Appendix B

Advance Materials Provided to Panel

STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION

BEVERLY EAVES PERDUE
GOVERNOR

EUGENE A. CONTI, JR.
SECRETARY

October 13, 2011

Subject: Bonner Bridge Replacement Project- Phase II Peer Exchange Meeting

Dear Participant,

On behalf of the North Carolina Department of Transportation, I want to thank you for agreeing to participate in the peer exchange meeting to discuss Phase II of the Bonner Bridge Replacement Project. This meeting is an essential step in the process for determining how to proceed with future phases of this project, and NCDOT values your participation in this effort.

The meeting will be held on the afternoon of Monday, October 24 and all day on Tuesday, October 25. We will meet at NCDOT's Century Center Complex, Building A, in the Structure Design Conference Room; directions and a map to this facility are attached.

A draft agenda for the meeting is attached to this letter; please note that there may be some changes to the discussion topics prior to the meeting itself. A key item for discussion is item #4 on the agenda- "Post-Irene Project Area Conditions;" a list of questions has been included with this agenda item to assist you in preparing for this part of the discussion. Please feel free to bring any additional photographs, figures, or data that you think the group may find useful; we will have a laptop and projector available to display this information. However, due to time constraints, there will not be time for any individual presentations during the meeting.

We have also included a set of DVD's that contain recent aerial photography of the project area and a sampling of the previous coastal studies that have been completed as part of the Bonner Bridge Replacement Project and other NC 12 studies. This is certainly not a comprehensive list of the studies concerning the project area; it is meant only to provide you with an idea of the types of studies that NCDOT has prepared to date. Please feel free to bring with you any other studies that you feel would be useful to the group.

If you have any questions about our upcoming meeting, please feel free to contact me at (919) 707-6043 or at bsmyre@ncdot.gov. Again, thank you for agreeing to participate, and I look forward to seeing you on October 24!

Sincerely,

Beth Smyre, PE
Project Planning Engineer

MAILING ADDRESS:
NC DEPARTMENT OF TRANSPORTATION
PROJECT DEVELOPMENT AND ENVIRONMENTAL ANALYSIS
1548 MAIL SERVICE CENTER
RALEIGH NC 27699-1548

TELEPHONE: 919-707-6000
FAX: 919-250-4224

WEBSITE: WWW.NCDOT.ORG/DOH/PRECONSTRUCT/PE/

LOCATION:
CENTURY CENTER, BUILDING A
1000 BIRCH RIDGE DRIVE
RALEIGH NC 27610

Bonner Bridge Replacement Project
Phase II Peer Exchange Meeting
List of DVD Files

DVD 1

Bonner Bridge Replacement Project Studies

- Sections 3.6 and 4.6 of the 2008 Final Environmental Impact Statement (summary of coastal engineering analyses for the project)
- Pea Island Shoreline: 100-Year Assessment (FDH, 2004)
- Shoreline Change and Stabilization Analysis (FDH, 2005)
- Potential Inlet Formation Technical Report (FDH, 2005)
- Summary and maps of the Parallel Bridge Corridor Alternatives
- Description of the NC 12 Transportation Management Plan from the 2010 Record of Decision

For more information about the Bonner Bridge Replacement Project and the studies completed to date, please refer to the project's web page at:
http://www.ncdot.gov/projects/bonnerbridgerepairs/

Offshore Sand Resource Investigation (NC Geological Survey, 2009)

Shoreline Monitoring at Oregon Inlet Terminal Groin, Report 40 (Overton, 2011); *this is included as a sample of the current monitoring that NCDOT conducts at Oregon Inlet*

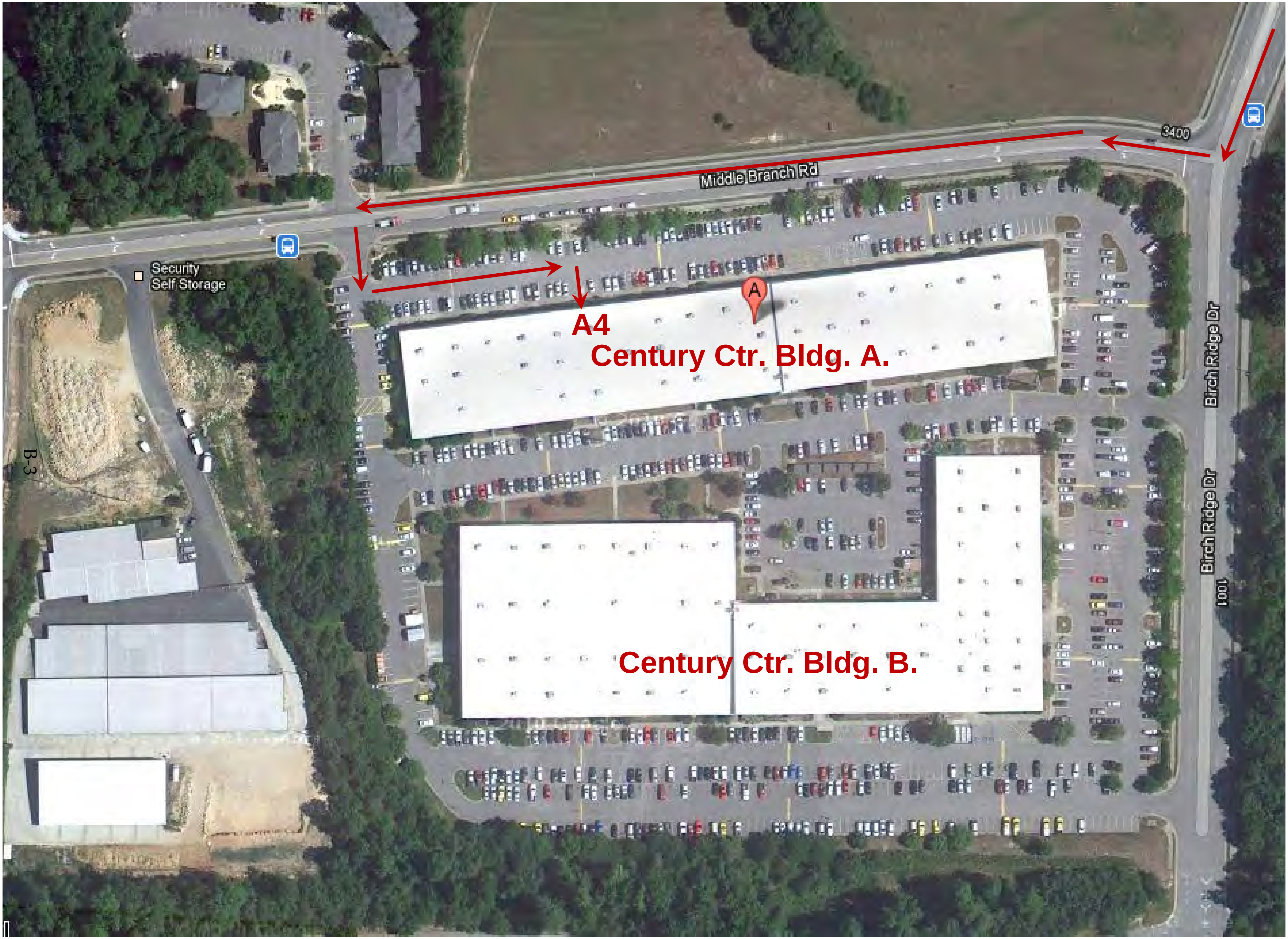
Copies of Technical Reports submitted by participants

- Critique Report on the Closure of Buxton Inlet (USACE, 1963)
- Hatteras Breach Closure, by Michael Wutkowski (from Spring 2004 *Shore & Beach*)
- *Excerpt from* Inlet Hazard Areas, The Final Report and Recommendations to the Coastal Resources Commission (NC Division of Marine Fisheries, 1978)
- Copy of email correspondence and initial data from USGS at the Rodanthe Ferry Terminal; USGS also provided a link to their Hurricane Irene web page, which can be found at http://water.usgs.gov/osw/floods/2011_HIrene/index.html

DVD 2

NCDOT Aerial Photography

- August 2, 2011 (Oregon Inlet to Rodanthe)
- August 28, 2011 (Oregon Inlet to Rodanthe)
- August 30, 2011 (Pea Island and Rodanthe breach sites)



Middle Branch Rd
3400
Security
Self Storage
B-3
A
A4
Century Ctr. Bldg. A.
Century Ctr. Bldg. B.
Birch Ridge Dr
Birch Ridge Dr
1001

Bonner Bridge Replacement Project
Phase II Peer Exchange Meeting
Directions to NCDOT Century Center

Directions-Points East of Raleigh
From I-40 West,

- Take exit 301 for I-440 Outer/US-64 E
- Take the next exit, Exit 15, Poole Rd.
- Turn left at the top of the ramp.
- Go across the bridge and thru the stoplight, turn at the next left on Birch Ridge Dr. There will be a Burger King and a McDonalds at the intersection.
- Turn right onto Middle Branch Rd.
- Turn left into the NCDOT Entrance.

From US 64 West,

- Merge onto I-440 E (*exit left, toward I-40/Durham/Benson*)
- Take the next exit, Exit 15, Poole Rd.
- Turn right at the top of the ramp.
- At the next light, turn left on Birch Ridge Dr. There will be a Burger King and a McDonalds at the intersection.
- Turn right onto Middle Branch Rd.
- Turn left into the NCDOT Entrance.

Directions-Points West of Raleigh
From I-40 East,

- Merge onto I-440 Outer/US-64 E
- Take the next exit, Exit 15, Poole Rd.
- Turn left at the top of the ramp.
- Go across the bridge and thru the stoplight, turn at the next left on Birch Ridge Dr. There will be a Burger King and a McDonalds at the intersection.
- Turn right onto Middle Branch Rd.
- Turn left into the NCDOT Entrance.

Enter Century Center Building A through the security station at door A-4. You will be directed to the Structure Design Conference Room.

For those that would like to map directions from the internet, the address is 1000 Birch Ridge Drive, Raleigh, NC.

3.6 Coastal Conditions

Coastal processes drive the physical changes in the Oregon Inlet area. This section first discusses the floodplains in the project area. Next, it documents and analyzes historic trends and existing coastal conditions, including:

- Inlet migration;
- Changes in inlet gorge alignment and location;
- Historic shoreline changes for Hatteras and Bodie islands; and
- The natural and manmade factors that drive inlet and shoreline changes.

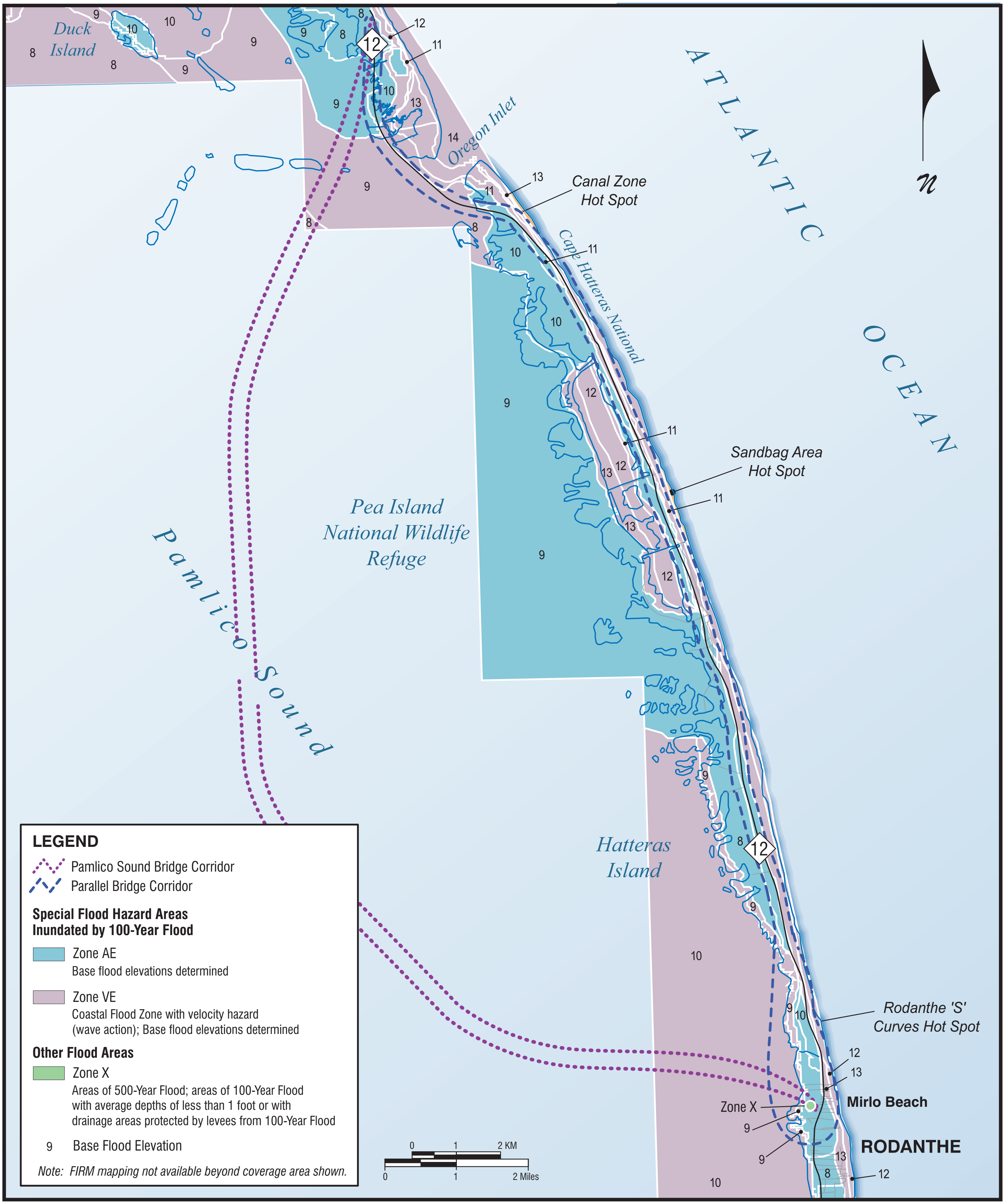
Finally, this section presents projections of future coastal conditions, including:

- The Hatteras Island shoreline through 2060;
- Potential breach locations in the Pea Island National Wildlife Refuge; and
- Oregon Inlet movement through 2085 based on historical data.

The Hatteras Island shoreline material is derived from *Bonner Bridge Replacement – Parallel Bridge Corridor with NC 12 Maintenance – Shoreline Change and Stabilization Analysis* (Overton and Fisher, June 2005). The breach location findings are based on available research materials and the observations of an expert panel based on that research. The material on Oregon Inlet movement summarizes the coastal study findings of *Bonner Bridge Replacement: Oregon Inlet Movement Consideration* (Moffatt & Nichol, September 25, 2003). It is also based on three previous reports: *Existing Coastal Conditions at Oregon Inlet, North Carolina* (Moffatt & Nichol, June 1990), *Future Coastal Conditions at Oregon Inlet, North Carolina* (Moffatt & Nichol, October 1990), and *Coastal Engineering Technical Memorandum* (Moffatt & Nichol, July 1991).

3.6.1 Floodplains

The entire project area is within flood zones mapped by the Federal Emergency Management Agency (FEMA) under the National Flood Insurance Program (see Figure 3-4). In addition, much of the floodplain within the project area is classified as being a coastal flood zone with velocity hazard because of wave action. However, the floodplains in the project area do not serve the same function (i.e., as a natural moderator of floods) as floodplains in non-coastal areas because water levels in the project area are not dependent on floodplain storage capacity. Rather the project area is subject to coastal flooding caused by both hurricanes in the summer and fall months and northeasters in the winter and spring, both of which can raise water levels substantially via storm surge. The tidal surge comes into shore with the storm, and then begins to retreat almost immediately once the storm moves on. The only storage that occurs in the project area floodplains is during the brief interval between the surge and the ebb of the storm-induced tide. The 100-year storm surge elevation is 6.89 feet (2.1 meters), and the 500-year storm surge



Source: Flood Insurance Rate Maps dated September 20, 2006.

FLOODPLAINS

Figure 3-4

elevation is 7.58 feet (2.3 meters). Beneficial floodplain values are associated with this tidal surge. They are:

- Serving as a buffer (therefore flood control) to protect mainland shoreline areas by dampening tidal surges;
- Contributing to the natural barrier island evolution, whose benefits are discussed in Section 4.7.7; and
- Contributing to beneficial ecological change and habitat creation associated with barrier island evolution, also described in Section 4.7.7.

3.6.2 Existing Coastal Conditions

Oregon Inlet, Bodie Island, and Hatteras Island are part of a migrating barrier system characteristic of the southeast Atlantic Coast. The south end of Bodie Island is an actively prograding (growing) spit system that has back-filled the Bodie Island shoulder of Oregon Inlet with modern beach and island sediments as Oregon Inlet has migrated southward. Oregon Inlet is migrating south-southwest and historically has eroded the north side of Hatteras Island.

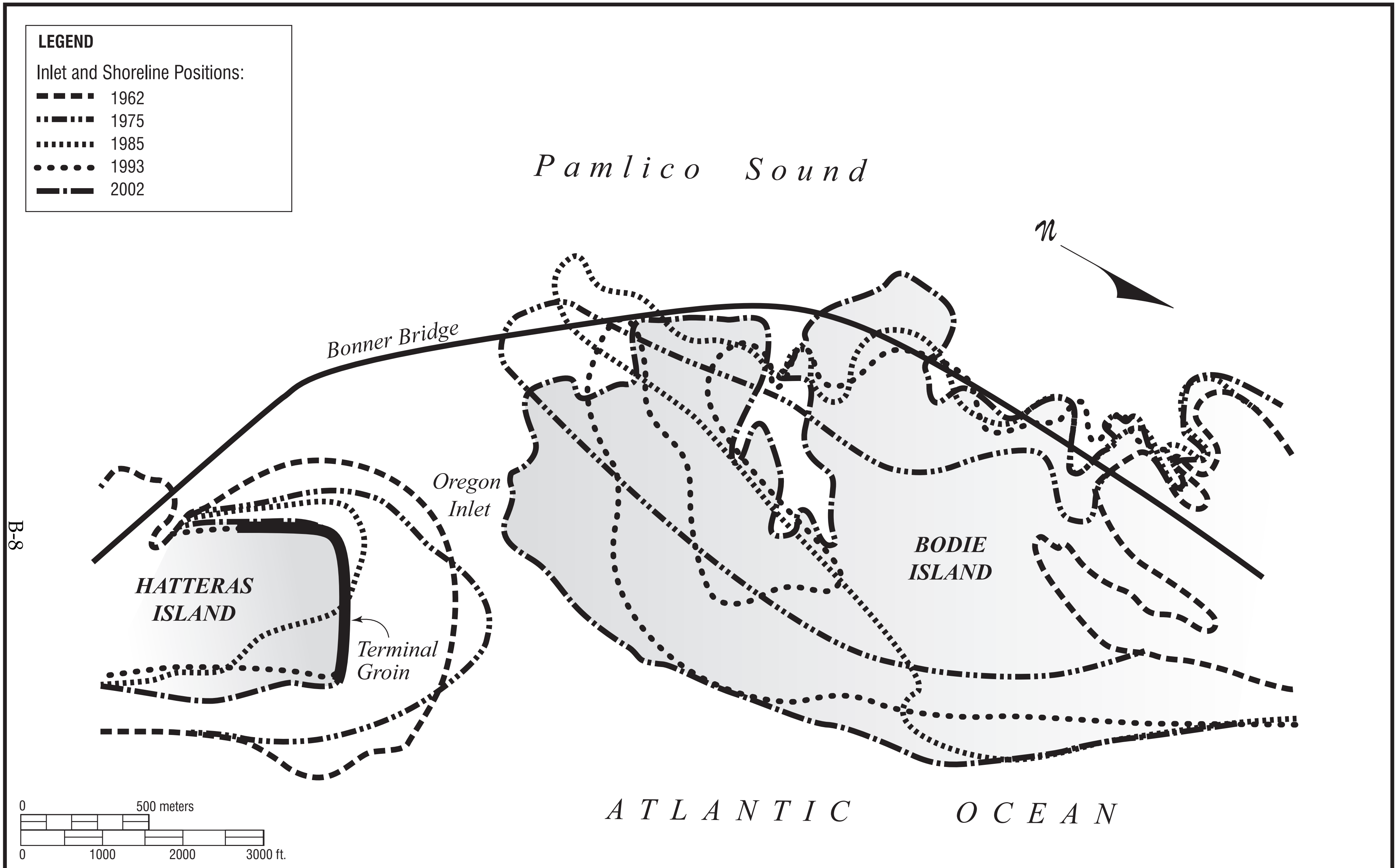
In this natural process, the north end of Hatteras Island (within 3 miles [4.8 kilometers] of Oregon Inlet) historically is a zone of high erosion. As a result of the continued inlet migration threatening the southern terminus of Bonner Bridge and the north end of Hatteras Island, the NCDOT built a terminal groin at the northern end of Hatteras Island to protect the southern approach to Bonner Bridge. The groin was designed by the USACE Wilmington District. Construction of the terminal groin began in October 1989 and was completed in March 1991. As a result of the construction of the terminal groin, Hatteras Island migration has halted. However, Bodie Island has continued to exhibit both along-shore and cross-shore migration. This continued migration has resulted in changes in both inlet width and orientation.

3.6.2.1 Inlet Migration

Since its opening during a storm in 1849, the midpoint of Oregon Inlet has migrated steadily southward just over 2.2 miles (3.5 kilometers) and landward approximately 2,070 feet (630 meters). The history of Oregon Inlet's migration has been punctuated by alternate widening and narrowing, typically in response to severe storms and primarily reflected by the erosion and accretion of the Bodie Island shoulder of Oregon Inlet. Inlet location changes since the opening of Bonner Bridge are illustrated in Figure 3-5. Until the construction of the terminal groin, the Hatteras Island shoulder moved steadily southward, showing little tendency toward significant accretion and northward movement. After construction of the terminal groin commenced, the southern migration of Hatteras Island halted. In recent years, Bodie Island has continued to accrete, causing Oregon Inlet width to narrow further, reaching a minimum width of 2,000 feet (610 meters) in 2002.

During the period from 1849 to 1945 (New Inlet, approximately 15 miles [24 kilometers] south of Oregon Inlet, closed in 1945), the Bodie Island shoulder migrated 6,000 feet (1,830 meters) or 63 feet (19 meters) per year south of its original position. Hatteras Island migrated 8,250 feet (2,510 meters) or 86 feet (26 meters) per year south of its original position.

From 1945 to 1989 (construction of the terminal groin began in 1989), the Bodie Island shoulder migrated 3,770 feet (1,150 meters) or 84 feet (26 meters) per year south of its original position.



Sources: US Army Corps of Engineers "Historic Changes in Oregon Inlet" and 1993 and 2002 aerial photography

INLET AND SHORELINE CHANGES

Figure 3-5

In that period, the Hatteras Island shoulder migrated 4,640 feet (1,410 meters) or 103 feet (31 meters) per year southward. The maximum inlet width of 6,670 feet (2,033 meters) was achieved in 1962, following a storm-laden period from 1953 through 1962, which culminated in the Ash Wednesday Storm of March 1962. The general tendency is for Oregon Inlet to widen after stormy periods, during which both shoulders of Oregon Inlet experience severe erosion. During calm periods, Oregon Inlet tends toward its minimum width of about 2,100 feet (640 meters).

The period from 1962 to 1983 generally was storm-free, and the Bodie Island shoulder spit redeveloped rapidly, accreting southward into Oregon Inlet for a total distance of 6,560 feet (2,000 meters) or 312 feet (95 meters) per year.

From 1983 to 1989, both the Bodie Island and the Hatteras Island shoulders eroded rapidly. The Bodie Island shoulder eroded 1,850 feet (560 meters) or 308 feet (94 meters) per year, and the Hatteras Island shoulder eroded 1,640 feet (500 meters) or 273 feet (83 meters) per year. However, between April 1988 and March 1989, the north end of Hatteras Island eroded at an extreme rate of 1,150 feet (350 meters) per year; with 350 to 400 feet (110 to 120 meters) of erosion occurring in the four-day period of March 6 to 10, 1989, when a severe northeaster storm pounded the coast. The width of Oregon Inlet increased steadily from 1,983 to 5,000 feet (605 to 1,520 meters) in 1989.

From 1990 to 2001, Bodie Island migrated southward 1,955 feet (600 meters) or 163 feet (50 meters) per year. Erosion of Hatteras Island was halted by the terminal groin during this period. Hatteras Island actually accreted 1,120 feet (340 meters) or 93 feet (28 meters) per year with the construction of the terminal groin.

Recent inlet position comparisons from September 2001 and March 2002 surveys show that Bodie Island's inlet shoulder advanced 443 feet (135 meters) over the six-month period. By March 2002, the spit had migrated almost two-thirds of the way across the preferred channel alignment projecting from the navigation span of Bonner Bridge. This updated rate of spit movement equals 886 feet (270 meters) per year.

3.6.2.2 Inlet Profile and Gorge Alignment

As Oregon Inlet migrated, the profile of Oregon Inlet (a cross-section through the narrowest point of Oregon Inlet) has changed configuration. The profile falls between two extreme shapes. Like the location of Oregon Inlet's shoulders, the shapes are related to stormy and storm-free periods. During relatively storm-free periods when the Bodie Island shoulder is in the shape of an elongated spit, the cross-section of Oregon Inlet is narrow but deep with steep banks. After stormy periods, when Oregon Inlet's shoulders are well-rounded, the configuration is a shallow channel with wide overbanks on one or both sides.

Conveyance (the ability to allow the passage of water) of Oregon Inlet generally has been stable since the most recent closure of New Inlet in 1945. The presence of multiple inlets on an estuary results in the separation of tidal flow volumes through each inlet. After New Inlet's closure, its effect on the behavior of Oregon Inlet was removed. During the past 60-year period, Oregon Inlet's conveyance was computed and found to vary by approximately 36 percent over this time. Changes in the cross-sectional area of Oregon Inlet have ranged from 37,440 to 58,700 square feet (3,480 to 5,450 square meters), an approximate 36 percent difference. Despite the changing shape of Oregon Inlet's cross-section, Oregon Inlet's hydraulic efficiency has been relatively stable.

The inlet cross-sectional area and hydraulic conveyance have decreased, however, since 1996. Since 1996, the cross-sectional area decreased by 29 percent, and the conveyance decreased by 24 percent; however, these values still fall within historical ranges. The groin tends to help create a narrower and deeper inlet.

The location of Oregon Inlet's gorge—or the deepest part of Oregon Inlet's cross-section—at times has remained relatively stable, but there is a constant tendency for the gorge to migrate southward. Dramatic shifts in the location of the gorge appear to be associated with the occurrence of major storms and are accomplished during short time frames. The gorge has tended to remain at the center of Oregon Inlet as the inlet migrates southward. After severe storms, however, when the Bodie Island shoulder has retreated northward substantially, the gorge has not also moved northward any great distance.

The movement of Oregon Inlet's gorge has created difficulty for the USACE in maintaining the navigation channel beneath the Bonner Bridge's navigation span. In the first few years after the completion of Bonner Bridge, the location of the channel through the navigation span was maintained by the natural scouring action of tidal currents. However, beginning in 1968, the shoaling rate for this part of the channel increased markedly as the fully developed sand spit on the Bodie Island shoulder began migrating southward toward the span. Bottom profiles have shown the gorge somewhere other than at the navigation span most of the time since 1971. Furthermore, the movement of the gorge has complicated the maintenance of the ocean bar channel. In 1981, the ocean bar channel adjacent to the south end of Bodie Island began to deteriorate, and a new bar channel formed in a more central location between Oregon Inlet's shoulders. Intense dredging efforts have failed to maintain desired depths for any substantial length of time.

3.6.2.3 Island Shoreline Changes

The island shorelines north and south of Oregon Inlet have eroded generally since the opening of Oregon Inlet in 1846. During the period from 1846 to 1980, both the Bodie Island shoreline and the Hatteras Island shoreline eroded at a rate between 10 and 20 feet (3 to 6 meters) per year. The greatest erosion rates occurred in the immediate vicinity of Oregon Inlet and declined with increased distance from Oregon Inlet.

Storms that occurred between September 9, 1960, and March 28, 1962, which included Hurricane Donna and the Ash Wednesday Storm, produced the most dramatic shoreline responses. The cumulative effect of the two storms was a general recession of the shoreline of both Hatteras and Bodie islands. The average annual erosion during this time (1960 to 1962) was approximately 200 feet (60 meters) per year, except near Oregon Inlet and just to the north on Bodie Island where the erosion averaged 389 feet (119 meters) per year. During severe storms such as Hurricane Donna and the Ash Wednesday Storm, sediment along the beach face generally moves offshore as the beach profile flattens to absorb the increased wave energy. During the recovery stage, sediment migrates onshore back to the upper portions of the beach profile. By October 1965, the recovery stage was basically complete.

During the next 10-year period (1965 to 1975, a relatively calm period), the areas adjacent to Oregon Inlet experienced slight accretion. The accretion along Bodie Island likely was associated with the redevelopment of the Bodie Island spit following the Ash Wednesday Storm.

From 1983 to 1990, there was a large build-up of material on the ocean shoreline of Bodie Island extending about 2 miles (3.2 kilometers) north from Oregon Inlet. Shoreline accretion rates averaged about 180 feet (55 meters) per year directly adjacent to Oregon Inlet from November 1983 through January 1990.

Long-term average annual shoreline erosion rates along Bodie Island were released by the DCM through 1998. Within the first 2.5 miles (4.0 kilometers) north of Oregon Inlet on Bodie Island, the shoreline erosion was estimated to be 2 feet (0.6 meters) per year. Over the first 5.5 miles (8.9 kilometers) of shoreline north of Oregon Inlet, the observed shoreline change rates varied, ranging from 2 feet (0.6 meters) per year to 10 feet (3 meters) per year of erosion. Some areas north of Oregon Inlet have been influenced by beach nourishment projects either for beach protection or dredge disposal.

The shoreline of Hatteras Island near Oregon Inlet experienced severe erosion until the construction of the terminal groin began in 1989. From 1983 to 1989, the shoreline area extending 3 miles (0.9 kilometers) south of Oregon Inlet eroded at an average rate of 33 feet (10 meters) per year. During this period, erosion rates increased substantially in proximity to Oregon Inlet; within 6,000 feet (1,830 meters) of Oregon Inlet, the average erosion rate was 53 feet (16 meters) per year.

Long-term average annual shoreline erosion rates along Hatteras Island through 1998 also were released by the DCM. Within the first 0.5 mile (0.8 kilometers) south of the groin, the shoreline erosion was estimated to be 16 feet (4.9 meters) per year. Over the first 4 miles (6.4 kilometers) of shoreline south of the groin, the observed shoreline change rates were highly variable, ranging from 7 feet (2.1 meters) per year to 16 feet (4.9 meters) per year of erosion. In addition to these accelerated rates of erosion, three hot spots (Canal Zone, Sandbag Area, and Rodanthe 'S' Curves) or areas of concern with regard to beach and dune erosion, as well as highway vulnerability to overwash, were identified south of Oregon Inlet and in the project area. There are six such hot spots identified along the length of NC 12. In these areas, NC 12 is particularly vulnerable to overwash because of narrow beaches and low dune heights. See Section 1.1.3 for an additional discussion of these hot spots. The locations of the three hot spots in the project area are shown in Figure 1-1. A forecast of future shoreline erosion on Hatteras Island in the project area was developed and is discussed in Section 3.6.3.1.

3.6.2.4 Natural Factors Affecting Inlet and Shoreline Changes

<u>Storms</u>

The North Carolina coast is subject to two types of severe windstorms: extra-tropical northeasters and hurricanes. Northeasters, with accompanying high tides and waves, can rapidly erode the shoulders of Oregon Inlet. Northeasters are fairly common in this area, with between 30 and 35 of varying severity hitting the coast each year. Hurricanes may be responsible for major events, such as inlet openings and closings and gorge shifts, but because of their relative infrequency (approximately one hurricane every two years) and the north-northwest/south-southeast barrier island orientation, the overall impact of hurricanes is less significant than northeasters on this section of the coast.

<u>Winds</u>

Water levels in Oregon Inlet are determined mainly by local winds rather than by astronomical tides. Winds produce either an increase or decrease in water levels depending upon wind direction. Westerly and southerly winds substantially increase water levels in Pamlico Sound at Oregon Inlet, while easterly winds produce dramatic reductions in water levels. Storm surges associated with hurricanes and extra-tropical lows have dramatic impacts on Oregon Inlet by generating water level differences between the sound and the ocean, which potentially could be more than 10 feet (3 meters). The maximum sound water level of 7.5 feet (2.3 meters) over mean sea level was recorded during Hurricane Donna, in September 1960; during the Ash Wednesday Storm in March 1962, the maximum ocean surge level of 8 feet (2.4 meters) over mean sea level was recorded.

Currents are mostly wind-determined and have been estimated to have reached a maximum of about 7 feet per second (2 meters per second) at the Bonner Bridge navigation span zone during the Ash Wednesday Storm (1962) and Hurricane Donna (1960), with even higher velocities at other points along the bridge. During model studies conducted by the USACE, a peak velocity of 17 feet per second (5 meters per second) in the Oregon Inlet channel was estimated to result from the combined effort of currents and the water particle velocities associated with passing waves.

Local Wave Climate

Significant wave heights at Oregon Inlet average about 3 feet (0.9 meters), with yearly extreme significant wave heights of at least 10 feet (3.0 meters). Research has indicated that waves of 5 feet (1.5 meters) or higher cause some degree of beach change along the mid-Atlantic coast barrier islands. Wave heights exceeding 5 feet (1.5 meters) occur approximately 10 percent of the time in the project area. The majority of the wave energy at Oregon Inlet comes from the northeast and east directions; this accounts for the southward migration of Oregon Inlet.

Scour

Local scour and the shifting navigational channel within Oregon Inlet often have threatened Bonner Bridge since its construction in 1962. Because of such conditions, numerous retrofits have been built.

Sand Bypassing

Sand is driven naturally by waves and currents along the coast until its movement is interrupted by an obstruction, such as a tidal inlet or a large manmade structure like a jetty. These obstructions tend to trap the sand and can cause the downdrift shoreline to erode because it becomes starved of its former supply of sand. In the case of Oregon Inlet, the downdrift shoreline is along Hatteras Island. Eventually, the obstruction becomes filled with sand and movement resumes. This is known as sand bypassing. For a tidal inlet, a common natural bypassing method is movement of sand along the large ebb tidal shoals that follow a curved path out into the ocean and span from one side of Oregon Inlet to the other. In order to mitigate the effects of man-made structures, natural sand bypassing can be supplemented or assisted by placing sand that is dredged from Oregon Inlet on the beach of the downdrift shoreline.

3.6.2.5 Navigation Channel Dredging Operations

Like all active tidal inlets, Oregon Inlet requires periodic dredging to maintain a navigation channel. In 1950, when the Oregon Inlet ocean entrance channel project was authorized, the channel configuration was specified as 14 feet (4.3 meters) deep at mean low water with a bottom width of 400 feet (122 meters). Maintenance dredging began in 1960, and, since then, the USACE has used hopper, sidecast, and ocean-going pipeline dredges for the work. Large amounts of dredging have been needed on a regular basis. Despite the large-scale efforts, however, the Oregon Inlet channel continues to migrate.

3.6.3 Future Coastal Conditions

Three aspects of future coastal conditions were considered. High erosion (i.e., assuming an erosion rate greater than past trends) Hatteras Island shorelines for 2010 to 2060 (in 10-year increments) were developed primarily as an aid to determining the location and other requirements of the NC 12 maintenance component of the Parallel Bridge Corridor. The potential for a breach to occur in Hatteras Island within the project area was examined so that if a breach was likely, the cost of closing the breach and the economic loss to Dare County until the breach was closed could be considered in project decision-making. Finally, the potential for movement of Oregon Inlet with and without the terminal groin was considered, since that with the Pamlico Sound Bridge Corridor, the groin would no longer be needed to protect the southern terminus of a bridge across Oregon Inlet.

3.6.3.1 Hatteras Island Shoreline through 2060

The forecast 2010 to 2060 high erosion shorelines in the project area on Hatteras Island are shown at 10-year intervals in Figure E-1 of Appendix E. Long-term shoreline change was determined from an analysis of aerial photography and historic topographic sheets from the US Coast and Geodetic Survey dating from 1946 to 2004, a 58 year time period. Linear trends were determined for 106 transects (shoreline location cross-sections) within the project area from northern Rodanthe to Oregon Inlet.

The highest erosion rates occur in the northern Rodanthe area with an average of 11 feet (3.4 meters) per year. In the ponds area, the average rate is 7 feet (2.1 meters) per year. For the area north of the ponds, the erosion rate is approximately 5 feet (1.5 meters) per year.

In order to capture the uncertainty of predicting shoreline locations through 2060 with these data, 95 percent prediction intervals also were calculated from the data (i.e., a range of shoreline locations for which there is a 95 percent chance that the future shoreline will actually lay within these bounds). The width of the prediction interval depended on the variability and quantity of the historical shoreline data at each transect and therefore varied from transect to transect. The spatial average of the prediction interval in 2060 was found to be 240 feet (73.2 meters), with a maximum value of 600 feet (182.9 meters) and a minimum value of about 80 feet (24.4 meters).

The prediction of future shoreline position assumes that the trend in the shoreline change from the historical data will continue for the next 55 years. Because of the complex interactions that cause shoreline change, a high erosion shoreline (i.e., a shoreline that experiences an erosion rate greater than past trends) was assumed in developing alternatives for NC 12 maintenance through 2060. This high erosion scenario is assumed to be the upper bound (or landward extent) of the shoreline position range determined by the mean (average) plus the prediction interval. In addition, highway vulnerability to long-term erosion is defined as being susceptible to flooding and overwash when the distance from the edge-of-pavement to the active shoreline (i.e., the mean high water line) becomes less than or equal to 230 feet (70.1 meters) (i.e., the buffer width between the road and the ocean discussed in Section 2.6.2.1). This distance of 230 feet (70.1 meters) was added to the 2060 high erosion shoreline in order to establish the closest point to the ocean appropriate for NC 12 relocation alternatives. (The 2060 high erosion shoreline was referred to as the “2060 worst-case shoreline” in the SDEIS and SSDEIS.)

High erosion rates, when combined with narrow island widths in several locations, correspond with potential storm-caused Hatteras Island breach locations. The processes described above do not include potential alongshore and cross-shore changes that might occur if a breach forms and is allowed to remain open.

3.6.3.2 Sound-Side Erosion near Oregon Inlet

Erosion on the estuarine side of the terminal groin has developed since 1993. The observed erosion mimics the inner-bank erosion processes found in inlets stabilized with jetties (Seabergh, 2002). The ebb flow (tide returning to ocean) channel on the Hatteras Island side of Oregon Inlet has migrated to be relatively shore parallel. The channel currents have capacity to scour at the base of the rock revetment, the terminus of the protection for Bonner Bridge. The maximum shoreline erosion to 2006 is 275 feet (83.8 meters), and substantial shoreline change extends approximately 1,000 feet (304.8 meters) south of the rock revetment. Similar erosion in stabilized inlets with jetties has been observed to lead to breaching and subsequent isolation of the jetty from the shoreline (Seabergh, 2002).

If this inner-bank erosion continues near Oregon Inlet, it could contribute to breaching and could cause substantial changes in the geomorphology around the inlet. If the breach develops into an inlet just south of Oregon Inlet and isolates the terminal groin, this breach will compete with the existing Oregon Inlet for hydraulic control. In this case, the assumptions associated with the location of the navigation channel, the maintenance dredging required for the desired level of performance, and the long-term erosion expected south of the new inlet would be affected.

This potential for breaching, because of inner-bank erosion, is highly dependent on the characteristics of the ebb and flood (tide coming from the ocean) channels, associated ebb and flood deltas, and the impact these features have on the estuarine shoreline. Both long-term and short-term change resulting from storm events play an important role.

The potential breach can be accounted for in the Parallel Bridge Corridor alternatives that extend the Oregon Inlet bridge south of the inlet (with All Bridge and with Phased Approach [including the Preferred Alternative]) in the design of their substructure. The Pamlico Sound Corridor would bypass this location and associated issue.

3.6.3.3 Accelerated Sea Level Rise

As noted above, the data used to compute the shoreline change rates and the prediction intervals are derived from 58 years of shore line data. Thus any rise in sea level during that time is captured in the data. Data collected from 1978 to 2002 at Duck, North Carolina reveal past sea level rise trends in the area are 4.27 (+/-1.45) millimeters per year (0.17 inches per year, +/- 0.06 inches per year).

