Monitoring and Analyses of the 2011 Nags Head Beach Nourishment Project

2015
BEACH MONITORING REPORT

Prepared for:

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[CSE2387–YR4]
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COVER PHOTOS: Nags Head beach condition on 28 June 2015. **[LEFT]** South Nags Head, looking northeast in the vicinity of Outer Bank's Pier. **[RIGHT]** Reach 2 around Jennette's Pier, looking southwest.

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EXECUTIVE SUMMARY

Overall Performance and Nourishment Sand Remaining

This report contains results of Year 4 monitoring of Nags Head beach following the 2011 nourishment project. As of June 2015, the 10-mile project area retains 3.92 million cubic yards (cy)* of ~4.6 million cubic yards (~85 percent) placed by dredge between 24 May and 27 October 2011. Sand losses have averaged 192,000 cubic yards per year (cy/yr) or ~3.6 cubic yards per foot per year (cy/ft/yr) of beachfront. These "4-year" averages are lower than the design values of 275,000 cy/yr and 5.2 cy/ft/yr, which confirm that the project is performing better overall than predicted. During the past year (June 2014 to June 2015), Nags Head lost ~476,000 cy*, a quantity nearly twice the average predicted loss.

Four reaches are referenced each year in these monitoring reports. Every reach lost sand this year with the south half of Reach 3 and Reach 4 (comprising ~1.2 miles at the south end of the project) sustaining the greatest losses (~280,000 cy or >25 cy/ft). This area includes properties around Seagull Drive and McCall Court. The relatively high occurrence of waves originating from the northeast likely produced a higher southerly transport this year than a normal year. The results are given in Figure A and are summarized as follows.

Reach 1 – The northern ~5.8 miles of beach from Mile Posts 11 to 16.8. It lost ~118,000 cy over the past year, but has gained ~90,000 cy since project completion.* This amount of gain is equivalent to 5 percent of the nourishment volume in that area, over and above the volume placed during the project.

Reach 2 – The center to south ~2.4 miles of beach from Mile Posts 16.8 to 19.2. It similarly lost ~78,000 cy over the past year. Compared to the condition after project completion, it remains stable with only a 2 percent loss of nourishment volume.* The results are given in Figure A.

Reach 3 – South ~1.6 miles of beach from Mile Posts 19.2 to 20.8. It lost ~226,500 cy over the past year. Compared to the condition after project completion, it has lost 38 percent of the nourishment volume.*

Reach 4 – Southernmost ~0.2 mile of beach from Mile Posts 20.8 to 21. It lost ~53,000 cy over the past year. Compared to the condition after project completion, it has lost 65 percent of the nourishment volume.*

[**Measured from the foredune to the FEMA reference depth of −19 ft NAVD, which is seaward of the outer bar.*]

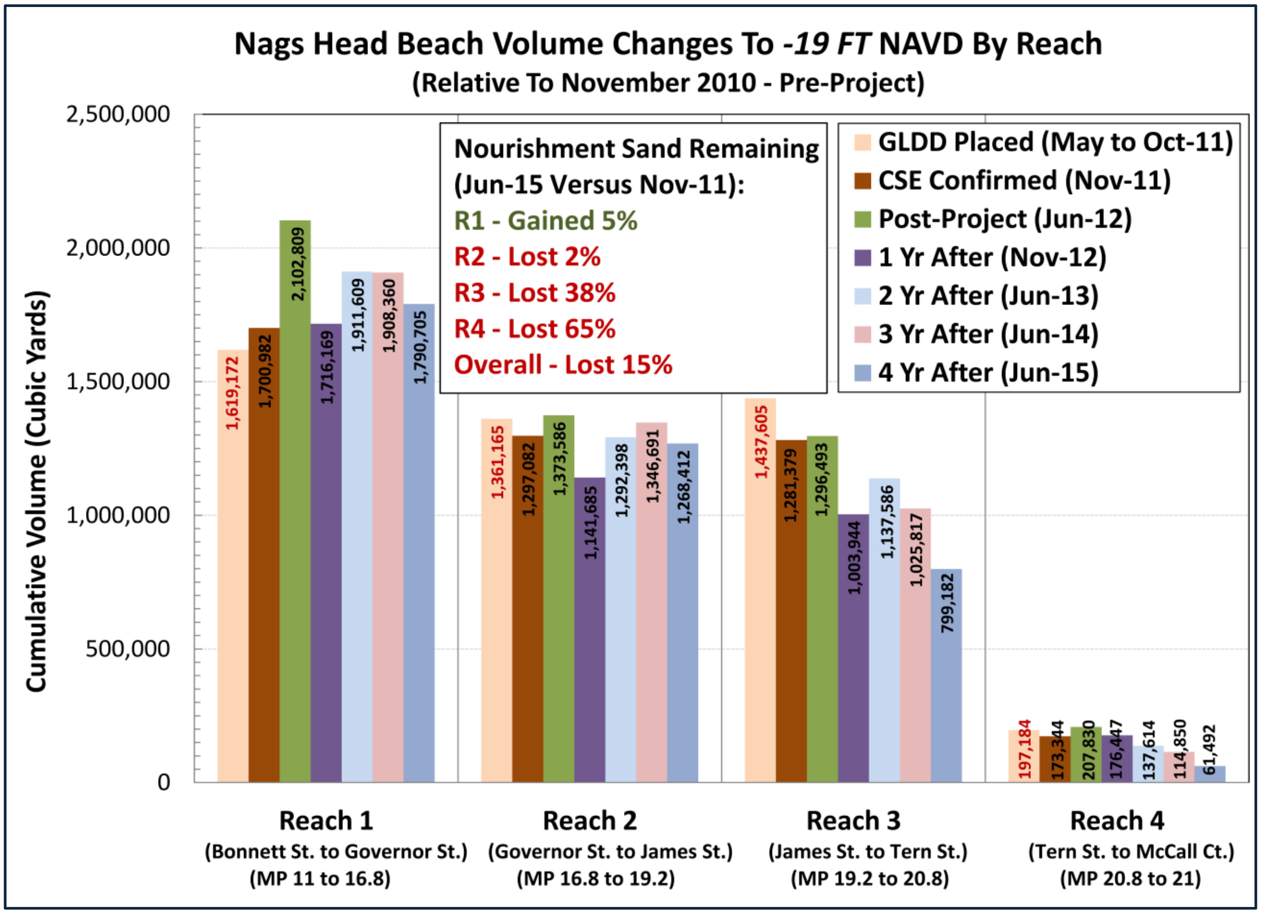

FIGURE A. Beach volume changes by reach relative to November 2010 survey results from the face of dune to −19 ft NAVD.

The overall volumes of sand remaining in the foredune and upper beach, the recreational beach zone to low tide wading depth, as well as the inshore and offshore zone to the FEMA depth limit were also computed from the condition surveys. Figure B shows overall results compared with the reference nourishment quantity. The foredune section of the beach remained stable, retaining nearly 1 million cubic yards more than the pre-nourishment condition. The recreational part of the beach from the foredune to the low tide wading depth retained ~2.6 million cubic yards in June 2015 compared to ~3 million cubic yards in June 2012. The details of the results are given in Section 5.0, and comparisons to additional depth contours are given in the appendices.

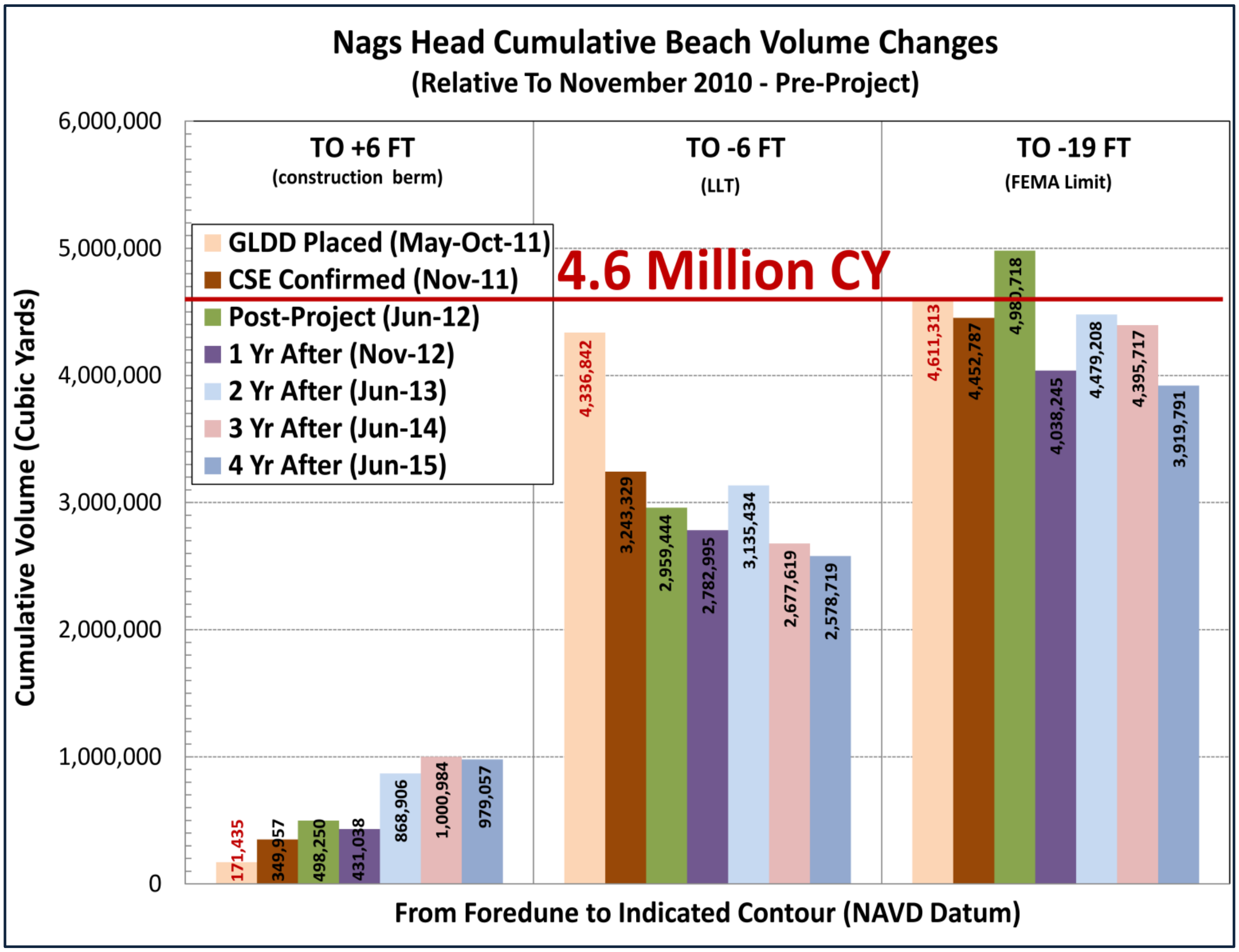

FIGURE B. Cumulative, overall beach-volume changes relative to November 2010 survey results between the foredune and indicated contours.

Project Performance Along Nags Head

Annual monitoring surveys have also documented great variations from station to station every 500 feet along the coast. These variations reflect the dynamic nature of beaches and the underwater profile to the outer bar. Figure C shows such irregularity station by station comparing November 2010 (pre-nourishment) and June 2015 (3.6 years post-nourishment). The dashed trend lines show the relative increase in volume from north to south. However, there are several specific stations where the lines cross meaning those particular localities in June 2015 had no more sand than they had in 2010. The report identifies specific "erosion hot spot" areas and presents data showing these areas tend to move alongshore from year to year, which accounts for some of the natural waviness of the shoreline, looking down the beach.

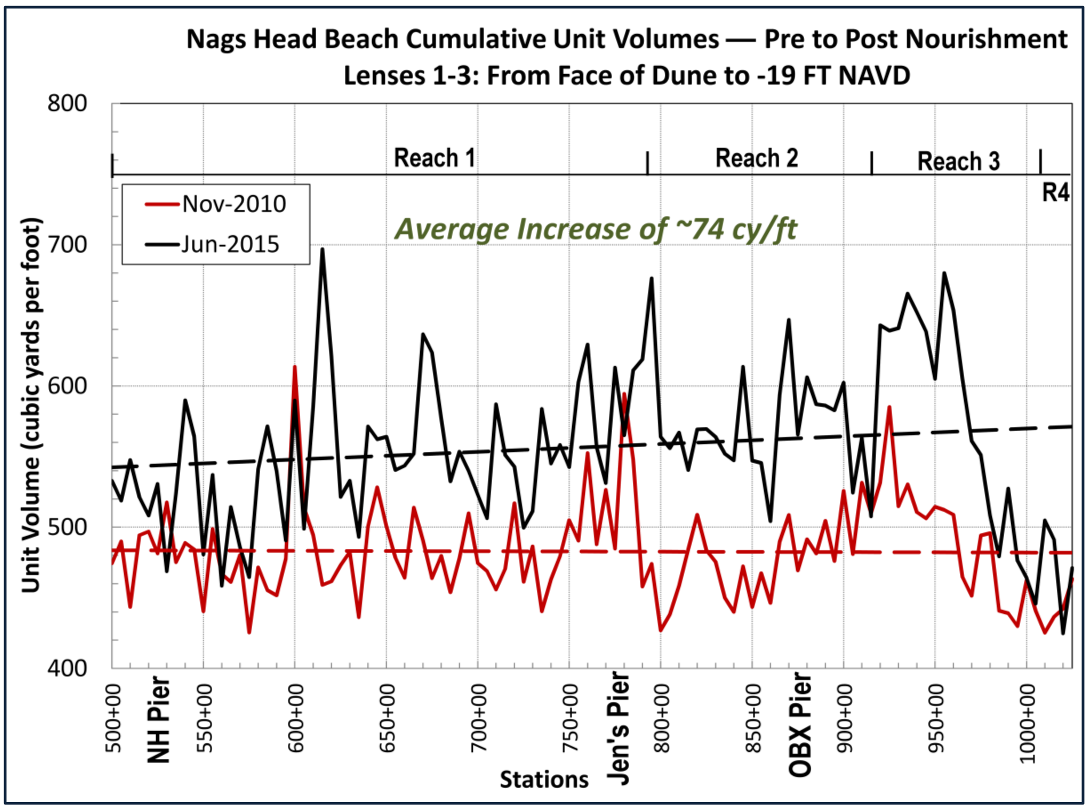

FIGURE C. Comparison of <u>cumulative</u> unit volumes by station between the face of dune and −19 ft NAVD.

Dune Behavior Along Nags Head

The report also details the added dune protection gained by winds and sand fencing as a result of nourishment. Figure D shows much more sand in the foredune at nearly all stations. This is the portion of the profile that prevents wave runup and overtopping of dunes during major storm events.

CSE computed average dry-beach width in June 2015 using the present survey results. Figure E shows beach widths (by 1-mile average) as measured between the toe of dune (+10 ft NAVD) and the approximate edge of dry sand (+5 ft NAVD) for November 2010 (pre-nourishment), June 2014 and June 2015. This unvegetated berm width is a measure of the effective dune building fetch for each mile of shoreline. It also provides an indicator of how much area exists over which dunes could form.

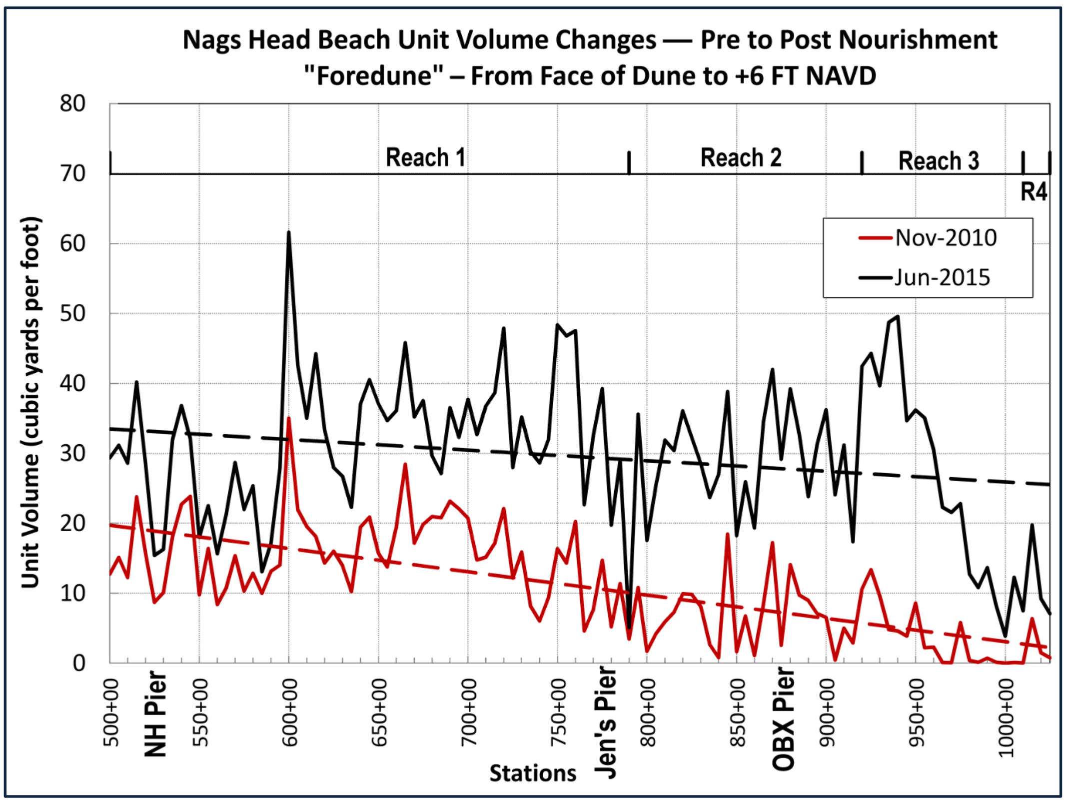

FIGURE D. Comparison of unit volumes along Nags Head from the toe of dune to +6 ft NAVD contour before nourishment (November 2010) and the most recent survey condition (June 2015). It shows significant increase of unit volumes after the project at most stations. Unit volumes in previous surveys (November 2011, June 2012, November 2012, June 2013, and June 2014) are plotted in earlier reports by CSE (2013a,b,c).

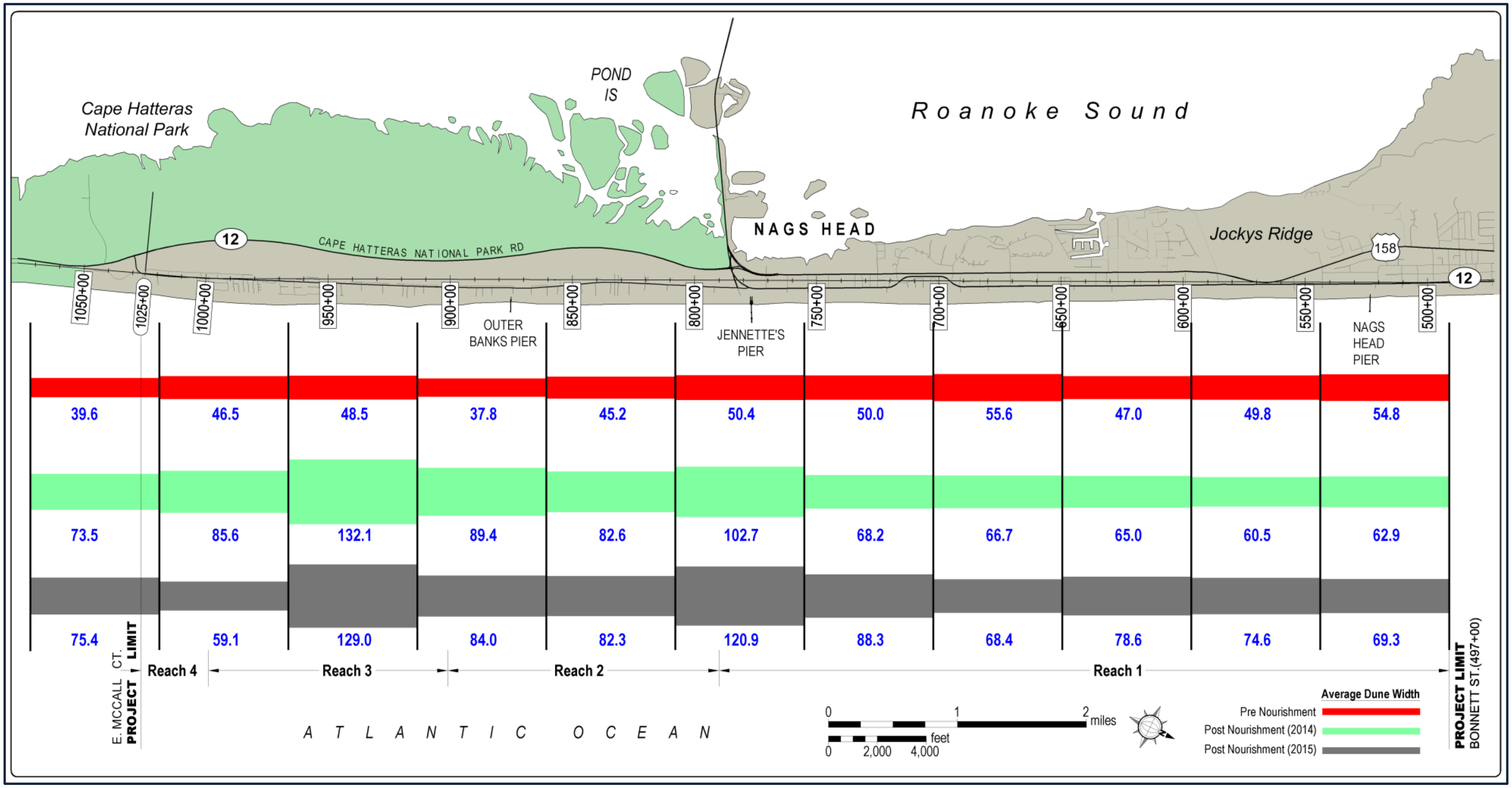

FIGURE E Average beach widths (ft) before and after nourishment between the toe of dune (+10 ft NAVD) and the approximate seaward edge of the dry beach (+5 ft NAVD) by mile along Nags Head. The overall average dry-beach width was ~47.7 ft in November 2010 before nourishment and has increased to ~72.4 ft in June 2014 after nourishment and profile adjustment. It continued to increase to ~84.5 ft in June 2015.

Figure E shows that the beach berm is wider in June 2015 than last year along the northern half of Nags Head (ie – Reach 1). The southern 1-mile of Nags Head (ie – Reach 4 and about one-third of Reach 3) lost 26.5 ft of dry beach over the past year. Reach 2 and the other two-thirds of Reach 3 were relatively stable with slightly decreased berm width. The average berm width at Nags Head was ~48 ft in November 2010 and has increased ~37 ft to 85 ft in June 2015.

Possible Erosion Hot Spots

The south end of the project is losing sand at the fastest rate. The highly eroded area is between stations 975+00 and 1025+00 as marked in Figure F. This is occurring for two reasons:

1) Natural erosion rates exceed 10 feet per year along the adjacent Cape Hatteras National Seashore, so its high erosion draws off sand from Nags Head.
2) The nourishment project had to end in a long taper around McCall Street.

The bulge in the shoreline produced by nourishment became a focal point for erosion. Such "end losses" are unavoidable in this project. To better track erosion hot spots and document the condition of the entire profile, the Town should consider performing a fall survey along this portion of the project.

For properties at the south end of the project near McCall Court and Seagull Street, the only practical, short-term measures to to maintain protection of some properties are sand scraping or hauling in more sand from inland. As the graphs in Figures C and E indicate, the northern half of Reach 3 retains a large volume of sand which is expected to feed the end of the project over the next two years. Much of Reach 3 contains upward of 150 cy/ft more sand than the pre-nourishment condition.

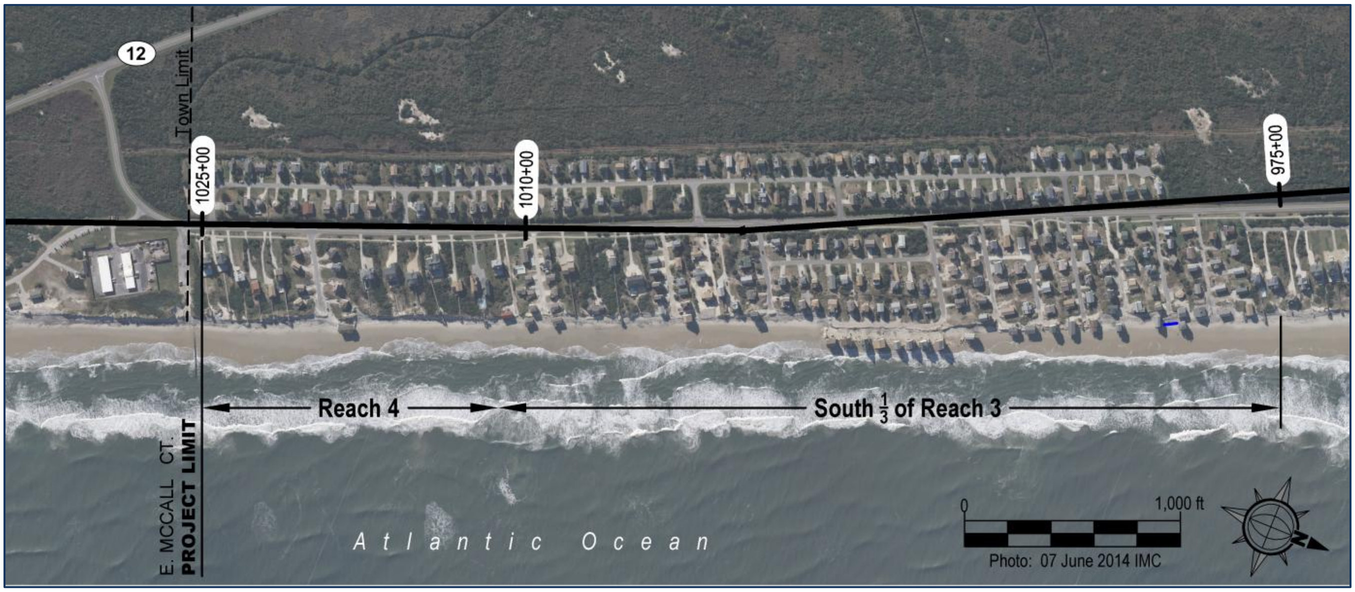

FIGURE F. Higher erosion area along south Nags Head between station 975+00 in Reach 3 and station 1025+00 in Reach 4. The background aerial photo was taken on 7 June 2014 by IMC. The portion of Reach 3 to the north (out of the image) retained a large reservoir of nourishment sand which will continue to mitigate erosion at the south end of the project.

Upcoast and Downcoast

Despite higher-than-average sand losses this past year, the upcoast mile of beach has over 100,000 cy more sand than pre-project conditions from the foredune to the FEMA depth limit (−19 ft NAVD), and the ~1-mile-long downcoast has over 125,500 cy more sand than pre-project conditions (Figs G and H). As Figure G illustrates, most of the erosion losses since June 2013 have occurred underwater, leaving added volume above +6 ft and providing more beach width for users and wildlife. The relatively low volume accumulated downcoast (Fig H) suggests only a small portion of the Nags Head project has been lost to the national seashore during the past four years.

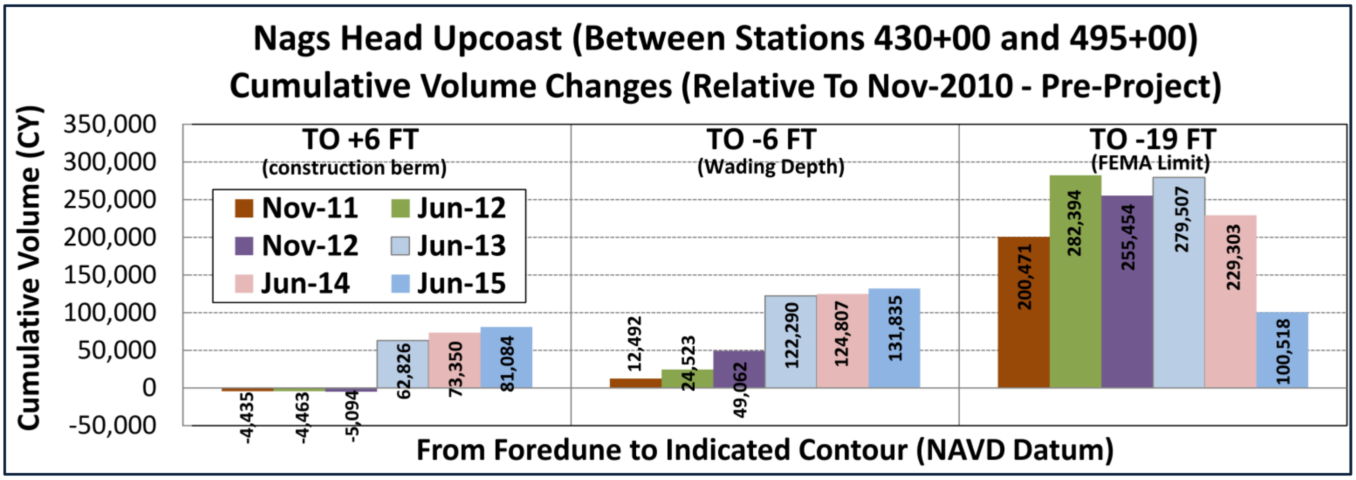

FIGURE G. Cumulative volume changes from the foredune to the indicated contour relative to the November 2010 condition along **upcoast** stations outside the project area.

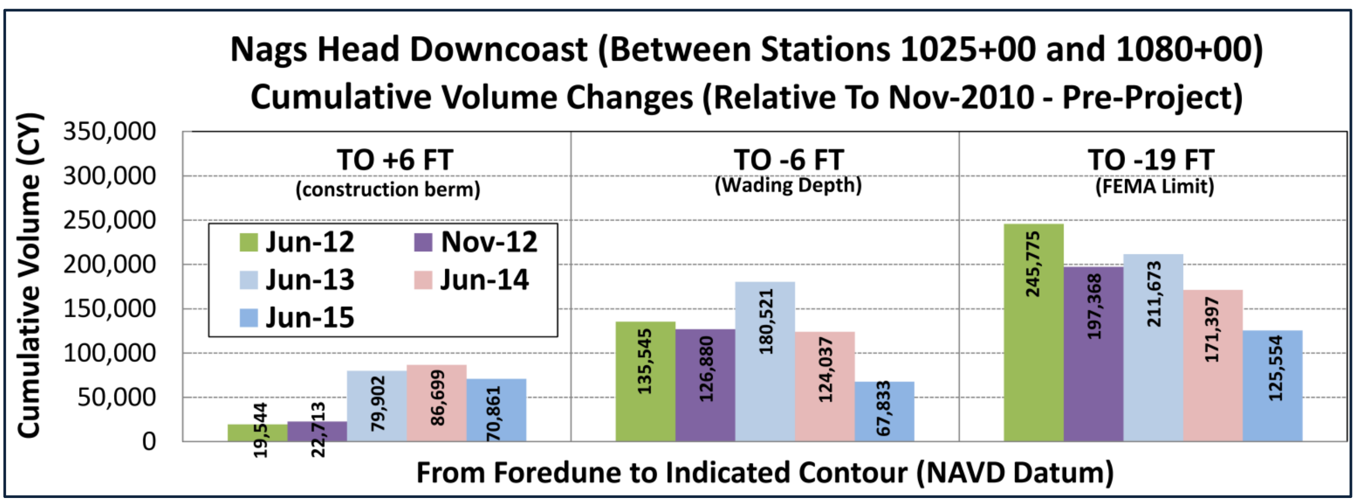

FIGURE H. Cumulative volume changes from the foredune to the indicated contour relative to the November 2010 condition along **downcoast** stations outside the project area.

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ACKNOWLEDGMENTS

The Year 4 monitoring was funded by the Town of Nags Head under its budget for beach nourishment and monitoring. CSE thanks the Nags Head Board of Commissioners and the Town staff (Cliff Ogburn, Town Manager, and David Ryan, Town Engineer and Project Coordinator) for their continued support. CSE thanks the Public Information Officer (Roberta Thuman), the Nags Head Public Works Department (Ralph Barile) and the Nags Head Police Department (Kevin Brinkley) for their assistance during our surveys.

