## SUMMARY REPORT

# Rodanthe Sand Needs Assessment

Prepared for

**Dare County, North Carolina**

COASTAL SCIENCE & ENGINEERING

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# SUMMARY REPORT

# Rodanthe Sand Needs Assessment
# Dare County, North Carolina

*Prepared for:*


**Dare County Board of Commissioners**
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[CSE–2577]

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## Executive Summary

This report presents a basic analysis of beach volumes and project costs along 5.7 miles of beachfront in Dare County, NC. Three reaches (Pea Island National Wildlife Refuge 'PINWR', 'Rodanthe', and 'Waves') exhibit varying degrees of dry beach width, dune crest height, and storm protection. CSE calculated a sand deficit along a critically-eroded portion of the study area to determine the base line volume needed to restore a dry sand beach and protective dune along Rodanthe and adjacent beaches.

The base line deficit is 2.3 million cubic yards (cy) over the 14,000-foot critically eroded area. Erosion rates along that area measure ~300,000 cy per year. CSE recommends the County seek to fill the deficit and place enough sand to offset 5 years' worth of erosion. Such an effort will require ~3.8 million cy. Assuming mobilization/demobilization costs of $4.5 million, and unit costs of $8 to $10 per cy, **a one-time effort of this scale would cost ~$40 million**.

Alternatives presented herein include a range of nourishment volumes as well as the potential impacts of including hardened structures such as groins as part of the County's long-term (eg ~30-year) management strategy for the beach at Rodanthe. **Estimated costs for a one-time nourishment range from ~$22 to ~$40 million, while one-time costs for groin installation are ~$15 million. Over a 30-year period, a nourishment-only management strategy would cost ~$40 million more than a strategy using groins as well as nourishment.**

These volumes and costs are rough estimates. Erosion rates vary, sea levels change, and market conditions for coastal engineering services evolve. While this report is a robust starting point for determining the feasibility of oceanfront work at Rodanthe, CSE recommends the County consider sponsoring a more complete feasibility astudy including model-based assessments and economic analyses.

This report was prepared on behalf of Dare County under grant award #NA20NOS4190044 to the Department of Environmental Quality, Division of Coastal Management from the Office for Coastal Management, National Oceanic and Atmospheric Administration. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of DEQ, OCM, or NOAA.

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## 1.0 INTRODUCTION

This summary report is prepared by Coastal Science & Engineering, Inc. (CSE) at the request of Dare County, North Carolina. The County wishes to measure beach volumes along a portion of Hatteras Island in the vicinity of the village of Rodanthe (the 'study area') and determine sand needs for a possible future renourishment of a critically eroded shoreline.

The study area lies along the north end of the developed Rodanthe-Waves-Salvo oceanfront and covers approximately 5.7 miles of beach facing the Atlantic Ocean (Figure 1.1). This area can be divided into three reaches with distinct erosion patterns: 1) the northern third lying within Pea Island National Wildlife Refuge ('PINWR'); 2) the central third lying within the village of Rodanthe ('Rodanthe'); and 3) the southern third lying within the village of Waves ('Waves').

The beach at PINWR and Waves generally contains more sand than Rodanthe. The difference in volumes is evident through visible beach conditions along the reaches. Along PINWR there are continuous high dune crests with elevations exceeding 30 ft above mean sea level (Figure 1.2a). At Rodanthe, smaller beach volumes are reflected in the lack of a dry sand beach with dune and the recent collapse of homes into the surf at Mirlo Beach (Figure 1.2b). Along Waves there are dunes and a dry sand beach, though sand waves migrating alongshore can cause dune heights and beach widths to vary (Figure 1.2c). These beach conditions indicate long-term sediment transport patterns, with Waves and PINWR maintain or gaining sand and Rodanthe chronically losing sand.

Based on the survey presented herein, there is a critically eroded area along ~14,000 linear feet (lf) of beach from the southern PINWR reach to the northern Waves reach, including all of the Rodanthe reach. CSE defines the critically eroded portion of the beach as lacking a protective dune, having a state-adopted annual erosion rate greater than 10 feet per year (ft/yr), and with a unit volume seaward of the first row of buildings below 1200 cubic yards per foot (cy/ft).

This assessment briefly reviews relevant background information and presents estimates of the minimum sand volumes needed to restore the beach and provide five years of storm protection along the critically eroded area. Cost estimates based on prevailing market conditions for dredge-and-fill projects are also compared to an alternative plan in which the community installs sand-retaining structures to extend the lifetime of nourishment sand within the critically eroded area.


**FIGURE 1.1.** The 5.7-mile study area lies along the north end of the developed Rodanthe-Waves-Salvo oceanfront facing the Atlantic Ocean.

**FIGURE 1.2a.** Beach conditions along the PINWR reach vary depending on the proximity to storm-cut overwash or the former roadbed of NC highway 12 along the s-curves. Much of the reach contains a relatively wide dry sand beach and high continuous foredune crest. The ground photo location is marked in the upper photo with a red circle.

**FIGURE 1.2b.** Beach conditions along the Rodanthe reach offer little to no storm protection for many first-row homes, with several properties on the intertidal wet beach. The recent collapse of multiple such properties has compelled the County to investigate sand needs for a nourishment project at Rodanthe. The ground photo location is marked in the upper photo with a red circle.

**FIGURE 1.2c.** Beach conditions along the Waves reach offer greater storm protection than Rodanthe, with a dry sand beach and continuous dune crest between the first row of properties and the ocean. The ground photo location is marked in the upper photo with a red circle.

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## 2.0 EROSION RATES & HISTORICAL SHORELINE POSITIONS

Hatteras Island between Oregon Inlet and Rodanthe has been migrating landward with rising sea levels for many years; historical data document shoreline retreat from at least the mid-19th century (Figure 2.1). Parts of PINWR are among the narrowest on Hatteras Island; sections along the recently completed Rodanthe 'Jug Handle' Bridge are less than 1,000 feet (ft) from mean high water to Pamlico Sound (Velasquez-Montoya et al 2021). Steady shoreline retreat is punctuated by short-lived storm-cut breaches that have periodicaly opened and closed throughout the last two centuries (Riggs et al 2009).

Because PINWR is an undeveloped beach, the long-term migration and periodic overwash of the island along that reach does not necessarily present a hazard to private property. This is particularly true along the portion of the island now bypassed by the Jug Handle Bridge. However, alongshore drift tends to flow from north to south such that any volume deficits along PINWR reduce the supply of sand maintaining a beach along Rodanthe.

The most dramatically eroded section of the study area is along a ~10,000-foot reach from the PINWR-Rodanthe boundary at Mirlo Beach to just south of Rodanthe Pier. Annual beach erosion of >10 horizontal feet per year (ft/yr) has fragmented the foredune, which now offers little-to-no storm protection with discontinuous crest elevations of 10–15 ft NAVD (NCDENR 2021, Hapke and Henderson 2015). This chronic erosion, and resulting exposure of private and public property, prompted a 2014 US Army Corps of Engineers (USACE) nourishment project that placed ~1.6 million cubic yards (cy) over ~10,000 linear feet (lf) of shoreline between PINWR and Rodanthe Pier (Sciaudone and Overton 2021).

In contrast, south of the Pier along Waves portions of the beach have exhibited long-term stability over the same period with annualized shoreline movement of less than five (5) ft/yr. Along the southern end of the surveyed area, a lack of erosion since the mid-19th century has allowed dune crests to grow to 20–30 ft above sea level along this reach. State-adopted shoreline change rates also document stability and accretion since at least 1946 (NCDENR 2021).

