MONITORING AND ANALYSES
OF THE 2011 NAGS HEAD
BEACH NOURISHMENT PROJECT

# 2016 BEACH MONITORING

*Prepared for:*

Town of Nags Head

Dare County North Carolina

CSE

COASTAL SCIENCE & ENGINEERING

# Monitoring and Analyses of the 2011 Nags Head Beach Nourishment Project

# 2016
# BEACH MONITORING REPORT

*Prepared for:*

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[CSE2387–YR5]
SEPTEMBER 2016

COVER PHOTOS: Nags Head beach condition around Jennette's Pier looking northeast. [LEFT] Photo taken on 24 February 2011 before nourishment by TW Kana. Beach was narrow and water ran up to the foot of Comfort Inn (located near the left bottom). [RIGHT] Photo taken on 13 June 2016 (five years after nourishment) by HL Kaczkowski. Survey results show that the dune has grown ~70 ft seaward and the dry-sand beach has expanded seaward ~100 ft along this stretch of beach. The wider beach in front of Comfort Inn has prevented it from storm damages since project completion.

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# EXECUTIVE SUMMARY

## Project Background Information and Volume Analysis Methodology

Nags Head 2011 nourishment project was conducted between 24 May and 27 October 2011 during which time 4.6 million cubic yards of sand were placed along a 10-mile stretch of beach. Coastal Science & Engineering Inc (CSE) has conducted comprehensive beach condition surveys semi-annually in 2012 and annually since 2013. Each survey provides a measure of the total volume of sand contained within the Nags Head littoral zone from the foredune out to a depth of the FEMA depth limit at 19 feet (ft) NAVD. This report contains the June 2016 survey results, and it is the fifth annual report following the 2011 project.

Similar to previous reports, CSE computed the volume of sand contained in the littoral zone (also called "sand box") between the foredune and three reference depth contours as follows, and illustrated in Figure A.

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. This lens includes the sand quantities in the dune and the upper portion of dry-sand beach above +6 ft NAVD.

Lens 2) "**Beach**" – Between +6 ft and −6 ft NAVD. It includes the dry-sand beach and the wet-sand beach, and extends to low-tide wading depth.

Lens 3) "**Underwater**" – Between −6 ft and −19 ft NAVD. It includes the underwater portion of beach from low-tide wading depth to the depth set forth for the FEMA post-storm restoration criteria at -19 ft NAVD.

*[*CSE surveys the beach including the dune area to the landward back of the dune along each survey station. A landward starting point for volume analysis of each station was originally determined at the time of project planning (CSE 2011a). It is normally located landward of the crest of the dune as illustrated in Figure A. This landward starting point may vary from station to station but remains the same for a certain station unless significant changes occur landward of the station that prevents data collection. If the landward starting point of a station has to be changed, volumes at this station will be recalculated for all survey dates so that volume comparison can be based on the same boundaries of a "sand box".*]

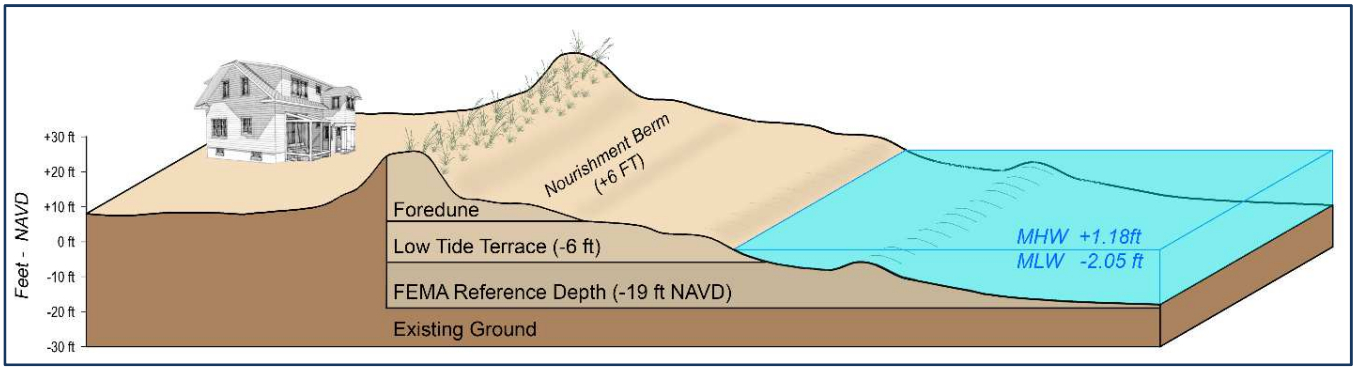



**FIGURE A.** Illustration of the three lenses used in the profile volume analysis for Nags Head.

## Overall Performance

The overall volumes of sand remaining in the "foredune" (Lens 1), the "foredune" and the "Beach" (Lenses 1 and 2), as well as the above two lenses plus the "underwater" portion (Lenses 1, 2, and 3 as illustrated in Fig A) were computed from the condition surveys, and compared in Figure B. The foredune section of the beach (the first set of bars in Fig B) remained stable over the past three years, retaining over 1 million cubic yards more sand in June 2016 than the pre-nourishment condition in November 2010. The recreational part of the beach from the foredune to the low tide wading depth (the second set of bars) retained ~2.5 million cubic yards in June 2016 compared to ~3 million cubic yards in June 2012 (Year 1 after project completion), indicating nourishment sand adjustment since project completion.

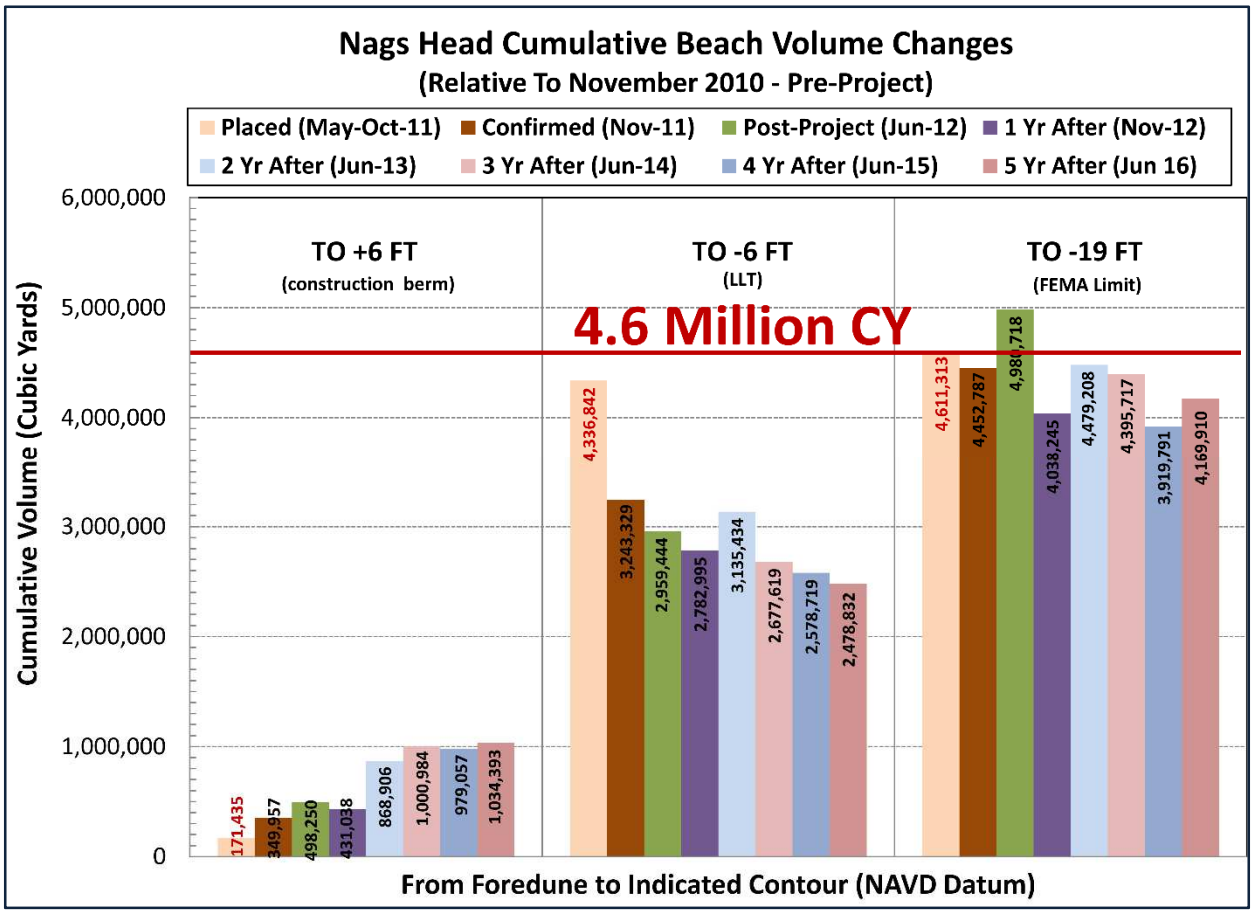



**FIGURE B.** Cumulative, overall beach-volume changes relative to November 2010 survey results between the foredune and indicated contours.

The third set of bars in Figure B show the total volume changes in the entire "sand box" measured from the foredune to the FEMA reference depth of -19 ft NAVD. During the past year (June 2015 to June 2016), Nags Head gained ~250,000 cy within the sand box. As of June 2016, the 10-mile project area retains ~4.17 million cubic yards (cy) more sand than the pre-nourishment condition. This volume represents **~90 percent remaining** of the 4.6 million cubic yards of sand placed during the 2011 project. Sand losses have averaged ~93,500 cubic yards per year (cy/yr) or ~1.8 cubic yards per foot per year (cy/ft/yr) of beachfront. These "5-year" averages are lower than the design values of 275,000 cy/yr and 5.2 cy/ft/yr adopted at the time of planning and designing for the 2011 project (CSE 2005, 2011a), confirming that the project is performing better overall than predicted.

## Performance by Reach and Subreach

Four main reaches are referenced each year in these monitoring reports, and Reach 3 are further divided into two subreaches this year to better distinguish variations in sand volumes and erosion rates. From north to south, Reaches 1 and 2 gained sand since project completion while Reaches 3 and 4 lost sand. The results are given in Figure C and are summarized as follows.

**Reach 1 (R1)** – The northern ~5.8 miles of beach from Mile Posts 11 to 16.8 (CSE stations 497+00 to 790+00) gained 297,937 cy* over the past year and has gained 387,660 cy (~13 cy/ft or 2.8 cy/ft/yr) since project completion in November 2011. The total gain as of June 2016 is equivalent to ~23 percent of the nourishment volume in this reach, over and above the volume placed during the project.

*[*Unless otherwise specified, volumes in this section are measured from the foredune to the FEMA reference depth of –19 ft NAVD.*]

**Reach 2 (R2)** – The center to southern ~2.4 miles of beach from Mile Posts 16.8 to 19.2 (CSE stations 790+00 to 920+00) gained 36,614 cy over the past year. Compared to the condition after project completion in November 2011, Reach 2 remains stable with a minor gain of ~8,000 cy, which is equivalent to a 0.6 percent increase over the nourishment volume.

**Reach 3 (R3)** – The southern ~1.6 miles of beach from Mile Posts 19.2 to 20.8 (CSE stations 920+00 to 1010+00) lost 38,991 cy over the past year. Compared to the condition after project completion, Reach 3 has lost over 520,000 cy (~58 cy/ft or ~13 cy/ft/yr), equivalent to ~40 percent of the nourishment volume placed along this reach. In order to better document the nourishment performance and delineate erosion variations along south Nags Head, Reach 3 is further divided into two subreaches in some of the analysis.

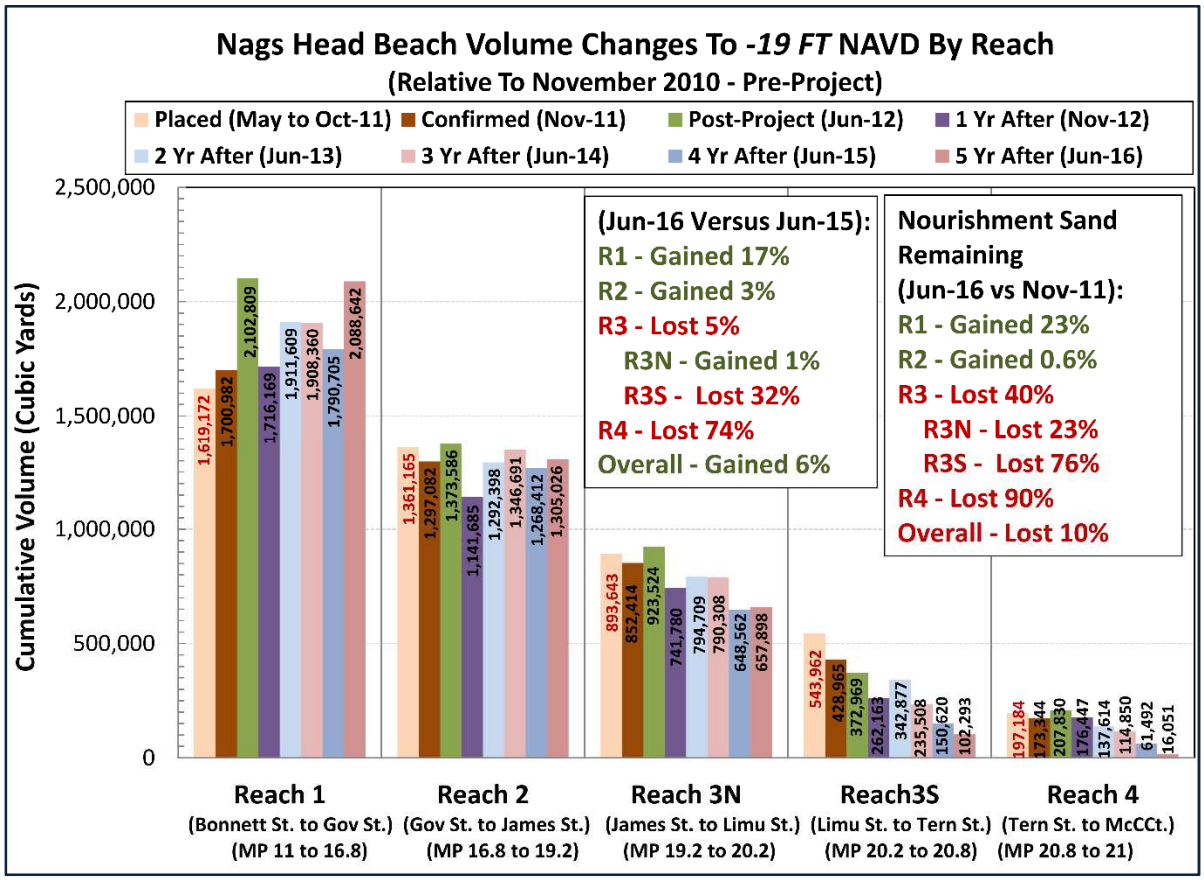



**FIGURE C.** Beach volume changes by reach and subreach relative to November 2010 survey results from the face of dune to −19 ft NAVD.

**Subreach 3N (R3N)** – The northern two-thirds of Reach 3 from Mile Posts 19.2 to 20.2 (CSE stations 920+00 to 975+00) gained 9,336 cy over the past year, indicating stability along this section of beach. Compared to the condition after project completion in November 2011, Subreach 3N has lost 194,516 cy (~35 cy/ft or ~8 cy/ft/yr), which is equivalent to ~23 percent of the nourishment sand placed here. This rate compares favorably with the volume loss rate of 40 percent for the entire Reach 3.

**Subreach 3S (R3S)** – The southern one-third of Reach 3 from Mile Posts 20.2 to 20.8 (CSE stations 975+00 to 1010+00) lost 48,327 cy over the past year. Since project completion, Subreach 3S has lost 326,672 cy (~93 cy/ft or ~20 cy/ft/yr), which is equivalent to 76 percent of the nourishment volume placed. This rate is much higher than the average volume loss rate for all of Reach 3 and about 2.5 times the erosion rate for Subreach 3N.

**Reach 4** – The southernmost ~0.2 mile of beach from Mile Posts 20.8 to 21 (CSE stations 1010+00 to 1025+00) lost 45,441 cy over the past year. Compared to conditions after project completion, Reach 4 has lost over 90 percent of the nourishment volume. The average erosion rate is as high as ~105 cy/ft or ~23 cy/ft/yr which is similar to Subreach 3S. The beach condition in June 2016 along this 1,500-ft-long-end of the project area has now returned to conditions before nourishment based on the volume analysis.

## Performance Along Nags Head

Annual profile surveys at 500-ft intervals have also documented large variations from station to station. The differences in sand volume reflect the dynamic nature of beaches and the underwater profile to the outer bar. Figure D shows such irregularity station by station comparing November 2010 (pre-nourishment) and June 2016. The dashed trend lines show the relative increase in volume from north to south. Nearly all profiles contain more sand in 2016. However, there are several specific stations where the lines touch, meaning those particular localities in June 2016 had no more sand than in 2010. Section 4.2.5 of the report identifies specific "erosion hotspot" 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. The lowest unit volumes occur south of station 975+00 (Subreach 3S and Reach 4) consistent with the sand loss trends previously illustrated in Figure C.

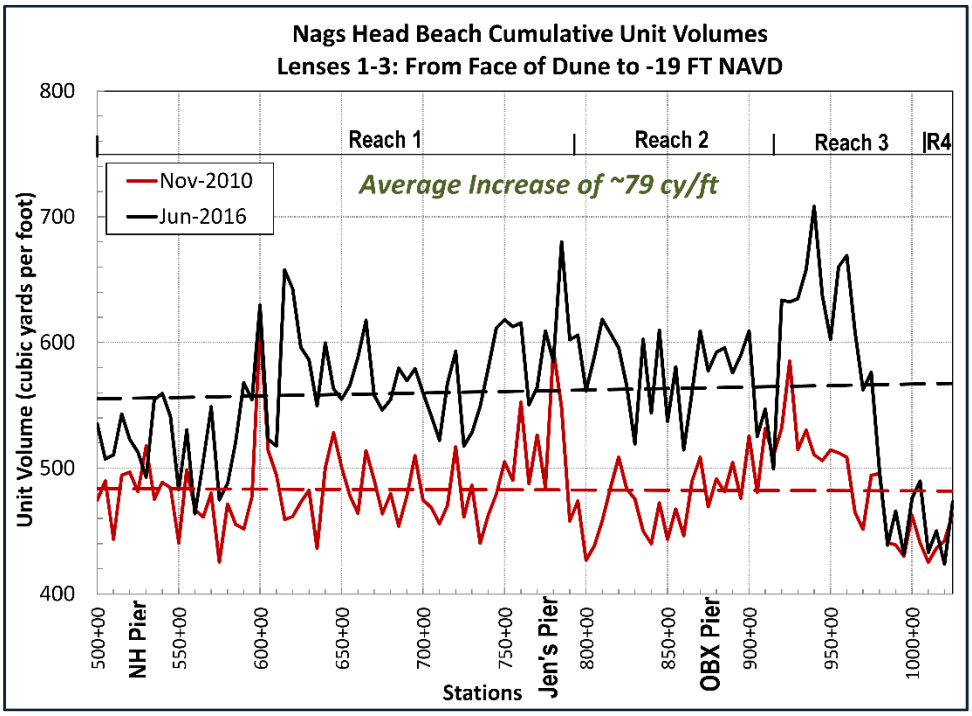



**FIGURE D.** Comparison of cumulative unit volumes by station between the face of dune and −19 ft NAVD.

## 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 E shows there is 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.

Before nourishment (1994–2010), Nags Head experienced sand losses averaging ~1 cy/ft/yr in the foredune area above elevation +6 ft NAVD. The nourishment berm was set to +6 ft NAVD along the majority of the project area with an exception of +7 ft NAVD in some areas where the natural beach was higher. No sand was placed on the foredune above the design berm elevation during the 2011 project. However, since completion of the nourishment in 2011, the foredune has gained ~685,000 cy along the 10−mile project beach as of June 2016, which is equivalent to a unit volume increase of ~13 cy/ft or ~3 cy/ft/yr. Compared to the pre-project condition in November 2010, Nags Head dunes have gained an average of 19.5 cy/ft as of June 2016, equivalent to an accretion rate of 3.5 cy/ft/yr (Fig E).

Erosion and accretion rates before and after nourishment are summarized in Figure F. 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 helped concentrate sand along the back beach and enhanced the foredune.

CSE computed average dry-beach width in June 2016 using the survey results. Figure G shows beach widths (by 1-mile average) as measured between the toe of dune (+10 ft NAVD) and the approximate seaward edge of dry sand (+5 ft NAVD) for November 2010 (pre-nourishment) and June 2016. This unvegetated beach 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.

*[*A distance over which the wind can blow unimpeded and build up waves in the ocean or transport sand over the dry-sand beach.*]

The results show that the dry beach is narrower in June 2016 than last year along the northern half of Nags Head (ie – Reach 1). [Results of June 2014 and June 2015 can be found in CSE's reports (CSE 2014b; 2015).] Figure G illustrates that the average beach width at Nags Head was ~48 ft in November 2010, increased to ~74 ft in June 2014, further increased to 85 ft in June 2015, then decreased to ~68 ft in June 2016. While the dry beach has narrowed, the dunes have widened, accumulating sand at higher elevations. The net result is a seaward shift of the recreational beach relative to the pre-nourishment condition.

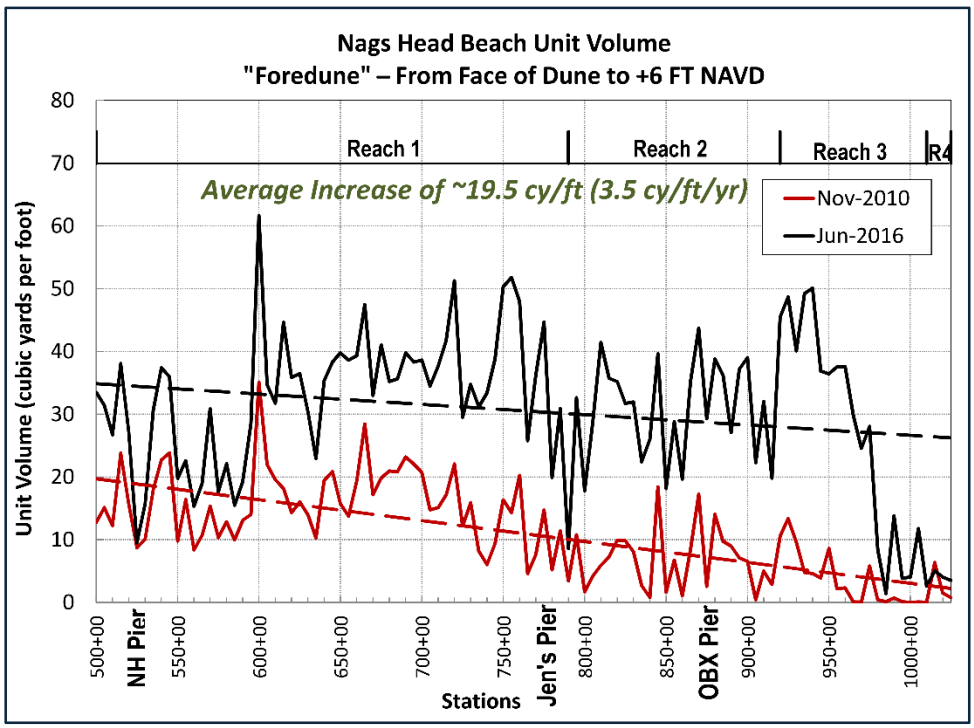



**FIGURE E.** Comparison of unit volumes along Nags Head from the face of dune to +6 ft NAVD contour before nourishment (November 2010) and the most recent survey condition (June 2016). It shows significant increase of unit volumes after the project at most stations. Unit volumes in previous surveys (November 2011, June 2012, November 2012, June 2013, June 2014, and June 2015) are plotted in earlier reports by CSE (2013a,b,c, 2014b, 2015).

