Town of Duck
North Carolina

Erosion & Shoreline Management

Feasibility Study


Photo Provided by Bill Birkemeier and the US Army Corps of Engineers

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EXECUTIVE SUMMARY

The Town of Duck is investigating shoreline management alternatives to mitigate for long term erosion trends and provide storm damage reduction for public and private development. This analysis identifies shoreline change trends occurring between 1996 and 2011 along the Town's oceanfront shoreline as well as the vulnerability of the shoreline to storm damage. Factors such as offshore bars, sand waves, wind waves, storm frequency/intensity, and the impact of the FRF pier were evaluated to discern any contributing factors that may be impacting shoreline change.

This report estimates potential damages in the form of land and structural losses if established shoreline change rates persist. A storm damage vulnerability analysis was conducted using SBEACH to determine which segments of the shoreline may be vulnerable to storm damage. A number of different management alternatives were developed to provide different levels of erosion mitigation and storm damage reduction. Alternatives were compared based on cost, schedule to complete, and anticipated project performance. The alternative analysis resulted in recommendations for moving forward with a long-term solution, presented herein.

Shoreline Change Analysis

Shoreline changes along the Duck shoreline were evaluated using 5 sets of survey data collected between 1996 and 2011. The analysis identified 10 shoreline segments that appeared to behave in a similar manner. Segment 7, which covers 5,000 feet of shoreline between the northern property line of the FRF pier and Dianne Street, experienced the greatest shoreline recession over the study period. The average recession in Segment 7 was 73 feet which is equivalent to an annual rate of -4.82 ft./yr.

The other segments that register a recession trend during the analysis period include Segments 4, 6, and 9. Segment 4 which is located between Duck Landing Lane and Ships Watch Drive, experienced a landward migration rate of -1.04 ft./yr. Segment 6, located on the FRF property north of the pier, eroded at a rate of -1.68 ft./yr. Segment 9, located in the northern study region between Martin Lane and Sanderling Resort, also receded at an average rate of -0.56 ft./yr rate. The remaining segments experienced net accretion during the study period.

In addition to shoreline changes that occurred between 1996 and 2011, long-term trends (1940-2011) were also examined based on limited data available through the state of North Carolina. These data show that although a shoreline advance (seaward movement) has occurred in Segment 8, which covers the 8,000 feet north of Segment 7, this area experienced the greatest shoreline retreat (landward movement) of any of the 10 Segments between 1980 and 1999.

Factors Influencing Shoreline Change

An EVEN-ODD analysis of shoreline changes was centered on the FRF pier to determine if the pier is having a significant impact of the behavior of the shoreline. The analysis considered three time periods; 1997 – 2005, 1998 – 2008, and 1997 – 2008. The results of this analysis found the pier did have some impact on shoreline changes in the immediate vicinity of the pier, but the extent of the impact was confined to the FRF property.

The behavior of the shoreline in the various segments over different time periods suggests the possible presence of migratory sand waves. Sand waves are perturbations in the shoreline that tend to migrate along the shore in response to wave action. Possible sand wave migrations were evident in Sections 8 to 10 north of the pier as these segments experienced sinusoidal patterns of accretion and erosion. However, the persistent erosion of the shoreline in Segment 7 and to some extent in Segment 6 implies that if sand waves were active in the area north of the pier, the sand waves did not move into Segments 6 and 7. As a result, Segments 6 and 7 have not shown a propensity to reverse the long-term erosion trend that was apparently initiated sometime around 1980 and continues today.

Abnormal shoreline behavior along sections of the Duck shoreline in particular Section 7, have been theorized to be associated with the presence of oblique sand bars in the nearshore. Shore oblique sandbars can form in the nearshore or in the surf zone and are generally accompanied by gravel outcroppings. The existence of the shore oblique sandbars has also been strongly correlated to the presence of buried paleo-channels beneath the modern shoreface. Observations by FRF staff have confirmed the occasional presence of shore oblique sand bars offshore Duck. FRF staff have also indicated that geophysical surveys conducted offshore of the Town of Duck, have identified what are interpreted to be paleo-channels; however, these data have not been published to date.

Wave data collected by the FRF since 1980 was used to determine alongshore sediment transport potentials for various time increments between shoreline datasets. Overall, the FRF wave data suggest the predominant direction of sediment transport in the vicinity of the FRF pier is to the north. Also, the wave data indicated an increase in the rate of northward transport beginning around July 2004. However, the comparison of sediment transport potential did not provide any clear indication varying wave conditions contributed to the observed difference in shoreline response from one segment to another.

The study also included an attempt to correlate shoreline response to storms. This was done by computing a value designated as the storm intensity factor (SIF) which combines the wave height in a storm with the duration of the storm. The SIF was calculated for three (3) time frames; namely, October 1980 to September 1996, September 1996 to September 1999, and September 1999 to November 2011. While the September 1996 to September 1999 time period had the highest value for the SIF, the shoreline response within the various segments varied during this active storm period. Also, there was no correlation between the behavior of the various shoreline segments and the SIF computed for the other two time periods. Therefore, within the Town of Duck, the shoreline appears to have independent reactions to varying levels of storm intensity from one segment to another.

Economic Impact Analysis

Should the Town of Duck elect to take no action to address shoreline erosion (No Action Alternative), 53 homes could be lost over the next 30 years based on measured erosion rates from 1996 through 2011. The potential economic impact associated with the loss of these 53 homes as well as associated pools and land totals approximately $43.7 million. All 53 homes predicted to be lost given a continuation of existing erosion rates, are located within Segment 7. Projected losses in Segment 7 alone total $40.5 million or 93% of the total erosion related losses.

Storm Damage Vulnerability Analysis

The analysis showed that some structures within Segments 2, 3, 4, 7, and 8 are vulnerable to various storm conditions. Structures along Segments 7 and 8 are the most vulnerable to storm impacts under the given shoreline conditions (November 2011). Approximately 37 structures were estimated to be vulnerable to storm damage from a 10-year return interval storm (a storm that has a 10% chance of occurring in any one year). All 37 structures are within Segments 7 and 8. Approximately 47 structures were estimated to be vulnerable to storm damage from a 20-year return interval storm (a storm that has a 5% chance of occurring in any one year) in Segments 7 and 8. One (1) structure was identified in Segment 3 and Segment 4 as being vulnerable to the 20-year storm, however, this study assumes such a level of damage would not warrant beach fill being placed along these sections. Approximately 54 structures were estimated to be vulnerable to storm damage from a 25-year return interval storm (a storm that has a 4% chance of occurring in any one year) in Segments 7 and 8. Four (4) structures were identified in Segments 2, 3, and 4 as being vulnerable to the 25-year storm, however, this study assumes such low number of vulnerable structures would not warrant beach fill being placed along these sections.

Management Alternatives

A number of potential shoreline management alternatives were developed to address erosion and storm damage vulnerability. The alternatives were developed by taking into account the physical setting of the Town, density of development, rates of shoreline change, storm damage vulnerability, and availability of sand to implement a shoreline management plan.

In addition to a “No Action” alternative that was considered as a baseline, conceptual alternatives evaluated included:

- Retreat;
- Dune restoration by truck haul;
- Beach restoration by truck haul
- Erosion mitigation project by offshore dredging; and,
- Storm damage reduction projects by offshore dredging.

<u>Retreat</u>. The option of ‘Retreat’ would allow the habitable structures to be relocated beyond the immediate threat of erosion. The ‘Retreat’ option assumes the 53 threatened homes identified in the study area will be relocated to a currently vacant lot within the Town’s jurisdictional limits. When compared to the total loss of land and structures predicted by the ‘No Action’ alternative, the ‘Retreat’ option is approximately 10% less expensive when costs such as relocation costs and purchasing of a new lot are considered.

Dune Restoration by Truck Haul

The first in a series of active conceptual alternatives involving placement of sand on the beach is dune restoration along vulnerable shoreline segments. A dune restoration project would minimize some of the permitting concerns while still providing some measure of erosion mitigation. Based solely on the shoreline change rates measured, an estimated volume of 30,000 cy of sand would be required to provide 1 year of erosion mitigation.

A benefit of a dune restoration is that diffusion losses, which are realized when fill is placed on the foreshore portion of the beach profile, would not occur as material is placed well above the MHW line. Thus, the volume intended to be placed in the dune would be a direct reflection of the necessary material to accomplish the intended task.

Limiting fill placement to the dune would not directly address shoreline erosion but would provide immediate short-term aid for threatened or soon to be threatened structures. As the shoreline erodes into the dune, the fill material would be displaced onto the beach and in so doing, provide an indirect source of beach nourishment material.

A dune restoration project could be completed in approximately 10 months. The permitting process would encompass approximately 6 to 8 months and construction would entail the additional time. The estimated total cost for constructing a dune fill project in Segment 7 using truck haul, including environmental permitting and design is approximately $939,000.

Beach Restoration by Truck Haul

An alternative to conducting a dune restoration would be a small scale beach restoration using truck haul. Material could be placed along the active beach system beginning at the toe of the dune and extending seaward including below MHW. Conducting the project by means of a truck haul makes smaller scale jobs more economical when compared to mobilizing a dredge. Permitting requirements would increase compared to a dune restoration but may remain below that required for a larger scale dredge and fill project.

As previously discussed, diffusion losses must be considered when placing material within the active littoral zone that extends landward to berm crest. The diffusion equations were applied to a beach fill project covering the 5,000 feet of shoreline in Segment 7 that would spread 30,000 cubic yards along the shoreline to provide 1 year of erosion mitigation. This resulted in a required 43,000 cubic yards of fill to be placed to account for both 1 year of erosion mitigation and diffusion.

The USACE would need to make a determination on the type of documentation required to support a permit. The process of developing this document and working it through the review process could range from 8 – 36 months. The main variable affecting the schedule is the unknown factor of what type of federal environmental documentation will be required. The estimated total cost for design, permitting, and construction of a beach fill project in Segment 7 using trucks could range between $1,746,000 and $1,846,000, depending on the permitting process.

Erosion Mitigation Project with Offshore Dredging

While truck haul is a reasonable option for small scale projects, construction of a large beach nourishment project that could provide multiple years of erosion protection would involve identifying a suitable offshore borrow source and mobilization of high production ocean going dredges to deliver the material to the beach.

The erosion mitigation project using offshore sand would be constructed along the length of both Segments 7 and 8. The shoreline change analysis for the 1996 to 2011 time period would seem to suggest Segment 7 is the only segment in need of protection. However, Segment 8 experienced the largest recession rate of any of the segments north of the pier between 1980 and 1999. Likewise, the storm damage vulnerability analysis conducted using the SBEACH storm erosion model found both Segments 7 and 8 had high potentials for significant damage due to storm related shoreline erosion. Therefore, an erosion mitigation project using offshore sand resources should be provided along both Segments 7 and 8. Ironically, the volume of material needed to protect both segments would be approximately the same as protecting Segment 7 alone. This is due to the relatively short length and high rate of shoreline recession in Segment 7 which would be conducive to large spreading losses if the project was limited to that segment. By distributing the fill over the longer shoreline reach, spreading losses would be greatly reduced. Also, some of the material that would be moved out of Segment 8 would migrate into Segment 7 further enhancing the performance of the fill in that area.

The combined shoreline length for Segments 7 and 8 is 13,000 ft. A 1,000 ft. long taper would be added to either side to help reduce spreading losses. Initial construction of a project that would provide 5 years of erosion mitigation along the lengths of both Segments 7 and 8 would require the placement of approximately 842,000 cubic yards of sand. Unlike the small-scale truck haul projects where only the volume of sand anticipated to be lost due to erosion and diffusion is being placed on the beach, this alternative seeks to re-establish a beach berm. The initial construction includes a 40 ft. wide berm plus placement of enough advanced fill to account for 5 years of erosion as well as diffusion losses. Figure 7 shows a cross section view of the 40 ft. wide design berm.

The timeframe anticipated to acquire state and federal permits for a beach restoration utilizing an offshore borrow source is 24 – 36 months. Two different borrow sources are being considered for offshore dredge and fill projects. Based on the final selection of the borrow source, the unit cost for sand could range from $8.61 / cubic yard to $10.63 / cubic yard. Mobilization cost for either borrow site would remain the same and is estimated at $2.9 Million. The total estimated range of cost for this alternative is $13.04 Million to $14.96 Million. This includes construction costs, soft costs, and a 15% contingency added to the construction costs. The difference in the two costs is due to the two separate unit cost estimates based on the two different borrow area locations.

Storm Damage Reduction Project with Offshore Dredging

The storm damage vulnerability analysis suggests that a beach fill project to reduce storm damage reduction is warranted along Segments 7 and 8. Nine (9) different beach fill designs were developed to mitigate the storm damage vulnerability for a given storm.

The timeframe anticipated to acquire state and federal permits for a storm damage reduction project is the same as previously mentioned for the erosion mitigation with offshore dredging, 24 – 36 months. The following table lists the range of costs for each of the different designs to mitigate storm damage given a specific storm.

Storm Event	Project Cost for Storm Damage Reduction Project	
	Using Area 1 (Kill Devil Hills)	Using Area S1 (Nags Head)
1-Year Return Interval	17,419,000	$20,348,000
5-Year Return Interval	20,878,000	$24,619,000
10-Year Return Interval	20,878,000	$24,619,000
20-Year Return Interval	25,637,000	$30,494,000
25-Year Return Interval	27,839,000	$33,213,000
50-Year Return Interval	34,004,000	$40,824,000

Recommendations

Given the number of structures and property that is vulnerable to both long-term erosion and storm damage, the ultimate goal of the shoreline management program should be to permit and construct a large scale beach fill project. All of the dredge and fill projects discussed herein have a high probability of providing the level of protection for which they are designed. The deciding factor as to which option to choose will likely come down to what the Town can afford and/or economically justify.

Given the limited amount of protection that would be afforded by a small-scale truck haul beach nourishment project, this option should only be considered in the event of an extreme emergency situation that would imminently threaten multiple structures. The Town could opt to apply for permits to construct such a project and hold the permits in reserve. With permits in hand, a small-scale project could be initiated within a matter of weeks once such a decision has been made.

Such a limited scope project could become necessary even if the Town elects to pursue a larger scale beach nourishment or storm damage reduction project. Permitting the larger scale project could take 2 to 3 years which would increase the likelihood some structures could become threatened prior to construction of the larger project.

Regardless of what management strategy the Town might pursue, monitoring of the beach is an invaluable tool. Regular monitoring allows for the adaptation of strategies to the highly dynamic coastal environment. Even the best designed beach nourishment project requires adaptive management over the long term. Beach surveys are the most important tool in successfully adapting and refining an effective beach management plan. This study recommends that the Town continue to monitor the beaches in a similar fashion.

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INTRODUCTION

The Town of Duck undertook this study to investigate potential management options for the oceanfront shoreline within their jurisdictional limits. The investigation consists of three phases referenced as (1) data collection, (2) coastal processes and shoreline impact analysis, and (3) alternative analysis. The results establish long term trends in shoreline movement, vulnerability of coastal development to storm damage, and provide mitigation measures to manage the coast.

The data collection process, referenced as Phase 1, was conducted by the U.S. Army Corps of Engineers Field Research Facility (FRF) located in the Town of Duck. Elevations of the existing beach were collected for the shoreline within the project area in November 2011. The Town contracted with Coastal Planning & Engineering of North Carolina, Inc. to complete Phase 2 & 3. The results of Phase 1 are incorporated into the analysis of Phase 2 & 3, along with additional shoreline information.

This report identifies annual shoreline change dating back to 1996 and estimates potential damages if they continue. A storm damage vulnerability analysis was conducted using SBEACH to determine which segments of the shoreline may be vulnerable to storm damage. Coastal processes including historical wave and storm records were analyzed to define underlying reasons for the shoreline movement. Other potential influences on the trends such as offshore bars, sand waves, and the impact of the FRF pier were also evaluated to discern any contributing factors.

A description and comparison of management alternatives is also provided. The 2011 data collected by the FRF establishes a baseline for the shoreline position that is used in evaluating management options. The alternative analysis resulted in recommendations for moving forward with a long-term solution, which are presented herein.

SHORELINE CHANGE ANALYSIS

A shoreline change analysis determines accretion or erosion rates along a beachfront area. The shoreline is defined as a specific elevation such as mean high water (MHW). For this study, the MHW elevation is represented as the +1.2 foot NAVD88 contour. It is based on the 1983 to 2001 tidal epoch collected at the FRF pier (Robertson et al., 2004). The change in MHW position over time is averaged as an annual movement to provide the respective erosion or accretion rate.

Methodology

Shoreline changes along the Town of Duck were evaluated using LiDAR (Light Detection and Ranging) data collected by USACE CLARIS (Coastal LiDAR and Ranging System), USACE JALBTCX (Joint Airborne LiDAR Bathymetry Technical Center of Expertise), USGS (U.S. Geological Survey), NASA (National Aeronautics and Space Administration), and NOAA (National Oceanographic and Atmospheric Administration). LiDAR is an optical remote sensing technology that measures the ground elevation or seafloor at relatively high spatial resolutions. LiDAR data are better suited for surveying subaerial platforms since light penetration may be restricted by water clarity. For this reason, only elevations collected along the dry beach and higher are evaluated. Five (5) sets of LiDAR data collected between 1996 and 2011 were used for the shoreline study. The date of each LiDAR data set is as follows:

10 Oct 1996
08 Oct 1999
16 July 2004
22 March 2008
30 Nov 2011

Three (3) LiDAR surveys were taken between September and October 1999, all apparently in response to the passage of separate tropical storms or hurricanes. The three named storms were Dennis, Floyd, and Irene. The respective surveys for these storms were 09 September, 18 September, and 08 October. Only the last LiDAR dataset obtained after the passage of all three (3) storms was used for this analysis.