Field data collection and analysis were directed by Dr. Haiqing Liu Kaczkowski (PE, NC 37281 — project engineer) with assistance by Drew Giles, Steven Traynum, Trey Hair, and Luke Fleniken. The report was written by Dr. Kaczkowski and Dr. Tim Kana (PG, NC 1752) with assistance by Steven Traynum, Trey Hair, Diana Sangster, and Julie Lumpkin. Photos were taken by Kaczkowski, unless otherwise specified in the report.

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1.0 INTRODUCTION

This is the fourth annual report on the beach condition along Nags Head following successful completion of the 2011 beach nourishment project at Nags Head, Dare County, North Carolina. The 2011 project was conducted between 24 May and 27 October 2011 during which time 4.6 million cubic yards (cy) of sand were placed along a 10-mile stretch of beach. Following project completion, a comprehensive beach condition survey was conducted in November 2011 right after the project completion; two semi-annual surveys were completed in June and November 2012 (Year 1); an annual survey was conducted in June 2013 (Year 2), June 2014 (Year 3), and June 2015 (Year 4) (respectively). Post-project conditions and a summary of project implementation are given in CSE (2012), and the results of Year 1, 2, and 3 surveys documenting project performance are given in CSE (2013a,b; 2014b).

The present report covers the monitoring period from June 2014 to June 2015, representing the fourth year after project completion. During this monitoring period, an annual beach condition survey was performed in June prior to hurricane season. The report provides a summary of the surveys and the physical condition of the beach in Year 4 after nourishment, and quantifies sand volume changes relative to pre-project conditions (November 2010). The survey results are used to evaluate the project performance, document volume changes within various calculation limits, and identify erosion hot spots.

In the previous monitoring period in June 2014, additional beach profiles were collected in the vicinity of 11 project stations where sand encroachment problems were considered representative. Per the Town's request, CSE re-surveyed these same extra profiles plus additional lines around station 1010+00 near the south end of Nags Head beach. Volume changes at these locations were analyzed, and recommendations for a dune management plan were given.

The outline of the report is as follows:

- Brief review of the 2011 beach nourishment project.
- Brief review of the previous post-project monitoring efforts for Year 1 (2012), Year 2 (2013), and Year 3 (2014).
- Beach monitoring requirement and scope of survey work.
- Data collection methodology and survey control information.
- Beach and inshore surveys and profile comparisons.
- Profile volume analyses for representative contour intervals.

- Net volume changes by profile and reach.
- Calculation of nourishment volumes remaining in the project area.
- Dune volume changes and management plan.
- Upcoast and downcoast volume changes.
- Representative aerial photos and ground photos.
- Monitoring and maintenance recommendations.

Certain information about the project and previous survey efforts are repeated in each monitoring report to aid the reader. The project planning, design, implementation and initial performance are detailed in CSE's reports (2007a, 2008, 2011a, 2011b, 2012). A summary of these project aspects is presented in two papers in the proceedings of the International Conference of Coastal Engineering (Kana & Kaczkowski 2012; Kaczkowski & Kana 2012). In addition, details of the project performance and volume changes during Hurricane *Irene* are described in a paper published in a dedicated issue of *Shore & Beach* (Kana et al 2012).

1.1 Project Background, Design and Implementation

The Town of Nags Head encompasses ~11 miles of ocean shoreline along North Carolina's Outer Banks, a chain of barrier islands along the Atlantic Ocean, 90 miles south of Norfolk (VA). Figure 1.1 shows the project location. The Town faces east to northeast and is bordered by the Town of Kill Devil Hills to the north and Cape Hatteras National Seashore to the south. Roanoke Sound borders the Town on the west, and the Atlantic Ocean makes up the Town's eastern limits. The northern boundary of the Town is situated about 15 miles from the USACE Field Research Facility (FRF) Pier at Duck (NC) and about 40 miles from the Virginia border. Oregon Inlet, the closest inlet to Nags Head, is located about 5 miles south of the Town line.

Nags Head is exposed to high-wave energy during storm events, particularly hurricanes in summer and northeasters which are common in fall and winter. The Town has sustained chronic erosion over the past 50 years due to storms and sand losses to Oregon Inlet. Net sand transport is south along Nags Head, and erosion rates increase from north to south and remain high in the ~5-mile-long National Seashore reach between Nags Head and Oregon Inlet. The purpose of the 2011 beach nourishment project was to restore a protective beach for a minimum of ten years, replace sand lost during the period of delay in the startup of the federal Dare County beach erosion control project, and expand the recreational beach for the benefit of the community.

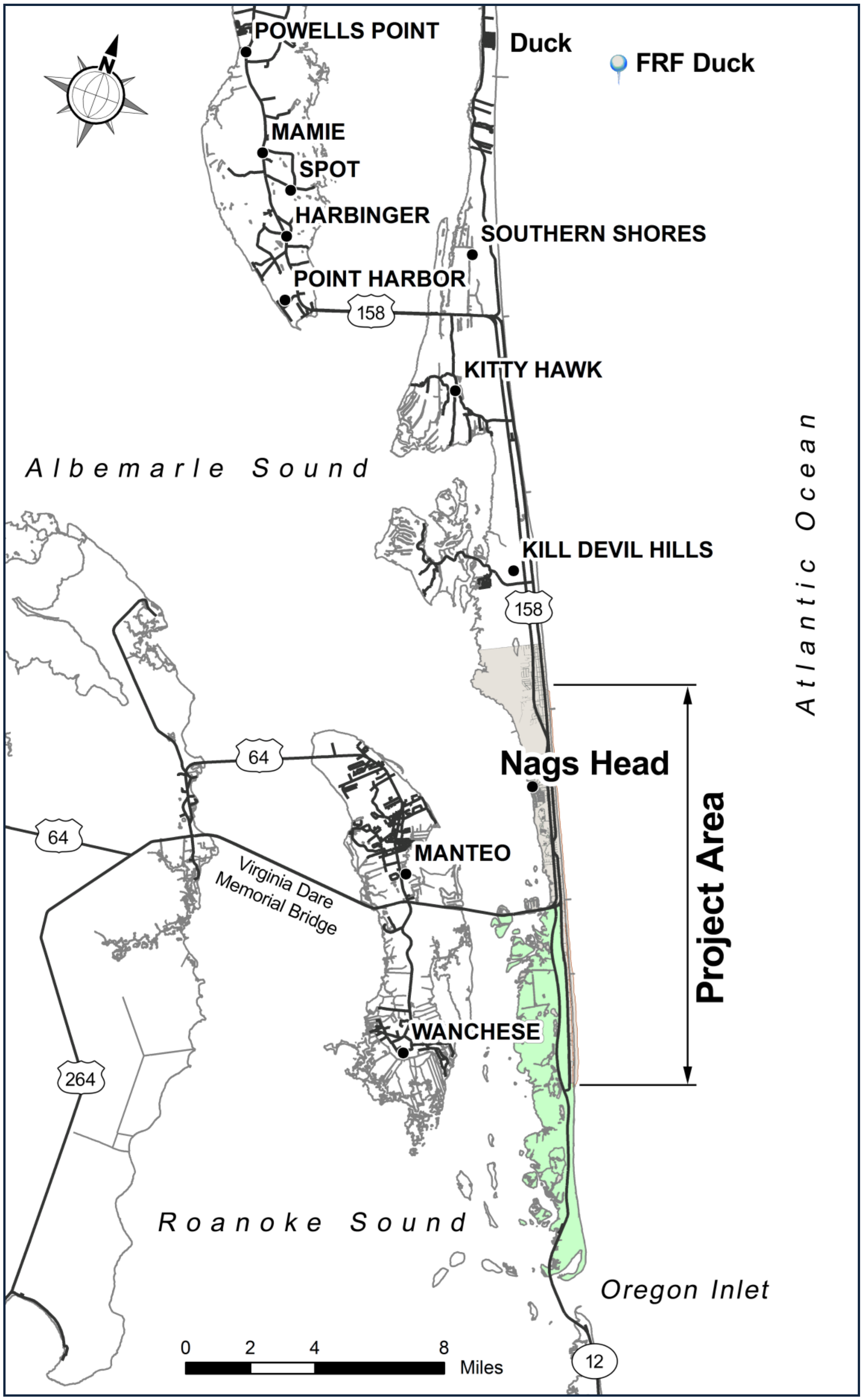

FIGURE 1.1. Nags Head (NC) project vicinity map.

The 2011 project totals ~10.0 miles of shoreline beginning ~1 mile from the Town's northern limit near the Bonnett Street public beach access (milepost 11.25, CSE station 497+00) and extending south to the town line (milepost 21, CSE station 1025+00*****) adjacent to the Cape Hatteras National Seashore. CSE reoccupied USACE 1994 survey lines and collected extensive profiles from the dunes to deep water as many as six times over the 5-year planning period between 2005 and 2010. *[Estimated profile closure depth is −24 ft NAVD** for this setting (CSE 2007a).]*

**Stationing for profiles approximately matches USACE stationing established for the planned federal project. The specific coordinates for control points vary by a small amount from the USACE baseline (see Appendix 2 for baseline and control information.)*

***NAVD — North American Vertical Datum of 1988 which is 0.42 ft above local mean sea level (MSL). NGVD — National Geodetic Vertical Datum of 1929 which is 0.96 ft below NAVD datum of 1988 at FRF Duck (NC). Relationship of various water levels and survey datum at Duck is shown in Figure 1.2. [Source: NGS–NOAA]*

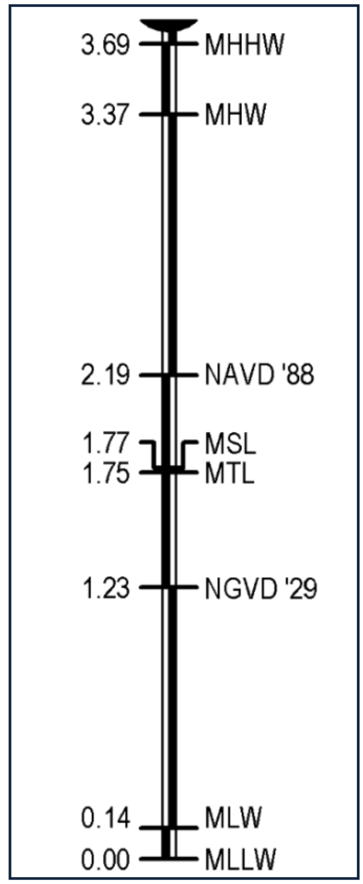

FIGURE 1.2. Relationship of various water levels and survey datum at Duck (NC). [Source: NGS–NOAA]

An average annual erosion rate of 275,000 cubic yards (cy) was determined after comparing field surveys and was adopted in the planning and design. Longshore and cross-shore numerical models were applied to refine the nourishment plan and increase potential longevity of the project. Model results were used to identify the potential occurrence of erosional hot spots and to optimize the nourishment design so that the effects of such hot spots could be avoided or minimized where possible. Four reaches were delineated based on the historical erosion rates. The fill density was 87 cubic yards per foot (cy/ft) on average and ranged 50–170 cy/ft from north to south in relation to historical erosion rates.

The overall project limits and project reaches are shown in Figure 1.3 along with the borrow areas approved for use within USACE-designated borrow area S1. Subareas 2 and 3 contained over 7 million cubic yards of beach-quality sand (7-ft excavation) and were used in the 2011 project (CSE 2011).

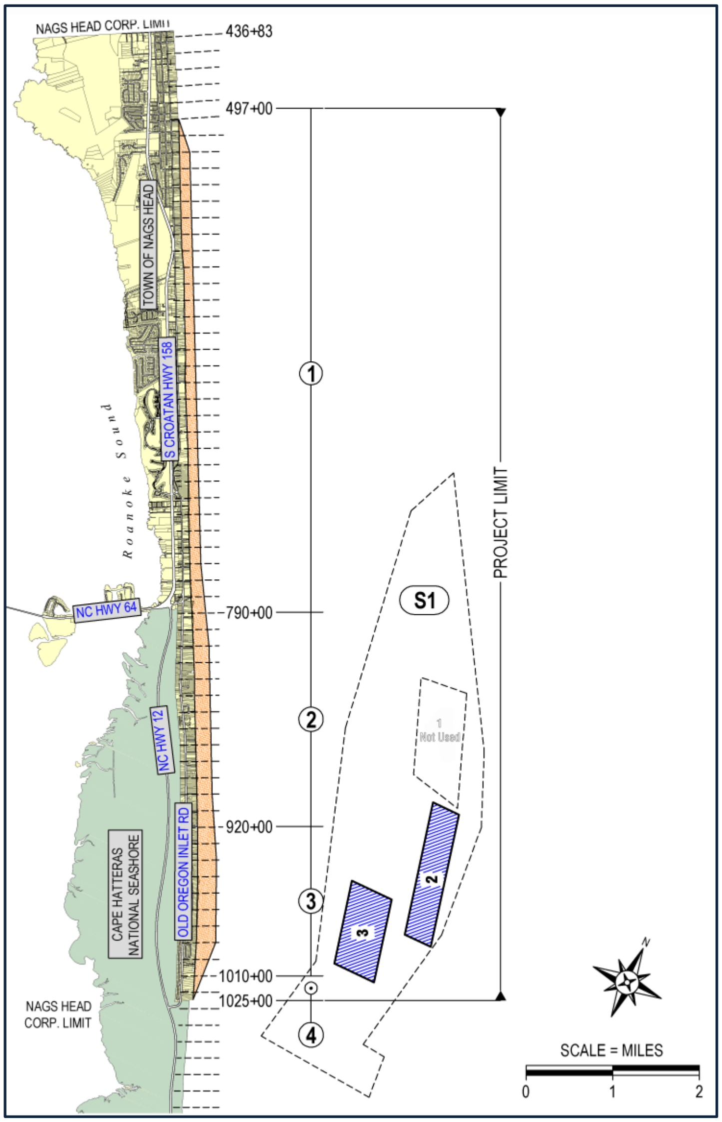

FIGURE 1.3.

Nags Head (NC) project reaches along with fish-shaped USACE-designated borrow area.

The town limits are around stations 436+83 and 1025+00; the project limits are between stations 497+00 and 1025+00. Subareas 2 and 3 were used in the 2011 project.

During the design and planning phases of the nourishment project, CSE collected and analyzed over 200 sediment samples of the native beach. The results show that the beach is composed of medium sand with a mean grain size of ~0.306 millimeters (mm), which represents an integrated result of cross-shore samples between the foredune and the ~18-ft NAVD depth contour.

CSE also obtained over 100 borings in the USACE-designated borrow area to locate the most compatible material. The borings [~8−10 feet (ft) long] are in water depths ranging from 45 ft to 60 ft. The average core density was 1 per 20 acres, which allowed CSE to prepare relatively detailed isopach maps of sediment quality for final delineation of borrow areas. The designated borrow areas met the updated North Carolina Coastal Resources Commission (NCCRC) sediment criteria and were selected to produce a stable project that would be economical and as environmentally compatible as possible.

The 2011 project was sponsored by the Town of Nags Head (Dare County, North Carolina), and the Town served as project owner and administrator. The favorable bid received from Great Lakes Dredge & Dock Company, Inc (GLDD, Oak Brook, Illinois) allowed the Town to accomplish the maximum permit volume of 4,600,000 cy, and the single contract between GLDD and the Town for this project totaled $30,184,000. Coastal Science & Engineering (CSE, Columbia, South Carolina) served as the project engineer—planning and designing the project, preparing the approved environmental impact statement along with state and federal permit applications, collecting and analyzing field data, applying numerical models, and performing construction administration and observations (detailed in CSE's reports 2011a, 2011b, and 2012).

The contractor (GLDD) used three, ocean-certified hopper dredges (*Liberty Island, Dodge Island,* and *Padre Island*) and one cutterhead suction dredge (*Texas*) to construct the project between 24 May and 27 October 2011. Three months into construction, GLDD had placed ~3.8 million cubic yards on the beach, representing almost 85 percent of the contracted volume. Reaches 2 and 3 were complete by late August, leaving about half of Reach 1 and Reach 4 (the taper section at the downcoast end) incomplete when Hurricane *Irene* impacted the project area on 27 August 2011.

The newly placed sand served to absorb storm-wave energy, reduced the height of wave runup at the dune line, and prevented damage to the foredune, buildings, and roads during *Irene*. While the construction berm was overtopped by waves, no ocean overwash penetrated the dunes or left dune escarpments along the nourished sections. Several condemned properties on the active beach at Seagull Drive, which received nourishment about two weeks before the storm, made it through the storm without further damage. With numerous weather delays in September and October that were associated with passage offshore of Hurricanes *Katia* (8 September) and *Maria* (16 September), and at least five extratropical cyclones, the remaining work on the project was accomplished by 27 October 2011.

The contractor's construction surveys for purposes of payment showed a total of 4,615,126 cy were placed along 10.0 miles of project area between 24 May and 27 October 2011. CSE completed a detailed survey of the beach and inshore zone in November 2011 within one month of project completion and compared the post-project conditions against the pre-project November 2010 condition (same-season comparison). CSE confirmed that there were 4,713,927 cy (±3 percent) more sand volume in the ten-mile project area after nourishment. Details of the volume comparisons by reach are listed in Table 1.1.

In summary, the 2011 Nags Head beach nourishment project was completed under budget, on time, and without any environmental incidents. CSE's November 2011 survey after hurricanes and fall storms showed two positive outcomes: (1) no loss of sand by natural processes between November 2010 and November 2011 within the project limits, and (2) a gain of at least 4.6 million cubic yards via the 2011 nourishment. Beach profiles were adjusting to a shape and configuration which was indistinguishable from a natural beach.

TABLE 1.1. Summary of fill volume versus design volume for each reach based on before-dredging and after-dredging surveys by GLDD and November 2010 (pre-project) and November 2011 (post-construction) surveys by CSE. Volume calculations for the November 2011 survey extended to the −12 ft depth contour ~800 ft from the foredune.

Reach	Limits	Length (ft)	CSE Design Volume (cy)	GLDD Applied Fill Volume (cy)	Diff between Design and Fill (%)	CSE Verified Volume (cy)
1	497+00 to 790+00	29,900	1,634,700	1,645,812	0.68%	1,819,532
2	790+00 to 920+00	13,000	1,366,500	1,405,498	2.85%	1,358,359
3	920+00 to 1010+00	9,000	1,480,000	1,423,771	-3.80%	1,377,313
4	1010+00 to 1025+00	1,500	118,800	140,045	17.88%	158,723
Total	**497+00 to 1025+00**	**52,800**	**4,600,000**	**4,615,126**	**0.33%**	**4,713,927**

1.2 Summary of Year 1 (2012), Year 2 (2013) and Year 3 (2014) Beach Monitoring

Beach monitoring and maintenance are required by the state and federal permits for the project and are also a prerequisite for FEMA's post-storm beach restoration funding. As part of the Years 1-3 monitoring efforts, CSE conducted compaction tests in March 2012, March 2013, and March 2014. Comprehensive survey data of the beach and inshore zone were collected in June and November 2012, as well as in June 2013 and June 2014. Sediment compaction was found to be comparable to the natural beach. As a result, NCDENR and USACE officials did not request special beach tilling ahead of the 2012, 2013, or 2014 sea turtle nesting season.

Figure 1.4 shows the accumulated total volume changes relative to pre-project condition (November 2010) between the foredune and the indicated depth contour. GLDD's survey during construction (light brown bars) confirmed that ~94 percent of the nourishment sand (~4.3 million cubic yards) was placed above low-tide wading depth (−6 ft NAVD) (fourth set of bars from left) and only ~6 percent settled in deeper water. After initial profile adjustment and the effects of Hurricane *Irene* (landfall on 27 August 2011) along with the fall storms, CSE's post-construction survey in November 2011 (dark brown bars) confirmed that ~70 percent of the nourishment sand (~3.2 million cubic yards) remained above low-tide wading depth. The remainder was found between the 6-ft and 12-ft depth contours, which are about 400–800 ft from the foredune. CSE's measurements in November 2011 detected over 4.7 million cubic yards **more** sand along Nags Head beach (calculated to −12 ft contour shown in the fifth set of bars) compared with conditions in November 2010.

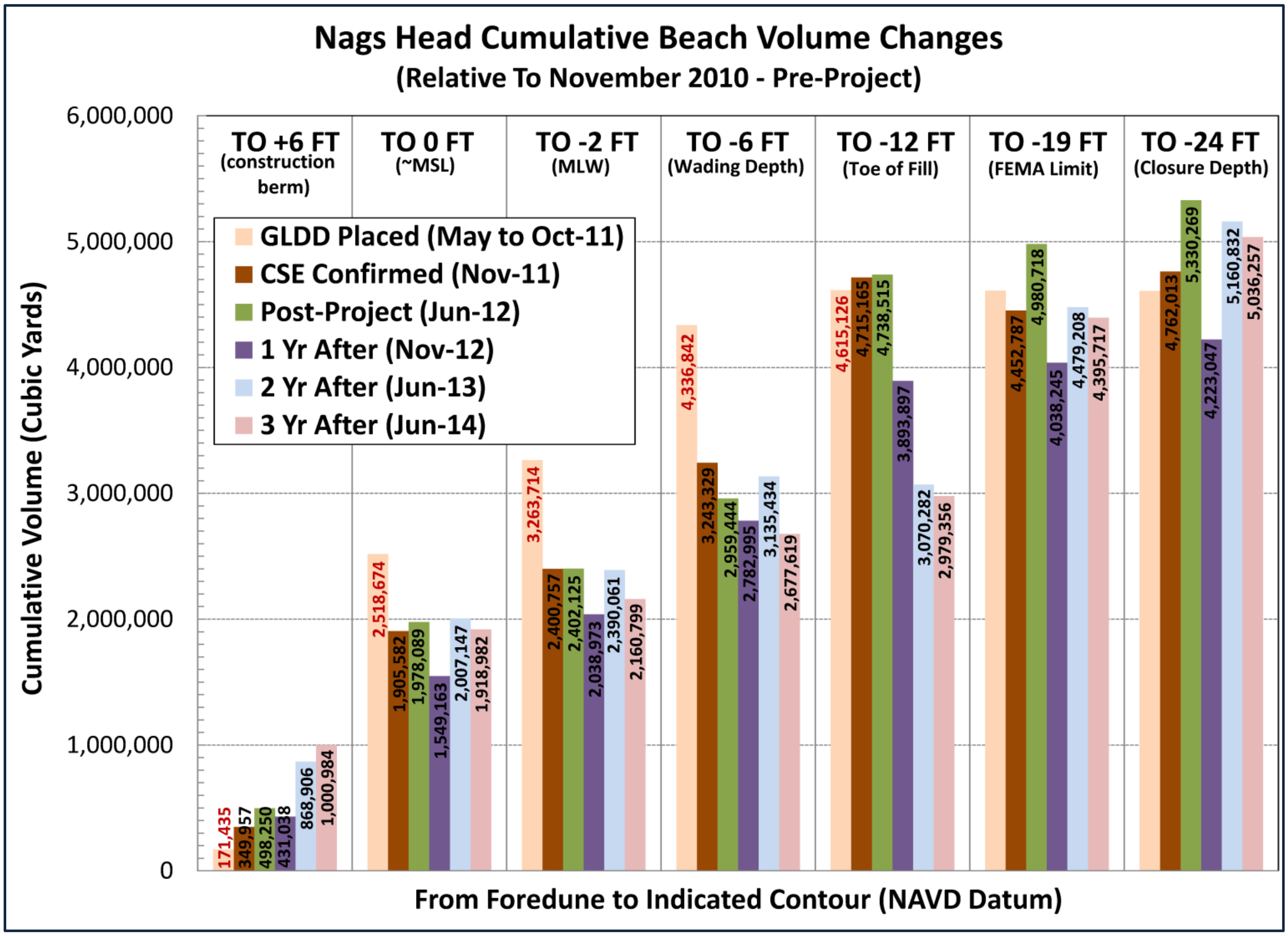

FIGURE 1.4. Accumulated volume changes relative to November 2010 (pre-project condition) between the foredune and the indicated contour (from CSE 2014).

The June 2012 survey (green bars in Fig 1.4) confirmed there was negligible change in sand volume from November 2011 to June 2012 measured between the foredune and −12-ft NAVD depth contour. A total of 4,738,515 cy were detected within these project boundaries in June 2012. These volumes are relative to the November 2010 pre-project condition and, therefore, reflect the impact of nourishment. The June 2012 survey also detected an additional 242,203 cy gained between the −12-ft and −19-ft contour, and 591,754 cy gained between the −12-ft and −24-ft contour. In short, by June 2012, significantly more sand was gained in the project area measured into deep water than was placed in the nourishment project.

Following the June 2012 survey, a series of northeasters and Hurricane *Sandy* (28 October 2012) impacted the project area. CSE's second survey of 2012 was accomplished within approximately two weeks after *Sandy* (CSE 2014b). The timing of this planned survey was fortuitous after the storm. Results (purple bars in Fig 1.4) confirm that the project area lost upward of 844,618 cy (measured to −12 ft) between June 2012 and November 2012. Losses to the −19 ft contour (FEMA – reference contour) totaled nearly 942,473 cy relative to the June 2012 condition, and 414,542 cy relative to the November 2011 post-nourishment condition.

The June 2013 survey (light blue bars in Fig 1.4) showed accretion in every lens except for the lens between −6 and −12 ft compared to June 2012. It confirmed that ~3.14 million cubic yards of sand (ie – 68 percent of the project volume) remained between the foredune and the low-tide wading depth (-6 ft), and ~4.48 million cubic yards of sand (ie – 97 percent of the project volume) remained within the FEMA–reference limit (−19 ft NAVD). Total volume change since completion of the project (November 2011) was negligible with a gain of ~0.4 cy/ft if measured to the estimated depth of closure of −24 ft NAVD.

The June 2014 survey (pink bars in Fig 1.4) indicated there were ~4,396,000 cy more sand than pre-nourishment condition (November 2010). This quantity represents ~96 percent of the placed volume, suggesting that net losses were well below the projected ~6 percent per year. As much as 15 percent of the nourishment sand had shifted landward and built up the foredune and upper beach (landward of the +6-ft contour). Another major quantity has shifted into deeper water between the -12 ft and -19 ft contours.

As Figure 1.4 illustrates, the overall changes in sand volume vary with the depth contour used as a reference. The deeper contours introduce more error because the changes are applied over a much broader littoral zone. Nevertheless, results confirm that by June 2014 the majority of nourishment sand (~96 percent) remained in the project area. This implies ~200,000 cy were lost in ~2.6 years since nourishment, or an average of ~80,000 cy/yr, which is significantly lower than the average annual losses of ~275,000 cy/yr adopted in the project design. This is considered a favorable result because of the higher-than-normal incidence of storms that impacted Nags Head between 2011 and 2014, particularly *Irene* and *Sandy*.

Dune encroachment worsened along numerous properties between June 2013 and June 2014. Encroachment on structures was particularly significant where there was no established dune, sand fencing, or vegetation fronting the structure. CSE studied the dune growth mechanics and evaluated the pre-nourishment and post-nourishment dune behavior for purposes of developing rational criteria for dune management. Prior to nourishment, the dunes were losing ~1 cy/ft/yr from 1994 to 2010. Since nourishment, the dunes have gained an average of 4.7 cy/ft/yr as of June 2014, which is a much higher-than-normal accretion.

Post-nourishment growth rates at Nags Head reflected strong winds plus a much wider dry beach which is a pre-requisite for dune building.

Surveys along the upcoast and downcoast reaches extending about one mile in either direction from the project area indicate there were an additional ~230,000 cy (upcoast) and ~170,000 cy (downcoast) as of June 2014 relative to the pre-project condition. Survey results after nourishment in November 2011 to June 2014 indicated the spread of nourishment sand in either direction, although the magnitudes are relatively low compared with the overall nourishment volume. Since the Nags Head project area contained 96 percent of the nourishment sand in June 2014, the majority of the gain along the upcoast and downcoast reaches is likely associated with possible sand movement from deeper water during higher-than-normal winter waves in winter rather than redistribution of nourishment sand.

Sediment samples were collected in the second year (June 2013) after nourishment. Sediment analysis supported visual evidence and confirmed that the sand remaining on the recreational beach was similar to the pre-nourishment beach and continued to be stable. The new sand was somewhat coarser than the native pre-nourishment beach sand along south Nags Head.

Detailed aspects of survey methodology, beach volume analysis, upcoast and downcoast changes, and maintenance recommendations were included in the previous monitoring reports (CSE 2013a,b; 2014b).

2.0 BEACH MONITORING REQUIREMENTS AND SCOPE OF WORK

2.1 Beach Monitoring Requirements

Before the commencement of the 2011 nourishment project, the Town of Nags Head obtained permits under the National Environmental Policy Act (NEPA) and the state Coastal Area Management Act (CAMA) permitting process.

The North Carolina major CAMA permit (45−110) was received on 29 April 2011, and the federal permit (SAW 2006-40282) was received on 30 November 2011. The state and federal permits require a beach monitoring and maintenance plan (Appendix 1), and such a plan is also a prerequisite for FEMA's post-storm beach restoration funding. Certain thresholds are specified for renourishment, including:

- Net sand losses due to a storm (declared disaster) measured within defined project limits which, for Nags Head, span 10 miles of oceanfront between the foredune and the −19 ft NAVD offshore contour (or −18-ft NGVD, see Fig 1.2 for explanations on NAVD and NGVD datums).
- Chronic sand losses equating to more than 50 percent of the placed sand (ie – more than 2.3 million cubic yards) at 6 years. If 50 percent or more of the sand remains on the beach at 6 years post-initial project, then renourishment would commence when 50 percent or more is lost.

As per special conditions of the USACE permit, annual sediment compaction tests are required (following completion of the nourishment project) prior to the next three (3) sea-turtle nesting seasons along the Nags Head project area and adjacent unnourished reaches. Compaction measurement methods and evaluation criteria are prescribed by Item 2 in the USFWS Biological Opinion (18 August 2008, page 31-32). [Note: "The applicant" is the Town of Nags Head in the following paragraphs.]

2. *Immediately after completion of the beach construction project and prior to May 1 for three subsequent years, sand compaction must be monitored in the project area in accordance with a protocol agreed to by the USFWS, the North Carolina Wildlife Resources Commission, and the applicant. The applicant should not be allowed to routinely till all or part of the constructed beach as a substitute for systematic sand compaction monitoring. At a minimum, the protocol provided under 2a and 2b below must be followed . . . A report on the results of the compaction monitoring shall be submitted to the Raleigh Field Office of the USFWS prior to any tilling actions being*

taken. Out-year compaction monitoring and remediation are not required if sediment imported for beach construction no longer remains on the dry beach.

2a. Compaction sampling stations must be located at 500-foot intervals along the project area. One station must be at the seaward edge of the dune/bulkhead line (when material is placed in this area), and one station must be midway between the dune line and the high water line (normal wrack line).

At each station, the cone penetrometer will be pushed to a depth of 6, 12, and 18 inches three times (three replicates). Material may be removed from the hole if necessary to ensure accurate readings of successive levels of sediment. The penetrometer may need to be reset between pushes, especially if sediment layering exists. Layers of highly compact material may lie over less compact layers. Replicates will be located as close to each other as possible, without interacting with the previous hole and/or disturbed sediments. The three replicate compaction values for each depth will be averaged to produce final values for each depth at each station. Reports will include all 18 values for each transect line, and the final six averaged compaction values.

2b. If the average value for any depth exceeds 500 pounds per square inch (psi) for any two or more adjacent stations, then that area must be tilled immediately prior to May 1. If values exceeding 500 psi are distributed throughout the project area but in no case do those values exist at two adjacent stations at the same depth, then consultation with the USFWS will be required to determine if tilling is required. If a few values exceeding 500 psi are present randomly within the project area, tilling will not be required.

In the event USFWS deems it necessary and as required by the monitoring plan, the Town of Nags Head will conduct tilling/disking of the compacted beach fill area prior to May 1 to reduce the likelihood of impacting sea turtle nesting and hatching activities.

Overall, based on the monitoring requirements specified in the state and federal permits, physical condition surveys after the project will include the following:

- Beach compaction tests for three years prior to the start of turtle nesting season.
- Beach and inshore profiles at minimum 500-ft spacing at USACE/CSE stations, including upcoast and downcoast areas to track the project condition and the spread of nourishment sand to adjacent areas.
- Data analysis to determine nourishment volumes remaining by reach and volumes remaining with respect to the renourishment threshold.