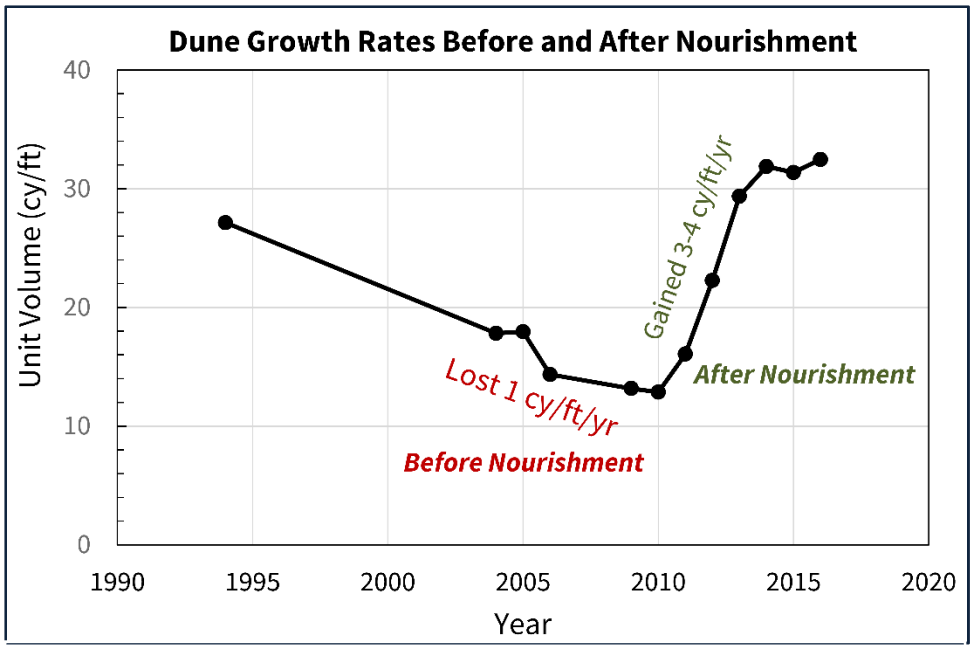



**FIGURE F.** Dune erosion and accretion rates before and after 2011 nourishment measured above the +6-ft NAVD contour.

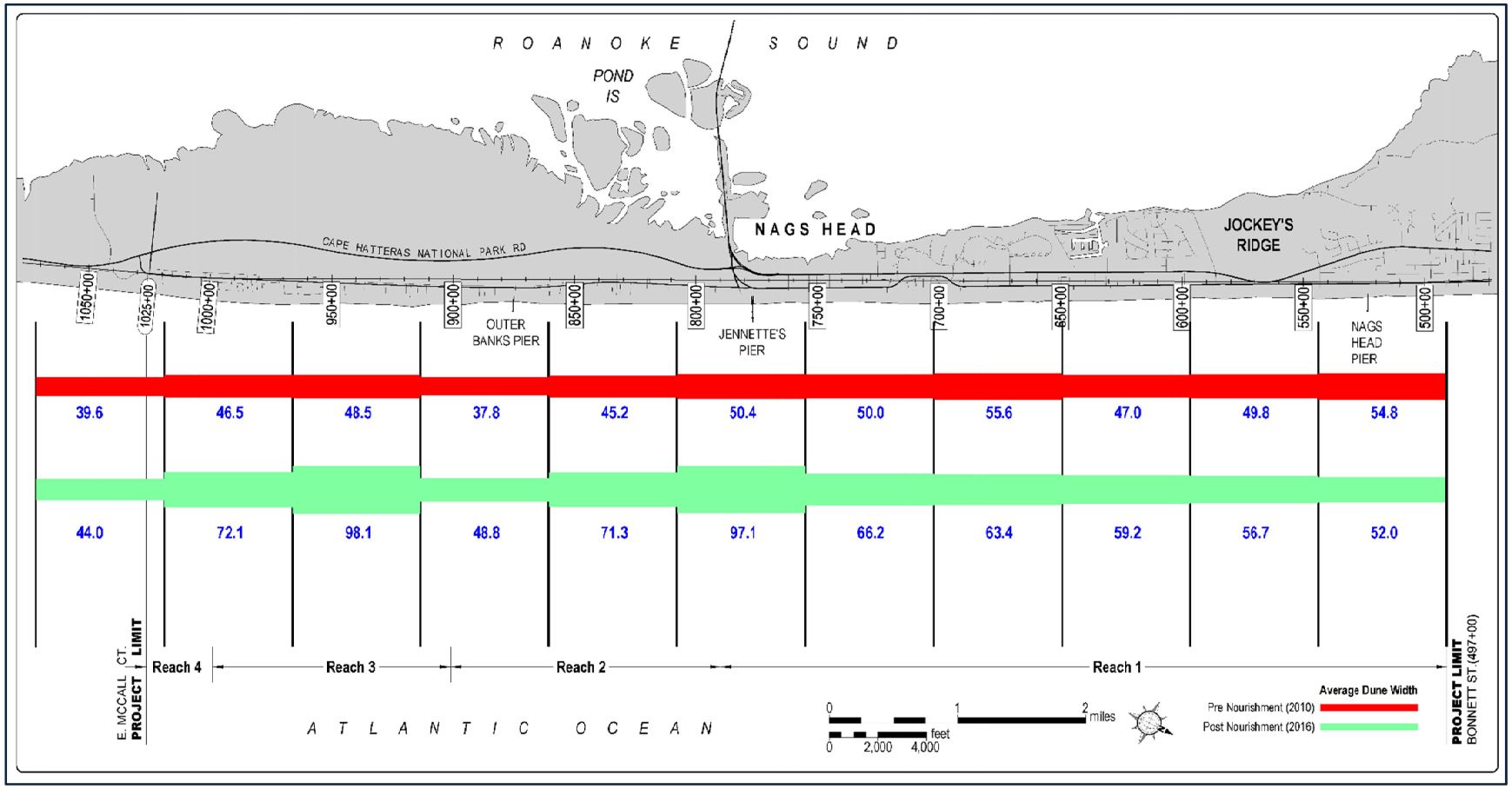



**FIGURE G.** Average beach widths (ft) before and after nourishment between the toe of dune (+10 ft NAVD) and the approximate seaward edge of the dry beach (+5 ft NAVD) by mile along Nags Head. The overall average dry-beach width was ~47.7 ft in November 2010 before nourishment and increased to ~72.4 ft in June 2014 after nourishment and profile adjustment. It continued to increase to ~84.5 ft in June 2015, then decreased to ~68.2 ft in 2016. While the dry beach has narrowed, the dunes have widened, accumulating sand at higher levels. The net result is a seaward shift of the recreational beach relative to the pre-nourishment condition.

## Possible Erosion Hotspots

The south end of the project is losing sand at the fastest rate, particularly the southern mile of Nags Head. The highly eroded area encompasses Subreach 3S (R3S) and Reach 4 between stations 975+00 and 1025+00 as indicated in Figures C, D, and E, and marked in Figure H. This is occurring for two reasons:

1) Historical erosion rates exceed 10 ft/yr along the adjacent Cape Hatteras National Seashore, drawing off sand from Nags Head.
2) The nourishment project had to end in a long taper around McCall Court, thus leaving a bulge in the shoreline which became a focal point for wave attack and sand spreading.

The "end losses" in this case are unavoidable because the underlying erosion rate increases systematically along south Nags Head and the Seashore. To better track erosion hotspots and document the condition of the entire project area in winter when the dry beach is narrower, the Town of Nags Head has approved a fall survey in 2016. That special survey together with the annual surveys will provide an indication of where the foredune is most vulnerable to damage and how much the dry-sand beach fluctuates between summer and fall (post-storm) conditions. This should help the Town to develop a long-term beach management strategy including a possible renourishment in summer 2018.

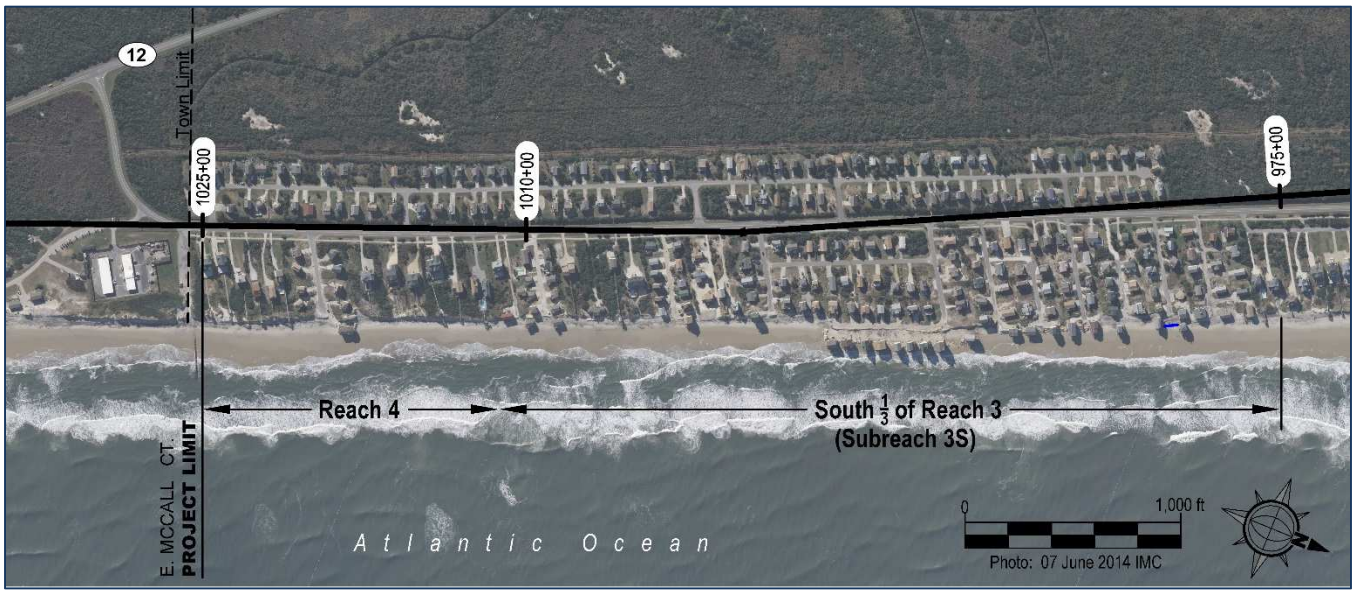


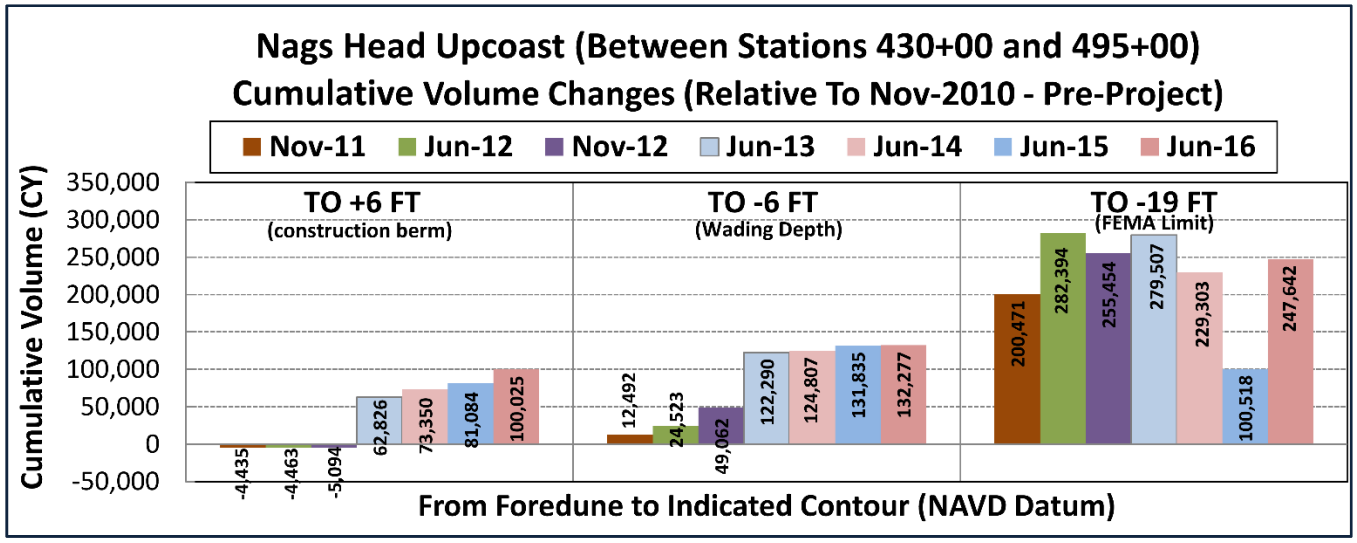

**FIGURE H.** Reach 3 is divided into two subreaches [ie – Subreach 3N is between stations 920+00 and 975+00 (out of the image) and Subreach 3S is between stations 975+00 and 1010+00]. Higher erosion occurred along Subreach 3S and Reach 4. Subreach 3N retained a large reservoir of nourishment sand which may mitigate erosion at the south end of the project. [The background aerial photo was taken on 7 June 2014 by IMC before removal of houses along Seagull Street at the right half of the image.]

## Upcoast and Downcoast

As the upper graph in Figure I illustrates, the upcoast area gained sand over the past year with most of the buildup occurring underwater. As of June 2016, the upcoast ~1-mile of beach has over 200,000 cy more sand than pre-project conditions from the foredune to the FEMA depth limit (−19 ft NAVD).

Since nourishment, the downcoast mile has accumulated about 65,000 cy in the foredune areas but has lost sand in the intertidal and underwater zones. The net change in volume when measured to −19 ft is near zero (Fig I lower). Despite the sand loss to −19 ft in the downcoast area, there had been added volume above +6 ft (the first set of bars) and providing more beach width for users and wildlife since project completion.

It is likely the downcoast 1-mile area would have sustained losses averaging ~80,000 cy/yr based on pre-nourishment erosion rates (CSE 2011a). Natural losses in this case were offset by upward of 180,000 cy/yr passed downcoast from Reaches 3 and 4. Because of the time it takes for sand to move downcoast, shoaling in Oregon Inlet in recent years has been principally related to erosion along the Seashore.



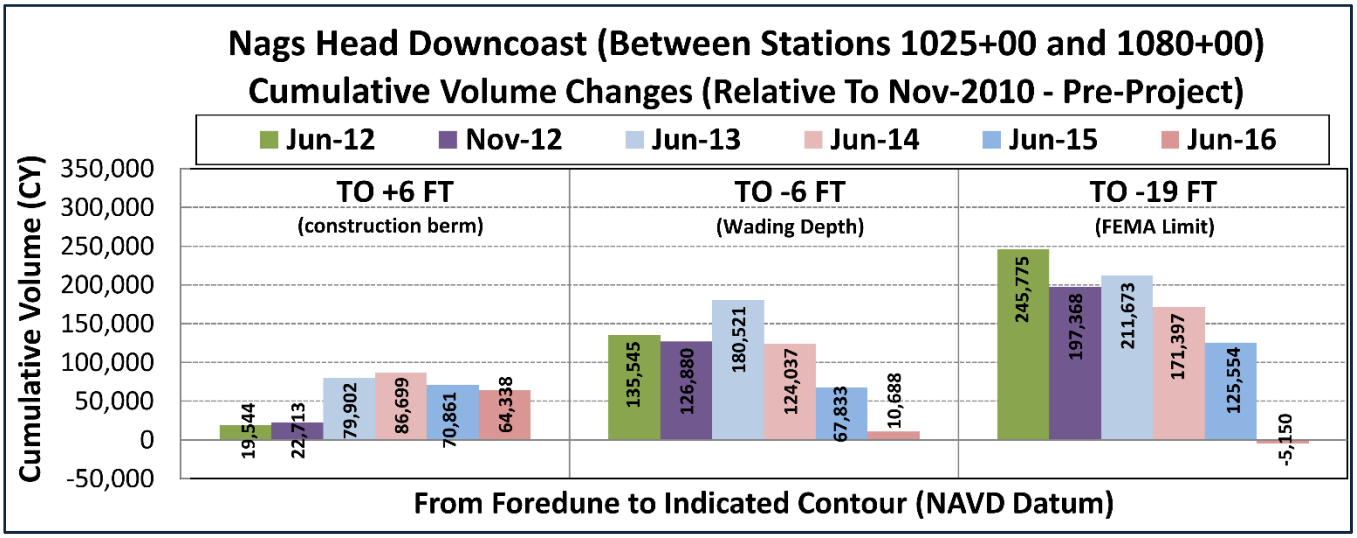




**FIGURE I.** Cumulative volume changes from the foredune to the indicated contour relative to the November 2010 condition along upcoast (upper) and downcoast (lower) stations outside the project area.

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# ACKNOWLEDGMENTS

The Year 5 post-nourishment survey was funded by the Town of Nags Head under its budget for beach monitoring. CSE thanks the Nags Head Board of Commissioners, the Town staff, and the Shoreline Management Committee for their continued support (Cliff Ogburn, Town Manager; David Ryan, Town Engineer and Project Coordinator; Andy Garman, Deputy Town Manager; and John Ratzenberger and Marvin Demers, Town Commissioners). CSE also thanks Roberta Thuman (Administrative Assistant), Ralph Barile (Nags Head Public Works Department Director), and the Nags Head Police Department (Chief of Police – 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, Luke Fleniken, and Alexandra Muscalus. The report was written by Dr. Kaczkowski and Dr. Tim Kana (PG, NC 1752) with assistance by Steven Traynum, Trey Hair, and Diana Sangster. Photos were taken by Kaczkowski, unless otherwise noted in the report.

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# INTRODUCTION

This is the fifth 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 of sand were placed along a 10-mile stretch of beach. The state and federal permits of the project required the Town of Nags Head to prepare a monitoring and maintenance plan (Appendix 1). According to the plan, a comprehensive beach condition survey was conducted in November 2011 right after the project was finished, and semi-annual or annual surveys have been conducted since project completion. Two semi-annual surveys were completed in June and November 2012 (Year 1). Annual surveys were conducted in June 2013 (Year 2), June 2014 (Year 3), June 2015 (Year 4), and June 2016 (Year 5) (respectively). Post-project conditions and a summary of project implementation are given in CSE (2012), and the results of Year 1, 2, 3, and 4 surveys documenting project performance are given in CSE (2013a,b; 2014b; 2015).

The present report covers the monitoring period from June 2015 to June 2016, representing the fifth year after project completion. During this monitoring period, an annual beach condition survey was performed in the week of June 20$^{th}$ prior to hurricane season. The report provides a summary of the surveys and the physical condition of the beach in Year 5 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 hotspots.

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), Year 4 (2014), and Year 4 (2015).
- 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 (2005, 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 US Army Corps of Engineers (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.

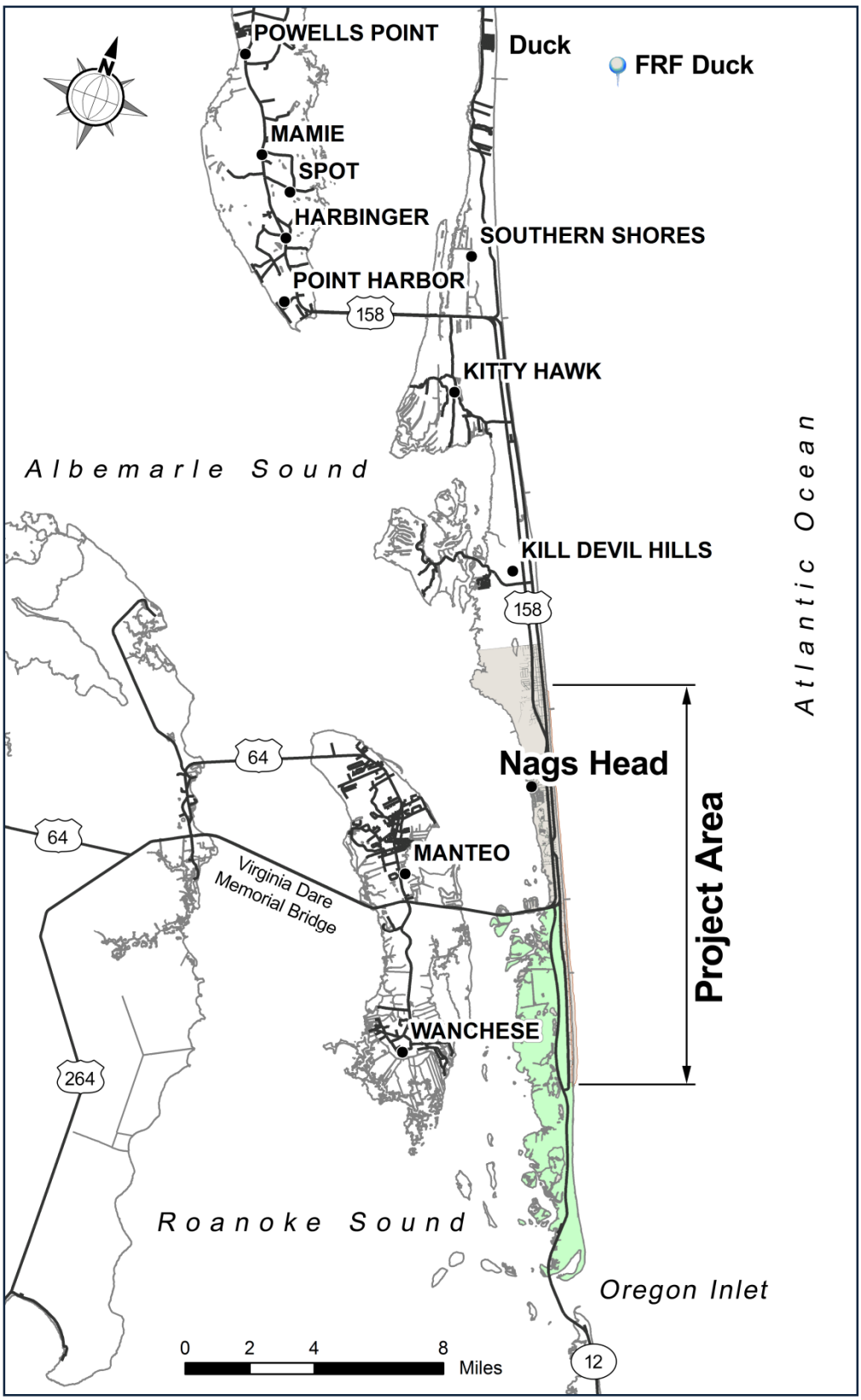


**FIGURE 1.1.** Nags Head (NC) project vicinity map.

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]*

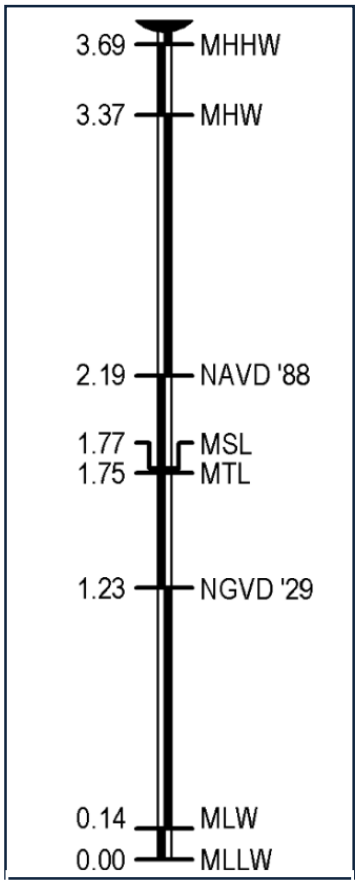


**FIGURE 1.2.** Relationship of various water levels and survey datum at Duck (NC). [Source: NGS–NOAA]

An average annual erosion rate of 275,000 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 hotspots and to optimize the nourishment design so that the effects of such hotspots could be avoided or minimized where possible. Four reaches were delineated based on the historical erosion rates. The fill density was 87 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).

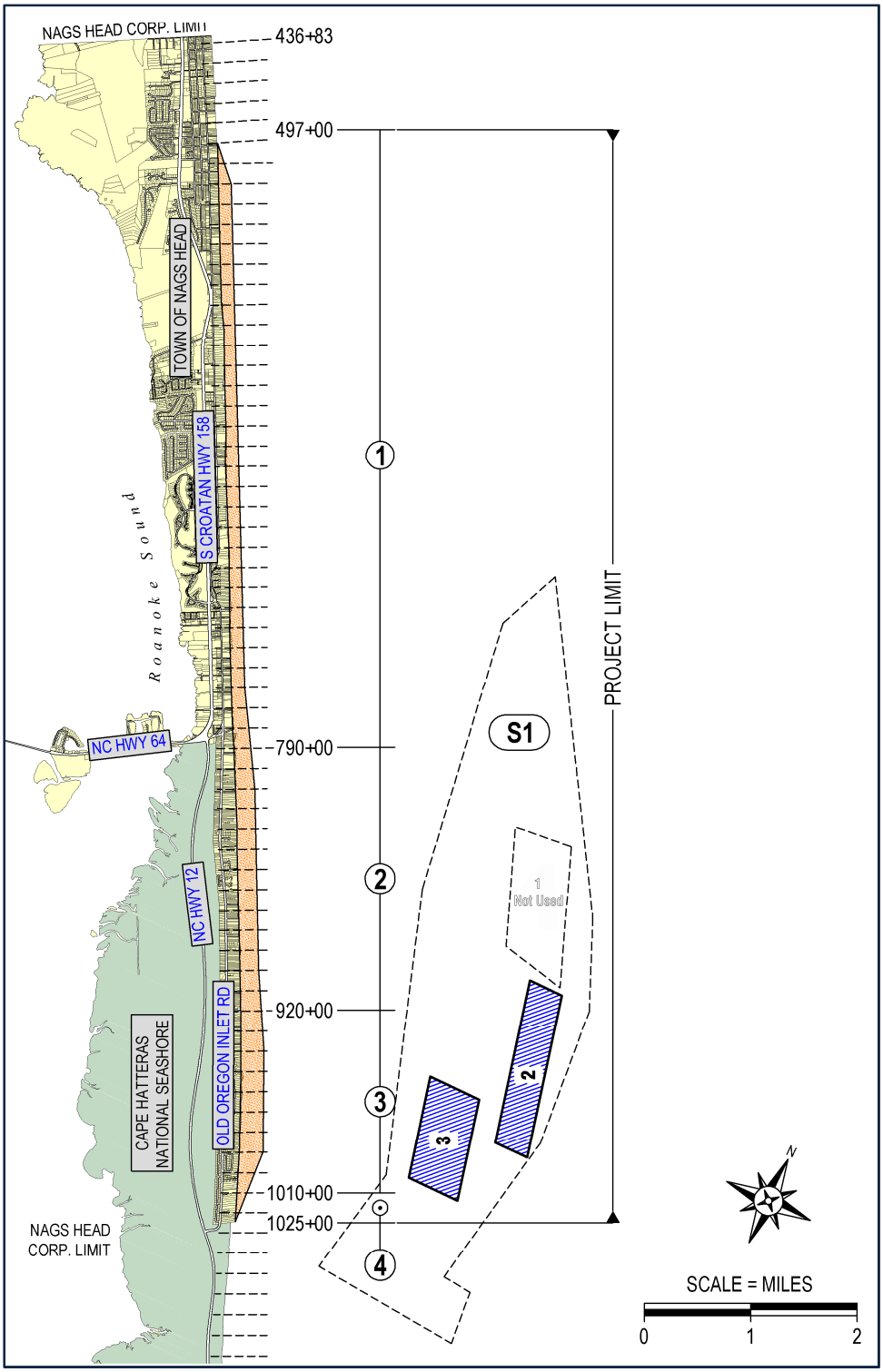


**FIGURE 1.3.** Nags Head (NC) project reaches along with fish-shaped USACE-designated borrow area. The town limits are around stations 436+83 and 1025+00; the project limits are between stations 497+00 and 1025+00. Subareas 2 and 3 were used in the 2011 project.

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 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. The unit price was $6.56/cy including mobilization/ demobilization and placement of nourishment sand. 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 10-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 Years 1–4 (2012–2015) 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. Sediment compaction was found to be comparable to the natural beach. As a result, North Carolina Department of Environment and Natural Resources (NCDENR) and USACE officials did not request special beach tilling ahead of the 2012, 2013, or 2014 sea turtle nesting season. No compaction tests were required after Year 3.

Comprehensive survey data of the beach and inshore zone were collected in June and November 2012, as well as in June 2013, June 2014, and June 2015. 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 (beige bars) confirmed that ~94 percent of the nourishment sand (~4.3 million cubic yards) was placed above low-tide wading depth (−6 ft NAVD) (second 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 (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 19-ft depth contours, which are about 400–1500 ft from the foredune. CSE's measurements in November 2011 detected over 4.45 million cubic yards more sand along Nags Head beach [calculated to −19 ft contour (FEMA depth limit) shown in the third set of bars] compared with conditions in November 2010.