The alongshore variations in volume are related to a few different dynamics. Overwash events at PINWR draw sand out of the beach system by depositing it landward of the foredune, periodically reducing beach volumes (Wamsley and Kraus 2005). Some of the highest year-to-year sand losses along PINWR and Rodanthe (as well as other locations on the Outer Banks) are centered near closed breaches (Mallinson et al 2008). Outside the breaches, PINWR features a continuous foredune with crest elevations above 20 ft and some reaching nearly 40 ft NAVD. Since 2011, there has been a steady decrease in erosion rates (ie – less sand is being lost) along the southern half of PINWR (Sciaudone and Overton 2021). In general, reduced erosion, storage of beach sand in vegetated dunes, and periodic overwash limit the sand volume passed towards Rodanthe.

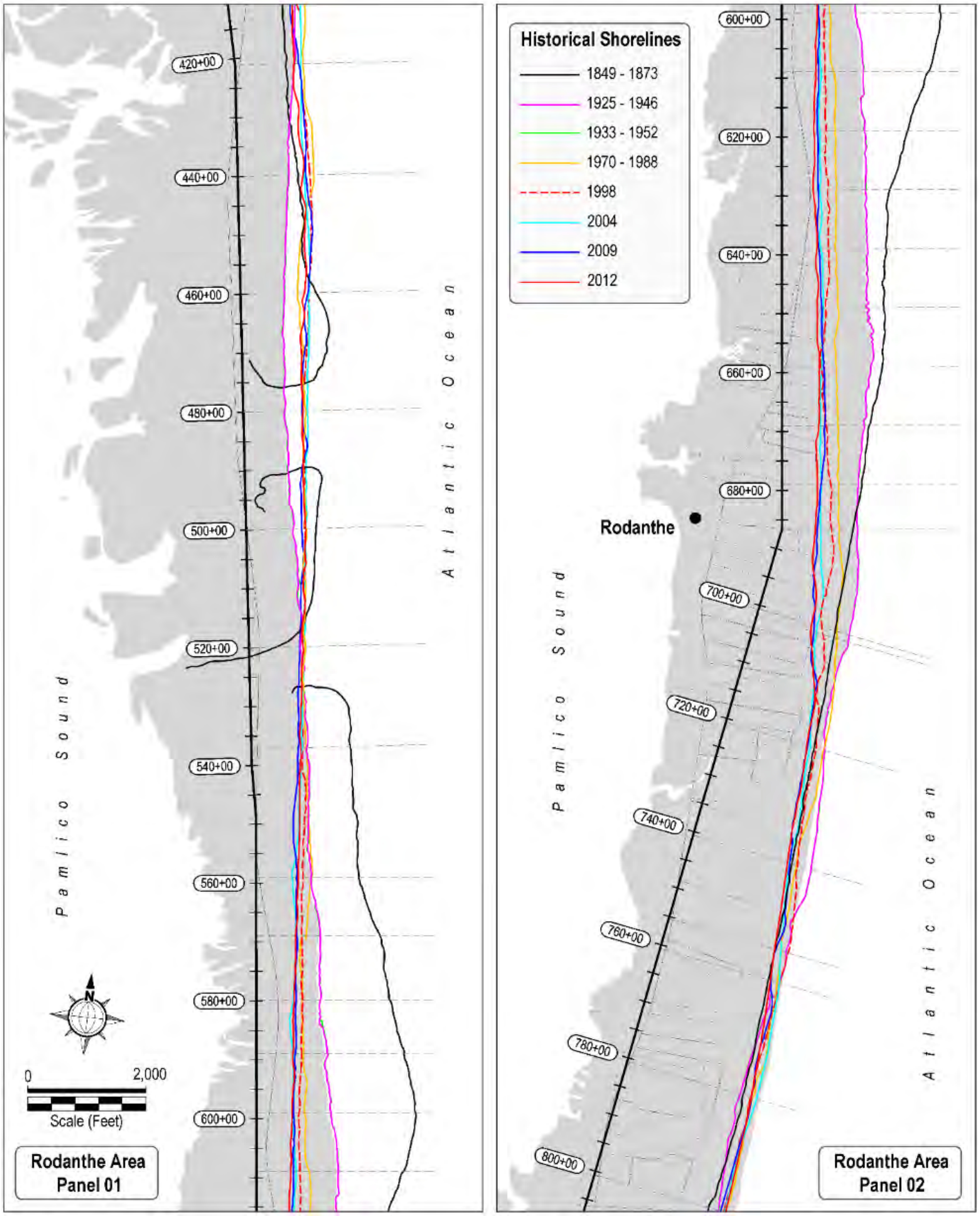


**FIGURE 2.1.** Historical shoreline data shows the portion of Hatteras Island between Oregon Inlet and Rodanthe has been migrating landward with rising sea levels since the mid-19th century.

Moreover, the Rodanthe beachfront is probably in a relatively high wave energy zone compared to PINWR and Waves. The shoreline shape is convex towards the ocean and is located just landward of the gap between Platt and Wimble Shoals (Figure 2.2). Convex shorelines concentrate wave energy and often experience greater erosion than adjacent beaches, while the alignment of the shoals with rough northeasterly waves in this location helps funnel the highest waves onto the Mirlo Beach area (Kamphuis 2010). This creates a slightly higher background erosion rate along Rodanthe than PINWR and Waves.

As less sand is being transported south from PINWR into Rodanthe due to overwash and storage, and more sand is bypassed southward from Rodanthe towards Waves due to greater erosion, there is an imbalance in alongshore sand budgets between the three reaches. As a result, horizontal erosion rates average >10 ft/yr between Rodanthe Pier and PINWR (NCDENR 2021).

This section of the beach was identified as 'critically eroded' in a 2013 assessment completed by CSE. In that report, CSE determined sand deficits at Rodanthe and identified offshore resources for a nourishment project (CSE 2013). At that time, the minimum volume needed to provide storm protection at Rodanthe for a five-year period was 1,565,000 cy along 12,000 lf of beach, with sand dredged from an offshore borrow area near Rodanthe. The conclusions of that analysis are discussed in Section 3.