The MHW position for each survey was created along established transects using an ArcGIS custom application. A MHW position was recorded on 543 transects spaced at 100-foot intervals across the approximate 10 mile study area. Figure 1 shows an example excerpt of the transect spacing and positioning. A plan view of the entire study area is provided in Appendix A. Included in the plan view are the MHW shoreline positions obtained from the various LiDAR datasets and transect locations (Note: transects are shown on 1,000-foot spacings for clarity).

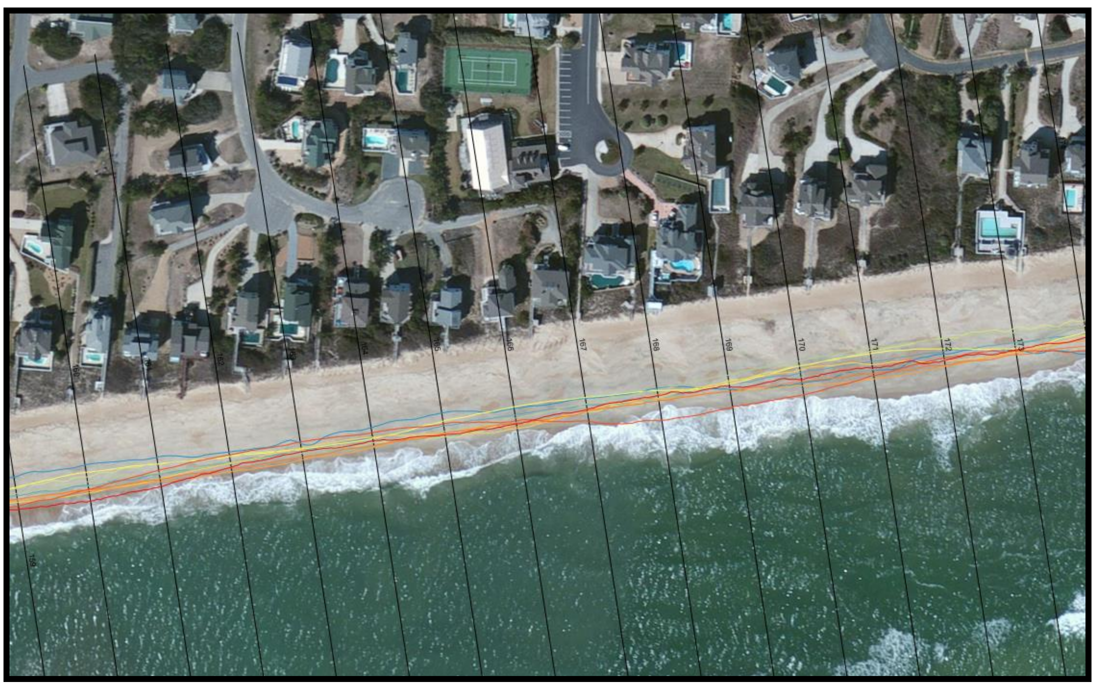

Figure 1. Example Of 100-Foot Transects and Shorelines Derived from LiDAR Data

Segment Identification

The transects were positioned from approximately 1 mile south to 1 mile north of the Town's incorporated limits. The southern and northern borders for the Town of Duck are at Transects 109 and 415, respectively. The FRF pier is represented by Transect 229. Transects with similar shoreline trends were grouped together in segments and average shoreline change rates were calculated for each segment.

Ten (10) separate segments were identified along the project area. The boundaries of each segment in terms of street names and other development features are presented in Table 1. As a matter of note, the southern boundary of Segment 10, which is 16,000 feet north of the FRF pier, is located near the last known position of Caffey's Inlet. Caffey's Inlet was open in 1852 but apparently closed sometime after as it did not appear on later maps (Fisher, 1962).

Table 1. Shoreline Segment Boundaries Referenced To Landmarks and Transect Groups

Shoreline Segment	Transect Grouping	Boundaries by Landmark (Approximate)	Shoreline Length (ft.)
1	9 to 89	Dolphin Run to 9th Ave.	8,000
2	89 to 149	9th Ave. to Four Seasons Drive	6,000
3	149 to 169	Four Seasons Drive to Duck Landing Ln.	2,000
4	169 to 209	Duck Landing Ln. to Ships Watch Dr.	4,000
5	209 to 229	Ships Watch Drive to FRF Pier	2,000
6	229 to 239	FRF Pier to N. FRF Property Line	1,000
7	239 to 289	N. FRF Property Line to Dianne St.	5,000
8	289 to 369	Dianne St. to Martin Ln.	8,000
9	369 to 389	Martin Ln. to Sanderling Resort	2,000
10	389 to 529	Sanderling Resort to Hampton Inn	14,000

Shoreline change patterns observed during the 1996 to 2011 study period, which were used to identify the various shoreline segments, are shown in Appendix B. Segment 1, positioned in the southern project area, was relatively stable to accretionary between 1996 and 2011. The 8,000 ft. shoreline area exhibits a consistent seaward advance except for approximately 2,000 ft. at the southern boundary. Segments 3, 5, 8, and 10 were also characterized by at least a partial trend of shoreline advance (seaward movement). Segment 3 experienced a consistent shoreline advance between 1996 and 2011. Segment 5 displays shoreline advance between 1996 and 2004 and fluctuates with shoreline retreat for the remaining timeframe. Segment 8 has a pattern of seaward advance between 1996 and 2008 and develops a stable trend through 2011. Segment 10 shows relative stability between 1996 and 2004, but then shows shoreline advance from 2004 to 2011.

Segments 2, 4, 6, 7, and 9 were identified due to shoreline retreat trends observed. Segment 2 shows consistent shoreline retreat between 2004 and 2011 with a mixed trend during remaining timeframes. Segment 4 shows shoreline retreat between 1996 and 1999, presumable due to the storm impacts of 1999. Some shoreline recovery, i.e., shoreline advance, was observed after 1999 but the amount of recovery did not compensate for all the losses. Segment 6, located north of the FRF pier, experienced shoreline retreat between 1996 and 2008. The segment does show shoreline advance trends between 2008 and 2011; however, the overwhelming trend is shoreline retreat since 1996. Segment 7 shows the most significant shoreline retreat in the study period with the majority of the retreat occurring between 1996 and 2008. The migration patterns then fluctuate in the 2008 to 2011 timeframe, but the overall trend is retreat. Segment 9 experiences shoreline retreat between 1996 and 2004 and then shows smaller patterns of advance occurring up to 2011.

Shoreline Change (1996 – 2011)

Shoreline change rates were calculated on a weighted average after the shoreline segments were identified. The rates were weighted by the change occurring and the number of years between each survey event. Table 2 shows the rates calculated for each shoreline segment.

Table 2. Shoreline Change Rates (1996-2011)

Shoreline Segment	Transect Grouping	Weighted Shoreline Trend by Segment for 1996 to 2011	
		Overall Trend (ft./yr)	Total Movement (ft.)
1	9 to 89	0.67	10
2	89 to 149	-0.37	-6
3	149 to 169	1.81	27
4	169 to 209	-1.04	-16
5	209 to 229	0.15	2
6	229 to 239	-1.67	-25
7	239 to 289	-4.79	-73
8	289 to 369	1.1	17
9	369 to 389	-0.56	-8
10	389 to 529	1.53	23

Note: Negative trends or movements are landward, positive are seaward

The calculations show Segment 7 experienced a landward retreat approximately three (3) times greater than any other segment. Recession rates for the segment averaged approximately -4.8 ft./yr with an average landward movement of -73 ft. The highest recession rate was measured at Transect 270 and totals greater than -6 ft./yr. This transect is positioned along Bufflehead Road between Widgeon Drive and Pintail Drive. Segment 6, located between Segment 7 and the FRF pier, experienced the next largest average recession at -25 ft. Figure 2 shows the shoreline change rates along each transect in the study area for the period of 1996 to 2011.

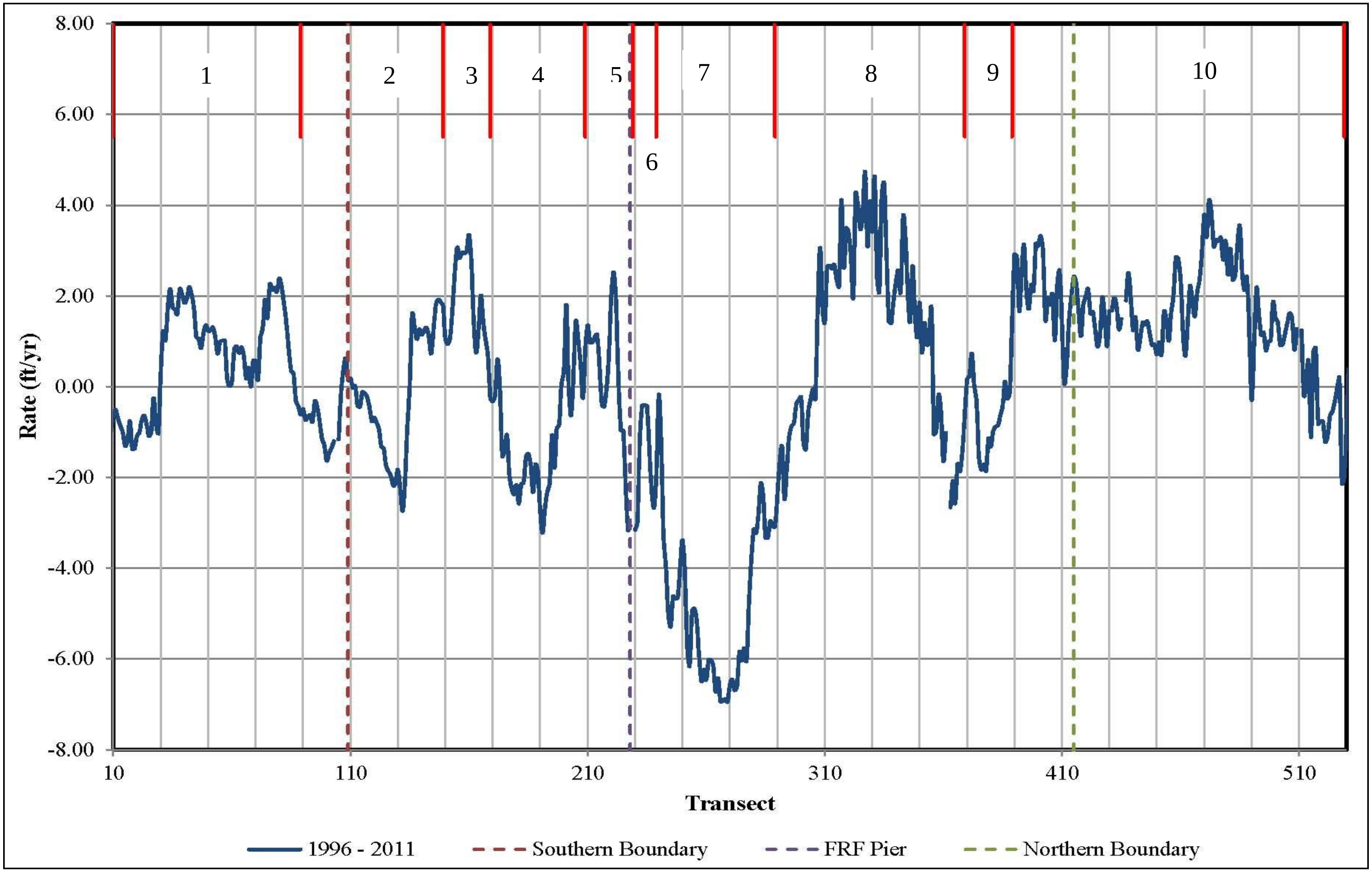

Figure 2. Town of Duck shoreline change rates, 1996 to 2011. Negative rates indicates recession (landward movement), positive rates represents accretion (seaward movement). Numbers at top designate shoreline segments.

Historical Long-Term Trends (1940 – 2011)

For the purpose of comparing the calculated trends from 1996 to 2011, an analysis was conducted to evaluate patterns dating back to 1940. The results of this additional analysis identify long-term trends and potential focal points in migration rates occurring since 1940. The data is presented as Cumulative Shoreline Change (Figures 3 & 4). Data identifying the 1940 and 1980 shoreline were supplemented with the shoreline analysis data referenced above and additional LiDAR surveys from 1996 to 2011. The 1940 & 1980 shoreline information was obtained from the USGS National Assessment Project and are available from NCDENR (2012). The additional LiDAR data includes surveys from September 1997, September 1998, two post storm surveys from September 1999, November 2005, and May 2010. These data sets were obtained from a combination of sources including USGS, NASA, and NOAA.

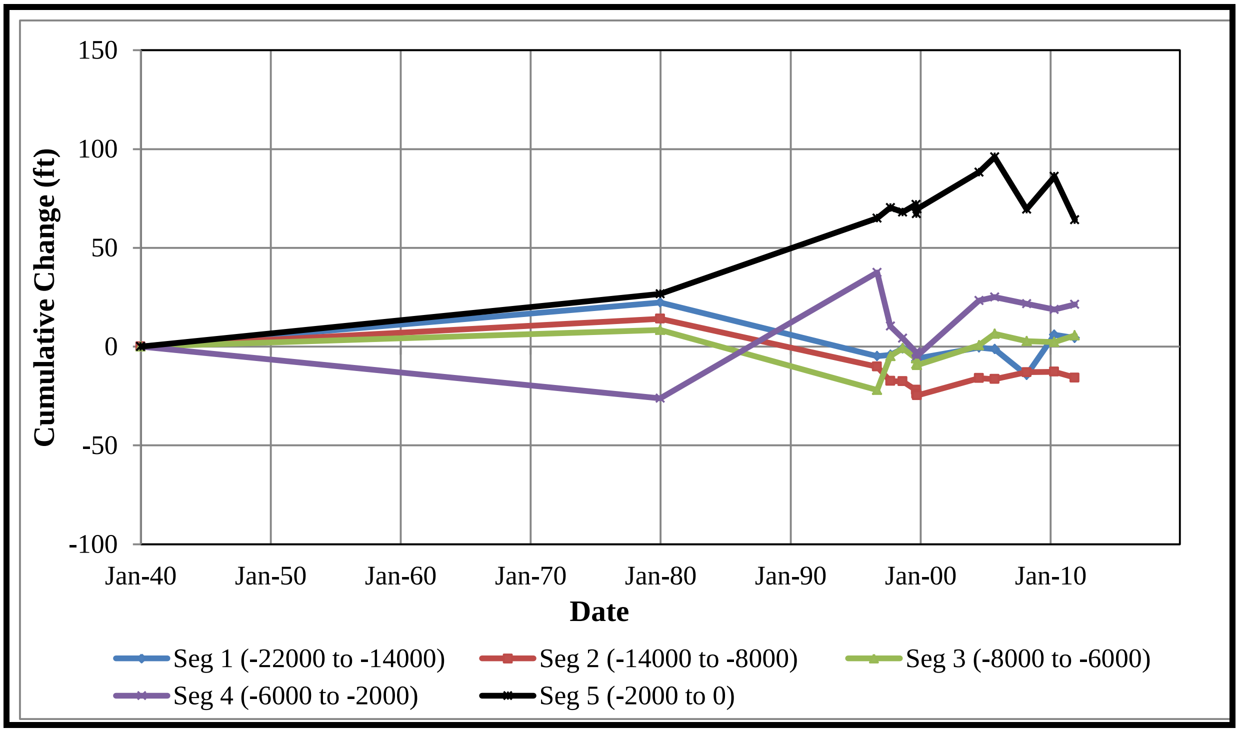

Figure 3. Cumulative Shoreline Changes South of the FRF Pier (1940 to 2011)

<u>Cumulative Shoreline Positions</u>

Shorelines south of the FRF pier were relatively stable to accretionary in comparing their 1940 and 2011 locations. This is demonstrated by the relative minimal variance in the 1940 and 2011 shoreline positions for Segments 1 to 4. An inflexion point does appear to exist in the 1980 time period as Segments 1, 2, & 3 begin a recession trend and Segment 4 begins a pattern of shoreline advance. Segment 4 does experience a significant recession trend between approximately 1996 and 2005, however the 2011 position is significantly seaward of the 1980 position. Segment 5, located closest to the pier, was not influenced by the inflexion near 1980 as this segment continued to experience a trend of shoreline advance until 2005. Segment 5 shows the highest shoreline advance trend for the 71 year period from 1940 to 2011 at over 50 ft. But since 2005 this segment has experienced an overall recession.