The June 2012 survey (green bars in Fig 1.4) confirmed the continuing volume gain in the dune area (first set of bars) since project completion and that significantly more sand was gained in the project area measured to −19 ft than was placed in the nourishment project.

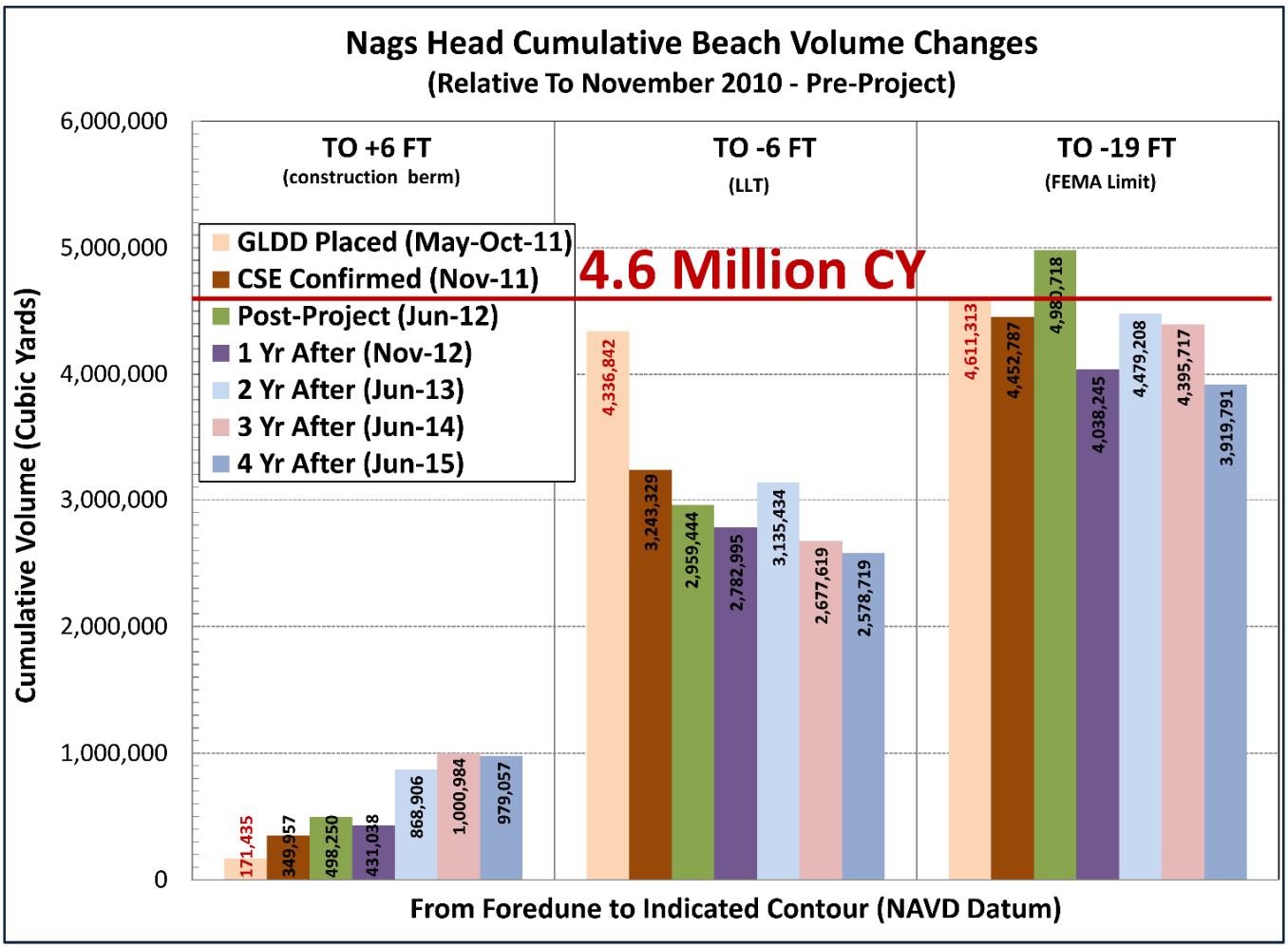


**FIGURE 1.4.** Accumulated volume changes relative to November 2010 (pre-project condition) between the foredune and the indicated contour (from CSE 2015).

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 nearly 942,473 cy relative to the June 2012 condition, and 414,542 cy relative to the November 2011 post-nourishment condition (measured to the −19 ft contour).

The June 2013 survey (light blue bars in Fig 1.4) showed accretion in every lens 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 depth limit (−19 ft NAVD).

The June 2014 survey (pink bars in Fig 1.4) indicated there were ~4,396,000 cy more sand than the pre-nourishment condition (November 2010) measured to the FEMA depth limit. 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) resulting in over 1 million cubic yards of sand gain in the dune area (first set of the bars).

The June 2015 survey (dark blue bars in Fig 1.4) showed that 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. As of June 2015, the 10-mile project area retained 3.92 million cubic yards of the nourishment sand placed by the 2011 project, equivalent to ~85 percent of nourishment volume remaining. Sand losses averaged 192,000 cy/yr (or ~3.6 cy/ft/yr) over the first four years after project completion, which is lower than the design estimates of 275,000 cy/yr (or 5.2 cy/ft/yr).

Post-project surveys documented the natural dune growth after nourishment. As of June 2015, there were nearly 1 million cubic yards more sand retained in the foredune area than November 2010 (before nourishment). Four years after project completion, Nags Head has gained an annual average of ~3.3 cy/ft/yr in the foredune area. This natural gain through aeolian transport (ie – wind-generated sand transport) has helped prevent wave runup and overtopping of Nags Head dunes during major storm events.

CSE also computed 1-mile average dry-beach width as measured between the toe of dune (+10 ft NAVD) and the approximate edge of dry sand (+5 ft NAVD). It 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. The results show that the average berm width at Nags Head increased from ~48 ft in November 2010 to ~85 ft in June 2015.

Surveys along the upcoast and downcoast reaches extended about one mile in either direction from the project area. The results indicate there were an additional ~100,000 cy (upcoast) and ~125,000 cy (downcoast) as of June 2015 relative to the pre-project condition. Survey results after nourishment in November 2011 to June 2015 indicated the spread of nourishment sand in either direction, although the magnitudes are relatively low compared with the overall nourishment volume.

Sediment samples were collected in the second and fourth years (June 2013 and June 2015) 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; 2015).

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# 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 2010, and the federal permit (SAW 2006–40282) was received on 30 November 2010. 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, June 2014, and June 2015. 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.

The most recent 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) database with a 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.

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.

**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]

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 Present Monitoring Period Wave Climate (June 2015 – June 2016)

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 seven months out of the twelve months were higher (as highlighted in the table), and the average wave height is ~0.2 ft higher than the 21-year average. Overall, the one-year average is comparable in all three parameters (ie – wave height, period and direction), indicating a slightly higher-than-normal year over the past year.

**TABLE 3.1.** Monthly, average wave climate from 1986 through 2006 (CSE 2011) and from July 2015 through June 2016.

| | 21-Year Record (1986–2006) | | | 1-Year Record (Jul 2015–Jun 2016) | | |
|---|---|---|---|---|---|---|
| | Wave Height (ft) | Wave Period (s) | Wave Direction | Wave Height (ft) | Wave Period (s) | Wave Direction |
| January | 3.58 | 8.58 | 75.3 | 4.35 | 9.4 | 69.7 |
| February | 3.84 | 8.55 | 71.2 | 4.34 | 9.0 | 77.2 |
| March | 3.84 | 8.74 | 79.0 | 3.42 | 9.1 | 80.1 |
| April | 3.42 | 8.60 | 79.4 | 4.22 | 8.8 | 76.2 |
| May | 3.01 | 8.45 | 84.2 | 2.84 | 8.1 | 88.5 |
| June | 2.45 | 8.13 | 96.4 | 2.45 | 7.8 | 95.9 |
| July | 2.11 | 8.15 | 95.2 | 2.16 | 8.8 | 94.2 |
| August | 2.75 | 8.66 | 92.6 | 2.69 | 9.1 | 87.0 |
| September | 3.58 | 9.16 | 84.9 | 3.99 | 8.6 | 85.7 |
| October | 3.86 | 8.67 | 76.7 | 4.70 | 8.8 | 76.7 |
| November | 3.50 | 8.53 | 72.0 | 3.90 | 8.2 | 78.3 |
| December | 3.68 | 8.49 | 70.5 | 3.07 | 8.4 | 81.2 |
| **Average** | 3.30 | 8.56 | 81.5 | 3.51 | 8.7 | 82.56 |

The waves measured at Buoy 630 from July 2015 to June 2016 were predominantly from the east. Significant wave heights, associated with wave periods at this buoy, are summarized in 10° 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 2015 to June 2016). *[Note: There is no wave direction record prior to 1997.]* Waves beginning from north and ending at 150° from south represented 99.2 percent of the waves in the one-year record and 99.3 percent in the ten-year record. More than 65 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 ten-year record were from the same directions.

The highest-energy waves originated from the northeast. During the present monitoring period, waves originating from northeasterly directions (between 0° and 90° from north) represented ~56 percent of the waves and have an average significant wave height of 1.25 m (~4 ft), which is slightly higher than the ten-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 (70 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 2015 to June 2016 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° sectors), and their probability of occurrence at Buoy 630 for the periods of 1997–2006 and July 2015 to June 2016. [*Note: There is no direction record prior to 1997.]

| Wave Direction (° True North) | 10-Year Record (1997–2006)* | | | 1-Year Record (Jul 2015 to Jun 2016) | | |
|---|---|---|---|---|---|---|
| | Wave Height (ft) | Wave Period (s) | Probability (%) | Wave Height (ft) | Wave Period(s) | Probability (%) |
| 0–10 | 3.45 | 4.54 | 1.19 | 3.55 | 4.58 | 1.53 |
| 10–20 | 4.12 | 5.10 | 2.13 | 3.90 | 5.01 | 2.25 |
| 20–30 | 4.31 | 5.55 | 3.59 | 4.04 | 5.38 | 3.90 |
| 30–40 | 4.26 | 6.05 | 4.42 | 4.23 | 5.69 | 4.30 |
| 40–50 | 4.20 | 6.77 | 5.19 | 4.52 | 6.23 | 4.78 |
| 50–60 | 4.34 | 8.17 | 6.10 | 4.89 | 7.82 | 5.23 |
| 60–70 | 3.98 | 9.69 | 8.22 | 4.30 | 9.94 | 8.87 |
| 70–80 | 3.51 | 10.47 | 10.85 | 3.85 | 10.36 | 12.86 |
| 80–90 | 3.13 | 10.25 | 11.08 | 3.55 | 10.41 | 12.70 |
| 90–100 | 2.70 | 9.79 | 11.85 | 3.16 | 9.98 | 14.17 |
| 100–110 | 2.56 | 9.42 | 13.24 | 2.84 | 9.24 | 12.42 |
| 110–120 | 2.70 | 8.82 | 12.09 | 2.64 | 8.06 | 9.35 |
| 120–130 | 2.63 | 7.60 | 5.94 | 2.40 | 7.16 | 4.37 |
| 130–140 | 2.31 | 6.49 | 2.56 | 2.10 | 5.96 | 2.06 |
| 140–150 | 2.12 | 5.16 | 0.83 | 2.29 | 4.25 | 0.29 |
| Totals | – | – | 99.29 | – | – | 99.19 |

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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. During and after the data were collected, CSE performed QA/QC on the measurement systems and output by a combination of procedures. These procedures 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; 2015), 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.

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.

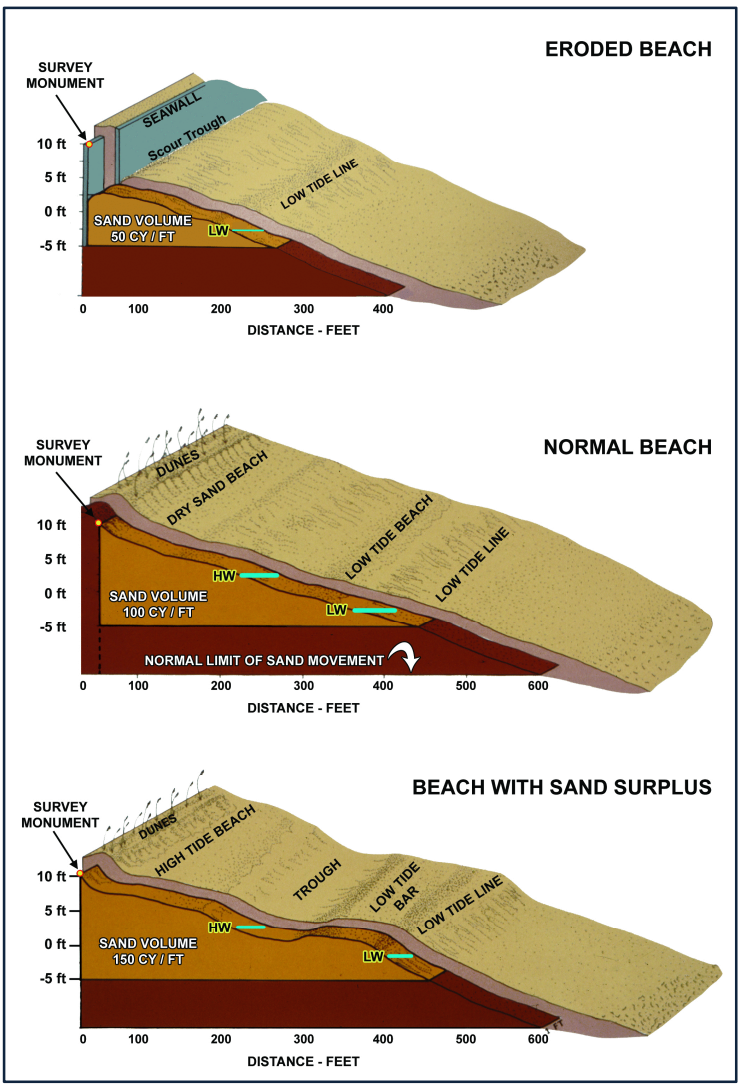


**FIGURE 4.1.** The concept of unit-width profile volumes for a series of beach profiles showing an eroded beach with a deficit, a normal beach, and a beach with a volume surplus. [After Kana 1990]

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.

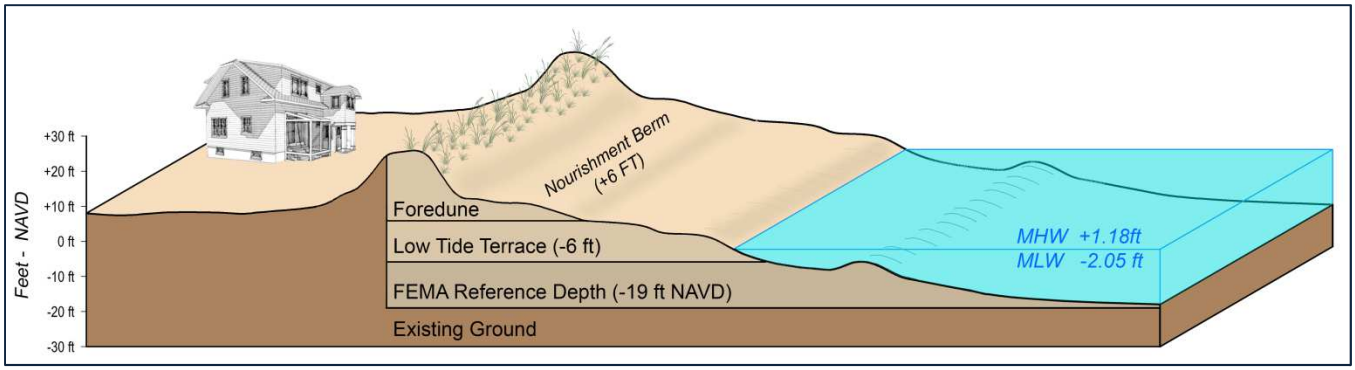


**FIGURE 4.2.** Illustration of the three (3) lenses used in the profile volume analysis for Nags Head. Lens 1 includes the dune and the upper portion of the beach above the 2011 project construction berm. Lens 2 represents the active beach to low-tide wading depth; and Lens 3 represents the outer surf zone extending 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).

*[*CSE surveys the beach including the dune area to the landward back of the dune along each survey station. A landward starting point for volume analysis of each station was originally determined at the time of project planning (CSE 2011a). It is normally located landward of the crest of the dune as illustrated in Figure A. This landward starting point may vary from station to station but remains the same for a certain station unless significant changes occur landward of the station that prevents data collection. If the landward starting point of a station has to be changed, volumes at this station will be recalculated for* <u>*all survey dates*</u> *so that volume comparison can be based on the same boundaries of a "sand box".*]

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.
- June 2015 for Year 4 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 2016 (black line in the graphic) are plotted against the pre-construction condition (red line in the graphic).

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 low dune (or no dune) and 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 2016 results (black line in Fig 4.3) show a continuation of this trend (see the descending black dashed line which shows the linear trend).

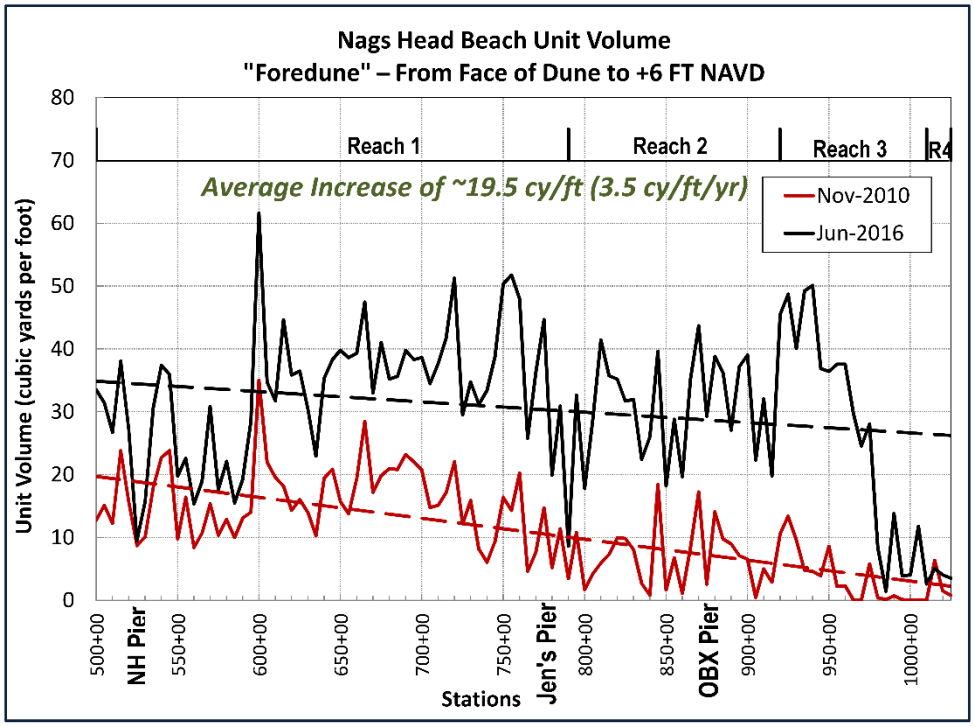


**FIGURE 4.3.** Comparison of unit volumes along Nags Head from the face of dune to +6 ft NAVD contour before nourishment (November 2010) and the most recent survey condition (June 2016). It shows significant increase of unit volumes after the project at most stations. Unit volumes in previous surveys (November 2011, June 2012, November 2012, June 2013, June 2014, and June 2015) are plotted in earlier reports by CSE (2013a,b; 2014b; 2015).

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 foredune) have steadily increased in all reaches following project completion. The June 2016 results show relatively stable dune volumes in Reaches 1–3, but show a significant volume drop in Reach 4 compared to the previous years. 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, and slightly increased to 30.6 cy/ft in June 2016. The results indicate a **natural growth** of ~19.5 cy/ft (or ~3.5 cubic cy/ft/yr) in June 2016 compared to the pre-project condition in November 2010. All reaches show similar trends and sand gain at a rate ranging from 3.66 cy/ft (Reach 4), 17.12 cy/ft (Reach 1), 23.26 cy/ft (Reach 2) to 24.61 cy/ft (Reach 3) as of June 2016. The wider dry beach constructed by the 2011 nourishment (especially in Reaches 2 and 3 where fill density was higher) has provided an ample sand source for aeolian transport (ie – wind-generated sand transport). Sand fencing installed after the project and vegetation planted by the Town have efficiently accumulated sand along the back beach, adding height and width to the dunes.

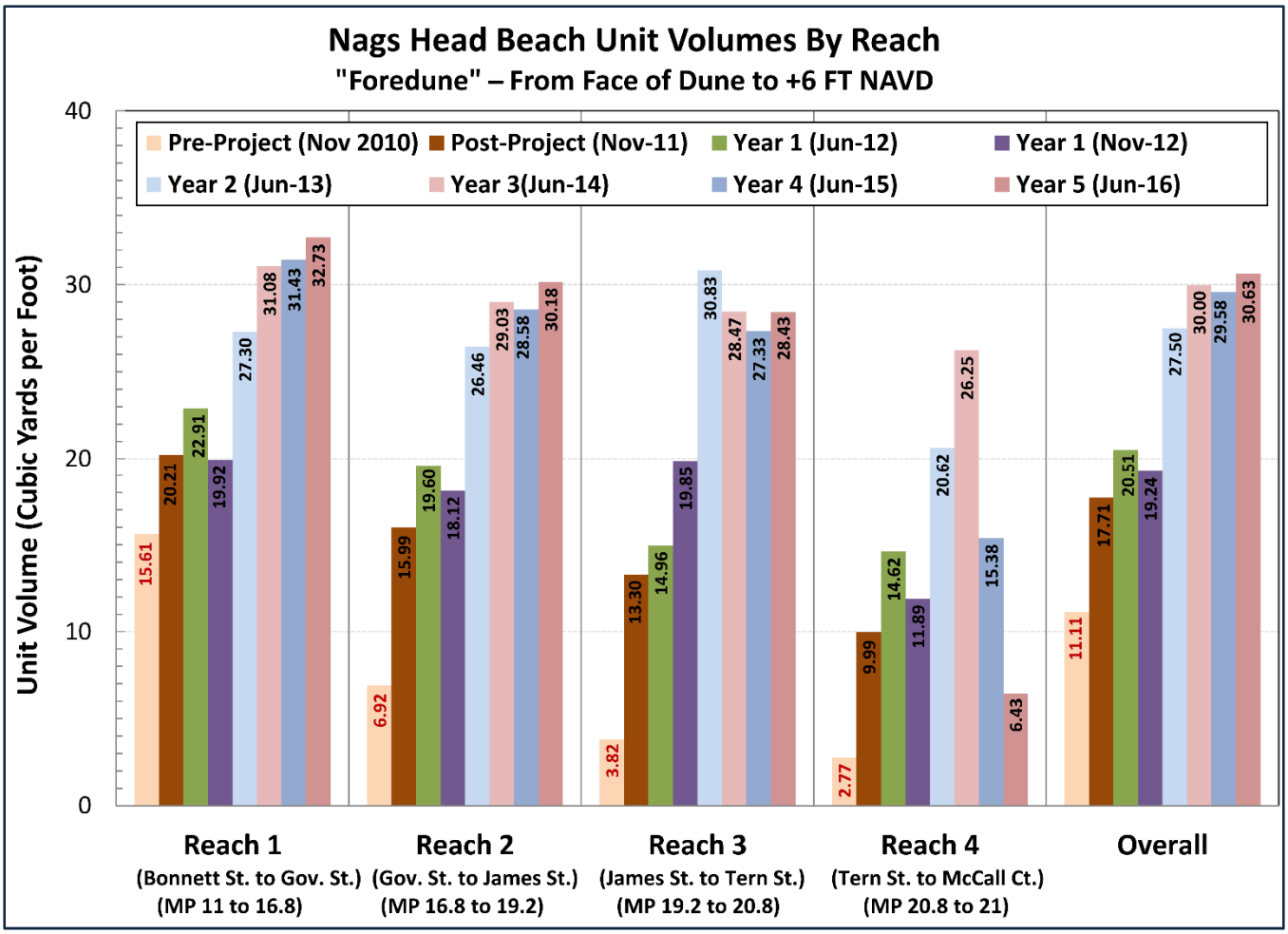


**FIGURE 4.4.** Comparison of unit volumes along Nags Head from the face of the dune to +6-ft NAVD contour. It shows the general increase of volume after the project by comparing volumes by reach and year from November 2010 to June 2016.

### *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 2016 (most recent survey). Figure 4.6 shows the comparisons **by reach** for all surveys between November 2010 and June 2016. 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 ~27 cy/ft more sand as of June 2016 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 ft 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 4.6 years, unit volumes in the recreational beach now average ~100 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 14.25 cy/ft (Reach 1) to 64.86 cy/ft (Reach 3) as of June 2016. There are mainly two reasons for the higher erosion rates along south Nags Head:

1) Historical erosion rates exceed 10 ft/yr along the adjacent Cape Hatteras National Seashore, drawing off sand from Nags Head.
2) The nourishment project had to end in a long taper around McCall Court, thus leaving a bulge in the shoreline which became a focal point for wave attack and sand spreading.

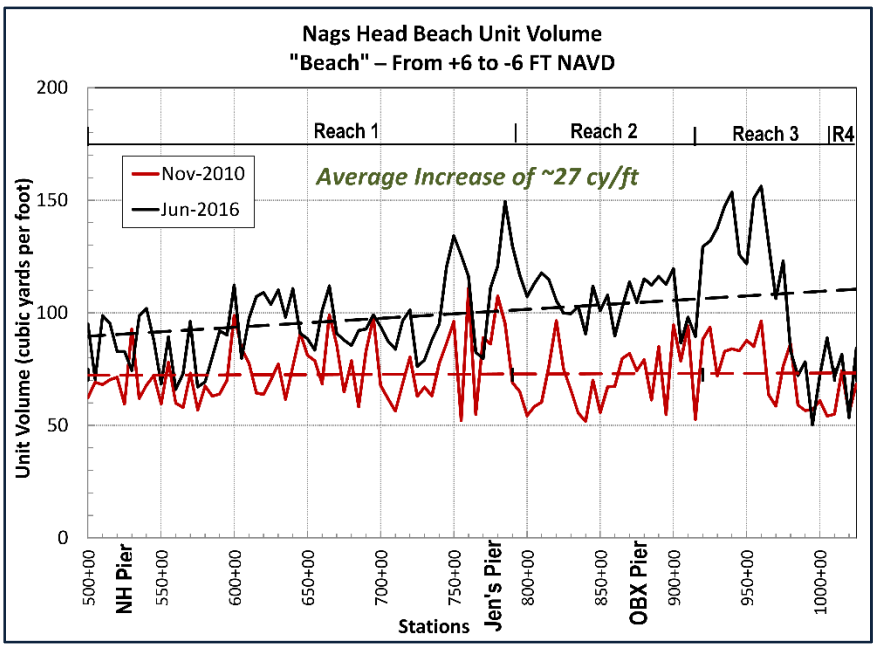


**FIGURE 4.5.** Comparison of unit volumes on the "recreational beach" by station along Nags Head between +6 ft and −6 ft NAVD.