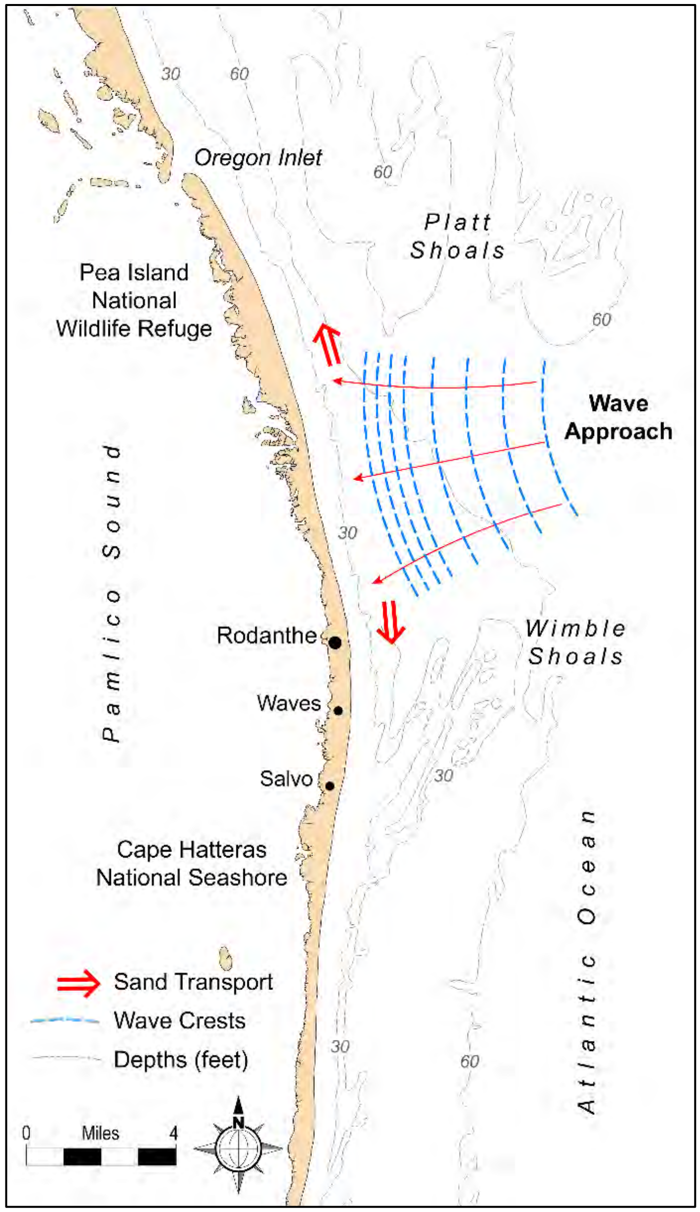


**FIGURE 2.2.** The shape of Rodanthe's shoreline is convex towards the ocean and located just landward of the gap between Platt and Wimble Shoals. Convex shorelines concentrate wave energy and often experience greater erosion than adjacent beaches. The alignment of the shoals with rough northeasterly waves helps funnel the highest waves onto the Mirlo Beach area.

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## 3.0 METHODOLOGY

### 3.1 Comparing Historical and Modern Data

In addition to the linear shoreline erosion rates described in Section 2, CSE computed volumetric erosion rates that account for all the sand making up a beach profile from some point inland to a pre-determined depth offshore. That depth is determined by comparing repeat profiles to identify where significant elevation changes and volume changes cease to occur. This point is known as the depth of closure (DOC) and is a useful metric in coastal management because it establishes limits to the active beach-dune system.

Assuming there is minimal volume exchange between the seafloor offshore and the beach landward of that depth, managers can track changes in the active beach profile over time. This yields a more realistic measure of change in the system compared to linear horizontal erosion rates, which cannot account for changes in the underwater portion of the beach profile. This approach also provides more actionable results because the volumetric changes can be compared to an ‘ideal’ beach volume and therefore used to determine sand needs for a nourishment project where there may not be abundant data.

The basic approach for beach monitoring is to track the active beach zone within the project area as a sand box filled nearly to the top along one edge (the dune line) and tapering to a thin layer along the opposite edge (often the local DOC). The total volume in the sand box is measured periodically, and differences between the volumes provide a measure of sand losses (erosion) or gains (accretion) over time.

Profile volumes are a convenient way to determine the condition of the beach and quantitatively compare one area with another. They convert a two-dimensional measure of the beach area to a "unit volume" measure. Unit volume, given in cubic yards per linear foot (cy/lf), is a measure of the amount of sand contained in a 1-ft (unit) length of beach. Specific volumes reflect a quantity in a wedge of sand extending from the dune line or seawall to a particular depth offshore. This is why variations in erosion rates and volumes discussed below will tell a similar story to the ground photos of each reach in Section 1.

Unit volumes for each survey date and unit-volume changes between selected dates were calculated to determine the quantity of sand in one (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 study area. Changes in unit volume (or beach width, etc.) can be determined by overlaying sequential profiles and computing the differences in the cross-sectional area.

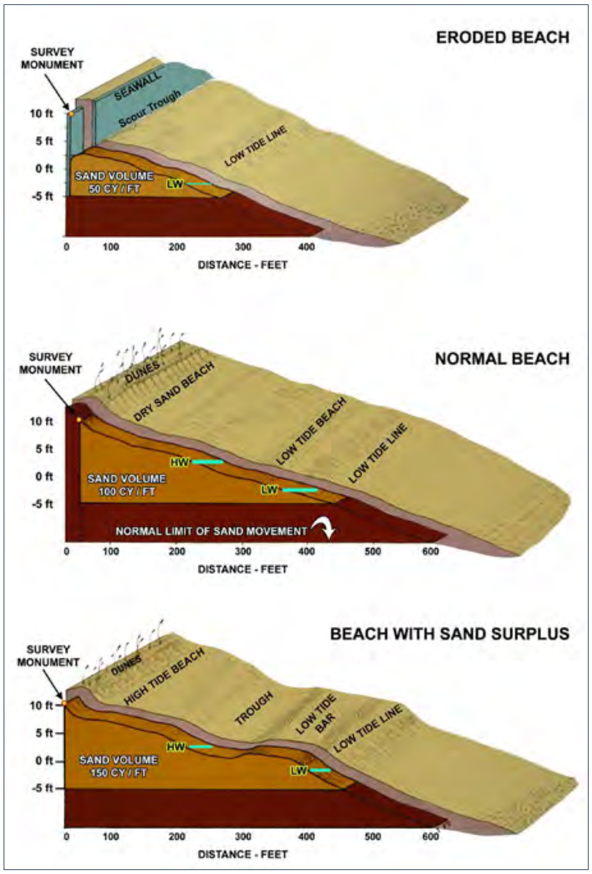


**FIGURE 3.1.** The concept of unit-width profile volumes for a series of beach profiles showing an eroded beach with a deficit, a normal beach, and a beach with a volume surplus. [After Kana 1990]

The change in cross-section (in two dimensions) can be interpolated between adjacent profiles to yield net volume change (in cubic yards) along that section of beach. Using standard statistical techniques (average-end-area method), the overall (net) change is computed from year to year and profile to profile for subreaches and for the study area.

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 3.1 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.

Fortunately, volumetric and horizontal shoreline changes can be compared using a simple conversion. A long-time rule of thumb used by the US Army Corps of Engineers (USACE) assumes a loss of one square foot of beach area is equivalent to a loss of one cubic yard of sand (CERC 1984). This ratio has also been assumed for some analyses performed for NCDOT (M Overton, pers comm, October 2013).

It can be shown that this ratio varies according to the dimensions of the active profile, but remains constant between fixed contours regardless of slope (see Dean 2002). Typically, the vertical dimension extends along the active profile to local DOC. So, if the average elevation at the top of the profile is 12 ft NAVD and the local DOC is –15 feet, 27 cubic feet (cf) of sand will be contained in one foot of beach. Conveniently, 27 cubic feet equals one cubic yard, so the volume (cy) to area (sf) ratio equals one (1). If the vertical distance between the upper elevation and DOC is greater, the ratio is >1. If DOC and the beach surface are closer, the ratio is <1.

CSE estimates DOC at Rodanthe to be –30 ft NAVD, based on repeat profiles and statistical analysis of surveys at Nags Head and Buxton. The dune crest along the study area averages an elevation of ~18 ft NAVD. So, each foot of beach at Rodanthe represents approximately 1.8 cubic yards of sand between the dune crest and DOC.