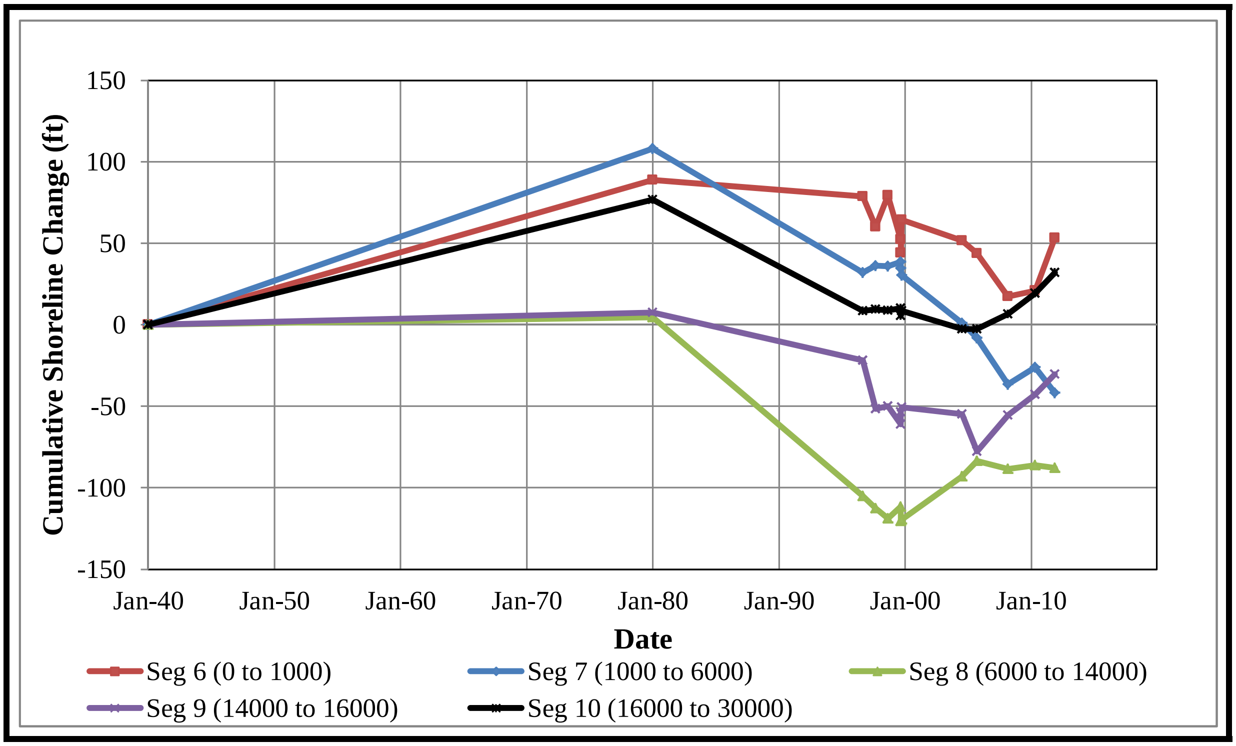

Figure 4. Cumulative Shoreline Changes North of the FRF (1940 to 2011)

North of the pier, the shorelines in Segments 8 and 9 were stable between 1940 and 1980 while Segments 6, 7, and 10 advanced approximately 75 to 100 ft. As a result of this advance, the shorelines in Segments 6, 7, and 10 were 80 to 160 feet seaward of the adjacent segments, forming a bulge or seaward protuberance of the shoreline in these areas.

Multiple segments north of the pier experienced considerable and consistent recession between 1980 and 1999. Of these, Segment 8 experienced the greatest shoreline recession of approximately -126 feet. Between 1999 and 2011, only Segment 7 continued the recession trend resulting in a total recession approaching -150 ft. in this segment for the 1980 to 2011 time period. This erosion trend in Segment 7 over the 1980 to 2011 time period was preceded by a period of accretion between 1940 and 1980 during which time the shoreline within Segment 7 advanced seaward an average of 100 feet. As a result, the shoreline within Segment 7 developed a seaward protrusion relative to Segment 6 to the south and Segment 8 to the north. The natural reaction to the development of such a shoreline protuberance is for wave energy to be focused on these areas resulting in higher rates of sediment transport out of the area until some equilibrium shoreline orientation is realized. This may be an explanation of why the shoreline in Segment 7 continued to recede after 1999 while the other segments north of the pier experienced some degree of accretion.

The shoreline change plot, shown in Figure 4, does show a potential influence from a 1992 to 1993 dune restoration project in Segment 8. The project was conducted by local property owners in the Sanderling Property Owner's Association. Project construction entailed placement of an estimated 30,000 cy for a 20 ft. wide by 20 ft. tall berm over 2,400 ft. of shoreline. The fill limits extended from approximately Blue Heron Lane (Transect 345) to Martin Lane (Transect 369) (Garman, 2012). Influence from the restoration is visible in Figure 4 by the reversal of shoreline change trends just after the project circa 1996. The reversal continued for approximately 5 years with an average advance of approximately +25 ft. The trend stabilized around 2005 and appears to have remained relatively stable with slight recession through 2011.

Short-Term and Long-Term Trend Comparison

The long-term shoreline change trends dating back to 1940 generally agree with the results of the short-term shoreline analysis previously discussed that focused on the period between 1996 and 2011. Most of the segments south of the pier experience either a relatively stable or seaward advance in the short-term and long-term trends. The short-term analysis shows shoreline advance for Segments 1 and 3 while the the long-term trends show relative stability dating back to 1940. Segement 2 is considered relatively stable with an average recession of -6 ft since 1996. The long-term trends also show Segment 2 as relatively stable when comparing the 1940 and 2011 positions.

Segments 4 and 5 both show changes in trends depending on the time range being analyzed. Segment 4 experienced retreat between 1996 and 2011 at an average rate of approximatley -1 ft/yr. The long-term trends show this segment has advanced seaward approximately +25 ft since 1940. Segment 5 exhibits shoreline advance between 1996 and 2011 and over the long-term since 1940. However, a general landward recession has occured since approximatley 2005. These mixed results suggest future monitoring should be a priority for both Segments 4 and 5 to document and identify future shoreline change.

Segments 6 and 8, north of the FRF pier, also show varying trends when comparing short-term and long-term shoreline change. The short-term analysis determined Segment 6 was receding; whereas, the long-term trends show the 2011 position of Segment 6 to be approximately 50 ft. seaward of the 1940 position. Allthough recession was the trend between 1996 and 2011, Segment 6 has experienced shoreline advance since approximately 2005 as shown in Figure 4. Segment 8 advanced between 1996 and 2011; however, the long-term trends suggest the 2011 Segment 8 shoreline is on average approximately 80 ft landward of the 1940 shoreline. A trend of seaward advance characterized this segment between approximately 1998 and 2005; however, since 2005 the shoreline has remained fairly stable with minimal change.

Short-term and long-term trends are similar along Segments 7, 9, and 10. Segment 7 was calculated to have an average recession rate of approximately -4.8 ft/yr since 1996. The long-term trend shows the segment has receded approximately -150 ft over an almost 30 year period (1980 – 2011). The short-term analysis shows Segment 9 has receded at a rate of -0.5 ft/yr since 1996. The long-term trends agree with this by showing a recession of approximately -35 ft over a 70 yr period (1940 – 2011). Results for Segment 10 are also consistent as both the short-term and long-term trends show a slight trend of shoreline advance.

POTENTIAL CONTRIBUTING FACTORS TO SHORELINE CHANGE

Although the process for measuring shoreline change is straight forward, determining factors that may contribute to trend reversals proves a far greater challenge. Factors that may be contributing are discussed below, including construction of the FRF pier, migrating sand waves, oblique sandbars, and differing wave patterns.

FRF Pier Construction

Shoreline change data discussed previously and highlighted in Figures 3 and 4 indicate a stark reversal in trends north and south of the FRF pier. The reversal occurred circa 1980 shortly after the 1977 pier construction (FRF, 2012). However, it is not clear exactly when the reversal took place because only two data points exist between 1940 and 1980. If the reversal did coincide with the construction of the FRF pier, it is reasonable to hypothesize the pier created a sediment transport blockage. Subsequently, an EVEN-ODD analysis is presented in Appendix C to investigate the influence that the pier has on longshore transport.

The EVEN–ODD analysis shows the pier structure does create a longshore transport barrier. However, the impacted shoreline does not extend beyond the FRF property. The analysis shows the impacts may reach from 400 to 1,000 feet. However, the FRF property limits reach approximately 1,700 ft. south and 1,600 ft. north of the pier. The impact limits interpolated through the analysis are not suggested to be finite but should provide a reasonable boundary estimate.

The analysis also suggests sediment transport in the cross-shore direction is altered by the pier. Graphical representation of the EVEN function, which generally shows the cross-shore shoreline change rate, advocates shoreline close to the pier is sheltered by the structure. This reduces the wave impacts around the pier and aids in decreasing erosion. Alleviating the erosion stress is considered a benefit; however, the benefit is considered minor and is not valid for all analyses time frames.

Migrating Sand Waves

Figure 5 shows the shoreline change rates along the study area for the periods of 1940 – 1980, 1980 – 1996, and 1996 – 2011. The cyclic nature of the shoreline changes shown in Figure 5 could be an indication of the alongshore movement of sand waves. Sand waves are perturbations in the shoreline that tend to migrate in response to wave action. As the "crest" of a sand wave passes by a particular section of the shoreline, that section will accrete while the "trough" of the wave will cause an adjacent shoreline to erode. Over time, as the sand wave migrates, adjacent shorelines could respond in an opposite manner as the crest and trough each migrate through the area.

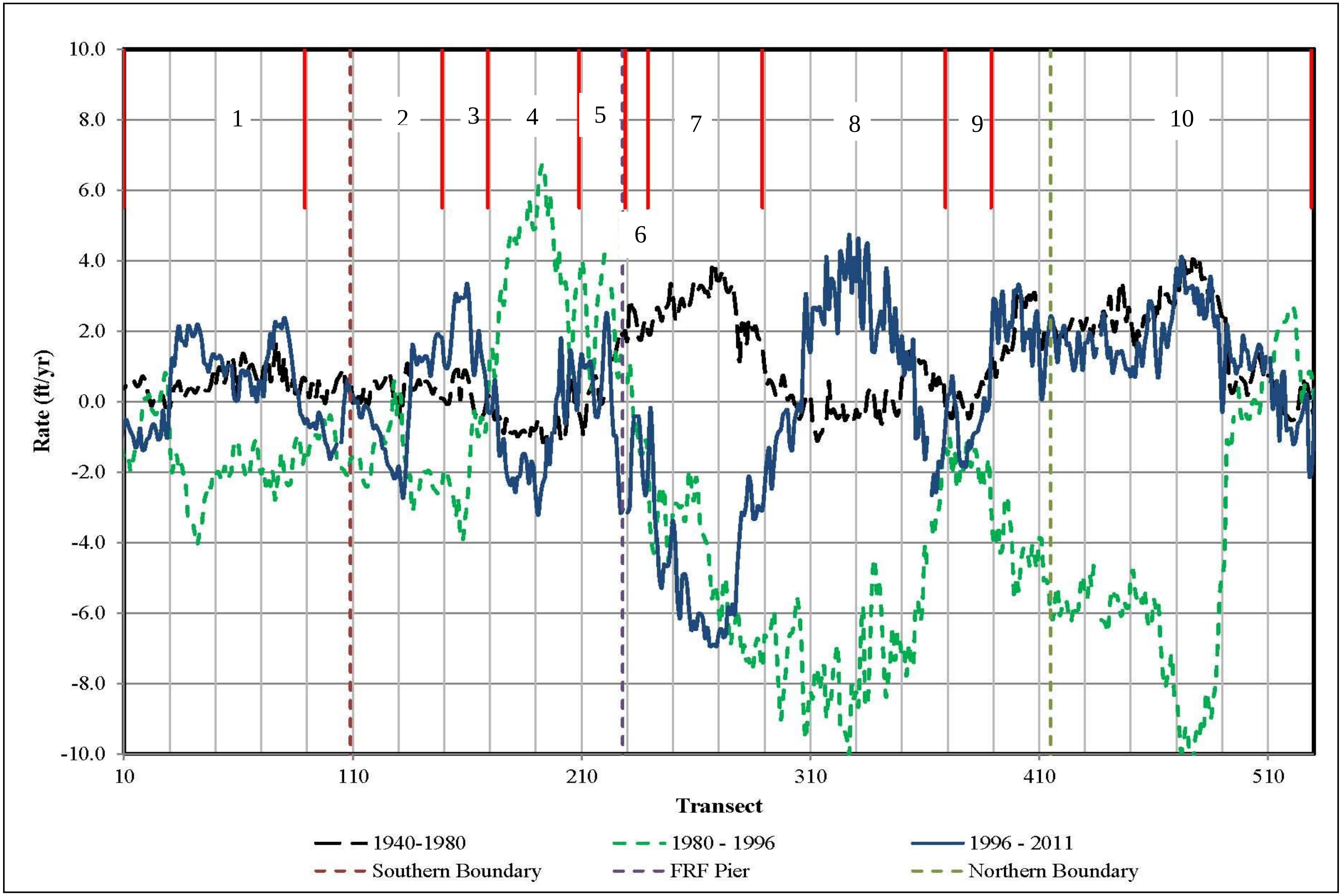

Figure 5. Town of Duck Shoreline Change Rates for 1940 -2011. Negative rates indicates recession (landward movement), positive rates represents accretion (seaward movement). Numbers at top designate shoreline segments.

Based on the 1940 and 1980 shoreline data set (Figure 5), the shoreline south of the FRF pier appears to have been relatively stable. However, the shoreline north of the pier exhibited a sinusoidal pattern of accretion and erosion. During the subsequent period (1980 to 1996), Segments 4 and 5 located immediately south of the FRF pier, accreted. During the same period Segments 6, 7, and 8 north of the pier exhibited consistent erosion. Farther north in Segment 9, erosion occurred at a rate less than the adjacent southern segments. This may have been an artifact of a small scale beach fill project, but comparative rates excluding the fill were not available. Segment 10 also experienced erosion comparable to the shoreline extending from Segment 7. Again, this alternating response would seem to imply the presence of sand waves.

During the 1996 to 2011 time period, Segments 8 to 10 experienced shoreline advance (seaward movement) on average. Along some transects the shoreline advanced seaward beyond the 1980 position. However, a more significant observation was the failure of Segments 6 and 7 to rebound. If sand waves were responsible for the advance along Segments 8 to 10, the sand wave has not moved into Segment 7. As a result, Segment 7 saw sustained shoreline retreat since at least 1980. The persistence of erosion over the last 30+ years strongly suggests management strategies need to be developed for this segment.

Oblique Sandbars

Over the past 30 years a vast amount of research has been undertaken to establish the theory that underlying geologic framework plays a major role in shoreline behavior (Demarest and Leatherman, 1985; Riggs et al., 1995; Gayes, 1998; and McNinch, 2004). More recent work by Browder and McNinch (2006) describes spatial correlation between paleo-channels and nearshore morphology along the Outer Banks of North Carolina and Southeastern Virginia. Specifically, the existence of shore-oblique sand bars and outcropping gravel patches have been correlated to underlying paleo-deposits. Other studies have linked the presence of shore-oblique sand bars and outcropping gravel patches to hot spots (McNinch, 2004).

McNinch and Browder’s 2006 study did not specifically identify shore-oblique sand bars off the coast of Duck, North Carolina. However, observations by FRF staff have confirmed the occasional presence of such features (Pers. Comm. McNinch 2012). FRF staff have also indicated that geophysical surveys conducted offshore of the Town of Duck, have identified what are interpreted to be paleo-channels; however, these data have not been published to date.

Wave Impacts

Wave statistics for corresponding time frames between the various survey dates included in the analysis were investigated to determine if differences in wave patterns influenced shoreline changes. The statistical analysis is provided in Appendix D. The sediment transport direction and potential created by incoming waves was also evaluated for trend deviations.

Wave Characteristics

Results from the wave statistical analysis produced a distinct predominance of net sediment transport to the north. This differs from the results of similar studies carried out by the USACE for the area between Kitty Hawk and Oregon Inlet (USACE, 2000). Whether or not this applies to the entire Duck shoreline is not known because wave data was only collected in the vicinity of the FRF pier.

Given the knowledge that predominant sand transport in the Virginia Beach, VA area is to the north, Duck may lie in an area where the net transport changes from a net southerly component to a net northerly component. These areas of divergence are generally referred to as nodal zones. In order for the Town to have a more comprehensive understanding of the littoral processes affecting its shoreline, a detailed wave transformation analysis to determine how waves impact the entire length of its shoreline would be required. This information combined with estimates of volume changes in the various shoreline segments could be used to construct a sediment budget that would connect the performance of the shoreline in one segment to adjacent segments. Based on the shoreline erosion threat and storm damage vulnerability identified in this investigation, the Town should concentrate its present efforts on developing a shoreline management strategy that addresses the critical erosion hot spot in Segment 7 and the storm damage vulnerability in both Segments 7 and 8. An effective shoreline management strategy involving the placement of beach fill in these two segments can be developed without conducting the comprehensive littoral processes evaluation. As part of the overall shoreline management plan, the placement of beach fill in Segments 7 and 8 should be accompanied by a shoreline monitoring plan covering the Town's entire shoreline. The monitoring survey data would track the performance of the beach fill as well as document the behavior of adjacent shoreline segments. The documented behavior of the Town's entire shoreline would provide valuable information to help the Town formulate future shoreline management needs.

Trends in Transport Rates Between LiDAR Surveys

The analysis of the wave data also includes computations of relative sediment transport rates between the LiDAR survey dates. The focus of this portion of the study was to determine if there are any compelling differences in the wave and sediment transport conditions during the various time periods.