- Sediment sample collection and analysis for monitoring the as-built quality of sand on the visible beach every other year.
- Aerial photography to document the general conditions of the shoreline each year and periodic controlled vertical photography approximately once every three years.
- Contour movement analysis and mapping to illustrate for the community the shift over time of key reference contours including local mean high water (MHW), the edge of the dry-sand beach, and the face of the foredune.

Based on the above monitoring requirements, for Years 1-3 (2012-2014) after the project, beach compaction measurements were made in March, two semi-annual profile surveys were performed in June and November, and one annual profile survey was performed in June 2013 and June 2014. There is no need to conduct sediment compaction tests after Year 3 (2014), but profile surveys in subsequent years will continue to be performed annually in June (weather permitting). These surveys will provide pre-storm condition data and will serve as the annual baseline for comparison with post-storm condition surveys.

2.2 Data Collection Methodology

Hydrographic data collection methodology followed procedures set forth in the USACE Hydrographic Surveying Manual (EM 1110-2−1003; January 2002, updated April 2004). CSE's survey was completed using an RTK-GPS (Trimble™ Model R8 GNSS) for data collection. The offshore work was performed using the Trimble™ linked to an Odom™ Echotrac CV100 precision survey fathometer for direct measurements of the bottom without the need for tide corrections. Measurements over subaerial portions of Nags Head extended to low-tide wading depth.

Offshore profiles were collected at 5 Hz (hertz–a unit of frequency) at high tide overlapping the wading-depth measurements. The raw data were then filtered to eliminate spikes and to provide a 5–7 point floating average. Smoothed inshore data were edited to a manageable size and merged with subaerial data. Survey baseline and control USACE/CSE station coordinates and elevations are listed in Appendix 2. Plotted beach profiles for selected dates are given in Appendix 3.

Ground photos were taken at representative monitoring stations and compared to pre- and post-project photos of the same areas. This offers a simple visual assessment of dry beach width, dune condition, vegetative growth, escarpments, and general condition of the beach through time. Photos were also taken of any areas or features of particular importance or interest observed during the monitoring event. The photos are not required under the maintenance and monitoring plan, but they provide a convenient visual record for illustrating pre-storm conditions to FEMA officials and the community.

Oblique aerial photos were taken from an aircraft for purposes of obtaining views of the overall project. Representative images are included in the monitoring report along with pre- and post-construction images to illustrate the general condition of the beach.

Aerial orthophotos of the project area were taken by Independent Mapping Consultants Inc (Charlotte, NC) on 7 June 2014. This use of aerial orthophotography technology is the only one scheduled during the five-year monitoring period between 2012 and 2016. Orthophotography is a spatially rectified image representing the earth's surface in the area of coverage. It can be imported and utilized in the creation of a Geographic Information System (GIS) and defined coordinate system.

3.0 WIND AND WAVE CONDITIONS AT THE PROJECT SITE

3.1 Wave Buoy at USACE-FRF

The USACE Field Research Facility (FRF) in Duck (NC), located about 15 miles north of the northern boundary of Nags Head (see Fig 1.1), has been monitoring littoral processes for over 30 years. Because of its proximity to Nags Head, the wave data collected at FRF were used to approximate wave conditions at Nags Head.

FIGURE 4.1.

Datawell Directional Waverider 630 (WMO ID 44056) is located at 36°11.993N, 75°42.843W, 3 km (~1.9 miles) offshore where water depths are ~17.4 m (57 ft). It has collected wave height, period, and directional data since 1997.

[Source: USACE-FRF]

Waverider Buoy 630 is located ~1.9 miles offshore of the FRF site in ~57 ft of water (Fig 4.1), and it computes mean wave direction, significant wave height, and wave period from recorded wave data. A 21-year record (1986-2006) of wave data at Buoy 630 was used to determine seasonal variations in the wave climate at Nags Head (CSE 2011a). Wave height, period, and direction were summarized by month and listed in Table 3.1. Average significant wave heights are greatest from September to April (3.4–3.9 ft) and decrease from May to August (2.1–3.0 ft). Average wave periods remain consistent (~8-9 seconds), with highest wave period being in September, coinciding with the peak of the Atlantic hurricane season. Wave direction during the fall and winter is from the east-northeast, averaging between 70° and 80° from north, coinciding with larger waves produced from northeaster storms. During the spring and summer months, waves approach more from the east and average between 84° and 96°.

3.2 Wave Climate during the Present Monitoring Period (July 2014 – June 2015)

A 12-month wave record at Buoy 630 was downloaded from the USACE-FRF website and analyzed by month. Table 3.1 lists the monthly results compared with the 21-year wave record. It shows that average wave heights in January and February 2015, and July and December 2014 were higher (as highlighted in the table), but the average wave height is slightly lower than the 21-year average. Overall, the one-year average is comparable in all three parameters (ie – wave height, period and direction), indicating a normal year over the past year.

TABLE 3.1. Monthly average wave climate from 1986 through 2006 (CSE 2011) and from July 2014 through June 2015.

	21-Year Record (1986-2006)			1-Year Record (Jul 2014-Jun 2015)		
	Wave Height (ft)	**Wave Period (s)**	**Wave Direction**	**Wave Height (ft)**	**Wave Period (s)**	**Wave Direction**
January	3.58	8.58	75.3	3.71	8.19	75.4
February	3.84	8.55	71.2	4.90	9.11	70.9
March	3.84	8.74	79.0	3.27	7.64	79.4
April	3.42	8.60	79.4	3.03	8.03	78.7
May	3.01	8.45	84.2	2.85	7.98	90.3
June	2.45	8.13	96.4	2.36	8.82	88.7
July	2.11	8.15	95.2	2.26	7.77	102.4
August	2.75	8.66	92.6	2.73	8.43	97.2
September	3.58	9.16	84.9	3.36	9.10	75.6
October	3.86	8.67	76.7	3.29	8.97	92.1
November	3.50	8.53	72.0	3.32	7.78	77.7
December	3.68	8.49	70.5	4.01	9.01	68.3
Average	3.30	8.56	81.5	3.26	8.40	83.06

The waves measured at Buoy 630 from July 2014 to June 2015 were predominantly from the east. Significant wave heights, associated with wave periods at this buoy, are summarized in 10-degree increments in Table 3.2 along with their probability of occurrences, based on the long-term record (1997-2006) as well as the one-year record (June 2014 to June 2015). *[Note: There is no wave direction record prior to 1997.]* Waves beginning from north and ending at 150° from south represented 98.4 percent of the waves in the one-year record and 99.3 percent in the 10-year record. More than 55 percent of the waves in the one-year record were from between 70° and 130° (measured from north), while 59 percent of the waves in the 10-year record were from the same directions.

The highest-energy waves originated from the northeast. Waves originating from north-easterly directions (between 0° and 90° from north) represented ~56 percent of the waves and have an average significant wave height of 1.27 m (4.15 ft), which is slightly higher than the 10-year record (ie – significant wave height is 1.20 m or 3.92 ft with occurrence of ~52 percent). The relatively high occurrence of waves from 60° to 120° True (65 percent) in the past year is similar to what is shown in the long-term statistics (67 percent). This relatively high occurrence of waves likely produced an average southerly transport along Nags Head during the June 2014 to June 2015 period. [Nags Head shore-normal wave direction is ~68° True.]

TABLE 3.2. Significant wave heights (meters and feet), associated wave periods (seconds), wave directions (degrees true by 10-degree sectors), and their probability of occurrence at Buoy 630 for the periods of 1997–2006 and July 2014 to June 2015. [*Note: There is no direction record prior to 1997.]

Wave Direction (° True North)	10-Year Record (1997–2006)*			1-Year Record (Jul 2014 to Jun 2015)		
	Wave Height (ft)	Wave Period (s)	Probability (%)	Wave Height (ft)	Wave Period(s)	Probability (%)
0-10	3.45	4.54	1.19	3.85	4.60	1.39
10-20	4.12	5.10	2.13	4.01	5.07	2.50
20-30	4.31	5.55	3.59	4.25	5.58	3.55
30-40	4.26	6.05	4.42	4.49	6.01	4.74
40-50	4.20	6.77	5.19	4.40	6.49	5.92
50-60	4.34	8.17	6.10	4.09	7.53	7.15
60-70	3.98	9.69	8.22	3.98	9.50	9.34
70-80	3.51	10.47	10.85	3.47	10.30	10.74
80-90	3.13	10.25	11.08	2.77	10.05	10.41
90−100	2.70	9.79	11.85	2.45	9.60	10.97
100−110	2.56	9.42	13.24	2.38	9.18	12.85
110−120	2.70	8.82	12.09	2.71	8.45	10.44
120−130	2.63	7.60	5.94	2.98	7.27	5.08
130−140	2.31	6.49	2.56	2.46	5.87	2.66
140−150	2.12	5.16	0.83	1.92	4.37	0.69
Total	-	-	99.29	-	-	98.44

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4.0 BEACH AND INSHORE SURVEYS AND PROFILE COMPARISONS

CSE collected beach and inshore profile data following the protocol stated in Section 2 and also following the permit requirements described in the same section. After the data were collected, CSE performed QA/QC on all data by a combination of procedures. These included measurement of speed of sound, sounding-bar checks, direct soundings in deep water, real-time overlays with historical data using Hypack™ software, and cross-tracking lines for statistical analysis of survey accuracy.

Field data were entered into CSE's beach profile analysis system (BPAS) and combined with historic profile data. Each profile was checked for proper juxtaposition and datum correction with previous profile data. Consistent with previous reports (CSE 2011a; 2012; 2013a,b; 2014b), the November 2010 survey was used as the baseline condition to calculate volume changes. Overall volume changes by reach were computed by extrapolating unit volume changes over representative shore lengths.

4.1 Beach Volume Analysis Method

Profile volumes are a convenient way to determine the condition of the beach and compare one area with another. They convert a two-dimensional measure of the beach to a "unit volume" measure. Unit volume, given in cubic yards per linear foot, is a measure of the amount of sand contained in a 1-ft (unit) length of beach. This unit-volume concept is illustrated in Figure 4.1. Specific volumes reflect a quantity in a wedge of sand extending from the dune line or seawall to a particular depth offshore.

Unit volumes for each survey date and unit-volume changes between selected dates were calculated to determine the quantity of sand in 1 linear foot of beach at each station. These unit volumes were used to calculate the station-to-station net volumes, the net volumes of reaches, and finally the net volume for the entire project.

Changes in unit volume (or beach width, etc) can be determined by overlaying sequential profiles and computing the differences in cross-sectional area. The change in cross-section (in two dimensions) is extrapolated between adjacent profiles to yield net volume change (in cubic yards) in that section. Using standard statistical techniques (average-end area method), the overall (net) change is computed by summing the changes from profile to profile for subreaches and for total project reach.

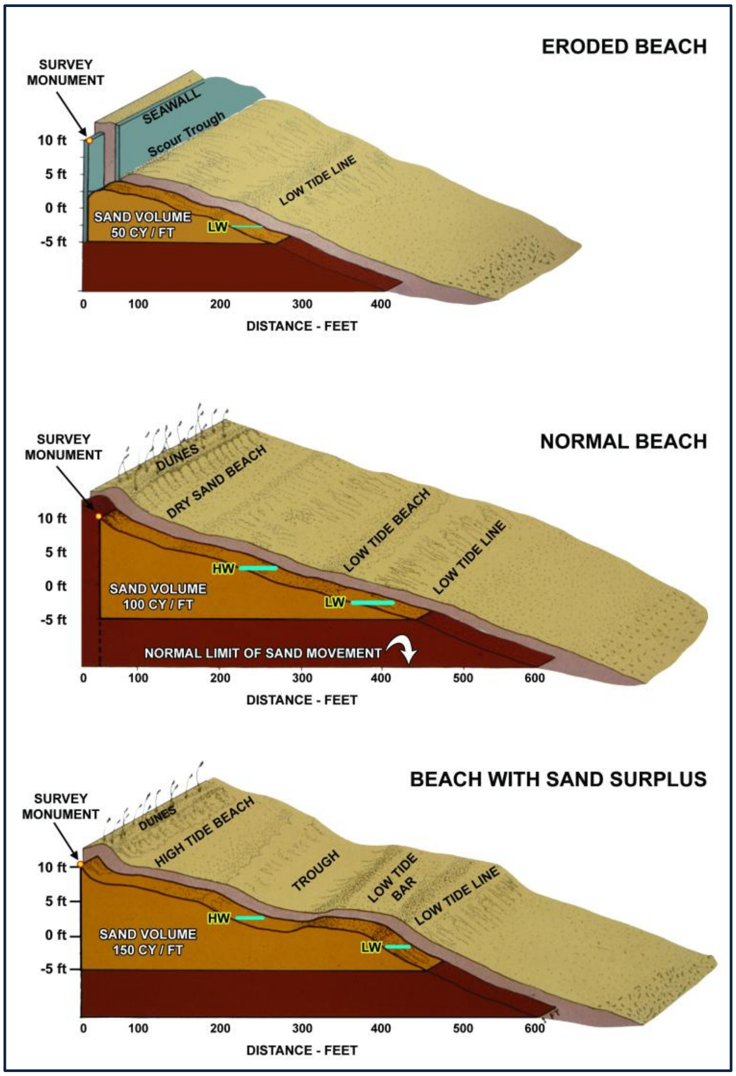

FIGURE 4.1. The concept of unit-width profile volumes for a series of beach profiles showing an eroded beach with a deficit, a normal beach, and a beach with a volume surplus. [After Kana 1990]

Profile volumes integrate all the small-scale perturbations across the beach and provide a simple objective measure of beach condition (Kana 1993). They provide quantitative estimates of sand deficits or surpluses when compared against a target or desirable beach condition.

The examples of profile volumes in Figure 4.1 show a "normal beach" with a typical unit volume of 100 cy/ft measured to low-tide wading depth. The other profiles in the graphic illustrate values for an eroding beach (in this case, backed by a seawall) and a beach with a sand surplus.

The unit volume of the eroded profile is much lower than the normal beach. Beaches near inlets often incorporate wide low-tide bars resulting in a surplus of sand relative to beaches away from inlets. The calculation limits can be arbitrary as long as they are consistently applied. Ideally, they should encompass the entire active zone of profile change for the time period(s) of interest.

Volume change at Nags Head was estimated using standard methods (average-end-area method) and common cross-shore boundaries and contour datums. Per the Town's request, three (3) lenses (ie – volumes between particular reference contours) were used in the present analysis for purposes of evaluating levels of dune protection, beach, and the underwater zone. Figure 4.2 illustrates the cross-sectional areas of these three lenses for Nags Head.

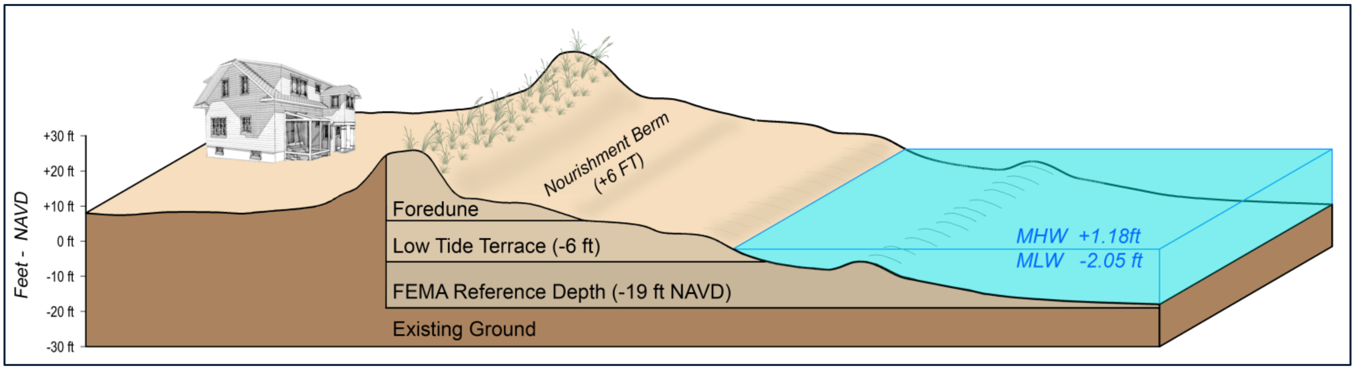

FIGURE 4.2. Illustration of the three (3) lenses used in the profile volume analysis for Nags Head. Lens 1 is the back beach and foredune; Lens 2 represents the active beach to low-tide wading depth; and Lens 3 represents the outer surf zone extended to the FEMA depth limit.

Lens 1) "Foredune" – From the face of dune to +6 ft NAVD – The 2011 nourishment construction berm was designed at +6 ft with several areas up to +7 ft NAVD. The volume above the +6 ft elevation is a measure of the sand quantities shifted toward the dunes and upper beach. Therefore, this is a measure of storm and flood protection levels associated with the project or gains in dune volume due to post-project buildup above this contour.

Lens 2) "Beach" – Between +6 ft and -6 ft NAVD – It includes the dry-sand beach ("berm") and the wet-sand beach, and extends to low-tide wading depth. The majority of the nourishment sand (~4.165 million cubic yards or 90 percent) was initially placed in this lens during the 2011 nourishment project for construction convenience. This is not only the primary recreational portion of beach, but also is the inner surf zone where a significant proportion of wave-breaking and energy dissipation occurs.

Lens 3) "Underwater" – Between -6 ft and −19 ft NAVD – It represents the outer surf zone extending seaward from low-tide wading depth to the depth set forth for the FEMA post-storm restoration criteria (−19 ft NAVD).

Unit volumes for Nags Head profiles were calculated to determine the quantity of sand in one linear foot of beach at each lens at each survey line. These unit volumes were then used to calculate the line-to-line net volumes, the reach net volumes, and finally the net volume for the entire project. The line-to-line net volumes are proportional to the distance between lines and represent the alongshore distribution of sand volume in the project area. The net volumes by reach were subsequently divided by the applicable reach lengths to yield weighted average unit volumes, taking into account the variations in applicable shoreline distances from line to line.

Conveniently, the stations for Nags Head are evenly spaced at 500 ft. If they are not evenly spaced, the station-to-station net volumes should be proportional to the distance between stations in order to represent the actual alongshore distribution of sand volume. Beach profiles at CSE survey stations are plotted in Appendix 3. Unit volumes of the three lenses at each survey line are given in Appendix 4 for comparisons with previous surveys, which include:

- November 2010 for pre-project.
- November 2011 for post-construction.
- June 2012 for Year 1 post-project but before the hurricane season and November 2012 for Year 1 post-project but after the hurricane season.
- June 2013 for Year 2 post-project and before the hurricane season.
- June 2014 for Year 3 post-project and before the hurricane season.

Unit volumes of representative lenses and cumulative lenses are discussed in detail in this section, and total volumes will be discussed in Section 5.

4.2 Unit Volume Results

4.2.1 Foredune – Lens 1 (from Face of Dune to +6 ft NAVD)

CSE expected the higher dry beach (formed by storm overwash and a landward shift of some sand after the completion of the 2011 project) would remain dry most of the time and would serve as a feeder for dune growth. Unit volumes of Lens 1 from face of dune***** to +6 ft NAVD **by station** along Nags Head are shown in Figure 4.3. For graphic clarity, only unit volumes for June 2015 (black line in the graphic) are plotted against the pre-construction condition (red line in the graphic).

> *[*Landward limit of this lens was originally determined at the face of dune at the time of project planning and design (CSE 2011a). It remains the same for most stations unless significant changes occur landward of a station (eg – structure) that prevents data collection. If the landward limit of a station is changed, volumes at this station will be re-calculated for* ***all survey dates*** *so that volume comparison will be based on the same portion of beach.*]

Before nourishment, north Nags Head had higher unit volumes than south Nags Head (red dashed line shows the linear trend), indicating the dune condition of the north was healthier than the south and had more storm protection than the south. Some portion of south Nags Head had zero or near-zero volume in this lens, indicating little protection before the project. The 2011 nourishment project placed higher fill density at the south and provided a wider beach for dune growth. The nourishment berm has been a "feeder" for the upper beach and dune area, with sand fencing installed by the Town after project completion, helping to trap sand moving toward the backshore into this lens.

By June 2013, survey results showed that relatively similar dune protection existed from north to south along the entire project area (CSE 2013b). Starting from June 2014, survey results showed that the south end of the project was losing sand and had lower unit volumes compared to the north end (CSE 2014b). The June 2015 results (black line in Figure 4.3) show a continuation of this trend (see the descending black dashed line which shows the linear trend).

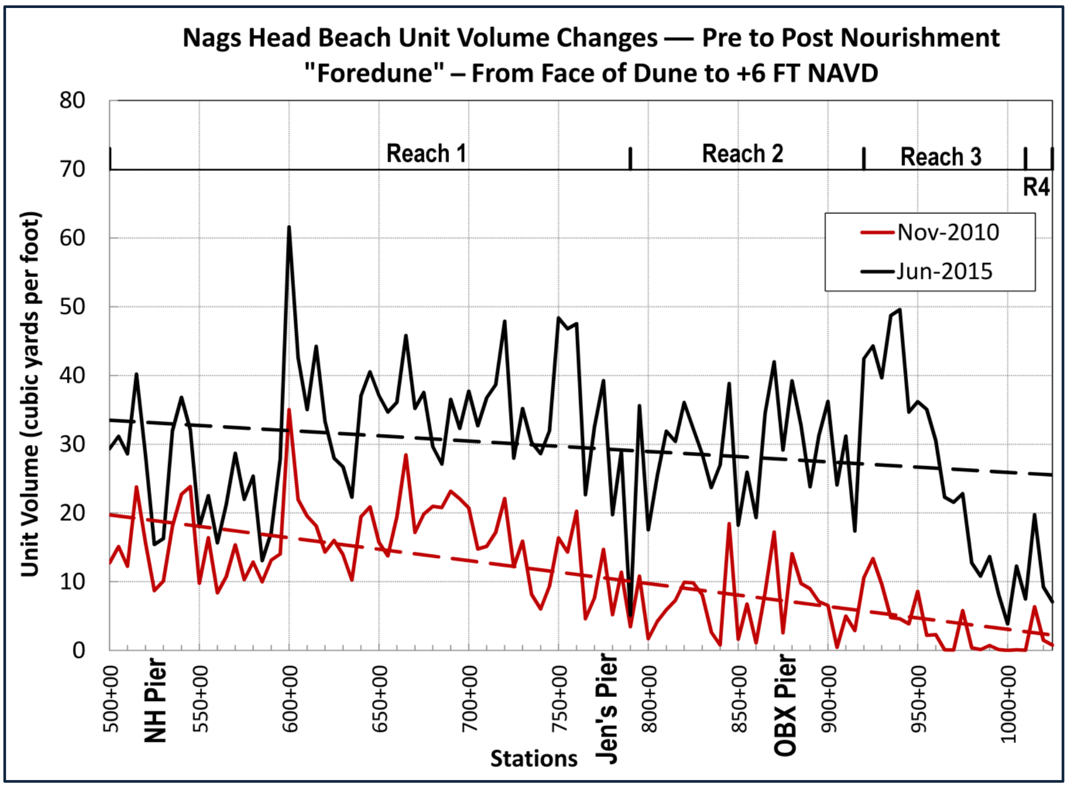

FIGURE 4.3. Comparison of unit volumes along Nags Head from the toe of dune to +6 ft NAVD contour before nourishment (November 2010) and the most recent survey condition (June 2015). It shows significant increase of unit volumes after the project at most stations. Unit volumes in previous surveys (November 2011, June 2012, November 2012, June 2013, and June 2014) are plotted in earlier reports by CSE (2013a,b; 2014b).

Figure 4.4 shows the average unit volume **by reach** in Lens 1 for all surveys since November 2010. Results show that unit volumes in this lens (ie in the base of the foredune) have steadily increased in all reaches following project completion. The June 2015 results show relatively stable dune volumes in Reaches 1–3, but show a significant volume drop in Reach 4 compared to the previous year. As projected in the 2014 monitoring report, dune growth has declined as the dry sand beach has narrowed by natural profile evolution.

The right group of bars in Figure 4.4 represents the overall performance to date along the project area. They show that foredune volume increased from 11.1 cy/ft in November 2010 (before the project) to 17.7 cy/ft in November 2011 (after construction). After nourishment, the unit volume in the foredune continued to increase to 20.5 cy/ft in June 2012 and slightly dropped to 19.2 cy/ft in November 2012. It significantly increased to 27.5 cy/ft in June 2013, and steadily increased to 30 cy/ft in June 2014. The unit volume remained relatively stable at 29.6 cy/ft in June 2015. The results indicate a **natural growth** of ~12 cy/ft (or 3.3 cubic yards per foot per year—cy/ft/yr) for the past 3.6 years since the project completion (November 2011). Sand fencing installed after the project and vegetation planted by the Town have efficiently accumulated sand along the back beach, adding to protection.

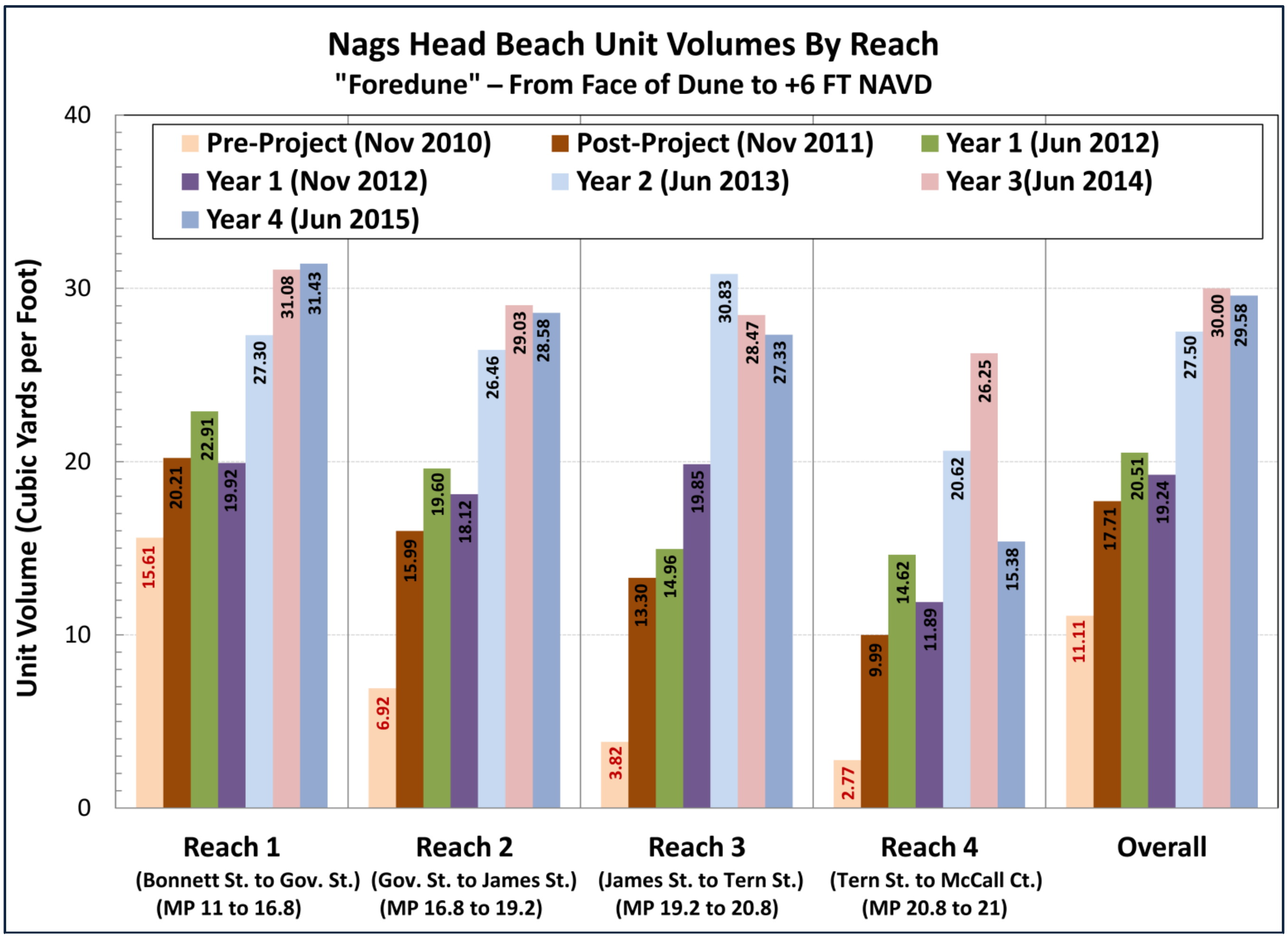

FIGURE 4.4. Comparison of unit volumes along Nags Head from the face of the dune to +6-ft NAVD contour. It shows the general increase of volume after the project by comparing volumes by reach and year from November 2010 to June 2015.

4.2.2 Recreational Beach – Lens 2 (from +6 ft to −6 ft NAVD)

Lens 2 represents the recreational beach to low-tide wading depth. Figure 4.5 shows unit volume comparisons **by station** in November 2010 (pre-project) and June 2015 (most recent survey). Figure 4.6 shows the comparisons **by reach** for all surveys between November 2010 and June 2015. Before the nourishment project, average unit volume in this lens was 72.8 cy/ft, and would be 83.9 cy/ft if the volume in Lens 1 is added. It is considered an "eroded" beach in this setting (cf – Fig 5.1).

Unlike unit volumes in Lens 1, the trend of unit volumes in Lens 2 was flat from north to south, reflecting the general uniformity of recreational beach width along Nags Head prior to nourishment. After nourishment, Nags Head retains an average of ~30 cy/ft more sand as of June 2015 compared to the pre-nourishment condition (November 2010). The trend of unit volumes in the recreational part of the beach shows that south Nags Head contains more volume (greater width) than north Nags Head.

The majority (~90 percent) of the 2011 nourishment sand volume was initially placed on the beach between the +6 and -6 ft contours for reasons of construction convenience. Nourishment sand will then shift underwater by wave action, and the newly constructed beach will be gradually reshaped toward its equilibrium profile. Such profile adjustment generally occurs in 1–2 years after project completion under normal conditions. Hurricane *Irene* and the following fall storms accelerated the initial adjustment, so that by November 2011, overall average unit volume was ~127.4 cy/ft (ie about 55 cy/ft more than pre-project conditions). After further profile adjustment and exposure to storms over the past 3.6 years, unit volumes in the recreational beach now average ~103 cy/ft (see the right group of bars in Fig 4.6).

Compared to the post-project condition (November 2011) in Figure 4.6, all reaches show similar trends and sand loss at a rate ranging from ~13.22 cy/ft (Reach 1) to ~54.97 cy/ft (Reach 3) as of June 2015. There are mainly two reasons for the higher erosion rates along south Nags Head:

1) Historically, south Nags Head has had a higher erosion rate than the north.
2) During nourishment, a higher fill density was placed in the south to relieve the sand deficit there. The natural tendency after nourishment is to spread the extra sand alongshore and even out the "bulges" created by the project. Such natural tendency increases the local erosion rate.

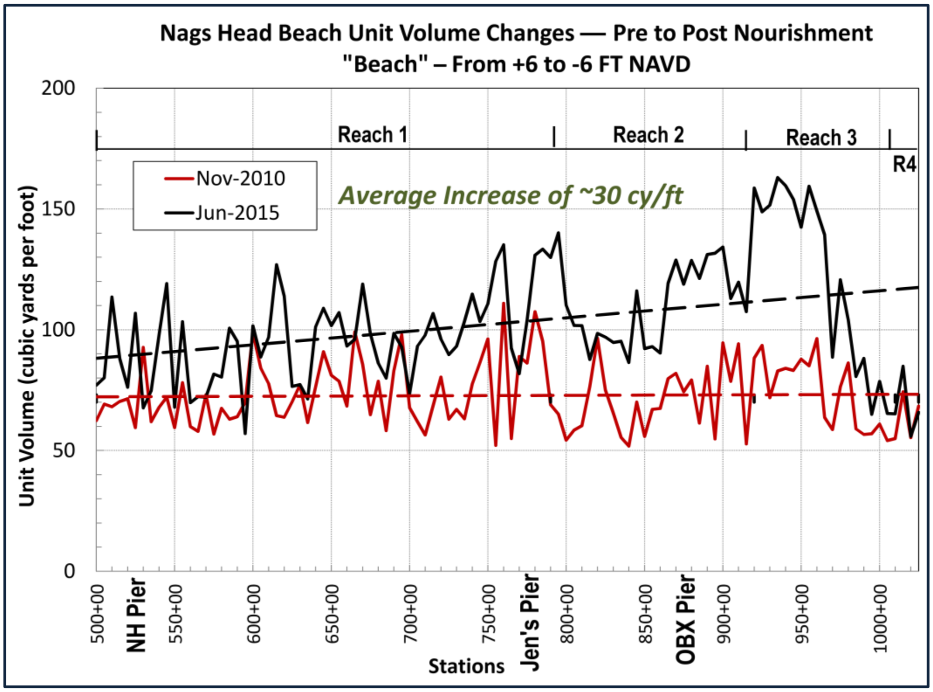

FIGURE 4.5. Comparison of unit volumes on the "recreational beach" by station along Nags Head between +6 ft and −6 ft NAVD.