With this ratio, we can compare horizontal and volumetric changes in beach condition. The adopted NC Department of Environmental and Natural Resources (NCDENR) erosion rate for the Rodanthe reach is 11.6 ft/yr, equivalent to a volumetric loss of 20.5 cy/ft/yr. The PINWR reach averages 5.5 ft/yr (9.7 cy/ft/yr), while the Waves reach averages 2.7 ft/yr (4.8 cy/ft/yr). These converted volumetric rates are roughly equivalent to the measured volume changes described in Section 4.0 and have persisted for several decades.

## 3.2 Re-establishing Survey Control

In March 2023, CSE mobilized a field team to survey elevations along 30,000 ft of ocean-facing beach within PINWR, Rodanthe, and Waves. CSE established survey control in this area in 2013 as part of a feasibility assessment sponsored by Dare County, using a baseline first adopted by USACE during nourishment for the S-curves at Rodanthe. The baseline generally follows NC Highway 12, and stationing is in standard engineering units beginning near the Oregon Inlet jetty (Station 0+00) and ending in the Cape Hatteras National Seashore near Buxton (Station 1983+77, or 198,377 ft from Oregon Inlet).

For that first effort, CSE measured 21 profiles along PINWR-Rodanthe-Waves at variable spacing from 1,000 to 2,000 ft. The present survey re-occupied the original baseline and surveyed from Station 500+00 (in PINWR) to Station 800+00 (in the village of Waves) at 500-ft spacing. Due to odd stationing used in the 2013 survey, some of the older profiles are transposed ~100 ft alongshore to match the 2023 survey data. The locations of the baseline and stations used in this report are shown in Figure 1.1.

Surveys were performed using a Trimble™ Model R12 GNSS with VRS RTK-GPS for backshore, intertidal, and surf-zone work. Bathymetry seaward of the surf zone was obtained using an Applanix POS MV Surfmaster positioning system linked to a precision fathometer (Odom Echotrac CV 100 and SMSW200–4a transducer) mounted on CSE's research vessel, the R/V *Southern Echo*. Raw data were collected at 50 hertz (Hz) (or 50 points per second). Data were collected in x–y–z format and converted to x–z format (distance–elevation pairs), referencing survey monuments for direct comparison with historical data. Raw data were filtered and averaged using HYPACK® software and were reduced to a manageable size for each profile. CSE's precision for bathymetric profiles is ±3 centimeters in the horizontal and ~5 centimeters (~2 inches) in the vertical, with vessel track lines ±20 ft from the planned route.

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## 4.0 DETERMINING SAND NEEDS AT RODANTHE

The results presented herein outline a three-step process used to determine the sand needs to restore a dry-sand beach along Rodanthe and provide advance fill to account for future erosion. Raw beach profiles and volumes comparing 2013 and 2023 surveys are included in Attachment A.

First, an ideal unit volume is determined by comparing beach conditions between the three reaches. Determining an ideal unit volume using a 'healthy' profile as a model is useful because it provides a starting point for estimating the volume deficit (eg 'deficit fill') between eroded and non-eroded profiles. Second, annualized erosion rates are determined using the 2013 and 2023 CSE surveys as well as NCDENR-adopted erosion rates. The annualized erosion rate is extrapolated over a 5-year period to determine the amount of sand needed to offset anticipated losses (eg 'advance fill'). Finally, the deficit and advance fill volumes are added to estimate the volume needed to restore a dry sand beach, protective dune, and withstand 5 years of erosion.

### Step 1 – Determining an Ideal Unit Volume

The first step relies on the measured alongshore variation in beach condition between healthier sections like much of Waves, and eroding sections like Rodanthe. This requires identifying an ideal unit volume needed to maintain a dry sand beach and protective dune. Once that volume is determined, the deficit fill volume can be calculated for all profiles in a deficit.

The 2013 CSE analysis identified an ideal unit volume of 800 cy/ft between the foredune crest and –24 ft NAVD. This unit volume is sufficient to maintain a dry sand beach and protective dune (CSE 2013). Because some portions of the critically eroded area do not have a foredune crest, and bottom elevation change out to -30 ft NAVD was measured by the 2023 survey, volumes presented herein are measured from the seaward edge of oceanfront structures ('structure line') to the -30 ft depth contour. Comparing the 2013 and 2023 survey results suggests that an 800 cy/ft volume from the foredune to -24 ft is approximately equivalent to 1200 cy/ft from the structure line to -30 ft. For the analysis presented herein, CSE will reference this 1200 cy/ft ideal profile volume for comparison with existing conditions.

The beach between Sta 620+00 and Sta 760+00 falls beneath this ideal unit volume (Figure 4.1). However, Sta 740+00 to Sta 760+00 contain a protective dune. As mentioned in Section 1.0, CSE considers an individual profile to be critically eroded if it lacks a continuous foredune, has an NCDENR-adopted erosion rate exceeding 10 ft/yr, and a unit volume seaward of the structure line below 1200 cy/ft. These criteria are met from Sta 600+00 (~3,500 ft north of the Mirlo Beach sign) to Sta 740+00 (~2,500 ft south of Rodanthe Pier).

By applying the average-end-area method to interpolate volume deficits between profiles, the net sand deficit along that ~14,000 ft of the study area is ~2.3 million cy. This is the volume needed to re-establish a dry sand beach and protective foredune along the 14,000-ft critically eroded area. This volume does not take year-to-year shifts in erosion into account, which can draw sand off a nourishment template more rapidly than anticipated and necessitate additional sand placement to prolong the project's positive impact on shoreline recession.

In order to account for those shifts in erosion, CSE elected to use two methods for determining the average annual erosion rate along the 14,000 ft critically eroded area. These rates will be used to determine the total project volume included that needed to restore the dry sand beach described above, as well as advance fill needed to offset erosion over a 5-year period.