Identifying temporal trends in wave patterns can add to the understanding of difference in shoreline response. The results of this analysis are provided in Table 3. The data includes the relative rates of sediment transport between surveys normalized to annual quantities, i.e., cy/yr. The calculation applies the longshore energy flux as determined by the process discussed in detail in Appendix D to the wave conditions encountered between the LiDAR survey dates. An assumption of an approximate 1 million cubic yard average annual transport rate was made for the exclusive purpose of providing a baseline for which to compare changes in transport rates due to episodic wave conditions. As such, the calculated values are relative and should not be interpreted as absolute.

The primary difference in the relative sediment transport rates is an apparent increase in net transport to the north beginning around July 2004. This trend continued through the end of the analysis period (November 2011). For the previous time periods, which included a relatively stormy period from September 1996 to October 1999, net sediment transport to the north was reduced by a factor of 3.5. This seems to have some credence as most severe storms that impact the Duck area have waves approaching from the northern quadrants. The northern approach would create a southern sediment drift. Also, the higher northern net transport rates, which appeared to begin around 2004, have some correlation, albeit weak, with the measured shoreline accretion in the northernmost shoreline segments (Segments 8 to 10). These higher northern net transport rates generally occur after 2004. Since the analysis of the wave data is limited to a singular point near the FRF pier, relating measured shoreline changes over the 10-mile study area to wave conditions at that singular point is not possible.

Table 3. Relative longshore sediment transport rates between LiDAR survey dates.

Time Period	Transport to the south (cy/yr)[1]	Transport to the north (cy/yr)[1]	Gross Rate (cy/yr)[2]	Net Rate (cy/yr)[3]
Oct 96 to Sep 97	382,000	-467,000	849,000	-85,000
Sep 97 to Sep 98	483,000	-636,000	1,119,000	-153,000
Sep 98 to Oct 99	455,000	-618,000	1,073,000	-163,000
Oct 99 to Jul 04	352,000	-482,000	834,000	-130,000
Jul 04 to Oct 05	307,000	-866,000	1,173,000	-559,000
Oct 05 to Mar 08	342,000	-545,000	887,000	-203,000
Mar 08 to May 10	288,000	-806,000	1,094,000	-518,000
May 10 to Nov 11	192,000	-747,000	939,000	-555,000

(1) Positive values = transport to south, Negative values = transport to the north
(2) Gross rate = sum of absolute values of south and north transport.
(3) Net Rate = difference

Storm Impacts

Some of the shoreline recession observed between 1980 and 1999 may have been caused by tropical and extra tropical storms. This may be the case particularly for the tropical storms that impacted the area between July 1996 and October 1999. Named tropical storms during this period included Bertha (July 1996), Fran (September 1996), Josephine (October 1996), Bonnie and Earl (August 1998), Dennis and Floyd (September 1999), and Irene (October 1999). Hurricane Dennis, with a duration of about 6 days and maximum wave height measured by the FRF of 23.3 feet (7.1 meters), probably had the greatest impact on the shoreline.

With regard to storm activity, the FRF has compiled a list of tropical and extra tropical (nor'easters) storms that have impacted the facility since October 1980. The storms included in the list have maximum wave heights equal to or greater than 6.6 feet. Based on this storm compilation, the frequency and characteristics of storms from 1980 to 1996, 1996 to 1999, and 1999 to 2011 are evaluated with the results provided in Table 4.

Table 4. Storms with wave heights ≥ 2 meters measured at the FRF.

Time Period	Number of Storms	Years	Storms/Year	Ave. Wave Height(1) (ft.)	Ave. Storm Duration (hrs.)	Annual Average SIF(2)
Oct 80 – Sep 96	170	15.9	10.7	10.6	31.8	49,751
Sep 96 – Sep 99	45	3	15	10.4	38.8	97,026
Sep 99 – Nov 11	177	12.2	14.5	9.9	31.2	60,528
Oct 80 – Nov 11	392	31.1	12.6	10.2	32.3	58,527

(1) Average maximum wave height for all storms during the time period.
(2) Annual Average SIF = Total of = H^2 (ft.) x storm duration, defined as the Storm Intensity Factor, summed over the entire time period divided by the number of years in the period.

The annual average Storm Intensity Factor (SIF) included in Table 4 is defined as the maximum wave height measured during each storm squared (H_{max}^2) multiplied by the storm duration in hours. This factor, which includes both tropical and extra tropical storms, was summed for all storms during the respective time period. The value was then divided by the number of years in the respective period to arrive at an annual average SIF. The significance of the SIF is it includes a relative measure for wave energy and duration for each storm. The wave energy is represented by the maximum wave height squared. Both the wave energy and duration play an important role in defining how a particular event could impact the shoreline. Intuitively, the more wave energy the greater the potential for shoreline impacts. Also, a shoreline has a greater exposure to storm conditions, including higher wave energy, with longer storm duration. The duration could last over several flood tide events which may saturate the sand and make it more mobile.

In terms of storm intensity, the September 1996 to September 1999 timeframe produced the highest SIF values by approximately 50% of any other period. The October 1980 to September 1996 timeframe was relatively mild compared to 1996 - 1999. The 1980 - 1996 period registers a SIF value approximately one-half the value calculated for the 1996 - 1999 period, or roughly 50,000. The SIF value for September 1999 to November 2011 reduced a value of approximately 36,000 from the 1996 – 1999 value. The 1999 - 2011 value was calculated at roughly 61,000. The average value for the complete study period of 1980 to 2011 was calculated at approximately 59,000.

Recounting the long-term shoreline change shown in Figures 3 and 4, the period from September 1996 to September 1999 caused significant short-term recession in Segments 4, 6 and 9. Segment 2 showed a minor increase in recession but not to the scale of the other segments. As discussed above and shown in Table 4, the 1996 to 1999 timeframe reflects the greatest SIF factor for any period. However, Segments 1, 3, 5, 7, 8, and 10, showed a stabilizing or shoreline advancement to the increased storm activity. A definitive correlation between the SIF and shoreline response does not seem to exist based on the mixed response for the majority of segments.

Following the stormy period of September 1996 through September 1999, all segments except Segment 7 showed a trend of relative stability or slight shoreline advance between September 1999 and November 2011. Segment 7 on the other hand, continued to recede at a rate comparable to that prior of the 1996 – 1999 between 1999 and 2011. Given this variation in shoreline trends compared to changes in storm intensity, there does not appear to be a uniform correlation between them. Within the Town of Duck the shoreline appears to have independent reactions to the increased storm intensity from one segment to another.

The scope of this study did not endeavor to establish absolute influences on shoreline change but rather to provide insight into a number of different factors. Further development of any or all of the potential factors influencing shoreline change discussed herein would require a more rigorous analysis and still may not provide definitive conclusions.

ECONOMIC IMPACT ANALYSIS

An important item to consider in deciding how to proceed with any action is the financial cost of doing nothing. In the case of shoreline management, the cost of doing nothing includes loss of public and private property, loss of recreational beach, loss of environmental habitat, loss of tourism related jobs, etc. Extensive economic analyses are required to accurately estimate the cumulative cost of these factors. That type of analysis is beyond the scope of this study. However, determining the potential loss of property directly related to shoreline retreat is a straight forward calculation. This analysis only considers the financial 'loss' associated with loss of land and upland structures.

Methodology

The analysis applies shoreline change rates calculated as part of this feasibility study to forecast future dune locations. The shoreline change rates developed for the period between 1996 and 2011 were applied to the seaward dune toe position to project future migration. The dune toe is the horizontal location where the dune connects with the sandy beach or berm. For this analysis, the dune toe is specifically defined by the 13.12 ft. contour referenced to NAVD88.

The position of the dune toe was chosen as a better indicator of when a structure could be lost. The translation of recession rates from MHW to the dune toe is justified given the similar migration patterns between the two features. Figure 6 shows a comparison of rates between the dune toe and MHW. The rates are consistent during periods of MHW recession. During periods of accretion the consistency is not observed due to the slow process of dune recovery that relies on entrapment of wind-blown sand. This discontinuity is not considered a concern as this study concentrates on the average recession trends.

Predicted positions of the dune toe were superimposed across the study area to determine potential economic losses. Damages were assessed based on a parcels land and structure values. The land value was proportionately reduced based on the percentage of the parcel located seaward of the dune toe at a given point in time. In contrast, the entire value of any structure was considered "lost" when the forecasted dune toe intersects or moves landward of the structure's footprint. The land and structure values were based on the 2013 Dare County property appraiser values (Dare County, 2013). No attempt to correct the values for inflation has been made.

Figure 6. Comparison of Migration Rates between Dune Toe (+13.12 NAVD88) and MHW (+1.2 NAVD88) for Time Period 1996 - 2011

The information obtained from the Dare County Tax Office did not list separate values for multiple structures on individual parcels, but rather the improved value. In many cases, parcels had a primary structure such as a house, and also a pool, or separated garage. Some parcels also had a secondary dwelling. For this reason values were categorized as pools or buildings, where appropriate. The value of any pool was assumed at $50,000 and buildings encompassed the remaining amount. If multiple buildings were positioned on the same parcel the the total improved value was divided equally by the number of structures to determine an individual value for each structure.. The losses were then calculated based on the number of buildings or pools lost.

Damage may not occur the instant the dune toe comes into contact with any structures landward extent. However, the event establishes a basis for comparison at a timeframe when action should be in process to prevent any potential damage. Delays in action beyond this timeframe likely would not allow proper planning to implement mitigation measures to prevent damage.

To perform the analysis, the 1996 to 2011 migration rates listed in Table 2 were applied to the 2011 dune toe location. The 2011 dune toe origin was chosen because it is the last temporal location in the LiDAR data incorporated for this report. The future dune toe position was forecasted from 2011 out to 5, 10, 15, and 30 years.

A 1,000 ft. transition area was assumed between each of the ten (10) shoreline segments used in the analysis. The transitions were centered between adjoining segments to allow a smooth shift between migration rates. Appendix E shows the forecasted dune toe position for the analysis timeframes referenced above.

Results

Table 5 summarizes the potential damages along the study area if measured trends persist. Losses were summed according to shoreline segments as defined in Table 1. The total land and structure losses anticipated over the 30 year period are $43,715,292.

Table 5. Land and Structure Losses Based on Dune Migration Predictions (USD)

Segment Number	Time Period				Total
	2011-2016	2016-2021	2021-2026	2026-2041	
1	n/a	n/a	n/a	n/a	n/a
2	$191,025	$143,842	$150,124	$458,864	**$943,855**
3	$3,892	$0	$0	$0	**$3,892**
4	$368,626	$352,322	$353,500	$1,062,553	**$2,137,001**
5	n/a	n/a	n/a	n/a	**n/a**
6	n/a	n/a	n/a	n/a	**n/a**
7	$3,148,671	$5,688,858	$15,501,796	$16,115,731	**$40,455,056**
8	$34,258	$15,159	$15,166	$45,287	**$109,870**
9	$26,410	$7,140	$7,514	$24,554	**$65,618**
10	$0	$0	$0	$0	**$0**
Total	**$3,772,882**	**$6,207,321**	**$16,028,100**	**$17,706,989**	**$43,715,292**

Note: Segment 1 and portions of Segment 2 & 10 are located outside the Town of Duck Territorial Limits. Losses associated with Segments 5 and 6 were exclusively property within the FRF property and therefore have not been considered.

Appendix F includes a table showing the damage value occurring within each shoreline segment separated into land and building values. The value of lost pools is also shown for reference. The quantity for each category of parcels, buildings, or pools lost or damaged during the respective time period is also shown.

Segments 2, 4, 6, and 9 experience overall recession trends. However, due to the present location of the shoreline in these segments relative to the position of upland structures and the minor rate of recession, measures to mitigate future losses due to shoreline recession rates only are not considered a priority in these segments.

The majority of predicted losses due to continuation of long-term erosion occur in Segment 7, which extends from approximately the north FRF property line pier to Dianne Street. These losses represent approximately 93% of the total erosion losses and are approximately nineteen (19) times greater than the erosion losses computed for Segment 4, which is the segment with the next largest predicted erosion loss. Segment 7 is also the only segment forecast to suffer losses of buildings or pools due to the continuation of long-term shoreline recessions prior to the year 2041. Approximately 7 pools are forecast to sustain damage prior to 2016. Houses within Segment 7 are not anticipated to be damaged until after 2016, but 7 are projected to be lost prior to 2021. Due to the level of projected damage in Segment 7 compared to the remaining segments, the highest priority should be placed on Segment 7 when determining erosion mitigation management alternatives.

Again, these predicted losses are based on the continuation of shoreline trends developed in the shoreline change analysis. The advent of episodic events such as tropical and extra-tropical storms could accelerate the timeframe when structures could be damaged or destroyed. In this regard, subsequent to the conclusion of this economic analysis, Hurricane Sandy impacted the area in October 2012. This storm took out 12 pools along Segment 7. A series of nor'easters that impacted the area throughout the winter of 2012/2013 inflicted additional shoreline erosion along portions of Segment 7 to the point that one (1) house has been condemned at the time this report was published. The loss of these structures prior to the time that was predicted by the economic impact analysis illustrates the significant influence that episodic events can have on structures and property. The vulnerability of structures to storm damage is discussed in the following section.

STORM DAMAGE VULNERABILITY

An assessment of storm damage vulnerability was conducted to determine the number of structures along the Town of Duck shoreline that are vulnerable to different storms. The assessment entailed the modeling of specific return interval storm events to identify the number of structures likely to be impacted with each event. Damage results were determined through the Storm Induced Beach Change Model (SBEACH) for the 1, 5, 10, 20, 25 and 50-year return interval storms. The analysis also evaluated potential beach fill designs that would mitigate modeled storm shoreline recession levels. A summary of this analysis is provided herein; whereas the full analysis is included in Appendix G.

Methodology

Return interval events were determined by ranking historical storm parameters such as wave height, water levels, wave period, and wind speed. Each event occurrence probability was determined based on the sample data. Table 6 lists the statistical parameters used to define the return period events. For comparison, Table 7 shows measured storm parameters for several historic storms that have impacted the region.

Table 6. Statistical Parameters defining the Return Period for Various Storm Events.

Return Period (years)	Storm Stage[1] (ft, NAVD)	Wind Speed[2] (mph)	Wind Speed[2] (m/s)	Peak Wave Period, Tp[3] (sec)	Significant Wave Height, Hs[3] (ft)	Significant Wave Height, Hs[3] (m)
1	4.0	50.2	22.4	9.9	17.6	5.4
5	4.2	53.9	24.1	12.9	21.2	6.5
10	4.8	64.0	28.6	14.2	22.7	6.9
20	5.7	78.5	35.1	15.5	24.3	7.4
25	5.8	81.0	36.2	16.0	24.8	7.6
50	6.2	91.0	40.7	17.3	26.3	8.0

[1]FEMA, 2006

[2]USACE Technical Note I-36, 12/85

[3]WIS Station 63219 from 1980-1999 (36.167°N, 75.500°W, Water Depth: 75')

Table 7. Measured Storm Parameters for Historical Storms in the Region.

Storm	Date	Measured Data H_S (ft.)	Measured Data T_p (s)	Measured Data Water Level (ft. NAVD)	Approximate Return Period (years) H_S	Approximate Return Period (years) T_p	Approximate Return Period (years) Water Level
Perfect Storm	Oct-91	15.1	22.5	4	< 1	> 50	1
Hurricane Isabel	3-Sep	27.3	15.6	5.6	>50	20	10 to 20
Hurricane Irene	11-Aug	24.8	13.6	3	25	5 to 10	< 1
Hurricane Sandy	12-Oct	17.3	13.3	4.5	~ 1	5 to 10	5 to 10

The SBEACH model was used to estimate the level of recession that may be anticipated from each simulated storm event. Shoreline recession levels were recorded for each of the 10 segments established in the shoreline change analysis. The recession levels were based on the landward distance an impact of 1 vertical foot of profile lowering could be anticipated. A structure was considered to be damaged if the recession limits reached or exceeded any portion of the building footprint. The 1 foot profile change signals a reasonable threshold for estimating when structures would become vulnerable for wave damage, including undermining and/or inundation (USACE, 1985).

Nine (9) separate beach fill designs were developed and modeled using SBEACH to provide different levels of storm damage reduction based on the extent of storm damage anticipated in a given segment for a given storm. Table 8 lists the design features of each of the nine (9) designs. Ultimately only five (5) of the nine (9) designs were used to develop storm damage reduction projects to mitigate predicted storm damages. The five (5) designs used to develop storm damage reduction projects are 1, 5, 6, 7, and 9 (Table 8). Figures 7 and 8 show cross section views of the 5 designs used to formulate the storm damage reduction project discussed in the following section. Additional information on these designs is available in Appendix G.