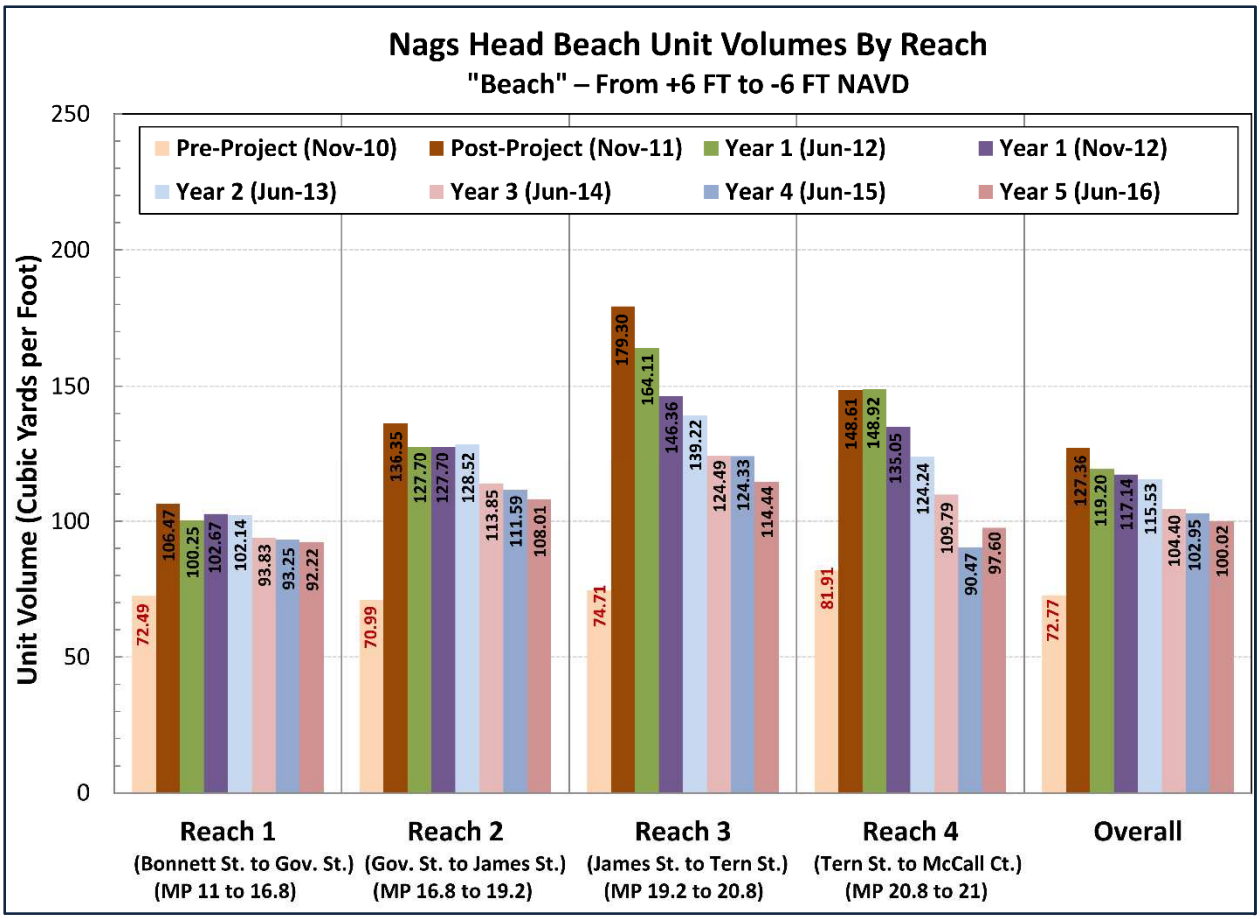


**FIGURE 4.6.** Comparison of unit volumes on the "recreational beach" by reach between +6 ft and −6 ft NAVD.

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 has increased the overall longevity of the project.

In summary, the project area has lost an average of 27.34 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 reference "sand box." It includes inshore and offshore bars and extends to the FEMA depth limit of −19 ft NAVD. 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. 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 2016 (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 ~32 cy/ft.

Figure 4.8 shows the comparisons **by reach** for all surveys between November 2010 and June 2016. Over the initial comparison period between November 2010 (pre-project) and November 2011 (post-project), unit volume increased by ~22.8 cy/ft. This is confirmation that some 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 ~9 cy/ft higher in June 2016 than November 2011, and ~31.9 cy/ft higher in June 2016 than November 2010 (pre-project). 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 Reach 3, there are still ~20.12 cy/ft more sand in this reach in June 2016 than pre-project in November 2010. For the first time since project completion, Reach 4 contains less sand in June 2016 than pre-project.

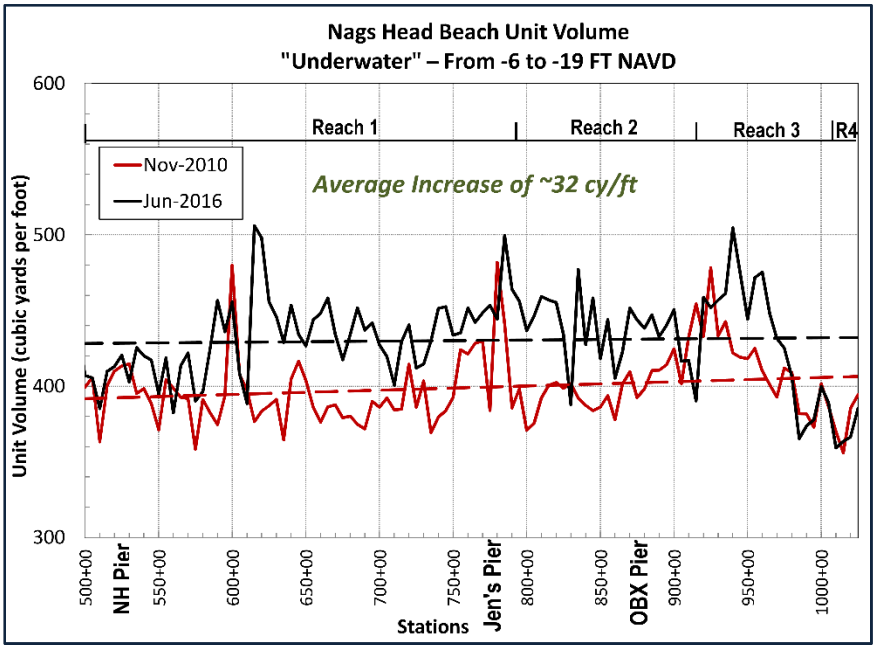


**FIGURE 4.7.** Comparison of unit volumes "underwater" by station along Nags Head between −6 ft and −19 ft NAVD.

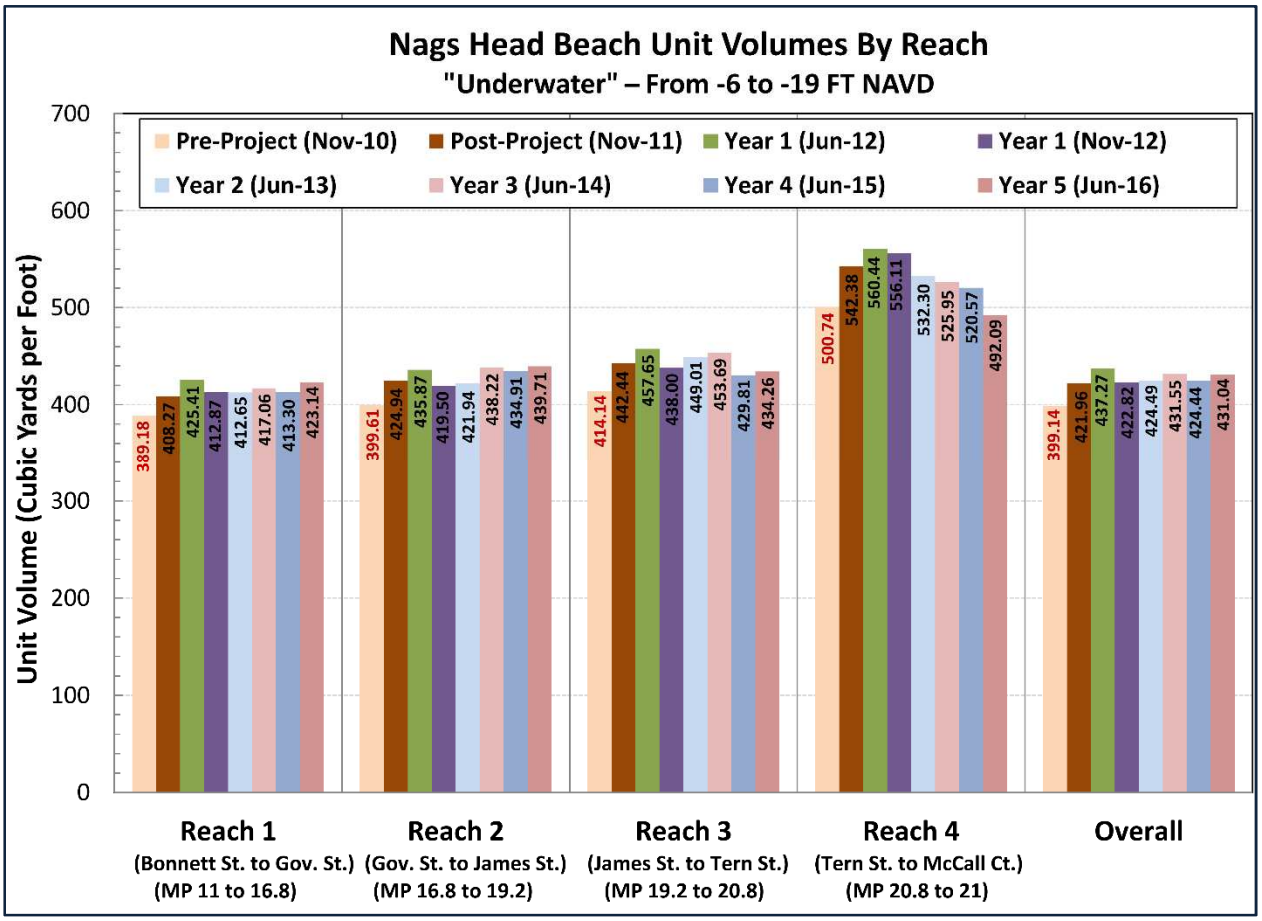


**FIGURE 4.8.** Comparison of unit volumes "underwater" by reach along Nags Head between -6 and −19 ft NAVD.

### *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 depth 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 2016. 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 resulting from 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 average unit volume increased to ~567 cy/ft after project completion in November 2011 and decreased slightly to ~562 cy/ft as of June 2016. The ~5 cy/ft less volume is equivalent to an ~1.2 cy/ft/yr erosion rate over the past 4.6 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).

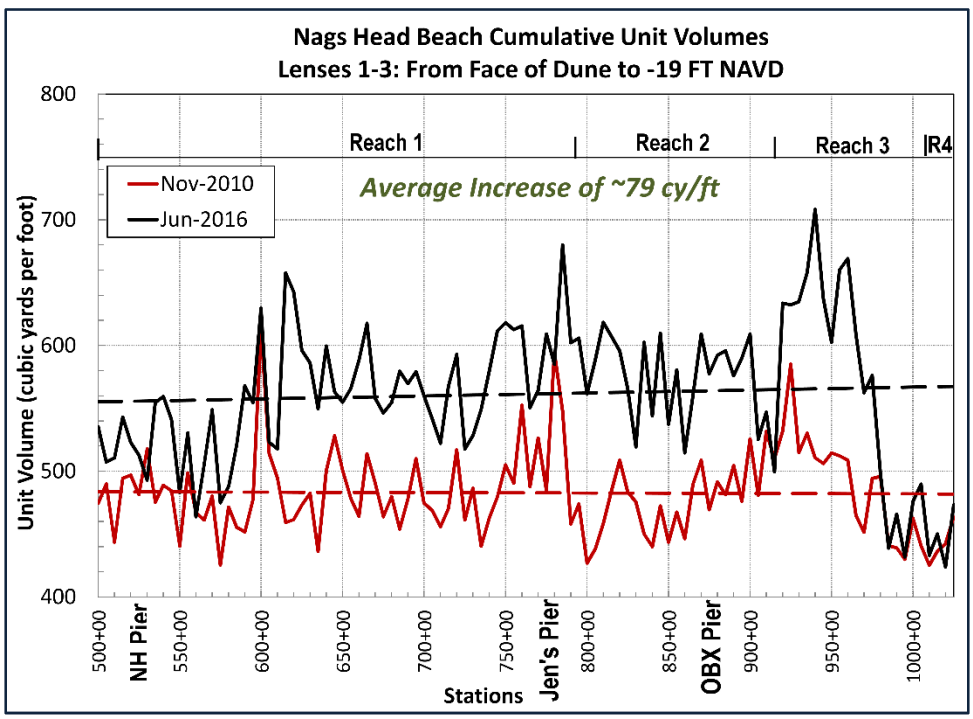


**FIGURE 4.9.** Comparison of cumulative unit volumes by station between the face of dune and −19 ft NAVD.

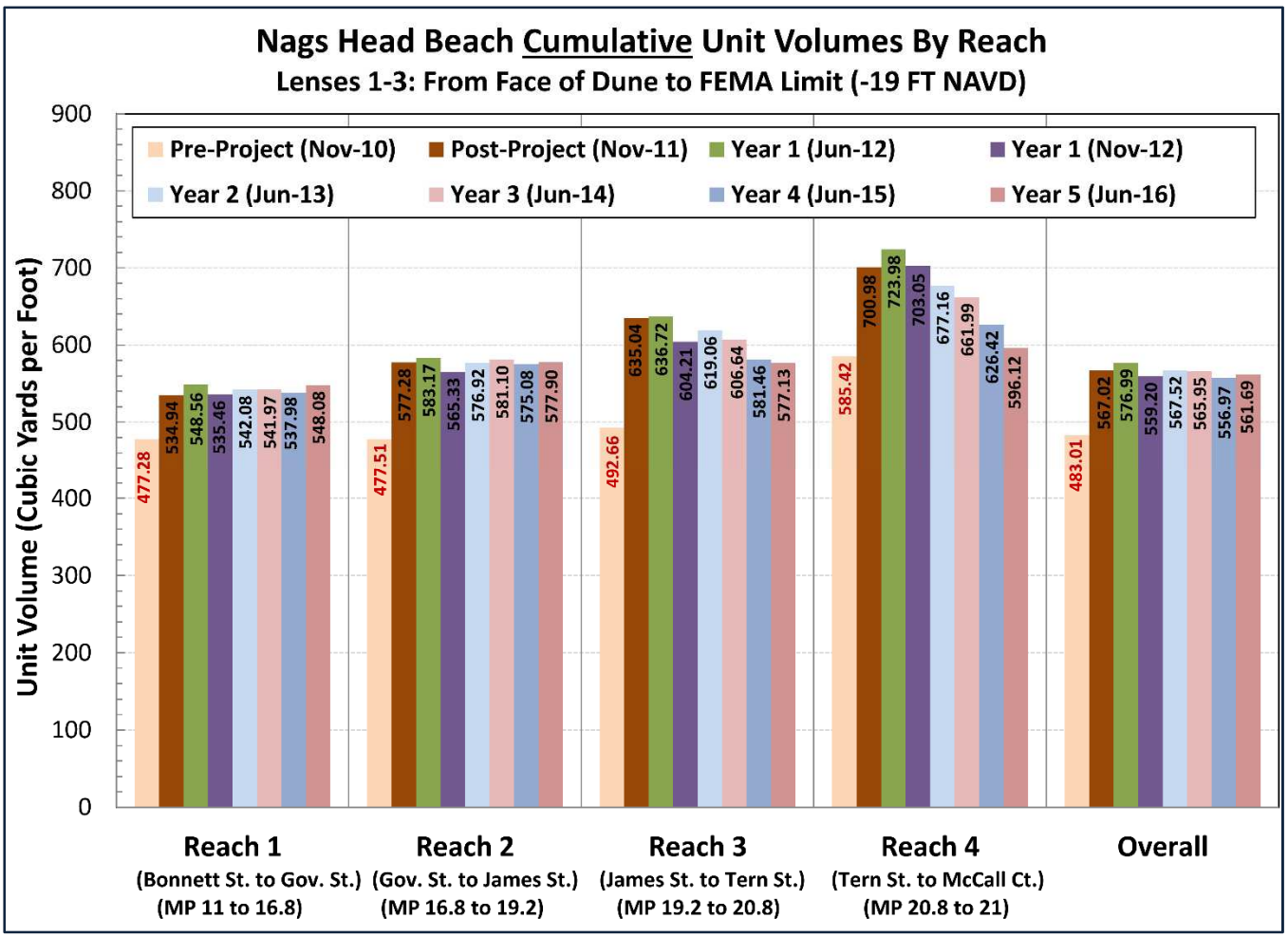


**FIGURE 4.10.** Comparison of cumulative unit volumes by reach between the face of dune and −19 ft NAVD.

### *4.2.5 Erosion Hotspots Along Nags Head – Migration and Persistance*

Unit volumes have varied from survey to survey, and identifying possible "erosion hotspots" is one of the purposes of annual monitoring efforts. Erosion hotspots in one survey are generally not persistent for all surveys at a station, but often shift to an adjacent station (CSE 2014; 2015). Figure 4.11 shows the comparison of the unit volumes along Nags Head in the last two years. Some lower unit volume areas remained the same (such as around stations 550+00 to 575+00 in Reach 1, stations 860+00 and 915+00 in Reach 2, and station 950+00 in Reach 3), but some have migrated north or south (see the green arrows in Fig 4.11).

Areas south of station 975+00 in Reach 3 have had low unit volumes in the past three years and are considered to be persistent erosion hotspots. These areas will be discussed in more detail in the next section.

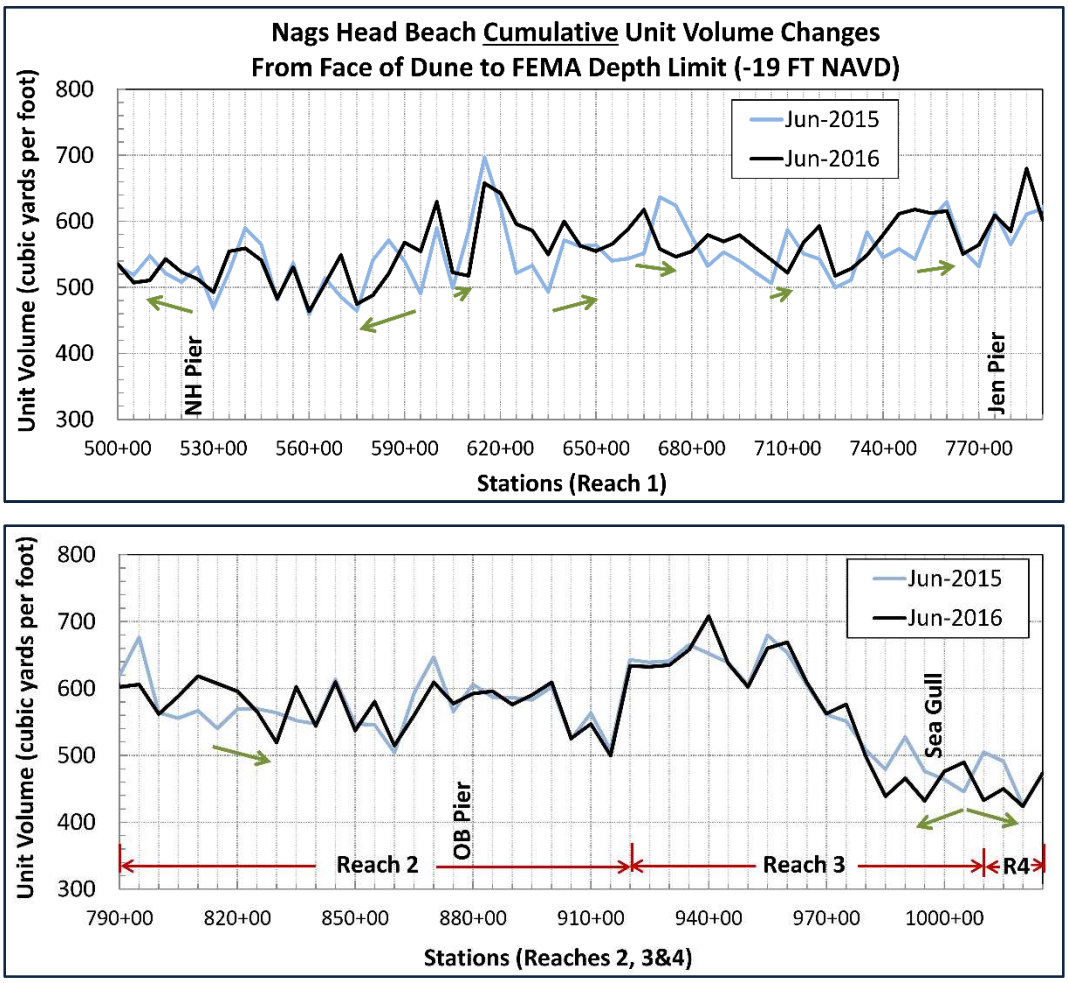


**FIGURE 4.11.** Shift in volume among adjacent stations between June 2015 and June 2016 which reflects general movement of sand lenses alongshore.

At a few stations, unit volumes in the June 2016 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), 915+00 (near Eagle Street), and 1020+00 (near McCall Court). Stations with a similar volume drop last year have recovered naturally for some volume levels—for example, station 605+00 (south of Dune Street). Scattered erosion hotspots are not an immediate concern, because they are migrating and the overall beach condition remains much healthier in June 2016 than the pre-nourishment condition.

Before and after photos of the nourishment project were taken by CSE looking northeast from the roof of the Comfort Inn. Photos from June 2010 (before the project) and June 2016 (Year 5) are presented in Figure 4.12. Photos from other survey times can be found in previous reports (CSE 2013b, 2014b, 2015). The approximate location of station 785+00 is shown on the upper 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 (see the insert on

the right in Fig 4.13). 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 and ~206 ft in June 2015. The most recent survey in June 2016 shows the sloping beach face (area between MHW and MLW on Fig 4.13) matching the November 2011 post-nourishment condition. The width of the dry beach is ~35 ft wider than the previous two years despite the buildup of a foredune (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 2016 (lower). At the lower left side of the bottom image, note the walkover (in front of the Dolphin Motel) is now buried.

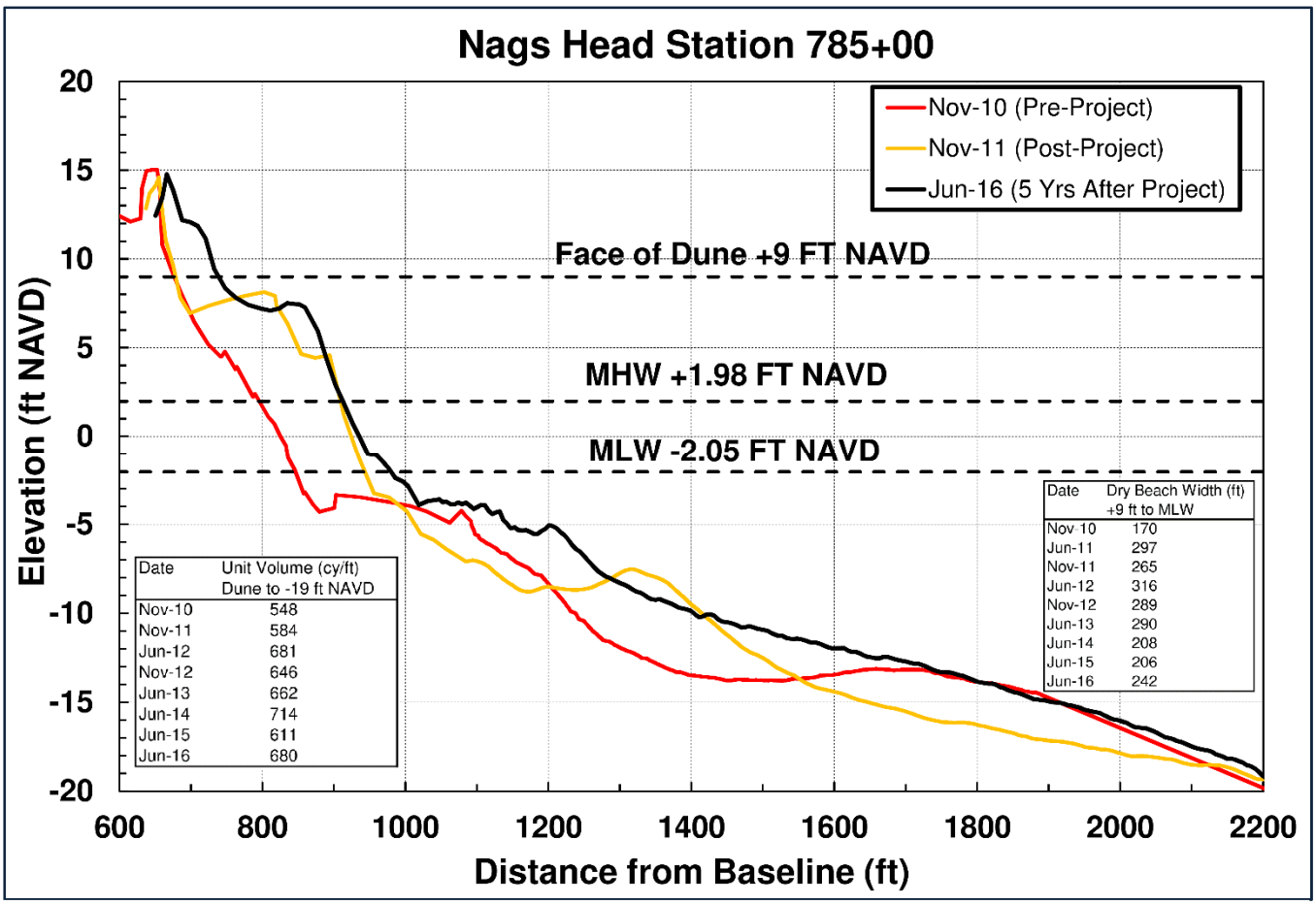


**FIGURE 4.13.** Beach profiles and unit volumes for pre- and post-project surveys at station 785+00 in Reach 1. Note the overlapping lines between MHW and MLW for the November 2011 and June 2016 profiles confirm the same position of the sloping intertidal beach.