The potential for shoreline change because of accelerated sea level rise along the Mid-Atlantic region was recently reported by Gutierrez et al (2007) using four scenarios. The time frame was defined in this report as long-term, or up through the end of this century (i.e., 2100). The scenarios are:

1. A continuation of the 20th century sea level rise rate (accounted for in project shoreline change rates);

2. The 20th century rate + two millimeters (0.08 inches) per year;

3. The 20th century rate + seven millimeters (0.28 inches) per year; and

4. A two meter (6.6 feet) rise over the next few hundred years.

Scenarios 2 and 3 were developed to be within the range of increased rates presented by the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Bindoff et al., 2007) and are the two addressed in this Final Environmental Impact Statement (FEIS). For wave dominated barriers such as Hatteras Island, Gutierrez et al (2007) report that for scenario 2 it is "virtually certain" morphological change such as overwash, erosion and inlet formation will continue, and that it is “very likely” that portions of the barriers will exhibit “threshold behavior.” Indicators of threshold behavior are "a) rapid landward recession of the ocean shoreline, b) decrease in barrier width and height, c) increased overwash during storms, d) increased barrier breaching and inlet formation, and e) chronic loss of beach and dune sand volume." For scenario 3, it is "about as likely as not" that there will be loss of the back barrier marshes and shallow shoals, leading to changes in the hydrodynamic conditions and thus the evolution of the barriers.

During the development of the FEIS, FHWA hosted a Peer Exchange workshop seeking to incorporate recent scientific research on global climate change effects and accelerated sea-level rise into the previous shoreline analysis for this project. The outcome of the Peer Exchange was to identify if any analytical gaps exist between the shoreline erosion forecast conducted for the project (see Section 3.6.3.1) compared to recent and relevant research on global climate change. The Peer Exchange included a panel of coastal engineering and geology experts with knowledge of the local area as well as experts with knowledge of recent research on global climate change. The Peer Exchange panelists agreed that there is not a good predictive model that should be considered further in regards to shoreline change as a result of accelerated sea level rise. Therefore, the best response to considering accelerated sea level rise is to address how the shoreline studies completed for this FEIS reflect the outcomes of accelerated sea level rise. As described in Section 3.6.3.1, the overall approach to the coastal analysis through 2060 in this FEIS takes into account shoreline change predictions based on past conditions and episodic events (e.g., formation of the inlets), data which is based on geologic and geomorphological characteristics, combined with site specific knowledge of the history of the barrier islands. The conditions expected to occur in the shoreline forecasts in this FEIS are precisely those which scenario 2 above considers “virtually certain” to occur (overwash, erosion, and inlet formation). Project planning acknowledges this expected certainty. The effect of uncertainties in determining exact location and timing of shoreline change are addressed to different extents by the detailed study alternatives, as discussed in the impact assessment in Chapter 4.

In the Rodanthe area, the shoreline issues reflected in project planning are consistent with the indicators of "threshold behavior", also a potential partial outcome of scenario 2:

- Rapid landward recession (forecast shoreline change);
- Decrease in barrier width and height, increased overwash, and loss of sand volume (reflected in the potential for storm maintenance activities in the Rodanthe area prior to the completion of the project; and
- The potential for a breach or inlet.

With scenario 3, the characterization is that sea level will rise at such a fast rate that the barrier islands will not have a chance to “roll over.” That is, the naturally expected overwash, deposition on the back barrier, erosion on the oceanside will not occur. Though not stated by Gutierrez et al, (2007), this will lead to further loss of island width and “threshold behavior” leading to island segmentation and disintegration.

3.6.3.4 Potential for Island Breaches

This section addresses potential breach locations, the potential for a breach to open in the project area, potential depth of breaches, and the potential affect of breach formation on coastal change assumptions.

Potential Breach Locations

The starting point for the consideration of potential breach locations was a draft product of the ongoing Coastal Cooperative Research Program, sponsored by East Carolina University, the US Geological Survey, and the North Carolina Geological Survey, which has been intensively studying the northeastern North Carolina coastal system since 2000. This study found that there are five potential breach locations within the Refuge (see Figure E-1 in Appendix E and Figure 2-8). The word "breach" is used rather than the word "inlet" because, if a breach were to occur, it would likely close eventually (although not necessarily immediately) and likely would not become a long-term phenomenon like Oregon Inlet. The one possible exception to this likelihood is Site 5 (described below). Following is a brief description of the characteristics of the five potential breach locations:

- Site 1. A molar-tooth (shaped) marsh platform with sand-filled overwash tidal channels underlies the entire barrier island. This site could open from either the ocean or the sound, with multiple channels that would be 100 to 300 feet (30.5 to 91.5 meters) wide and 10 to 25 feet (3.0 to 7.6 meters) deep (similar to the Hurricane Isabel breach that opened in 2003 at the north end of Hatteras Village).

- Site 2. The historic New Inlet (open during the early twentieth century) and associated flood-tide delta with one large sand-filled inlet channel underlying the entire barrier island. This breach could open from either the ocean or sound, with a single channel that could be 500 to 2,500 feet (152.4 to 762.2 meters) wide and 15 to 35 feet (4.6 to 10.7 meters) deep.

- Site 3. The historic Chickinacommock Inlet (open during the eighteenth and nineteenth centuries) with one large sand-filled inlet channel underlying the entire barrier island. This breach could open from either the ocean or sound, with a single channel that could be 500 to 2,500 feet (152.4 to 762.2 meters) wide and 15 to 35 feet (4.6 to 10.7 meters) deep (similar to the historic New Inlet).

- Sites 4 and 5. A single molar-tooth marsh platform has two sand-filled overwash tidal channels on each side of the platform that probably do not yet underlie the east side of the barrier island. However, in an exceptionally large storm or if Oregon Inlet is stabilized, the flooding or ebbing storm surge could flank the existing inlet channel and open small flanking channels that would be 100 to 300 feet (30.5 to 91.5 meters) wide and 10 to 25 feet (3.0 to 7.6 meters) deep or perhaps deeper adjacent to the terminal groin.

Breaching generally occurs during storm events and results from overtopping from the oceanside, elevated water levels and flow from sound to ocean, and/or seepage and liquefaction. Following a breach, the hydraulics of the system will dictate whether the breach grows into an inlet or whether it naturally closes. Longshore sediment transport (movement of sand along the ocean bottom parallel to the shore) will tend to close the breach, while the tidal exchange will tend to scour out the breach. Assuming that the flux (flow or movement of water) between ocean and sound is in equilibrium before the breach, the new breach will compete with the existing inlets for hydraulic exchange (water movement between the ocean and sound). In other words, the total hydraulic exchange quantified in terms of volume flow rate (e.g., cubic feet per second [meter per second]) could be split between multiple inlets. In addition, since flow rate is the product of average flow velocity times cross-sectional area, a wider inlet with smaller depths and velocity may exchange the same amount as narrower, deeper, higher velocity inlet. How this balance is achieved may either serve to continue the growth of the new inlet while closing down the old inlet, or it may serve to close the breach. A breach in the vicinity of a coastal structure (jetty, terminal groin, etc.) has the potential to undermine the structure and/or isolate it (leave it surrounded by water). If the new inlet grows in size, the navigation channel of the existing inlet will likely shoal at a more rapid rate than previously observed. If the trend continues toward "closure" of the existing inlet, the navigation channel will have to be relocated in the new inlet (Kraus, 2003).

Potential for a Breach to Open in the Project Area

The information from the Coastal Cooperative Research Program provided the starting point for an expert panel that considered the likelihood that a storm would open a breach in Hatteras Island at one of these five locations by 2060. The expert panel also reviewed other models and techniques for inlet prediction and met to reach a consensus estimate on potential inlet formation. The panel members were:

- Dr. Robert Dean, coastal engineer, Professor Emeritus, University of Florida;
- Dr. Robert Dolan, coastal geologist, Professor, University of Virginia;
- Mr. Carl Miller, research oceanographer, Field Research Facility, USACE, Duck, North Carolina;
- Mr. Michael Wutkowski, coastal engineer, Wilmington District, USACE;
- Dr. Stanley Riggs, coastal geologist, Professor Emeritus, East Carolina University;
- Dr. Margery Overton, coastal engineer, FDH Engineering/Professor, North Carolina State University;
- Mr. Tom Jarrett, coastal engineer, FDH Engineering, recently retired head of the Coastal Processes Branch, Wilmington District, USACE; and
- Dr. John Fisher, coastal engineer, FDH Engineering/Professor, North Carolina State University.

Prior to the meeting of the expert panel, members were sent the recent potential inlet report prepared by Dr. Riggs as well as a paper written by Mike Wutkowski on the Hatteras Village breach closure. In addition, the panel was sent an overview of the problem and the objectives of the meeting.

There was general agreement that there is a risk of a storm-related breach forming in the southern part of the Refuge (Site 3) prior to 2060. In addition, a storm event of the nature required to create a breach would probably occur once during that period. The southern part of the Refuge is the location of a prior inlet, and this part of the island is very narrow with relatively small dunes. There is also a relic channel across the estuarine marsh.

There was little panel agreement for a storm-related breach to develop at the other potential locations in the next 50 years. The panel noted that there are several factors that might preclude the occurrence of a storm-related breach at any site other than the southern part of the Refuge. These factors include the proximity to Oregon Inlet, that the Rodanthe site is the weakest section, and the current shoaling in Pamlico Sound (e.g., Oregon Inlet Shoal, see Figure 3-7 in Section 3.7.2.1) at the north end of Hatteras Island because of the shift in the channel through Oregon

Inlet. Dr. Dean noted that beach nourishment would greatly reduce the potential for breach formation.

At Site 5 near Oregon Inlet and the terminal groin, erosion on the estuarine (sound) side of the terminal groin has been observed since 1993. The observed erosion mimics the inner-bank erosion processes found in inlets stabilized with jetties (Seabergh, 2002). The ebb flow (water flow back towards the ocean) channel on the Hatteras Island side of the inlet (Davis Slough) has migrated to be relatively parallel to the shore. The Davis Slough channel's currents provide the capacity for scour at the base of the rock revetment protecting the southern terminus of Bonner Bridge. As indicated by Seabergh, if left "unabated, a crenulated [notched or scalloped] shaped shoreline region will develop from the terminus…" The maximum shoreline erosion to date is 275 feet (83.8 meters), and substantial shoreline change extends approximately 1,000 feet (304.8 meters) south of the rock revetment. Similar erosion in stabilized inlets with jetties has been observed to lead to breaching and subsequent isolation of the structure from the shoreline (Seabergh, 2002). If this inner-bank erosion continues, the immediate vicinity of the terminal groin (the northern portion of Site 5) will become more vulnerable than was concluded by the panel. This potential for breaching because of sound-side erosion at Site 5 in the immediate vicinity of the terminal groin is highly dependent upon the characteristics of the ebb and flood (flowing in of the tide) channels and associated ebb and flood deltas (area of sediment deposits) and the impact these features have on the estuarine shoreline. Both long-term (e.g., erosion) and short-term change because of storm events are important.

Shoreline change on the ocean side at Site 5 is also dependent on the natural inlet processes, as well as on the continuity of USACE's maintenance dredging and disposal program for Oregon Inlet. Accretion of the shoreline has occurred just south of Oregon Inlet since 1993, and this accretion is reflected in the shoreline model used to determine the future shoreline positions described in Section 3.6.3.1. Two features serve to promote accretion in this location. One is the disposal of dredged material in this location by the USACE. The USACE placed dredged material in this location in 1991 and in 2004. Two additional times, sand has been placed just south of Site 5, potentially supplying sand to Site 5 to the north. Longshore sediment transport is south to north in the vicinity of the terminal groin. Evidence of this is seen in the material deposited on the inlet side of the terminal groin. In addition, the USACE has placed dredged material in the nearshore off of Hatteras Island, effectively bypassing sand around the inlet and keeping it within the littoral system. These features provide a sediment rich environment on the ocean side of Site 5, serving to reduce the vulnerability of this location to a breach because of ocean overwash, where as noted in the previous paragraph, soundside erosion increases the vulnerability for a breach near the terminal groin.

Potential Depth of Breaches

The tidal prism is the volume of water moving through an inlet between high and low tides (or alternatively low and high tides). If Hatteras Island is breached, the relationship between the tidal prism and the cross-sectional area of flow in Oregon Inlet will be altered. Opening a breach will increase the inlet cross-sectional area of the two inlet system and will tend to decrease the velocities in the existing inlet (Kraus and Wamsley, 2003). It is not possible to precisely predict the depth and cross-sectional areas of the potential breaches given the unknowns (e.g., magnitude and duration of the storm, storm track, water elevation in the sound) related to the storm scenarios that might trigger a breach. Further, breaches have been documented to grow in depth and width after opening.

Documentation of breaching on Hatteras Island indicate varied depth responses. The breach on Hatteras Island that opened near Hatteras Village as a result of Hurricane Isabel in 2003 developed three channels that were truncated by more resistant peat filled deposits in between the channels. The west channel developed depths of 8 to 10 feet (2.4 to 3.0 meters), the middle channel approximately 5 feet (1.5 meters), and the east channel up to 20 feet (6.1 meters) before it was closed (Wamsley and Hathaway, 2004). Just north of Buxton, the Ash Wednesday storm opened a breach (Buxton Inlet) which developed depths of 8 to 11 feet (2.4 to 3.4 meters) before being closed (Wamsley and Kraus, 2005).

A review of historic US Coast and Geodetic Survey Hydrographic charts available through National Oceanic and Atmospheric Administration (NOAA) Historical Map and Chart Project reveals one chart with depth soundings during a period when both Oregon Inlet and New Inlet were open. At that time, 1913, Oregon Inlet is mapped with maximum depths of 4 fathoms (24 feet/7.3 meters) while New Inlet has a maximum depth of 2.5 fathoms (15 feet/4.6 meters). Later charts (1932, 1933) show New Inlet to be closed but indicate up to 11 feet (3.4 meters) of depth in the sound side channel associated with the historic location of New Inlet. The 1942 charts show New Inlet to be open, but no soundings are charted within New Inlet or the remnant sound side channels. Oregon Inlet is charted with a maximum depth of 32 feet (9.8 meters).

Recent experience with barrier breaching on Hatteras Island, as well as the documented relationship between Oregon Inlet and New Inlet (and assuming similar storm characteristics), suggest that expecting up to 10 to 20 feet (3.0 to 6.1 meters) post-storm depths in the three potential inlet sites (i.e., Sites 1, 2, and 3) from Rodanthe to the New Inlet area south of the Refuge's ponds would be reasonable given the range of what has been observed. At the northern-most sites, as described in Section 3.6.3.2, inner-bank erosion near Oregon Inlet could contribute to breaching and could cause substantial changes in the geomorphology around the inlet. If the breach develops into an inlet just south of Oregon Inlet and isolates the terminal groin, this breach will compete with the existing Oregon Inlet for hydraulic control. In this case, depths of a breach at the north end of Hatteras Island would be similar to depths experienced in Oregon Inlet.

Effect of Breach Formation on Coastal Change Assumptions

If breaches at Sites 1, 2, or 3 were to remain open, they would compete hydraulically with Oregon Inlet; however, the separation distance between the inlets would affect how the flow patterns between the ocean and the sound would be reestablished. In addition, the location of the throat of the inlet and the influence of the inlet on the up and downdrift beaches would affect predicted shoreline change. Shoreline change estimates presented in Section 3.6.3.1 would have to be reconsidered once a new dynamic is achieved. As noted in the previous section, Site 3 is the most likely location for a future storm-related breach.

Site 4 is close enough to Oregon inlet to compete for hydraulic exchange and thus potentially change the preferred location for maintaining a navigation channel. Further, shoreline change estimates between Oregon Inlet and an inlet at Site 4, as well as the area south of Site 4, would be affected by the opening of a breach at Site 4. However as noted in the previous section, the likelihood of an inlet forming in this location is thought to be less than other locations. In addition, a comparison of 1993 and 2006 aerial photographs indicates that sound-side erosion has not occurred in the Site 4 area since 1993 to the extent it has at Site 5.

For Site 5, the close proximity of the potential breach to the terminal groin suggests that an opening in that location could affect the performance of the terminal groin in terms of accelerated destabilization and increased costs of repair, as well as result in increased costs for channel maintenance dredging and loss of navigability in Oregon Inlet (based on Kraus and Wamsley's list of ten impacts of an unintended breach in a barrier island, 2003). A breach from the sound side just south of Oregon Inlet (Site 5) could cause substantial changes in the geomorphology (development of the land forms) around Oregon Inlet, particularly if the breach isolates the terminal groin from Hatteras Island and the existing channel shoals (fills in or becomes more shallow). Thus, unlike other potential breach locations, a breach at this location is more likely to become permanent and deep. In this case, the assumptions associated with the location of the navigation channel, the maintenance dredging required for the desired level of performance, and the long-term erosion expected south of the new inlet would necessarily change.

3.6.3.5 Oregon Inlet Movement Through 2085

As described above, the Oregon Inlet area is highly dynamic. In order for a replacement crossing to be sited properly in either of the project corridors, future inlet migration, shoreline erosion/ accretion, and channel movement and depth must be predicted, taking into account naturally occurring and man-induced influences.

The permit from the Refuge that allowed the construction of the terminal groin states that the purpose of the terminal groin is to: "…protect the southern segment of the existing Herbert C. Bonner Bridge and its southern approach of North Carolina Highway 12." The permit also states that the NCDOT can use the lands and waters occupied by the terminal groin for as long as they "are used for the purpose granted." The NCDOT has no current plans to remove the terminal groin on Hatteras Island after Bonner Bridge is demolished. If an Oregon Inlet bridge were built in the Parallel Bridge Corridor, the groin would be needed to protect its south approach, just as it currently protects Bonner Bridge's south approach. If a bridge were built in the Pamlico Sound Bridge Corridor, the terminal groin could serve parties other than the NCDOT and other immediate needs besides protecting Bonner Bridge or its replacement. It is conceivable, however, that circumstances could change at some time in the future, and it could prove prudent to remove the terminal groin if the Pamlico Sound Bridge Corridor is used for the replacement bridge. A new Special Use Permit for the retention of the terminal groin and revetment would be required if it is to remain in place with any of the replacement bridge corridor alternatives once Bonner Bridge is demolished. Without a new permit, the NCDOT would be obligated under the terms of the existing permit to remove the terminal groin and revetment two years after the construction of a replacement bridge at the request of the USFWS.

Thus, the effects of both the continued presence and the removal of the terminal groin on Oregon Inlet were examined, and these would be considered when placing the navigation zone as described for the proposed bridge in the Pamlico Sound Bridge Corridor in Section 2.9.2. For the Oregon Inlet bridge in the Parallel Bridge Corridor, the navigation zone would span much of Oregon Inlet. Findings presented below are based entirely on engineering judgments derived from a critical review of the information presented in the report, *Bonner Bridge Replacement: Oregon Inlet Movement Consideration* (Moffatt & Nichol, September 25, 2003). No quantitative analyses or numerical modeling were performed. At the time of the study in 2003, it was assumed that if a bridge were build in the Pamlico Sound Bridge Corridor that the project would be complete by 2010 and the groin removed at that time. The findings of the post-groin removal Oregon Inlet movement trends described in this section would begin in whatever year the groin would be removed and the constraint on inlet movement applied by the groin is released.

<u>*Oregon Inlet Conditions with the Terminal Groin*</u>

As of March 2002, the Bodie Island spit has migrated almost two-thirds across the preferred natural channel alignment projecting from the navigation span of Bonner Bridge. Between 1999 and 2001, the channel gorge at the narrowest cross-section had moved south approximately 830 feet (250 meters). If left unattended, the migration of Bodie Island likely will engulf the existing navigation span and channel, and scour could become a potential threat at the terminal groin on

Hatteras Island. The rate of spit movement could not continue to be as great as 886 feet per year (270 meters per year) (see Section 3.6.2.1) over the next 10 to 15 years with the terminal groin remaining in place. At that rate, Oregon Inlet, which is approximately 2,000 feet (610 meters) wide, would have closed within only three years.

Until the proposed project is completed, it is assumed that the USACE will use dredging to maintain the navigation channel by trimming off the end of the Bodie Island spit. This will result in Oregon Inlet maintaining an almost constant width of 2,000 feet (610 meters), assuming no major storm activity. Oregon Inlet dredging will help to channel a large volume of water through the navigation span section, thereby increasing water velocities at that location and reducing the propensity for Oregon Inlet's gorge to move farther south toward the terminal groin. The gorge depth should remain generally constant barring any extreme storm activity.

After the construction of the proposed project, it is assumed the USACE will cease to dredge a channel at the Bonner Bridge navigation span, given the flexibility of either the long navigation zone with the Parallel Bridge Corridor or the lack of a navigation span in Oregon Inlet (but rather further back in Pamlico Sound) with the Pamlico Sound Bridge Corridor. As a result, Oregon Inlet likely will narrow slightly, but it is not expected to close completely because of the tidal prism that must continue to pass through Oregon Inlet. Also, the gorge might re-establish its historical migration southward toward the terminal groin.

<u>Short-Term Impacts of the Removal of the Terminal Groin</u>

Should the terminal groin be removed at some point after completion of a bridge in the Pamlico Sound Bridge Corridor, the ocean shoreline could respond initially by adjusting back to a position that corresponds to a continuation of historic trends. This means that substantial shoreline erosion could occur on the northern end of Hatteras Island. Since Oregon Inlet is currently very narrow compared to historical trends, Oregon Inlet likely would widen and become shallower, while maintaining a consistent conveyance as it has done throughout its existence. The average width after the closure of New Inlet—and prior to the construction of the groin—was approximately 3,925 feet (1,200 meters) based on available historical data. If Oregon Inlet were to revert to its historical migration patterns, and assuming that there is no substantial erosion on the Bodie Island spit, the Hatteras Island shoulder might migrate south nearly 2,000 feet (610 meters) to assume an average width similar to those prior to the construction of the terminal groin. This trend could be accelerated by storm events, which historically have caused Oregon Inlet to widen and shallow. Conversely, if this period were relatively storm-free, this reversion to a wider inlet could be mitigated. Thus, the period for this to occur is unpredictable because of the randomness of such events. Figure 3-6 illustrates the predicted short-term migration of Hatteras Island. It first shows the history of movement for the Bodie Island shoulder, the mid-point of Oregon Inlet, and Hatteras Island from 1930 to the current time. It shows that Hatteras Island stopped its movement when the terminal groin was constructed. After the completion date of a bridge in the Pamlico Sound Bridge Corridor, the figure shows first the potential short-term movement of Hatteras Island as described above.

As stated previously, the movement of Oregon Inlet's gorge has created difficulty for the USACE in maintaining the navigation channel beneath the Bonner Bridge's navigation span. The removal of the terminal groin would pose new challenges for maintaining the current navigation channel because of probable inlet migration.

<u>Long-Term Impacts of the Removal of the Terminal Groin</u>

If the terminal groin is removed, Oregon Inlet eventually would be expected to revert to historical migration trends. Since the closure of New Inlet (and in the 15 years prior to its closure), Oregon

Inlet followed a nearly linear migration pattern with the exception of the Ash Wednesday Storm in 1962. The Hatteras Island shoulder has migrated in a linear (i.e., constant) fashion over the last 70 years (within ± 1,500 feet [460 meters] for a 3,000-foot [910-meter] total range). With the exception of the migration after the Ash Wednesday Storm of 1962, the entire inlet has migrated linearly (within ± 1,700 feet [520 meters] for a 3,400-foot [1,040-meter] total range). Figure 3-6 depicts the linear migration of Oregon Inlet over the last 70 years.

Figure 3-6 also illustrates the potential migration of Oregon Inlet through 2090. It illustrates the potential short-term and maximum long-term location of the north end of Hatteras Island, assuming both the retention of the terminal groin and a return to past trends should the groin be removed.

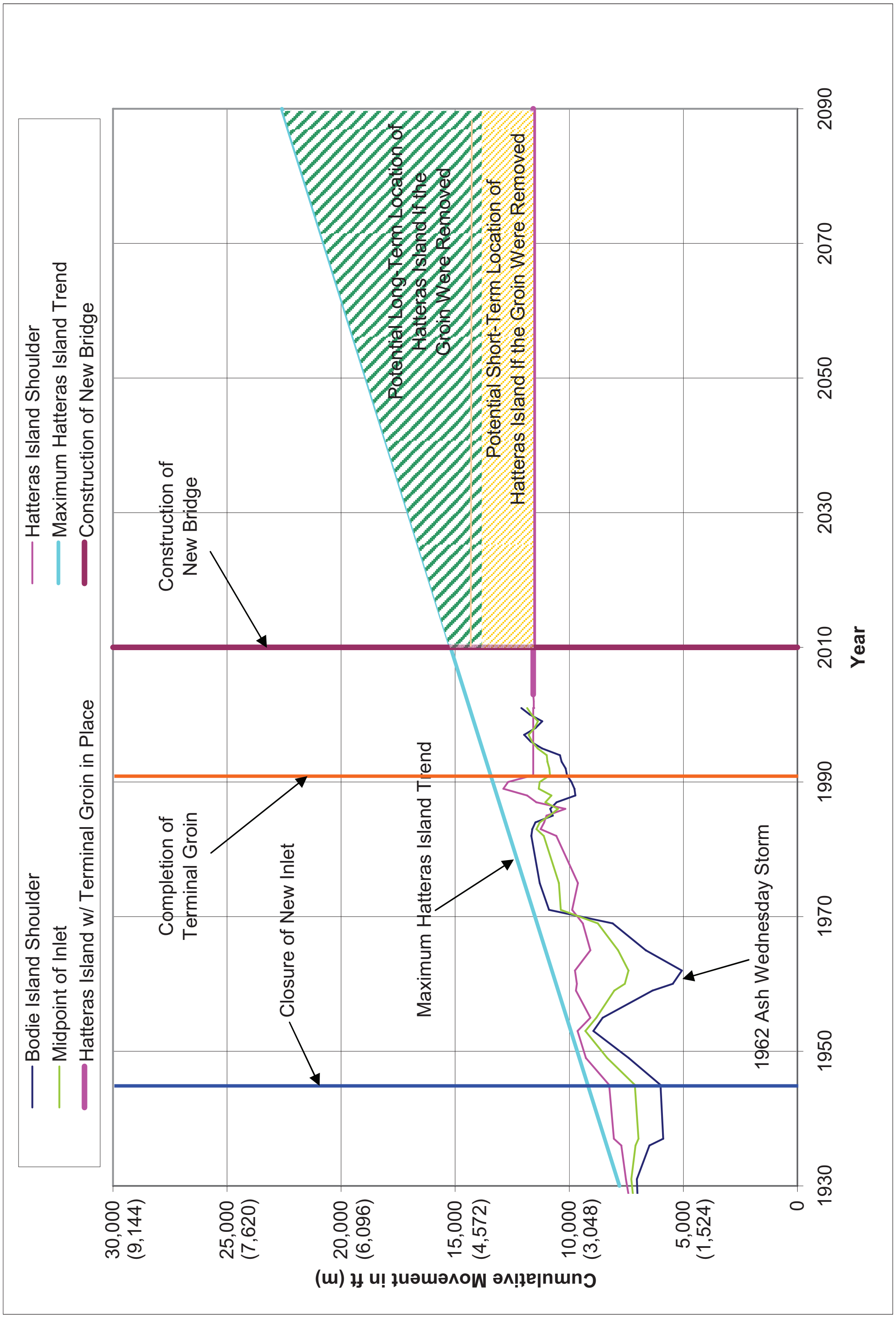
The movement south of the northern end of Hatteras Island over the life of a Pamlico Sound bridge would be the greatest if the groin were removed shortly after the bridge opens. For example, if the groin were removed 3 years after the bridge opens, and Oregon Inlet began to migrate in the same linear fashion as it did before the groin was built, then 50 years after the bridge opens, the Oregon Inlet shoulders of Hatteras and Bodie islands would migrate between 4,600 and 8,000 feet (1,400 and 2,440 meters) south. (This range represents the ± 1,700-foot [520-meter] deviation.) After 75 years, Oregon Inlet would have migrated between 6,900 and 10,300 feet (2,100 and 3,140 meters) south. (This range also represents the ± 1,700-foot [520-meter] deviation.) This example represents a "worst-case" situation, which is prudent to consider in long-range planning. It does not represent FHWA's and NCDOT's present expectations or their intent to remove the groin. If USFWS officials ask the NCDOT to remove the groin following completion of the demolition and removal of Bonner Bridge, the NCDOT and representatives of the USFWS would assess the impacts of groin removal in a separate environmental study, as needed, prior to any final decision to remove the terminal groin.

If Oregon Inlet were to migrate between 6,900 and 10,300 feet (2,100 and 3,140 meters) south, it would be located in the north pond of the Refuge, which is also just behind the Canal Zone hot spot. If Oregon Inlet migrates in a southward direction, another channel, Davis Channel (Slough), could become the more-preferred flow pattern, since it is already substantially deep and a notable connection of Oregon Inlet to Pamlico Sound. According to a 2001 survey, Davis Channel depths reached almost -50 feet (-15 meters) NAVD-88.

Relation of Hatteras Island Change to Navigation Zone Location with the Pamlico Sound Bridge Corridor

One navigation zone would be built for a bridge in the Pamlico Sound Bridge Corridor to serve boats passing through Oregon Inlet. The location of the zone would be determined in coordination with the USACE and the US Coast Guard. The USACE currently maintains the Oregon Inlet/Old House navigation channel. As discussed above, movement of Oregon Inlet over the life of the bridge could shift the natural channel gorge to the Davis Channel area. This eventuality would be addressed in conversations with the USACE. The NCDOT's goal would be to place the navigation zone of the bridge in a location that facilitates channel maintenance over the full life of the bridge.

Figure 3-6. Historic and Predicted Migration of Oregon Inlet



4.5.4 Pamlico Sound Recreational Use Impacts

For recreational users of the Pamlico Sound, such as wind surfers, kayakers, and kite boarders, the Pamlico Sound Bridge Corridor would place an obstruction in the Sound as the bridge moves from shore at Rodanthe to a point approximately 5 miles (8 kilometers) west of Hatteras Island where the bridge corridor then would proceed north. The ability of recreational users to pass from one side of the bridge approach to the other, particularly for wind surfers and kite boarders, would be limited by its 140- to 150-foot (42.7- to 45.7-meter) span length between piers and vertical clearance of approximately 10.0 feet (3.1 meters) above mean high water (outside the navigation zone).

The Parallel Bridge Corridor with Road North/Bridge South and All Bridge alternatives also would place an obstruction in the Sound as the Rodanthe area bridge moves out from shore in the Refuge to a point about 1,500 feet (480 meters) west of Hatteras Island. This bridge would have a 100-foot (30.5- meter) span length between piers and vertical clearance of approximately 10.0 feet (3.1 meters) above mean high water. Because of this bridge's close proximity to the shore, the impacts to recreational users would be more substantial. The Nourishment Alternative and the two Phased Approach alternatives (including the Preferred Alternative) would not affect the use of Pamlico Sound.

Numerous additional opportunities exist for these activities, however. Near the project area, these activities occur primarily south of the replacement bridge corridor alternatives.

Near the northern end of the Pamlico Sound Bridge Corridor, activities such as windsurfing, kayaking, and kite boarding are not common; the Pamlico Sound Bridge Corridor would not affect these non-motorized watercraft activities in this area. This area of the Pamlico Sound is used primarily for fishing and by other commercial and recreational vessels (see Section 4.1.7).

The No-Action Alternative would not affect the use of Pamlico Sound but would remove roadway access across Oregon Inlet to Hatteras Island. This change would dramatically lessen the ability of visitors to reach all recreational resources on Hatteras Island.

4.6 Coastal Conditions

This section discusses the impact of the detailed study alternatives on coastal conditions from the perspective of: inlet migration, profile, and gorge alignment; flooding during major storms; performance of the terminal groin; navigation channel dredging operations; natural overwash; island breach in the Refuge; and off-shore coastal processes (with the Phased Approach alternatives [including the Preferred Alternative]).

4.6.1 Inlet Migration, Profile, and Gorge Alignment

A bridge within the replacement bridge corridor alternatives would have a negligible effect on Oregon Inlet migration, profile, and gorge alignment other than the continued effect of the presence of the terminal groin with the Parallel Bridge Corridor alternatives (including the Preferred Alternative). These processes are driven by the movement of sediment along the ocean shoreline and tidal hydraulics processes within Oregon Inlet. A bridge within the replacement bridge corridor alternatives would represent a very minor additional component in the Oregon Inlet system, especially considering there is already a bridge within the inlet. In any case, storm events that typically cause the major adjustments to the inlet through increased wave activity and water flows would vastly overshadow any minor effects the proposed bridge in Pamlico Sound or across Oregon Inlet might have on inlet processes.

4.6.2 Flooding During Major Storms

All of the replacement bridge corridor alternatives, as well as the existing Bonner Bridge and NC 12, are within the floodplain discussed in Section 3.6.1. In addition, all of the replacement bridge corridor alternatives, as well as the existing Bonner Bridge and NC 12, are partially within coastal flood zones with a velocity hazard because of wave action. According to Federal Emergency Management (FEMA) floodplain maps (Figure 3-4), all of the Parallel Bridge Corridor alternatives would be subjected to wave heights as high as 11 feet (3.4 meters) over Oregon Inlet and in several other locations along the corridor, but could be subjected to wave heights as high as 13 feet (4.0 meters) near the southern end of South Pond. Existing Bonner Bridge and NC 12 also are subject to the same wave heights. The Pamlico Sound Bridge Corridor alternatives would be subjected to wave heights as high as 10 feet (3.0 meters) in Pamlico Sound near their southern terminus in Rodanthe.

4.6.2.1 Significant Encroachment

FHWA policies and procedures for the location and hydraulic design of highway encroachments on floodplains are defined in 23 CFR 650, Subpart A (Location and Hydraulic Design of Encroachments on Floodplains). With respect to floodplain highway encroachments, it is the policy of the FHWA "to avoid significant encroachments, where practicable." According to 23 CFR 650, Subpart A:

> "*Significant encroachment* shall mean a highway encroachment and any direct support of likely base floodplain development that would involve one or more of the following construction or flood-related impacts:
>
> – A significant potential for interruption or termination of a transportation facility which is needed for emergency vehicles or provides a community's only evacuation route;
>
> – A significant risk, or;
>
> – A significant adverse impact on natural and beneficial floodplain values."

<u>Transportation Facility Interruption</u>

All of the proposed replacement bridge corridor alternatives, as well as existing NC 12 through the project area, meet the definition of "significant encroachment" in that they include a road at an elevation below the storm surge. This also is true for the balance of Hatteras Island and the development served by NC 12. However, all of the proposed replacement bridge corridor alternatives would reduce the risk of NC 12 overwash and temporary closure within the project area in comparison to the risk that exists today through (depending on the alternative) beach nourishment, road relocation back from the shoreline, and bridging. The use of a bridge to replace parts of the existing NC 12 road with the Pamlico Sound Bridge Corridor, All Bridge, and Phased Approach alternatives (including the Preferred Alternative) would raise those parts of NC 12 above the storm surge. They also would either bypass or bridge potential Hatteras Island breach locations within the project area. All of the bridges, however, ultimately end at existing NC 12 below the storm surge, including the ends of the bridges on Bodie Island and Hatteras Island, and the 2.1- to 2.3-mile (3.3- to 3.7-kilometer) segment of NC 12 unchanged by the Parallel Bridge Corridor alternatives.

Dare County recognizes the risks associated with the storm surge and has an emergency management program that tracks storms and orders the voluntary evacuation of Hatteras Island and the entire Outer Banks prior to a storm surge. Dare County also has a helicopter to transport patients to area hospitals if NC 12 is severed as a result of a storm. NCDOT maintains emergency ferry docks and a channel across Pamlico Sound between Rodanthe and Stumpy Point to provide an alternate route of travel if NC 12 is severed between Rodanthe and Oregon Inlet. NCDOT has the capability and does mobilize equipment needed to begin re-opening NC 12 immediately after a storm passes.

Significant Risk

None of the alternatives would create a significant risk beyond risks associated with development on the Outer Banks that exist today. Risks on the Outer Banks are associated with storms and their consequences. All of the alternatives (including the Preferred Alternative) were developed taking into account the presence of storms and their potential impact on island change and the integrity and operation of the alternatives. The bridge superstructure associated with the replacement bridge corridor alternatives (including the Preferred Alternative) would be elevated above the highest potential water level.

The alternatives do vary in terms of their mitigation of the risk of NC 12 being closed as a result of an island breach. The Pamlico Sound Bridge Corridor alternatives would bypass potential breach locations. The Parallel Bridge Corridor with All Bridge and Phased Approach Rodanthe Bridge (Preferred) alternatives both bridge potential breach locations. Section 4.6.7 discusses in detail the relationship between all of the alternatives and the potential breach locations.

Impact to Beneficial Floodplain Values

Beneficial floodplain values were described in Section 3.6.1. The replacement bridge corridor alternatives would not have a significant adverse impact on natural and beneficial floodplain values.

The piles of the bridge substructure would not affect existing hydraulics, since the size of Pamlico Sound and the low water velocities would combine to create a situation where the small area blocked by the alternatives would not create backwater or adverse hydraulic conditions.

From the perspective of the beneficial floodplain values associated with natural barrier island evolution, as well as the ecological change and habitat creation associated with barrier island evolution, most of the alternatives (including the Preferred Alternative) would benefit these values. Except for the alternatives that involve the retention of the artificial dunes (Parallel Bridge Corridor with Nourishment and to a limited extent the Road North/Bridge South and Phased Approach/Rodanthe Nourishment alternatives), the project alternatives would restore natural shoreline overwash, as discussed in Section 4.7.7.

4.6.2.2 Only Practicable Alternative Finding

According to 23 CFR 650, Subpart A, a proposed action which includes a significant encroachment shall not be approved unless the FHWA finds that the proposed significant encroachment is the only practicable alternative. Practicable replacement bridge corridor alternatives must be within the floodplain because the area to be served, as specified in the project's Statement of Purpose and Need in Chapter 1, is within the floodplain. As such, alternatives that do not involve a significant encroachment were not considered. The replacement bridge corridor alternatives conform to applicable State and local floodplain protection standards because they would not affect the storm surge elevation.

4.6.3 Performance of the Terminal Groin

The performance of the terminal groin would not be affected by any of the replacement bridge corridor alternatives or the No-Action Alternative. With the Pamlico Sound Bridge Corridor and the No-Action Alternative, there would no longer be a bridge landing on the north end of Hatteras Island, so the terminal groin no longer would be needed (the stated purpose for the groin in the USFWS permit that allowed the groin's construction is to protect the south end of Bonner Bridge). If USFWS officials ask the NCDOT to remove the groin following completion of the demolition and removal of Bonner Bridge, the NCDOT and representatives of the USFWS would assess the impacts of groin removal in a separate environmental study, as needed, prior to any final decision to remove the terminal groin.

With the Parallel Bridge Corridor, the terminal groin would need to be retained to protect the road south of the southern terminus of the new Oregon Inlet bridge. The NCDOT would apply for a new permit for any of the Parallel Bridge Corridor alternatives (including the Preferred Alternative). Hydraulic analyses associated with the design of the Parallel Bridge Corridors alternatives that include bridges through the northern part of Hatteras Island would incorporate the potential for either the eventual terminal groin removal or the groin's flanking. The potential affect of groin removal or flanking on Hatteras Island is addressed in Section 3.6.3.5.

4.6.4 Navigation Channel Dredging Operations

A replacement bridge within either of the replacement bridge corridors would make navigation channel dredging operations easier to undertake by reducing the frequency and size of dredging operations from what is required today.

The proposed bridge in either corridor would have one navigation zone (see Section 2.9.2) for boats passing through Oregon Inlet.

The proposed bridge in the Pamlico Sound Bridge Corridor and its navigation zone would be west of Oregon Inlet in Pamlico Sound, where sand movement is less. This change alone could reduce the amount of dredging required to maintain a channel through Oregon Inlet compared to the existing situation with Bonner Bridge. The location of the zone would be determined in coordination with the USACE. The USACE currently maintains the Oregon Inlet Channel/Old House Channel. As discussed in Section 3.6.3, movement of Oregon Inlet over the life of the proposed bridge could shift the natural channel gorge to the Davis Channel area. This eventuality would be addressed in conversations with the USACE. The NCDOT's goal would be to place the navigation zone of a bridge in the Pamlico Sound Bridge Corridor in a location that facilitates channel maintenance over the full life of the bridge.