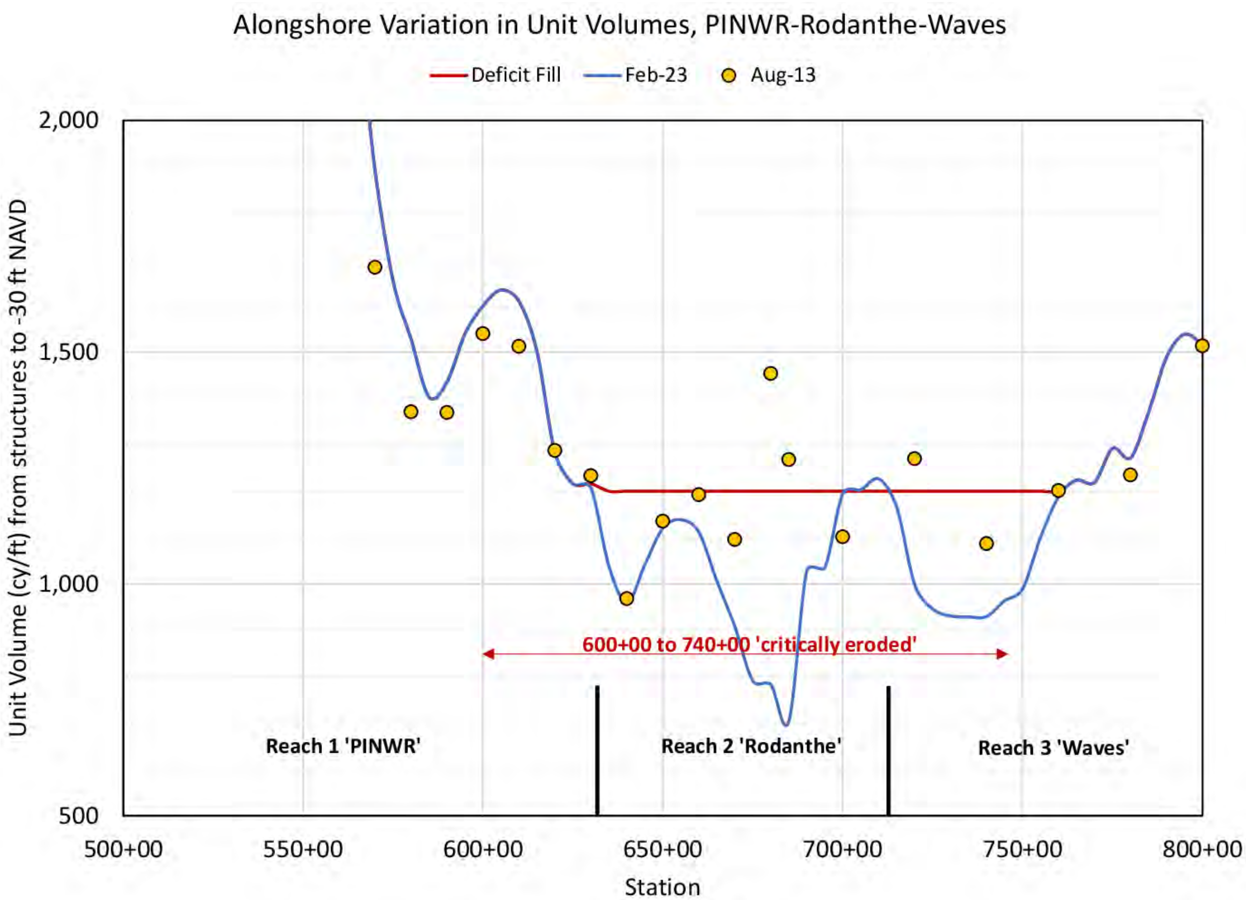


**FIGURE 4.1.** Comparing qualitative beach conditions across the three reaches helps determine what unit volume is necessary for providing a dry sand beach and protective dune. Borrowing from the initial feasibility study published in 2013 by CSE, the present study determined a unit volume of ~1,200 cy/ft from the seaward structure line to DOC provides adequate protection. This condition is met along much of the PINWR and Waves reaches, but is not met along the Rodanthe reach. The 'critically eroded' section of shoreline falls below that ideal volume and erodes at >10 ft/yr and lacks a protective foredune, while the line labeled 'Deficit Fill' indicates the section of shoreline where unit volumes are below 1200 cy/ft.

## Step 2 – Determining Annualized Erosion Rates

### *Method 1 – CSE profiles*

The first erosion rate determination method relies on direct comparison between CSE's 2013 and 2023 surveys of the study area. Because of the different line spacing between the surveys, not all of the 2023 data can be compared to the 2013 data; however, 22 lines surveyed in 2013 were re-occupied in 2023. The comparative results of CSE's 2013 and 2023 surveys are shown in Table 4.1.

Initial raw results show a mixture of erosion and accretion, with volume increases of up to 10 cy/ft/yr along PINWR and losses exceeding 20–30 cy/ft/yr in Rodanthe and Waves. However, these results did not factor in the 2014 USACE nourishment that placed 1,618,083 cy along 10,718 ft between PINWR and Rodanthe Pier. With that volume factored in, a more realistic picture of 'natural' background erosion emerges.

Relative shoreline stability at the northern end of the study area corroborates accretion documented by NCDENR, while modest losses to the south in Waves occurred mostly along the underwater portions of the profile. In between, erosion rates from Station 600+00 to 740+00 average 22.0 cy/ft/yr, equal to annual losses of ~307,900 cy. Accounting for the USACE project, an annual erosion rate of 22 cy/ft/yr represents a 5-year loss of ~1.5 million cy between Sta 600+00 and Sta 740+00.

| | | | Unit Volume (cy/ft) | | Unit Volume Change since last survey (cy/ft) | | Annualized Unit Volume Change since last survey (cy/ft/yr) | |
|---|---|---|---|---|---|---|---|---|
| Station | Reach | | Aug-13 | Feb-23 | Feb-23 | Feb-23 (minus USACE) | Feb-23 | Feb-23 (minus USACE) |
| 500 | PINWR | | 1411.9 | 1484.5 | 72.6 | 72.6 | 7.6 | 7.6 |
| 520 | PINWR | | 1417.7 | 1405.8 | -11.9 | -11.9 | -1.3 | -1.3 |
| 540 | PINWR | | 1316.4 | 1310.9 | -5.4 | -5.4 | -0.6 | -0.6 |
| 550 | PINWR | | 1293.9 | 1328.8 | 34.9 | 34.9 | 3.7 | 3.7 |
| 560 | PINWR | | 1335.7 | 1416.4 | 80.7 | 80.7 | 8.5 | 8.5 |
| 570 | PINWR | | 1277.0 | 1336.6 | 59.6 | 59.6 | 6.3 | 6.3 |
| 580 | PINWR | | 1262.2 | 1360.7 | 98.5 | 98.5 | 10.3 | 10.3 |
| 590 | PINWR | | 1291.7 | 1327.1 | 35.3 | 35.3 | 3.7 | 3.7 |
| 600 | PINWR | 'Critically Eroded' | 1243.2 | 1251.0 | 7.7 | -152.3 | 0.8 | -16.0 |
| 610 | PINWR | 'Critically Eroded' | 1236.0 | 1257.2 | 21.2 | -138.8 | 2.2 | -14.6 |
| 620 | PINWR | 'Critically Eroded' | 1191.5 | 1176.6 | -14.9 | -174.9 | -1.6 | -18.4 |
| 630 | Rodanthe | 'Critically Eroded' | 1065.4 | 1014.0 | -51.4 | -211.4 | -5.4 | -22.2 |
| 640 | Rodanthe | 'Critically Eroded' | 946.9 | 940.2 | -6.7 | -166.7 | -0.7 | -17.5 |
| 650 | Rodanthe | 'Critically Eroded' | 1035.1 | 1027.9 | -7.2 | -167.2 | -0.8 | -17.5 |
| 670 | Rodanthe | 'Critically Eroded' | 1247.9 | 1059.6 | -188.4 | -348.4 | -19.8 | -36.6 |
| 680 | Rodanthe | 'Critically Eroded' | 1397.4 | 1090.0 | -307.3 | -467.3 | -32.3 | -49.0 |
| 700 | Rodanthe | 'Critically Eroded' | 1195.9 | 1296.8 | 100.9 | -59.1 | 10.6 | -6.2 |
| 720 | Waves | 'Critically Eroded' | 1234.2 | 972.2 | -262.1 | -262.1 | -27.5 | -27.5 |
| 740 | Waves | 'Critically Eroded' | 1088.5 | 931.0 | -157.5 | -157.5 | -16.5 | -16.5 |
| 760 | Waves | | 930.7 | 890.8 | -39.8 | -39.8 | -4.2 | -4.2 |
| 780 | Waves | | 923.2 | 845.2 | -77.9 | -77.9 | -8.2 | -8.2 |
| 800 | Waves | | 956.6 | 810.3 | -146.3 | -146.3 | -15.3 | -15.3 |

| From Sta 600+00 to Sta 740+00: | Feb-23 | Feb-23 (minus USACE) |
|---|---|---|
| cy/ft/yr | -8.3 | **-22.0** |
| cy/yr | 115,618 | **307,954** |
| cy per 5 years | 578,089 | **1,539,771** |

**TABLE 4.1.** Comparing the 2013 CSE survey with the updated February 2023 data suggests the highest erosion rates measuring >10 cy/ft/yr occur along a ~14,000 ft critically eroded portion of the study area between Sta 600+00 (~3,500 ft north of the Mirlo Beach sign) and Sta 740+00 (~3,000 ft south of Rodanthe Pier).