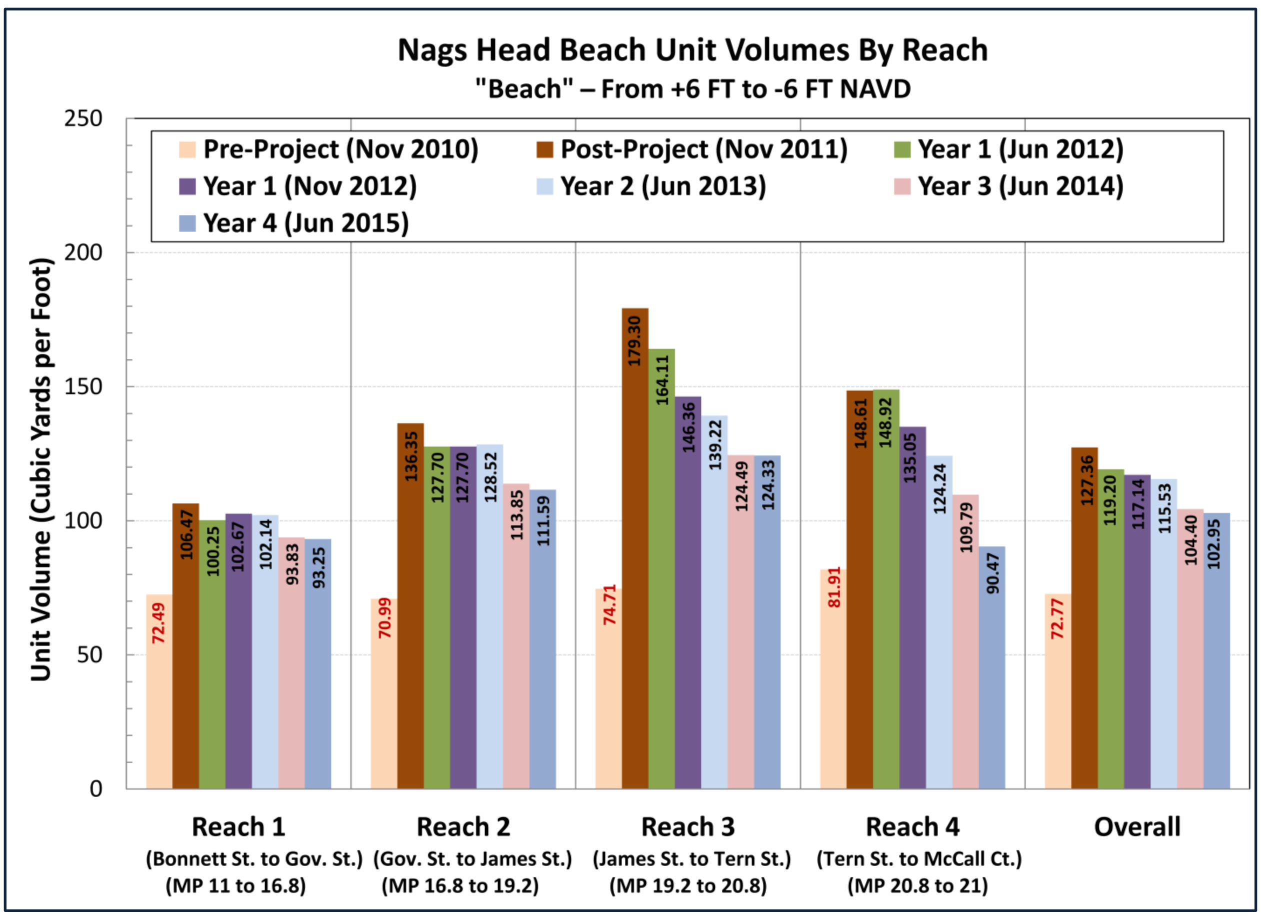

FIGURE 4.6. Comparison of unit volumes on the "recreational beach" by reach between +6 ft and −6 ft NAVD.

Despite the higher erosion rate in the south, the extra nourishment sand placed there has provided a wider recreational beach and served as a feeder for natural dune growth. This increased the overall longevity of the project.

In summary, the project area has lost an average of ~24.4 cy/ft since project completion on the "recreational beach." Despite this loss, the average unit volume in Lens 2 is still ~30 cy/ft more than the pre-project condition.

4.2.3 Underwater – Lens 3 (from −6 ft to −19 ft NAVD)

Lens 3 represents the underwater portion of the profile used for calculating volumes in the sand box. It includes inshore and offshore bars and extends to the FEMA depth limit of -19 ft NAVD. Natural bars tend to develop over gentle slopes within this lens, and the bars tend to shift alongshore or cross-shore under varying waves. All nourishment sand was placed within or above this lens during the 2011 project, indicating this is the construction and initial adjustment limit of the nourishment.

Figure 4.7 shows unit volume comparisons **by station** in November 2010 (pre-project) and June 2015 (most recent survey). Unit volumes do not change much from north to south along Nags Head in Lens 3 as shown in Figure 4.7, but the overall volume increase is obvious. Although the unit volume changes vary from station to station, the average gain in this lens is ~25 cy/ft.

Figure 4.8 shows the comparisons **by reach** for all surveys between November 2010 and June 2015. Over the initial comparison period between November 2010 (pre-project) and November 2011 (post-project), unit volume was increased ~22.8 cy/ft. This is an indication that nourishment sand, placed mainly on the "recreational beach," shifted underwater into this lens soon after construction. Since November 2011, unit volumes in Lens 3 have remained relatively stable, and the average unit volume is only 2.5 cy/ft higher in June 2015 than November 2011. However, Reaches 1 and 2 have continued to gain underwater sand, while Reaches 3 and 4 have lost some volume since November 2011.

Despite the noticeable loss of underwater sand in Reaches 3 and 4, there is still ~15.5 cy/ft and ~20 cy/ft more sand in these reaches (respectively) in June 2015 than pre-project in November 2010. The profiles in Appendix 3 generally show a broad, longshore bar positioned ~1,200 ft to 2,000 ft offshore in the Lens 3 depth zone.

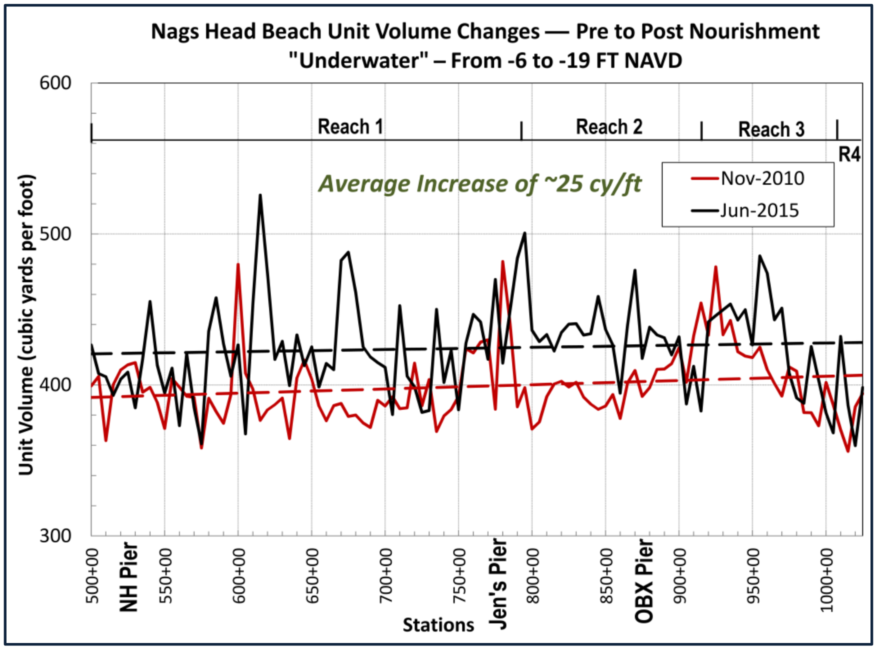

FIGURE 4.7. Comparison of unit volumes "underwater" by station along Nags Head between −6 ft and −19 ft NAVD.

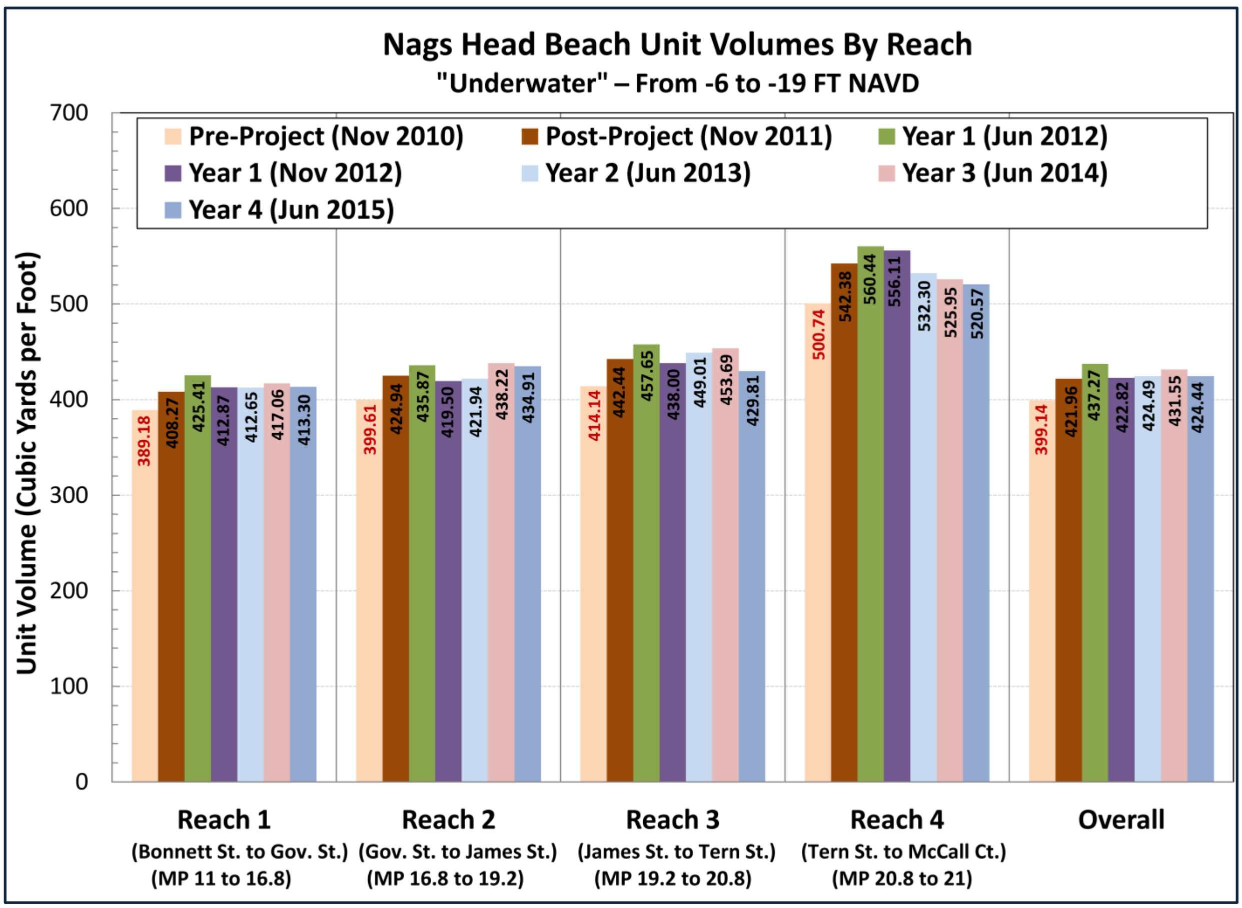

FIGURE 4.8. Comparison of unit volumes "underwater" by reach along Nags Head between -6 and −19 ft NAVD.

4.2.4 Cumulative Unit Volumes — Lens 1–3 (from face of dune to −19 ft NAVD)

Figures 4.9 and 4.10 show the cumulative unit volumes by station along the beach and by reach from Lens 1 to Lens 3 (ie – from the face of dune to −19 ft NAVD—FEMA limit). The same layout as Figures 4.3, 4.5 and 4.7, the two dashed lines in Figure 4.9 represent the trend of volume variations for November 2010 (pre-project) and June 2015. The results indicate that despite local fluctuations between adjacent stations, average unit volumes in these lenses were generally uniform along Nags Head before the project. After the project, average volumes increase from north to south reflecting the higher fill density placed in the south.

Results in Figure 4.10 show that the cumulative unit volume has not changed significantly since project completion. Nags Head had an average unit volume of ~483 cy/ft in November 2010 before the project. The unit volume increased to ~567 cy/ft after project completion in November 2011 and decreased to ~557 cy/ft as of June 2015. The 10 cy/ft less volume is equivalent to an ~2.8 cy/ft/yr erosion rate over the past 3.6 years since project completion (November 2011). This loss rate is much smaller than the historical erosion rate of ~5.2 cy/ft/yr adopted in the nourishment design (CSE 2011a).

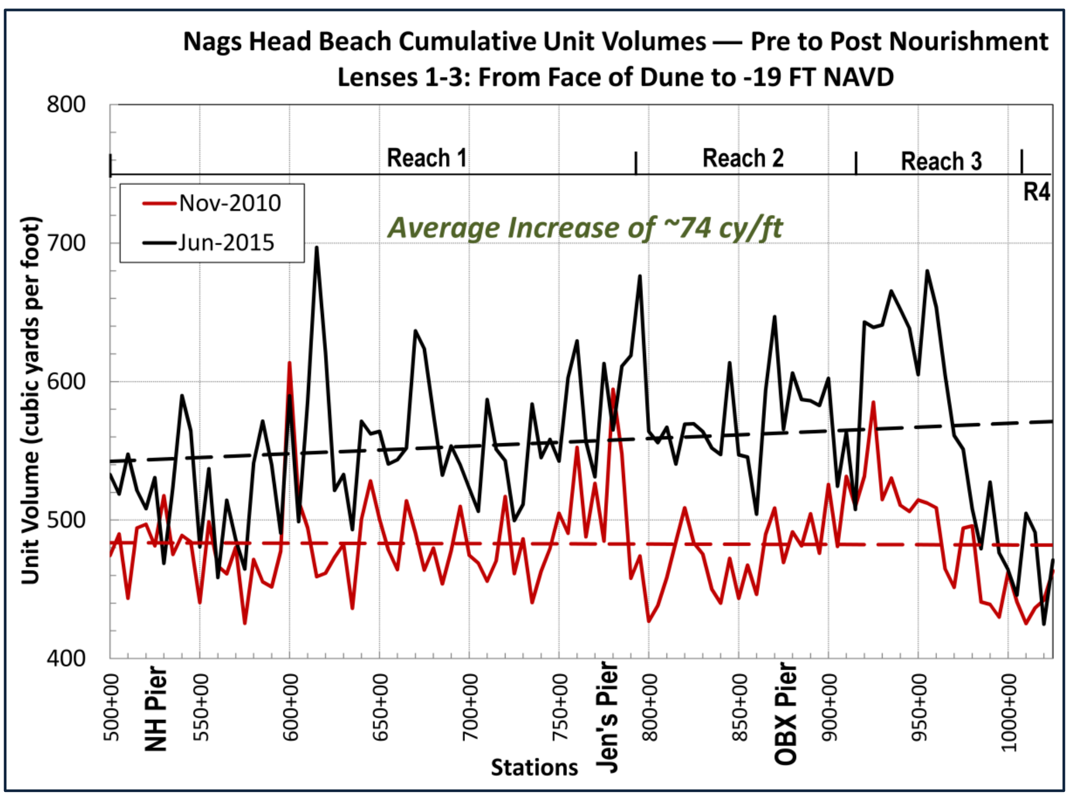

FIGURE 4.9. Comparison of cumulative unit volumes by station between the face of dune and −19 ft NAVD.

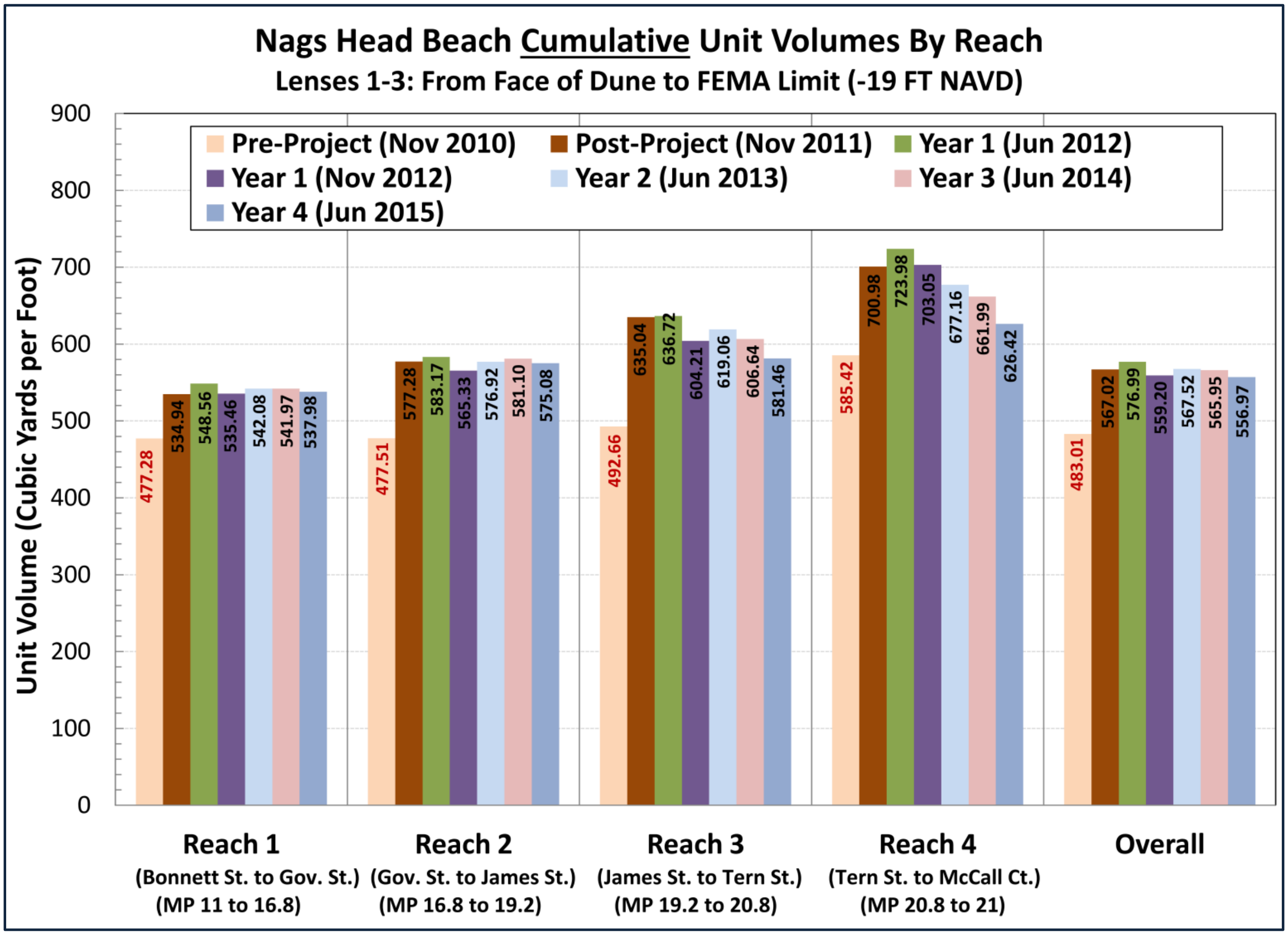

FIGURE 4.10. Comparison of cumulative unit volumes by reach between the face of dune and −19 ft NAVD.

4.2.5 Erosion Hot Spots Along Nags Head

Unit volumes have varied from survey to survey, and identifying possible “erosion hot spots” is one of the purposes of annual monitoring efforts. Erosion hot spots in one survey are generally not persistent for all surveys at a station, but often shift to an adjacent station. Figure 4.11 shows the comparison of the unit volumes along Nags Head in the last two years. For example, station 585+00 (near Sound Side Road) had a lower unit volume in June 2014, but had recovered to a normal value in June 2015. The unit volumes at its adjacent stations 575+00 and 595+00 had lower values in June 2015 and became erosion hot spots. Similar transitions can be found near other stations—for example, stations 530+00, 625+00, 690+00, 715+00, 740+00, 780+00, 800+00, 875+00, 905+00, and 985+00 as marked with green arrows in Figure 4.11.

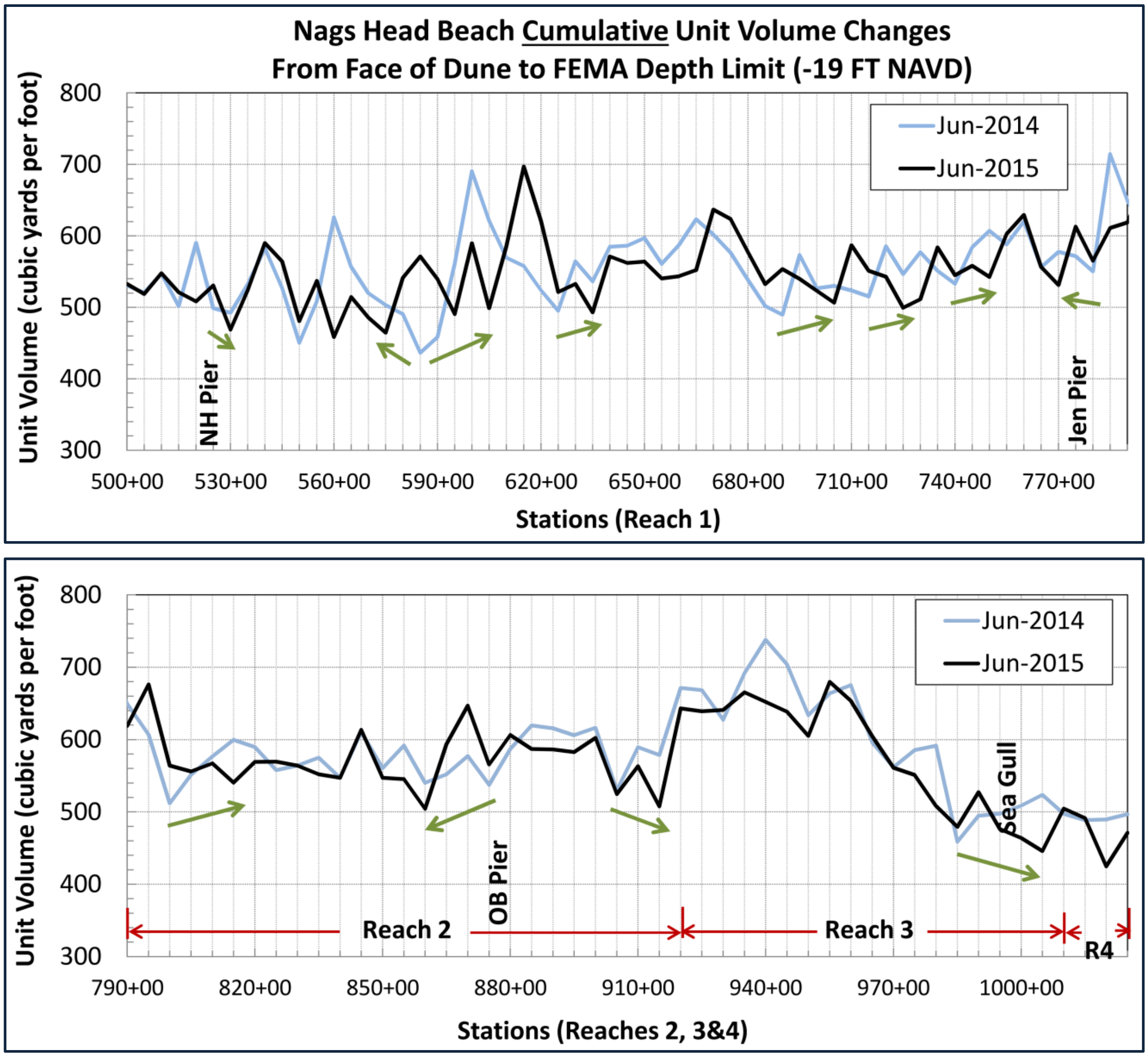

FIGURE 4.11. Shift in volume among adjacent stations between June 2014 and June 2015 which reflects general movement of sand lenses alongshore.

At a few stations, unit volumes in the June 2015 survey dropped to near November 2010 conditions (see Fig 4.9)—note, for example, stations 530+00 (near Curlew Street), 560+00 (south of E. Conch Street), 605+00 (south of Dune Street), 915+00 (near Eagle Street), and 1020+00 (near McCall Court). Stations with a similar volume drop last year have recovered naturally for some levels—for example, stations 550+00 (north of E. Conch Street), 585+00 (Sound Side Road), and 985+00 (E. Oriental Street). Scattered erosion hot spots are not an immediate concern, because they are migrating and the overall beach condition remains much healthier in June 2015 than the pre-nourishment condition.

CSE took photos before and after the nourishment project from the roof of the Comfort Inn looking northeast. Photos from June 2010 (before the project) and June 2015 (after the project, Year 4) are presented in Figure 4.12. Photos from other survey times can be found in previous reports (CSE 2013b, 2014b). The approximate location of station 785+00 is shown on the top image of Figure 4.12, and profiles at this station are plotted in Figure 4.13. Beach width from the face of the dune to MLW (at −2.05 ft NAVD) was ~170 ft in November 2010. It increased to ~265 ft after the nourishment project and continued to increase to ~316 ft by June 2012. Seasonal dry beach erosion reduced the width by 27 ft to ~289 ft in November 2012. It remained stable at ~290 ft in June 2013 then dropped to ~208 ft in June 2014. The most recent survey in June 2015 shows the sloping beach face (area between MHW and MLW on Figure 4.13) matching the November 2011 post-nourishment condition. The width of the dry beach, however, is narrower because a foredune has built up (see Fig 4.12 lower).

FIGURE 4.12. Photos taken from the roof of Comfort Inn looking northeast. Station 785+00 showing pre-project conditions (upper) versus recent conditions in 2015 (lower). Note the buried walkover right below this station.

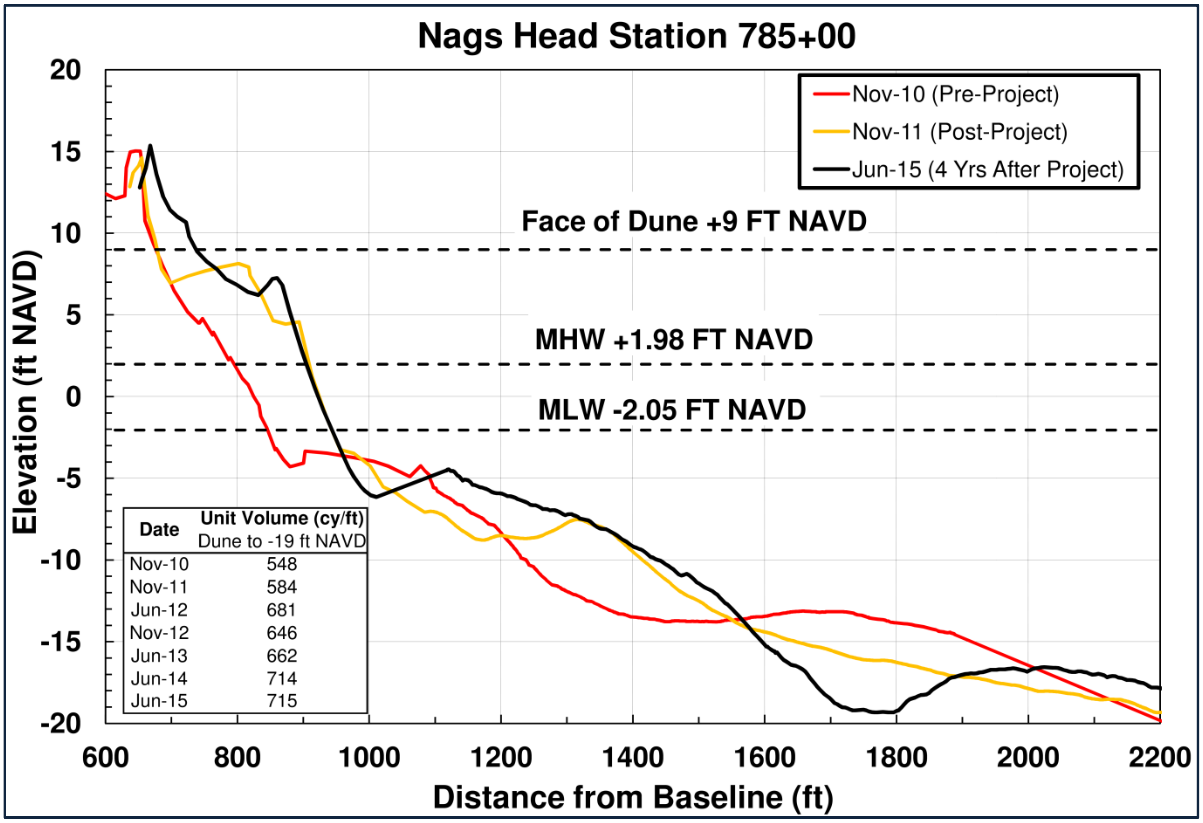

FIGURE 4.13. Beach profiles and unit volumes for pre- and post-project surveys at station 785+00 in Reach 1. Note the overlapping lines between MHW and MLW for the November 2011 and June 2015 profiles confirm the same position of the sloping intertidal beach.

Compared to the pre-project condition, the dune (at +9 ft NAVD) has grown over 60 ft seaward, and the beach width (at mean high water) has expanded ~110 ft as of June 2015. The unit volume at this station has been stable over the past year and is presently 167 cy/ft greater than the pre-project condition between the foredune and the FEMA depth limit. In the past two years, the unit volume at this station increased to its highest value since project completion. The June 2015 photo (see Fig 4.12, lower) shows that vegetation has propagated on the dune and the dry beach, while the walkover to the motel (*Dolphin Motel,* Nags Head, at the bottom of the photo) is almost buried. Sand fencing installed over the past year will help sand accumulation and enhance the natural dune growth.

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5.0 TOTAL VOLUME CHANGES AND VOLUME REMAINING

The total beach volume was estimated by applying the unit volume calculated at each measured profile over an applicable shoreline distance. The method (known as the average-end-area method) uses the average unit volume of two adjacent profiles multiplied by the distance between the profile stations to estimate the volume of sand between the two profiles. The total volume of sand in the project area is simply the sum of the individual section volumes measured to common vertical datums.

Since Nags Head stations are evenly spaced, the trends in total volume along the project site are similar to results using unit volumes. The same seven lenses were used to estimate the total volume, and detailed numbers for each station are listed in Appendix 5.

In November 2010 before nourishment, the project area contained 41,695,693 cy of sand between the face of dune and −24 ft NAVD (Table 5.1). The contractor's construction survey showed that 4,615,126 cy of sand were placed along 10.0 miles of Nags Head between 24 May and 27 October 2011. In November 2011 after project completion, CSE's surveys confirmed the total volume within the project limit was 4,762,013 cy (±3 percent survey error) more than the pre-project conditions (November 2010) (Table 5.2). CSE conducted two surveys in the first year after the project, and one survey in each of the following years (2013–2015). The volume changes relative to November 2010 (before the project) are listed in Tables 5.3 to 5.7. The three lenses used in this study are shaded in these tables.

TABLE 5.1. Total volume by reach in the seven lenses (CSE's survey in November 2010 before the nourishment project).

