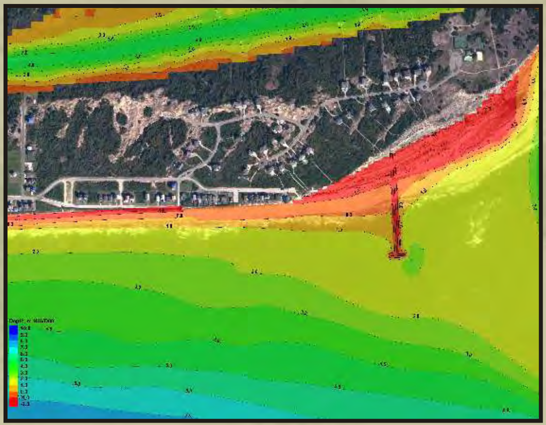
APPENDIX H

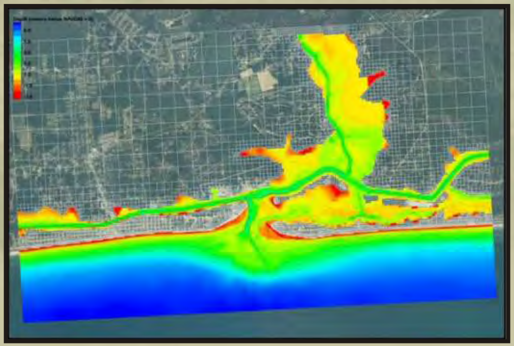
ATM ENGINEERING ANALYSIS

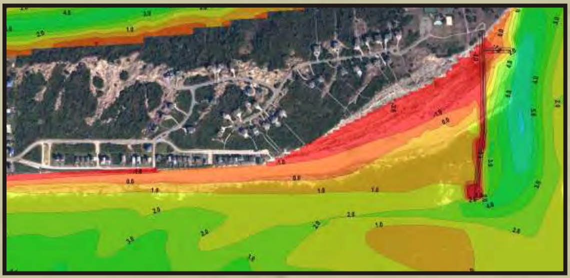
Holden Beach

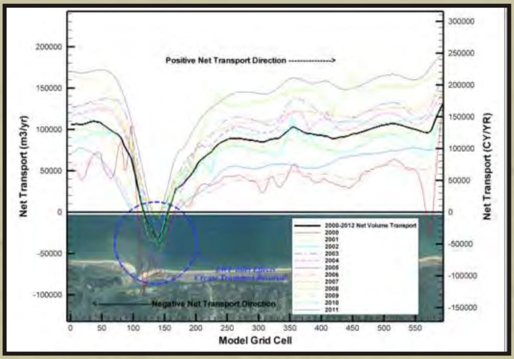
East End Shore Protection Project Engineering and Modeling Report

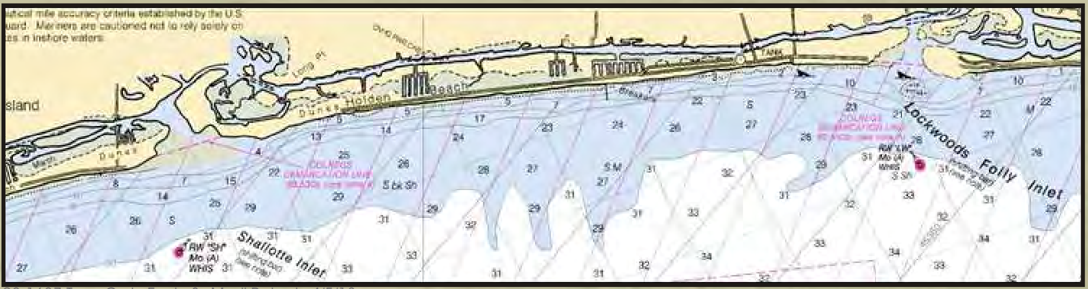
Prepared For:
Town of Holden Beach, North Carolina











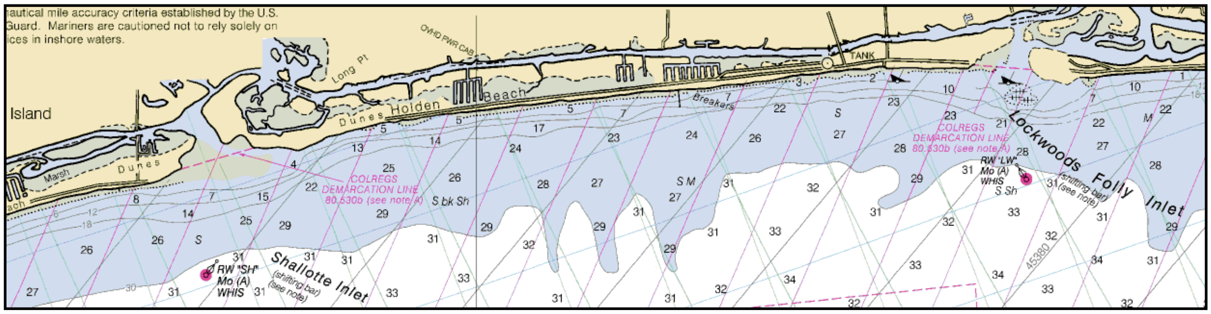
08-1687 Term Groin Engin & Modl Rpt.cdr 4/5/13

August 2013

ATM
APPLIED TECHNOLOGY & MANAGEMENT

EAST END SHORE PROTECTION PROJECT
ENGINEERING AND MODELING REPORT

HOLDEN BEACH
BRUNSWICK COUNTY, NORTH CAROLINA



PREPARED FOR:
THE TOWN OF HOLDEN BEACH
HOLDEN BEACH, NC

SUBMITTED TO:
U.S. ARMY CORPS OF ENGINEERS
WILMINGTON DISTRICT, REGULATORY BRANCH
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WILMINGTON, NC 28402

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APPLIED TECHNOLOGY & MANAGEMENT, INC.
CHARLESTON, SC

AUGUST 2013

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1.0 INTRODUCTION

This document presents the alternatives and modeling analysis for a shore protection project on the east end of Holden Beach, adjacent to Lockwoods Folly (LWF) Inlet. The Town of Holden Beach (also referred to herein as the Town) is positioned to the west of LWF Inlet, with Oak Island to the east. Both Holden Beach and Oak Island are located within Brunswick County, North Carolina (Figure 1-1).

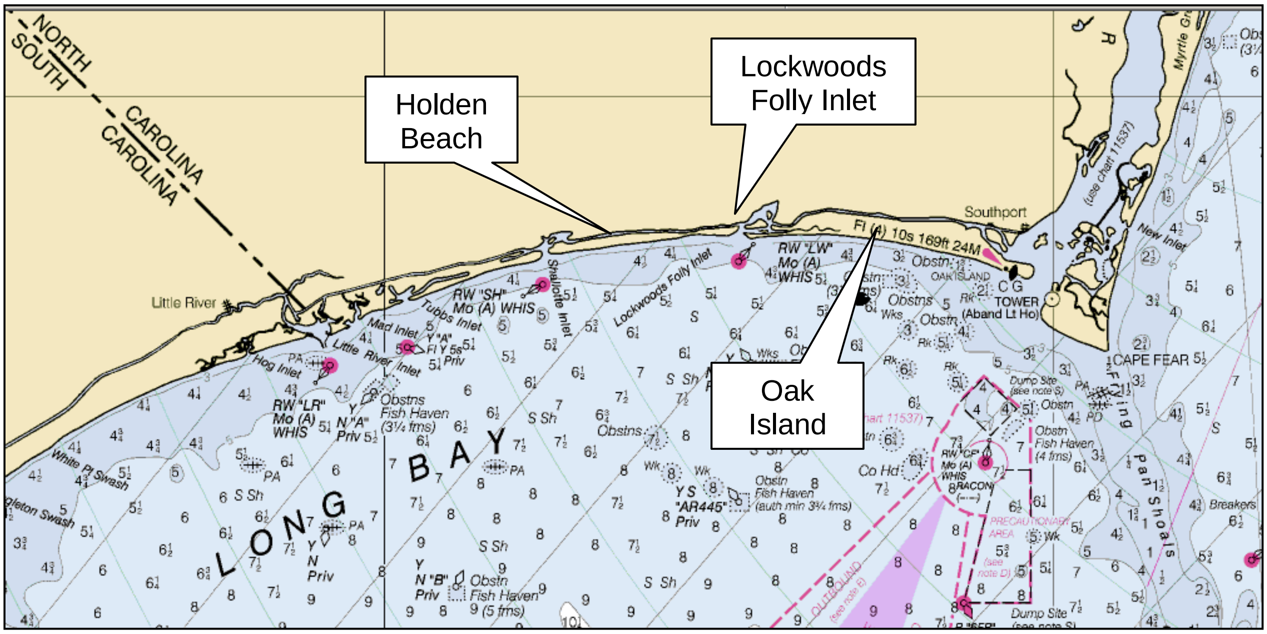
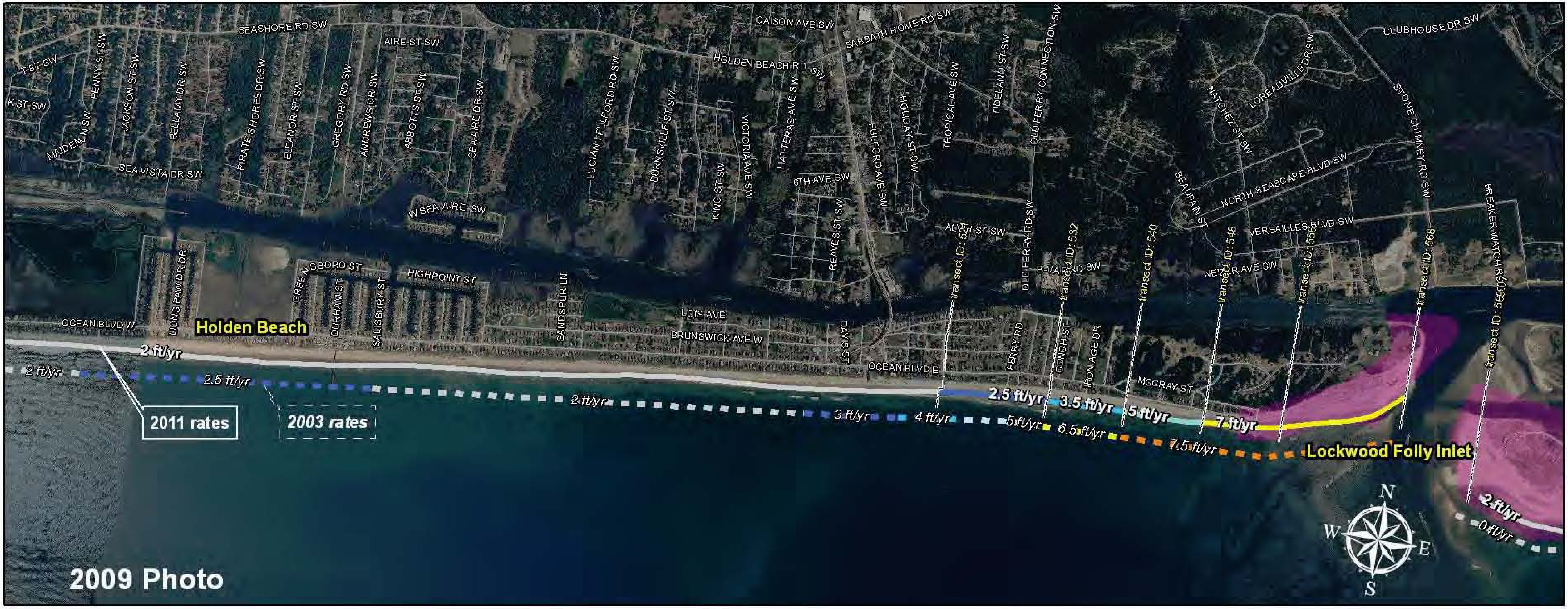


Figure 1-1. Project Location Map of Holden Beach and Lockwoods Folly Inlet, NC (NOAA Chart 11520)

The east end of Holden Beach has and is experiencing consistent, relatively severe erosional conditions. Figures 1-2 and 1-3 present 2011 North Carolina Division of Coastal Management (DCM) long-term erosion rate maps of Holden Beach and the west end of Oak Island. The long-term erosion rates through 2011 are slightly less than 2003 rates for eastern Holden Beach due, in part, to recent nourishment activities. The beach and dune system experience chronic and episodic erosion, which has necessitated several erosion control projects during the past decades.

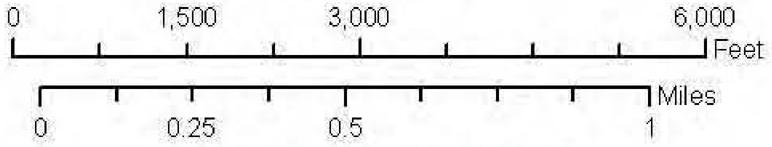


2011 Long-Term Average Annual Erosion Rate Update
at Holden Beach, North Carolina

Legend

2011 Setback Factors (feet/year)	2003 Setback Factors (feet/year)
▬ 2.0	▪▪ 0.0 - 2.0
▬ 2.1 - 3.0	▪▪ 2.1 - 3.0
▬ 3.1 - 4.0	▪▪ 3.1 - 4.0
▬ 4.1 - 5.0	▪▪ 4.1 - 5.0
▬ 5.1 - 6.0	▪▪ 5.1 - 6.0
▬ 6.1 - 7.0	▪▪ 6.1 - 7.0
▬ 7.1 - 8.0	▪▪ 7.1 - 8.0
▬ > 8.0	▪▪ > 8.0
┄ Erosion Rate Factor Transition Boundary	▨ Inlet Hazard Area
▬ Beach Fill Project > 300,000 cubic yards	**Photo: 2009 USDA NAIP**

Map Scale: 1:20,000



Horizontal Datum: NC State Plane NAD 83 Feet

Setback Factors on this map represents long-term average annual erosion rates measured in feet per year. Shoreline segments that are accreting or have erosion rates less than two feet per year receive a setback factor value equal to two.

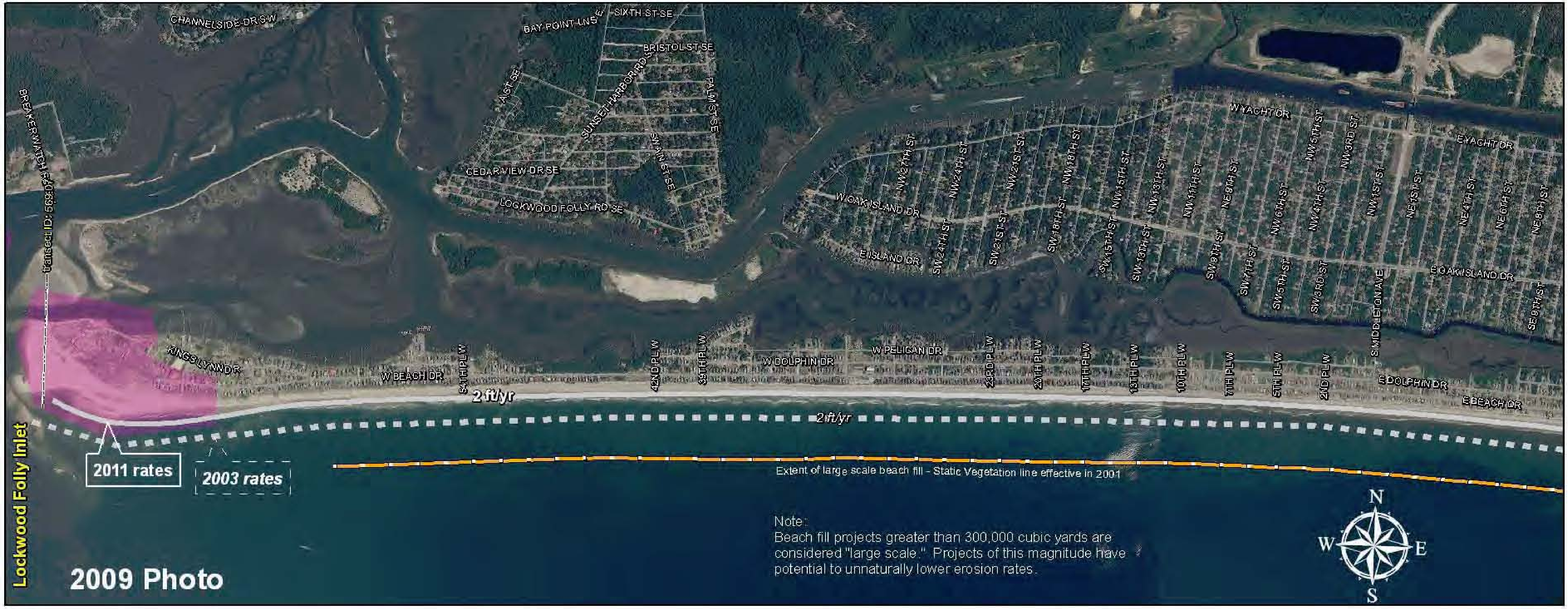
The information presented here is not predictive, nor does it reflect short-term erosion potential. This map may not be suitable for property specific determination of erosion rate factors near rate transition boundaries due to its small scale. For site specific determinations contact your CAMA Local Permit Official, or regional Division of Coastal Management field office.

400 Commerce Avenue
Morehead City, North Carolina 28557
1-888-4RCOAST

http://www.nccoastalmanagement.net

FIGURE 1-2: 2011 Long-Term Average Annual Erosion Rates Eastern Holden Beach

Ken Richardson - April, 2011



Note:
Beach fill projects greater than 300,000 cubic yards are considered "large scale." Projects of this magnitude have potential to unnaturally lower erosion rates.

2011 Long-Term Average Annual Erosion Rate Update

at Oak Island, North Carolina

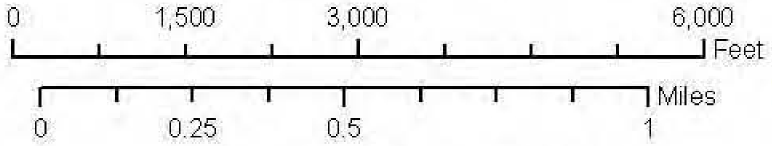
Legend

2011 Setback Factors (feet/year)
- ▬ 2.0
- ▬ 2.1 - 3.0
- ▬ 3.1 - 4.0
- ▬ 4.1 - 5.0
- ▬ 5.1 - 6.0
- ▬ 6.1 - 7.0
- ▬ 7.1 - 8.0
- ▬ > 8.0
- ---- Erosion Rate Factor Transition Boundary
- ▬ Beach Fill Project > 300,000 cubic yards

2003 Setback Factors (feet/year)
- ▪▪ 0.0 - 2.0
- ▪▪ 2.1 - 3.0
- ▪▪ 3.1 - 4.0
- ▪▪ 4.1 - 5.0
- ▪▪ 5.1 - 6.0
- ▪▪ 6.1 - 7.0
- ▪▪ 7.1 - 8.0
- ▪▪ > 8.0
- ▨ Inlet Hazard Area

Photo: 2009 USDA NAIP

Map Scale: 1:20,000



Horizontal Datum: NC State Plane NAD 83 Feet

Setback Factors on this map represents long-term average annual erosion rates measured in feet per year. Shoreline segments that are accreting or have erosion rates less than two feet per year receive a setback factor value equal to two.

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FIGURE 1-3: 2011 Long-Term Average Annual Erosion Rates Western Oak Island

Ken Richardson - April, 2011

Dune breaching and flooding has also occurred, most recently during Hurricane Hanna in 2008 (Figure 1-4). Since 1993, approximately 27 oceanfront properties (including houses, infrastructure, etc.) on the east end of Holden Beach have been lost to erosion. Figure 1-5 presents a comparison of 1993 and 2008 aerials on the east end, where 27 structures can be identified as lost due to erosion effects.

Figure 1-4. Holden Beach East End Dune Restoration Activities Following Hurricane Hanna Dune Erosion and Breaching

Periodic nourishments by both the Town and the U.S. Army Corps of Engineers (USACE) have relieved this erosion; however, the intermittent fill placement provides only a short-term benefit for the east end. A more long-term solution is required to help reduce the large fluctuations that occur along the west shoulder of LWF Inlet.

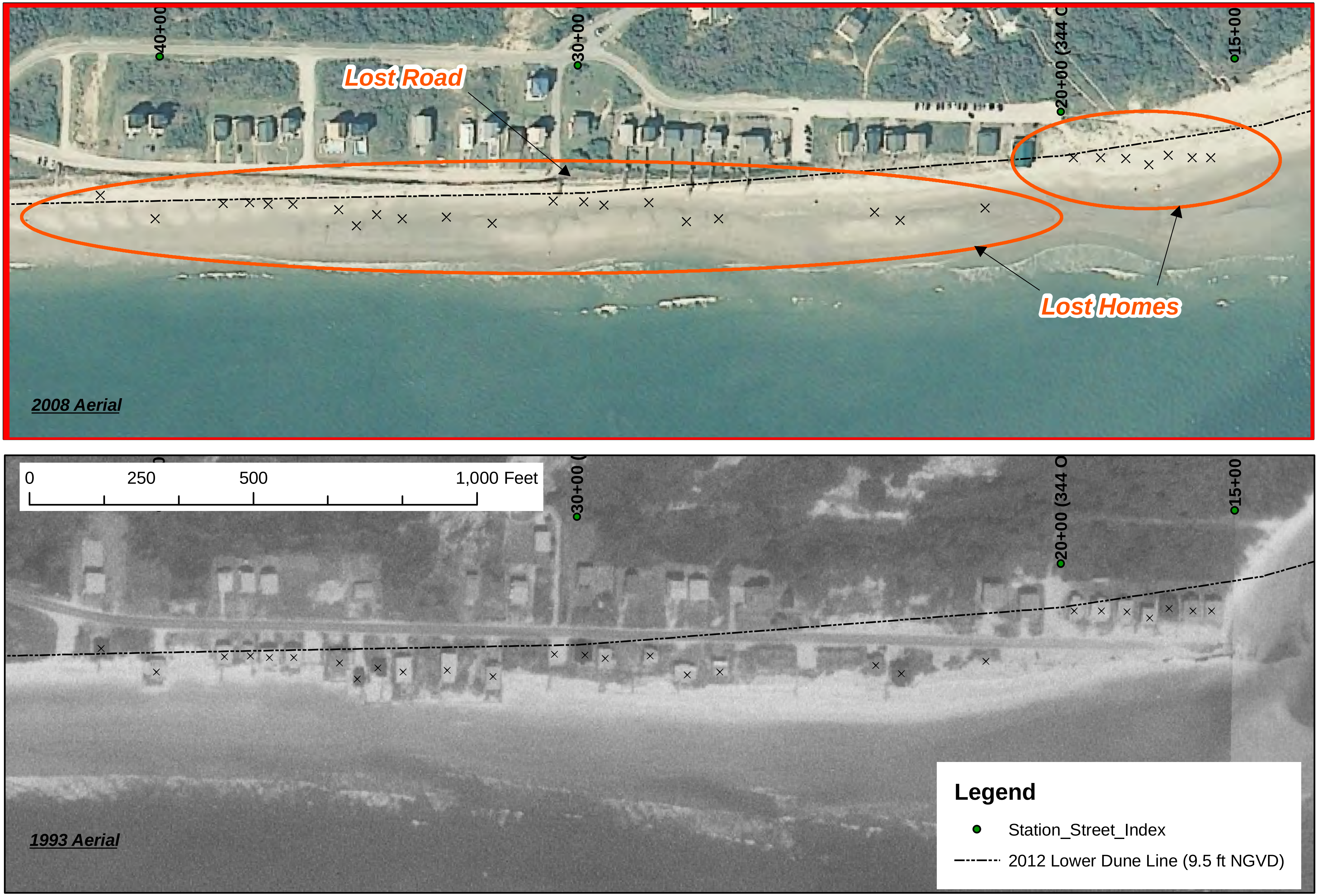

Figure 1-5
1993 and 2008 Aerial Comparison - East End
27 structures (black 'x' marks) identified that have been lost over this time span in this area.

After careful analysis it has been determined that, in addition to nourishment activities and proactive sand management of Lockwoods Folly Inlet, a terminal groin structure on the eastern end of Holden Beach is the Town's locally preferred alternative to reduce the high erosion losses that have historically occurred in the area and that are beyond the ability of beach fill placement alone to effectively address. The proposed terminal groin and concurrent nourishment project is one component of the Town's ongoing comprehensive beach management program, further described in the *Holden Beach 2009 Beach Management Plan* (ATM, 2009).

Note that this project is different in size and scope than that of Figure 8 terminal groin study and other locations currently under study for terminal groin feasibility. As a result, direct comparisons may not be applicable.

2.0 PURPOSE AND NEED

The purpose of the proposed project is to implement erosion control and beach/dune restoration that will provide short-term and long-term protection for threatened residential structures, Town infrastructure, and recreational assets, including beach area, public parking, and public beach access, along the east end of Holden Beach.

Given the threat of continued erosion (and subsequent consequences briefly described in the previous section), the proposed project seeks to satisfy following needs:

- Stabilize the shoreline and maintain a healthy, dry upper beach (berm) and dune;
- Maintain and increase opportunities for recreation, beach access, and enhance available environmental habitats (i.e., potential to stabilize or increase inlet area shoreline sea turtle nesting, shorebird habitat, and benthic community activity);
- Reduce future beach nourishment project frequency and required beach maintenance (dune rebuilding and revegetation, sand fending and walkover repair/replacement);
- Optimize the groin benefits with reduction of both annual maintenance costs and future beach nourishment costs;
- Preserve the tax base;
- Continue to help maintain the island’s tourist industry, which is critical to the local economy; and
- Complement the existing central reach nourishment protection activities.

3.0 INDEPENDENT BEACH MANAGEMENT ACTIVITIES

In addition to seeking a permit for a terminal groin project, several other permitting projects are ongoing or planned by either the Town or USACE. *Note that the proposed terminal groin project will include an east end nourishment*. Please see the *Holden Beach Terminal Groin Work Plan* (ATM, 2011) for more information.

There are essentially two reaches of beach that are historically nourished on Holden Beach:

1. Central Reach (baseline Station 40+00 west to Station 270+00)
2. East End (Station 40+00 east to LWF Inlet)

Figure 3-1 presents these two reaches, with Holden Beach and USACE beach fill placements since 2001. This document refers to the east end as defined above. Applied Technology and Management, Inc. (ATM) observations and modeling indicate that the net transport between approximately Stations 0+00 and 40+00 (see Figure 3-1) is toward the east (opposite that of the regional net transport), due to the strong influence of the LWF Inlet processes.

Both the Town and USACE perform nourishment activities on Holden Beach as the primary sponsor. The Town has historically funded the entirety of its nourishment projects, from permitting through design, construction, and monitoring. The USACE projects typically require a local sponsor for 25-50% of project costs.

Historically, the Town has not placed material on the east end beach and has relied on USACE navigation maintenance dredging projects for east end sand placement. The USACE east end beneficial nourishment projects (which use sand from Atlantic Intracoastal Waterway [AIWW] dredging) are primarily funded by the USACE. The USACE is also responsible for permitting, design, construction and monitoring for these east end projects. The USACE also places sand on the central reach. The USACE sponsored the 2001/2002 beach nourishment along a portion of the central reach (Section 933 Project), with cost sharing by the Town, as a beneficial use of dredged material associated with the deepening of the Wilmington Harbor. The USACE is also in the process of developing a 50-year plan for the Brunswick County Beaches (BCB) project that includes nourishment of portions of the central reach (USACE, 2012).

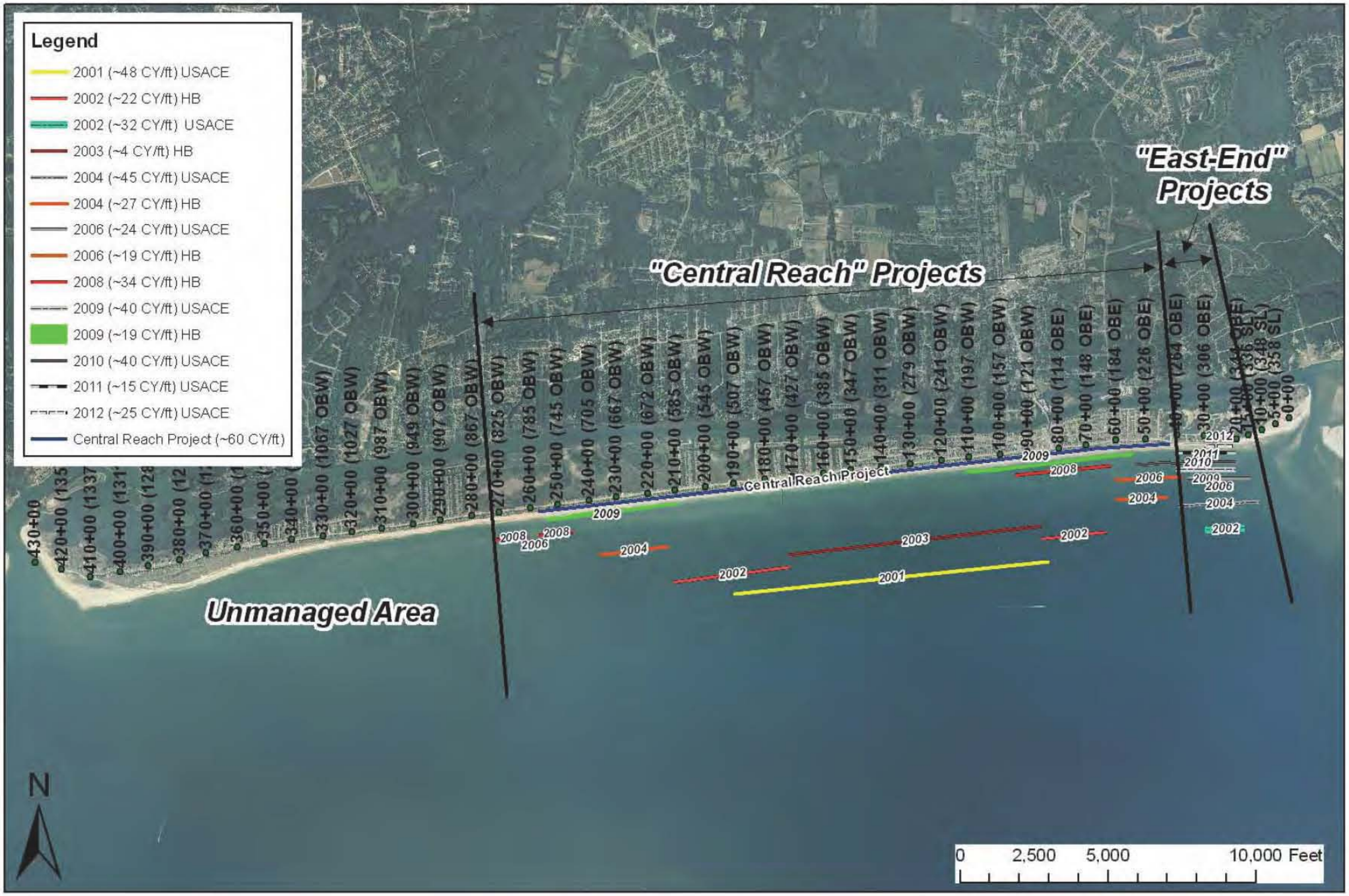

Figure 3-1

Holden Beach Nourishment Activity Since 2001
Note only USACE projects occur on East End
HB = Holden Beach

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Table 3-1. Town of Holden Beach Nourishment Summary over the Last Decade (USACE fill placement is not included in this table).

Date	Baseline Stations Nourished	Approximate Volume of Material Placed (cy)	Material Source
3/02 – 4/02	66+00 - 90+00 and 175+00 – 217+00	141,700	Oyster Harbor upland site
Winter 2002-2003	90+00 – 175+00	30,000	Boyd Street Disposal Area
12/03 – 4/04	46+00 – 68+00 and 215+00 – 238+00	123,000	Smith borrow site
Early 2006	40+00-60+00	42,000	Smith borrow site
Early 2006	260+00 – 262+00	3,200	Smith borrow site
1/08 – 3/08	60+00 – 95+00 and 245+00 – 270+00	201,000	Smith borrow site
03/09 – 4/09	55+00 – 110+00 and 210+00 – 255+00	190,000	Smith borrow site

Town fill placement is done in coordination with USACE east end fill placement when possible. For example, in 2009, the Town began its Central Reach fill placement where the USACE east end fill placement stopped (See Figure 3-1). Since 2002, the Town has not placed sand farther east than Station 40+00 (see Table 3-1) as a berm/beach nourishment. The Town has performed limited *dune restoration efforts* on the east end in response to storm events.

Historically, regulatory agencies have established approximately Station 30+00 as the eastern-most limit of fill placement for Town projects. Natural resource agencies have promoted this to maintain a buffer for the shorebird habitat adjacent to LWF Inlet.

One of the primary goals of the Town's beach management strategy is to have no net reduction in sand volume along Holden Beach. Additional goals include increasing storm protection to upland infrastructure, increasing recreational beach area, and/or addressing erosional hot spots.

4.0 PROJECT SITE HISTORY

4.1 PREVIOUS STUDIES

Numerous studies have documented accretion and erosion patterns in the LWF Inlet vicinity, including the following (in chronological order):

- USACE, 1973. General Design Memorandum – Phase I; Hurricane Wave Protection – Beach Erosion Control; Brunswick County, NC, Beach Projects, Yaupon and Long Beach Segments.

- Machemehl, J.L. 1975. Dredge Material Containment in Nylon Bags in the Construction of Mini-Projects for Beach Stabilization. Proceedings of the Eighth Dredging Seminar; Held November 8 1975, Houston, Texas. Sea Grant Report No. CDS-195, TAMU-SG-77-102, Texas A&M University, College Station, p 82-122, December 1976.

- Machemehl J.L. 1975. Beach Erosion Control Project for Long Beach, NC. Report prepared for the Town of Long Beach, NC and the Department of Natural Resources and Community Development, State of North Carolina.

- Machemehl, Chambers and Bird. 1977. Flow Dynamics and Sediment Movement in Lockwoods Folly Inlet, North Carolina. UNC Sea Grant College Publication, UNC-SG-77-11.

- Machemehl, et al., 1977. An Engineering Evaluation of Low Cost Stabilization Projects in Brunswick County, NC. Coastal Sediments 1977.

- Miller, 1983. Beach Changes at Holden Beach, NC, 1970-74. Miscellaneous Report No. 83-5. Prepared by USACE CERC.

- Cleary, W. J., 1996, Lockwood's Folly Inlet: Its Impact on the Eastern Margin of Holden Beach, NC, Unpublished report submitted to the Town of Holden Beach, 20p.

- Thompson, E. F, Lin, L., and Jones, D.L. 1999. Wave Climate and Littoral Sediment Transport Potential, Cape Fear River Entrance and Smith Island to Ocean Isle Beach, North Carolina, U.S. Army Corps of Engineers, Engineer Research and Development Center, Technical Report CHL-99-18. Prepared for the U.S. Army Engineer District, Wilmington. 101 p.

- Applied Technology and Management, Inc. (ATM), 2001. Holden Beach, NC Beach Nourishment Project, Preliminary Design Report. Prepared for Town of Holden Beach, May 2001.

- Moffatt and Nichol. 2005. Final Report on Costs, Benefits, and Management Issues Related to Maintaining North Carolina's Shallow Draft Navigation Channels. Prepared for the North Carolina General Assembly

- Offshore & Coastal Technologies, Inc. (OCTI). 2008. Brunswick County Phase 1 Report. Prepared for the U.S. Army Engineer District, Wilmington, NC.

- Cleary, W., 2008. Overview of Oceanfront Shorelines: Cape Lookout to Sunset Beach, NC. Report prepared for Moffat & Nichol.

- USACE-CHL, 2008. Memorandum for Record: Regional Analysis for Beach Nourishment Planning, Brunswick County, NC. Coastal and Hydraulics Laboratory, US Army Engineer Research and Development Center.

- CSE (Coastal Science and Engineering). 2009. Preliminary Design Report – Phase 1 Lower Lockwoods Folly River Aquatic Habitat Restoration Project Brunswick County, North Carolina. Prepared for: Brunswick County Board of Commissioners Bolivia, North Carolina

- ATM, 2009. Beach Management Planning and Borrow Area Investigation. Prepared for Town of Holden Beach, August 2009.

- Moffatt & Nichol. 2010. Final Report – Terminal Groin Study. Prepared for NC Coastal Resources Commission. March, 2010.

- USACE. 2011. Review Plan - Integrated General Reevaluation Report and Environmental Impact Statement for Brunswick County Beaches, North Carolina. October 2011

As seen from this list, LWF Inlet and the adjacent shorelines of Holden Beach and Oak Island have been studied extensively from a shoreline change and sediment transport perspective since the 1970s. Many of these studies include shoreline change and inlet movement analyses dating back to the mid 1800s.

In 1983, Miller documented that net longshore sand transport is westward (contrary to the 1973 USACE study). Since that time, westward net sand transport has been documented, although seasonal switches under spring/summer southwest wind/wave conditions are common. Miller (1983) also states, “Before 1973, the east end of Holden Beach was identified as having the highest erosion rate of any beach in Brunswick County. This severe condition damaged the end of a road and caused the removal of six houses.” Miller cites that at least 280,000 cubic meters (m^3) [364,000 cubic yards (cy)] of sand was added from 1970 to 1974 and that the nourishment activities were effective, primarily to the eastern region of the Central Reach (i.e., approximately Stations 40+00 to 120+00). Figure 4-1 highlights a primary consensus of previous studies and current observations: *that severely erosional conditions exist along the east end of Holden Beach relative to the surrounding areas*.

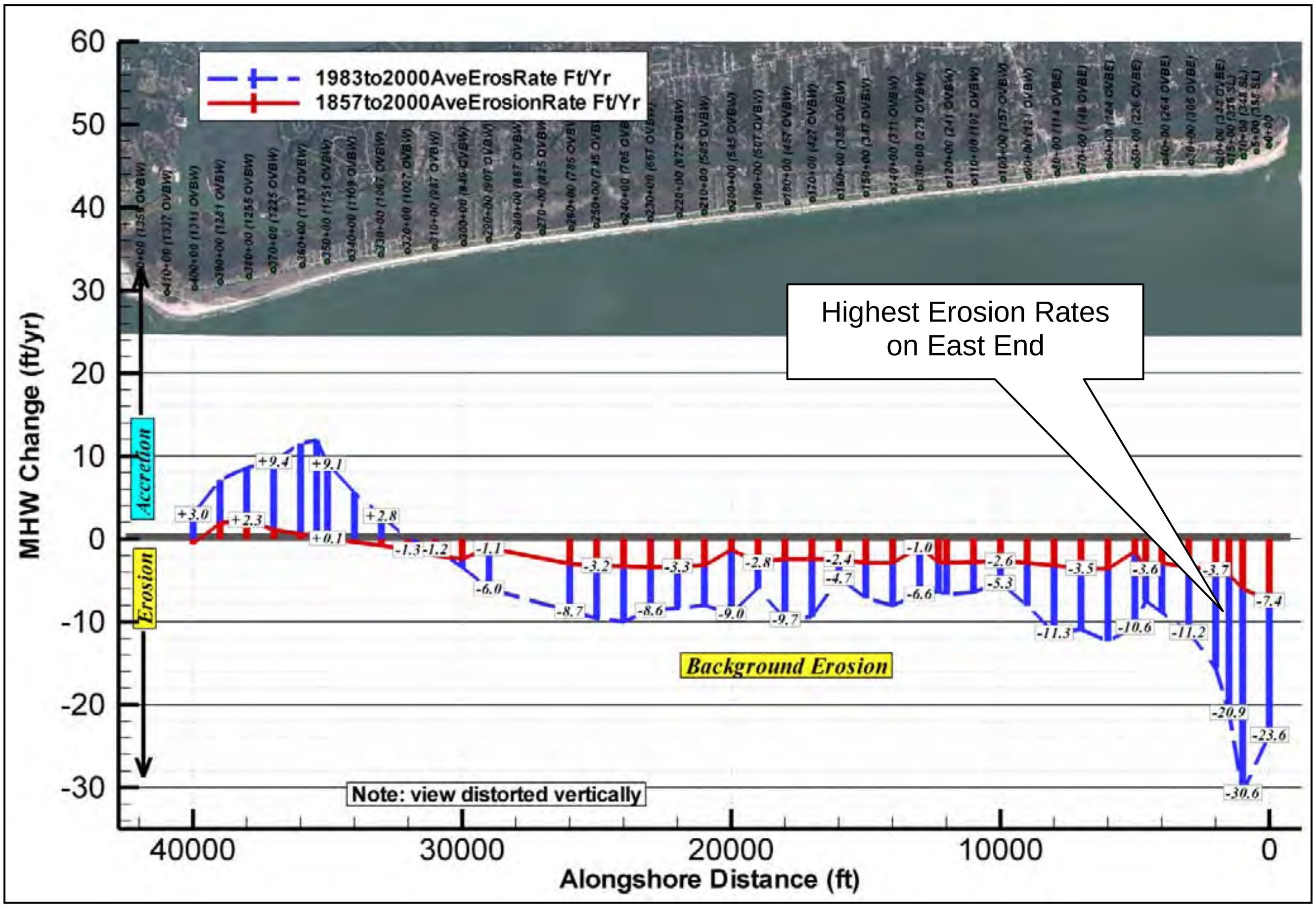

Figure 4-1. Historic Shoreline Erosion Rates (ATM, 2001). Note high erosion on east end from 1983 to 2000.

4.2 LOCKWOODS FOLLY INLET

LWF Inlet connects Lockwoods Folly River and the AIWW to the Atlantic Ocean. Historical maps and coastal charts have identified LWF River and Inlet as far back as 1672. In contrast to this, the AIWW in this area was constructed around 1930. Prior to the dredging of the AIWW, Holden Beach and Oak Island were accessible from the mainland by crossing the intervening marsh at low tide [North Carolina Beach and Inlet Management Plan (NC BIMP), 2011].

4.2.1 LOCKWOODS FOLLY INLET MOVEMENT

Between 1858 and 1938, LWF Inlet migrated westward approximately 2,300 feet to its present location (NC BIMP, 2011). Cleary and Marden (2001) estimate that the midpoint of LWF Inlet has migrated approximately 500 feet west since 1938. Several other studies have analyzed the movement of LWF Inlet over the last century, including Cleary (1996, 2008) and CSE (2009).

The North Carolina Department of Environment and Natural Resources (NCDENR) also developed a shoreline analysis using historical aerials shown in Figure 4-2. While many inlets in North Carolina can be described as highly migratory (e.g., Oregon Inlet, Mason Inlet, etc.), these studies confirm that LWF Inlet has remained relatively stationary over the last century (i.e., there is no significant long-term movement to the east or west). However, a stable inlet does not imply an absence of erosional conditions. As Cleary (1996) states, “Although the inlet has been locationally stable, there has been considerable morphologic change within the inlet, its shoals and along adjacent shorelines.”

A chronic erosion trend exists along the east end of Holden Beach, up to 2 kilometers (km) (about 1.2 miles) from LWF Inlet. The approximate influence of LWF Inlet is 2 km in both the eastern (Oak Island) and western (Holden Beach) directions (Cleary, 1996; Cleary, 1998).

A brief LWF Inlet characterization is excerpted from Cleary (1996):

> LWF Inlet is characterized by a small inlet minimum width with a mean value of 272 m. The widths ranged from 93.3 m (1938) to 410 m (1992). The inlet’s minimum width has varied considerably but in general there has been an overall increase, particularly in the past decade. The variation can be correlated with the periodic development of a major spit on the downdrift Long Beach [Oak Island] shoulder, and accretion along the Holden Beach shoulder near the AIWW. It is difficult to determine if the apparent increased width is a cause or an effect of the erosion on the eastern margin of Holden Beach.

4.2.2 EBB TIDAL DELTA

An important feature of inlet morphology and dynamics is the ebb shoal. Figure 4-3 is a general schematic of an ebb tidal delta. Figure 4-4 presents the ebb tidal delta feature at LWF Inlet.

Cleary (1996) concluded that during the 1938 to 1995 period of aerial photographic coverage, the mean area of the ebb tidal delta was 1 million square meters (m^2). The data suggest there has been an increase in the ebb delta area over time, particularly during the past several decades (Cleary, 1996). Cleary postulated that an increase in the inlet’s width and depth would contribute to a larger retention capacity of the offshore shoals and, therefore, in its aerial extent (1996). Refer to Cleary (1996) for a detailed description of aerial photos from 1938 to 1995.

Figure 4-2:
LWF Inlet Historic Shorelines (source: NCDCM)
Aerial from 2008.

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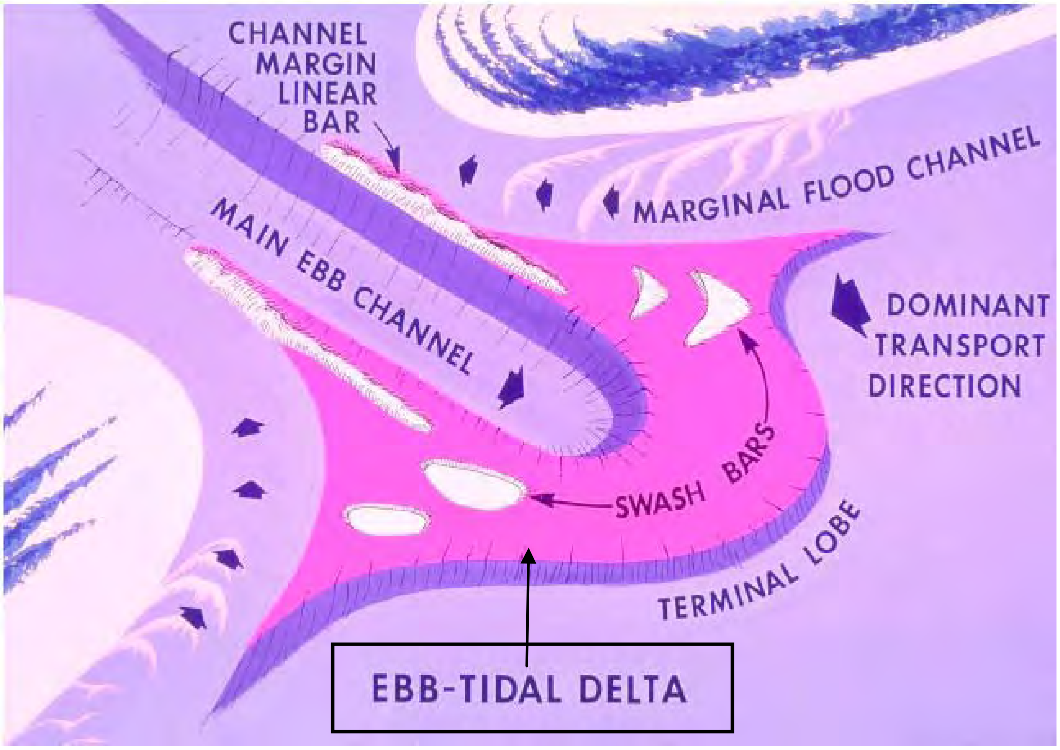


Figure 4-3. *Ebb Tidal Delta Schematic (source: Hayes, 1994)*

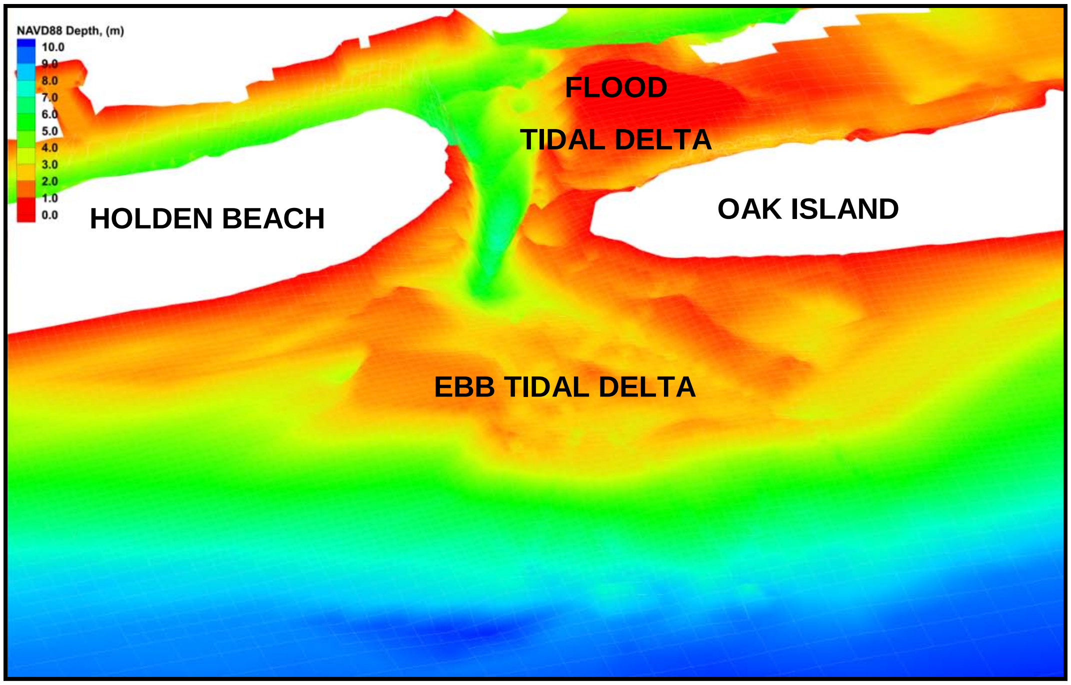


Figure 4-4. *Bird's-Eye View of Ebb and Flood Tidal Deltas (April 2012 Holden Beach survey and 2012 USACE inlet bathymetry data).*

4.2.3 OUTER CHANNEL ORIENTATION

LWF Inlet's outer channel orientation/alignment has been documented to affect shoreline erosion intensity (Cleary, 1996; 2008). The USACE Navigation Branch conducts outer channel sidecast dredging and follows "deep water" to achieve a 150-foot wide channel at 8-foot MLW depth. The dredging occurs out to the natural 8-foot MLW contour, which is typically around 2,000 to 3,000 feet offshore (depending on channel orientation). Additional outer channel alignment restrictions arise from the presence of four shipwrecks (three of which are of historic significance) in the ebb tidal delta area. The Holden Beach Terminal Groin Work Plan provides more information on this topic. Over the last century, channel alignment has been closer to the Oak Island shoreline, which has been cited as favorable for Oak Island, while increased erosion occurs on Holden Beach. This effect results from the alignment affecting wave propagation and various flood channels (see Figure 4-3 for schematic of marginal flood channels). Figure 4-5a presents the alignment of the LWF Inlet in 2000, as well as an inset rose figure documenting historical channel alignment. Figure 4-5b shows the Merritt sidecaster dredge working the outer channel.

4.2.4 LWF SHORELINE INFLUENCE

A relevant excerpt from Cleary (1996):

> Within 100 m of LWF Inlet, the Holden Beach shoreline has eroded 260 meters during the past 58 years, at an average of 4.5 meters per year. For a brief period during the late 1970s, accretion took place along this reach due to reorientation of the ebb channel, but today erosion continues along much of the eastern margin of the island.
>
> The most dramatic changes to Long Beach [Oak Island] have occurred within 400 meters of the inlet. Since 1938, this area has experienced an average net accretion of 1 meter per year, though it was plagued by serious erosion in the 1970s and 1980s. Almost 100 meters of shoreline eroded between 1974 and 1986, at an average of 8 meters per year. During this time, the flood channel was positioned along the Long Beach shoulder, causing rapid erosion, but since 1986, the shoreline has built up again by 185 meters.

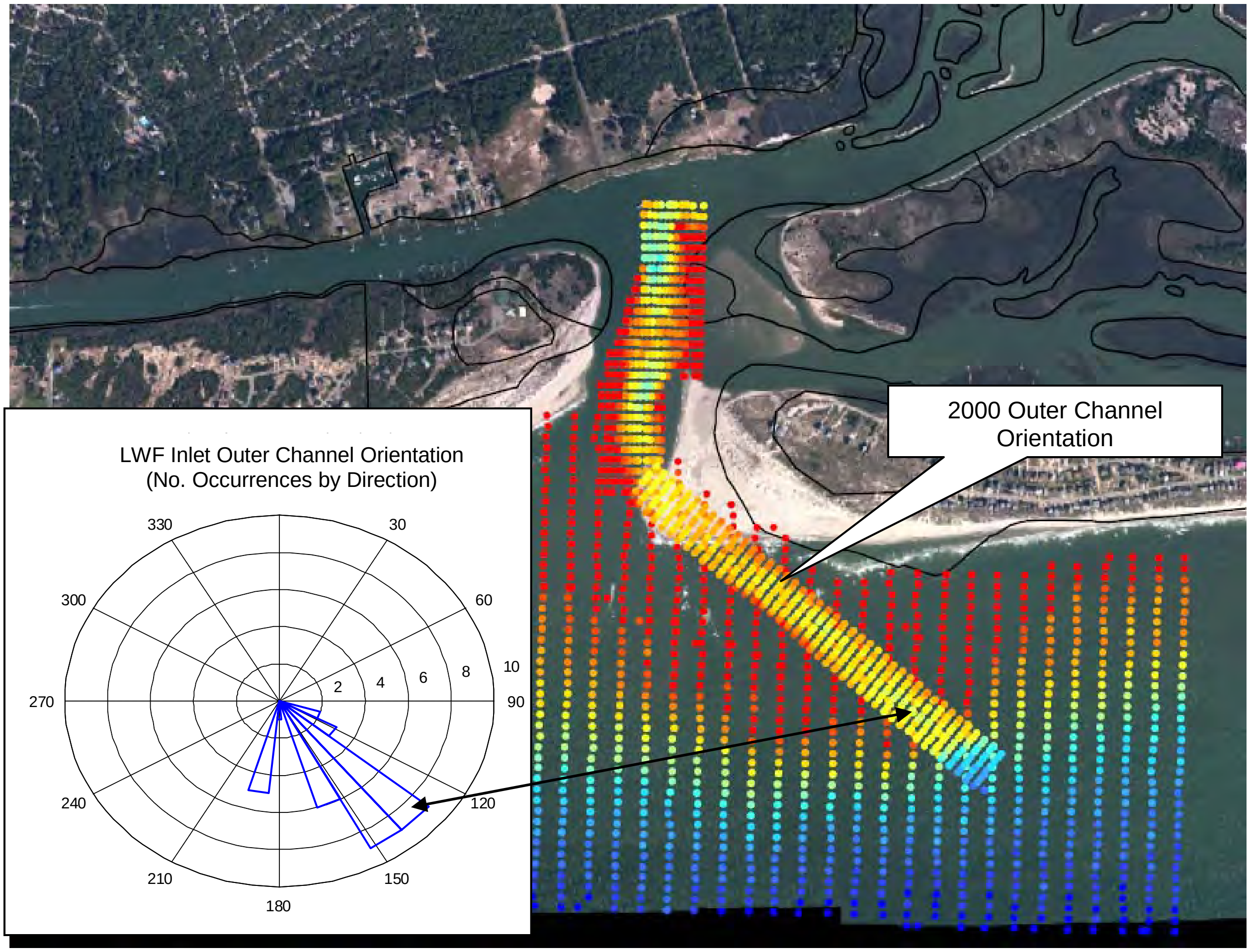


Figure 4-5a. *2000 LWF Inlet Outer Channel Orientation. Inset – Number of occurrences by direction of outer channel orientation since 1938 (Cleary, 1996).*

Figure 4-5b. *Merritt Sidecasting Dredge Working the LWF Outer Channel in Spring 2012. "Deep water" channel orientation is closer to the Holden Beach shoreline for this particular event.*

While outer channel location has been correlated with shoreline erosion trends at LWF Inlet and at other inlets, shoreline erosion along the east end is also affected by beach fill activities, which began occurring in the 1970s. The LWF Inlet channel is relatively small due to the presence of nearby inlets and relatively insignificant freshwater inflows (USACE, 1992; NCDENR, 2010; USGS, 2002). Therefore, outer channel location is only one component of east end shoreline erosion.

Warren and Richardson (2010) performed a statistical shoreline analysis (standard deviation of shoreline position and average rate of shoreline change) that identified Transect 530 as the point along the oceanfront where LWF Inlet processes were no longer dominant (see Figure 4-6 for DCM and ATM stationing). Between Transects 530 and 538, the proposed Inlet Hazard Area (IHA) boundary followed the line of maximum historical beach width (Warren and Richardson, 2010). Therefore, the Warren and Richardson's proposed area of influence of LWF Inlet along Holden Beach extends approximately 1.2 miles. This area generally coincides with the east end, as defined in this study, and represents the reach of shoreline that is the focus of the proposed project. This distance also agrees with Cleary research (Cleary, 1996; Cleary, 1999).

The influence of LWF Inlet on Oak Island is also approximately 1.2 miles (see Oak Island Figure 4-7). Warren and Richardson (2010) state, "The thin, bar-like nature of the entire western end of Oak Island, added to the fact that the proposed IHA is adjacent to the location of the inlet breach during Hurricane Hazel (1954), justified the inclusion of the entire barrier island within the proposed IHA from transect 605 westward to the inlet."

The 2011 setback factors (SBF) as determined by DCM are also presented in Figures 4-6 and 4-7. Note that the western Oak Island SBF is 2 feet, which is the state minimum and generally denotes stable/accretional shoreline conditions for the long-term period of analysis (1944 to 2009).

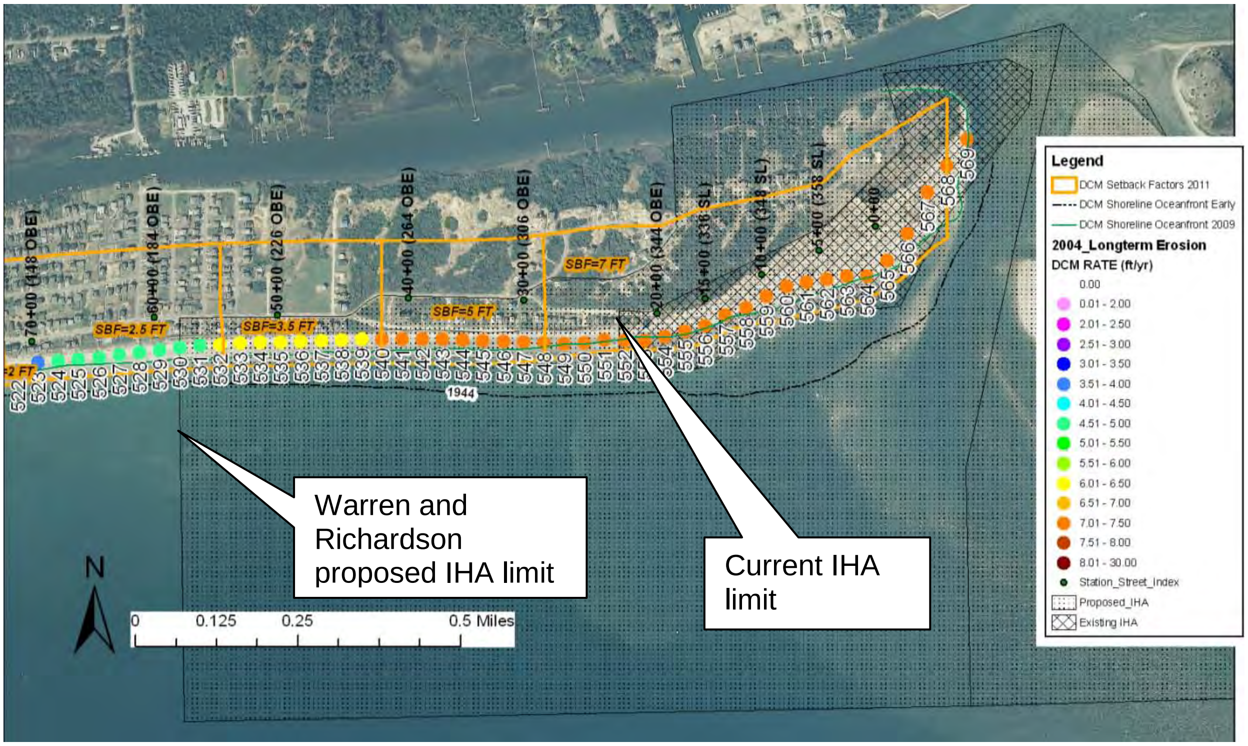


Figure 4-6. Current and Proposed IHA Boundaries. 2011 setback factors (SBF) and 2004 erosion rates also pictured.

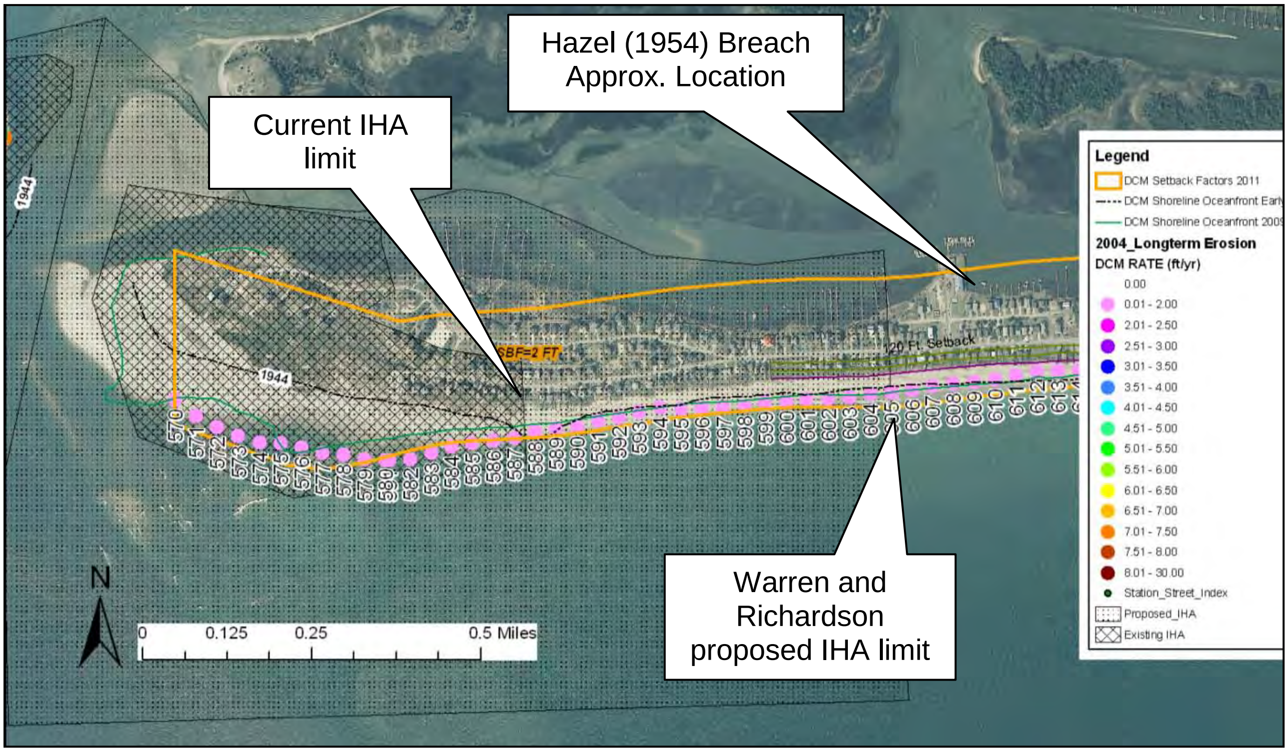


Figure 4-7. Oak Island Existing IHA and Proposed IHA. The IHA areas indicate areas of inlet influence (as well as historical breaches, although the Hurricane Hazel inlet breach is east of the IHAs).

4.2.5 HURRICANES

Hurricanes are typically the most extreme episodic events to affect shorelines in the region. Most recently, Hurricane Irene affected Holden Beach shorelines for several days. The hurricane began significantly affecting project site shorelines on Wednesday, August 24, 2011, with long-period storm swell. Hurricane Irene was a slow-moving storm and spanned a large area. It reached Category 2 and 3 offshore of Holden Beach (August 24 to August 26).

Prior to Irene, Hurricane Hanna significantly affected the Holden Beach shoreline in 2008. The Federal Emergency Management Agency (FEMA) assisted with storm-induced damage for both Hurricanes Irene and Hanna. Hurricane Hanna made landfall approximately 20 miles west of Holden Beach on September 6, 2008. This subjected the Holden Beach shoreline to the most intense northeast quadrant conditions due to the counter-clockwise storm rotation. As a result, the entire area suffered damage; however, the east end exhibited more erosion than the rest of the island. Table 4-1 presents losses per linear foot along the east end resulting from Hurricane Hanna. Up to 21.2 cubic yards per foot (cy/ft) was lost at Station 20+00, while the Central Reach shoreline lost an average of 8 cy/ft. Figure 4-8 presents a post-Hanna photo on the east end showing significant dune and upper beach erosion. Dune unit volumes [above 7 feet referenced to the National Geodetic Vertical Datum (ft NGVD)] on the east end have averaged approximately 6 cy/ft, according to surveys ranging from 2000 through 2012. The Town has actively worked on enhancing this area through dune fencing installation and dune revegetation; however, adequate storm buffer volumes cannot be achieved through these limited measures alone.

Table 4-1. Unit Volume Change due to Hurricane Hanna

Station	Unit Volume Change (cy/ft) due to Hurricane Hanna
15+00	-1.6
20+00	-21.2
30+00	-5.3
40+00	-12.3

Figure 4-8. Post Hurricane Hanna Image Showing Dune Losses on the East End (~Station 25+00).

Historically, Hurricane Hazel (October 1954) was the most severe storm to impact the area during the 20th century (NC BIMP, 2011). In addition to the almost absolute destruction of the homes along the barrier, the hurricane's waves and storm surge breached Holden Beach and Oak Island in several locations. The LWF Inlet breach (see Figure 4-7 for approximate location) remained open for several years (NC BIMP, 2011).

As stated in NC BIMP (2011), "The Brunswick County area has the highest storm surge potential along the North Carolina Coast. When Hurricane Hazel made landfall on October 15, 1954 at nearby Calabash, NC the 17 ft storm surge ultimately led to the massive destruction along the barriers and the formation of a number of breaches that dissected the island of Holden Beach into numerous segments. These breaches ranged in width from ~2,300 ft immediately east of Shallotte Inlet to 5-10 ft elsewhere. An inlet ~985 ft wide opened at the former location of Mary's Inlet [~Station 310+00]. This new inlet remained opened until the summer of 1955 when it was artificially closed."

4.2.6 LWF INLET DREDGING

As described in previous sections, the USACE is responsible for maintaining the federally authorized shallow draft navigation channel at LWF Inlet. The USACE performs routine maintenance dredging for navigation using pipeline (i.e., cutterhead), split-hull hopper, and side-cast dredges (when funding is available). Due to different USACE funding sources, there are two basic routine maintenance activities that occur at LWF Inlet:

1. Outer Bar side-cast dredging, and
2. LWF Inlet AIWW crossing (LWFIX) cutter-head dredging and beach fill placement.

Figure 4-9 provides a representation of these two regions. Outer bar side-cast dredging is performed up to 4 times a year when funding is available, however this project has recently been impacted by federal cost-cutting measures and typically only occurs 2 times per year with local sponsors (i.e., NCDWR, Brunswick County, Holden Beach, Oak Island) providing the funding. The LWFIX projects typically occur every 2 years, but this is also dependent on federal funding as well as shoaling conditions.

Maintenance dredging of LWF Inlet due to shoaling has been documented for more than 50 years. A 1973 USACE study found that, based on 1961 and 1970 surveys, the rate of accumulation of material on the ebb shoal was found to be approximately 180,000 cubic yards per year (cy/yr). In addition, maintenance dredging in the LWF AIWW inlet crossing (LWFIX) during the same time period required removal of approximately 60,000 cy/yr. Thus, approximately 240,000 cy or about 40 percent of gross littoral transport is entrapped within the LWF system (USACE, 1973).

The USACE Navigation Branch conducts surveys of channel and AIWW conditions typically several times a year, or as warranted. In addition to surveys, USACE also takes aerial photographs of the inlet. Appendix A presents aerial photos of LWF dating back to 1939. The aerials contained in Appendix A have been georeferenced and the National Oceanic and Atmospheric Administration (NOAA) Electronic Navigation Chart (ENC) shorelines have been overlain on each aerial. Figure 4-10 presents an example figure of the 1939 aerial. Aerial georeferencing was performed by CSE (2009) and ATM. More recent aerials are generally issued with georeferencing by U.S. Geological Survey (USGS), NOAA, etc., and have varying horizontal tolerances.

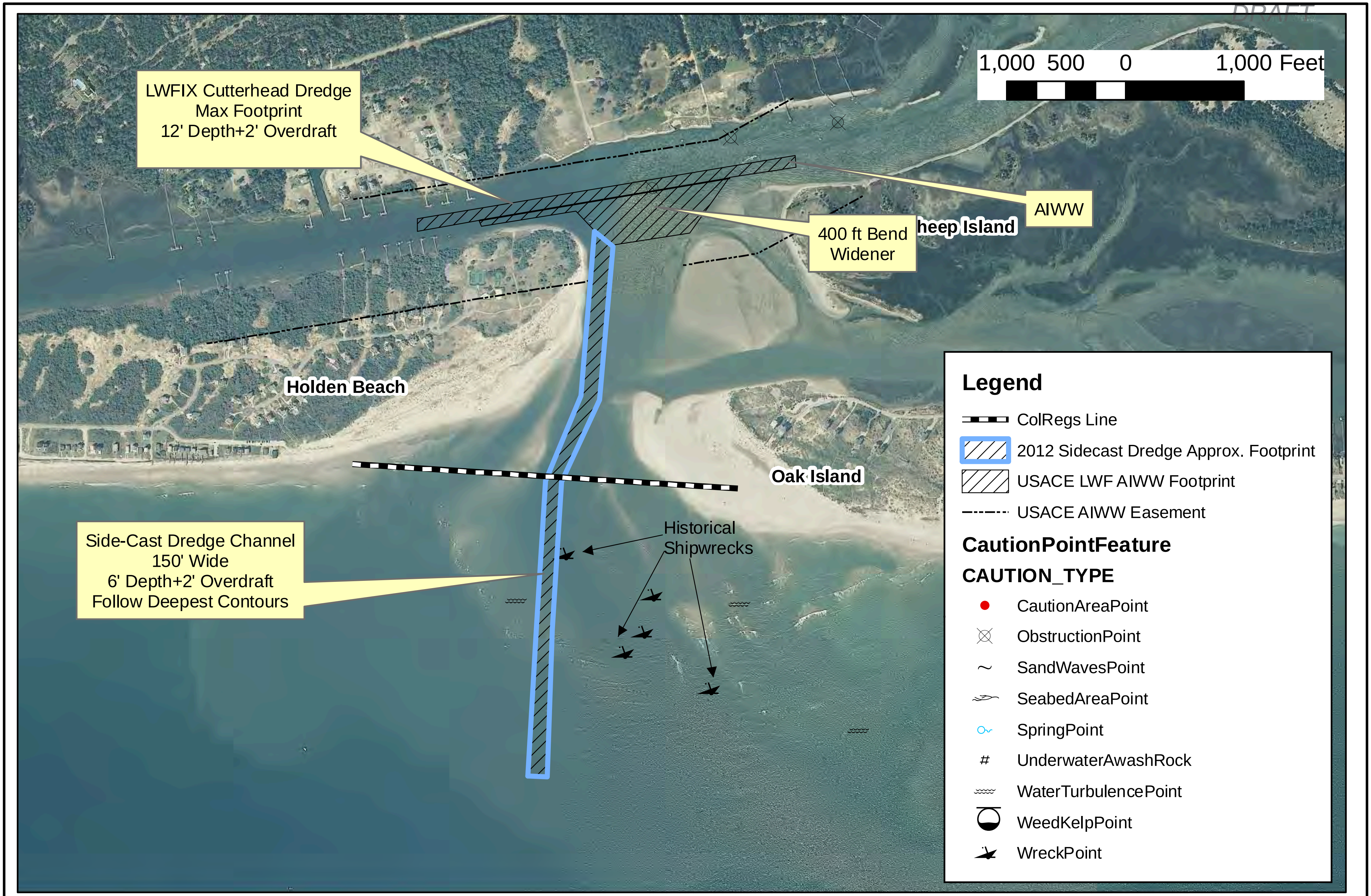


Figure 4-9:
Lockwood Folly Inlet Existing Dredging Activities.
LWF Inlet AIWW Crossing (LWFIX) is dredged by cutterhead and sand is placed on the East End shoreline.

ATM
APPLIED TECHNOLOGY & MANAGEMENT

Figure 4-10:
1938 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

APPLIED TECHNOLOGY & MANAGEMENT

The NC BIMP and the NC Shallow Draft Inlet report discuss LWF shoaling and dredging in detail. Below is an excerpt from the Shallow Draft Inlet report (NCDENR, 2005):

> **Lockwoods Folly Inlet, NC Open Water and Beach**
> Lockwoods Folly Inlet is located between Long Beach and Holden Beach. The entrance channel is 12 ft deep and 150 feet wide and connects the AIWW with the Atlantic Ocean.
>
> From 1975 to 2004 it was dredged fifty-one times, primarily by side-caster dredges and the USACE special purpose dredge CURRITUCK. Material from the AIWW inlet crossing in this area and material not disposed in open water has been placed on the beach at the east end of Holden Beach and west end of Oak Island. Records indicate that 3,517,840 cy of material has been dredged over the period of record, averaging 68,977 cy of material per project. The last year the inlet was dredged was 2004, when the side-casters FRY and MERRITT conducted operations on five occasions.
>
> **Lockwoods Folly River, NC Open Water and Beach**
> Lockwoods Folly River project area consists of a 100 ft wide by 6 ft deep channel extending from the Intracoastal Waterway to the bridge at Supply. It has been dredged thirty-three times from 1975 to 2004, with side-caster dredges as well as pipeline and USACE special purpose dredges. Some material from the river channel has been placed on the beach at Long Beach strand. Over the period of record 3,458,467 cy of material has been dredged, averaging 60,856 cy per project. The river was last dredged in 2002.