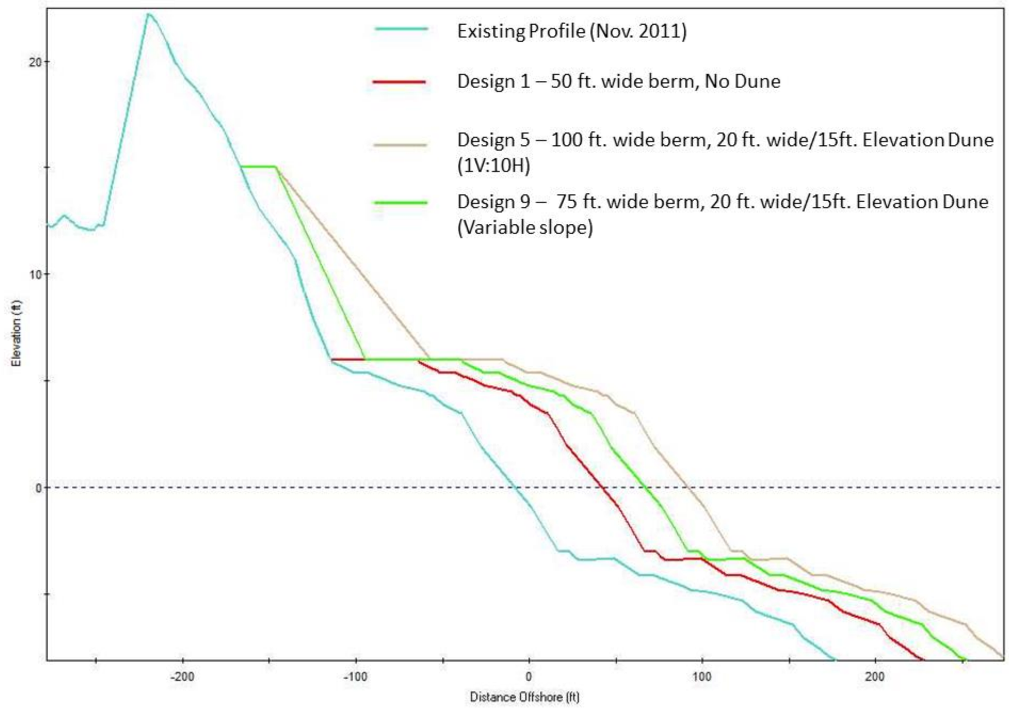

Figure 7. Design cross sections for Design 1, 5, and 9.

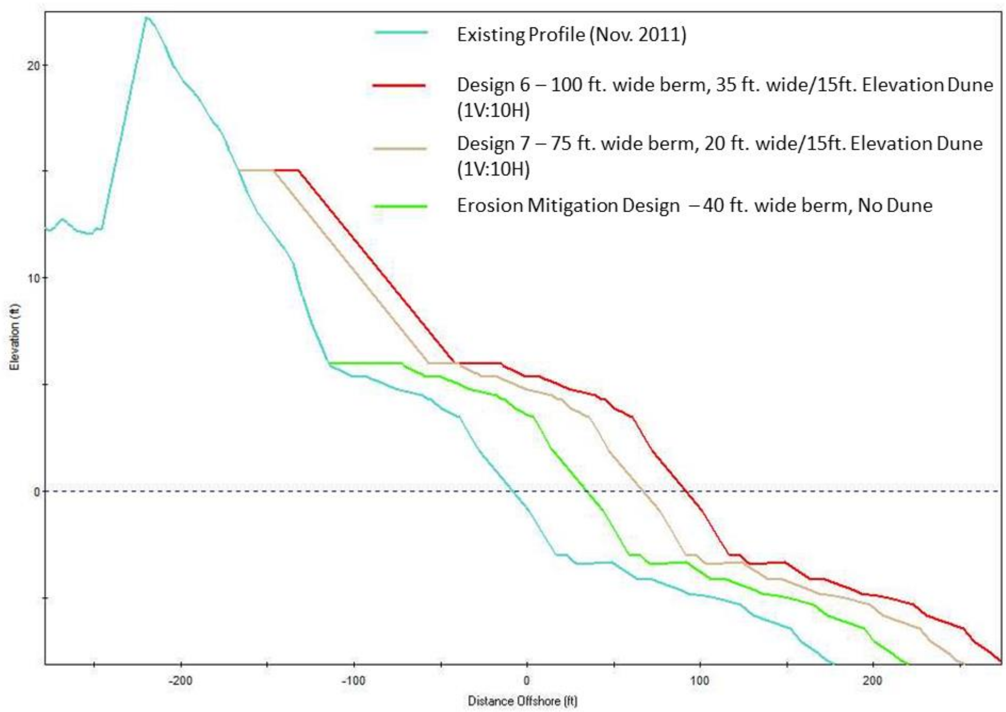

Figure 8. Design cross sections for Design 6, 7, and the Erosion Mitigation Project.

Table 8. Beach fill designs modeled with SBEACH

Design	Storm Dune Width[1] (ft)	Storm Dune Crest (ft, NAVD)	Storm Dune Side Slope	Berm Width[2] (ft)	Berm Crest (ft, NAVD)	Depth of Closure (ft, NAVD)	Fill Density (CY/ft)
1	-	-	-	50	6	-24	55.6
2	-	-	-	100	6	-24	111.1
3	-	-	-	100	8	-24	118.5
4	-	-	-	100	12	-24	133.4
5	20	15	1V:10H	100	6	-24	124.3
6	35	15	1V:10H	100	6	-24	129.3
7	20	15	1V:10H	75	6	-24	96.5
8	20	15	Variable[3]	100	6	-24	120.8
9	20	15	Variable[3]	75	6	-24	93.0

[1]Width of the storm dune was measured as the horizontal distance from the crest to the intersection of the existing profiles at the +15.0 feet, NAVD contour.

[2]Width of the berm was measured as the horizontal distance from the crest to the intersection of the existing profiles at the +6.0 feet, NAVD contour.

[3]The toe of the storm dune extended 20 feet seaward from the +6.0 feet, NAVD contour of the existing profile. Thus, the side slope of the dune was a function of the existing profile.

Results

The results of the storm damage vulnerability analysis were incorporated into the development of several storm damage reduction beach fill projects which are presented below in the Management Alternatives section.

Table 9. Structures Impacted during Storm Event Without Project

	Structures Impacted during Storm Event under Existing Conditions					
Segment	**1-Year**	**5-Year**	**10-Year**	**20-Year**	**25-Year**	**50-Year**
1	-	-	-	-	-	-
2	-	-	-	-	2	2
3	-	-	-	1	1	2
4	-	-	-	1	1	8
5	-	-	-	-	-	-
6	-	-	-	-	-	-
7	15	19	23	27	32	36
8	2	6	14	20	22	23
9	-	-	-	-	-	-
10	-	-	-	-	-	-

MANAGEMENT ALTERNATIVES

A number of potential shoreline management alternatives were developed to address erosion and storm damage vulnerability throughout the Town. The primary design considerations in developing these alternatives were mitigation of long-term erosion and providing storm damage reduction. The alternatives were developed by taking into account the physical setting of the Town, density of development, rates of shoreline change, storm damage vulnerability, and availability of sand to implement a shoreline management plan.

The alternatives described herein are those that are most likely to be successful under the given conditions as of November 2011. The alternatives described below include cost estimates for permitting and implementation. The analysis of predicted property losses previously described has been further developed to include demolition costs under a "No Action" alternative and structure relocation costs under a "Retreat" alternative.

The alternatives evaluated include:

- No action;
- Retreat;
- Beach restoration by truck haul;
- Dune restoration by truck haul;
- Erosion mitigation project by offshore dredging; and,
- Storm damage reduction projects by offshore dredging.

Although it may seem logical to make a direct cost comparison between those alternatives involving placement of sand and the losses reported for the "No Action" and "Retreat" alternatives, there are many other factors that play into weighing these options which are outside the scope of this study. Many of these factors are related to a decrease in tourism due to the reduction or elimination of a recreational beach. A decrease in tourism leads to loss of jobs, loss of revenue to individuals and companies that rent vacation homes, as well as loss of room accommodation tax revenues to the County and Town. Under a "No Action" or "Retreat" management plan, a decrease in property value should also be anticipated as houses are left standing out on the beach or removed from oceanfront lots. This can affect the reputation of the entire Town as an attractive tourist destination, which results in economic hardships to a much greater extent of property owners than just those situated on the oceanfront in high erosion areas.

Anticipated construction costs are based on estimates from work conducted in 2012. Property and structural values used to calculate potential losses are based on 2011 property assessments.

Diffusion Losses

Diffusion or spreading losses will occur with any sand placement activity as the nourished beach evolves into an equilibrium planform comparable to the adjacent shorelines (Dean, 2002). While beach fill projects normally include 500-foot to 1,000-foot transition or taper sections on each end of the fill area, waves acting on the fill will generally transport material away from the immediate placement and spread it to the adjacent shoreline areas.

Sediment losses from the beach fill placement area resulting from diffusion or spreading should be accounted for in the placement volume. Dean (2002) presents the following equations to provide estimates of diffusion losses:

$$y(x,t) = {}^{Y}\!/_{2}\left\{\mathrm{erf}\left[\frac{l}{4\sqrt{Gt}}\left({}^{2x}\!/_{l}+1\right)\right]-\mathrm{erf}\left[\frac{l}{4\sqrt{Gt}}\left({}^{2x}\!/_{l}-1\right)\right]\right\}$$

Where: y(x,t) = Shoreline width at distance x (from project center) and time (t) from initial construction.
Y = Initial shoreline width after construction
Erf = Error function
x = distance from project center
l = Project length
G = Longshore diffusivity

And : $$G=\frac{KH_b^{5/2}\sqrt{\frac{g}{k}}}{8(s-1)(1-p)(h_*+B)}$$

Where: K = Sediment transport coefficient
H_b= Breaking wave height
g = Gravity constant
k = Breaking coefficient
s = Sediment specific gravity
p = Sediment porosity
h_* = Depth of closure
B = Berm height

As spreading occurs along the constructed section of beach, adjacent shoreline segments will benefit. The term feeder beach has been used to describe the process of overfilling a relatively short section of beach in order to provide nourishment to adjacent beaches as spreading occurs. In order to illustrate this principle, the spreading formula was applied to a theoretical beach fill along Segment 7 that would push the shoreline out 100 ft. Figure 9 shows the theoretical planform evolution of this beach fill. The analysis suggests that the fill would spread both north and south out of the initial placement area and eventually spread over most of the Town of Duck shoreline. Based on this theoretical simulation, the shoreline 7,000 feet beyond the fill limits could advance approximately 10% of the constructed width in the placement area. In this instance, the spreading of the material would cover the shoreline from Duck Landing Lane at Transect 169 to Waxwing Lane at Transect 359.

The application of this relatively simple model demonstrates the potential positive impact of a fill outside the initial placement area. A more rigorous numerical model evaluation would be needed to further define the performance of a fill in Segment 7 and how it might potentially positively impact adjacent areas.

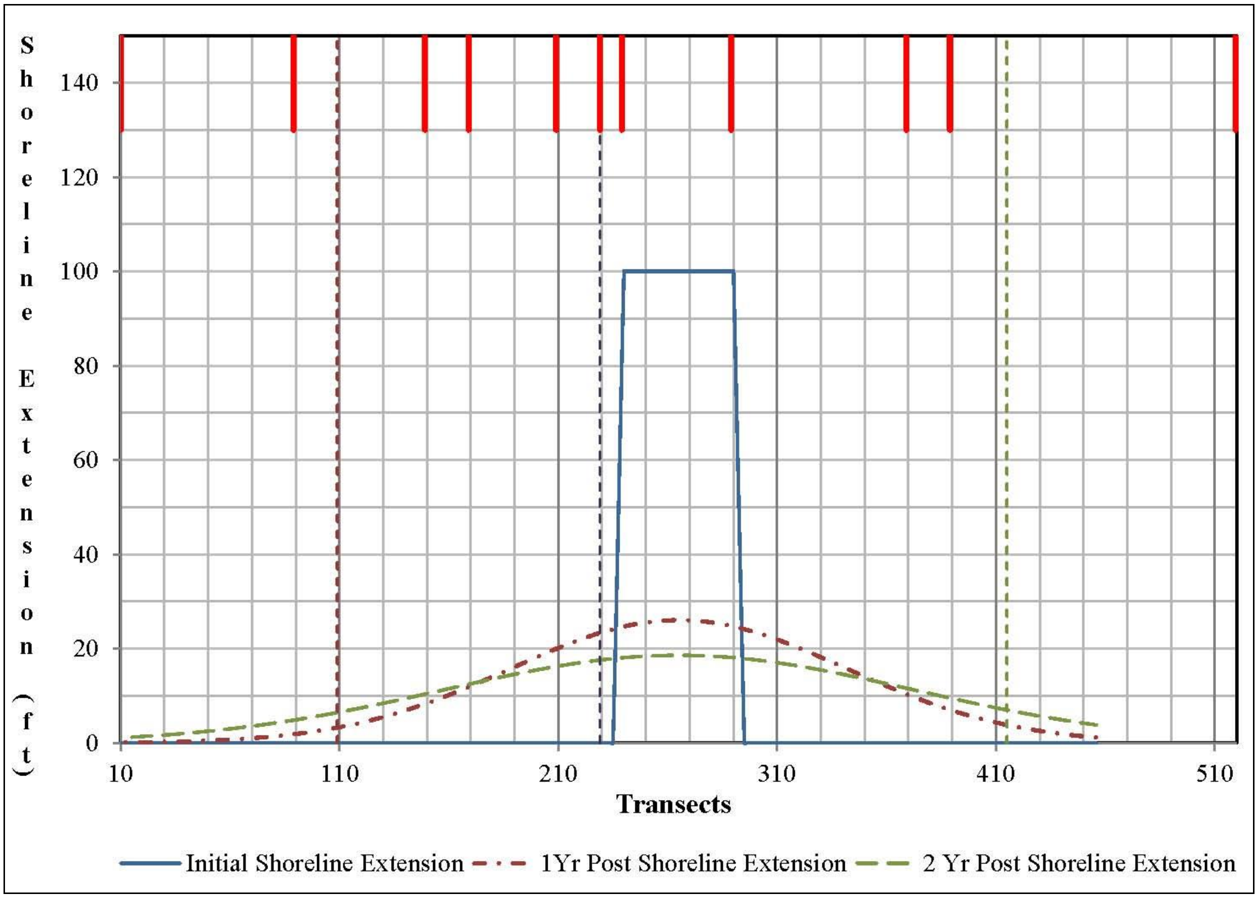

Figure 9. Example of Theoretical Shoreline Evolution due to Diffusion

No Action

In this report, several conceptual shoreline management alternatives have been described and cost estimates for each alternative have been developed. Inherently, there is cost associated with any management plan; however, shoreline managers must also consider the cost to a town if no action is taken to manage the shoreline. Management decisions should be based on an understanding of the economic consequences of an active management strategy (beach nourishment) versus a passive management approach (no action/retreat). Extensive economic analyses are required to accurately compare the cost of active and passive management. That type of analysis is beyond the scope of this study.

The economic impact section of this report does provide some insight into the level of land and structure damage to be anticipated based on a continuation of current erosion rates. These predicted estimates for land and structural losses are shown in Table 5 and represent the predicted damages assuming a continuation of long-term shoreline changes (refer back to Economic Impact Analysis section for Table 5).

As previously mentioned, private property damage is only part of the economic impact of no action. Factors such as rebuilding/redirecting public and private infrastructure, reduction in tourism, and a decrease in property values are also economic impacts associated with no action. The assessment of damages reflected in Table 5 does not include the cost to clean and remove any abandoned structure or legal fees brought about by lawsuits. Recently, the Town of North Topsail Beach spent over $2 million in legal fees, demolition, and removal of 6 duplexes that were condemned by the Town after erosion resulted in the houses standing landward of the Mean High Tide line (Pers. Com, Foster, 2012).

The average cost for demolition and disposal of impacted buildings is estimated at $25,000 per structure (Matyiko, 2012). There are an estimated 54 homes that may be impacted by 2041. This yields an estimated demolition cost of $1,350,000. All 54 houses are located in Segment 7.

Retreat

Another passive alternative to be considered is to relocate threatened structures. Homes critically threatened by erosion may be moved landward prior to sustaining erosion induced damages. The land or parcel damage estimated under the "No Action" option would be the same for the "Retreat" alternative. However, relocation of threatened structures would require the owner to purchase a new lot. The new parcel price was taken as the average value of approximately 265 vacant parcels located within the Town of Duck. The parcel values are determined by the Dare County property appraiser values (Dare County, 2013). The average value for the vacant parcels was calculated as $212,628. This cost is increased to $250,000 for estimating purposes to account for new foundations, heating and cooling appliances, septic or sewer hookups, and installation to other utilities such as water. Not all vacant lots are currently listed for sale; however, this method assumes that owners of the vacant properties would be willing to sell allowing the houses to be relocated.

The cost of relocating a structure to a new lot would include additive costs such as demolition of 1st floor utility rooms, capping or removal of existing septic systems, foundations, or pilings. The need to raise power lines for transport is also considered (Matyiko, 2012). There would also be some permitting cost involved in the move. Taking all of this into consideration, the cost to move a structure to a new lot would be $100,000.

Combining the purchase price for a new parcel and relocation cost for moving homes, the retreat option entails an approximate $350,000 cost per house. Based on the 2013 tax values obtained from Dare County, the average value of the 53 buildings within the Town of Duck expected to be impacted by current erosion trends prior to 2041 is estimated at $435,381. Pools impacted by erosion would be considered a total loss and their replacement cost at the new lot is not included in this estimate.

The expected cost for "Retreat" from the shoreline is provided in Table 10. All relocation cost would occur in Segment 7.