A bridge across Oregon Inlet in the Parallel Bridge Corridor would have a series of navigation spans (or zone) with a minimum 200 feet (61 meters) of horizontal clearance. The main navigation span of Bonner Bridge has 130 feet (39.6 meters) of navigation clearance. The navigation zone on Bonner Bridge is 504 feet (153.6 meters). With the two Phased Approach alternatives (including the Preferred Alternative), that navigation zone would be 3,300 feet (1,006 meters) long. With the other Parallel Bridge Corridor alternatives, the zone would extend across the width of the inlet (up to 5,000 feet [1,524 meters]). The shorter distance with the Phased Approach alternatives is necessitated by the inclusion of ramps accessing the north end of Hatteras Island from the alternative's bridges. Bonner Bridge is limited to three navigation spans. A longer navigation zone provided by the Parallel Bridge Corridor alternatives would allow the dredged navigation channel to be placed more readily at the natural inlet gorge and likely would reduce the amount of dredging at both the bridge and within the throat of the inlet, where a natural gorge exists. This benefit would be greater with the longer navigation zone associated with the Nourishment, Road North/Bridge South, and All Bridge alternatives.

With all alternatives, some additional dredging west of existing Bonner Bridge could be required to connect the natural inlet gorge to the channels maintained within Pamlico Sound in cases where the natural inlet gorge moves well beyond the location of Bonner Bridge navigation spans. In those cases, the USACE would have to determine, based on experience, whether it would be easier or more efficient to extend the back channels by dredging to meet the natural inlet gorge, or to force the inlet channel to take a different path than it might otherwise take on its own. The best strategy to be followed at any given time would depend on the complex and ever changing variation in shoal and channel locations that will naturally occur on the soundside of the Parallel Bridge Corridor. The greater latitude in potential channel locations that the Parallel Bridge Corridor would allow, however, would result in a net decrease in the dredging effort within the inlet.

The ocean bar channel dredging, which accounts for the majority of the dredging at Oregon Inlet, would not be affected by either of the replacement bridge corridor alternatives or the No-Action Alternative.

4.6.5 Natural Overwash

Overwash is the natural landward transport of sand and water. The deposit is called a washover fan. Overwash is a storm generated process that serves a critical function in barrier island evolution, as it is the source of sand for the soundside of the island. In this way, sand is removed from the beach and dune system and builds up on the soundside. The length of penetration of a washover fan is a function of the sediment supply, storm characteristics, and topography. Overwash occurs where the island is low relative to the storm surge/wave run-up and/or where breaks in the dune system create conduits for flow to be funneled from the oceanside landward. The dune breaks may be present before the storm or may develop during the storm as the dune erodes from the oceanside. The washover fan provides not only elevation through sediment deposition, but it creates new habitat by covering existing habitat and providing a bare sand flat for new populations. Removing sand from the washover interrupts the process of barrier island rollover by putting the sand back in the dune system.

As is evident in NC 12 maintenance activity data from NCDOT, overwash has become a substantial factor in determining the need for maintenance. Twelve cleanup projects since 2003 have been attributed to overwash, primarily in the Canal Zone, Sandbag, and Rodanthe 'S' Curves hot spots. In order to minimize the impact of NC 12 on overwash processes, the road could either be moved landward beyond the point of expected washover or elevated. The following alternatives would minimize the affect on overwash fans through at least 2060:

- Pamlico Sound Bridge Corridor alternatives, since they remove NC 12 from Hatteras Island north of Rodanthe.

- Parallel Bridge Corridor with Road North/Bridge South, since it moves NC 12 beyond the 2060 high erosion shoreline at the north end of Hatteras Island and places NC 12 on a bridge at the south end of the project area, with the exception of three locations where dunes are proposed late in the project's design life.

- Parallel Bridge Corridor with All Bridge and Phased Approach alternatives (including the Preferred Alternative) (in bridging areas) by placing NC 12 on a bridge through most of the project area. In the case of the Phased Approach, interruption of overwash fans could occur until each Phase is implemented, as discussed in Section 4.6.8.6.

With NC 12 on bridges, the piles supporting the structure would interfere locally with the overwash; however, the overall structure would be very porous, and the overall impact should be restricted to the areas around the piles. The overwash would be streamlined between the pilings in a group where the velocities would be slightly greater than the velocities away from the group because of flow constriction. This might serve to create points of greater landward penetration resulting from higher flow velocities, which would correspond to each bridge foundation. There also would be some local scour around the piles providing an additional source of sand for the washover fan. Once the road is elevated, there would be no need to remove the sand from the washover and rebuild the dune.

The alternatives that would involve nourishment and extensive dune building also would interrupt the overwash process. When overwash occurs, the replacement of sand on the dunes would interrupt the overwash process; the impact could be reduced by removing the sand from the road (defined to be pavement and easement), but leaving the washover fan created landward of the NC 12 right-of-way. Not as much sand then would be available for post storm dune repairs, thereby leaving the road more vulnerable to overwash in the next event. The road could then require more extensive post storm repairs as a result of the weir flow damage, in which the pavement acts like a weir (dam), and the high velocities scour the sand on the landward side of the highway.

4.6.6 Accelerated Sea Level Rise

Section 3.6.3.3 noted that historic sea level rise is accounted for in the project's shoreline forecasts and described in two potential scenarios for accelerated sea level rise (scenarios 2 and 3). As a result of recently published research on global climate change and sea level rise, FHWA wanted to consider how the new information on global climate change may affect the development and implementation of this project. FHWA hosted a Peer Exchange workshop on May 14 to 15, 2008, in Raleigh, North Carolina. The peer exchange included a panel of coastal engineering and geology experts with knowledge of the local area, as well as experts with knowledge of recent research on global climate change. The objectives of the workshop were to identify recent scientific research on global climate change effects and to relate how that research can help inform the development of the Bonner Bridge Replacement project. The outcome of the workshop was to identify whether or not any analytical gaps exist between the NC 12 vulnerability analysis and shoreline erosion forecast conducted for the project (described in Section 3.6.3.1) compared to recent and relevant research on global climate change. The workshop included presentations on the following: the overall project; the technical report *Bonner Bridge Replacement – Parallel Bridge Corridor with NC 12 Maintenance – Shoreline Change and Stabilization Analysis* (Overton and Fisher, June 2005); relevant vulnerability studies for NC 12; and potential impacts of climate change for both the entire US Transportation System and the specific project area.

The analysis conducted for the project in the technical report *Bonner Bridge Replacement – Parallel Bridge Corridor with NC 12 Maintenance – Shoreline Change and Stabilization Analysis* (Overton and Fisher, June 2005) and described in Section 3.6.3.1 predicts future changes in the shoreline based on the historical record. Panelists generally agreed that the analysis's high erosion results of shoreline position may account for a portion of sea level rise caused by future changes in climate. In addition to this analysis, past sea level rise in one location and a range of potential future sea level rise scenarios for the mid-Atlantic coast were also considered. There was consensus that the current global sea level rise analytical models are not fully developed to predict local effects. The wide range of future sea level rise information considered illustrates the uncertainty associated with estimating future sea levels and shoreline locations. Panelists generally agreed that the Parallel Bridge Corridor with Phased Approach/Rodanthe Bridge Alternative (Preferred) with the island monitoring program outlined in Section 2.10.2.5 is the most practical method for carrying out the project with the given constraints, in part because it provides the opportunity to review and incorporate new analysis prior to commencement of each phase.

The Pamlico Sound Bridge Corridor would bypass the northern part of Hatteras Island and would likely be unaffected by accelerated shoreline erosion or breaches resulting from accelerated sea level rise. However, if Hatteras Island were to be fragmented, the existing hydrodynamics in Pamlico Sound could change, including the location of the natural navigation channel.

Accelerated sea level rise under scenario 2 would affect the Parallel Bridge Corridor alternatives as follows:

- <u>With Nourishment</u>. Increased demand for nourishment material (larger and/or more frequent projects). Erosion rates could increase such that beach nourishment would be practicably ineffective.

- <u>With Road North/Bridge South</u>. Possible shorter design life in the roadway section if the shoreline erodes faster than the project's high erosion forecast. The bridge component would bridge two of the three potential island breach areas.

- <u>With All Bridge</u>. It is possible that the bridges expected to remain over land would be in the ocean prior to 2060 if the shoreline migrates faster than the project's high erosion forecast. All five potential breach locations would be bridged.

- <u>With Phased Approach/Rodanthe Bridge (Preferred)</u>. The uncertainties in determining exact location and timing of shoreline change would be addressed by designing an appropriate monitoring plan, as described in Section 2.10.2.5. This alternative would bridge the five potential breach locations. Four of the five potential breach locations would be bridged in Phase II and the fifth would be bridged in Phase III. So while the shoreline predictions do not incorporate the increase in sea level rise used in scenario 2, the overall approach of the Phased Approach/Rodanthe Bridge Alternative (Preferred) plans for conditions that will occur under scenario 2.

- <u>With Phased Approach/Rodanthe Nourishment</u>. The effects of the Phased Approach/Rodanthe Bridge Alternative (Preferred) are still applicable, except in the nourishment area, where the effects would be similar to the Nourishment Alternative. This alternative would bridge three of the five potential breach locations, but would not bridge the location in the Rodanthe area where a breach is considered most likely to occur.

If scenario 3 occurs, it could be argued that the processes reflected in the shoreline change rates used in project planning will change substantially, and past shoreline trends cannot predict future behavior. Since future monitoring is planned with the Phased Approach/Rodanthe Bridge Alternative (Preferred), one outcome of the monitoring could be to assess the predictions and develop new indicators as new information allows. The monitoring plan associated with the

Phased Approach/Rodanthe Bridge Alternative (Preferred) would provide important information since data collection would be in the projected period of accelerated sea level rise. Indicators of change could potentially be developed from the monitoring information and be used to modify Phase II-IV and allow adaptation in the design to accommodate the new information. Both the extent of bridging and timing could need to be modified. Monitoring of areas currently considered stable would be necessary because of the potential for changing processes.

Worst-case imagined scenarios, such as scenario 3 described in Section 3.6.3.3, suggest substantial island disintegration with substantial change in the hydrodynamics (the hydraulic exchange) between sound and ocean. Thus, it is important to keep in mind that this dramatic change in trends would affect not just the project area but the entire barrier island system.

4.6.7 Island Breach in the Pea Island National Wildlife Refuge

As indicated in Section 3.6.3.4, the potential exists in five locations for a breach to occur in Hatteras Island as a result of a storm between now and 2060 (though only the Rodanthe breach is likely). The word "breach" is used in this discussion rather than the word "inlet" because if a breach were to occur, it would likely close eventually (although not necessarily immediately) and likely would not become a long-term phenomenon like Oregon Inlet.

4.6.7.1 Island Breach at Site 3

Based on the opinions of the expert panel described in Section 3.6.3.2, the location most likely for a breach to occur would be at the southern end of the Refuge just north of Rodanthe (Site 3 shown on Figure E-1 in Appendix E). A breach at this location would not be of concern with the Pamlico Sound Bridge Corridor because the area would be bypassed by the bridge. Though the potential for such a breach would have to be taken into account in bridge location and foundation design, a breach at this location also would not be a concern with the Road North/Bridge South and All Bridge alternatives with the Parallel Bridge Corridor. The Rodanthe area bridge associated with these alternatives would span the potential breach location. The nourishment program associated with the Parallel Bridge Corridor with Nourishment Alternative would reduce the risk of a breach occurring, but it still would remain a possibility. The Phased Approach/Rodanthe Bridge Alternative (Preferred) also would bridge Site 3. The Phased Approach/Rodanthe Nourishment Alternative would bridge approximately 65 percent of Site 3, while nourishment would occur within the remaining 35 percent. Again, nourishment would reduce the risk of a breach occurring. However, the design of the nourishment program for the Phased Approach/Rodanthe Nourishment Alternative is not intended to provide protection throughout the potential breach location; thus breaching remains a possibility with this alternative.

With the Parallel Bridge Corridor with Nourishment or Phased Approach/Rodanthe Nourishment alternative, it is assumed the State of North Carolina would close a breach in the Rodanthe area to maintain the continuity of NC 12. Using the experience of closing the breach that formed just north of Hatteras Village near the southern end of Hatteras Island in 2003, it is estimated that between 400,000 and 500,000 cubic yards (306,000 and 382,000 cubic meters) of sand would be required to close a breach at the Rodanthe site. This estimate was not based upon specific dimensions for this potential breach, but rather it was based on the assumption that the breach would be similar to, but somewhat larger than, the Hatteras Village breach. A breach also could be bridged.

The expert panel considered two potential borrow areas for the sand to close a breach at the south end of the Refuge: offshore of Rodanthe and the outer bar at Oregon Inlet. Information available related to the ocean bar indicates that sand from that location is likely to be acceptable in terms of its characteristics and volume to use to close a breach. The borrow site offshore of Rodanthe needs additional field work, including sediment cores, to confirm there is sand of acceptable characteristics and volume to be used to close a breach.

Based upon the 2003 experience at the Hatteras Village breach, the expert panel agreed that $10.00 per cubic yard ($7.60 per cubic meter) is a reasonable estimate for sand taken from the offshore borrow site at Rodanthe. For sand taken from the outer bar, because of the longer pumping distance, $15.00 per cubic yard ($11.50 per cubic meter) was the suggested unit cost estimate. Assuming 500,000 cubic yards (382,000 cubic meters) to fill a breach, an additional 30 percent of over fill (150,000 cubic yards [115,000 cubic meters]) because of multiple uncertainties, design and environmental assessment costs of $500,000, and an additional four percent for construction supervision, the total cost for closing a breach is estimated to range between:

- $7.28 million if the sand comes from the offshore site at Rodanthe, and

- $10.66 million if the sand comes from the ocean bar near Oregon Inlet.

The Hatteras Village breach was closed in approximately 60 days. This short time was in large part because of the declared emergency status of the project. While the expert panel agreed that a breach at Rodanthe would also be an emergency, the generally higher wave climate and the logistics of moving sand from either of the two potential borrow sites could result in a longer time to achieve closure. The expert panel considered two scenarios: 1) where no prior work had been done before the breach opened, and 2) where most of the design, permitting, and borrow material determination had been done in advance.

For the first scenario, where there was no advance preparation, the expert panel concluded that it might take as long as six months to close the breach. Several factors account for this longer time than for the Hatteras Village breach. Both the offshore borrow site and the inlet borrow site would be logistically more difficult to use than the borrow site at Hatteras Village. The dredges (probably two hopper dredges) would be working in the ocean (as opposed to Pamlico Sound), and weather delays would be likely. If the inlet borrow site were used, one or perhaps two booster pumps would be needed to move the material the approximately 12-mile (19.3-kilometer) distance to the breach. Substantial fieldwork would be required to map the borrow site and identify an adequate quantity of compatible material. Again, this fieldwork would take place at an offshore location during tropical storm season. Because the breach would be in the Refuge, additional environmental issues would potentially cause delays. All of these factors, plus other unforeseen problems, would probably lead to the longer time required to close the breach.

For the second scenario, with most of the preparation done in advance, the expert panel estimated that it would take up to three months to close the breach. This 90-day estimate is still a month longer than the recent experience at Hatteras Village. This is largely due to the expert panel's concern about the additional difficulties of using either an inlet source or an offshore borrow site, as well as the higher wave and storm exposure for this portion of the Outer Banks.

The expert panel suggested that advanced data gathering for the closure of a breach at the southern end of the Refuge would be prudent. This would be the case both in the near-term, until the proposed replacement project could be completed, or as a part of long-term planning if the Parallel Bridge Corridor with Nourishment or Phased Approach/Rodanthe Nourishment Alternative were implemented. Such advanced data gathering also should include the source of funding and a decision on whether the work should simply close the breach or use a wider configuration. The post-closure island cross-section (width) at the Hatteras Village breach is smaller than the island cross-section prior to Hurricane Isabel. Thus, the Hatteras site is more vulnerable now than it was prior to the breach. This smaller cross-section is in part related to the source of funding to close the breach. A substantial portion of the cost for closing the breach was covered by the FHWA, which included limits that precluded building up the cross-section of the island to make it less vulnerable.

4.6.7.2 Island Breaches at Sites 1, 2, and 4

The potential for a breach to occur at these three locations between now and 2060 is considered minimal (see Section 3.6.3.4), with the potential being somewhat greater south of the Refuge's ponds at the location of the former New Inlet. The Pamlico Sound Bridge Corridor would bypass all of these sites. The Parallel Bridge Corridor with Phased Approach alternatives (including the Preferred Alternative) and with All Bridge Alternative would also bridge these sites. The Parallel Bridge Corridor with Road North/Bridge South Alternative would bridge only Site 1. The nourishment program associated with the Parallel Bridge Corridor with Nourishment Alternative would reduce the risk of a breach occurring, but it still would remain a possibility.

4.6.7.3 Island Breach at Site 5

Section 3.6.3.4 contains information related to the potential for a breach to occur near Oregon Inlet (potential breach Site 5). It describes the potential effect of soundside shoreline erosion, the presence of the Davis Slough channel behind Hatteras Island, and oceanside accretion. It is stated that a breach at Site 5 that isolates the terminal groin could cause substantial changes in the geomorphology (development of the land forms) around Oregon Inlet. It is assumed for this study that no mitigating activity will occur to prevent continued "inner bank" erosion. Therefore, the potential for soundside erosion to contribute to the formation of an inlet near the terminal groin that is deeper and more permanent than might occur elsewhere in the project area was taken into consideration during the development of the two Phased Approach alternatives (including the Preferred Alternative) by assuming larger and deeper bridge piles. This approach also could be taken with the Parallel Bridge Corridor with All Bridge Alternative. The discussion of the Site 5 breach relates to the various bridge alternatives evaluated in this FEIS in the following ways:

- Pamlico Sound Bridge Corridor. This corridor would bypass the north end of Hatteras Island; therefore, a breach near Oregon Inlet would not affect the bridge.

- Parallel Bridge Corridor with Nourishment Alternative. As noted in Section 3.6.3.4, nourishment reduces the vulnerability of this location to a breach because of ocean overwash. However, nourishment would not mitigate the risk from soundside erosion. If a breach were to occur, even though the likelihood is minimal, NC 12 would be severed with this alternative. In addition, as noted in Section 3.6.3.4, a breach that completely isolates the terminal groin would be difficult to fill with sand and keep closed. The Oregon Inlet bridge would need to be extended in order to keep NC 12 open.

- Parallel Bridge Corridor with Road North/Bridge South Alternative. Like the Nourishment Alternative, this alternative would involve maintaining a road at the north end of Hatteras Island. Thus, the outcome of a breach for this alternative, however minimal the risk, would be similar to the Nourishment Alternative. The additional reduction in the potential for a breach offered by nourishment to reduce the vulnerability of this location to a breach would not occur with this alternative because the Road North/Bridge South Alternative includes no nourishment or dune maintenance.

- Parallel Bridge Corridor with All Bridge Alternative. This alternative would generally bridge the potential breach location at the north end of Hatteras Island. The design assumptions for the alternative presented in this FEIS would have two limitations in terms of the impact of a breach. First, the foundation assumptions included in the cost estimates for this alternative are lighter and shallower than those for the Phased Approach alternatives (including the Preferred Alternative), since they presume that the bridge would cross land and not be subjected to a breach, particularly one that would be deep and permanent as it competes hydraulically with Oregon Inlet. The same foundation currently assumed for the Phased Approach alternatives (including the Preferred Alternative), however, could be assumed for this alternative at additional cost. Second, this alternative assumes that access to the Refuge at the north end of Hatteras Island would be via a surface road. Such a road could be affected by a breach, however minimal the risk, with the same effects as described for the Nourishment Alternative. Again, the same access strategy assumed for the Phased Approach alternatives (including the Preferred Alternative) (i.e., bridge with ramps to the ground) could be assumed for this alternative at additional cost.

- Parallel Bridge Corridor with Phased Approach Alternatives (including the Preferred Alternative). This alternative would be the best suited to accommodate a breach at the north end of Hatteras Island, in that larger and deeper bridge foundations are presumed and the potential breach location would be fully bridged. Thus, in terms of the Parallel Bridge Corridor alternatives, this alternative would be best suited to accommodate a breach, however minimal the risk, should one occur at the north end of Hatteras Island. This alternative would not, however, be at navigation height. Thus, if Davis Slough became the more-preferred flow pattern between the ocean and Pamlico Sound, as it could if the terminal groin were removed (see Section 3.6.3.5 under "Long-Term Impacts of the Removal of the Terminal Groin"), dredging the Oregon Inlet channel could become more challenging since the dredged channel would have to remain in Oregon Inlet. The channel could not be moved to a location south of the terminal groin because of the presence of the bridge.

Physical modeling of the hydraulics of the Oregon Inlet area could provide additional insight into the degree to which waves and/or current control the erosion processes and the risk of inlet formation. Modeling also would be useful in developing mechanisms for mitigating that risk, particularly as it relates to the design of the bridges associated with the All Bridge and Phased Approach alternatives (including the Preferred Alternative). Such modeling would be conducted as a part of design development for the Phased Approach/Rodanthe Bridge Alternative (Preferred), as discussed in Section 2.10.1.2 under "Wave Energy, Storm Surge, and Scour."

4.6.8 Off-Shore Coastal Processes with the Phased Approach Alternatives

The two Phased Approach alternatives (including the Preferred Alternative) add several additional considerations related to coastal processes that are addressed in this section. They relate to the effect of bridge piles in the ocean on scour, longshore sediment transport, wave climate, beach erosion, breach formation, and short-term NC 12 maintenance needs until Phases II to IV are implemented.

The coastal zone potentially affected by the two Phased Approach alternatives (including the Preferred Alternative) is generally depicted as being made up of four distinct regions. Using nomenclature defined in the USACE *Coastal Engineering Manual*, (USACE, 2002) these zones are referred to as upland, shore, shoreface, and offshore. The upland zone is landward of the toe of the dune, inclusive of the dune. The shore extends from the mean low water (MLW) to the upper extent of storm damage (toe of the dune) and is divided into the backshore and the foreshore. The backshore is from the MHW to the toe of the dune and the foreshore is between the MHW and MLW. The shoreface extends from MLW to the flattened slope seaward of the offshore (sand) bar and is referred to as the nearshore. The offshore is seaward of the nearshore.

The upland area includes the dune field. The dune (in the absence of human intervention) is built, enlarged, or altered by wind-blown sand transport. Onshore winds provide the fuel for transport, and a wide dry beach supplies the source. The presence of obstructions to the wind (vegetation, topographic change, man made structures) lowers the wind energy available for transport and "traps the sand," resulting in the formation, growth, and migration of sand dunes. The upland area also is affected by larger storms in which water overwash of the dune field occurs. The characteristics of sediment (e.g., sand) transport during these events is a function of the hydraulics (water movement) of the event. Sediment can be transported landward, creating overwash fans of sediment. If however, the water level on the Pamlico Sound side is elevated, the flow of water from the soundside to the ocean side can sweep quantities of sand seaward. This latter phenomena is associated with inlet breaching.

The backshore, characterized as being landward of the MHW, is typically the dry beach. Therefore, the backshore also is subjected to wind blown transport. It is expected that the backshore loses sand to the dune when onshore winds dry the beach and move sand landward. In addition, the backshore is affected by wave action during high water events or storms. Sand can either be transported onto the backshore or eroded from the backshore, depending on the wave characteristics. The upward limit of transport is related to the wave run-up limit, that is, typically long period waves transport sand landward and short period waves erode the backshore.

The foreshore is subjected to the action of swash (water movement associated with waves and the tide) on a daily basis and thus substantial volumes of sand are transported onshore and offshore daily. Sediment is continually reworked and transport is dependent on the rising and falling of the tide and the wave conditions.

The nearshore zone extends from the “breaker zone” of the shore, through the surf zone and seaward of the offshore (sand) bar. Waves initially break over the offshore bar, reform, and break again just offshore of the MLW (breaker zone). This is a zone of high energy dissipation (because of wave breaking) and potentially a zone of substantial modification of the beach profile during storm events.

The offshore zone is assumed to be seaward of the wave breakers, and while transport can occur, much less modification of the profile is observed during storm events.

Nearshore currents act to transport sand in the longshore direction, generally from north to south. Waves breaking obliquely (neither perpendicular nor parallel) to the shoreline create a momentum flux (change) that drives longshore currents. Wind also can contribute to the development of these currents. These currents flow parallel to the shore and are strongest in the surf zone, decaying substantially once seaward of the breakers.

4.6.8.1 Effect of Bridge Piles on Scour

The extent of scour in the ocean bottom associated with the bridges built as a part of Phases II to IV of the Phased Approach/Rodanthe Bridge Alternative (Preferred) would be dependent on:

- The length of bridge in the ocean by year;
- Whether or not bridge is in or out of the area where the ocean waves break (breaker area); and
- The size and proximity of the individual piles that make up the bridge's foundation.

The portions of Phased Approach/Rodanthe Bridge Alternative (Preferred) in the ocean would create a total scour area on the ocean bottom as large as approximately 15.6 acres (6.3 hectares) by 2060. The displaced volume of sand in 2060 would be as large as approximately 152,678 cubic yards (116,714 cubic meters). The following paragraphs describe how these findings were reached.

Length of Bridge in Ocean (Phases II to IV)

Assuming both the high erosion shoreline (shown in Figure E-1 of Appendix E) modeled for the development and assessment Bonner Bridge project alternatives and the estimated completion of Phase II in 2015, Phase III in 2020, and Phase IV in 2030, the length of the bridge in the ocean would be:

- 2020: 1.6 miles (2.6 kilometers);
- 2030: 2.8 miles (4.5 kilometers);
- 2040: 4.2 miles (6.8 kilometers);
- 2050: 5.2 miles (8.4 kilometers); and
- 2060: 5.9 miles (9.5 kilometers).

Breaker Area

Scour depth in breaking waves has been studied in the lab and observed in the field at two research piers (USACE Field Research Facility at Duck, North Carolina and by Bayram and Laursen using data from a research pier in Japan). These studies found that, in the breaker area, scour occurred around piles, but that the high turbulence produced by breaking waves and the subsequent large volumes of sediment transport acted to fill in these holes landward of the breaking point. Thus, scour holes are expected to occur in association with Phases II to IV of the Phased Approach/Rodanthe Bridge Alternative (Preferred) only once they are seaward of the wave breaking point. Landward of the breaker, the piles could alter the development of a "barred" profile and contribute to the formation of rip currents, features that occur naturally along the coast but have been noted occurring in relationship to piers.

To determine the depth at which the waves break (depth of breaking), two conditions were investigated: 1) the yearly average conditions (average of the depth at breaking for January through December) and 2) the average depth of breaking during the primary fish transport season (February through May). These depths were applied to offshore profiles taken in 2004 at 89 locations in the project area. For each station, the distance from mean high water (the shoreline) to the depth of breaking was determined. In the case of an offshore (sand) bar that was higher than the depth of breaking, the depth of breaking on the seaward side of the bar was taken. In these locations, waves will likely reform and break again closer to shore. In general the distance to the breaking depth from the shoreline is greater in the northern part of the project area (450 to 500 feet or 137 to 152 meters). These distances decrease to 200 to 300 feet (61 to 91 meters) further south with the exception of the hot spot in the Rodanthe area. The distance offshore in the Rodanthe area is controlled by the steep foreshore and the presence of an offshore bar.

In addition, the zone of impact of the wave generated longshore current was delineated relative to the depth of breaking. The longshore current is a function of the breaking wave height and the wave breaker angle to the shore. The distance to breaking described in the paragraph above was multiplied by 2 as a conservative estimate of this type of influence.

An overlay of the position of Phases II to IV, projected high erosion shoreline positions, and the width of the breaker zone resulted in the characterization of the project in relation to the breaker zone shown in Table 4-10 from 2020 to 2060.

Table 4-10. Bridge Length Inside and Outside the Breaker by Year

Location	Phase	in feet (meters)									
		2020		2030		2040		2050		2060	
Inside the Breaker											
Rodanthe/'S' Curves Hot Spot	II	4,625 1,445	(1,410) (441)	6,450	(1,966)	4,750	(1,448)	3,749	(1,143)	1,575	(480)
New Inlet/South Ponds	III/IV					2,173	(663)	3,208	(978)	3,779	(1,152)
Visitor Center	II			2,328	(710)	3,939	(1,201)	5,553	(1,693)	5,221	(1,592)
North Ponds	IV			262	(80)	1,925 431	(587) (131)	3,878	(1,182)	4,287	(1,307)
Canal Zone and Sandbag Hot Spots	II	2,120	(646)	2,649	(808)	3,632	(1,107)	3,554	(1,084)	2,851	(869)
TOTAL		8,190	(2,497)	11,689	(3,564)	16,850	(5,137)	19,942	(6,080)	17,713	(5,400)
Outside the Breaker											
Rodanthe/'S' Curves Hot Spot	II			2,874	(876)	5,230	(1,595)	6,791	(2,070)	9,471	(2,888)
New Inlet/South Ponds	III/IV										
Visitor Center	II									2,316	(706)
North Ponds	IV										
Canal Zone and Sandbag Hot Spots	II							741	(226)	1,860	(567)
TOTAL				2,874	(876)	5,230	(1,595)	7,532	(2,296)	13,647	(4,161)

Note: Where two numbers are shown in a single location, it indicates that two separate bridge segments are in the water inside the breaker area.

Pier Assumptions

The scour analysis assumed that the pier configuration in the Sandbag and Canal Zone hot spot areas (beginning approximately at the north end of the Refuge's ponds and included in Phase II) would consist of eight piles each arranged in a 2x4 configuration. The piles were assumed to be 54-inch (137-centimeter) cylinder piles (circular cross-sections). The piles for each pier would be placed within a 21-foot x 48-foot (6.4-meter to 14.6-meter) area. For the rest of the project, four pier configurations were considered:

1. Eight piles each arranged in a 2x4 configuration using 30-inch (76.2 centimeter) square piles in an area 15 feet x 48 feet (4.6 meters x 14.6 meters);

2. Three groups of four 20-inch (50.8 centimeter) square piles arranged in a 2x8 configuration in an area 10 feet x 36 feet (3.0 meters x 11.0 meters);

3. Four 6-foot (1.8-meter) cylindrical piles arranged in a linear (1x4) configuration in an area 10 feet x 36 feet (3.0 meters x 11.0 meters); and

4. Eight 4-foot (1.2-meter) cylindrical piles arranged in a 2x4 configuration in an area 10 feet x 36 feet (3.0 meters x 11.0 meters).

The configuration at the northern end of Hatteras Island and the configuration for the rest of the project reflect the representative description of the Phased Approach/Rodanthe Bridge Alternative (Preferred) presented in Section 2.10.2.4. Alternate configurations are considered to determine if scour holes would be substantially different in area with different configurations. It was assumed that the material scoured was sand.

Scour Analysis

When a vertical cylinder (pile) is placed in a uniform flow field (waves and current), the flow will be modified as the water and the pile interact, which can result in scour of the ocean bottom. The scour analysis looked at the potential depth and area of scour around both individual piles in a pier and the groups of piles that make up the pier.

Scour depths were calculated in three locations along Phase II to IV: the Canal Zone Hot Spot area (north end of the project on Hatteras Island), the Refuge Visitor Center area (middle of the project area), and in the ‘S’ Curves Hot Spot area (south end of the project area). Three locations were examined to determine if scour depths would substantially vary across the project area. Scour also was calculated by month to determine if there was substantial seasonal variation. The scour depths in each case were similar.

The seasonal range of individual pile scour depth for the three locations is:

- ‘S’ Curves: 3.9 to 4.3 feet (1.2 to 1.3 meters);

- Visitor Center: 4.1 to 4.7 feet (1.2 to 1.4 meters); and

- Canal Zone: 3.9 to 5.0 feet (1.2 to 1.5 meters).

The deepest holes all occurred in September.

Increased scour around an entire group of piles has been observed to be a general lowering of the bed around the group to depths greater than for individual piles. This group scour is a function of the increase in velocity between the piles within the gap and the turbulence generated by the piles. When analyzing scour depths of groups, seasonal depth ranges found were:

- ‘S’ Curves: 7.3 to 8.7 feet (2.2 to 2.7 meters);

- Visitor Center: 8.2 to 9.4 feet (2.5 to 2.9 meters); and

- Canal Zone: 7.9 to 9.9 feet (2.4 to 3.0 meters).

Again, the deepest holes all occurred in September. Given that group scour results in greater depth of scour, the rest of the scour analysis focused on group scour.

The area affected by group scour was determined for two scenarios. In the first, the long side of the area scoured is aligned in the long shore direction (roughly parallel with the project). Under this scenario, the group scour associated with one pier (group of piles) would overlap with the next with an assumed pier spacing of 120 feet. In the second scenario, it was assumed that the area scoured was not aligned such that the group scour holes overlap. Scenario two would result in the larger area of effect. Volume is computed for the non-overlapping case so that the maximum impact for each pier assumption is reported.

<u>*Results*</u>

For the foundations south of the Canal Zone Hot Spot, Foundation Alternatives 1 and 2 above would result in the maximum and minimum scour holes impact, respectively, of the four alternative pile designs considered. Scour area and volume estimates for these alternatives and the Canal Zone area foundation are presented in Table 4-11 and Table 4-12, respectively.

The smaller pile size (20 inches [50.8 centimeters]) and smaller footprint (10 feet x 36 feet [3.0 meters x 11.0 meters]) of Foundation Alternative 2 would yield the smallest scour areas, as would be expected for the smallest pile size and smaller footprint area.

Table 4-11. Area Affected by Scour by Location and Year[1]

	Canal Zone Hot Spot in acres (hectares)		Visitor Center Area in acres (hectares)		'S' Curves Hot Spot in acres (hectares)	
	Overlap	No Overlap	Overlap	No Overlap	Overlap	No Overlap
			Visitor Center/'S' Foundation Alternative 1			
2030	0.0	0.0	0.0	0.0	4.1 (1.7)	4.6 (1.9)
2040	0.0	0.0	0.0	0.0	7.6 (3.1)	8.6 (3.5)
2050	1.3 (0.5)	1.5 (0.6)	0.0	0.0	9.9 (4.0)	11.2 (4.5)
2060	3.1 (1.3)	3.8 (1.5)	3.6 (1.5)	4.3 (1.7)	13.8 (5.6)	15.6 (6.3)
			Visitor Center/'S' Foundation Alternative 2			
2030	0.0	0.0	0.0	0.0	3.1 (1.3)	3.1 (1.3)
2040	0.0	0.0	0.0	0.0	5.7 (2.3)	5.9 (2.4)
2050	1.3 (0.5)	1.5 (0.6)	0.0	0.0	7.5 (3.0)	7.6 (3.1)
2060	3.1 (1.3)	3.8 (1.5)	2.7 (1.1)	2.8 (1.1)	10.4 (4.2)	10.6 (4.3)

[1] The area affected by group scour was determined for two scenarios. In the first, the long side of the area scoured is aligned in the long shore direction (roughly parallel with the project). Under this scenario, the group scour associated with one pier (group of piles) would overlap with the next with an assumed pier spacing of 120 feet (36.6 meters). In the second scenario, it was assumed that the area scoured was not aligned such that the group scour holes overlap. Scenario two would result in the larger area of effect.

Table 4-12. Volumes of Sand Displaced by Scour

	in cubic yards (cubic meters)			
	Canal Zone Hot Spot	Visitor Center Area	'S' Curves Hot Spot	Total
		Visitor Center/'S' Foundation Alternative 1		
2030	0.0	0.0	29,083 (22,236)	29,083 (22,236)
2040	0.0	0.0	54,372 (41,570)	54,372 (41,570)
2050	10,126 (7,742)	0.0	70,810 (54,138)	80,937 (61,881)
2060	25,315 (19,355)	28,733 (21,968)	98,629 (75,407)	152,678 (116,731)
		Visitor Center/'S' Foundation Alternative 2		
2030	0.0	0.0	16,862 (12,892)	16,862 (12,892)
2040	0.0	0.0	31,525 (24,103)	31,525 (24,103)
2050	10,126 (7,741)	0.0	41,055 (31,389)	51,182 (39,131)
2060	25,315 (19,355)	15,618 (11,941)	57,184 (43,720)	98,118 (75,017)

The volume of sand displaced in the areas is approximated based on the assumed geometry of the hole and is shown in Table 4-12. The higher no overlap acres are assumed. The total volume of sand displaced by scour by 2060 would be between 100,000 cubic yards (76,455 cubic meters) and 153, 000 cubic yards (116,977 cubic meters). This is roughly 50 to 75 percent of the 200,000 cubic yards (159,911 cubic meters) of sand that NCDOT plans to remove from the terminal groin fillet in 2008 to replenish the beach berm in the 'S' Curves Hot Spot area. The net littoral sand transport to the south around Oregon Inlet is estimated to be about 862,000 cubic yards (659,046 cubic meters) per year.

The area that is projected to have the largest areal extent of scour holes is the 'S' Curves Hot Spot. The holes could develop earlier in the timeline of the project because of the steep offshore slopes in this area. Because more pile groups would be affected, more total area (and volume) would be removed. The volume removed would stay within the littoral system, initially deposited downdrift of the piles, and then subjected to the local background cross shore and/or longshore sediment transport patterns. The holes would shift in size and shape with change in wave height and direction and could contribute to localized changes in the nearshore wave characteristics given the alongshore length expected to be affected. Perhaps more important, however, to the projection of impacts to coastal processes for the 'S' Curves Hot Spot is that this is the area determined to have the highest "breach" potential (see Section 3.6.3.4).

In the event of a breach, the hydrodynamics and sediment transport in and around the pilings would be dominated by inlet processes (not wave and longshore currents) and the scour holes that would develop would be in the inlet throat, not offshore. The dynamics of scour would be similar to that found in inlets (for example, Oregon Inlet), but the magnitude of the scour holes would depend on the characteristics of the new inlet (i.e., width, depth, volume of flow, and sediment size), as well as the bridge pier design. The characteristics of the scour in the new inlet should be similar to that found in inlets of comparable flow velocity, sediment characteristics, and bridge pier design. However, because of the uncertainty of the characteristics of a potential new breach (see Section 3.6.3.4), this potential scour is not determined.

4.6.8.2 Effect of Bridge Piles on Wave Climate

Wave climate is generally defined as the long-term statistical characterization of waves in the ocean. The presence of the bridge piles is not expected to change the wave climate seaward of the bridge pile vicinity.

The potential for the bridge piles to impact the wave climate in the vicinity of the bridge piles and landward is first delineated by considering the pile diameter to wavelength ratio. Large pile diameters combined with short wavelengths have the greatest potential for wider spread wave impacts. For the Phased Approach alternatives (including the Preferred Alternative), the diameter to wavelength ratio is such that the flow would be in the slender-pile regime. This indicates that the presence of the piles (as an object that blocks the flow) should not substantially influence the wave form other than in the immediate vicinity of the pile group (Sumner and Fresoe, 2002).

In addition to the presence of the piles, the wave/structure/sediment interaction contributes to the change in the bathymetry (bottom topography) in and around the pile groups in the form of scour. This change in bottom topography could result in wave refraction (bending), wave reflection, local wave diffraction (bending around an object), and wave dissipation in the vicinity of a scour hole. This impact would be greatest when the piles are seaward of the breaking zone (where scour holes develop). Changes in the wave form from these effects also could affect the longshore currents since longshore current is a function of wave height and wave direction.

Finally, the presence of piles has the potential to interrupt the development of an offshore bar (see Section 4.6.8.1). The lack of development of the bar could cause relative changes in the alongshore wave height by changing the location of the breaking. This change could contribute to the formation of rip currents, a feature that occurs naturally along the coast but has been noted occurring in relationship to piers. The presence of the piles (and subsequent break in the bar) could serve to fix the location of a rip current under and aligned seaward with the bridge pier, but should not increase the frequency of occurrence since rip currents also are a function of the wave and tide conditions.

4.6.8.3 Effect of Bridge Piles on Longshore Sediment Transport

The local scour impact described in Section 4.6.8.1 could extend to a more global impact on the coastal processes if the structure were to interfere with either the longshore (north to south) transport of sediment or the cross-shore transport associated with storms. Although the scour holes would dominate in the vicinity of bridge piles, the USACE Field Research Facility (FRF) data shows no net loss of beach downdrift of its pier that would be suggestive of the trapping of sand that can be associated with structures perpendicular to the shore. The spacing of the pier's piles is such that the longshore sediment transport is not globally affected by the local scour that occurs. The cross-shore transport associated with storm events is dependent on the local bathymetry of the beach face; thus the scour holes necessarily change the cross-shore wave dynamics and sediment transport. The FRF data from the research pier does not suggest that the pier's piles have a substantial impact on the cross-shore transport. The upland areas at the FRF's pier, however, have higher elevations than those on Hatteras Island and have not experienced the repeated dune erosion and overwash that is common in the project area.