### Step 2 – Determining Annualized Erosion Rates

***Method 2 – NCDENR shorelines***

The second method relies on state-adopted erosion rates published periodically by NCDENR (NCDENR 2021). Results are presented in Table 4.2. Using the conversion from horizontal to volumetric erosion described in Section 3.1, the natural background erosion rates at PINWR and Waves are 9.7 and 4.8 cy/ft/yr, respectively. At Rodanthe, erosion measures 20.5 cy/ft/yr.

Because the critically eroded area includes portions of PINWR and Waves, the adopted erosion rate along that portion of the study area is marginally less than along the Rodanthe reach (18.2 cy/ft/yr). Without accounting directly for the 2014 USACE project, Method 2 yields a 5-year loss of ~1.2 million cy.

This is a long-term estimate that simply compares shoreline positions from 1946 to 2020, so these figures are likely somewhat lower than the actual background erosion rate. However, both the CSE and NCDENR data suggest 5-year erosion rates on the order of 1.2 to 1.5 million cy along 14,000 ft of the study area.

**Erosion Rates from NCDENR Study (1946-2020)**

| Reach | PINWR | Rodanthe | Waves | Critically Eroded |
|---|---|---|---|---|
| ft/yr | -5.5 | -11.6 | -2.7 | -10.3 |
| cy/ft/yr | -9.7 | -20.5 | -4.8 | -18.2 |
| cy/yr | -116,261 | -154,674 | -41,002 | -246,422 |
| | | | 5-yr losses> | 1,232,112 |

**TABLE 4.2.** By applying the correction factor discussed Section 3.1 to the horizontal adopted erosion rates measured by NCDENR, we can estimate volumetric change from the foredune to DOC. Using this method, we see erosion rates along the Rodanthe reach are more than twice those along PINWR and Waves. Within the 14,000-ft critically eroded area, volumetric changes average 18.2 cy/ft/yr.

### Step 3 – Identifying a project volume for planning purposes

The 2.3-million-cy deficit volume represents the initial volume required to restore the critically eroded beach to a condition similar to healthier adjacent reaches. Additions of sand along the critically eroded area beyond this deficit volume represent an advance fill that can accommodate 5 years' worth of erosion. Upon placement, the nourishment volume is expected to erode from the center (widest beach initially) and spread in either direction to adjacent healthy sections of beach. At the end of the 5-year period, the majority of the **deficit** volume is expected to remain in place, providing an erosion buffer for additional years.

Based on the above analysis, the deficit volume along 14,000 ft of critically eroded beach between PINWR and Waves is ~2.3 million cy. Annualized erosion rates fall between ~250,000 and 300,000 cy per year along that portion of the study area. So, the advance fill volume needed to offset these losses over a 5-year period ranges from ~1.2 to 1.5 million cy.

Combining and comparing deficit and advance fill volumes helps deliver a realistic picture for what a beach restoration project at Rodanthe would look like. Placing ~1.5 million cy would offset 5 years' worth of erosion. However, this volume is expected to be mostly depleted at the end of that 5-year period and the critically eroded area will look much as it does today.So, the recommended minimum volume for nourishment at Rodanthe is 2 million cy along 14,000 ft. A nourishment project placing ~2.3 million cy would provide the volume necessary to restore a dry sand beach and protective dune, but would probably last 10 years or less like the USACE 2014 effort. A full-scope project designed to restore the deficit and provide advance fill to offset 5 years worth of erosion would require ~3.5 to 3.8 million cy.

Examining the 2013 and 2023 profiles reveals that some of the volume placed as part of the 2014 USACE project remains in the study area. With this in mind, it is important to remember that any of the above scenarios will result in additional beach sand and therefore some degree of additional protection. If the USACE project (~1.6 million cy) had been repeated on a 5-year interval, it is likely the current beach condition would have been avoided.

Based on recent experience, nourishment projects at this scale require mobilization/demobilization costs of ~$4.5 million with a unit cost of ~$8 to $10 per cy. Assuming these price ranges, beach nourishment at Rodanthe could be accomplished for between $27 and $40 million. The scenarios outlined in Table 4.3 assume project volumes ranging from 1.5 million to 3.8 million cy, and average ~$33.8 million for mob/demob, permitting, and construction costs. These project costs are compared with structural alternatives over a 30-year period in the following sections.

| | | Mob/Demob | Base Bid Quantity (cy) | Total Pumping Cost | Total Base | Total + Permit |
|---|---|---|---|---|---|---|
| Unit cost (per cy) | $ 8.00 | $ 4,500,000 | 3,800,000 | $ 30,400,000 | $ 34,900,000 | $ 40,135,000 |
| | $ 8.50 | $ 4,500,000 | 3,500,000 | $ 29,750,000 | $ 34,250,000 | $ 39,387,500 |
| | $ 9.00 | $ 4,500,000 | 2,300,000 | $ 20,700,000 | $ 25,200,000 | $ 28,980,000 |
| | $ 9.50 | $ 4,500,000 | 2,000,000 | $ 19,000,000 | $ 23,500,000 | $ 27,025,000 |
| | $ 10.00 | $ 4,500,000 | 1,500,000 | $ 15,000,000 | $ 19,500,000 | $ 22,425,000 |

**Table 4.3.** Assuming a mobilization-demobilization cost of $4.5 million and unit prices per cubic yard between $8 and $10, the average cost for a 5-year nourishment project at Rodanthe is ~$33.8 million.

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## 5.0 ALTERNATIVE APPROACHES

Planning a nourishment project around steep alongshore gradients in erosion can be difficult. Beaches feature multiple directions of sand transport, including bars moving onshore and offshore, shoals migrating about the lower shoreface, and alongshore drift. Many approaches to oceanfront engineering—including survey profiles, computer models, and even some wave and current measurements—make certain assumptions to provide more clarity and consistency. Unfortunately, natural conditions are frequently much messier than maps and models indicate. What's more, natural conditions along the Outer Banks are particularly unforgiving.

There are offshore shoals and nearshore bars along the study area. Bars move landward and seaward depending on prevailing wave conditions, but the offshore shoals are more permanent features. The shoals run northeast-to-southwest and attach to Hatteras Island near PINWR and Waves. Similar features have been studied in Long Island, NY (Wei and Miselis 2022), northeastern South Carolina (Barnhardt et al 2009), and the Gulf of Mexico (Houser and Hamilton 2009). In multiple settings, these can influence physical processes along adjacent beaches.

During 'normal' relatively calm wave conditions, the shoals are below the depth of significant sand transport. But during relatively rough storm conditions, they are above that depth. As a result, the waves are transformed from deep-water swell to more turbulent breakers. Through this transformation, wave heights are amplified, wave crests refract to become parallel with depth contours, and overlapping wave crests can stack upon one another to create rhythmic differences in wave energy along the beach.

Over time, such interactions between offshore features and beach volumes can lead to alongshore variations in parameters like beach width, shoreface steepness, and dune height. These variations occur naturally, but can lead to hazards wherein homes may be in danger of collapse due to beach erosion. The Rodanthe reach lies in a gap between locations where shoals attach to the active shoreface, meaning larger waves can travel closer inshore and lead to more beach erosion along this reach than adjacent beaches. Beach nourishment helps to mitigate this hazard by placing excess sand volumes so that project sand washes away before developed properties. However, because natural variations in the position of shoals occur thousands of feet offshore, mitigating and planning for this hazard with sand placement alone can be difficult.

