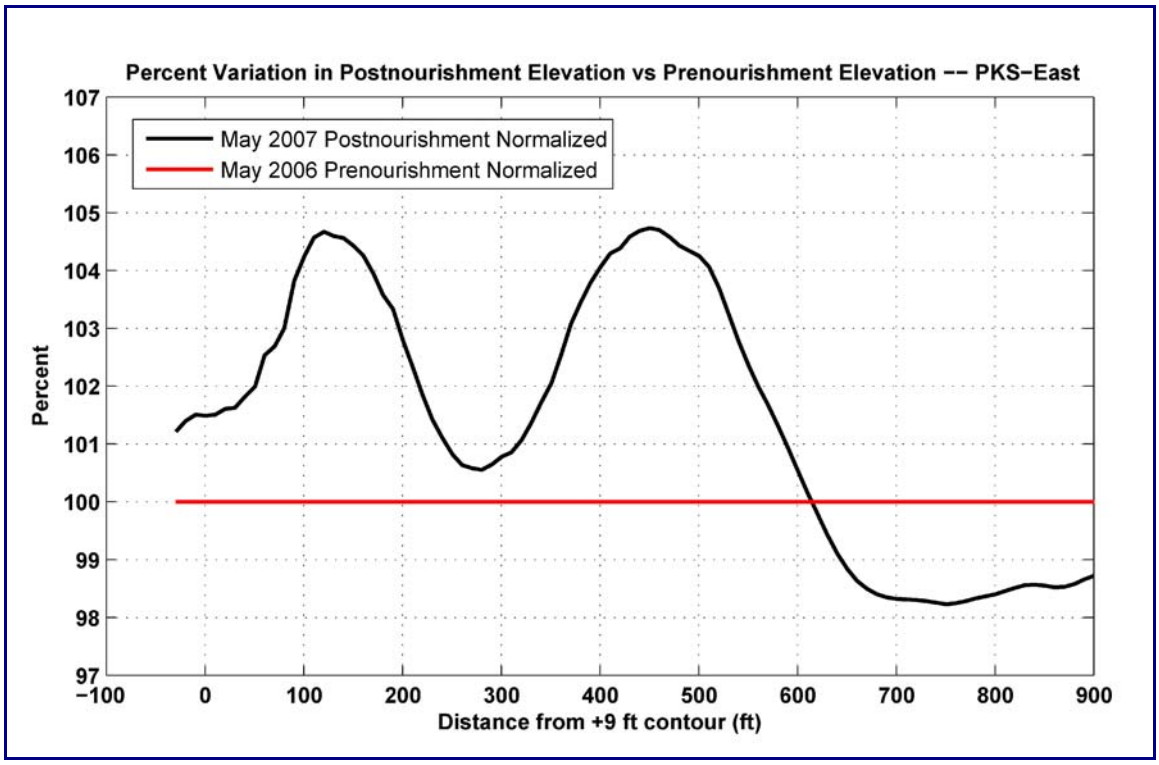


FIGURE 3.12-6. Composite profiles before and after nourishment juxtaposed at the postnourishment +9 ft contour. PKS-East received the most sand of any reach during the past year.

3.13 Shoreline Changes

One indicator of the health of the beach is its width, particularly above mean high water level. The beach above mean high water level (the "dry" beach) protects the backshore from storm surge and waves, allows for more recreational area throughout the tidal cycle, and provides property appreciation benefits (Dean 2002). A wide beach offers more protection, recreation, and economic benefits than does a relatively narrower beach.

The beach width was estimated from the May 2007 survey data and compared with the earliest measured shoreline position of 1999. The postnourishment shoreline of 2007 is also compared to the prenourishment shoreline of May 2006 to quantify the net change in beach width due to natural erosion and accretion, and the addition of 1.7 million cubic yards of sand to the beach in 2007. The mean high water line was used to define the position of the shoreline. CSE assumes the mean high water level is +2.1 ft NGVD based on a tidal benchmark at the Morehead City (NC) harbor (Fig 3.13-1 to Fig 3.13-11).