The FRF configuration resembles the case of a single pile group, but does not model the impact of a series of scour holes in the alongshore direction. In general, longshore sediment transport is a function of the breaking wave height and breaking wave angle. The length of shoreline along which these wave characteristics are changed because of the presence of the scour hole is a factor in the assessment of impact. Thus, the development of scour holes described in Section 4.6.8.1, as well as the subsequent effect on the local wave characteristics described in Section 4.6.8.2, could potentially have an impact on the localized longshore sediment transport and resulting erosion and accretion patterns along the shoreline, depending on the size and orientation of the holes.

4.6.8.4 Effect of Bridge Piles on Beach Erosion

Wave transformation over scour holes (see Section 4.6.8.1) would likely cause refraction of the incoming wave creating a persistent non-uniform wave climate on the beach. The degree of refraction would be a function of the scour depth and size and orientation of the holes. By bending the waves around the holes, energy would be focused in different patterns than without the presence of the holes. This could preferentially redistribute sediment creating erosional hot spots/troughs (or cold spots/crests), (Kraus and Galgano, 2001). If the effect is strong enough, it could result in a highly cuspate (scallop-like) beach, with the troughs being locations of erosion and crests the relative lack of erosion or accretion. The spatially alternate troughs and crests would be associated with the location of the scour holes, developing a rhythmic pattern of erosion and accretion along the shoreline.

The break in the offshore bar described in Section 4.6.8.2 would allow waves to move closer to shore before breaking. Once through the gap, waves would diffract (bending back toward the bar) creating complex flow patterns landward of the bar. Erosional hot spots could develop directly landward of the gap from the resulting larger wave heights that would propagate through the gaps (Kraus and Galgano, 2001).

Rips are observed to form in gaps in the bar (either in association with a structure such as a pier or without). Rips are strong shore perpendicular currents in the seaward direction and thus have the potential to transport sediment seaward. Erosional hot spots in association with rips locally narrow the beach. If the beach becomes too narrow, the rips also can be associated with dune erosion (Thorton et al., 2007).

Cusps, rips and breaks in the bar are all naturally occurring features along Hatteras Island today. The impacts on beach erosion as noted are already part of the system. However, the formation of these features associated with fixed locations (e.g., the piles) could create persistent features that would lead to focused erosional hot spots that are not currently present in the system.

4.6.8.5 Effect of Bridge Piles on the Potential for an Island Breach During Storm Events

In the foreshore, backshore and upland zones the impact on cross-shore sediment transport because of the Phased Approach alternatives' (including the Preferred Alternative) piles generally would be during storm events. Two impacts can be anticipated. Scour around the bridge supports is expected during events that bring the water level in contact with the bridge. The scour hole that would develop should be a function of water level, current, and wave action, as well as the duration of the storm. In the case of an overwash event in which sand is transported landward, scour holes would develop but sediment transport should not be substantially interrupted and a washover fan should develop. During an event in which flow is reversed from sound to ocean because of elevated water levels in Pamlico Sound, there could be more erosion because of the presence of the bridge supports. The combination of scour around the piles and the channeling of the flow in the cross shore direction would increase the erosion potential. Since these events are associated with the creation of a breach in the island, it is possible that the presence of the structure could accelerate the development of a breach during these events.

During non-storm conditions, the bridge elements in the upland area could increase sediment accumulation because of the interruption of the windblown transport processes. In the backshore, the interruption of windblown sediments could cause a loss of transport from the beach to the dune.

4.6.8.6 Short-Term NC 12 Maintenance Needs until Phases II, III, and IV are Implemented

This section identifies, based on past experience, potential short-term maintenance activities that likely would occur prior to implementation of Phases II, III, and IV with the Phased Approach alternatives (including the Preferred Alternative). One difference from past experience is that the Refuge has concluded that the selection of the Phased Approach/ Rodanthe Bridge Alternative (Preferred) as the project for implementation in a Record of Decision (ROD) will preclude future storm-related maintenance outside of the NC 12 easement from being found compatible with the Refuge under the requirements of National Wildlife Refuge System Improvement Act of 1997. Thus, after the issuance of the ROD for this project, NCDOT would confine future NC 12 maintenance in the Refuge, including storm-related maintenance, to the existing NC 12 easement. Maintenance prior to the completion of Phase I is not addressed because it would occur with all of the alternatives (Pamlico Sound Bridge Corridor and Parallel Bridge Corridor) and, thus, it is not a factor in the decision-making process.

Based on past experience, there are five characteristic types of maintenance needed to keep NC 12 clear and open to traffic. These activities occur on Hatteras Island. Such activities do not occur, nor are expected to occur, on Bodie Island in the project area. The five activities are listed and defined in Table 4-13.

Activity 1 (road scraping) can occur as part of routine maintenance whenever wind blown sands are deposited on NC 12 to such a degree that mechanical removal is necessary. Activities 2 (dune maintenance), 3 (dune rebuilding), and 4 (sandbag-based dune and berm replenishment) are generally storm related activities. Factors which play into determining whether these activities occur or how often they occur at any given location on NC 12 increases with:

1. Decrease in the distance between NC 12 and shoreline;
2. Degradation of the dunes along the shoreline;
3. Magnitude of a storm event;
4. Frequency of storm event; and
5. Sediment supply.

In the past, activity 5 (dune translation) has occurred only in the Canal Zone Hot Spot area because of the large supply of windblown sand available from the terminal groin fillet and the wider beaches just north of the hot spot.

The existing dunes protect NC 12 from overwash. When the dune is lost either because of long-term erosion or storm events, NC 12 is more vulnerable to sand and water on the pavement. Under conditions dominated by long-term erosion, the beach width narrows, the ocean is closer to the toe (ocean side) of the dune, and daily waves and tides can erode the base of the dune until the dune face collapses providing sand to the beach. The beach may temporarily widen (providing

Table 4-13. Types of Past Storm-Related NC 12 Maintenance Activities and Frequency

Activity	Characteristics	General Past Frequency of Events Necessitating These Activities[1]
Minimal to none (MN)	Shoreline and dune characteristics expected to be adequate to keep sand off the road.	
1. Road Scraping	Pushing sand off the road on to the shoulders of the road and regrading swales (within the easement).	1 to 2 times per month
2. Dune Maintenance	Patching small holes or loss of elevation in the dune. Sand is typically moved from the shoulder on the seaward side and pushed up on the dune. In areas of existing vegetation, equipment with rubber tires is used to minimize damage if the vegetated site cannot be avoided entirely. Sand fencing may also be a minor repair or used in areas dune growth and dune stabilization is desired.[2]	2 to 3 times per year
3. Dune Rebuilding	Similar to 2 but at a larger scale. Sand from the landward shoulder of the easement (or other source on Hatteras Island) needed. Bulldozers are typically used to push sand up into a dune formation from the landward side of the dune. Minimal work is done from the seaward side. Efforts from the seaward side are intended to shape the dune. There is no beach scraping to obtain material to form the dune. Dune planting to attempt re-vegetation also may occur, as well as sand fencing to help stabilize the dune.[2]	1 to 2 times per year
4. Sandbag-Based Dune and Berm Replenishment	Because of the lack of beach width, the dune is rebuilt with a sandbag core. Sand is placed on the beach to rebuild a berm. This berm provides habitat that would be available in the absence of the dune, as well as provides protection for the dune. The sole example of this in the project area is the maintenance project planned for Rodanthe in 2008 in which approximately 200,000 cubic yards (152,911 cubic meters) of sand will be excavated from the terminal groin fillet and trucked hauled and placed in the Rodanthe 'S' Curves Hot Spot. Sand is placed as much as possible above the high water line and natural processes are allowed to rework the material. Placement below the high water line occurs when the distance from toe of the dune to the high water line is less than that distance needed to operate the necessary equipment.	Only one occurrence of this activity; it is currently (2007/2008) being completed at the southern end of the Refuge. Prior to 2015, the sandbag area will need to be lengthened up to about 1,500 feet (762 meters).
5. Dune Translation	When the large windblown dunes migrate onto the shoulder of NC 12, excavating equipment is used to "scoop" the sand from the backside of the dune and place the sand forward of the dune crest so that it replenishes the front slope of the dune. This currently only occurs in the Canal Zone Hot Spot.[2]	1 to 2 times per year

[1] Based on NCDOT storm frequency and maintenance activity experience in the three hot spots found within the Refuge.
[2] In the past, this activity has generally occurred partially or completely outside of the existing NC 12 easement.

distance), but the lowering of the maximum elevation of the dune leaves the road vulnerable to overwash in subsequent storms. During storm events in which the water level is elevated because of the storm surge (water elevated by storm winds) the dune can be systematically undermined or overtopped, creating a dune blowout, overwash, and washover fan.

Using distance to shoreline, apparent dune integrity, and past storm maintenance experience (keeping in mind that future maintenance would occur within the NC 12 easement), the susceptibility of the NC 12 area needing maintenance can be projected. In addition, NC 12 maintenance experience has revealed that when the dune heel (side of the dune facing the sound) gets within 10 feet (3 meters) of NC 12 and the dune is un-vegetated, windblown sand on the road is a common occurrence. This has occurred in the Canal Zone Hot Spot area. The wind blown sand also creates a problem with water on the pavement because of the storm creates high shoulders and swales filled with sand. The road becomes a low point for standing water.

Table 4-14 and Table 4-15 present forecast shoreline areas likely to require maintenance activities assuming the average and the high erosion shoreline findings, respectively, that were prepared as a part of this FEIS. Maintenance activities are assumed to cease as each portion of the Phased Approach/Rodanthe Bridge Alternative (Preferred) is completed.

The tables contain the following elements:

- Activities estimated under 2010, 2015, 2020, and 2030 shoreline conditions with the presumption that Phase II is completed shortly after 2015, Phase III is completed shortly after 2020, and Phase IV is completed shortly after 2030 (see Section 2.10.2.5);

- The length of NC 12 forecast to be likely to require each activity in each year; and

- The percent length of NC 12 within the Refuge that would require each activity in each year, including the length of NC 12 where the distance to the shoreline and dune integrity is expected to be great enough that none of the activities are expected to occur.

Given that maintenance would stay within the existing NC 12 easement, and the past activities presented in Table 4-13 can occur outside the easement, Table 4-14 and Table 4-15 assume the following three projected future activities:

1. <u>Road Scraping</u>. Same as defined in Table 4-13;

2. <u>Dune Building and Maintenance in Easement</u>. Since dunes that develop small holes or lose elevation as a result of a storm are generally outside of the NC 12 easement, they could no longer be repaired. Instead, a small dune would be built in the NC 12 easement to account for the weaker dune outside of the NC 12 easement. This activity could occur somewhere along NC 12 within the Refuge two to three times per year based on past experience with the development of small holes or loss of elevation in existing dunes. Maintenance of this dune also would occur once built. Once dunes are built, their maintenance or repair could occur at intervals more frequent than the manifestation of the original need since this activity would not restore the damaged original dune.

3. <u>Sandbag Dune Building and Maintenance in Easement</u>. In the past, dunes that have been substantially lost to a storm have been rebuilt. Because of the greater exposure to NC 12 resulting from the substantial loss of a segment of dune and because rebuilding would need to be confined to available space within the NC 12 easement, the dune would be rebuilt with a

Table 4-14. Forecast Areas in Refuge Susceptible to Three Projected Future Storm-Related NC 12 Maintenance Activities (Average Erosion Shoreline)

General Location	Phase	Total Length in Refuge in feet (meters)	Susceptible[1] Area and Activities							
			2010		2015		2020		2030	
			Length of Susceptible Area in feet (meters)	Activities	Length of Susceptible Area in feet (meters)	Activities	Length of Susceptible Area in feet (meters)	Activities	Length of Susceptible Area in feet (meters)	Activities
Rodanthe/'S' Curves Hot Spot	II	9,980 (3,043)	1,000 (305)	1,2,3	2,500 (762)	1,2,3	9,980 (3,043)	MN	9,980 (3,043)	MN
			2,500 (762)	1,2,3	2,000 (610)	1,2,3				
			4,000 (1,220)	1,2	3,000 (915)	1,2				
			2,480 (756)	MN	2,480 (756)	MN				
No Improvement Area	NA	9,944 (3,032)	9,944 (3,032)	MN	9,944 (3,032)	MN	9,944 (3,032)	MN	9,944 (3,032)	MN
New Inlet	III	11,400 (3,476)	11,400 (3,476)	MN	500 (152)	1	500 (152)	1	11,400 (3,476)	MN
					10,900 (3,324)	MN	10,900 (3,323)	MN		
South Ponds	IV	8,280 (2,524)	2,500 (762)	1	3,000 (915)	1,2	3,500 (1,067)	1,2	3,500 (1,067)	1,2
			5,780 (1,762)	MN	5,280 (1,609)	MN	1,500 (457)	1	1,500 (457)	1,2,3
							3,280 (1,000)	MN	3,280 (1,000)	MN
Visitor Center	II	3,720 (1,134)	1,000 (305)	1,2	1,500 (457)	1,2	3,270 (1,134)	MN	3,270 (1,134)	MN
			2,720 (829)	MN	2,220 (677)	MN				
North Ponds	IV	5,160 (1,573)	5,160 (1,573)	MN	5,160 (1,573)	MN	500 (152)	1	1000 (305)	1,2
							4,650 (1,421)	MN	4,160 (1,268)	MN
Canal Zone and Sandbag Hot Spots	II	13,560 (4,134)	1,000 (305)	1	1,000 (305)	1	13,560 (4,134)	MN	13,560 (4,134)	MN
			1,500 (457)	1,2	500 (152)	1,2,3				
			4,500 (1,372)	1,2	2,000 (610)	1,2,3				
			6,560 (2,000)	MN	4,000 (1,220)	1,2				
					6,060 (1,847)	MN				
Total Length		62,044 (18,911)								
Total Impact by Activity Type			**2010**		**2015**		**2020**		**2030**	
			Length	**Percent**	**Length**	**Percent**	**Length**	**Percent**	**Length**	**Percent**
MN			44,044 (13,424)	71%	42,044 (12,818)	68%	56,034 (17,084)	90%	56,044 (17,087)	90%
1			18,000 (5,488)	29%	20,000 (6,098)	32%	6,000 (1,829)	10%	6,000 (1,829)	10%
2			14,500 (4,421)	23%	18,500 (5,641)	30%	3,500 (1,067)	6%	6,000 (1,829)	10%
3			3,500 (1,067)	6%	7,000 (2,134)	11%	0	0%	1,500 (457)	2%

[1] The lengths reflect each location's susceptibility to the need for the storm-related maintenance activities indicated. The area actually affected by any given storm generally would be less than the lengths shown. Minor events tend to result in spotty activities and larger events tend to result in activities that affect larger portions of the susceptible locations. At locations susceptible to the more intensive activity 3, minor events are likely to cause more extensive 1 and 2 activities than at locations not susceptible to activity 3.

Table 4-15. Forecast Areas in Refuge Susceptible to Three Projected Future Storm-Related NC 12 Maintenance Activities (High Shoreline Erosion)

General Location	Phase	Total Length in Refuge in feet (meters)	Susceptible[1] Area and Activities							
			2010		2015		2020		2030	
			Length of Susceptible Area in feet (meters)	Activities	Length of Susceptible Area in feet (meters)	Activities	Length of Susceptible Area in feet (meters)	Activities	Length of Susceptible Area in feet (meters)	Activities
Rodanthe/'S' Curves Hot Spot	II	9,980 (3,043)	4,500 (1,372)	1,2,3	6,500 (1,982)	1,2,3	9,980 (3,043)	MN	9,980 (3,043)	MN
			3,000 (915)	1,2,3	1,000 (305)	1,2,3				
			2,480 (756)	MN	2,480 (756)	MN				
No Improvement Area	NA	9,944 (3,032)	9,944 (3,032)	MN	9,944 (3,032)	MN	9,944 (3,032)	MN	9,944 (3,032)	MN
New Inlet	III	11,400 (3,476)	1000 (305)	1	1,000 (305)	1,2	1,500 (457)	1,2,3	11,400 (3,476)	MN
			10,400 (3,171)	MN	10,400 (3,171)	MN	9,900 (3,019)	MN		
South Ponds	IV	8,280 (2,524)	1,000 (305)	1,2	1,500 (457)	1,2	1,000 (305)	1,2,3	2,000 (610)	1,2,3
			2,500 (762)	1	2,000 (610)	1,2	3,000 (915)	1,2	2,500 (762)	1,2
			4,780 (1,457)	MN	4,780 (1,457)	MN	4,280 (1,304)	MN	3,780 (1,152)	MN
Visitor Center	II	3,720 (1,134)	1,500 (457)	1,2	1,500 (457)	1,2,3	3,720 (1,134)	MN	3,720 (1,134)	MN
			1,000 (305)	1,2,3	2,220 (677)	1,2				
			1,220 (372)	MN						
North Ponds	IV	5,160 (1,573)	5,160 (1,573)	MN	5,160 (1,573)	MN	1,000 (305)	1,2	1,000 (305)	1,2
							4,160 (1,268)	MN	3,000 (915)	1,2
									1,160 (353)	MN
Canal Zone and Sandbag Hot Spots	II	13,560 (4,134)	3,000 (915)	1,2,3	4,000 (1,220)	1,2,3	13,560 (4,134)	MN	13,560 (4,134)	MN
			5,500 (1,677)	1,2,3	5,000 (1,524)	1,2,3				
			2,000 (610)	1,2	1,000 (305)	1,2				
			3,060 (932)	MN	3,560 (1,085)	MN				
Total Length		62,044 (18,911)								
Total Impact by Activity Type			**2010**		**2015**		**2020**		**2030**	
			Length	**Percent**	**Length**	**Percent**	**Length**	**Percent**	**Length**	**Percent**
MN			37,044 (11,293)	60%	31,544 (9,617)	51%	55,544 (16,934)	90%	53,544 (16,342)	86%
1			25,000 (7,623)	40%	25,720 (7,842)	41%	6,500 (1,982)	10%	8,500 (2,592)	14%
2			21,500 (6,556)	35%	23,720 (7,232)	38%	6,500 (1,982)	10%	8,500 (2,592)	14%
3			17,000 (5,184)	27%	18,000 (5,488)	29%	2,500 (762)	4%	2,000 (610)	3%

[1] The lengths reflect each location's susceptibility to the need for the storm-related maintenance activities indicated. The area actually affected by any given storm generally would be less than the lengths shown. Minor events tend to result in spotty activities and larger events tend to result in activities that affect larger portions of the susceptible locations. At locations susceptible to the more intensive activity 3, minor events are likely to cause more extensive 1 and 2 activities than at locations not susceptible to activity 3.

sandbag core. This activity could occur somewhere along NC 12 within the Refuge one to two times per year based on past experience with substantial dune loss. Maintenance of this dune also would occur once built. Once sandbag dunes are built, their maintenance or repair could occur at intervals more frequent than the manifestation of the original need since this activity would not restore the substantially lost original dune.

Items 2 and 3 in Table 4-13 could still be done if they could be done within the existing easement, but are not assumed in Table 4-14 and Table 4-15 because those solutions are generally applicable to repairs when the dunes are still outside or partially outside of the NC 12 easement. Item 4 could not be done as described in Table 4-13 because berm replenishment would occur outside of the NC 12 easement. Item 5 in Table 4-13 could not be done within the existing NC 12 easement.

The lengths shown in Table 4-14 and Table 4-15 reflect locations expected to require the storm-related maintenance activities indicated. The area actually affected by any given storm generally would be less than the lengths shown. Minor events tend to result in spotty activities, and larger events tend to result in activities that affect larger portions of the susceptible locations. At locations susceptible to the more intensive activity 3, minor events are likely to cause more extensive 1 and 2 activities than at locations not susceptible to activity 3.

Past activities and their frequencies presented in Table 4-13 were derived primarily from maintenance records dating from 1991. Maintenance requirements at the hot spots have increased substantially since 1999 with Hurricanes Dennis, Bonnie, and Floyd, and increased again with Hurricane Isabel in 2003. The projected three activities that likely would be used for maintenance in the future and their associated frequencies were developed from a post-1999 storm activity baseline. From 1999 to November 2007, there were six hurricanes, one tropical storm, and 13 nor'easters or other storms that required cleanup activities. Even larger, more frequent storms that directly affect Hatteras Island could alter the assessments of Table 4-14 and Table 4-15. Also, with this in mind, the category minimal to none carries two connotations: 1) the activity itself is minimal (infrequent occurrences of activity 1), or 2) there is a minimal probability of occurrence using the criteria just described.

Table 4-14 and Table 4-15 indicate that the level of NC 12 maintenance related to storms will continue in the three hot spots and likely increase in those areas until Phase II is completed. Again, NCDOT would confine this work to the existing NC 12 easement, since the Refuge has indicated that such work would not be found compatible with the Refuge under the requirements of the National Wildlife Refuge System Improvement Act of 1997. Recognizing the desirability of ending these activities, NCDOT intends to place a high priority on the implementation of Phase II, as discussed in Section 2.10.2.5. The completion of Phase II would substantially decrease the amount of storm-related maintenance on NC 12, but some would remain and would increase prior to the completion of Phases III and IV, but not to the extreme currently occurring in the three hot spots.

As indicated in Section 2.10.2.5 and in commitment number 15 of the Project Commitments section, NCDOT also would not perform storm-related NC 12 maintenance work outside of the existing easement in the Phase III, IV, and no action areas on NC 12 for the reason noted in the previous paragraph. Limiting the growth in the need for NC 12 storm-related maintenance in the Phase III and IV areas to the extent practicable given the availability of transportation funding and the efficient use of those funds also is considered desirable. In order to help accomplish that objective, NCDOT would implement a monitoring program, the particulars of which would be developed in consultation with representatives of the Refuge, including development of decision-making criteria for translating monitoring findings into a decision to move forward with an additional phase and how to refine the location of each phase to reflect actual future shoreline change.

Final Report

Pea Island Shoreline: 100-Year Assessment

Prepared by

John S. Fisher, Ph.D., P.E.
Margery F. Overton, Ph.D.
Tom Jarrett, P.E.

FDH Engineering, Inc.

Prepared for

URS Corporation – North Carolina

July 2004

This report has been prepared based on certain key assumptions made by FDH Engineering that substantially affect the conclusions and recommendations of this report. These assumptions, detailed in the report, although thought to be reasonable and appropriate, may not prove to be true in the future. The conclusions and recommendations of FDH Engineering are conditioned upon these assumptions.

Pea Island Shoreline: 100-Year Assessment

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Pea Island Shoreline: 100-Year Assessment

Executive Summary
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The ocean shoreline on Pea Island between Oregon Inlet and Rodanthe (North Carolina Outer Banks) is highly variable and includes some of the highest shoreline erosion rates found along the entire North Carolina coast. FDH Engineering, Inc. was retained by URS Corporation to participate in a study for the North Carolina Department of Transportation to estimate the cost to stabilize this shoreline with beach nourishment for a 100-year period. This shoreline stabilization would be used in conjunction with a new bridge over Oregon Inlet that would incorporate the existing position of NC12 between the Oregon Inlet and the Village of Rodanthe. The study begins at a point approximately 1 mile south of the Oregon Inlet terminal groin and extends about 12 miles south along Pea Island to the southern limit of the Pea Island National Wildlife Refuge or just north of the Village of Rodanthe.

In completing this shoreline stabilization analysis, FDH utilized existing shoreline change data from several sources including NCDOT data collected in conjunction with the monitoring of the Oregon Inlet terminal groin, a historical shoreline database compiled by Dr. Robert Dolan at the University of Virginia, and shoreline data collected for the North Carolina Division of Coastal Management. These data were combined to yield the rate of shoreline change for the study area that includes both the long-term trends for this coast (based upon a records dating back over 50 years) as well as the influence of the Oregon Inlet terminal groin that was constructed in 1989. The construction of the terminal groin has resulted in significant reduction of the erosion pattern over a distance of about three miles south of Oregon Inlet.

The cost for beach nourishment to protect NC12 over the next 100 years was based on the following set of assumptions:

1) The Pea Island terminal groin would remain in place over the next 100 years.
2) Beach nourishment would be required to protect the highway when the shoreline encroaches within 230 feet of the right-of-way.
3) The minimum length of highway that would be protected by beach fill is 1 mile.
4) The initial beach fill operation would not begin until the year 2007 due to the estimated amount of time required to obtain necessary permits and environmental clearances.
5) The material needed for beach nourishment would come from USACE maintenance dredging of the Oregon Inlet ocean bar channel and from two offshore borrow areas previously identified by the NC Geological Survey for NCDOT as part of an Outer Banks Task Force initiative.
6) The materials in the two offshore borrow areas, one located just seaward of Oregon Inlet and the other seaward of Rodanthe, are assumed to be 100%

compatible with the native beach sands; however, there would be a 20% loss of borrow material during placement on the beach.

7) The minimum design berm width for the beach fills would be approximately 50 feet.
8) Beach fill quantities were computed for the entire depth of the active profile which extends from a berm crest elevation of +7 feet msl offshore to a depth of -30 feet msl.
9) Volumetric erosion from the fills were based on the average shoreline change rate for the area adjusted for end losses and offshore losses by applying an erosion rate factor of 3 for relatively short beach fill segments (less than 2 miles) and 1.5 for longer beach fill segments (greater than 2 miles).
10) The nourishment interval for each beach fill segment was based on the amount of time required to completely erode the design berm width.

Assumption 1) is critical due to the positive influence the terminal groin has had on the northern 3 miles of Pea Island. Removal of the groin would likely result in the rapid deterioration of the north end of Pea Island which would negate beach nourishment as a protection option in this section. Assumption 2) is based on past studies that have shown the highway becomes vulnerable to damage during large storms when the shoreline moves to within 230 feet of the right-of-way. With regard to Assumption 5), maintenance dredging of the Oregon Inlet ocean bar channel has averaged 400,000 cubic yards per operation. Presently, the USACE disposes of this material in nearshore areas just off the north end of Pea Island using hopper dredges. For this cost estimated, the maintenance material was assumed to be removed by an ocean certified pipeline dredge with disposal directly on the north end of Pea Island. NCDOT would only be responsible for the added cost of placing the maintenance material directly on the beach rather than in the nearshore disposal areas. Material from the two offshore borrow areas would be delivered to the beach via hopper dredges employing direct pumpout techniques. Assumption 9) was based on the actual behavior and nourishment history of beach fill projects in North Carolina; namely, the Carolina Beach and Wrightsville Beach federal storm damage reduction projects which have been maintained over the last 40 years.

Using these assumptions, an estimate was made of the beach nourishment required to protect that portion of NC12 in the study area for a 100-year period beginning in 2007. Based on the shoreline erosion rates adopted for this study, the area south of Oregon Inlet to Rodanthe was divided into six segments that would require nourishment at sometime during the 100-year analysis period. For a 2-mile section of the highway located just south of Oregon Inlet in the area commonly referred to as the "Canal Area", nourishment would be required in 2007 with nourishment continuing throughout the entire 100-year period. Also, a 1.5-mile section of the highway located just north of the Village of Rodanthe is also presently vulnerable and would need nourishment for the entire 100-year period. The other 4 segments, totaling approximately 6 miles, would phase in at various times over the next 100 years. Accordingly, about 9.5 miles of the 12-mile study area would need to be nourished over the next 100 years to protect NC12. The 2.5 mile segment that would not need to be protected with beach nourishment is presently accreting.

For the entire 100-year project period, a total of approximately 105.7 million cubic yards of sand will be needed to protect the current position of NC12 with the 230 ft buffer. Approximately 91.3 million cubic yards of the material would come from the two offshore borrow areas with the remaining 14.4 million derived from the maintenance dredging in Oregon Inlet. Nourishment intervals for the discrete segments would range from 2 to 4 years depending on the average erosion rate within each segment. The total cost of this nourishment for the entire 100-year period is estimated to be $930,000,000. This total cost includes an allowance for engineering and design, construction management, and contingencies for each nourishment operation. This estimate does not include the cost for additional geophysical surveys that would be required should this project actually be pursued nor does it include the cost for preparation of and Environmental Impact Statement. It is important to note that there are a number of critical assumptions that are incorporated in this preliminary assessment of the cost to protect the present position of NC12 in the study area. This total cost estimate can only be used as an initial guide in analysis of a project of this magnitude. It is unusual to plan a beach nourishment project for a 100-year period. The uncertainties that apply to a more common 50-year project are necessarily magnified when one doubles the time period.

Pea Island Shoreline: 100-Year Assessment

1. Background

FDH Engineering, Inc. was retained by URS Corporation – North Carolina to undertake an analysis of the Pea Island Shoreline adjacent to Oregon Inlet on the North Carolina Outer Banks. The analysis is intended to compliment other ongoing studies dealing with the analysis of alternative designs for a replacement bridge over Oregon Inlet. In the present analysis the specific alternative being considered includes the retention of the present terminal groin at the inlet and the present location of NC12 on Pea Island, at the south end of the potential replacement bridge.

The ocean shoreline along the north end of Pea Island is highly variable and includes some of the highest shoreline erosion rates found along the entire North Carolina coast. In order maintain the present position of NC12 in this area it would be necessary to employ an extensive program of beach nourishment to mitigate these high erosion rates. The specific focus of this study is to estimate the magnitude and cost of this beach nourishment for a period of 100-years; the expected useful life of the proposed bridge alternative.

2. Methodology

The estimate of the volume of sand needed for beach nourishment to protect NC12 is based upon the assumption that the minimum distance between the ocean-side edge of pavement and the shoreline should be maintained at a minimum critical buffer distance of 230 ft. This minimum distance is based upon other studies of highway vulnerability undertaken for NCDOT, Overton and Fisher (2004). The analysis computes the beach nourishment needed to provide for this buffer over the 100-year study period. The sand needed for the beach nourishment is assumed to be available from either the maintenance dredging of the navigation channel in Oregon Inlet, or from one of the potential nearshore borrow sites along the northern end of Pea Island. The design of the nourishment and the cost estimates are based upon recent U.S. Army Corps of Engineers projects in North Carolina. The shoreline change rates used in the present analysis are based upon the best available shoreline data and includes recent studies for both NCDOT (Overton and Fisher, 2004) and the NC Division of Coastal Management (Overton and Fisher, 2003???).

3. Shoreline Change Rates

Three shoreline position databases were used in this study to compute the rate of shoreline change. In the immediate vicinity of Oregon Inlet, there is an extensive shoreline change database available as a consequence of the monitoring of the terminal groin. The construction of the groin was completed in the Fall of 1989. One of the conditions for the permit for the groin construction is that NCDOT monitor the shoreline position for a 6 mile distance of south of the structure. The shoreline position is determined from NCDOT digital aerial photography flown every two months. The analysis of shoreline change is undertaken at North Carolina State University, Department of Civil, Construction and Environmental Engineering (Overton and Fisher, 2004).

The second shoreline position database used in this analysis was compiled by Dr. Robert Dolan at the University of Virginia. The shorelines in this database were collected from historical aerial photography dating from the 1940's to the late 1980's. Most of these shorelines were digitized using an analog technique with a zoom transfer scope.

The third shoreline database is was compiled for the North Carolina Division of Coastal Management (DCM) as the basis for their periodic update of the long-term annual erosion rate used in their permitting procedures, Overton and Fisher (2003). The database includes both a shoreline digitized from the 1949 T-sheets as well as a 1998 digital aerial photograph. (A T-sheet is the National Ocean Survey's baseline used in the preparation of navigation charts. These are considered to be some of the best sources for early shoreline position data).

The rate of shoreline change was computed from the individual shoreline positions by linear regression. This technique combines all of the appropriate shorelines positions over the time period they span into a single rate of change. Equal weight is given to each shoreline included in the regression. Figure 1 shows the results of this analysis. The "DCM data" combines all of the Dolan data with the DCM data and covers the period from 1949 to 1998. The "Oregon Inlet monitoring data" (OIMD) covers the period since the construction of the terminal groin (October 1989) to June 2003. It is important to note that these data only extend 6 miles south of the inlet.

As shown on Figure 1, there are significant differences between the rates of shoreline change, depending upon the database. Recall that the OIMD data covers the period after groin construction (1989-2003) and the DCM data covers the period from 1949 to 1998. Prior to the construction of the terminal groin there was extensive erosion on the north end of Pea Island and the historic rate of shoreline change was on the order of 10 to 15 ft/yr. Since the DCM data covers both the period before and after groin construction, it is not surprising to find high erosion rates close to the inlet. However, these previous high erosion rates have been reduced by the construction of the terminal groin. These changes since groin construction are clearly seen in Figure 1. The OIMD shoreline change rates closest to the groin are in fact accretion (negative values on this figure). Since the construction of the terminal groin the shoreline closest to the inlet has built out, and thus the groin has been providing the intended protection to the present Oregon Inlet bridge.

Comparison of rates in the first three to four miles of the study area clearly show the influence of the terminal groin as well as sand supplied to this area during beach disposal from inlet dredging. Further south, it is more difficult to determine whether the rate is primarily determined by the post-groin activities. The diminished impact of the groin with distance, the natural variability in shoreline position and the temporal differences in the databases all contribute to this difficulty. The "DCM rate" is a long-term rate (>50 yr period) using sparse data (5-10 yr intervals) while the OIMD rate is a short-term (<15 yr period) rate built on a robust dataset (2 month intervals). In order to integrate the impact of the groin with the long-term data, the two datasets were combined and a new rate based on the linear regression of all the data was computed. This new rate is shown in Figure 1 (Merged DCM and OI data). As expected, the rate from the merged data falls somewhere between the DCM rate and the OIMD rate.

Because of the strong influence of the groin in stabilizing the shoreline in the 3 to 4 miles just south of the groin, the OIMD data was used to establish a rate for this section of the study area. The merged data (DCM plus OIMD) was used to determine the rate in the next 2 miles (miles 4 to 6). This two miles is in an area where the dominant influence of the groin is not well established and the long-term data may reasonable provide relevant information in determining the current trend in shoreline change. Further south, we only have the DCM long-term data. Merging the data in this mid-region helps transition the change from short-term to long-term data. The modified combination of rates is shown on Figure 2 as "Project rate".

The Selected shoreline change rates (Project rate) for the entire study area range from the small area of accretion in the vicinity of the terminal groin (with rates as high a 13 ft/yr), a second small area of accretion near mile 7.5 (around 5 ft/yr), and the more dominate pattern of erosion with a maximum value of around 13 ft/yr nearest Rodanthe. The fact that there are significant spatial variations in the rates of shoreline change are not unusual along an ocean coast, and especially not uncommon near inlets.

These modified combined rates of shoreline change (Project rate, Figure 2) are the basis for the determination of the timing and volumes of beach nourishment used in the following analysis of beach nourishment volumes and costs.

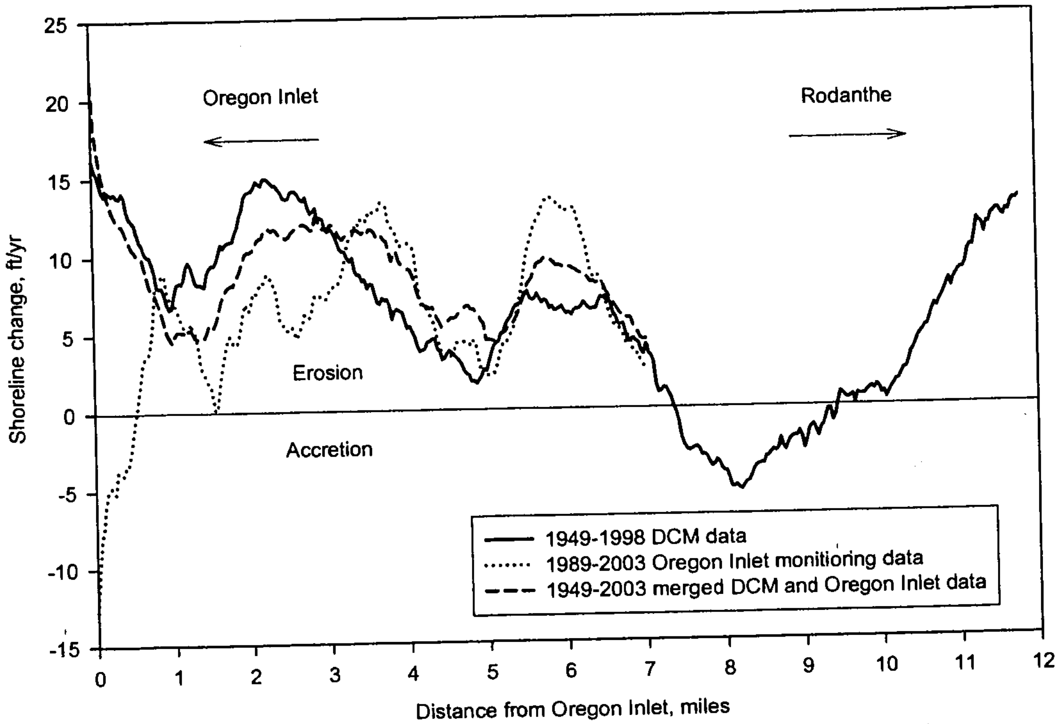

Figure 1. Comparison of rates of shoreline change, ft/yr.

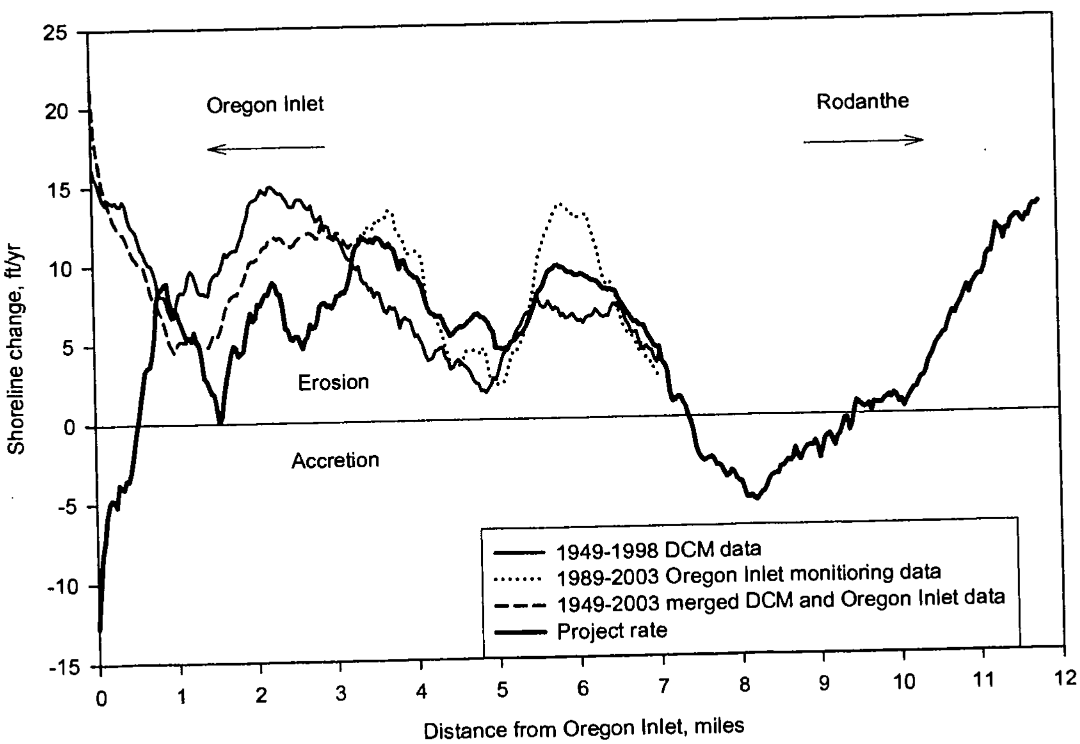

Figure 2. Project shoreline change rate, ft/yr.

4. Cost Estimates for 100-year Beach Nourishment Program

4.1 Highway Vulnerability

Cost estimates for protecting NC Highway 12 (NC12) between Oregon Inlet and the Village of Rodanthe over the next 100 years using beach nourishment were prepared based on projections as to when certain sections of the highway would become vulnerable to loss due to erosion. As noted previously in the context of this study, vulnerability means that the distance from the ocean-side edge of pavement for NC12 to the shoreline is less than the critical buffer distance of 230 ft.

Two sections of NC12 are vulnerable today, namely, 6,600 feet of highway beginning about 4,000 feet south of the Pea Island terminal groin (Oregon Inlet south shoulder) designated as Reach 1 and the other covering 5,250 feet of highway just north of the Village of Rodanthe designated as Reach 4. Beginning in 2023 and 2027, two other sections of the highway, designated as Reach 2 and Reach 3 respectively, will become threatened with additional sections being threatened by the year 2067. The locations of the various reaches of NC12 between Oregon Inlet and Rodanthe that would become vulnerable during the next 100 years are shown on Figure 3. By the year 2067, the total length of NC12 situated south of Oregon Inlet that would be threatened by erosion would total approximately 6.5 miles.