Note that while the LWFIX is dredged to 12 feet relative to mean low water (ft MLW) (+2 ft overdraft), the outer channel is only dredged to 6 ft MLW (+2 ft overdraft). Table 4-2 presents the dredge types available to USACE for LWF dredging (source: NC Shallow Draft Report). Figure 4-11 presents cost and volume information. Dredge volumes and costs include outer channel (i.e., side-caster) projects. Outer channel dredging is typically performed four times a year (quarterly) by side-caster, when funds are available.

No federal funding was available for the fiscal year of 2012; however, the State, Brunswick County, Holden Beach, and Oak Island have been able to provide funding to USACE through a memorandum of agreement (MOA) for the interim to continue outer channel dredging. A future long-term funding plan is difficult to establish due to variations and unknowns with annual Federal and State budgets. Additionally, relatively little advance notice is provided for these annual budgets. The U.S. Coast Guard (USCG) removes the LWF Inlet navigation buoys when hazardous shoaling conditions occur. Between 2009 and 2012, LWF Inlet navigation buoys have been removed for significant time spans (several months at a time; refer to USCG Notice-to-Mariner records).

LWFIX dredging is typically performed every 2 years and occurs during the winter environmental dredging window. Refer to the *Holden Beach Terminal Groin Work Plan* for more information.

Table 4-2. Excerpted Table from Shallow Draft Inlet Report (NCDENR, 2005)

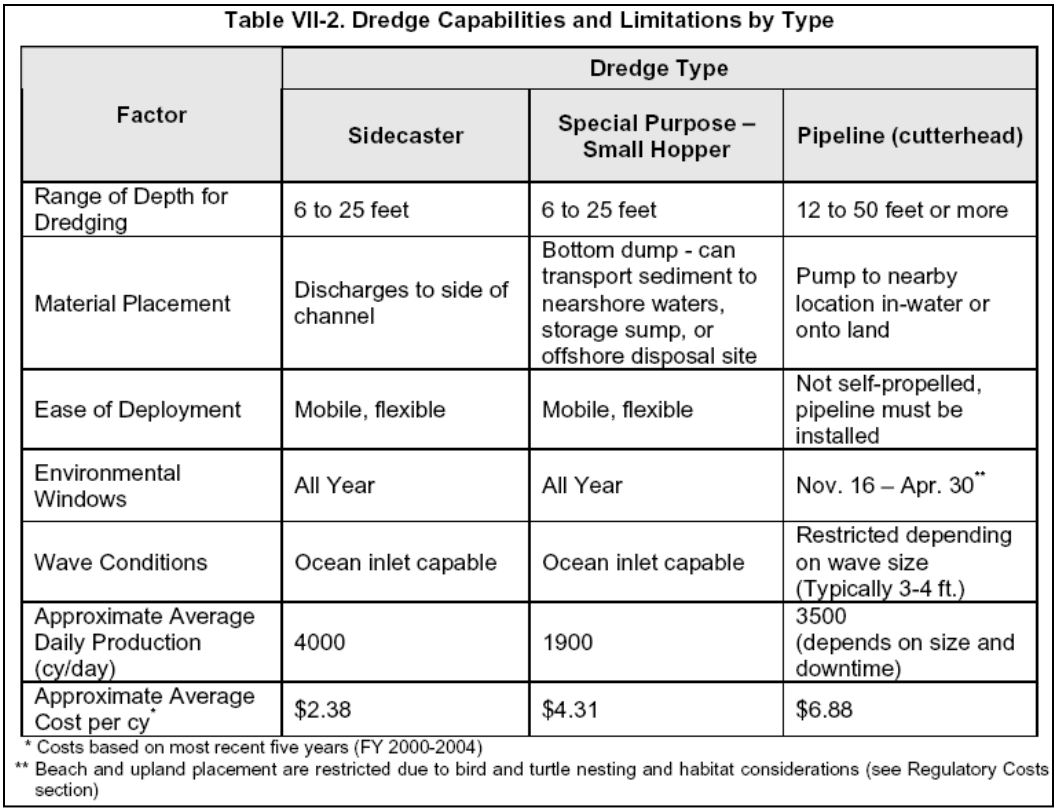


Table VII-2. Dredge Capabilities and Limitations by Type

Factor	Dredge Type		
	Sidecaster	Special Purpose – Small Hopper	Pipeline (cutterhead)
Range of Depth for Dredging	6 to 25 feet	6 to 25 feet	12 to 50 feet or more
Material Placement	Discharges to side of channel	Bottom dump - can transport sediment to nearshore waters, storage sump, or offshore disposal site	Pump to nearby location in-water or onto land
Ease of Deployment	Mobile, flexible	Mobile, flexible	Not self-propelled, pipeline must be installed
Environmental Windows	All Year	All Year	Nov. 16 – Apr. 30**
Wave Conditions	Ocean inlet capable	Ocean inlet capable	Restricted depending on wave size (Typically 3-4 ft.)
Approximate Average Daily Production (cy/day)	4000	1900	3500 (depends on size and downtime)
Approximate Average Cost per cy*	$2.38	$4.31	$6.88

* Costs based on most recent five years (FY 2000-2004)

** Beach and upland placement are restricted due to bird and turtle nesting and habitat considerations (see Regulatory Costs section)

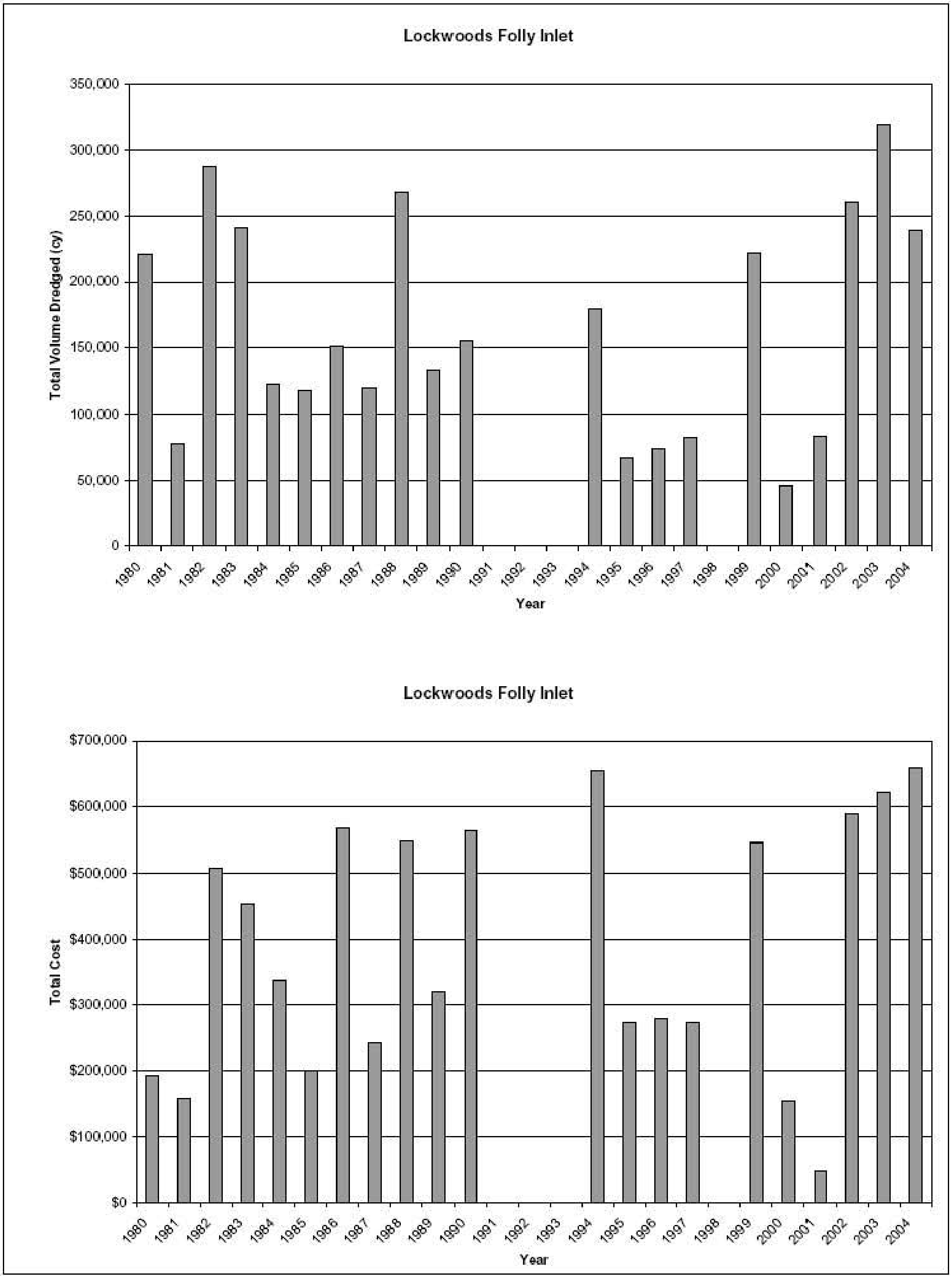


Figure 4-11. Excerpted LWF Inlet Dredging Costs from the NC Shallow Draft Inlet Report (NCDENR, 2005)

4.2.7 CIVIL WAR SHIPWRECKS

The presence of three Civil War shipwrecks also plays a factor in limiting the size and location of the LWF Inlet outer channel. Figure 4-12 presents a side-scan sonar image of the Blockade Runner *Bendigo*.

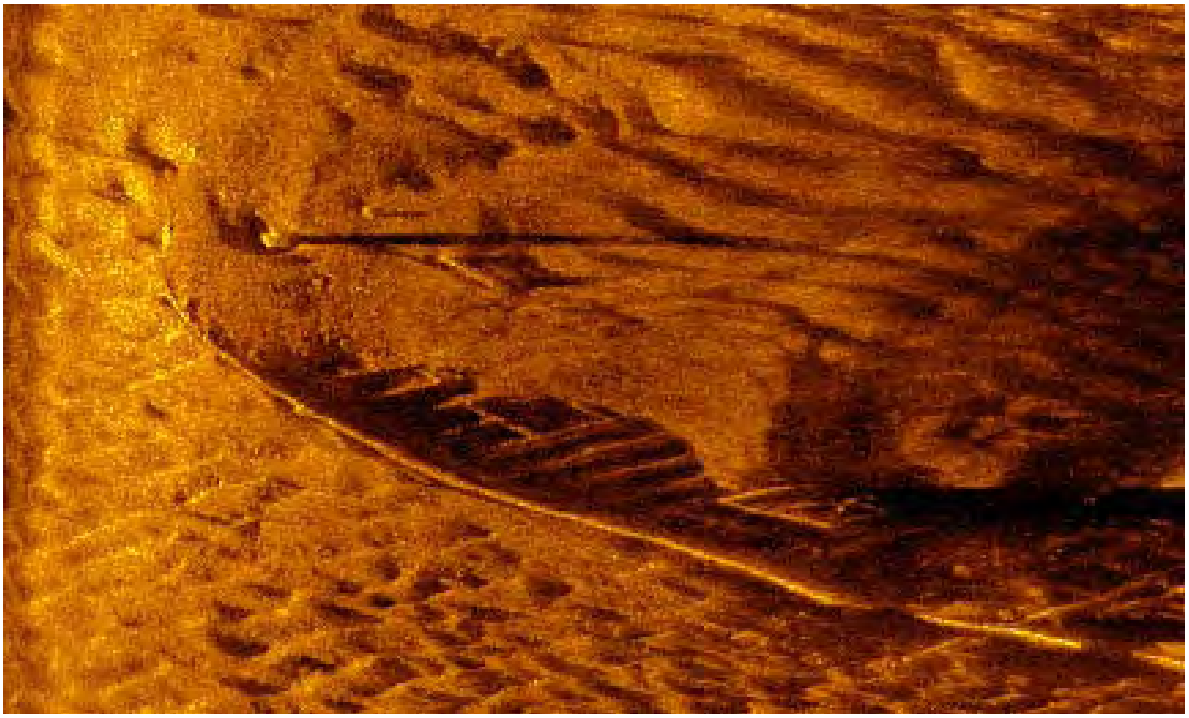


Figure 4-12. Civil War Bendigo Shipwreck Sidescan (source: USACE, 2010)

The Blockade Runner *Elizabeth*, and the Blockade Runner *Bendigo* are owned by the State of North Carolina and listed in the National Register as part of an archeological district. The *USS Iron Age* is owned by the U.S. Department of the Navy and it is listed in the National Register as part of an archeological district. All of these vessels are approximately 200 ft long, and, therefore, cover a large area that poses a navigation hazard as well as limits the possible dredged channel locations.

The NC Cape Fear Civil War Shipwreck Register states “Lockwoods Folly Inlet has remained in its same general location since the Civil War, however, the inlet channel has moved back and forth across the wrecks periodically.” The Register also describes the LWF Inlet vessels as follows:

- Iron Age: The estimated dimensions of the original vessel is 150 feet by 26 feet, while artifact dispersion is estimated to 200 feet by 50 feet.

- Elizabeth: Artifact dispersal is roughly estimated to lie within a 250-foot diameter area centering on the steam machinery.
- Bendigo: Projected vessel length of 176 feet; other measurements produced an estimated hull beam of 20 feet 2 inches, a maximum beam of 36 feet 2 inches, and a depth of hold of 10 feet.

An additional relevant quote related to the Bendigo is as follows: "Embedded in a shoal near the Lockwoods Folly Inlet channel and exposed at high tide, it was obvious to staff underwater archaeologists that maintenance dredging with the shifting inlet at times came very close to the wreck and appeared to be causing detrimental under-cutting of the wreck" (NC Cape Fear Civil War Shipwreck Register, 1985).

4.3 SEDIMENT TRANSPORT PROCESSES

Gross transport is defined as the sum of sand movement directed both eastward and westward, depending on wind and wave direction, currents, etc. Net transport is defined as the difference between eastward- and westward-directed littoral drift and is typically used when describing sediment transport. Net transport in the Holden Beach region has been estimated to be approximately 228,000 cy/yr to the west (Thompson et al., 1999). Gross transport is also important, especially for the east end of Holden Beach, where sand moving from west to east moves into LWF Inlet and is lost from the beach system into the shoals and channel. OCTI (2008) estimates gross transport to be approximately 650,000 cy/yr at LWF Inlet (approximately 400,000 cy/yr to the west and 150,000 cy/yr to the east, resulting in a net transport of approximately 250,000 cy/yr to the west). Figure 4-13 presents the sediment budget as proposed by OCTI (2008).

In addition to alongshore sand transport, there is also cross-shore transport and transport in and out of LWF Inlet. Cross-shore transport refers to the movement of littoral material onshore (onto the beach) and offshore. Offshore transport is a common response of the beach during storms (i.e., formation of nearshore sand bar), while onshore transport is known to predominate during mild wave activity (i.e., movement of sandbar back onshore). A recent study of Long Bay beaches (North Myrtle Beach, Myrtle Beach, and Garden City) found the most active profile changes occurred in the surf-zone between the +2 m (+6.5 ft) North American Vertical Datum (NAVD) contour (approximately the upper beach berm) and the -4 m (-13 ft) NAVD depth contour (Park et al., 2009).

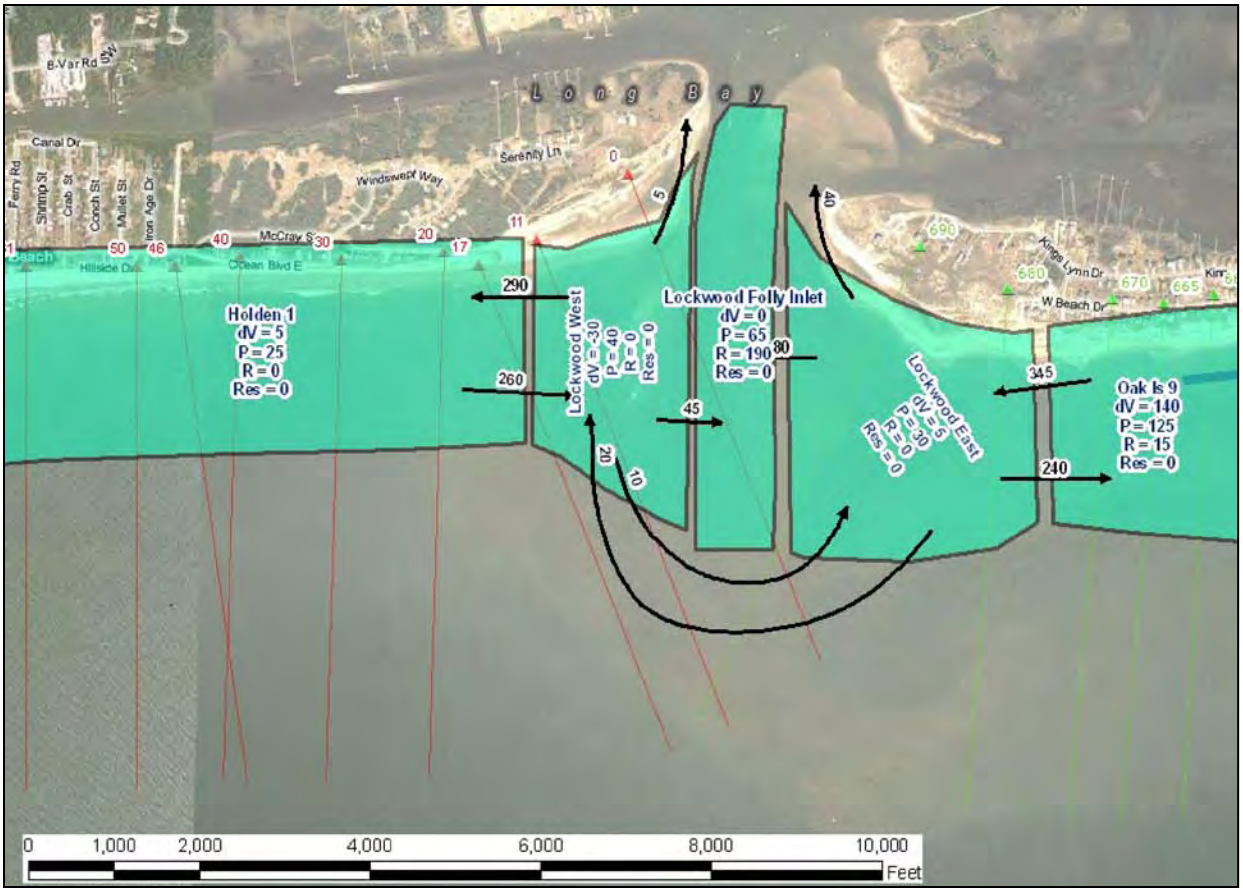


Figure 4-13. *LWF Inlet Sediment Budget as Developed by OCTI (2008). All values are 1,000 cubic yards (cy) (e.g., 290 = 290,000 cy). Black arrows indicate sediment transport in/out of cells. dV=annual volume change, P=annual placement, R=annual removal, Res=annual residual.*

In terms of sediment transport in and out of LWF Inlet, sediment budget estimates for LWF Inlet (USACE, 1973; Machemehl , Chambers and Bird, 1977; OCTI, 2008) indicate a "sink" of sand (material lost from the adjacent beaches and deposited into the inlet flood shoals and LWFIX) ranging from 125,000 to 240,000 cy/yr (generated from both Holden and Oak/Long Beach shorelines). The proposed terminal groin is anticipated to reduce the amount of sand lost to this "sink" effect and, in turn, reduce annual maintenance dredging costs.

Terminal groins, as with all groins, typically hold sand on the updrift side (forming a "fillet"), with potentially detrimental effects to downdrift beaches under extremely erosional conditions. It is important to note that sediment transport along the southeastern coast is compartmentalized and does not constitute an integrated "river of sand" (Foyle et al., 2004; Mathews et al., 1980). In a regional net transport sense, Holden Beach is downdrift of the proposed eastern end terminal groin. However, locally (where the net transport is toward the east), the inlet throat itself is downdrift of any groin placed along the inlet margin (Figure 4-14). Therefore, terminal groin design must consider the potential impacts, mainly to Holden Beach itself as well as the shoreline adjacent to LWF Inlet.

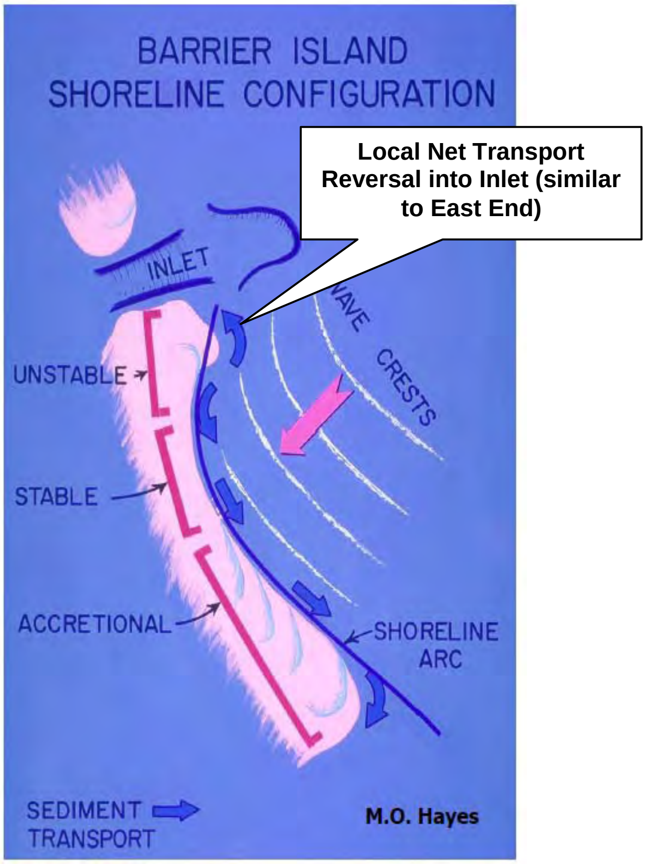


Figure 4-14 Generalized Net Sand Transport near an Inlet (Source: Hayes, 1979). Note that net transport reverses just below the inlet. The above schematic very closely resembles typical net transport trends on Holden Beach (i.e., unstable on East End, ~stable/moderate erosion on Central Reach, accretional on western end)

It is important to note that nourishment is proposed to be included with any groin installation to minimize potential for negative downdrift impacts. Additionally, combining beach fill and groin structures is typically more effective than nourishment only in areas where longshore processes dominate and adverse impacts can be minimized or avoided

4.4 <u>EAST END EROSION</u>

The primary cause of shoreline retreat along Holden Beach is due to long-term erosion through natural processes of littoral sediment transport, sea level rise, and storm-related recession. Tidal currents, wave focusing, and storage of sediment in the ebb and flood shoals of surrounding inlets (Shallotte and LWF) have also considerably affected the shoreline history of Holden Beach. Along the east end of the island, erosion has been prominent due to the continual shifting and reorientation of the main ebb and flood channel(s) of LWF Inlet. Figure 4-15 presents a typical schematic of these ebb and flood channel features.

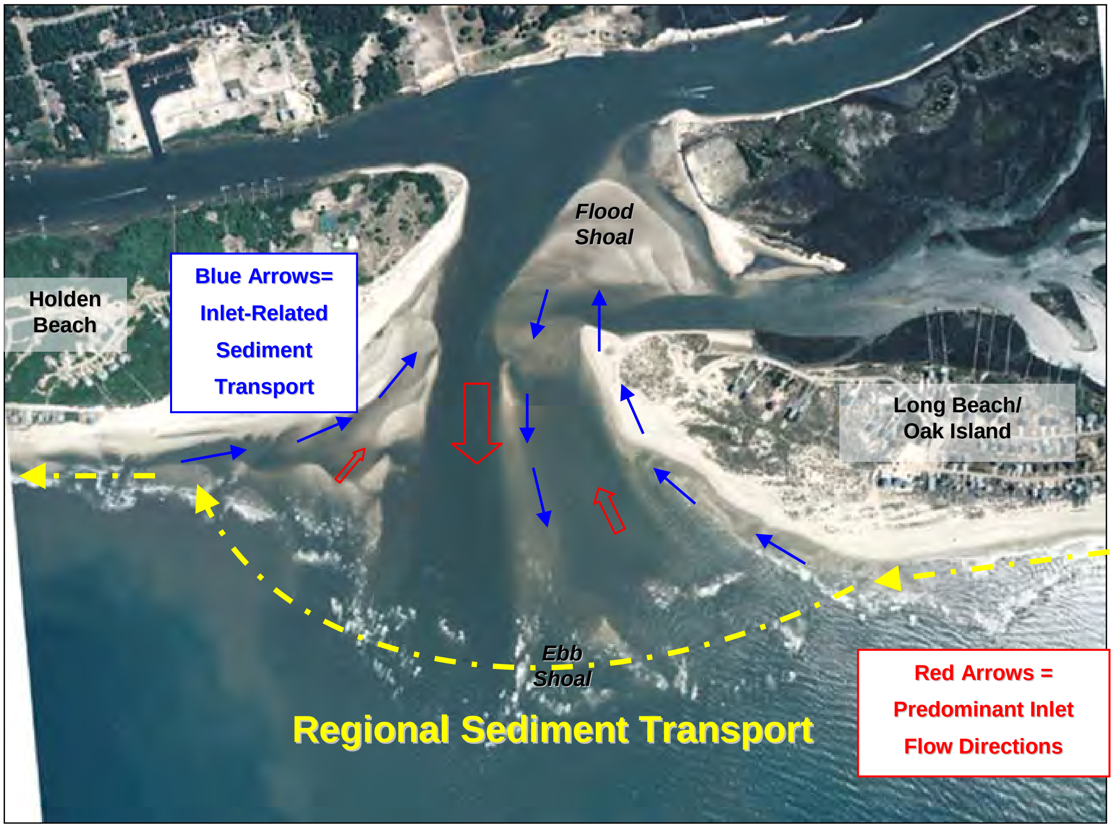


Figure 4-15. Conceptual Regional and Local Net Sediment Transport Schematic at Lockwoods Folly Inlet (2004 aerial)

Sediment transport along the shorelines adjacent to LWF Inlet has a net direction toward (into) the inlet, due to refraction of waves by the ebb shoal and inlet-induced flood tidal currents. As a result, much of the sand on the inlet shorelines of Holden Beach and Long Beach (Oak Island) travels into LWF Inlet (especially during flood tides). During ebb tides, flow is concentrated in the main channel, creating a centrally located "jet" that transports sediment onto the outer ebb shoal. Refer to the *Holden Beach Terminal Groin Work Plan* for more discussion on this topic.

4.5 EAST END 1970S GROIN FIELD

Due to the extreme erosion on the east end of Holden Beach, a temporary terminal groin field was constructed in the 1970s along the east end of Holden Beach. In general, terminal groins imply the placement of one groin. However, terminal groin fields are not uncommon and can be more effective at stabilizing inlet shorelines by incorporating two or more shorter groins than one longer terminal structure.

The project consisted of 15 sand-filled nylon tubes that were found to be beneficial in stabilizing dredged material from LWF Inlet (Machemehl, 1975a). Figure 4-16 presents a layout of the 15 groins on the east end of Holden Beach. Figure 4-17 presents photos of the groins (Machemehl, 1975b). While the groin field was successful and economical, the temporary nature of the nylon material and the lack of ongoing nourishment activities limited its long-term effectiveness. The *Holden Beach Terminal Groin Work Plan* provides more discussion on this topic.

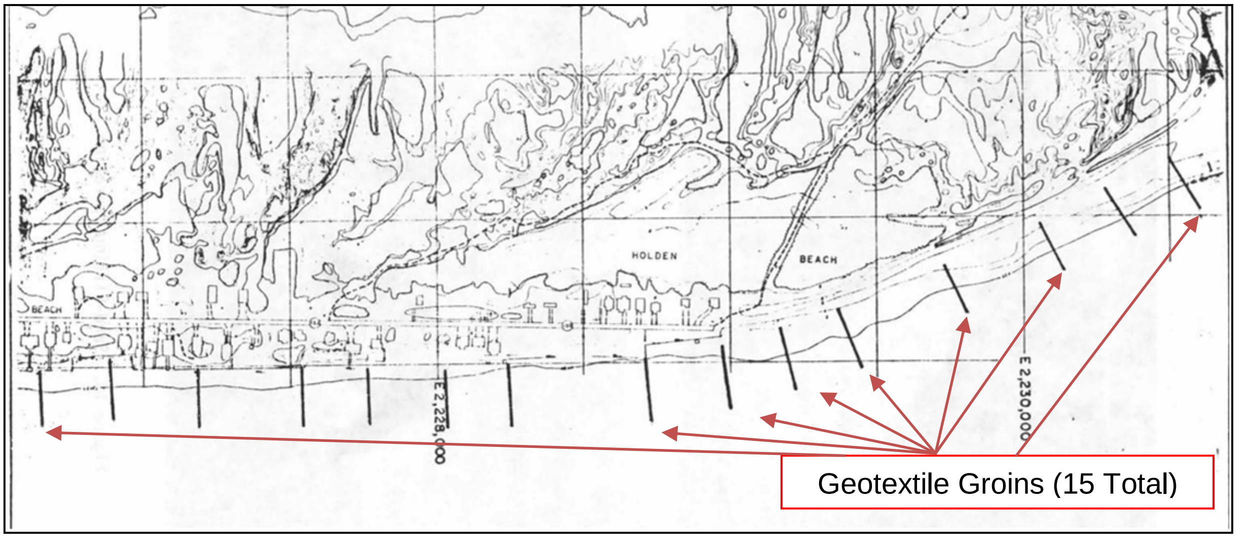


Figure 4-16. 1970s Groin Layout on East End of Holden Beach (source: Machemehl, 1975b)

Figure 4-17. Groin Construction and Placement in 1970s (source: Machemehl, 1975b)

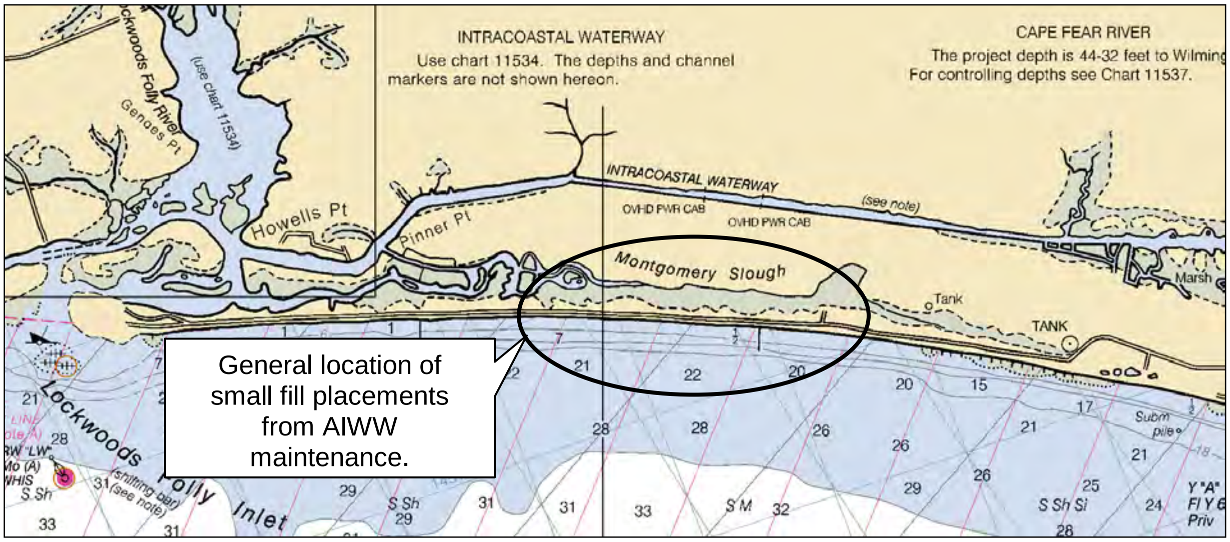
4.6 EAST END NOURISHMENT ACTIVITIES

Nourishment activities for the central reach and the east end of Holden Beach within the last decade were detailed within the *Holden Beach Terminal Groin Work Plan*. In general, an annual average of approximately 50,000 cy has been dredged from the LWFIX and placed on the east end of Holden Beach, beginning at Station 20+00 and typically ending around Station 40+00 (depending on the quantity of material).

Similar inlet-related activities have been occurring since the 1970s. Refer to the NC BIMP and NC Shallow Draft excerpts in Section 4.2.6. The Town also sponsored projects in an attempt to mitigate the erosion along the inlet margin where fill material was placed along the oceanfront “on a number of occasions without much success” (NC BIMP, 2008). One such attempt involved the construction of an artificial dune along the eastern 5 miles of the oceanfront between April 1997 and March 1998 (NC BIMP, 2008). The 202,150 cy of fill material was derived from the mainland and truck hauled to the site (NC BIMP, 2008). While these fill projects have been described in the NC BIMP as unsuccessful, they most likely did offset erosion to some degree. However, these fill activities alone could not overcome background erosion on the east end.

4.7 OAK ISLAND NOURISHMENT ACTIVITIES

Western Oak Island has traditionally been stable to accretional and, therefore, minimal nourishment activity has occurred. A static vegetation line that terminates approximately 1 mile from LWF Inlet was established for Oak Island for the 2001/2002 USACE nourishment project. Other small nourishment activities also occur on western Oak Island and these projects are similar to LWFIX projects (i.e., AIWW dredging with beneficial placement of beach compatible dredged material). Projects are typically small (i.e., approximately 25,000 cy) and infrequent, with placement typically in the Montgomery Slough area (and related to the location of the AIWW reach to be dredged) (see Figure 4-18). Figure 4-19 presents the general locations of the planned USACE Brunswick County Beaches (BCB) fill placement on Oak Island. The BCB project is tentatively scheduled to occur in 2021, depending on funding (USACE, 2012).



General location of small fill placements from AIWW maintenance.

Figure 4-18. General Vicinity of Western Most Small-Scale Beach Fills Related to AIWW Dredging and Beneficial Placement of Dredged Material (Approximately 3 miles from LWF)

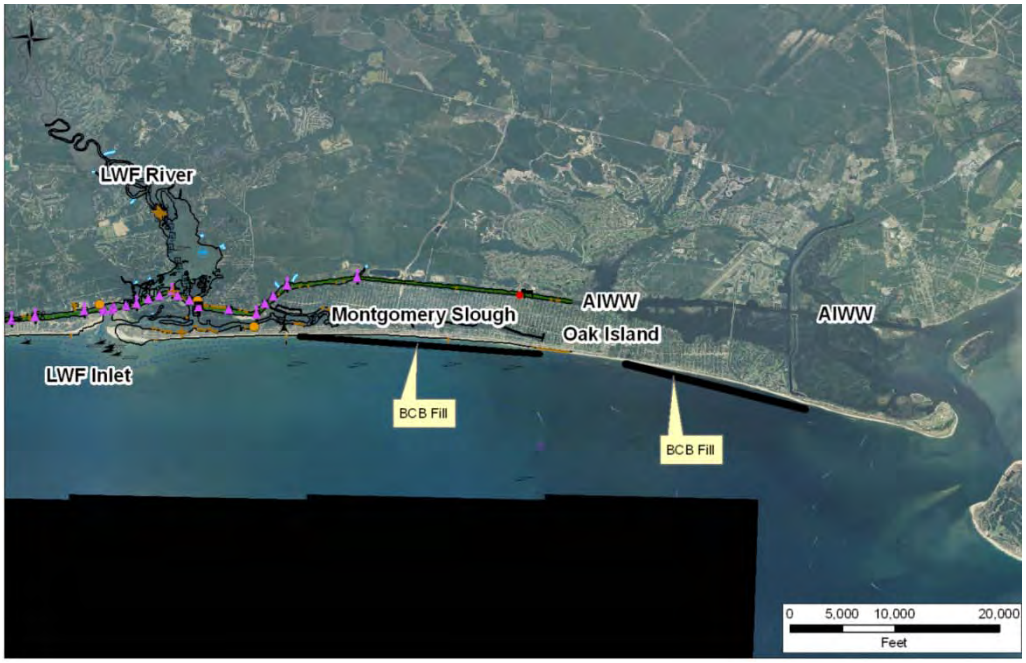


Figure 4-19. Approximate Oak Island Locations of Planned USACE BCB Nourishments.

4.7.1 OAK ISLAND ANNUAL MONITORING

Dr. Bill Cleary has been providing annual monitoring to the Town of Oak Island since the late 1990s, and 13 annual monitoring reports from 1997 to 2011 were reviewed for this study. The monitoring reports are titled Shoreline *Changes and Beach Monitoring along Oak Island, NC*. A brief summary of the annual monitoring reports is provided in this section, with more focus on the western end of the island (i.e., closer to the LWF Inlet study area). Figure 4-20 presents an image of the Oak Island transects and regions.

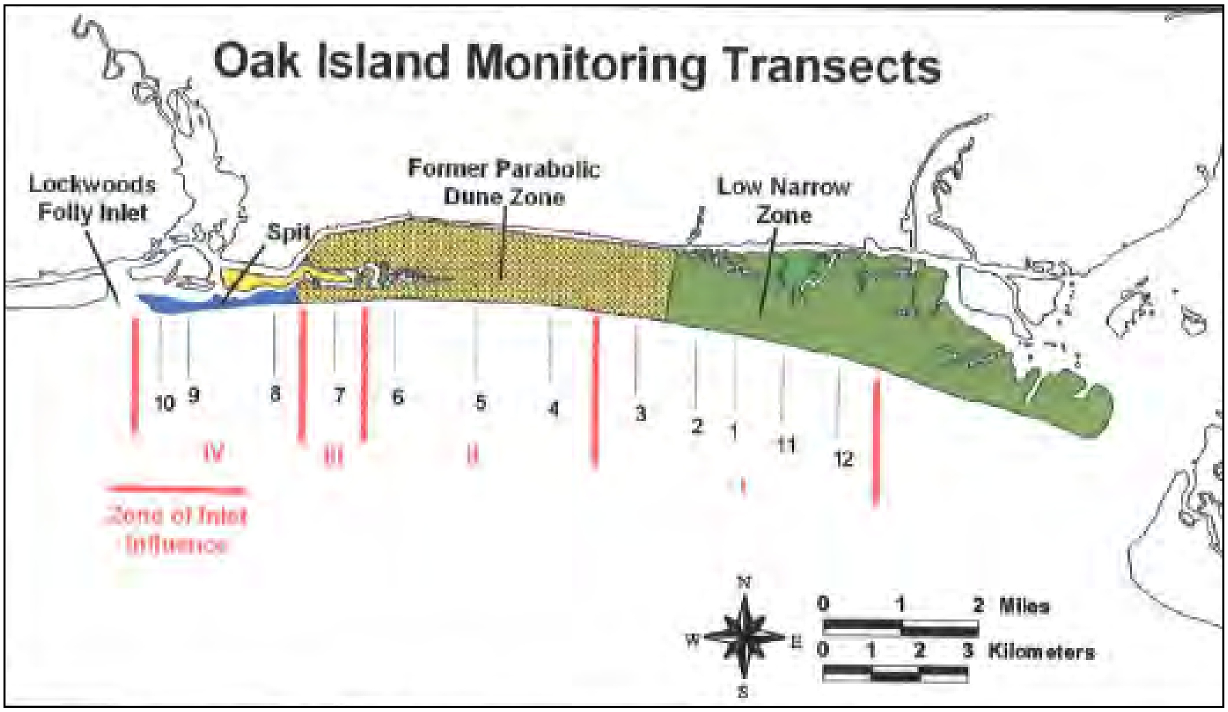


Figure 4-20. Map of Oak Island Showing Location of Beach Monitoring Transects, Reaches I to IV and the LWF "Zone of Inlet Influence" (source: Cleary, 2011).

Oak Island transect monitoring stations are generally the same from monitoring report to report, however, a few additional transects have been added to the east (away from LWF) and some have shifted slightly. Transects are taken with rod and level and generally extend from the primary dune to mean low water (MLW), which is approximately -1.1 m (-3.6 ft) NAVD88. Transect data is typically performed several times a year and bi-monthly in some years. Because transects only extend to MLW, the analysis of sediment transport is limited, however, still useful in evaluating "dry beach" changes. This monitoring and analysis is also useful because DCM long-term averages are not suitable for short-term management considerations (Cleary, 1998).

Reach IV (adjacent to LWF) is of specific interest to this study. The 1998 monitoring report states that Reach IV has been a zone of accretion during the past 15 years and this trend will continue until changes in the configuration and orientation of the main channel at LWF Inlet occur. Inlet-related processes clearly control the shoreline changes along the western margin of

Long Beach (Oak Island) and excess sand along the western section of Oak Island at LWF Inlet is evidenced by a series of low relief dune ridges which front the homes (Cleary, 1998).

The western segment's bulbous shape reflects the temporary storage of sand within the accretion zone (Cleary, 1998). The actual shape of this area, and the surplus sand it contains, plays a significant role in the recession of the mid-barrier segment (Cleary, 1998).

The 1999 Oak Island Monitoring report states: "The main LWF inlet channel has been skewed to Long Beach over the last decade. This alignment affords the extreme western segment of the beach a modicum of protection due to the breakwater effect of the shoals." While shoals can act as a breakwater in some instances, they can also exacerbate erosion.

Table 4-3 presents annual monitoring results for Reach IV from 1997 to 2011. While Reach IV has been characterized as stable to accretional over the last decade, there have been years where significant volumes of sediment were lost. This is similar to the western end of Holden Beach, which is generally accretional and has never required beach renourishment; however, there are years where significant erosion can occur.

Table 4-3. Annual Reach IV (adjacent to LWF) volume change (source: Oak Island Annual Monitoring Reports)

Time Interval	Volume Change (cy)	Significant Events
7/1997 to 6/1998	17,334	-
6/1998 to 6/1999	7,511	-
6/1999 to 6/2000	-87,293	Hurricane Floyd
6/2000 to 6/2001	85,945	Nourishment
6/2001 to 6/2002	304,597	Nourishment
6/2002 to 6/2003	-12,204	-
6/2003 to 6/2004	40,152	-
6/2004 to 5/2005	89,193	-
5/2005 to 6/2006	-114,375	-
6/2006 to 8/2007	-42,195	-
8/2007 to 7/2008	-361,986	-
7/2009 to 11/2010	13,850	Nourishment
11/2010 to 12/2011	90,674	-
Total Change	31,203	

The nourishments listed in Table 4-3 did not occur in the project area except for the 2001/2002 933 project where fill was placed as far west as Transect 9. The Reach IV losses from 2006 to 2007 were attributed to “realignment of the inlet’s ebb channel and the associated reconfiguration of the ebb shoals” (Cleary, 2007). The entire island lost a considerable amount of sand (~780,000 cy) based on monitoring data for the 2007/2008 period, which preceded Hurricane Hanna (October 2008) landfall. Figure 4-21 presents Oak Island Transect 10 from the 1999 annual monitoring report.

Plate 10. June 1998 views taken at Transect 10 showing low-relief vegetated dune field and wide unvegetated recreational beach and berm.

Figure 4-21. Transect 10 (closest to LWF Inlet) Photo Excerpted from 1999 Oak Island Monitoring Report.

5.0 AVAILABLE ALTERNATIVES

The DCM has identified several alternatives to consider for the proposed project, including:

1. No-action (abandonment),
2. Threatened structure relocation (buyout),
3. Beach nourishment without inlet relocation,
4. Beach nourishment with inlet relocation, and
5. Terminal groin with beach nourishment (with potential inlet relocation included).

The alternatives are described briefly in the following sub-sections. The subsequent descriptions were also included in the Work Plan (ATM, 2011). These alternatives, among others, will be further analyzed in Sections 6 through 9 of this report.

Channel relocation, not inlet relocation, will be analyzed for this report. Inlet relocation is a viable alternative for highly migratory inlets such as Mason Inlet; however, LWF Inlet is locationally stable. Additionally, making an inlet cut through Oak Island closer to the mouth of the LWF River is not feasible primarily due to upland development. Channel relocation, particularly the outer channel, is an alternative that has been cited to have an effect on shoreline erosion and will be discussed in more detail in the following sections.

5.1 NO-ACTION

The no-action alternative would allow erosion to continue and would result in the loss of additional property. Under this alternative, the Town of Holden Beach is assuming that USACE funding for the LWFIX project will continue. While this alternative can offset some background erosion, properties would likely be condemned and require removal where homes and infrastructure are impacted in the long term. This would result in tax revenue losses accumulated to Brunswick County and the Town of Holden Beach, in addition to the substantial loss of property value to the individual property owners. The no-action alternative would also likely limit beach recreation and tourism due to reduced access and minimal available dry beach at higher tides.

Between 1993 and 2000, approximately 27 homes were lost to erosion on Holden Beach. Figure 5-1 presents a comparison of 1978 and 2002 aerials on the east end, where the loss of more than 40 structures is shown. The no-action alternative does not address the Town's purpose and need to restore eroded beaches, maintain its “no net sand loss” policy and to provide a widened dry-sand beach for storm buffer as well as recreational and habitat reasons.

Under the no-action alternative, buildings will eventually become undermined. Public and private use of the beachfront would be adversely affected by the presence of failed structure(s) along the shoreline. Once a structure is on active public trust beach, it can either be left to deteriorate or removed. Derelict structures would hinder the public’s recreational use of the shorefront and represents a hazard to the public and wildlife (e.g., nesting sea turtles).

Addressing abandoned structures on an active beach has many legal ramifications. Theoretically, removal of the structure would be the responsibility of the landowner. However, a case currently progressing through the legal system involving the Town of Nags Head versus owners of condemned houses puts this assumption in question (K&L Gates, 2012). In any event, potentially dozens of adversely impacted properties would require removal in the long term, while others may be in short-term jeopardy due dune breaches from episodic storm events. This is not a practicable alternative considering the possible damage to the oceanfront environment due to derelict structures and the potential cost to the town for removal of condemned structures and legal fees.

From a short-term perspective, the no-action alternative results in little to no recreational beach at high tide, which affects tourism and rental properties (with associated indirect impacts). From a natural resources perspective, sea turtle nesting habitat would likely decrease and require more nest relocations. A general decrease in dune habitat would also occur.

5.2 THREATENED STRUCTURE RELOCATION

Relocation of buildings within Holden Beach, away from the path of the eroding beach, is not feasible and does not meet the Town’s purpose and need. Aside from the cost of relocation (see Table 5-1 for an example), there is simply not enough comparable oceanfront/waterfront property available to receive all of the potentially threatened structures. Relocation of these structures to non-waterfront locations would diminish their value as vacation rental, primary residence, and/or investment properties. The Town and County would lose revenue from the loss of the eroded property as well as the tourism-driven economic benefits derived from these properties. Finally, relocation of structures does not address the loss of the beach itself.

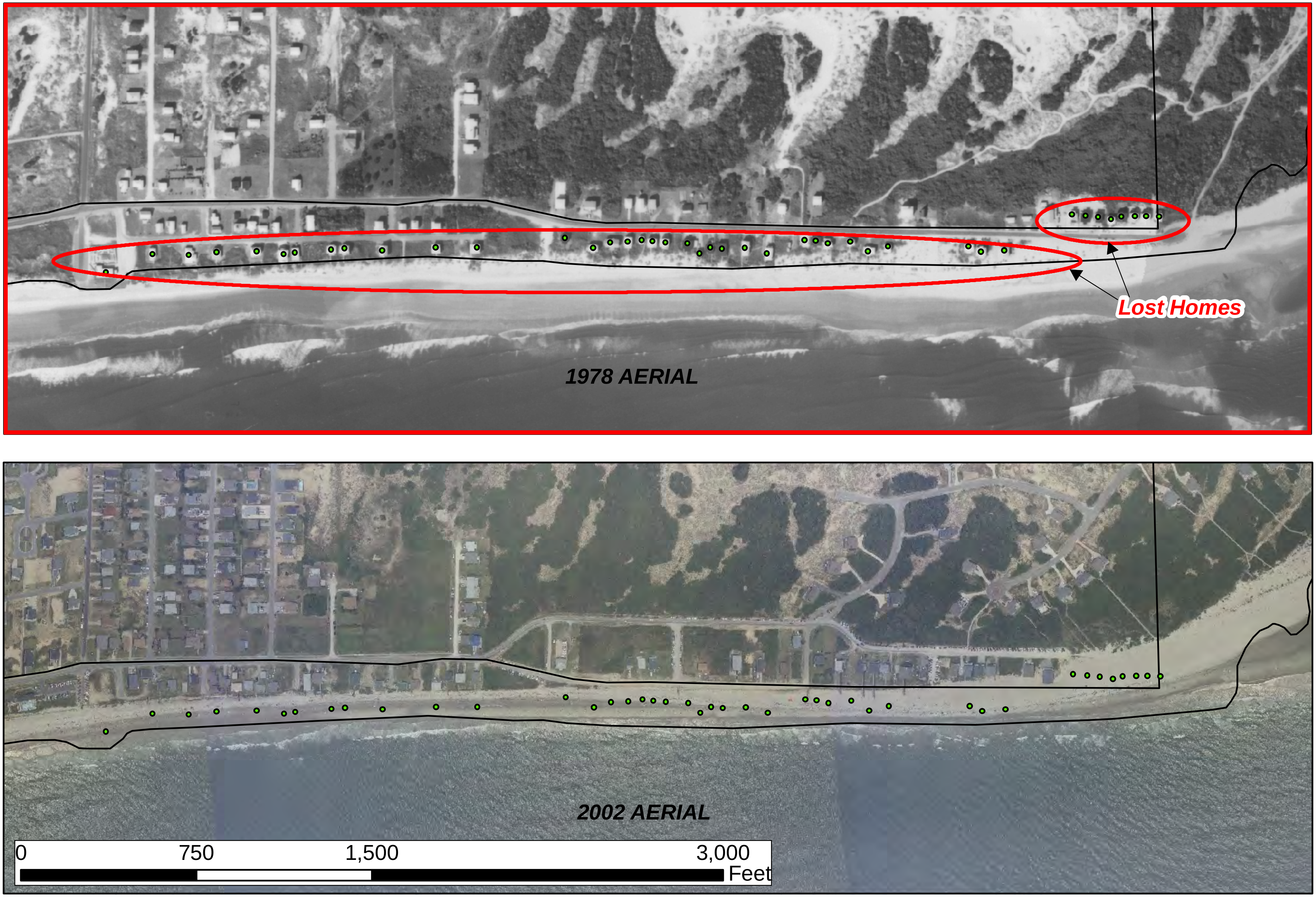


Figure 5-1:
1978 and 2002 Aerial with identical NOAA Electronic Navigation Chart (ENC) polylines
41 Structures are identified (yellow dots) that have been lost over this time span.
Note that this is not all inclusive.

Table 5-1. Nags Head Estimated Structure Relocation Costs

Structure Relocation Alternative	Estimated Cost/House
Relocate house to non-oceanfront lot (including condemned property losses and new property acquisition)	$1,579,000

Note: Estimates based on 1,350 ft^2 footprint (therefore a two story structure can be estimated as 2,700 sq ft.) (CSE, 2006).

5.2.1 PROPERTY BUYOUTS

FEMA has buy-out assistance programs for properties that are in jeopardy of being destroyed. These programs are geared generally toward lower income owners and properties that are categorized as a primary residence. Qualification for such funds is prioritized for those primary residences that have experienced a repetitive loss or that have owners who are currently displaced in temporary housing. Due to the resort nature along Holden Beach, high property values, and current status of most of the properties, the Town believes that it is highly unlikely that FEMA would qualify these properties for buy-out funding at this time. The voluntary buy-out program for Superstorm Sandy also exhibited a similarly unfavorable response from most resort-destination communities (Schuerman, 2013).

The Heinz (2000) report also found that:

> A previous attempt to encourage removal and relocation of threatened structures—the Upton-Jones Program, which existed from 1987 to 1994–was suspended because of limited usage and unintended outcomes. A relocation program, if pursued, would have to be carefully designed to avoid the shortcomings of the Upton-Jones Program.

Additionally, a recent study of the beaches in the state of Delaware by Parsons and Powell weighs the cost of beach retreat against the cost of beach nourishment over the next 50 years. The study concluded that the cost of retreating from eroding coasts will be approximately four times the cost of renourishing the state's beaches (Parsons and Powell, 2001).

Salvesen (2004) also noted that buy-out programs can have disadvantages, including:

- High up-front cost
- Reduced local tax base
- Disrupted neighborhood
- Potential increased housing costs (in short term)

- Incomplete participation limits effectiveness
- Higher costs of replacement housing

5.3 BEACH NOURISHMENT WITHOUT INLET CHANNEL RELOCATION

Beach nourishment without inlet channel relocation has been implemented on Holden Beach for the last decade. While beach erosion has been reduced under this alternative (in comparison with the 1970s to 1990s, when many homes and properties were lost), additional alternatives (such as the proposed terminal groin project) may prove to be more practicable. Storm-related erosion as well as long-term erosion continues to make the east end of Holden Beach vulnerable under this alternative. Terminal groins (as well as groins in general) are employed typically in areas where beach erosion rates have been historically large enough that treatment with fill alone is impractical. Figure 5-2 presents a photo of a recent USACE AIWW dredge and beach nourishment project on the east end of Holden Beach.

Figure 5-2. April 2010 Photograph of the USACE Lockwoods Folly Inlet AIWW Nourishment Project. Note Town-funded dune planting in the foreground.

5.4 BEACH NOURISHMENT WITH INLET CHANNEL RELOCATION

The beach nourishment with inlet channel relocation alternative is also being considered during the National Environmental Policy Act (NEPA) permitting process. Inlet main ebb channel orientation been cited as having a direct effect on erosion/accretion trends on the adjacent shorelines (refer to Section 4). The present inlet location is favorably positioned (Cleary, 2008), however, erosion continues to threaten the eastern end of Holden Beach, while the western end of Oak Island has a low [2 feet per year (ft/yr)] DCM long-term erosion rate (see Figure 1-3). Additionally, the USACE policy of "dredge following deep water" must be more flexible to keep the channel more centrally located. The Draft Inlet Management Plan (Appendix D) includes recommendations for additional measures to maintain a favorable orientation/ alignment of the inlet's main ebb channel.

5.5 TERMINAL GROIN WITH NOURISHMENT

An additional alternative proposed herein is the construction of a terminal groin with beach nourishment. This pending preferred alternative is discussed in detail in subsequent sections. A terminal groin/nourishment/channel relocation alternative is also evaluated in Sections 7 through 9 of this report.

6.0 BORROW SITE ANALYSIS/SELECTION

The Town of Holden Beach, as a part of its ongoing beach management program, has developed a rather comprehensive list of potential borrow areas over the last decade. The 2009 Holden Beach Management Plan (ATM, 2009) considered several borrow sources that generally include upland, inlet/AIWW dredged disposal areas, offshore, and LWF Inlet. All borrow sites were evaluated for sediment quality and quantity, as well as permitting and logistical requirements.

Borrow areas types in this analysis and general positive and negative aspects associated with each alternative are summarized below.

Upland Sources

- Suitable for small projects (less than 200,000 cy) and to supplement other larger fill projects
- Good for dune rebuilding and creation
- Sand color and grain size typically not as good as in-water sources
- Slow production rates and shorter lifecycles (every 1 to 3 years)
- Truck traffic and NC Department of Transportation (NCDOT)/road maintenance issues
- Turkey Trap Road upland site and Smith upland site are currently permitted

Dredge Spoil Islands along the AIWW [i.e., Confined Disposal Facilities (CDFs)]

- Consist of layered material that would require separation of beach compatible and non-beach compatible material
- Reuse of this material would increase CDF disposal capacity and allow continued disposal operations
- Islands have become valuable for natural resources, recreation, and in some cases, development

Lockwoods Folly (LWF) Inlet

- Currently not fully utilized/optimized because of side-casting operation and only following “deep-water” USACE permit criteria
- USACE AIWW related navigation dredging (i.e., LWFIX project) has placed approximately 500,000 cy of material on the beach since 2002 (about 50,000 cy/yr)

- USACE regional analysis supports placement of 156,000 cy/yr (625,000 cy every 4 years) from LWF ebb shoals on Holden Beach
- Critical to long-term beach and inlet management
- Sand color and grain size typically very compatible
- Channel alignment/orientation and shoaling patterns have been cited to cause problems to adjacent shorelines

Offshore Borrow Areas

- Suitable for large projects (greater than 500,000 cy)
- Sand color and grain size typically very compatible
- Fast production rates and longer lifecycles (every 5 to 10 years)
- Large ocean-certified hopper dredge mobilization/demobilization costs ($1 to $4 million)

Figure 6-1 presents a general location map of the upland and AIWW borrow areas to be included in this analysis. Additional discussion on borrow area sources is provided in the following sections.

6.1 AVOIDANCE AND MINIMIZATION

The Town has been actively assessing available borrow areas since 2001 and one overarching goal during this process was avoidance and minimization of potential impacts. Reducing potential impacts included, but was not limited to, the following:

- Borrow area location that is reasonably accessible to Holden Beach and a sufficient distance from significant natural resources
- Documented strata of high-quality beach-compatible sediment suitable for meeting both recently adopted State standards and post-placement performance criteria acceptable to the Engineer
- Lack of significant benthic or other resources to be temporarily impacted by borrow area excavation
- Exposed hardbottom resource avoidance (including 500-meter (m) borrow area buffer)
- Cultural resource avoidance
- Piping plover critical habitat avoidance
- Essential Fish Habitat (EFH) Habitat Areas of Particular Concern (HAPCs) avoidance/minimization

Figure 6-1

Holden Beach Upland and AIWW Potential and Historical Borrow Area Locations

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- Proposed work to occur in established environmental winter window (to minimize natural resource impacts)
- Implementation of beach nourishment construction best management practices (BMPs) and following of all established protocols related to dredging

6.2 NATIVE BEACH CHARACTERIZATION

ATM utilized sand samples collected by the USACE Wilmington District in 1998 to characterize the native beach sediments prior to beach nourishment projects that commenced in earnest in 2001-2002. Samples collected by USACE included four baseline stations along the island, specifically Stations 40+00, 120+00, 180+00, and 240+00. These stations are spaced approximately 6,000 to 8,000 ft apart and are the best characterization of the pre-engineered beach native condition. Note that the proposed terminal groin project will not place sand west of Sta 40+00.

For the 1998 USACE data collection, sediment grab samples were taken at the toe of dune, berm crest, mean high water (MHW), mean tide level (MTL), mean low water (MLW), and at 2-ft vertical intervals from -2 ft to -24 ft depth. Sample grain size statistics were averaged in a cross-shore manner and then alongshore. Results for the native beach composite are provided in Table 6-1.

Table 6-1. Composited Native Beach Sediment Characteristics from 1998 USACE Sampling

	Mean Grain Size (mm)	Sorting (Phi)	Percent Fines (%)
Composited Average	0.24	0.72	2.0

Percent carbonate, percent gravel and granular fractions are not available from the 1998 USACE data. However, other sources (Moffatt & Nichol, 2011; Rice, 2003; Williams, 2005) indicate average percentages of carbonate (2.7 percent) and gravel (0.55 percent) for the Holden Beach and Ocean Isle Beach vicinity.

6.3 UPLAND BORROW AREAS

The Town’s use of upland borrow areas has proven valuable for recent nourishment projects and it plans to continue to use this resource. Fill projects utilizing upland borrow areas can be extremely valuable for unplanned/emergency mitigation efforts, such as the 2009 Holden Beach project in response to Hurricane Hanna. Additionally, truck haul projects do not involve the expensive mobilization/demobilization costs associated with offshore dredges and can occur much more quickly.

Potential negative aspects of upland borrow areas in the region include variations in sand color, practical volume limitations, and placement methods (i.e., trucking). Additionally, the NCDOT requires permitting and has the ability to shut down operations or require roadway mitigation.

Three potential upland borrow areas - Turkey Trap Road, the Smith Borrow site, and the Tripp Upland Site - are described in the following sections.

6.3.1 TURKEY TRAP ROAD (PERMITTED)

The Turkey Trap Road Borrow Site is located near the intersection of Turkey Trap Road and Stanbury Road and is an approximate 3.6-mile drive to the beach strand. The 38-acre site is owned by the Town. In early 2005, ATM contracted with Engineering Consulting Services, Inc. (ECS) to collect 10 soil borings from within the site. The borings were driven to a depth of approximately 35 to 40 ft below grade. From these 10 borings, ECS analyzed 40 composite samples according to standard methods.

The Turkey Trap Road Borrow Site is expected to yield approximately 460,000 cy of material. The site, known as the Kirby Walter site in previous permitting documents, has the necessary permits from NCDENR, USACE, Brunswick County, and NCDOT (driveway permit). The Turkey Trap Road site is presented in Figure 6-2. There are some wetland areas within the 38-acre site so the entire area cannot be used. The available borrow area volume is based only on areas that can be used. Wetland buffers and post-project borrow site revegetation and monitoring were also included in the permitting of this site.

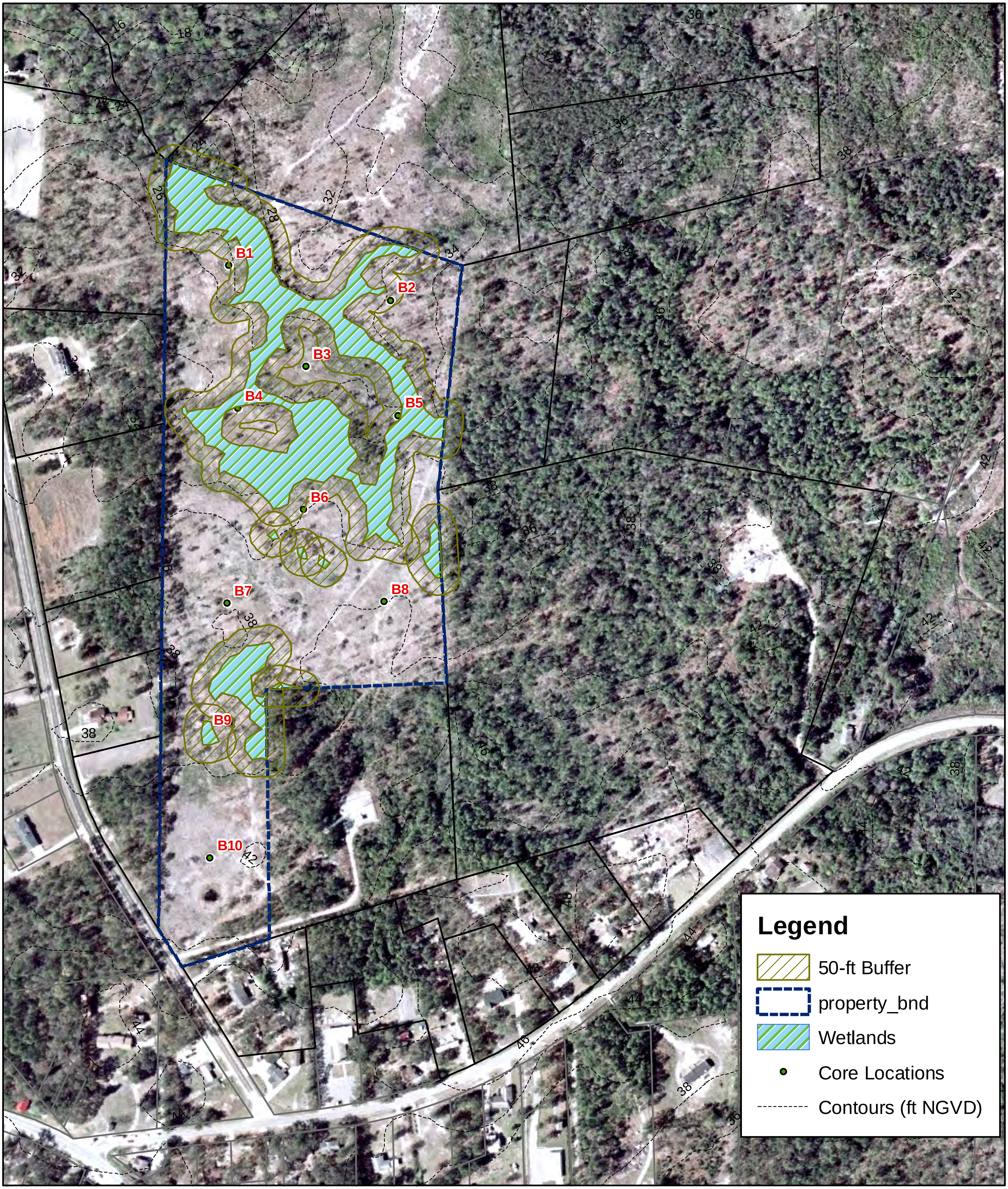

Figure 6-2
Turkey Trap Road Permitted Borrow Area

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6.3.2 SMITH BORROW SITE (PERMITTED)

The Smith Borrow Site has been tested previously (borings were taken in 2002, 2007 and 2009) and used for several of the Town's beach nourishments over the last decade. The material quality varies depending on location within the property but, in general, has been found to be suitable. The Smith Site is an approximate 4.0-mile haul distance from the beach strand. The site has been for sale for several years for residential development and, therefore, may not be available for future use.

For planning purposes, this site can be relied on as a short-term source only. However, potentially 250,000 cy of beach-compatible material could be obtained, and possibly more. Figure 6-3 presents a photo of the Smith Site during nourishment operations in 2009. Only borings within the location where favorable sediment occurs were used in the sediment compatibility analysis. Figure 6-4 presents an aerial of the Smith Site with the proposed borrow area delineated.

Figure 6-3. Smith Upland Borrow Area during 2009 Holden Beach Nourishment Project

6.3.3 TRIPP UPLAND SITE

Limited boring information as well as test pit observations indicates that the Tripp Upland Site contains potentially a large quantity of light-colored beach-quality sand. The Tripp Site is an approximate 64-acre parcel located off Makatoka Road in Supply. The site is located west of Highway 17N and is approximately a 13-mile drive from the beach strand. Figure 6-5 presents a photograph of a test pit at the Tripp Site.

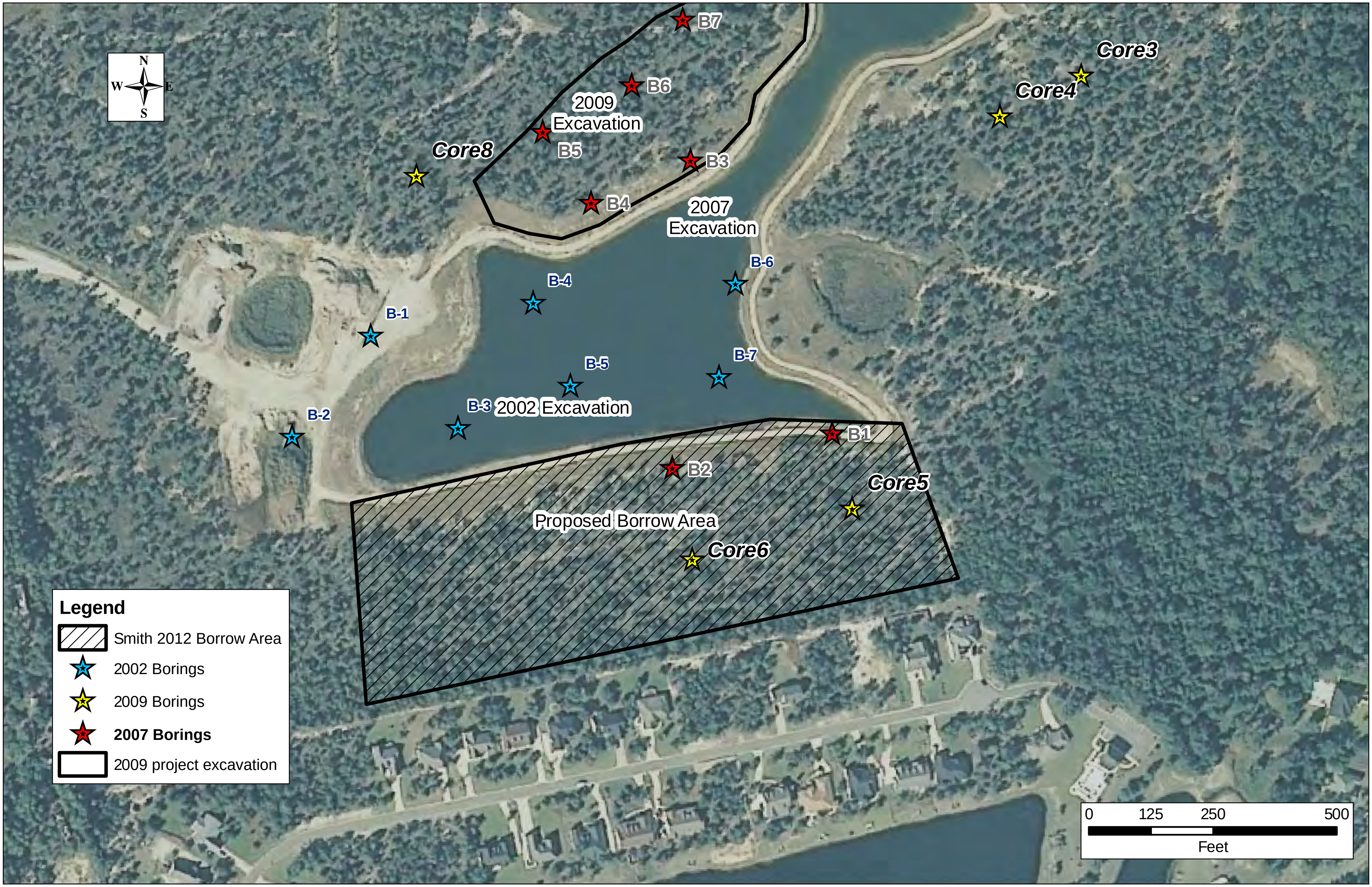

Figure 6-4
Smith Borrow Site Proposed and Previous Excavations
2008 aerial shown

ATM
APPLIED TECHNOLOGY & MANAGEMENT

Figure 6-5. Tripp Site Test Pit

In comparison to the existing permitted borrow sites, borings indicate that this site represents the best upland material in terms of color. A large pond excavated at this site previously is approximately 55 ft deep, therefore, a relatively large amount of material may be available. The site also has an existing mining permit (similar to the existing permitted borrow areas). For planning purposes, approximately 250,000 cy is also available for the site (Figure 6-6).

6.4 AIWW BORROW AREAS

AIWW borrow areas include LWF Inlet and nearby CDFs and are described in the following sections.

6.4.1 LOCKWOODS FOLLY INLET AIWW CROSSING (LWFIX)

The LWFIX borrow area has acted as a beneficial use of dredged material (i.e., a borrow area for beach nourishment) since the 1970s. The primary reason for the USACE LWFIX dredging project is navigation; however, the dredged material is beach compatible and the Station 20+00 on the east end (beginning of the beach fill placement) is less than 4,000 feet away.

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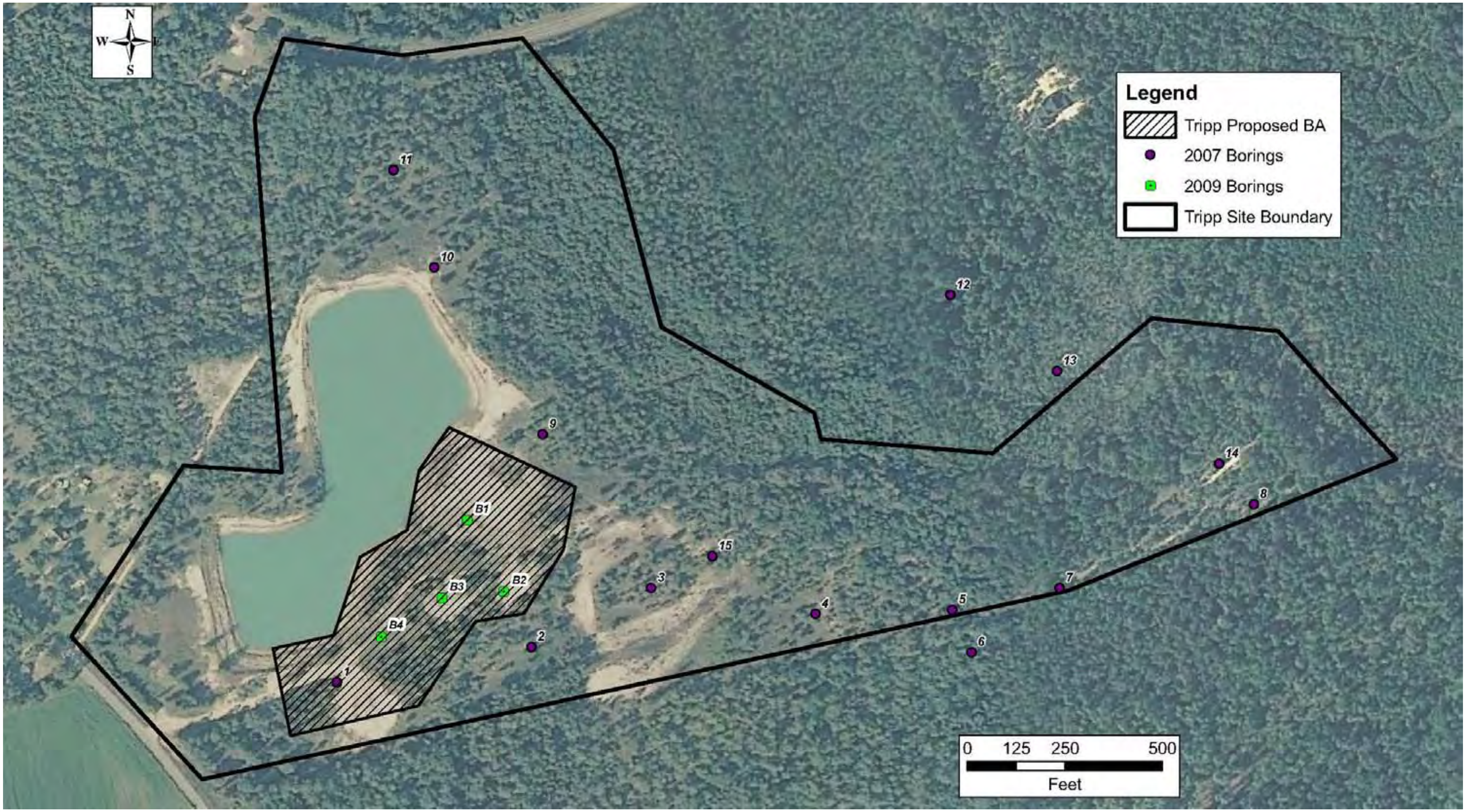


Figure 6-6

Tripp Site with Proposed Borrow Area
2008 Aerial Shown

ATM
APPLIED TECHNOLOGY & MANAGEMENT

Figure 6-7 presents the typical LWFIX borrow area and east end placement footprint of the USACE project. The USACE projects have historically placed between approximately 25,000 and 140,000 cy of beach-compatible material on an annual or bi-annual basis (although this is subject to funding).