Compared to the pre-project condition (November 2010), the dune (at +9 ft NAVD) has grown over 70 ft seaward, and the beach at MHW has expanded seaward ~110 ft as of June 2016, confirming the visual observations. The unit volume at this station has increased over the past year and is presently 132 cy/ft greater than the pre-project condition. The June 2016 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 completely buried. Sand fencing installed over the past year will help accumulate sand and enhance the natural dune growth.

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# 5.0 TOTAL VOLUME CHANGES AND VOLUME REMAINING

## 5.1 Total Volume Summary before and after Nourishment

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 (estimated ±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 (2013–2016). The volume changes relative to November 2010 (before the project) are listed in Tables 5.3 to 5.8. 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 |

**TABLE 5.8.** Total volume changes by reach between November 2010 and June 2016.

| Reach | Length (ft) | Volume Changes Between Nov-10 And Jun-16 (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 | 505,044 | 847,400 | 949,293 | 1,086,961 | 1,425,683 | 2,088,642 | 2,551,384 |
| **Reach 2 (790-920)** | 13,000 | 302,382 | 569,254 | 656,488 | 783,717 | 807,560 | 1,305,026 | 1,391,912 |
| **Reach 3 (920-1010)** | 9,000 | 221,481 | 470,829 | 516,565 | 579,130 | 617,606 | 760,191 | 801,539 |
| **Reach 4 (1010-1025)** | 1,500 | 5,486 | 25,964 | 29,270 | 29,024 | 42,620 | 16,051 | 3,098 |
| **Total (495-1025)** | 53,000 | 1,034,393 | 1,913,447 | 2,151,617 | 2,478,832 | 2,893,469 | 4,169,910 | 4,747,932 |

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 brown 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, the pink bars represent the results of the June 2014 survey, and the dark blue bars represent the results of the June 2015 survey. The most recent survey in June 2016 is represented by the beige bars in the graphic.

The first set of bars in Figure 5.1 represent net volume changes in the foredune (ie – Lens 1), the second set of bars represent net volume changes along foredune and beach (ie – Lenses 1&2), and the third set of bars represent net volume changes from foredune to beach and underwater (ie – the FEMA reference “sand box” or Lenses 1, 2 and 3).

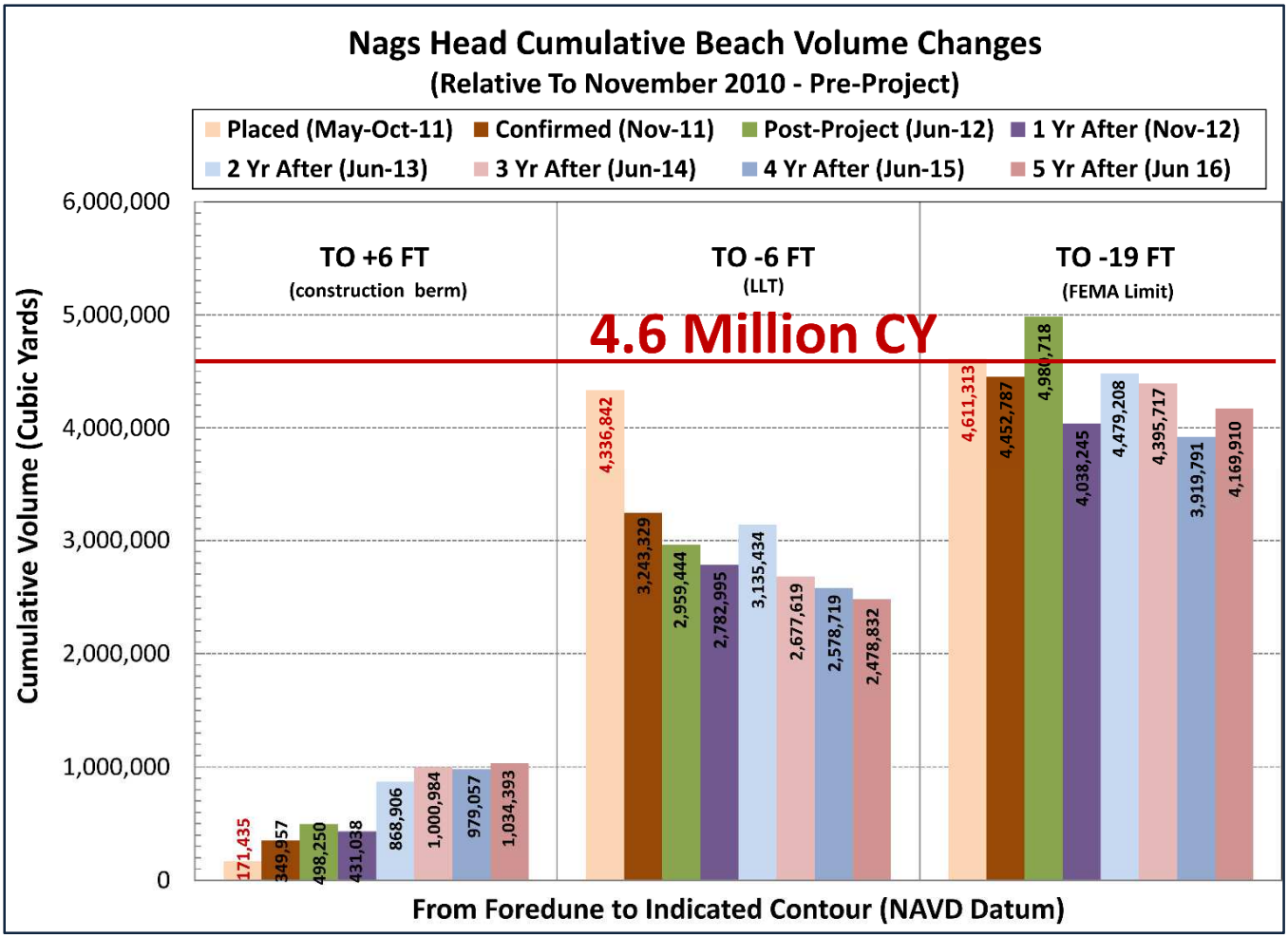



**FIGURE 5.1.** Cumulative, overall beach-volume changes relative to November 2010 survey results between the foredune and indicated contours.

**Foredune (Lens 1)**

As of June 2016, the foredune areas (the first set of bars in Fig 5.1) have accumulated over 1 million cubic yards more sand than the condition before nourishment. This is equivalent to a gain of over 19 cy/ft or ~3.5 cy/ft/yr above +6 ft NAVD (nourishment berm elevation) since pre-project conditions in November 2010, and ~13 cy/ft or ~3 cy/ft/yr of gain since project completion in November 2011. Such gain is considered significant for Nags Head because before nourishment between 1994 and 2010 Nags Head experienced dune losses averaging ~1 cy/ft/yr along this portion of beach. Dune behavior before and after nourishment will be discussed in detail in Section 6.

**Foredune and Beach (Lenses 1&2)**

The second set of bars in Figure 5.1 show the total volume changes from the face of the dune to low–tide wading depth (−6 ft NAVD). After the initial sand adjustment occurred in the first year following project compeltion, the beach volume has been relatively stable over the past three years. The June 2016 survey shows over 50 percent of the nourishment sand remains in the foredune and the beach.

**Foredune, Beach and Underwater (Lenses 1, 2&3)**

The third set of bars in Figure 5.1 show the cumulative volume change from the face of the dune to −19 ft (FEMA depth limit). The June 2016 results indicate that ~10 percent of the nourishment sand has shifted away from the "sand box" due to the chronic erosion at Nags Head, resulting in an average loss of ~90,000 cy/yr (1.6 cy/ft/yr) since project completion. This average erosion rate is much lower than the 275,000 cy/yr (5.2 cy/ft/yr) historical erosion rate between 1994 and 2005 adopted in the 2011 project formulation (CSE 2011a).

## 5.2 Total Volume Changes by Reach and Subreach

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-tide terrace (LTT) at the −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 (FEMA depth limit).

### *5.2.1 Compared to Last Year (June 2015)*

The survey results of June 2016 show that Reaches 1, 2 and 3 gained sand while Reach 4 (southern end of the project) lost sand in the foredune (Fig 5.2):

| | |
|---|---|
| Gained 38,140 cy | in Reach 1 |
| Gained 20,719 cy | in Reach 2 |
| Gained 9,906 cy | in Reach 3 |
| Lost 13,429 cy | in Reach 4 |
| Gained 55,336 cy | total (for the four reaches) |

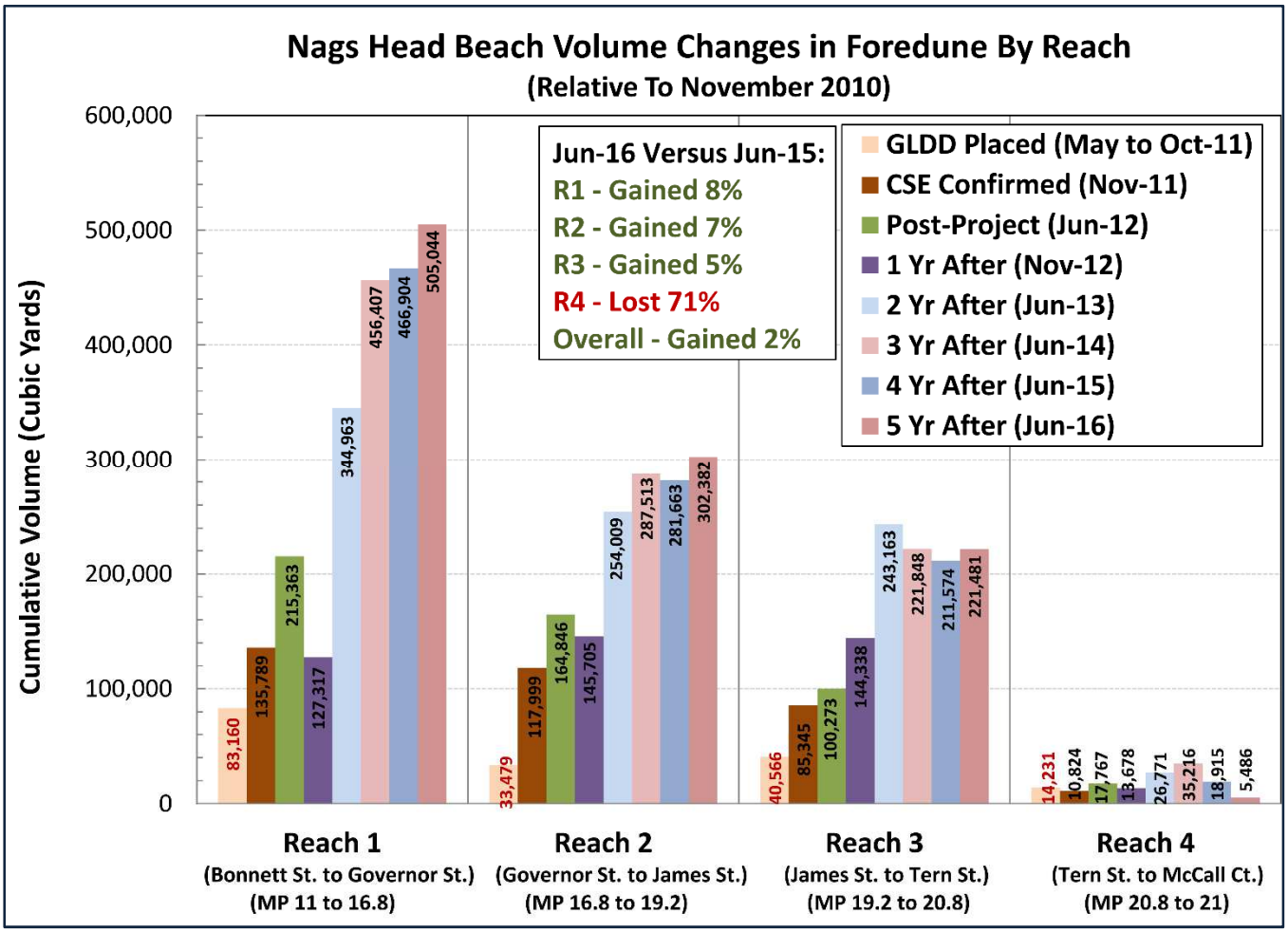



**FIGURE 5.2.** Beach volume changes by reach relative to November 2010 survey results in the foredune (from the face of dune to +6 ft NAVD). Nourishment sand loss or gain relative to last year (June 2015) is illustrated in the graph.

Figure 5.3 shows volume changes in the foredune and beach from the face of dune to −6 ft NAVD. Compared to 2015, all reaches except for Reach 1 lost sand. However, the overall loss is only ~4 percent.

| | |
|---|---|
| Gained 7,605 cy | in Reach 1 |
| Lost 25,737 cy | in Reach 2 |
| Lost 79,027 cy | in Reach 3 |
| Lost 2,728 cy | in Reach 4 |
| Lost 99,887 cy | total (for the four reaches) |

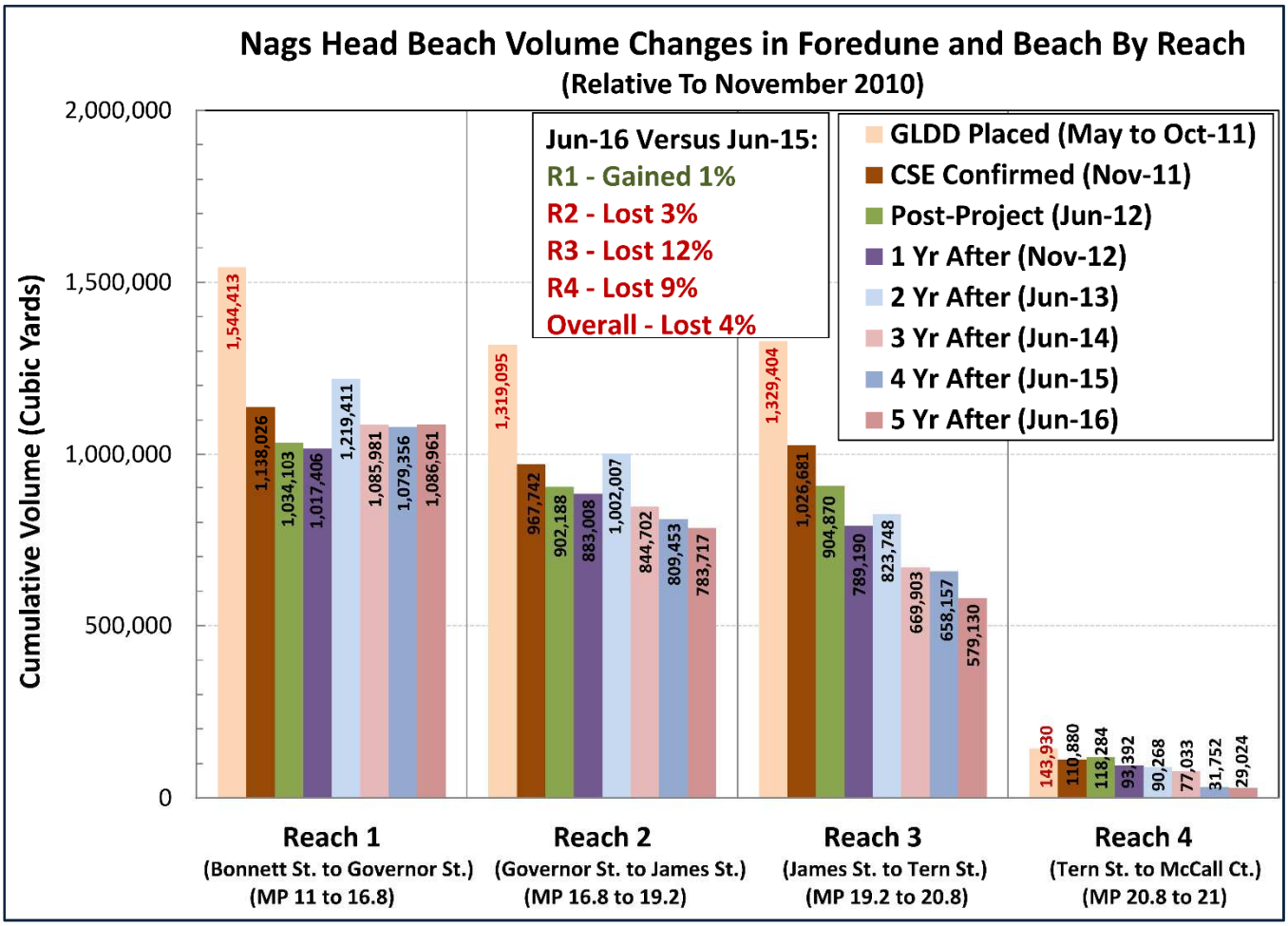



**FIGURE 5.3.** Beach volume changes by reach relative to November 2010 survey results from the face of dune to low tide wading depth (−6 ft NAVD). Nourishment sand loss or gain relative to last year (June 2015) is illustrated in the graph.

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 2016 show net gains in Reaches 1 and 2 but net losses in Reaches 3 and 4 from the face of dune to −19 ft NAVD in the past year:

| | |
|---|---|
| Gained 297,937 cy | in Reach 1 |
| Gained 36,614 cy | in Reach 2 |
| Lost 38,991 cy | in Reach 3 |
| Lost 45,441 cy | in Reach 4 |
| Gained 250,119 cy | (or ~4.7 cy/ft) total (for the four reaches) |

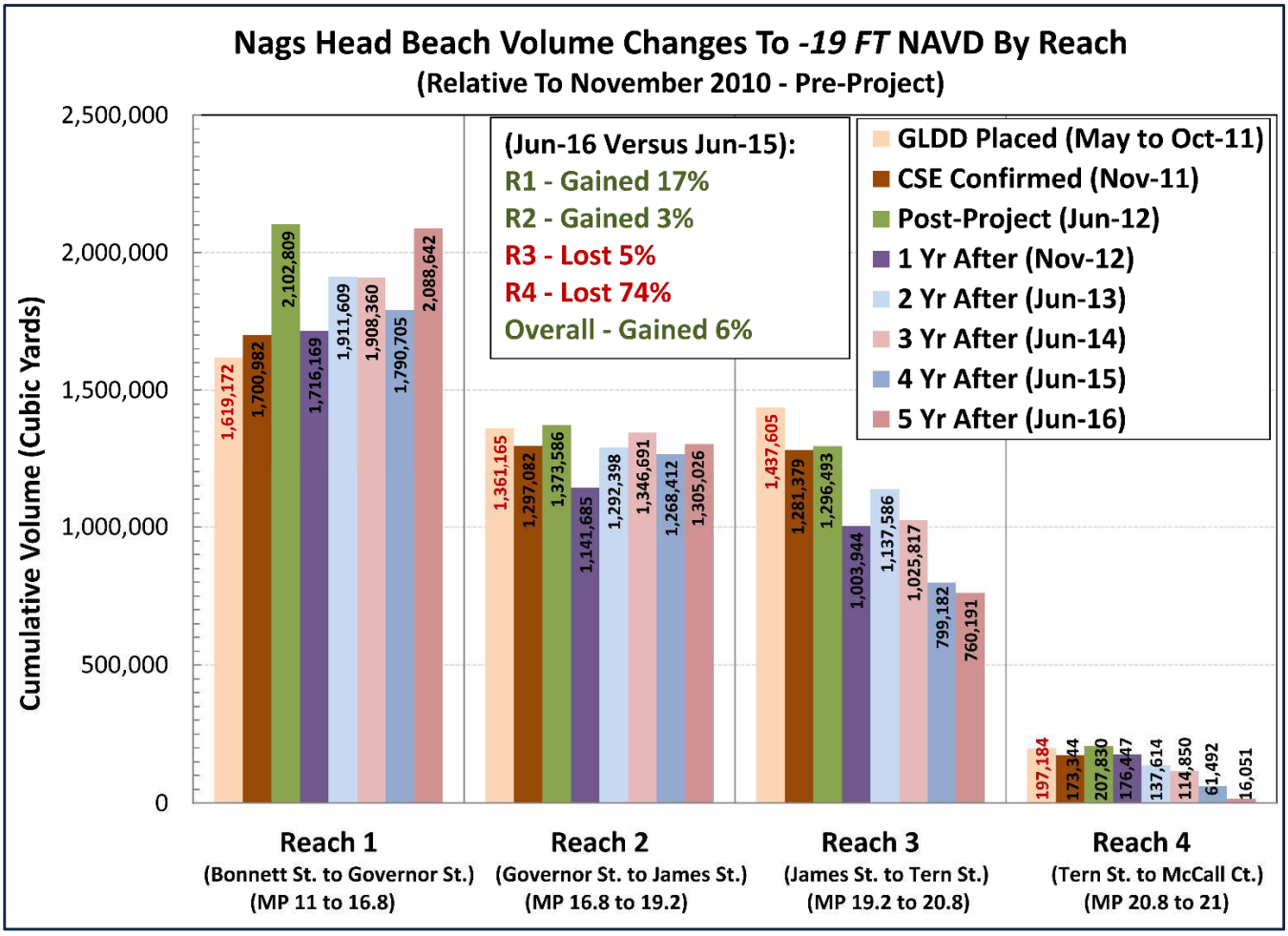



**FIGURE 5.4.** Beach volume changes by reach relative to November 2010 survey results from the face of dune to −19 ft NAVD. Nourishment sand loss or gain relative to last year (June 2015) is illustrated in the graph.

### *5.2.2 Compared to Project Completion (November 2011)*

All reaches except for the southernmost 1,500 ft of Reach 4 have significantly more volume in the foredune in 2016 compared with November 2011 (see Fig 5.2). Figure 5.3 showed that all reaches have lost volume to −6 ft since project completion due to the adjustment of nourishment sand. Figure 5.4 showed that Reach 1 (northern half of the project) has gained a significant amount of sand totaling ~387,660 cy (or ~23 percent of the nourishment sand placed in this reach). Reach 2 has been stable with a slight gain of ~7,944 cy 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 ~521,188 cy (~40 percent) and 157,293 cy (~90 percent) (respectively) of the nourishment sand since November 2011. The annual loss rate for Reach 3 and Reach 4 since November 2011 has been ~12.6 cy/ft/yr and ~22.8 cy/ft/yr (respectively). Sand losses were projected to be higher along south Nags Head than north Nags Head based on historical trends, but the erosion rates of the last two years in these two reaches are significantly higher than CSE's original design estimate. This difference is likely related to the shoreline offset produced by placing a higher fill density at the south end of the project to account for higher erosion rates.

In conclusion, the total volume remaining after nourishment to −19 ft NAVD (FEMA depth limit) in June 2016 is **~4,169,910 cy (~90 percent of the nourishment volume placed)**. The overall annual erosion rate since nourishment is ~93,500 cy/yr (~1.8 cy/ft/yr), which is well below CSE's design estimate of 5.2 cy/ft/yr. 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 still ~760,200 cy (~84 cy/ft) and ~16,000 cy (~11 cy/ft) (respectively) more sand in these reaches as of June 2016 than before nourishment.

### *5.2.3 Subreaches in Reach 3 and Erosion Rates Variations*

The results shown previously in Figures 5.2 to 5.4 suggest that more variability occurs underwater in the cross-shore as well as the longshore directions. Reach 1 has gained sand and Reach 2 has been relatively stable since project completion, but Reaches 3 and 4 have lost sand at a rate that is much higher than the overall project area. In order to better document the nourishment performance and evaluate the erosion variations in south Nags Head, Reach 3 is further divided into two subreaches 3N and 3S. Subreach 3S and Reach 4 together are considered as "erosion hotspots" for Nags Head as shown in Figure 5.5. Volume results including percentages of nourishment lost or gained by reach and subreach are plotted in Figure 5.6 and are summarized as follows.

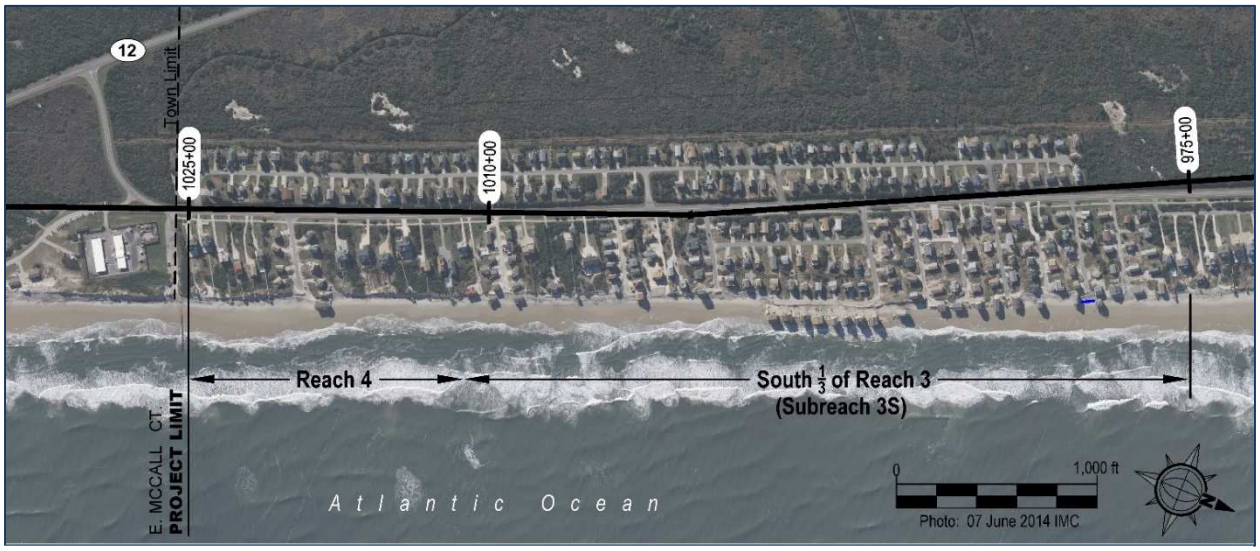



**FIGURE 5.5.** Higher erosion area along south Nags Head between station 975+00 in Reach 3 and station 1025+00 in Reach 4. The background aerial photo was taken on 7 June 2014 by IMC. The portion of Reach 3 to the north (out of the image) retained a large reservoir of nourishment sand which will continue to mitigate erosion at the south end of the project.