The shoreline increased in width by an average of 78 ft along Bogue Banks (Emerald Isle line 8 to Fort Macon State Park line 112) between June 1999 and May 2007 (Table 3.13-1). The Pine Knoll Shores-East reach gained the most beach width of the eight reaches studied. The Pine Knoll Shores-East beach increased by an average of 123 ft. The beaches from the Emerald Isle-Central reach to the PKS-West reach gained an average between 99 and 104 ft of beach width above mean high water. The Emerald Isle-West reach gained 75 ft of beach width. The reaches that did not receive nourishment sand in 2007, Atlantic Beach and Fort Macon State Park, saw the lowest gains in volume between 1999 and 2007 and lower than average gains in "dry" beach width. Interestingly, Indian Beach/Salter Path (the reach that saw the highest gain in volume between 1999 and 2007 at 89.0 cy/ft) ranked fifth out of the eight reaches in beach-width change for the same time period.

For the May 2006-May 2007 period, the entire beach averaged an increase of 9 ft of beach width (Table 3.13-2).* The largest beach width loss from 2006-2007 occurred in Atlantic Beach at the Circle (Line 90), where the mean high water line receded ~91 ft. The largest gain in beach width occurred in Pine Knoll Shores at the Iron Steamer (line 67).

[*CSE 2006 reported a 1999-2006 increase of 71 ft, which would suggest an increase of 7 ft between 2006 and 2007. The estimates are based on an assumption of equal spacing between profiles, which is not actually the case. Therefore there is some built-in roughness in the average width estimates.]

The one-year, shoreline width and volume change ranks correlate well:

- PKS-East and PKS-West rank 1 and 2 in volume change and shoreline-width change.
- Atlantic Beach and Fort Macon State Park rank 7 and 9 in the same categories.

The 9-ft average gain in beach width between 2006 and 2007 is due to the 2007 nourishment projects, which added an average of 27 ft of "dry" beach width to the nourished areas (Table 3.13-3) and resulted in an additional 32.9 acres of beach. The unnourished beach actually lost 3.3 ft (9.2 acres) of "dry" beach between 2006 and 2007.

The relationship between beach-width change at MHW and volume change to –11 ft NGVD from 2006-2007 is statistically significant with a correlation of 0.76 ($R^2 = 0.58$) (Fig 3.13-12). The one-year profile elevation data suggest that for 10 cy/ft of beach gained (on average) over the observed range of one-year volume change, there is an expected increase of 9.4 ft of beach width gained. Conversely, the same is true for beach volume lost – with a loss of 10 cy/ft of beach, the width at MHW level is expected to decrease by 9.4 ft at the particular profile. Keep in mind that beach width is more sensitive to the beach cycle than profile volume. As profiles adjust to storm and poststorm conditions, there is a tendency for mean high water to move landward or seaward by tens of feet, while the profile volume changes by only a small amount.

[Following 11 pages]

FIGURE 3.13-1 through FIGURE 3.13-11.
Approximate mean high water elevation contours for June 1999, May 2006, and May 2007 overlain on rectified orthophotos by Independent Mapping Consultants (Charlotte NC); 2004 rectified orthophotos provided by Carteret County. Mean high water of (~)+2.1 ft NGVD is based on observations at Morehead City harbor channel. Positions of profile lines 1–111 are shown. The shading indicates shoreline movement between May 2006 and May 2007. Red shading indicates landward shoreline movement and green shading indicates seaward shoreline movement.

TABLE 3.13-1. Shoreline change (June 1999 — May 2007) determined with beach width change at the Mean High Water elevation. At Bogue Banks, the MHW is +2.1 ft NGVD. Volume change for each reach is also shown in order to compare the change in shoreline position with respect to the volume change. (* Bogue Inlet - Ocean reach is not used in this analysis). Volume change is to -11 ft NGVD.