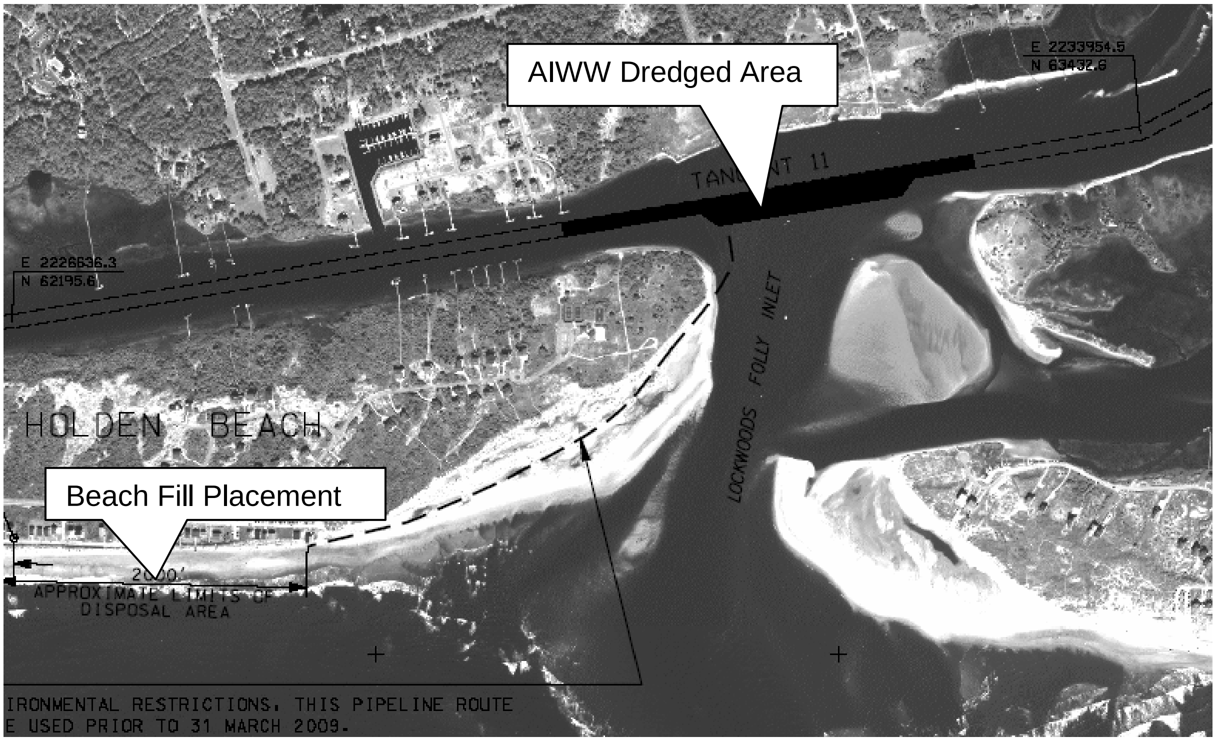


Figure 6-7. Annual USACE Lockwoods Folly Inlet AIWW Dredging and Beach Placement Schematic. Placement typically occurs between Holden Beach Station 20+00 and Station 40+00.

The “bend widener” typically varies from 50 feet wide (Figure 6-7) to 400 feet wide (Figure 6-8). The 400-ft bend widener is the largest widener allowed by USACE permit conditions. This widener was last utilized for the 2010 project, where approximately 140,000 cy of material was excavated and placed along the beach. The 400-ft bend widener is rarely dredged due to limited funding. The 140,000 cy project coincided with economic stimulus funding (i.e., American Reinvestment and Recovery Act). It is anticipated that future LWFIX projects will not include this bend widener and only minimal effort/cost will occur to maintain the AIWW by the USACE.

Average sedimentation rates of the LWF Inlet are estimated at approximately 100,000 cy/yr (refer to Section 4). Dredging and survey data indicate that, when the 400-ft bend widener is included, 100,000 cy/yr is a realistic volume for the LWFIX borrow area. The USACE

June/July 2012 survey data indicate that approximately 110,000 cy is available (assuming a cut-depth of 12 ft with a 2-ft overdredge allowance) (Figure 6-8). Therefore, assuming additional sedimentation prior to project construction, ample material will be available. Note that the 2010 USACE borrow area encompasses a larger area than that calculated to arrive at the 110,000 cy estimate.

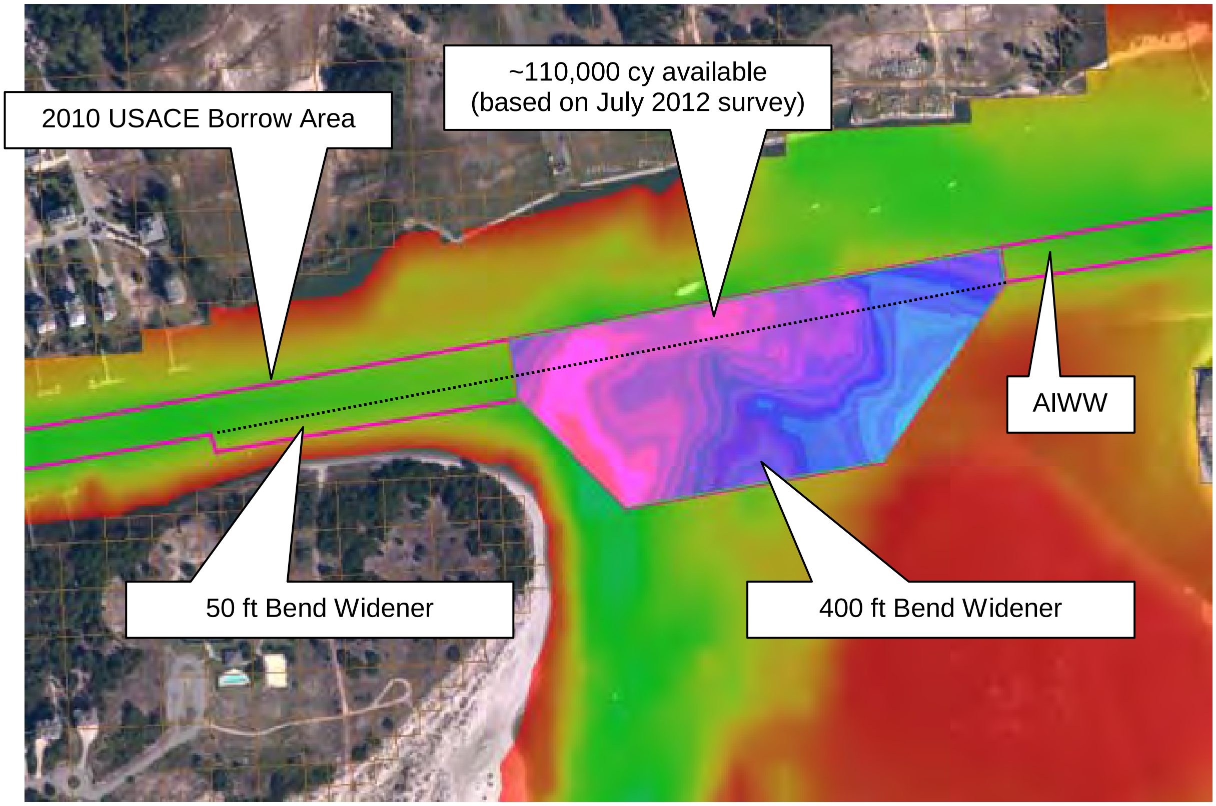


Figure 6-8. Preferred Borrow Area Delineation. This borrow area is within the federal navigation corridor.

The Town will develop a nourishment plan separately from the ongoing USACE east end nourishment in the event that the USACE AIWW dredging project does not continue due to funding limitations. The USACE Navigation Branch did not perform LWFIX dredging in the winter of 2012/2013, and future funding is unknown (personal communication, Bob Keistler, SAW Navigation Branch, September 2012). An LWFIX project of ~80,000 cy is planned for the 2013/2014 winter dredging window.

To maximize dredged volume for navigation and to maximize beach fill placement, the Town would like to permit the portions of the USACE navigation channel that fall inland of the International Regulations for Preventing Collisions at Sea 1972 (COLREGs) demarcation line and have beach-compatible sand. Figure 6-9 presents an image of the COLREGS demarcation line as well as historical USACE dredge footprints. Small cutterhead dredges are not ocean certified and cannot work seaward of the COLREGS line.

The Town's projected borrow area footprint includes the 400-ft bend widener. Note that the channel directly between Holden Beach and Oak Island represents a "pinch-point" where naturally deep bathymetry (~20 feet deep) occurs due to tidal flow. Areas deeper than the established federal navigation channel dimensions are not proposed to be dredged at this time. The reusable nature of the LWFIX borrow area is also anticipated to continue and will most likely satisfy any ongoing nourishment requirements for the groin.

LWF Vibracore Data

The LWF Inlet area has been the potential source for numerous successful USACE beach nourishment projects. As a result, many vibracore borings exist in this location. The latest USACE borings conducted in this area are from 2009 (see Appendix B). The USACE has additional borings in this location dating back to the 1990s (Table 6-2). Section 6.6 provides a sediment compatibility analysis of the 2009 LWFIX vibracores with native beach.

Table 6-2. USACE LWF Vibracore Data Sets Provided to ATM in 2008

Location	Year	Vibracores
Lockwoods Folly Inlet	1998	11
Eastern Channel	2002	15
Lockwoods Folly Inlet	2002	28
Lockwoods Folly River	2002	10
Lockwoods Folly AIWW Crossing	2009	10

6.4.2 LWF OUTER CHANNEL DREDGING

As described in the Work Plan, side-caster dredges are primarily used by the USACE to maintain the outer navigation channel at LWF Inlet. However, the new USACE shallow draft split-hull hopper dredge (the *Murden*) is slated to slowly replace the side-caster dredge (personal communication, Bob Keistler, USACE Navigation Branch, 2011). This would allow for nearshore placement of beach-compatible material that is currently side-cast. This option will continue to be explored with the USACE as the transition from side-casting to hopper dredging the outer channel occurs. Beyond the COLREGS line, it is estimated that between 15,000 cy and 30,000 cy may be available for each dredging event.

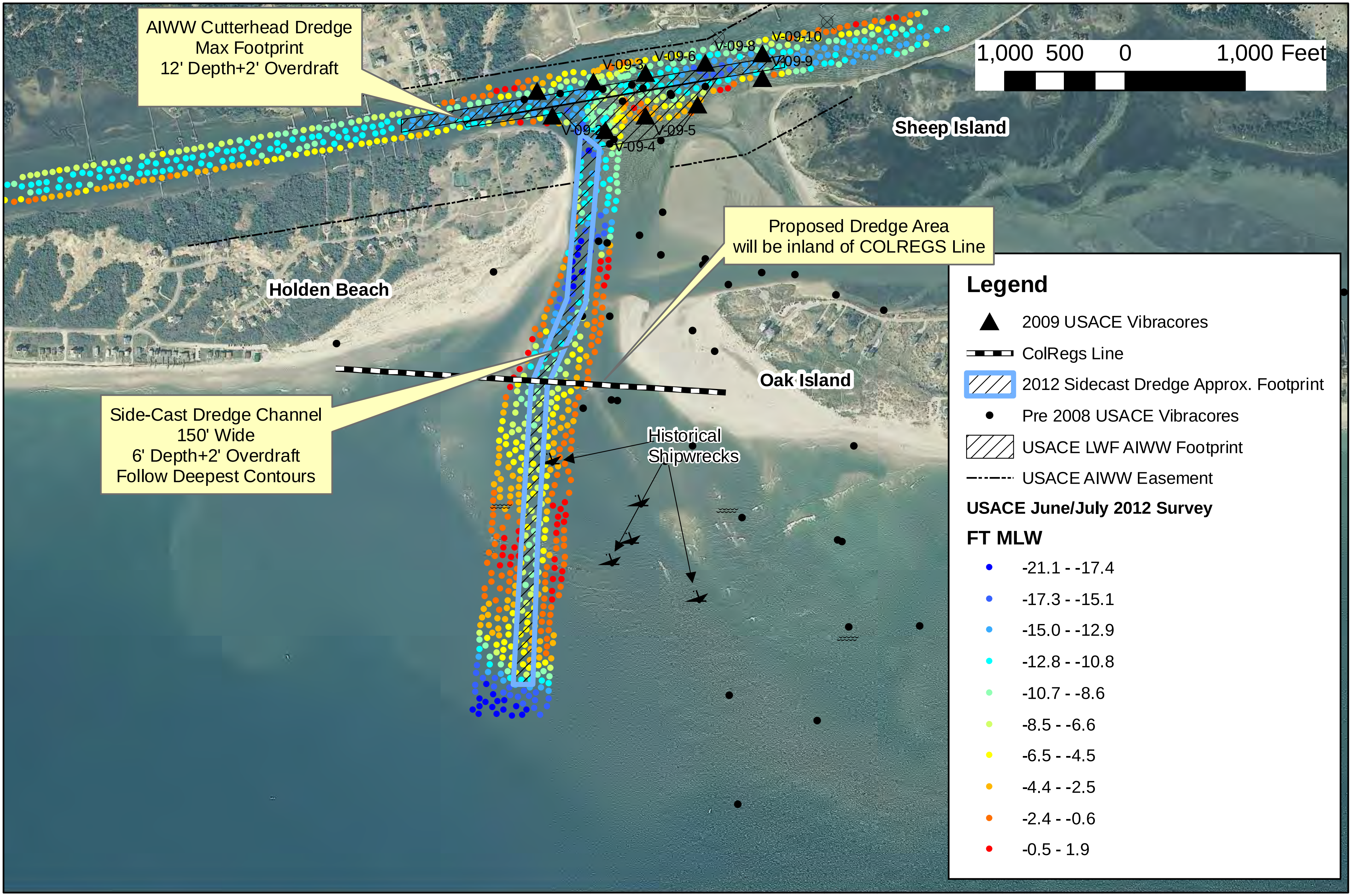


Figure 6-9:
Lockwood Folly Inlet Proposed Dredging Footprint
Proposed Dredging will occur Inland of COLREGS line.

Holden Beach, Oak Island, Brunswick County, and NCDENR Division of Water Resources (DWR) have recently entered into an agreement with the USACE to provide $450,000 to continue USACE dredging of the outer navigation channel for the second half of the 2012 federal fiscal year (i.e., October 1, 2011 to September 30, 2012). It is unknown whether Federal dredging funds will be available in future budgets for this inlet. The USCG removes LWF Inlet navigation buoys when navigation becomes hazardous. Buoys have been removed on several occasions over the last few years and are publicized in weekly USCG.

6.4.3 MONKS ISLAND

Monks Island is a dredge spoil site located adjacent to the AIWW on the western end of Holden Beach. The island is long and narrow, with roughly uniform topography. The western half of the island has been divided into five residential lots. The eastern end is available for mining. The potential borrow area consists of about 10 acres of land up to an elevation of +20 ft NGVD (approximately mean sea level). Based on a site visit by ATM and Holden Beach personnel, the material contained within the existing dikes consists of fine- to medium-grained sand and may be suitable for placement on the beach (or potentially for dune enhancement). According to USACE staff, the site consists of a layered mixture of beach-compatible/non-compatible material and is constructed on a wetland base. However, currently there are no available borings to quantify sediment quality and quantity.

In 2010, the USACE raised the Monks Island perimeter dike/berm to increase capacity. Monks Island CDF is used infrequently for nearby AIWW maintenance dredging, allowing for significant vegetation to grow between events. Its potential use as a borrow area for beach nourishment is questionable, however, it cannot be excluded with current data. Figure 6-10 presents a photograph of this location.

Figure 6-10. Monks Island Confined Disposal Facility (CDF)

6.4.4 SHEEP ISLAND

Sheep Island is a dredge spoil site located adjacent to the AIWW north of Oak Island. Central portions of this long, narrow island lie at elevations near or a few feet above sea level, while topography peaks at either end where dikes have been constructed by the USACE to contain dredge spoil (Figure 6-11).

Figure 6-11. Sheep Island Confined Disposal Facility (CDF)

At the western end of the island, the spoil area covers approximately 4 acres and fill reaches a height of +20 ft NGVD. At the eastern end, the spoil area covers approximately 28 acres and the fill reaches a height of +20 ft NGVD. Based on an ATM site visit in July 2009, the material contained within the dikes consists of fine- to medium-grained sand and may be suitable for placement on the beach. However, currently there are no available borings to quantify sediment quality and quantity. Sheep Island is used infrequently for disposal of dredged material from nearby reaches of the AIWW and LWF River.

Similar to Monks Island, Sheep Island was formed by side-casting and pipelining dredged material onto wetlands decades ago. Therefore, the base of Sheep Island consists of cohesive muddy sediment (i.e., wetland soil), while the material within the CDF consists of a layered mixture of beach-compatible and non-compatible material. As a result, its potential use as a borrow area for beach nourishment is questionable and would require additional geotechnical data collection.

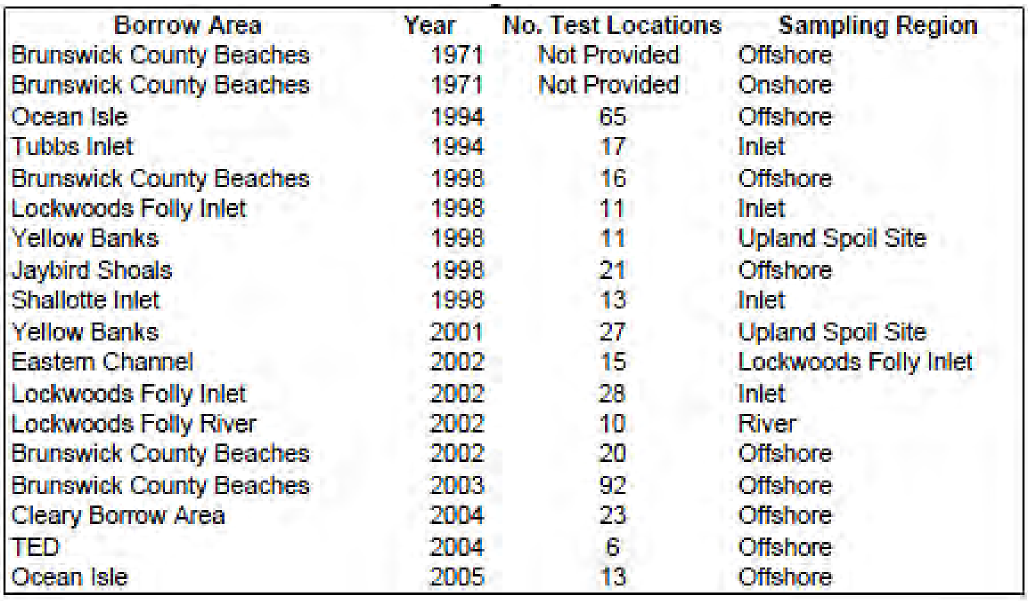
6.5 OFFSHORE BORROW AREAS

Holden Beach began to actively pursue potential offshore borrow areas in 2008. Relevant offshore data resources used include:

1. USACE Vibracores (1990s and 2000s)
2. C&C 1999 Seismic/Subsurface Investigation
3. C&C 2003 Seismic/Subsurface Investigation
4. Artificial Reef Locations
5. NCDENR Coastal Habitat Protection Plan (CHPP) (based on 1995 unpublished data, and 2001 SEAMAP)
6. NCDENR Biological/Wildlife Diversity data (2012)
7. Sonographics Seismic/Subsurface Investigation (2010)
8. Tidewater Atlantic Research (TAR) Seismic, Magnetometer, Sidescan Investigation (2011)
9. Athena Vibracore Collection (2010)
10. ARC Surveying high-resolution multi-beam bathymetric data collection (2011)
11. Athena Vibracore Collection (2011)

The USACE has performed hundreds of vibracores in the region (Table 6-3). In addition to vibracore data, the USACE subcontracted two seismic/subsurface investigations to C&C Technologies in 1999 and 2003.

Table 6-3. Known USACE Vibracore Borings in Northern Long Bay Area (provided by USACE in 2008)



Borrow Area	Year	No. Test Locations	Sampling Region
Brunswick County Beaches	1971	Not Provided	Offshore
Brunswick County Beaches	1971	Not Provided	Onshore
Ocean Isle	1994	65	Offshore
Tubbs Inlet	1994	17	Inlet
Brunswick County Beaches	1998	16	Offshore
Lockwoods Folly Inlet	1998	11	Inlet
Yellow Banks	1998	11	Upland Spoil Site
Jaybird Shoals	1998	21	Offshore
Shallotte Inlet	1998	13	Inlet
Yellow Banks	2001	27	Upland Spoil Site
Eastern Channel	2002	15	Lockwoods Folly Inlet
Lockwoods Folly Inlet	2002	28	Inlet
Lockwoods Folly River	2002	10	River
Brunswick County Beaches	2002	20	Offshore
Brunswick County Beaches	2003	92	Offshore
Cleary Borrow Area	2004	23	Offshore
TED	2004	6	Offshore
Ocean Isle	2005	13	Offshore

Under contract with the USACE Wilmington District (SAW), C&C Technologies performed geophysical sub-bottom profiling and mapping offshore of Ocean Isle and Holden Beach in 1999 and offshore Holden Beach and Oak Island in 2003. The 1999 study focused on the 1.0- to 3.5-mile range offshore of Ocean Isle and Holden Beach, while the 2003 study focused on the 2.5- to 6.0-mile range offshore of Holden Beach and Oak Island (Figure 6-12).

USACE vibracore locations and clustering is indicative of areas that the USACE found to be most promising. Initial ATM investigations found several areas for further investigation (Figure 6-13). The permitted Central Reach borrow area is presented in Figure 6-12.

Note that ATM avoided the “limestone outcrop” layer as delineated by C&C (2003). Interestingly, C&C proposed a very large borrow area where limestone outcrops occur (Figure 6-12). Followup vibracores in the C&C proposed borrow area generally exhibited sand with greater than 10 percent fines.

Dr. Cleary suggested a borrow area for the BCB 50-year project within the same general area as the Central Reach borrow area, although slightly closer to shore. The primary purpose of the USACE studies was to find 50 years’ worth of sand for the BCB 50-year project (over 20,000,000 cy).

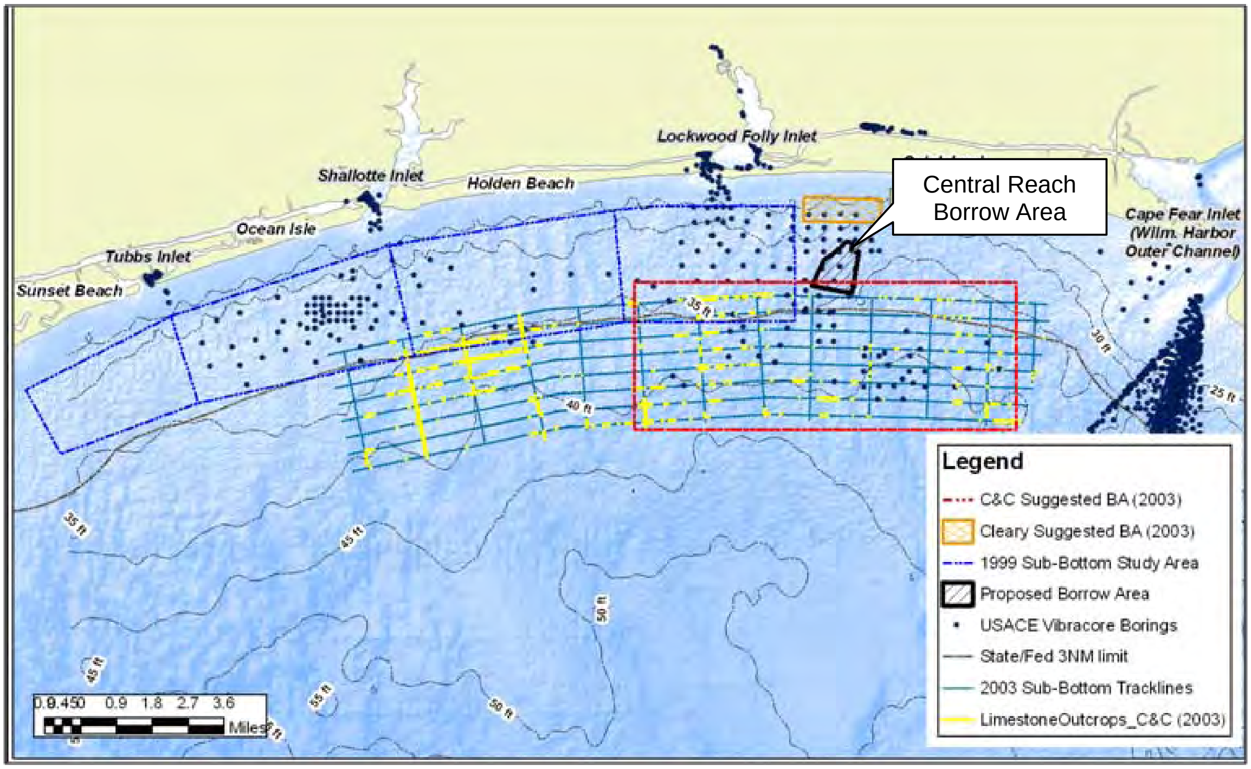


Figure 6-12. Central Reach Borrow Area Related to USACE Studies and Suggested Borrow Areas by C&C and Cleary.

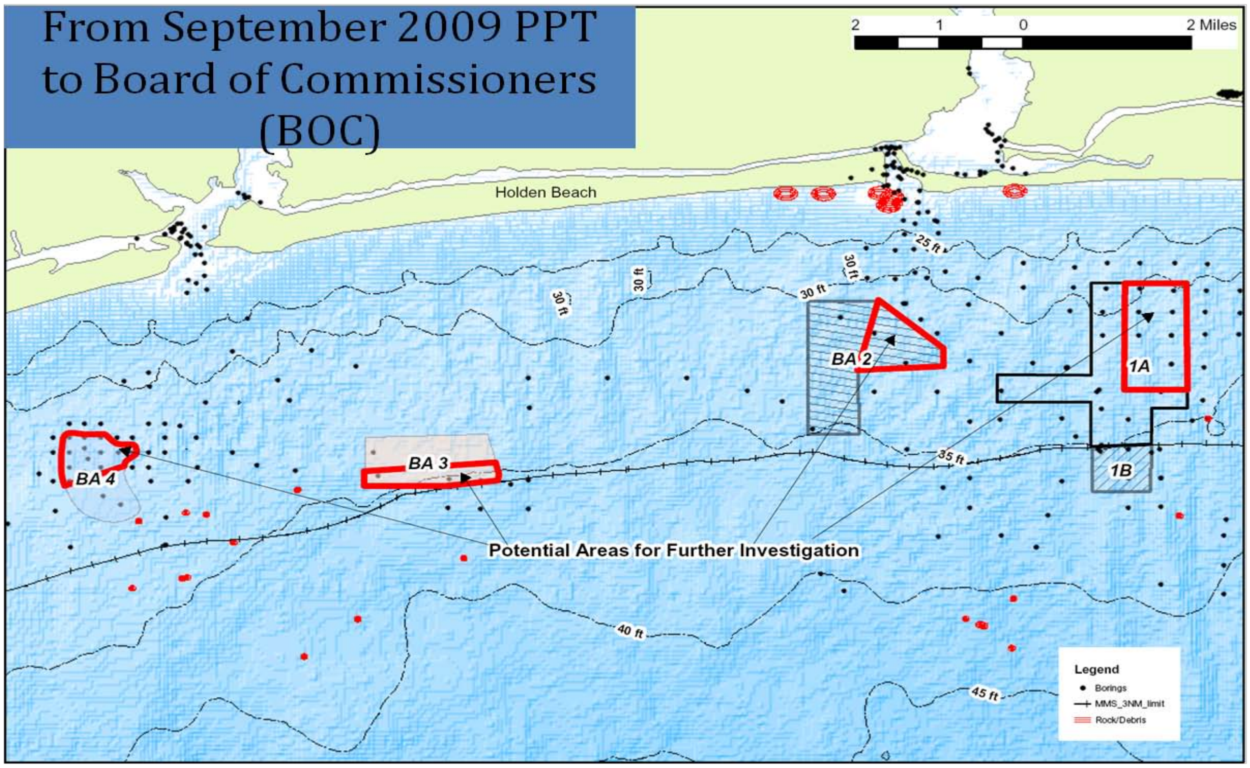


Figure 6-13. 2009 Recommended Areas for Further Investigation. Four potential borrow areas were chosen for seismic/subsurface profiling. Borrow Area 1A represents the approximate area of the permitted Central Reach borrow area.

Following the above-mentioned studies, the USACE determined that the best chances of finding such a large volume of sand were at Jay Bird and Frying Pan Shoals. USACE offshore studies have since focused on these locations (USACE, 2012).

The Central Reach offshore borrow area indicated in the Town's January 2012 permit drawings has been delineated based on more than 100 miles of seismic, bathymetric, side-scan, and magnetometer remote sensing surveys completed between 2010 and 2011. In addition, 32 vibracores (25 by the Town taken to supplement 7 by USACE) were collected within the limits of the Central Reach borrow area to characterize the existing sediments. Vibracore spacing is approximately 1,000 ft or less.

The Central Reach offshore borrow area is approximately 590 acres in size and is located between about 1.8 and 3 miles offshore of western Oak Island and to the southeast of LWF Inlet. Borrow area existing elevations range from -33 to -39 ft NGVD29. Estimated volume yield of compatible beach sand for a cut depth of 3.5 ft is 3.3 million cubic yards (MCY). Assuming the permitted volume of 1.31 MCY is placed on the Central Reach, sufficient volume will be available for at least 2 to 3 more large (greater than 500,000 cy) projects. It is noted that quantities of borrow materials to be excavated will be typically 15 to 25 percent larger than the "in place" beach fill quantity due to the overfill factor and losses inherent to the hydraulic dredging and conveyance process.

6.6 BORROW AREA SEDIMENT COMPATIBILITY

Potential borrow area data were compiled and analyzed to arrive at a composite grain size to represent the material in their respective borrow areas. This was accomplished via a volumetric weighting, where each core was assigned an influence area (acreage) and vertically composited to the cut depth. Composite sediment characteristics for the borrow area are provided in Table 6-4.

All of the criteria (mean grain size, percent gravel, percent granular, percent fines, and percent carbonate) listed in Table 6-4 are required according to DCM's 2008 sediment criteria regulations. Percent "gravel" essentially refers to large shells or limestone (e.g., coquina) rock. Percent granular essentially refers to shell-hash. Percent carbonate also essentially tests for shell and shell material. The presence of potential mud balls (i.e., cohesive sediments) would be reflected in high percent fines.

Table 6-4. Summary of Conformance of Borrow Area Alternatives with DCM Sediment Compatibility Criteria

	Mean Ave (mm)	Sorting	Percent Gravel	Percent Granular	Percent Fines	Percent Carbonate
Native Beach	0.24	0.72	0.6	n/a	2	2.7
DCM Sediment Criteria	N/A	N/A	Native + 5%	Native + 5%	Native + 5%	Native + 15%
DCM Threshold	N/A	N/A	5	5	7	17.7
Offshore Borrow Area	0.35	1.26	2.1	3.4	5.0	12.4
LWFIX	0.41	0.81	2.7	1.1	6.1	10.9
Turkey Trap (Upland)	0.28	0.80	0.0	0.5	1.3	0.00
Smith Site (Upland)	0.34	0.75	0.0	0.1	1.3	0.00
Tripp Site (Upland)	0.17	0.68	0.0	0.2	2.1	0.00

Based on the composite grain size characteristics of the borrow areas, the material from all borrow sites in Table 6-4 meets the sediment criteria requirements. Also note that the LWFIX borrow area is within a Federally maintained navigation channel and that State sediment criteria are slightly more relaxed for these locations, based on prior successful usage.

6.7 BORROW AREA VOLUMES

Conceptual volumes available for each borrow area were estimated based on available vibracore data and corresponding cut depths. Table 6-5 presents these conceptual available volumes.

Table 6-5. Volumes Available for Borrow Area Alternatives

Location	Volume Available	Reusable
Offshore Borrow Area	2,000,000	Possible
Turkey Trap	460,000	No
Smith Site	250,000	No
Tripp Site	250,000	No
LWFIX	110,000	Yes

The LWFIX borrow area is the preferred borrow area due to its reusable qualities. This has proven to be a reliable beach-compatible borrow source for the USACE and, now that funding has limited the USACE's use of the bend widener, the Town would like to continue this project independently. The upland borrow areas (Turkey Trap, Tripp, and Smith) are not reusable in the sense that the borrow areas will not naturally refill with beach-compatible sediment. The Tripp and Smith sites do have additional areas available, however. Future upland borrow areas may also become available.

The offshore borrow area has a significant amount of sediment; however, the costs of mobilizing an “ocean-certified” dredge can range from 1 to 2 million dollars. A recent Bogue Banks FEMA mitigation project estimated hopper dredge mobilization at $4 million (Carteret County, 2012 – April 2012 Newsletter). Therefore, only very large beach nourishment projects (greater than 500,000 cy) would justify its use. The offshore borrow area is currently permitted for a Central Reach nourishment project placing up to 1,310,000 cy of material. Post-project monitoring of the borrow area infilling will be conducted to determine reuse potential.

ATM 2009 Borrow Area Study

Table 6-6 presents a summary of available volumes of additional borrow areas from the 2009 ATM 2009 *Beach Management Planning and Borrow Investigation* for Holden Beach.

Table 6-6. Potential Borrow Area Volumes from 2009 Study

Borrow Area	Acreage	Estimated Average Thickness (ft)	Estimated Yield (cy)
Sheep Island CDF Borrow Area	28	10-20	452,000
Monk Island CDF Borrow Area	10	10-20	161,000
Offshore Borrow Area 1A	1,669	1.5-4	4,039,000
Offshore Borrow Area 1B	268	1.5-4	649,000
Offshore Borrow Area 2	1,103	1.5-3.5	2,669,000
Offshore Borrow Area 3	646	1.5-4	1,563,000
Offshore Borrow Area 4	527	1.5-3	1,275,000
Total			10,808,000

Note that the borrow area volumes presented in Table 6-6 may be reduced based on additional follow-up data collections, depending on the site.

7.0 MODELING STUDIES

A rigorous modeling analysis of the proposed project alternatives was conducted. The analysis includes two sediment transport models: 1) CMS (Coastal Modeling System) and 2) GENESIS-T (Generalized Model for Simulating Shoreline Change). The USACE developed both models and they have been applied extensively in the United States and abroad.

CMS is an integrated modeling system designed to simulate nearshore processes, especially with respect to navigation channel performance and sediment exchange between inlets and adjacent beaches. CMS couples flow, wave, and sediment transport models to simulate waves, current, water level, sediment transport, and morphology change.

The GENESIS-T shoreline response model allows calculation of shoreline response for a wide variety of coastal features and engineering activities, under the assumption that wave-generated currents dominate longshore sediment transport. These features and activities include protective measures such as groins, jetties, seawalls, beach fills, bypassing operations, and linear or point sources and sinks of sediment.

The basis of this modeling analysis will be the CMS model application. The GENESIS-T model was developed previously for the Holden Beach Central Reach nourishment project. Its application for the terminal groin alternatives is a secondary and complementary role. The GENESIS-T model also runs much more quickly, allowing more expedient alternatives screening.

7.1 WAVEWATCH

The National Oceanic and Atmospheric Administration (NOAA) WaveWatch III (WW3) model was used to establish regional wave conditions for the project site. WW3 data are then provided as input to the CMS Wave model and the GENESIS-T wave model [steady-state spectral wave model (STWAVE)].

The WW3 model has been thoroughly tested in the western North Atlantic, and the operational wave forecasting systems at NOAA are based on the WW3 model (Tolman, 2009). Archived WW3 data for the project site is available from NOAA from 1999-2011. This 12-year time period correlates well with available beach and inlet survey data and all wave modeling occurs within this 12-year time span.

NOAA WW3 data was output approximately 11 miles south of the project site (see Figure 7-1). Note that three different NOAA WW3 grids are available from 1999-2012, the 4-minute ATL grid and the 15-minute North Atlantic Hurricane (NAH) and Western North Atlantic (WNA) grids. The NAH grid is typically only run by NOAA during hurricane months, and wind forcing resolution is denser to account for occasionally steep hurricane wave height gradients. All grids have some overlap, and differences were analyzed. Due to the increased wind forcing resolution, the NAH grid had highest priority, then the 4-minute ATL grid, then the WNA grid. Refer to the NOAA WW3 website for additional information on model grids and intercomparisons.

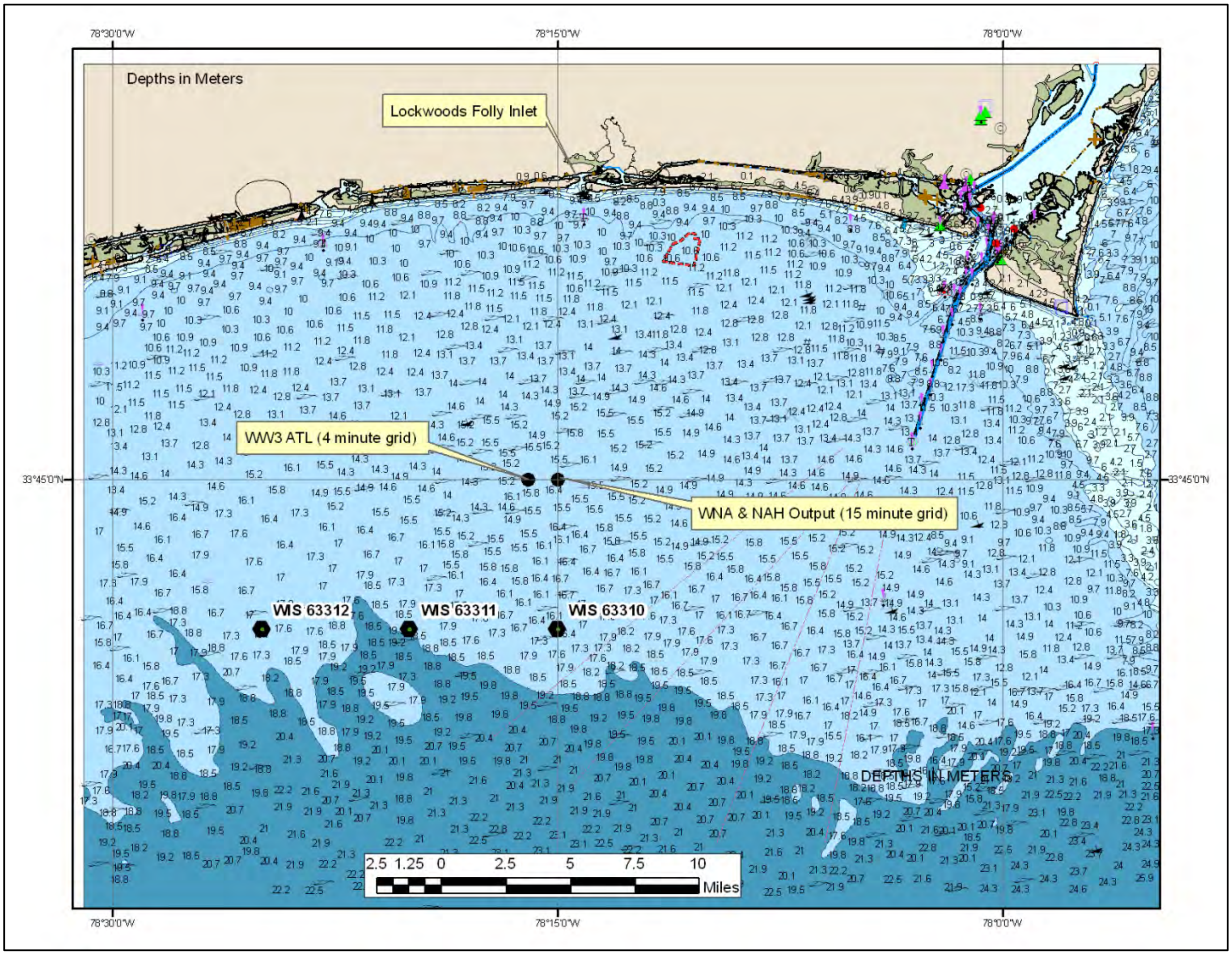


Figure 7-1. NOAA WW3 Output Locations

The combined data set was transformed to CMS Wave and STWAVE model grid boundaries using the USACE-developed WISPH3 tool. The CMS Wave and STWAVE model boundaries are co-located at the 11-m depth contour approximately 3 miles offshore of the project site shoreline (see following sections for details). Figures 7-2 and 7-3 present significant wave height and wave period roses for the CMS Wave and STWAVE boundaries.

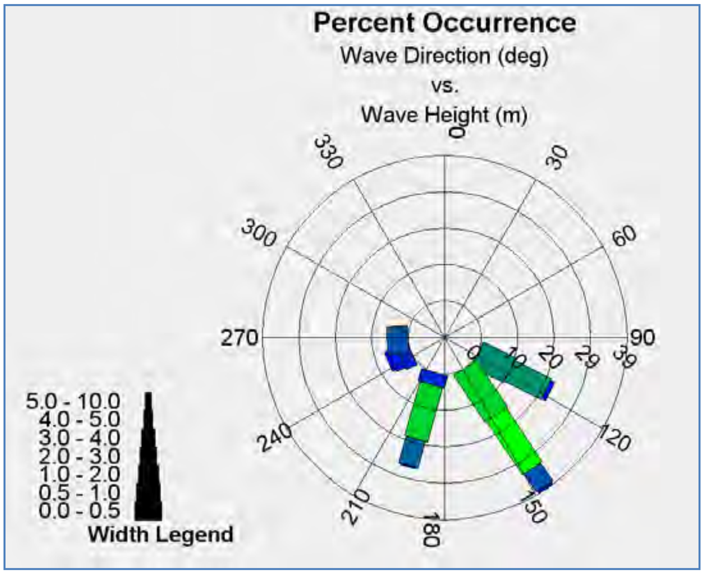


Figure 7-2. *Wave Height Rose following WISPH3 Transformation (1999-2011 data)*

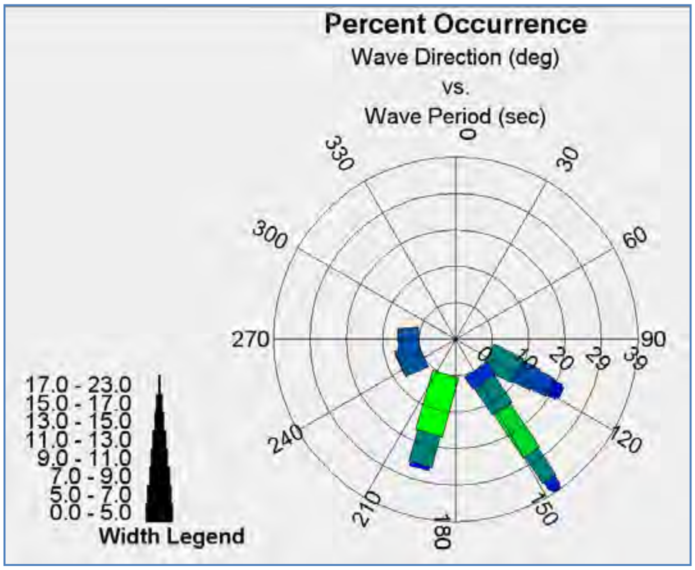


Figure 7-3 *Wave Period rose following WISPH3 Transformation (1999-2011 data)*

7.2 COASTAL MODELING SYSTEM (CMS)

The CMS was used to model several alternatives to provide insight into the relative effects each option would have within the immediate project vicinity, as well as adjacent areas.

7.2.1 MODEL CONFIGURATION

Bathymetric and topographic data used in the model study were compiled from the following sources:

- Holden Beach annual beach and bathymetric surveys
- USACE AIWW and LWF Inlet bathymetric surveys
- LIDAR topographic data (NOAA Digital Coast, 2004 North Carolina Flood Mapping)
- Coastal Science and Engineering (CSE) 2008 survey (inlet/AIWW, Eastern Channel, LWF River)
- USACE LWF River surveys
- NOAA Charts (inshore and offshore)

Data sets were typically collected between 2000 and 2012 and combined based on date. Figure 7-4 presents example data coverages. The combined data sets were adjusted to the North American Vertical Datum of 1988 (NAVD88) and interpolated onto the CMS grids (Figures 7-5 and 7-6). Table 7-1 presents a tide table used for modeling and analysis.

Figure 7-4. Example of USACE Survey Data Coverages (Inlet, AIWW, and LWF River data sets shown).

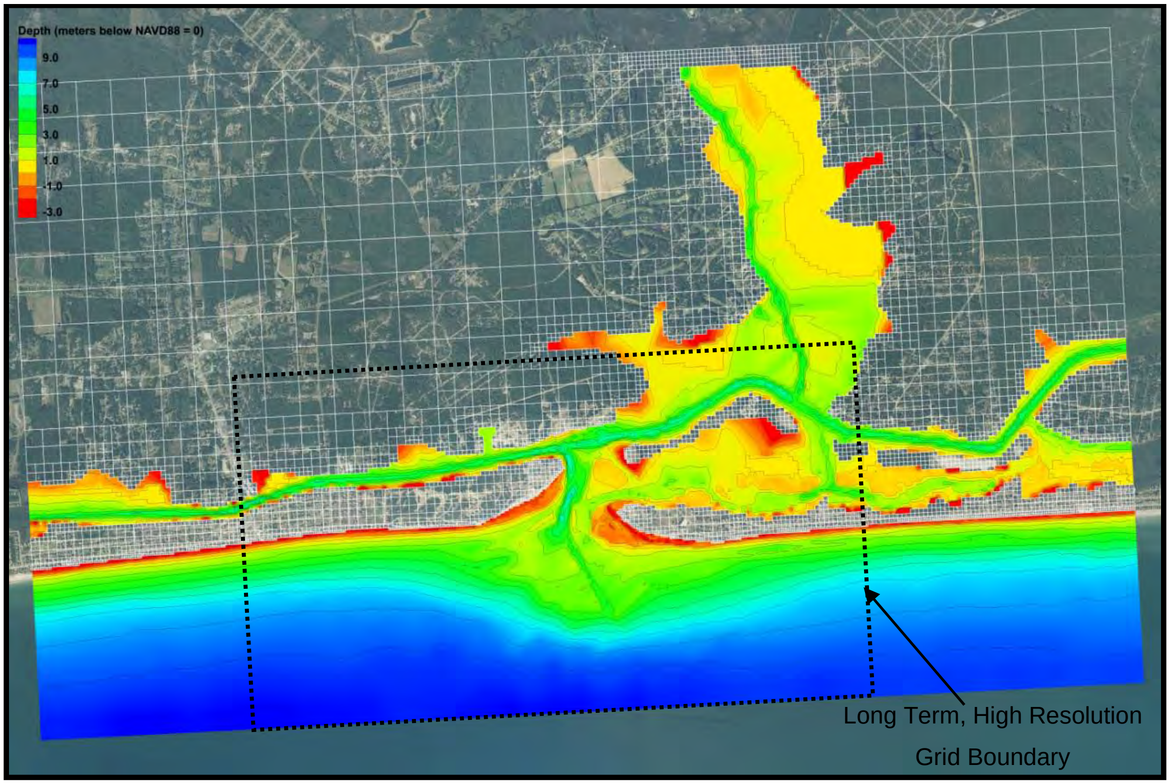


Figure 7-5. CMS Flow (initial, with high resolution annotation) Model Grid with Interpolated Bathymetry (2009) and Aerial Photograph (2008). Computational (i.e., water) cells not shown for clarity.

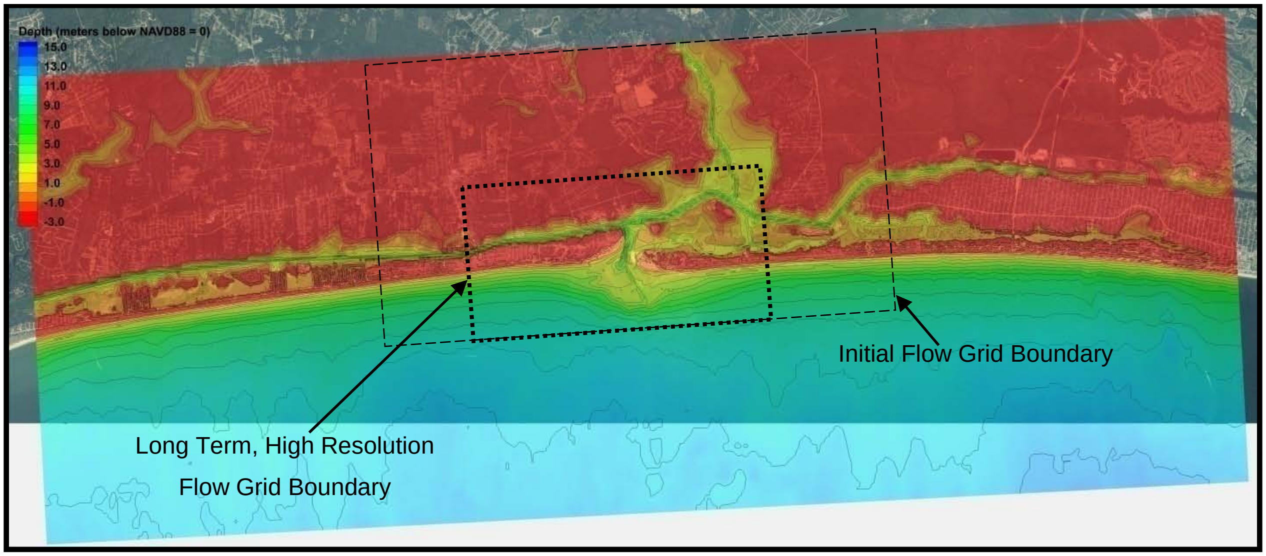


Figure 7-6. Wave Model Grid with Interpolated Bathymetry (2009) and Aerial Photograph (2008). Computational cells not shown for clarity

Table 7-1. Project Site Tidal Datums

Tidal Datum	Feet	Meters
MHW	1.8	0.55
NAVD88	0	0.00
NGVD29	-1.1	-0.34
MLW	-2.9	-0.88
Range (MHW-MLW)	4.7	1.43

Grids were developed for several different bathymetric conditions including 2000, 2004, 2008, 2009, and 2012. The CMS Wave grid is larger while the CMS Flow grid (which performs sediment transport) is nested within the CMS Wave grid. All modeling was performed in metric units, as required by CMS.

Flow and sediment transport was initially modeled on a grid covering approximately 21 square miles (55 km^2) and included nearshore areas, shoreline, LWF Inlet, AIWW, LWF River, wetlands, and other upland areas. For long-term runs, a higher resolution flow grid focused on the project vicinity and surrounding areas. Grid resolution progressively increased from about 984 ft (300 m) in areas of less concern or with large-scale processes to approximately 60 and 30 ft (19 and 9 m) for the initial and long term grids, respectively. Waves were modeled on a grid covering about approximately 73 square miles (190 km^2), extending about 3 miles (5 km) to the east and west of LWF Inlet. It encompasses the flow grid as well as offshore regions and a majority of shoreline along Holden Beach and Oak Island. The resolution of the wave model increased from about 295 ft (90 m) near the model corners to about 65 ft (20 m) at LWF Inlet and along the shorelines of Holden Beach and Oak Island (Figure 7-6).

Time series of wave and water surface elevation data were used to force the CMS application at specified boundaries. Water surface elevation (WSE) data from NOAA Station 8661070 in Myrtle Beach, South Carolina was used to drive water surface elevations in the nearshore and offshore areas. An inflow of 265 ft^3/sec (7.5 m^3/sec) was specified for LWF River at the northern boundary of the initial flow grid, based on a LWF River total maximum daily load (TMDL) report (NCDENR, 2010) and the USGS Enhanced River Reach File (ERF) database (USGS, 2002). Wave data extracted from NOAA's WW3 was used to force the CMS Wave model. The CMS Wave model then feeds these results to the CMS Flow model dynamically.

For the initial flow and sediment transport grid, Manning's N coefficients and mean sediment grain size (D_{50}) values were set to constants of 0.025 and 0.24 millimeter (mm), respectively, based on known conditions/report values (USACE, 1992; ATM Monitoring-Related Reports from 2002-2010). The long term Manning's N coefficient was spatially variable (0.025 for sandy bottom and 0.06 for marsh) to more precisely represent present environmental conditions.

7.2.2 CMS SENSITIVITY ANALYSIS

A sensitivity analysis was performed to qualify model response to parameters within the system and determine the most efficient and realistic model configuration. Thirteen model runs, each simulating a 2-week period, were configured using varied combinations of seven parameters typically used to calibrate and control sediment transport in the CMS. They included:

- Sediment transport model formula
- Adaptation length coefficient
- Wave mass flux calculation
- Wave roller mass flux calculation
- Bed load coefficient
- Suspended load coefficient
- Morphological acceleration factor

Simulated sediment transport through selected cross-shore transects was calculated for evaluation. Sediment transport results were extrapolated to yearly rates for comparison with typical values and known conditions. Historically, erosion along the east end of Holden Beach has been partially due to the continual shifting and reorientation of the main ebb and flood channel(s) of LWF Inlet. The result has been a starvation of sand along the eastern portion of the island that has caused an "erosional wave" propagating west, slowly dissipating. The west end of Oak Island, adjacent to LWF Inlet, has been known to be historically stable/accretional, similar to the west end of Holden Beach.

Final coefficient/parameters values for the model application were either recommended default values or within the recommended ranges provided in the CMS manual. The CMS developers at the USACE Waterways Experiment Station (WES) were also consulted during the model application process. The chosen modeling coefficient/parameter configuration closely represented sediment transport processes in the area, including the following:

- The eastern portion of Holden Beach experiencing relatively high erosion rates,
- Stability/accretion on western end of Oak Island, and
- A net western transport through a majority of all transects.

7.2.3 CMS MODEL CALIBRATION

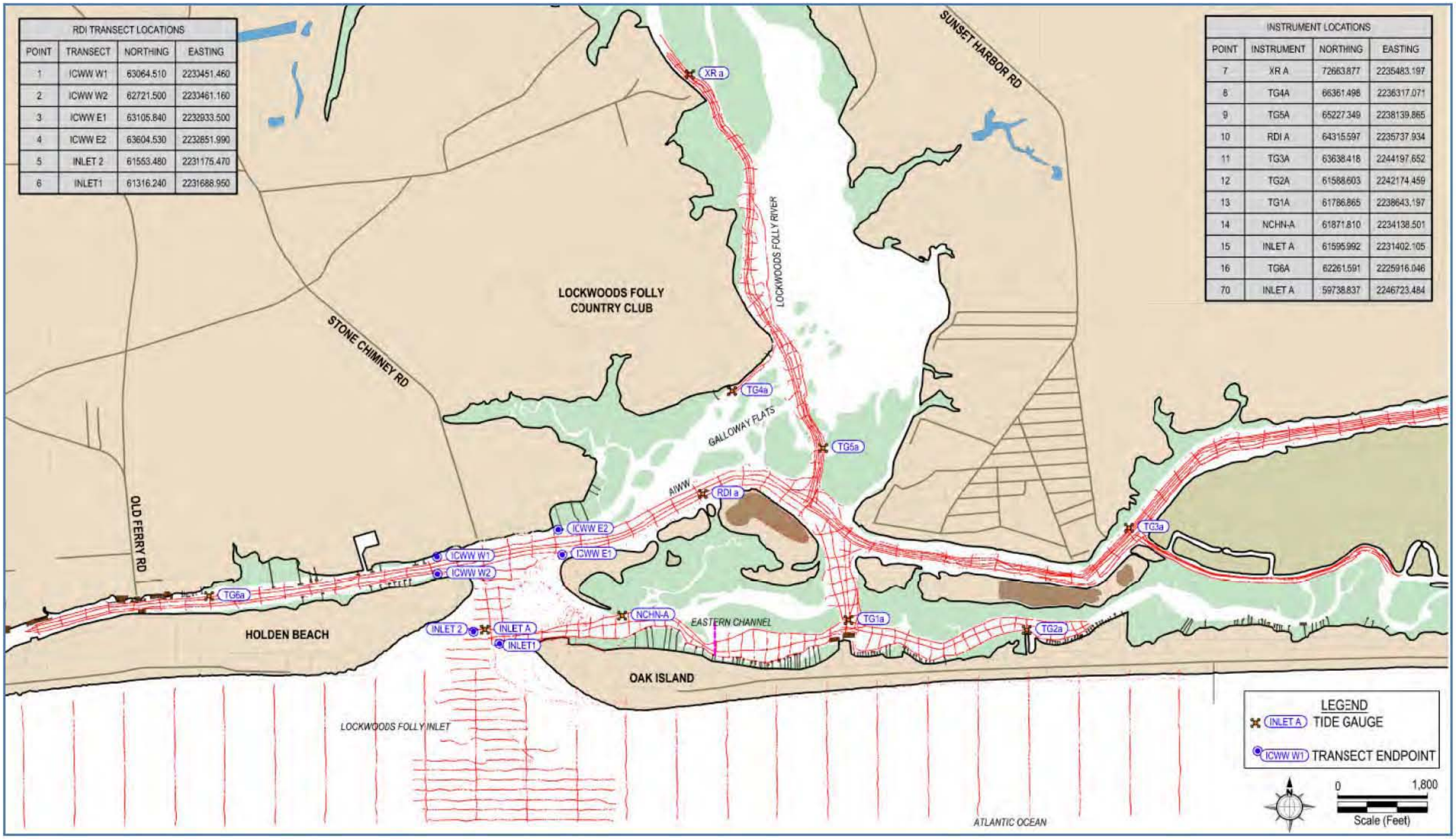
The CMS Flow model was calibrated to water level and current measurements collected during a LWF River flushing study performed by Coastal Science and Engineering (CSE) in September 2008. Results are summarized in this section and in CSE (2009). Four tide/current gages and six tide gages were deployed from September 10 to September 26, 2008 (16 days) at locations shown in Figure 7-7.

Some of the summary findings of the CSE study include:

- The maximum velocity measured in the Eastern Channel was 3.3 feet per second (ft/s) during ebb flow. The maximum flood flow velocity was 2.3 ft/s.
- The velocities measured in LWF Inlet showed a maximum of 4.9 ft/s during ebb discharge and 4.5 ft/s during flood discharge.
- Of the total inlet prism, nearly 80 percent can be accounted for flowing east, either in the eastern AIWW or in the Eastern Channel. Twenty percent of the inlet flow is directed west along the AIWW (behind Holden Beach).

Calibration focused on the inlet area, and model results are in good agreement with measured data (see Figures 7-8 through 7-10). Note that the ADP gage was shifted/moved by currents/flows in the inlet throat, which resulted in missing data and a potential shift in gage elevation.

The CSE study also included current profile surveys along three transects using vessel-mounted instrumentation over a normal tidal cycle (approximately 24 hrs). These current profile surveys were used by CSE to compute discharge (flow) at different times during the tidal cycle. Figure 7-9 presents the locations of measurement transects collected on September 19-20, 2008. Figures 7-10 through 7-12 illustrate predicted currents from calibration runs overlain on observed velocity transects at typical times during the tidal cycle. Timing of all data in Figures 7-10 through 7-12 is within approximately 40-minute windows due to model output and survey boat transect timing. Flow was also compared for calibration and Figure 7-13 shows good correlation between the modeled and measured discharges during the observation period.



RDI TRANSECT LOCATIONS			
POINT	TRANSECT	NORTHING	EASTING
1	ICWW W1	63064.510	2233451.460
2	ICWW W2	62721.500	2233461.160
3	ICWW E1	63105.840	2232933.500
4	ICWW E2	63604.530	2232851.990
5	INLET 2	61553.480	2231175.470
6	INLET1	61316.240	2231688.950

INSTRUMENT LOCATIONS			
POINT	INSTRUMENT	NORTHING	EASTING
7	XR A	72663.877	2235483.197
8	TG4A	66361.498	2236317.071
9	TG5A	65227.349	2238139.865
10	RDI A	64315.597	2235737.934
11	TG3A	63638.418	2244197.652
12	TG2A	61588.603	2242174.459
13	TG1A	61786.865	2238643.197
14	NCHN-A	61871.810	2234138.501
15	INLET A	61595.992	2231402.105
16	TG6A	62261.591	2225916.046
70	INLET A	59738.837	2246723.484

Figure 7-7

2008 CSE Tide and Current Data Collection Locations

Source: CSE, 2009

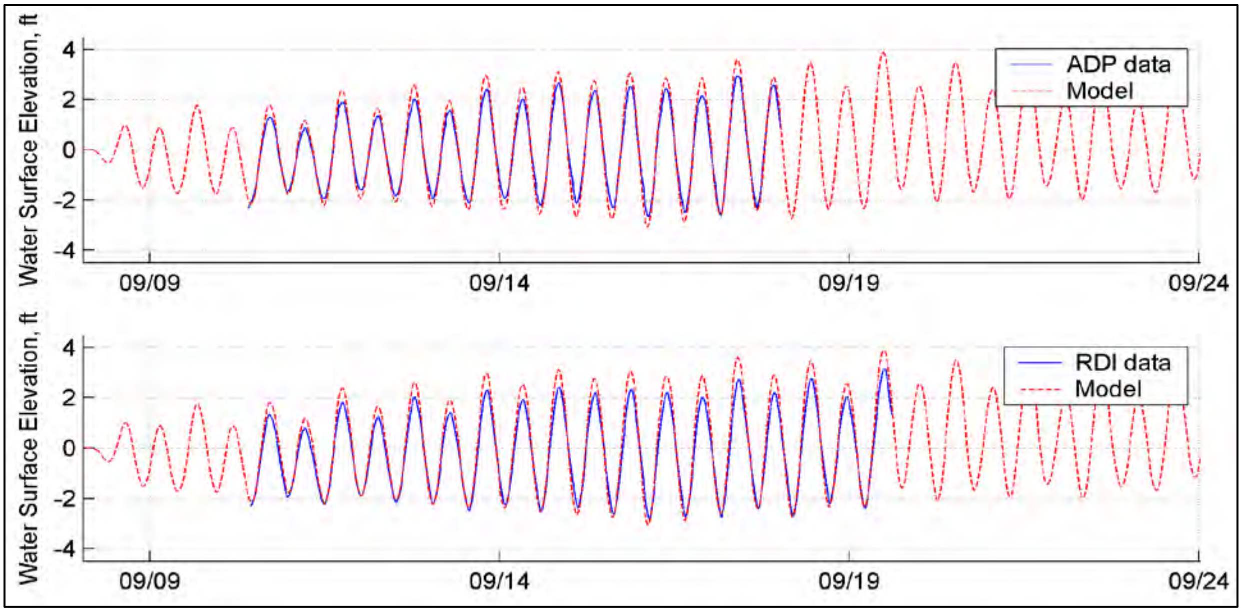


Figure 7-8. *Water Surface Elevation (WSE) Figure. See Figure 7-7 for gage locations.*

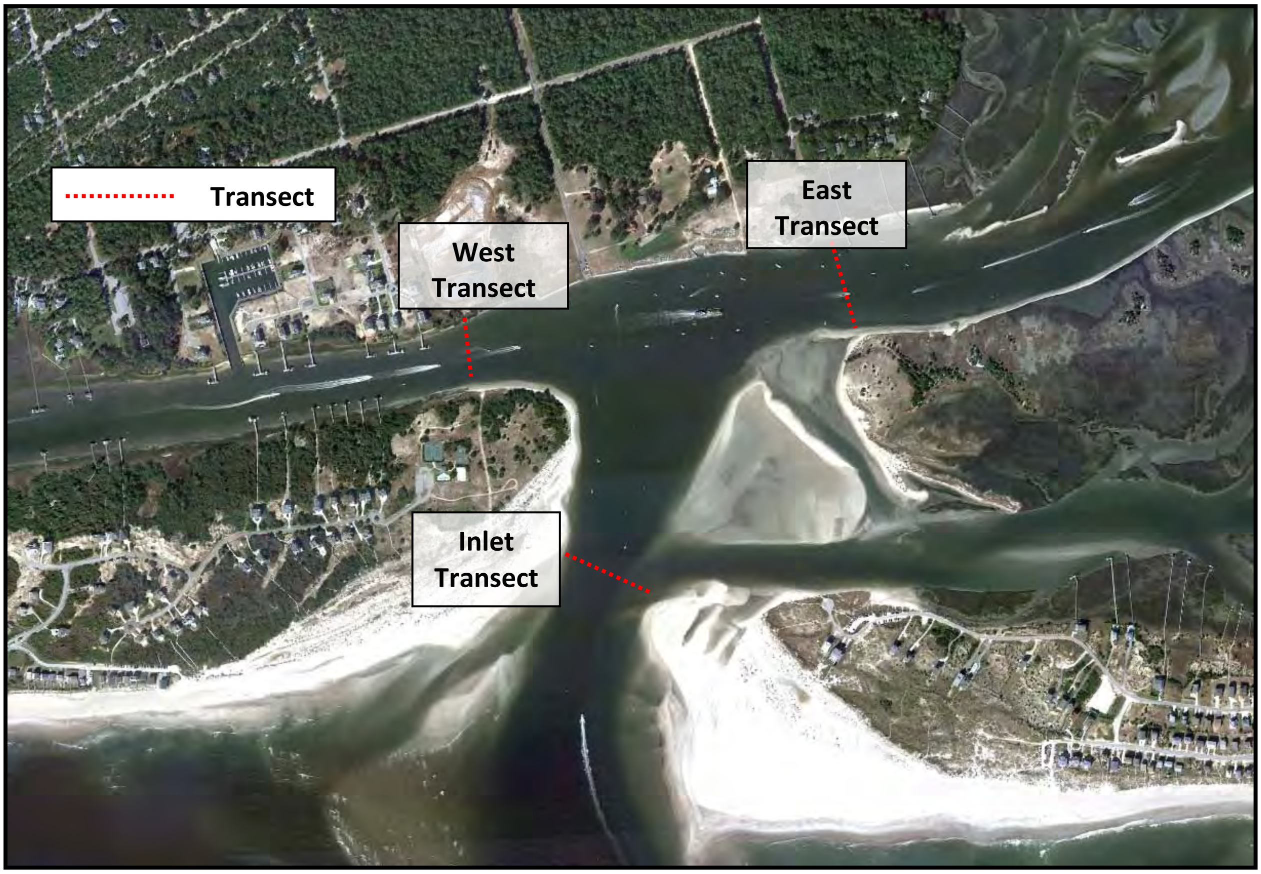


Figure 7-9. *Locations of Measurements during the Transect Current Survey (September 19-20, 2008)*

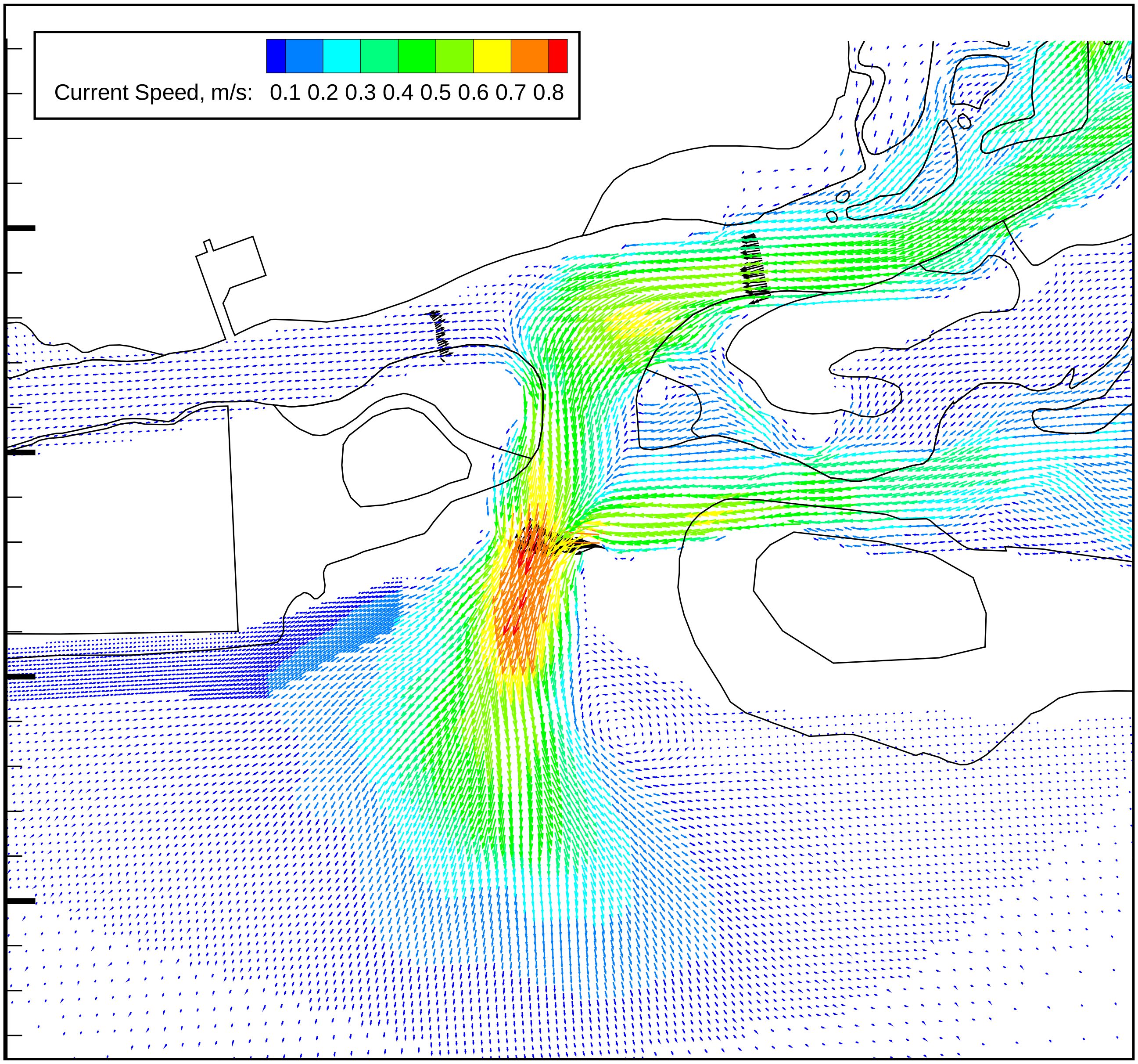


Figure 7-10. Overview of Typical Ebb Current Conditions. Model outputs (colored) and measured transects (black, to scale). Black lines are NOAA ENC water/marsh/land boundaries.

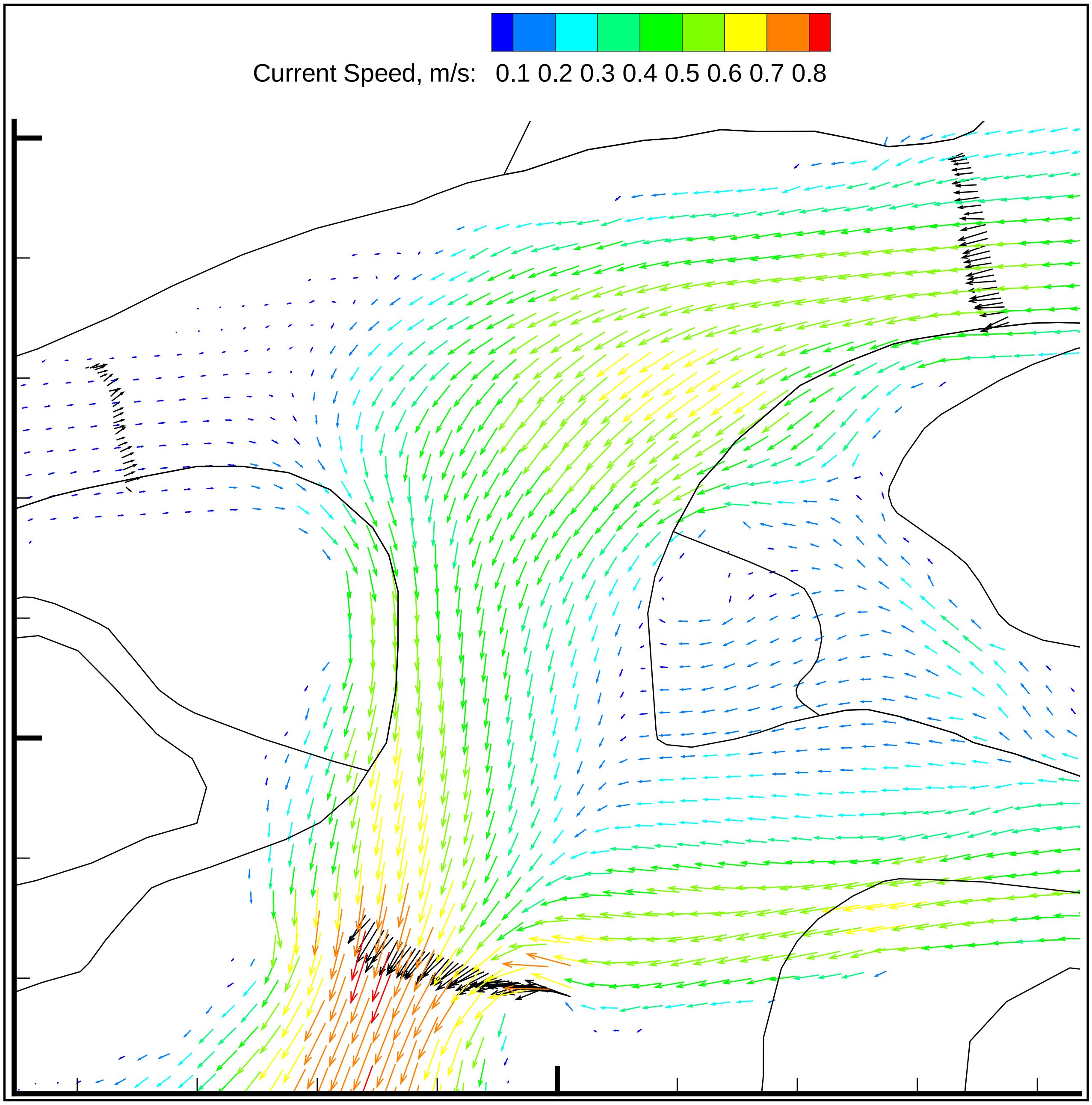


Figure 7-11. Typical Ebb Current Conditions. Model outputs (colored) and measured transects (black, to scale).