One strategy adopted in other locations is hardened structures such as groins, which help anchor a shoreline in place by slowing the alongshore migration of beach sands. Given the location of Rodanthe away from inlets, and current rules concerning hardened structures on oceanfront beaches in North Carolina, such an approach is currently not feasible. However, regulatory landscapes evolve and a structural solution at Rodanthe may be viable at some point.

So, we include below a brief review of potential strategies for maximizing the lifetime of nourishment at Rodanthe. This review is intended to provide a comparison between long-term costs of structural and non-structural options for maintaining a beach along the critically eroded area.

Increasing project longevity requires keeping nourishment sand along the critically eroded area longer than a 5-year lifetime. Two potential options exist for increasing sand retention along ocean-facing beaches—groins and offshore breakwaters. Due to a number of considerations including construction costs and potential litigation, offshore breakwaters are likely to be prohibitively expensive at this location (eg >$200 million – Tutarime and d'Angremond 1998). However, CSE has permitted and managed the construction of cost-effective groins in multiple locations, most recently at Debidue Beach, South Carolina.

At Debidue Beach, a shoreline salient like that at Rodanthe was triggering rapid beach erosion and exposing a timber bulkhead. The community elected to pursue a project in which sand placement was paired with three groins constructed using marine mattress, fiberglass sheet piles, and armor stone (Figure 5.1). The net cost of three of these structures spaced along 2,000 ft of shoreline was $2,375,000, and it took approximately six months to construct working around tides and weather. According to modeling analyses performed as part of the permit application process, CSE estimates the Debidue groins and nourishment plan combined extend nourishment life by by ~50%. This reduces the long-term management costs for the community.

Given the alongshore extent of the critically eroded area identified in this report, the Rodanthe site would likely require more than three groins to make a meaningful difference in sand budgets over a several-year period. The structures would also need to be larger to account for the steeper shoreface and rougher wave climate along the Outer Banks compared to South Carolina. Given that the location of the critically eroded area at Rodanthe is more remote than the project site at Debidue, unit costs for construction materials and labor on the Outer Banks will likely run higher as well.

With all of this in mind, a series of groins along Rodanthe is likely to cost at least $15 million to construct, separate from nourishment. At Debidue, long-term sand budget and cost-benefit analyses found that the project sponsor could increase the amount of time between nourishments. If a similar degree of project performance could be achieved along Rodanthe, it would reduce erosional losses from ~1.5 million cy every five years to ~1 million cy every seven and a half years.

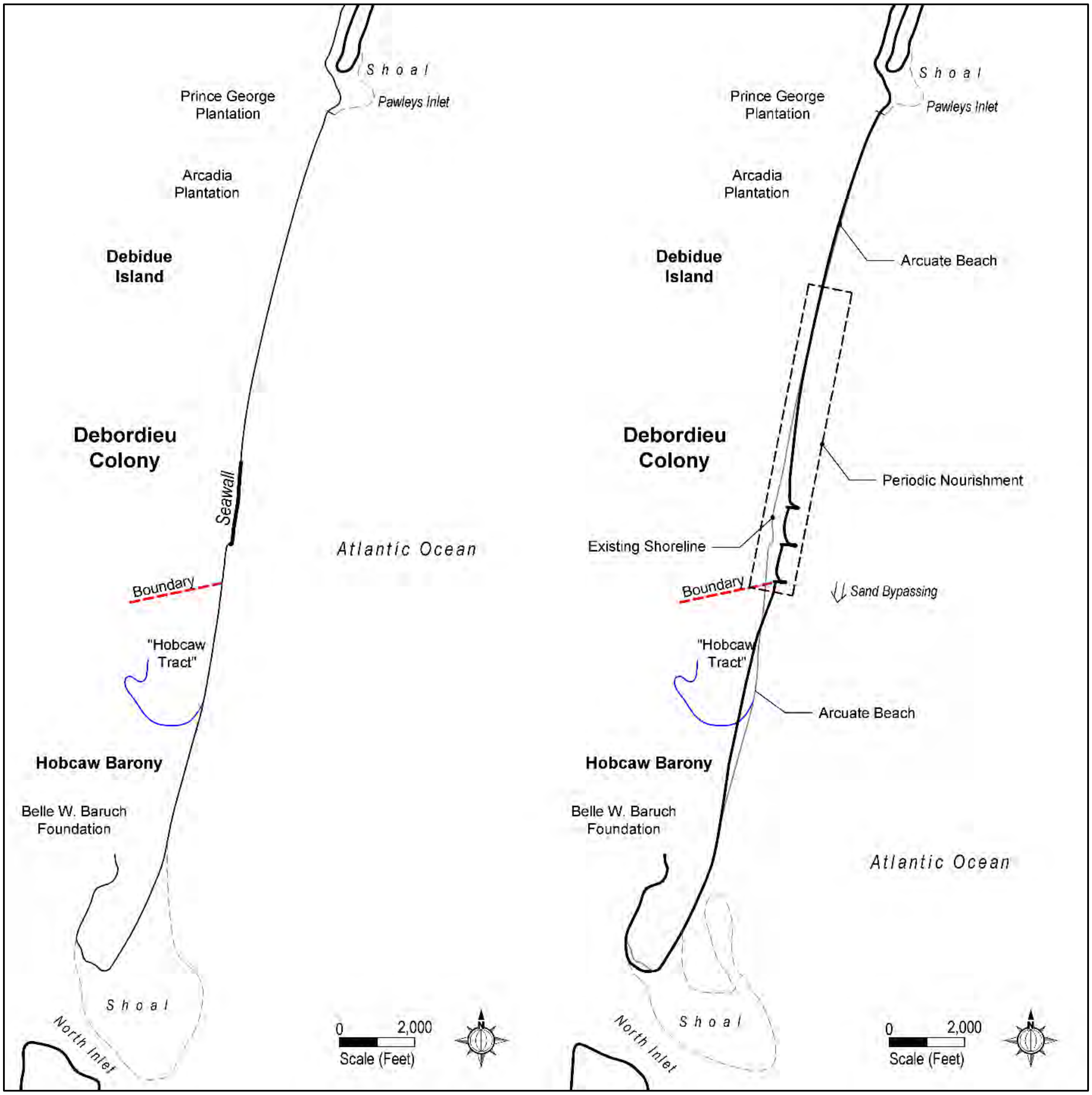


**FIGURE 5.1.** At Debidue Beach, a shoreline salient like that at Rodanthe was triggering rapid erosion of a beach and exposing a timber bulkhead. The community recently completed a project which included sand placement was paired with three groins constructed using marine mattress, fiberglass sheet piles, and armor stone.

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## 6.0 COMPARING COSTS OVER 30 YEARS

This report presents a basic analysis of beach volumes and project costs along 5.7 miles of beachfront in Dare County, NC. Three reaches (PINWR, Rodanthe, and Waves) exhibit varying degrees of dry beach width, dune crest height, and storm protection. CSE calculated a sand deficit along a critically-eroded portion of the study area to determine the base line volume needed to restore a dry sand beach and protective dune along Rodanthe.

That base-line deficit is 2.3 million cy over the 14,000 ft critically eroded area. Erosion rates along the critically eroded area measure ~300,000 cy/yr. So, to restore the sand deficit and provide 5 years of additional protection beyond that baseline would require ~3.8 million cy of sand. Based on Table 4.3, a one-time effort of this scale would cost ~$40.1 million.