4.2 Nourishment Requirements

The volume of material needed to nourish each reach was based on the long-term erosion rates (Project rate, Figure 2) for the respective reach with adjustments made to account for end and offshore losses. For fills less than 2 miles in length, these adjustments would increase the erosion rate by a factor of 3. This increase in the erosion rate was based on the observed behavior of similar beach fill projects located at Carolina Beach and Wrightsville Beach, N.C. In order to widen the beach by one foot, a sufficient volume of material must be placed to widen the entire active beach profile from the top of the berm seaward to the depth where sediment movement becomes insignificant for engineering considerations. For the Pea Island area, the total depth of the active profile is 37 ft and extends from the 7-ft mean sea level (msl) berm crest elevation to a depth of -30 ft msl. Therefore, in order to widen the beach by one foot, 1.37 cubic yards (cu yd) of fill/lineal foot of beach would be required.

The fills within Reaches 1, 2, and 3 would initially be constructed with 2,000-ft transition sections north and south of the main fills. By the year 2067, the gap between Reach 2 and Reach 3 would be filled with the construction of Reach 3A-N. The total area nourished in 2067 would be further increased by the addition of Reach 3A-S south of Reach 3 resulting in an almost continuous 6.5 mile beach fill south of Oregon Inlet. Due to the length of the fill in 2067, end and offshore losses from the fill were assumed to be reduced by a factor of 2, i.e., the historic erosion rate was increased by a factor of 1.5 rather than 3 for Reaches 1 to 3A-S. Due to the relatively short length of Reach 4, losses

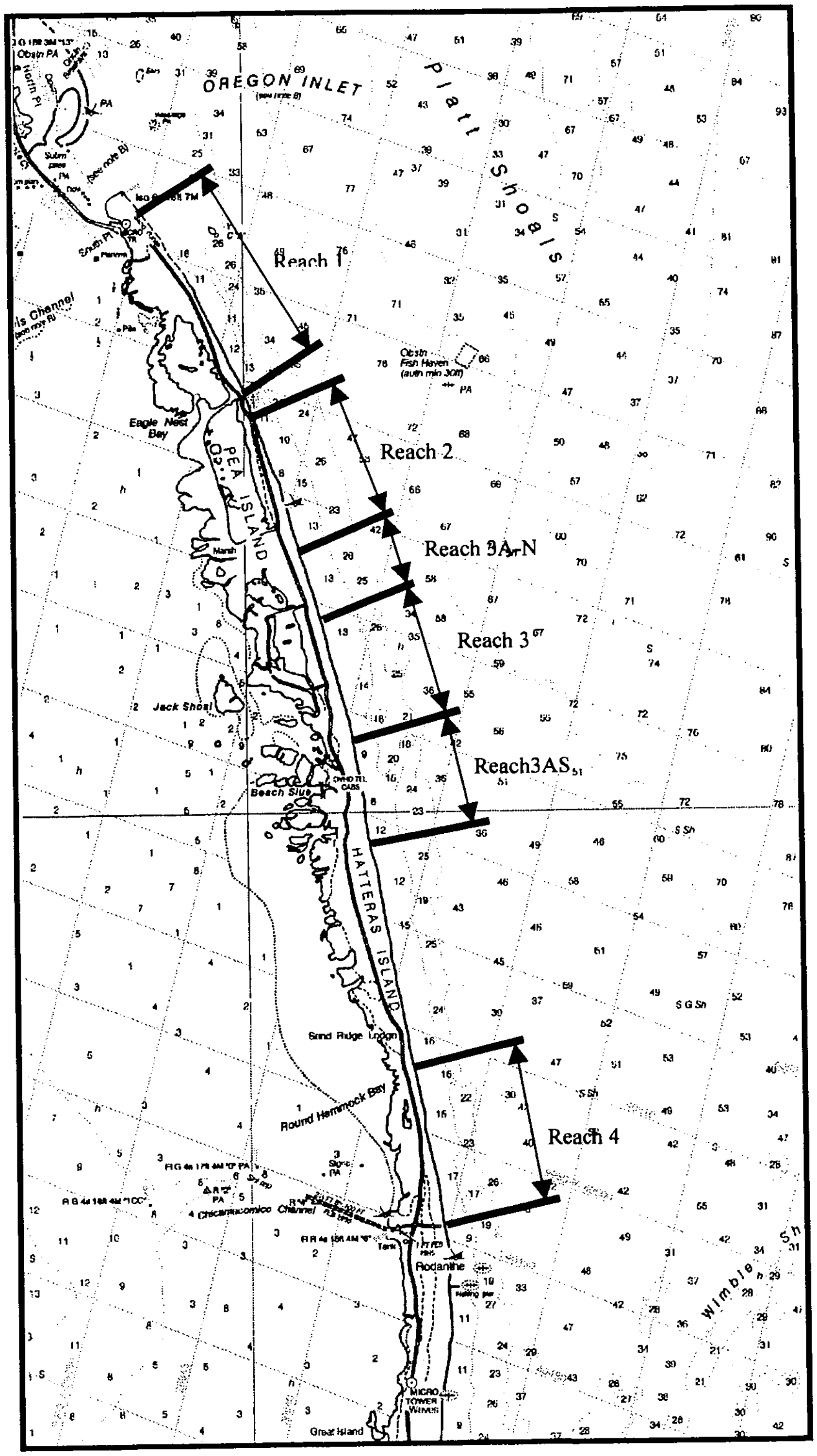

Figure 3. Locations of Nourishment Reaches

from the fill were assumed to remain at 3 times the long-term rate for the entire 100-year period. Except for Reach 1, the design berm width within each segment was selected to provide at least 2 years between nourishment operations during the period from 2007 to 2067. Due to the relatively small annual nourishment requirement for Reach 1, the width of the berm selected would provide 4 years between nourishment operations.

Nourishment requirements for each Reach south of Oregon Inlet are summarized in Table 1.

Table 1
Summary of Pea Island – Nourishment Requirements
Between Oregon Inlet and Rodanthe
2007 to 2067

Reach	Total Length Of Fill Including Transitions (ft)	Year Fill Begins	Current Erosion Rate (ft/yr)	Fill Erosion Rate Factor	Erosion Rate of Fill (ft/yr)	Design Berm Width (ft)	Fill Interval (yrs)	Fill Needed each cycle (cu yd)
1	10,652	2007	5.0	3.0	-15.0	60	4	850,000
2	9,250	2023	10.3	3.0	-30.9	62	2	740,000
3	11,872	2027	8.0	3.0	-24.0	48	2	780,000
4	9,250	2007	10.7	3.0	-32.1	64	2	770,000

Nourishment Requirements beginning in 2067

Reach	Total Length Of Fill Including Transitions (ft)[(a)]	Year Fill Begins	Current Erosion Rate (ft/yr)	Fill Erosion Rate Factor	Erosion Rate of Fill (ft/yr)	Design Berm Width (ft)	Fill Interval (yrs)	Fill Needed each cycle (cu yd)
1	10,652	2067	5.0	1.5	-7.5	60	8	850,000
2	7,250	2067	10.3	1.5	-15.5	62	4	640,000
3	7,872	2067	8.0	1.5	-12.0	48	4	620,000
3A-N	2,133	2067	6.0	1.5	-9.0	36	4	130,000
3A-S	6,265	2067	6.8	1.5	-10.2	41	4	360,000
4	9,250	2067	10.7	3.0	-32.1	64	2	770,000

(a) Total fill lengths within some Reaches reduced after 2067 due to the elimination of transaction sections as adjacent fills merge.

4.3 Sources of Borrow Material

In July and August 1994, the North Carolina Department of Transportation (NCDOT) acting through the auspices of the Outer Banks Task Force, conducted preliminary sand searches offshore of Pea, Hatteras, and Ocracoke Islands using a combination of seismic profiling and vibracores. Results of the sand search for northern Pea Island were reported by Boss and Hoffman (2000). Based on these preliminary results, two potential borrow areas were identified, one located off the north end of Pea Island near Oregon Inlet and the other located seaward of Rodanthe. The general location of these two potential borrow areas, designated as PBA-A for the north area and PBA-B for the southern area, are shown on Figure 4. The preliminary assessment of the amount of material available from these two potential borrow areas is 69 million cu yd for PBA-A and 56 million cu yd for PBA-B. A detailed assessment of the compatibility of the borrow material with the native beach material has not been accomplished; however, the grain size analysis performed on samples collected from the vibracores appears to indicate that the material would be suitable. Accordingly, the cost estimates were made based on the assumption that there would be enough suitable material in the two potential borrow areas to support beach nourishment over the next 100 years. In the absence of a detailed compatibility analysis, an overfill factor of 1.2 was assumed for the offshore borrow material, i.e., in order to obtain 1 cu yd of compatible beach fill material in place along the beach, 1.2 cu yd of material would have to be removed from the borrow areas.

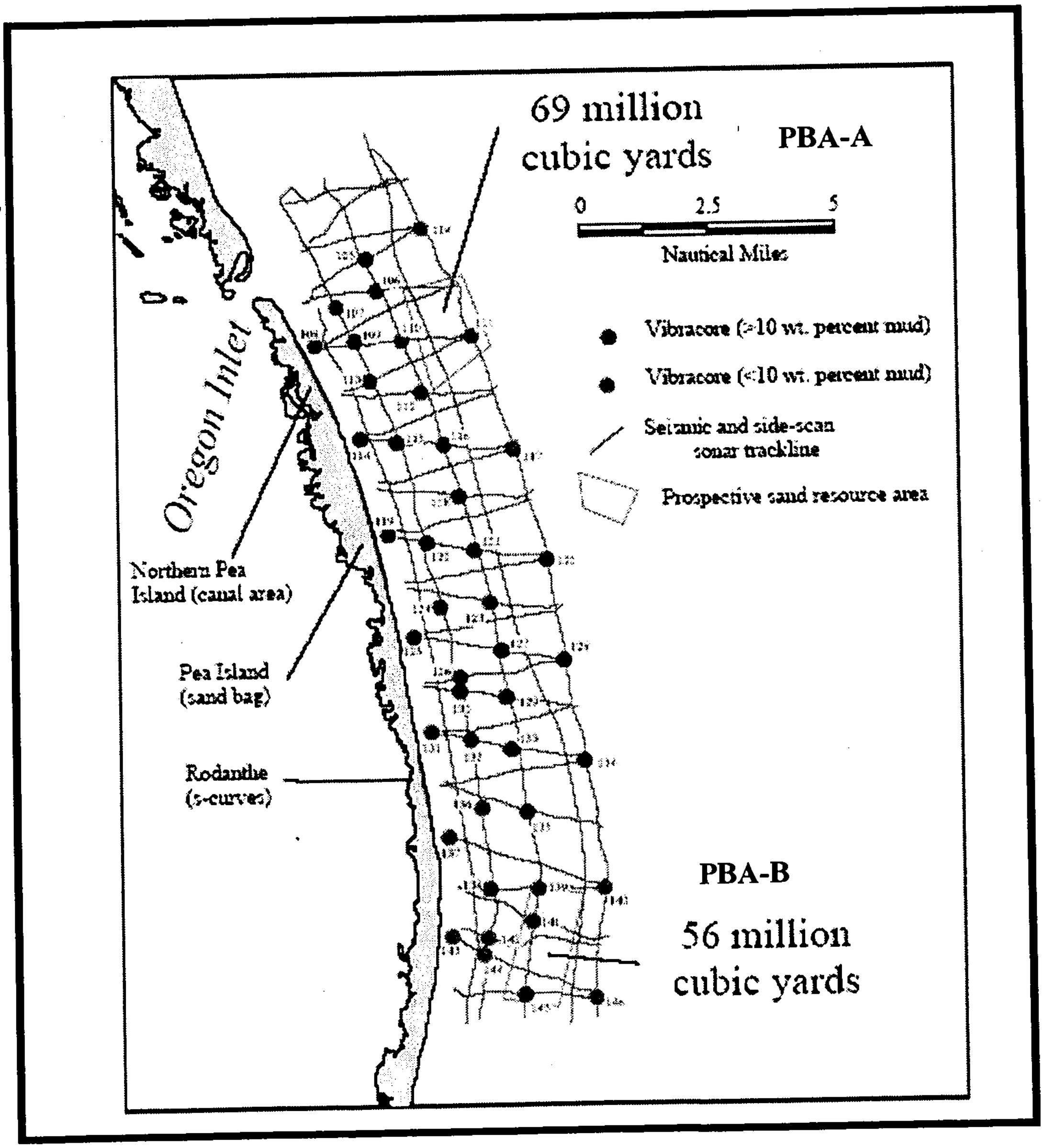

Figure 4 Potential Borrow Areas

4.4 Dredging Operations from Offshore Borrow Areas

Material from PBA-A would be used to nourish Reaches 1 to 3A-S while material from PBA-B would be used for Reach 4. Material would be delivered to the various Reaches via hopper dredges with direct pumpout capability. That is, material would be removed from the potential borrow areas and transported by the hopper dredges to a pumpout barge situated just offshore of the receiving beach. The hopper dredges would connect to the barge and pump material through a pipeline leading from the barge to the beach. Due to the length of pipe involved, each operation would require a booster pump. Earth moving equipment would be used in the beach disposal area to shape the fill to the desired template.

4.5 Contributions from Oregon Inlet Navigation Dredging

In addition to the material available from the two potential borrow areas, the nourishment requirements for the north end of Pea Island were assumed to be augmented by the deposition of navigation maintenance material removed from the Oregon Inlet ocean bar channel. In this regard, the Corps of Engineers has been maintaining the Oregon Inlet ocean bar channel since 1960 employing a combination of U.S. Government sidecast dredges, U.S. Government hopper dredges, contract hopper dredges, and contract pipeline dredges. Prior to 1983, maintenance dredging was performed exclusively by U.S. Government dredges. Beginning in 1983 and continuing today, the Corps has used contract hopper and pipeline dredges to maintain the ocean bar channel and the channel segment that passes through the navigation span of the Bonner Bridge with some supplemental dredging performed by U.S. Government dredges. Most of the pipeline dredging performed in Oregon Inlet since 1991has been performed in the vicinity of the Bonner Bridge navigation span with the material deposited on the northern 1 to 2 miles of Pea Island. Once the existing Bonner Bridge is replaced, the navigation span will be enlarged from its current 130 ft width to at least 2,000 ft. This increase in the navigation span width should eliminate the use of pipeline dredges with essentially the entire ocean bar channel dredging being performed by contract hopper dredges. Material removed from the ocean bar channel by contract hopper dredges is presently deposited in a nearshore disposal area located between 2 and 4 miles south of Oregon Inlet. Since 1983, an average of approximately 400,000 cu yd/yr has been removed from the ocean bar channel by hopper dredge at an average cost of $1,660,000.

The cost estimates for nourishing Pea Island assumed that 400,000 cu yd would be available from the Oregon Inlet ocean bar channel with this material deposited either within Reach 1 or Reach 2 (depending on the nourishment sequence). While hopper dredges with direct pumpout capability could perform the work, an ocean certified pipeline dredge could accomplish the task much quicker and at a lesser cost than the hopper dredge. Therefore, the cost estimates were based on the use of a pipeline dredge to deliver the 400,000 cu yd of channel maintenance material to either Reach 1 or 2 over the next 100 years. Since the pipeline dredge operation would cost more than the present operation that involves the disposal of the material in the nearshore area, the added cost for beach disposal via pipeline dredge would be the responsibility of the NCDOT. The average unit cost for hopper dredge disposal of the ocean bar material in the nearshore disposal area has been approximately $4.15/cu yd based on Corps of Engineers records. Therefore, the present cost for nearshore disposal of 400,000 cu yd was taken to be $1,660,000. Assuming that the Corps of Engineers would agree to cost share in the channel dredging operation to this extent, the cost to NCDOT for depositing the 400,000 cu yd either in Reach 1 or Reach 2 was reduced by this amount.

4.6 Nourishment Sequences

Between 2007 and 2002, the only reaches that would require nourishment are Reaches 1 and 4. Reach 1 would be nourished by a combination of hopper dredge pumpout operation with material from PBA-A and 400,000 cu yd of pipeline dredge material from Oregon Inlet. Reach 4 was assumed to be nourished with material from PBA-B during the entire 100-year analysis period. Nourishment in Reach 2 would begin in 2023 followed by nourishment in Reach 3 in 2027. Since Reach 1 would be on a 4-year nourishment cycle between 2007 and 2067 with Reaches 2 and 3 on 2-year cycles, beginning in 2027 and continuing to 2065, the 400,000 cu yd of material from the Oregon Inlet ocean bar channel would be deposited in Reach 2 during operations that do not include Reach 1. Beginning in 2067, the nourishment intervals for Reaches 1 to 3A-S would double, however, the 400,000 cu yd from Oregon Inlet would continue to be deposited in Reaches 1 and 2 with Reach 2 receiving the material during operations that do not involve Reach 1.

4.7 Cost Estimates for Various Operations

Due to sequencing in which various reaches of NC12 would become vulnerable and the difference in the nourishment cycles, individual cost estimates were prepared for 7 combinations involving Reaches 1 to 3A-S over the next 100 years as well as one cost estimate for Reach 4. The cost estimates for the various combinations are provided in Tables 2 to 9. In some cases, more than one hopper dredge would be required in order to complete the operation within the normal dredging window.

Table 2
Cost Estimate for Reach 1
(400,000 cu yd via pipeline from Oregon Inlet plus
450,000 cu yd from PBA-A via Hopper Dredge)

Item	Quantity	Unit	Unit Cost	Cost
Mob & demob (dredge, pumpout, booster, pipeline)	1	job	L.S.	$979,000
Hopper Dredging	450,000	cu yd	$6.20	$2,790,000
Subtotal Hopper Dredge				$3,769,000
Mob & demob (dredge, booster, pipeline)	1	Job	L.S.	$661,000
Pipeline Dredging	400,000	cu yd	$4.29	$1,716,000
Subtotal Pipeline Dredge				$2,377,000
Total Hopper and Pipeline				$6,146,000
Contingencies (20%)				$1,229,200
Subtotal Construction Cost				$7,375,200
Engineering and Design				$221,256
Supervision and Administration				$295,008
Total Cost Nourishment				$7,891,464
Normal Cost Nearshore Disposal of 400,000 cy				-$1,660,000
Net Cost to NCDOT				$6,231,464
Rounded Total Nourishment Cost for NCDOT				**$6,231,000**

Table 3
Cost Estimate for Reach 2
(400,000 cu yd via pipeline from Oregon Inlet plus
340,000 cu yd from PBA-A via Hopper Dredge)

Item	Quantity	Unit	Unit Cost	Cost
Mob & demob (dredge, pumpout, booster, pipeline)	1	Job	L.S.	$1,002,000
Hopper Dredging	340,000	cu yd	$6.39	$2,172,000
Subtotal Hopper Dredge				$3,174,000
Mob & demob (dredge, booster, pipeline)	1	Job	L.S.	$704,000
Pipeline Dredging	400,000	cu yd	$4.51	$1,804,000
Subtotal Pipeline Dredge				$2,508,000
Total Hopper and Pipeline				$5,682,000
Contingencies (20%)				$1,136,520
Subtotal Construction Cost				$6,819,120
Engineering and Design				$204,574
Supervision and Administration				$272,765
Total Cost Nourishment				$7,296,458
Normal Cost Nearshore Disposal of 400,000 cy				-$1,660,000
Net Cost to NCDOT				$5,636,458
Rounded Total Nourishment Cost for NCDOT				**$5,636,000**

Table 4
Cost Estimate for Combined Reaches 1 & 2
(400,000 cy via pipeline from Oregon Inlet plus
1,190,000 cu yd from PBA-A via Hopper Dredge)

Item	Quantity	Unit	Unit Cost	Cost
Mob & demob (dredge, pumpout, booster, pipeline)	1	job	L.S.	$1,007,000
Hopper Dredging	1,190,000	cu yd	$6.49	$7,723,000
Subtotal Hopper Dredge				$8,793,000
Mob & demob (dredge, booster, pipeline)	1	Job	L.S.	$661,000
Pipeline Dredging	400,000	cu yd	$4.29	$1,716,000
Subtotal Pipeline Dredge				$2,377,000
Total Hopper and Pipeline				$11,170,000
Contingencies (20%)				$2,234,020
Subtotal Construction Cost				$13,404,120
Engineering and Design				$402,124
Supervision and Administration				$536,165
Total Cost Nourishment				$14,342,408
Normal Cost Nearshore Disposal of 400,000 cy				-$1,660,000
Net Cost to NCDOT				$12,682,408
Rounded Total Nourishment Cost for NCDOT				**$12,682,000**
Prorated Cost to Reach 1 and 2				
Reach 1				**$6,780,000**
Reach 2				**$5,902,000**

Table 5
Cost Estimate for Combined Reaches 1, 2, & 3
(400,000 cy via pipeline from Oregon Inlet plus
1,190,000 cu yd from PBA-A via Hopper Dredge)

Item	Quantity	Unit	Unit Cost	Cost
Mob & demob (dredge, pumpout, booster, pipeline)	1	job	L.S.	$1,141,000
Mob & demob second hopper dredge	1	job	L.S.	$501,000
Hopper Dredging	1,970,000	cu yd	$6.85	$13,494,500
Subtotal Hopper Dredge				$15,136,500
Mob & demob (dredge, booster, pipeline)	1	job	L.S.	$661,000
Pipeline Dredging	400,000	cu yd	$4.29	$1,716,000
Subtotal Pipeline Dredge				$2,377,000
Total Hopper and Pipeline				$17,513,500
Contingencies (20%)				$3,502,700
Subtotal Construction Cost				$21,016,200
Engineering and Design				$630,486
Supervision and Administration				$840,648
Total Cost Nourishment				$22,487,334
Normal Cost Nearshore Disposal of 400,000 cy				-$1,660,000
Net Cost to NCDOT				$20,827,334
Rounded Total Nourishment Cost for NCDOT				**$20,827,000**
Prorated Cost to Reach 1 and 2				
Reach 1				**$7,470,000**
Reach 2				**$6,503,000**
Reach 3				**$6,854,000**

Table 6
Cost Estimate for Combined Reaches 2, & 3
(400,000 cu yd via pipeline from Oregon Inlet plus
1,120,000 cu yd from PBA-A via Hopper Dredge)

Item	Quantity	Unit	Unit Cost	Cost
Mob & demob (dredge, pumpout, booster, pipeline)	1	job	L.S.	$1,093,000
Mob & demob second hopper dredge	1	job	L.S.	$501,000
Hopper Dredging	1,120,000	cu yd	$6.85	$7,672,000
Subtotal Hopper Dredge				$9,266,000
Mob & demob (dredge, booster, pipeline)	1	job	L.S.	$704,000
Pipeline Dredging	400,000	cu yd	$4.29	$1,804,000
Subtotal Pipeline Dredge				$2,508,000
Total Hopper and Pipeline				$11,774,000
Contingencies (20%)				$2,354,800
Subtotal Construction Cost				$14,128,800
Engineering and Design				$423,864
Supervision and Administration				$565,152
Total Cost Nourishment				$15,117,816
Normal Cost Nearshore Disposal of 400,000 cy				-$1,660,000
Net Cost to NCDOT				$13,457,816
Rounded Total Nourishment Cost for NCDOT				**$13,458,000**
Prorated Cost to Reach 1 and 2				
Reach 2				**$6,552,000**
Reach 3				**$6,906,000**

Table 7
Cost Estimate for Combined Reaches 1 to 3A-S
(400,000 cu yd via pipeline from Oregon Inlet plus
2,200,000 cu yd from PBA-A via Hopper Dredge)

Item	Quantity	Unit	Unit Cost	Cost
Mob & demob (dredge, pumpout, booster, pipeline)	1	job	L.S.	$1,047,000
Mob & demob 2nd dredge with pumpout & pipeline	1	job	L.S.	$1,047,000
Mob & demob third hopper dredge	1	job	L.S.	$501,000
Hopper Dredging				
North Half of Area	1,120,000	cu yd	$6.46	$7,106,000
South Half of Area	1,120,000	cu yd	$6.78	$7,458,000
Subtotal Hopper Dredge				$17,159,000
Mob & demob (dredge, booster, pipeline)	1	job	L.S.	$661,000
Pipeline Dredging	400,000	cu yd	$4.29	$1,716,000
Subtotal Pipeline Dredge				$2,377,000
Total Hopper and Pipeline				$19,536,000
Contingencies (20%)				$3,907,200
Subtotal Construction Cost				$23,443,200
Engineering and Design				$703,296
Supervision and Administration				$937,728
Total Cost Nourishment				$28,084,224
Normal Cost Nearshore Disposal of 400,000 cy				-$1,660,000
Net Cost to NCDOT				$23,424,224
Rounded Total Nourishment Cost for NCDOT				**$23,424,000**
Prorated Cost to Reach 1 and 2				
Reach 1				**$7,658,000**
Reach 2				**$5,766,000**
Reach 3				**$5,586,000**
Reach 3A-N				**$1,171,000**
Reach 3A-S				**$3,243,000**

Table 8
Cost Estimate for Combined Reaches 2 to 3A-S
(400,000 cu yd via pipeline from Oregon Inlet plus
1,350,000 cu yd from PBA-A via Hopper Dredge)

Item	Quantity	Unit	Unit Cost	Cost
Mob & demob (dredge, pumpout, booster, pipeline)	1	job	L.S.	$1,047,000
Mob & demob second hopper dredge	1	job	L.S.	$501,000
Hopper Dredging	1,350,000	cu yd	$6.89	$9,301,500
Subtotal Hopper Dredge				$10,918,500
Mob & demob (dredge, booster, pipeline)	1	job	L.S.	$704,000
Pipeline Dredging	400,000	cu yd	$4.51	$1,8046,000
Subtotal Pipeline Dredge				$2,508,000
Total Hopper and Pipeline				$13,426,500
Contingencies (20%)				$2,685,300
Subtotal Construction Cost				$16,111,800
Engineering and Design				$483,354
Supervision and Administration				$644,472
Total Cost Nourishment				$17,239,626
Normal Cost Nearshore Disposal of 400,000 cy				-$1,660,000
Net Cost to NCDOT				$15,579,626
Rounded Total Nourishment Cost for NCDOT				**$15,580,000**
Prorated Cost to Reach 1 and 2				
Reach 2				**$5,698,000**
Reach 3				**$5,520,000**
Reach 3A-N				**$1,157,000**
Reach 3A-S				**$3,205,000**

Table 9
Cost Estimate for Reach 4
770,000 cu yd from PBA-B via Hopper Dredge)

Item	Quantity	Unit	Unit Cost	Cost
Mob & demob (dredge, pumpout, booster, pipeline)	1	job	L.S.	$841,000
Hopper Dredging	770,000	cu .yd	$5.72	$4,404,400
Subtotal Hopper Dredge				$5,245,400
Contingencies (20%)				$1,049,080
Subtotal Construction Cost				$6,294,480
Engineering and Design				$188,834
Supervision and Administration				$251,779
Total Cost Nourishment				$6,735,094
Rounded Total Nourishment Cost for NCDOT				**$6,735,000**

4.8 Nourishment Cost over 100 years

Table 10 provides a summary of the costs of the various beach fill operations that would be required to protect NC12 between Oregon Inlet and Rodanthe over the next 100 years. Costs are given in both current dollars (2004) with no inflation and the present worth of future operations based on an interest rate of 6 percent. Over the entire 100-year period, the uninflated cost for beach nourishment would total over $932 million with the present worth of these cost equal to approximately $133 million (using an interest rate of 6 percent).

Table 10
Summary of Beach Nourishment Costs for 100-year Period

Reach	Nourishment Cost	Nourishment Cost Present Worth
1	$152,352,000	$31,633,022
2	199,476,000	21,753,600
3	193,196,000	18,333,951
3A-N	11,654,000	153,537
3A-S	32,278,000	425,243
4	343,485,000	61,064,696
Total	$932,441,000	$133,364,049

5. Conclusions

The cost for beach nourishment to protect NC12 over the next 100 years was based on the following set of assumptions:

- The Pea Island terminal groin would remain in place over the next 100 years.
- Beach nourishment would be required to protect the highway when the shoreline encroaches within 230 feet of the right-of-way.
- The minimum length of highway that would be protected by beach fill is 1 mile.
- The initial beach fill operation would not begin until the year 2007 due to the estimated amount of time required to obtain necessary permits and environmental clearances.
- The material needed for beach nourishment would come from USACE maintenance dredging of the Oregon Inlet ocean bar channel and from two offshore borrow areas previously identified by the NC Geological Survey for NCDOT as part of an Outer Banks Task Force initiative.
- The materials in the two offshore borrow areas, one located just seaward of Oregon Inlet and the other seaward of Rodanthe, are assumed to be 100% compatible with the native beach sands; however, there would be a 20% loss of borrow material during placement on the beach.
- The minimum design berm width for the beach fills would be approximately 50 feet.
- Beach fill quantities were computed for the entire depth of the active profile which extends from a berm crest elevation of +7 feet msl offshore to a depth of -30 feet msl.
- Volumetric erosion from the fills were based on the average shoreline change rate for the area adjusted for end losses and offshore losses by applying an erosion rate

factor of 3 for relatively short beach fill segments (less than 2 miles) and 1.5 for longer beach fill segments (greater than 2 miles).

- The nourishment interval for each beach fill segment was based on the amount of time required to completely erode the design berm width.

For the entire 100-year project period, a total of approximately 105.7 million cubic yards of sand will be needed to protect the current position of NC12 with the 230 ft buffer. Approximately 91.3 million cubic yards of the material would come from the two offshore borrow areas with the remaining 14.4 million derived from the maintenance dredging in Oregon Inlet. Nourishment intervals for the discrete segments would range from 2 to 4 years depending on the average erosion rate within each segment.

The total cost of this nourishment for the entire 100-year period is estimated to be $930,000,000. Using an interest rate of 6 percent, the present value for the total cost of this nourishment for the 100-year period is $136,000. This total cost includes an allowance for engineering and design, construction management, and contingencies for each nourishment operation. This estimate does not include the cost for additional geophysical surveys that would be required should this project actually be pursued nor does it include the cost for preparation of and Environmental Impact Statement. It is important to note that there are a number of critical assumptions that are incorporated in this preliminary assessment of the cost to protect the present position of NC12 in the study area. This total cost estimate can only be used as an initial guide in analysis of a project of this magnitude. It is unusual to plan a beach nourishment project for a 100-year period. The uncertainties that apply to a more common 50-year project are necessarily magnified when one doubles the time period.

6. References

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Bonner Bridge Replacement
Parallel Bridge Corridor with NC12 Maintenance

Shoreline Change and Stabilization Analysis

Prepared by

Margery F. Overton, Ph.D.
John S. Fisher, Ph.D., P.E.

FDH Engineering, Inc.

Prepared for

URS Corporation – North Carolina

June 2005

Task Orders 18 and 20
TIP No. B-2500

This report has been prepared based on certain key assumptions made by FDH Engineering that substantially affect the conclusions and recommendations of this report. These assumptions, detailed in the report, although thought to be reasonable and appropriate, may not prove to be true in the future. The conclusions and recommendations of FDH Engineering are conditioned upon these assumptions.

Bonner Bridge Replacement
Parallel Bridge Corridor with NC12 Maintenance

Shoreline Change and Stabilization Analysis

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Bonner Bridge Replacement
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Shoreline Change and Stabilization Analysis

Executive Summary

As part of a study of alternatives for the replacement of the Bonner Bridge over Oregon Inlet, FDH Engineering, Inc. was retained by Parsons Brinckerhoff Quade & Douglas, Inc., through URS Corporation –North America to undertake an analysis of the Pea Island shoreline adjacent to Oregon Inlet on the North Carolina Outer Banks. The focus of this study was the analysis of the different alternatives to reduce the vulnerability of NC12 from Oregon Inlet to Rodanthe. The replacement bridge has an expected useful life of 50 years thus setting the timeframe for the current analysis. The NC12 alternatives studied were one, relocating the road away from the ocean shoreline with the addition of new dunes where needed to reduce flooding and overwash, and two, leaving the road in its current position and using beach nourishment and dune maintenance to protect the highway. The analysis divided the study area into three areas: Northern Rodanthe, Ponds and North of Ponds.

The first task of the study was to identify sections of NC12 that would become vulnerable to long-term erosion and storm damage at six specified dates 2010, 2020, 2030, 2040, 2050 and 2060. Using this information, the distance the highway would have to be relocated was determined. This analysis was based upon the long-term shoreline erosion rate as determined from a regression analysis of the historic shorelines including a 95 percent prediction interval. A worse case relocation position was found such that the edge of pavement (on the ocean side) was predicted to be a minimum of 230 ft from the ocean shoreline (including the prediction interval) for the year in question. The relocated road would also have a new barrier dune constructed when erosion reduced the distance from the edge of pavement to the shoreline to 500 ft. The dune was designed such that there is a 50 percent risk that 50 percent of the dune would be lost during a single storm in a 12-year period. For the Northern Rodanthe Area the dune would have a crest elevation of 20 ft above grade. For both the Ponds Area and the North of Ponds Area the dune would have a 10 ft crest elevation.

The beach nourishment alternative assumed that the highway would remain in its current location. Beach nourishment would be used to maintain a beach such that the distance from the edge of pavement to the ocean shoreline would have a minimum value of 230 ft. Beach nourishment would have a 4-year cycle. Dunes

would be repaired and/or maintained such that they meet the same risk criteria used in the analysis of the highway relocation option. The sand for the beach nourishment was assumed to be available from two borrow sites just offshore of the study area. These sites have been identified in preliminary investigations by the North Carolina Geological Survey and would require additional field studies before a final determination could be made regarding the beach nourishment alternative.

Cost estimates were prepared for each alternative. For the road relocation alternative the dune construction costs is $2.2 million for Northern Rodanthe Area and $1.6 million for the Ponds Area. There was no significant dune construction needed for the North of Ponds Area with the road relocation alternative.

The cost estimates for the beach nourishment alternative for the Northern Rodanthe Area is $254 million. For the Ponds Area the cost is $118 million, and for the North of Ponds Area the cost is $65 million.

The potential for using sand from the maintenance dredging of Oregon Inlet was considered and significant cost savings could be realized from this practice. Regardless if the sand for beach nourishment came from the inlet or from the offshore sites there would have to be a determination that the material is compatible with the native beaches in the Pea Island Wildlife Refuge.

Bonner Bridge Replacement
Parallel Bridge Corridor with NC12 Maintenance

Shoreline Change and Stabilization Analysis

1. Background

FDH Engineering, Inc. was retained by Parsons Brinckerhoff Quade & Douglas, Inc., through URS Corporation – North America to undertake an analysis of the Pea Island shoreline adjacent to Oregon Inlet on the North Carolina Outer Banks. The analysis is a part of a study of alternatives for the replacement of the Bonner Bridge over Oregon Inlet. The FDH Engineering portion of the study includes an analysis of the expected shoreline change between the inlet and the Village of Rodanthe as well as an analysis of several different scenarios for the protection and or relocation of NC12. The latter component includes both an investigation of the possibility of using beach nourishment to mitigate the impacts of shoreline erosion as well as the construction of barrier dunes to reduce the frequency of overwash and flooding.

2. Analysis of Shoreline Change

The shoreline position database used in this study to compute the rate of shoreline change was compiled from multiple sources as described in Fisher et at., 2004. To bring the database up-to-date, NCDOT supplied rectified aerial photography for June 2004 so that continuous shoreline coverage from Oregon Inlet to Rodanthe representing current conditions was included in the database. In addition, some modifications to the 2004 report need to be noted. The earliest shoreline in the database is the NOS T-sheet. The NOS T-sheet coverage in this area dates to surveys undertaken in 1946 and 1949. Since the majority of the study area is covered by the 1946 T-sheet, the early date will be referred to as 1946. The post Ash Wednesday storm (March 1962) date was dropped from the dataset to avoid any post storm bias in the long-term trend. The post-Isabel imagery, though available, was not used for the same reason.

Because of the NCDOT long term monitoring of the shoreline downdrift of the Oregon Inlet terminal groin, the shoreline in the first 6 miles of the study area has the most temporally robust database (60 to 70 shorelines), with most of the data being taken after 1989 (Fisher et al. 2004). South of the Oregon Inlet monitoring project to Rodanthe, only 11 shorelines were available for analysis.

The 12 mile study area is represented by analysis of data at 99 locations. These locations are referred to as transects. These transects are spaced 500 or 1,000 ft apart, are numbered from south to north, as shown in Figures 1 - 5. The transect number is the distance, in hundreds of feet, from a reference station. Therefore, the difference between any two transect numbers is the distance, in hundreds of feet, between the two transects.

For purposes of discussion and organization, the study area is divided into four reaches, Reach A through D. Reach A, "Northern Rodanthe", is about 2.4 miles long, Figure 1. Reach B, "South of Ponds", is 2.3 miles in length, Figure 2. Reach C, "Ponds", is 5.4 miles in length and is presented in Figures 3 and 4. Reach D, "North of Ponds", is 1.8 miles in length, Figure 5.

At each transect, the rate of shoreline change was computed from the shoreline position versus time using linear regression. The slope of the best fit line is the shoreline change rate, expressed in feet per year. Equal weight is given to each shoreline included in the regression. Figure 6 shows the results of this analysis. Northern Rodanthe has the highest erosion rates with a maximum rate of about 15 ft/yr. Reach B is an isolated pocket of accretion within the study area with rates ranging from less than 0.5 ft/yr of erosion up to as much as 5 ft/yr of accretion. The erosion rates in the Ponds Reach fluctuate between 5 and 10 ft/yr while the rates in Reach D, North of Ponds is between 0 and 8 ft/yr.

3. Predicted Shoreline Position

The project required that the location of the shoreline be determined in 10-year increments beginning in 2010 and ending in 2060. Standard application of the long-term shoreline change rate is to predict the change in shoreline position by multiplying the shoreline change rate times the interval of time. The current shoreline position is then adjusted landward (erosion) or seaward (accretion) by this amount. This adjusted position represents the mean of possible positions as predicted by the data. Estimates of the noise or uncertainty in the dataset used to predict the future position can be added to the mean value to understand the reliability of this prediction. One statistical technique to quantify that uncertainty is to compute a prediction interval for each point in time that predictions are made and to bracket the predicted value by this value (e.g., 200 ft, +/- 20 ft). The prediction interval is a function of the noise in the data and increases with distance from the average position. Prediction intervals can be computed for different levels of certainty (e.g., 95 percent chance that the actual future shoreline will fall within the interval).

Future shoreline positions were calculated at each transect using the shoreline change rate and the time interval. In addition, 95 percent prediction intervals were computed for each set of shoreline data. While both the mean (rate times time) and worst cast (rate times time plus prediction interval) were calculated for each transect, the upper bound (the most landward shoreline) was chosen for design purposes since this position minimized the risk associated with predictions based on highly variable historical shoreline position data. The results of this analysis are presented in Tables 1 - 3 for Sections A, C and D respectively. Both the mean position (rate times time) and the worst case position (rate times time plus prediction interval) are presented for each 10 year interval (2010, 2020, 2030, 2040, 2050 and 2060). Shoreline position is measured as distance along the transect from NC12 to the active shoreline or mean high water (MHW).

Table 1. Distance from NC12 to MHW, Northern Rodanthe.

	Mean position						Worst case					
Transect	2010	2020	2030	2040	2050	2060	2010	2020	2030	2040	2050	2060
2846	1242	1128	1013	899	785	671	881	738	590	438	284	126
2851	953	826	700	573	447	321	602	447	288	125	-41	-209
2856	710	566	422	279	135	-9	362	191	15	-165	-348	-533
2861	522	372	222	72	-78	-228	161	-18	-202	-389	-580	-773
2866	451	301	150	-1	-152	-303	56	-127	-315	-507	-702	-900
2871	415	260	106	-49	-204	-359	30	-155	-346	-541	-739	-940
2876	338	184	29	-125	-280	-434	-8	-190	-377	-567	-761	-957
2881	248	94	-59	-212	-366	-519	-60	-238	-420	-605	-793	-983
2886	161	29	-104	-237	-369	-502	-88	-240	-396	-554	-715	-877
2891	121	-5	-132	-259	-385	-512	-100	-244	-391	-540	-692	-844
2896	144	14	-116	-247	-377	-507	-68	-214	-364	-516	-670	-826
2901	199	68	-62	-193	-324	-454	22	-123	-270	-419	-569	-721
2906	265	140	15	-111	-236	-361	129	-7	-145	-284	-424	-566
2911	367	243	120	-4	-127	-251	181	43	-98	-241	-385	-531
2916	394	277	159	42	-75	-193	223	92	-41	-177	-313	-451
2921	371	269	167	64	-38	-140	181	64	-56	-179	-302	-427
2926	330	239	147	56	-36	-127	153	48	-60	-170	-281	-394
2931	255	170	84	-1	-86	-172	92	-7	-107	-209	-313	-418
2936	185	101	16	-69	-153	-238	-11	-111	-214	-320	-426	-534
2941	191	115	39	-36	-112	-187	20	-69	-161	-254	-349	-445
2946	277	215	153	91	28	-34	102	26	-52	-132	-214	-297
2951	356	302	248	195	141	87	168	99	28	-45	-120	-196
2971	668	648	627	607	587	566	491	457	420	381	341	300

Table 2. Distance from NC12 to MHW, Ponds.