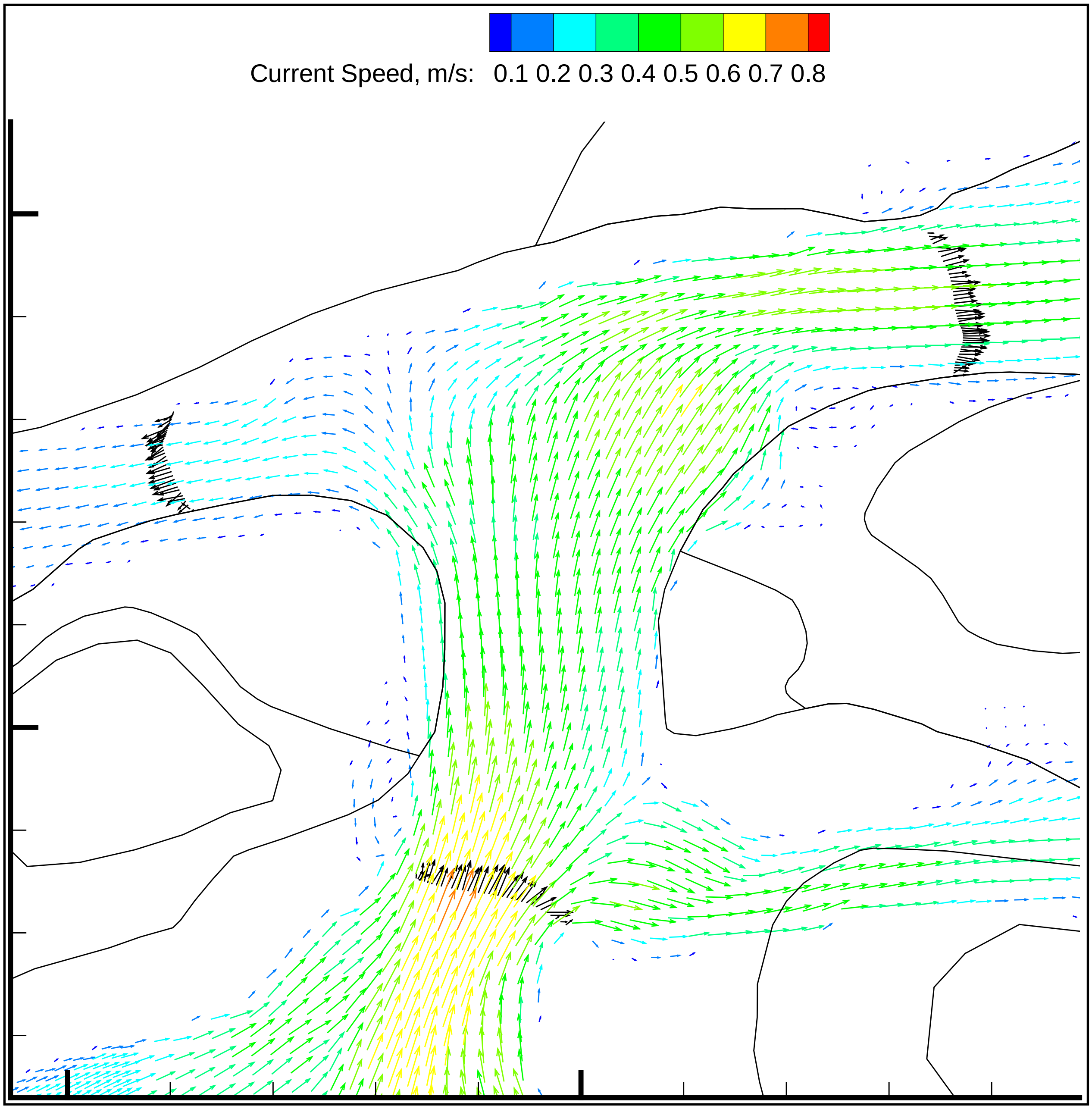


Figure 7-12. Typical Flood Current Conditions. Model outputs (colored) and measured transects (black, to scale).

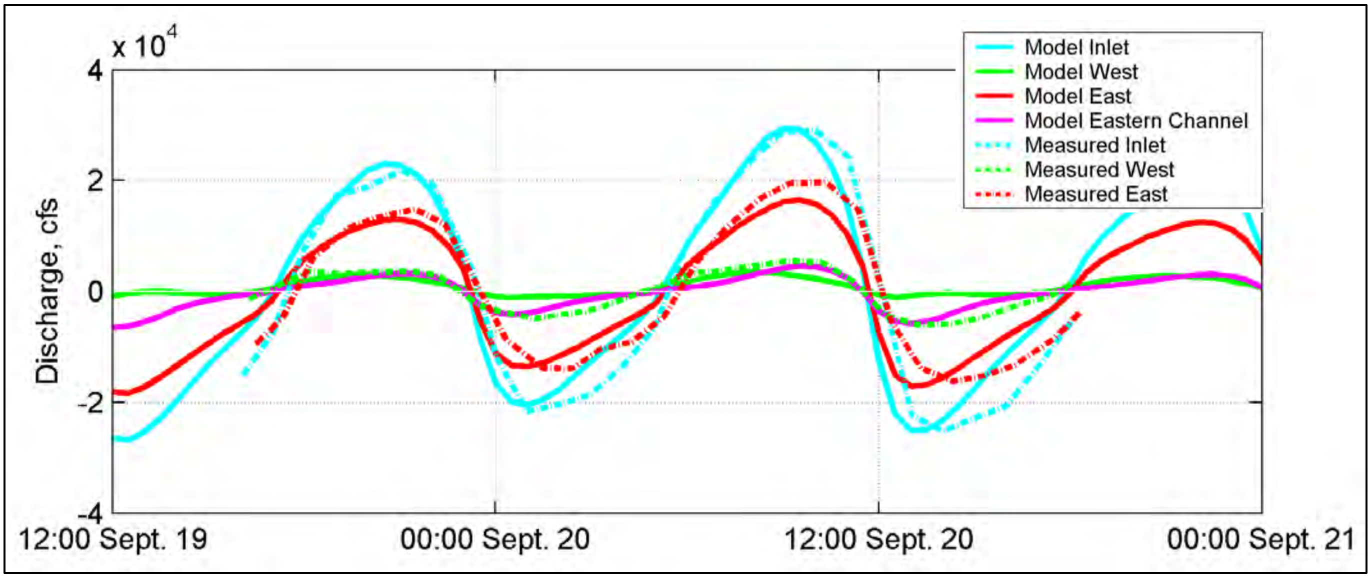


Figure 7-13. Comparison of Measured and Modeled Flows during the 2-Day Observational Period. Flood tide=positive, ebb tide=negative.

Note that while Eastern Channel flow/current boat transects were not conducted during the CSE data collection, measured flows can be estimated by subtracting AIWW flows from LWF Inlet flows. Eastern Channel measured flows were generally of the same magnitude as flows measured in the AIWW behind Holden Beach. Modeled flows of the Eastern Channel also exhibited this trend.

7.2.4 CMS ALTERNATIVES MODELING

In order to determine relative effects of proposed alternatives, numerous model simulations were performed. Initially, 10 alternatives (or cases), described further in Appendix C, were simulated. These alternatives include:

1. Baseline no-action case
2. “Short” groin and 60,000 cy nourishment
3. “Long” groin and 90,000 cy nourishment
4. 60,000 cy nourishment
5. 90,000 cy nourishment
6. “Short” groin only case
7. “Long” groin only case
8. 1,310,000 cy Central Reach nourishment
9. Outer channel re-location
10. “Short” groin, 60,000 cy nourishment, and outer channel relocation.

The “short” groin refers to Alternative 2 in the Work Plan, while the “long” groin refers to Alternative 1 in the Work Plan. Figure 7-14 presents both these alternatives as well as the beach fill areas and the AIWW bend widener.

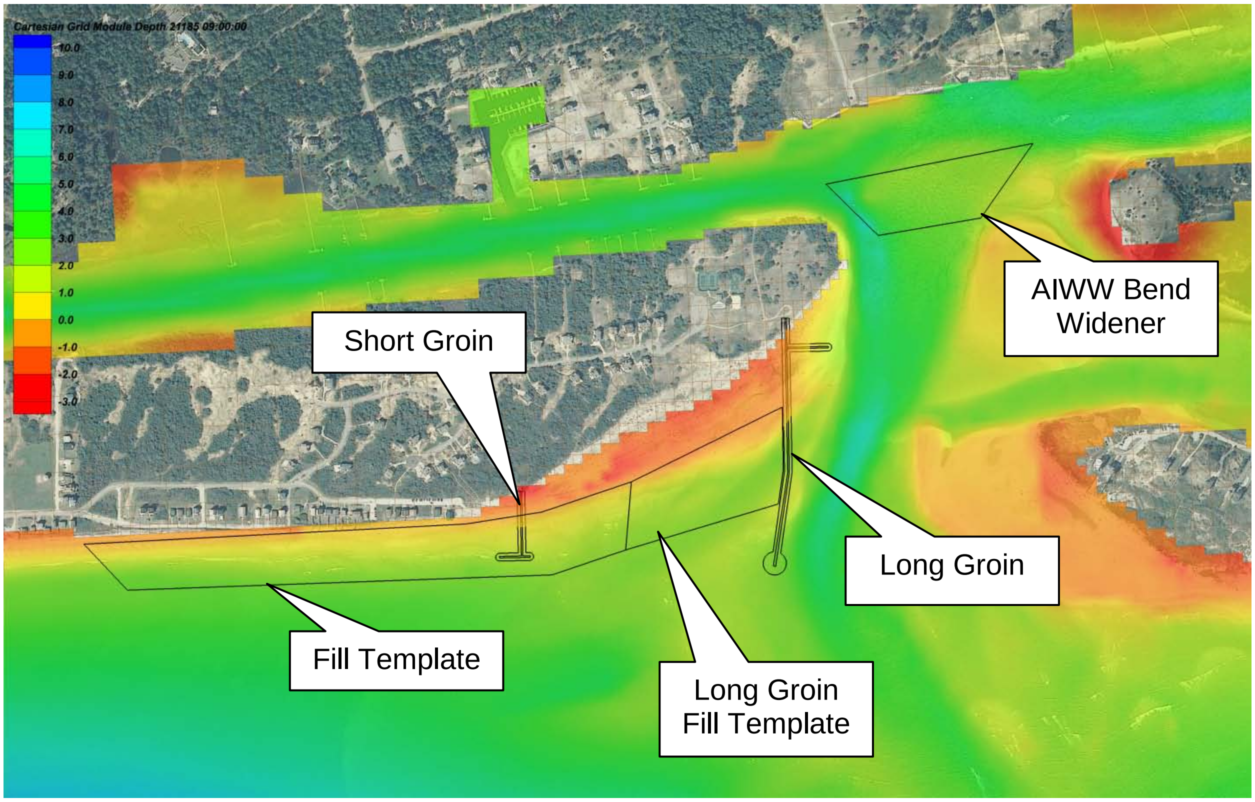


Figure 7-14. Features Modeled for 2009 Runs (detailed results in Appendix C).

The “short” groin is about 550 feet long, whereas the “long” groin is about 1,600 feet long. Groins were modeled as non-erodible and as a rubble mound structure in the CMS Flow and Wave grids, respectively. These designations represent a conservative approach to understanding the impacts of the groin on sediment transport since no sediment is allowed to pass through the structure (i.e., it is *im*permeable). Normally, the porosity of the groin allows some sediment transport through the structure, decreasing the impact on natural transport patterns. The preferred groin design will be designed as a “leaky” structure, where some sediment will pass through it (see Section 8 for more information).

Nourishment volumes were calculated based on the groin length and profile as well as shoreline effects. In general, a shorter groin requires less fill. The currently permitted Central Reach nourishment was also modeled.

Important Note: For the modeling, “no-action” refers to simulations that include no beach management activity (nourishment, groins, dredging, etc.) and essentially represents background erosion. For the other sections of this report (alternatives, costs, etc.), “no-action” refers to currently occurring activities, which include some nourishment activity (depending on funding and other factors).

Following the initial simulations and analysis presented in Appendix C, another set of models was run to evaluate one year performance of several selected alternatives. These alternatives, described further in Section 7.2.4.4, include:

1. Baseline no-action case
2. “Short” groin and 80,000 cy nourishment
3. “Short” groin without a “T head” and 80,000 cy nourishment
4. “Short” groin, 80,000 cy nourishment, bend widener borrow area, and outer inlet channel relocation
5. Dredged Eastern Channel
6. Dredged larger outer channel with 120,000 cy nourishment

Finally, long-term project performance was investigated using several suites of 4-year simulations run under various alternatives. After Suite 1 was run and analyzed, groin design and beach nourishment templates were adjusted to maximize the alternatives’ efficiencies. As a result, these updated configurations are labeled Suite 2 and Suite 3 design iterations, respectively. An alternative location for the short groin case was considered in Suite 3 and denoted as the “intermediate” groin. Table 7-2 shows a matrix of long-term model simulations with varying alternatives. These cases are described further in Section 7.2.4.5.

Table 7-2. Long-Term Model Simulation Matrix

Suite	Simulation	Alternative ID*	Alternative Description
1	1	NA	No Action
	2	NR	Nourishment Only
	3	SGNR	Short Groin & Nourishment
	4	LGNR	Long Groin & Nourishment
2	5	NR	Nourishment Only
	6	SGNR	Short Groin & Nourishment
3	7	NR	Nourishment Only
	8	SGNR	Short Groin & Nourishment
	9	INTGNR	Intermediate Groin & Nourishment
	10	LGNR	Long Groin & Nourishment
	11	OCNR	Wide Outer Channel Dredging & Nourishment

**Nourishments (NR) with short groin (SG) alternatives are ~120,000 cy. Intermediate Groin (INTG) nourishments are ~130,000 cy. Long groin (LG) nourishments are ~200,000 cy.*

7.2.4.1 Sediment Transport Vectors and Analysis

A preliminary sediment transport analysis was conducted using model results from several cases to:

1. Validate large-scale sediment transport processes in the area based on knowledge of existing and historic conditions, and
2. Conduct an initial comparison of the existing no-action case with any effects alternatives modeling may produce on transport processes.

Transects were chosen at seven specific locations: three along Holden Beach stretching from the dune out to the 20-ft (6-m) depth contour, one across LWF Inlet, and three along Oak Island stretching from the dune out to the 20-ft (6-m) depth contour. Figure 7-15 shows the resulting sediment transport vectors for the three selected model simulations. Selected model simulations include no-action, the short groin and nourishment (SG+NR), and the short groin/nourishment/ channel relocation/LWFIX borrow area (SG+NR+INL+BRW) alternatives. Table 7-3 quantifies the integrated net transport across each transect.

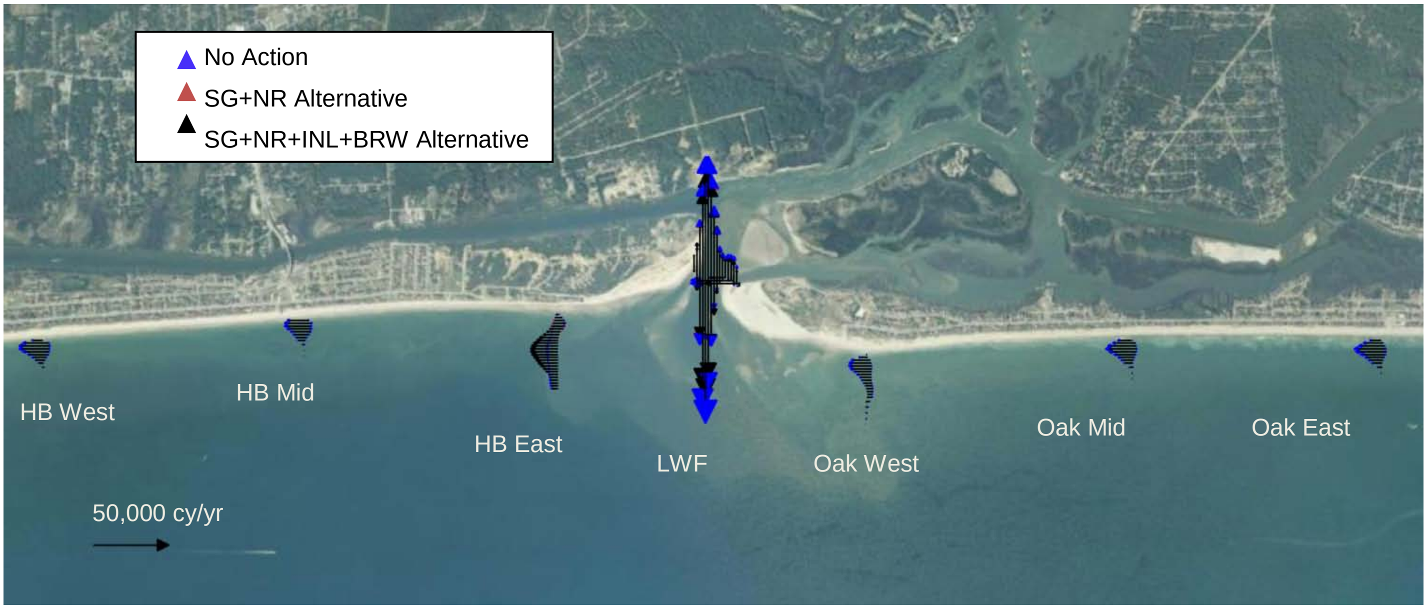


Figure 7-15. Regional Sediment Transport for 2004 Full-Year Model Simulations. Note that red (SG+NR) arrows not seen since directly under blue (NA) arrows except for HB East (see Figure 7-16).

Table 7-3. Net Sediment Transport (cy/yr) for 2004 Simulations.

Alternative	HB West	HB Mid	HB East	Inlet (Y)	Oak West	Oak Mid	Oak East
No-Action (NA)	-50,295	-30,515	-131,150	75,885	-34,051	-77,454	-88,235
SG+NR	-50,228	-30,614	-133,540	75,884	-34,114	-77,547	-88,296
SG+NR+INL+BRW	-51,044	-30,690	-229,280	67,917	-33,051	-77,657	-88,394

*Negative=Net Westerly (out of inlet for Inlet Transect); Positive=Net Easterly (into inlet for Inlet Transect)

Transport vectors represent gross transport within each model cell. Net transport is to the west from a regional perspective, although changes in sediment transport patterns do occur near LWF Inlet (Figure 7-15). At the inlet transect, significant gross sediment transport is exhibited. A close up of the HB-East vector transect is illustrated in Figure 7-16.

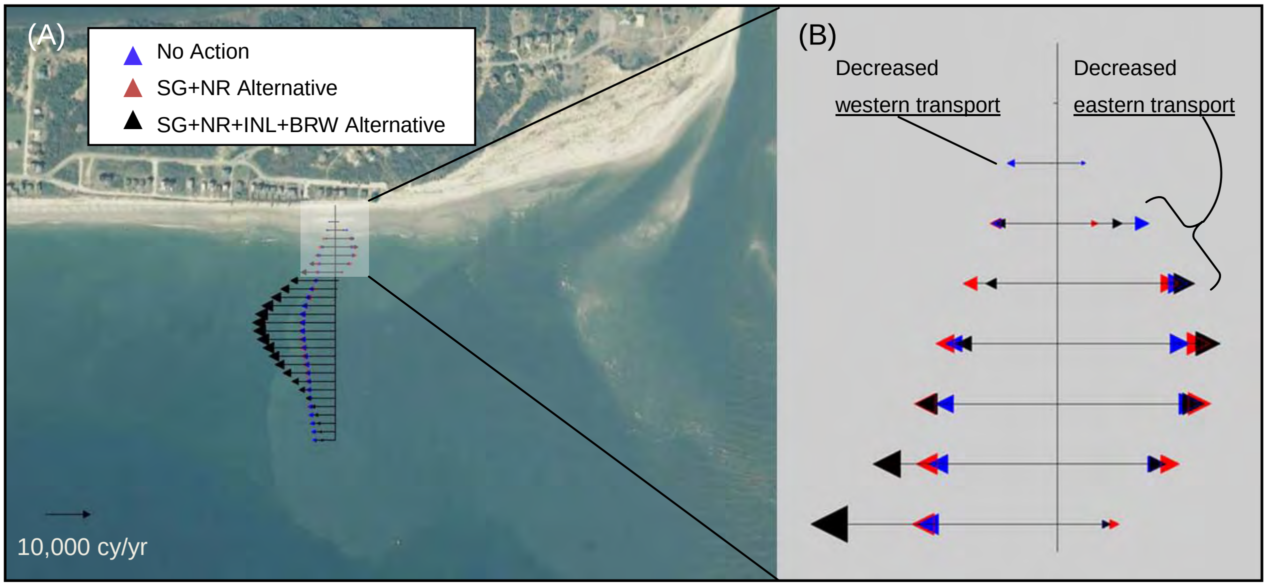


Figure 7-16. *(A) HB East Transect Sediment Transport (2004 simulation).*
(B) Close-Up of Area Affected by Groin.
Note decreased eastern (into inlet) and western sediment transport with groin alternatives. Increases in outer transport vectors with groin alternatives can be attributed to increased available sediment from nourishments and the relocated inlet channel.

The results of full-season (1-year) simulations and sediment analyses illustrate several key processes:

1. Longshore transport generally occurring in the nearshore (correlating with sandbars and surf zone);
2. Transects bordering the inlet also show varied sediment movement associated with inlet processes;
3. Net longshore sediment transport to the west;
4. Increased erosion along eastern Holden Beach relative to the surrounding areas;
5. Decreased erosion along western Oak Island and Middle Holden Beach relative to the surrounding areas;
6. Alternatives produced increased “outer” (farther offshore) transect vector sediment transport due to inlet relocation and additional available sediment from nourishments; and
7. Groin alternatives decreased local sediment transport in the nearshore (“inner” transect vectors) on eastern Holden Beach, while regional transport remained unaffected.

The transport vectors shown in Figure 7-15 are summed in Table 7-3 to provide net sediment transport values. Selected model simulations include no-action (NA), the short groin and nourishment (SG+NR), and the short groin/nourishment/channel relocation/inlet borrow area (SG+NR+INL+BRW) alternatives. The SG+NR alternative has only minor localized effects when compared to the no-action alternative. Conversely, the alternative that includes the inlet channel relocation and the LWFIX borrow area exhibits a large increase in net sediment transport at the HB East transect. All hydrodynamic and sediment-related CMS settings were identical for these runs.

Annual net sediment transport rates presented in Table 7-3 are within the range of previous reports and studies (Thompson et al., 1999; etc. – see *Work Plan* and previous sections for more information). In general, the HB East transect exhibits significantly higher sediment transport rates than other transport vector locations. This agrees with historical erosion rates on the east end and is the primary reason why a terminal groin is being proposed for this location.

While the *gross* sediment transport at the inlet throat location is significantly larger than all other transect locations (see Figure 7-15), *net* transport at the Inlet throat location agrees well with LWF Inlet historical sedimentation rates. For 2004 conditions simulated in this model run, approximately 75,000 cy of material is moved into the inlet over the yearlong run. The ability of the CMS model and subsequent sediment transport analyses to accurately predict the large-scale sediment processes in the area provides an important means by which to asses any effects of the proposed alternatives. These will be discussed further in the following sections.

7.2.4.2 2009 Model Runs

Appendix C contains the 2009 model runs where the 10 model alternative cases listed in Section 7.2.4 were simulated for 190 days, running from June 1, 2009 to December 8, 2009. This period was chosen due to its lack of nourishment/dredging projects and the availability of bathymetric survey data coinciding with the start and near-end dates of simulations (for model verification). Additionally, this 190-day period coincides with more easterly net transport conditions, therefore “downdrift” (i.e., into the inlet) effects are more noticeable.

7.2.4.3 Relative Impacts of 2009 CMS Simulated Alternatives

The 2009 CMS model simulations revealed two areas of Holden Beach that were significantly affected by the nourishment-only, short-groin-only, and short-groin-and-nourishment alternatives (see Figure 7-17). Area 1 extends over about 2,700 ft of shoreline and includes the nourished beachfront (when applicable) and updrift shoreline west of the short groin (when applicable). Area 2 covers about 1,700 ft of shoreline and includes the downdrift shoreline east of the short groin (when applicable).

Similarly, the CMS simulations revealed two areas of Holden Beach that were affected by the long-groin-only and long-groin-and-nourishment alternatives (Figure 7-17). Area 3 covers about 4,300 ft of shoreline and includes the nourished beachfront (when applicable) and updrift shoreline west of the long groin. Area 4 covers about 400 ft of shoreline and includes the downdrift shoreline east of the long groin and edges of the inlet channel.

Depending on the modeled alternative, all areas experienced a number of effects, including increased or decreased erosion, shoreline accretion due to sediment trapping, shoreline accretion due to nourishment activity, and other varied morphology changes.

Morphology change in the areas was assessed to compare relative impacts of the alternatives. Volume calculations were performed to determine the initial and final sand volumes in the areas relative to the no-action baseline condition. Table 7-4 presents the results of the relative impact assessment for Areas 1 and 2. The magnitude of sediment loss is affected differently in each area by the varying alternatives. For example, the short-groin-only alternative (SG) results in accretion in Area 1 and erosion in Area 2, relative to the no-action alternative. As expected with this alternative, sections of shoreline in Area 1 also grow seaward due to updrift sediment trapping by the groin, whereas Area 2 experiences some shoreline erosion from a lack of available sediment. The inclusion of nourishment along Area 1 has obvious benefits for this reach of shoreline.

Therefore, as seen in Table 7-4, the short groin by itself traps approximately 9,000 cy of material over approximately 2,700 feet (when compared with no-action results). The groin and nourishment alternative benefit the updrift shoreline by approximately 23.7 cy/ft, while some downdrift impacts are still exhibited (-6,518 cy). The sediment downdrift impacts of the short groin are approximately 8,000 cy over 190-days. Therefore, an approximate annual downdrift impact of the short groin is 16,000 cy. This is a conservative estimate because 1) the groin is modeled as impermeable, and 2) the 190-day model simulation occurs from June to December, when more westerly transport is seen due to increased south-southwest wind-wave conditions.

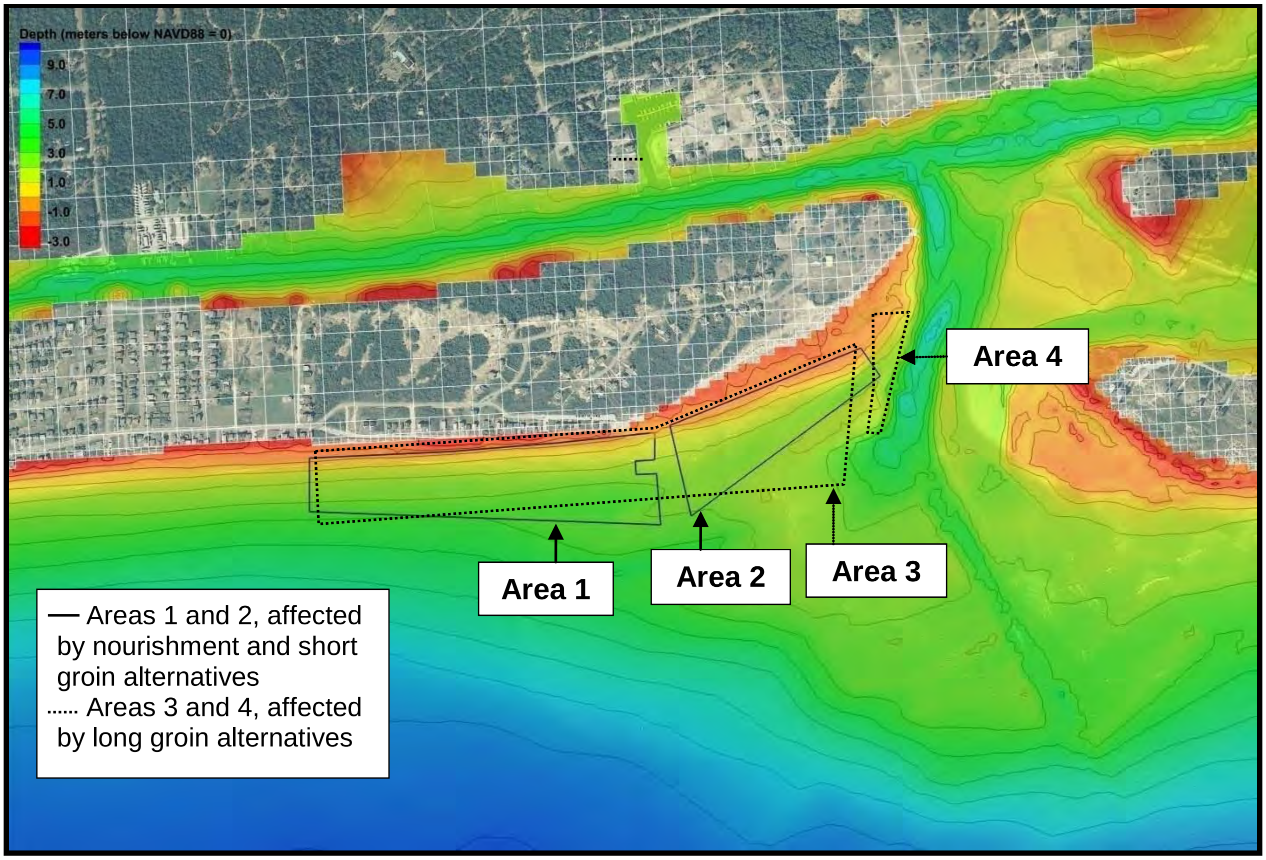


Figure 7-17. Areas Considered for Relative Impact Comparison.

Table 7-4. Relative Impact Assessment Results from 190-Day Simulations, Areas 1 and 2

Alternative	Area 1 Volume Change (cy)	Area 2 Volume Change (cy)
60,000 cy Nourishment Only	55,029	1,451
Short Groin Only	9,004	-8,032
Groin and Nourishment	64,033	-6,518
Channel Relocation	-11,479	-1,099
Central Reach Nourishment	31,035	65
Groin, Nourishment, Channel Relocation, LWFIX Borrow Area	60,939	-15,408

Figures 7-18 and 7-19 present morphological change figures relative to Areas 1 and 2. Figure 7-18 presents results for the channel relocation only (i.e., no nourishment or groin was simulated). In general, the channel relocation alternative induces the most change within the ebb shoal/inlet system (see Appendix C for more details). While there is some accretion in the nearshore of Area 2, erosion is exhibited overall for Areas 1 and 2. More modeling and description related to channel relocation is presented in Section 7.2.4.4.

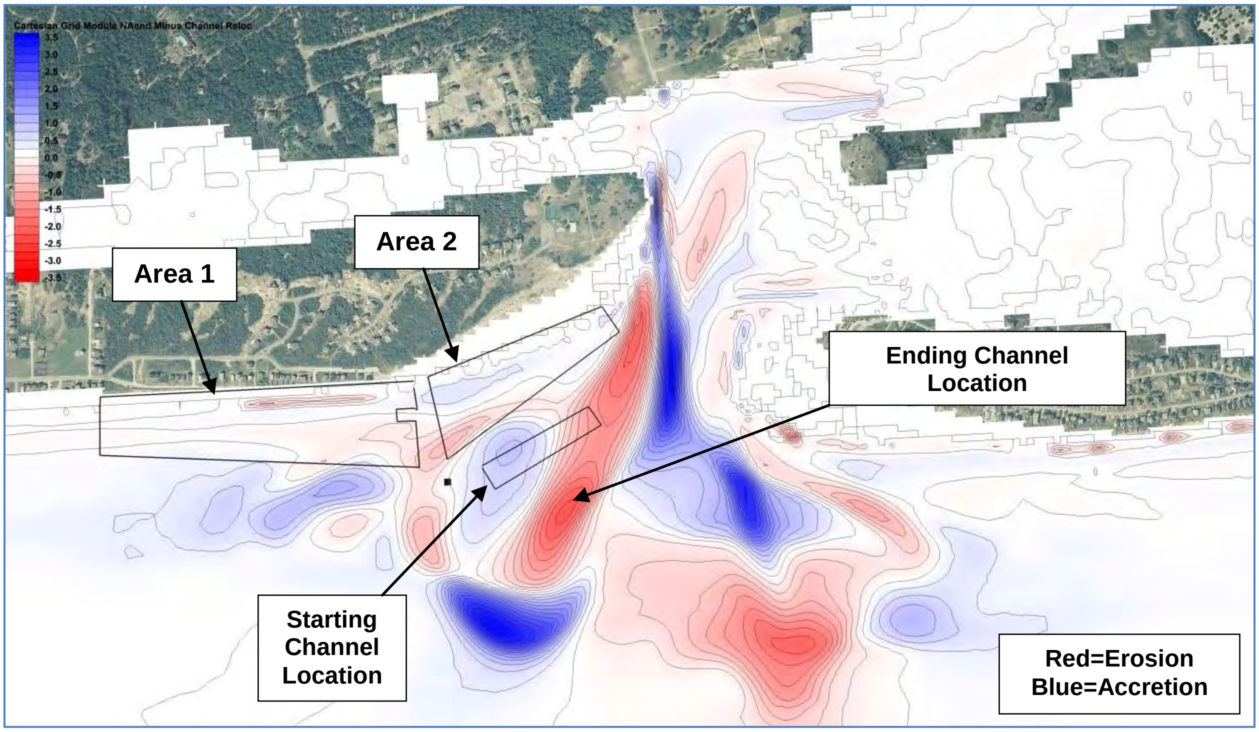


Figure 7-18. *Morphology Change of Channel Relocation Only Relative to Areas 1 and 2 (no nourishment or groins are simulated). Area 1 exhibits overall erosion while Area 2 exhibits some accretion near the shoreline and erosion in deeper water. For all morphology change figures, red=erosion and blue=accretion.*

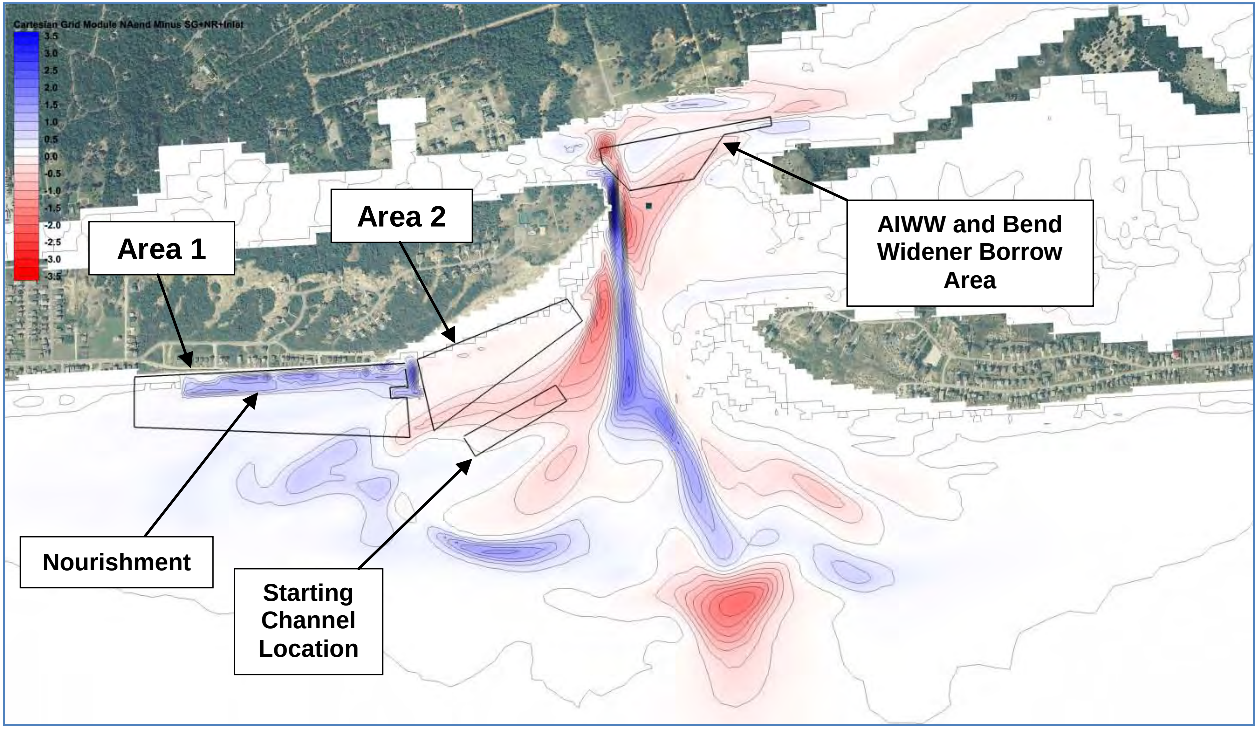


Figure 7-19. *Morphology Change of Short Groin, 60,000 cy Nourishment, Channel Relocation, and Inlet Borrow Area versus No-Action. As expected, Area 1 exhibits accretion. Area 2 exhibits some erosion, although this is also due to the channel relocation.*

Figure 7-19 presents the short groin, a 60,000 cy nourishment, the channel relocation, and the LWFIX borrow area. In general, the short groin exhibits relatively local effects (see Appendix C, where changes with each component were separated with modeling). No significant synergistic effects are exhibited in Figure 7-19. In comparing Figures 7-18 and 7-19, the inlet channel relocation component exhibits the largest effect on the ebb shoal system.

As seen in Figure 7-19, the LWFIX/bend widener borrow area has a significant effect by easing the “pinching” of the channel thalweg alongshore of Holden Beach. This effect can also be seen in Figure 7-20, which presents results of 2012 USACE survey data.

Table 7-5 presents volume changes in Areas 3 and 4, which are for assessing long-groin alternatives relative to no-action baseline conditions. The long groin by itself traps approximately 46,000 cy over 4,300 ft during the 190-day simulation. Downdrift losses attributed to the long-groin-only alternative are approximately 16,000 cy. In terms of downdrift effects in Area 4, a negligible amount of nourishment sand is bypassed during the simulation (15,677 cy for groin-only versus 15,336 cy for groin-and-nourishment). An approximate annual downdrift impact of the long groin is 32,000 cy/yr. As mentioned with the short groin downdrift effects, this is a conservative assumption because the groin is modeled as impermeable during a period of more easterly sediment transport.

7.2.4.4 Selected One Year Simulations

Several selected alternatives were modeled for investigation of 1 year project performance. Initial bathymetry and historical model forcing from 2004 and 2008 was used to simulate varying wave and water level climates, as well as examine responses of different bathymetries. A baseline, no-action case was modeled for comparison.

Short Groin and 80,000 cy Nourishment

The 1 year short groin and 80,000 cy nourishment simulation was similar to the 2009 Case 2. However, this alternative utilized 2004 bathymetric data and model forcings, included an additional 20,000 cy of beach fill, and was run for a 1-year period. The 20,000 cy of additional fill is primarily due to different existing topographic/bathymetric conditions (i.e., 2004 conditions vs. 2009 conditions). Figure 7-21 shows the ending morphological differences between the baseline, no-action case and the alternative. The model showed expected similar performance based on the 2009 Case 2 run. Fill material has moved out of the template area to the east, west, and offshore/cross-shore. Cross-shore transport can be a significant process in the study area due to the ebb shoal feature.

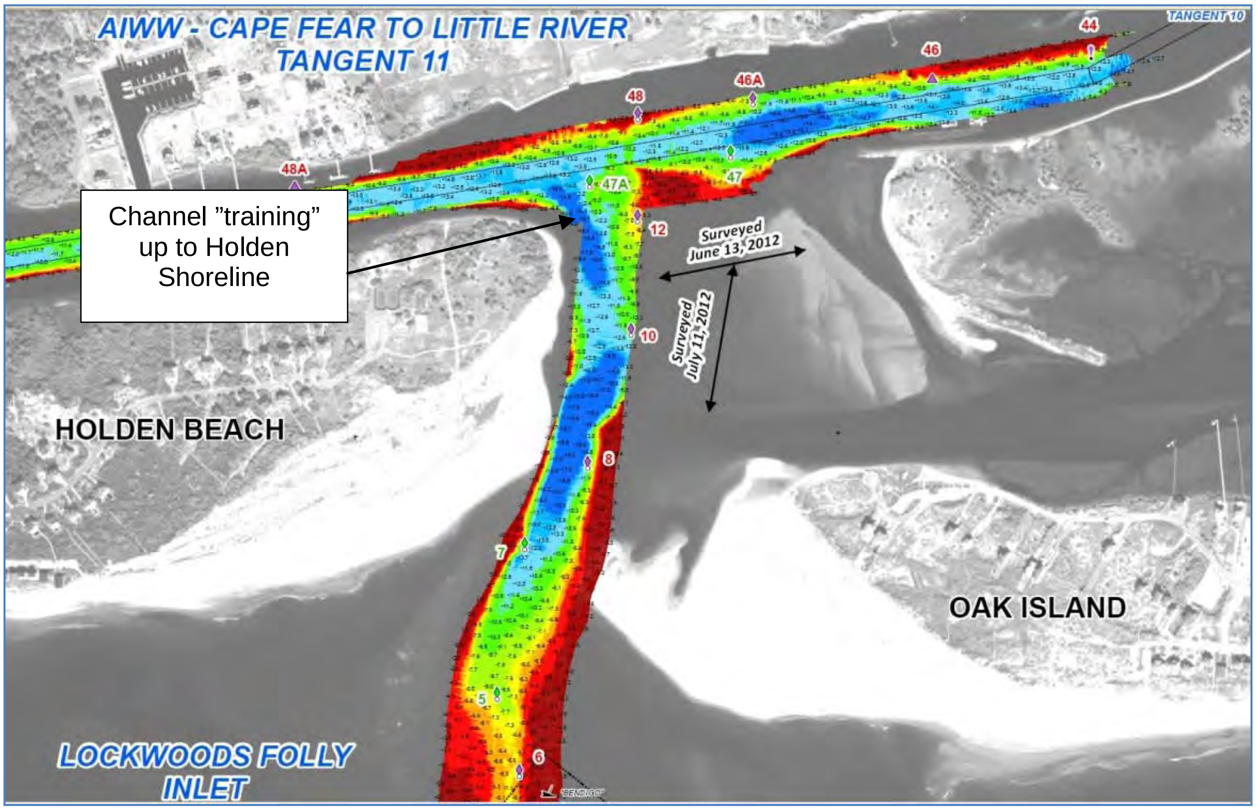


Figure 7-20. June/July 2012 Survey of LWF and the AIWW. Channel seen to be "training up" to Holden Beach, which is also exhibited in the modeling.

Table 7-5. Relative Impact Assessment Results from 190-Day Simulations, Areas 3 and 4.

Alternative	Area 3 Volume Change (cy)	Area 4 Volume Change (cy)
90,000 cy Nourishment	87,327	509
Long Groin Only	45,963	-15,677
Groin and Nourishment	131,887	-15,336
Channel Relocation	-18,674	-18,687
Central Reach Nourishment	30,607	238

Figure 7-21. One-Year Morphological Differences between the No-Action (NA) and Short Groin and Nourishment (SGNR) Cases. Blue=accretion, red=erosion.

Short Groin Without a "T-Head" and 80,000 cy Nourishment

Similar to the previous case, a short-groin-and-nourishment alternative was modeled for 1 year. This case was run under 2008 conditions and compared to the 2008 baseline, no-action case (which is also presented below). The groin design for this alternative does not include a T-Head to investigate any potential negative impacts resulting from the small T-Head feature (see Section 8.1 for more discussion on the T-Head design). Figure 7-22 shows the ending morphological differences between the baseline, no-action case and the alternative. Figure 7-23 and 7-24 show that the T-Head results in no significant impacts differing from the groin design without the T-Head; besides some additional trapping capacity of the T-Heads. The T-Head design is relatively minimal when compared with other more traditional T-Head structures (see Section 8.1 for more discussion) and is designed to minimize rip currents and associated sediment losses. In terms of average currents, the T-Head feature also exhibits negligible differences (typically less than 0.02 m/s) during model simulations.

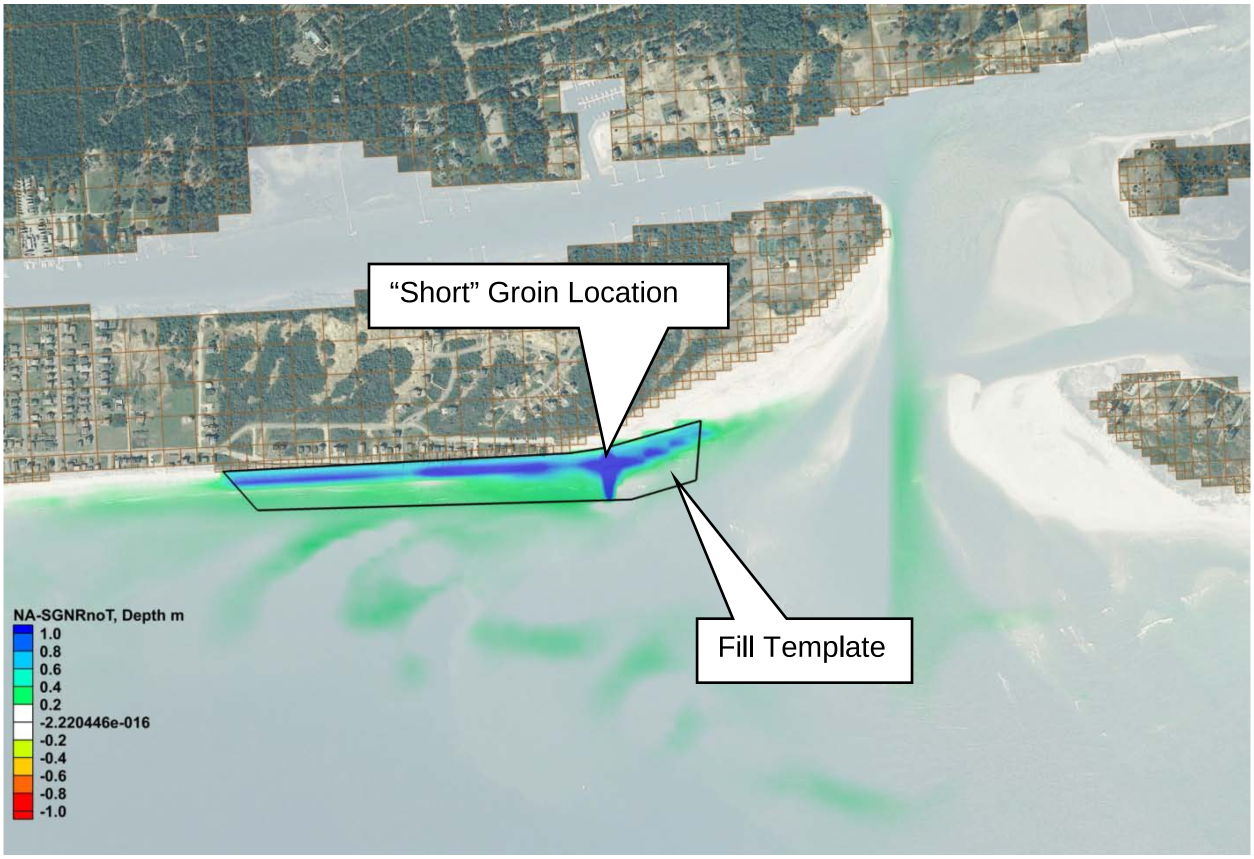
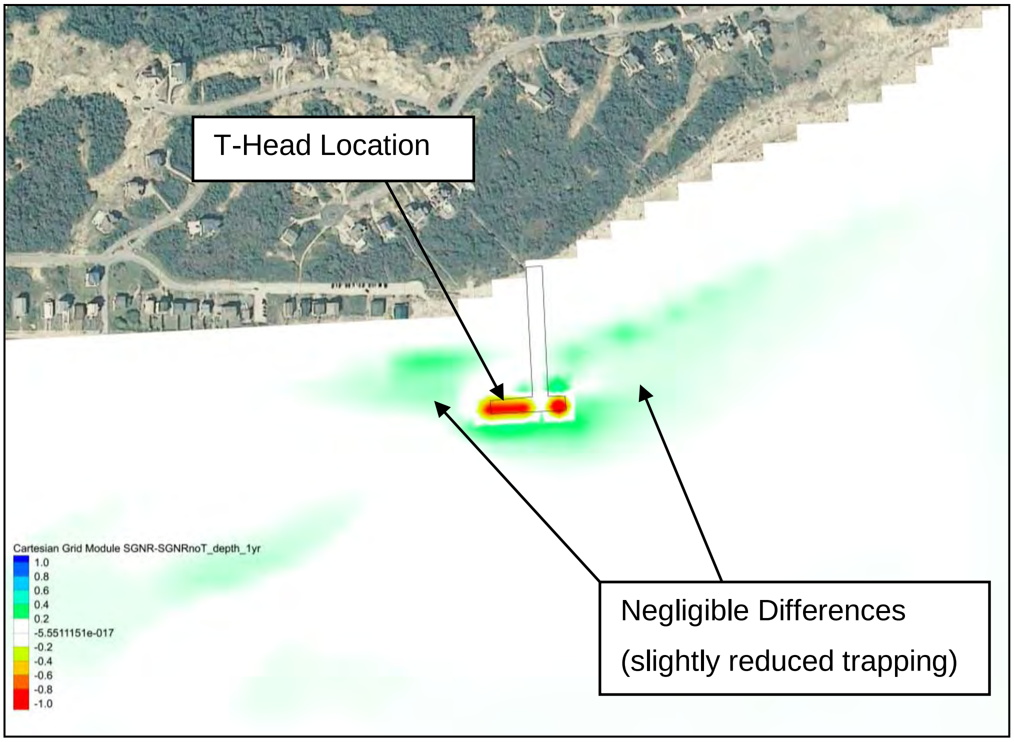


Figure 7-22. One-Year Morphological Differences between the No-Action (NA) and Short Groin and Nourishment (SGNR) "no T-Head" Cases. Blue=accretion, red=erosion.

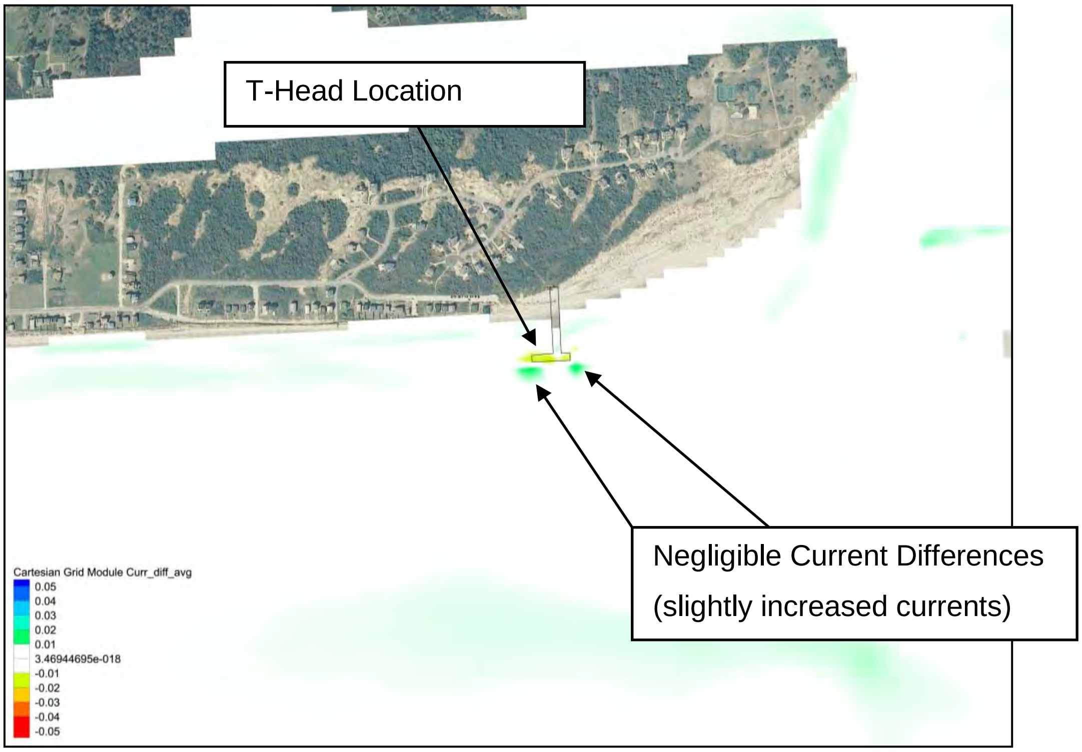


T-Head Location

Negligible Differences

(slightly reduced trapping)

Figure 7-23. One-Year Morphological differences between the Short Groin and Nourishment (SGNR) and SGNR “no T-Head” 2008 Cases.



T-Head Location

Negligible Current Differences

(slightly increased currents)

Figure 7-24. One-Year Average Current Differences (m/s) between the Short Groin and Nourishment (SGNR) and SGNR “no T-Head” 2008 Cases. Average current differences are typically less than 0.02 m/s.

Short Groin, 80,000 cy Nourishment, Bend Widener Borrow Area, and Outer Inlet Channel Relocation

This simulation was similar to the 2009 Case 10. However, this alternative utilized 2008 bathymetric data and model forcings, included an additional 20,000 cy of beach fill, and was run for a 1-year period. Figure 7-25 shows the initial bathymetric conditions, including the dredged borrow area, and filled and relocated channels. In order to relocate the channel, the existing channel was filled for model simulations (essentially representing completely shoaled-in conditions). Figure 7-26 displays ending morphological differences between the baseline, no-action case and the alternative. The model showed expected similar performance based on the 2009 Case 10 run (i.e., the channel relocation and borrow area exert more significant effects on the erosion/accretion processes in the study area).

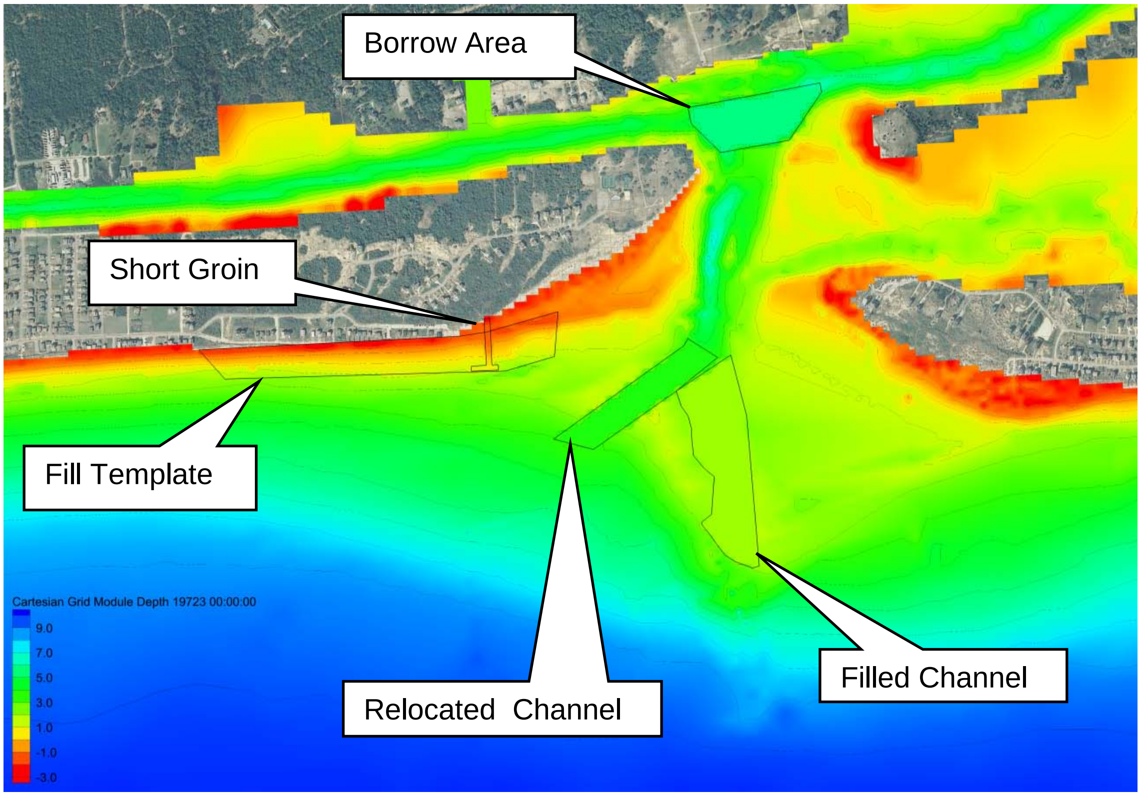


Figure 7-25. Initial Bathymetric Conditions for Short Groin, Nourishment, Inlet Borrow Area and Channel Relocation (SGNRINLBRW) 1-Year Alternative.

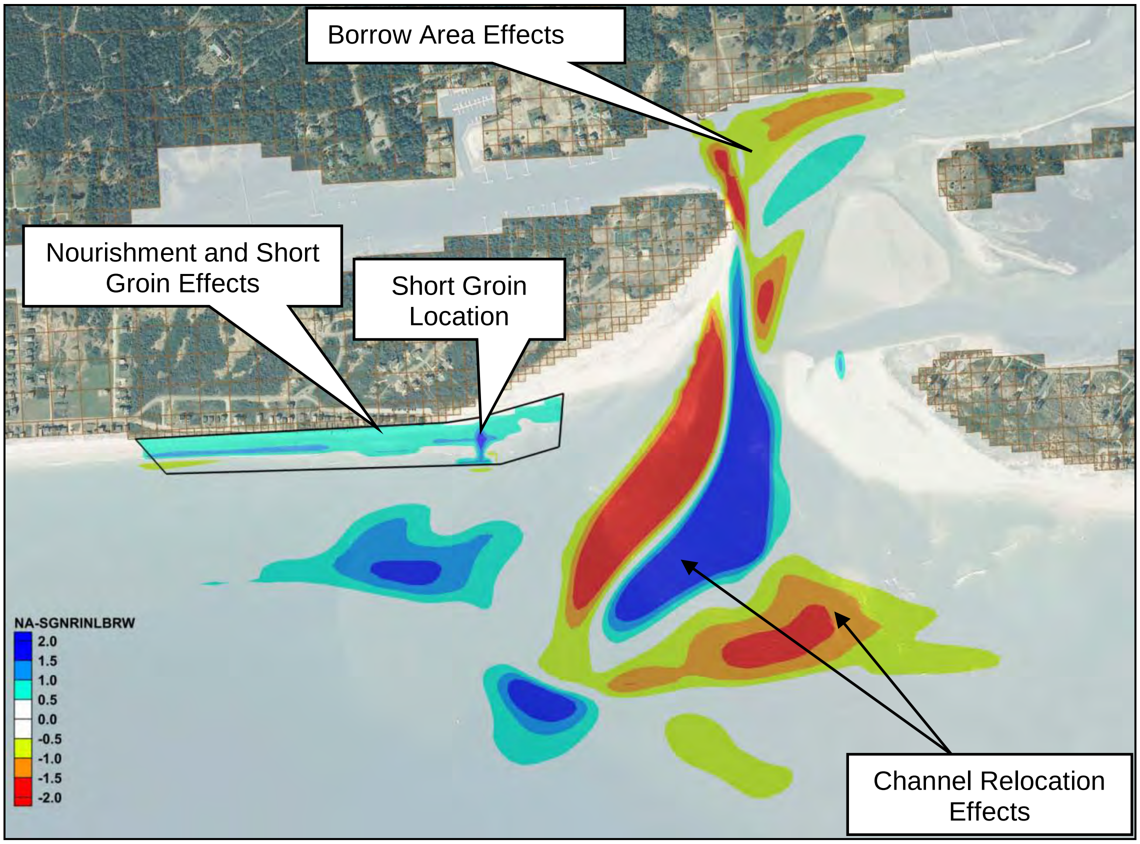


Figure 7-26. One-Year Morphological Differences between the No-Action (NA) and Short Groin/Nourishment/Inlet Borrow Area/Channel Relocation (SGNRINLBRW) Cases.

As seen in Figure 7-26, channel relocation has a significant effect on sediment processes, however, this is relatively temporary and highly variable. USACE maintenance of the outer bar typically occurs every 3 months (assuming funding is available).

Dredged Eastern Channel

An alternative simulating an Eastern Channel dredging case was modeled to investigate any potential impacts or improvements. As discussed in Section 4, realignment of the Eastern Channel as well as dredging of the Eastern Channel has been investigated to improve flushing of LWF River. The 2008 CSE data collection used for CMS model calibration was originally in support of an Eastern Channel dredging project. Figure 7-27 highlights the bathymetric changes (dredge and fill) made to the baseline case. The dredged channel alignment in Figure 7-27 is based on historical channel configurations and was based on the 2009 CSE report.

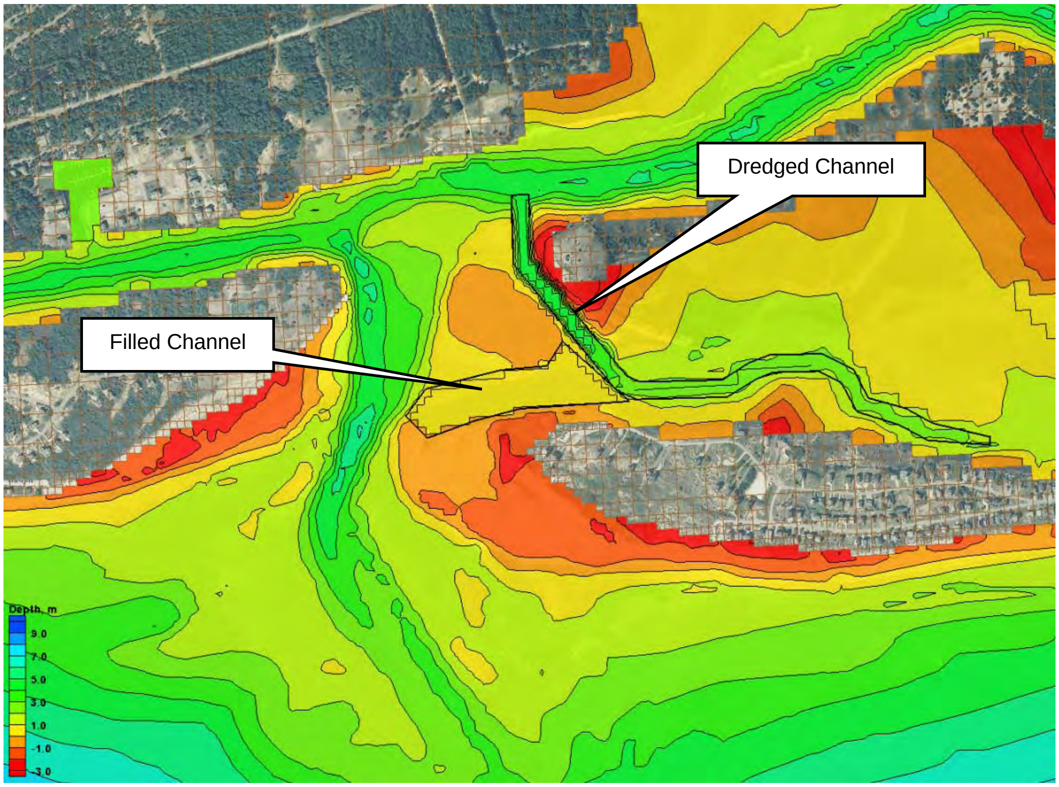


Figure 7-27. Dredged Eastern Channel Initial Bathymetry.

Figure 7-28 shows the morphological differences between the alternative and the baseline, no-action case after 1 year of simulation. It can be seen that the relocated Eastern Channel maintains its depth and shifts the main inlet channel more towards the center of LWF Inlet. The AIWW is also shown to train more to the north where the dredged Eastern Channel meets it past the western end of Sheep Island. While this channel alignment may aid in flushing of the area between Sheep Island and Oak Island, it does not have a significant effect on the adjacent shorelines (i.e., Holden Beach east end as well as Oak Island).

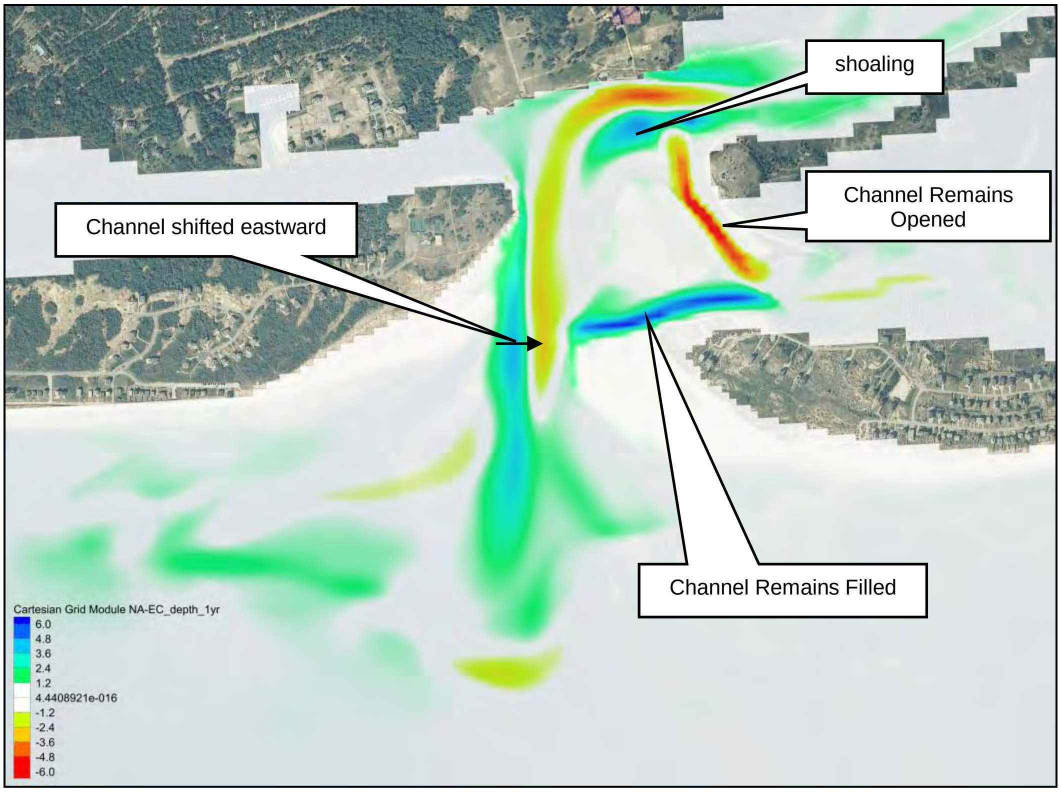


Figure 7-28. One-Year Morphological differences between the No-Action (NA) and Eastern Channel (EC) Cases. Negligible benefits exhibited on the Holden Beach and Oak Island shorelines.

Wide Outer Channel Dredging and 120,000 cy Nourishment

An additional alternative considered included the dredging of a relatively wide and deep channel from LWF Inlet to deep water. The channel, shown in Figure 7-29, is approximately 350 ft wide where it meets the inlet channel and widens to approximately 850 ft when it finally reaches deep water (14 ft MLW) offshore.

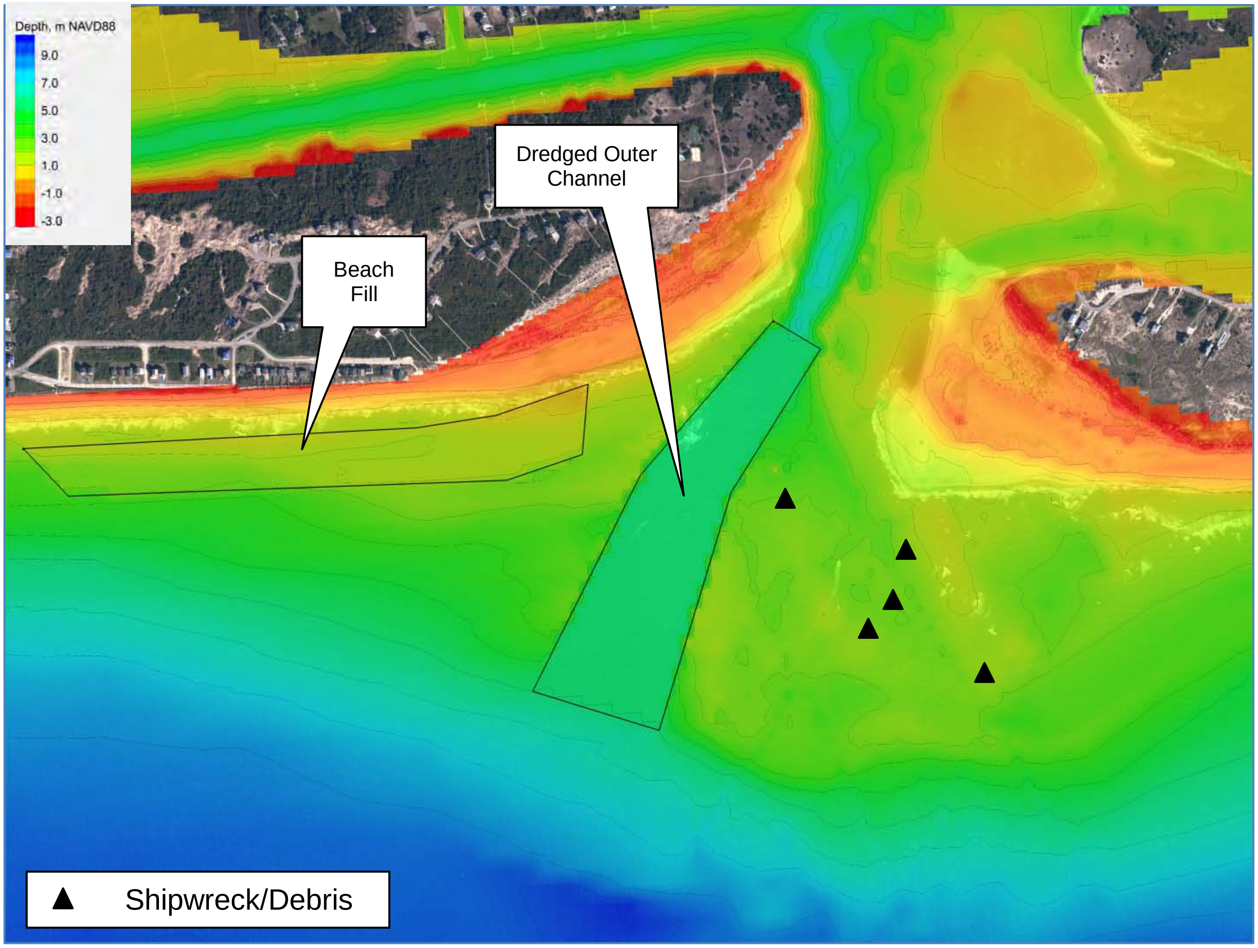


Figure 7-29. Wide Outer Channel Dredging and Nourishment Alternative. Shipwreck/debris locations from NOAA.

This channel alternative design was based on the Shallotte Inlet channel dimensions. The channel alternative was “dredged” to a depth of 14 ft MLW (~5 m NAVD88) and aligned to avoid all shipwrecks of historical significance in the inlet area (see Figure 7-30). Under current conditions and assuming avoidance of historical shipwrecks, a wider and deeper channel similar to Shallotte Inlet would have to be aligned towards Holden Beach.