Reach	GLDD Reported Volume (cy)	Length (ft)	Total Volume (CY) Nov-2010						
			To +6 ft	To 0 ft	To -2.05 ft	To -6 ft	To -12 ft	To -19 ft	To -24 ft
Reach 1 (495-790)	1,619,172	29,500	460,353	1,229,793	1,603,262	2,598,903	5,881,865	14,079,811	22,766,566
Reach 2 (790-920)	1,361,165	13,000	89,909	357,170	513,340	1,012,731	2,576,143	6,207,611	10,140,563
Reach 3 (920-1010)	1,437,605	9,000	34,351	192,801	307,178	706,701	1,859,746	4,433,970	7,311,386
Reach 4 (1010-1025)	197,184	1,500	4,161	29,243	47,179	127,022	354,983	878,133	1,477,177
Total (495-1025)	4,615,126	53,000	588,773	1,809,007	2,470,960	4,445,358	10,672,737	25,599,524	41,695,693

TABLE 5.2. Total volume changes by reach between November 2010 and November 2011.

Reach	Length (ft)	Volume Changes Between Nov-10 And Nov-11 (CY)						
		To +6 ft	To 0 ft	To -2.05 ft	To -6 ft	To -12 ft	To -19 ft	To -24 ft
Reach 1 (495-790)	29,500	135,789	628,366	804,495	1,138,026	1,820,770	1,700,982	1,896,965
Reach 2 (790-920)	13,000	117,999	619,674	769,748	967,742	1,358,359	1,297,082	1,357,039
Reach 3 (920-1010)	9,000	85,345	586,855	736,277	1,026,681	1,377,313	1,281,379	1,332,193
Reach 4 (1010-1025)	1,500	10,824	70,687	90,237	110,880	158,723	173,344	175,816
Total (495-1025)	53,000	349,957	1,905,582	2,400,757	3,243,329	4,715,165	4,452,787	4,762,013

TABLE 5.3. Total volume changes by reach between November 2010 and June 2012.

Reach	Length (ft)	Volume Changes Between Nov-10 And Jun-12 (CY)						
		To +6 ft	To 0 ft	To -2.05 ft	To -6 ft	To -12 ft	To -19 ft	To -24 ft
Reach 1 (495-790)	29,500	213,713	699,596	842,208	1,032,425	1,900,618	2,101,133	2,400,434
Reach 2 (790-920)	13,000	164,846	622,300	753,514	902,188	1,387,186	1,373,586	1,374,533
Reach 3 (920-1010)	9,000	100,273	576,284	707,895	904,870	1,264,045	1,296,493	1,346,085
Reach 4 (1010-1025)	1,500	17,767	78,229	96,829	118,284	184,993	207,830	207,538
Total (495-1025)	53,000	496,599	1,976,409	2,400,445	2,957,766	4,736,841	4,979,042	5,328,590

TABLE 5.4. Total volume changes by reach between November 2010 and November 2012.

Reach	Length (ft)	Volume Changes Between Nov-10 And Nov-12 (CY)						
		To +6 ft	To 0 ft	To -2.05 ft	To -6 ft	To -12 ft	To -19 ft	To -24 ft
Reach 1 (495-790)	29,500	124,589	397,135	597,102	1,014,648	1,517,204	1,713,410	1,842,395
Reach 2 (790-920)	13,000	145,705	535,471	687,337	883,008	1,151,399	1,141,685	1,142,648
Reach 3 (920-1010)	9,000	144,338	546,616	666,292	789,190	1,068,920	1,003,944	1,052,841
Reach 4 (1010-1025)	1,500	13,678	67,185	85,484	93,392	153,622	176,447	182,404
Total (495-1025)	53,000	428,309	1,546,407	2,036,215	2,780,237	3,891,144	4,035,486	4,220,288

TABLE 5.5. Total volume changes by reach between November 2010 and June 2013.

Reach	Length (ft)	Volume Changes Between Nov-10 And Jun-13 (CY)						
		To +6 ft	To 0 ft	To -2.05 ft	To -6 ft	To -12 ft	To -19 ft	To -24 ft
Reach 1 (495-790)	29,500	344,963	709,240	829,877	1,219,411	1,251,419	1,911,609	2,426,419
Reach 2 (790-920)	13,000	254,009	626,918	768,321	1,002,007	859,510	1,292,398	1,402,892
Reach 3 (920-1010)	9,000	243,163	602,371	708,803	823,748	851,338	1,137,586	1,190,208
Reach 4 (1010-1025)	1,500	26,771	68,619	83,059	90,268	108,016	137,614	141,313
Total (495-1025)	53,000	868,906	2,007,147	2,390,061	3,135,434	3,070,282	4,479,208	5,160,832

TABLE 5.6. Total volume changes by reach between November 2010 and June 2014.

Reach	Length (ft)	Volume Changes Between Nov-10 And Jun-14 (CY)						
		To +6 ft	To 0 ft	To -2.05 ft	To -6 ft	To -12 ft	To -19 ft	To -24 ft
Reach 1 (495-790)	29,500	456,407	743,325	805,974	1,085,981	1,321,751	1,908,360	2,428,109
Reach 2 (790-920)	13,000	287,513	590,206	685,370	844,702	899,942	1,346,691	1,452,637
Reach 3 (920-1010)	9,000	221,848	507,594	580,317	669,903	718,590	1,025,817	1,048,064
Reach 4 (1010-1025)	1,500	35,216	77,858	89,139	77,033	39,073	114,850	107,448
Total (495-1025)	53,000	1,000,984	1,918,982	2,160,799	2,677,619	2,979,356	4,395,717	5,036,257

TABLE 5.7. Total volume changes by reach between November 2010 and June 2015.

Reach	Length (ft)	Volume Changes Between Nov-10 And Jun-15 (CY)						
		To +6 ft	To 0 ft	To -2.05 ft	To -6 ft	To -12 ft	To -19 ft	To -24 ft
Reach 1 (495-790)	29,500	466,904	811,279	888,989	1,079,356	1,346,970	1,790,705	2,682,009
Reach 2 (790-920)	13,000	281,663	641,470	734,960	809,453	763,863	1,268,412	1,495,487
Reach 3 (920-1010)	9,000	211,574	500,008	565,949	658,157	646,187	799,182	924,939
Reach 4 (1010-1025)	1,500	18,915	41,953	46,153	31,752	24,696	61,492	69,398
Total (495-1025)	53,000	979,057	1,994,711	2,236,051	2,578,719	2,781,717	3,919,791	5,171,832

Figure 5.1 plots the overall volume changes compared to November 2010 (before nourishment) in the 10-mile project area between the foredune and the three depth contours used in this study. The tan bars show the nourishment volume placed within the various beach areas during the dredging operations. The brownish-red bars show the sand remaining in November 2011 after project completion, Hurricane *Irene*, and the fall 2011 northeasters. The green bars show the results of the June 2012 survey before the 2012 hurricane season, and the purple bars show the results of the November 2012 survey after Hurricane *Sandy*. The purple bars also show same-season comparison with the baseline (November 2010) and the condition upon project completion (November 2011). The light blue bars represent the results of the June 2013 survey, and the pink bars represent the results of the June 2014 survey. The most recent survey in June 2015 is represented by the dark blue bars in the graphic.

The first set of bars in the graphic represents net volume changes in the "foredune" area. As of June 2015, the back beach and dune area accumulated 979,057 cy more sand than the condition before nourishment. This is equivalent to an average gain of ~18.5 cy/ft since November 2010 or ~4 cy/ft/yr above +6 ft NAVD. Compared to the condition a year ago, there are ~22,000 cy less sand in place, which is equivalent to a volume decrease of ~0.4 cy/ft/yr. Some of this loss probably represents sand migrating landward of the foredune (outside the calculation limits) and encroaching on oceanfront structures in the past year. This will be discussed in detail in the next section.

The next set of bars in Figure 5.1 shows the total volume changes from the face of dune to low–tide wading depth (−6 ft NAVD) (ie – cumulative volume of Lenses 1 and 2 relative to the calculation limits used in the unit volume analysis). The June 2015 survey shows ~4 percent sand loss to this contour compared to last year, and ~20 percent sand loss compared to the November 2011 (post-nourishment) condition.

The third set of bars in Figure 5.1 shows the cumulative volume change from the face of dune to −19 ft (FEMA limit) (ie – cumulative volume change of Lenses 1 to 3 relative to the calculation limits used in the unit volume analysis). Some of the sand loss from the dune to the −6 ft contour since November 2011 is offset by accumulation of sand between the −6 ft and −19 ft contours. The 2015 results indicate ~12 percent of sand was lost compared to the November 2011 condition (ie a decrease from ~4,453,000 cy to ~3,920,000 cy.

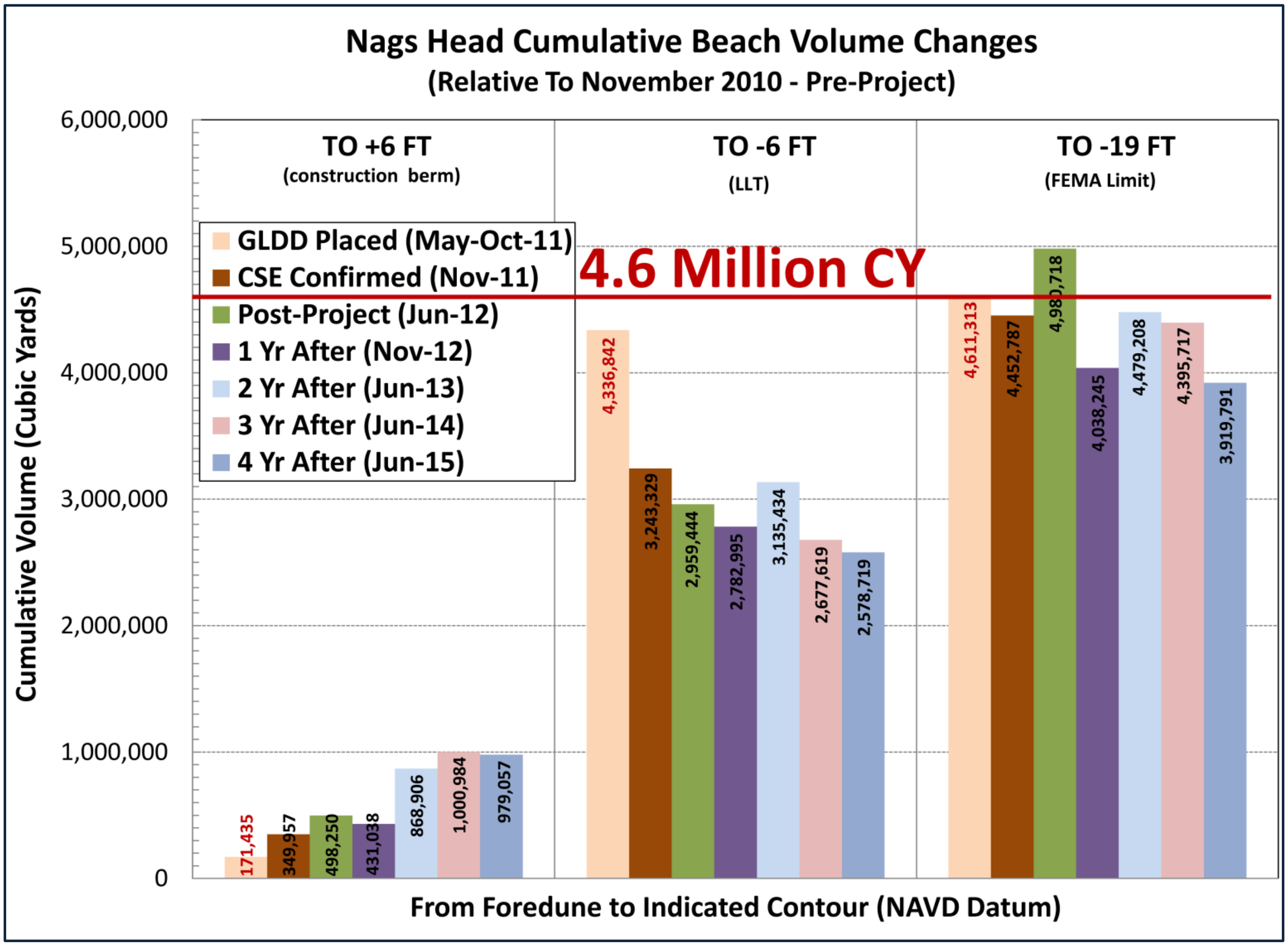


FIGURE 5.1. Cumulative, overall beach-volume changes relative to November 2010 survey results between the foredune and indicated contours.

Figures 5.2, 5.3, and 5.4 provide comparisons of volumes remaining by reach relative to the November 2010 pre-project condition. Figure 5.2 shows the volume remaining in the foredune area, and Figure 5.3 shows the results to the low-wading terrace (LTT) at −6 ft NAVD contour. *[Ninety four percent (94%) of nourishment sand was placed landward of this contour]*. Figure 5.4 shows results to −19 ft NAVD—the FEMA limit.

Compared to Last Year (June 2014) — The survey results of June 2015 show that Reaches 2, 3 and 4 lost sand while Reach 1 (northern half of the project) gained sand in the foredune (Fig 5.2):

Gained 10,497 cy	in Reach 1
Lost 5,850 cy	in Reach 2
Lost 10,273 cy	in Reach 3
Lost 16,300 cy	in Reach 4
Lost 21,927 cy	total (for the four reaches)

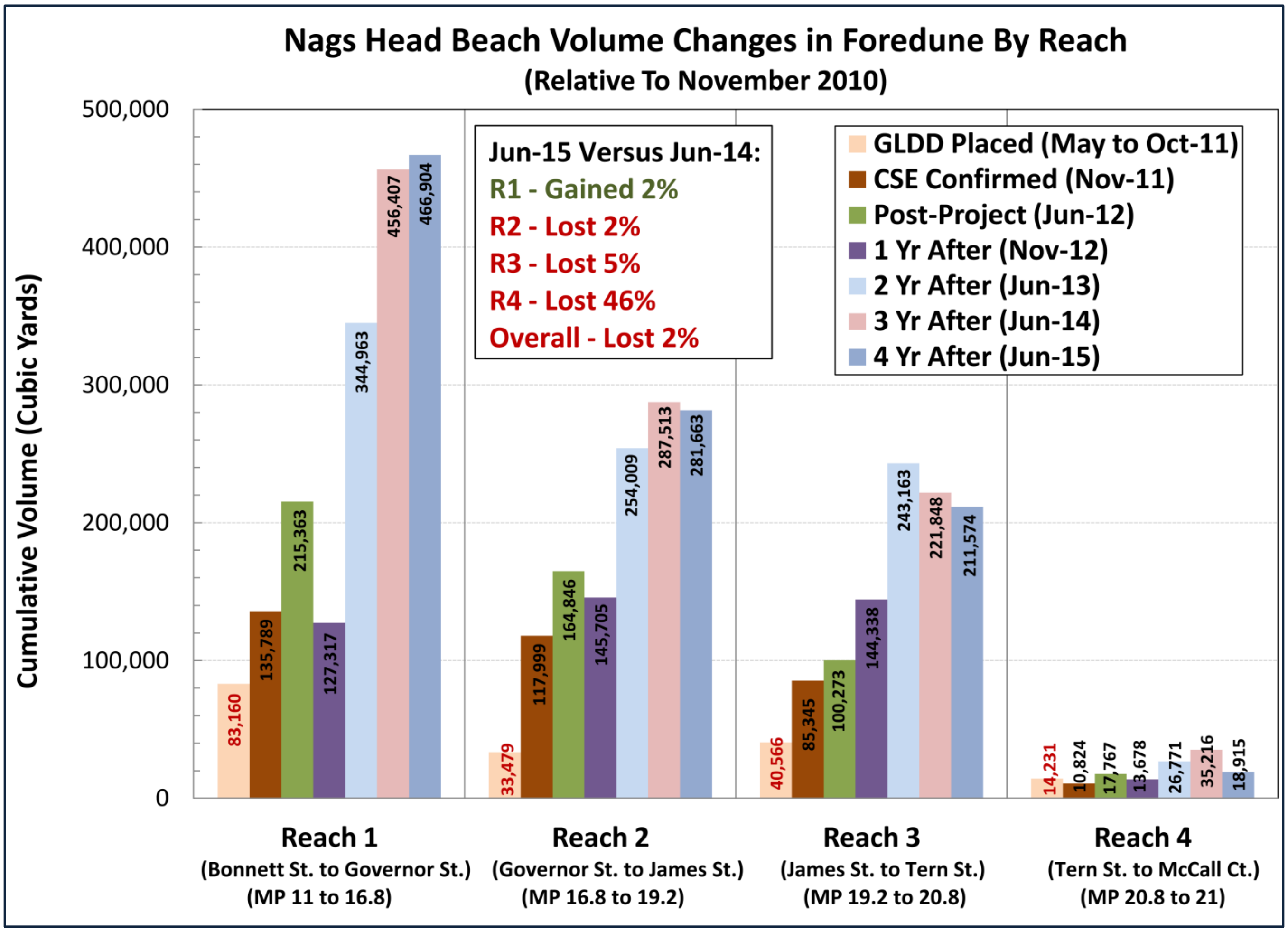


FIGURE 5.2. Beach volume changes by reach relative to November 2010 survey results in the foredune (from the face of dune to +6 ft NAVD).

Figure 5.3 shows volume changes in the foredune and beach from the face of dune to -6 ft NAVD. Compared to last year, all reaches lost sand. Reach 4 lost more than half of the volume although the overall loss is only ~4 percent.

Lost 6,625 cy	in Reach 1
Lost 35,249 cy	in Reach 2
Lost 11,746 cy	in Reach 3
Lost 45,281 cy	in Reach 4
Lost 98,901 cy	total (for the four reaches)

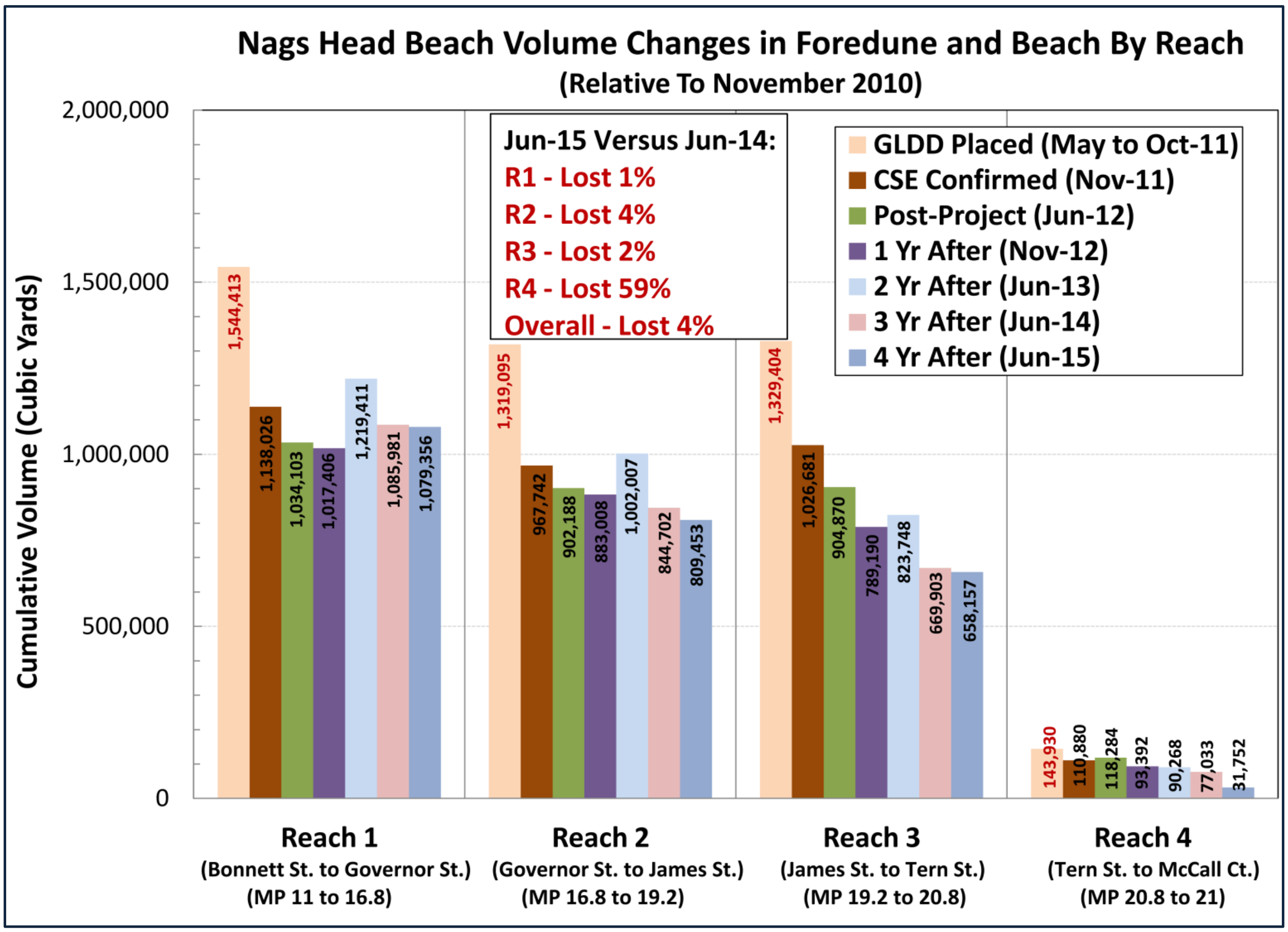


FIGURE 5.3. Beach volume changes by reach relative to November 2010 survey results from the face of dune to low tide wading depth (−6 ft NAVD).

Figure 5.4 extends the calculation to the −19-ft contour, which is the depth limit established for final design and FEMA reimbursement of sand losses. The results from June 2015 show net loss in all reaches from the face of dune to −19 ft NAVD in the past year:

Lost	117,655 cy	in Reach 1
Lost	78,278 cy	in Reach 2
Lost	226,635 cy	in Reach 3
Lost	53,358 cy	in Reach 4
Lost	475,926 cy	(or ~9 cy/ft/yr) total (for the four reaches)

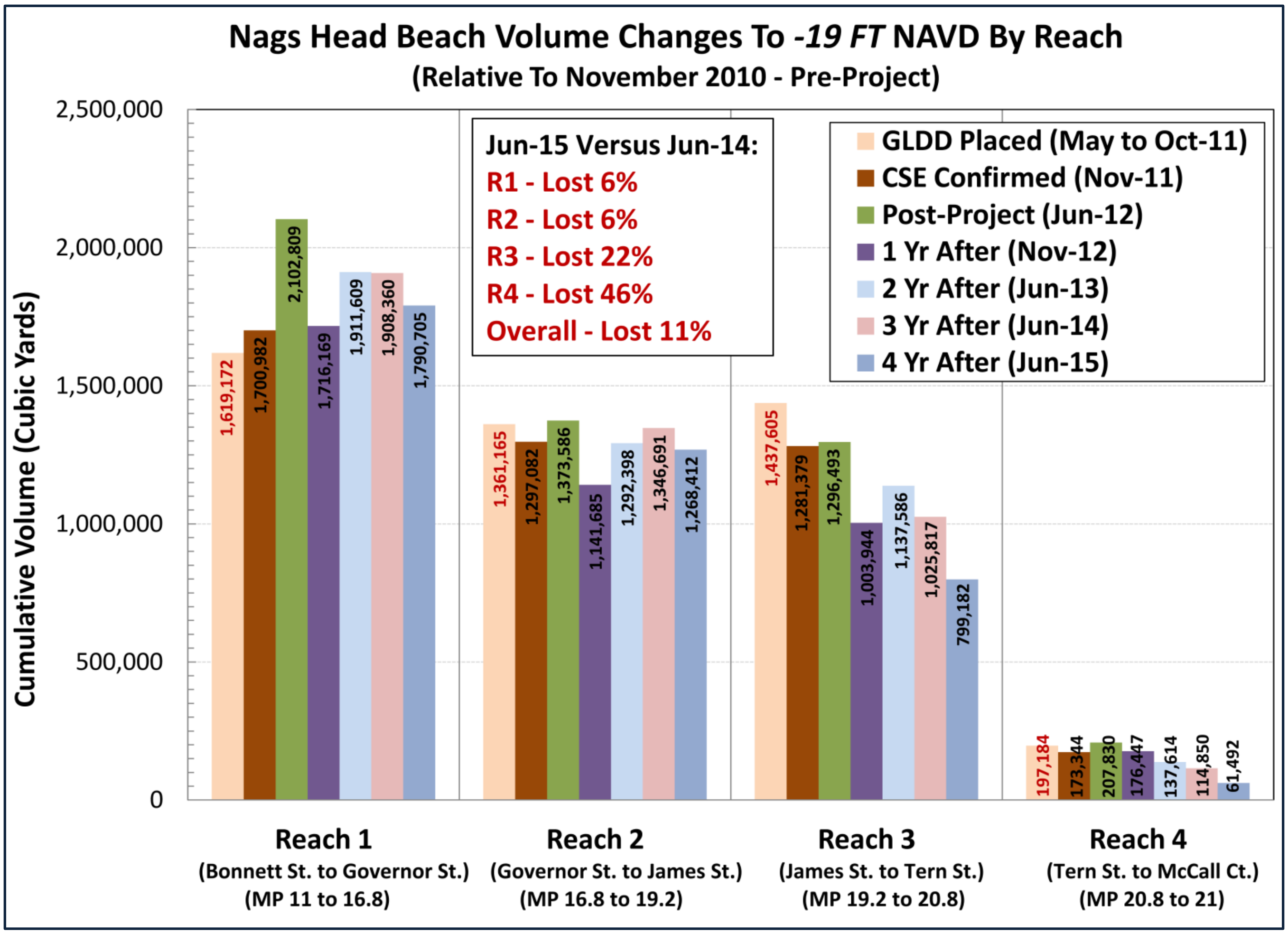


FIGURE 5.4. Beach volume changes by reach relative to November 2010 survey results from the face of dune to −19 ft NAVD. Nourishment sand loss or gain relative to last year (June 2014) is illustrated in the figure.

The results in Figure 5.2 to Figure 5.4 suggest that more variability occurs underwater in the cross-shore as well as the longshore directions. All three lenses eroded over the past year, and the total erosion loss of last year is ~200,000 cy higher than the average annual erosion loss of ~275,000 cy/yr that was adopted in the final design of the nourishment project (CSE 2011).

Nourishment Sand Remaining – Compared to Project Completion (November 2011)

All reaches have more volume in the foredune (see Fig 5.2) in 2015 compared with November 2011. The volume increases are significant in all reaches except for the southernmost 1,500 ft of Reach 4. Figure 5.3 showed that all reaches have lost volume to −6 ft in the past 3.6 years. Figures 5.4 and 5.5 show that Reach 1 (northern half of the project) has gained ~89,723 cy (or gained 5 percent of the nourishment sand placed in this reach). Reach 2 (middle to southern ~2.5 miles of project area) has lost ~28,670 cy (or lost ~2 percent of nourishment sand) between the face of dune and the −19 ft contour.

Reaches 3 and 4 (representing the southernmost ~2 miles of the project area) have lost ~482,197 cy (or lost ~38 percent of nourishment sand) and 111,852 cy (or lost ~65 percent of nourishment sand) (respectively) since November 2011. The annual loss rate for Reach 3 and Reach 4 since November 2011 has been ~15 cy/ft/yr and ~20.7 cy/ft/yr (respectively). Sand losses were projected to be higher along south Nags Head than north Nags Head based on historical trends, but last year's erosion rates in these two reaches are higher than CSE's design estimates.

In conclusion, the total volume remaining after nourishment to −19 ft NAVD (FEMA reference limit) in June 2015 is **~3,919,791 cy (~85 percent of the nourishment volume remaining)**. Overall volume changes in the project area were negligible (a loss of ~0.4 cy/ft/yr) between November 2011 (post-nourishment) and last year (June 2014), which was well below design (a loss of 5.2 cy/ft/yr). However, by June 2015, more sand had shifted to deeper water as evidenced by the longshore bar being further offshore. The present bar configuration is favorable for future movement into shallower water.

The overall annual erosion rate since nourishment is ~192,000 cy/yr (~3.6 cy/ft/yr), which is still below CSE's design estimates. Alongshore changes confirm that Reach 1 has gained volume, and Reach 2 remains stable. Reaches 3 and 4 have lost more sand than the other two reaches, but there were ~800,000 cy (~89 cy/ft) and ~61,500 cy (~41 cy/ft) (respectively) more sand in these reaches as of June 2015 than before nourishment.

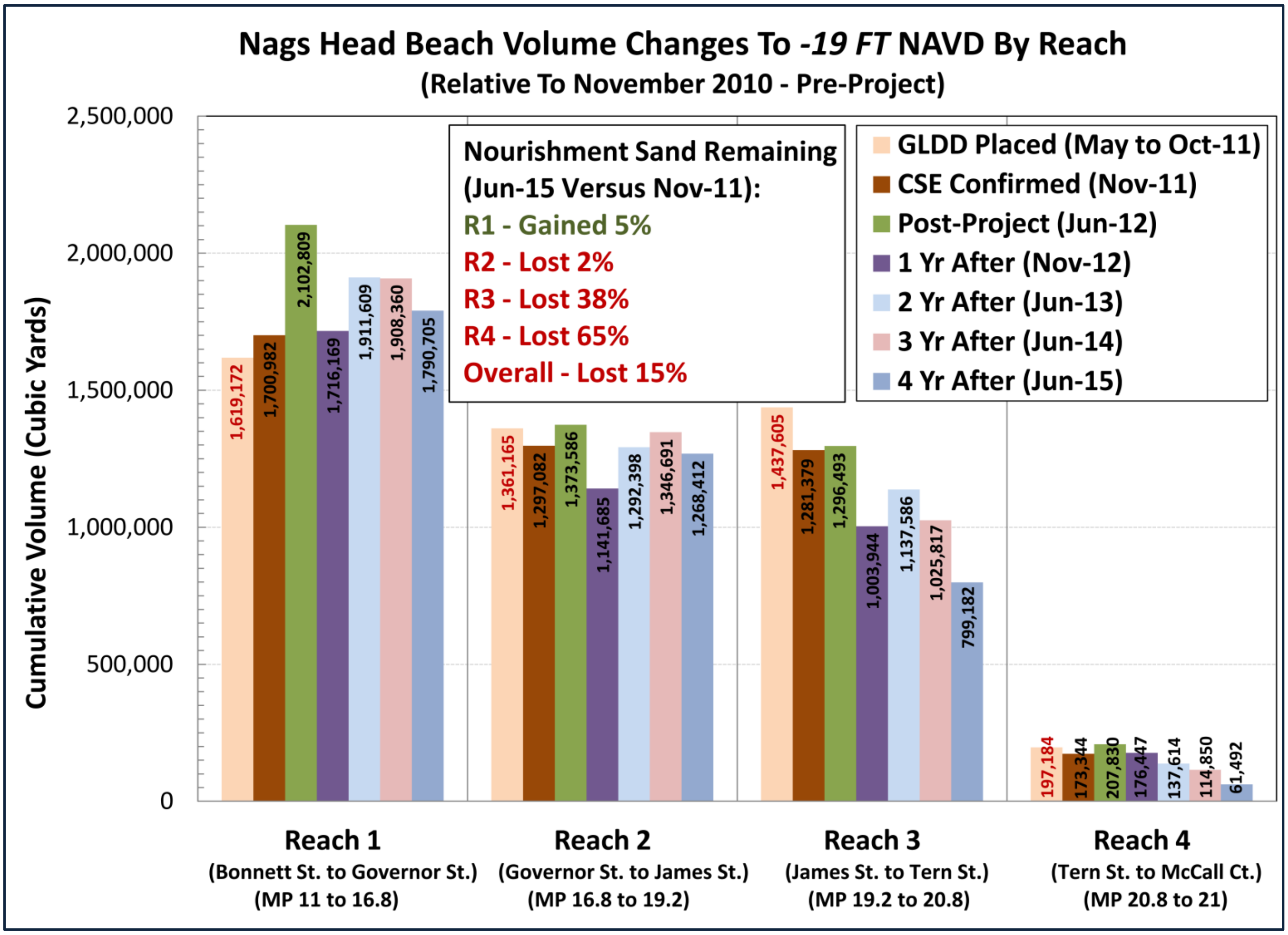


FIGURE 5.5. Beach volume changes by reach relative to November 2010 survey results from the face of dune to −19 ft NAVD. Nourishment sand loss or gain since project completion in November 2011 is illustrated in the figure.