	Mean position						Worst case					
Transect	2010	2020	2030	2040	2050	2060	2010	2020	2030	2040	2050	2060
3091	1159	1159	1159	1159	1159	1159	971	956	939	919	898	876
3101	958	958	958	958	958	958	787	773	757	739	720	700
3111	809	803	798	792	786	781	625	605	582	557	531	503
3121	652	625	598	570	543	516	484	444	401	356	311	264
3131	603	551	500	448	397	345	531	477	423	368	312	256
3141	539	485	431	377	323	270	470	414	357	300	242	183
3151	485	418	350	283	215	147	416	347	276	205	134	62
3161	641	560	479	399	318	237	580	497	414	330	245	160
3169	720	636	552	468	384	300	651	565	479	391	304	215
3174	669	580	491	403	314	226	598	507	416	324	231	138
3179	561	470	378	286	194	102	485	392	297	201	105	8
3184	405	311	218	125	31	-62	318	223	126	28	-70	-169
3189	348	254	160	66	-28	-122	261	164	67	-31	-130	-230
3194	290	195	101	7	-87	-181	200	104	6	-92	-191	-291
3199	299	205	111	17	-77	-172	209	112	15	-84	-183	-283
3204	337	245	154	62	-29	-121	245	151	56	-40	-137	-234
3209	371	288	205	122	39	-44	277	191	105	17	-72	-161
3214	399	328	257	186	115	44	302	229	154	78	1	-76
3219	461	405	350	294	239	183	357	299	240	179	118	55
3224	457	408	359	310	261	212	346	294	241	187	131	75
3229	497	452	408	363	318	274	393	346	298	248	198	146
3234	508	467	425	383	341	300	409	364	319	272	225	177
3239	517	472	427	382	337	291	411	363	314	264	213	161
3244	522	465	409	352	295	239	406	346	285	223	159	95
3249	535	474	412	350	289	227	422	358	292	224	156	87
3254	534	472	410	348	287	225	430	365	300	233	165	96
3259	589	531	473	414	356	298	497	436	375	312	249	185
3264	626	570	514	458	402	346	538	480	421	360	299	238
3269	637	584	530	477	424	371	542	486	429	371	312	253
3274	608	546	484	422	360	299	507	443	377	311	243	175
3279	519	454	389	323	258	193	414	346	276	206	134	62
3284	376	304	233	161	90	18	259	185	109	32	-47	-126
3289	226	139	52	-35	-122	-209	123	33	-58	-151	-244	-338
3294	205	113	21	-71	-163	-255	114	19	-76	-173	-270	-368
3299	285	185	85	-14	-114	-214	189	87	-17	-121	-226	-332
3304	314	206	99	-9	-116	-224	200	89	-23	-136	-250	-365
3309	332	221	111	1	-110	-220	213	99	-16	-132	-250	-368
3313	383	269	155	41	-72	-186	275	158	40	-79	-199	-320
3323	438	326	213	101	-12	-125	340	225	108	-9	-127	-246
3333	518	426	335	243	152	60	404	297	186	71	-46	-165
3343	516	449	382	316	249	182	396	313	225	134	40	-55
3353	458	397	337	277	217	157	358	285	207	127	44	-39
3363	487	444	401	359	316	273	391	336	276	214	150	84
3373	424	384	343	303	263	223	338	287	232	174	115	55
3376	395	345	295	245	196	146	306	245	180	112	42	-29

Table 3. Distance from NC12 to MHW, North of Ponds.

	Mean position						Worst case					
Transect	2010	2020	2030	2040	2050	2060	2010	2020	2030	2040	2050	2060
3381	344	274	204	133	63	-7	250	167	80	-9	-101	-193
3386	291	213	135	57	-21	-99	187	96	-1	-100	-201	-304
3391	304	233	161	90	19	-53	203	118	29	-63	-157	-252
3396	232	166	100	33	-33	-100	143	64	-18	-103	-189	-277
3401	339	282	226	169	112	56	246	177	105	29	-48	-127
3406	299	257	215	174	132	90	207	154	96	36	-27	-90
3411	268	221	175	128	82	35	163	103	38	-30	-100	-171
3416	289	264	238	213	188	163	176	137	92	44	-6	-58
3421	330	330	330	330	329	329	214	199	178	154	128	100
3426	285	265	246	227	208	189	174	140	101	59	15	-30
3431	240	211	181	152	122	93	131	87	39	-13	-67	-123
3436	289	243	198	152	106	60	176	115	50	-19	-91	-164
3441	174	122	71	19	-32	-84	52	-16	-89	-166	-245	-326
3446	159	94	29	-35	-100	-165	6	-78	-169	-266	-364	-465
3451	204	132	61	-11	-82	-154	34	-59	-161	-267	-377	-489
3456	256	173	89	6	-77	-160	61	-48	-165	-288	-415	-545
3461	288	220	153	86	19	-49	78	-17	-121	-231	-346	-463
3466	410	376	342	308	273	239	201	140	68	-9	-90	-174
3471	457	439	421	403	385	367	255	211	157	98	34	-32

Table 4. Distance from NC12 to MHW, Reach B.

	Mean position						Worst case					
Transect	2010	2020	2030	3040	2050	2060	2010	2020	2030	2040	2050	2060
2981	728	709	691	672	653	635	588	558	526	493	459	423
2991	702	687	673	658	643	629	629	609	587	565	542	519
3001	745	745	745	745	745	745	659	652	644	635	626	616
3011	890	890	890	890	890	890	770	761	750	737	724	709
3021	986	986	986	986	986	986	834	822	808	792	775	757
3031	1132	1132	1132	1132	1132	1132	962	948	932	915	895	875
3041	1213	1213	1213	1213	1213	1213	1008	991	972	951	928	903
3051	1228	1228	1228	1228	1228	1228	1018	1001	981	959	936	911
3061	1354	1354	1354	1354	1354	1354	1153	1137	1118	1097	1075	1051
3071	1316	1316	1316	1316	1316	1316	1147	1133	1117	1100	1081	1061
3081	1232	1232	1232	1232	1232	1232	1054	1039	1023	1004	984	963
3091	1159	1159	1159	1159	1159	1159	971	956	939	919	898	876

The long-term trend in Reach B is accretion suggesting a very stable section of the island. Values presented in Table 4 for Reach B represent the 2004 position of the highway minus the magnitude of the prediction interval. This was proposed as the estimate of the worst case position considering the noise in the historical dataset in this Reach.

4. Highway vulnerability

The vulnerability criterion applied in this analysis is consistent with previous studies done for NCDOT by the authors and originates with the first highway vulnerability study completed in 1991 (Stone, Overton and Fisher 1991). That work proposed that a *critical buffer* distance of 230 ft from highway to active shoreline, interpreted as the mean high water (MHW), be used to indicate when a coastal highway became vulnerable to repetitive overwash and sand deposits and maintenance by NCDOT crews became excessive. This conclusion was based on the review of NCDOT maintenance for NC12.

The shoreline position values in Tables 1 - 4 are shaded gray if the distance from NC12 and the active shoreline is less than or equal to the critical buffer of 230 ft. This provides a graphic representation of the time at which the highway will become vulnerable as well as an indication of the length of highway that will be vulnerable. The North of Rodanthe section has the most vulnerable locations due to the high erosion rates, high prediction interval and current proximity of NC12 to the ocean. In contrast, the highway is not vulnerable in Section B. Both Section C and D have increasingly vulnerable sections of NC 12 by the year 2060.

5. Alternatives

The alternatives (or combination of alternatives) for the protection of the NC12 corridor analyzed by FDH Engineering include the follow options.

a. Leave NC12 in its current location and use beach nourishment to mitigate the exposure due to long-term shoreline erosion. This alternative includes the maintenance of the existing dunes, and where necessary the construction of new dunes. The preliminary design of these dunes is included in this analysis.

b. Relocate NC12 away from the eroding shoreline. This alternative includes the construction of new dunes where necessary.

6. Analysis of Alternatives

In order to evaluate the two alternatives, three analyses were undertaken by FDH Engineering. These included the estimation of the volumes and potential sources of sand for beach nourishment, dune construction guidelines for both the nourishment and move the road alternatives and the location of the relocated NC12.

6.1 Beach Nourishment

The volume of sand needed to nourish each section was based upon the following assumptions:

1. The minimum distance between the shoreline (assumed to be mean high water (MHW) and the ocean-side edge of pavement was set at the critical buffer of 230 ft.

2. In order to provide a reasonable level of efficiency, the minimum length (along the shoreline) for each nourishment project was generally set at 5,000 ft (4,900 ft was used in one location). In addition, a 500 ft taper was added to each end of the project resulting in a minimum effective length of 6,000 ft. The 500 ft taper is relatively short when compared to other beach nourishment projects undertaken by the Corps of Engineers and others along the North Carolina coast. In the current preliminary analysis the use of this taper length results in a possible underestimate of the total volume of sand needed for beach nourishment. However, the fact that the three nourishment areas are relatively close together means that they will be exchanging sand between them. This fact, coupled with the use of a four-year interval between beach nourishment projects supported the use of the short tapers in the current preliminary analysis. The final engineering design will include an evaluation of the best choice for the taper length.

3. It was assumed that 1.37 cu yd of fill (per ft of shoreline) are required to widen the beach 1 ft. This estimate is based upon the assumption that the total depth of the active profile is 37 ft and extends from the 7 ft mean sea level (MSL) berm crest elevation to a depth of –30 ft MSL. While this estimate for the volume of sand needed per foot of shoreline is consistent with other North Carolina beach nourishment projects (Fisher et al. 2004), it would need to be refined during the engineering design phase of the beach nourishment project.

4. It is well recognized that a nourished shoreline erodes at a higher rate than the native beach. This is due to the fact that the fill material has to adjust to the wave and longshore current conditions. In the current analysis, the background erosion rate was increased by an erosion factor of 1.5 for reaches C and D, and by a factor of 3 for reach A. The selection of these values for the erosion rate factor was based upon the authors' previous beach nourishment study for this area (Fisher et al. 2004).

5. The interval between nourishment projects was set at four years in the current preliminary analysis. This is a somewhat arbitrary number, and could be adjusted either up or down for either environmental or other reasons.

6. The current study did not include an independent investigation of sand resources for beach nourishment. As with the related previous study (Fisher et al. 2004), the investigation undertaken by NCDOT for the Outer Banks Task Force by the NC Geological Survey (Boss and Hoffman 2000) was used as a basis to identify the potential sand volumes available for beach nourishment. It is important to note that a considerable field survey effort would be needed to verify that the sand volumes reported in this 2000 survey are indeed present and that this sand is shown to be compatible with the native sand in the Pea Island Wildlife Refuge.

Using the assumptions listed above, estimates were prepared for the volume of sand required to protect NC12 for the 50-year project timeline.

6.2 Dune Construction

The large dunes between NC12 and the ocean provide protection from flooding and the transport of sand across the highway via overwash. These dunes were originally constructed as a major public works project during the 1930s, and have gone through many cycles of neglect and repair since then. At present there are portions of these barrier dunes in relatively good condition, and other portions that have been overwashed and essentially flattened.

The objective for this analysis was to determine the volume of sand required in the dune in order to provide adequate storm protection to NC12. Adequate storm protection for this study is defined such that there is a 50 percent (+/-5 percent) chance that 50 percent of the dune would be lost in a given storm in a 12-year period. It was also assumed that the dunes built should be large enough to survive for a significant portion of the project life and yet would narrow enough to be built within the 230 ft minimum distance between NC12 and shoreline. The 12-year life satisfied these criteria. This so called "50/50" criterion has been previously used by the authors in other related studies of NC12 vulnerability (Overton and Fisher 2003)

Following the earlier NC12 analysis (Overton and Fisher 2003), beach and dune profiles were analyzed to determine the likelihood of occurrence of dune loss leading to overwash using SBEACH (Storm-Induced Beach Change) and EST (Empirical Simulation Technique) models. SBEACH is a storm specific analysis of a beach and dune response to storm waves and surge. Storm induced changes are modeled for any number of storm scenarios as needed. In this study, 16 historical hurricanes were identified for use within the Atlantic basin hurricane (or HURDAT) database. An additional 10 hurricanes were modeled using storm surge data obtained from the USACE Field Research Facility at Duck, NC. These 26 storms made up the storm database for the analysis. EST is a statistical technique that takes the results of each of the SBEACH runs and simulates a statistically similar set of occurrences (or events) in order to produce statistically valid probability of occurrence results. From this output, the probability of eroding a certain volume of sand from the dune is computed.

Due to dune construction considerations, it was assumed that it would be unreasonable to expect that a different sized dune should be designed at each transect. As much as possible, the same dune should be used within a nourishment section of the beach or within a reasonable length of beach. Therefore, an attempt was made to characterize the three reaches (A, C and D) with respect to controlling offshore features. Simple overlays of profiles indicated similarities within each reach between profiles. In addition, a significant difference between profiles in Reach A and the rest of the study area was noted. In reach A, Northern Rodanthe, the nearshore drops quickly to a depth of about 10 ft creating a very steep nearshore profile or "hole" just offshore, Figure 7. The profiles in Reaches C and D do not exhibit this feature.

Sediment data were collected by NCDOT to support the SBEACH analysis. Samples were taken from the swash zone to the dune toe to capture the average sediment size of the beach face. Average sediment size in the Northern Rodanthe area is approximately 0.4 mm. The sediment size decreases closer to the inlet to about 0.2 mm.

Representative profiles from each reach were used to test design dunes. Assumptions used in "building" the dunes include 1) the constructed dune is triangular in shape, 2) the dune heel is located 25 ft seaward of edge of pavement , 3) the dune side slopes are 1:3 and 4) the minimum beach width is 50 ft. Dune sizes were tested in an iterative manner for all three reaches. The minimum dune for each reach that met the criterion for "adequate" storm protection was determined from the combined SBEACH/EST analysis.

6.3 Road Relocation

The worst case scenario (rate multiplied times time plus prediction interval) was used to determine the position of the relocated road from the active shoreline (mean high water, MHW). For each 10-year interval, the worst case position plus the 230 ft critical buffer was used to determine the possible scenarios for relocating NC12. After discussions with NCDOT, FDH was asked to pursue a road relocation option that included the 2060 position for Reaches C and D and the 2020 position for Reach A.

7. Results

7.1 Beach Nourishment Volume Estimates

7.1.1 Northern Rodanthe Area

Table 5 presents the beach nourishment volume estimates for Reach A – Northern Rodanthe Area. The table lists the nourishment volume, the dimension of the additional berm width (the dry beach above MHW) as a result of the nourishment, the beginning and ending transects, and the length along the shoreline for the project. This length dimension does not include the 500 ft taper on either end. The volume of sand does however include the tapers.

The relatively large berm width for the initial 2007 nourishment is due to the fact that by 2007 a portion of NC12 will be within the proposed 230 ft critical buffer dimension. Between nourishment cycles, the shoreline is assumed to erode at an erosion rate computed as an average rate over the length of the project that has been increased by a factor of 3 as described in section 6.1 above. The post-2007 nourishment projects have berm widths that are based upon the 230 ft buffer being the minimum distance between the MHW and the edge of pavement at the end of each respective nourishment cycle. The lengths of the projects get longer for later nourishment cycles because an increasing portion of NC12 requires protection with time as the persistent long-term shoreline erosion threatens the highway.

Table 5. Nourishment Estimates for the Northern Rodanthe Area.

Year	Project Length, ft	Berm Width, ft	Volume cu yd	Transect No. Begin	Transect No. End
2007	5,500	203	2,174,467	2886	2941
2011	5,500	133	1,416,234	2886	2941
2015	6,500	140	1,726,016	2876	2941
2019	6,500	140	1,726,016	2876	2941
2023	7,500	145	2,032,017	2866	2941
2027	7,500	145	2,032,017	2866	2941
2031	8,500	137	2,139,383	2866	2951
2035	9,000	139	2,289,213	2861	2951
2039	9,000	139	2,289,213	2861	2951
2043	9,500	141	2,432,258	2856	2951
2047	9,500	141	2,432,258	2856	2951
2051	9,500	141	2,432,258	2856	2951
2055	9,500	141	2,432,258	2856	2951
		Total Volume	27,553,608	cu yd	

7.1.2 Ponds Area

Tables 6 and 7 presents the beach nourishment volume estimates for the Ponds Area. This area has been defined as extending from Transect 3091 to Transect 3376. Within this overall area there are two separate areas requiring nourishment, listed here as areas C1 and C2. The shoreline between areas C1 and C2 (from approximately Transects 3229 to 3274) will not need nourishment based upon the assumptions used in the current preliminary analysis.

As shown in the Table 6, the initial date for beach nourishment in area C1 is 2023. The relatively large size of this initial nourishment is due to the fact that by the 2023 date a 110 ft berm will be needed to increase the distance between the shoreline and the edge of pavement to the minimum 230 ft critical buffer distance. Subsequent nourishment projects will only require approximately one-half this berm width. With the passage of time the specific location of beach nourishment in area C1 shifts to the south although the total project length only requires a small increase.

Table 6. Nourishment Estimates for Ponds Area (C1).

Year	Project Length, ft	Berm Width, ft	Volume cu yd	Transect No. Begin	Transect No. End
2023	5,000	110	1,083,101	3179	3229
2027	5,000	47	463,958	3179	3229
2031	5,000	47	463,958	3179	3229
2035	5,000	47	463,958	3179	3229
2039	5,000	47	463,958	3179	3229
2043	5,000	47	463,958	3179	3229
2047	5,300	53	546,970	3151	3204
2051	5,300	53	546,970	3151	3204
2055	5,300	53	546,970	3151	3204
		Total Volume	5,043,801	cu yd	

Table 7 lists the nourishment results for area C2. The first project begins in 2011. With time the length increases to 6,400 ft and the area shifts to the north.

Table 7. Nourishment Estimates for Ponds Area (C2).

Year	Project Length, ft	Berm Width, ft	Volume cu yd	Transect No. Begin	Transect No. End
2011	4900	90	869,248	3274	3323
2015	4900	55	536,477	3274	3323
2019	4900	55	536,477	3274	3323
2023	4900	55	536,477	3274	3323
2027	4900	55	536,477	3274	3323
2031	4900	55	536,477	3274	3323
2035	4900	55	536,477	3274	3323
2039	4900	59	573,025	3284	3333
2043	4900	59	573,025	3284	3333
2047	6400	53	640,218	3289	3353
2051	6400	53	640,218	3289	3353
2055	6400	53	640,218	3289	3353
		Total Volume	7,154,812	cu yd	

7.1.3 North of Ponds

The beach nourishment data for the North of Ponds Area (Reach D) is listed in Table 8. This is the area closest to the inlet, extending from transects 3376 to Oregon Inlet. The initial nourishment project would occur in 2007 with an initial berm width of 81 ft. Over the entire period of interest the project length and berm width changes to account for the variations in the long-term erosion rates in this area and the 230 ft buffer criterion.

Table 8. Nourishment Estimates for North of Ponds.

Year	Project Length, ft	Berm Width, ft	Volume cu yd	Transect No. Begin	Transect No. End
2007	6,000	81	927,694	3396	3456
2011	6,500	29	355,780	3391	3456
2015	7,000	30	395,222	3386	3456
2019	6,000	30	345,819	3396	3456
2023	6,000	30	345,819	3396	3456
2027	5,000	30	296,416	3386	3436
2031	7,500	30	419,923	3386	3461
2035	7,500	30	419,923	3386	3461
2039	7,500	30	419,923	3386	3461
2043	8,500	31	480,250	3376	3461
2047	8,500	31	480,250	3376	3461
2051	8,500	31	480,250	3376	3461
2055	8,500	31	480,250	3376	3461
		Total Volume	5,847,516	cu yd	

7.2 Dune Construction Volume Estimates

Two typical dune profiles were determined to meet the 50/50 criterion described in section 6.2 for Reaches A, C and D. In the Northern Rodanthe Area a 20 ft dune (above grade) is required for storm protection of NC12 (Figure 8). In the Ponds and North of Ponds areas a 10 ft dune (above grade) is required (Figure 8). The difference is most likely due to the steep profile just offshore Northern Rodanthe.

Dunes are used in combination with both the beach nourishment and road relocation options. Volume estimates in the context of these alternatives are provided below.

7.2.1 Dunes and Beach Nourishment

If the beach nourishment alternative is selected it is assumed that the first project would take place in 2007. An analysis of the current condition of the dunes, extrapolated out to 2007 (using the shoreline erosion rates) provides a basis for determining the probable condition of the dunes and the required action. With time the shoreline erosion between beach nourishment cycles and the storms that will occur within these cycles will take a toll on the dunes. In the current analysis, it is assumed that one half (1/2) of the dune will be needed to be repaired with every third beach nourishment project, i.e., every 12 years. This 12-year assumption is of course just an educated estimate and will depend upon the specific storms and conditions that occur. Having made this assumption it is then possible to estimate the volume of sand that will be needed to repair the dunes in conjunction with the beach nourishment projects.

7.2.1.1 Northern Rodanthe Area

Table 9 lists the expected dune repair/construction action that is expected to be needed in the Northern Rodanthe Area in conjunction with beach nourishment. A new dune will be needed for the greater portion of the area by the year 2007.

Table 10 summarizes the dune volume estimates for the Northern Rodanthe Area over the 50-year project period. The estimate assumes that every 12 years the dunes will be reduced to one-half of their needed volume and have to be rebuilt. The volume estimates in Table 10 reflect this assumption as well as the fact that the transects needing new dune construction change with time. This relatively large volume of sand would presumably be obtained from the same offshore source of sand needed for the beach nourishment projects. As with the other two project areas this estimate is based upon the stated assumptions and is therefore subject to a high degree of uncertainty.

Table 9. Dune Repair and Construction Schedule for the Northern Rodanthe Area.

Transect No.	Year	Action Required	Project Length, ft	Volume, cu yd
2886	2007	new	500	22,222
2891	2007	repair	500	11,111
2896	2007	repair	500	11,111
2901	2007	repair	500	11,111
2906	2007	repair	500	11,111
2911	2007	new	500	22,222
2916	2007	new	500	22,222
2921	2007	new	500	22,222
2926	2007	new	500	22,222
2931	2007	new	500	22,222
2936	2007	new	500	22,222
2941	2007	new	500	22,222
2946	2007	new	500	22,222
2951	2031	new	500	22,222

Table 10. Dune Sand Volume Estimate for the Northern Rodanthe Area.

Year	Volume, cu yd
2007	244,444
2019	144,444
2031	166,667
2043	155,556
2055	155,556
Total Volume	866,667

7.2.1.2 Ponds Area

Table 11 lists the expected dune repair/construction action that is expected in the Ponds Area in conjunction with beach nourishment. The dunes in this area are in relatively good condition, and the first action is not expected until 2011. This estimate is based upon the long-term erosion rates. A single severe storm before 2011 would perhaps require some action earlier. For the Ponds Area the dune size required to meet the criterion that there is a 50 percent chance of losing 50 percent of the dune in a single storm includes a crest elevation of 10 ft above grade. The existing dunes at Transects 3151 to 3169 are not expected to require any significant repair until 2023. However, as shown in Table 11, it is suggested that the dunes at these transects be assisted with sand fencing to promote sand deposition and stabilization.

The volume of sand needed over the life of the project to maintain the dunes for the Ponds Area when used in conjunction with beach nourishment is shown in Table 12. Over the 50-year life of the project the total estimated volume of sand needed to maintain the dunes in this area is only estimated to be 144,444 cu yd. When compared to the much larger volume of sand needed for beach nourishment this is a relatively small number. As with the other project areas it is assumed that the sand for the dunes would come from the same borrow area as the sand for beach nourishment.

Table 11. Dune Repair and Construction Schedule for the Ponds Area.

Transect No.	Year Dune	Action Required	Project Length, ft	Volume, cu yd
3151	2047	fence		
3161	2047	fence		
3169	2047	fence		
3174	2023	new	500	5,556
3179	2023	new	500	5,556
3184	2023	new	500	5,556
3189	2023	new	500	5,556
3194	2023	new	500	5,556
3199	2023	new	500	5,556
3204	2023	new	500	5,556
3209	2023	repair	500	2,778
3214	2023	repair	500	2,778
3234	2023	new	500	5,556
3289	2011	new	500	5,556
3294	2011	repair	500	2,778
3299	2011	repair	500	2,778

Table 12. Dune Sand Volume Estimate for the Ponds Area.

Year	Volume, cu yd
2011	11,111
2023	61,111
2035	36,111
2047	36,111
Total Volume	144,444

7.2.1.3 North Ponds Area

Table 13 lists the estimated volumes and timing for the dunes in the North of Ponds Area. When compared to the other two areas the dunes here will only require minimum attention. Table 14 presents the total volume estimate of 22,224 cu yd for the entire project 50-year time period. All of the assumptions and uncertainties discussed for the other two areas hold for this area as well.

Table 13. Dune Repair and Construction Schedule for the North of Ponds Area.

Transect No.	Year	Action Required	Project Length, ft	Volume, cu yd
3386	2019	Repair	500	2,778
3391	2019	Repair	500	2,778

Table 14. Dune Sand Volume Estimate for the North of Ponds Area.

Year	Volume, cu yd
2019	5,556
2031	5,556
2043	5,556
2055	5,556
Total Volume	22,224

7.2.2 Dunes and Road Relocation

If the road relocation alternative is selected there may be a need to construct new dunes in order to protect NC12 toward the end of the project design life (2048 and later). In the present analysis it was assumed that a dune should be built when the distance between the ocean-side edge of pavement and the MHW line was 500 ft. This value is approximately twice the 230 ft critical buffer used to define highway vulnerability. Doubling the buffer distance as a criterion to be used for future dune construction projects serves multiple purposes. One, it provides greater protection given the uncertainty of future storm magnitude and frequency. Two, it provides additional time for the dunes to become vegetated and stabilized before they are exposed to storm waves and tides.

7.2.2.1 Northern Rodanthe Area

As noted above, the dune needed to satisfy the 50/50 criterion for the Northern Rodanthe Area has a crest elevation of 20 ft above grade. The volume of sand required for this dune is 1,200 cu ft per ft of shoreline, or 44.44 cu yd/ft. Table 15 lists the volumes of sand needed for dune construction for each transect in the Northern Rodanthe Area. This table also identifies in what year the dune would be needed, that is, when the distance between MHW and the edge of pavement is expected to be 500 ft or less.

Table 15. Dune Volumes for the Northern Rodanthe Area.

Transect	Year Dune Needed	Volume cu yd
2901	2018	22,222
2906	2014	22,222
2911	2016	22,222
2916	2014	22,222
2921	2016	22,222
2926	2019	22,222
2931	2017	22,222
2936	2013	22,222
2941	2013	22,222
2951	2020	22,222
	Total cu yd	222,222

In the Northern Rodanthe Area the road relocation alternative assumes that the project would be expected to last until the year 2020. After 2020 a bridge would be used to maintain the transportation corridor. As shown in Table 15 all of the dunes would be needed on or before 2020 with the earliest being Transects 2936 and 2941 in year 2013. Transect 2946 (not listed in the table) would need a dune constructed sometime in 2020 and could have been included in the list for a more conservative estimate of the total dune volume required. By a similar argument, Transect 2951 is predicted to need a dune late in 2019 (rounded here to 2020), and therefore one can question as to whether this transect should have been included. Again, it is important to recall that there are a number of assumptions that are used to calculate these estimates for the volumes of sand for the dunes and when exactly they will be required. The total volume of 222,222 cu yd is at best an estimate and should only be used to provide some guidance as to what will really be needed.

7.2.2.2 Ponds Area

For the Ponds Area the road relocation option is expected to last 50 years. As shown in Table 16, the transects in this area will require dune construction as early as 2029 and as late as 2047. The dune for this area has a crest elevation of 10 ft above grade based upon the 50/50 criterion. Not all of the transects will require a new dune, as illustrated by the transects that are skipped in the table. The total sand volume required for new dune construction in this area is 155,556 cu yd.

Table 16. Dune Volumes for the Ponds Area.

Transect	Year Dune Needed	Volume cu yd
3131	2029	11,111
3141	2032	11,111
3151	2037	11,111
3161	2039	11,111
3169	2042	5,556
3174	2042	5,556
3179	2047	5,556
3184	2047	5,556
3194	2044	5,556
3199	2044	5,556
3204	2045	5,556
3209	2045	5,556
3214	2045	5,556
3224	2046	5,556
3229	2048	5,556
3244	2044	5,556
3249	2042	5,556
3254	2038	5,556
3259	2042	5,556
3264	2043	5,556
3269	2046	5,556
3274	2042	5,556
3279	2045	5,556
3289	2047	5,556
	Total cu yd	155,556

7.2.2.3 North of Ponds Area

Transect 3411 was the only transect in the North of Ponds Area that would meet the requirement that the distance between the MHW and the edge of pavement would be 500 ft or less within the project period (by year 2060). For Transect 3411 this distance is predicted to be reached in 2046. Given that it is only one transect in the entire area a decision was made to assume that no new dunes would be needed in the North of Ponds Area. Of course, as stated above, the actual storm history and shoreline erosion patterns may require some dune construction.

7.3 Offshore Sediment Resources

The present study did not include a new assessment of the size and quantity of sediment available offshore of the project areas to be used as potential borrow areas for beach nourishment. In a previous study of beach nourishment for this area (Fisher et al. 2004) it was noted that a preliminary survey of offshore sediment was undertaken for the Outer Banks Task Force by the North Carolina Geological Survey (NCGS) (Boss and Hoffman 2000). In that study two potential borrow sites were identified in the vicinity of the study areas, Figure 9. The first site is labeled PBA-A with approximately 69 million cu yd of sand. Only one core sample was reported for this area and therefore additional sampling would be needed to determine if the material is compatible with the native beaches on Pea Island.

The second site, PBA-B is potential source of sediment for the Northern Rodanthe Area. The preliminary estimate is that there are 56 million cu yd of sand in this borrow site. In this case there were three cores collected, but additional analysis would be needed to determine if this sand is compatible with the native beach.

Preliminary discussions with representatives of the US Fish and Wildlife Service (USFWS) have suggested that there are significant concerns regarding both the size and percentage of heavy minerals in sediment that has previously been placed on the Pea Island Wildlife Refuge by the Corps of Engineers as part of Oregon Inlet dredging activities. Additional studies would be needed to determine if the material identified by the NCGS would be acceptable to the USFWS.

8. Cost Estimates

8.1 Beach Nourishment

The analysis of the volume of sand required for beach nourishment for each of the three project areas, Northern Rodanthe, Ponds, and North of Ponds was used to develop a cost estimate using the following assumptions:

1. The sources for the borrow material would be the offshore sites documented in Section 7.3, and a pipeline dredge would pump the sand to the beach.

2. A dredging mobilization/demobilization fee of $1,000,000 would be included with the cost estimate. There is the possibility that one or more areas could be nourished at the same general time resulting in a reduction in this fee, but given the uncertainty of project timing the more conservative inclusion of the independent mob/demob fees was applied.

3. An engineering design fee of three percent was used on each individual project. This is also a conservative estimate. It is likely that by combining one or more projects for any given beach nourishment cycle this fee may be reduced.

4. A construction supervision fee of four percent was used for each project. As with the design fee, it may be possible to reduce this fee with careful project timing.

5. A contingency cost of 20 percent was added to the cost estimate. With time and experience it may be possible to reduce this estimate. However, given the many assumptions and uncertainties associate with the 50-year project timeline, this relatively high number for the contingencies seems reasonable for this preliminary estimate.

6. A unit cost of $6.50 per cu yd was used in the cost estimate for all three project areas. This value is based upon recent history with other beach nourishment projects in North Carolina, including both Corps of Engineers projects as well as non-federal projects. The reader is cautioned to note that the unit cost for beach nourishment sand is difficult to predict, and given that it is a critical value in the total cost estimate, there can be significant differences between pre-project estimates and final costs.

Using these assumptions cost estimates have been prepared for each project area for every beach nourishment cycle. Recall that a 4-year interval between nourishment projects at each area was assumed in the volume estimates in Section 7.

7. An interest rate of 7 percent was used to calculate a present worth of the cost estimates with time.

8.1.1 Northern Rodanthe Area

Table 17 presents the cost estimate for the Northern Rodanthe Area. Note that the initial beach nourishment project in 2007 is building a larger beach (wider berm width) in order to make up for the fact that in 2007 a significant portion of NC12 in this area is predicted to be within the 230 ft critical buffer area. The proposed beach nourishment project builds out the beach such that four years later, in 2011 the narrowest section will just be at the minimum 230 ft distance.

Table 17. Beach Nourishment Cost Estimate for the Northern Rodanthe Area.

Year	Volume, cu yd	Cost	Discounted Cost (7%)
2007	2,174,467	$19,432,098	$19,432,098
2011	1,416,234	$13,103,885	$9,996,891
2015	1,726,016	$15,689,327	$9,131,331
2019	1,726,016	$15,689,327	$6,966,249
2023	2,032,017	$18,243,212	$6,179,607
2027	2,032,017	$18,243,212	$4,714,393
2031	2,139,383	$19,139,291	$3,773,246
2035	2,289,213	$20,389,770	$3,066,667
2039	2,289,213	$20,389,770	$2,339,545
2043	2,432,258	$21,583,629	$1,889,333
2047	2,432,258	$21,583,629	$1,441,363
2051	2,432,258	$21,583,629	$1,099,609
2055	2,432,258	$21,583,629	$838,886
Total	27,553,608	$246,654,410	$70,869,218

8.1.2 Ponds Area

The beach nourishment cost estimate for the Ponds Area is presented in Table 18. The first year beach nourishment would be required is 2011. As with the Northern Rodanthe Area, the first project would have to be larger than subsequent years in order to increase the distance between the edge of pavement and MHW to the minimum critical buffer of 230 ft.

Table 18. Beach Nourishment Cost for the Ponds Area.

Year	Volume, cu yd	Cost	Discounted Cost (7%)
2007	0	$0	$0
2011	869,248	$8,538,744	$6,514,167
2015	536,477	$5,761,435	$3,353,207
2019	536,477	$5,761,435	$2,558,146
2023	1,619,578	$14,800,995	$5,013,609
2027	1,000,435	$9,633,629	$2,489,513
2031	1,000,435	$9,633,629	$1,899,237
2035	1,000,435	$9,633,629	$1,448,919
2039	1,036,983	$9,938,663	$1,140,373
2043	1,036,983	$9,938,663	$869,985
2047	1,187,187	$11,192,266	$747,424
2051	1,187,187	$11,192,266	$570,206
2055	1,187,187	$11,192,266	$435,007
Total	12,198,612	$117,217,619	$27,039,795

8.1.3 North of Ponds Area

Table 19 presents the beach nourishment costs for the North of Ponds Area. Nourishment would be needed to be started in 2007, and as with the other two areas, the first project would have to be somewhat larger than later years.

Table 19. Beach Nourishment Cost for the North of Ponds Area.

Year	Volume, cu yd	Cost	Discounted Cost (7%)
2007	927,694	$9,026,535	$9,026,535
2011	355,780	$4,253,339	$3,244,852
2015	395,222	$4,582,519	$2,667,068
2019	345,819	$4,170,204	$1,851,621
2023	345,819	$4,170,204	$1,412,592
2027	296,416	$3,757,889	$971,110
2031	419,923	$4,788,677	$944,071
2035	419,923	$4,788,677	$720,228
2039	419,923	$4,788,677	$549,458
2043	480,250	$5,292,163	$463,252
2047	480,250	$5,292,163	$353,413
2051	480,250	$5,292,163	$269,617
2055	480,250	$5,292,163	$205,689
Total	5,847,516	$65,495,372	$22,679,506

8.2 Dune Costs

There are two alternatives for which dune costs would be incurred: with beach nourishment and with road relocation. When used with beach nourishment the unit cost for dune sand was assumed to be $8.00/cu yd. A unit cost of $10.00/cu yd was assumed for the dunes to be built with the road relocation option. The higher costs for the latter alternative was used since the material would probably have to be truck hauled for an off-site location. Both of these estimates for the unit cost of dune sand are subject to a high degree of uncertainty and would need to be refined in subsequent studies.

8.2.1 Dunes and Beach Nourishment

The beach nourishment alternative includes the use of a barrier dune to reduce the frequency and degree of flooding and overwash during extreme storms. Since the beach nourishment alternative leaves the highway in its current location, where possible the current dune position would be maintained as well. In some locations the current dune would initially require repair, while at other locations the dune would essentially need to be rebuilt. The details of the sand requirements for each transect are presented in Section 7. At all locations the required dune is designed to meet the 50/50 criterion. This criterion is that there is a 50 percent risk the 50 percent of the dune would be lost in a single event within a 12-year period. An important additional assumption is that after the initial repair or new dune construction an entirely new dune would be needed every 12 years. As noted above, the unit cost of sand was assumed to be $8.00/cu yd.

8.2.1.1 Northern Rodanthe Area.

The dune needed to meet the 50/50 criterion for the Northern Rodanthe Area includes a dune crest elevation of 20 ft above grade. This is almost twice the size of the dune for the other two areas. This larger size is due in part to the somewhat steeper nearshore profiles for this area when compared to the other locations. Table 20 presents the estimated costs for the dunes for the Northern Rodanthe Area when used with the beach nourishment alternative.

Table 20. Dune Costs with Beach Nourishment for the Northern Rodanthe Area.

Year	Volume, cu yd	Cost	Discounted Cost (7%)
2007	244,444	$1,955,556	$1,955,556
2011			
2015			
2019	144,444	$1,155,556	$513,080
2023			
2027			
2031	166,667	$1,333,333	$262,862
2035			
2039			
2043	155,556	$1,244,444	$108,933
2047			
2051			
2055	155,556	$1,244,444	$48,368
Total	866,667	$6,933,333	$2,888,799

8.2.1.2 Ponds Area

Table 21 presents the cost estimates for the dunes with the beach nourishment alternative for the Ponds Area. No dune construction is predicted to be needed until 2011.

Table 21. Dune Costs with Beach Nourishment for the Ponds Area.

Year	Volume, cu yd	Cost	Discounted Cost (7%)
2007			
2011	11,111	$88,889	$67,813
2015			
2019			
2023	61,111	$488,889	$165,604
2027			
2031			
2035	36,111	$288,889	$43,450
2039			
2043			
2047	36,111	$288,889	$19,292
2051			
2055			
Total	144,444	$1,155,556	$1,300,000

8.2.1.3 North of Ponds Area

Table 22 presents the cost estimates for the dunes with the beach nourishment alternative for the North of Ponds Area. Due to the present condition of the dunes in this area, new dune construction is not expected until 2019. As seen from Table 22, the total costs for dune construction in the North of Ponds Area is small.

Table 22. Dune Costs with Beach Nourishment for the North of Ponds Area.

Year	Volume, cu yd	Cost	Discounted Cost (7%)
2007			
2011			
2015			
2019	5,556	$44,444	$19,734
2023			
2027			
2031	5,556	$44,448	$8,763
2035			
2039			
2043	5,556	$44,448	$3,891
2047			
2051			
2055	5,556	$44,448	$1,728
Total	22,224	$177,788	$34,115

8.2.2 Dune Construction Costs Associated with Road Relocation

The road relocation alternative includes the construction of new dunes to reduce the possibility of flooding and overwash. As discussed in Section 7 the dunes for this alternative were designed to the same 50/50 criterion as the dunes for the beach nourishment alternative such that there is a 50 percent risk that 50 percent of the dune would be eroded in a single storm within any 12-year period. The design dune for the Northern Rodanthe Area has a crest elevation of 20 ft above grade while the dunes for the other two areas have crest elevations of 10 ft. This analysis assumes that dunes will be needed for the relocated road when the long-term shoreline erosion reduces the distance from MHW to the edge of pavement to 500 ft.

The assumed unit cost for dune construction for this alternative is $10.00/cu yd. As noted above, this is higher than the $8.00/cu yd used in the cost estimate for dunes in conjunction with beach nourishment. The higher cost for this alternative was selected since it is likely that the material will be hauled by truck and may have to be transported a relatively long distance.