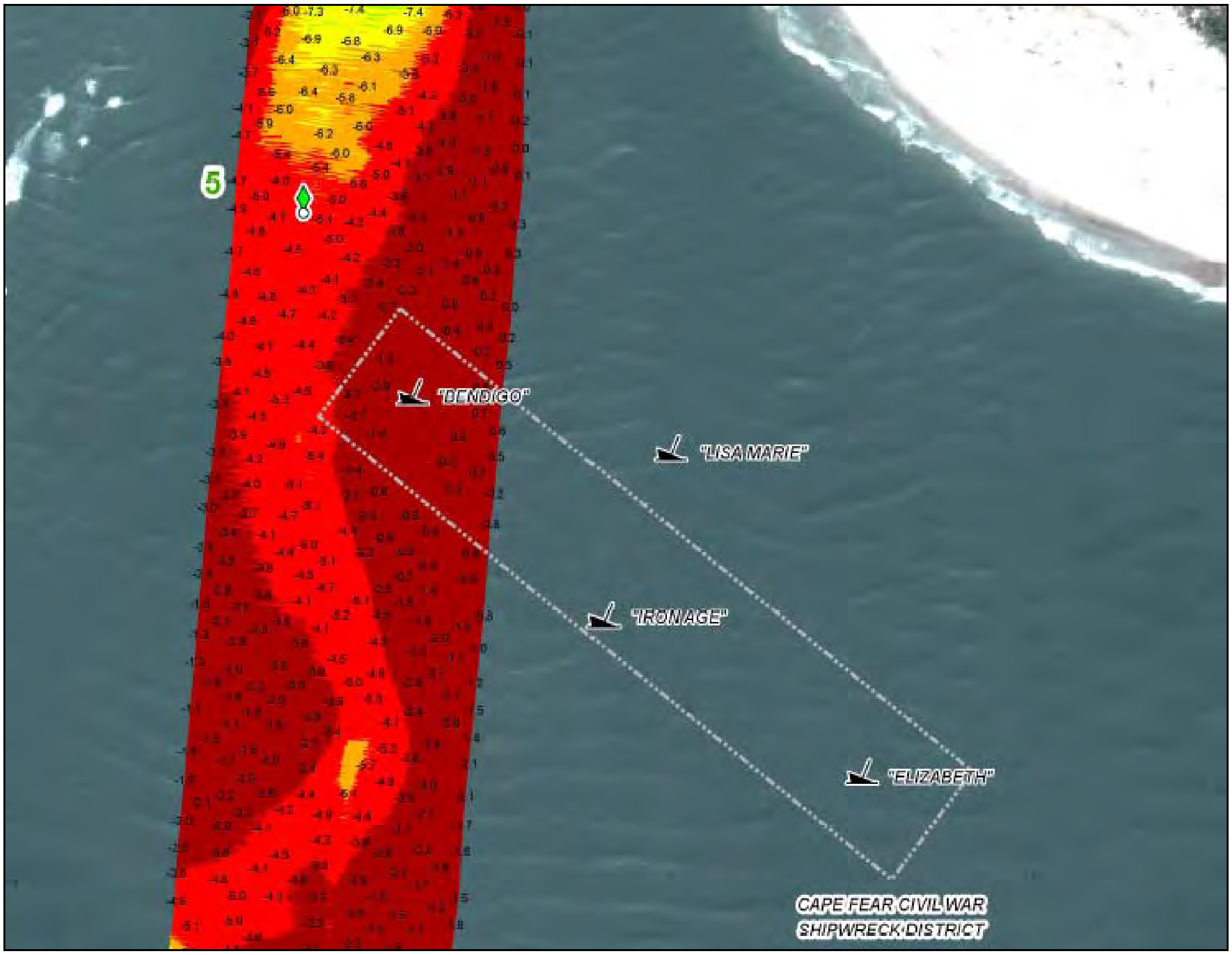


Figure 7-30. Cape Fear Civil War Shipwreck District for LWF Inlet (image source: Nov 2012 USACE Survey). The Lisa Marie is a fishing vessel and not of historical significance.

Approximately 500,000 cy of material is yielded from the excavation of this wide outer channel; however, only a 120,000 cy nourishment was included in the simulation. This was done for more consistent comparison to other nourishment alternatives. Note that the nourishment template has been moved slightly seaward in comparison to previous simulations to ensure all fill material significantly interacts in the sediment transport process. Previous modeling has shown that fill material placed above the approximate spring MHHW line (~1.2 m NAVD88) does not experience a significant level of interaction. Of course movement of material above the spring MHHW line is reduced for all alternatives (nourishment only, groin and nourishment, groin only, etc.); thereby still allowing for effective comparison of alternatives. While more sediment transport is expected above the approximate spring MHHW line, this is in general agreement with the Park et al. (2009) study of nearby Garden City, Myrtle Beach and North Myrtle Beach that showed reduced shoreline variation above the approximate 1.5 m to 2.0 m

NAVD88 contour. Nonetheless, fill and groin templates have been moved seaward slightly to account for this effect in the modeling.

Figure 7-31a shows the morphology change of this alternative after 1 year of simulation. The dredged channel is nearly completely filled in by the end of the simulation. Figure 7-31b presents modeled bathymetry at the end of this 1 year simulation. This alternative is also seen to have significant effects not only to the ebb shoal, but to the AIWW and inland waterways. This is essentially the only alternative that changes the tidal prism of the inlet, where an extended area of the AIWW behind Oak Island is influenced. The LWF inlet has been historically stable and the inlet "throat" remains scoured and deep (up to 20 feet deep at the throat); according to USACE surveys (see Figure 7-20). The wider and deeper channel simulated in this alternative allows more water to flow in and out of LWF Inlet. This results in significant changes to the sediment processes in the AIWW.

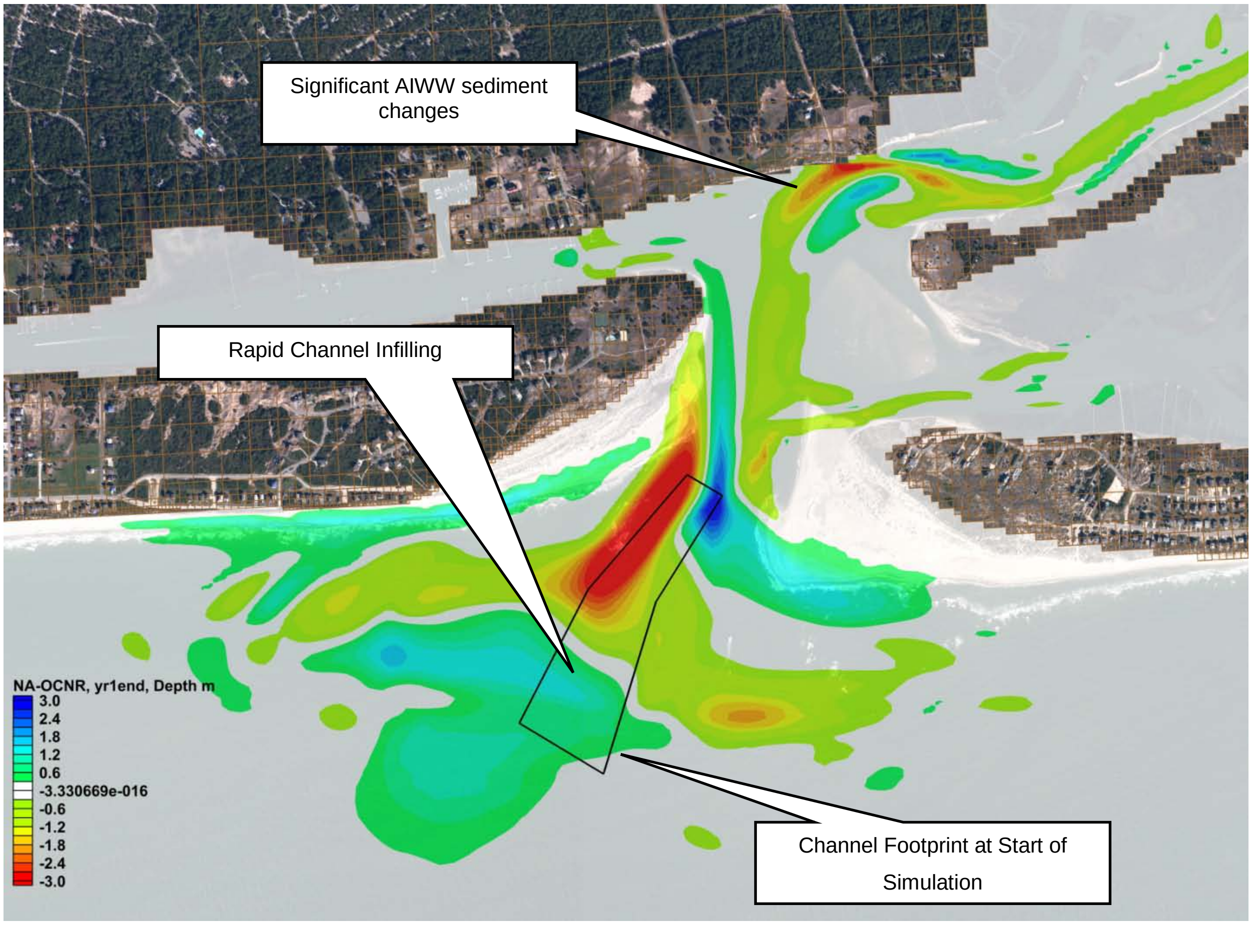


Figure 7-31a. One-Year Morphological Differences between the No Action (NA) and Outer Channel Dredging Case. Note dredged channel nearly completely filled in and significant changes in the AIWW due to the increased tidal prism.

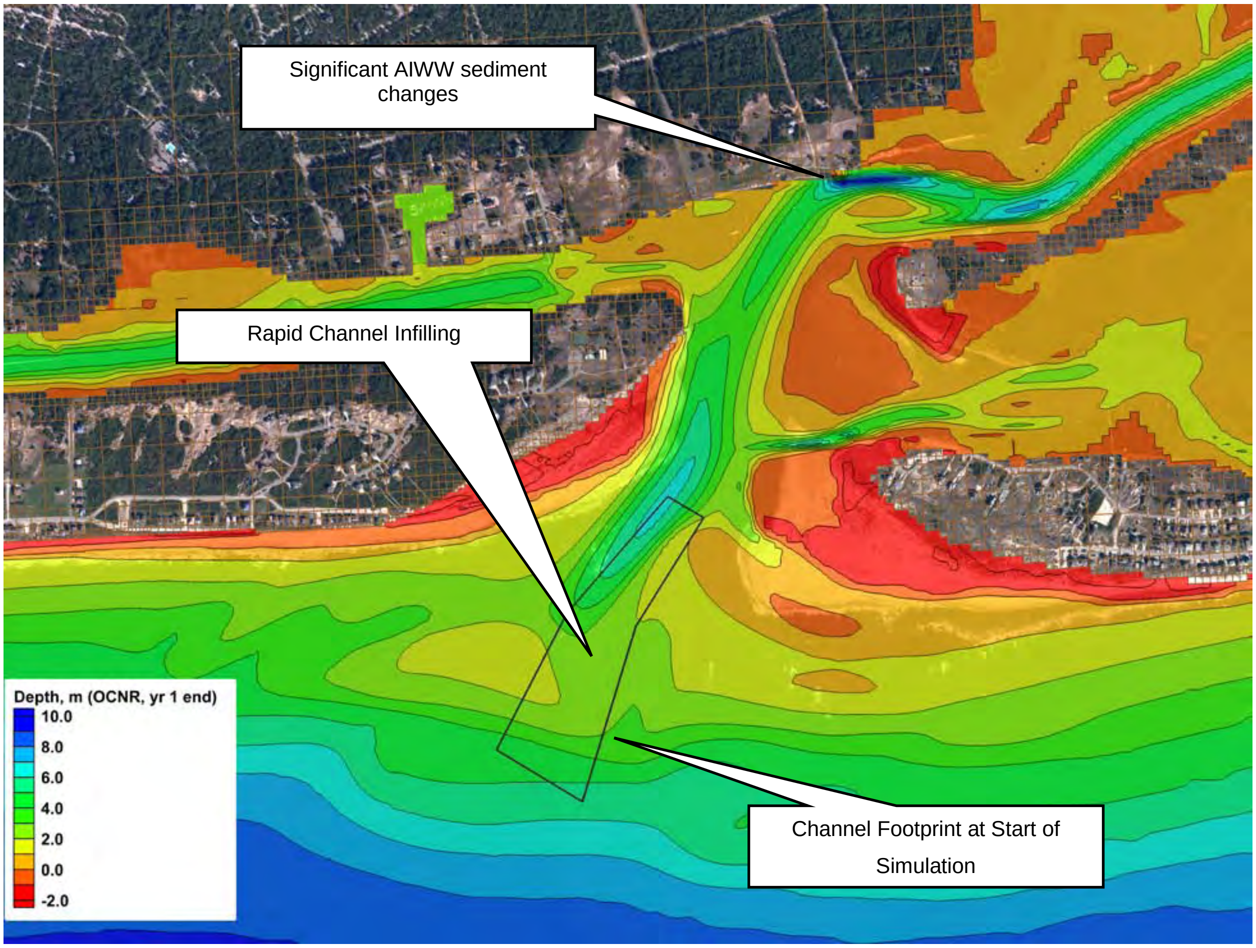


Figure 7-31b. One-Year Bathymetry of Outer Channel Dredging Case (i.e., "wide channel"). Note dredged channel nearly completely filled in and significant changes in the AIWW due to the increased tidal prism.

In general, utilizing large ebb shoal borrow areas is typically discouraged because it can interrupt the natural sediment bypassing process by creating a "sediment trap." Shallotte Inlet ebb shoal dredging has been cited as acting as an "effective sediment trap" (OCTI, 2008). The USACE CASCADE modeling also analyzed several ebb shoal borrow area alternatives in support of the BCB 50-year project for LWF Inlet. In most cases, the use of the ebb shoal as a borrow area was not sustainable. CASCADE modeling for the LWF Inlet ebb shoal concluded that approximately 125,000 cy/yr of material is the approximate upper sustainable limit for long-term use. The BCB 50-year project currently proposes to use Frying Pans Shoals as the sole borrow area (USACE, 2012).

Another key component to the Shallotte Inlet channel project is that the borrow site was cut perpendicular to the shoreline through the inlet's ebb tidal delta. This channel position is expected to be favorable for both shoulders of the inlet (USACE, 2002). This alignment is not possible for LWF Inlet due to the historical shipwreck locations. Because there was some benefit exhibited to the east end and Oak Island shorelines for this alternative, 4-year model runs were conducted for this alternative and are discussed in the following section.

7.2.4.5 Long-Term Model Simulations

Long-term project performance was investigated using the suites of 4-year simulations run under various input conditions and alternatives seen in Table 7-2. Similar to previous runs, by comparing relative effects to the no action case, these simulations help predict longer term morphology, anticipated nourishment frequency and the anticipated decreased frequencies associated with alternatives, as well as any other longer term effects arising from project alternatives.

7.2.4.5.1. Suite 1 Alternatives Configuration

The initial suite of 4-year simulations was completed with the groin and nourishment configurations used in previous model runs. It should be recalled that during these simulations, as with all other CMS model runs, no dredging or nourishment activities were simulated in the middle of a model run. For example, outer channel sidecasting can occur up to four times a year and this activity was not included during an active model simulation.

For the 4-year runs, some AIWW dredging is realistically expected to occur over this time span, however this was not included in the modeling. Consequently, some areas of atypical erosion/accretion (e.g., some infilling in portions of the AIWW) is anticipated, since normal dredging projects would have occurred during the model run. A key benefit of not including some of these ongoing activities in the modeling is to be able to more clearly identify project-related effects. As seen in previous modeling sections, dredging of the AIWW and/or the inlet channel can have a much more significant effect on the ebb shoal and sedimentation patterns, when compared to some east end groin-and-fill alternatives.

Figure 7-32 presents the differences in final depths of the no-action (NA) and nourishment-only (NR) alternatives after the 4-year simulations. It can be seen that the inlet channel moves to a more central part of the inlet for the NR alternative versus the no-action alternative, where the channel tends to train up closer to Holden Beach. This process is related to the fact that no maintenance dredging of the AIWW is occurring during the simulated 4-year run. Considering that the AIWW was cut behind Holden Beach in the 1930s and assuming no maintenance dredging, significant infilling of the AIWW behind Holden Beach or other changes may occur over the long-term.

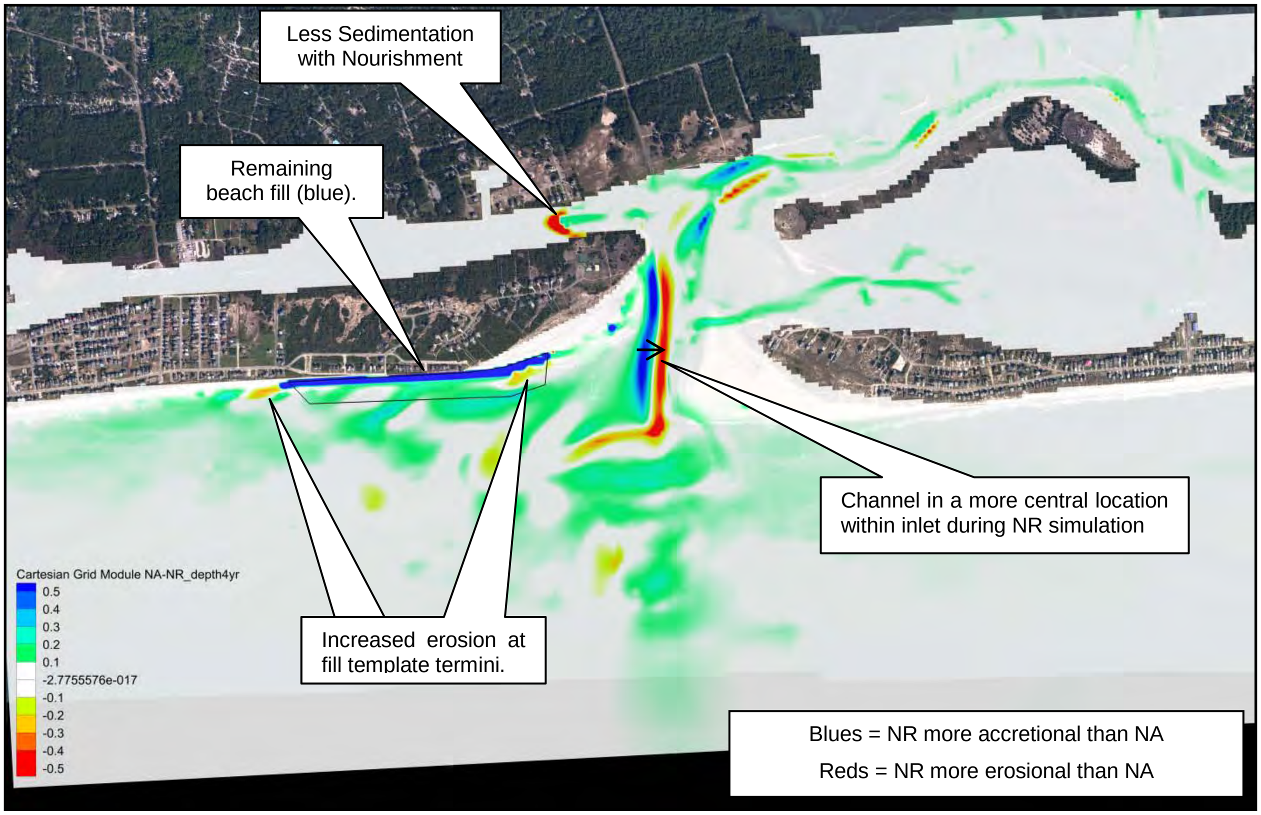


Figure 7-32. Difference in Final Depths (m) for No-Action (NA) vs. Nourishment Only (NR) Alternatives after 4-Year Run. Fill template shown for reference.

In relative terms, some reduced sedimentation is occurring within the AIWW behind Holden Beach for the nourishment-only alternative. This is most likely related to the eastward shift of the inlet channel. Remaining beach fill is also shown in Figure 7-32, along with some increased erosion at the termini of the fill template, as expected. As previously mentioned, the model simulations do not move sediment above the approximate spring MHHW as compared to typical conditions. Consequently, fill on the upper portion of beach [see “remaining beach fill (blue)” on Figure 7-32] remains after the 4-year run when this material historically does not typically remain. Note that Suite 2 and Suite 3 model runs compensate for this effect by shifting the fill template and groin alternatives into more active model sediment transport areas.

The relative impacts of the short groin and nourishment (SGNR) alternative were similar to those of the nourishment-only (NR) alternative with respect to the no-action (NA) case. Therefore, Figure 7-33 presents the differences between the final depths of the nourishment-only and SGNR alternatives. Note that any accretion or erosion shown in Figure 7-33 is in addition to that seen in Figure 7-32, when comparing the SGNR alternative to the no-action case. Figure 7-33 illustrates some areas of sediment trapping, where the groin successfully decreased erosion of the local shoreline (in comparison to the nourishment-only alternative).

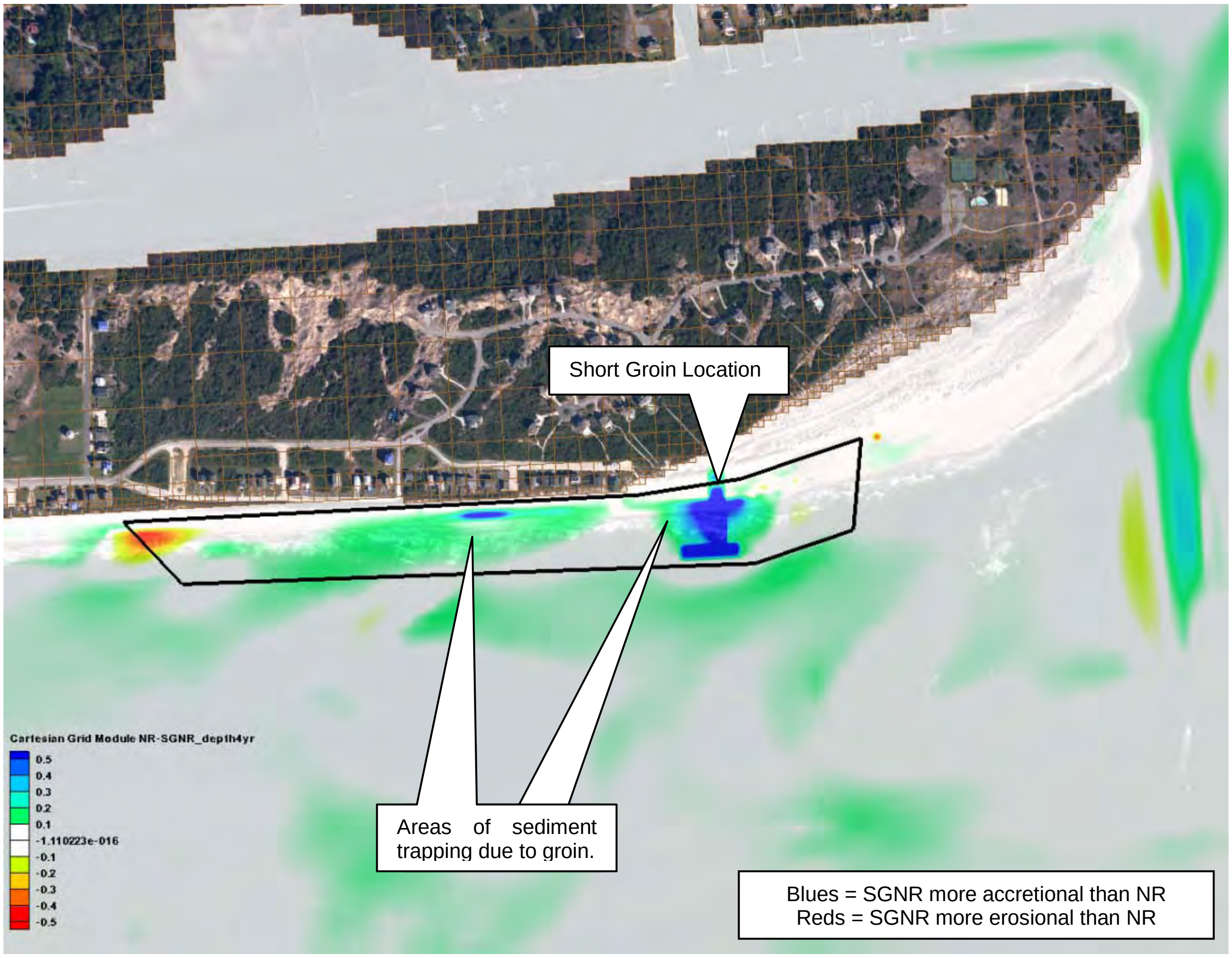


Figure 7-33. Difference in Final Depths (m) for Nourishment-Only (NR) vs. Short Groin and Nourishment (SGNR) Alternatives after 4-Year Runs. Fill template shown for reference.

Figure 7-34 presents the relative impacts of the 4-year long groin and nourishment (LGNR) alternative with respect to the no-action (NA) case. The long-groin alternative is effective at retaining sand whereas the LWF Inlet channel has shifted west (similar to other long-groin runs).

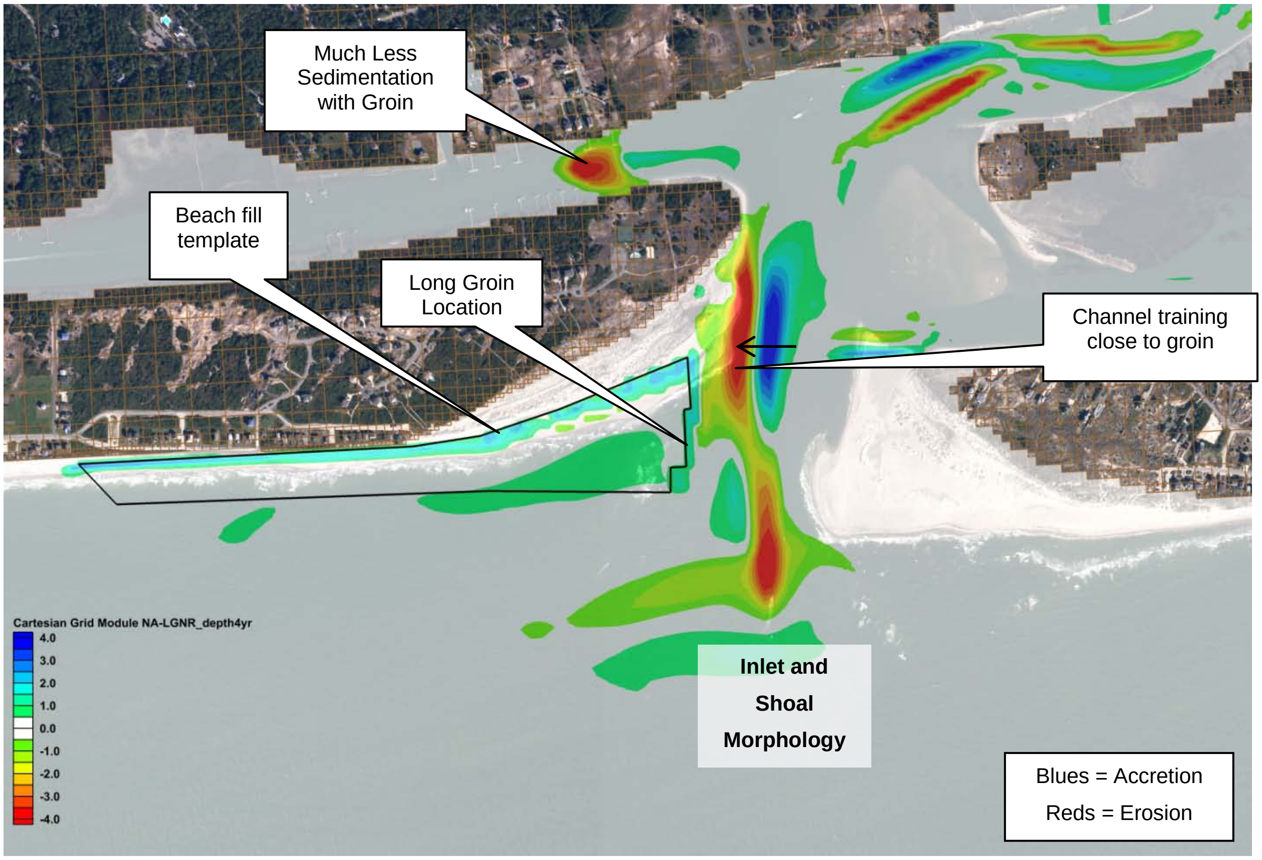


Figure 7-34. Difference in Final Depths (m) for No-Action (NA) vs. Long Groin and Nourishment (LGNR) Alternative after 4-Year Run. Fill template shown for reference.

7.2.4.5.2. Suite 2 Alternatives Configuration

Based on the results of long-term morphology and groin effects exhibited in Suite 1, the groin and fill designs were adjusted to optimize fill placement and groin efficiency for the various alternatives. In general, Suite 2 groin/fill configurations were shifted seaward to allow for more exposure to sediment transport processes occuring below the approximate spring MHHW elevation. In this respect, the “effective” groin length has not changed.

Figure 7-35 compares the final depths of the no-action (NA) and nourishment-only (NR) alternatives after the 4-year simulations. Beach fill has eroded almost entirely, which is expected. Some fill was transported onshore and was able to decrease the erosion in a localized area when compared to the no-action case.

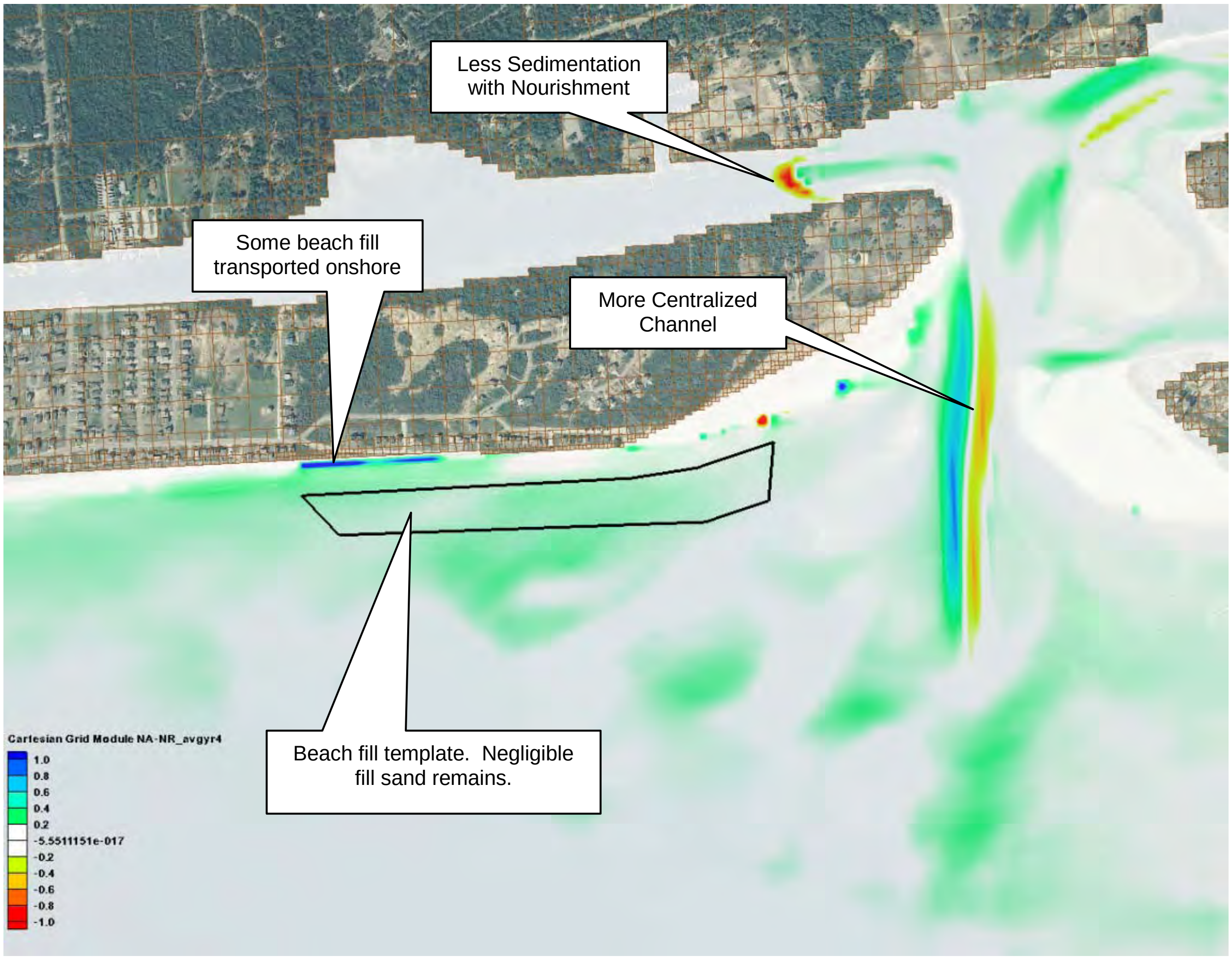


Figure 7-35. Difference in Year 4 Average Depths (m) for No-Action (NA) vs. Nourishment-Only (NR) Alternatives after 4-Year Runs. Fill template shown for reference.

The relative impacts of the short groin and nourishment (SGNR) alternative were similar to those of the nourishment-only (NR) alternative with respect to the no-action (NA) case. Therefore, Figure 7-36 presents the differences between the final depths of the nourishment-only and SGNR alternatives. Recall that any accretion or erosion shown in Figure 7-36 is in addition to that seen in Figure 7-35, when comparing the SGNR alternative to the no-action case. Areas of sediment trapping can be seen, where the groin successfully decreased erosion of the local shoreline.

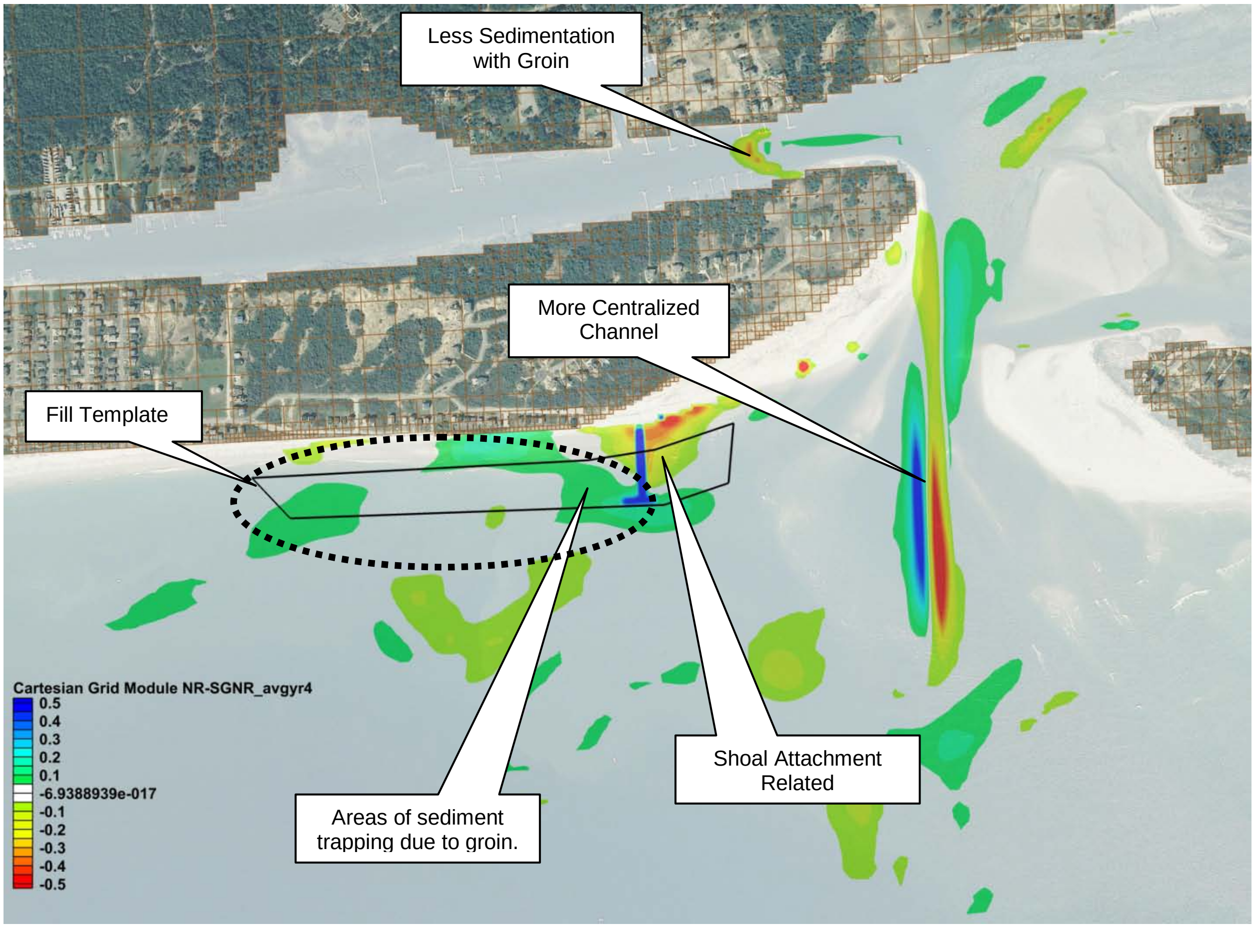


Figure 7-36. Difference in year 4 average depths (m) for Nourishment-only (NR) vs. Short Groin and Nourishment (SGNR) Alternatives after 4-Year runs. Fill template shown for reference.

The area immediately east of the short groin in Figure 7-36 is more erosional than the nourishment-only alternative due a change in the shoal attachment. More discussion on shoal attachments can be found in the next section.

7.2.4.5.3. Suite 3 Alternatives Configuration

Based on results of long-term morphology seen in Suites 1 and 2, a final groin and fill design iteration was prepared that included elements of the first two groin designs (short and long groins). The new Suite 3 groin is known as the "intermediate" groin and Figure 7-37 shows the layouts of all groin alternatives modeled in Suite 3 (i.e., short, intermediate, and long groins). Note that the fill template varies based on the groin modeled. The wide outer channel alternative was also included in this modeling analysis and is presented following the groin alternatives.

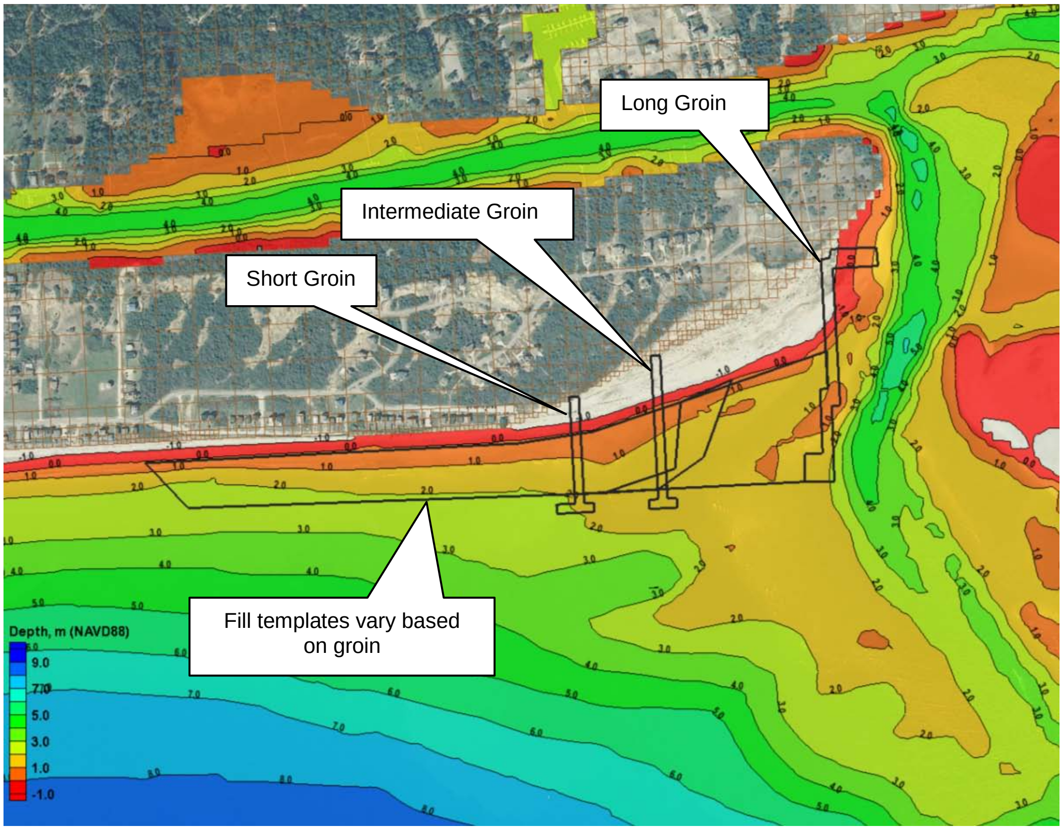


Figure 7-37. Suite 3 Long-Term Alternative Groin/Fill Layouts.

Figure 7-38, shows, as an example, the modeled profile of the intermediate groin. For the intermediate groin, the groin profile is similar to that of the short groin while both extend out the same approximate distance. In fact, the intermediate groin terminates in shallower water than the short groin (under most bathymetric conditions, see Figure 7-37).

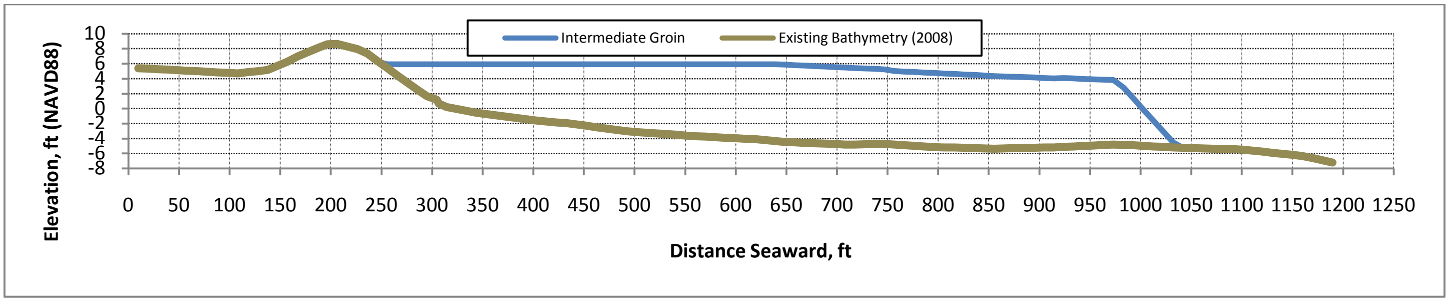


Figure 7-38. Intermediate Groin Profile. Note Exagerated Vertical Scale. Note that the above profile represents the simulated groin. The effective length (i.e. below spring MHHW, or ~4 ft NAVD88) of the modeled intermediate groin is approximately 700 ft.

The intermediate groin was developed based on shoal attachments and general sediment processes that occurred in the modeling. During the modeling, shoal attachments were occurring to the east of the short groin (i.e., towards the inlet). Figure 7-39a presents a recent aerial image that documents a recent shoal attachment while Figures 7-39 (Panes "b" through "d") present the general progression of a shoal attachment process as modeled. The shoal has moved west and is seen attaching on the east end of Holden Beach. This shoal represents approximately 50,000 cy of material. Figure 7-39b through 7-39d occurs over an approximate 12-month time span.

As a result of these shoal attachments, the short groin location was not as efficient in building up the shoreline west of the structure. The Work Plan (ATM, 2011) noted that the final location the proposed terminal groin was subject to change following additional analysis and modeling.

Figure 7-39a. Google Earth Aerial Image from 1/3/2013. Note "bump" in shoreline indicating a recent shoal attachment on the east end (~Station 10+00).

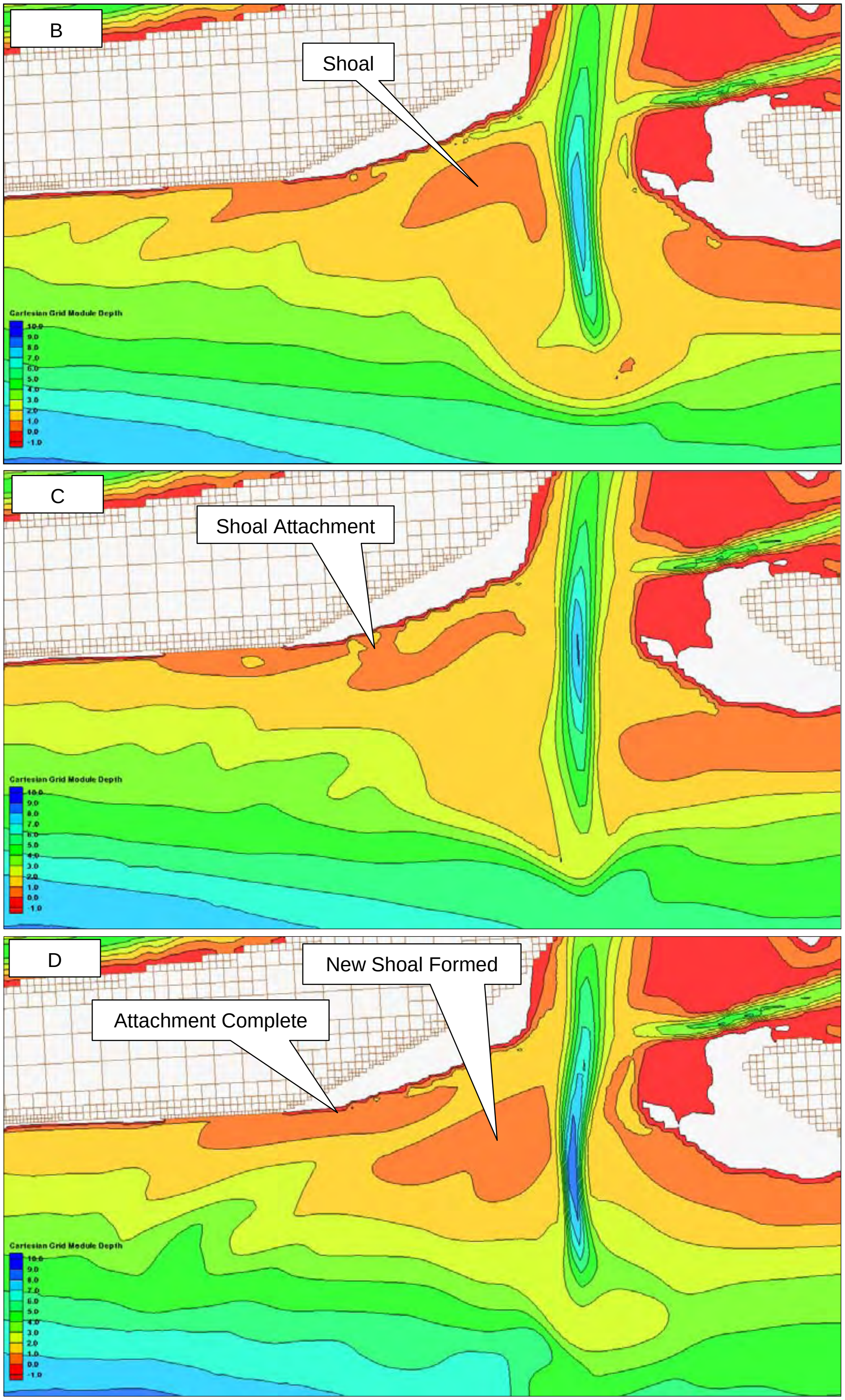


Figure 7-39b, c, d. Shoal Attachment at Beginning (b), Middle (c), and End (d) of Year 3.

Figures 7-40 through 7-43 compare average depths during Year 4 of the simulation of alternatives and the no-action case. Average depths were used to avoid any morphology extremes seen with seasonal changes or episodic events. Note that shoal attachment events occurred during Years 3 to 4 of the simulation. These shoal attachements are beneficial to all alternatives, but also slightly mask additional benefits of the groin alternatives. A thorough impact analysis of these long-term runs can be found in Section 7.2.4.6.

Figure 7-40 shows the nourishment-only effects after 4 years. This illustration is different than a traditional pre-project comparison, where morphology is tracked in relation to the intial condition, rather than undisturbed conditions simultaneously exposed to erosional forces. Trace amounts of additional bathymetry change (greens and blues) seen along the shore are due to the comparison with erosive conditions of the no-action case, a situation that has not been present on Holden Beach since the 1990s. Larger changes are exhibited in the inlet and in the AIWW behind Holden Beach. Historically, the nourishment-only alternative has had beneficial effects to the east end shoreline for about 2 years only (depending on fill volume, nearby projects, etc.).

All three groin alternatives shown in Figures 7-41 to 7-43 exhibit a benefit to the nourishment-only alternative. Sedimentation in the AIWW is reduced for all groin alternatives, while some variation is exhibited in the inlet channel location. These simulations do not include the bend widener borrow area; however, previous simulations showed the bend widener component has a significant effect on channel location. In general, the short-groin and the intermediate-groin alternatives that include a nourishment are the most favorable in terms of minimizing downdrift impacts. The long-groin alternative is the least favorable in terms of downdrift impacts.

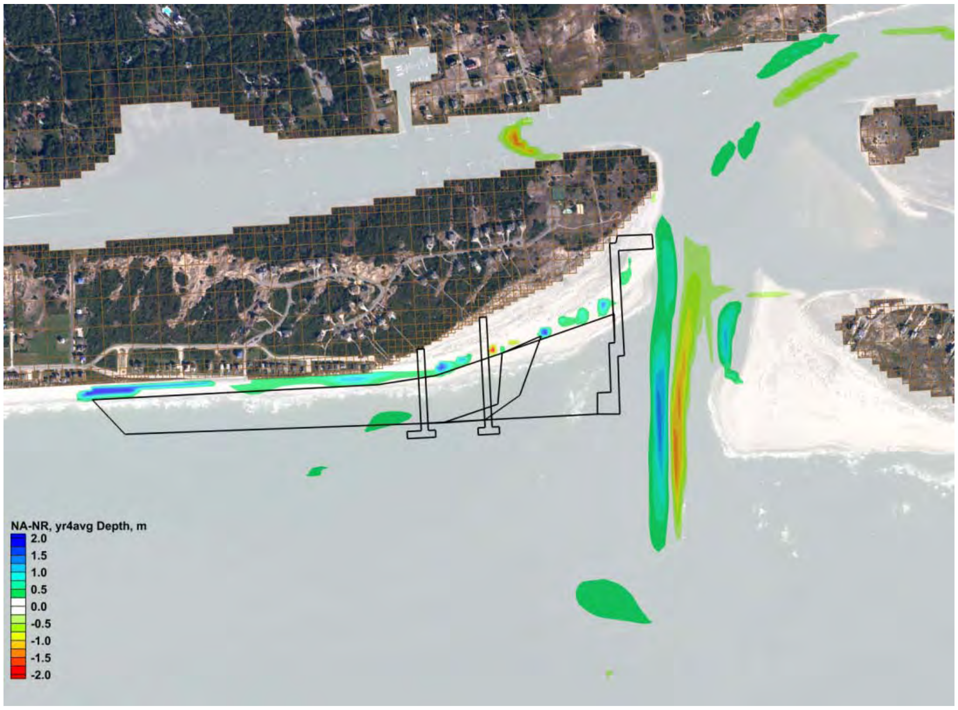


Figure 7-40. *Nourishment-Only (NR) Year 4 Average Depths Relative to No-Action (NA). Essentially all nourishment sand has eroded away. Fill and groin templates shown for reference.*

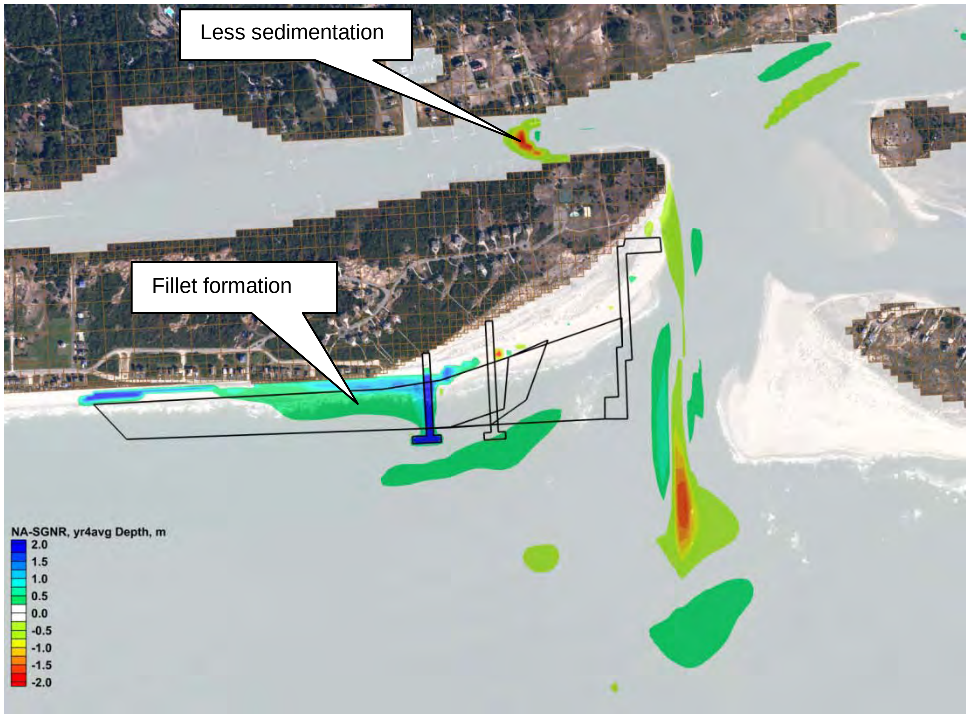


Figure 7-41. *Short Groin and Nourishment (SGNR) Year 4 Average Depths Relative to No-Action (NA). Fill and groin templates shown for reference.*

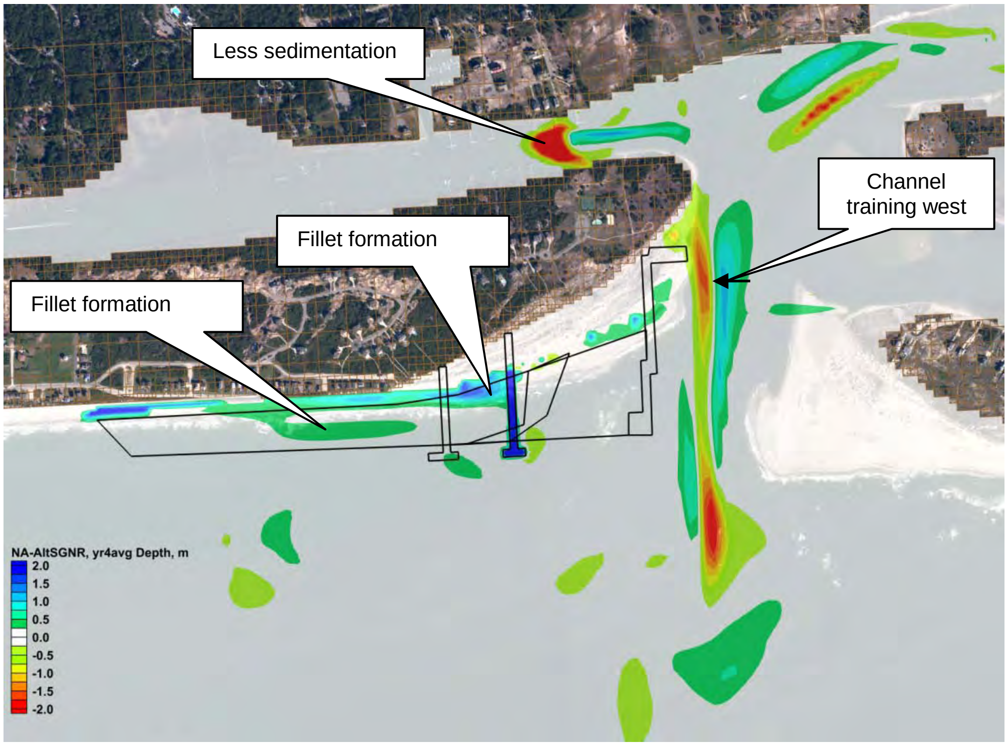


Figure 7-42. Intermediate Groin and Nourishment Year 4 Average Depths Relative to No-Action. Fill and groin templates shown for reference.

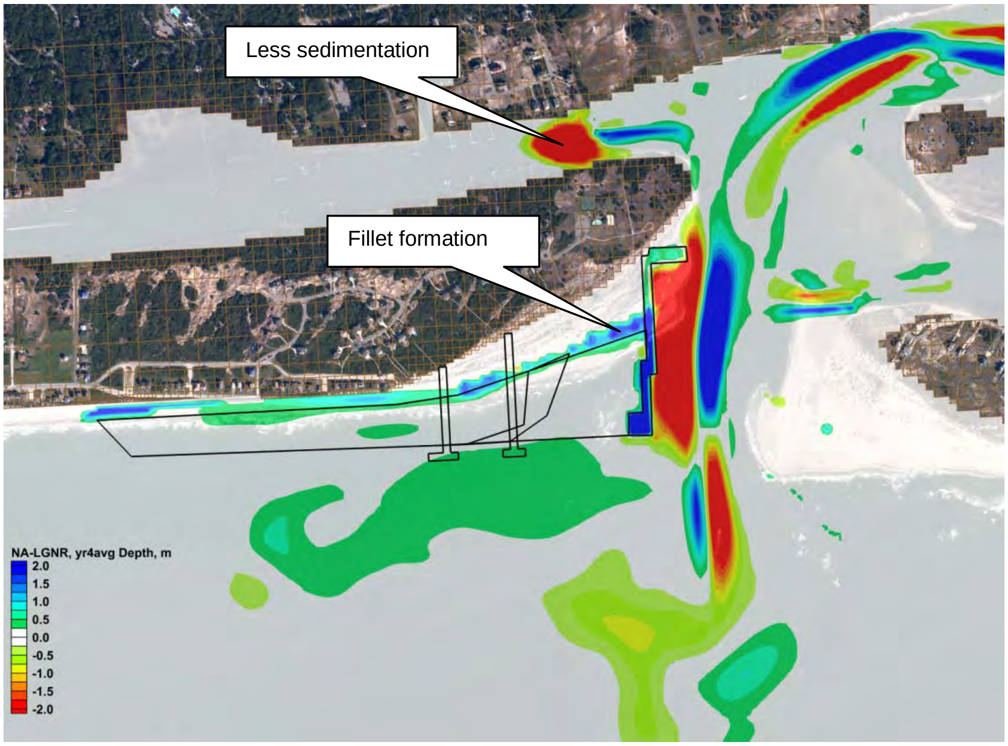


Figure 7-43. Long Groin and Nourishment Year 4 Average Depths Relative to No-Action. Fill and groin templates shown for reference.

Figures 7-44 through 7-47 show the average depths in Year 4 of the groin alternatives. The sediment trapping ability of the groins is apparent, even in Year 4 of the project alternatives. These figures are not relative to no-action and fillet formation is evident. In addition to the typical groin/nourishment alternatives, Figure 7-45 presents the intermediate groin without an accompanying nourishment in order to assess individual component effects.

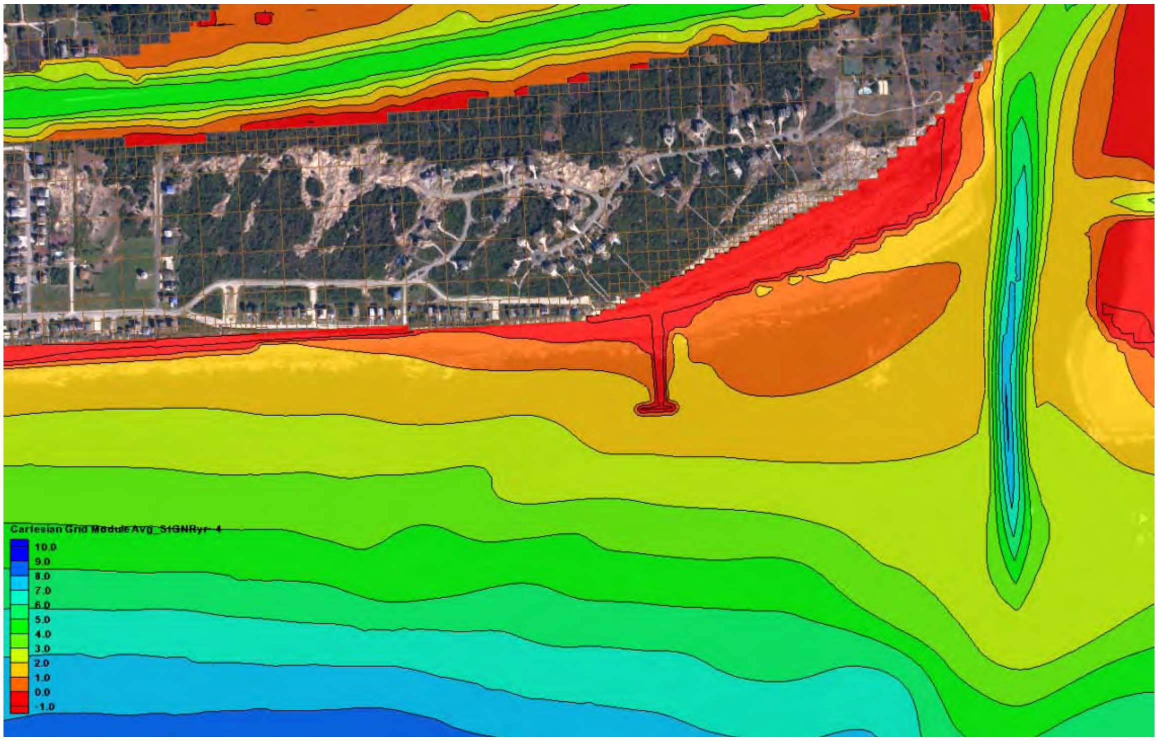


Figure 7-44. Short Groin and Nourishment Year 4 Average Depths.

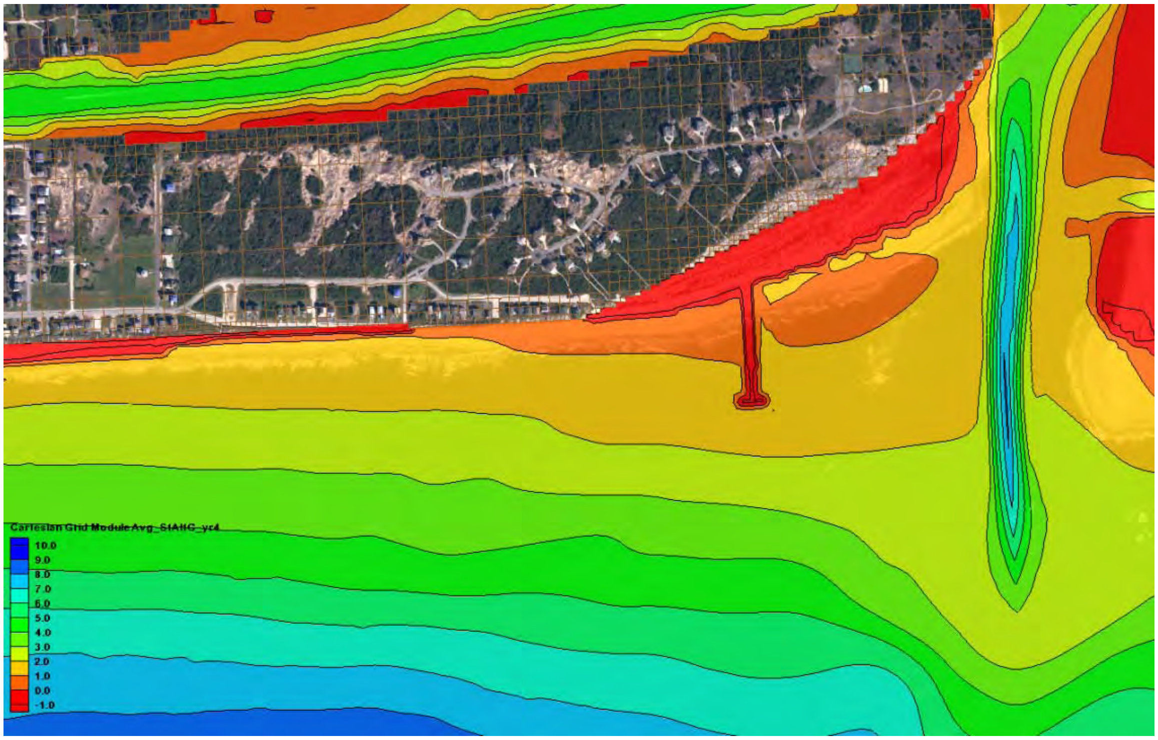


Figure 7-45. Intermediate Groin Only (i.e, no nourishment) Year 4 Average Depths.

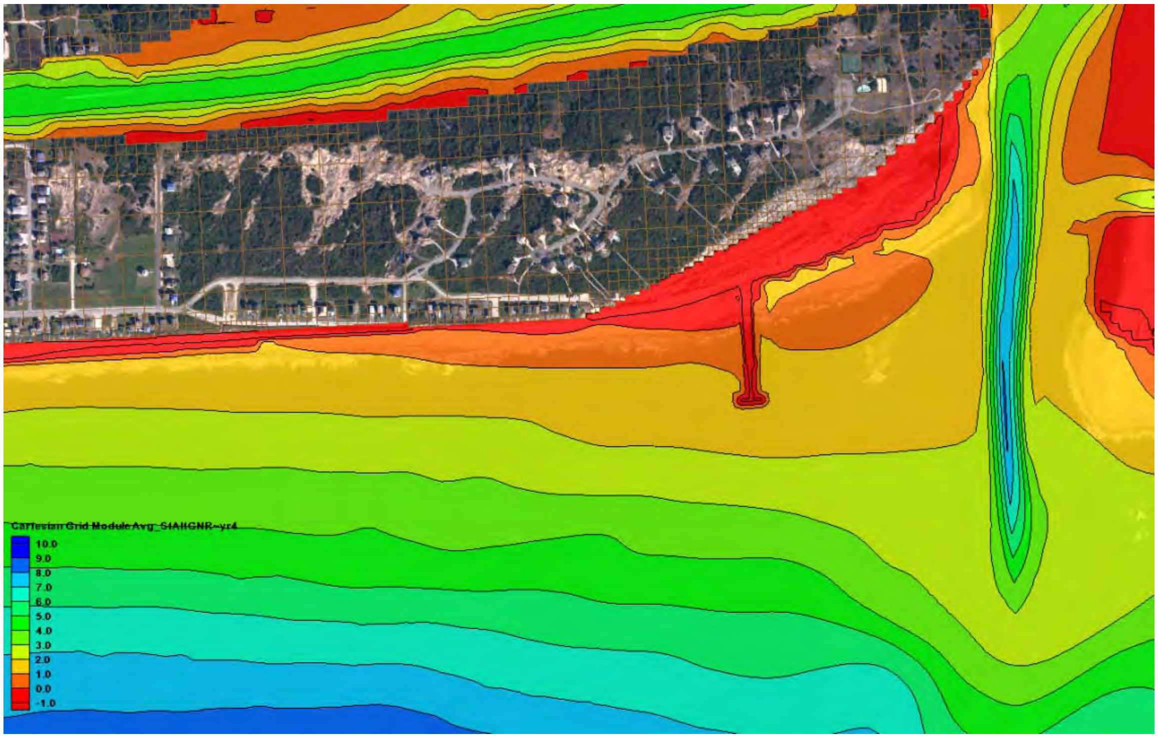


Figure 7-46. Intermediate Groin and Nourishment Year 4 Average Depths.

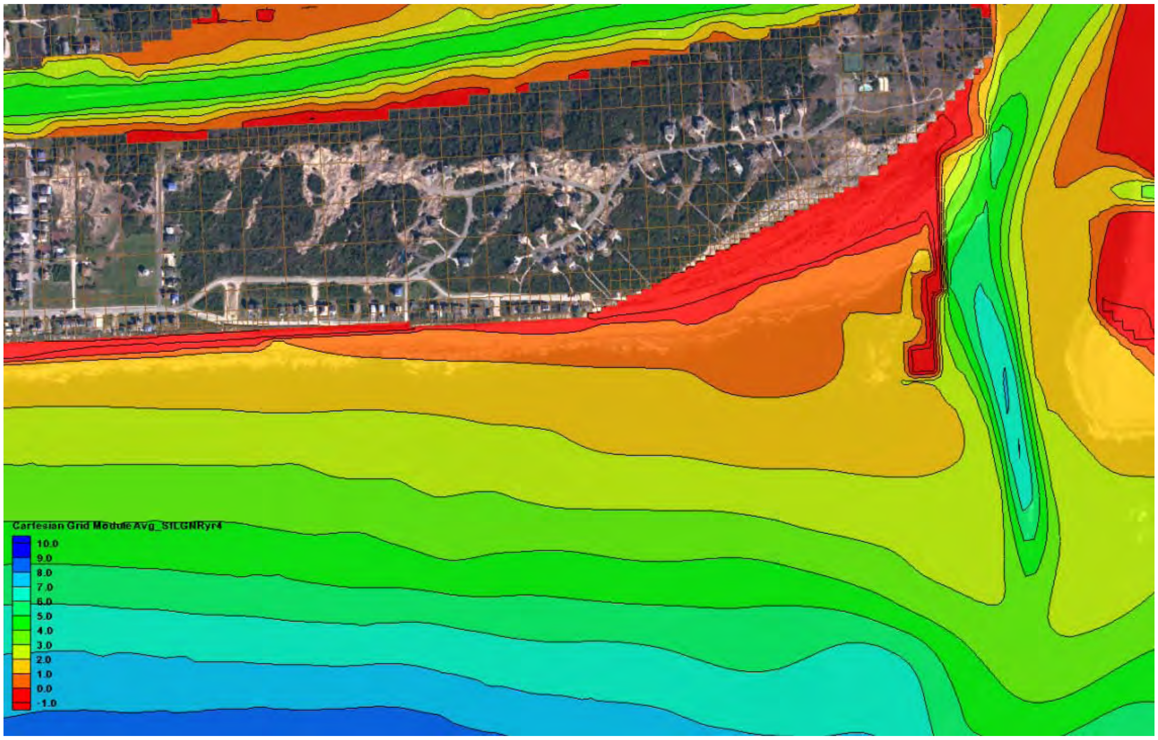


Figure 7-47. Long Groin and Nourishment Year 4 Average Depths.

Wide Outer Channel Alternative

As discussed in Section 7.2.4.4, the wide outer channel alternative exhibited the most extreme changes to the AIWW and estuarine system for the 1 year alternative simulations. However there was also some benefit to the Holden Beach east end and the Oak Island shoreline. As a result, this alternative was simulated for 4 years and results are presented in the below figures. Figures 7-47a and 7-47b present the wide channel alternative relative to the no-action alternative at the 3 and 4 year intervals, respectively. Some positive effects to Holden Beach and Oak Island ocean shorelines are still exhibited; however estuarine effects remain significant. Erosion of the Holden Beach LWF Inlet shoulder shoreline is also exhibited.

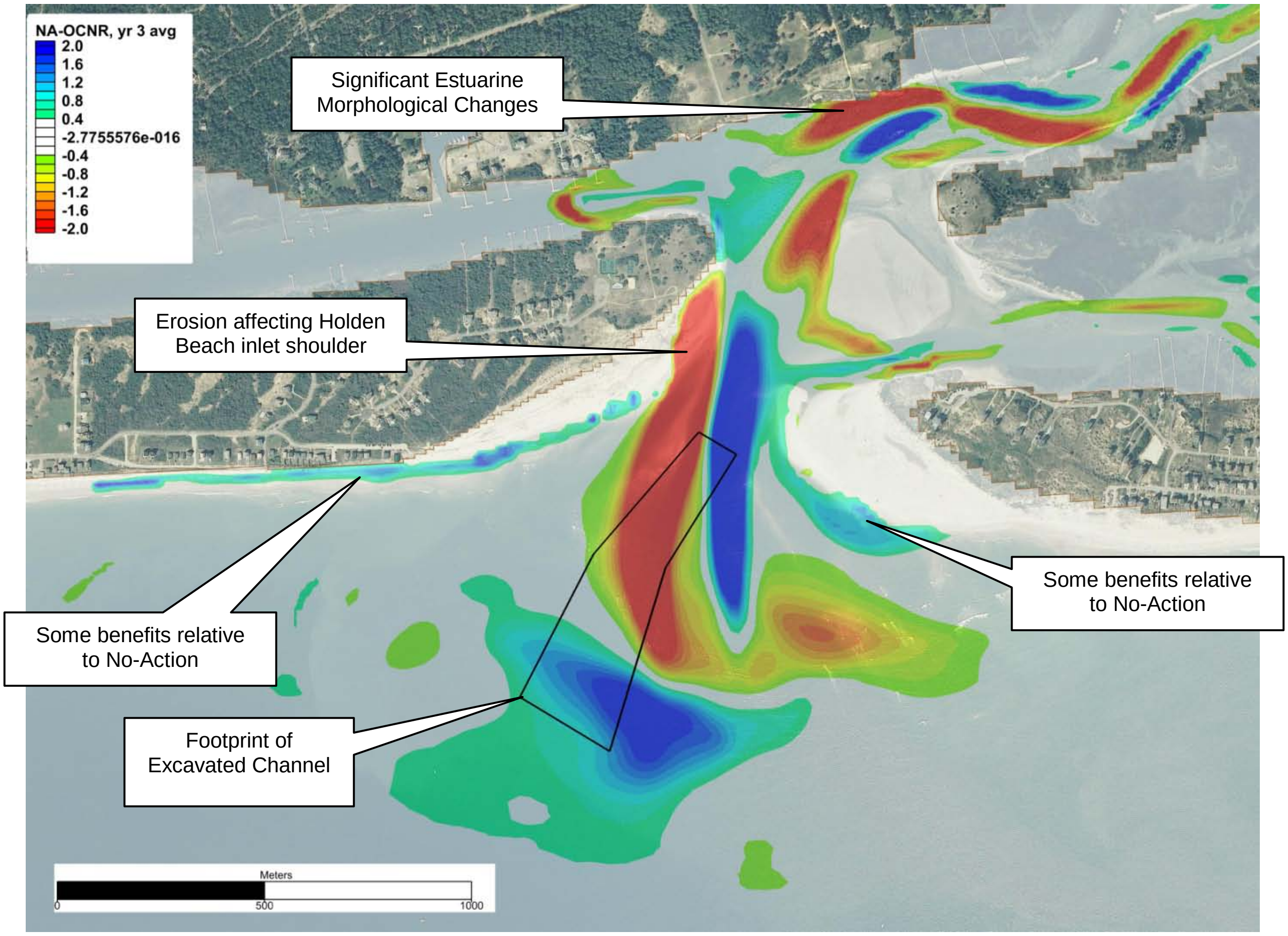


Figure 7-47a : Wide outer channel and Nourishment Year 3 Average Depths Relative to No-Action.