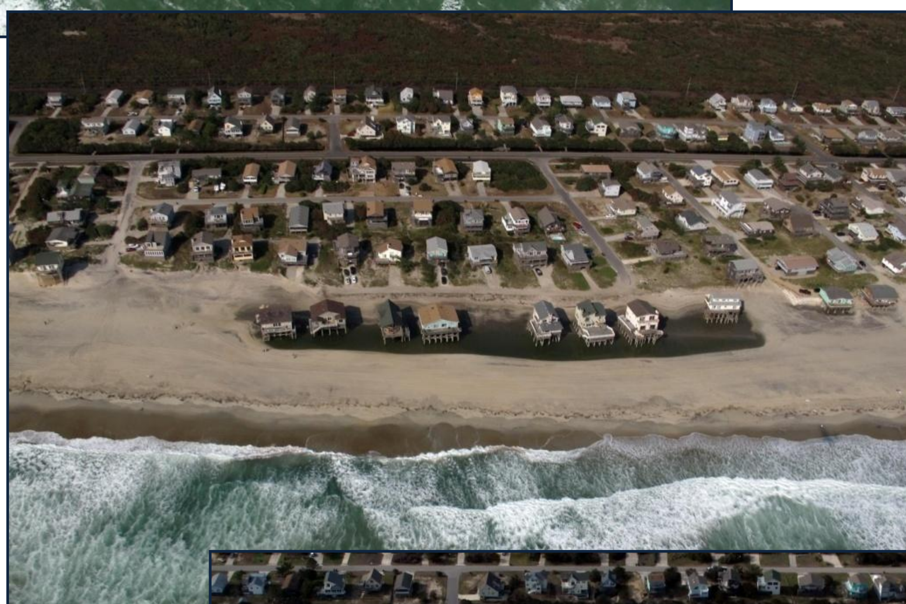
Figure 5.6 and Figure 5.7 illustrate conditions before and after nourishment at Seagull Drive near station 995+00. Prior to nourishment, condemned houses along Seagull Drive were sitting in the surf, and the official MHW contour was positioned under the buildings. The remnant of dry beach terminated 60 ft **landward** of the houses before the project. State regulations precluded nourishment over exposed sandbags, so the project had to work around the Seagull houses. This resulted in no sand placement in the low areas around the houses, which resulted in a pond (see middle photo of Fig 5.6).

Fall northeasters in 2011 washed over the nourished beach and eventually pushed sand into the pond (see bottom photo of Fig 5.6). The width of dry beach increased as much as 190 ft **seaward** of the houses after project completion. Although the dry-beach width is clearly narrower since project completion (Fig 5.7 and Fig 5.8, upper), the unit volume to −19 ft at this station remained relatively stable between November 2012 and June 2014 (Fig 5.8, lower). During the past year, unit volume at this station decreased ~20 cy/ft to the −19 ft depth contour, leaving only ~46.4 cy/ft more sand along this station than before nourishment. Sand accretion under the houses and seaward movement of the +6-ft contour are obvious in the profile comparisons in Figure 5.8 (lower).

The landward and offshore shift of sand had the important effect of creating a more natural profile with new sand bars forming in shallow water. Prior to adjustment of the nourishment project, surf conditions were unfavorable and dangerous in some areas because of the steep slope of the wet beach. However, after storms impacted Nags Head and modified the profile, the resulting underwater bars produced more favorable surfing conditions.*

*[*All beaches experience profile adjustment which is simply the response of the beach to changing wave heights and water levels. Beaches absorb and dissipate wave energy with the universal response being a flattening of the profile as wave energy increases (Komar 1998). A flatter profile provides a broader wet-sand beach over which waves lose their energy. The character of breaking waves and swash also produces favorable changes. This is why the wave runup during Irene across the wide nourished beach did not attain the heights along some narrow-beach sections of Dare County (cf – McNinch et al 2012). After storms subside, the flatter profile tends to adjust again. Lower waves will shift sand from the shallow-water bars back to the dry beach.*

The initial adjustment of the Nags Head beach nourishment project was, therefore, a combination of offshore movement due to the inherently unstable configuration of sand upon placement and the adjustment due to storms. Profile volumes, as measured before and after the project, provide an objective measure of the net impact. CSE believes the single most important finding of the pre- and post-construction surveys is the negligible loss of nourishment sand within the project limits. The critical boundaries of concern are the ten-mile alongshore length and the cross-shore between the foredune and −19-ft NAVD contour. These boundaries define a box which contained 4.6 million cubic yards less sand before the project. The volume of nourishment sand remaining in that box over time will define the performance of the project. (CSE 2012)]



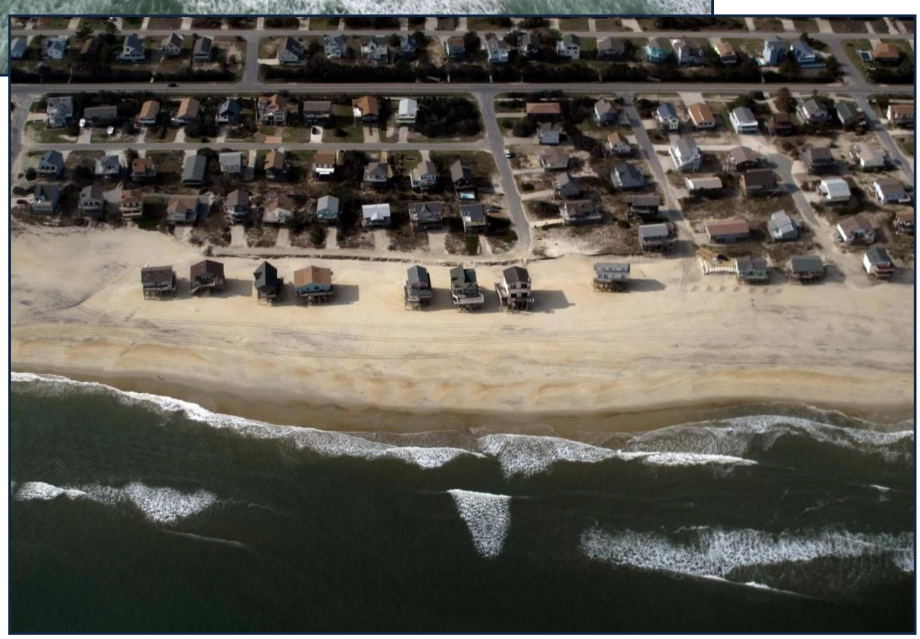


FIGURE 5.6.

Aerial views of south Nags Head at Seagull Drive.

[UPPER]
23 February 2011 – before nourishment.

[MIDDLE]
2 September 2011 – after nourishment and Hurricane *Irene* (note pond).

[LOWER]
21 November 2011 – after nourishment and fall northeasters.

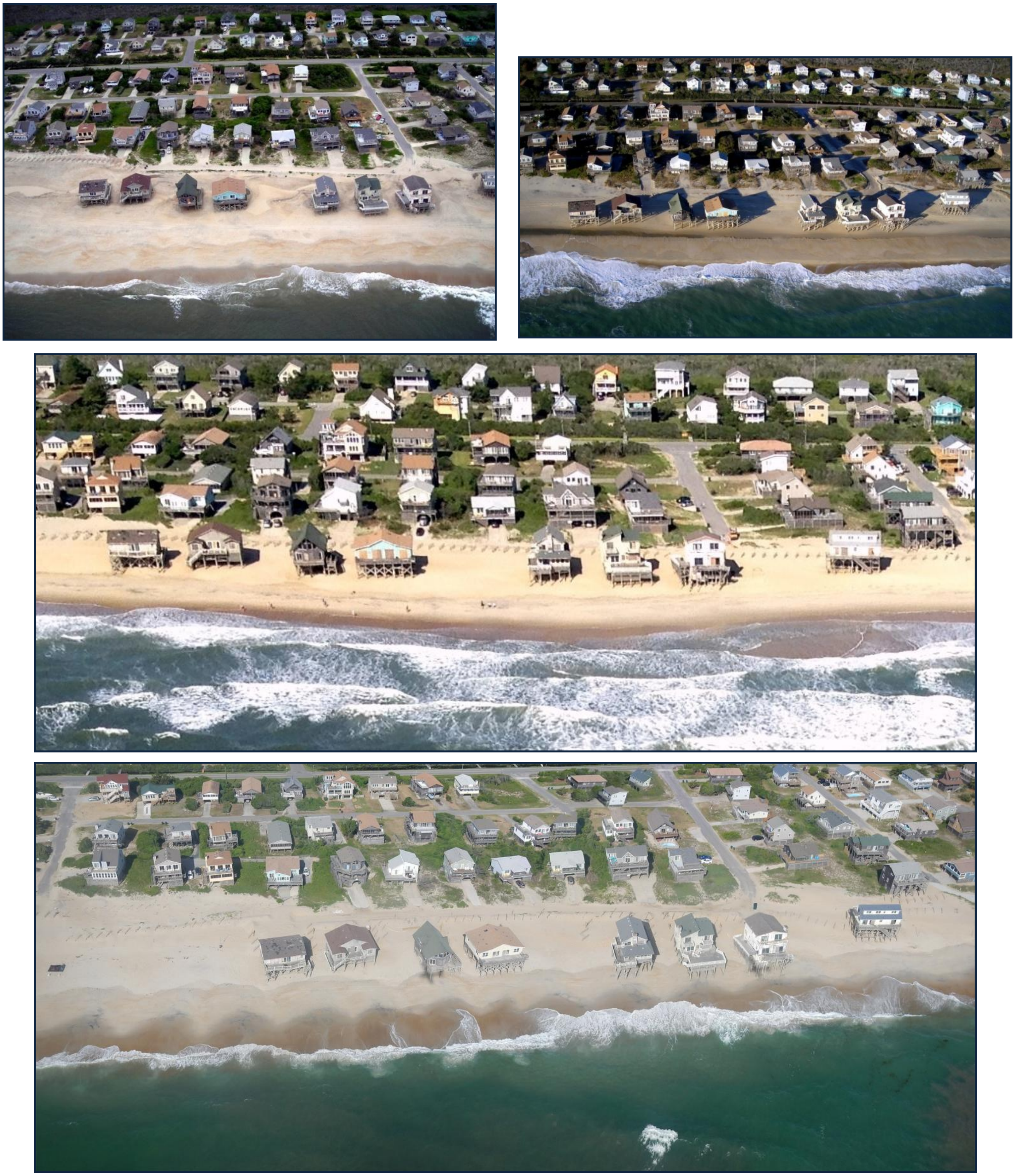
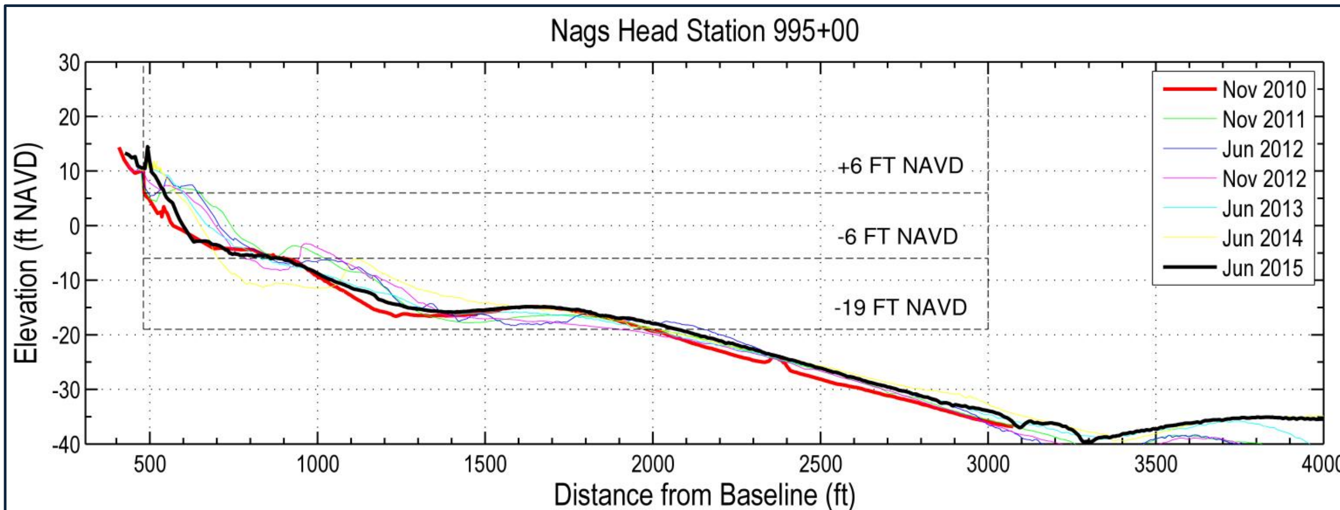


FIGURE 5.7. Aerial views of south Nags Head at Seagull Drive.
[UPPER LEFT] 12 June 2012 – before 2012 hurricane season. **[UPPER RIGHT]** 3 November 2012 – after Hurricane *Sandy*. **[MIDDLE]** 20 JUNE 2013 – before 2013 hurricane season. **[LOWER]** 7 June 2014 – before 2014 hurricane season.



Unit Volume from the Face of Dune to Indicated Depth Contour (CY/FT)

Date	To +6 FT	To -6 FT	To to -19 FT
Nov 2010	0.1	57.0	429.9
Nov 2011	2.3	127.0	524.7
Jun 2012	6.3	114.1	521.2
Nov 2012	5.6	107.6	499.7
Jun 2013	14.0	107.1	493.6
Jun 2014	13.4	88.1	497.5
Jun 2015	8.2	73.1	476.3

Photo: 7 Jun 2014 IMC

FIGURE 5.8. **[UPPER]** Aerial photo taken on 28 June 2015 – before 2015 hurricane season. Six abandoned houses were removed in May 2015, and only one remained at the time when the photo was taken. **[LOWER]** Complete profile from the back of the house to deep water. Unit volumes of each survey are listed in the figure.

6.0 DUNE BEHAVIOR

Dunes play an important role in protecting the developed coast from erosion by providing a buffer to high waves and winds. Extreme storm activity inevitably results in elevated water levels and beach erosion and may lead to coastal flooding. If a well-developed dune system is present behind the beach, storm waves will dissipate their energy against the dune, rather than penetrating into developed backshore areas. The sand eroded from the dune system will be transported offshore, but much of it will eventually return to the beach under fair-weather conditions. As the sediment is returned to the beach, aeolian (ie – wind-generated) processes lead to renewed dune development. Therefore, maintenance of coastal dune systems is an important component of coastal protection and management.

6.1.1 Dune Behavior – Before and After Nourishment

Unit volumes in the dune (between the face of the dune to +6 ft NAVD) along Nags Head for numerous surveys before nourishment are plotted and compared in Figure 6.1. The quantity of sand varied from north to south, as did the volume-change rates from survey to survey. However, the general trends reveal an average annual loss of ~1 cy/ft/yr in the back beach and dune areas between 1994 and 2010. Note how much more sand was along the south Nags Head dune line in 1994 (green line in Fig 6.1).

In 2011, 4.6 million cubic yards of sand from offshore borrow areas were placed along the 10-mile stretch of beach in Nags Head. Ninety-four percent (94%) of the nourishment sand was placed on the beach between +6 ft NAVD (nourishment berm) and -6 ft NAVD (low-tide terrace). After project completion, CSE's survey in November 2011 showed that there was 171,435 cy more sand above +6 ft NAVD in the foredune compared to the pre-project condition in November 2010 (see Figure 5.1). Three and a half years after project completion in June 2015, an additional 807,622 cy were detected in the foredune along the 10−mile beach compared to the November 2011 condition, equivalent to an increase of 15.3 cy/ft or 4.2 cy/ft/yr. Surveys between November 2010 and June 2015 are plotted and compared in Figure 6.2.

The wide dry beach constructed by nourishment provided a new sand source for aeolian transport and made natural dune growth possible. Sand fencing, installed after the project, has concentrated sand along the back beach and enhanced the foredune. The extra volume and elevation in the dunes has provided a higher level of storm protection, which helped Nags Head avoid any major damage to oceanfront properties during Superstorm *Sandy* (28 October 2012) or numerous severe winter storms since project completion.

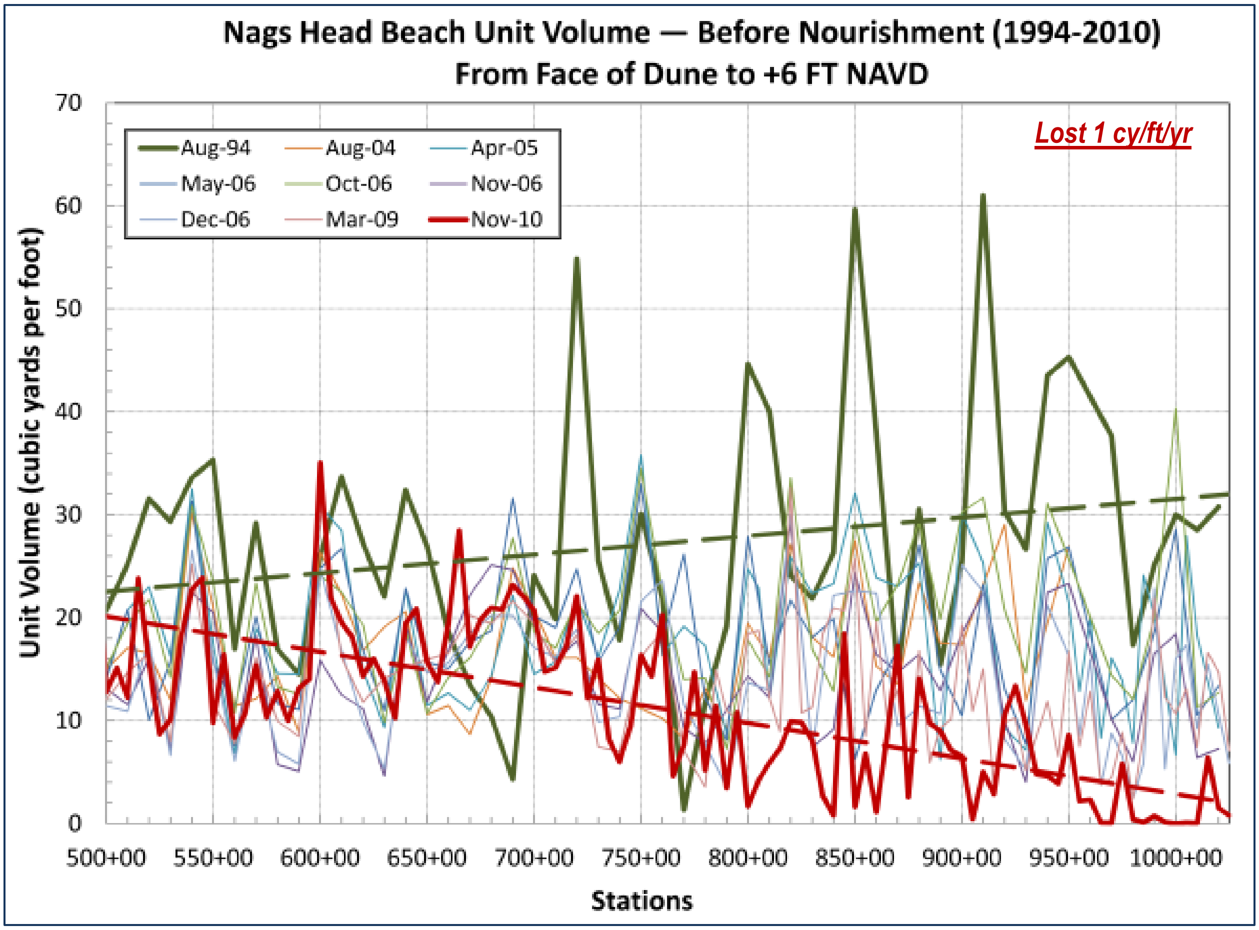


FIGURE 6.1. Nags Head unit volume changes before nourishment between August 1994 and November 2010 in the back beach and dune areas above the +6 ft contour.

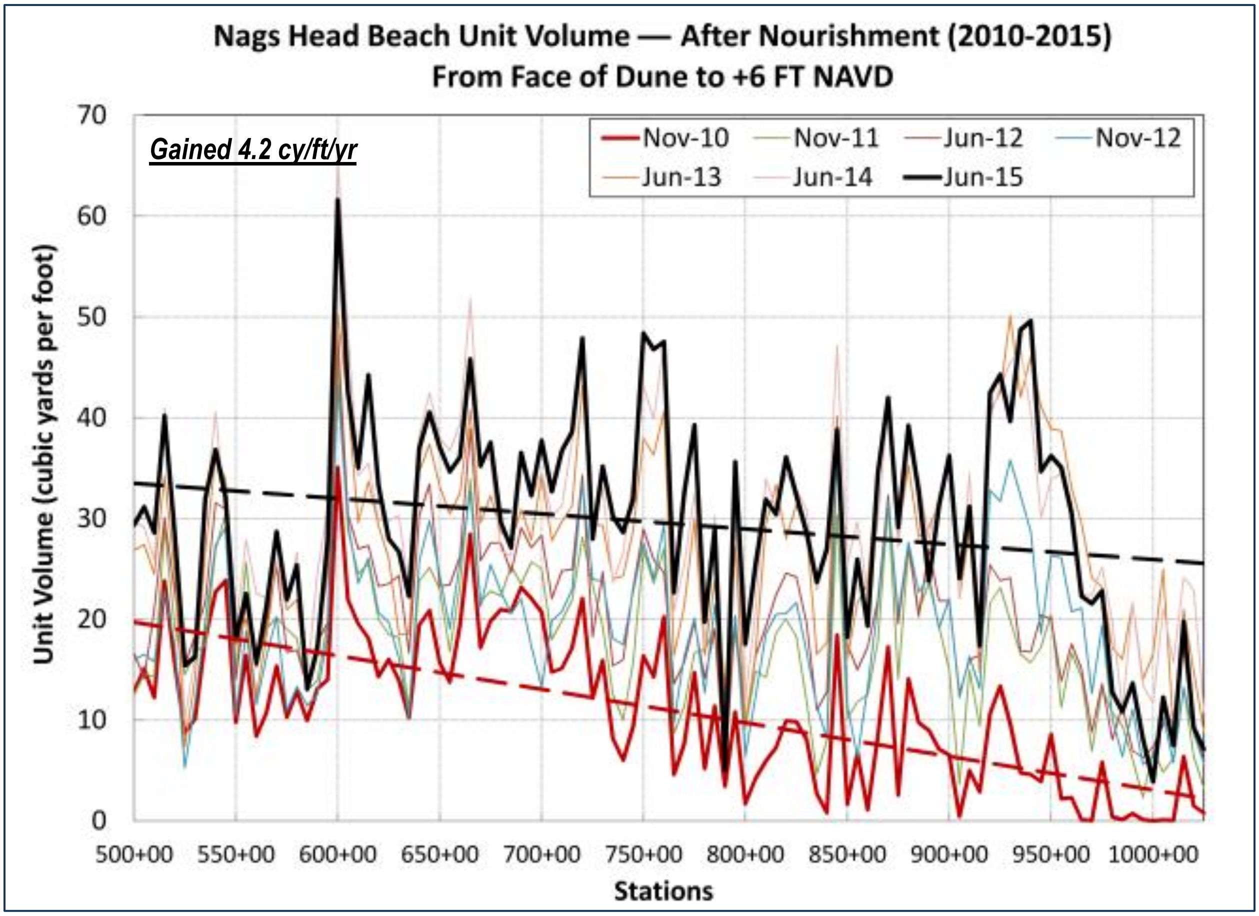


FIGURE 6.2. Nags Head unit volume changes after nourishment between November 2011 and June 2015 in the back beach and dune areas. Unit volume in November 2010 (before nourishment) is plotted as well for comparison.

6.2 Incipient Dune – Formation and Stabilization after Nourishment

Foredunes are shore-parallel, convex, and symmetric to asymmetric dune ridges formed on the top of the backshore by aeolian sand deposition within vegetation. There are generally two main stages of foredunes — incipient and established — within which there can be wide morphological and ecological variations. On stable shores, incipient foredunes have an episodic life, tending to be eroded or completely removed by severe storm events, commonly scarped by minor to moderate erosion, and growing to the high-tide swash limit during accretionary periods. Given sufficient time and suitable conditions (onshore winds and adequate sand supply, ie – nourishment or natural accretion), the incipient foredunes will coalesce, forming a continuous foredune or foredune ridge.

The photos in Figure 6.3 from station 855+00 in south Nags Head show sand accumulating over sand fences, gradually establishing an incipient dune. The lower image shows emergent vegetation on the dune. Similar new dune growth is occurring in other places along Nags Head. Ideally, the incipient dune will continue to grow and eventually become an established dune. However, as this occurs, the recreational beach is expected to narrow along south Nags Head within the next five years due to natural sand losses. The growth of a stable dune ridge will be checked by erosion, and the incipient dunes may not become fully established before the beach returns to the pre-nourishment condition.

FIGURE 6.3. Incipient dunes formed and stabilized after nourishment near station 855+00, and sand bags gradually buried. **[UPPER]** Photo taken on 11 June 2012, seven months after project completion, shows a row of sand fencing seaward of the sand bags. **[MIDDLE]** Photo taken on 5 June 2014, two years and seven months after project completion, shows a second row of sand fencing seaward of the first row. **[LOWER]** Photo taken on 27 June 2015, three years and seven months after project completion, shows a third row of sand fencing and sprouted vegetation on the dunes.

6.3 Dune Management – Strategy and Practice

One negative aspect of dune buildup has been encroachment of sand into private property where there is no fencing or vegetation to intercept it. This problem led the Town of Nags Head to apply for an emergency permit modification to the existing beach nourishment permit (CAMA Major Development Permit #45-10) for a dune maintenance and augmentation program in March 2014 (Appendix 6A).

The Town's four-level dune program was intended to "*provide the property owner flexibility should site constraints prohibit them from achieving one established standard.*" Based on the Town's records, 120 individual permits were issued in 2014, covering 145 separate oceanfront properties. The Town received 240 applications in 2015; these applications are good for one time only and are nonrenewable (per communication with D. Ryan on 7 October 2015).

Figure 6.4 shows evidence of dune encroachment on a swimming pool at the Sandspur Hotel in February 2014 and its condition after the emergency sand removal in June 2014 and June 2015.

After the Town's "First Phase – Short Term" emergency program, CSE helped the Town develop the "Second Phase – Long Term" plan in fall 2014 to establish uniform standards for enhancing dune growth and to provide guidance for positioning dunes relative to existing structures. Three categories of properties were determined based on the structure positions relative to the stable vegetation line (or projection of the line from adjacent properties). A strategy of sand fencing and vegetation was recommended for each category (CSE 2014b).

Dune profile data were collected by CSE in the vicinity of 11 stations (585+00, 620+00, 640+00, 745+00, 770+00, 820+00, 870+00, 895+00, 935+00, 970+00, and 995+00) in June 2014. Dune profile data near station 1010+00 at the south end of Nags Head were collected in June 2015 in addition to the above-listed 11 stations. The additional dune profiles depict conditions at nearby houses in the vicinity of the indicated monitoring stations.

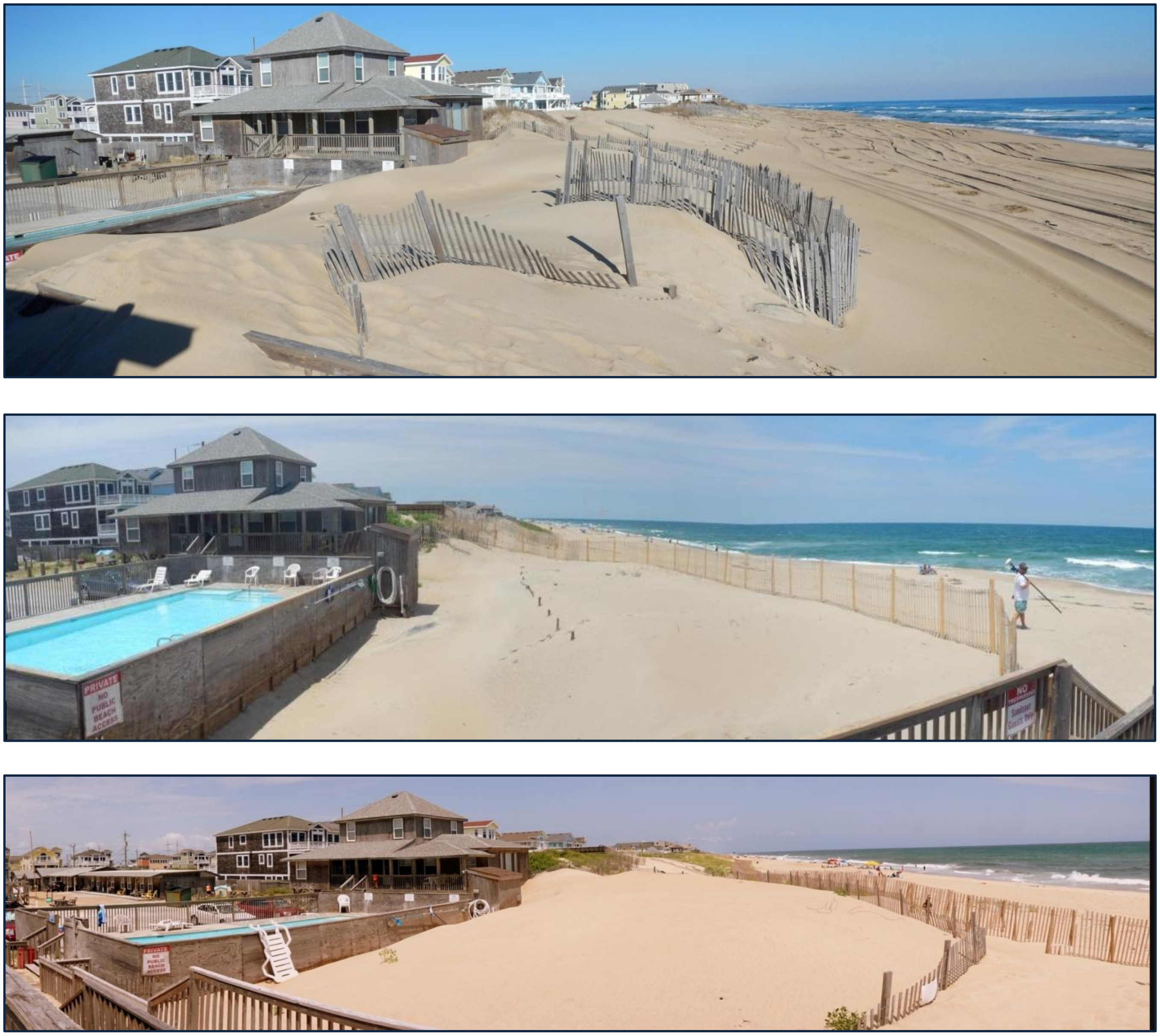


FIGURE 6.4. Photos at Sandspur Hotel near project station 735+00 and Jennette's Pier.

[UPPER] Photo taken by T Hair on 28 February 2014 showing the accreted sand encroaching on the swimming pool.

[MIDDLE] Photo taken on 6 June 2014 after the emergency sand relocation. Old fencing was almost completely buried, and new sand fencing was installed further seaward of the old line. Note that the new sand fencing was installed continuously like property boundary fencing.

[LOWER] Photo taken on 27 June 2015. Old fencing shown in the upper and middle photos was completely buried, and a new row of sand fencing was installed further seaward of the existing line. Note that the new sand fencing was installed at an ~45-degree angle to the shoreline, which is in compliance with the NCDCM's guidance on sand-fencing installation.