Table 10. Property Damage and Relocation Costs Based on Dune Migration (USD)

Segment Number	Time Period				Total
	2011-2016	2016-2021	2021-2026	2026-2041	
1	n/a	n/a	n/a	n/a	**n/a**
2	$191,025	$143,842	$150,124	$458,864	**$943,855**
3	$3,892	$0	$0	$0	**$3,892**
4	$368,626	$352,322	$353,500	$1,062,553	**$2,137,001**
5	n/a	n/a	n/a	n/a	**n/a**
6	n/a	n/a	n/a	n/a	**n/a**
7	$3,148,671	$5,730,058	$12,928,346	$14,373,881	**$36,180,956**
8	$34,258	$15,159	$15,166	$45,287	**$109,870**
9	$26,410	$7,140	$7,514	$24,554	**$65,618**
10	$0	$0	$0	$0	**$0**
Total	**$3,772,882**	**$6,248,521**	**$13,454,650**	**$15,965,139**	**$39,441,192**

Note: Segment 1 and portions of Segment 2 & 10 are located outside the Town of Duck Territorial Limits. Losses associated with Segments 5 and 6 were exclusively property within the FRF property and therefore have not been considered.

Dune Replenishment by Truck Haul

The first in a series of active conceptual alternatives involving placement of sand on the beach is dune restoration along vulnerable shoreline segments. A dune restoration project would minimize some of the permitting concerns while still providing some measure of erosion mitigation. Based solely on the shoreline change rates measured, an estimated volume of 30,000 cy of sand would be required to provide 1 year of erosion mitigation. These preliminary estimates would require verification through a more detailed assessment of current dune volumes and berm width seaward of the dune.

A benefit of a dune restoration is that diffusion losses would not occur as material is placed well above the MHW line. Thus, the volume intended to be placed in the dune would be a direct reflection of the necessary material to accomplish the intended task.

Limiting fill placement to the dune would not directly address shoreline erosion but would provide immediate short-term aid for threatened or soon to be threatened structures. As the shoreline erodes into the dune, the fill material would be displaced onto the beach and in so doing, provide an indirect source of beach nourishment material.

Permitting Requirements

Permitting requirements for a dune restoration would only require state authorization. Because this option involves the placement of material above MHW, the USACE does not have jurisdiction and therefore Department of Army permits would not be required. In addition, the state would not require a Division of Water Quality (DWQ) 401 certificate. However a CAMA Major Permit from the state's Division of Coastal Management (DCM) would be required since the project area would cover more than 60,000 square feet. The CAMA Major Permit application would be reviewed by DCM as well as ten (10) state agencies. This permit would be valid for 3 years; however, it could be reissued on an annual basis via a minor permit modification procedure.

Material to be used for dune restoration does not have to meet the same sediment criteria as material used for beach nourishment. A reasonable source of the material would be an established mine or sand pit. The mine operator should be able to provide a range of achievable grain size characteristics including color, mean grain size, and sorting.

Construction Constraints

A truck haul project would create disruptions to upland properties due to the number of tuck loads needed. A typical dump truck can carry an approximate load of 12 cubic yards. Trucks are available up to the 40 cubic yard size, however weight limits and access paths would need to be confirmed prior to planning for vehicles of this size.

Assuming a typical 12 cubic yard truck is employed, approximately 83 truckloads would be needed to deliver 1,000 cubic yards. For Segment 7, a total of 2,500 truckloads would be needed to deliver the design volume of 30,000 cubic yards. The truck haul operation could be limited to daytime hours thus eliminating the nighttime noise and the need for lighting in the placement area.

Consideration of the use of a conveyor system was considered to overcome issues with access to the beach. A conveyor system, similar to the one shown in Figure 10, can be beneficial in allowing material placement where access is restricted across private properties. Cost estimates obtained from a contractor with experience using such equipment ranged as high as $175,000 for one month rental and mobilization and demobilization from out of state (Eastman, 2012). Based on discussions with F&H Land Development, a contractor that has conducted several truck haul operations for individual oceanfront land owners in the Town of Duck, access issues along the project area are not sufficient to warrant the use of a conveyor system. Likewise, alternative ways of spreading material from stock pile locations (i.e. loaders and off road dump trucks) would be more economical than bringing in a conveyor system.

Figure 10. Photographs depicting conveyor system used to move sand through areas with limited access.

Ideally, all of the material placed in the dune should be located above an elevation of approximately 10 ft. NAVD in order to limit the day-to-day interaction of the placed fill with littoral processes, thereby avoiding spreading losses previously discussed. For some properties within segment 7 sufficient space may not exist between the existing structures and the 10 ft. NAVD elevation contour. This could preclude an equal distribution of the proposed 30,000 cubic yards along the proposed fill section.

Schedule

A dune restoration project could be completed in approximately 10 months. The permitting process would encompass approximately 6 to 8 months and construction would entail the additional time. The permitting process can be separated into tasks of completing the permit application and agency review. Approximately 2 months should be allocated to complete the application and up to an additional 6 months should be anticipated for review. DCM would be the lead in reviewing the submittal, but would disseminate the package to other state agencies. An initial 75-day window is provided for agency review however, the window may be doubled if warranted, at the sole discretion of DCM. The additional 1 month period is provided to address agency concerns through requests for additional information or other logistical issues.

The construction timeframe would be dependent on the level of noise and traffic impacts acceptable to the Town. Dump trucks carrying approximately 12 cubic yards could work on an eight (8) hour per day basis during the standard five (5) day work week. Under these conditions, a 30,000 cubic yard project could be completed in approximately 8 weeks with an average of 65 deliveries per day. A 2 month construction period is consistent with the winter time environmental window (Nov. 16 – March 31) expected with a state authorization.

Again, larger size trucks are also available and a cost comparison to identify the most efficient truck size and schedule could be conducted during the design phase to solidify the construction details.

Costs

Construction costs for a dune fill using truck haul were based on supplying 30,000 cubic yards to offset one year of anticipated erosion. The cost to truck haul 30,000 cubic yards of sand to Duck would be $750,000 based on a unit cost of $25/cubic yard. The design and permitting cost associated with obtaining the CAMA Major authorization are estimated at $65,000. This assumes all material will be placed above MHW and the sand source is an upland pit. The project would require preparation of plans and specifications as well as construction oversight, which are estimated at $124,000. Thus, the total cost for constructing a dune fill project in Segment 7 using trucks would total approximately $939,000.

Additional Considerations

Given the amount of erosion that has taken place along Segment 7 since the November 2011 survey, whether or not there is sufficient room between the Mean High Water (MHW) Line and the existing structures to construct even a minimal dune fill (1-year of erosion mitigation) is uncertain. The limiting factor is not a function of cost or logistics to deliver more sand but rather whether or not there is enough room to place the material and have some level of assurance that it would not immediately wash away. Based on information provided to us by the Town regarding some of the individual fill projects that property owners have constructed over the past year, fill densities for these individual projects appear to be on the order of 3 cubic yards/linear foot of property. This is approximately half the density proposed in the 1-year erosion mitigation dune fill project (6 cubic yards/linear foot). Given the minimal protection provided by the stop gap projects constructed by individual homeowners over the past year, and the uncertainty that sufficient area exists between the 10 ft. NAVD88 contour and the structures to construct a dune fill project, the effectiveness of any dune fill project that could be constructed is uncertain.

Beach Restoration by Truck Haul

An alternative to conducting a dune restoration would be a small scale beach restoration using truck haul. Material could be placed along the active beach system beginning at the toe of the dune and extending seaward including below MHW. Conducting the project by means of a truck haul makes smaller scale jobs more economic when compared to mobilizing a dredge. Permitting requirements would increase compared to a dune restoration but may remain below that required for a larger scale dredge and fill project.

As previously discussed, diffusion losses must be considered when placing material within the active littoral zone that extends landward to berm crest. The diffusion equations were applied to a beach fill project covering the 5,000 feet of shoreline in Segment 7 that would spread 30,000 cubic yards along the shoreline to provide 1-year of erosion mitigation. This resulted in a required 43,000 cubic yards of fill to be placed to account for both 1 year of erosion mitigation and diffusion.

Permitting Requirements

Placement of the truck haul material from the toe of the dune to below MHW would require a federal permit from the Department of the Army (USACE). Discussions with USACE's Wilmington District Regulatory Division indicate that this option would likely be permitted via the issuance of a Department of Army Individual Permit (IP) or the issuance of a Department of Army General Permit (GP) 291. Unlike IPs, which entails extensive formal review, the use of GP 291 transfers the majority of review responsibilities to the state. Under this arrangement, USACE coordinates federal agency review of the project and conducts a cursory review itself. As is the case for other general permits, USACE retains the discretionary authority to conduct a separate federal review and require an IP if deemed necessary. If the federal agency review is favorable and USACE does not require an IP, substantive review would be conducted by the state's Division of Coastal Management (DCM). Federal authorization via the GP 291would follow after the CAMA permit has been issued.

The determination of whether an IP or GP would suffice is a decision made by USACE following analysis of the project description and consultation with relevant federal agencies. Should USACE determine the project has a potential to elicit impacts outside the purview/jurisdiction of the DCM or it may establish a precedent to a controversial issue, USACE would most likely process the project as an IP. However, if the USACE receives feedback from federal agencies suggesting impacts would be minimal and no controversial issues are identified, USACE may determine the permitting could proceed via the GP 291. In order to expedite the determination on the appropriate permitting process, an interagency meeting including representatives from state and federal agencies would convene. State approvals would include the issuance of a Major CAMA permit.

Construction Constraints

A beach restoration by truck haul would carry the same constraints as a dune restoration in regards to increased traffic and noise. Added constraints would include an increase in heavy equipment activity on the beach as material is positioned seaward of the toe of the dune. The additional equipment may entail trucks, loaders, bulldozers, excavators and/or additional conveyor systems on the beach. The bulldozers would push material deposited by a truck, loader, or conveyor system to form a design beach. This added constraint is not considered major as the same action, perhaps to a lesser degree, is required for each sand placement alternative.

Additional traffic would also be required on the roadways although the impacts are considered very similar to a dune restoration project. To provide adequate material sufficient to maintain 1 year worth of erosion mitigation a volume of 43,000 cubic yards is needed. Using the model of approximately 83 truckloads required for every 1,000 cubic yards delivered, a total of 3,583 loads would be required. As with a dune restoration, project completion could be controlled through the use of multiple trucks and multiple offloading sites.

Schedule

The permitting path would be determined by the USACE which could extend from 8 – 36 months. The main variable affecting the schedule is the unknown federal environmental documentation that may be required. Options include a Biological Assessment (BA), an Environmental Assessment (EA), or an Environmental Impact Statement (EIS). The difference in the document entails the level of detail required to quantify existing habitats and any potential impact. Other federal documents would also be required such as an Essential Fish Habitat (EFH) and Cumulative Effects Assessment (CEA). However, the formulation of these documents is included in the given schedule.

Again, the construction timeframe would be dependent on the level of noise and traffic impacts acceptable to the Town. Dump trucks carrying approximately 12 cubic yards could work on an eight (8) hour per day basis during a five (5) day work week. Under these conditions, a 43,000 cubic yard project could be completed in approximately 11 weeks with an average of 65 deliveries per day. This construction period is consistent with the winter time environmental window (Nov. 16 – March 31) expected with the state and federal authorizations.

Costs

Pending the permitting route determined by USACE, permitting costs are anticipated to be approximately $250,000. Based on past experience, the permitting process will likely require an IP with an Environmental Assessment (EA). However, if there are any controversial aspects of the project or if an EIS is mandated, permitting costs could rise significantly. USACE will not make a determination on the required permitting path without additional project details and consultation with other federal agencies. Engineering design, which would include surveys of the placement area, is estimated at $100,000. In addition to environmental documentation and engineering design, a geotechnical investigation would be required to satisfy the Technical Standards for Beach Fill Projects (15A NCAC 07H.0312). These efforts could range between $150,000 and $250,000. The project would require preparation of plans and specifications as well as construction oversight, which are estimated at $171,000.

Construction costs for a beach fill using truck haul were based on supplying 43,000 cubic yards to offset one year of anticipated erosion and account for diffusion losses. Construction costs would be dependent on any restrictions limiting the quantity of trucks allowed per day. These limitations would have a direct impact on the time required to secure equipment and man-hours necessary to complete the project. Trucking cost should remain constant regardless of any scheduling constraints assuming trucks on the project could be expected to work at least 8 hours per day. The construction costs assume a rate of $25 per cubic yard. Therefore, the estimated cost to truck haul 43,000 cubic yards to Duck would be $1,075,000.

Thus, the total cost for design, permitting, and construction of a beach fill project in Segment 7 using trucks could range between $1,746,000 and $1,846,000, depending on the permitting process.

Additional Considerations

Ideally, extending the berm seaward along Segment 7 would provide both erosion mitigation and at the same time provide a wider base upon which a dune could be constructed that could provide additional short term protection. Without conducting a more thorough examination of the existing conditions, it is difficult to determine how far out the beach would need to be extended to provide an adequate base for dune construction. The truck haul beach fill project was based on providing approximately 30,000 cy of sacrificial fill. This amount of fill spread over 5,000 ft. would result in the beach being pushed out approximately 4.8 feet. Predicted diffusion losses expected along this relatively short section of shoreline (5,000) suggests that approximately 43,000 cubic yards of fill would need to be placed along this area to account for both normal erosion rates and diffusion. As the beach fill width becomes wider, the diffusion losses increase exponentially. Table 11 shows the volumes required to construct incrementally larger beach fill projects that would provide enough fill to account for historic annual erosion rates and diffusion along Segment 7. Options have also been included that would extend the berm seaward and provide dune fill.

Table 11. Volume and Cost Estimates for Incrementally Larger Beach Fill Projects by Truck Haul.

Years of Erosion Mitigation	Beach Fill Width (Ft.)	Volume (Cubic Yards)	Number of Trucks (12 cubic yards)	Cost Estimates
1-Year	4.8	43,000	3,583	$1,796,000
1-Year + 1-Year worth of Dune Fill	4.8	73,000	6,083	$2,546,000
2-Year	9.6	100,000	8,333	$3,221,000
2-Year + 1-Year worth of Dune Fill	9.6	130,000	10,833	$3,971,000
3-Year	14.4	171,000	14,250	$4,996,000
3-Year + 1-Year worth of Dune Fill	14.4	201,000	16,750	$5,746,000

Costs assume $25 per cubic yard and $721,000 in soft costs, which is the average of the two ranges provided.

Depending on which of the projects listed in Table 11 would be constructed, anywhere from 3,583 to 16,750 truckloads could be required to transport fill assuming 12 cubic yard trucks. Using the estimate of 65 deliveries per day, even if construction occurred 7 days a week with no shut downs for weather, an upper limit of approximately 105,300 cubic yards could be transported within the November 16th – March 31st environmental window. Given issues with access to the beach, this schedule may be overly optimistic as there could be additional bottlenecks with spreading the material once it is delivered. Consultation with agencies may result in an extension to construct the project; however, at some point construction may interfere with tourist season. Depending on actual production rates there may also be concern with being able to keep up with erosion and diffusion losses.

The wear and tear on both main roads and residential roads from this volume of loaded dump trucks is significant. A transportation expert should be consulted to determine what limitations may exist with regards to the impacts on existing infrastructure. This wear and tear coupled with disruptions and added traffic for a long period of time are things that should be considered when assessing the feasibility of projects of this size. Considering all these factors, the confidence in such a project constructed over a long period of time to be able to provide the level of erosion mitigation that it is being designed for is less than ideal.

Erosion Mitigation Project by Offshore Dredging

While truck haul is a reasonable option for small scale projects, construction of a large beach nourishment project that could provide multiple years of erosion protection would involve identifying a suitable offshore borrow source and mobilization of high production ocean going dredges to deliver the material to the beach.

The erosion mitigation project using offshore sand would be constructed along the length of both Segments 7 and 8. The shoreline change analysis for the 1996 to 2011 time period would seem to suggest Segment 7 is the only segment in need of protection. However, Segment 8 experienced the largest recession rate of any of the segments north of the pier between 1980 and 1999. Likewise, the storm damage vulnerability analysis conducted using the SBEACH storm erosion model found both Segments 7 and 8 had high potentials for significant damage due to storm related shoreline erosion. Therefore, an erosion mitigation project using offshore sand resources should be provided along both Segments 7 and 8. Ironically, the volume of material needed to protect both segments would be approximately the same as protecting Segment 7 alone. This is due to the relatively short length and high rate of shoreline recession in Segment 7 which would be conducive to large spreading losses if the project was limited to that segment. By distributing the fill over the longer shoreline reach, spreading losses would be greatly reduced. Also, some of the material that would be moved out of Segment 8 would migrate into Segment 7 further enhancing the performance of the fill in that area.

The combined shoreline length for Segments 7 and 8 is 13,000 ft. A 1,000 ft. long taper would be added to either side to help reduce spreading losses. Initial construction of a project that would provide 5 years of erosion mitigation along the lengths of both Segments 7 and 8 would require the placement of approximately 842,000 cubic yards of sand. Unlike the small-scale truck haul projects where only the volume of sand needed to counter erosion and diffusion losses would be placed on the beach, this alternative seeks to re-establish a beach berm. The initial construction includes a 40 ft. wide berm plus placement of enough advanced fill to account for 5 years of erosion as well as diffusion losses while theoretically still maintaining the 40-foot design berm width. Figure 8 shows a cross section view of the 40 ft. wide design berm (refer back to Storm Damage Vulnerability section for Figure 8).

Permitting Requirements

Permit requirements are similar to those discussed previously for the beach restoration by truck haul project. The USACE will have discretion as to what type of decision document to prepare

(EA or EIS) to assist in making a permit decision. More stringent environmental requirements may apply due to the project scale.