Shoreline Change (June 1999 — May 2007)			Observed Beach Width Change (ft) Seaward (+) Landward (-)			Shoreline Width	Volume Change (1999 —2007)	Volume Change
Reach	Profiles	Reach Length (ft)	Minimum	Maximum	Average	Rank	(cy/ft)	Rank
EI-West*	8-25	22,303	42	116	75	6	53.1	5
EI-Central	25-36	15,945	40	159	100	4	49.0	6
EI-East	36-48	12,900	67	149	104	**2**	73.4	3
IB/SP	48-58+	12,986	77	117	99	5	89.0	**1**
PKS-West	58-65	9,182	59	144	102	3	74.1	**2**
PKS-East	65-76	14,785	91	162	123	**1**	72.6	4
AB	76-102	26,322	-14	71	30	**7**	45.4	**7**
FMSP	102-112	7,199	-60	48	13	**8**	28.5	**8**
Total Reach	**8-112**	**121,620**	**-60**	**162**	**78**			

TABLE 3.13-2. Shoreline change (May 2006 — May 2007) determined with beach width change at the Mean High Water elevation. At Bogue Banks, the MHW is +2.1 ft NGVD. Volume change for each reach is also shown in order to compare the change in shoreline position with respect to the volume change. (* Bogue Inlet - Ocean reach is not used in this analysis). Volume change is to -11 ft NGVD.

Shoreline Change (May 2006 — May 2007)			Observed Beach Width Change (ft) Seaward (+) Landward (-)			Shoreline Width	Volume Change (2006 —2007)	Volume Change
Reach	Profiles	Reach Length (ft)	Minimum	Maximum	Average	Rank	(cy/ft)	Rank
EI-West*	8-25	22,303	-21	55	14	4	5.1	5
EI-Central	25-36	15,945	-9	48	18	3	2.4	6
EI-East	36-48	12,900	-29	34	4	5	11.1	3
IB/SP	48-58+	12,986	-16	13	-1	6	9.2	4
PKS-West	58-65	9,182	-27	85	34	**2**	35.2	**2**
PKS-East	65-76	14,785	-1	106	61	**1**	45.5	**1**
AB	76-102	26,322	-91	10	-28	**8**	-4.2	**8**
FMSP	102-112	7,199	-44	18	-5	**7**	-2.6	**7**
Total Reach	**8-112**	**121,620**	**-91**	**106**	**9**			

TABLE 3.13-3. Shoreline change (May 2006 — May 2007) at the 2007 nourishment reaches determined with beach width change at the Mean High Water elevation. At Bogue Banks, the MHW is +2.1 ft NGVD. Volume change for each nourishment reach is also shown in order to compare the change in shoreline position with respect to the volume change following nourishment. Volume change is to -11 ft NGVD.

Shoreline Change (May 2006 — May 2007) Nourishment Reaches[1]			Observed Beach Width Change (ft) Seaward (+) Landward (-)			Shoreline Width	Volume Change (2006 —2007)	Volume Change
Nourishment Reach	Profiles	Reach Length (ft)	Minimum	Maximum	Average	Rank	(cy/ft)	Rank
(1) EI-West	10-20	13,663	-21	55	22	3	10.7	4
(2) EI-East/Central	33-45	14,058	-22	35	13	4	14.4	3
(3) IB/SP	48-58	12,986	-16	13	-1	**5**	9.2	**5**
(4) PKS-West	62-65	3,907	57	85	70	2	48.0	2
(5) PKS-East	66-73	9,715	31	106	76	**1**	48.5	**1**
Total Reach	**(1) - (5)**	**54,328**	**-22**	**106**	**27**			