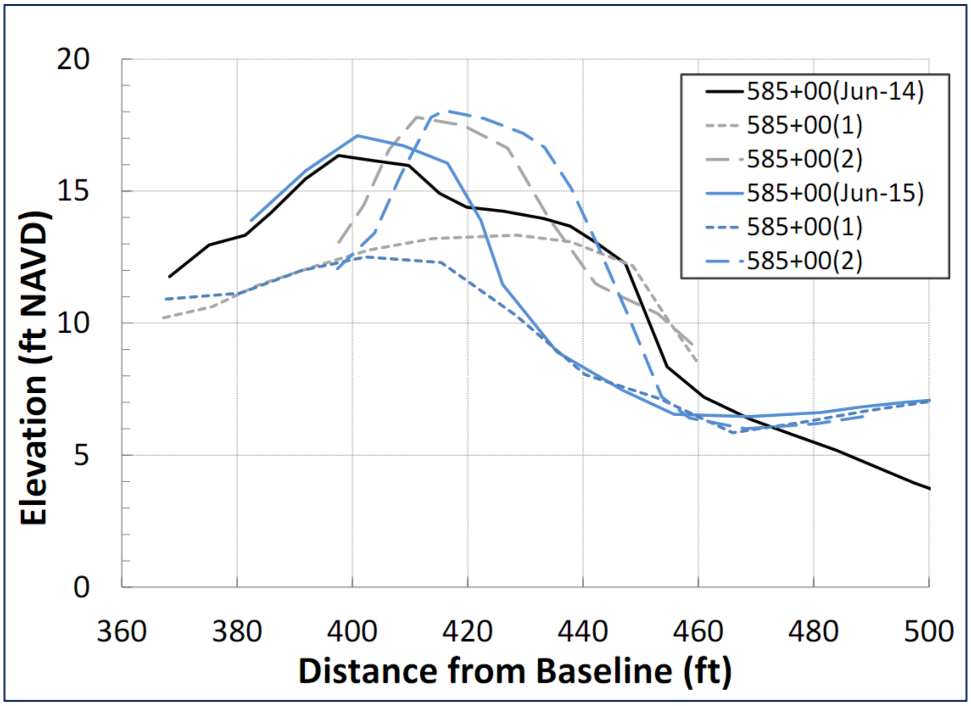
The upper graph of Figure 6.5(a) is an example of dune profiles collected near the vicinity of station 585+00. Locations of station 585+00 and lines 585+00(1) and 585+00(2) are marked on the aerial photo in Figure 6.5(a). *[Note that survey lines running across the properties are numbered in increasing order from south to north. The group of blue lines represents June 2014 profiles, and the group of black lines represents June 2015 profiles.]* Unit volumes in the foredune at station 585+00 are 14.1 cy in June 2014 and 13.1 cy in June 2015. The slight decrease of unit volume over the past year at this locality is consistent with the overall slight decrease of dune volume along the project area.

Photos in Figures 6.5(b) are ground photos taken on 27 June 2015 at this locality. There is no established dune in front of the property as can also be seen from the profile comparisons in Figure 6.5(a). The blue and gray, small dashed lines in the upper graph of Figure 6.5(a) represent profiles along line 585+00(1) in June 2014 and June 2015 (respectively). The lines show a much lower elevation compared to the adjacent station 585+00 and line 585+00(2).

Profiles for the other stations are plotted and compared in Appendix 6B. Representative ground photos near each station and the aerial photos showing the location of the stations are also included in Appendix 6B.

CSE computed average dry-beach width in June 2015 using the present survey results. Figure 6.6 shows beach widths (by 1-mile average) as measured between the toe of dune (+10 ft NAVD) and the approximate edge of dry sand (+5 ft NAVD) for November 2010 (pre-nourishment), June 2014 and June 2015. This unvegetated berm width is a measure of the effective dune building fetch for each mile of shoreline. It also provides an indicator of how much area exists over which dunes could form.

Figure 6.6 shows that the beach berm is wider in June 2015 than last year along the northern half of Nags Head (ie – Reach 1 or north of Jennette's Pier). The southern 1-mile of Nags Head (ie – Reach 4 and about one-third of Reach 3) lost 26.5 ft of dry beach over the past year. Reach 2 and the other two-thirds of Reach 3 were relatively stable with slightly decreased berm width. **The average berm widths at Nags Head are 47.7 ft in November 2010, 72.4 ft in June 2014, and 84.5 ft in June 2015.**



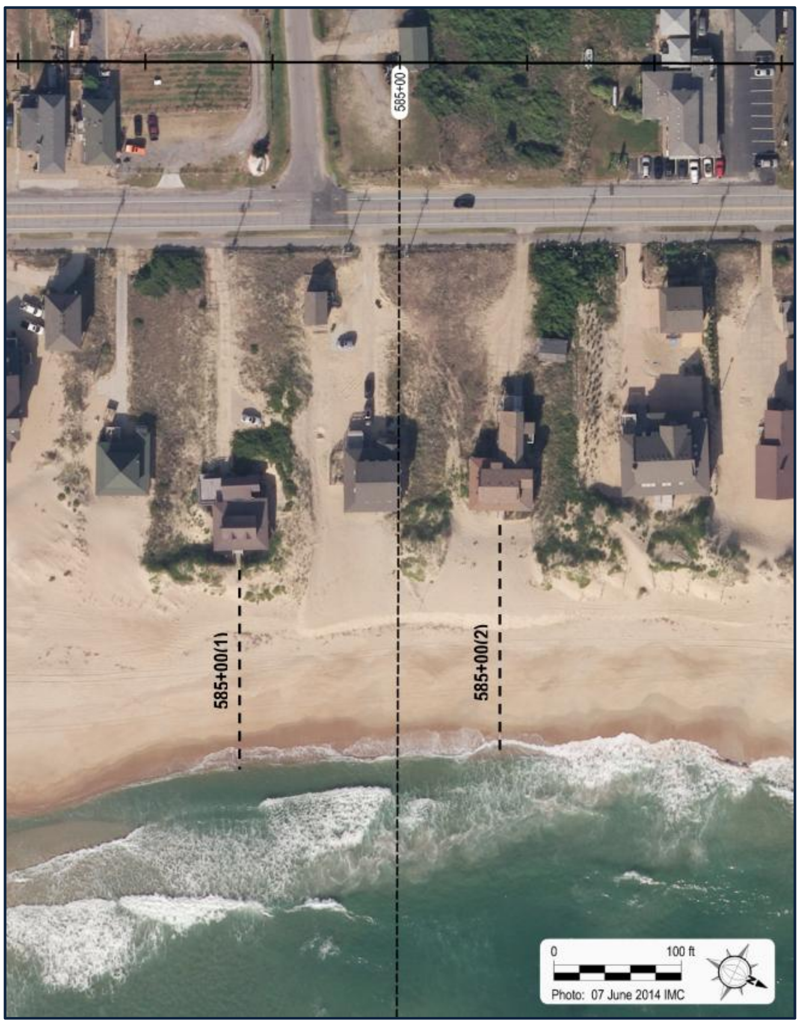


FIGURE 6.5(a).

[UPPER] Dune profiles in the vicinity of station 585+00. Black and gray lines represent profiles of June 2014, and blue lines represent profiles of June 2015.

[LOWER] Aerial photos showing the locations of station 585+00 and lines 585+00(1) and 585+00(2).

FIGURE 6.5(b). Ground photos taken on 27 June 2015 near line 585+00(1) showing the mature vegetation on both sides of the property, but lack of dune and vegetation in front of the property. **[UPPER]** Looking southwest. **[LOWER]** Looking northeast.

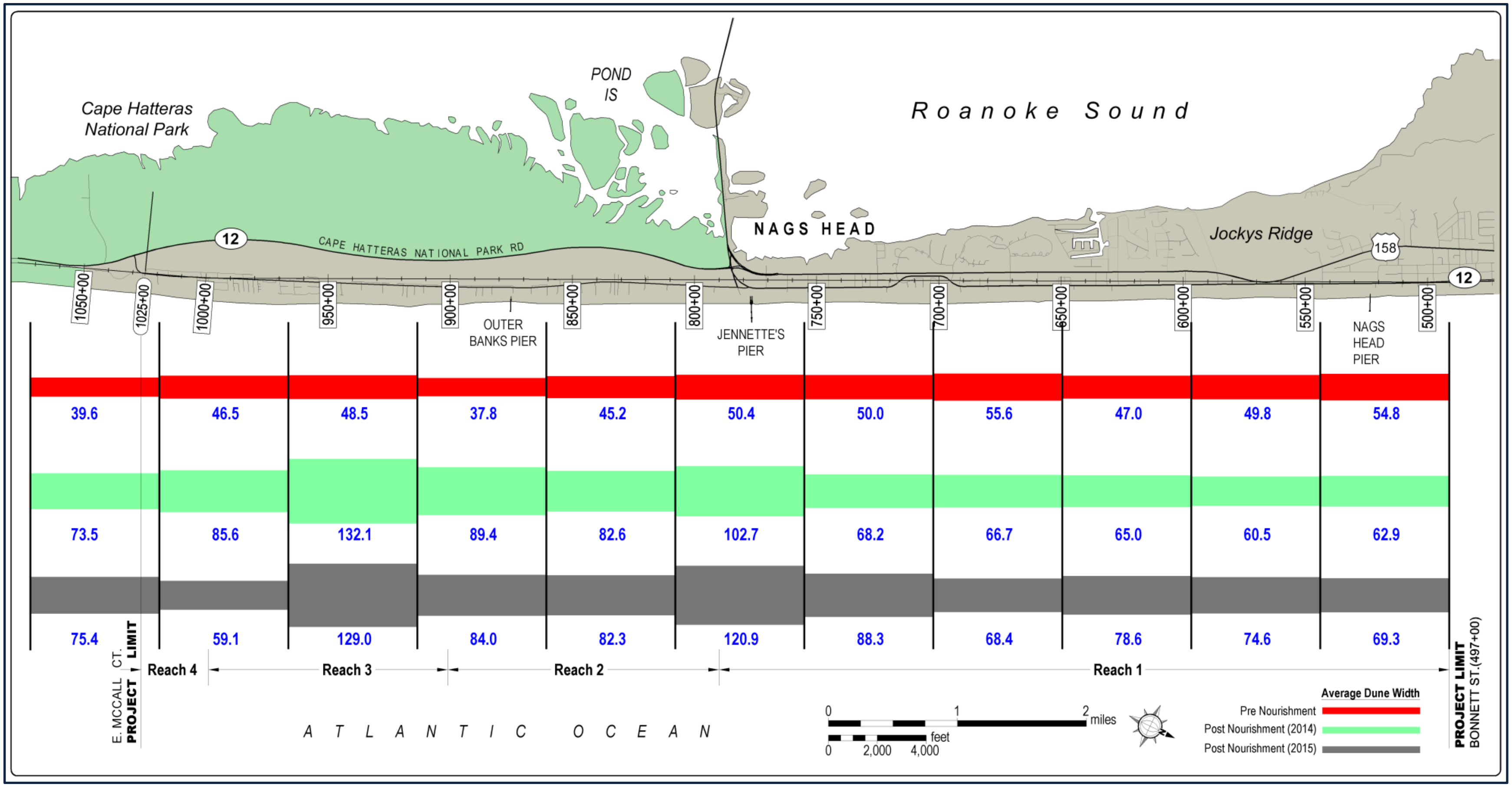


FIGURE 6.6. Average beach widths (ft) before and after nourishment between the toe of dune (+10 ft NAVD) and the approximate seaward edge of the dry beach (+5 ft NAVD) by mile along Nags Head. The overall average dry-beach width was ~47.7 ft in November 2010 before nourishment and has increased to ~72.4 ft in June 2014 after nourishment and profile adjustment. It continued to increase to ~84.5 ft in June 2015.

If the assumption is made that normal beach width varies by ~50 ft (summer to winter—a realistic approximation for Nags Head), the excess berm width beyond 50 ft provides a measure of space available for stable dune growth. It should be apparent from Figure 6.6 that Reach 1 has ~18–70 ft of berm width to accommodate dune expansion under this criteria. If Reach 1 continues to gain sand, that width will increase.

Reach 2 has an average dry-beach width of ~83 ft giving it an extra ~33 ft of width to accommodate dune building, which is slightly narrower than last year's results. As projected in CSE's previous report (CSE 2014b), this area is expected to diminish in the next five years as erosion removes sand and the beach narrows. Thus, new dunes significantly seaward of the existing vegetation line are not likely to grow and persist. Enhancement of the pre-nourishment scarp line is the preferred approach in this area.

The north half of Reach 3 (stations 920+00 to 970+00) contains the widest beach section with as much as 79 ft of extra width beyond the 50-ft criteria as of June 2015. This provides room for a new dune line, but with anticipated erosion, the new line should be positioned close to the existing vegetation line (ie – ≤25 ft seaward). The south half of Reach 3 (Stations 975+00 to1010+00) is losing sand rapidly due to its proximity to the end of the project area. Buildings encroaching more than 50 ft onto the beach in this reach generally cannot be protected by a new dune line in the next five years. Any encroachment measures implemented along these properties are likely to wash out during minor storms.

7.0 UPCOAST AND DOWNCOAST CHANGES

As part of the annual condition surveys, CSE obtained profiles upcoast and downcoast of the project area. The upcoast dataset covers station 430+00 (inside Kill Devil Hills town line) to station 495+00 (near the Nags Head project limit). The Nags Head town line is around station 436+83 (see Fig 1.2). Data are available for November 2010 and 2011, June and November 2012, June 2013, June 2014, and June 2015.

Downcoast of the project, CSE obtained profile data between station 1025+00 (project limit) and station 1080+00 (~1 mile south of the project along the Cape Hatteras National Seashore). Data are available for November 2010, June and November 2012, June 2013, June 2014, and June 2015. Changes in the downcoast and upcoast beaches partly reflect spreading of nourishment volume away from the project. Some changes are also associated with onshore and offshore transport. The available profiles are included in Appendix 3. Unit volumes are in Appendix 4; total volumes are in Appendix 5.

7.1 Upcoast Reach

Figure 7.1 and Table 7.1 show the cumulative volume changes relative to the November 2010 condition for the upcoast area. As the November 2011 bars indicate, there was a gain of ~12,492 cy (to −6 ft) and ~200,471 cy (to −19 ft) relative to the November 2010 condition. This initial gain, soon after completion of nourishment, mainly reflects sand spreading to the un-nourished area.

The June 2015 survey shows continued sand gains north of the project in the foredune and the beach with a net gain of ~81,084 cy (to +6 ft) and ~131,835 cy (to −6 ft) relative to the November 2010 condition. These net gains are similar to the last two years, indicating a relatively stable condition in the foredune and the beach. Measured to −19 ft NAVD, the upcoast reach lost ~50 percent of the volume over the past year compared to the post-project condition. This phenomenon is similar to the trend that was observed along Nags Head, and the annual erosion rate is equivalent to ~4.3 cy/ft/yr since project completion.

Regardless of the loss this year, the upcoast mile of beach has over 100,000 cy more sand than pre-project conditions from the foredune to the FEMA depth limit (−19 ft NAVD).

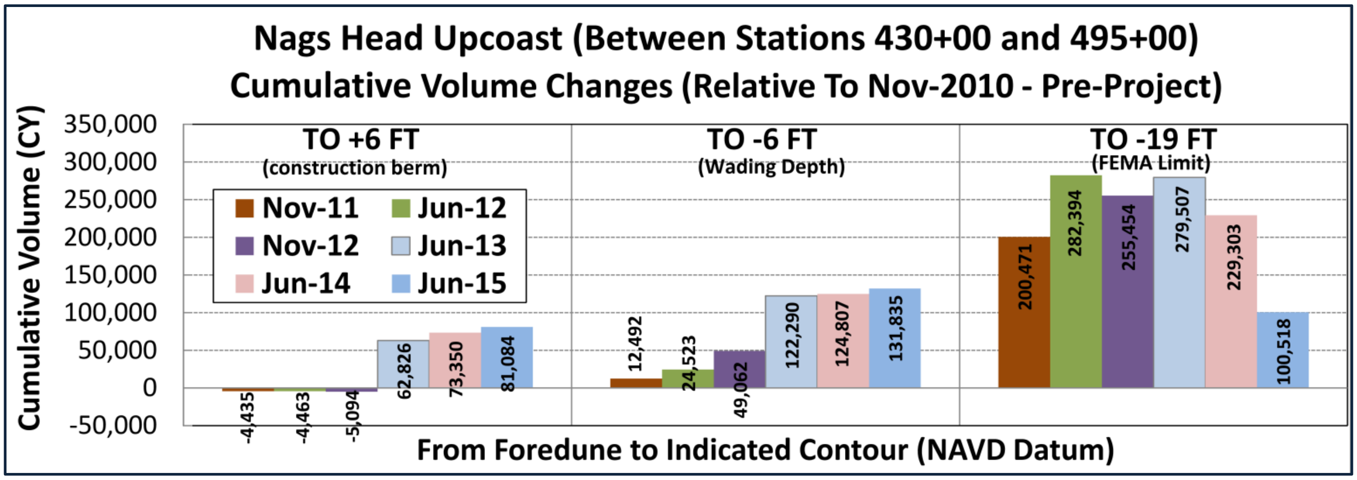


FIGURE 7.1. Cumulative volume changes from the foredune to the indicated contour relative to the November 2010 condition along **upcoast** stations outside the project area.

TABLE 7.1. Cumulative volumes and volume changes relative to November 2010 for **upcoast** stations. The north town line is near station 436+83. (The three lenses discussed in this study are highlighted in the table.)

Survey Date	Accumulated Total Volume Between Stations 430+00 and 495+00 (CY)						
	To +6 ft	To 0 ft	To -2.05 ft	To -6 ft	To -12 ft	To -19 ft	To -24 ft
Nov-10	188,552	393,413	485,402	717,713	1,457,903	3,303,789	5,325,401
Nov-11	184,117	394,245	491,605	730,205	1,592,815	3,504,260	5,575,476
Jun-12	184,089	409,282	506,847	742,237	1,592,444	3,586,183	5,669,514
Nov-12	183,458	373,066	481,599	766,775	1,553,377	3,559,243	5,597,602
Jun-13	251,377	485,736	584,105	840,003	1,629,315	3,583,296	5,741,959
Jun-14	261,902	490,759	583,541	842,520	1,593,835	3,533,092	5,668,875
Jun-15	269,636	502,457	595,064	849,548	1,577,677	3,404,307	5,573,375
Survey Date	**Total Volume Changes Relative to Nov-2010 (CY)**						
	To +6 ft	To 0 ft	To -2.05 ft	To -6 ft	To -12 ft	To -19 ft	To -24 ft
Nov-11	-4,435	832	6,203	12,492	134,912	200,471	250,075
Jun-12	-4,463	15,868	21,445	24,523	134,541	282,394	344,113
Nov-12	-5,094	-20,348	-3,803	49,062	95,474	255,454	272,201
Jun-13	62,826	92,323	98,703	122,290	171,412	279,507	416,558
Jun-14	73,350	97,345	98,139	124,807	135,932	229,303	343,474
Jun-15	81,084	109,044	109,663	131,835	119,774	100,518	247,974

7.2 Downcoast Reach

The ~1-mile-long downcoast reach between station 1025+00 and station 1080+00 **lost** sand in the foredune and on the beach over the past year (Fig 7.2 and Table 7.2). This erosional trend is consistent with the sand loss observed in the project area (see the third group of bars from the left in Fig 5.1), with an offshore shift of the outer bar to deeper water. The extra volumes relative to November 2010 conditions reduced from 245,775 cy (June 2012) to 125,554 cy (June 2015), measured from the face of dune to −19 ft depth contour, which is equivalent to an annual loss of ~7.3 cy/ft/yr during this period of time. Still, the downcoast reach contained more sand measured to the +6-ft, −6-ft, or −19-ft depths in June 2015 relative to November 2010 conditions. Some of this gain is likely associated with redistribution of nourishment sand under northeast wave conditions and possible sand movement from deeper water during high waves associated with Hurricane *Sandy*. Despite a trend of moderately high erosion since June 2013, the added volume above +6 ft has persisted, providing more beach width for users and wildlife.

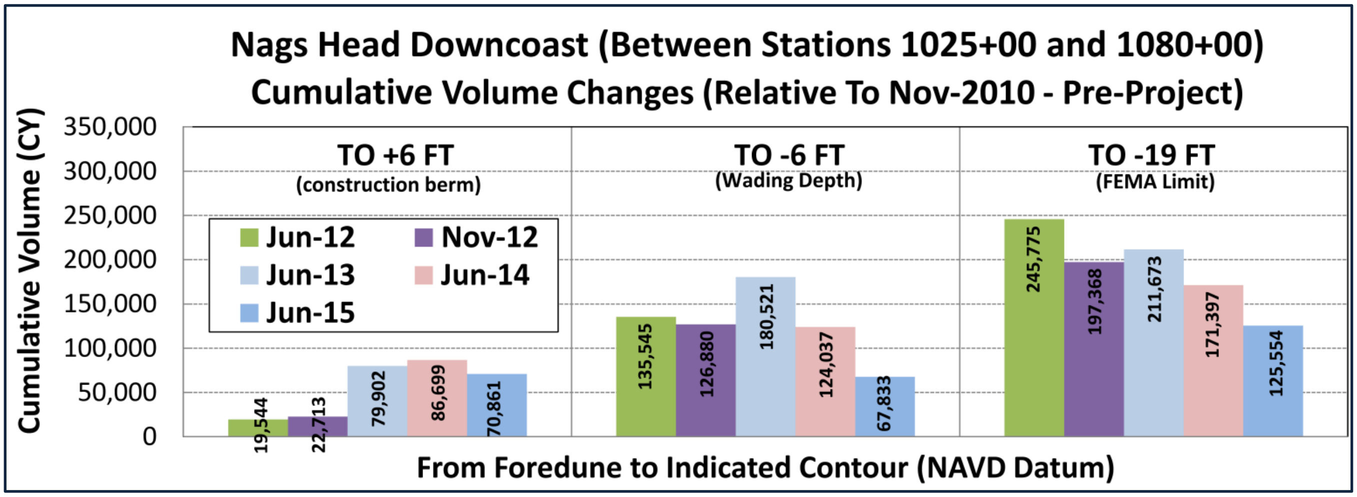


FIGURE 7.2. Cumulative volume changes from the foredune to the indicated contour relative to the November 2010 condition along **downcoast** stations outside the project area.

TABLE 7.2. Cumulative volumes and volume changes relative to November 2010 for **downcoast** stations. The south town line is near station 1025+00. The three lenses used in this study are highlighted in the table.

Survey Date	Accumulated Total Volume Between Stations 1025+00 and 1080+00 (CY)						
	To +6 ft	To 0 ft	To -2.05 ft	To -6 ft	To -12 ft	To -19 ft	To -24 ft
Nov-10	38,193	174,326	262,701	545,196	1,236,126	2,938,097	4,769,783
Jun-12	57,737	308,036	416,536	680,741	1,557,880	3,183,872	4,965,775
Nov-12	60,906	278,340	391,103	672,076	1,482,467	3,135,464	4,931,230
Jun-13	118,095	376,022	483,202	725,717	1,407,959	3,149,770	4,970,939
Jun-14	124,892	344,686	435,738	669,233	1,328,651	3,109,494	4,881,475
Jun-15	109,054	322,919	410,960	613,029	1,282,624	3,063,650	4,934,400
Survey Date	**Total Volume Changes Relative to Nov-2010 (CY)**						
	To +6 ft	To 0 ft	To -2.05 ft	To -6 ft	To -12 ft	To -19 ft	To -24 ft
Jun-12	19,544	133,711	153,835	135,545	321,753	245,775	195,992
Nov-12	22,713	104,014	128,402	126,880	246,341	197,368	161,446
Jun-13	79,902	201,696	220,501	180,521	171,833	211,673	201,155
Jun-14	86,699	170,360	173,037	124,037	92,524	171,397	111,692
Jun-15	70,861	148,594	148,259	67,833	46,497	125,554	164,617

8.0 BEACH SEDIMENTS

In accordance with the monitoring plan, periodically CSE collects representative sediment samples. These samples are taken from the project area and immediately adjacent unnourished sections of Nags Head and Bodie Island for the recreational beach zone for purposes of documenting changes in sediment texture. *[Note: Some of the sediment sampling has been performed in connection with seasonal biological sampling (2011–2013). CSE only collected sediment samples in Years 2 (2013) and 4 (2015) during the present five-year performance monitoring period.]*

8.1 Pre-Project Sediment Analyses for the Recipient Beach and the Borrow Areas

Before nourishment, sediment samples of the native beach were collected by CSE from the dune to outer bar at −20 ft NGVD following the NCCRC standard sampling protocols in November 2008 (CSE 2011a). The positions of the 14 transects are noted in Figure 8.1, and the 13 sample positions across each profile are illustrated in Figure 8.2. The mean grain size of all native beach sand samples (from dune to −20 ft NGVD) ranged from 0.136 millimeters (mm) to 1.641 mm, and averaged 0.306 mm. The mean grain size of the **visible beach** (from dune to mean low water) averaged 0.385 mm with a standard deviation of 0.641 mm and shell content of 1.9 percent. No samples possessed sediment in the pebble or cobble (4.76 mm or greater) size class.

Based on collection of 100 borings by CSE between 2005 and 2008 in the borrow areas (CSE 2005, 2008, 2011a), mean grain size for the offshore samples was generally uniform with sparse areas of fine and coarse sand occurring. Mean grain size ranged from 0.194 mm to 0.782 mm for individual samples with an average grain size of **0.410 mm**. Gravel-sized (or greater) sediment comprised negligible amounts in the offshore samples. Shell content was also relatively minor, generally <3 percent.

8.2 Sediment Analysis during Construction Phase

During the 2011 nourishment construction, CSE collected a composite-grab sample from the last station completed during their daily construction observations. A composite sample consisted of a series of grab samples at ~10-ft spacing along a transect from the landward limit of fill to the low-tide line mixed together to form one representative sample for the given station. Some additional single-point grab samples in the vicinity of the discharge point were also collected.

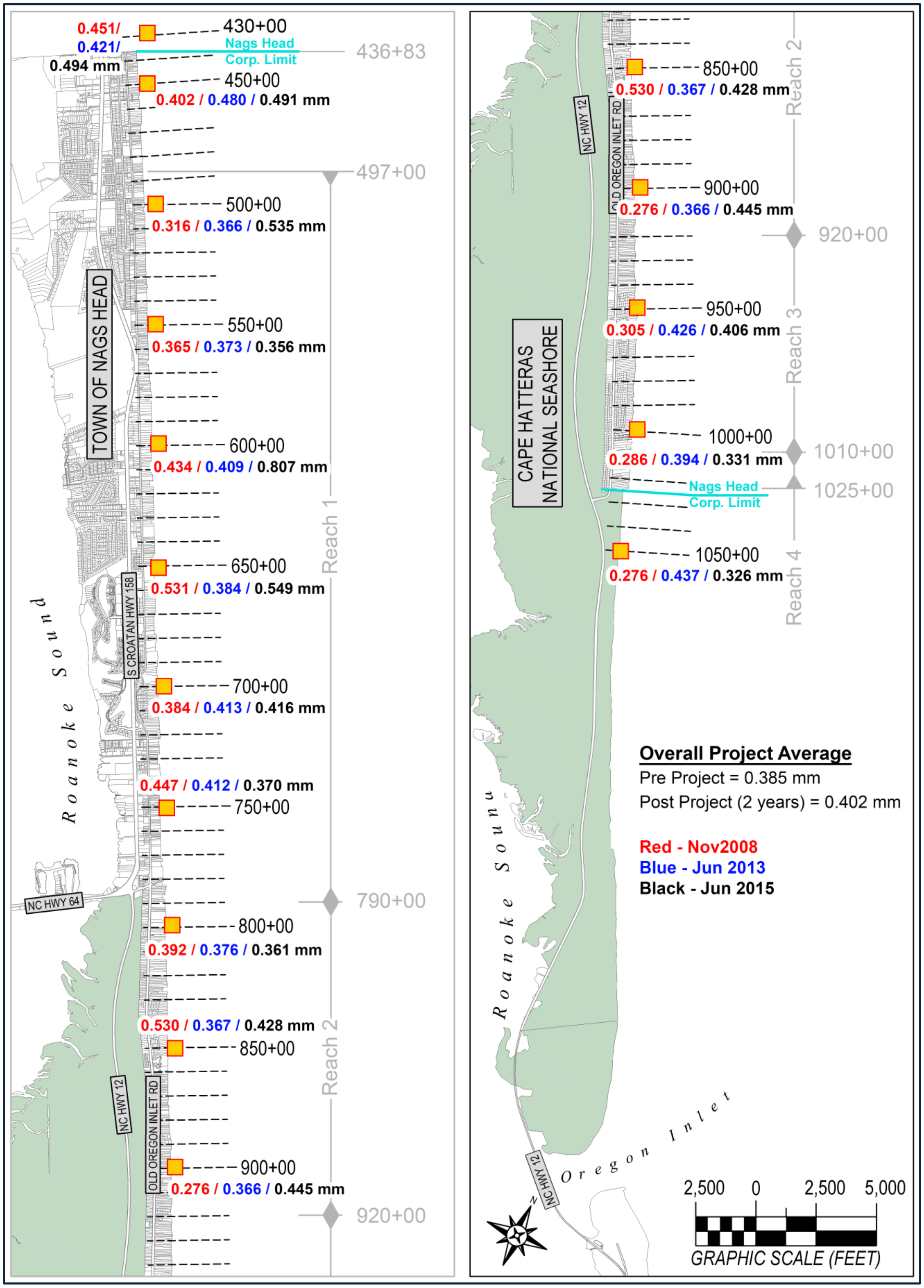


FIGURE 8.1. Location of sediment samples collected at Nags Head (NC) from stations 430+00 to 1050+00. Mean grain sizes at sampling stations in June 2013 and June 2015 are illustrated in blue and black numbers; and red numbers are for November 2008.

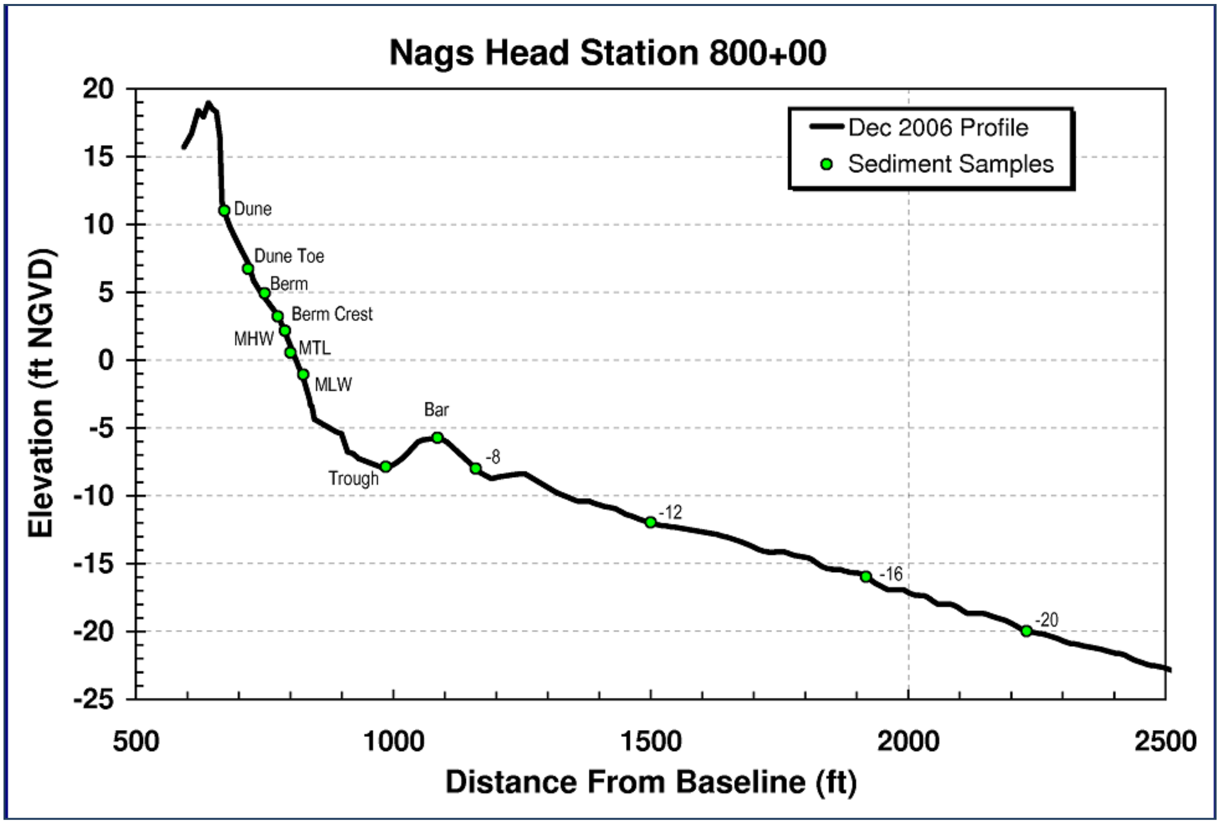


FIGURE 8.2. Sampling positions of 13 samples per transect from dune to −20 ft NGVD (green dots) used to characterize the recipient beach at Nags Head prior to nourishment. June 2015 samples focus on the visible beach and included only the dune, berm, berm crest, MHW, and LTT (near MLW).