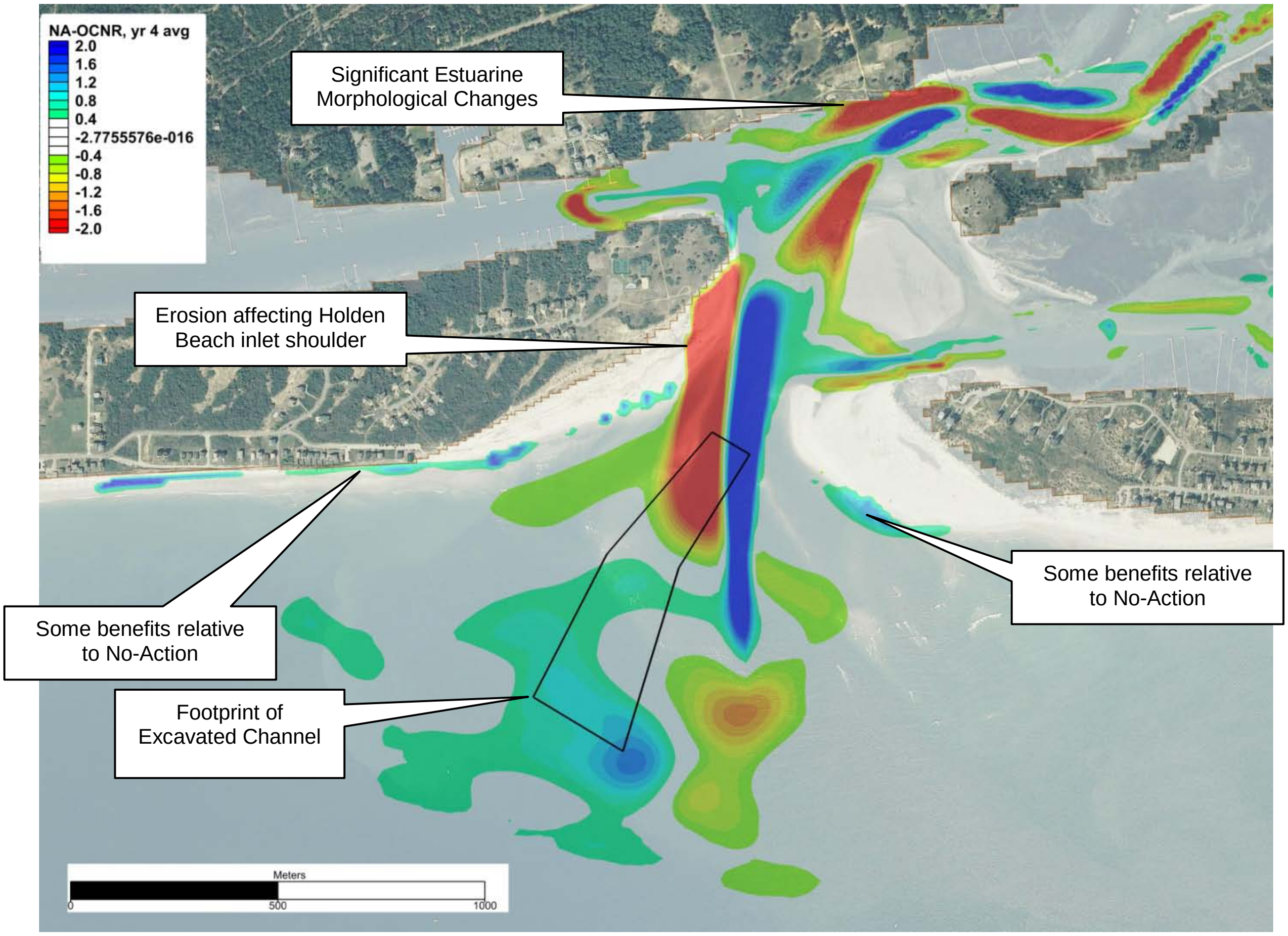


Figure 7-47b : Wide outer channel and Nourishment Year 4 Average Depths Relative to No-Action.

In general, the wide outer channel alternative produced generally less positive impacts on the east end of Holden Beach compared to other alternatives. In addition, significant morphological impacts were seen in the inlet, ebb and flood shoals, and AIWW relative to the no action and other proposed alternatives. This is due to the fact that the wider outer channel alternative is allowing significantly more water into the estuarine system and is increasing the area of influence for this inlet relative to adjacent inlets. According to measured flows, approximately 80 percent of total LWF flow is to the east, therefore an increase in the amount of water into the inlet would be expected to change this area (i.e., the AIWW behind Sheep Island) the most. Model results confirm this effect.

Rapid dredged channel infilling was also observed, therefore there is no long-term navigational benefit either. Figure 7-47c presents year 4 average depths for the wide outer channel alternative. In addition to rapid infilling, the channel is also meandering back to the east where the historical shipwrecks occur. While the existing outer channel (150 ft wide, 8 ft deep) has been known to affect the historical shipwrecks due to its meandering, it is anticipated that the wide outer channel alternative (350 ft wide, 14 ft deep) could have a much more detrimental effect on these historical shipwrecks.

As previously mentioned, this wide channel alternative is based on the existing Shallotte Inlet outer channel borrow area. While this borrow area strategy has helped to offset erosion on the east end of Ocean Isle, the Town of Ocean Isle is still investigating the need for a terminal groin. Therefore the wide outer channel alternative has not been a successful replacement to a terminal groin project at Shallotte Inlet and it is not expected to for LWF Inlet either.

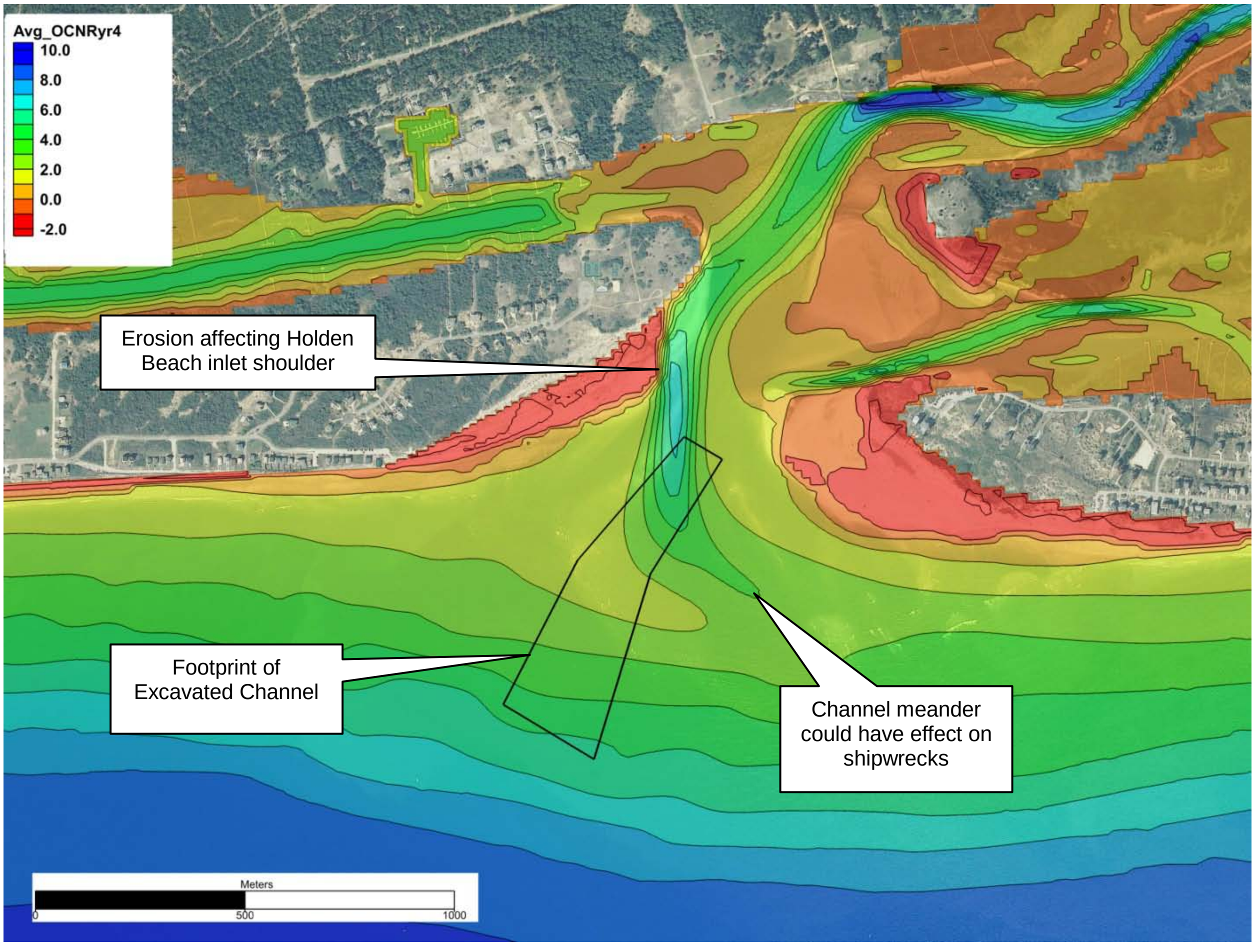


Figure 7-47c : Wide outer channel Year 4 Average Depths.

7.2.4.6 Relative Impacts of Long Term Alternatives

The relative impacts analysis of long-term simulations focused on Suite 3 as analyses revealed them to be the most effective of the alternative designs. Beach renourishment interval, shoreline change, and sediment transport investigations were performed to compare the long-term relative impacts of all alternatives. Sediment transport investigations were performed for long-term Suites 1, 2, and 3 for comparison.

Long Term Beach Renourishment Interval Analysis

Figure 7-48 illustrates a possible nourishment schedule scenario comparing the nourishment-only and intermediate-groin-and-nourishment alternatives. These nourishment schedules are based upon the erosion rates simulated for each alternative and assume 100,000 cy renourishments after the initial project (120,000 cy). Since the nourishment-only alternative erodes faster than the groin alternative, Figure 7-48 shows that the nourishment-only alternative is anticipated to occur every 2 years whereas the intermediate-groin-and-nourishment alternative is anticipated to occur every 4 years. The project schedule of the groin/nourishment alternative results in substantial savings over the shown 40-year timespan by reducing 20 nourishment-only events to 10 nourishment events with the intermediate-groin constructed. Figure 7-48 also shows the nourishment only and groin/nourishment volume plots slowly diverging. Assuming the nourishment schedules shown, this implies the nourishment only alternative will slowly lose beach volume (without increased beach fill volumes or project frequency) while the intermediate-groin-and-nourishment alternative will actually grow the beach over time. The benefits of decreased nourishment frequencies provided by the groin are discussed further in subsequent sections.

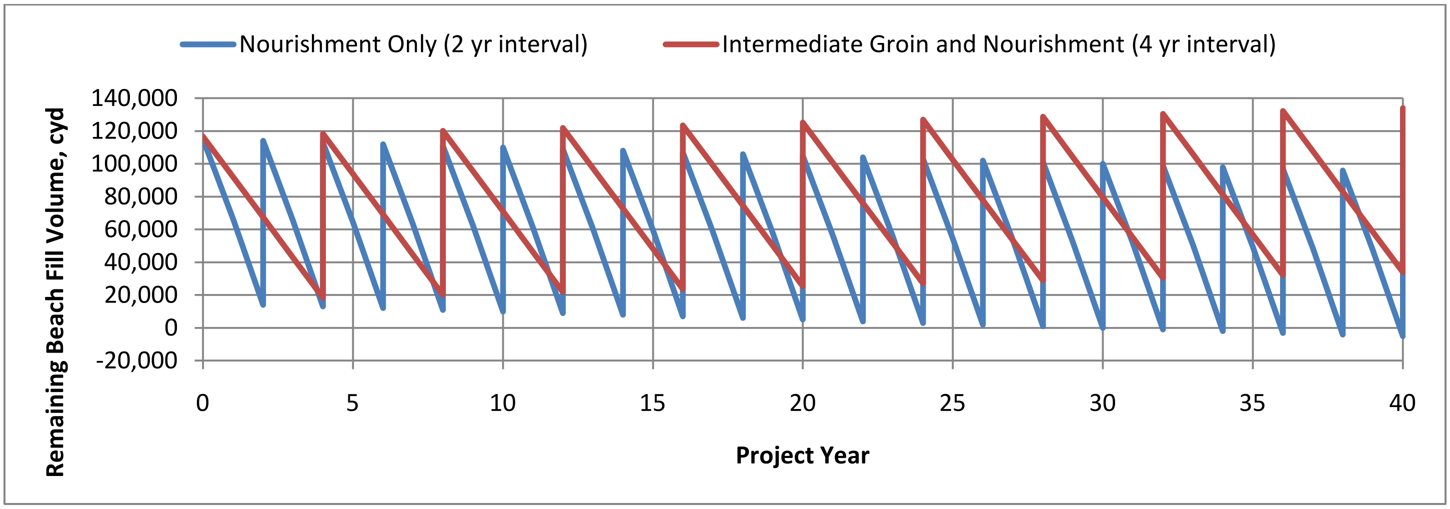


Figure 7-48. Potential Beach Volumes and Nourishment Schedules Based on Decreased Groin Alternative Nourishment Frequency.

An additional benefit provided by the groin alternatives is reduced infilling (and subsequently reduced dredging costs) of the AIWW behind Holden Beach. Figure 7-49 illustrates depth differences between the intermediate groin/nourishment and no-action cases after 1 year of simulation. The model shows that the groin alternative reduces sediment deposition within the noted area of the AIWW by about 16,000 cy in the first year. It is noted that reduced sediment deposition also occurs with the nourishment-only alternative; however, this value is much less (about 4,000 cy in the first year).

Note that in Figure 7-49, there is some scour on the seaward tip of the groin. This effect is known to occur at existing groins, however, it is temporary and is not exhibited in the 4-year average figures. This effect is related to shoal bypassing/attachments and localized currents. The groins are modeled as impermeable, therefore the simulations are likely conservative in predicting scour in this area.

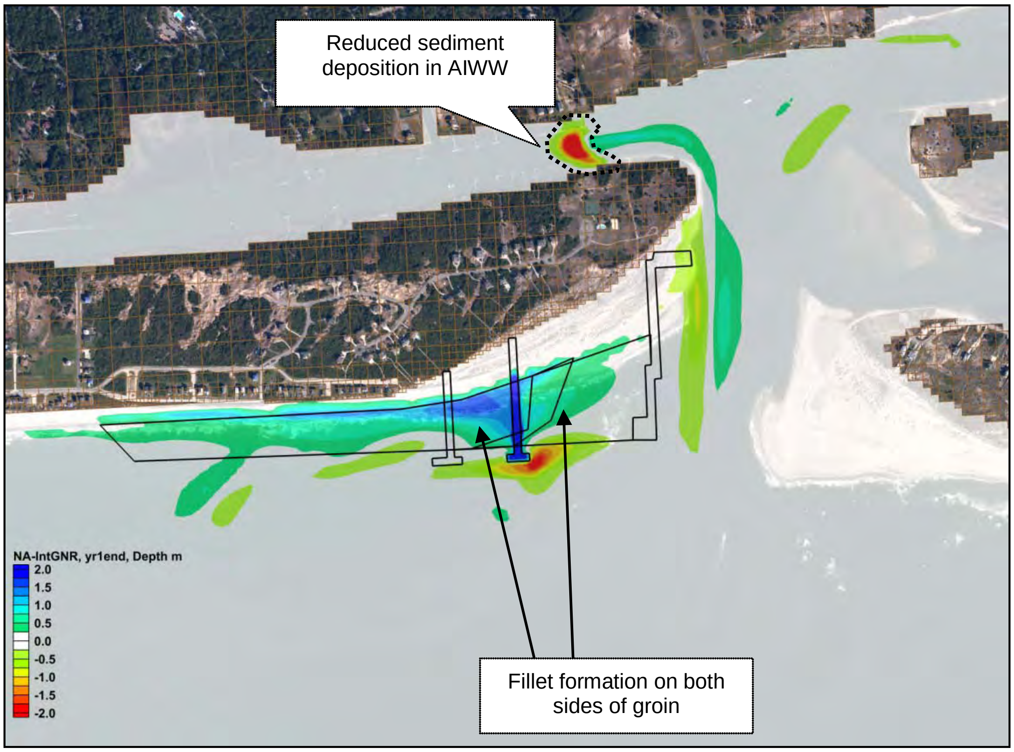


Figure 7-49. Intermediate Groin and Nourishment Alternative after 1-Year Relative to No-Action. Reds indicate less sediment deposition in the intermediate groin/nourishment alternative. Blues indicate more sediment deposition.

Long-Term Shoreline Change Analysis

Average shoreline change was investigated (Figure 7-50), where the project area was broken into three discrete zones. The west zone is the nourishment area west of the short groin (SG). The west (about 2900 ft) and middle (about 600 ft) zones incorporate the nourishment area west of the intermediate groin (IntSG). Finally, all zones combine to encompass the nourishment area west of the long groin (LG). Middle and East (~1300 ft) zones also cover areas on the inlet side of short and intermediate groin alternatives, where applicable.

The 0 ft NAVD88 shoreline contour (approximate mean sea level) for the various alternatives was averaged over each zone (or zones) and a distance relative to the same contour from the no-action case was calculated. This relative shoreline distance equates to an increase in beach width resulting from specific alternatives. Figure 7-51 shows a typical comparison of the average no-action (NA) and intermediate groin/nourishment NAVD88 shorelines at Year 2 of the simulation.

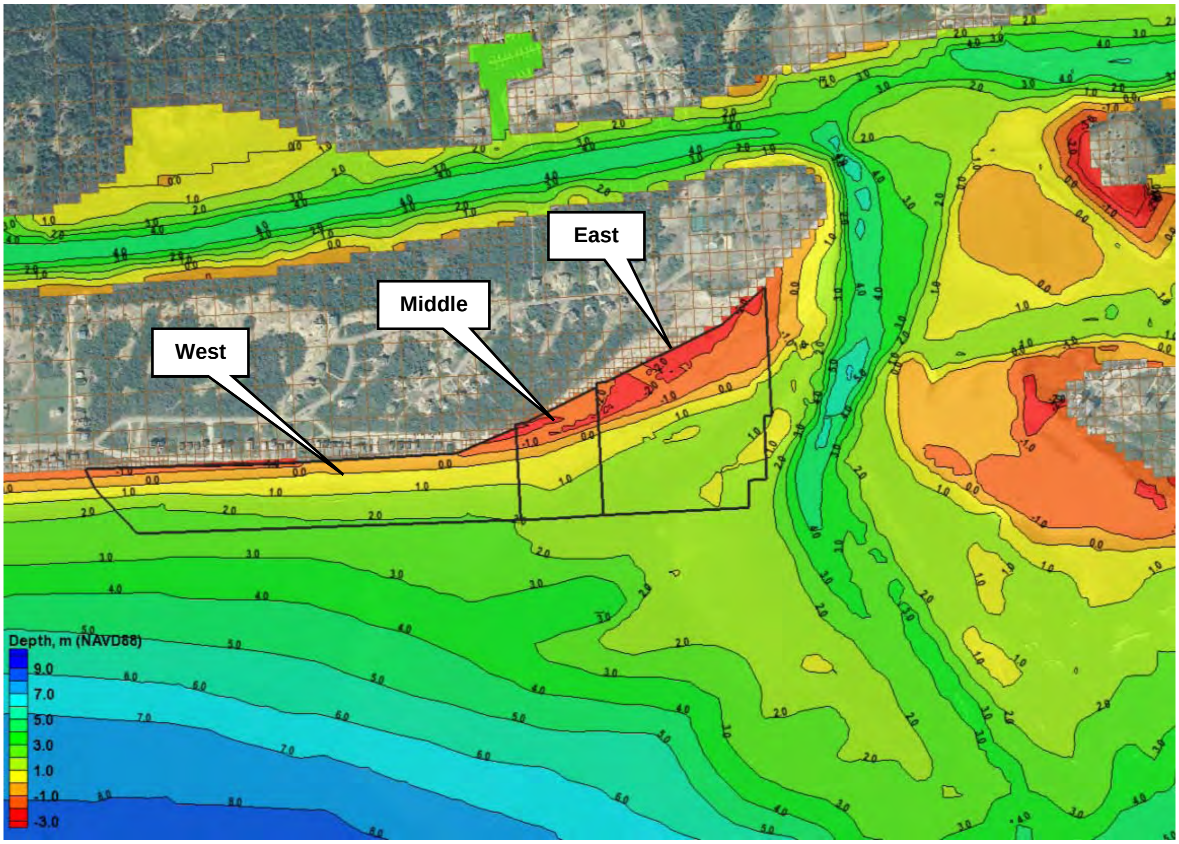


Figure 7-50. Long-Term Impact Analysis Zones

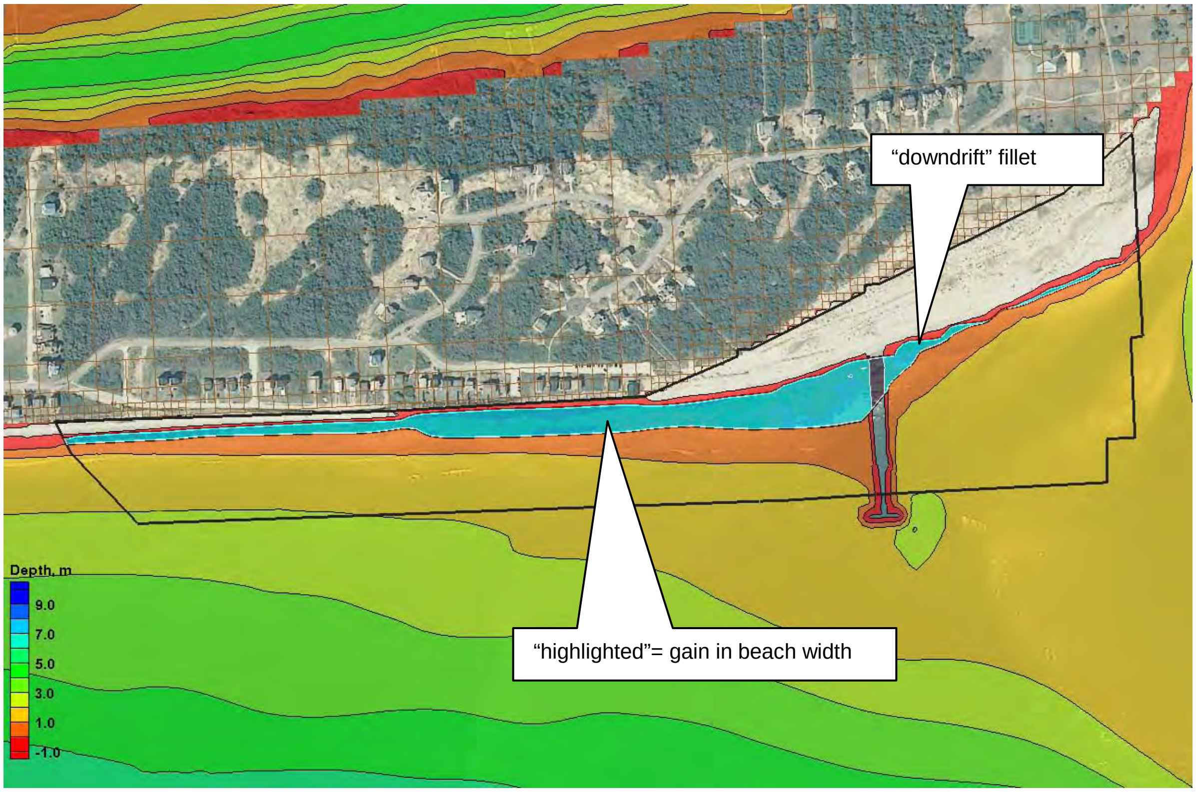


Figure 7-51. Comparison of No-Action and Intermediate Groin/Nourishment Average NAVD88 Shorelines during Year 2. Highlighted area indicates shoreline width increase for the groin/nourishment case.

The benefit of the intermediate groin to the east (the inlet side) during the project simulation is related to shoal attachments and general ebb shoal processes. Tables 7-6 through 7-8 present the results of the shoreline analysis for each zone or combination of zones.

Table 7-6. West Zone Average Relative Shoreline Widths

	West Zone Averages Relative Shoreline Width (0 ft NAVD88)				
Alternative	Start	Year 1	Year 2	Year 3	Year 4
No-Action (NA)	0	0	0	0	0
Nourishment-Only (NR)	91	87	69	42	27
Short Groin & Nourishment	91	90	78	62	52
Intermediate Groin & Nourishment	91	88	73	51	35
Long Groin & Nourishment	92	90	75	56	35

Table 7-7. West and Middle Zone Average Relative Shoreline Widths

	West and Middle Zone Averages Relative Shoreline Width (0 ft NAVD88)				
Alternative	Start	Year 1	Year 2	Year 3	Year 4
No-Action (NA)	0	0	0	0	0
Nourishment-Only (NR)	118	107	80	48	27
Short Groin & Nourishment	119	118	94	70	55
Intermediate Groin & Nourishment	119	126	125	107	85
Long Groin & Nourishment	120	124	112	85	57

Table 7-8. West, Middle, and East Zone Average Relative Shoreline Widths

	West, Middle, and East Zone Averages Relative Shoreline Width (0 ft NAVD88)				
Alternative	Start	Year 1	Year 2	Year 3	Year 4
No-Action (NA)	0	0	0	0	0
Nourishment-Only (NR)	85	78	57	34	19
Short Groin & Nourishment	85	84	64	47	36
Intermediate Groin & Nourishment	93	98	93	79	63
Long Groin & Nourishment	103	110	101	77	52

Figures 7-52 through 7-54 illustrate the calculated shoreline evolution over the model simulations. The groin alternatives (with nourishments) consistently had a wider beach than the no-action or nourishment-only cases. For example, the intermediate groin/nourishment alternative average NAVD88 shoreline along all project zones (including the East zone, which is on the inlet side of the groin) after 4 years was 63 and 43 ft wider than the no-action and nourishment-only cases, respectively. These increased beach widths over the approximately 4,800-ft project zone shoreline equate to substantially larger beach area. Increased intermediate groin/nourishment average shorelines jumped to 85 and 59 ft, respectively, when only the West and Middle zones were considered (the approximately 3500 ft within the groin's "effective area" of sediment trapping).

The intermediate groin/nourishment benefits are exhibited over the life of the groin and will allow for increased beach nourishment intervals.

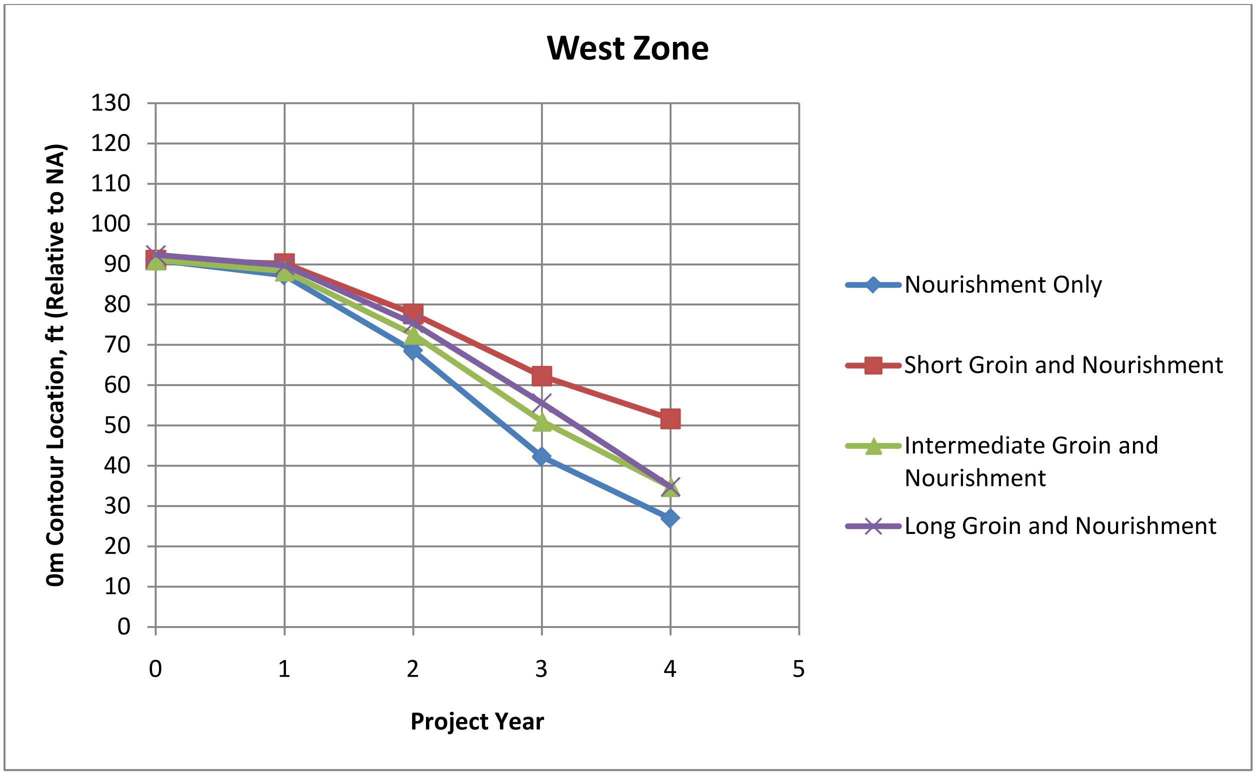


Figure 7-52. NAVD88 Shoreline Evolution of Alternatives during Simulation, West Zone.

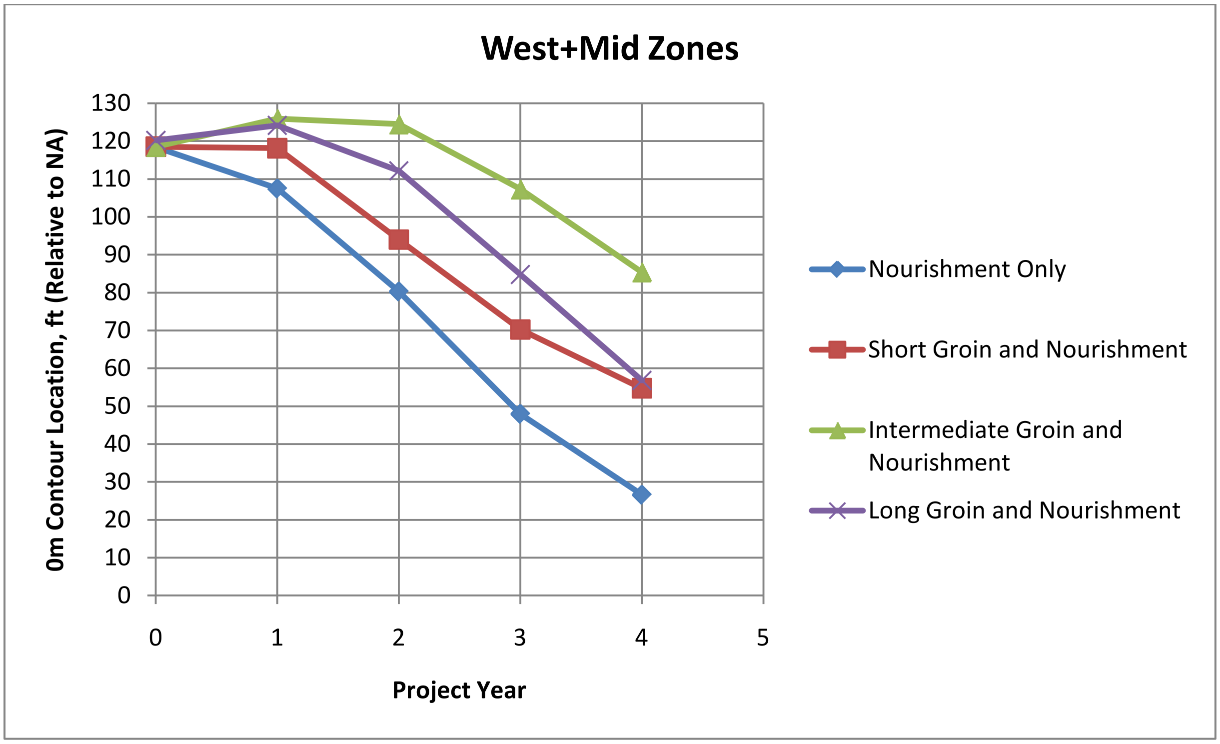


Figure 7-53. NAVD88 Shoreline Evolution of Alternatives during Simulation, West+Middle Zones.

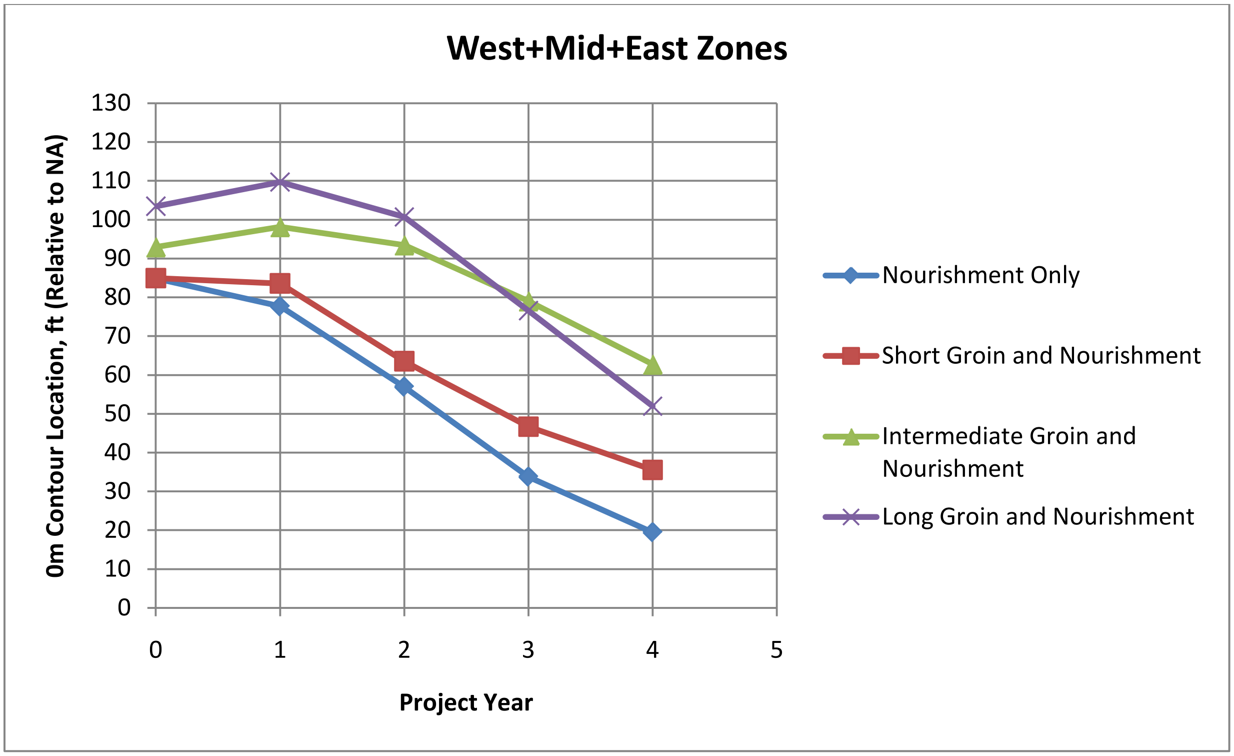


Figure 7-54. NAVD88 Shoreline Evolution of Alternatives during Simulation, All Zones.

Long Term Sediment Transport Analysis

Regional sediment transport was further investigated for the long-term simulations. Analyses for Suites 1 and 2 are provided in Appendix C. Table 7-9 and Figure 7-55 show the results of the annualized sediment transport analysis for Suite 3. While the results of each alternative differ slightly (contributing to the positive local impacts discussed in the previous two sections), the regional sediment transport system remains largely unaffected. Reduced sediment transport into LWF Inlet is also seen with the groin alternatives. Monitoring will occur to document any changes to the project area (including Holden Beach, LWF Inlet, Oak Island).

Table 7-9. Annualized Sediment Transport, Suite 3.

Suite 3	Annualized Net Sediment Transport, cy/yr Observation Profile		
Alternative	Holden Beach	Inlet	Oak Island
No-Action	-262,331	75,496	-42,206
Nourishment-Only	-220,766	148,670	-34,807
Short Groin & Nourishment	-264,847	90,792	-32,411
Intermediate Groin & Nourishment	-280,772	71,821	-44,389
Long Groin & Nourishment	-278,253	57,743	-39,246

** Negative values indicate Western transport (or out of LWF Inlet)*

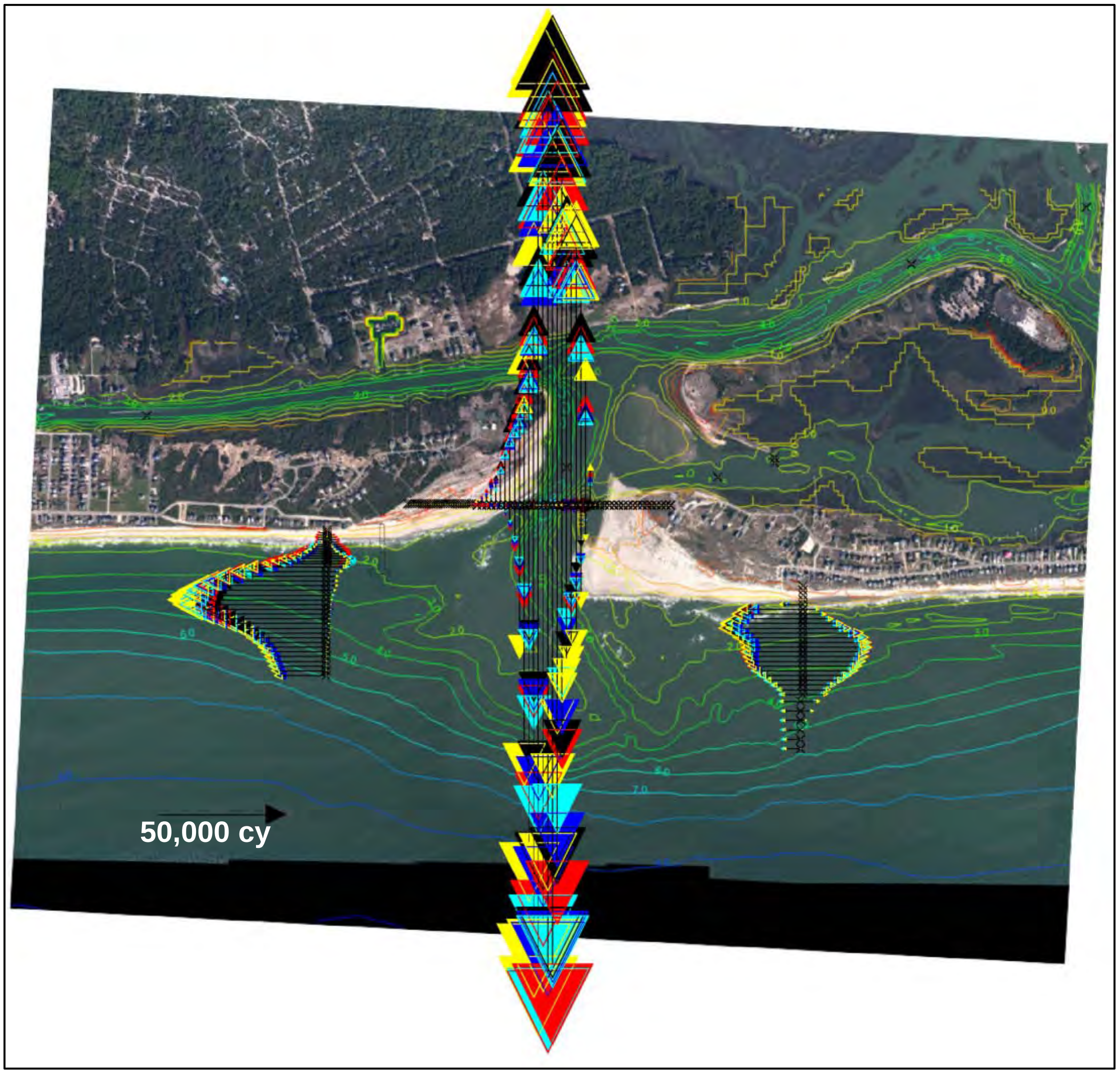


Figure 7-55. Gross Sediment Transport, Suite 3. Red (no-action), Black (nourishment-only R), Blue (short groin & nourishment), Cyan (intermediate groin and nourishment), Yellow (long groin and nourishment).

7.2.5 BIOLOGICAL RESOURCES

Many species of fish and crustaceans utilize the water column to migrate through inlets in North Carolina as part of their reproductive strategy. As cited in the 2010 NC Coastal Habitat Protection Plan (CHPP), successful transport of larvae through an inlet occurs within a narrow zone parallel to the shoreline and is highly dependent on along-shore transport processes (Blanton et al., 1999, and others). The proximity of the proposed project to LWF Inlet necessitates an examination of potential impacts a terminal groin may have on biological (larval) transport.

Biological particles (larvae, micro/macroscopic marine invertebrates) can be both active and passive travelers in the water column. Especially in higher energy environments, such as the surf and intertidal zones of the project area, patterns of biological transport are not significantly affected by biological parameters and transport can be represented by passive particles that are controlled exclusively by physical dynamics (Kim et al., 2010). Therefore, the CMS hydrodynamic and sediment transport simulations (physical dynamics interacting with passive particles) of the project were used to correlate larval transport in the area during no-action and alternative simulations.

Figure 7-56 shows the differences in average particle concentrations [kilograms per cubic meter (kg/m^3)] in the water column between the no-action and short groin/nourishment simulations (2004, full year). The blue shaded areas illustrate a decrease in particle concentration from the no-action to the alternative case. This is due to the dry beach fill occupying what was once intertidal zone. Effects are limited to the beach fill area, with higher decreases in the immediate vicinity of the groin. There are negligible changes in concentration from the no-action to the alternative case for areas outside of the beach fill footprint. For example, no significant changes occur seaward of the groin in Figure 7-56. This condition arises partially from the locally restricted affect of the groin on wave and tidally induced currents (Figure 7-57). Rip current formation has been known to be more prevalent during mid-low tidal stages (Engle et al., 2002).

Figure 7-56. Particle Concentration Comparison of No-Action and Short Groin/Nourishment Alternative. Blue indicates the no-action alternative exhibits increased particle concentrations. Significant changes are localized to the nourishment footprint.

Figure 7-57a presents a snapshot of current vectors during flood tide conditions. For flood tides, there is a considerable “push” of water into the inlet. As a result, currents flow right around the groin and into the inlet (along with all the other water in the ebb shoal region). Due to this large push of water, the modeling shows that the groin will have negligible impacts on fish larval passage into the inlet.

For ebb tides, the model does show more rip current activity in general (see Figure 7-57b). This rip current activity is not necessarily at the groin, but there is more of a chance of a rip current during ebb tide along the modeling domain. The absence of rip currents at the groin and insignificant increases in particle concentrations outside of the beach fill footprint in the alternative simulation indicate that particle (i.e., larval) transport is not affected significantly by the proposed groin.

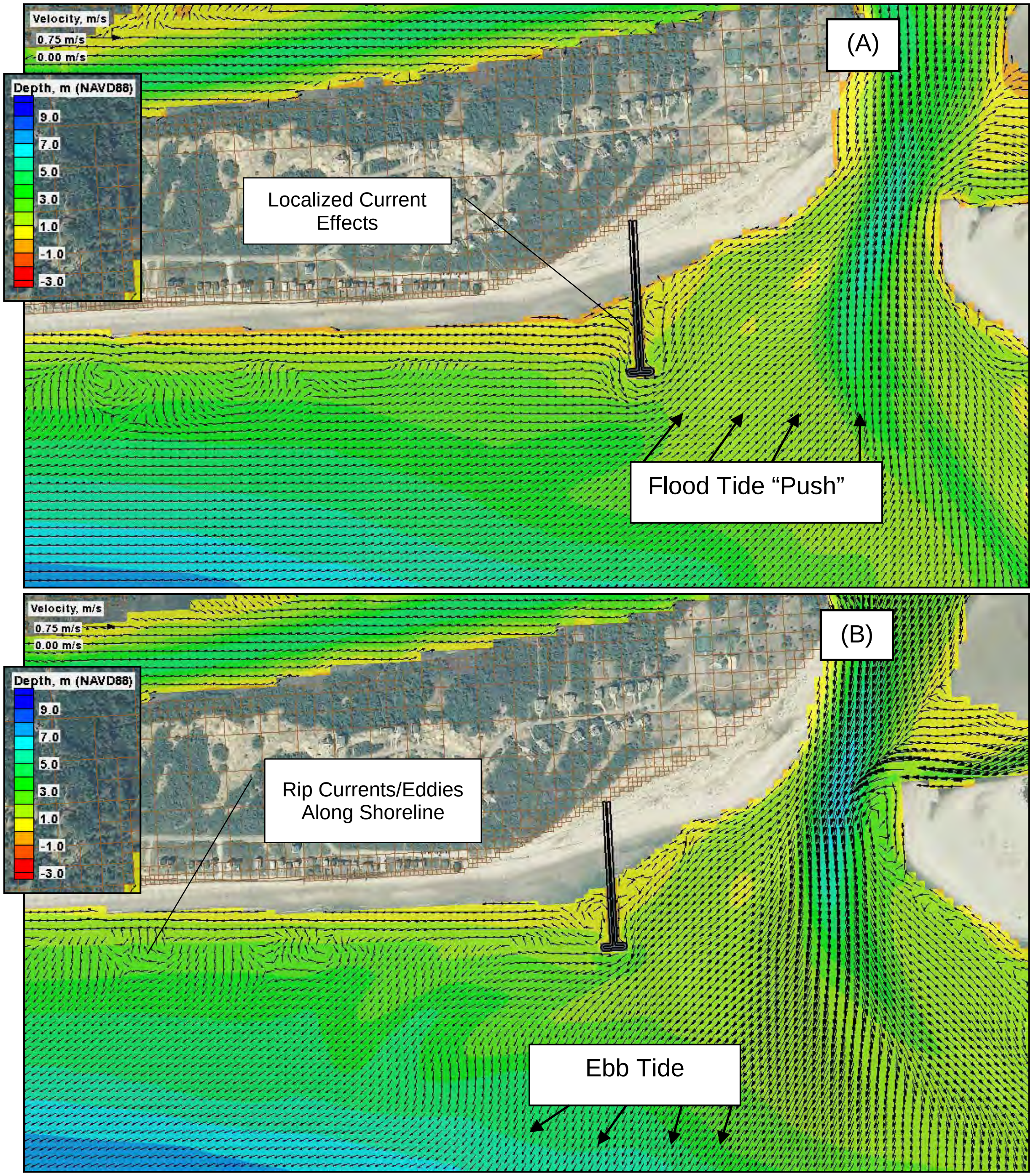


Figure 7-57. Current snapshots at Eastern Holden Beach during (A) Flood and (B) Ebb Tides. Note only localized effects of the proposed groin and natural rip currents/eddies during ebb tides.

Figures 7-58, 7-59, and 7-60 present average current magnitudes over the 2009 190-day model runs for the no-action, short groin/nourishment/LWFIX borrow area, and long-groin-only alternatives, respectively. General similarities are exhibited for all of these alternatives, although the most significant effects can be seen to the west of the long-groin-only alternative.

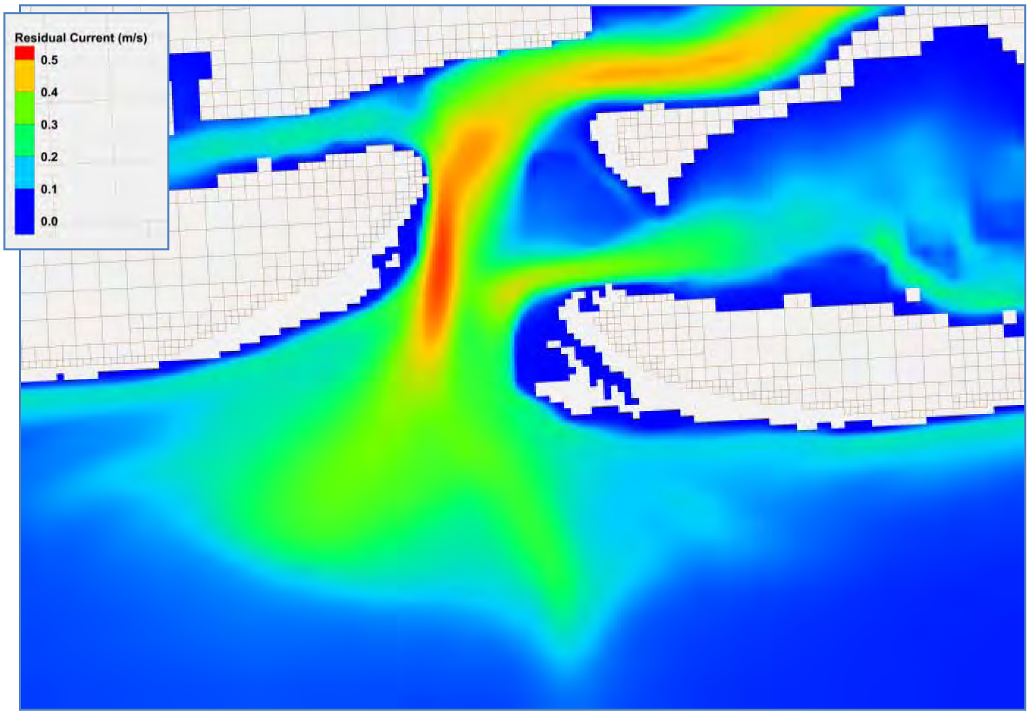


Figure 7-58. Average (Residual) Currents over the 2009 190-Day Period No-Action Alternative.

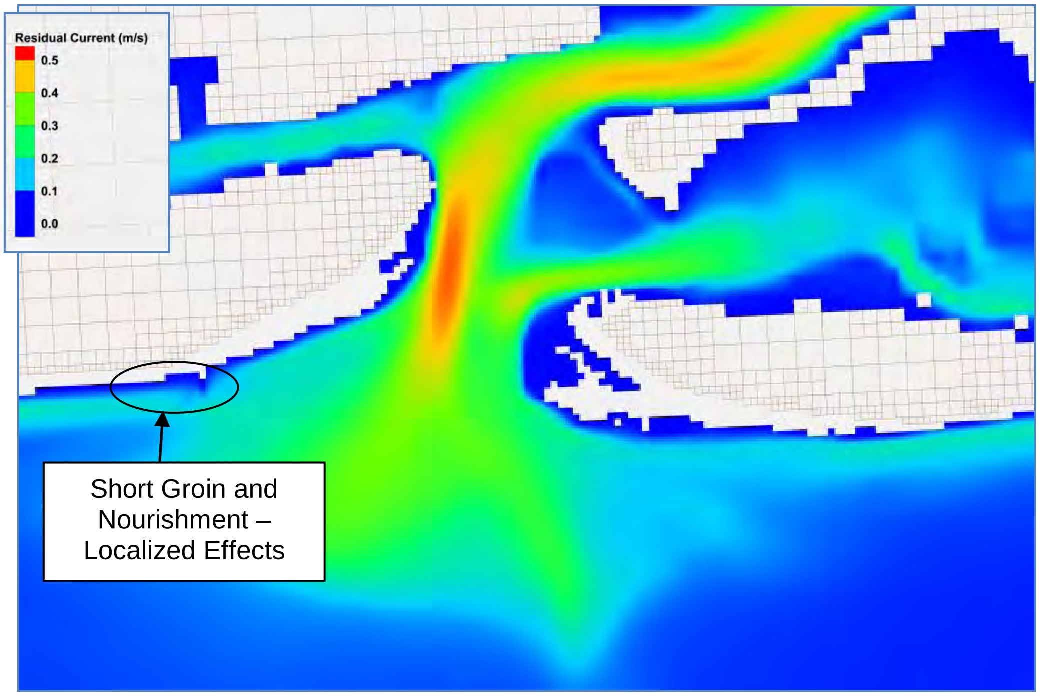


Figure 7-59. Average (Residual) Currents over the 2009 190-Day Period Short Groin, 60,000 Cy Nourishment, LWFIX Borrow Area Alternative

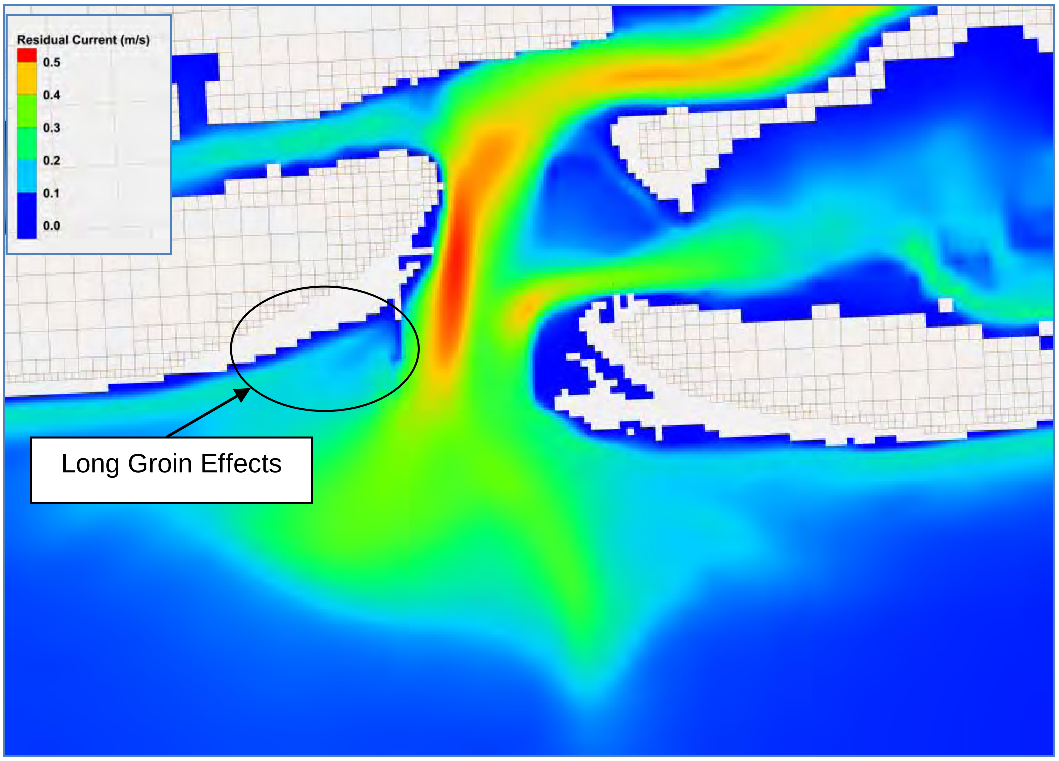


Figure 7-60. Average (Residual) Currents over the 2009 190-Day Period for the Long Groin Only Alternative

Blanton et al. (1999) performed the South Atlantic Bight Recruitment Experiment (SABRE) to study the transport of winter-spawned fish larvae into estuaries. Blanton et al. (1999) found larvae concentrated on the shelf in a narrow “withdrawal zone” upwind of an inlet within the 23-ft (7-m) depth contour. When the ocean currents were appropriate, the larvae passed through the inlets (Blanton et al., 1999). Even with the best wind and tidal conditions, only about 10 percent of the available larvae are successfully drawn into the inlet (Blanton et al., 1999).

The Blanton study found that the 7-m contour was of particular relevance to larval recruitment. Figure 7-61 identifies the 7-m contour relative to the short-, intermediate-, and long-groin alternatives. The 7-m contour is approximately 650 m (2,100 feet) seaward of the short groin structure.

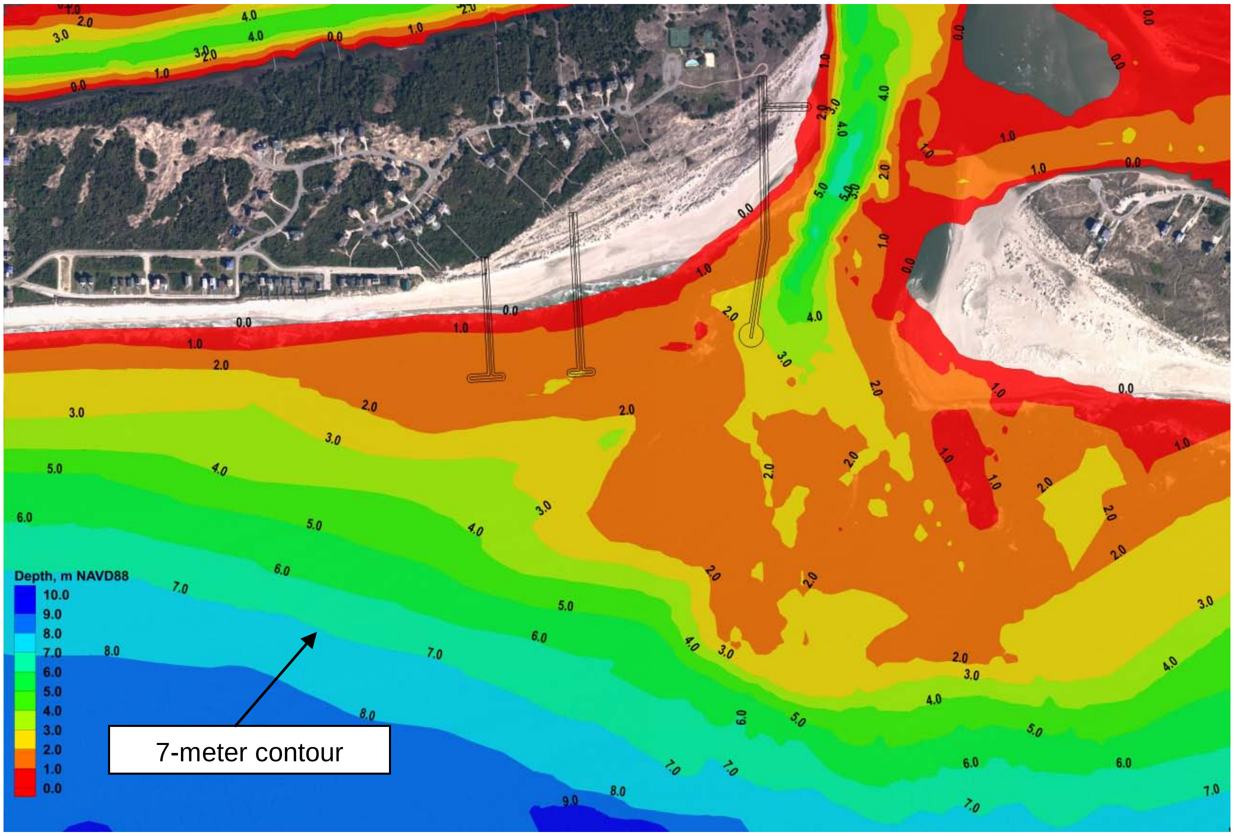


Figure 7-61. Short, Intermediate, and Long Groins Relative to Depth Contours (in meters). The 7-m depth contour is a significant distance from the structures (~ 500 m seaward of the short groin) (2012 bathymetry shown).

The *2010 NC Coastal Habitat Protection Plan – Appendix I* provides several factors that appear to minimize biological impacts of nourishment projects to the intertidal beach community. These include, but are not limited to the following:

- Use of sand similar in grain size and composition to original beach sands (specific minimum and maximum standard needed)
- Restrict beach nourishment to winter months to minimize mortality of infauna and enhance recovery rates of intertidal benthic organisms, an important prey source for many surf fish (Donoghue, 1999)
- Limit time interval between projects to allow full recovery of benthic communities (1 to 2 years, depending on timing of project and compatibility of sediment)
- Limit linear length of nourishment projects to provide undisturbed area as a source of invertebrate colonists for the altered beach and a food source for fish

All of these avoidance and minimization guidelines were used in evaluating the proposed project. A major goal of the groin and nourishment project is to increase the interval between projects. Additionally, another goal of the project is to limit the linear length of shoreline directly affected.

Potential impacts to natural resources were evaluated in the State Terminal Groin Report (Moffatt & Nichol, 2010). Excerpts of some potential benefits include the following:

- As supported by the NOAA National Marine Fisheries Service (NMFS), a rock rubble structure extending below the intertidal zone in a sandy bottom location would likely induce and support the development of a diverse benthic community supporting higher trophic levels of both fish and birds within the vicinity and footprint of a terminal groin.
- In the case of rubble-mound structures (e.g., jetties, groins, breakwaters, etc.), one beneficial aspect of construction is the creation of artificial reef habitat. This is evidenced by the popularity of coastal rubble-mound structures as recreational fishing spots.
- Groin habitat may provide a foraging site and shelter for fishes in the surf zone, and is associated with higher fish abundances and species richness than in other surf zone communities (Peters and Nelson, 1987; Clark et al., 1996).
- Birds in a few ecological categories feed on or near groins and can be considered part of the rubble structure community. These include surface-searching shorebirds, aerial searching birds, floating and diving waterbirds, and wading birds.
- The ruddy turnstone is often found feeding on groins in groups of 100 or more in the Fort Macon State Park area, and purple sandpipers are occasionally abundant in flocks of 40 to 50 on the jetties at Masonboro Inlet (Personal communication, R. Newman, Fort Macon State Park, October 2009; Personal communication, J. Fussell, Birder and Author, February 2010). Both species use rocks and groins as their primary feeding habitats. Other shorebirds use them only on occasion, feeding on surrounding habitats as well (Peterson and Peterson, 1979; Thayer et al., 1984).

A USACE (1996) study also found that: “Groins are very effective fish attractors and provide excellent sport fishing sites. These structures, particularly those of rubble-mound construction, may provide beneficial protective cover, as well as feeding and resting areas for both juvenile and adult fishes and shellfishes during coastal migrations.”

7.3 GENESIS-T

The GENESIS-T model was set up previously for the Central Reach nourishment project and was subsequently applied for the terminal groin studies. Its application for the terminal groin alternatives is a secondary and complementary role. While the model is capable of simulating groin and beach fill alternatives, inlet-related changes such as channel relocation and LWFIX borrow area inclusion are more difficult to model with the GENESIS-T model application.

The need to calculate long-term shoreline change and compare performance of numerous engineering alternatives over long spatial extents and time frames has led to a wide use of the 1-line (shoreline response) models, which have proven their value successfully in a wide range of projects (Hanson and Kraus, 2004). Among these 1-line models, GENESIS has likely been applied more than any other model of its kind, exceeding installation at more than 1,000 sites worldwide (Hanson and Kraus, 2004).

Jetties and groins, as shore-normal structures, interrupt the longshore transport of sand. GENESIS was formulated to represent macro-scale properties of shore-normal structures. Hanson and Kraus (2004) identified 27 parameters that can potentially influence the response of the shoreline to shore-normal structures for a particular site. Of these 27 parameters, Hanson and Kraus (2004) concluded that three non-dimensional parameters exert decisive control:

1. Structure permeability,
2. Ratio of net to gross longshore sand transport rate (which varies between 0 and 1), and
3. Bypassing ratio defined as the depth at the groin tip to average deepwater wave height.

The GENESIS model includes the above parameters and has been upgraded many times since its original development. GENESIS-T represents the most recent upgrade to the GENESIS model and includes an explicit solution scheme (as opposed to implicit) and the ability to form tombolos due to detached breakwaters. Additionally, GENESIS-T features a regional contour that allows for more precise modeling adjacent to inlets.

In GENESIS and GENESIS-T, two types of sand movement past a shore-normal structure (e.g., groin) are simulated. One type is around the seaward end of the structure, called bypassing, and the other is through and over the structure, called sand transmission (Hanson and Kraus, 2004).

7.3.1 MODEL SETUP

The GENESIS-T model covers 15,000 m (~9.3 miles) of shoreline and model grid cells are 25 m in size (see Figure 7-62 for model extents). The STWAVE model was used for wave propagation, which is used as input by GENESIS-T. The STWAVE model boundary was co-located with the CMS wave model, approximately 3 miles offshore. To provide inputs from varying directions, periods, and wave heights for the GENESIS-T application, 177 wave model cases were run.

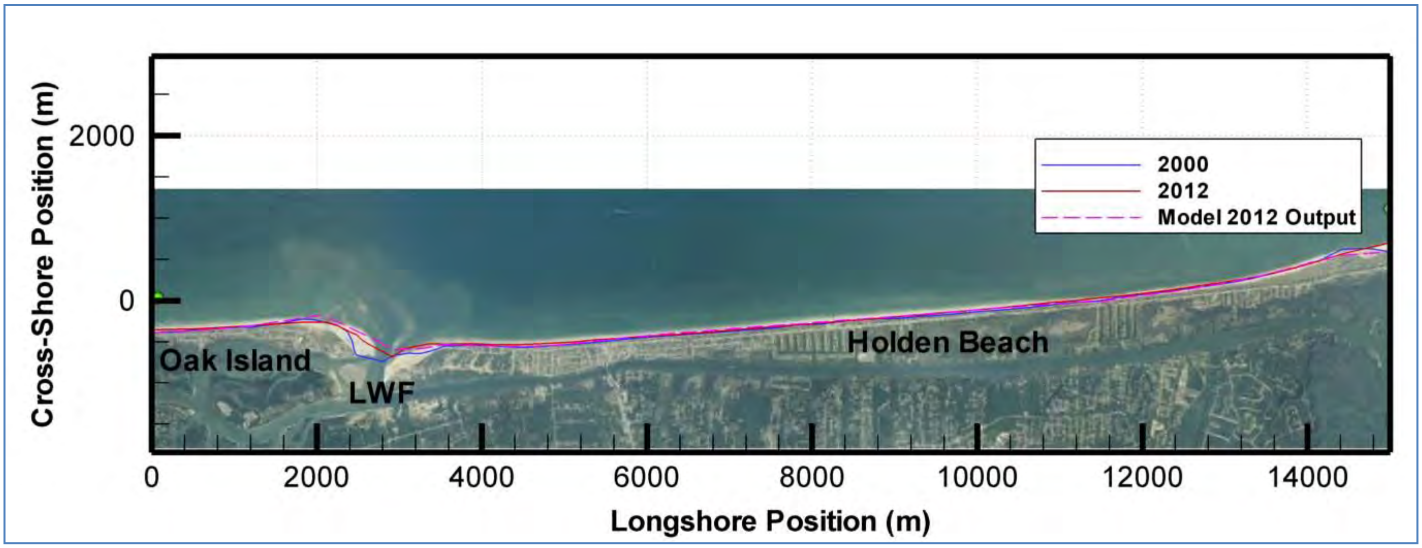


Figure 7-62. Extents of GENESIS-T Modeled Shoreline. 2000 and 2012 measured shorelines are presented, as well as the modeled 2012 shoreline.

The model was run from 2000 to 2011 (about 12 years) (modeling did extend a few months into 2012 to correlate with survey data). To more clearly compare measured and modeled shorelines, shoreline change rather than absolute shoreline position is presented in Figure 7-63.

Model results are in good general agreement with measured shoreline change over the 12-year time period. All nourishment activities have been included in the modeling effort (GENESIS allows for nourishment activities to occur mid-run). An overall accretional trend is noted in Figure 7-63 for most of the Holden Beach shoreline and western Oak Island. Note that without including nourishment activities (i.e., no-action), the modeled shoreline exhibits a significantly stronger erosional trend (as expected).

Also note that while the west end is accretional in the long-term (e.g., over decades) and has a significant buildup of sand, some shorter term changes/undulations have been documented in surveys to the 0 ft NAVD shoreline between 2000 and 2012. Such a change is exhibited near model grid cell 575 in Figure 7-63.

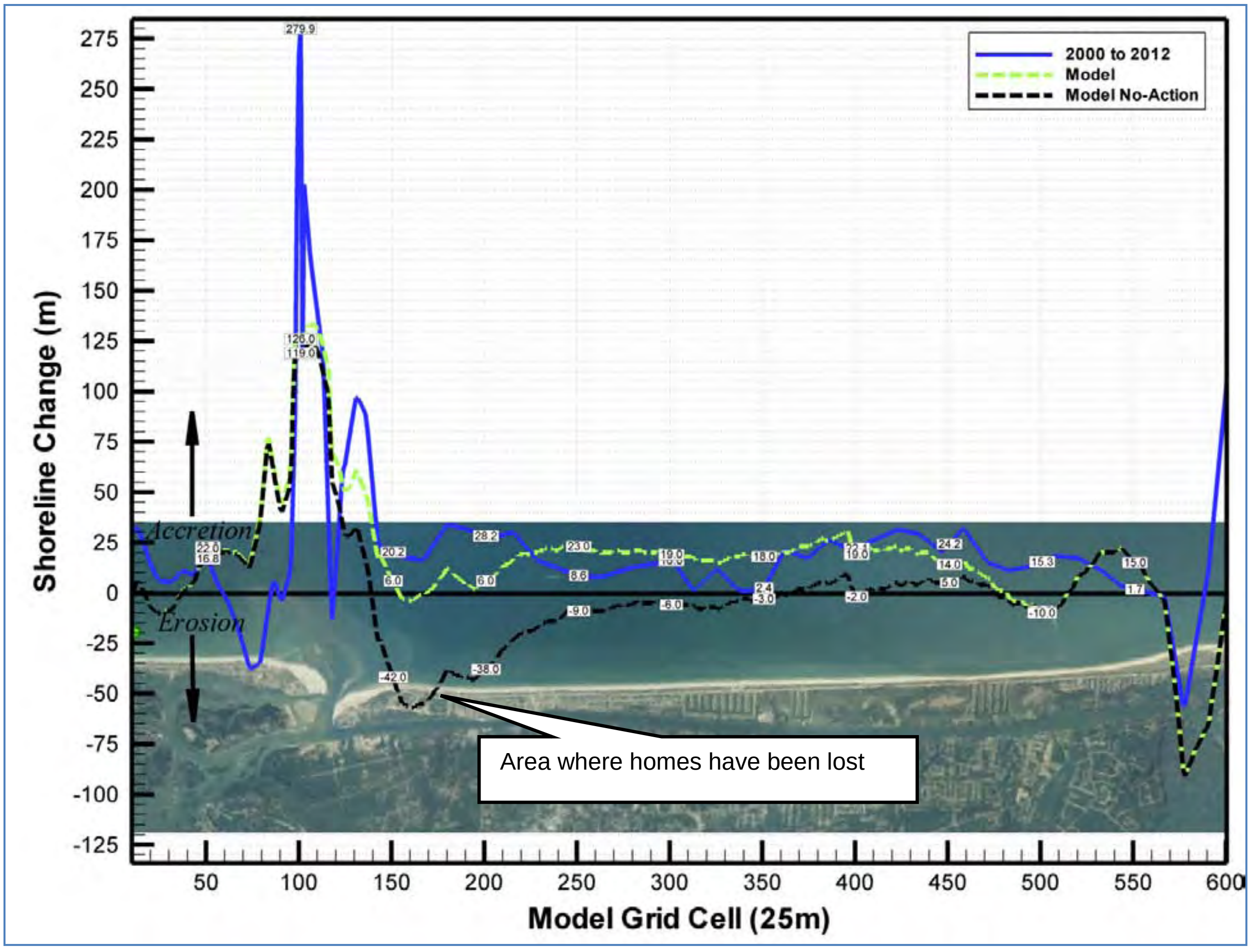


Figure 7-63. Measured versus Modeled Data from 2000 to 2012. No-action alternative is also shown for the 2000-2012 time period, where no beach fills are included.

The simulated shoreline on the east end of Holden Beach shows a stable/slightly erosional trend, despite the significant nourishment activities in this area over the last 12 years (Figure 7-63). This is the area of highest erosion on Holden Beach, and GENESIS-T results capture this trend. Figure 7-64 presents a zoom-in of model results on the east end. Significant erosion of up to 50 meters (165 feet) is exhibited on the east end under the no-action alternative. Therefore, without all of the nourishment activity on Holden Beach over the last 12 years, significant losses would have occurred.

The LWF Inlet shoreline is also included in the modeling application where the NAVD (~MSL) shoreline was interpolated between Holden Beach and Oak Island. This can be done in GENESIS-T by utilizing the regional contour feature to define the offset between the shorelines. As seen in Figure 7-65, the Oak Island shoreline is approximately 300 m (1,000 feet) seaward of the Holden Beach shoreline, relative to LWF Inlet.