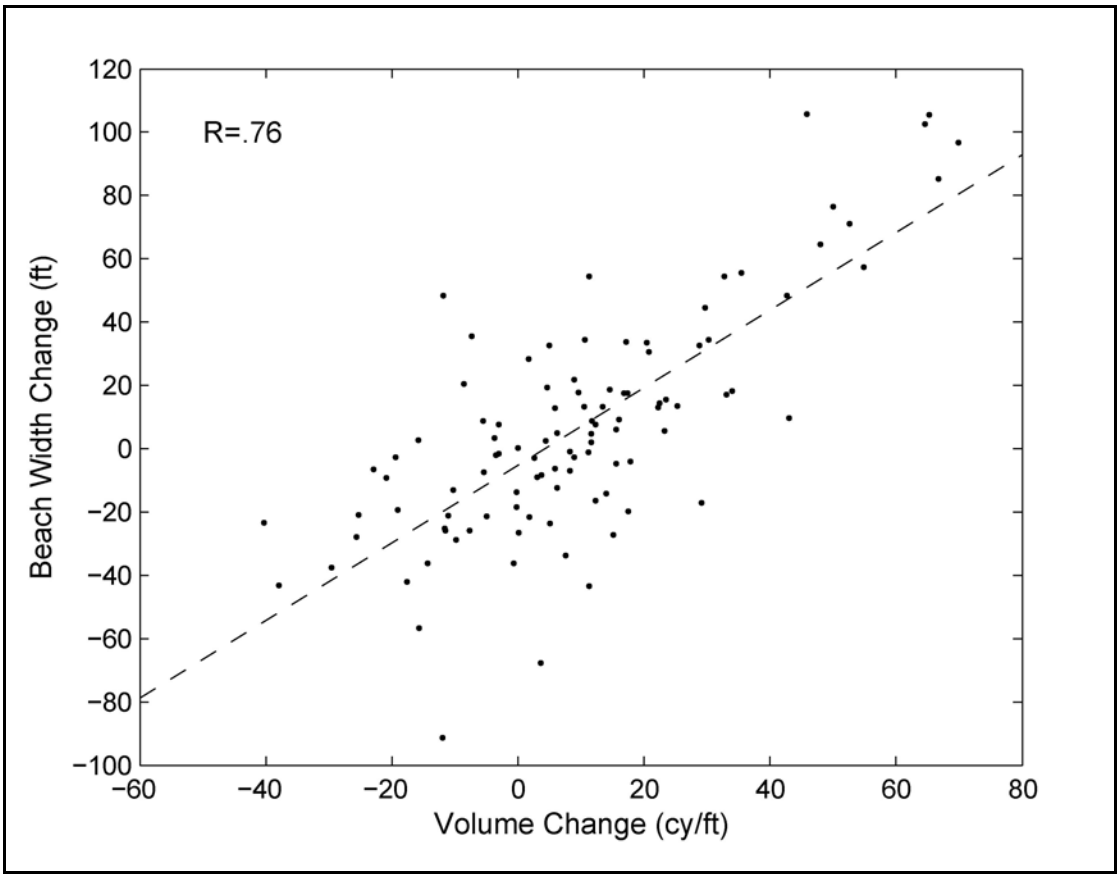


FIGURE 3.13-12. Correlation between beach width change (measured at mean high water) and profile volume change (measured between the toe of dune and –11 ft NGVD).

4.0 DISCUSSION AND RECOMMENDATIONS

The present survey documented changes between May 2006 and May 2007 for Bogue Banks, Bear Island, and Shackleford Banks. CSE also analyzed volume changes from June 1999 to May 2007 on Bogue Banks in relation to nourishment volumes added over that time period. In May 2007, survey data accounted for 72 percent of the nourishment volume measured to –11 ft NGVD (outer bar).

The May 2006 and May 2007 surveys documented an overall sand volume gain along Bogue Banks. All but one community and reach along Bogue Banks gained sand volume both on the beach to low-tide wading depth and to the outer bar. That exception was Atlantic Beach, which lost sand when measured to these elevations. All reaches exceeded the target minimum profile volume of 225 cy/ft to the outer bar in May 2007. Nourishment projects at Bogue Banks placed ~1.74 million cubic yards of sand on the beach in 2007. Seventy percent of the nourishment sand was supplied by the FEMA sand replacement project and covered deficit areas in Emerald Isle, Indian Beach/Salter Path, and Pine Knoll Shores. The remaining nourishment came from the federal Section 933 navigation maintenance disposal; it was placed entirely within Pine Knoll Shores.