Selected sand samples were analyzed to determine grain-size characteristics and shell content as a means of monitoring the quality of the material actually placed on the beach. No samples possessed abundant sediment in the gravel-size (2.0 mm or greater) class, and the mean grain size of the composite samples averaged 0.439 mm with a standard deviation of 0.588 mm and shell content of 1.7 percent (CSE 2012).

8.3 Sediment Analysis in June 2015

CSE collected sediment samples in June 2015 (Year 4) at the same 14 transects (~5,000-ft spacing, spanning stations 430+00 to 1050+00) as the pre-project studies. Five samples per transect were collected between the toe of the dune and the low-tide wading zone. *(Positions of the transects and cross-shore sample locations are given in Figures 8.1 and 8.2.)* Samples were split for granulometric and shell analysis and were tested in the lab using standard ASTM (American Society for Testing and Materials) procedures. Grain-size distributions were based on 0.25-phi intervals (21 sieves in the sand-size range). Additional coarse sieves were used for samples which showed observable concentrations of coarse-shell or gravel material. Fines were reported as a percentage of the total based on the quantity passing the #230 sieve (ie − <0.0625 mm diameter).

The results, composited by station, were compared with pre-project and construction data by means of tables and graphs. Results of individual grain-size distributions are reported in Appendix 7 using the Method of Moments as well as traditional graphic methods for calculating mean grain size and related sorting and skewness statistics.

Abbreviations corresponding to morphologic features listed on laboratory data sheets are as follows:

- Dune Toe – near base of dune at the primary change in slope
- Berm – on top of the dry beach between the dune and the berm crest
- Berm Crest – near the high-tide swash line and seaward edge of the dry beach
- MHW – about midway along the sloping beach face in the swash zone
- LTT – near the low-tide mark, wave plunge point

As the cross-section in Figure 8.2 shows, the samples collected in June 2015 represent the primary features of the visible beach. Typical grain sizes by position on the beach were produced by averaging the results of the individual samples. The primary size statistics for the dune, berm, berm crest, MHW, LTT, and all samples combined are listed in Table 8.1. The results indicate the June 2015 samples did not contain significant gravel-sized sediment, and the mean grain size of the nourished beach was **0.451 millimeters (mm) with standard deviation of 0.616 mm and an average shell content of 1.2 percent**.

Beach sediments in June 2015 were only 0.066 mm coarser than the pre-project condition. Size distributions along the length of the beach in June 2015 were slightly more uniform than before the project.

TABLE 8.1. Summary of sediment characteristics for samples at the 14 stations along Nags Head and the adjacent beach.

Nags Head — Beach Sediment Characteristics — June 2015										
CSE Station	Sample		Grain Size Distribution					Sediment Description		
	Location	ID	Mean (mm)	STD (mm)	Skewness	% Shell	% Gravel			
430+00	Dune Toe	430Dune	0.591	0.631	-0.232	2.8	0.9	cs	mws	sym
	Berm	430Berm	0.718	0.528	0.033	2.4	3.2	cs	ms	sym
	Berm Crest	430BC	0.455	0.530	-0.780	2.9	2.0	ms	ms	c-s
	MHW	430MHW	0.321	0.650	-0.984	1.5	0.1	ms	mws	c-s
	LTT	430LTT	0.384	0.580	-0.744	2.3	0.7	ms	ms	c-s
450+00	Dune Toe	450Dune	0.673	0.677	-0.071	1.6	0.6	cs	mws	sym
	Berm	450Berm	0.638	0.723	-0.116	1.3	0.1	cs	ws	sym
	Berm Crest	450BC	0.451	0.633	-0.189	1.3	0.4	ms	mws	sym
	MHW	450MHW	0.276	0.662	-2.123	0.9	0.3	ms	mws	sc-s
	LTT	450LTT	0.415	0.534	-1.007	1.9	2.0	ms	ms	c-s
500+00	Dune Toe	500Dune	0.548	0.594	0.228	1.6	0.2	cs	ms	sym
	Berm	500Berm	0.501	0.573	-0.472	1.5	1.5	cs	ms	c-s
	Berm Crest	500BC	0.439	0.593	-0.938	1.3	1.2	ms	ms	c-s
	MHW	500MHW	0.491	0.433	-0.623	1.9	7.6	ms	ps	c-s
	LTT	500LTT	0.699	0.350	-0.208	1.9	19.3	cs	ps	sym
550+00	Dune Toe	550Dune	0.292	0.689	-1.665	1.0	0.3	ms	mws	sc-s
	Berm	550Berm	0.419	0.392	-1.277	3.6	14.7	ms	ps	c-s
	Berm Crest	550BC	0.284	0.693	-1.202	1.0	0.1	ms	mws	c-s
	MHW	550MHW	0.268	0.647	-1.551	1.3	0.2	ms	mws	sc-s
	LTT	550LTT	0.516	0.411	-0.275	2.0	5.1	cs	ps	sym
600+00	Dune Toe	600Dune	0.352	0.712	-0.132	0.3	0.0	ms	ws	sym
	Berm	600Berm	0.364	0.631	-1.572	0.7	0.8	ms	mws	sc-s
	Berm Crest	600BC	0.389	0.626	-0.306	0.7	0.1	ms	mws	sym
	MHW	600MHW	1.655	0.268	0.451	4.2	52.5	vcs	ps	f-s
	LTT	600LTT	1.275	0.490	0.069	2.4	22.9	vcs	ps	sym
650+00	Dune Toe	650Dune	0.493	0.691	0.023	1.0	0.0	ms	mws	sym
	Berm	650Berm	0.380	0.682	-0.499	0.8	0.1	ms	mws	c-s
	Berm Crest	650BC	0.344	0.696	-0.622	0.6	0.0	ms	mws	c-s
	MHW	650MHW	0.300	0.635	-1.309	0.7	0.3	ms	mws	sc-s
	LTT	650LTT	1.227	0.342	0.184	2.6	35.9	vcs	ps	sym
700+00	Dune Toe	700Dune	0.358	0.685	-0.106	0.3	0.0	ms	mws	sym
	Berm	700Berm	0.462	0.738	-0.309	0.5	0.1	ms	ws	sym
	Berm Crest	700BC	0.408	0.684	-0.342	0.9	0.1	ms	mws	sym
	MHW	700MHW	0.361	0.666	-0.739	0.8	0.2	ms	mws	c-s
	LTT	700LTT	0.490	0.533	-1.069	1.6	3.1	ms	ms	c-s
750+00	Dune Toe	750Dune	0.354	0.649	-0.144	0.6	0.1	ms	mws	sym
	Berm	750Berm	0.377	0.799	-9.969	0.6	0.0	ms	vws	sc-s
	Berm Crest	750BC	0.333	0.721	-0.331	0.8	0.0	ms	ws	sym
	MHW	750MHW	0.348	0.650	-0.871	1.0	0.1	ms	mws	c-s
	LTT	750LTT	0.437	0.515	-0.300	1.7	0.9	ms	ms	sym
800+00	Dune Toe	8000Dune	0.339	0.758	0.038	0.5	0.0	ms	ws	sym
	Berm	800Berm	0.413	0.703	-0.136	0.6	0.1	ms	mws	sym
	Berm Crest	800BC	0.301	0.706	-0.683	0.7	0.1	ms	mws	c-s
	MHW	800MHW	0.256	0.676	-1.239	1.1	0.0	ms	mws	c-s
	LTT	800LTT	0.497	0.389	-0.279	2.9	5.4	ms	ps	sym

TABLE 8.1. (continued) Summary of sediment characteristics for samples at the 14 stations along Nags Head and the adjacent beach.

Nags Head — Beach Sediment Characteristics — June 2015										
CSE Station	Sample		Grain Size Distribution					Sediment Description		
	Location	ID	Mean (mm)	STD (mm)	Skewness	% Shell	% Gravel			
850+00	Dune Toe	850Dune	0.353	0.626	-0.641	0.7	0.1	ms	mws	c-s
	Berm	850Berm	0.288	0.666	-1.041	0.6	0.1	ms	mws	c-s
	Berm Crest	850BC	0.304	0.629	-1.412	0.9	0.8	ms	mws	sc-s
	MHW	850MHW	0.524	0.491	-0.155	1.7	1.9	cs	ps	sym
	LTT	850LTT	0.672	0.429	-0.450	1.8	8.5	cs	ps	c-s
900+00	Dune Toe	900Dune	0.475	0.550	-1.046	0.6	1.4	ms	ms	c-s
	Berm	900Berm	0.416	0.588	-1.434	0.9	2.1	ms	ms	sc-s
	Berm Crest	900BC	0.373	0.634	-1.023	0.4	0.6	ms	mws	c-s
	MHW	900MHW	0.298	0.682	-0.897	0.5	0.1	ms	mws	c-s
	LTT	900LTT	0.665	0.441	-1.026	1.1	11.2	cs	ps	c-s
950+00	Dune Toe	950Dune	0.453	0.703	-0.236	0.5	0.0	ms	mws	sym
	Berm	950Berm	0.412	0.786	-0.045	0.3	0.0	ms	vws	sym
	Berm Crest	950BC	0.421	0.735	-0.444	0.6	0.0	ms	ws	c-s
	MHW	950MHW	0.306	0.701	-0.588	1.0	0.0	ms	mws	c-s
	LTT	950LTT	0.438	0.472	-1.133	1.3	4.2	ms	ps	c-s
1000+00	Dune Toe	1000Dune	0.400	0.717	-0.498	0.2	0.0	ms	ws	c-s
	Berm	1000Berm	0.345	0.729	-0.151	0.3	0.0	ms	ws	sym
	Berm Crest	1000BC	0.290	0.702	-1.247	0.3	0.3	ms	mws	c-s
	MHW	1000MHW	0.290	0.684	-0.380	0.4	0.0	ms	mws	sym
	LTT	1000LTT	0.329	0.589	-0.952	1.1	0.7	ms	ms	c-s
1050+00	Dune Toe	1050Dune	0.472	0.739	-0.188	0.5	0.0	ms	ws	sym
	Berm	1050Berm	0.295	0.679	-0.689	0.8	0.3	ms	mws	c-s
	Berm Crest	1050BC	0.266	0.728	-0.406	0.8	0.0	ms	ws	sym
	MHW	1050MHW	0.329	0.600	-0.586	0.7	0.2	ms	ms	c-s
	LTT	1050LTT	0.269	0.646	-0.642	1.1	0.1	ms	mws	c-s
All Samples	Dune Toe		0.439	0.673	-0.334	0.9	0.3	MS	ms	sym
	Berm		0.431	0.658	-1.263	1.1	1.6	MS	mws	sym
	Berm Crest		0.361	0.665	-0.709	0.9	0.4	MS	mws	sym
	MHW		0.430	0.603	-0.828	1.3	4.6	MS	mws	sym
	LTT		0.594	0.480	-0.559	1.9	8.6	MS	mws	c-s
	Composite		0.451	0.616	-0.739	1.2	3.1	MS	mws	sym

CS-Coarse Sand; MS-Medium Sand; FS-Fine Sand
ps-poorly sorted; ms-moderately sorted; mws-moderately well sorted; ws-well sorted; vws-very well sorted
sc-s - strongly coarse-skewed; c-s - coarse-skewed; f-s - fine-skewed; sf-s - strongly fine-skewed; sym-near symmetrical

The composite texture and classification at the beach face were determined to be quartz sand, medium in size, and moderately well sorted.* The average content of shell material ($CaCO_3$) was 1.2 percent, and no sample tested more than 5 percent shell material which tends to be much coarser than quartz sand particles (Appendix 7). The composite grain size at **<u>all</u>** locations was determined to be medium sand. Except for dune toe samples, composite samples at other cross-shore locations were moderately well sorted. Except for low-tide terrace samples, composite samples at other cross-shore locations were symmetrical (ie – neither skewed toward coarser or finer sizes).

*[*Sorting indicates textural maturity. Well-sorted sediment samples imply that the sediments were transported over a great distance or have been in place for a long period of time, causing the grains to become well-rounded and well-sorted. Moderate to poor sorting indicates relatively shorter transport distances, or in the case of a renourished beach, more recent placement of sand.]*

The trend in mean grain size (referenced to CSE sampling stations and cross-shore positions) is shown in Figure 8.3. It is common for surficial grab samples to vary according to the wave and tide conditions that affect the sediment around the time of sampling. The June 2015 mean sediment sizes at different cross-shore positions are relatively uniform, varying from 0.361 mm (at berm crest) to 0.594 mm (low-tide terrace) in comparison to the 2008 samples which varied from 0.272 mm to 0.679 mm.

As Figure 8.3 suggests, the results in 2008 were skewed by a few samples (dune at station 850+00; berm at stations 550+00, 750+00, and 850+00; and LTT at stations 430+00 and 650+00), and so were the results in June 2015. A few samples had higher than average grain size, especially at MHW and LTT at station 600+00, LTT at station 650+00, and LTT at stations 850+00 and 900+00. The MHW sample at station 600+00 (Fig 8.4) contained 52.5 percent gravel (2.0 mm or greater). The samples at dune, berm, and berm crest were more uniform in 2015 than 2008.

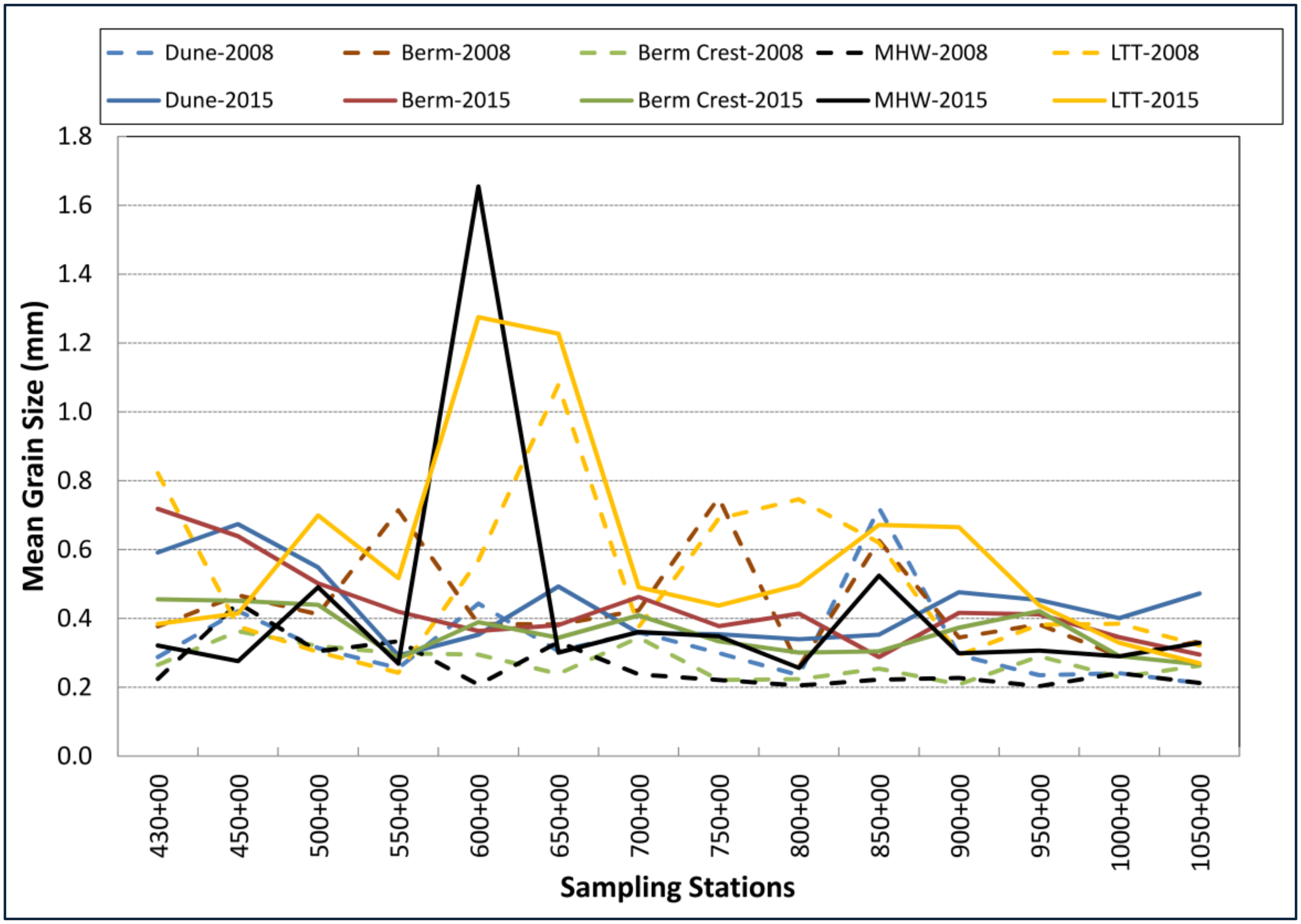


FIGURE 8.3. Alongshore sediment distribution of average grain size at specific cross-shore locations for all transects at Nags Head in June 2015 compared to the pre-project condition in November 2008.

FIGURE 8.4.

Sediment sample collected on the beach around mean high water mark at station 600+00. Note rounded pebbles.

Gravel content was 52.5 percent at this locality at the time of sample collection on 25 June 2015.

9.0 MONITORING & MAINTENANCE RECOMMENDATIONS

In accordance with FEMA Publication 321 and Code of Federal Regulations 44 CFR 206.226(j), a maintenance program involving periodic renourishment of sand must be established and adhered to by the Town of Nags Head to qualify for FEMA post-disaster assistance. The purpose of such a program is to track the physical condition of the beach after nourishment, quantify sand-volume changes, and determine whether the project qualifies for emergency renourishment following declared disasters. It is also intended to identify erosion hot spots and recommend small-scale maintenance renourishment, placement of sand fencing, and/or sand scraping so as to increase the life of the project.

CSE recommends that the Town of Nags Head continue to conduct an annual assessment of the physical condition of the nourished shoreline. The beach should be surveyed annually using the transect plan initiated by the USACE and CSE. Such surveys will give the Town an annual assessment of the beach condition and will reveal problem areas or erosion hot spots that require attention. Annual surveys should be conducted in May or June before the hurricane season. They will serve to document the beach condition prior to the occurrence of a major erosion event, such as a hurricane.

The principal monitoring results including sand volumes remaining in June 2015 by reach and depth limit were reported to the Town on 28 September 2015 at the Board Meeting. The area of south Nags Head including Reach 4 and the south half of Reach 3 has experienced higher erosion over the past two years. This area is between project stations 975+00 and 1025+00 as shown in Figure 9.1. However, the northern half of Reach 3 contains the widest beach (see Fig 6.6) and can be a large reservoir of nourishment sand which will continue to mitigate erosion at the south end of Nags Head. To better track erosion hot spots and document the condition of the entire profile, the Town should consider performing a fall survey along portions of the project. Erosion of the visible beach at a locality generally takes two forms:

1) Profile adjustment whereby sand in the upper beach shifts to the nearshore zone due to higher tides and waves (common in fall) or passage of storms.
2) Rhythmic shoreline salients and erosional arcs which propagate downcoast, alternately narrowing then widening the dry beach as a wave of sand moves along shore.

Supplemental surveys of Reaches 3 and 4 in November each year could be used to better document the fate of the nourishment along the critically eroding part of the project.

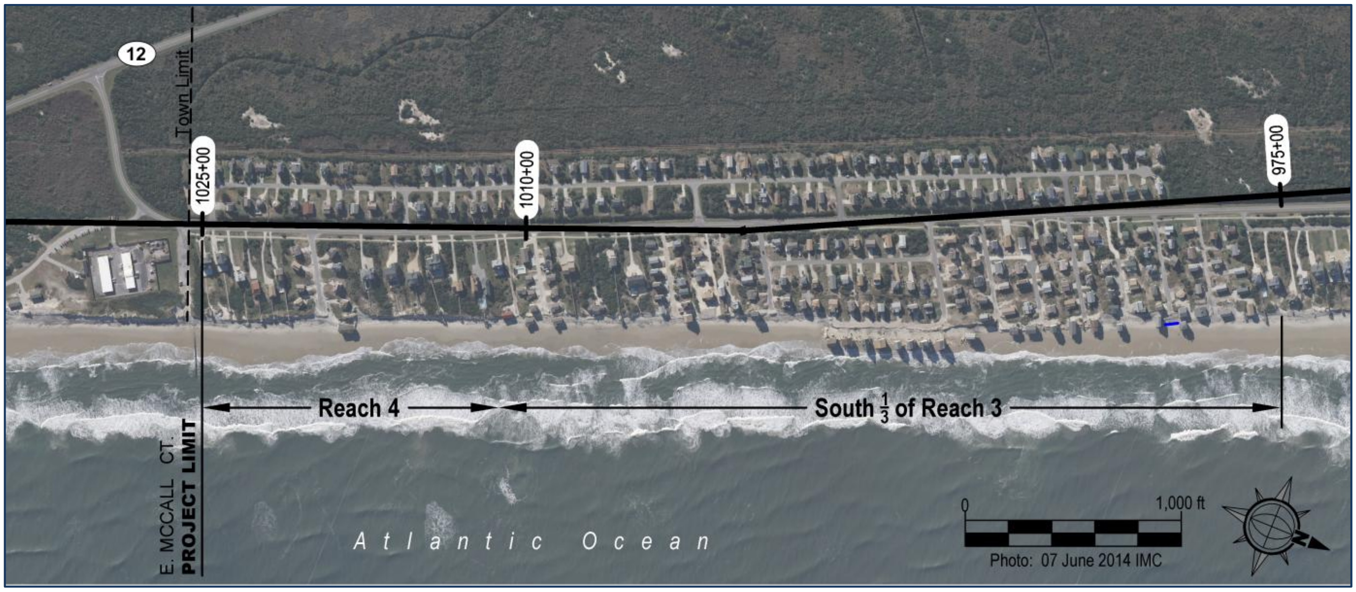


FIGURE 9.1. Higher erosion area along south Nags Head between station 975+00 in Reach 3 and station 1025+00 in Reach 4. The background aerial photo was taken on 7 June 2014 by IMC. The portion of Reach 3 to the north (out of the image) retained a large reservoir of nourishment sand which will continue to mitigate erosion at the south end of the project.

Should a major storm event occur, a post-storm survey should be completed for damage assessment as soon as possible after the storm. Since the project is an engineered beach fill, the annual and post-storm surveys can provide a basis for reimbursement and reconstruction of the beach with federal disaster funds under a community assistance grant (eg – FEMA Category G post-storm restoration funds).

Since project completion, especially under the Town's dune management program, sand fencing installed along Nags Head has been proven to trap sand effectively and to facilitate dune growth. Sandbags were nearly buried, and incipient dunes had formed. A new line of sand fencing, installed on top of the existing fence line or seaward near the toe of dune, has trapped more sand. Vegetation propagation has been observed along the project area.

News reports during the present monitoring period for the Nags Head nourishment project are included in Appendix 8. The next physical monitoring activity scheduled under the present agreement between the Town of Nags Head and CSE is a full condition survey in June 2016 before the hurricane season.

10.0 SELECTED PHOTOGRAPHS

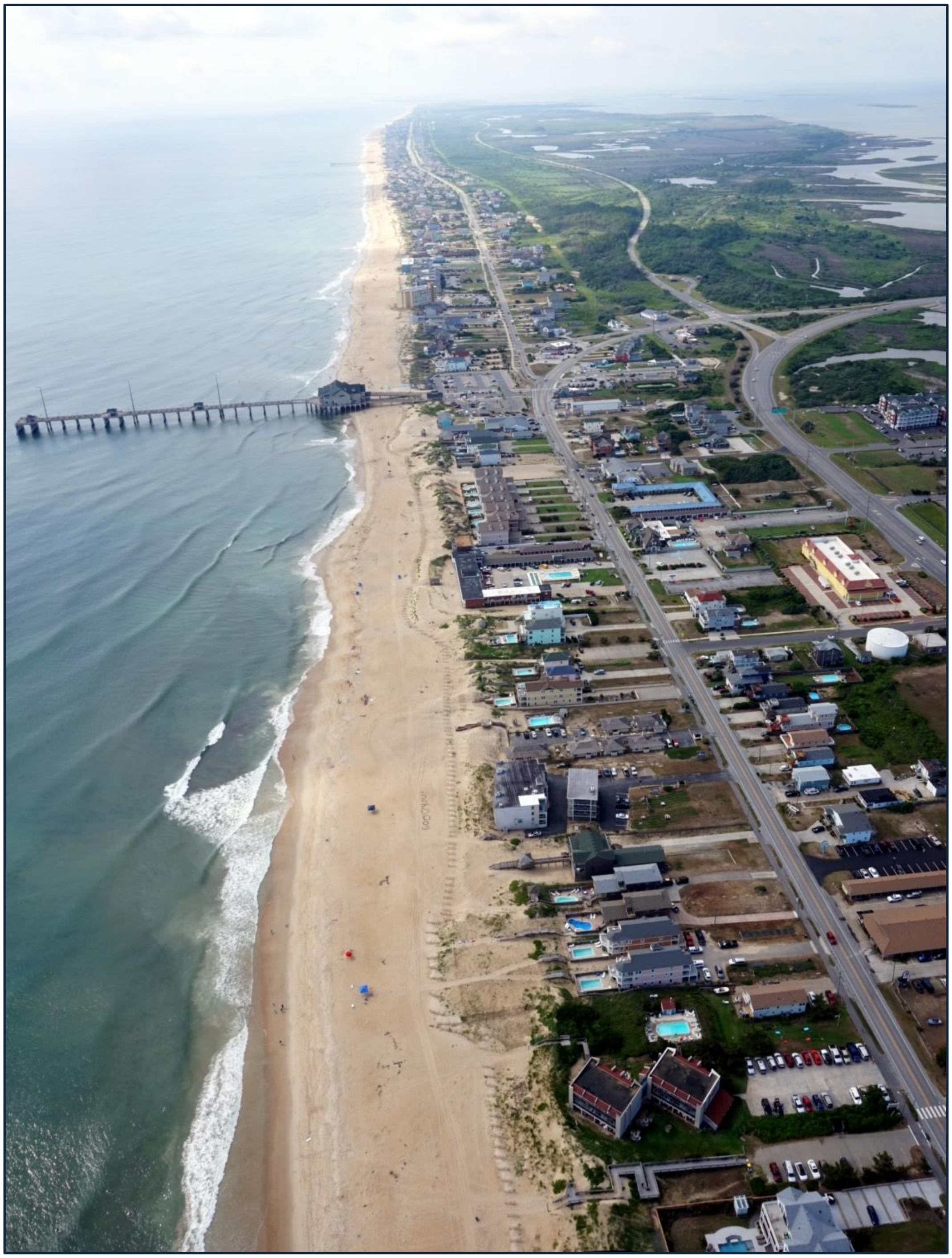


PHOTO 1 — Nags Head Reaches 1 and 2 condition on 28 June 2015. Jennette's Pier is situated near one-third of the photo, and Outer Banks Pier is above (south of) Jennette's Pier.

PHOTO 2 — Nags Head Reaches 1, 2 and 3 condition on 28 June 2015. Jennette's Pier is situated at the very top of the photo, and Outer Bank's Pier is below (south of) Jennette's Pier.

PHOTO 3 — Nags Head Reach 1 condition on 28 June 2015. Nags Head Pier is shown in the photo.

PHOTO 4 — Nags Head Reach 1 condition on 28 June 2015. Nags Head Pier is situated at the very right (north of) the photo, and Jockey's Ridge is on the upper middle of the photo:

PHOTO 5 — Nags Head Reach 1 condition on 28 June 2015. Jennette's Pier is shown in the photo, and Comfort Inn is on the left (south of) the pier. North of Comfort Inn is Reach 1, and south of Comfort Inn is Reach 2.

PHOTO 6 — Beach condition near Outer Bank's Pier in Reach 3 on 28 June 2015.

PHOTO 7 — Beach condition near Surfside Drive in Reach 3 on 28 June 2015.

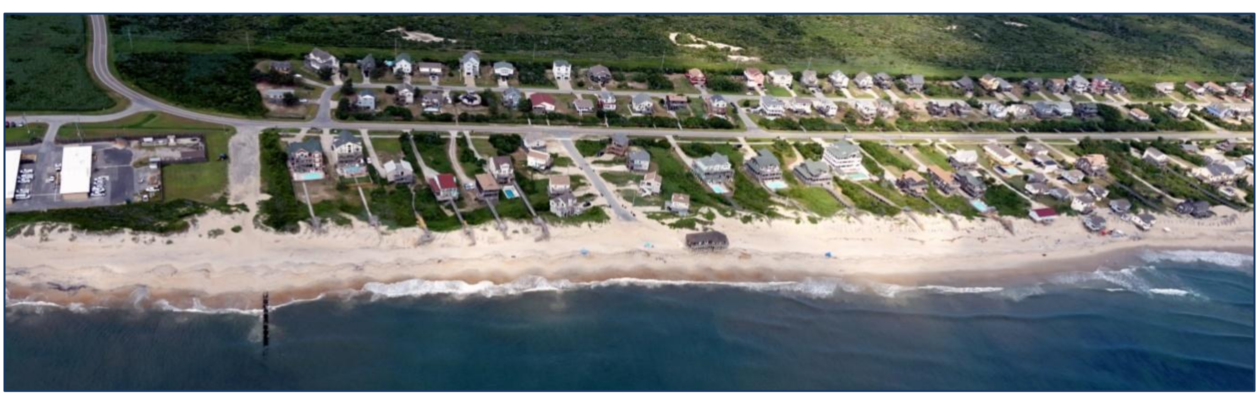


PHOTO 8 — Reach 4 and south end of Reach 3 on 28 June 2015.

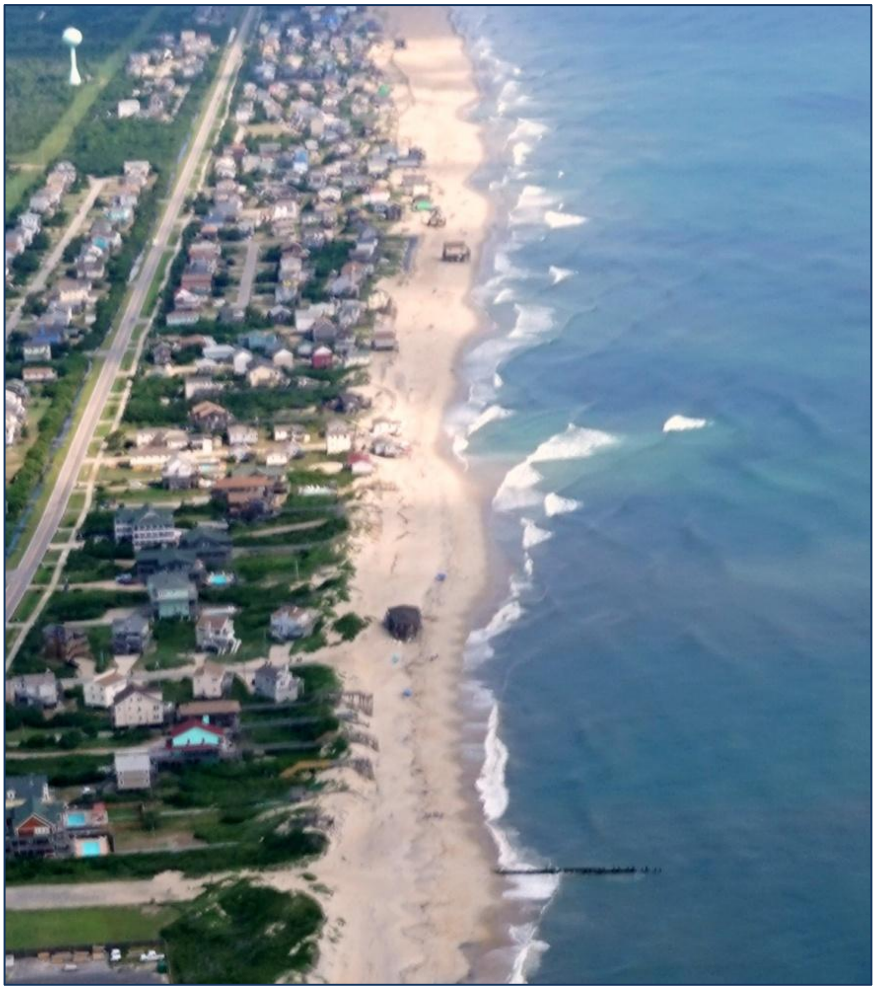


PHOTO 9 — South Nags Head near Seagull Drive on 28 June 2015. Five condemned houses have been removed by June 2015.

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