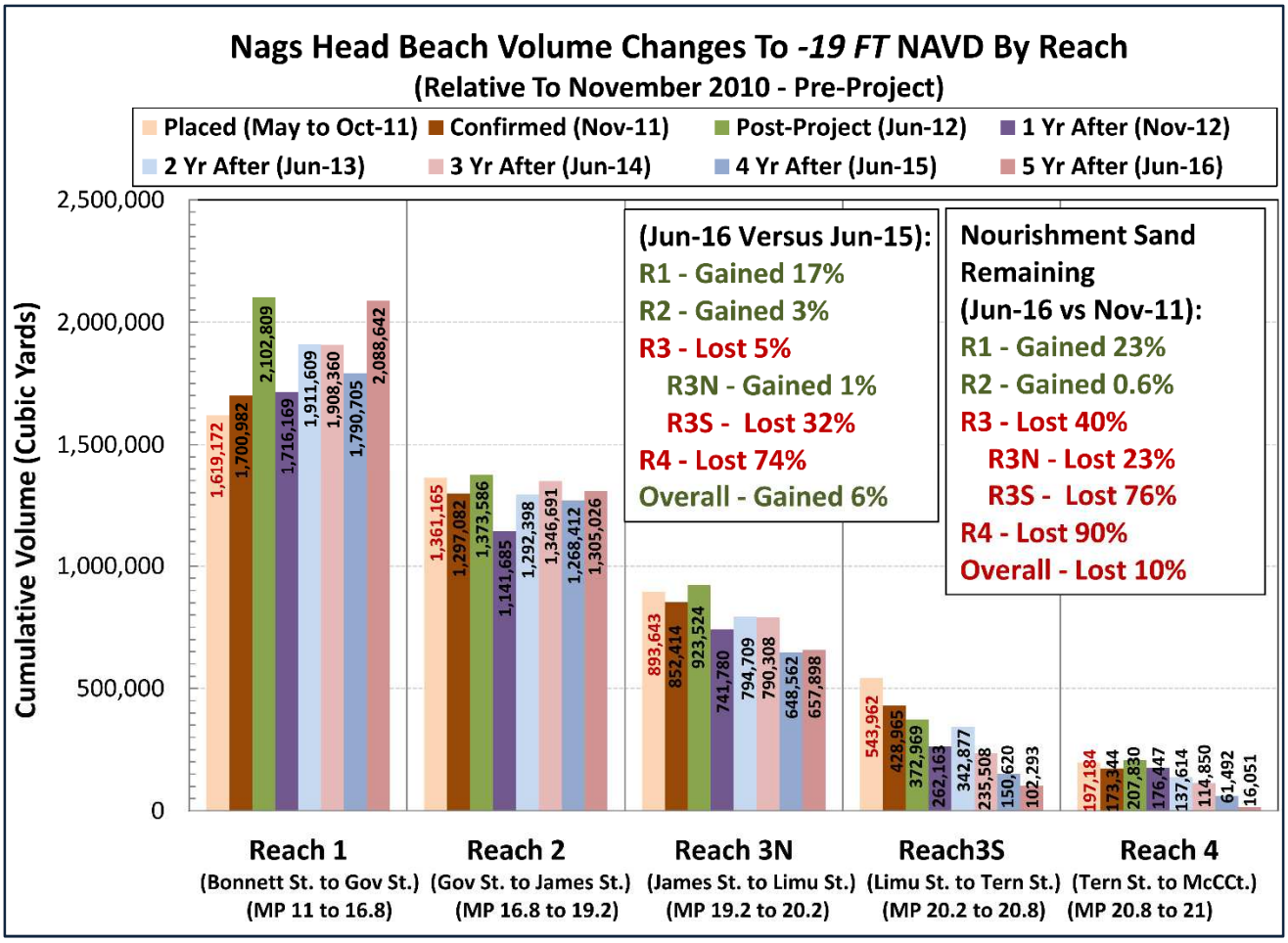



**FIGURE 5.6.** Beach volume changes by reach and subreach relative to November 2010 survey results from the face of dune to −19 ft NAVD.

**Reach 1 (R1)** – The northern ~5.8 miles of beach from Mile Posts 11 to 16.8 (CSE stations 497+00 to 790+00) gained 297,937 cy* over the past year and has gained 387,660 cy (~13 cy/ft or 2.8 cy/ft/yr) since project completion in November 2011. The total gain as of June 2016 is equivalent to ~23 percent of the nourishment volume in this reach, over and above the volume placed during the project.

*[*Unless otherwise specified, volumes in this section are measured from the foredune to the FEMA reference depth of −19 ft NAVD.*]

**Reach 2 (R2)** – The center to southern ~2.4 miles of beach from Mile Posts 16.8 to 19.2 (CSE stations 790+00 to 920+00) gained 36,614 cy over the past year. Compared to the condition after project completion in November 2011, Reach 2 remains stable with a minor gain of ~8,000 cy, which is equivalent to a 0.6 percent increase over the nourishment volume.

**Reach 3 (R3)** – The southern ~1.6 miles of beach from Mile Posts 19.2 to 20.8 (CSE stations 920+00 to 1010+00) lost 38,991 cy over the past year. Compared to the condition after project completion, Reach 3 has lost over 520,000 cy (~58 cy/ft or ~13 cy/ft/yr), equivalent to ~40 percent of the nourishment volume placed along this reach. In order to better document the nourishment performance and delineate erosion variations along south Nags Head, Reach 3 is further divided into two subreaches in some of the analysis.

**Subreach 3N (R3N)** – The northern two-thirds of Reach 3 from Mile Posts 19.2 to 20.2 (CSE stations 920+00 to 975+00) gained 9,336 cy over the past year, indicating stability along this section of beach. Compared to the condition after project completion in November 2011, Subreach 3N has lost 194,516 cy (~35 cy/ft or ~8 cy/ft/yr), which is equivalent to ~23 percent of the nourishment sand placed here. This rate compares favorably with the volume loss rate of 40 percent for the entire Reach 3.

**Subreach 3S (R3S)** – The southern one-third of Reach 3 from Mile Posts 20.2 to 20.8 (CSE stations 975+00 to 1010+00) lost 48,327 cy over the past year. Since project completion, Subreach 3S has lost 326,672 cy (~93 cy/ft or ~20 cy/ft/yr), which is equivalent to 76 percent of the nourishment volume placed. This rate is much higher than the average volume loss rate for all of Reach 3 and about 2.5 times the erosion rate for Subreach 3N.

**Reach 4** – The southernmost ~0.2 mile of beach from Mile Posts 20.8 to 21 (CSE stations 1010+00 to 1025+00) lost 45,441 cy over the past year. Compared to conditions after project completion, Reach 4 has lost over 90 percent of the nourishment volume. The average erosion rate is as high as ~105 cy/ft or ~23 cy/ft/yr which is similar to Subreach 3S. The beach condition in June 2016 along this 1,500-ft-long-end of the project area has now returned to conditions before nourishment based on the volume analysis.

Figure 5.7 to Figure 5.9 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, leaving a small pond (see middle photo of Fig 5.7).

Fall northeasters in 2011 washed over the nourished beach and pushed sand into the pond (see bottom photo of Fig 5.7). The width of dry beach increased as much as 190 ft **seaward** of the houses after project completion. Although the dry-beach width steadily narrowed after project completion (Fig 5.8 and Fig 5.9, upper and middle), the unit volume to −19 ft at this station remained relatively stable between November 2012 and June 2014 (Fig 5.9, lower). By June 2015, 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. During the past year, unit volume at this station continued to decrease by another 45 cy/ft, bringing conditions to nearly the same as pre-project conditions in November 2010.

Overall, the landward and offshore shift of sand following nourishment had the important effect of creating a more natural profile with new sand bars forming in shallow water. Prior to adjustment of the nourishment construction profile, 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 10-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 5.7.** 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.

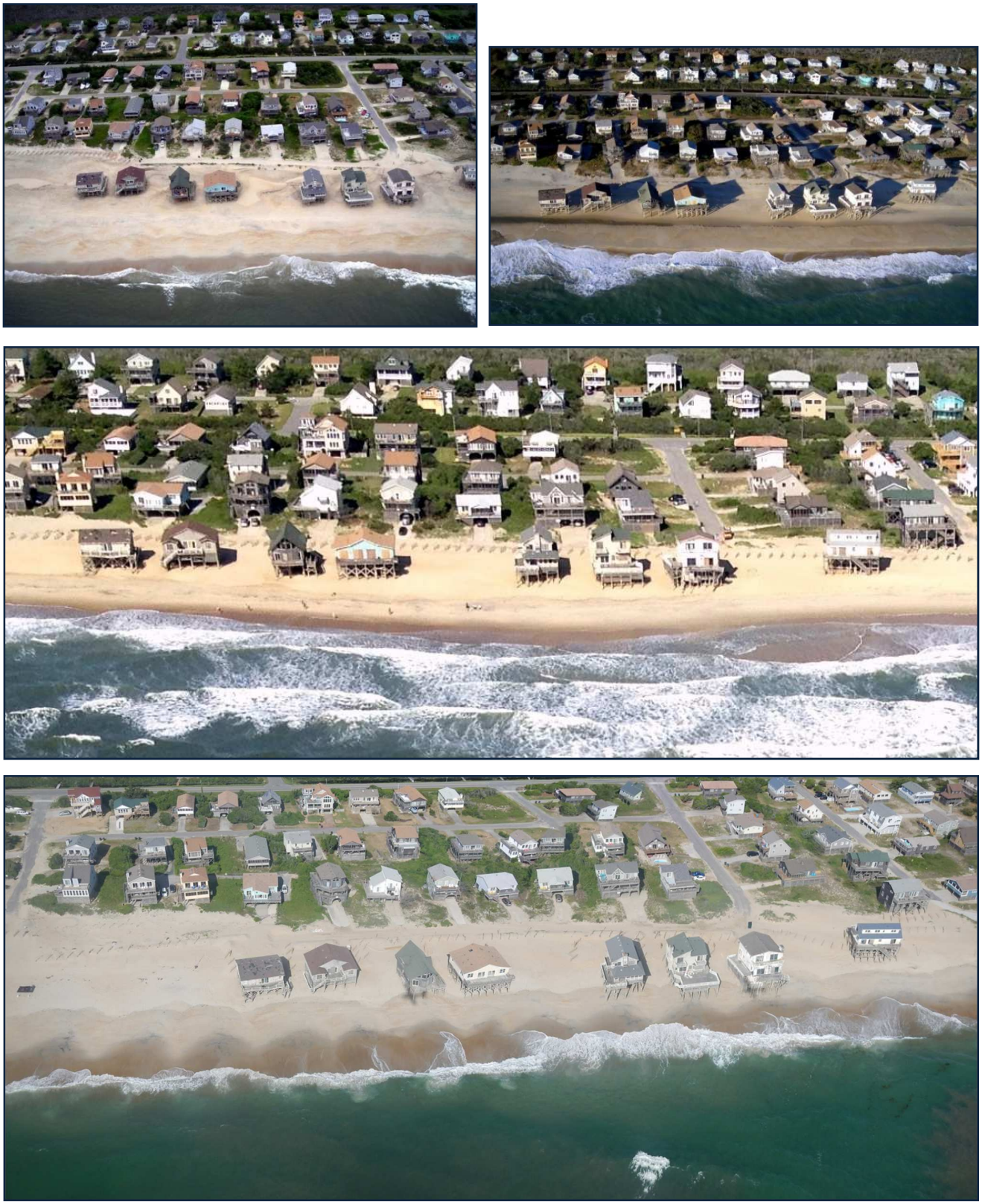
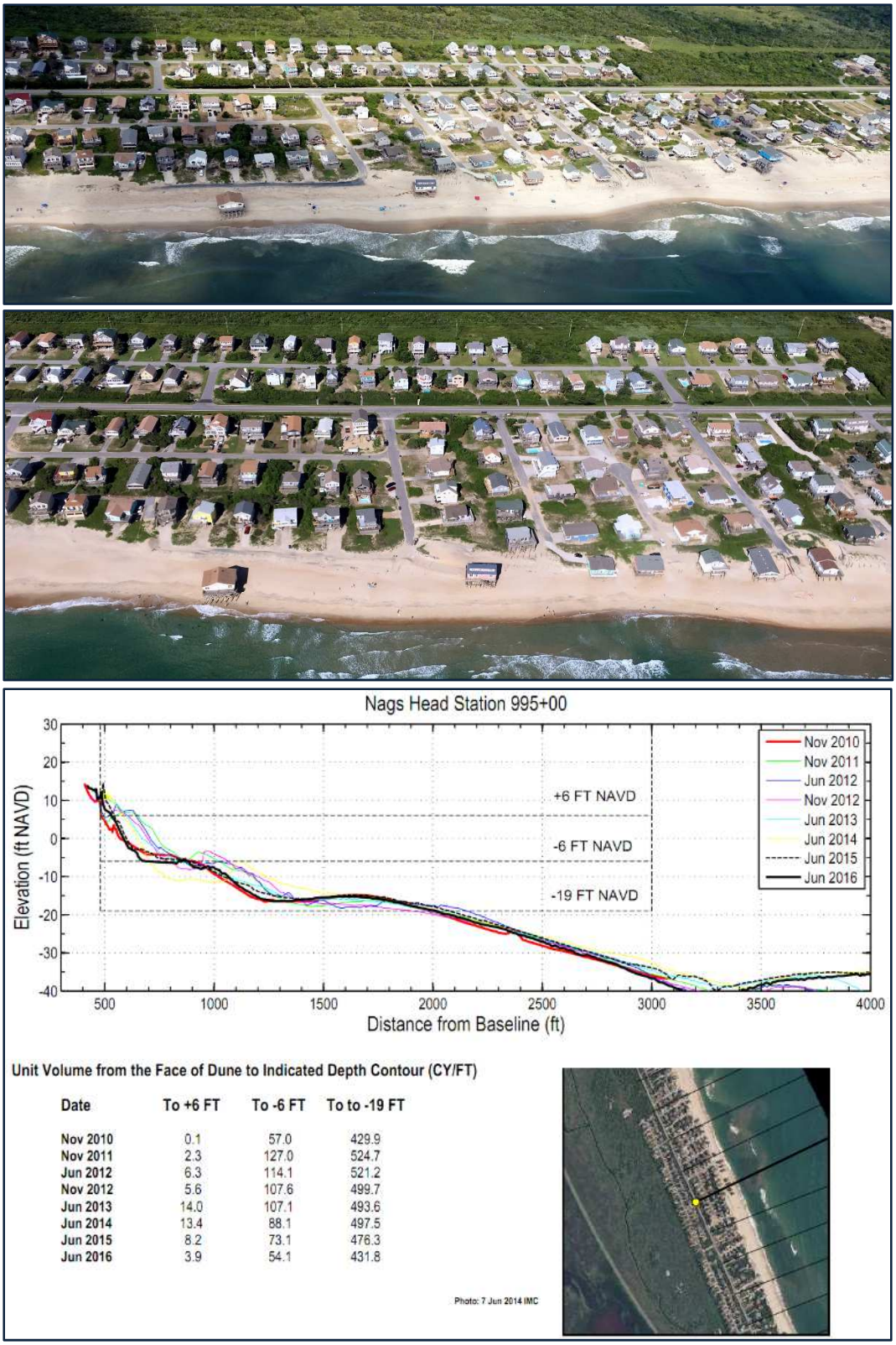


**FIGURE 5.8.** Aerial views of south Nags Head at Seagull Drive. [UPPER LEFT] 12 June 2012 – before 2012 hurricane season. [UPPER RIGHT] 3 November 2012 – after Hurricane *Sandy*. [MIDDLE] 20 JUNE 2013 – before 2013 hurricane season. [LOWER] 7 June 2014 – before 2014 hurricane season.




**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 |
| Jun 2016 | 3.9 | 54.1 | 431.8 |

**FIGURE 5.9.** [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. [MIDDLE] Aerial photo taken on 13 June 2016 – before 2016 hurricane season. [LOWER] Complete profile from the back of houses to deep water. Unit volumes of each survey are listed in the graph.

# 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. 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 greatly 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 foredune 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 349,957 cy more sand above +6 ft NAVD in the foredune compared to the pre-project condition in November 2010 (see Figure 5.1).

Four and a half years after project completion in June 2016, an additional ~685,000 cy were detected in the foredune along the 10−mile beach compared to the November 2011 condition, equivalent to an increase of 13 cy/ft or 3 cy/ft/yr. Surveys between November 2010 and June 2016 are plotted and compared in Figure 6.2. Dune erosion or accretion rates before and after nourishment are summarized in Figure 6.3. As Figure 6.3 indicates, the rate of dune growth has slowed since 2014. This trend is likely to continue because the width the dry-sand beach is narrower, providing a smaller fetch for wind-blown sand to accumulate.

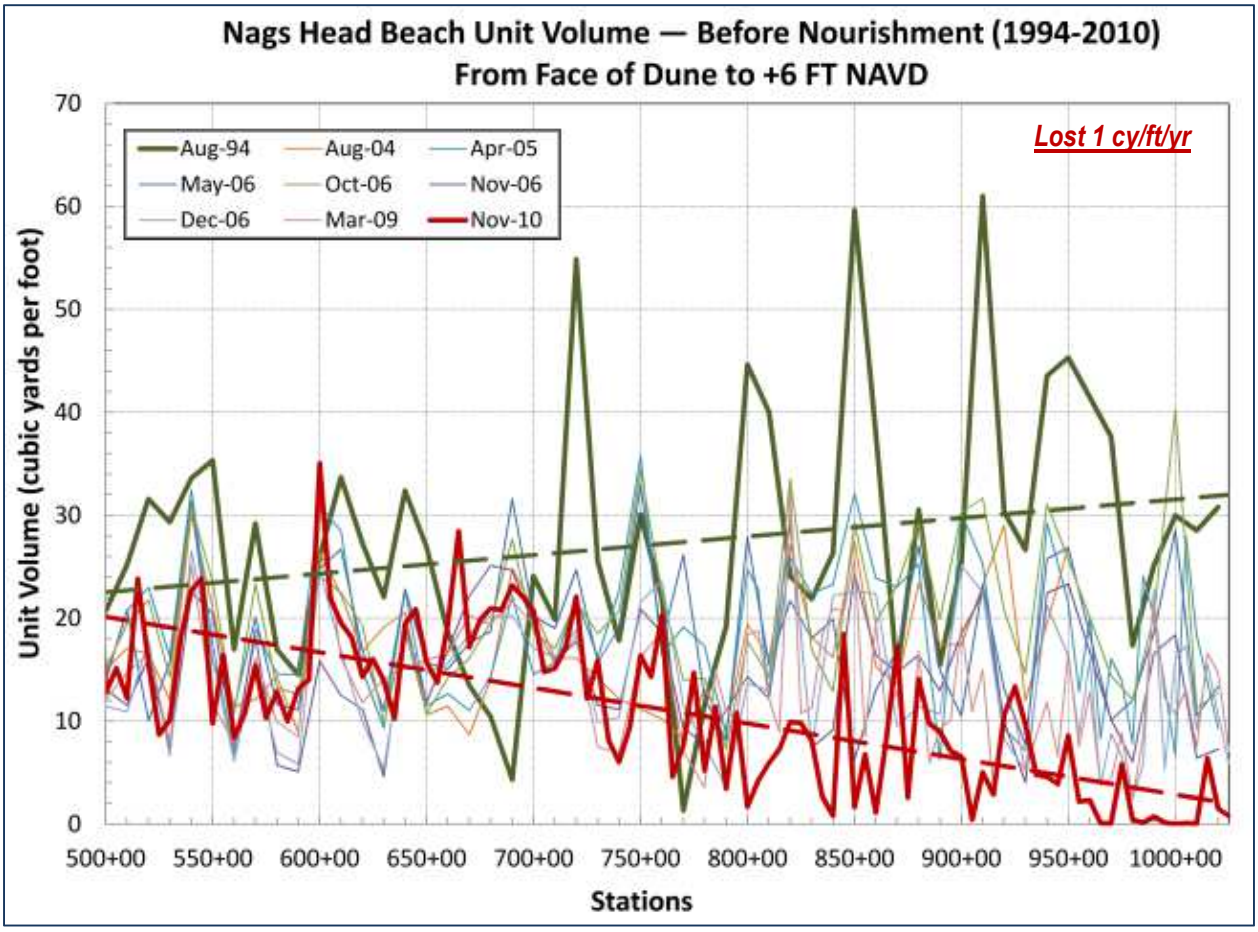



**FIGURE 6.1.** Nags Head unit volume changes before nourishment between August 1994 and November 2010 in the foredune areas above the +6 ft contour.

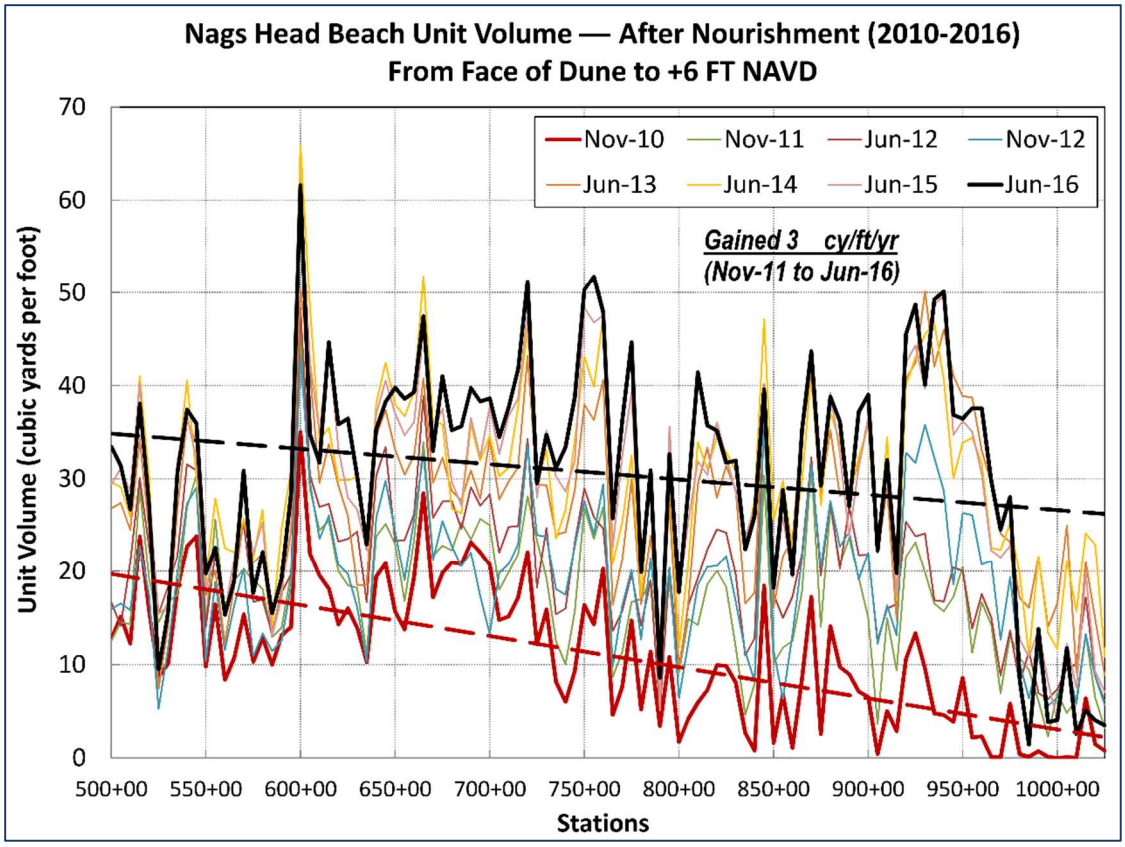



**FIGURE 6.2.** Nags Head unit volume changes after nourishment between November 2011 and June 2016 in the foredune areas. Unit volume in November 2010 (before nourishment) is plotted as well for comparison.

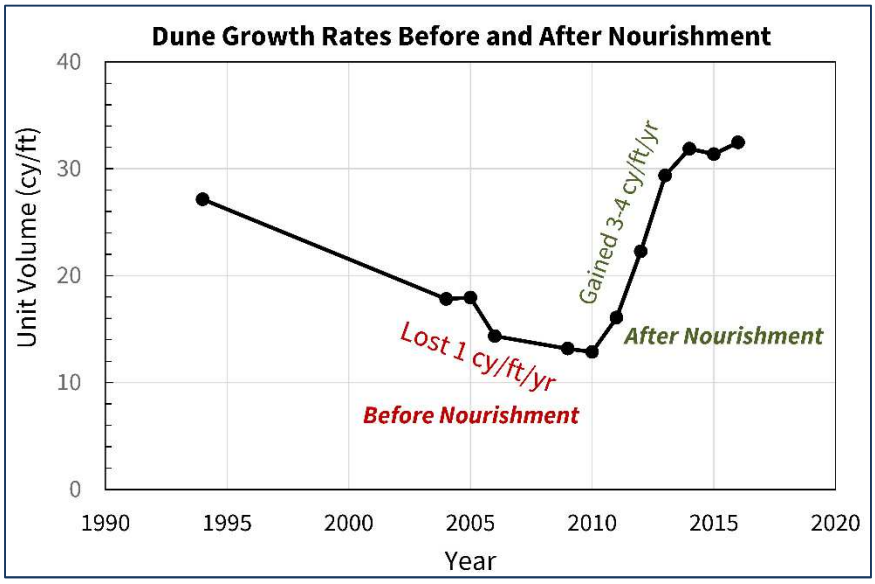



**FIGURE 6.3.** Nags Head dune erosion or accretion rates before and after 2011 nourishment measured above the +6-ft NAVD contour.

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.

## 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, that is, nourishment or natural accretion), the incipient foredunes will coalesce, forming a continuous foredune or foredune ridge.

The photos in Figure 6.4 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 (if no renourishment sand is added) 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.