8.2.2.1 Northern Rodanthe Area

The dunes and construction costs that will be needed for the Northern Rodanthe Area are listed in Table 23. It has been assumed that the road relocation option for the Northern Rodanthe Area is only intended until the year 2020, when a bridge alternative will be substituted. As seen from Table 23, the earliest new dunes would be needed is at Transects 2936 and 2941 in 2013. While these dunes as well as the ones scheduled to be built in 2014 and 2016 may in fact be needed, it is possible that the actual conditions at the time may suggest that the others are not needed.

Table 23. Dune Costs with Road Relocation for the Northern Rodanthe Area.

Transect	Year Needed	Volume, cu yd	Cost	Discounted Cost (7%)
2901	2018	22,222	$222,222	$105,576
2906	2014	22,222	$222,222	$138,389
2911	2016	22,222	$222,222	$120,874
2916	2014	22,222	$222,222	$138,389
2921	2016	22,222	$222,222	$120,874
2926	2019	22,222	$222,222	$98,669
2931	2017	22,222	$222,222	$112,967
2936	2013	22,222	$222,222	$148,076
2941	2013	22,222	$222,222	$148,076
2946				
2951	2020	22,222	$222,222	$92,214
	Total	222,222	$2,222,220	$1,224,1044

8.2.2.2 Ponds Area

Table 24 lists the estimated date dunes will be needed and the costs for the Ponds Area.

Table 24. Dune Costs with Road Relocation for the Ponds Area.

Transect	Year Needed	Volume, cu yd	Cost	Discounted Cost (7%)
3131	2029	11,111	$111,111	$25,079
3141	2032	11,111	$111,111	$20,472
3151	2037	11,111	$111,111	$14,596
3161	2039	11,111	$111,111	$12,749
3169	2042	5,556	$55,556	$5,203
3174	2042	5,556	$55,556	$5,203
3179	2047	5,556	$55,556	$3,710
3184	2047	5,556	$55,556	$3,710
3194	2044	5,556	$55,556	$4,545
3199	2044	5,556	$55,556	$4,545
3204	2045	5,556	$55,556	$4,248
3209	2045	5,556	$55,556	$4,248
3214	2045	5,556	$55,556	$4,248
3224	2046	5,556	$55,556	$3,970
3229	2048	5,556	$55,556	$3,467
3244	2044	5,556	$55,556	$4,545
3249	2042	5,556	$55,556	$2,018
3254	2038	5,556	$55,556	$6,821
3259	2042	5,556	$55,556	$5,203
3264	2043	5,556	$55,556	$4,863
3269	2046	5,556	$55,556	$3,970
3274	2042	5,556	$55,556	$5,203
3279	2045	5,556	$55,556	$4,248
3289	2047	5,556	$55,556	$3,710
	Total	155,556	$1,555,556	$160,575

8.2.2.3 North of Ponds Area

As discussed in Section 7, it has been assumed that there will not be a need for new dune construction in the North of Ponds Area due to the prediction that the edge of the pavement will not be within 500 ft of MHW during the 50-year life of the proposed project.

8.3. Risk and Uncertainty

The prediction of future shoreline positions, the impacts of individual severe storms and the behavior of beach nourishment projects are complex problems that by necessity include a relatively high level of uncertainty. The use of the prediction interval with the estimate of future shoreline positions is one way in which the uncertainty in the data used for shoreline predictions has been included in this analysis.

Since it is impossible to know in advance where the shoreline will be at a specific time in the future, there is by default a risk that the shoreline may in fact be closer to the edge of the highway than predicted. To some degree this risk is mitigated by the use of the 230 ft critical buffer. With the exception of an extremely large storm (something greater that one that would occur on average every 100 years) it is unlikely that the highway will be destroyed. This assumption does not take into consideration the potential for an inlet to have formed. The potential for inlet formation is being reviewed by a separate report prepared by Dr. Stan Riggs.

As noted above, the science of predicting future shoreline positions is an imprecise art due to the complex interactions of waves and beaches. Predicting the behavior of a beach nourishment project in some respects is even more difficult than predicting the behavior of a natural beach. The additional complexity is due to the fact that there will normally be some difference between the sediment grain size of the natural beach and the sediment being used in the nourishment project. This difference in grain size can result in differences in the rate of shoreline change (when compared to the historical rates with the native sediment) as the nourished beach responds to the wave and storm climate.

In addition to changes from the historical erosion rates due to the sediment size, the rate of shoreline change for a nourished beach is a function of the length to width ratio for a nourished beach. A recently nourished beach will experience losses from the lateral ends of the project (perpendicular to the shoreline). The longer the project length (measured by the dimension parallel to the shoreline) the less significant are these lateral end losses. This is why a minimum of 5,000 ft has been assumed for the beach nourishment projects in the current analysis. As a beach nourishment project adjust it will normally have a shoreline erosion rate that is greater than the background historical rate for the project area. This increase in erosion rate is the erosion rate factor discussed in Section 6. An erosion rate factor of 3 has been assumed for the Northern Rodanthe Area, and an erosion rate factor of 1.5 for the other areas. The higher factor for the Northern Rodanthe Area was based upon the fact that the dominant direction of longshore sediment transport is north to south, as well as the fact that this area has higher erosion rates in general. The Ponds and the North of Ponds areas are adjacent and will share beach nourishment sediment as the shorelines adjust. While this adjustment process will certainly transport material to the Northern Rodanthe Area as well, it seem prudent to assume the higher erosion factor for this area.

The assumptions regarding the beach nourishment erosion rate factors are based upon engineering judgment and may in fact prove to be either high or low. Since the total volume of sand needed to protect NC12 is strongly linked to the erosion factors, the cost of beach nourishment is also dependent on these assumptions. Table 25 illustrates how these issues come together to impact the estimated cost of beach nourishment. Three scenarios are presented based upon three combinations of erosion rate factors: 1.5 for all areas, 3.0 for all areas, and 3.0 for Northern Rodanthe and 1.5 for the other two areas. This latter scenario is the one recommended in this analysis.

Table 25. Beach Nourishment Cost Comparison.

Area	Scenario 1	Scenario 2	Scenario 3
Northern Rodanthe	$134,837,311	$246,654,410	$246,654,410
Ponds	$117,217,619	$211,082,561	$117,217,619
North of Ponds	$65,495,372	$109,327,593	$65,495,372
Total	$317,550,302	$567,064,564	$429,367,401
Difference from Scenario 3	$111,817,099	-$137,697,163	$0

The costs listed in Table 25 are the total beach nourishment project costs. As shown in the table, the assumptions with regard to the erosion rate factor will have an impact in excess of $100,000,000 on the total estimated cost of beach nourishment. The recommended scenario with the higher erosion factor only assumed for the Northern Rodanthe Area lies between the two other scenarios. The uncertainty as to what will actually happen as the project proceeds is an important consideration when evaluating the beach nourishment alternative.

8.4 Oregon Inlet Dredging

The beach nourishment analysis detailed in this report assumes that all of the sand would be taken from the two borrow sites described in Section 6. As noted previously, there is considerable field work that will be required to determine if the sediment in these offshore borrow sites is compatible with the native beaches in the refuge. The US Fish and Wildlife Service (FWS) have expressed concerns with regard to the potential for a reduction in mean sediment grain size as well as a possible increase in the percentage of heavy minerals as a consequence of a long-term beach nourishment program.

According to the FWS, sediment currently being dredged by the Corps of Engineers from the outer channel at Oregon Inlet may be more compatible with the beaches in the Pea Island Wildlife Refuge than dredged material for other locations. Assuming that this assumption is correct it may be possible to reduce the cost of beach nourishment for NCDOT by entering into a joint Oregon Inlet Sediment Management Program with the U. S. Army Corps of Engineers. The scope and details of such a program would of course have to be negotiated by the respective agencies.

A basic element of the sediment management program would be that the Corps would place some of the material scheduled to be dredged from the inlet onto the beaches in the refuge (Ponds and North of Ponds Areas). This has in fact been done on an ad hoc basis over the past ten plus years. The total quantity of material needed to be dredged from Oregon Inlet in order for the Corps to maintain the authorized navigation channel depth is greater than the quantity of sediment needed to protect NC12 via beach nourishment for the Ponds and North of Ponds Area. If beach nourishment is needed for the Northern Rodanthe Area the material would presumably have to be dredged from the borrow area offshore of this site.

The total volume of sediment needed for the Ponds and the North of Ponds area over the 50-year life of the project is about 20 million cu yd. On an annual basis this is 400,000 cu yd/yr, or less than the quantity needed to be dredged to maintain the channel through Oregon Inlet. If the NCDOT and the Corps agreed to share (e.g., 50/50 split) the cost of this dredging/beach nourishment, both parties would benefit.

If the beach nourishment alternative is selected it would be worthwhile to explore if a long-term sediment management program for Oregon Inlet would be possible.

9. References

Boss, Stephen K. and Charles W. Hoffman, 2000, Sand Resources of the North Carolina Outer Banks, 4th Interim Report: Assessment of Pea Island Study Area, Prepared for the Outer Banks Task Force and the North Carolina Department of Transportation, Revised: February 2000.

Fisher, J. S., M. F. Overton and T. Jarrett, 2004, "Pea Island Shoreline: 100-Year Assessment", FDH Engineering, Inc., Raleigh, NC, Prepared for URS Corporation – North Carolina

Overton, M. F. and J. S. Fisher, 2003, "NC 12 Shoreline Erosion Analysis Canal and Sandbag Areas, December 2003 Update" FDH Engineering, Inc., Raleigh, NC, Prepared for URS Corporation – North Carolina.

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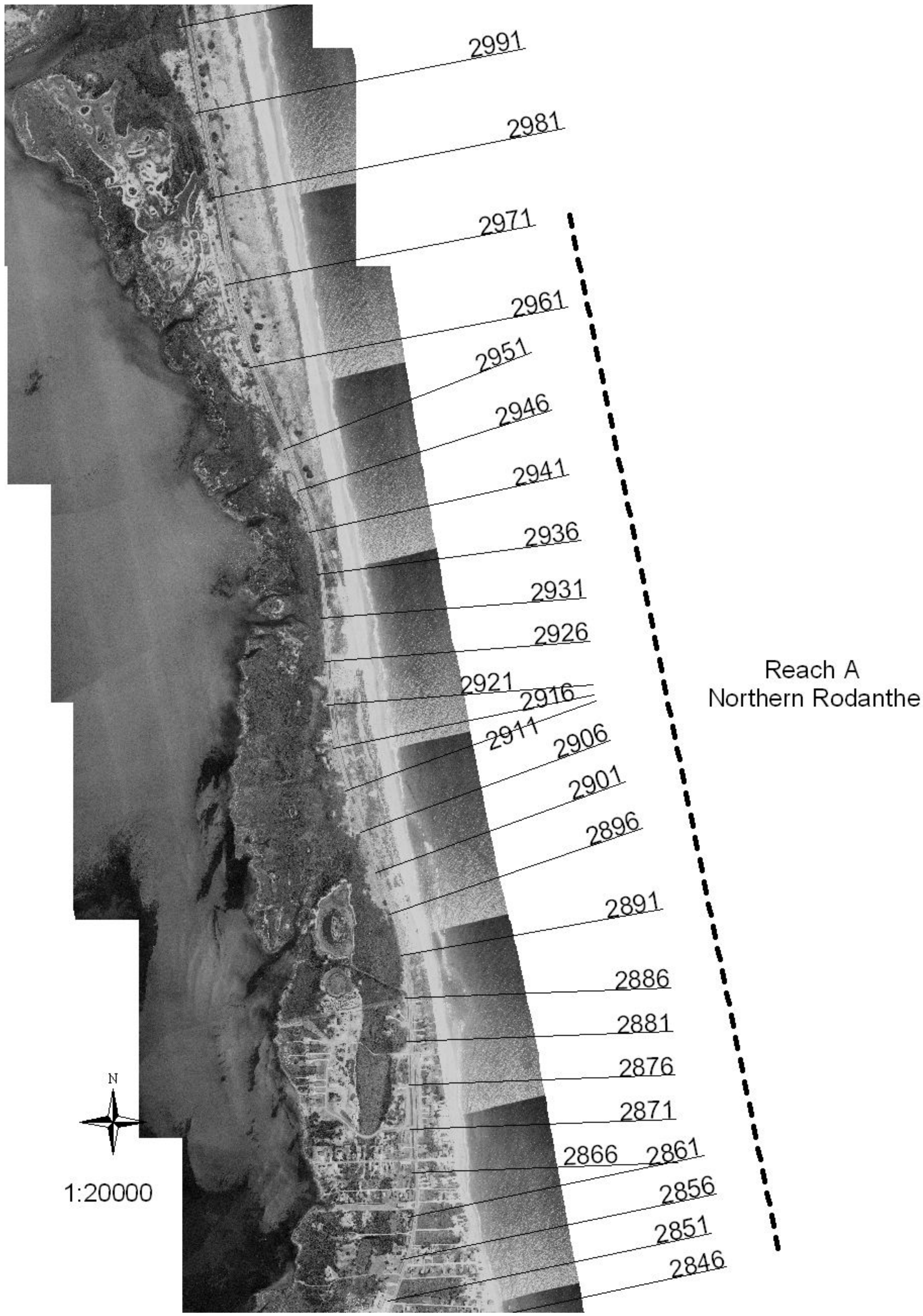


Figure 1. Transect locations North of Rodanthe, Reach A.

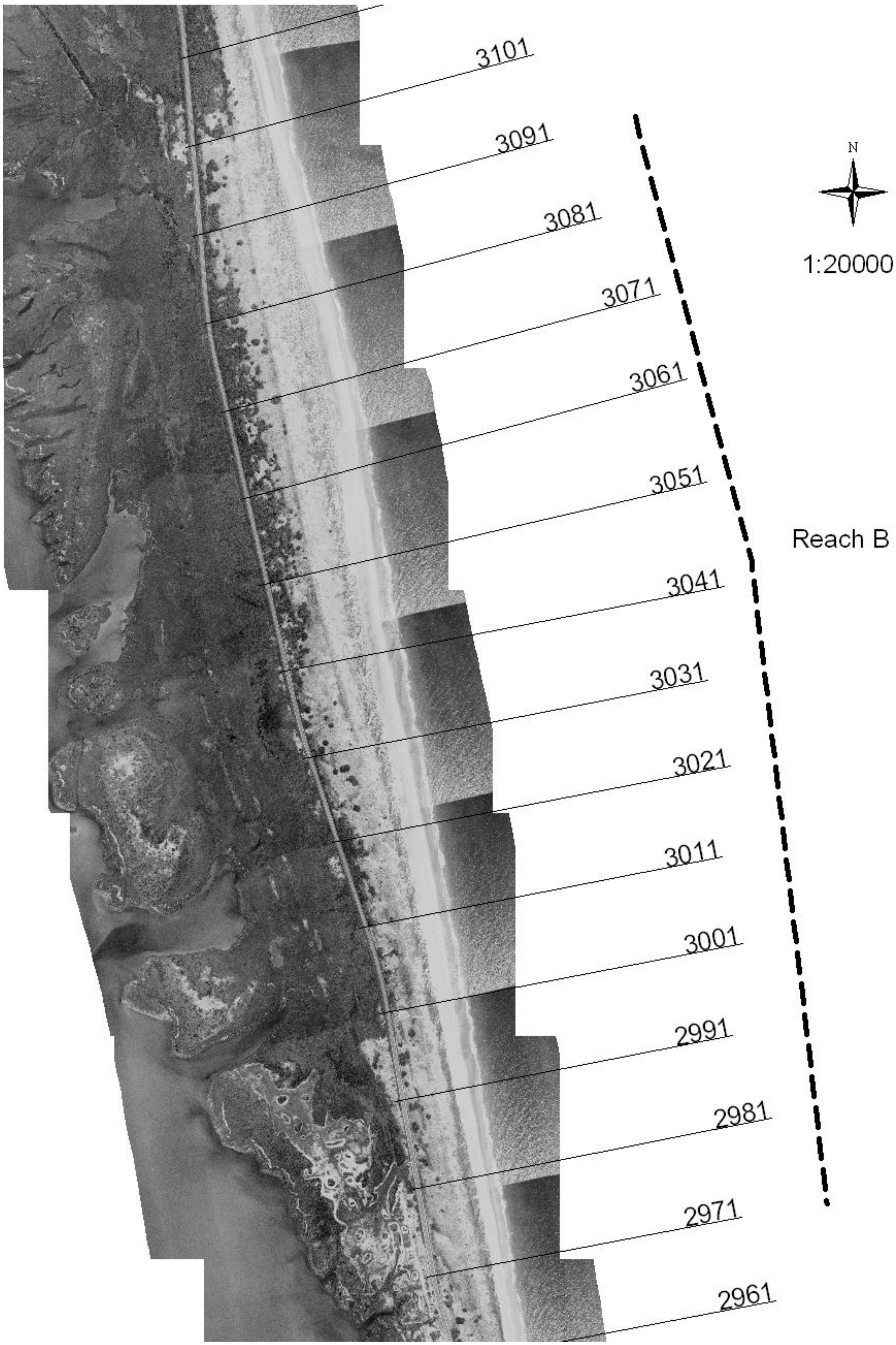


Figure 2. Transect locations in Reach B.

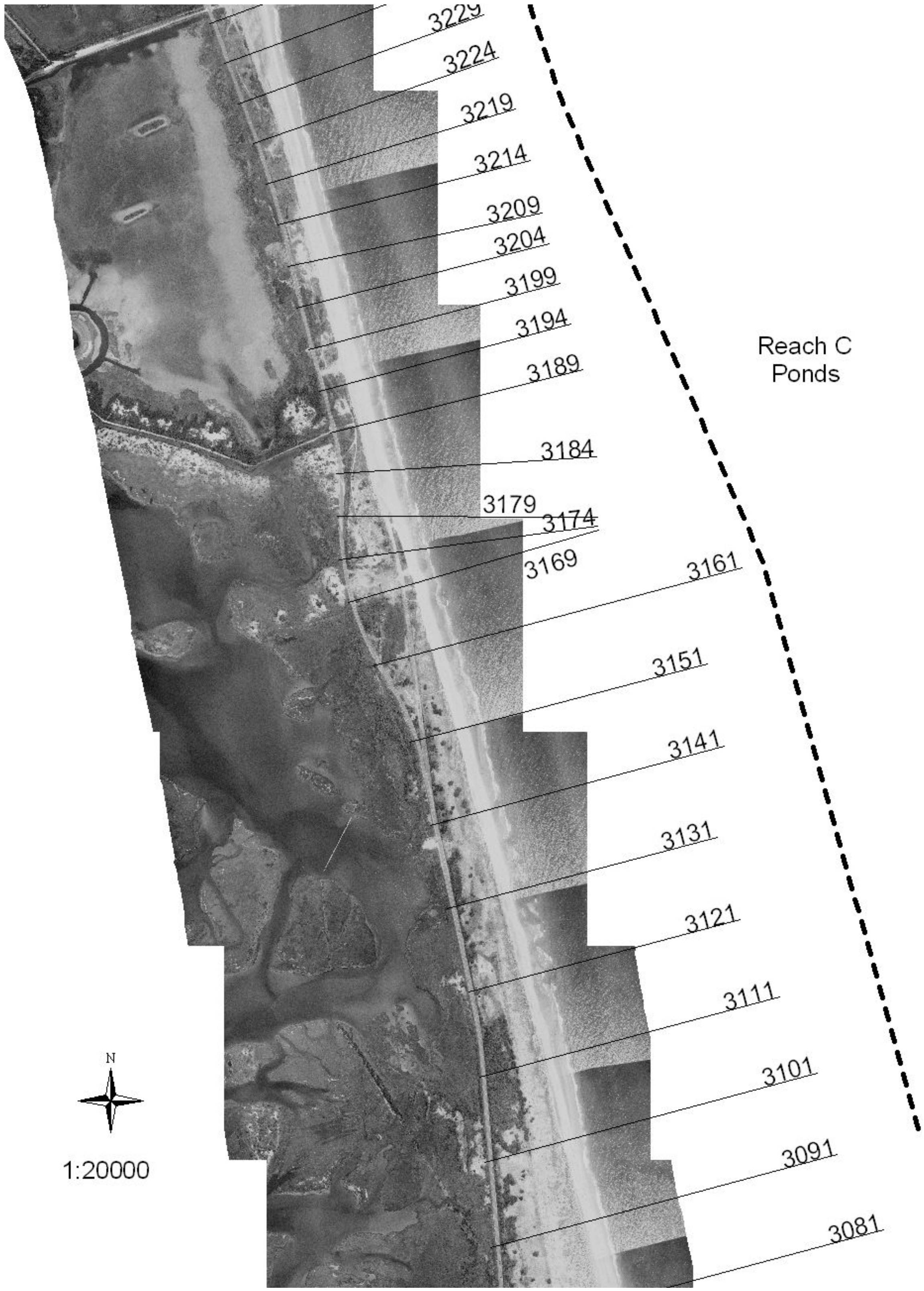


Figure 3. Transect locations in the northern part of Reach C, Ponds.

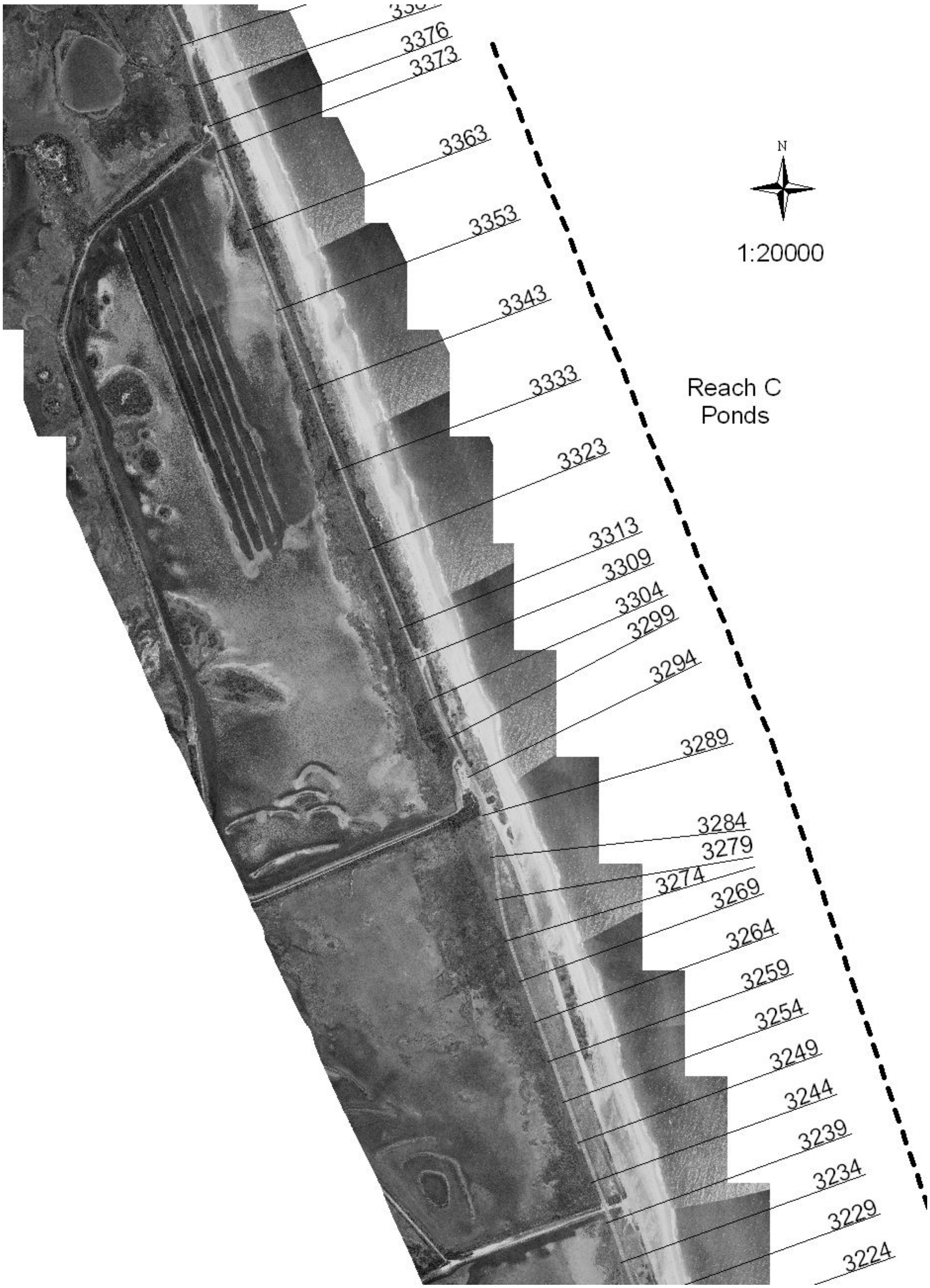


Figure 4. Transect locations in southern part of Reach C, Ponds.

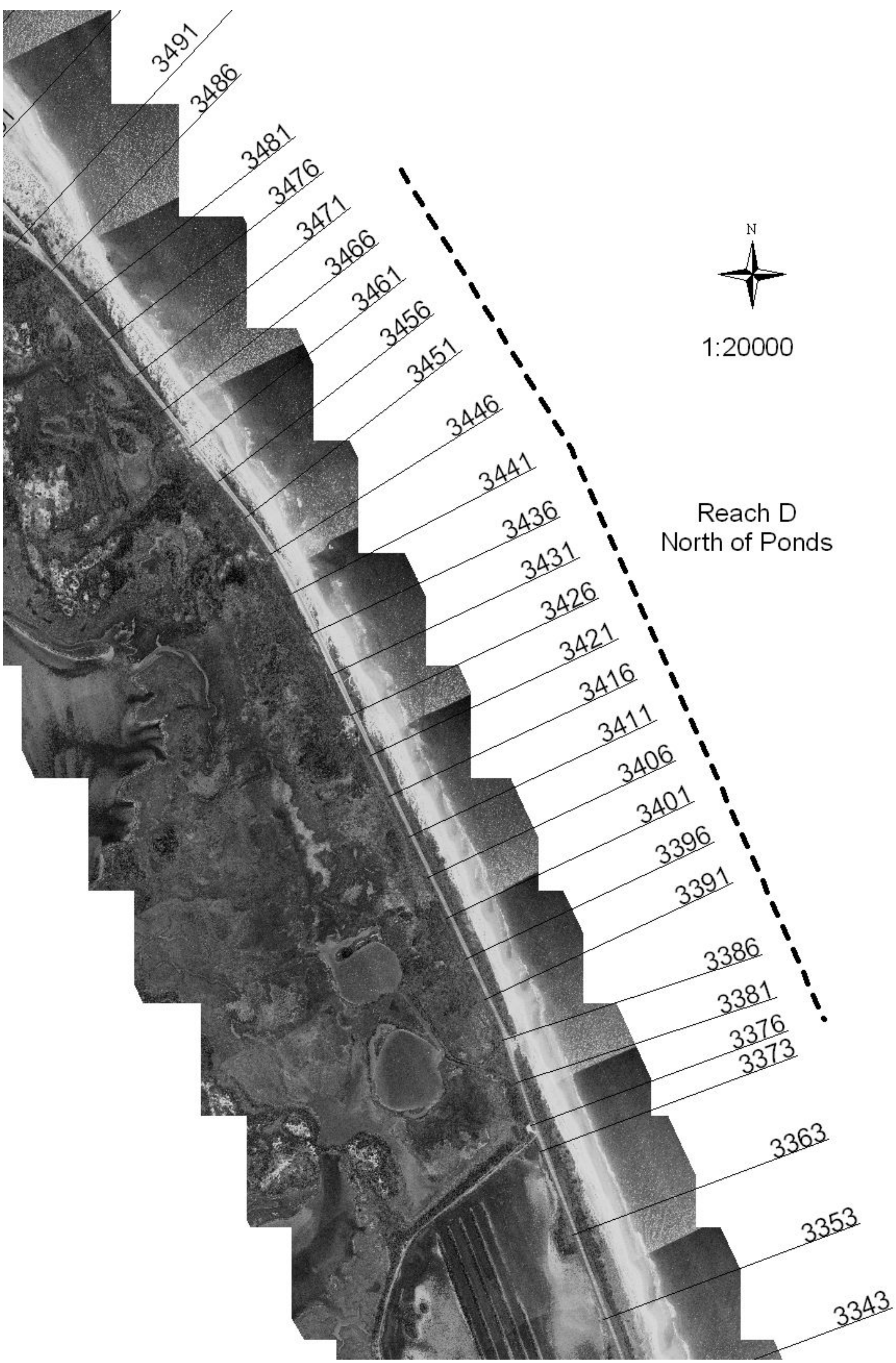


Figure 5. Transect locations in North of Ponds, Reach D.

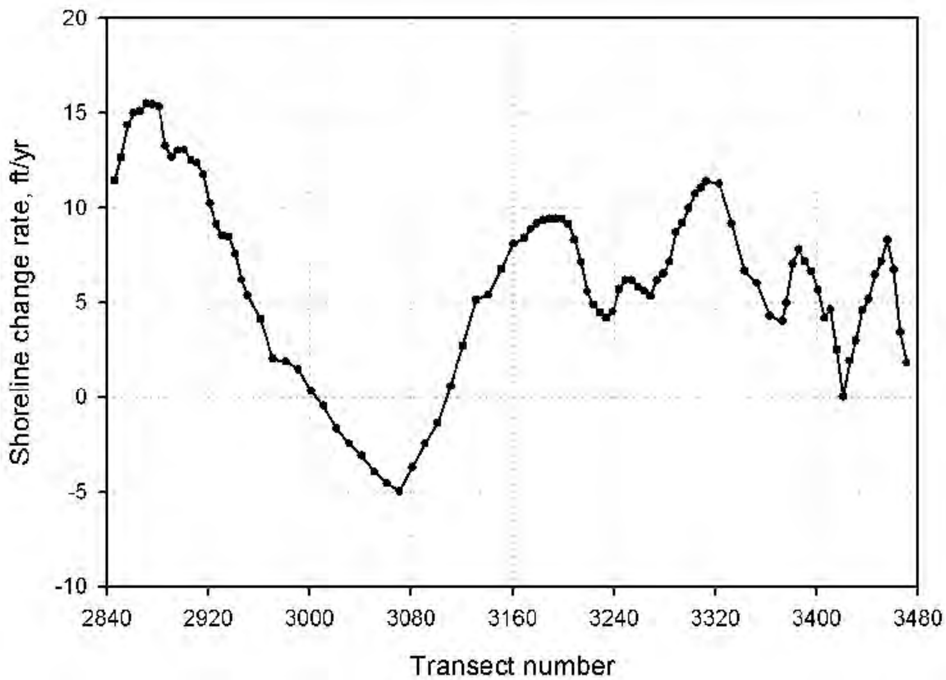


Figure 6. Long-term erosion rates.

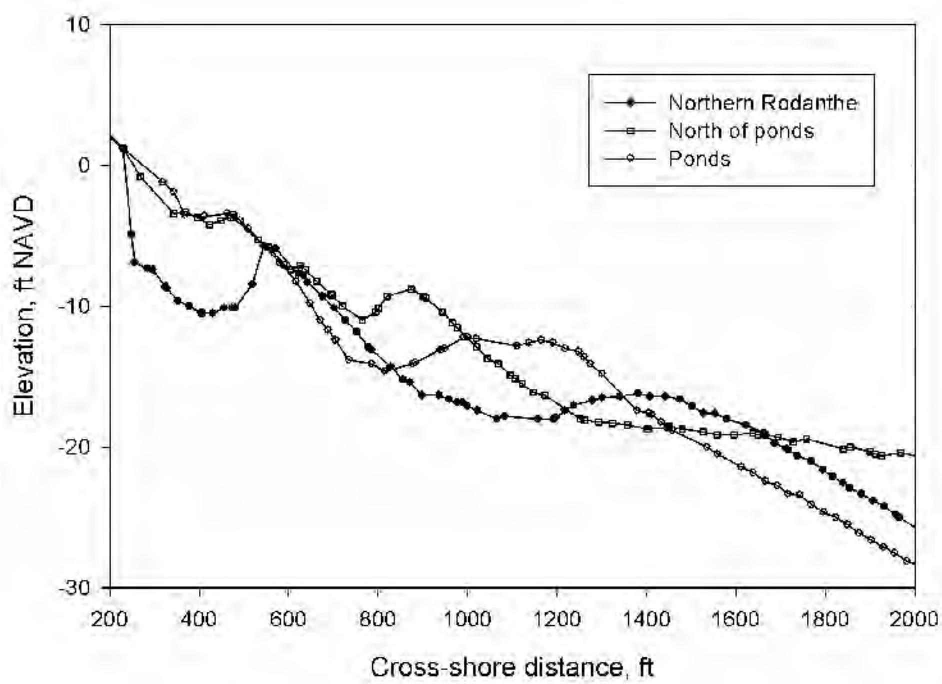


Figure 7. Offshore profiles used in dune erosion analysis.

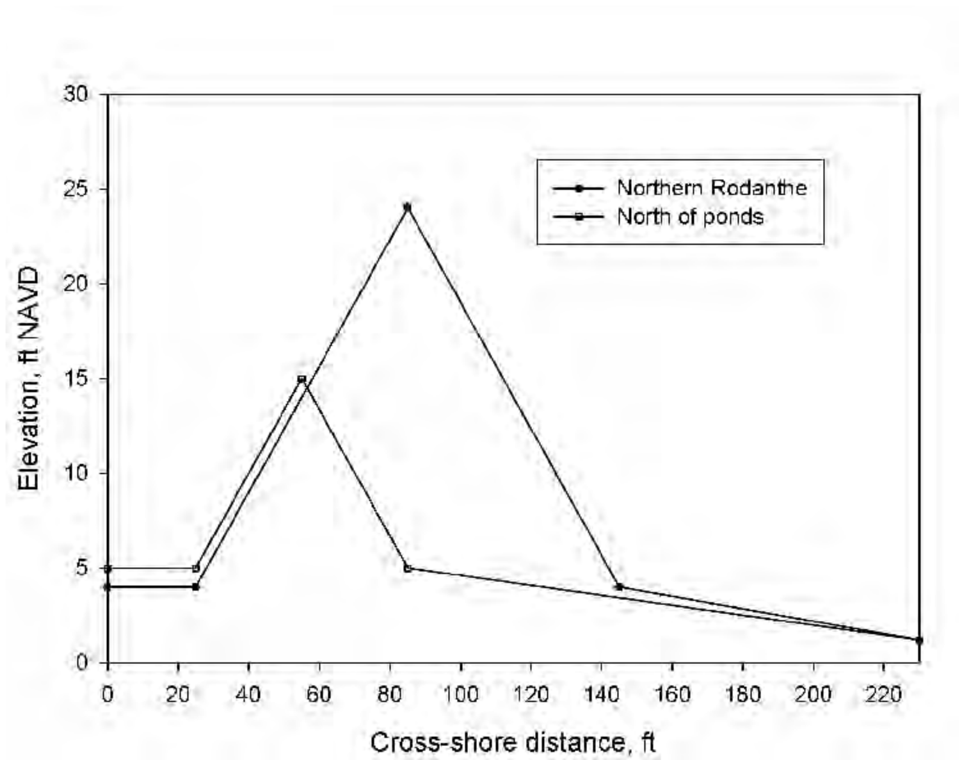


Figure 8. Typical sub-aerial cross-sections of constructed dunes.

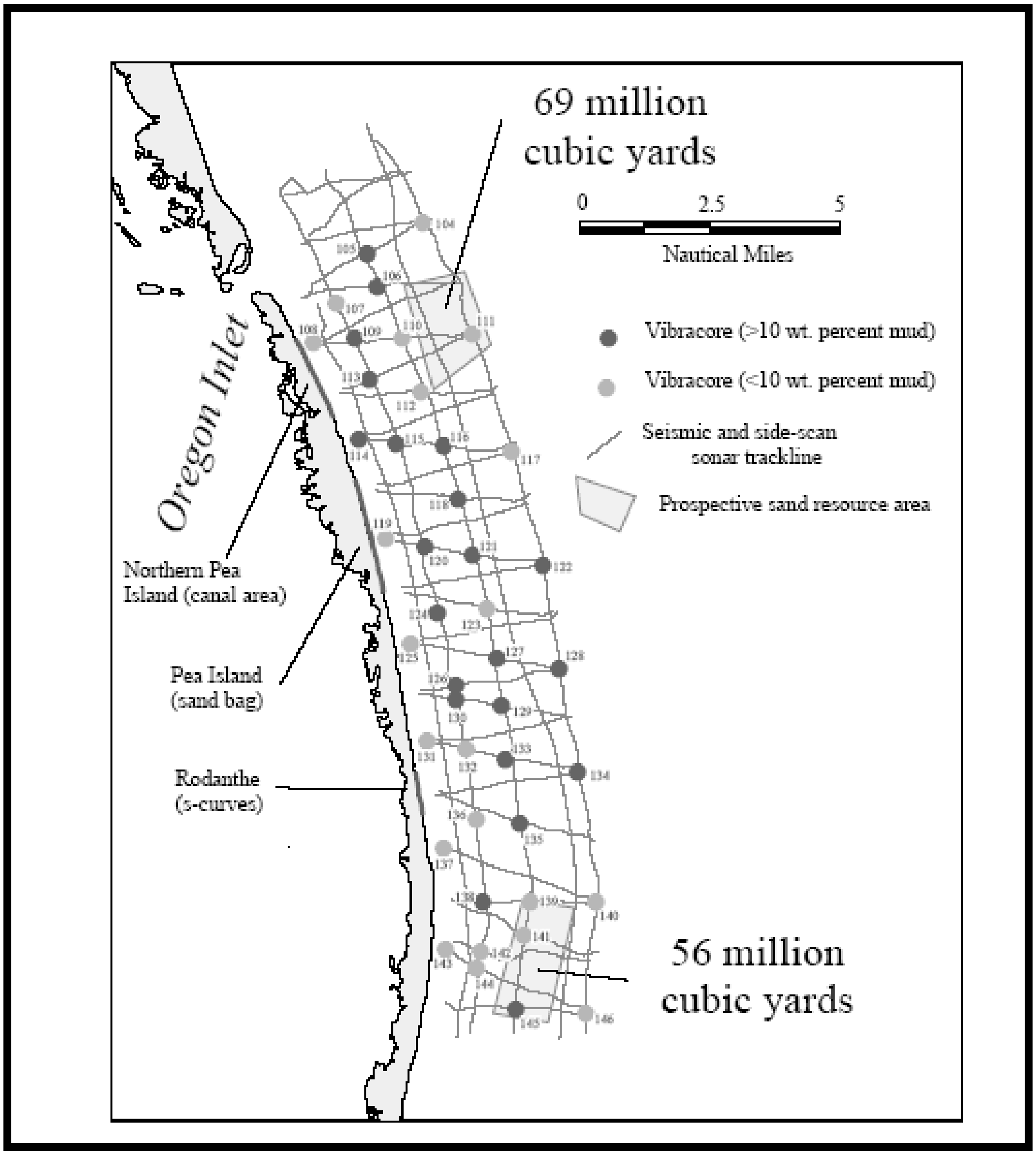


Figure 9. Potential Borrow Areas (from Boss and Hoffman 2000).

NC 12 REPLACEMENT OF THE HERBERT C. BONNER BRIDGE

POTENTIAL INLET FORMATION TECHNICAL REPORT

STATE PROJECT NO. 8.1051205
TIP NO. B-2500
DARE COUNTY

Prepared for:

PARSONS BRINCKERHOFF QUADE & DOUGLAS, INC.
909 Aviation Parkway, Suite 1500
Morrisville, North Carolina 27560

and for the

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
Project Development and Environmental Analysis Branch
Raleigh, North Carolina

Prepared by:

FDH Engineering, Inc.

September 2005

1. Introduction

The potential for new inlet formation in the study area warrants additional consideration. The report *Potential Inlets for Pea Island, North Carolina Outer Banks* prepared by Dr. Stanley Riggs (February, 2005) provided the starting point. A refinement of both the location and the risk of inlet formation are desirable. Given the considerable expense associated with the construction of bridges built in anticipation of possible inlet formation, it is prudent to use the best available guidance for this decision. This guidance was obtained by bringing together a panel of nationally recognized experts to meet with Dr. Riggs, discuss his ideas, review other models and techniques for inlet prediction, and compile a consensus estimate on potential inlet formation. This panel also was asked to render an opinion on potential inlet depth to be used as guidance on bridge foundation design.

2. Panel Members

The following nationally recognized experts in coastal engineering and geology participated on the study panel:

- Dr. Robert Dean, coastal engineer, Professor Emeritus, University of Florida. Dr. Dean is an internationally recognized expert in coastal engineering, well known for his research and consulting in the areas of beach nourishment, coastal processes, and inlet dynamics. He has extensive experience with the Outer Banks, and Oregon Inlet in particular.