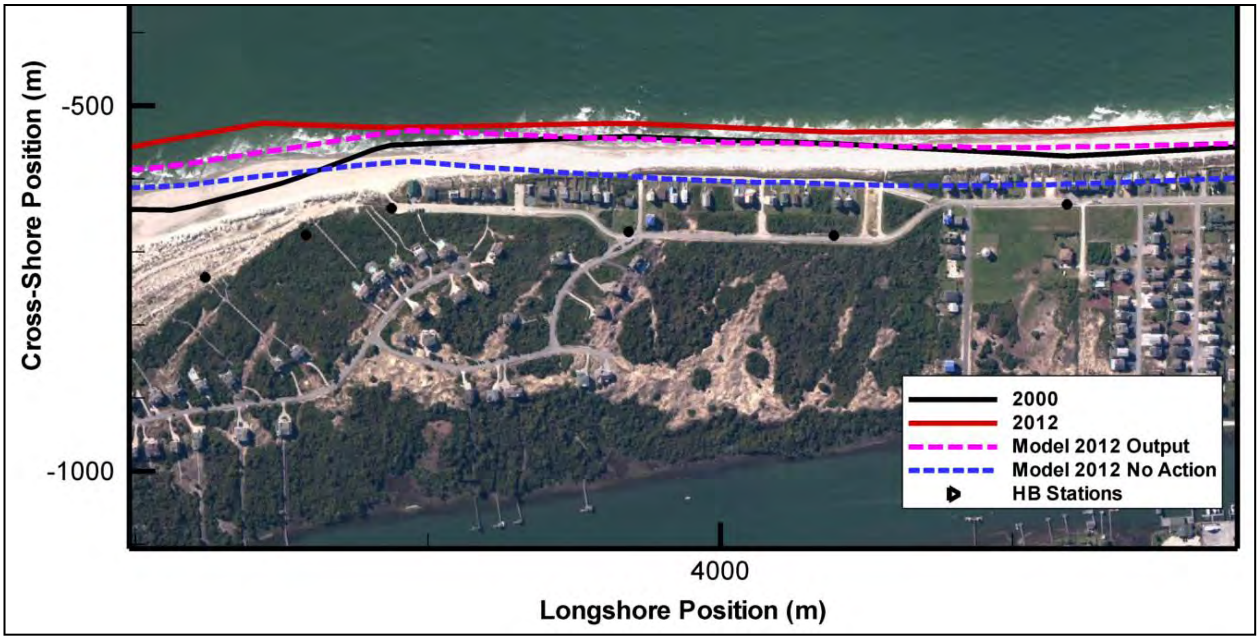


Figure 7-64. East End Measured versus Modeled Data from 2000 to 2012. No-action alternative is also shown for the 2000-2012 time period, where no beach fills are included.

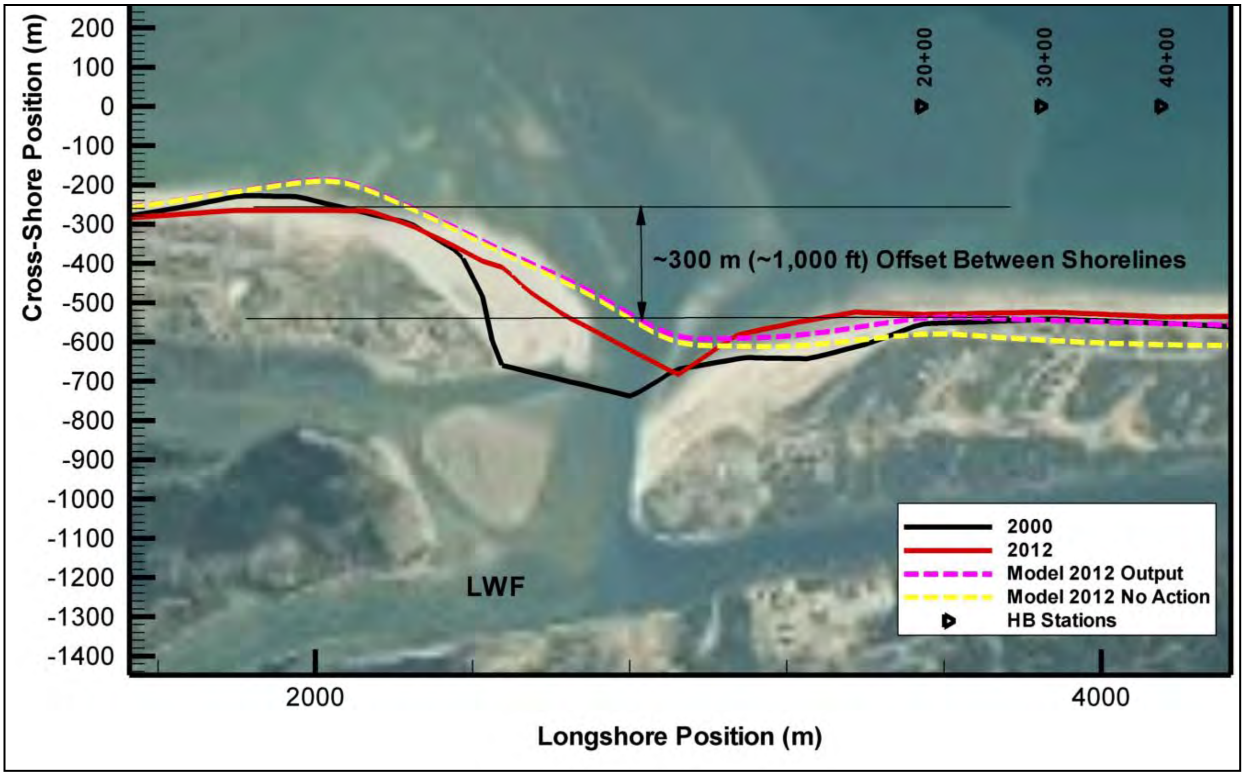


Figure 7-65. Shoreline Offset between Oak Island and Holden Beach of approximately 300 m (~1,000 ft)

7.3.2 NET VOLUME TRANSPORT

Modeled net transport rates are presented in Figure 7-66. The average transport rate over the 12-year time span is approximately 125,000 cy/yr and to the west. However, transport rates vary by shoreline reach and net transport on the east end of Holden Beach is generally to the east (i.e., into LWF Inlet). This agrees with nearshore CMS model transport vectors (i.e., near the 0 ft NAVD88 contour) as well as previous studies on the east end. Transport rates on a year-to-year basis can vary significantly from approximately 200,000 cy/yr (2005, 2008) to approximately 75,000 cy/yr (2000, 2006).

Thompson et al. (1999) estimated an annual average transport rate of 228,000 cy/yr for this general region using the Coastal Engineering Research Center (CERC) equation (K=0.023). Note that the CERC equation has been shown to overpredict net transport rates (Kamphius, 2000; Soulsby, 1997; Wang et al., 2002). In general, modeled transport results are reasonable and are in general agreement with the CMS model application.

7.3.3 ALTERNATIVES MODELING

GENESIS-T modeling was conducted for groin and nourishment alternatives. Model setup parameters include K1 transport coefficient = 0.3, K2 transport coefficient =0.15, effective grain size=0.24 mm; groin permeability=0.1. Alternative model simulations were conducted beginning with the 2012 shoreline. The model simulations were run for 12 years, however output at year 6 will be shown below for comparison purposes. All three groin alternatives with associated fills were simulated while nourishment-only alternatives were also run.

Figure 7-67 presents the short groin and nourishment alternative, the nourishment-only alternative, and the no-action alternative. The no-action alternative assumes no nourishment activity. All nourishment events occur 10 days into the simulation. The nourishment volume was 80,000 cy for both the short groin/nourishment and nourishment-only cases in Figure 7-67. The nourishment was placed over ~2,000 feet from Station 20+00 (model cell 143) to Station 40+00 (model cell 167). Note that for the GENESIS-T simulations, no nourishment material was placed to the “downdrift” of the groins (i.e., on the inlet side of the groin). This was performed in order to assess potential downdrift effects of the groin alternatives.

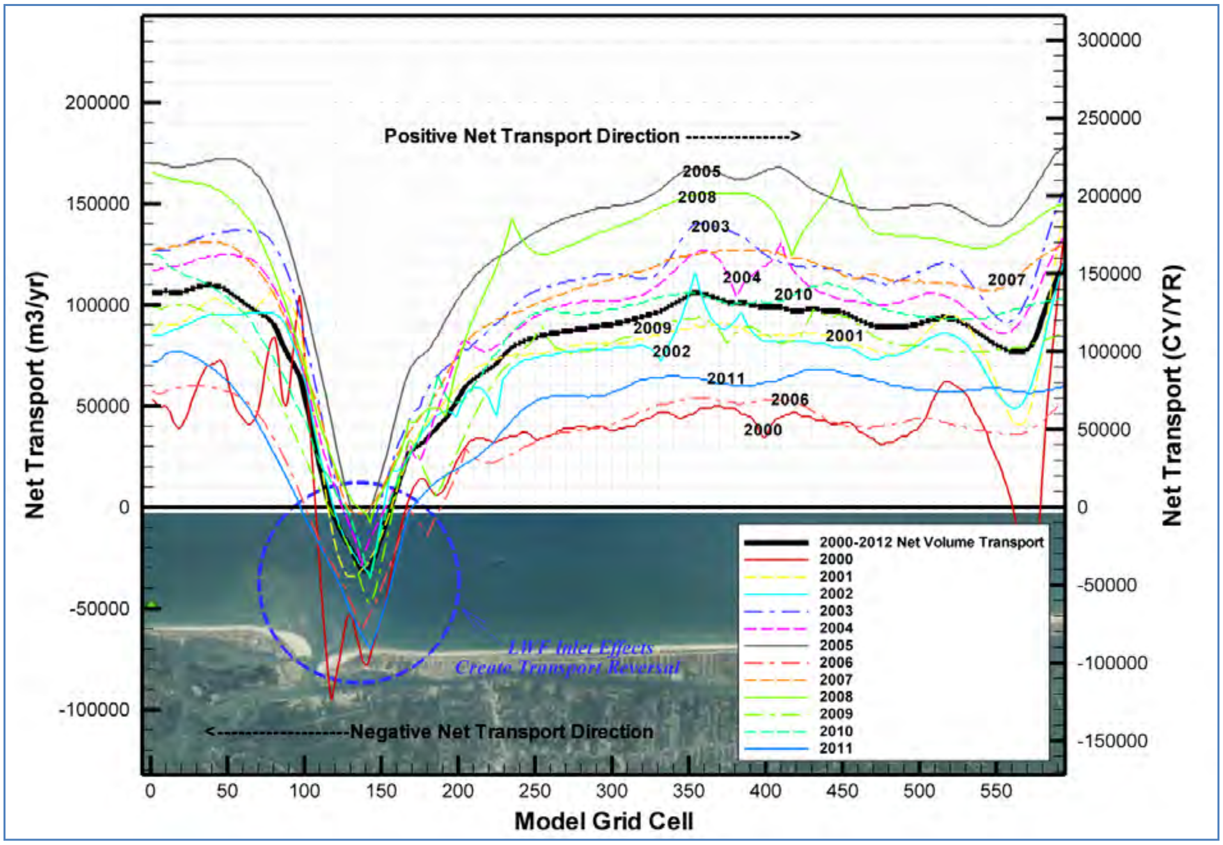


Figure 7-66. *Modeled Net Transport from 2000 to 2012. Note transport reversal on the East End of Holden Beach due to inlet effects.*

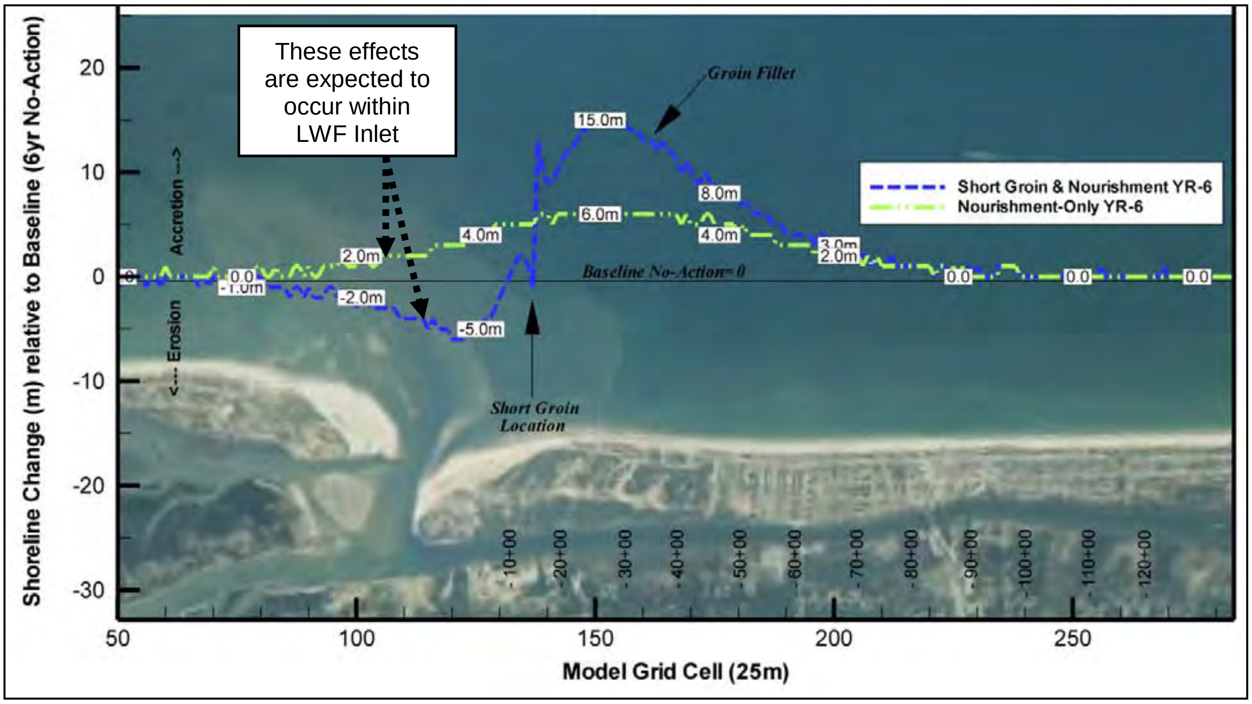


Figure 7-67. *Short Groin/Nourishment and Nourishment-only alternatives relative to no-action conditions after 6 years.*

As seen in Figure 7-67, both alternatives perform better than the no-action alternative after 6 years except for the LWF inlet area. The short groin alternative exhibits a significant effect at retaining updrift material when compared with the nourishment-only alternative. The updrift effect is greatest at approximately Station 30+00, while benefits extend up to Station 60+00. The groin/nourishment alternative benefits approximately 4,000 feet of shoreline (Station 20+00 to Station 60+00), relative to the nourishment-only alternative.

From a downdrift perspective, the short groin is preventing material from traveling into LWF Inlet. GENESIS-T does not include Inlet effects and is less complex than the CMS model. Nonetheless, this analysis also shows that a groin would significantly enhance beach fill longevity. The downdrift trapping effects shown in Figure 7-67 would likely occur within LWF Inlet, as exhibited in the CMS application; rather than on the Oak Island oceanfront shoreline. Note that the nourishment-only alternative is also shown to benefit the Oak Island oceanfront shoreline when in reality this is not known to occur. Instead, this sand travels into LWF Inlet.
The GENESIS-T one-line model does not simulate LWF Inlet hydrodynamic processes; therefore trapping effects are evidenced “downdrift”, which is on the Oak Island oceanfront shoreline (0 ft NAVD88 contour). However, CMS modeling, which does include inlet hydrodynamics, does not show any effects to the Oak Island oceanfront shoreline. In any event, monitoring of Oak Island oceanfront and estuarine shorelines will occur.

Figure 7-68 presents the intermediate groin/nourishment and nourishment-only alternatives relative to baseline no-action conditions after 6 years. Nourishments for these alternatives are approximately 120,000 cy and placed over 2,900 feet of shoreline (model cells 132 to 167). No nourishment material was placed downdrift (i.e., on the LWF Inlet side) of the intermediate groin. Similar results are exhibited, although the trapping capacity of the intermediate groin is greater than that of the short groin. Significant benefits of the intermediate groin/nourishment are evident compared to the nourishment-only alternative (up to 70 feet in beach width after 6 years).

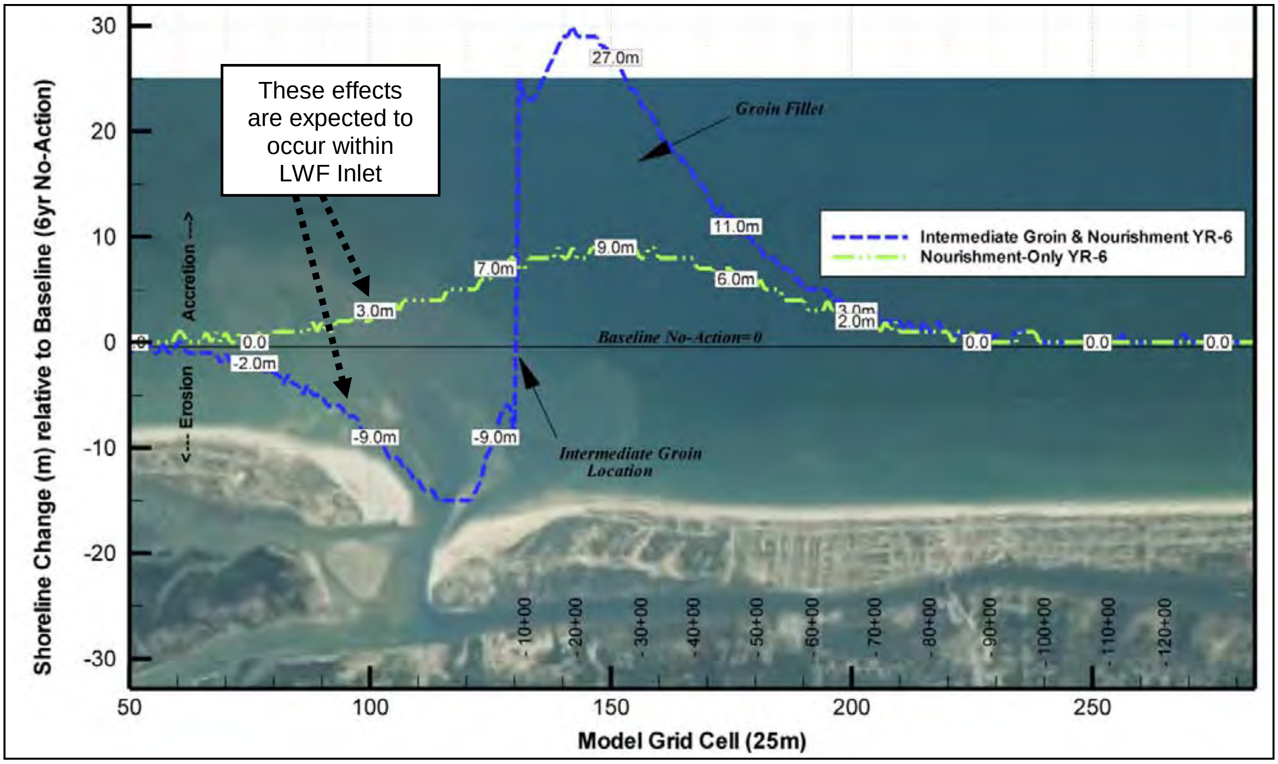


Figure 7-68. Intermediate Groin/Nourishment and Nourishment-only alternatives relative to no-action conditions after 6 years.

Note that while the model results shown depict the shoreline after 6 years, it is anticipated that beach renourishment will likely be required every 4 to 5 years. Some sand may also need to be placed downdrift, depending on existing conditions and final groin location and design. Similar to the previous figure, downdrift trapping effects shown in Figure 7-68 would likely occur within LWF Inlet, as exhibited in the CMS application; as opposed to the Oak Island oceanfront shoreline.

Figure 7-69 presents long groin/nourishment and nourishment-only alternatives relative to baseline no-action conditions after 6 years. The nourishment volume used for these simulations is 160,000 cy placed over 4,000 feet (model cells 119 to 167). As seen in the below figure, the long groin/nourishment alternative outperforms the nourishment-only alternative, however benefits do not protect the shoreline between Stations 20+00 and 40+00 as well as the intermediate groin alternative. The long groin nourishment also requires more beach fill volume.

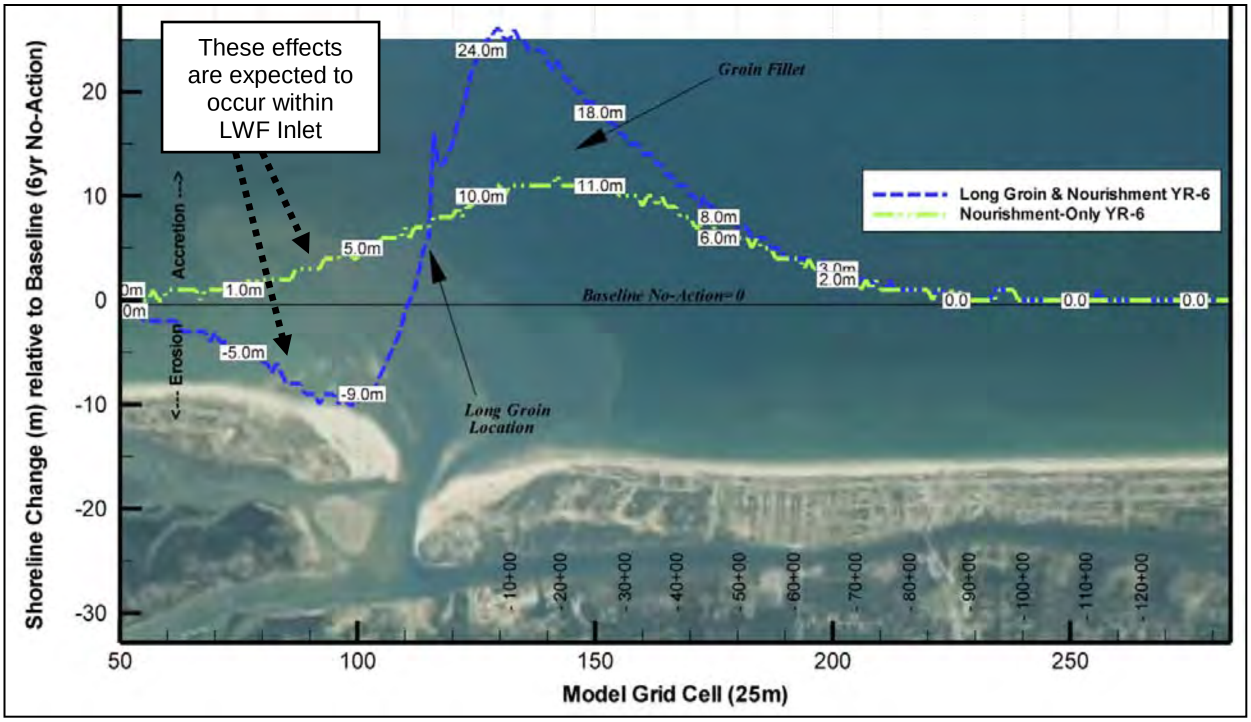


Figure 7-69. Long Groin/Nourishment and Nourishment-only alternatives relative to no-action conditions after 6 years.

Figure 7-70 presents a comparison of net transport for the intermediate groin/nourishment, nourishment-only, and baseline no-action runs. The 120,000 cy nourishment is used for both alternatives. Changes to the net transport from both alternatives remains relatively localized when compared with no-action conditions. The groin aids in minimizing transport into LWF Inlet while a slight increase in net transport into the inlet is exhibited with the nourishment-only alternative (similar to CMS results). This is not unexpected and generally agrees with historic project performance on the east end.

The GENESIS-T modeling application agrees with the CMS model application that the intermediate groin and nourishment alternative is the most successful relative to baseline no-action conditions. The intermediate terminal groin/nourishment alternative retains approximately 2 to 3 more times shoreline width than the nourishment-only alternative. The intermediate groin is anticipated to increase the nourishment interval from approximately 2 years to 4 years.

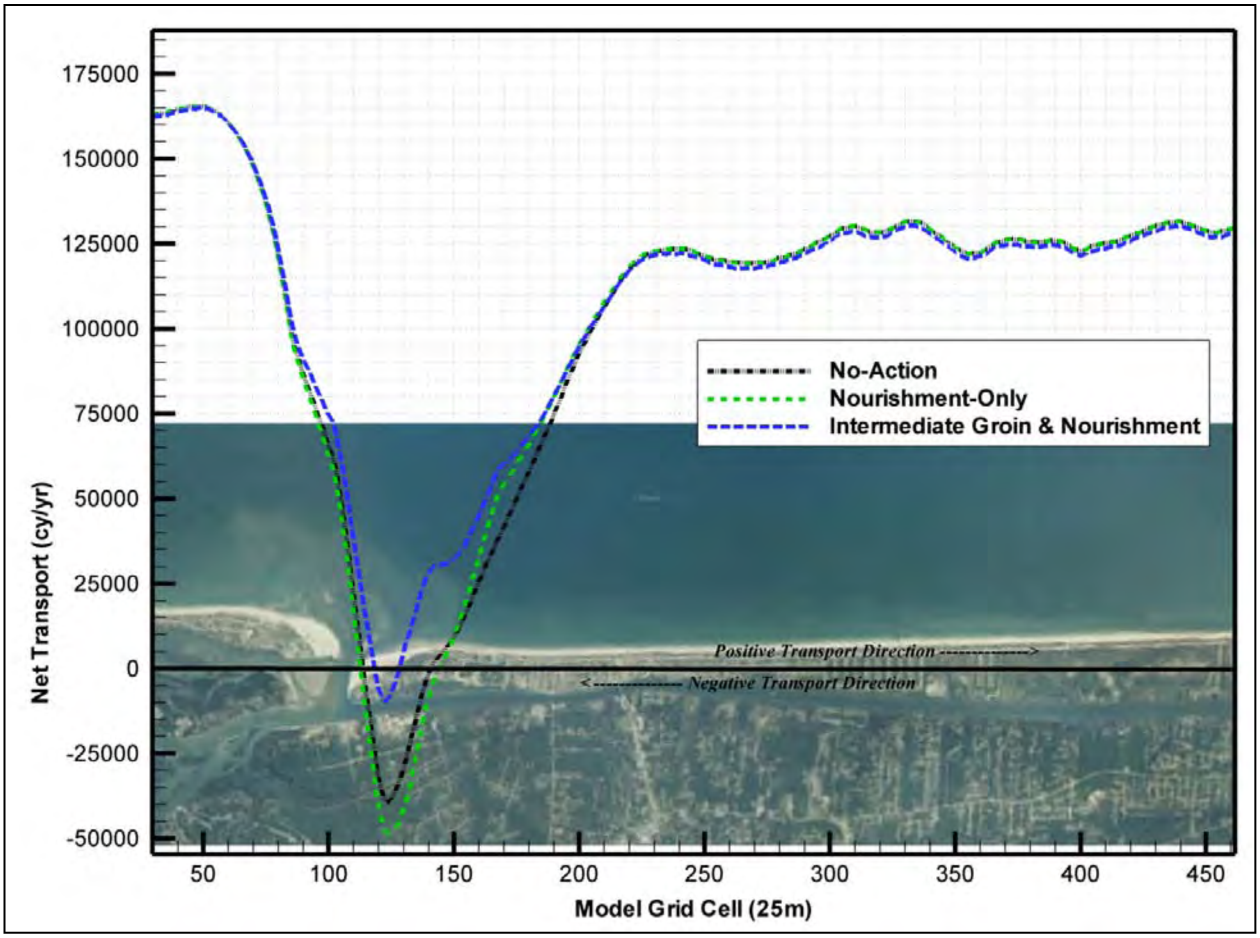


Figure 7-70. Net transport (6-yr average) comparison of intermediate groin/nourishment, nourishment-only, and no-action simulations.

8.0 GROIN DESIGN

Groins are an old and intuitive means of reducing beach erosion and are found along the coast worldwide as both engineered and non-engineered, ad-hoc structures (Kraus and Rankin, 2004). Additionally, groins can and have functioned effectively and economically when properly employed (Meadows et al., 1998). Without the use of groins in conjunction with beach nourishment, two rows of houses along Folly Beach and Edisto Beach, SC would now be in the surf and most of the high ground on the northern end of Pawleys Island, SC would have been destroyed (Kana et al., 2000).

Several proposed groin layouts were developed to preserve the beach and to reduce annual maintenance costs of the site. Groin design considerations are included in the modeling analysis and alternatives analysis and are described in more detail in this section.

The general design goals include: protection of public access, improvement of recreational beach area, enhancement of upper beach/dune habitat, stabilization of the east end of the beach (which represents the highest erosion rates on the island) from short-term and long-term fluctuations, and reduction of beach nourishment and LWFIX dredging maintenance costs. Groin design parameters have been selected based on the goal of maintaining a viable and accessible beach on the east end under all but the most extreme tidal/storm conditions, while also minimizing downdrift impacts.

8.1 DESIGN CONSIDERATIONS

8.1.1 LENGTH

In general, the length of the terminal groin is dictated by the size of the inlet, the configuration of the end of the island, and the length of shoreline the groin is designed to stabilize. The design groin length is based on modeling as well as on existing structures within Long Bay and other nearby areas. Long Bay extends approximately 100 miles from Bald Head Island, NC down to North Island, SC and displays a similar geology as well as similar tides and waves.

Existing groin structures in Long Bay include Bald Head Island and Garden City, SC (Figure 8-1) and Pawleys Island, SC. Additional analysis on existing groins in other areas of the State (e.g., Oregon Inlet, Hatteras, and Fort Macon) and the region were also assessed. The North Carolina Terminal Groin Report also contains significant information on this topic.

An effective groin length of approximately 500 to 1,000 ft is considered appropriate. The short groin (550 ft effective length) and the intermediate groin (700 ft effective length) modeled in Section 7 fall within this range. The modeled long groin has an effective length of approximately 1,100 feet. Note that *effective* groin length refers to the portion of the structure within the active beach zone (i.e., seaward of the dune).

Figure 8-1. Garden City, South Carolina, Sheetpile Groin after Construction during Low Tide (photo date: January 2003)

To prevent flanking, a terminal groin should be extended landward of the primary dune and account for historic shoreline positions as well as potential future positions. This “anchor” distance is estimated to be approximately 300 ft for the intermediate groin. Figure 8-2 on the next page presents the intermediate groin relative to historic shorelines. The landward “anchor” section will be buried. For the long groin, the anchor section is estimated at approximately 500 feet due to its proximity to the LWF Inlet channel and subsequent increased flanking potential. Note that effective length and active length will change based on topographic and bathymetric conditions (e.g., more erosion = longer effective length, more accretion = shorter effective length).

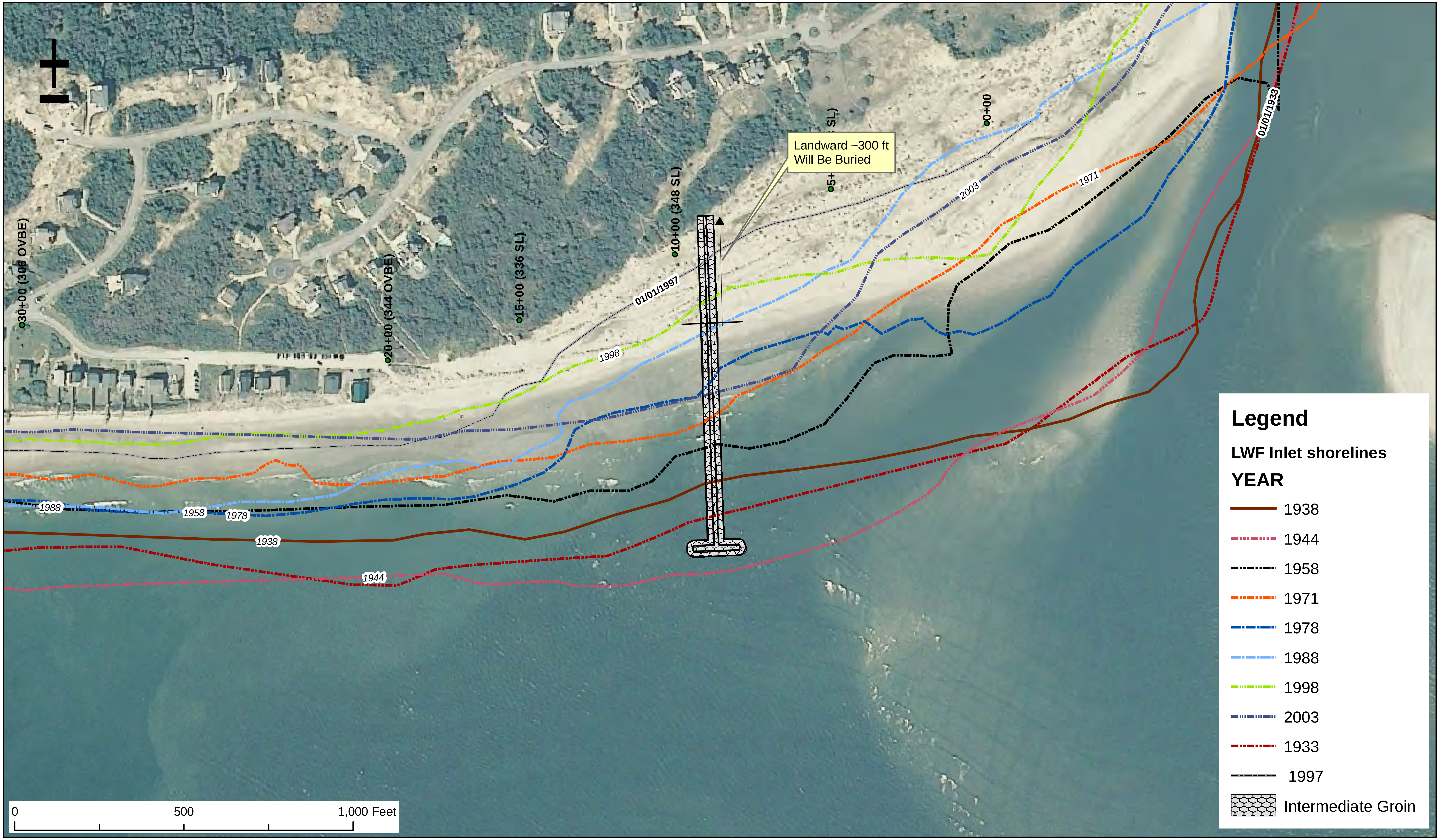


Figure 8-2:
Intermediate Groin and Historic Shorelines. Design must extend landward sufficiently to prevent flanking.
Aerial from 2008.

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APPLIED TECHNOLOGY & MANAGEMENT

8.1.2 MATERIALS AND DURABILITY

Terminal groin structures are typically composed of rock (i.e., rubble mound), sheetpile (steel or aluminum), concrete pre-fabricated units, or some combination of these materials. A rubble mound structure is the preferred material due to durability and permeability considerations. Durability is affected primarily by stone size and placement-slope of groin. The stone size is preliminarily set at 4 to 5 ft in diameter. This is in line with or slightly larger than existing structures in the Long Bay region. More complete analyses will determine final stone gradation, but the current assumptions indicate that this size range is valid. It is anticipated that granite rock (as opposed to limestone, etc.) will be utilized.

The design incorporates the use of triton mattresses (or similar) as a bedding layer (Figure 8-3a). The primary function of the mattresses is to provide a base for the rock and prevent settlement. These mattresses can also aid in structure removal, if deemed necessary in the future.

Figure 8-3a. Groin Construction Showing Mattress Placement

In terms of design life, if groins are not maintained, they will eventually fail, and the design assumes this will begin to occur in 25 years. However, if the structure is routinely inspected and repaired as necessary, the structures should last more than 25 years. As an example, the original Fort Macon terminal groin structure was built in the 1840s. Over the decades, occasional restacking of stones and some modifications have occurred to the Fort Macon groin and it remains effective today. An additional study from Delaware found that the combined effects of the groins and beach fill essentially stabilized the shoreline for nearly 50 years with minimal groin maintenance (Galgano, 2004).

8.1.3 PERMEABILITY AND PROFILE

Groin permeability and profile are key elements in effectively trapping sand while also minimizing downdrift impacts. Groin permeability refers to the amount of sand able to pass through the groin. To enhance groin permeability, only armor stone and no core stone is used to allow for a “leaky” groin (Figure 8-3b). Leaky groin structures have been used successfully for the Amelia Island, Florida, terminal groin (refer to North Carolina Terminal Groin Report). A leaky terminal groin was recently constructed in Hilton Head, SC, in 2012 (Figure 8-4). The proposed crest width is anticipated to be approximately 10 ft (i.e., two armor stone units).

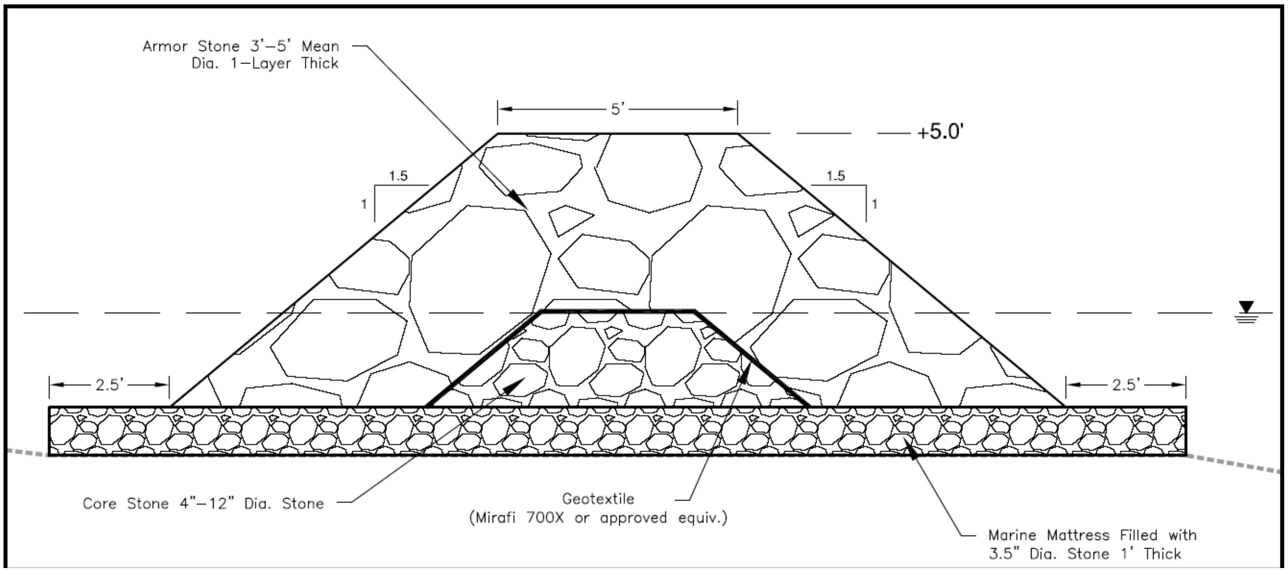


Figure 8-3b. Typical Groin Cross-Section (source: CEM, 2003). For a”leaky” groin, no core stone is used.

Figure 8-4. Recently Installed "Leaky" Terminal Groin on Hilton Head, SC during construction. Groin was constructed with only armor stone (no core stone was used) in 2012 (source: Olsen Associates).

The groin profile refers to its cross-shore slope and how well it mimics the natural shoreline slope from the dune out to the surf zone. All the groin alternatives in this report have been developed as relatively low-profile structures for both sand bypassing and recreational reasons. Lower profile groins allow more sand over-passing while recognizing beach walking and aesthetic considerations.

The landward section of the groin will be constructed to allow for sand cover and facilitating foot traffic along the beach. This elevation will limit sand trapping and allow some sand over-passing even at the end of a nourishment cycle (i.e., eroded conditions). Figure 8-5 presents the cross-shore profile of the intermediate groin. The final design may change the groin profile and/or crest width slightly. Note that while the bathymetry profiles in Figure 8-5 show a general growth trend, these profiles are not entirely representative of the 2000-2012 time span and they are not indicative of historical trends. The profiles do show a large variability in shoreline position (over ~300 feet between 2000 and 2012) and the need for the buried anchor section.

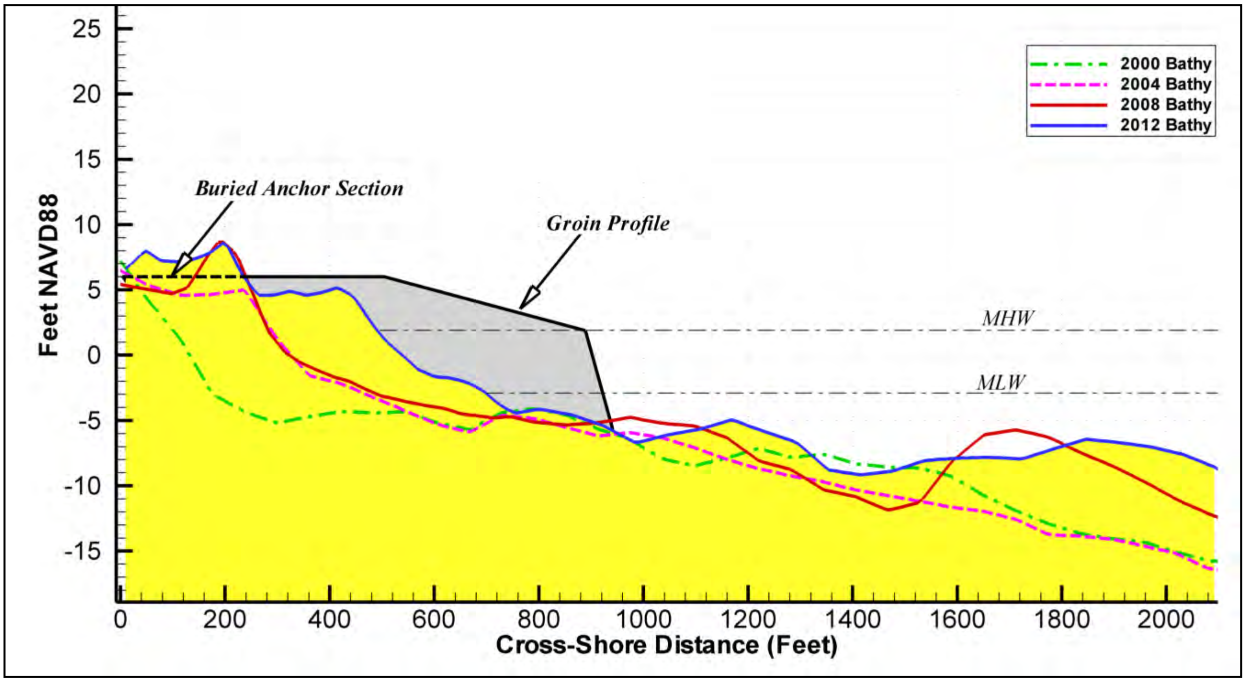


Figure 8-5. Groin Cross-Shore Profile in relation to Several Historic Bathymetric Profiles

8.1.4 SHAPE

The small "T-Head" feature on the seaward end of the short groin (~250 feet total) and intermediate groin (~60 feet off the main stem) is included to enhance fillet formation of the beach fronting the eastern shoreline area. The short groin features a larger T-Head since a shorter groin in this location would be expected to have less of a stabilizing effect on the shoreline than the intermediate groin alternative. T-Heads also help to minimize formation of potential offshore rip currents and sand losses during extreme wave conditions (see Section 8.1.5 for more discussion on rip currents). While the design does feature a T-Head, it is much smaller than traditional T-Head structures found in Florida and elsewhere. Figure 8-6 presents a figure of a Hunting Island, SC groin built in 2006/2007 with a smaller T-Head feature (similar to what is proposed for the intermediate groin).

Figure 8-6. *Hunting Island SC Groin at Low Tide. Hunting Island SC groins were constructed in 2006/2007.*

8.1.5 RIP CURRENTS

Rip currents are often cited as a detrimental side effect to groin construction. Along all coastlines, nearshore circulation cells may develop when waves break strongly in some locations and weakly in others. These weaker and stronger wave-breaking patterns are most often seen on beaches with a sand bar and channel system in the nearshore zone. They have also been noted at groins. Figure 8-7 shows the rip current effect between sandbars and at a groin. Rip currents are strongest under heavy wave conditions.

A Florida study of rip currents by Engle et al. (2002) determined that the frequency of rip current rescues increased during the following conditions:

1. Shore-normal wave incidence,
2. Mid-low tidal stages,
3. Deep water wave heights of 0.5 to 1.0 m, and
4. Wave periods from 8 to 10 seconds.

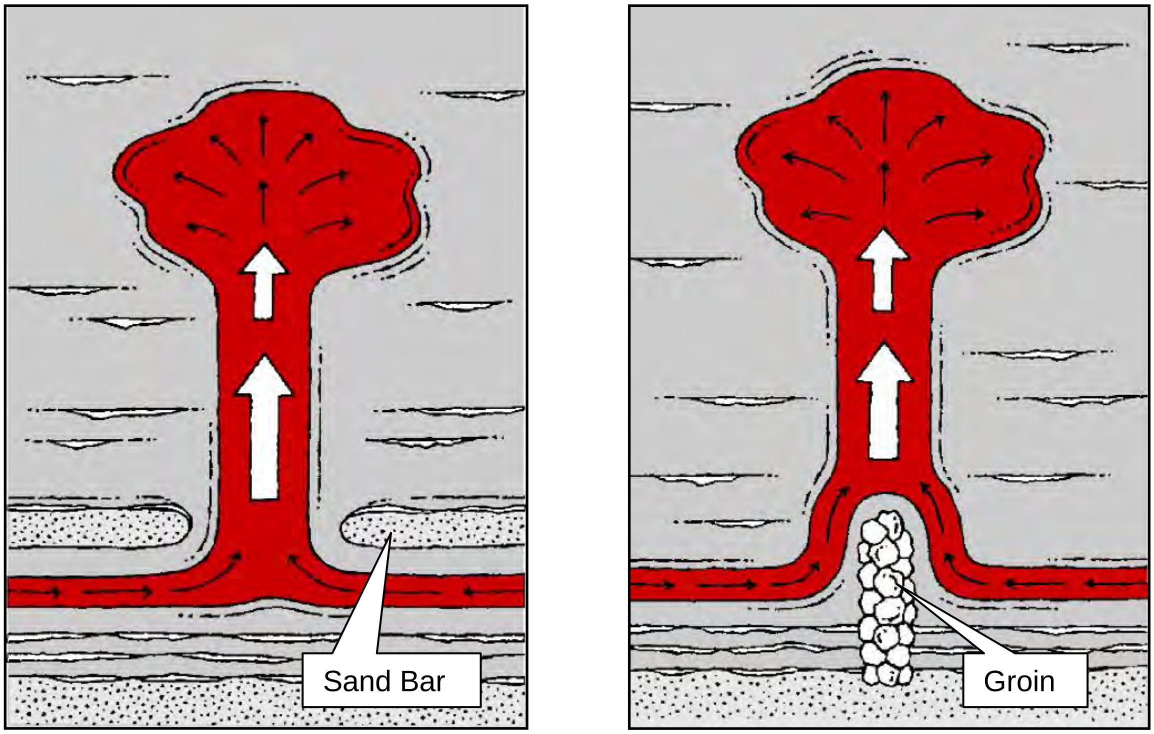


Figure 8-7. *Rip Current Schematic between Sand Bars (left) and Groin (right) (from www.ocean.udel.edu)*

LWF Inlet has had some problems related to rip currents, but these are not due to groins. The rip currents are primarily due to the LWF Inlet ebb tide outflow (Figure 8-8) and the expanded sandbar/shoal system associated with inlets. The proposed groin is designed to minimize rip currents; however, the LWF Inlet currents (greater than 5 ft/sec) will still be a hazard to swimmers, regardless of whether a terminal groin is constructed.

In a groin notching field study in New Jersey, Rankin et al. (2003) found that their study groin did not appear to exert an influence on the cross-shore flows (i.e., rip currents).

8.1.6 CONSTRUCTABILITY

The length of the proposed short and intermediate groins along with the relatively large tide range allows for the construction of these alternatives entirely from the shore, which is the most cost-effective alternative. Construction access and staging area for materials are also available via the public access parking lot. Additionally, road and bridge access to and from this site can handle relatively large payload trucks. The long groin alternative would likely require a barge or trestle system.

Figure 8-8. Existing Potential for Rip Current Effects at LWF Inlet (8/2005 photo) Source: USACE.

8.1.7 ADJUSTMENT/REMOVABILITY

The ability to adjust or remove the groin at a future date is a design consideration because of the regulatory stipulation that requires groin modification or removal if adverse downdrift impacts occur. Adjustments to the structure include increasing or decreasing crest width, notching, adding a weir, or grouting to make it less leaky (if future needs dictate). In terms of removal, this design incorporates the use of mattresses as a bedding layer. Some subsidence or covering by sand can be expected, but the mattresses can be uncovered by common construction methods (e.g., excavation, jetting). The rock should be readily available for removal because it will lie on top of the mattresses. More information on groin mitigation is included in Section 8.4.

8.2 SEA LEVEL RISE

Long-term sea-level rise (SLR) can have potential impacts along the coastline. While there is much debate about the magnitude and acceleration of SLR, the USACE (2011) suggests an analysis that includes predictions in SLR for projects related to water resources. Table 8-1 shows the SLR for the Holden Beach project location under scenarios of low, intermediate, and high conservatism (for 50 years of project life), based on an updated version of the recommended analysis (National Research Council, 1987; USACE 2011).

Table 8-1. Sea-Level Rise Predictions and Subsequent Beach Losses

	Sea-level rise		Shoreline Erosion, width (ft)	
Project Life	Scenario	SLR (ft)	SLR Shoreline Erosion (Bruun, 1988)	Existing DCM Background Erosion
50 years	Low	0.34	11.9	250 (min.*)
	Intermediate	0.74	25.9	-
	High	2.01	70.3	350 (max.*)

*Note: * min. uses 5 ft/yr erosion rate, max. uses 7 ft/yr*

A possible cumulative effect of SLR related to beach nourishment is the accelerated loss of beach and subsequent alteration of nourishment scheduling and volumes. Using a typical beach slope of 1V:35H, the predicted SLR under all scenarios is converted to shoreline erosion in Table 8-1. Table 8-1 also compares losses of beach width resulting from SLR projections and existing background erosion rates as established by DCM in 2011. For the majority of the proposed project shoreline, shoreline erosion rates range from 5 ft/yr to 7 ft/yr over an approximately 70-year period (for Holden Beach, DCM used 1940 and 2009 shorelines).

As seen in Table 8-1, shoreline erosion due to SLR is significantly less than existing background erosion. Existing background erosion does factor in historical SLR by default. Effects of long-term SLR (such as loss of usable beach width) are minor when compared to existing background erosion.

Over the next 50 to 100 years, incremental changes to SLR may become more significant to beach management. There are two primary ways to deal with increased erosion: 1) nourish more frequently with the same volume or 2) place more volume with the same frequency. An additional option to deal with increased erosion and sea level rise is to modify or enlarge the terminal groin structure. Repairs and modifications have occurred to the Fort Macon terminal groin since initial construction in the 1840s.

8.3 GROIN FILL REQUIREMENTS

For modern coastal engineering practice that adopts a regional perspective, provision exists in the groin functional design process to allow a certain amount of sediment to bypass a groin or groin field (Kraus and Rankin, 2004). When a well-designed groin fills to capacity with sand, longshore transport resumes at about the same rate as before the groins were built, and a stable beach is maintained.

The sand fillet volume of the proposed groin was calculated based on an area of sand accreting along the shoreline west of the proposed terminal groin. Nourishment volumes can be computed by determining the cross-sectional area differences between the groin profile and the latest surveyed beach profile, and then multiplying by the alongshore reach length. This is basically assuming that the updrift beach will match the groin profile. To arrive at a volume, total minimum beach nourishment equates to the minimum cy/ft multiplied by the alongshore reach length divided by 2 (for a triangular fillet).

In this way, a nourishment volume can be established for an individual groin. Fillet volume will change based on the latest shoreline position, with more volume needed for a more eroded condition.

Recent USACE east end beach fills have placed unit volumes from about 20 cy/ft to 40 cy/ft. Fill templates for recent projects typically feature an upper beach berm with crest elevation of +5 NAVD, which is relatively low. The USACE 933 project and all Holden Beach sponsored projects use a berm elevation of +6 ft or +7 ft NAVD. Figure 8-9 presents a conceptual profile of the intermediate groin with an accompanying beach fill. The landward groin crest is +6 ft NAVD and the profile generally follows the cross-shore slope of the shoreline. The proposed berm height in Figure 8-9 is +7 ft NAVD and includes a dune feature to build up the dry beach area on the east end.

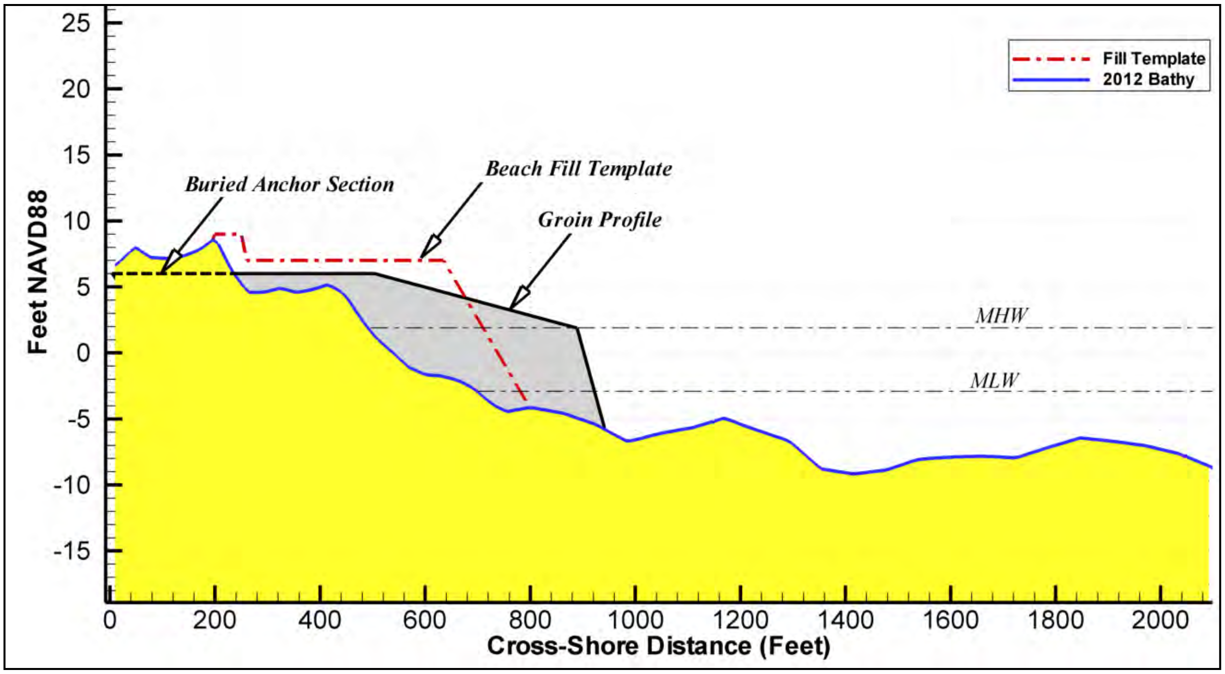


Figure 8-9. Short Groin Profile and constructed beach fill cross-section. The most recent 2012 bathymetric profile is plotted for reference.

The proposed beach fill template presented in Figure 8-9 represents approximately 95 cy/ft and includes a dune and berm component. Table 8-2 presents the proposed beach fill characteristics. Groin fill requirements based on 2012 survey data and the groin as shown in Figure 8-9 are approximately 95,000 cy. This volume assumes a fillet 2,000 feet alongshore which was exhibited in the modeling. The proposed fill template is 150,000 cy; therefore, significantly more volume is proposed to be placed than required. This additional fill will ensure immediate downdrift bypassing of sediment.

Table 8-2. Beach Fill Design Characteristics

Nourishment Feature	Dimension	
Dune Height	9	ft NAVD
Dune Width	50	ft
Dune/Berm Slope	5	
Berm Height	7	ft NAVD
Berm Width	varies	ft
Berm/Toe Slope	15	
Unit Fill Volume Range	20 - 100	cy/ft

Due to the leaky groin design, sand will not only pass around and over the structure, but through the structure as well. In terms of sand bypassing sediment characteristics, Aminti et al. (2003)

found that the sedimentological impact (mean grain size, percent fines, sorting) of a submerged groin on a beach is negligible (i.e., there was no significant difference between updrift and downdrift sand samples).

Groins can also have a beneficial effect on dune growth. A Westhampton, NY groin field study found that the largest rate of dune growth west (downdrift) of the groin field from initial construction in 1996 to February 2009 was approximately 2.0 cy/ft-yr while the beachwide average rate of growth was 1.25 cy/ft-yr (Bocamazo et al., 2011). Dune growth via Aeolian transport[1] due to the groin field has added to the stability of the beach-dune cross-section, contributed habitat to some creatures, and most significantly, has increased the width of the dunes for additional storm protection (Bocamazo et al., 2011). Holden Beach has a similar east-west orientation as Westhampton, NY and predominant southwest winds at Holden Beach can promote dune growth (through Aeolian transport) to the west of the proposed terminal groin.

8.4 GROIN MITIGATION

It is acknowledged that some groin projects (in most cases, without concurrent beach nourishment components) have been cited as adversely impacting downdrift shorelines. The Town has developed a beach nourishment and groin project to minimize downdrift impacts. A 2004 paper by Galgano found that “in many circumstances, groins have functioned effectively and stabilized an eroding beach without seriously harming adjacent areas….the groins, in conjunction with beach fill, arrested beach erosion at the site and effectively stabilized the beach for nearly 50 years notwithstanding their structural deficiencies.”

Pawleys Island, SC (in southern Long Bay) has 23 groins that were sand tightened and nourished in 1999. The downdrift neighbor, northern Debidue Island, has remained accretional or stable since this time (Kana et al., 2004). Kana found that “Pawleys Island groins indicate that groins can stabilize an entire littoral cell without adversely impacting the adjacent cell (northern Debidue Beach).”

Another example of a successful groin project is provided by the NOAA Coastal Services Center (CSC) regarding the Folly beach groins:

---

[1] Aeolian transport refers to the movement of sediment by wind

> The beach compartments between groins can be filled with beach quality sand to prevent the longshore material from being blocked until the groin field is filled by natural processes, as was the case, for example, in Folly Beach, South Carolina (Ebersole, Nielans, and Dowd 1996). There, the groins extended along about one-half mile of the nearly five miles of nourishment. The area where they were installed was more rapidly eroding than the adjacent beaches. After the nourishment, it was apparent that this "hot spot" had been largely controlled by the presence of the groins added at the time of the beach fill. (www.csc.noaa.gov/beachnourishment/html/geo/shorelin.htm)

Dr. Orrin Pilkey has also co-authored a paper stating that groins can increase beach nourishment longevity (Leonard, Dixon and Pilkey, 1990):

> On the Atlantic coast, groins appear to increase the longevity of replenished beaches. Examples of this include Edisto Beach, SC, where groins have been used in conjunction with replenishment, and Virginia Key, FL, where groins were added in 1977. In both cases, the presence of the groins is believed to have increased the stability of the emplaced fill, so that some of the fill was apparently still in place more than five years after emplacement.
>
> Similarly, the Pacific coast has repeatedly experienced general success at least partly attributable to the presence of groins. Capitola, Cabullo Beach, Redondo Beach, and Newport Beach are examples of beaches where a terminal groin has assisted in stabilizing the beach.

Many other studies or publications have supported the use of groins in conjunction with beach nourishment. As an example, the Select Committee on Beach Nourishment and Protection issued its final report in January 1995 (NRC, 1995). The Committee was under the auspices of the Marine Board of the National Research Council (NRC) and asked to conduct a multidisciplinary assessment of the engineering, environmental, economic and public policy aspects of beach nourishment. Committee members were:

> Orrin H. Pilkey, Duke University, Durham, North Carolina

Richard J. Seymour (chair) Texas A&M University and Scripps Institution of Oceanography

Nancy E. Bockstael, University of Maryland, College Park

Thomas J. Campbell, Coastal Planning and Engineering, Inc., Boca Raton, Florida

Robert G. Dean, NAE. University of Florida, Gainesville

Paul D. Komar, Oregon State University, Corvallis

Anthony. P. Pratt, Delaware State, Dept. of Natural Resources

Martin P. Snow, Great Lakes Dredge & Dock Co., Chicago, IL

Robert F. van Dolah, South Carolina, Dept of Natural Resources

J. Richard Weggel, Drexel University, Philadelphia, PA

Robert L. Wiegel, NAE, University of California, Berkeley

The following recommendations were made by this committee as applicable to the proposed project.

> RECOMMENDATION: Agencies should modify their prescriptive laws, regulations, and management plans for the coast to allow the use of fixed structures in conjunction with beach nourishment projects where project performance can be significantly improved, out-of-project negative effects are acceptably small or are mitigated as necessary, and beach access or use is not impaired. The costs of the structures should not exceed the savings achieved by increasing the level of protection or the times between successive renourishments. Environmental impacts should also be considered. (p. 143-144)
>
> and
>
> RECOMMENDATION: Each fixed structure that is used in conjunction with a beach nourishment project should be filled to the upper limit of its holding capacity if it would otherwise accumulate sand. Where uncertainties exist, fill should exceed the calculated upper limit of the holding capacity of the structure. If a beach, nourishment project is not maintained, adverse effects of any structure should be mitigated or the structure should be removed. (p. 144)

The groin and nourishment project is designed to continue allowing nourishment sand to benefit downdrift shorelines when compared to the naturally occurring background erosion. Therefore, negligible impacts are anticipated due to downdrift erosion. Downdrift monitoring will be conducted to document impacts. If negative impacts due to the presence of the groin are documented, mitigation, including additional sand placement, groin modification, and/or groin removal, may occur.

There have been several cases of successful groin notching modifications including northern New Jersey (Donahue et al., 2003) and Tybee Island, Georgia (USACE, 1997) (Figure 8-10). In a 1997 Tybee Beach groin tuning paper by the USACE, the estimated groin modification cost for removing (i.e., notching) six modules and placing these modules adjacent to a nearby seawall was a total of $5,800 for use of a small crane and labor. The groin modules are 14-ton concrete structures 8 ft long, 5 ft high, and 10 ft wide. Construction materials for the proposed project will differ and construction costs have increased, however, $5,800 for removing six groin modules to lower the groin profile (i.e., modify it) provides an example of the relatively inexpensive costs of groin modification/removal.

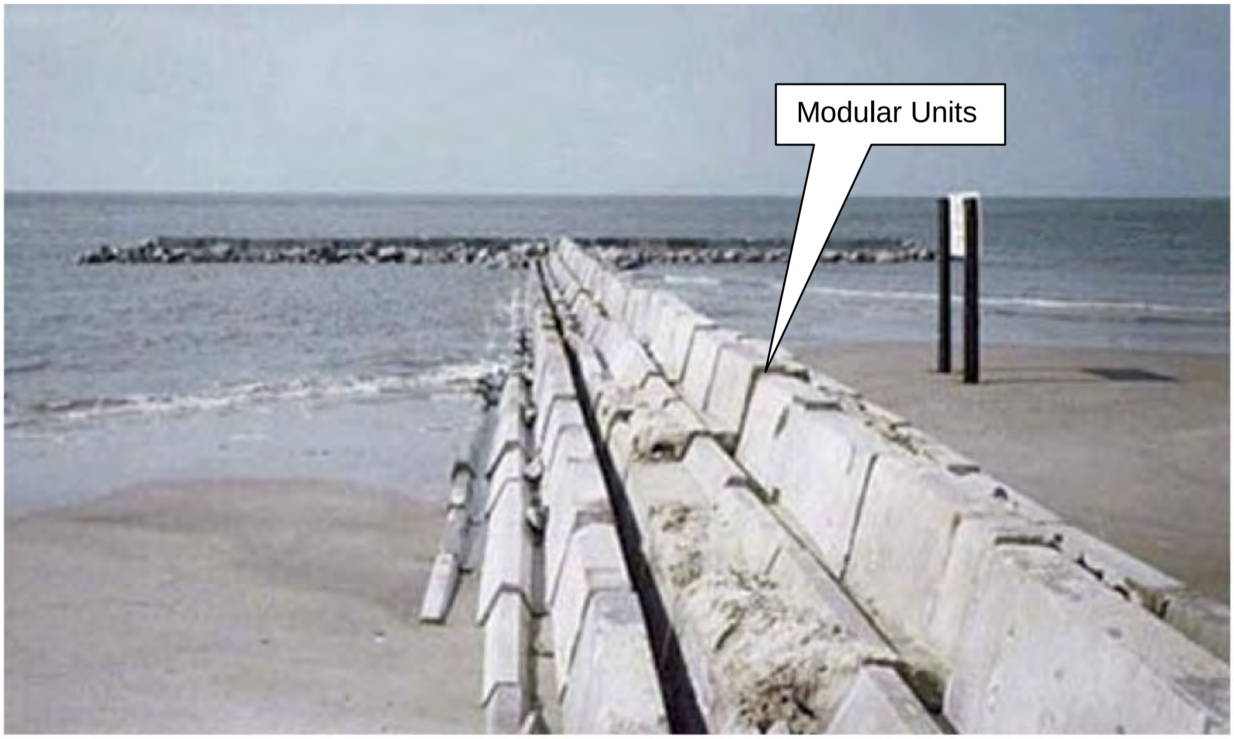


Figure 8-10. Tybee Island, Georgia Terminal Groin Structure that was Successfully Modified by Removing Six Modular Units on the Seaward End (source: USACE, 1997). Also note T-Head feature.

9.0 BENEFITS AND COSTS

Consideration of benefits and costs are very important when evaluating beach management alternatives. The key to a well-designed groin structure is ensuring that it will increase the nourishment interval while minimizing downdrift impacts once constructed. While increasing the nourishment interval represents the most significant construction-related cost savings for the proposed east end shoreline stabilization program, other benefits and cost savings are also anticipated.

A general overview of benefits and costs associated with maintenance of the east end of Holden Beach (e.g., nourishment, terminal groin, no-action) as well as benefits and costs associated with maintenance of LWF Inlet (e.g., AIWW dredging, side-caster dredging) are summarized in this section.

The preferred alternative includes several components:

- Terminal groin
- Beach nourishment (using LWFIX borrow area)
- Monitoring

In addition to these components, benefits and costs associated with other alternatives are discussed and include:

- Channel relocation
- Retreat
- Beach nourishment only (including no-action)

In general, major expenditure items (i.e., "hard" costs) such as dredge mobilization/ demobilization, beach nourishment, and structure relocation are identified, whereas additional costs such as permitting, design and surveying (i.e., "soft" costs) are also included when quantifiable. In other cases, assumptions are made (for example, permitting, design and surveying typically represent about 10 percent of the total construction costs).

Since there is no apparent low cost alternative and taking into account the value of coastal property, it would seem reasonable to contemplate all feasible strategies to protect or stabilize selected locations (Galgano, 2004).

9.1 GROIN CONSTRUCTION COSTS

Groin costs primarily include equipment and materials mobilization/demobilization, materials, and construction. Permitting, design, monitoring/surveying, nourishment, and mitigation costs are also related cost items.

Mobilization/demobilization (mob/demob) for groin construction is estimated at $100,000. Mob/demob for groin construction typically requires several truckloads of materials. As a relatively recent example of mob/demob costs, the 2007 Hunting Island, SC mob/demob cost for 5 groins was $143,000 (SC Dept. of Parks, Recreation, and Tourism, 2007). In terms of materials, armor stone, bedding stone and marine mattresses (Figure 9-1) will be used (core stones are not proposed). Armor stone tonnage calculations are typically based on a 25 percent void ratio assumption. These voids and the lack of core stone provide the groin with its proposed "leaky" characteristic.

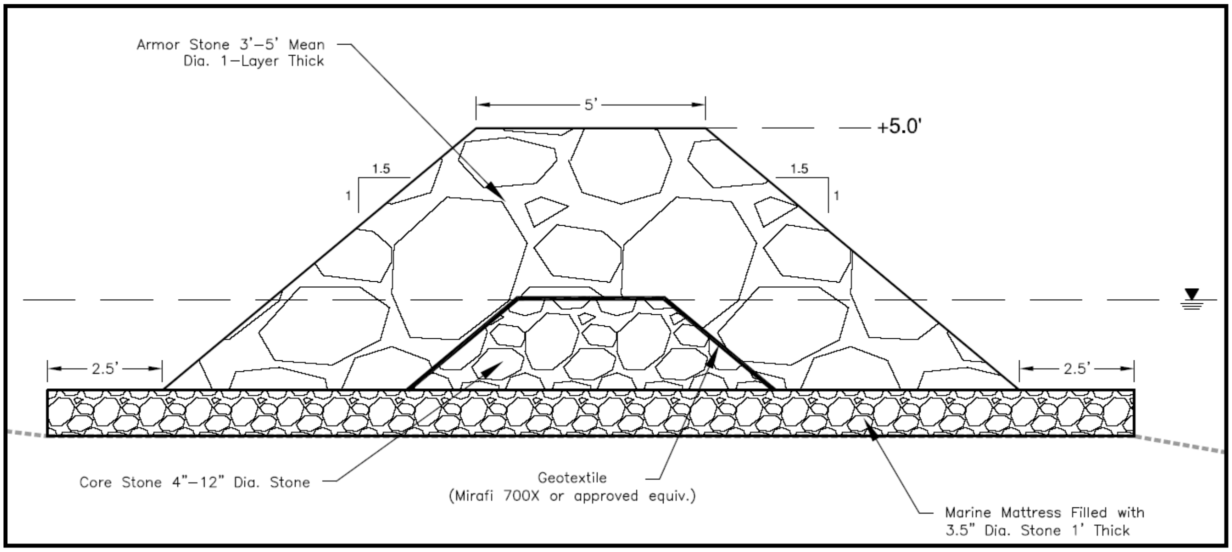


Figure 9-1. Typical Groin Cross-Section (note that core stones are not proposed)

Groin construction for several recent projects in South Carolina (Hunting Island, Daufuskie Island) have realized costs ranging between $1,000 and $1,500 per foot of groin length (Bloody Point POA, 2010; SC Dept of Parks, Recreation, and Tourism, 2007). These structures were built from land, which typically results in significant savings versus water-based construction from barges or temporary trestles.

Most recently in South Carolina, a 2012 terminal groin construction project occurred on Hilton Head Island where a ~1,000-foot rubble-mound terminal groin with T-Head was installed for $1.67 million (Olsen Associates, 2012). The next two most competitive bids for the groin project were $2.55 million and $2.58 million (Olsen Associates, 2012). The total project cost included site preparation, sand excavation and backfilling, offsite assembly, transport, delivery and placement of approximately 190 stone-filled marine mattresses, installation of geogrid/fabric composite underlayment, and placement of approximately 12,000 tons of granite (or equivalent) armor stone. Additional work also included establishment of access and staging area, site restoration, demobilization, safety and security measures, permit compliance, final grading, and surveying (Town of Hilton Head, 2012). Cost per linear foot for the awarded bid was approximately $1,670.

Another additional recent groin construction project occurred in Hideaway Beach, Florida, where the lowest bid for the construction of three T-Head groins was approximately $925,000 (MarcoNews.com, 2013). These groins were constructed of steel sheetpile and rock.

As previously mentioned, a longer groin may require construction of a trestle (similar to the Amelia Island, FL terminal groin project) or the use of standard barges. In some cases, a jack-up barge may be required in the nearshore area to reduce impacts of waves and currents on construction operations. The use of trestles and jack-up barges increases groin construction costs significantly.

The North Carolina Terminal Groin study (Moffatt & Nichol, 2010) proposed cost estimates for rubble-mound structures (i.e., $1,230/lf for a 450 ft groin on a mild sloping beach) similar to the recent South Carolina groin construction projects. To expedite groin construction, the beach nourishment component is often constructed immediately prior to groin construction. This allows for more work area that is unaffected by tides and waves. The proposed intermediate groin structure (about 1,000 ft total length) can be estimated at approximately $2,500,000.

9.2 GROIN REMOVAL

Groin removal typically requires much less time and effort than groin construction (as with most construction vs. demolition projects). The North Carolina Terminal Groin study (Moffatt & Nichol, 2010) estimated that for rock or concrete armor groins, the cost of removal is approximately $500 - $1,500 per linear ft. The recently permitted Hilton Head terminal groin had a removal estimate of $300,000 (about $300/ft) (Creed, personal communication, 2010). Note that a letter of financially binding commitment documenting this removal cost was provided to the State permitting agency (SCDHEC-OCRM). South Carolina regulations require a “financially binding commitment, such as a performance bond or letter of credit that is reasonably estimated to cover the cost of reconstructing or removing the groin and/or restoring the affected beach through renourishment pursuant” (SC Regulation R30-15(G)(2)). Other recently permitted groin projects in SC, such as Hunting Island (five groins) and DeBordieu (three groins) required a $200,000 letter of financially binding commitment.

Based on groin removal costs similar to the 2012 Hilton Head terminal groin, the estimated cost for the Holden Beach Terminal Groin removal is proposed at $300,000. Note that groin removal is a last resort and that nourishment and/or groin modification would represent initial mitigative steps. The actual volume for any potential mitigative beach nourishment will be dependent on monitoring; however, a 50,000 cy nourishment is assumed and represents a conservative typical annual placement amount on the east end of Holden Beach.

The source of funds for mitigative actions, if required, would be provided by the Town’s Beach Preservation/Access & Recreation/Tourism (BPART) Fund. The BPART Fund is a dedicated funding mechanism for beach management projects and can be used for any east end shoreline stabilization activities, including groin mitigation. The BPART Fund brought in approximately $1.4 million for the 2011/2012 fiscal year.

9.3 BEACH NOURISHMENT

Nourishment costs include a number of items; although dredge mob/demob and active pumping constitute the primary costs. Whether beach nourishment is considered independently or as a component of the terminal groin project, the preferred borrow area is the LWFIX (including the 400-ft bend widener). Nourishment costs are estimated at $7/cy (based on historical and recent projects of similar size and borrow area location).

The USACE typically bundles several Inlet/AIWW projects in the region to save on mob/demob fees. As an example, 2009/2010 mob/demob fees for the awarded contract were $1.2 million for seven AIWW-related projects (Brown Inlet Crossing, New River Inlet Crossing, Jacksonville Channel, Carolina Beach Inlet Crossing, LWF Inlet Crossing, LWF River Crossing and Shallotte

Inlet Crossing). LWFIX pumping costs for this project ranged from $5.41 to $6.50 per cy (150,000 cy estimated total volume).

This multiple project bundling is not feasible for the proposed project; however, the borrow area proximity to the nourishment area as well as the borrow area being situated landward of the COLREGS line (allowing the use of smaller, less expensive dredges which have smaller mob/demob fees than ocean-going dredges) should allow for relatively competitive pricing. Dredge mobilization for the proposed LWFIX project is estimated at $750,000 for the purposes of this document.