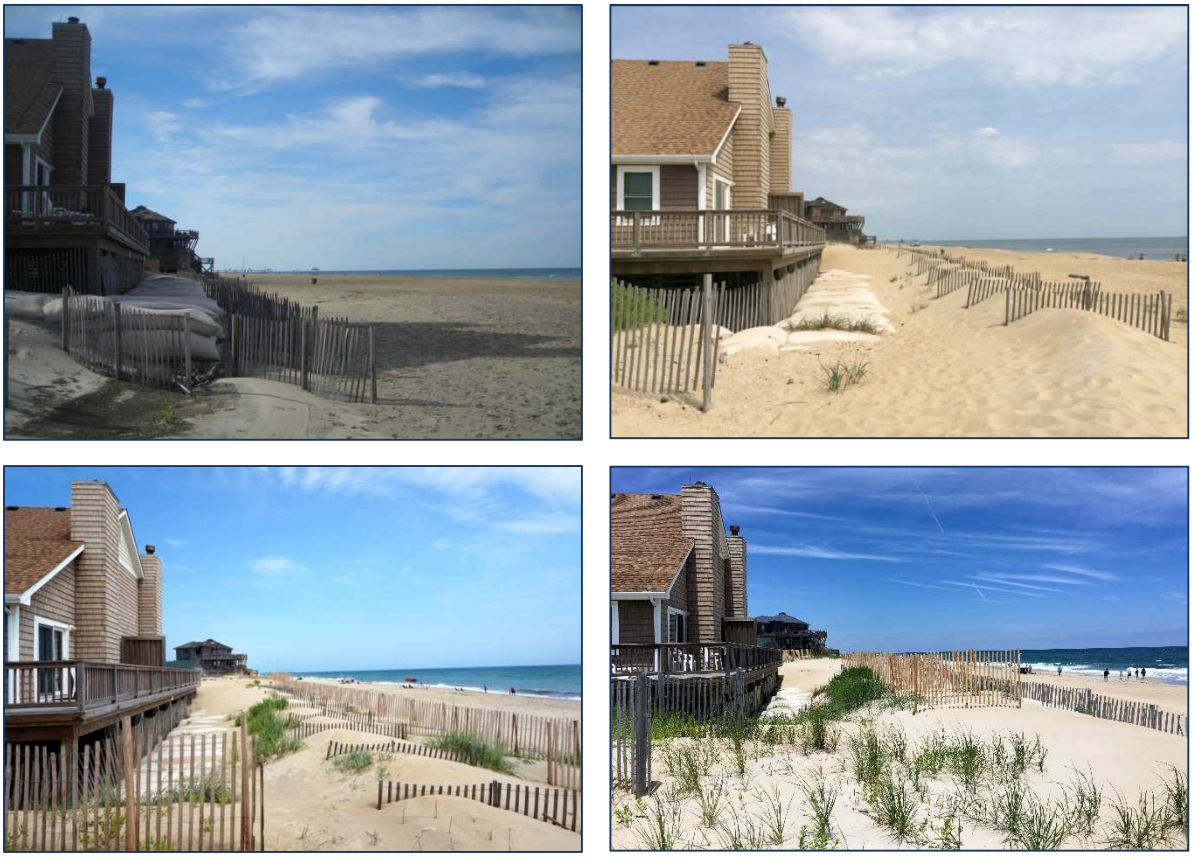


**FIGURE 6.4.** Incipient dunes formed and stabilized after nourishment near station 855+00, and sand bags gradually buried. [UPPER LEFT] Photo taken on 11 June 2012, seven months after project completion, shows a row of sand fencing seaward of the sand bags. [UPPER RIGHT] Photo taken on 5 June 2014, two years and seven months after project completion, shows a second row of sand fencing seaward of the first row. [LOWER LEFT] 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. [LOWER RIGHT] Photo taken on 13 June 2016, four years and seven months after project completion, shows new row of sand fencing and more mature vegetation on the dunes.

## 6.3 Dry Beach Width – Before and After Nourishment

CSE computed average dry-beach width in the past three years (June 2014, June 2015, and June 2016) using the survey results. Figure 6.5 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) and the present monitoring period (June 2016). 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 6.5 shows that the beach berm is overall much wider in June 2016 than pre-project in November 2010. Results from previous years can be found in CSE's annual monitoring reports (CSE 2014b; 2015). **The average berm widths at Nags Head are 47.7 ft in November 2010, 72.4 ft in June 2014, 84.5 ft in June 2015, and 68.2 ft in June 2016.**

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 6.5 that Reach 1 only has ~10–15 ft in most areas to accommodate dune expansion under this criterion.

Reach 2 has an average dry-beach width of ~66 ft, giving it an extra ~16 ft of width to accommodate dune building, which is narrower than results from last year. As projected in CSE's 2014 report (CSE 2014b), this area is expected to diminish in the next five years (if no renourishment sand is added) 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.

The northern two-thirds of Reach 3 (ie – Subreach 3N from stations 920+00 to 975+00) contains the widest beach section with as much as 102 ft of dry-sand beach, which indicates there are places with up to 52 ft extra width beyond the 50-ft criteria as of June 2016. 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 southern one-third of Reach 3 (ie – Subreach 3S from stations 975+00 to1010+00) is losing sand rapidly due to its proximity to the end of the project area, although there are still ~70 ft of dry-sand beach as of June 2016. Buildings encroaching more than 25 ft onto the beach in this reach cannot be protected by a new dune line in the next five years. Any dune encroachment measures implemented along these properties will wash out during minor storms, because of the ongoing sand losses in those profiles.

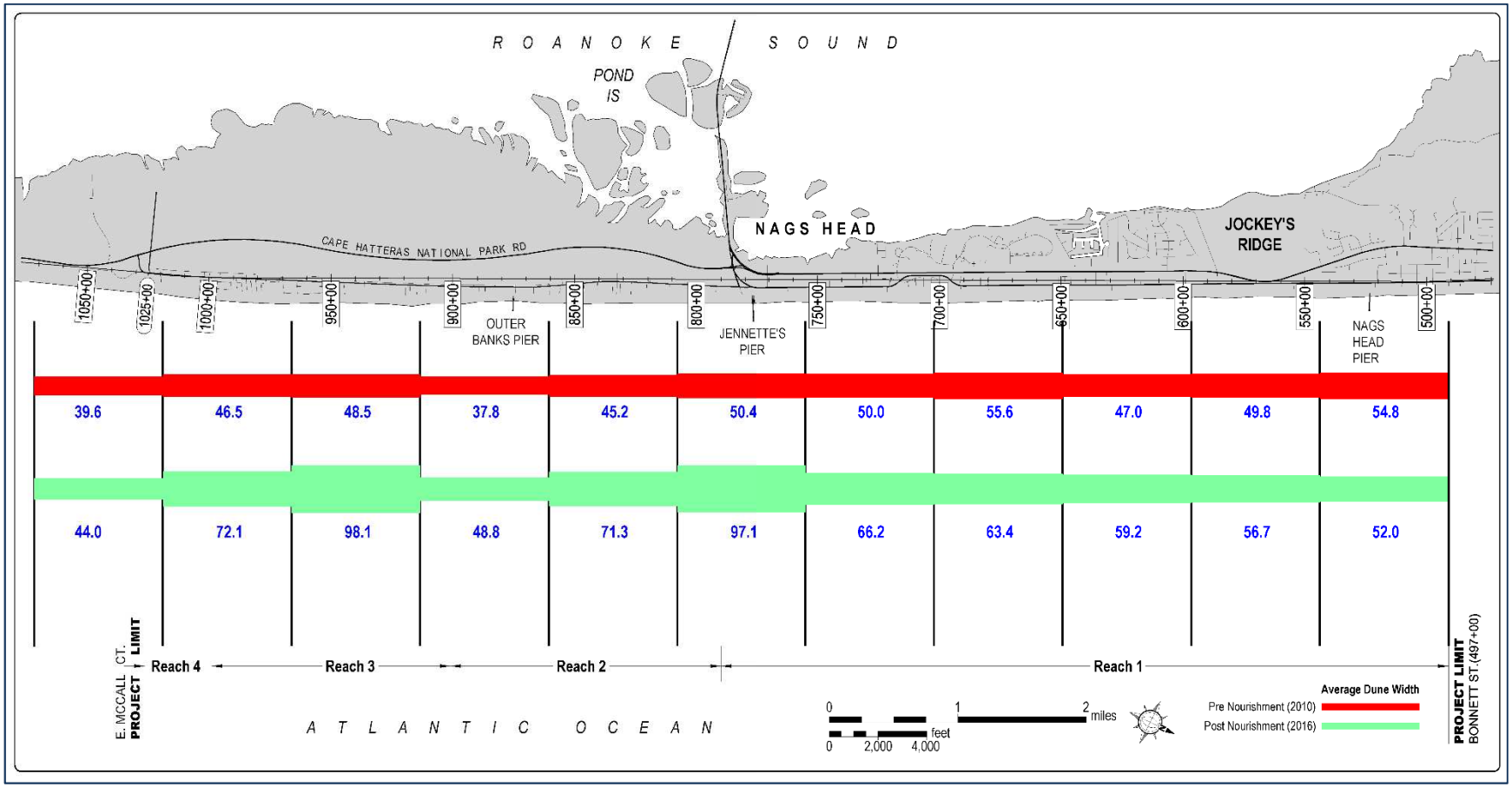



**FIGURE 6.5.** Average beach widths (ft) before and after nourishment between the toe of dune (+10 ft NAVD) and the approximate seaward edge of the dry beach (+5 ft NAVD) by mile along Nags Head. The overall average dry-beach width was ~47.7 ft in November 2010 before nourishment and increased to ~72.4 ft in June 2014 after nourishment and profile adjustment. It continued to increase to ~84.5 ft in June 2015, then decreased to ~68.2 ft in June 2016. Detailed results of 2014 and 2015 can be found in the annual monitoring reports (CSE 2014b; 2015).

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# 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, June 2015, and June 2016. Downcoast of the project, CSE obtained profile data between station 1025+00 (project limit) and station 1080+00 (~1 mile south of the project and ~4 miles north of Oregon Inlet along the Cape Hatteras National Seashore). Data are available for November 2010, June and November 2012, June 2013, June 2014, June 2015, and June 2016.

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 brown bars (November 2011) 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 2016 survey shows continued sand gains north of the project in the foredune and the beach with a net gain of over 100,000 cy (to +6 ft) and ~132,277 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 retained more sand over the past year compared to the post-project condition. This phenomenon is similar to the trend that was observed along Reach 1 and Reach 2 in Nags Head, and the annual **accretion** rate for upcoast is equivalent to ~6.8 cy/ft/yr since November 2010 and ~1.6 cy/ft/yr since project completion in November 2011.

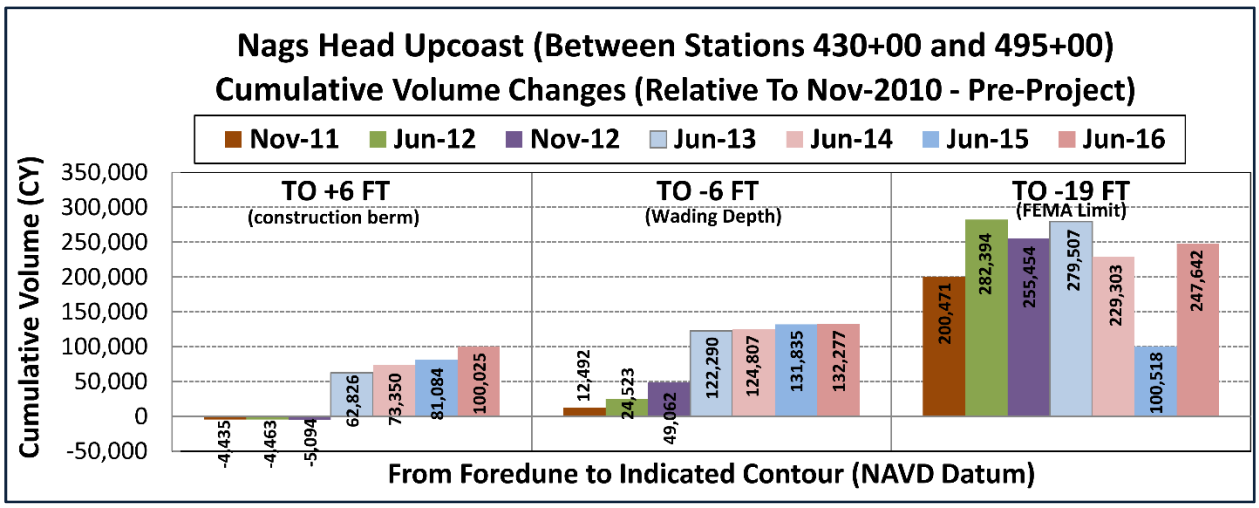


**FIGURE 7.1.** Cumulative volume changes from the foredune to the indicated contour relative to the November 2010 condition along upcoast stations outside the project area.

**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 |
| **Jun-16** | 288,577 | 521,035 | 617,730 | 849,990 | 1,646,946 | 3,551,431 | 5,654,875 |
| **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 |
| **Jun-16** | 100,025 | 127,621 | 132,328 | 132,277 | 189,043 | 247,642 | 329,474 |

## 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). There had been extra volumes in the downcoast reach between November 2011 and June 2015 relative to November 2010 conditions, measured from the face of dune to −19 ft depth contour. However, the downcoast reach lost significant volume over the past year, and its beach condition in June 2016 has returned to the pre-project condition. The high erosion rate (~46 cy/ft between June 2012 and June 2016 or ~11 cy/ft/yr) is comparable to the sand loss rate observed along the southern end of the project area (see the third group of bars from the left in Fig 5.3 to Fig 5.5), with an offshore shift of the outer bar to deeper water.

It is likely the downcoast 1-mile area would have sustained losses averaging ~80,000 cy/yr based on pre-nourishment erosion rates (CSE 2011a). Natural losses in this case were offset by upward of 180,000 cy/yr passed downcoast from Reach 3 and Reach 4. Because of the time it takes for sand to move downcoast, shoaling in Oregon Inlet in recent years has been principally related to erosion along the Seashore.

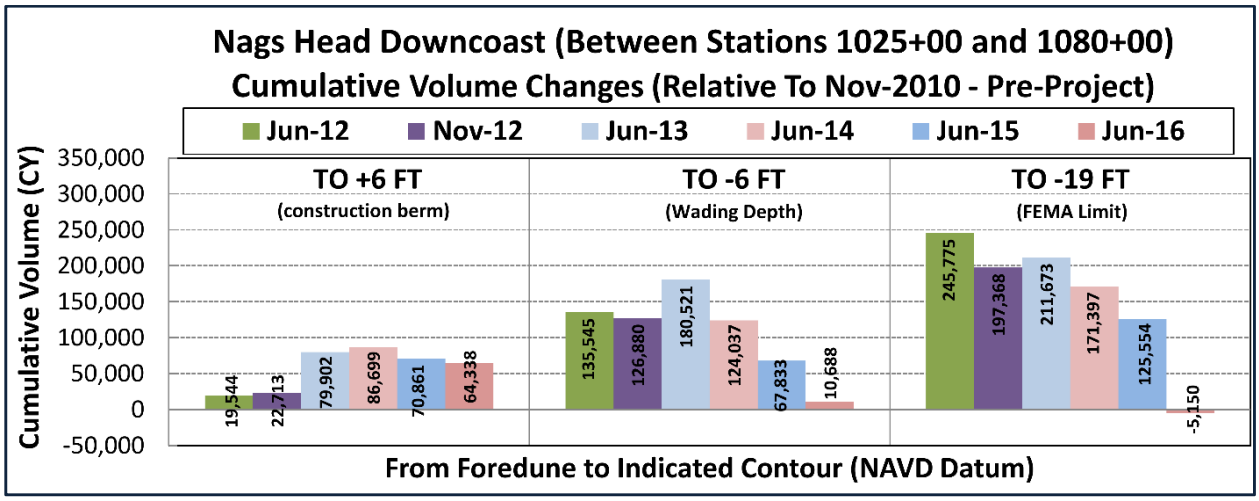


**FIGURE 7.2.** Cumulative volume changes from the foredune to the indicated contour relative to the November 2010 condition along downcoast stations outside the project area.

**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 |
| **Jun-16** | 102,531 | 272,325 | 350,925 | 555,884 | 1,262,548 | 2,932,947 | 4,753,875 |
| **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 |
| **Jun-16** | 64,338 | 97,999 | 88,224 | 10,688 | 26,421 | -5,150 | -15,908 |

## 8.0 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 hotspots 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 hotspots 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.

This year's annual surveys were conducted during the week of 20 June. The preliminary monitoring results, including sand volumes remaining in June 2016 by reach and depth limit, were summarized in a memorandum and reported to the Town on 8 August 2016 (CSE 2016). The principal results in this report are consistent with the memorandum but provide greater details. The area of south Nags Head, including Reach 4 and the southern half of Reach 3, have experienced higher erosion over the past two years. However, the northern half of Reach 3 contains the widest beach (see Fig 6.5) and can serve as a reservoir of nourishment sand which will mitigate erosion to some extent at the south end of Nags Head.

To better track erosion hotspots and document the condition of the entire profile, the Town has approved a fall survey along Nags Head in fall 2016. Supplemental surveys of Reaches 3 and 4 in November could be used to better document the fate of the nourishment along the critically eroding part of the project, and provide design guidance for a long-term management strategy including a possible renourishment in summer 2018.

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 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. Existing sandbags have been nearly buried, and incipient dunes are forming. 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.

Relevant news reports during the present monitoring period for the Nags Head nourishment project are included in Appendix 6.

## 9.0 SELECTED PHOTOGRAPHS (TAKEN ON 13 JUNE 2016)

**PHOTO 1 —** The northern most project boundary for the 2011 nourishment project is located near Bonnett Steet (CSE survey station 497+00).

**PHOTO 2 —** The southern most project boundary for the 2011 nourishment project is located near McCall Court (CSE survey station 1025+00).

**PHOTO 3 —** The three piers along Nags Head beachfront. [UPPER] Nags Head Pier near station 523+00. [MIDDLE] Jennette's Pier near station 777+00. [LOWER] Outer Banks Pier near station 875+00.

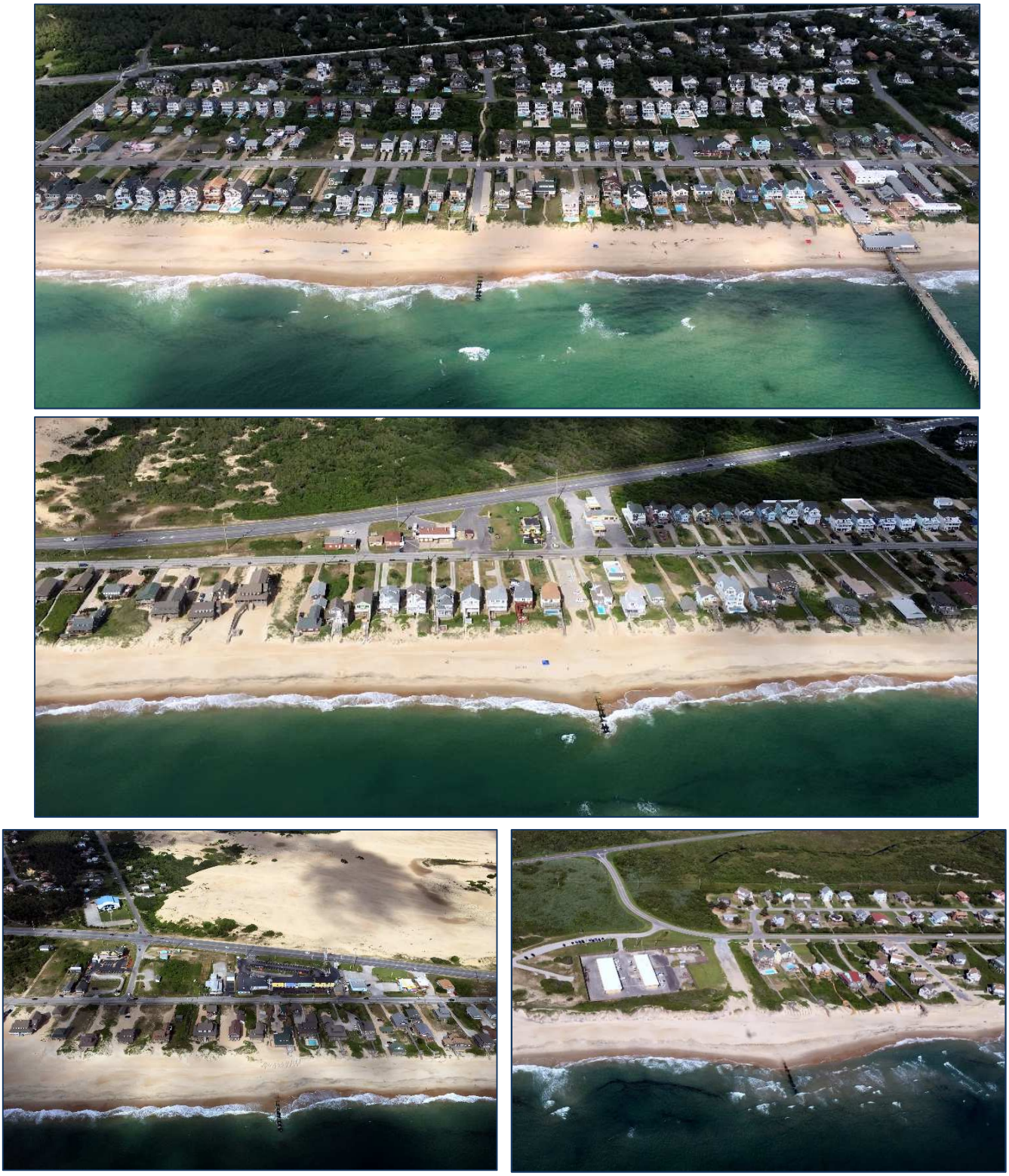

**PHOTO 4 —** The four ocean outfalls along Nags Head beachfront. [UPPER] the northernmost outfall near Curlew Street at station 531+40 south of Nags Head Pier. [MIDDLE] Near Conch Street at station 554+00. [LOWER LEFT] Near Sound Side Road at station 580+85. [LOWER RIGHT] Near McCall Court at station 1025+00.

**PHOTO 5** — Beach condition of Reach 3 (Subreach 3N)near Surside Drive at station 955+00.

**PHOTO 6** — Beach condition of Reach 3 (Subreach 3S) near Seagull Drive at station 990+00.

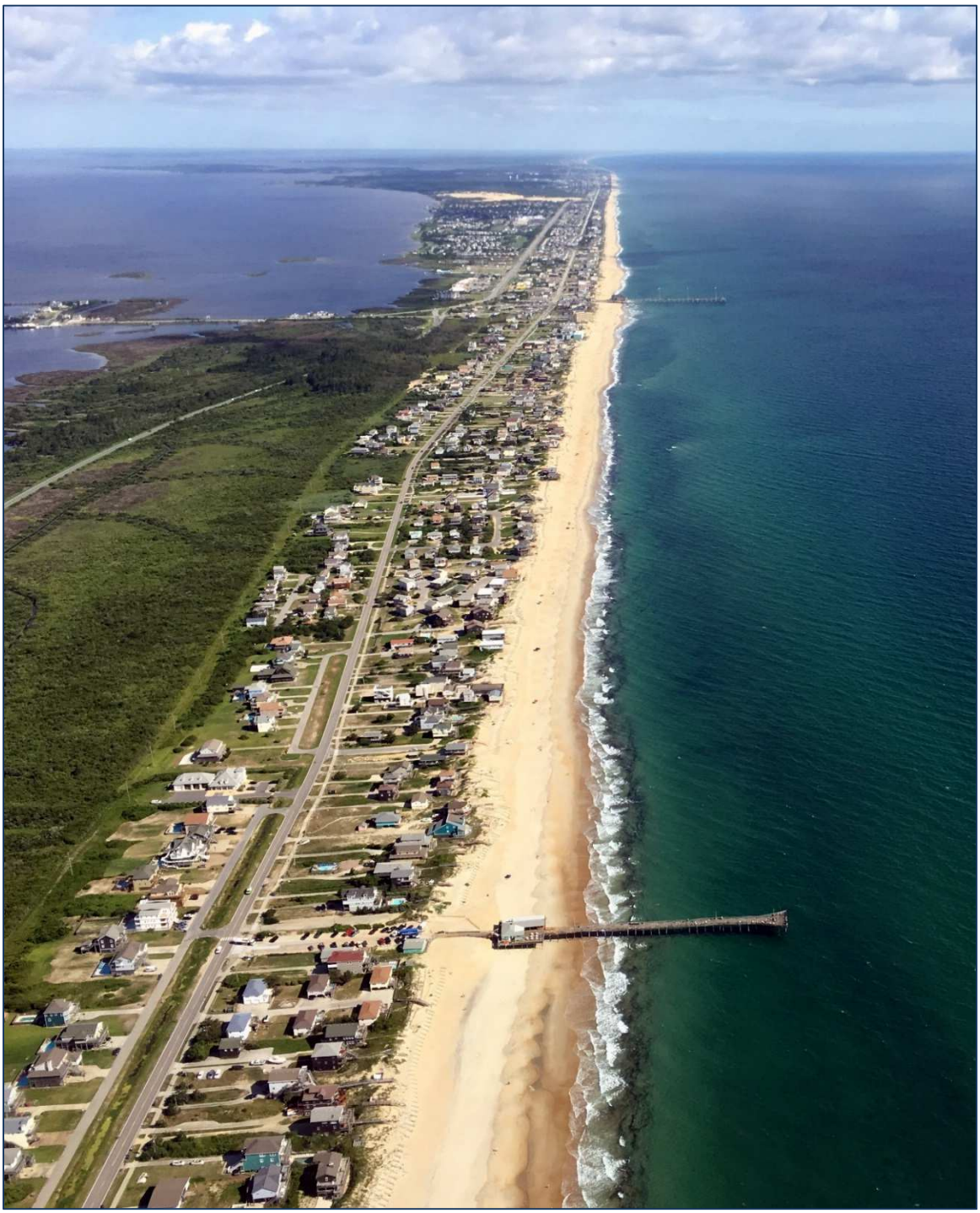

**PHOTO 7 —** Beach condition of Reaches 1–3 looking northeast. The three piers (Nags Head Pier, Jennette's Pier, and Outer Banks Pier) from top to bottom can be seen in the photo.

**PHOTO 8 —** Beach condition of Reaches 2–4 looking southwest. The pier located in the middle of the photo is Outer Banks Pier. Note slight change in shoreline azimuth at top of image is related to the increase in erosion rates along Subreach 3S and Reach 4.