Identification of an offshore borrow site would also entail additional effort. There are some existing data describing potential offshore sites. However, the sites would need additional investigations to ascertain their volume and compliance with state sediment criteria. Depending on whether the sand source is in state (within 3 miles of the shore) or federal waters (beyond 3 miles from shore), it may be necessary to obtain permits from the Bureau of Ocean Energy Management (BOEM). The BOEM has jurisdiction over mining operations in federal waters.

Submarine Sand Sources

A summary of a literature review conducted to identify potential offshore sediment sources for the Town of Duck is provided below.

The USACE conducted extensive sand source investigations offshore Dare County as part of the Dare County Storm Damage Reduction Project (USACE, 2000). The project includes two separate beach fill projects along portions of the Towns of Kitty Hawk and Kill Devil Hills (North Dare Project) and the Town of Nags Head (South Dare Project). The USACE identified sufficient quantities of sand for the 50 year life cycle of both projects. One borrow area referred to as N1 is identified offshore of Kitty Hawk and several other borrow areas are identified offshore of Nags Head (Figure 11). The largest of the southern borrow areas is referred to as S1 and is assumed to contain upwards of 100 million cubic yards of material. The Town of Nags Head used a portion of S1 for a non-federal project in 2011. This source has proven to be of high quality. USACE data suggests that the material contained within the N1 borrow area is generally finer and with higher silt content.

In 2001, Boss and Hoffman prepared a report that described their investigations to identify sand resources offshore Dare County between Oregon Inlet and the Town of Duck. This study was commissioned by the U.S. Minerals Management Service (currently known as BOEM). The study is in response to a perceived increase in the demand for offshore sand located beyond State Waters. This study is the most comprehensive investigation conducted in the vicinity of Duck, North Carolina. Figure 12 shows the extent of the study area investigated. A number of vibracores collected directly offshore of the FRF suggests sediment located in this vicinity has a high concentration of fine grained sand. This may preclude the use of this material for beach nourishment. However, only composite data for each individual vibracore (3 – 5 meters) is provided, and hence there may be portions of the core that indicate beach compatible material. The study identifies four target areas with potential for sand resources. These four sites, which may contain up to 77 million cubic yards, are located outside State Waters (beyond the 3-mile limit). The sites are located generally offshore of the Town of Kill Devil Hills and the Town of Nags Head (Figure 13) (Boss and Hoffman, 2001).

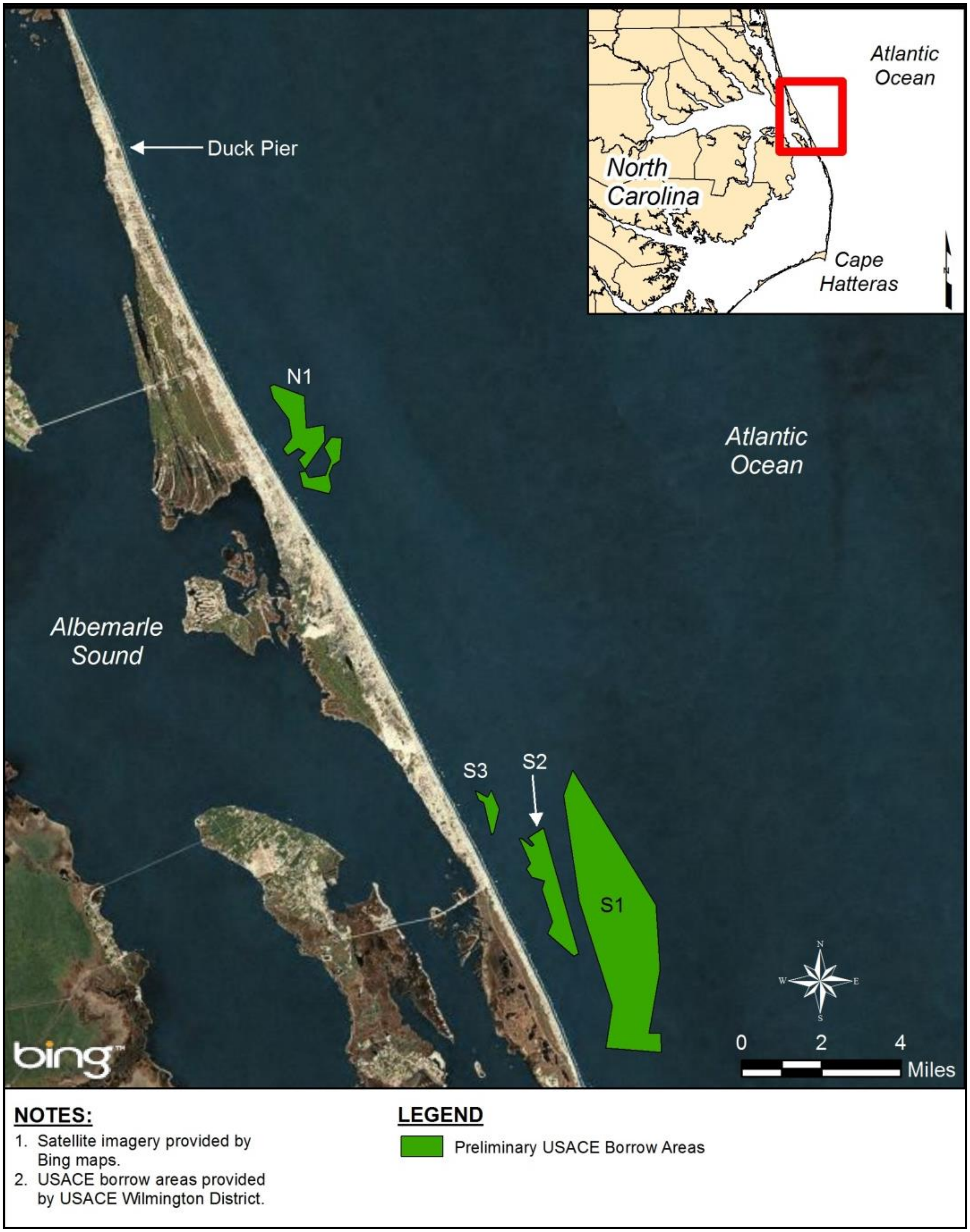

Figure 11. Location Map Showing USACE Established Borrow Areas Associated with the Dare County Storm Damage Reduction Project.

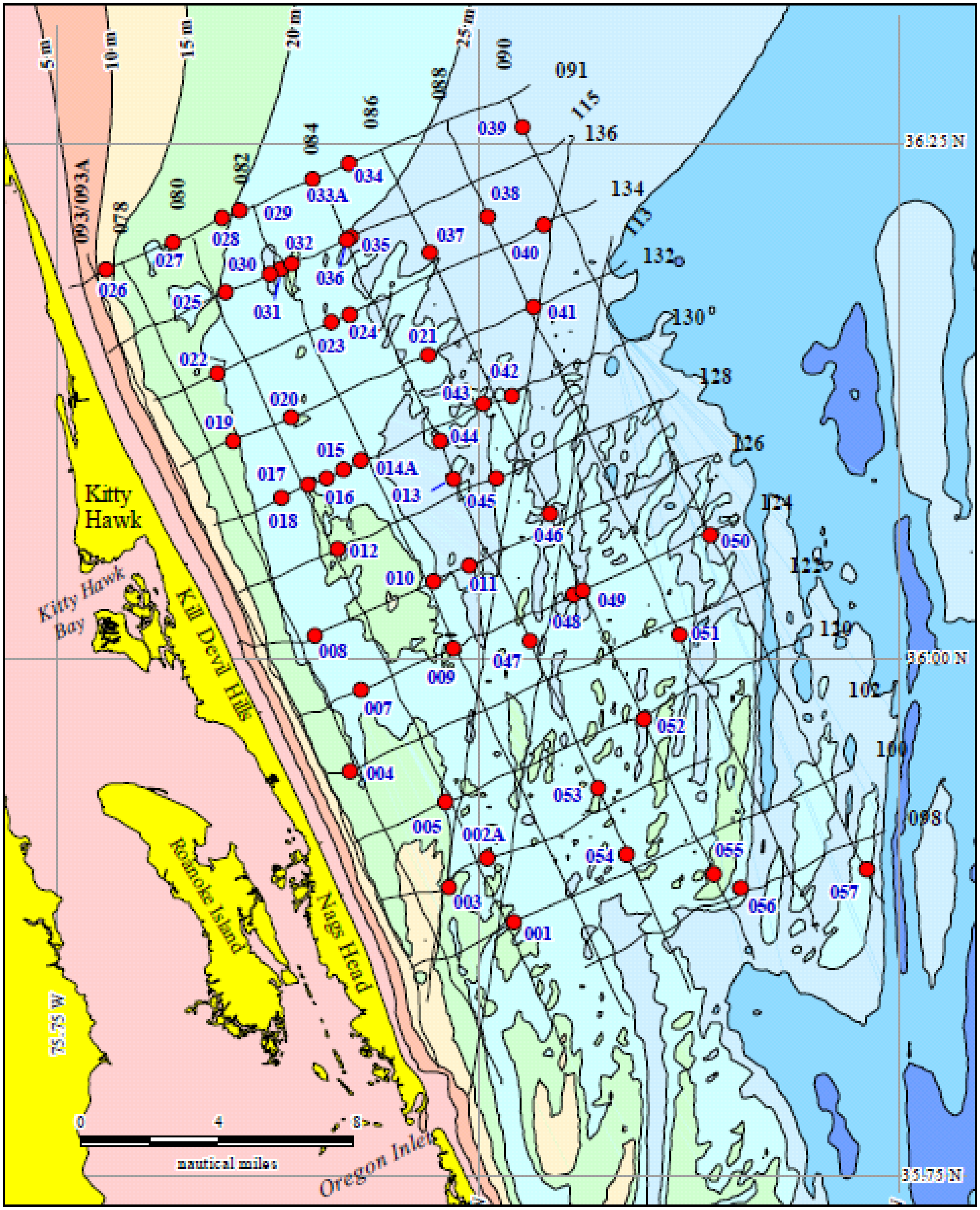

Figure 12. BOEM Study Area Offshore of Dare County, North Carolina and the Distribution of Geophysical and Geotechnical Data Collected (Boss & Hoffman, 2001)

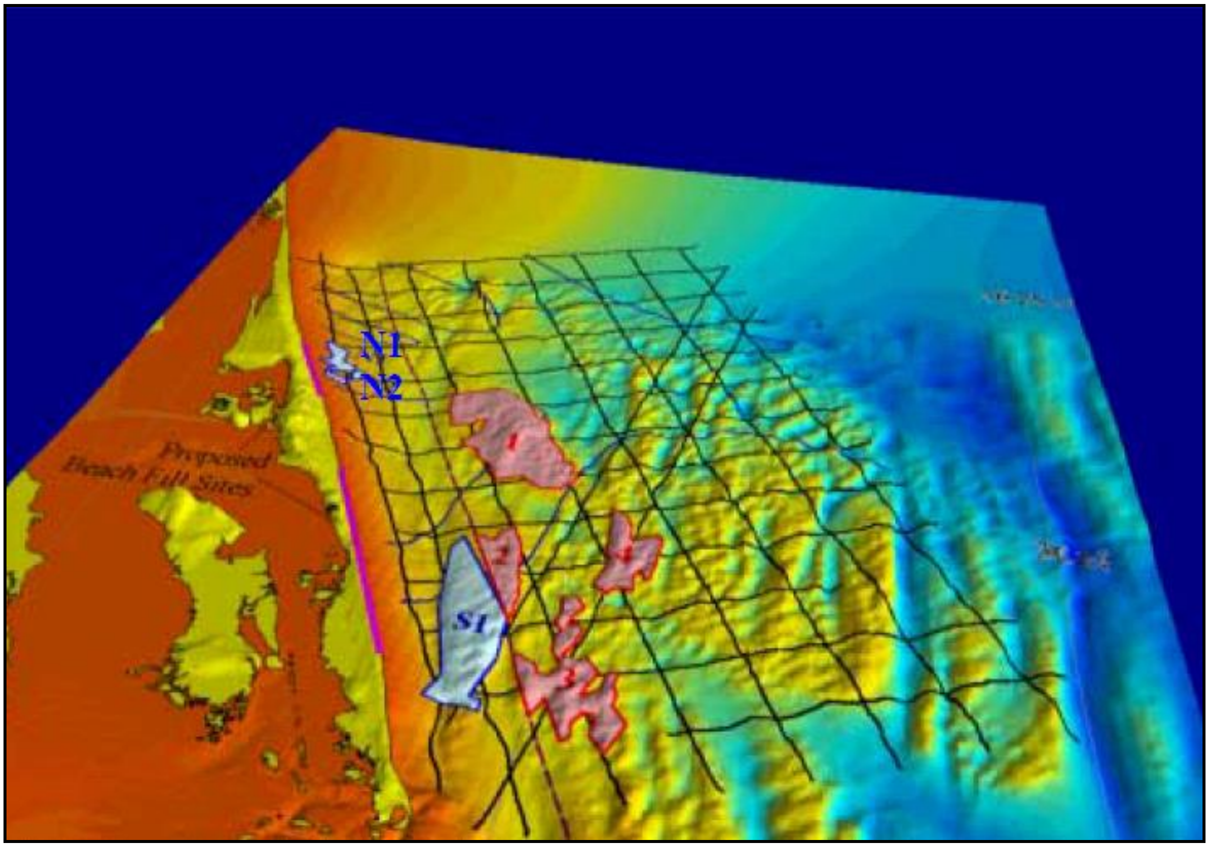

Figure 13. Perspective View of 4 Target Areas Identified by BOEM (Shown In Pink) and the Established USACE Borrow Areas N1, N2, and S1 (Shown In Blue) (Boss & Hoffman, 2001)

Data obtained from the National Ocean Services (NOS) processed to create a shaded relief bathymetric chart is provided as Figure 14. The figure shows presence of a number of offshore topographic features. Investigations conducted by the USACE, BOEM, and the Town of Nags Head have shown that many of these features contain beach quality material.

Minimal data exist in the Currituck Sound west of the Town of Duck to suggest the quality of sediment deposits. Data from several surface "grab" samples suggest there may be areas of sand deposits available. A number of sand pits have been permitted and mined in Currituck County indicating beach quality sand sources do exist regionally east of Duck. Historic charts indicate the existence of a tidal inlet north of the Town of Duck. Aerial photographs show the remnants of flood tide deltas on the sound side shoreline beginning at the Town's northern boundary and extending further north. FRF staff indicated they have collected sub-bottom geophysical data in the sound west of Duck; however, no ground truthing of the data has been conducted to date (McNinch, 2012). Sound side sand sources could prove more economical to exploit than offshore sand sources. However, initial discussions with resource agencies suggest permitting of such sources could be more difficult depending on the quantity of sensitive habitat present. Further coordination should be undertaken with permitting and resource agencies prior to making significant investments in developing these sand sources.

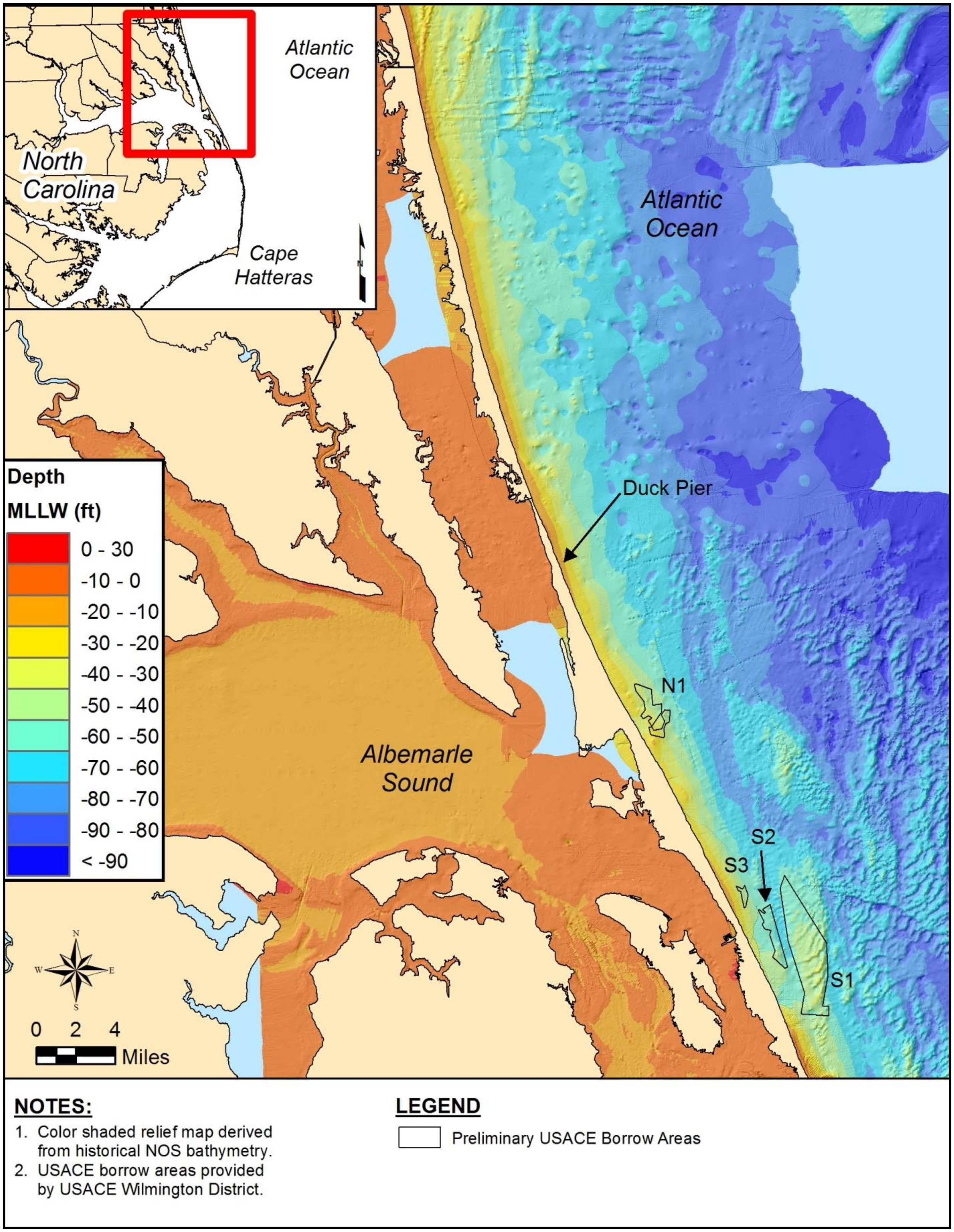

Figure 14. Regional map showing offshore bathymetry

Based on available data, sand resources do exist in sufficient quantity and quality to support beach nourishment efforts for the Town of Duck. However, significant efforts remain to define these sand resources to the extent needed to permit a borrow area. The State of North Carolina has adopted specific Technical Standards for Beach Fill Projects (15A NCAC 07H.0312) that must be met prior to the issuance of a Major CAMA permit. These standards include characterization of both the existing beach through sediment sampling and beach profile surveys as well as characterization of the borrow source through geophysical and geotechnical surveys.