With the addition of the nourishment sand and the relatively mild storm season, Bogue Banks increased its volume above the June 1999 condition to ~7.37 million cubic yards (57.4 cy/ft) when measured to the outer bar. The average shoreline width increased by 9 ft over the 2006 width to 78 ft. The beach width increases were greatest in Pine Knoll Shores where the maximum increase was 106 ft more than the previous year. Nourishment obviously is instrumental in expanding shoreline width. The average increase in width over 2006 within just the nourishment reaches was 27 ft. The average change in beach width along Indian Beach was a decrease of 1 ft. The IB/SP results are skewed by volume losses at either end of the project to low-tide wading depth.

CSE used two reference volumes to consider the amount of nourishment remaining. The first compares the postnourishment beach only against the “base” nourishment in Phase 1, Phase 2, and Phase 3 (1,733,580 cy; 1,847,762 cy; and 690,868 cy – respectively). The other includes the fill from Section 933 projects (699,282 cy to IB/SP PKS-West, 682,561 cy to PKS-East and PKS-West), post-*Isabel* and post-*Ophelia* nourishment (156,000 cy and 1,229,836 cy – respectively), and federal disposal projects along AB and FMSP (~3,434,000 cy). As the table in Appendix III-D shows, the percentage of base fill

remaining (compared with postnourishment) within the “county project” area to –11 ft NGVD is:

Phase 1 (PKS and IB/SP)	148.7 percent
Phase 2 (EI- East and EI-Central)	76.9 percent
Phase 3 (EI-West)	77.8 percent

There are large differences between certain reaches. For example, IB/SP retains ~189 percent of its sand, while EI-Central retains 75 percent of its base nourishment largely because of nourishment volume differences from Section 933 projects.

The second method compares the net volume change between June 1999 and May 2007 with the **total** nourishment placed. This latter method incorporates the impacts of all fills within a reach and the impact of changes between June 1999 and the first nourishment. The island-wide change is 7,369,677 cy through May 2007, which is ~72 percent of all nourishment placed. The percentage of fill remaining (to –11 ft NGVD) by reach (based on Table 4) is as follows (1999 to 2007 comparison):

FMSP	40.3 percent
AB	40.9 percent
PKS	81.1 percent
IB/SP	85.0 percent
EI-East and EI-Central	73.6 percent
EI-West	126.7 percent

The 1999 to 2007 result for EI-West (136.7 percent) appears to be anomalous compared with the FEMA beach maintenance calculations (77.8 percent). This reflects the different time periods used in the methods. The “FEMA’ method compares the May 2007 dunes with the prenourishment survey of June 2002, and the second method takes the comparison back to June 1999. The latter comparison shows that EI-West is much healthier with a net gain of ~1.3 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 2007 survey 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 volume changes 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 storms to quantify the 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 USACE for planning purposes in association with federal beach erosion and hurricane protection projects.

As with the 2007 survey, CSE strives to maintain uniformity and consistency with the analyses from year to year. This, CSE believes, makes it simpler for the lay interpreter to analyze changes and place them in context from year to year. At the same time, the large data set that CSE has developed provides additional opportunities for new statistical analyses that may better explain the observations (eg, profile shape analysis, erosional "hot spots"). 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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Eddie Dawkins	Atlantic Beach
Joan Lamson	Pine Knoll Shores
Ted Lindblad	Pine Knoll Shores
Tom Hoover	Emerald Isle
William "Buck" Fugate (chair)	Emerald Isle
Stewart Pickett	Indian Beach
James N. Willis, III	Bogue Banks
Jim Stephenson	County At-Large
Pete Allen	Board of Commissioners
Jack Goldstein	TDA

and previous commissioners:

Jerry Huml	Emerald Isle
Pat McElraft	Board of Commissioners

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