**PHOTO 9** — Beach condition looking northeast. The ocean outfall in the middle of the photo marks the south boundary of the 2011 nourishment project. Beach below the outfall belongs to National Park Service (NPS).

**PHOTO 10** — Beach condition looking southwest. The ocean outfall in the middle of the photo marks the south boundary of the 2011 nourishment project. Beach above the outfall belongs to National Park Service (NPS). Oregon Inlet, which is ~5 miles south of the outfall, is shown at the top of the photo.

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# APPENDIX 1

# Beach Monitoring & Maintenance Plan

# Town of Nags Head
# BEACH MONITORING AND MAINTENANCE PLAN
# Dare County, North Carolina

August 2011

Prepared by:

Cliff Ogburn
Town Manager
Town of Nags Head
5401 S. Croatan Highway
PO Box 99
Nags Head, NC 27959

Adopted by:
The Town of Nags Head Board of Commissioners
August 25, 2011

## Purpose

The purpose of the Beach Monitoring and Maintenance plan is to:

1. Provide a brief overview of the morphological setting of the Town of Nags Head.
2. Detail the construction of the Town of Nags Head's initial beach nourishment project.
3. Briefly summarize the Town's funding for the initial beach nourishment project.
4. Specify the physical beach monitoring activities.
5. Detail the beach maintenance planning guidelines.
6. Relate a plan for periodic renourishment funding.

### (1) Morphological Setting of Nags Head, NC

The Town of Nags Head encompasses ~11 miles of ocean shoreline on North Carolina's Outer Banks, a chain of barrier islands along the Atlantic Ocean, 90 miles south of Norfolk, Virginia.

The initial beach nourishment project totals ~10 miles of shoreline beginning ~1 mile from the town's northern limit, near the Bonnett Street public beach access, extending south to the town line adjacent to the Cape Hatteras National Seashore.

The Town faces east to northeast and is bordered by the Town of Kill Devil Hills to the north and the Cape Hatteras National Seashore to the south. The Roanoke Sound borders the town on the west and the Atlantic Ocean makes up the town's eastern limits. Oregon Inlet, the closest inlet to Nags Head, is located ~5.2 miles south of the town line. Due to its location, Nags Head has sustained chronic erosion over the past 50 years due to storms and sand losses. Erosion rates ranging from ~2 feet per year (ft/yr) to upward of 10 ft/yr (NCDENR 1998, 2004) have forced abandonment of property and left numerous structures with no dune protection. The Town is exposed to high wave energy during storm events (particularly hurricanes and northeasters) which are common in fall and winter. Net sand transport is south along Nags Head. Erosion rates increase from north to south and remain high in the National Seashore reach between Nags Head and Oregon Inlet. There are presently three ocean piers and five stormwater outfalls crossing the beach along the Town of Nags Head. The beach is composed of medium sand with a mean grain size of ~0.4 mm. Mean monthly average significant wave height ranges from 2.1 ft (July) to 3.9 ft (Oct) based on records from 1986-2006 (source: USACE-FRF unpublished data). Details regarding the morphological setting are given in CSE (2005) and CSE (2011a).

### (2) Initial Beach Nourishment Project Design

The initial project encompasses the same section of Nags Head shoreline as the "South Project Area" of the Dare County Hurricane Protection and Erosion Control Project (federal project), which has been in planning since the initial authorization by the US Congress on August 1, 1990. Funding for construction of the federal project has never been approved.

Nags Head's initial beach nourishment project consists of excavating, by hopper and cutterhead suction dredges, 4.6 million cubic yards of beach-quality sediment from ocean borrow area(s) situated ~2-3 miles offshore of the project area. Figure A summarizes the project plan. Figure B shows the basic cross-section on which the profile volume analysis for the plan is based. The borrow areas are within the originally proposed area designated "S1" to be used in the federal project. Nags Head is using only a small portion of the federally designated area. Sediment is being pumped onto the beach between the toe of the existing dune and the low waterline, and is being shaped by bulldozers into a profile that closely matches the contours and elevations of the natural beach. The dry beach elevation for the initial nourishment is +6 ft NAVD (~7.0 ft NGVD).

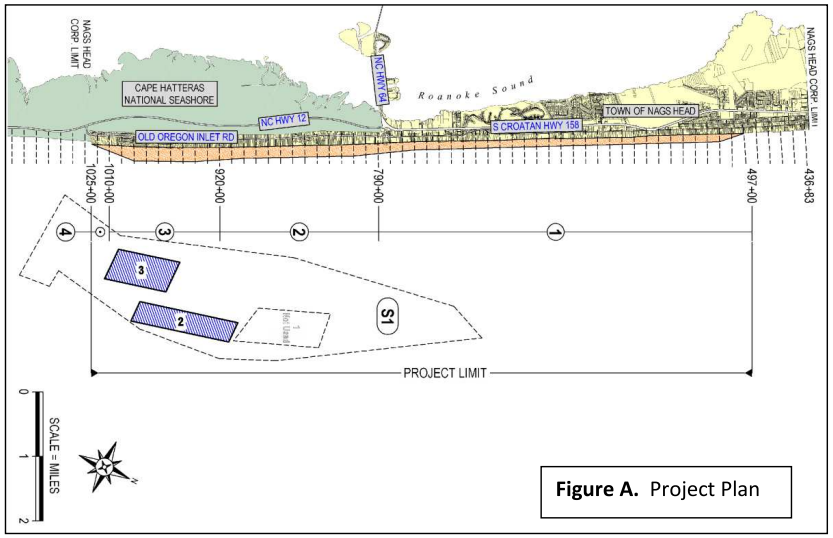


**Figure A.** Project Plan

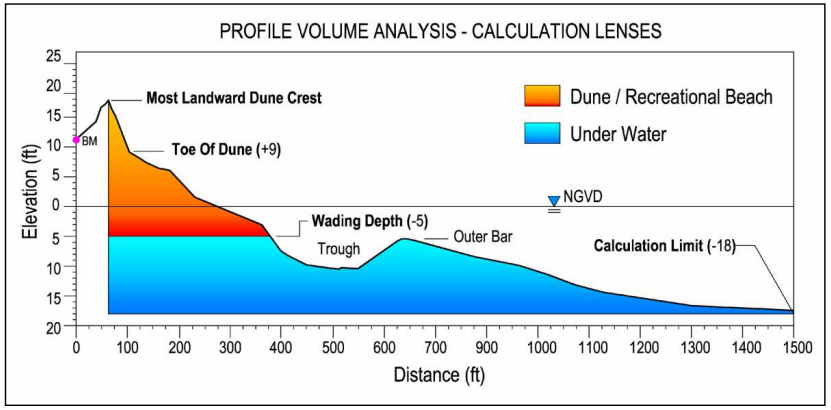


**Figure B.** Basis of design profiles

Approximately 50% of the excavations are being deposited by run-out from the discharge point between mean lower water and the outer bar (~500 ft offshore). Typical fill sections add ~60–160 cubic yards per linear foot (cy/ft) of beach and, upon adjustment, are expected to advance the shoreline 50 to 125 ft. The work covers 10 of Nags Head's 11 miles of coast and includes 4 reaches (from north to south):



- Reach 1 – 5.5 miles, up to 1.74 million cubic yards, base fill approximately 50.5 cy/ft
- Reach 2 – 2.5 miles, up to 1.3 million cubic yards, base fill approximately 90 cy/ft
- Reach 3 – 1.7 miles, up to 1.44 million cubic yards, base fill approximately 140 cy/ft
- Reach 4 – 0.3 miles, up to 120,000 cubic yards, base fill approximately 70 cy/ft

Construction of the project began on May 24th, 2011 and is expected to be completed by mid-September 2011. As of August 22nd , 2011, approximately 80% of the project was complete with an estimated 3.75 million cubic yards in place along 37,500 linear feet of beach. Three hopper dredges were on site and continuing to place sand in uncompleted sections of the project area according to approved state and federal permits and plans and specifications prepared by Coastal Science & Engineering (Project Engineer). The federal permit for the project is given in Attachment 1. Project plans are given in Attachment 2. The purpose of the project and basis of the design is given in Attachment 3. The final EIS for the project is contained in USACE (2010). Detailed specifications for the project are contained in CSE (2011b).

### (3) Initial Beach Nourishment Project Funding

Construction funding for the Federal Dare County Hurricane Protection and Beach Erosion Control Project has never been appropriated. Therefore, Nags Head, to meet the urgent problem of erosion in the town, is using local funding for its initial project. Funding includes:

- $18 million in cash from the Dare County Beach Nourishment Fund (fund will replenish $3-$3.5 million/year from the 1% occupancy tax that it currently receives)

- $18 million revenue bond to be paid back over 6 years with proceeds from a 1% increase to the occupancy tax. The 1% tax increase will generate about $2 million/year. Nags Head will be using the $2 million/year revenue for 5 years to pay back $10 million of the bond.

  The remainder of the bond will be paid back through an increase in taxes. The Board has adopted a town-wide tax increase of 2 cents (from last year's town tax rate of 15.75 cents to 17.75 cents) and a tax increase of 16 cents for the ocean-side properties from Bonnett Street (about Mile Post 11.25) south to the National Park Service line.

- $1 million from the Town's general fund (to cover engineering costs)

### (4) Monitoring

The Town of Nags Head's initial beach nourishment project and all subsequent renourishment projects currently comply and will comply with all federal and state required environmental monitoring including sea turtle and benthic organism monitoring. All fieldwork for pre-project environmental monitoring has been completed, and the Year 1 report is expected to be completed by September 2011. The Town has committed funds to cover up to two years (up to eight quarterly monitoring events) after completion of construction in accordance with the special conditions of state and federal permits.

In addition, the Town will perform physical beach monitoring, which is a non-permit initiative that is directly attributable to FEMA requirements for disaster assistance to repair improved beaches. Details of the physical monitoring are given in Attachment 4. Systematic condition surveys and computations of nourishment volumes remaining will be based on a set of beach and inshore profiles into deepwater used for the project design. The reference baseline and stationing for the

Nags Head project is consistent with pre-project federal surveys and profile data collection by the project engineer between 1994 and 2011. Volume change computations will reference the same stations and depth contours on which the design was based. In accordance with the engineering analyses, the basis of the Nags Head beach nourishment design was the beach condition measured between the toe of the foredune and −18 ft NGVD*. An average annual volumetric sand loss rate was determined for each project reach. The design nourishment volume was varied by reach according to the sum of ten (10) times the average annual volumetric erosion rate plus an ~50% safety factor (overfill) so as to provide benefits in the form of a healthier beach for up to ten years.

*[*USACE surveys and the Town of Nags Head's preliminary design (CSE 2005, 2007) were based on surveys referencing NGVD datum. Subsequent final design documents were based on NAVD datum which is 0.96 ft above NGVD datum at Nags Head (source: http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl).]*

**(5) Beach Maintenance Planning Guidelines**

In accordance with FEMA Publication 321 (Appendix B) 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 applicant (Town of Nags Head) to qualify for FEMA assistance.

The Town's beach nourishment engineer, Coastal Science & Engineering, has determined that average annual sand losses for 1994-2005 were ~275,000 cubic yards per year (cy/yr) (ie – ~6% of the permitted nourishment volume per year). Subsequent surveys (2006-2010) show lower loss rates for the period 1994-2010 on the order of ~275,000 cy/yr.

The Town intends to renourish the beach at 6 years, unless ~50% or more of the initial nourishment sand remains on the beach within the project boundaries calculated to −18 ft NGVD.

If 50% or more of the sand remains on the beach at 6 years post initial project, then renourishment would commence when 50% or more is lost. The Town understands that erosion rates will vary along the length of the project and is basing these projections on the law of averages which has been found to apply in other nourishment projects (Dean 2002).

The Town's US Army Corps of Engineers beach nourishment project permit allows for the placement of up to 4.6 million cubic yards of sand. For planning purposes and future renourishment, the Town has adopted an annual loss rate of 275,000 cy/yr after initial nourishment.

Therefore, the six-year post-nourishment loss (if we assume an annual loss rate of ~400,000 cy/yr) would equate to ~2.3 million cubic yards of sand (ie – one-half the nourishment volume placed in the initial project).

Therefore, 6 years post initial nourishment, if we assume an annual loss rate of 400,000 cy/yr for a total 6-year loss of 2.3 million cubic yards of sand, there will be no need to conduct renourishment.

However, if 6 years post-nourishment, Nags Head has lost more than 2.3 million cubic yards of sand, the Town will renourish the beach.

To determine nourishment volume remaining post initial project, Nags Head will conduct annual condition surveys which report the nourishment volume remaining (percent lost) and the unit-width volumes by reach relative to a target unit volume (to be determined).



**(6) Periodic Renourishment Funding**

The Nags Head Board of Commissioners (at their 1 December 2010 meeting) proposed funding the maintenance plan through the Town's share of occupancy tax or a special assessment.

**REFERENCES**


CSE. 2005 (August). Preliminary coastal engineering analyses for large-scale beach restoration at Nags Head. Technical Report for Town of Nags Head (NC). CSE, Columbia, SC, 88 pp + three appendices.

CSE. 2007. Biological assessment for Nags Head beach restoration project, Dare County, North Carolina (submitted in conjunction with EIS for Action ID SAW 2006-40282-128). Appendix H, Draft EIS for US Army Corps of Engineers, Washington Regulatory Field Office, NC. CSE, Columbia (SC), 104 pp + 13 attachments.

CSE. 2011a. Coastal engineering & geotechnical analyses for beach nourishment, Nags Head, North Carolina. Draft Final Design Report for Town of Nags Head, NC. CSE, Columbia (SC), 163 pp + appendices.

CSE. 2011b. Nags Head beach nourishment, Dare County, North Carolina. Final Project Manual for Construction for Town of Nags Head, NC. CSE, Columbia (SC).

Dean, RG. 2002. *Beach Nourishment: Theory and Practice*. World Scientific, NJ, 399 pp.

NCDENR. 1998, 2004. Long-term average annual shoreline change study and setback factors. NC Department of Environment and Natural Resources, Raleigh (updated Feb 2004) [see http://dcm2.enr.state.nc.us/maps/ER_1998/SB_Factor.htm]

USACE. 2010 (MAY). Final environmental impact statement, beach nourishment project, Town of Nags Head, North Carolina. US Army Corps of Engineers, Wilmington District, Washington Regulatory Field Office, NC (Action ID SAW-2006-40282-182), 164 pp+ executive summary, references, and appendices.

# APPENDIX 2

## Baseline & Control Station Coordinates and Elevations

# Nags Head Baseline & Station Coordinates

| | |
|---|---|
| Coordinate System: | US State Plane (feet) |
| Horizontal Datum: | NAD 1983 |
| Zone: | North Carolina 3200 |
| Vertical Datum: | NGVD '29 (feet) |

**NGS Monument** (Used for CSE Base Station Calibration)

| ***Name*** | ***Northing*** | ***Easting*** | ***Elevation*** |
|---|---|---|---|
| W 168 (BM 72) | 806,505.663 | 3,005,849.363 | 8.51 |

**CSE Base Station Monuments**

| ***Name*** | ***Northing*** | ***Easting*** | ***Elevation*** |
|---|---|---|---|
| Brew | 823,220.387 | 2,997,818.026 | 17.91 |
| Loggerhead | 814,707.576 | 3,001,986.071 | 16.47 |
| Eden | 799,348.283 | 3,009,247.099 | 33.64 |
| Brooke | 774,770.243 | 3,020,428.253 | 20.36 |

**CSE Baseline Coordinates** - Via RTK GPS (No Monument)

| ***Name*** | ***Northing*** | ***Easting*** | ***STA*** |
|---|---|---|---|
| CSE 1 | 871,890.781 | 2,971,224.440 | 0+00 |
| CSE 2 | 827,961.109 | 2,995,099.541 | 500+00 |
| CSE 3 | 782,952.894 | 3,016,870.156 | 1000+00 |
| CSE 4 | 736,372.221 | 3,035,031.202 | 1500+00 |

**Station Coordinates Along Baseline**

| ***Name*** | ***Northing*** | ***Easting*** | |
|---|---|---|---|
| **430+00 L** | **834,110.028** | **2,991,757.698** | |
| 430+00 | 836,497.616 | 2,996,150.809 | |
| **440+00 L** | **833,231.406** | **2,992,235.216** | |
| 440+00 | 835,618.994 | 2,996,628.327 | |
| **450+00 L** | **832,352.784** | **2,992,712.733** | |
| 450+00 | 834,740.372 | 2,997,105.844 | |
| **460+00 L** | **831,474.161** | **2,993,190.251** | |
| 460+00 | 833,861.750 | 2,997,583.362 | |
| **470+00 L** | **830,595.539** | **2,993,667.769** | |
| 470+00 | 832,983.127 | 2,998,060.880 | |
| **480+00 L** | **829,716.917** | **2,994,145.286** | |
| 480+00 | 832,104.505 | 2,998,538.397 | |
| **490+00 L** | **828,838.295** | **2,994,622.804** | |
| 490+00 | 831,225.883 | 2,999,015.915 | |
| **500+00 L** | **827,959.637** | **2,995,100.253** | |
| 500+00 | 830,136.830 | 2,999,601.345 | |
| **510+00 L** | **827,059.419** | **2,995,535.691** | |
| 510+00 | 829,236.611 | 3,000,036.784 | |
| **520+00 L** | **826,159.200** | **2,995,971.130** | |
| 520+00 | 828,336.393 | 3,000,472.222 | |
| **530+00 L** | **825,258.982** | **2,996,406.568** | |

| Station Coordinates Along Baseline | | | |
|---|---|---|---|
| ***Name*** | ***Northing*** | ***Easting*** | |
| 530+00 | 827,436.174 | 3,000,907.661 | |
| **540+00 L** | **824,358.763** | **2,996,842.007** | |
| 540+00 | 826,535.956 | 3,001,343.099 | |
| **550+00 L** | **823,458.545** | **2,997,277.445** | |
| 550+00 | 825,635.738 | 3,001,778.538 | |
| **560+00 L** | **822,558.327** | **2,997,712.884** | |
| 560+00 | 824,735.519 | 3,002,213.976 | |
| **570+00 L** | **821,658.108** | **2,998,148.322** | |
| 570+00 | 823,835.301 | 3,002,649.415 | |
| **580+00 L** | **820,757.890** | **2,998,583.761** | |
| 580+00 | 822,935.082 | 3,003,084.853 | |
| **590+00 L** | **819,857.671** | **2,999,019.199** | |
| 590+00 | 822,034.864 | 3,003,520.292 | |
| **600+00 L** | **818,957.453** | **2,999,454.638** | |
| 600+00 | 821,134.645 | 3,003,955.730 | |
| **610+00 L** | **818,057.234** | **2,999,890.076** | |
| 610+00 | 820,234.427 | 3,004,391.169 | |
| **620+00 L** | **817,157.016** | **3,000,325.515** | |
| 620+00 | 819,334.208 | 3,004,826.607 | |
| **630+00 L** | **816,256.797** | **3,000,760.953** | |
| 630+00 | 818,433.990 | 3,005,262.046 | |
| **640+00 L** | **815,356.579** | **3,001,196.392** | |
| 640+00 | 817,533.771 | 3,005,697.484 | |
| **650+00 L** | **814,456.360** | **3,001,631.830** | |
| 650+00 | 816,633.553 | 3,006,132.923 | |
| **660+00 L** | **813,556.142** | **3,002,067.269** | |
| 660+00 | 815,733.334 | 3,006,568.361 | |
| **670+00 L** | **812,655.923** | **3,002,502.707** | |
| 670+00 | 814,833.116 | 3,007,003.800 | |
| **680+00 L** | **811,755.705** | **3,002,938.146** | |
| 680+00 | 813,932.897 | 3,007,439.238 | |
| **690+00 L** | **810,855.486** | **3,003,373.584** | |
| 690+00 | 813,032.679 | 3,007,874.677 | |
| **700+00 L** | **809,955.268** | **3,003,809.023** | |
| 700+00 | 812,132.460 | 3,008,310.115 | |
| **710+00 L** | **809,055.049** | **3,004,244.461** | |
| 710+00 | 811,232.242 | 3,008,745.554 | |
| **720+00 L** | **808,154.831** | **3,004,679.900** | |
| 720+00 | 810,332.023 | 3,009,180.992 | |
| **730+00 L** | **807,254.612** | **3,005,115.338** | |
| 730+00 | 809,431.805 | 3,009,616.431 | |
| **740+00 L** | **806,354.394** | **3,005,550.777** | |
| 740+00 | 808,531.586 | 3,010,051.869 | |
| **750+00 L** | **805,454.175** | **3,005,986.215** | |
| 750+00 | 807,631.368 | 3,010,487.308 | |
| **760+00 L** | **804,553.957** | **3,006,421.654** | |

| Station Coordinates Along Baseline | | | |
|---|---|---|---|
| ***Name*** | ***Northing*** | ***Easting*** | |
| 760+00 | 806,731.149 | 3,010,922.746 | |
| **770+00 L** | **803,653.738** | **3,006,857.092** | |
| 770+00 | 805,830.931 | 3,011,358.185 | |
| **780+00 L** | **802,753.520** | **3,007,292.531** | |
| 780+00 | 804,930.713 | 3,011,793.623 | |
| **790+00 L** | **801,853.302** | **3,007,727.969** | |
| 790+00 | 804,030.494 | 3,012,229.062 | |
| **800+00 L** | **800,953.083** | **3,008,163.408** | |
| 800+00 | 803,130.276 | 3,012,664.500 | |
| **810+00 L** | **800,052.865** | **3,008,598.847** | |
| 810+00 | 802,230.057 | 3,013,099.939 | |
| **820+00 L** | **799,152.646** | **3,009,034.285** | |
| 820+00 | 801,329.839 | 3,013,535.377 | |
| **830+00 L** | **798,252.428** | **3,009,469.724** | |
| 830+00 | 800,429.620 | 3,013,970.816 | |
| **840+00 L** | **797,352.209** | **3,009,905.162** | |
| 840+00 | 799,529.402 | 3,014,406.254 | |
| **850+00 L** | **796,451.991** | **3,010,340.601** | |
| 850+00 | 798,629.183 | 3,014,841.693 | |
| **860+00 L** | **795,551.772** | **3,010,776.039** | |
| 860+00 | 797,728.965 | 3,015,277.131 | |
| **870+00 L** | **794,651.554** | **3,011,211.478** | |
| 870+00 | 796,828.746 | 3,015,712.570 | |
| **880+00 L** | **793,751.335** | **3,011,646.916** | |
| 880+00 | 795,928.528 | 3,016,148.008 | |
| **890+00 L** | **792,851.117** | **3,012,082.355** | |
| 890+00 | 795,028.309 | 3,016,583.447 | |
| **900+00 L** | **791,950.898** | **3,012,517.793** | |
| 900+00 | 794,128.091 | 3,017,018.885 | |
| **910+00 L** | **791,050.680** | **3,012,953.232** | |
| 910+00 | 793,227.872 | 3,017,454.324 | |
| **920+00 L** | **790,150.461** | **3,013,388.670** | |
| 920+00 | 792,327.654 | 3,017,889.762 | |
| **930+00 L** | **789,250.243** | **3,013,824.109** | |
| 930+00 | 791,427.435 | 3,018,325.201 | |
| **940+00 L** | **788,350.024** | **3,014,259.547** | |
| 940+00 | 790,527.217 | 3,018,760.639 | |
| **950+00 L** | **787,449.806** | **3,014,694.986** | |
| 950+00 | 789,626.998 | 3,019,196.078 | |
| **960+00 L** | **786,549.587** | **3,015,130.424** | |
| 960+00 | 788,726.780 | 3,019,631.516 | |
| **970+00 L** | **785,649.369** | **3,015,565.863** | |
| 970+00 | 787,826.561 | 3,020,066.955 | |
| **980+00 L** | **784,749.150** | **3,016,001.301** | |
| 980+00 | 786,926.343 | 3,020,502.393 | |
| **990+00 L** | **783,848.932** | **3,016,436.740** | |

| Station Coordinates Along Baseline | | | |
|---|---|---|---|
| ***Name*** | ***Northing*** | ***Easting*** | |
| 990+00 | 786,026.125 | 3,020,937.832 | |
| **1000+00 L** | **782,948.567** | **3,016,871.843** | |
| 1000+00 | 784,764.824 | 3,021,530.299 | |
| **1010+00 L** | **782,016.876** | **3,017,235.094** | |
| 1010+00 | 783,833.132 | 3,021,893.550 | |
| **1020+00 L** | **781,085.185** | **3,017,598.345** | |
| 1020+00 | 782,901.441 | 3,022,256.801 | |
| **1030+00 L** | **780,153.494** | **3,017,961.597** | |
| 1030+00 | 781,969.750 | 3,022,620.053 | |
| **1040+00 L** | **779,221.802** | **3,018,324.848** | |
| 1040+00 | 781,038.059 | 3,022,983.304 | |
| **1050+00 L** | **778,290.111** | **3,018,688.099** | |
| 1050+00 | 780,106.367 | 3,023,346.555 | |
| **1080+00 L** | **775,495.038** | **3,019,777.853** | |
| 1080+00 | 777,311.294 | 3,024,436.309 | |
| **1110+00 L** | **772,699.964** | **3,020,867.607** | |
| 1110+00 | 774,516.220 | 3,025,526.063 | |
| **1140+00 L** | **769,904.890** | **3,021,957.360** | |
| 1140+00 | 771,721.146 | 3,026,615.816 | |
| **1170+00 L** | **767,109.817** | **3,023,047.114** | |
| 1170+00 | 768,926.073 | 3,027,705.570 | |
| **1200+00 L** | **764,314.743** | **3,024,136.868** | |
| 1200+00 | 766,130.999 | 3,028,795.324 | |
| **1230+00 L** | **761,519.669** | **3,025,226.621** | |
| 1230+00 | 763,335.925 | 3,029,885.078 | |
| **1260+00 L** | **758,724.596** | **3,026,316.375** | |
| 1260+00 | 760,540.852 | 3,030,974.831 | |
| **1290+00 L** | **755,929.522** | **3,027,406.129** | |
| 1290+00 | 757,745.778 | 3,032,064.585 | |

***Notes:***

**(L)** - Landward Point In Bold Followed By Seaward Point Along Profile, Perpendicular To Baseline.

Station 0+00 Located Near The Kitty Hawk Pier. (Northern Town Limit)

Northern Nags Head Town Limit ~ 436+83

Southern Nags Head Town Limit ~ 1025+00

*NGS Monument Source:* http://www.ngs.noaa.gov/