Construction Constraints

Sand placement from an offshore dredge alleviates one main issue compared to truck hauls by removing any construction traffic from the roadways. However, the operational cost encourages a 24 hour per day operation. Operating on an around the clock schedule creates the potential for noise and lighting impacts through the night. Lighting impacts may be created from the offshore or land based equipment. Light sources can be shielded to limit the disruption but sufficient lighting is necessary to meet safety requirements and inspection of the work. Heavy equipment on the beach may impact residents and tourists through engine noise and back-up alarms. Back-up alarms are the most common disturbances and are a federal requirement.

Generally these impacts are focused in the projects beneficial area and can be mitigated through the increased beach width provided. Upland property owners receiving a direct benefit are more likely to overlook an inconvenience compared to residents impacted by traffic several miles away. However, the added noise and lighting necessary for night time construction should be considered.

Current environmental restrictions seek to limit construction of beach fill projects between November 16th and March 31st. Recent consultation between the USACE, federal and state resource agencies, and the Town of Nags Head resulted in the Town obtaining an exception to the dredge window restrictions. This allowed Nags Head to construct the project during summer and fall. The allowance for construction to take place during fair weather months resulted in very favorable bids to the Town of Nags Head. This report recommends that if the TOWN elects to move forward with an offshore dredge and fill project that a similar exception should be sought. Construction during summer and fall months may allow for significant cost savings; however, the TOWN must also consider temporary inconveniences that vacationers may experience during construction.

Schedule

The timeframe anticipated to acquire state and federal permits for a beach restoration utilizing an offshore borrow source is 24 – 36 months. This timeframe may be reduced if sufficient information to characterize a borrow source is available. However, initial investigations suggest a sand search would be necessary.

As previously mentioned, the time period in which construction of beach fill projects in North Carolina can occur is between November 16 and March 31 of any given year. The Town of Nags Head was successful in obtaining authorization for summer work. Pursuing this option may trigger the need to develop an EIS as opposed to a less stringent EA. That said, based on the potential cost savings realized with summer time dredging, the added effort is warranted. The decision for requesting summer construction can be made after an adequate sand source is identified and a more detailed understanding of the alternative is developed. Location of the sand source and proximity to the fill area is one of the key factors in plan formulation and cost estimating.

Costs

Several assumptions are considered in developing a conceptual cost for this dredge and fill project. The most significant assumption is the location of the offshore borrow area. Two separate borrow areas are considered for this alternative. The first is area “1” offshore of Kill Devil Hills shown in Figure 12. Estimated unit costs for this project are $8.61 per cubic yard. The second borrow site considered is the northern portion of area S1 off of Nags Head shown in Figures 9, 11, and 12. The estimated unit cost for this borrow area is $10.63 per cubic yard. Since construction of a beach fill using either borrow area would probably be accomplished by hopper dredges, mobilization and demobilization cost for the proposed project is estimated at $2.9 Million regardless of which borrow area is used.

Based on recent experience with similar projects, soft costs, or those costs not directly tied to construction, for this proposed alternative are estimated at $1.5 Million. This includes offshore investigations to design a borrow area, engineering design of the project, environmental documentation and permitting, preparation of construction plans and specifications, and construction oversight. This cost estimate assumes an EIS will be required for environmental documentation given the fact that an exception will be sought to allow for summertime dredging and the likelihood that consultation with BOEM will be required

The total estimated range of cost for this alternative is $13.04 Million to $14.96 Million. This includes construction costs, soft costs, and a 15% contingency added to the construction costs. The difference in the two costs is due to the two separate unit cost estimates based on the two different borrow area locations.

An option to reduce mobilization costs may exist if the Town of Duck chooses to waive the construction bid process or partner with another local government entity. North Carolina General Statute Section (NCGS) 143-129 allows government entities to contract directly with suppliers under certain conditions. The supplier or contractor must have completed similar work awarded through a competitive bid process within the previous 12 months with any federal or state entity. The price for each item of work cannot be raised above the prices listed in the original bid (NCGS, 2012). This enables the Town authority to negotiate directly to try and obtain a favorable price. This may be beneficial if a contractor is in the area so the mobilization cost might be reduced.

Partnering with another shoreline community would allow the mobilization cost to be divided between the entities. This option would create some logistical issues with scheduling but the financial benefit may be worth it. Partnering also increases the size of a potential project and creates more interest in the combined project. The Town might lose some control over where the contractor begins work in respect to the different sites. However, this may be overcome with proper coordination. The potential to reduce project cost recommends at least consideration of such coordinated efforts.

<u>Maintenance</u>

This conceptual alternative was designed based on a 5-year re-nourishment interval. This means that 5 years after the project is constructed the project would require renourishment. Renourishment volumes are often less than the initial construction of a project as the initial construction attempts to re-establish some baseline condition and add advanced fill in front of the new baseline condition to hold the line between construction events. Based on the long term shoreline change rates and predicted diffusion losses, the renourishment volume to be placed every 5 years is 470,000 cubic yards. Using the estimates for construction costs previously discussed and a 2% annual inflation rate the first renourishment event 5 years after construction could range in cost from $9.15 million to $10.35 million. This total assumes a 15% contingency for construction costs as well as $325,000 in soft costs.

Storm Damage Reduction Project by Offshore Dredging

The storm damage vulnerability analysis suggests that a beach fill project to reduce storm damage reduction is also warranted along Segments 7 and 8. Table 9 shows the number of structures with damage potential for each of the modeled storm scenarios (1, 5, 10, 20, 25, and 50 year return interval storms). Table 12 shows the volume of material needed to mitigate predicted storm damage given the 9 different beach fill designs considered. Note the volume required to provide protection from the 5 year return interval storm and the 10 year return interval storm are the same. This is due to the fact that of the nine different beach fill designs considered, the same designs would provide the level of protection needed to mitigate both scenarios. Although one structure in both Segments 3 and 4 were identified to be vulnerable to the 20 and 25-year return interval storms, as well as 2 structures in Segment 2 for the 25-year storm, this study concludes that a beach fill project is not economically justifiable for these segments given the relatively minimal vulnerability. For this reason the volumes shown in Table 12 only consider a beach fill project along Segments 7 and 8 for the 1, 5, 10, 20, and 25-year return interval storms. For the 50-year return interval storm eight (8) structures were identified as vulnerable in Segment 4; whereas 2 structures each in Segments 2 and 3 were identified as vulnerable. Further economic analysis may be required to determine if a beach fill project along Segment 4 is justified under the 50-year return interval storm scenario; however, for the purposes of this conceptual plan beach fill along Segment 4 is considered in the construction volumes shown in Table 12.

Table 12. Construction Volumes and Re-nourishment Volumes Required for Storm Damage Reduction Projects

Storm Event	Initial Construction Volume Required for Storm Event	Renourishment Volume Required Every 5 years
1-Year Return Interval	1,260,800	538,000
5-Year Return Interval	1,610,200	700,400
10-Year Return Interval	1,610,200	700,400
20-Year Return Interval	2,090,800	836,300
25-Year Return Interval	2,313,200	836,300
50-Year Return Interval	2,935,800	1,057,500

Permitting Requirements and Schedule

Permit requirements would be identical to those discussed previously for erosion mitigation project by offshore dredging regardless of which of the storm damage reduction projects is constructed. The same variables with regards to offshore sand sources would apply as well.

Likewise the schedule for permitting any of the storm damage reduction projects would be similar to that which was previously described under the erosion mitigation project by offshore dredging. No additional time is anticipated to develop the borrow area, obtain environmental clearances, or design the project. Therefore, 24 – 36 months are anticipated for permitting and design of the project. Since additional volume will be placed for any of the storm damage reduction projects as compared to the erosion mitigation project, construction time may increase dependent on which of the storm damage alternatives is selected.

Costs

As previously discussed under the erosion mitigation project by offshore dredging, the fact that the offshore borrow area has not yet been identified provides a degree of variability in the costs to consider. The same estimated unit costs listed for the erosion mitigation project by offshore dredging are appropriate to use for any of the storm damage reduction projects. Those estimates are $8.61 per cubic yards for the closer borrow site offshore of Kill Devil Hills (Area 1) and $10.63 per cubic yard for the borrow area further away offshore of Nags Head (Area S1). Mobilization and demobilization for the proposed projects are estimated at $2.9 Million regardless of which borrow area is used.

Given the permitting, engineering, and geotechnical investigations associated with the storm damage reduction projects are the same as those for the erosion mitigation project using offshore dredging, soft costs are similar to those previously estimated. An increase of $100,000 has been applied to the total soft cost to account for extended time to perform construction oversight given the increase in volume. Total estimated soft costs for the storm damage reduction alternatives is $1.60 Million. Again, this includes offshore investigations to design a borrow area, engineering design of the project, environmental documentation and permitting, preparation of construction plans and specifications, and construction oversight.

Table 13 lists the total costs for each of the storm damage reduction alternatives assuming the construction volumes provided in Table 12. These estimates include construction costs, soft costs, and a 15% contingency added to the construction costs. The difference in the two costs is primarily due to the two separate unit cost estimates determined for the different borrow area locations.

The same options for reducing costs discussed above for the erosion mitigation project by offshore dredging apply to these storm damage reduction projects.

Table 13. Estimated Total Cost for Storm Damage Reduction Projects.

Storm Event	Project Cost for Storm Damage Reduction Project	
	Using Area 1 (Kill Devil Hills)	Using Area S1 (Nags Head)
1-Year Return Interval	17,419,000	$20,348,000
5-Year Return Interval	20,878,000	$24,619,000
10-Year Return Interval	20,878,000	$24,619,000
20-Year Return Interval	25,637,000	$30,494,000
25-Year Return Interval	27,839,000	$33,213,000
50-Year Return Interval	34,004,000	$40,824,000

Maintenance

This conceptual alternative was designed based on a 5 year re-nourishment interval. This means that 5 years after the project is constructed the project would require renourishment. As previously stated, renourishment volumes are often less than the initial construction of a project. Renourishment volumes to be placed every 5 years were determined based on the long term shoreline change rates and predicted diffusion losses (Table 12).

Summary

Table 14 provides a summary of each of the proposed alternatives which includes the project length (spatial), the volume of sand required, sand source, the re-nourishment interval, and total cost. Anticipated engineering, environmental, geotechnical, and construction costs have been included in these cost estimates; however, no cost has been added to account for obtaining construction easements along the project lengths. The Town should consult legal counsel for estimates on the cost to obtain construction easements where needed.

Table 14. Summary Table of Conceptual Alternatives

Plan	Project Extent	Volume of Sand (CY)	Sand Source	Re-Nourishment Interval	Cost (x $1,000,000)
Dune Replenishment	Segment 7 (5000 Feet)	30,000	Upland/ Truck Haul	1 Year	**0.94**
Beach Replenishment	Segment 7 (5000 Feet)	120,000	Upland/ Truck Haul	1 Year	**1.75 - 1.85**
Long-Term Erosion Mitigation Project	Segments 7 & 8 (13,000 Feet)	828,200	Offshore/ Dredge & Fill	5 Years	**13.04 - 14.96**
1 Year Strom Damage Reduction Project	Segments 7 & 8 (13,000 Feet)	1,260,800	Offshore/ Dredge & Fill	5 Years	**17.42 - 20.35**
5 & 10 Year Storm Damage Reduction Project	Segments 7 & 8 (13,000 Feet)	1,610,200	Offshore/ Dredge & Fill	5 Years	**20.88 - 24.62**
20 Year Storm Damage Reduction Project	Segments 7 & 8 (13,000 Feet)	2,090,800	Offshore/ Dredge & Fill	5 Years	**25.64 - 30.49**
25 Year Storm Damage Reduction Project	Segments 7 & 8 (13,000 Feet)	2,313,200	Offshore/ Dredge & Fill	5 Years	**27.84 - 33.21**
50 Year Storm Damage Reduction Project	Segments 4, 7, & 8 (17,000 Feet)	2,935,800	Offshore/ Dredge & Fill	5 Years	**34.00 - 40.82**

RECOMMENDATIONS

The following recommendations for the Town of Duck have been developed based on the information provided in this report.

Large-Scale Beach Nourishment by Dredging

Given the number of structures and property that is vulnerable to both long term erosion and storm damage, the ultimate goal of the shoreline management program should be to permit and construct a large scale beach fill project. All of the dredge and fill projects discussed herein have a high probability of providing the level of protection for which they are designed. The deciding factor as to which option to choose will likely come down to what the Town can afford and/or economically justify.

Immediate inter-agency coordination should be initiated with the USACE, BOEM, DCM, and other federal and state agencies. This pre-project coordination will clearly define the permitting process and allow for a more detailed schedule and cost estimate to be developed for the permitting process. In parallel with these efforts, the Town should apply for a BOEM permit for geological prospecting for mineral resources or scientific research in the outer continental shelf related to minerals other than oil, gas, and sulfur (BOEM-0136). This permitting process should take 30 days, upon which the Town should authorize an exploratory reconnaissance survey to verify the quality and quantity of the sand located in area 1 as shown in Figure 12. This is the site that would result in the lesser of the two unit costs provided for offshore sand.

Upon completion of the reconnaissance survey and the inter-agency coordination, the Town should begin preparation of environmental documentation to support Department of the Army and Major CAMA permits. This includes conducting an offshore sand search investigation to fully delineate the offshore borrow area to the level required by the State Sediment Criteria Rules. In addition, the Town should initiate design work to refine the beach fill design for whichever option they choose to pursue. This may include the collection of beach profile data to verify present conditions.

Small-Scale Truck Haul Project

Given the limited amount of protection that would be afforded by a small-scale truck haul beach nourishment project, this option should only be considered in the event of an extreme emergency situation that would imminently threatened multiple structures. The Town could opt to apply for permits to construct such a project and hold the permits in reserve. With permits in hand, a small-scale project could be initiated within a matter of weeks once such a decision has been made.

Such a limited scope project could become necessary even if the Town elects to pursue a larger scale beach nourishment or storm damage reduction project. Permitting the larger scale project could take 2 to 3 years which would increase the likelihood some structures could become threatened prior to construction of the larger project.

Additional cost for permitting a small-scale beach nourishment project using truck haul are estimated to be approximately $425,000, assuming efforts are already underway to permit a large scale dredge and fill beach nourishment project. The permitting would take a minimum of 8 months. Most of the permitting time would be associated with the permit review process for both the USACE and the NC Division of Coastal Management. The time and cost estimate for the permit includes a detailed survey of the dune and beach within Segments 7 & 8 which would allow a more comprehensive evaluation of the feasibility of constructing a combined beach nourishment/dune enhancement project. Note that this survey information would also be used for the permitting of a larger-scale beach nourishment project so any cost for collection of additional survey data needed to support a small-scale project would have a comparable reduction in the permitting cost of the large scale project.

Continue the Comprehensive Town Wide Beach Monitoring Plan

Regardless of what management strategy the Town might pursue, monitoring of the beach is an invaluable tool. Regular monitoring allows for the adaptation of strategies to the highly dynamic coastal environment. Even the best designed beach nourishment project requires adaptive management over the long term. Beach surveys are the most important tool in successfully adapting and refining an effective beach management plan.

Activities can focus solely on the shoreline, which can be done with LiDAR data such as that which was collected by the CLARIS, or can expand to capture the complete profile through onshore and offshore beach profile surveys. Analyzing shoreline movement provides a reference to the amount of dry beach remaining. Over long time periods this method will provide extensive knowledge of the recession or erosion trends. Capturing the complete beach profile response leads to means of identifying changes in wave climates. Sediment transport rates can also be identified at a more accurate scale than with just shoreline measurements.

The Town has previously partnered with the FRF to provide comprehensive shoreline measurements across the study area. This study recommends that the Town continue to monitor the beaches in a similar fashion.

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