Considering the County wishes to maintain a dry sand beach and protective dune along Rodanthe, repeat renourishment projects will be necessary. If 5-year erosion rates average ~1.5 million cy along the critically eroded area, subsequent renourishment events would need to exceed this total and place ~2 million cy per event. Over a 30-year planning horizon, factoring background erosion of ~300,000 cy/yr, such a plan would leave the project area with 4.8 million cy more sand in 2054 than 2023 (dashed line, Figure 6.1).

If the County is able to install groins that can reduce post-project erosion by ~50%, the return interval between projects can be extended from 5 to 7.5 years while still retaining more sand than the no-groin alternative. Assuming the same initial project volume (eg 3.8 million) and installation of a groin field as described in Section 6.0, the County could renourish the critically eroded area with 2 million cy every 7.5 years. Over a 30-year planning period this results in a net volume increase of 5.3 million cy above the 2023 condition (solid line, Figure 6.1).

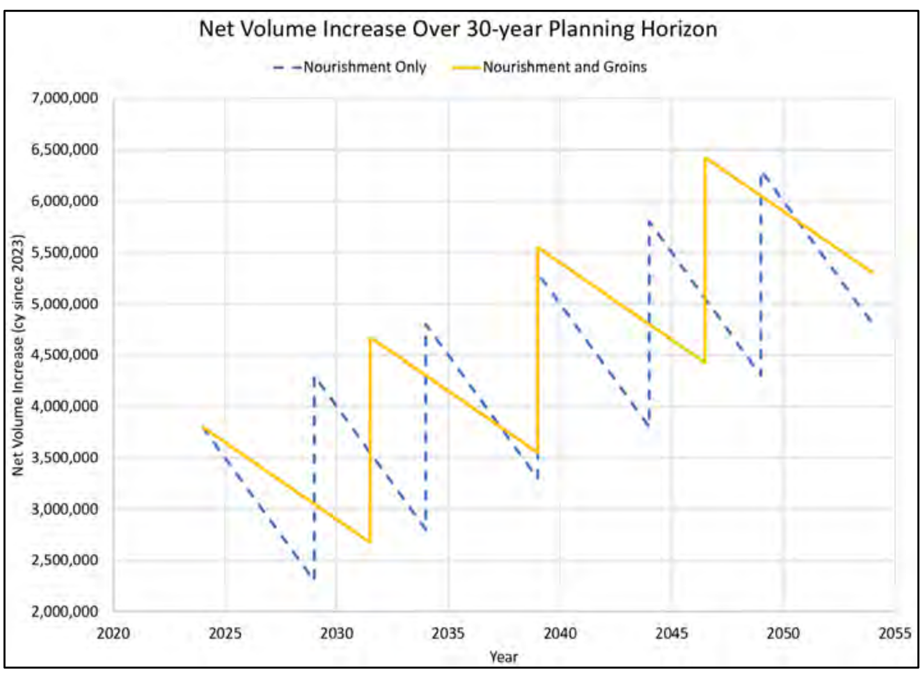


**FIGURE 6.1.** If groins are able to reduce annual erosion rates by 50% along Rodanthe – as has been observed in other project locations managed by CSE – then the interval between projects can reasonably be extended from 5 years to 7.5 years. Over a 30-year planning time frame, this results in fewer projects with more sand placed along the critically eroded area.

In addition to the volume differences between these methods, comparing long-term costs is also beneficial for planning purposes. With a nourishment-alone strategy, and a 5-year return interval between 2 million-cy projects, total costs over a 30-year period measure ~$175.3 million. If groins are installed and erosion is reduced by ~50% along the critically eroded area, the return interval is extended to one project every 7.5 years with the same (2 million cy) volume. Such an effort would cost ~$136.2 million in total including $15 million for groin installation. The installation of groins along with nourishment is initially more expensive, but becomes the cheaper option within ~10 years (Figure 6.2). The bulk of potential savings is due to the lower number of projects required to maintain the same volume. Building four projects versus six reduces the costly mobilization fees, permitting, and construction administration associated with renourishment.

Mean sea level is likely to be ~1 ft higher by the end of a 30-year planning period starting in 2023. Assuming a 1-on-20 shoreface slope along the survey area, a 1-ft rise in sea level over a 30-year period will result in 20 ft of landward movement in shoreline position over the same period. Using the multiplier described in Section 3.1 this will result in ~35 cy/ft of total erosion due to sea level rise alone by ~2054. This is an order of magnitude lower than the projected net input of nourishment sand over the same period (eg ~350 cy/ft). While this may not have a drastic impact on oceanfront processes in the short term, it is likely to increase overwash along PINWR, draw more sand off the critically eroded area, and complicate maintenance of a groin field along Rodanthe (cf Mariotti and Hein 2022). Over time periods beyond a 30-year horizon, such alongshore variance can affect barrier vulnerability to sea level rise (Reeves et al 2022).

These cost and volume projections are rough estimates. Year-to-year erosion rates may accelerate, and engineering/permitting costs for a groin field on the Outer Banks are likely to exceed costs for a similar scope of work elsewhere. While the present report is a robust starting point for determining the feasibility of nourishment at Rodanthe, CSE recommends the County consider sponsoring a more complete feasibility study including model-based assessments and economic analysis.

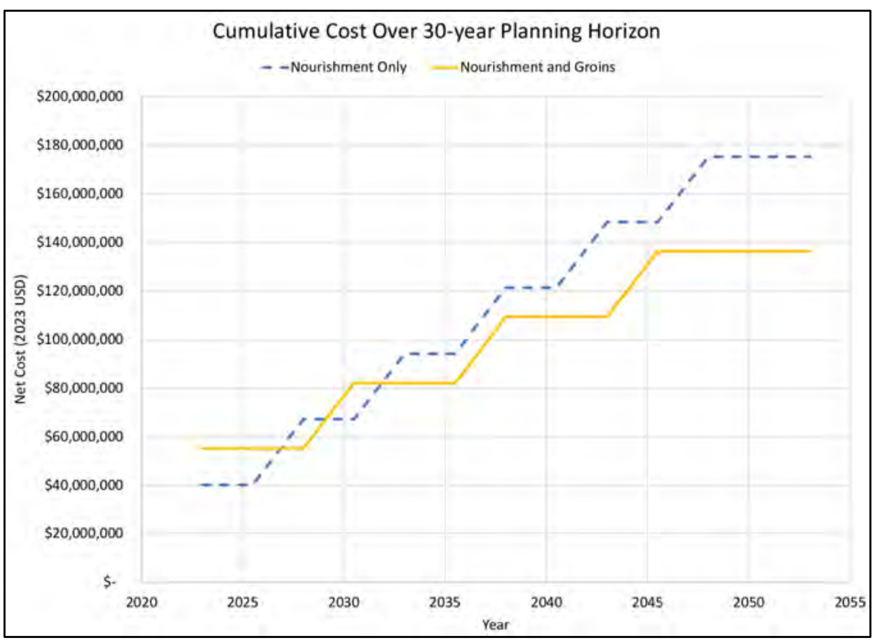


**FIGURE 6.2.** While the initial investment in groin installation and a large-scale beach restoration makes the structural alternative more expensive, those costs are surpassed by the nourishment-alone option by the mid-2030s. These projections assume constant mob/demob costs and unit costs throughout the 30-year planning horizon.

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