- Dr. Robert Dolan, coastal geologist, Professor, University of Virginia. Dr. Dolan is one of the most knowledgeable experts on the coastal geology of the Outer Banks. He has served as the senior scientific advisor for both the Cape Hatteras National Seashore and the Pea Island National Wildlife Refuge.

- Mr. Carl Miller, research oceanographer, Field Research Facility, US Army Corps of Engineers (USACE), Duck, NC. Mr. Miller has extensive research experience dealing with the coastal processes of the Outer Banks and Oregon Inlet in particular.

- Mr. Michael Wutkowski, coastal engineer, Wilmington District, USACE. Mr. Wutkowski was the project manager for the closure of the inlet that opened on Hatteras Island during Hurricane Isabel.

The study panel also included the following coastal engineering and geology experts from the Bonner Bridge Replacement project consultant team:

- Dr. Stanley Riggs, coastal geologist, Professor Emeritus, East Carolina University.

- Dr. Margery Overton, coastal engineer, FDH Engineering/Professor, North Carolina State University.

- Mr. Tom Jarrett, coastal engineer, FDH Engineering, recently retired head of the Coastal Processes Branch, Wilmington District, USACE.

- Dr. John Fisher, coastal engineer, FDH Engineering/Professor, North Carolina State University.

The following individuals were also in attendance at the study panel meeting:

- Mr. John Page, Parsons Brinckerhoff Quade & Douglas, Inc.
- Mr. David Griffin, URS Corporation
- Ms. Kim Leight, URS Corporation
- Mr. Roy Shelton, NCDOT
- Mr. John Conforti, NCDOT
- Mr. Rob Hanson, NCDOT

3. Background Material

Prior to the meeting, the Panel Members were sent the recent Dr. Riggs' report, as well as an article written by Mr. Wutkowski on the Hatteras breach closure after Hurricane Isabel in *Shore & Beach – Journal of the American Shore and Beach Preservation Association* (Vol. 72, No. 2, Spring 2004). In addition, the panel was sent an overview of the problem and the objectives of the meeting.

4. Panel Meeting

The meeting was held on July 5, 2005, at the Morrisville, NC offices of Parsons Brinckerhoff.

5. Cost Estimate for New Inlet and Panel Meeting Summary

The meeting was organized around two specific objectives: 1) what is the risk of a new inlet opening between Rodanthe and Oregon Inlet; and 2) if an inlet does open, what will it take to close it mechanically. Dr. Riggs made a presentation on his findings as a background to the discussion for Objective 1. Mr. Wutkowski made a presentation on his experience with the Hatteras breach as a background for the discussion for Objective 2.

<u>Objective 1: What is the risk of a new inlet?</u>

There was some confusion within the group regarding the use of the terms "inlet" as opposed to "breach". Once a breach forms during a storm, the process by which the new opening grows to become an inlet is very complex. For the most part the panel focused on the potential for a breach to form although there was some discussion as to the possibility that it would lead to an inlet. In either case, NC 12 and the island would be severed.

With the exception of Dr. Dolan, there was general agreement that there is a risk of a breach at Dr. Riggs' Site 1 (closest to Rodanthe) in the next 50 years. There was no general agreement on what the actual probability is other than it should be considered in the overall assessment of the project. As noted by Dr. Riggs, this is the location of a prior inlet, the island is very narrow with relatively small dunes, and there is a relic channel across the estuarine marsh.

Dr. Dolan suggested that the history since Oregon Inlet opened in 1846 does not support the idea that another inlet will remain open (north of the now closed New Inlet) while Oregon Inlet is still functional. However, Dr. Dolan did agree that a breach might open at this Rodanthe site in the 50-year period, but he argued that it would not become a stable inlet so long as Oregon Inlet remained opened. Others suggested that since there have been periods in the past when there have been as many as 12 inlets open at the same time along the Outer Banks, it is not unreasonable to speculate that an inlet at the Rodanthe site might be compatible with the present Oregon Inlet.

Mr. Miller suggested and others agreed that a site on the north side of the inlet (close to the Oregon Inlet Fishing Center) should be considered as a potential breach, but probably not a full-blown inlet. This may have some significant implications for a final bridge design. Mr. Miller stressed that there appears to be a continual change in the alignment of the main channel through Oregon Inlet. The channel is migrating to the south and is therefore becoming close to the terminal groin. Mr. Miller suggested that the groin itself might become threatened at some point. The panel noted that with this shift of the channel to the south there is increasing shoaling on the estuarine side of the north end of Pea Island. Several members speculated that this shoaling might reduce the risk of breaches forming at Dr Riggs' Sites 4 and 5 that are close to the current inlet. The panel also noted that the current USACE maintenance of the navigation channel plays an important role in this process, and therefore any significant change in channel dredging may alter the dynamics.

There was little panel support for Dr. Riggs' other four potential inlet sites, although there were few if any strong objections voiced to his arguments as to why they might become inlet sites at some undetermined time in the future. However, the panel noted that there are a number of factors that might preclude the occurrence of a breach at any site other than the Rodanthe site noted above. These factors include the proximity to Oregon Inlet, the fact that the Rodanthe site is the weakest section, and the current shoaling on the sound side of the north end of Pea Island because of the shift in the channel through Oregon Inlet. Dr. Riggs did agree that the Rodanthe site has the highest risk of forming in the next 50-years.

Dr. Dean reminded the panel that beach nourishment would greatly reduce the potential for inlet formation. He argued that nourishment would provide multiple benefits, including: sand-bypassing across the inlet to the downdrift beaches; stabilization of the inlet channel and thus the inlet hydraulics; shoreline stabilization within the project area, thereby protecting the road; and with periodic natural overwash, sand transport across the island in support of the natural geologic processes.

Dr. Dolan suggested that it might be possible to put together a model to predict the risk of inlet formation based upon a few key variables including storm frequency and island geometry. This is in contrast to a fairly complex model that Dr. Riggs is developing. None of these models are currently available for input to the SDEIS. As noted by Mr. Page at the beginning of the meeting, the panel was asked to consider the meeting objectives in the context of our present body of knowledge.

In summary:

The panel agreed (with the possible exception of Dr. Dolan) that the potential inlet site closest to Rodanthe has a risk of opening within the next 50 years. No specific level of risk was assigned to this site and no specific dimensions (width or depth) were developed. The panel also agreed with Mr. Miller that the NCDOT should be concerned with the potential for a breach to form on the north side of Oregon Inlet at a location that could have some impact on the new bridge. The panel was less concerned with the potential for breaches to form at Dr. Riggs' other sites.

<u>Objective 2: What would it take to close a breach at the Rodanthe site?</u>

The discussion began with the background presentation by Mr. Wutkowski on the closure of the Hatteras breach. Using this recent breach as a model, the panel estimated that it would take somewhere between 400,000 and 500,000 cubic yards of sand to close a breach at the Rodanthe site. (This estimate was not based upon any specific dimensions for this potential breach, but rather it was merely an educated guess that the breach would be similar but somewhat larger than the Hatteras breach.)

The panel considered two potential borrow areas for the sand to close the breach: offshore of Rodanthe, and from the outer bar at Oregon Inlet. The outer bar is an area where the US Fish and Wildlife Service (USFWS) scientist from the Pea Island National Wildlife Refuge has previously suggested that there would probably not be a sand compatibility problem. With additional analysis it may also be possible to use material from other portions of the Oregon Inlet navigation channel as well.

The borrow site offshore of Rodanthe needs additional field work, including sediment cores, to be sure there is sand of acceptable compatibility and volume to be used as fill in the Pea Island National Wildlife Refuge. Mr. Shelton said that the NCDOT is making plans to undertake some of this fieldwork. The panel encouraged Mr. Shelton to pursue these plans.

The panel speculated that using material from the inlet outer bar would be a reasonable alternative to the offshore site, specifically because there may be fewer environmental concerns at this location. However, since the inlet site is further away, there would be a higher unit cost for the material.

Cost estimate:

Based upon the recent experience at the Hatteras breach, the panel agreed that $10.00 per cubic yard is a reasonable estimate for sand taken from the offshore borrow site. For sand taken from the outer bar, because of the longer pumping distance, $15.00 per cubic yard was the suggested unit cost estimate. As noted above, the panel estimated it would take 500,000 cubic yards to close the breach. Using these figures from the panel, the following cost estimates have been prepared. (Note: these costs were not discussed in the panel meeting.)

<u>Borrow Site 1 – Offshore of Rodanthe</u>

Fill needed	500,000 cubic yards
Overfill	30 percent (a conservative estimate because of multiple uncertainties)
Total material	650,000 cubic yards
Unit cost	$10.00 per cubic yard
Material cost	$6,500,000
Design/EA	$500,000
Construction supervision	4 percent
Total cost	$7,280,000

<u>Borrow Site 2 – Oregon Inlet Outer Bar</u>

Fill needed	500,000 cubic yards
Overfill	30 percent (a conservative estimate because of multiple uncertainties)
Total material	650,000 cubic yards
Unit cost	$15.00 per cubic yard
Material cost	$9,750,000
Design/EA	$500,000
Construction supervision	4 percent
Total cost	$10,660,000

In more general terms, the cost of closing a breach at the Rodanthe site is estimated to range between $7 million and $11 million. These estimates are of course very preliminary and are based upon the many assumptions cited above.

Expected time to close breach:

The Hatteras breach was closed in approximately 60 days. This relatively short time was in large part because of the declared emergency status of the project. While the panel agreed that a breach at Rodanthe also would be an emergency, the generally higher wave climate and the logistics of moving sand from either of the two potential borrow sites could result in a longer time to achieve closure. The panel evaluated two scenarios: 1) where no advanced preparation was undertaken before the breach opened; and 2) where most of the design, permitting, and borrow material determination was done in advance of a breach.

For the first scenario, where there was no advanced preparation, the panel concluded that it might take as long as six months to close the breach. Several factors account for this longer time estimate than for the Hatteras breach. Either the offshore borrow site or the inlet borrow site would be logistically more difficult than the borrow site at Hatteras. The dredges (probably two hopper dredges) would be working in the ocean (as opposed to the sound), and weather delays are likely. If the inlet borrow site is used, one or perhaps two booster pumps would be required to move the material the approximately 12 mile distance. Substantial fieldwork would be required to map the borrow site and identify an adequate quantity of compatible material. Again, this fieldwork would be taking place at an offshore location during tropical storm season. Because the breach would be in the Refuge, additional environmental issues also could potentially cause delays. All of these factors, plus other possible unforeseen problems, led to the longer time estimate for the time required to close the breach.

For the second scenario, with most of the preparation done in advance, the panel estimated that it would take up to three months to close the breach. This estimate is still a month longer than the recent experience at Hatteras, and this is largely because of the panel's concern about using either an inlet source or an offshore borrow site, as well as the higher wave and storm exposure for this portion of the Outer Banks.

Other issues regarding breach closure:

The panel discussed the wisdom and practicality of using fill material from the sound. Although Dr. Riggs informed the panel that there are substantial pockets of beach size sand on the backside of the island, all agreed that the environmental problems, as well as the logistics of working a dredge in this very shallow water, makes using material from Pamlico Sound impractical.

The panel explored the idea of stockpiling material in advance at a location either on the island, or in the sound. Considering a volume on the order of 500,000 cubic yards, the panel concluded that it would not be cost effective to build a stockpile in advance. Since the material would probably have to be hauled by truck to the breach (as opposed to hydraulic dredging), the estimated costs were considered to be unreasonable.

Dr. Fisher suggested that it might be possible to erect a steel sheet pile barrier in the sound that would reduce (or perhaps eliminate) the potential for an inlet to open at the Rodanthe site. Dr. Dolan pointed out that a somewhat similar buried sandbag barrier had been used previously in the Buxton area. The panel acknowledged that the barrier idea has merit, but doubted that it would ever be seriously considered because of environmental issues.

The question of whether or not the NCDOT should build a bridge (in advance) at the Rodanthe site was discussed at length. The panel questioned if such a bridge could be properly designed prior to the occurrence of the breach. Given that there is no way to know for sure if the breach will occur, or where it would occur, the panel doubted if it was reasonable to build such a bridge strictly for that purpose.

The panel also considered the possibility of building a temporary bridge (either a fixed wooden structure, or a floating pontoon type structure) in the sound to carry the traffic while the breach was being closed. There was general agreement that these ideas were worthy of future consideration by the NCDOT.

Based upon Mr. Wutkowski's presentation on the Hatteras breach, the panel strongly suggested that the NCDOT have as much of the breach closure preparation as possible in place soon. Specifically, the panel agreed with Mr. Wutkowski that it is important to have a design for the closure. This design would specifically detail the desired configuration of the closure. He pointed out that the post-closure cross-section at the Hatteras breach is in fact smaller than the island cross-section prior to Hurricane Isabel. In reality, the Hatteras site is more vulnerable now than it was prior to the breach. This smaller cross-section is in large measure because a substantial portion of the cost for closing the breach was covered by FEMA, with certain restrictions that precluded building up the island to make it less vulnerable.

In addition to having a design in place, the panel also recommended that the NCDOT identify one or more borrow sites, complete all of the fieldwork needed to obtain the required permits, and, if possible, prepare the necessary contract documents.

The panel also agreed with Mr. Wutkowski's other recommendations based upon the lessons learned from the Hatteras breach:

1. If the decision is made to only place fill material from one side of the breach, be prepared to armor the far side to reduce the erosion of this bank.

2. The contractor should be required to stockpile a large quantity of material prior to closing the final section.

3. If possible, stockpile material on both sides and make the final closure from both sides.

4. The contractor should be prepared to use at least two bulldozers in the final stages.

5. The timing of the final push is critical and, if possible, should be scheduled such that the last section is closed at low tide.

6. Be prepared to pump a minimum of 20,000 cubic yards per day.

These ideas, as well as a considerable amount of additional information, are presented by Mr. Wutkowski in his article in *Shore & Beach*.

Additional general comments and recommendations:

Dr. Dean reminded the panel that long-term sand bypassing around Oregon Inlet is probably the best way to reduce the risk of inlet formation. By placing sand on the downdrift beaches (beach nourishment), the shoreline can be maintained and therefore the continued reduction in island cross-section reduced or perhaps even stopped. The benefits of such a practice include the maintenance of the navigation channel, protection of the highway by a wide beach, the supply of sand during overwash to the marsh side of the island, and, of course, the reduction in the risk of a breach opening. While the panel agreed in general with these ideas, several members noted that the relatively high shoreline erosion rates at the Rodanthe site might make beach nourishment extremely expensive. However, there was general agreement that this idea may indeed be appropriate for several, if not all, of the other potential inlet sites identified by Dr. Riggs.

Dr. Dean also suggested that it is unlikely that the state of North Carolina would ever decide to allow a breach to remain open. The possible adverse impacts a new inlet could have on Rodanthe could potentially be extreme, with a considerable increase in the rate of shoreline erosion downdrift of the inlet. These impacts would be exacerbated if the inlet migrated to the south through Rodanthe. Given the possibility of these shoreline impacts, Dr. Dean suggested that the state would have no choice other than to close the inlet. This being the case, he questioned the wisdom of considering a bridge alternative for the Rodanthe potential inlet site with bridging a potential breach as its sole purpose. Rather he suggested that the state (and therefore by default the NCDOT) would likely decide to use beach nourishment to maintain the shoreline. (It should be noted that although it was not discussed at the meeting, if such an inlet was allowed to remain open, the state would have the option to build a terminal groin similar to the one at Oregon Inlet to reduce the impacts on the downdrift beaches.)

Dr. Dolan expressed concerns with the NCDOT's current practice of pushing sand off the highway to the ocean dunes and shoreline. He feels that as the beach continues to become increasingly narrow this sand will be rapidly eroded. However, the panel explained to Dr. Dolan that this practice is not considered to be anything but a stopgap effort until one or more of the NC 12 maintenance interim or long-term solutions can be adopted.

Dr. Dolan also reminded the panel that the risk of a breach opening at any location is dependent upon the size and frequency of the storm waves and surge. A series of relatively small storms in a short time period may be as likely to cause a breach as a single larger event.

Dr. Riggs reiterated his concerns that when considered on a longer time scale (greater than 50 or even 100 years), the best alternative for the Outer Banks is to allow ocean overwash and inlet formation. He believes that the health of the islands and the sound are best achieved when there is a natural sand transport across the islands. He notes however that such a practice is incompatible with maintaining NC 12 on the island.

Summary of Parallel Bridge Corridor Alternatives

Parallel Bridge Corridor with Nourishment:
The Nourishment Alternative would maintain the NC 12 roadway in its current location through the use of beach nourishment and dune enhancement. (FEIS, Section 2.10.2.1)

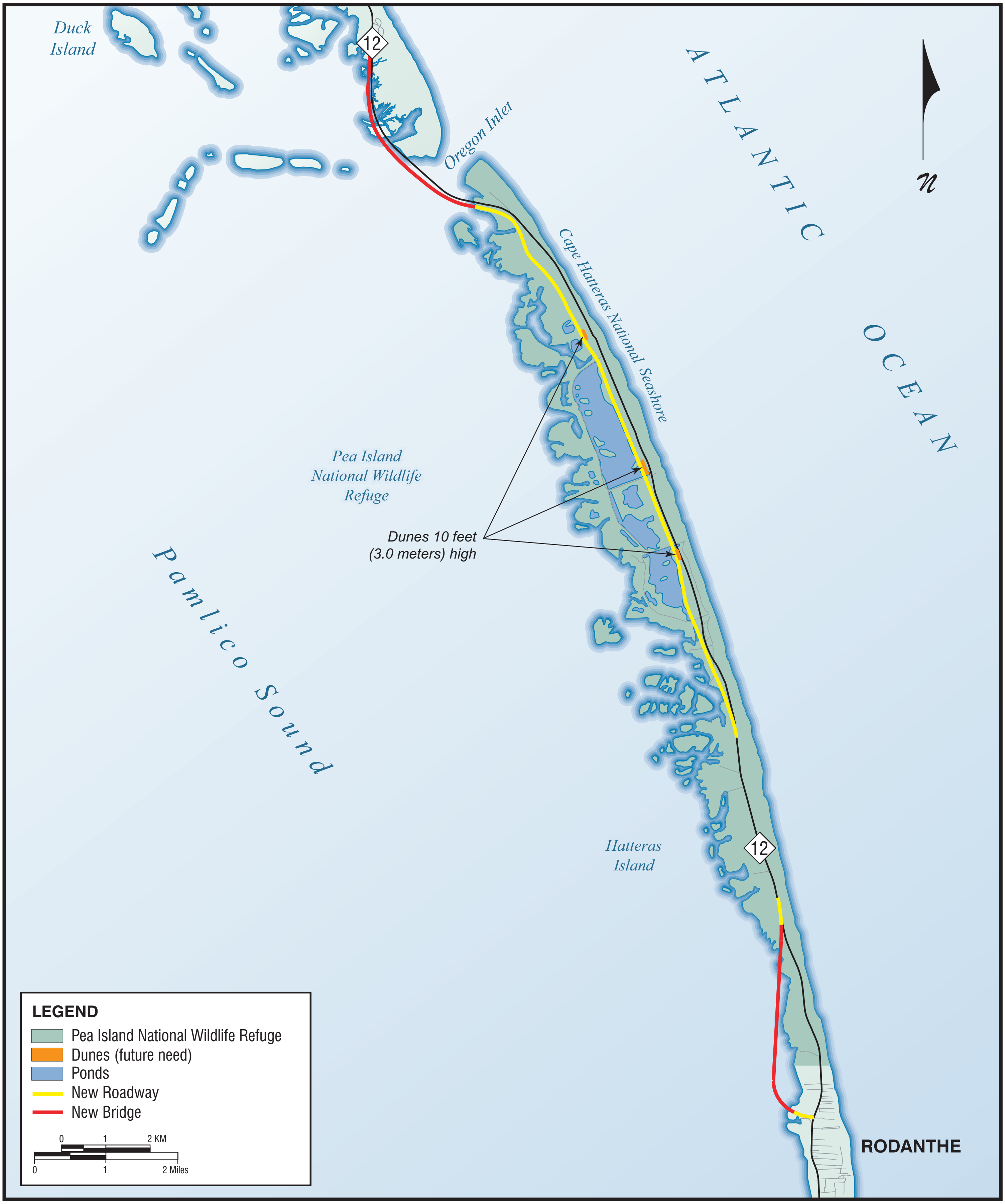
Parallel Bridge Corridor with Road North/Bridge South:
The Road North/Bridge South Alternative consists of constructing a new section of roadway west of the forecasted 2060 shoreline. The road relocation section would extend approximately seven miles south from the end of the Oregon Inlet bridge. At the southern end of the Pea Island National Wildlife Refuge and in Rodanthe, NC 12 would be relocated onto a bridge west of Hatteras Island. (FEIS, Section 2.10.2.2)

Parallel Bridge Corridor with All Bridge:
The All Bridge Alternative would relocate NC 12 onto bridges located west of the current roadway. The northern portion of the bridge would be constructed west of the forecasted 2060 shoreline and would extend from the end of the Oregon Inlet bridge to the beginning of a 1.8-mile stretch of existing roadway that will remain unchanged. The southern bridge portion of NC 12 would be constructed west of Hatteras Island and end in Rodanthe just north of the Rodanthe Historic District. This “Bridge South” section is the same bridge construction proposed in the Road North/Bridge South Alternative. (FEIS, Section 2.10.2.3)

Parallel Bridge Corridor with Phased Approach:
The Phased Approach Alternative would construct NC 12 onto a series of bridges within the current NC 12 easement in four phases. Phase I is the construction of the Oregon Inlet bridge. At the southern end of NC 12, there are two alternatives: the Phased Approach/Rodanthe Nourishment Alternative and the Phased Approach/Rodanthe Bridge Alternative. The Rodanthe Nourishment Alternative would maintain the current location of NC 12 in the Rodanthe Area with the addition of beach nourishment in northern Rodanthe. The Rodanthe Bridge Alternative would construct NC 12 as a bridge along its current roadway location in Rodanthe, ending just north of the Rodanthe Historic District. (FEIS, Section 2.10.2.4)

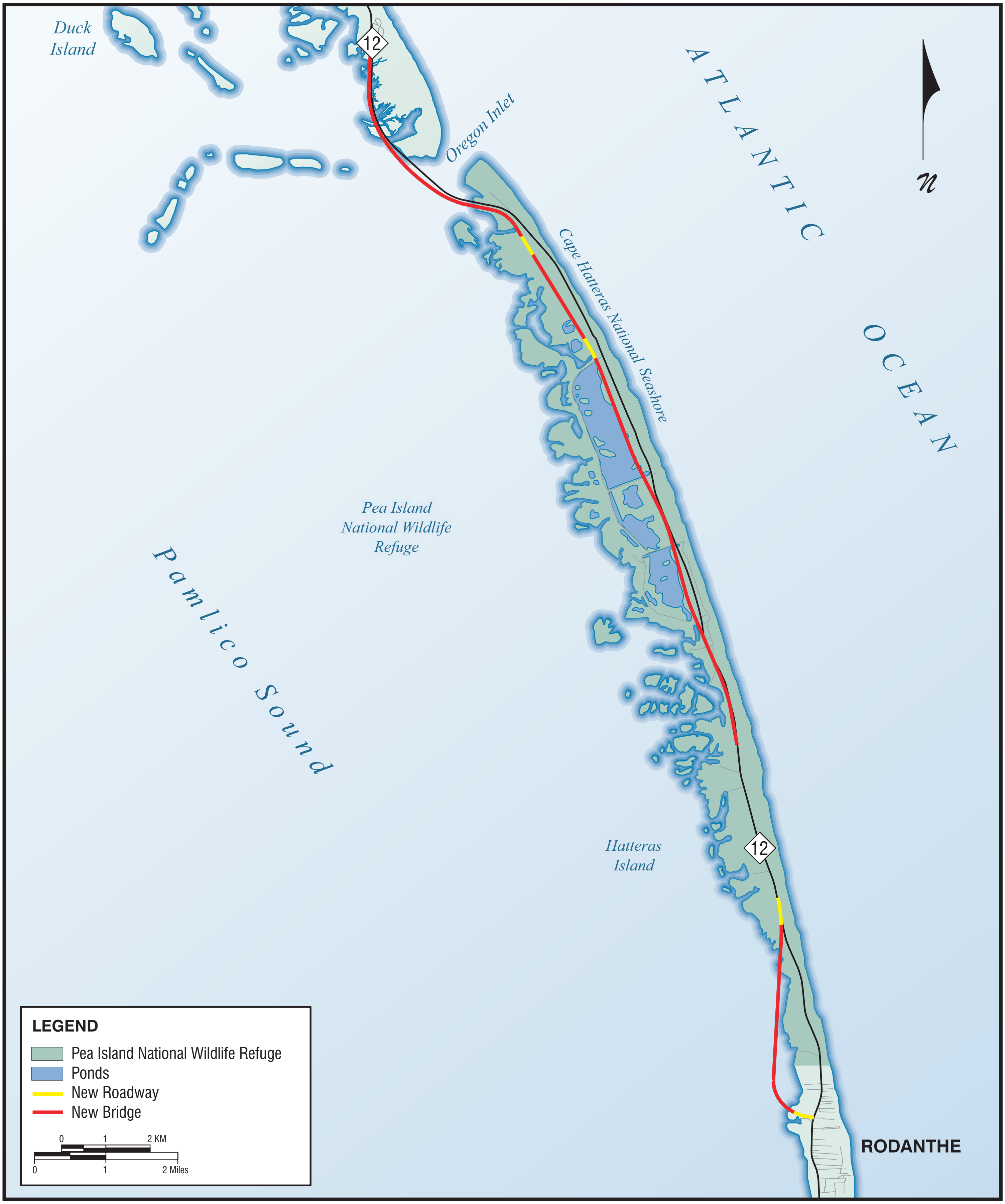
PARALLEL BRIDGE CORRIDOR WITH NOURISHMENT

Figure
2-18



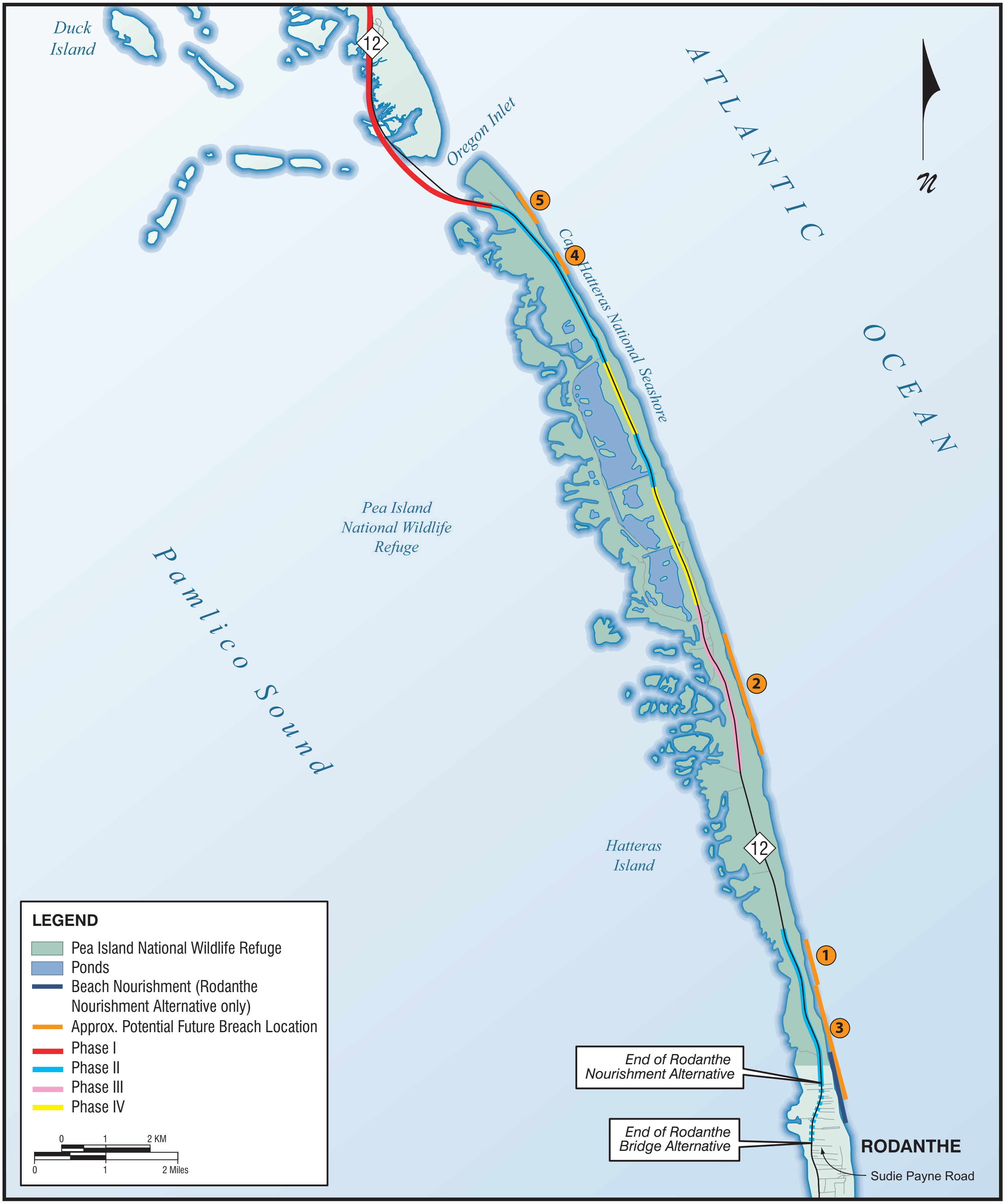
PARALLEL BRIDGE CORRIDOR WITH NC 12 RELOCATION ON ROAD NORTH/BRIDGE SOUTH

Figure 2-19



PARALLEL BRIDGE CORRIDOR WITH NC 12 RELOCATION ON ALL BRIDGE

Figure 2-20



PARALLEL BRIDGE CORRIDOR WITH PHASED APPROACH

Figure 2-21

All aspects of Phase I will be designed to conform to North Carolina highway specifications as approved by FHWA and NCDOT to ensure the safe construction and operation of the highway. In addition, other state and federal environmental resource and regulatory agencies will have an opportunity to review and comment on the final design prior to authorization of construction.

As discussed in Section 4.5.3.2 of the FEIS, NCDOT maintains catwalks on the southern end of Bonner Bridge. The catwalks provide access to the public to fish at Oregon Inlet. The type of access provided with the new Oregon Inlet bridge will be determined during the final design of Phase I; however, NCDOT is committed to restoring access to fishing at the northern end of Hatteras Island once construction of Phase I is complete. The existing catwalks will remain open to the public during construction as long as it is safely viable.

3.3.2 Later Phases (NC 12 Transportation Management Plan)

The Parallel Bridge Corridor with NC 12 Transportation Management Plan Alternative (Selected) does not specify a particular action at this time on Hatteras Island beyond the limits of Phase I because of the inherent uncertainty in predicting future conditions within the dynamic coastal barrier island environment. Instead, the alternative addresses the study and selection of future actions on Hatteras Island beyond the limits of Phase I through a comprehensive NC 12 Transportation Management Plan. The Transportation Management Plan will guide the implementation of future phases of the project through 2060. By actively monitoring the conditions and delaying decision-making as set forth in the NC 12 Transportation Management Plan, the environmental impacts beyond Phase I can be better quantified, minimized, and mitigated. This process is somewhat analogous to a tiered NEPA study, in that the entire end-to-end impacts have been studied but the detailed selection of a portion of the action is being delayed.

The Selected Alternative includes the following measures:

- NCDOT will fund and implement a coastal monitoring program on Hatteras Island within the project study area. The results of the monitoring program will be used to determine when planning of future phases of the project should begin.

- NCDOT will fund and implement a periodic Refuge habitat/NC 12 vulnerability forecasting study in consultation with USFWS. Through this program NCDOT and USFWS will work together to develop and assess alternative future scenarios including possible site-specific events and remedies.

- NCDOT and FHWA will utilize the results of the coastal monitoring program and the periodic Refuge habitat/NC 12 vulnerability forecasting study to determine when the environmental review for each phase should be initiated and what alternative actions should be studied in detail.

- The NEPA/Section 404 Merger Process will be utilized to study, select, and finalize future phases. It is anticipated that future phases will be subject to various permitting requirements. NCDOT will be required to obtain and comply with all applicable permits prior to beginning construction of future phases.

The NC 12 Transportation Management Plan incorporates the baseline coastal conditions identified in the FEIS (in Section 3.6.2, "Existing Coastal Conditions"), and then provides a detailed plan to closely monitor the coastal conditions for environmental changes over the next 50 years along with changes in associated road maintenance activities. Formal reports of the monitoring findings and updates to the forecasted shoreline predictions will be generated annually. Regular coordination with interested federal, state, and local agencies and the public will be conducted. When the coastal monitoring program identifies specified conditions at a location, then the NC 12 Transportation Management Plan provides for the initiation of an environmental review of a future phase of action at that location. The NC 12 Transportation Management Plan then describes the process for decision-making regarding the future phase actions.

Coastal Monitoring Program

The NC 12 Transportation Management Plan includes a comprehensive coastal monitoring program that NCDOT will begin implementing immediately upon issuance of this ROD. The coastal monitoring program is similar to but more refined than that proposed for the Phased Approach alternatives (see Section 2.10.2.5 of the FEIS). The coastal monitoring program will measure changes in the conditions on NC 12 and the surrounding environment, as compared to baseline coastal conditions, for the purpose of guiding NCDOT's planning for future phases of action through 2060.

As indicated above, the baseline coastal conditions for the NC 12 Transportation Management Plan are set forth in Section 3.6.2 of the FEIS, "Existing Coastal Conditions." In Section 3.6.3, the FEIS summarizes the predicted average and high erosion future shorelines in the project area for each decade through the year 2060 and assesses the potential likelihood, location, depth, and width of breaches that could open in the project area through the year 2060. Section 4.6.8.6 of the FEIS describes the five characteristic types of maintenance activities needed to keep NC 12 clear and open to traffic in detail and sets forth the baseline conditions for each maintenance activity. Based on past experience, the five characteristic types of maintenance activities are: road scraping, dune maintenance, dune rebuilding, sandbag-based dune and berm replenishment, and dune translation. The coastal monitoring program detailed below will be used to update the predicted shorelines and other coastal data discussed in the FEIS.

NCDOT will gather the following data within the project area on Hatteras Island:

- Geomorphological characteristics of the corridor, including the width and elevation of the island, dune height and vegetation, shoreline position, and nearshore bathymetry;

- Relative distance from NC 12 to critical geomorphological features, including the shoreline, dune, and estuarine shoreline for each section of the corridor;

- The extent and location of overwash occurrences for each section of the corridor;

- NC 12 roadway maintenance data, including the activities needed to maintain traffic and the manpower and cost involved, amount of time NC 12 is closed or reduced to one-lane traffic following storm events, etc.;

- Dredge disposal and beach nourishment projects undertaken by any party within the corridor or the adjacent nearshore area, including the volume of sand involved and the location and method of placement; and

- Data about major storm events.

The data gathered will be compared to the baseline conditions, and any changes noted will be tracked and assessed. The majority of the physical information will be collected utilizing NCDOT aerial photography, which will be generated biannually and immediately following storm events, as needed. This is consistent with current NCDOT practice; in recognition of the dynamic conditions within the project area, NCDOT has generated aerial photography biannually and following major storm events since 2002. Roadway maintenance data will be generated by NCDOT maintenance staff. Data regarding disposal or nourishment projects will be requested from the appropriate federal or state agencies overseeing those projects. Storm data will be compiled from agencies that track meteorological events, including the National Oceanic and Atmospheric Administration (NOAA), the National Hurricane Center, the State Climate Office, and other agencies as appropriate.

A report detailing the findings of the coastal monitoring program will be prepared on an annual basis. The erosion rates used to generate the baseline shoreline predictions also will be reassessed annually. NCDOT will provide a draft of each annual report to the Refuge manager for review. The draft report may be refined based on Refuge input. NCDOT will submit the final annual coastal monitoring reports to the Merger Team and will also post the reports on the internet for public review. An additional report that combines the monitoring findings with other geologic and biological datasets from other ongoing agency or university studies will be prepared every five years.

These efforts will be combined with the existing shoreline monitoring program that is underway as required by the existing terminal groin permit; any future monitoring efforts required as part of any new terminal groin permit also will be combined with the coastal monitoring. The coastal monitoring will be conducted by NCDOT staff (those with experience in aerial photography, coastal hydraulics, surveying, and roadway maintenance) and qualified coastal engineering consultants approved by NCDOT.

Refuge Habitat/NC 12 Vulnerability Forecasting Study

NCDOT will fund and implement a periodic Refuge habitat/NC 12 vulnerability forecasting study in consultation with USFWS. Through this program, NCDOT and USFWS will work together to develop and assess alternative future scenarios, including possible site-specific events and remedies. The purpose of the periodic Refuge habitat/NC 12 vulnerability forecasting study is to go beyond simply monitoring conditions and instead plan for potential events, such as storms, in order to minimize, to the extent possible, future threats to highway infrastructure and impacts to Refuge resources.

The periodic Refuge habitat/NC 12 vulnerability forecasting study will be conducted by a panel of coastal science experts whose credentials are acceptable to both NCDOT and USFWS. The first panel will be convened within six months after the initial coastal monitoring plan is finalized. The forecasts generated as part of this program will be re-visited every five years, within six months after the release of each five-year coastal monitoring report.

Environmental Review for Future Phases

The purpose of the environmental review is to determine, in coordination with all interested agencies and with an opportunity for public involvement, whether additional environmental study of a proposed future phase is needed prior to undertaking the future phase action. The environmental review will study the proposed action and the status of compliance with environmental laws that may be applicable to the proposed phase of action, including, but not limited to, Section 4(f), the National Historic Preservation Act, the Endangered Species Act, the Magnuson-Stevens Fishery Conservation and Management Act, the Coastal Area Management

Act (CAMA), the National Wildlife Refuge System Improvement Act of 1997, and the Clean Water Act. FHWA and NCDOT also will complete the appropriate NEPA documentation for each future phase of action in accordance with 23 CFR 771.129-130. Environmental conditions and the timing of each phase will be the primary factors in determining what type of NEPA documentation (a re-evaluation, a supplement, or a separate NEPA process) is the most appropriate.

The results of the coastal monitoring program, the updated shoreline erosion predictions, and the Refuge habitat/NC 12 vulnerability forecasting study will be used by NCDOT and FHWA, in consultation with representatives of the Refuge and the Merger Team, to determine: when an environmental review for each individual future phase of action will be initiated; the limits of the action area; potential actions that should be considered for the location; and measures to minimize and mitigate impacts. Based on previous NCDOT experience, findings that may warrant initiating an environmental review of a future phase include:

- An area with weak dunes (e.g., low dunes that lack vegetation) that potentially requires higher levels of storm-related NC 12 maintenance activity, proximity of the dune to NC 12, and the rate dunes may be advancing towards NC 12 (this recognizes that the frequency of dune maintenance is highest when a dune is less than 25 feet [7.6 meters] from the road);
- Significant increases in erosion rates over past trends;
- Significant increases in NC 12 storm-related maintenance frequency or activity over previous years;
- A determination that the distance between the active shoreline (mean high water) and NC 12 will be below the critical buffer distance of 230 feet (70.1 meters) within the next five years; or
- A determination that shoreline and dune conditions are such that the need for storm-related maintenance is likely to escalate significantly in the next five years.

As of the publication of this ROD, sections of the Canal Zone, Sandbag Area, and Rodanthe 'S' Curves hot spots (see Figure 2-7 of the EA) may already meet one or more of the listed criteria. The Rodanthe 'S' Curves Hot Spot was especially affected by a major storm event in November 2009 (Section 3.5.6 of the EA). The coastal monitoring program will provide the information needed to determine when future phases of action will be initiated in these areas.

<u>*Selection of Future Phases for Implementation*</u>

Once NCDOT and FHWA decide to initiate an environmental review of a later phase of the Selected Alternative in consultation with the Refuge, as described above, the study, selection, and finalizing of that phase will follow the provisions of the NEPA/Section 404 Merger Process that is currently utilized by NCDOT. Because the purpose and need (Concurrence Point 1) of the overall project will not change, NCDOT and FHWA will likely reconvene the Merger Team at Concurrence Point 2, the selection of detailed study alternatives. It is anticipated that future phases will be subject to various permitting requirements. NCDOT will be required to obtain and comply with all applicable permits prior to beginning construction of future phases.