In the future, increasing beach nourishment construction costs can be expected due to the following factors:

- Increased diesel fuel prices
- Increased environmental constraints (environmental windows, access restrictions/buffer, monitoring and mitigation related costs)
- Reduced local sand supply

Increased fuel costs are directly related to dredge mob/demob fees, which represent a significant portion of overall project costs. A recent example is the $4 million mob/demob fee for the 2013 Carteret County nourishment project. The Town of Hilton Head has also summarized dredge mob/demob fees in relation to increasing fuel costs over the last two decades (Figure 9-2). It is noted that the inflation rate exhibited for Figure 9-2 is approximately 6%, which is relatively high.

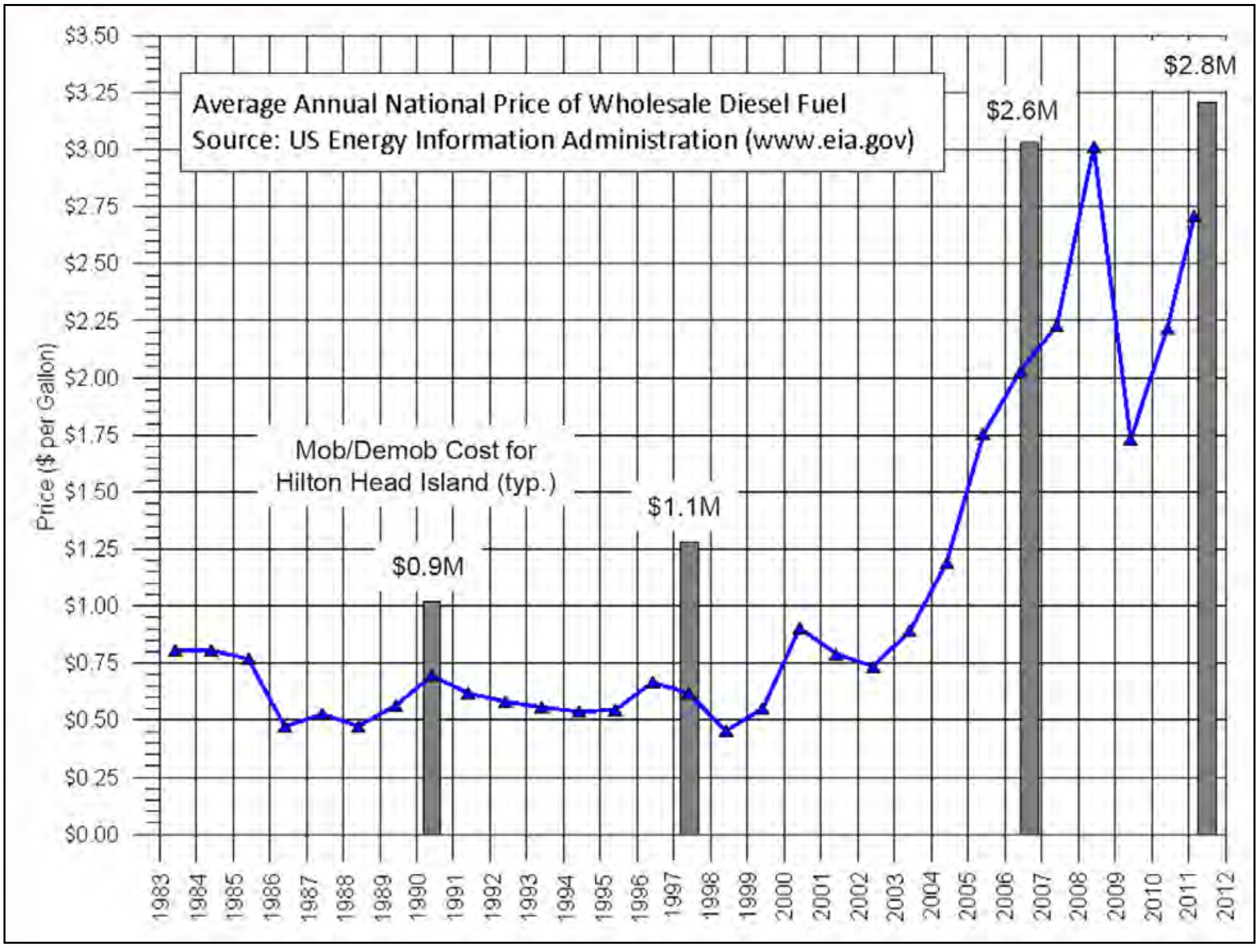


Figure 9-2. Average Annual National Price of Wholesale Diesel Fuel in Comparison to Hilton Head Nourishment Mob/Demob Costs (source: Olsen Associates, 2012).

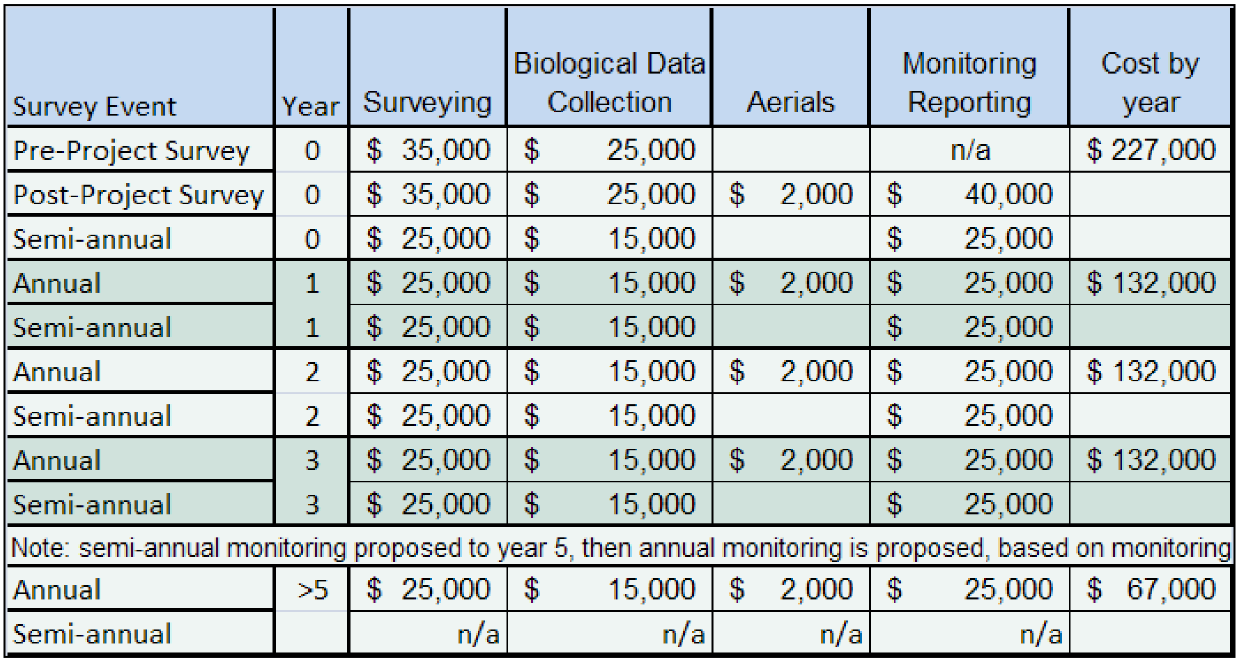
9.4 PROJECT MONITORING

Project monitoring for the preferred groin and nourishment project will involve physical and biological data collection components and will be combined to the greatest extent possible with the Town's existing monitoring program. Previous beach nourishment permitting on Holden Beach (including Town-sponsored and USACE projects) have included physical and biological surveys and reporting.

Briefly, the Town conducts annual physical (i.e., elevation) surveys, whereas biological surveying/sampling is nourishment project related (pre/post, 6-month, 1-year, etc.). The Town's biological sampling program includes the coquina or bean clam (*Donax variabilis* and *Donax parvula*), mole crab (*Emerita talpoida*), and ghost crab (*Ocypode quadrata*), which are three often-used indicators of beach ecological health (Greene, 2002). Note that sediment sampling also occurs to assess beach fill compatibility.

Other biological monitoring studies at Holden Beach include the Versar (2004) reports related to the USACE 933 project in 2001/2002. A conceptual monitoring program with estimated costs in presented in Table 9-1.

Table 9-1. Conceptual Monitoring Cost Estimates



Survey Event	Year	Surveying	Biological Data Collection	Aerials	Monitoring Reporting	Cost by year
Pre-Project Survey	0	$ 35,000	$ 25,000		n/a	$ 227,000
Post-Project Survey	0	$ 35,000	$ 25,000	$ 2,000	$ 40,000	
Semi-annual	0	$ 25,000	$ 15,000		$ 25,000	
Annual	1	$ 25,000	$ 15,000	$ 2,000	$ 25,000	$ 132,000
Semi-annual	1	$ 25,000	$ 15,000		$ 25,000	
Annual	2	$ 25,000	$ 15,000	$ 2,000	$ 25,000	$ 132,000
Semi-annual	2	$ 25,000	$ 15,000		$ 25,000	
Annual	3	$ 25,000	$ 15,000	$ 2,000	$ 25,000	$ 132,000
Semi-annual	3	$ 25,000	$ 15,000		$ 25,000	
Note: semi-annual monitoring proposed to year 5, then annual monitoring is proposed, based on monitoring						
Annual	>5	$ 25,000	$ 15,000	$ 2,000	$ 25,000	$ 67,000
Semi-annual		n/a	n/a	n/a	n/a	

Several assumptions were made during preparation of Table 9-1. The Surveying column includes beach transects on Holden Beach and Oak Island as well as the LWFIX borrow area. Appendix D includes a draft inlet management plan that outlines the proposed monitoring. Survey transects will be coordinated with annual beach monitoring transects and USACE LWF Inlet surveys (typically occurring several times a year) to minimize duplication of effort and costs.

Biological surveying and data collection is proposed to continue to focus on macro-invertebrates (i.e., bean clam, mole crab, ghost crab), while some shorebird monitoring may also occur. Five physical factors predominantly control the distribution and abundance of biota in the intertidal zone: wave energy, bottom type (substrate), tidal exposure, temperature, and salinity (Dethier and Schoch, 2000; Ricketts and Calvin 1968). Therefore, sediment sampling will also be an important component of the project monitoring.

Reporting and analysis of both physical and biological data is included in the Monitoring Reporting column in Table 9-1.

9.5 AIWW MAINTENANCE DREDGING

Another disposal option for LWFIX maintenance could potentially be the Sheep Island confined disposal facility (CDF). However, this is likely to be a costlier disposal alternative than the east end of Holden Beach. The Sheep Island CDF represents a similar disposal piping/pumping distance; however, the CDF is near capacity and would require dike expansion (see Section 6.4.4 for more information on the Sheep Island CDF). The beneficial use of beach-compatible dredged material placement on the beach would also not occur.

9.6 OUTER CHANNEL DREDGING

Outer channel dredging is currently performed primarily by side-caster dredge (typically the *Merritt*). Assuming adequate funding is available, USACE estimates outer channel dredging at $225,000 per quarter, including the associated surveys (USACE Navigation District, email communication). Therefore, annual costs to maintain the outer channel are estimated to be $900,000. As mentioned in Section 4, the State, Brunswick County, Holden Beach, and Oak Island funded this maintenance effort under an MOA for a 6-month period of 2012 due to lack of federal funding. The State, Brunswick County, Holden Beach, and Oak Island continue to coordinate with the USACE regarding funding to ensure safe navigation of the outer channel.

The outer channel is not recommended for incorporation into the preferred alternative because modeling and historical maintenance activity show that the cleared channel only lasts about 3 months before significant infilling occurs. After 3 months, either maintenance is again required or the navigation buoys are removed. Figure 9-3 presents an example of the ephemeral nature of the outer channel. As a result, the navigation buoys have been removed by the Coast Guard on several occasions. The relatively small size of the LWF outer channel (150 ft wide, 8 ft deep), relative to the local sediment transport rate, is a primary factor in its short-lived position and depth. The presence of three Civil War shipwrecks also plays a factor in limiting the size and location of the outer channel.

The North Carolina State Historic Preservation Office (NCSHPO) (Renee Gledhill-Earley, Environmental Review Coordinator) and the NCDCR Underwater Archaeology Branch (Chris Southerly, Project Archaeologist/Divemaster) were both contacted to assess the feasibility of removing these Civil War vessels. From a regulatory standpoint, Section 106 of the National Historic Preservation Act and the Advisory Council on Historic Preservation's Regulations for Compliance with Section 106 codified at 36 CFR Part 800 apply.

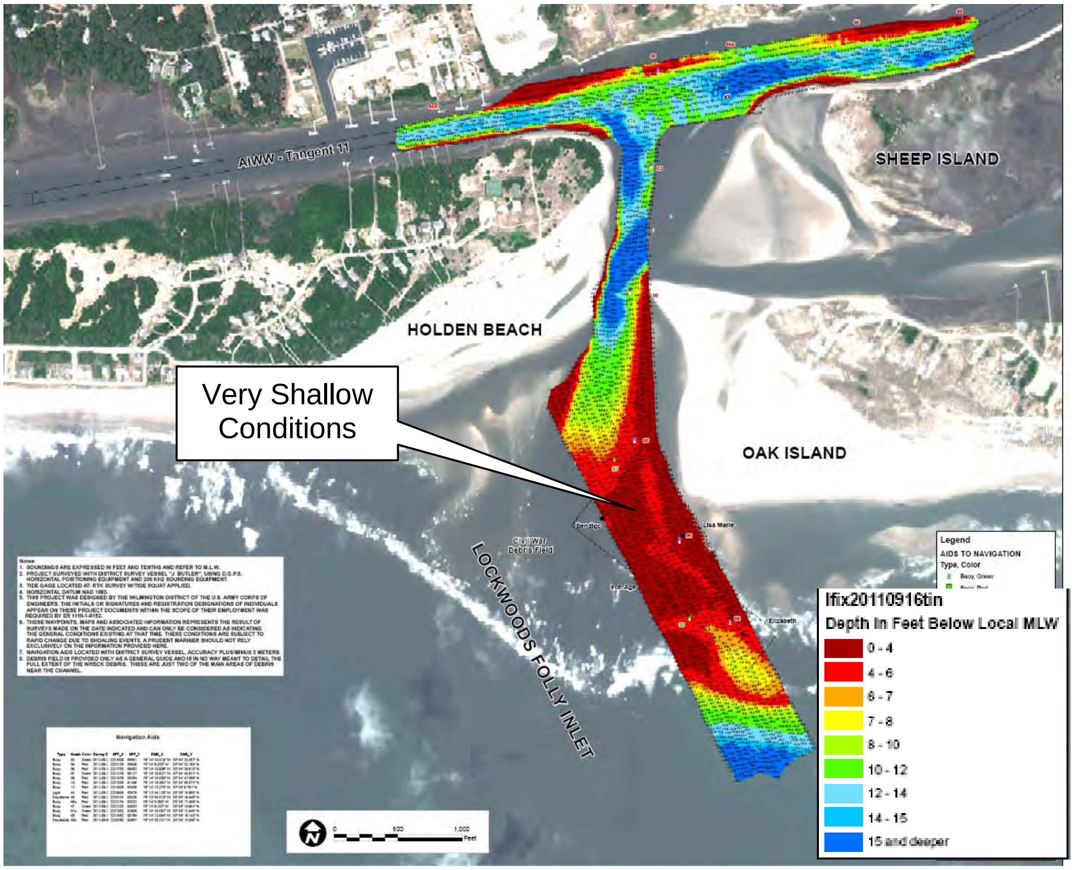


Figure 9-3. USACE September 2011 Survey of LWF Where Channel is Becoming Unnavigable. Navigation buoys are removed by the USCG when warranted.

It is the general policy to not disturb historical wrecks. Thus, the alternatives available include:

1. Avoidance
2. Minimization (e.g. take one, leave two)
3. Mitigate losses

Mitigation essentially refers to excavation, laboratory work, and long-term curation. Both the NCSHPO and NCDCR believe mitigation to be prohibitively expensive and time consuming. Similar excavation, conservation and curation projects have recently occurred for the CSS Hunley (Civil War submarine), Queen Anne's Revenge (Blackbeard's pirate ship), and the USS Monitor (Civil War ship).

Field operations alone can be cost prohibitive and the laboratory restoration process can take 5 to 10 years and millions of dollars (NCDCR, personal communication). Once restored, a perpetual budget for long-term curation (laboratory and museum) must be established. Additionally, political and public opinion can also thwart any mitigation/recovery effort. In terms of estimated costs, the CSS Hunley, which is a smaller vessel (about 40 ft length) than the LWF Inlet Civil War wrecks, has cost between $12 and $20 million (Byko, 2001). Long-term curation has been estimated at up to $40 million for the CSS Hunley (Hicks, 2004). For cost estimation purposes, historical shipwreck mitigation is approximated at $50 million per vessel over a 30-year period.

9.7 NO-ACTION

The no-action plan refers to the continuation of current beach management practices along the east end of Holden Beach. These measures to offset erosion include the USACE LWFIX nourishment project, dune repair and enhancement, and the deployment of sandbags. The USACE LWFIX project typically occurs every 2 years and has been occurring since the 1970s. While beneficial, it has not been able to prevent the loss of homes on the east end during this time span. As recently as 2008, the dune was breached in this region. From a cost perspective, several studies have quantified the east end erosion, including the NC Terminal Groin Report (Moffatt & Nichol, 2011) and the USACE BCB 50-year project (USACE, 2012).

The recently published NC Terminal Groin Report (Moffatt & Nichol, 2011) developed two different economic categories for a general assessment of terminal groin feasibility:

1. 30-Year Risk Area (YRA)
2. Imminent Risk Property (IRP)

The 30-YRAs were defined by lines on aerial photography maps provided by the DCM. The maps are based on aerial photos from 2003 to 2009. Any land existing seaward of the lines is assumed to be at risk in the next 30 years. IRP infrastructure is located immediately adjacent to erosion control sandbags locations or between two nearby sandbag locations (Moffatt & Nichol, 2011). These lines were agreed upon by the Science Panel for use in the NC Terminal Groin Report assessment (refer to Moffatt & Nichol, 2011 for more information).

The Terminal Groin Study included the following economic values in determining IRP and 30 YRA costs:

- Residential property
- Commercial property
- Government property
- Road infrastructure
- Waterline infrastructure
- Sewer infrastructure
- Property tax base and revenues
- Recreation and environmental value

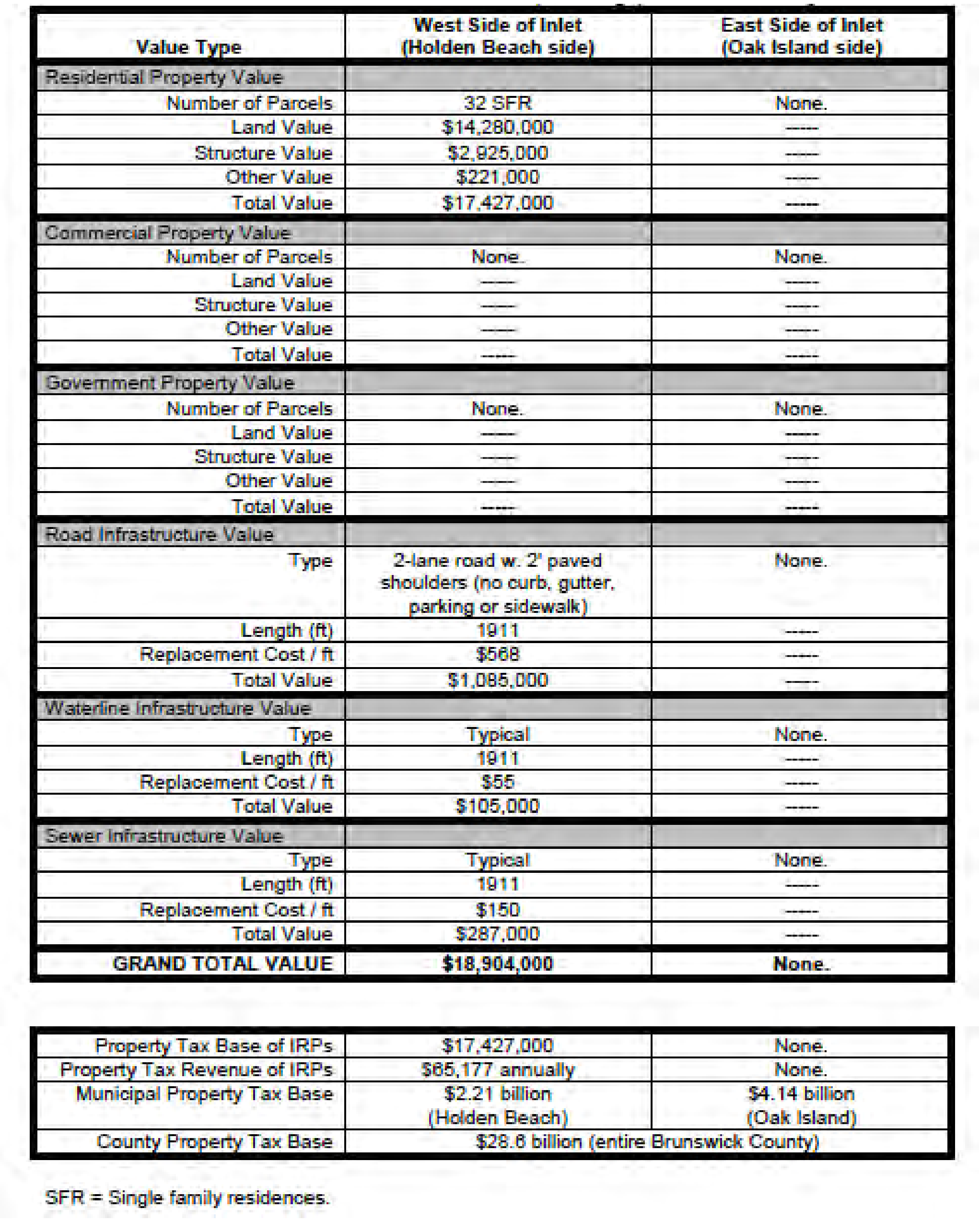
IRP and 30-YRA values for structures adjacent to LWF Inlet are presented in Table 9-2. As shown, almost $19 million in economic value is considered as imminent risk property on the east end. Table 9-3 is excerpted from the State Terminal Groin Report and itemizes IRP values for LWF Inlet. These values were estimated in 2009 and are likely to increase with time.

Table 9-2. Estimated Structure Costs adjacent to LWF Inlet (source: M&N, 2011)

	30-yr Risk Area (YRA)		Imminent Risk Properties (IRP)	
Inlet Hazard Area	West of Inlet (Holden Beach)	East of Inlet (Oak Island)	West of Inlet (Holden Beach)	East of Inlet (Oak Island)
Lockwoods Folly Inlet	$34,130,000	$118,259,000	$18,904,000	None

As previously mentioned, the no-action alternative would rely on existing beach management programs. However, the USACE LWFIX project is uncertain to continue in the long-term and can be assumed to occur much less frequently due to funding limitations. As a result, it is reasonable to assume that losses of homes similar to that exhibited from the 1970s to 1990s will occur. Note that the USACE LWFIX project has occurred since the 1970s (Shallow Draft Inlet Report, NCDENR, 2005) and that more than 40 properties were lost during this period. Therefore, losses between $19 million (IRP) and $34 million (30-YRA) may be expected to occur over the next 30 years.

Table 9-3. Economic Value at Imminent Risk at LWF Inlet
(source: Moffatt & Nichol Terminal Groin Report)



Value Type	West Side of Inlet (Holden Beach side)	East Side of Inlet (Oak Island side)
Residential Property Value		
Number of Parcels	32 SFR	None.
Land Value	$14,280,000	-----
Structure Value	$2,925,000	-----
Other Value	$221,000	-----
Total Value	$17,427,000	-----
Commercial Property Value		
Number of Parcels	None.	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None.	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	2-lane road w. 2' paved shoulders (no curb, gutter, parking or sidewalk)	None.
Length (ft)	1911	-----
Replacement Cost / ft	$568	-----
Total Value	$1,085,000	-----
Waterline Infrastructure Value		
Type	Typical	None.
Length (ft)	1911	-----
Replacement Cost / ft	$55	-----
Total Value	$105,000	-----
Sewer Infrastructure Value		
Type	Typical	None.
Length (ft)	1911	-----
Replacement Cost / ft	$150	-----
Total Value	$287,000	-----
GRAND TOTAL VALUE	**$18,904,000**	**None.**

Property Tax Base of IRPs	$17,427,000	None.
Property Tax Revenue of IRPs	$65,177 annually	None.
Municipal Property Tax Base	$2.21 billion (Holden Beach)	$4.14 billion (Oak Island)
County Property Tax Base	$28.6 billion (entire Brunswick County)	

SFR = Single family residences.

9.7.1 INFRASTRUCTURE

In addition to residential homes, principal elements of the Town's infrastructure include the streets, utilities, and public access parking areas that the Town owns and maintains. FEMA has helped cover damages that occurred during hurricanes and major storm events; however, the Town has to fund any repairs due to northeasters or other erosional events not declared a federal emergency. Table 9-3 lists the economic values associated with some of these items.

9.7.2 ECONOMIC LOSSES RELATED TO BEACH WIDTH

The NC BIMP conducted a study of losses attributed to 50 percent beach width loss and found that for Holden Beach, the 2008 estimated annual loss (including output/sales/ business activity) was $14.6 million. The losses calculated in the NC BIMP for Holden Beach are provided in Table 9-4.

Table 9-4. Estimated Annual Losses based on 50 Percent Beach Width Reduction (source: NC BIMP)

	2008 50% Beach Width Reduction			
Area	Loss in Annual Output/Sales/Business Activity (Total Impact)	Loss in Employment (Jobs)	Loss in Beachgoer Consumer Surplus	Loss in Shore/Bank Fishing Consumer Surplus
Holden Beach	$14,597,299	204	$743,938	$9,049

Assuming the proposed terminal groin will conservatively enhance approximately 2,500 feet of shoreline, that the Holden Beach shoreline is 8 miles long, and the estimated losses along the entire beach provided in Table 9-4, losses of approximately $864,000 annually can be attributed to narrower beach conditions on the east end.

In general, the no-action alternative has significant costs and economic consequences associated with it. Many communities, including Holden Beach, have adopted this alternative in the past and do not consider it a viable/practicable alternative in the long-term. The erosion rates on the east end are too high for the current beach management practices to work effectively and economically.

9.8 ABANDON/RETREAT

The abandon/retreat alternative assumes that no erosion mitigation measures will occur. Therefore, no nourishment projects, no beach/sand scraping, and no sandbag deployment would occur. As a result, erosion would occur unabated and result in the loss of land, property and the many benefits associated with a healthy beach and dune system. Under current conditions, only a minimal dune exists at Station 20+00, while extremely scarped conditions frequently occur between Stations 25+00 and 40+00. Figure 9-4 presents a 2010 photo of Station 30+00 looking east. Note the eroded/scarped dune conditions in this photo are typical for this reach of shoreline.

Figure 9-4. March 2010 Photo at Station 30+00 Looking East. Scarped dune conditions are typical for this reach.

9.8.1 USACE BCB ECONOMIC ANALYSIS

The USACE has developed an economic analysis in support of the BCB 50-year project, which includes Holden Beach. The east end was not included in the BCB 50-year fill template because "although the four reaches [M5 to M8] at the east end of Holden Beach have positive net benefits they are not included in the project segment since they are located in the inlet complex. The inlet currents and associated marginal channel prevent a full project template from being maintained in this area." Figure 9-5 presents Reaches M5 through M9 (about 2,500 ft) of the USACE study that will benefit from the proposed terminal groin and nourishment project.

Figure 9-5. USACE GRR Approximate Reaches M5 through M9 for the 2012 Economics Analysis.

National Economic Development (NED) benefits calculated for the GRR project are approximately $3 million, $4 million, $7 million, $8 million and $3 million for reaches M5 through M9, respectively. NED Benefits are increases in the net value of the national output of goods and services. The 50-year BCB project proposes to nourish 24,000 ft of Holden Beach shoreline with 4.5 MCY of sand (about 187 cy/ft). This is an enormous amount of sand, more than 8 times as much as the 2001/2002 USACE Section 933 project (525,000 cy) on Holden Beach. Therefore, while benefits are large, costs are also large, which make project construction (which are nationally competitive for USACE funding) unfeasible. Nonetheless, these calculated values establish a clear value to the project area and validate the idea that the proposed groin/nourishment project would benefit this reach of shoreline by reducing shoreline losses to inlet related processes. The presence of a groin may also allow the USACE to place a full template of sand on the east end in the future; assuming the USACE continues to investigate a 50-yr project for Holden Beach, Oak Island, and Caswell Beach.

The USACE developed a “non-structural” alternative for its economic analysis that represents the abandon/retreat alternative. Table 9-5 presents the USACE costs and benefits of the non-structural alternative (i.e., retreat, relocate, buyout) in Reaches M-5 through M-9 for the first row of houses only. The calculated cost exceeds the calculated benefits for this alternative by an approximate factor of 2, therefore, this is not an economically feasible option. This alternative would also result in a reduction in tax base and a reduction in growth potential of the community (which are not included in Table 9-5). Additionally, this alternative does not reduce damages to other more landward homes. The USACE study estimated that the total expected annual damages for Holden Beach are approximately $10.5 million (Table 9-6).

Table 9-5. Non-Structural Present Value Economic for 1st Row of Houses (Reaches M5 through M9) (USACE, 2012).

Reach	Structure Value	Land Value	Demolition Cost	Total Cost	Total Benefits
5	$989,649	$1,560,000	$600,000	$3,149,649	$1,171,870
6	$1,061,453	$1,820,000	$700,000	$ 3,581,453	$1,511,754
7	$536,970	$1,040,000	$400,000	$1,976,970	$2,246,932
8	$59,941	$260,000	$100,000	$ 419,941	$170,759
9	$64,936	$260,000	$100,000	$424,936	$200,431
			TOTAL	$ 9,552,949	$5,301,746

Table 9-6. Annual Damage Costs Related to Ongoing Erosion (USACE, 2012). Costs are rounded.

Location	Annual Storm Erosion	Annual Flood Inundation	Annual Wave Damage	Annual Long-term Erosion	**Total Expected Annual Damage Costs**
Holden Beach, Island Wide	$ 5,767,000	$ 210,000	$ 315,000	$ 4,194,000	$ 10,486,000
East End (2,500 ft)	$ 601,000	$ 22,000	$ 33,000	$ 437,000	$ 1,093,000

The annual damages in Table 9-6 include storm erosion, flood inundation, wave damage, and long-term erosion costs. This value can be extrapolated to the project site (2,500 ft of shoreline) to an approximate annual loss of $1 million. Note that when factoring in losses related to revenue, recreation and other benefits, estimated annual losses total between $2 and $3.5 million annually. Over a 30-year period, costs for this alternative exceed $33 million and may be up to $57 million (based on the USACE 2012 study results). More information on benefit calculations is presented in the following sections.

9.9 BENEFITS

Benefits are an important factor when evaluating beach management alternatives. The most basic benefit to the groin and nourishment alternatives is that they will increase the renourishment interval. In addition to longer nourishment intervals, the groin will provide damage reduction to the dune system and, subsequently, protect houses and property values. Additional benefits related to beach use include:

- More years in between disruptions (pipelines and heavy equipment) on the beach
- More walkable beach at high tide
- More turtle nesting due to more stable dune
- Increased ghost crab populations due to more stable dune

The beach and properties on the east end of Holden Beach comprise a major economic and social resource for the Town of Holden Beach. Continued erosion (under no-action conditions) of the east end oceanfront will result in a reduced tax base due to the loss of homes as well as reduced tourism due to restricted beach access and recreation area.

Benefits have been quantified by the USACE (Table 9-5) while the NC BIMP quantified the potential losses due to narrower beaches (Table 9-4) as well as recreational benefits as discussed in the following section.

An additional benefit to successful shoreline stabilization programs is reduced emergency costs (beach scraping, sandbagging, repairs to roads, public property walkovers, light posts, etc.), damages to private property other than structures/contents, and post-storm recovery process can also be estimated at approximately $20,000/mile annually (USACE, 2012).

9.9.1 RECREATION

Public access to the east end of Holden Beach and LWF Inlet is a critical economic revenue source to the Town. Popular activities include, but are not limited to, surf fishing, swimming, surfing, walking, shell hunting, sunbathing, bird watching, and boating. The NC BIMP report estimated the 2008 Beach Recreation Annual Total Impact Output for Holden Beach at $92.9 million, which accounted for 1,299 jobs. This extrapolates to approximately $5.5 million annually for $2,500 feet of shoreline on the east end, as well as about 77 jobs.

Currently, there are periods of significant loss of dry beach due to erosion, which limits many beach activities to low-tide periods. The proposed groin and nourishment project would make the beach more accessible during the year, particularly during times of high tide.

9.10 COST COMPARISON

In an effort to compare all of the alternatives, Table 9-7 presents a breakdown of annualized project construction-related costs over a 30-year period. Note that these are construction-related costs only, and that Table 9-8 includes non-construction-related (e.g., recreation, damage losses, benefits) costs and summarizes each alternative.

The conceptual construction cost table includes the following alternatives:

1. Annual Beach Nourishment
2. Bi-Annual Beach Nourishment
3. Groin and Nourishment (3-year renourishment interval)
4. Groin and Nourishment (4-year renourishment interval)
5. Groin and Nourishment (5-year renourishment interval)

The analysis in Table 9-7 spans from 2015 to 2044 (30 years). A 4 percent inflation rate was assumed for the analysis and is presented as the Consumer Price Index (CPI) Boost in Table 9-7. This rate agrees with the 2012 USACE GRR economics study and is typical when considering future nourishment-related costs (e.g., dredging, diesel fuel).

A discount rate is also provided in Table 9-7 and is used to “discount” cash flows in future years. This provides a present value of the money that a potential investment generated. This allows planners to get an idea of what a particular investment will generate in “today’s cash” and compare across alternative investments.

Nourishment volumes for each alternative are dependent on the renourishment interval and are based on historic shoaling, historic projects, and model results. Fill volumes for 2015 are estimated at 150,000 cy for all nourishment options based on the assumption that the bend widener has not been used as a borrow area since 2010. Nourishment volumes were adjusted between alternatives based on historic sedimentation rates within LWFIX and the renourishment interval. For example, the longer a nourishment interval, the more volume is assumed to have accumulated in the LWFIX borrow area. However, note that sedimentation is not a linear rate and that groin modeling has also shown some decreases in LWFIX sedimentation rates. Nourishments are assumed to occur during the winter dredging window.

Mob/demob costs for beach nourishments are estimated at $750,000 per event and remain constant for all alternatives. Groin construction is estimated at $2.5 million, based on intermediate groin length and recent Hilton Head terminal groin bidding (see Section 9.1). No groin maintenance beyond ongoing nourishments was included. Note that most existing groin systems require little to no maintenance over the first couple of decades (Moffatt and Nichol, 2010). Some minor rock restacking may be needed and this can be assumed to occur in conjunction with nourishment events.

Table 9-7 also includes monitoring costs. It is generally assumed that monitoring related to a nourishment/groin project will require more effort than nourishment-only monitoring. However after an initial period of 5 years, it is assumed that groin-related monitoring costs can be reduced based on monitoring results. See Section 9.4 for more details.

The nourishment-only alternatives (1-year and 2-year intervals) in Table 9-7 generally reflect current conditions (i.e., no-action). Due to the increased mob/demob fees, the 1-year renourishment interval is more costly than the 2-year renourishment interval alternative.

Three groin alternatives were included in the conceptual costs table (Table 9-7), with 3-year, 4-year, and 5-year renourishment intervals. All three groin alternatives are more economical than the nourishment-only alternatives, primarily due to reduced mob/demob fees. The preferred groin and nourishment project is designed to increase the nourishment interval to between 3 and 5 years and, therefore, realize cost savings as well as increase the recreation opportunities, beach width, reduce construction-event-related habitat disturbance, etc.

Table 9-8 summarizes Table 9-7 results while also including non-construction related (e.g., recreation, damage losses, benefits) costs. These non-construction-related costs were developed by the USACE GRR (2012), the NC Terminal Groin Report, and the NC BIMP.

Table 9-7. Conceptual Annualized Construction Cost Estimate over 30 years. NOTE - Annualized Benefits and Damage Costs are not included

ALTERNATIVE		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
Annual Nourishment		ANNUAL NOURISHMENTS --->																													PRORATED NOURISHMENT
CPI Boost	4.0%																														
Discount Rate	8.0%																														
Nourishment Interval	1 yr																														
Fill Volume		150,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Unit Cost ($/cy)		$7.00	$7.28	$7.57	$7.87	$8.19	$8.52	$8.86	$9.21	$9.58	$9.96	$10.36	$10.78	$11.21	$11.66	$12.12	$12.61	$13.11	$13.64	$14.18	$14.75	$15.34	$15.95	$16.59	$17.25	$17.94	$18.66	$19.41	$20.18	$20.99	$21.83
Estimated Fill Cost		$1,050,000	$364,000	$378,560	$393,702	$409,450	$425,829	$442,862	$460,576	$478,999	$498,159	$518,085	$538,809	$560,361	$582,776	$606,087	$630,330	$655,543	$681,765	$709,036	$737,397	$766,893	$797,569	$829,472	$862,650	$897,156	$933,043	$970,364	$1,009,179	$1,049,546	$1,091,528
Mob/Demob		$750,000	$780,000.00	$811,200.00	$843,648.00	$877,393.92	$912,489.68	$948,989.26	$986,948.83	$1,026,426.79	$1,067,483.86	$1,110,183.21	$1,154,590.54	$1,200,774.16	$1,248,805.13	$1,298,757.34	$1,350,707.63	$1,404,735.93	$1,460,925.37	$1,519,362.39	$1,580,136.88	$1,643,342.36	$1,709,076.05	$1,777,439.09	$1,848,536.66	$1,922,478.12	$1,999,377.25	$2,079,352.34	$2,162,526.43	$2,249,027.49	$2,338,989
Groin Construction Cost		$0																													
Monitoring/Surveying/Permitting Coordination		$125,000	$125,000	$135,200.00	$140,608.00	$146,232.32	$152,081.61	$158,164.88	$164,491.47	$171,071.13	$177,913.98	$185,030.54	$192,431.76	$200,129.03	$208,134.19	$216,459.56	$225,117.94	$234,122.66	$243,487.56	$253,227.06	$263,356.15	$273,890.39	$284,846.01	$296,239.85	$308,089.44	$320,413.02	$333,229.54	$346,558.72	$360,421.07	$374,837.91	$374,838
TOTAL Annual Cost		**$1,925,000**	**$1,269,000**	**$1,324,960**	**$1,377,958**	**$1,433,077**	**$1,490,400**	**$1,550,016**	**$1,612,016**	**$1,676,497**	**$1,743,557**	**$1,813,299**	**$1,885,831**	**$1,961,264**	**$2,039,715**	**$2,121,304**	**$2,206,156**	**$2,294,402**	**$2,386,178**	**$2,481,625**	**$2,580,890**	**$2,684,126**	**$2,791,491**	**$2,903,151**	**$3,019,277**	**$3,140,048**	**$3,265,650**	**$3,396,275**	**$3,532,127**	**$3,673,412**	**$3,805,355**
TOTAL Present Value Annual Cost (2015)		**$1,925,000**	**$1,175,000**	**$1,135,940**	**$1,093,868**	**$1,053,354**	**$1,014,341**	**$976,773**	**$940,596**	**$905,759**	**$872,213**	**$839,908**	**$808,801**	**$778,845**	**$749,999**	**$722,221**	**$695,472**	**$669,714**	**$644,910**	**$621,024**	**$598,023**	**$575,874**	**$554,546**	**$534,007**	**$514,229**	**$495,183**	**$476,843**	**$459,182**	**$442,176**	**$425,799**	**$408,419**
TOTAL Cost		**$69,380,000**																													
TOTAL Present Value Cost (2015)		**$23,110,000**		**$125,000**	**Beach Fill Monitoring**																										
AVERAGE ANNUAL COST (Total/30yrs)		**$2,310,000**																													
Bi-Annual Nourishment (No-Action)		NOURISHMENT		NOURISHMENT		NOURISHMENT		NOURISHMENT		NOURISHMENT		NOURISHMENT		NOURISHMENT		NOURISHMENT		NOURISHMENT		NOURISHMENT		NOURISHMENT		NOURISHMENT		NOURISHMENT		NOURISHMENT		NOURISHMENT	PRORATED NOURISHMENT
CPI Boost	4.0%																														
Discount Rate	8.0%																														
Nourishment Interval	2 yrs																														
Fill Volume		150,000		100,000		100,000		100,000		100,000		100,000		100,000		100,000		100,000		100,000		100,000		100,000		100,000		100,000		100,000	
Unit Cost ($/cy)		$7.00		$7.57		$8.19		$8.86		$9.58		$10.36		$11.21		$12.12		$13.11		$14.18		$15.34		$16.59		$17.94		$19.41		$20.99	
Estimated Fill Cost		$1,050,000		$757,120		$818,901		$885,723		$957,998		$1,036,171		$1,120,723		$1,212,174		$1,311,087		$1,418,072		$1,533,786		$1,658,943		$1,794,313		$1,940,729		$2,099,092	
Mob/Demob		$750,000		$811,200.00		$877,393.92		$948,989.26		$1,026,426.79		$1,110,183.21		$1,200,774.16		$1,298,757.34		$1,404,735.93		$1,519,362.39		$1,643,342.36		$1,777,439.09		$1,922,478.12		$2,079,352.34		$2,249,027.49	
Groin Construction Cost		$0																													
Monitoring/Surveying/Permitting Coordination		$125,000	$65,000	$135,200.00	$73,116.16	$146,232.32	$79,082.44	$158,164.88	$85,535.57	$171,071.13	$92,515.27	$185,030.54	$100,064.51	$200,129.03	$108,229.78	$216,459.56	$117,061.33	$234,122.66	$126,613.53	$253,227.06	$136,945.20	$273,890.39	$148,119.92	$296,239.85	$160,206.51	$320,413.02	$173,279.36	$346,558.72	$187,418.96	$374,837.91	$202,712.34
TOTAL Annual Cost		**$1,925,000**	**$65,000**	**$1,703,520**	**$73,116**	**$1,842,527**	**$79,082**	**$1,992,877**	**$85,536**	**$2,155,496**	**$92,515**	**$2,331,385**	**$100,065**	**$2,521,626**	**$108,230**	**$2,727,390**	**$117,061**	**$2,949,945**	**$126,614**	**$3,190,661**	**$136,945**	**$3,451,019**	**$148,120**	**$3,732,622**	**$160,207**	**$4,037,204**	**$173,279**	**$4,366,640**	**$187,419**	**$4,722,958**	**$905,425**
TOTAL Present Value Annual Cost (2015)		**$1,925,000**	**$60,185**	**$1,460,494**	**$58,042**	**$1,354,313**	**$53,822**	**$1,255,851**	**$49,909**	**$1,164,548**	**$46,281**	**$1,079,882**	**$42,916**	**$1,001,372**	**$39,796**	**$928,570**	**$36,903**	**$861,061**	**$34,220**	**$798,460**	**$31,732**	**$740,410**	**$29,425**	**$686,580**	**$27,286**	**$636,664**	**$25,302**	**$590,377**	**$23,462**	**$547,456**	**$97,177**
TOTAL Cost		**$46,210,000**																													
TOTAL Present Value Cost (2015)		**$15,690,000**		**$125,000**	**Beach Fill Monitoring**																										
AVERAGE ANNUAL COST (Total/30yrs)		**$1,540,000**		**$65,000**	**Annual Monitoring**																										
Nourishment & Groin (3yr Nour. Int.)		GROIN CONSTR. + NOUR.			NOURISHMENT			NOURISHMENT			NOURISHMENT			NOURISHMENT			NOURISHMENT			NOURISHMENT			NOURISHMENT			NOURISHMENT			NOURISHMENT		PRORATED NOURISHMENT
CPI Boost	4.0%																														
Discount Rate	8.0%																														
Nourishment Interval	3 yrs																														
Fill Volume		150,000			125,000			125,000			125,000			125,000			125,000			125,000			125,000			125,000			125,000		
Unit Cost ($/cy)		$7.00			$7.87			$8.86			$9.96			$11.21			$12.61			$14.18			$15.95			$17.94			$20.18		
Estimated Fill Cost		$1,050,000			$984,256			$1,107,154			$1,245,398			$1,400,903			$1,575,826			$1,772,589			$1,993,922			$2,242,891			$2,522,948		
Mob/Demob		$750,000			$843,648			$948,989			$1,067,484			$1,200,774			$1,350,708			$1,519,362			$1,709,076			$1,922,478.12			$2,162,526.43		
Groin Construction Cost		$2,500,000																													
Monitoring/Surveying/Permitting Coordination		$227,000	$132,000	$142,771	$255,344	$154,421	$160,598	$158,165	$85,536	$88,957	$177,914	$96,216	$100,065	$200,129	$108,230	$112,559	$225,118	$121,744	$126,614	$253,227	$136,945	$142,423	$284,846	$154,045	$160,207	$320,413	$173,279	$180,211	$360,421	$194,916	$202,712
TOTAL Annual Cost		**$4,527,000**	**$132,000**	**$142,771**	**$2,083,248**	**$154,421**	**$160,598**	**$2,214,308**	**$85,536**	**$88,957**	**$2,490,796**	**$96,216**	**$100,065**	**$2,801,806**	**$108,230**	**$112,559**	**$3,151,651**	**$121,744**	**$126,614**	**$3,545,179**	**$136,945**	**$142,423**	**$3,987,844**	**$154,045**	**$160,207**	**$4,485,782**	**$173,279**	**$180,211**	**$5,045,895**	**$194,916**	**$2,364,977**
TOTAL Present Value Annual Cost (2015)		**$4,527,000**	**$122,222**	**$122,403**	**$1,653,750**	**$113,504**	**$109,300**	**$1,395,390**	**$49,909**	**$48,061**	**$1,246,018**	**$44,567**	**$42,916**	**$1,112,636**	**$39,796**	**$38,322**	**$993,532**	**$35,536**	**$34,220**	**$887,178**	**$31,732**	**$30,557**	**$792,208**	**$28,335**	**$27,286**	**$707,405**	**$25,302**	**$24,365**	**$631,680**	**$22,593**	**$253,827**
TOTAL Cost		**$39,270,000**		**$227,000**	**Construction Monitoring**																										
TOTAL Present Value Cost (2015)		**$15,190,000**		**$132,000**	**Semi-Annual Monitoring**		**$125,000**	**Beach Fill Monitoring (year 2021 onward)**																							
AVERAGE ANNUAL COST (Total/30yrs)		**$1,310,000**		**$67,000**	**Annual Monitoring**		**$65,000**	**Annual Monitoring (year 2022 onward)**																							
Nourishment & Groin (4yr Nour. Int.)		GROIN CONSTR. + NOUR.				NOURISHMENT				NOURISHMENT				NOURISHMENT				NOURISHMENT				NOURISHMENT				NOURISHMENT				NOURISHMENT	PRORATED NOURISHMENT
CPI Boost	4.0%																														
Discount Rate	8.0%																														
Nourishment Interval	4 yrs																														
Fill Volume		150,000				150,000				150,000				150,000				150,000				150,000				150,000				150,000	
Unit Cost ($/cy)		$7.00				$8.19				$9.58				$11.21				$13.11				$15.34				$17.94				$20.99	
Estimated Fill Cost		$1,050,000				$1,228,351				$1,436,998				$1,681,084				$1,966,630				$2,300,679				$2,691,469				$3,148,638	
Mob/Demob		$750,000				$877,393.92				$1,026,426.79				$1,200,774.16				$1,404,735.93				$1,643,342.36				$1,922,478.12				$2,249,027.49	
Groin Construction Cost		$2,500,000																													
Monitoring/Surveying/Permitting Coordination		$227,000	$132,000	$142,771.20	$148,482.05	$265,557.89	$160,598.18	$167,022.11	$173,702.99	$171,071.13	$92,515.27	$96,215.88	$100,064.51	$200,129.03	$108,229.78	$112,558.97	$117,061.33	$234,122.66	$126,613.53	$131,678.07	$136,945.20	$273,890.39	$148,119.92	$154,044.72	$160,206.51	$320,413.02	$173,279.36	$180,210.54	$187,418.96	$374,837.91	$202,712.34
TOTAL Annual Cost		**$4,527,000**	**$132,000**	**$142,771**	**$148,482**	**$2,371,303**	**$160,598**	**$167,022**	**$173,703**	**$2,634,495**	**$92,515**	**$96,216**	**$100,065**	**$3,081,987**	**$108,230**	**$112,559**	**$117,061**	**$3,605,489**	**$126,614**	**$131,678**	**$136,945**	**$4,217,912**	**$148,120**	**$154,045**	**$160,207**	**$4,934,361**	**$173,279**	**$180,211**	**$187,419**	**$5,772,504**	**$316,724**
TOTAL Present Value Annual Cost (2015)		**$4,527,000**	**$122,222**	**$122,403**	**$117,870**	**$1,742,979**	**$109,300**	**$105,252**	**$101,354**	**$1,423,336**	**$46,281**	**$44,567**	**$42,916**	**$1,223,899**	**$39,796**	**$38,322**	**$36,903**	**$1,052,408**	**$34,220**	**$32,952**	**$31,732**	**$904,945**	**$29,425**	**$28,335**	**$27,286**	**$778,145**	**$25,302**	**$24,365**	**$23,462**	**$669,112**	**$33,993**
TOTAL Cost		**$34,410,000**		**$227,000**	**Construction Monitoring**																										
TOTAL Present Value Cost (2015)		**$13,540,000**		**$132,000**	**Semi-Annual Monitoring**		**$125,000**	**Beach Fill Monitoring (year 2021 onward)**																							
AVERAGE ANNUAL COST (Total/30yrs)		**$1,150,000**		**$67,000**	**Annual Monitoring**		**$65,000**	**Annual Monitoring (year 2022 onward)**																							
Nourishment & Groin (5yr Nour. Int.)		GROIN CONSTR. + NOUR.					NOURISHMENT					NOURISHMENT					NOURISHMENT					NOURISHMENT					NOURISHMENT				PRORATED NOURISHMENT
CPI Boost	4.0%																														
Discount Rate	8.0%																														
Nourishment Interval	5 yrs																														
Fill Volume		150,000					175,000					175,000					175,000					175,000					175,000				
Unit Cost ($/cy)		$7.00					$8.52					$10.36					$12.61					$15.34					$18.66				
Estimated Fill Cost		$1,050,000					$1,490,400					$1,813,299					$2,206,156					$2,684,126					$3,265,650				
Mob/Demob		$750,000					$912,490					$1,110,183					$1,350,708					$1,643,342					$1,999,377				
Groin Construction Cost		$2,500,000																													
Monitoring/Surveying/Permitting Coordination		$227,000	$132,000	$142,771	$148,482	$154,421	$276,180	$167,022	$173,703	$180,651	$187,877	$185,031	$100,065	$104,067	$108,230	$112,559	$225,118	$121,744	$126,614	$131,678	$136,945	$273,890	$148,120	$154,045	$160,207	$166,615	$333,230	$180,211	$187,419	$194,916	$202,712
TOTAL Annual Cost		**$4,527,000**	**$132,000**	**$142,771**	**$148,482**	**$154,421**	**$2,679,070**	**$167,022**	**$173,703**	**$180,651**	**$187,877**	**$3,108,513**	**$100,065**	**$104,067**	**$108,230**	**$112,559**	**$3,781,981**	**$121,744**	**$126,614**	**$131,678**	**$136,945**	**$4,601,359**	**$148,120**	**$154,045**	**$160,207**	**$166,615**	**$5,598,256**	**$180,211**	**$187,419**	**$194,916**	**$5,651,620**
TOTAL Present Value Annual Cost (2015)		**$4,527,000**	**$122,222**	**$122,403**	**$117,870**	**$113,504**	**$1,823,330**	**$105,252**	**$101,354**	**$97,600**	**$93,985**	**$1,439,843**	**$42,916**	**$41,326**	**$39,796**	**$38,322**	**$1,192,238**	**$35,536**	**$34,220**	**$32,952**	**$31,732**	**$987,213**	**$29,425**	**$28,335**	**$27,286**	**$26,275**	**$817,446**	**$24,365**	**$23,462**	**$22,593**	**$606,574**
TOTAL Cost		**$33,370,000**		**$227,000**	**Construction Monitoring**																										
TOTAL Present Value Cost (2015)		**$12,750,000**		**$132,000**	**Semi-Annual Monitoring**		**$125,000**	**Beach Fill Monitoring (year 2021 onward)**																							
AVERAGE ANNUAL COST (Total/30yrs)		**$1,110,000**		**$67,000**	**Annual Monitoring**		**$65,000**	**Annual Monitoring (year 2022 onward)**																							

Table 9-8. Total Costs of Conceptual Alternatives

Alternative	30-Year Construction Cost	Average Annual Construction Cost	Annual Damages	Revenue Losses	USACE Recreation Losses	NC BIMP Recreation Losses (50% beach width)	Total Annualized Cost	**Total 30-Year Cost**
Ebb Channel Borrow Area & Removal/Restoration of Civil War wrecks	>$50,000,000	>$1,670,000	$546,146	$32,589	$1,173,385	$431,975	$2,680,709 to $3,422,120	**$80,420,000 to $102,660,000**
Retreat/Relocate/Land Acquisition	$61,810,000	$2,021,419	$1,092,292	$65,177	$2,346,771	$863,950	$4,042,837 to $5,525,658	**$121,290,000 to $165,770,000**
Nourishment (1-yr Interval)	$69,380,000	$2,310,000	$546,146	$32,589	$1,173,385	$431,975	$3,320,709 to $4,062,120	**$99,620,000 $121,860,000**
Nourishment (2-yr Interval) (No Action)	$46,210,000	$1,540,000	$546,146	$32,589	$1,173,385	$431,975	$2,550,709 to $3,292,120	**$76,520,000 $98,760,000**
Groin and Nourishment (3-yr Interval)	$39,270,000	$1,310,000	n/a	n/a	n/a	n/a	$1,310,000	**$39,300,000**
Groin and Nourishment (4-yr Interval)	$34,410,000	$1,150,000	n/a	n/a	n/a	n/a	$1,150,000	**$34,500,000**
Groin and Nourishment (5-yr Interval)	$33,370,000	$1,110,000	n/a	n/a	n/a	n/a	$1,110,000	**$33,300,000**

Annual damages in Table 9-8 were extrapolated from the USACE GRR study and revenue losses w in the NC Terminal Groin Report. The retreat/abandon alternative is the most expensive in terms of damage and revenue loss. The nourishment-only alternatives were assigned half the cost of annual damages and revenue losses. This is due to the fact that the nourishment-only alternatives are more effective than retreat/abandon; however this “no-action” alternative has included losses to homes and infrastructure over the last few decades. The ebb channel borrow area alternative was also assigned half the cost of annual damages and revenue losses based on modeling and analysis (i.e., it performs similar to the nourishment-only alternatives). The groin alternatives are assumed to have no losses to annual damage and revenue.

USACE and NC BIMP recreation losses were both included in Table 9-8. The USACE recreation losses are higher than the NC BIMP losses. A range is provided in the Total columns reflecting these different values (i.e., the BIMP estimated recreation losses are included in the minimum value while the USACE recreation losses are included in the maximum value).

As seen in Table 9-8, the groin alternatives are the least expensive options. This analysis is conceptual in nature due to forecasting out to 2044 and the assumptions involved therein, however, it is clear that for a highly erosional area such as the east end, a groin will act to increase the nourishment interval and significantly reduce both long term construction-related costs (e.g., nourishment, monitoring) and total costs.

10.0 SUMMARY

The Town of Holden Beach has been actively and independently performing beach management activities on its shoreline for decades. More recently, the Town began performing several significant nourishment projects to augment and further the benefits of the USACE Wilmington Harbor Deepening 933 nourishment project in 2001/2002. The Town's projects are completely funded, permitted, designed, constructed, and monitored by Holden Beach. The study presented herein describes the alternatives available for the east end shoreline stabilization project, where a terminal groin and nourishment program is the Town's preferred alternative.

10.1 BACKGROUND

From a beach nourishment and erosion perspective, the Town and USACE have identified two general erosion control project reaches: 1) Central Reach and 2) East End. Note that the western ~3 miles of Holden Beach shoreline are stable/accretional and remain unmanaged (although erosion related to Shallotte Inlet processes can occur).

The central reach ranges from about Station 40+00 to approximately Station 270+00 (about 4.3 miles). The USACE 933 project and all Town nourishment projects over the last 13 years have occurred within the central reach. These projects have been devoted to offsetting central reach erosion and have been relatively successful in this endeavor.

The east end shoreline reach extends from Lockwoods Folly (LWF) Inlet to approximately Station 40+00 (about 0.8 miles), where the island's highest erosion rates occur. The annual/bi-annual USACE LWFIX dredging and fill placement projects have a primary goal of offsetting inlet-related erosion on the east end of Holden Beach. The east end projects concentrate on a smaller shoreline area; however, this reach continues to be the most vulnerable to erosion and dune breaching (which occurred as recently as 2008 during Hurricane Hanna). LWF Inlet has been relatively stable historically with respect to its inlet location, however, the adjacent shorelines are characterized by some of the largest inlet-induced erosion rates in southeastern North Carolina (Cleary, 1998). As a result, a terminal groin and beach nourishment program is proposed for the east end.

10.2 ALTERNATIVES

Several alternatives were analyzed and/or modeled including:

1. No-action,
2. Threatened structure relocation,
3. Beach nourishment without inlet relocation,
4. Beach nourishment with inlet relocation, and
5. Terminal groin with beach nourishment (with potential inlet relocation included).

The no-action alternative generally refers to existing beach management practices. The no-action alternative has been implemented since the 1970s; where over 40 structures have been lost on the east end over this time span. Additionally, USACE funding for the LWFIX project is likely to become more and more infrequent and, therefore, less effective. The USACE GRR project, which places sand on the central reach, may also not occur due to federal funding limitations. As a result, the Town has necessarily taken a more active role in its beach management, especially on the east end.

While nourishment-only alternatives do provide some benefit from background erosion, the east end is still susceptible to erosional episodes where infrastructure is at risk. Several studies, including the NC BIMP, the NC Terminal Groin Report, and the USACE Brunswick County Beaches 50-yr project studies (including the GRR) have advanced this same idea.

Additional alternatives, such as the LWF Inlet channel relocation and channel expansion alternatives were also assessed. LWF Inlet relocation would entail cutting through a portion of Oak Island, which is not feasible. LWF Inlet channel expansion was investigated by modeling a channel similar in dimension to Shallotte Inlet. The presence of 3 civil war shipwrecks on the ebb shoal limits shore-perpendicular alignment as well as Oak Island alignment of an expanded channel. Modeling also indicates that a larger channel aligned to closer to Holden Beach does not provide as significant a benefit to the east end (relative to other less costly alternatives) while effects to the estuarine system are significant.

Three terminal groin structures were modeled and are known as the “short”, “intermediate”, and “long” groin alternatives. Figure 10-1 presents these alternatives. Groin lengths were largely dictated on shoreline location and the need to protect/stabilize the east end. The accompanying beach nourishment also varied with each structure, with more fill needed for longer structures.

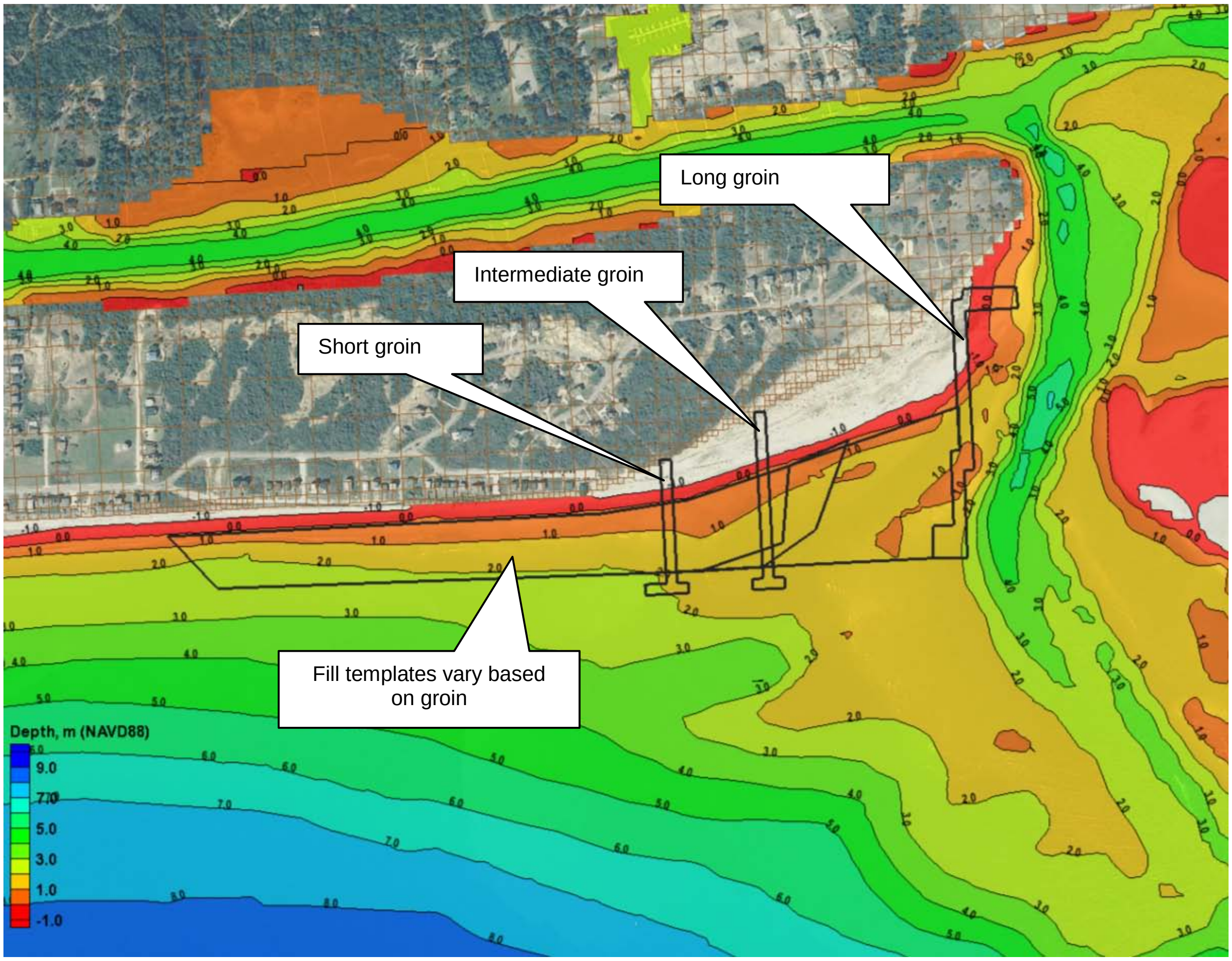


Figure 10-1. Alternative Groin/Fill Layouts Evaluated in the Coastal Modeling System (CMS).

10.3 PREFERRED ALTERNATIVE

Modeling and analysis indicates that the preferred alternative is the "intermediate" groin with a concurrent nourishment program. The pending preferred alternative includes three primary components:

- Terminal groin
- Beach nourishment (using LWFIX borrow area)
- Monitoring

The intermediate terminal groin features an approximate 700 ft effect groin length with an additional 300 ft "anchor" section length that will be buried. An initial nourishment volume of 150,000 cy is proposed, while subsequent nourishment volumes will range between 100,000 and 150,000 cy, depending on shoreline and borrow area conditions. Figure 10-2 presents the results of the intermediate groin and nourishment modeling after 4 years. The preferred alternative is shown to increase the nourishment interval from 2 years to 4 years, in comparison to the nourishment-only alternative. The proposed project was designed to deliver significant protection to the most vulnerable 2,500 feet of shoreline shown in Figure 10-2, while additional benefits to the west are anticipated. More discussion on effects to the east of the groin (i.e., “downdrift”) is provided below.

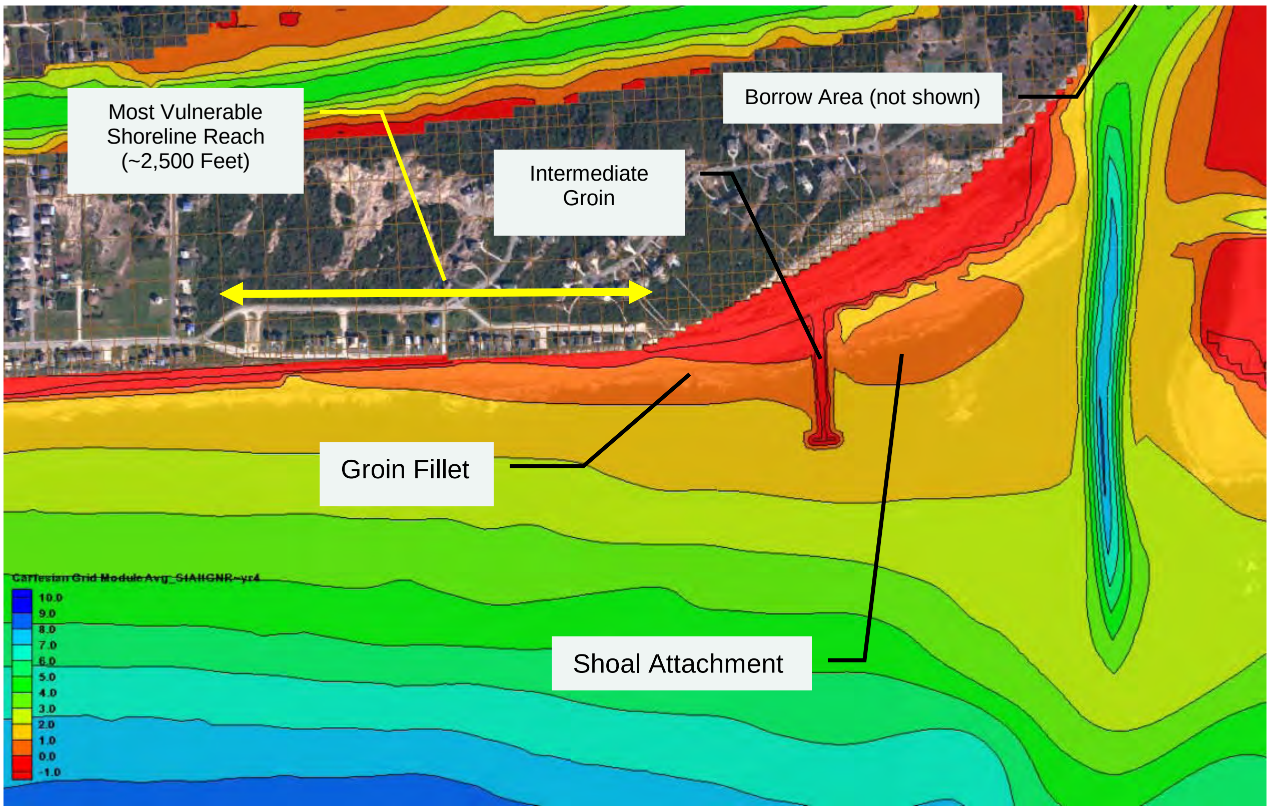


Figure 10-2. CMS simulated Intermediate Groin and Nourishment Year 4 Average Depths.

The preferred borrow area is the LWF Inlet AIWW Crossing (LWFIX), including the 400-ft bend widener. This is a reusable borrow area that is within the existing federal navigation channel. Currently, USACE does not fully utilized the LWFIX borrow area due to funding limitations and because it represents a lower priority in terms of navigation. The material is beach compatible, and modeling shows that dredging this area prevents the channel thalweg from training up to the Holden Beach LWF Inlet shoulder shoreline.

Downdrift Effects

“Downdrift” refers to the oceanfront and estuarine shorelines to the east of the proposed groin (i.e., towards LWF Inlet). The proposed nourishment template will include some downdrift placement of material (see Figure 10-3), while the groin itself will have a “leaky” design to enhance sediment bypassing. Additionally, modeling has shown that shoal attachments in this area can occur to the downdrift on the intermediate groin (see Figure 10-2). In this instance, the east end can be considered downdrift. Some sand fillet formation occurs to both the east and west of the proposed intermediate groin in the 4-year CMS model runs. In general, the proposed intermediate groin placement has been chosen to balance downdrift and updrift effects in this dynamic area.

Figure 10-3. Proposed Intermediate groin and nourishment.

The short and intermediate groin modeling showed relatively minor and localized effects to the LWF Inlet system. In contrast, modeling of the outer channel relocation alternative as well as the long groin alternative have a much greater effect on the LWF Inlet ebb and flood shoals. In general, the preferred intermediate groin and nourishment alternative minimizes downdrift impacts while effectively protecting and stabilizing the east end shoreline. A comprehensive monitoring program will be instituted to assess project-related effects to the LWF Inlet system and adjacent shorelines.

Costs

The 2011 NC Beaches and Inlets Management Plan (NC BIMP) report estimates that the 2008 Beach Recreation Annual Total Impact Output for Holden Beach was $92.9 million, which accounted for 1,299 jobs. Beach recreation is the primary economic engine for the Town of Holden Beach and the Town has a dedicated funding mechanism, the BPART Fund, in order to support its sustainable beach management program. The Town anticipates modest future growth of the BPART fund while State and Federal funding are forecast to become reduced. As a result, the Town is generally required to increase its effort in sustainable beach management relative to reduced State and Federal participation. The proposed terminal groin and nourishment program for the east end is estimated to result in substantial savings over the long-term. Over a 30-year period, the proposed project is estimated to result in over $40 million in total savings when compared to existing beach management practices.

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Appendix A

Lockwoods Folly Inlet Historical Aerials

Figure A-1:
1939 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

APPLIED TECHNOLOGY & MANAGEMENT

Figure A-2:
May 1958 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

ATM
APPLIED TECHNOLOGY & MANAGEMENT

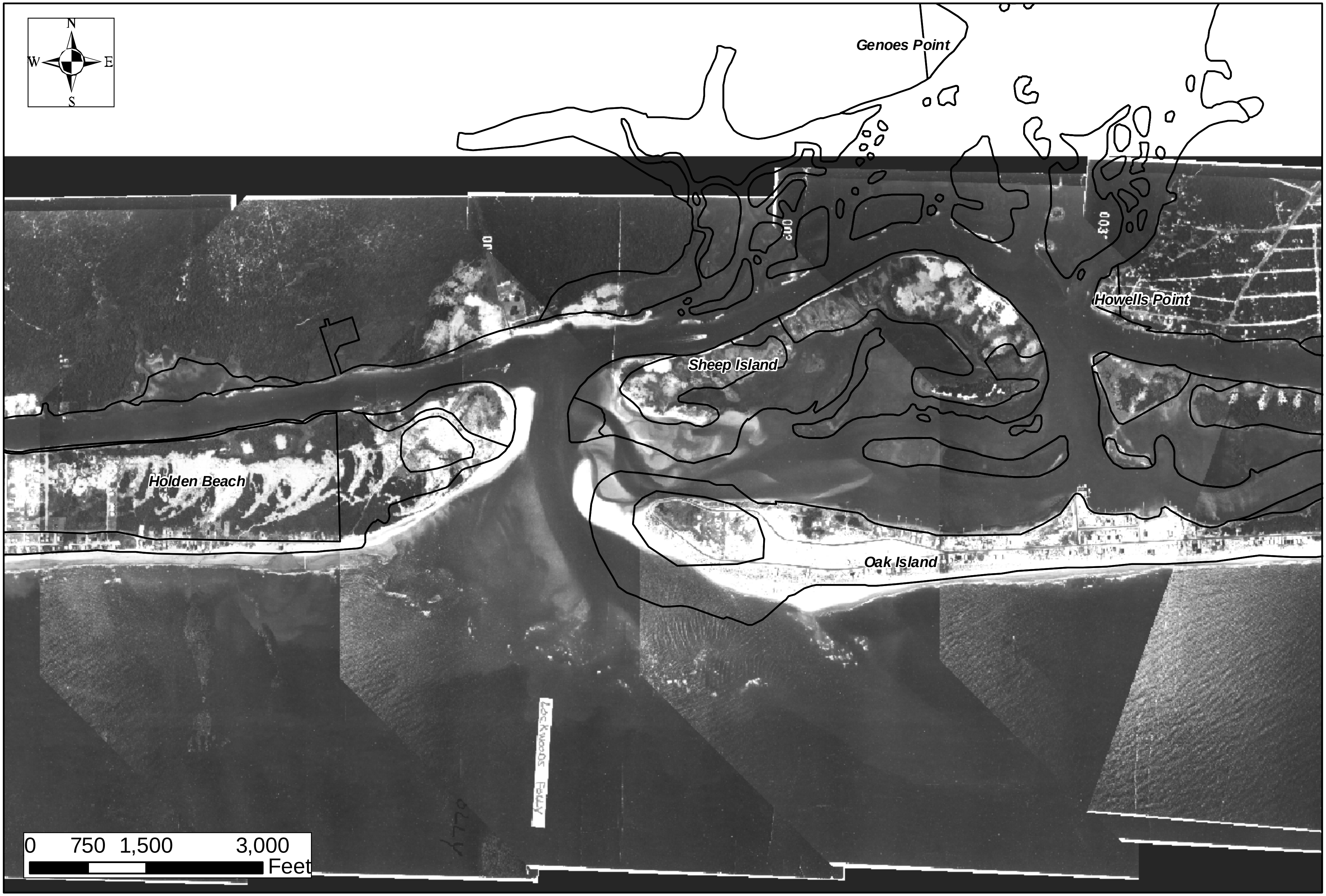


Figure A-3:
August 1971 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

APPLIED TECHNOLOGY & MANAGEMENT

Figure A-4:
November 1978 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

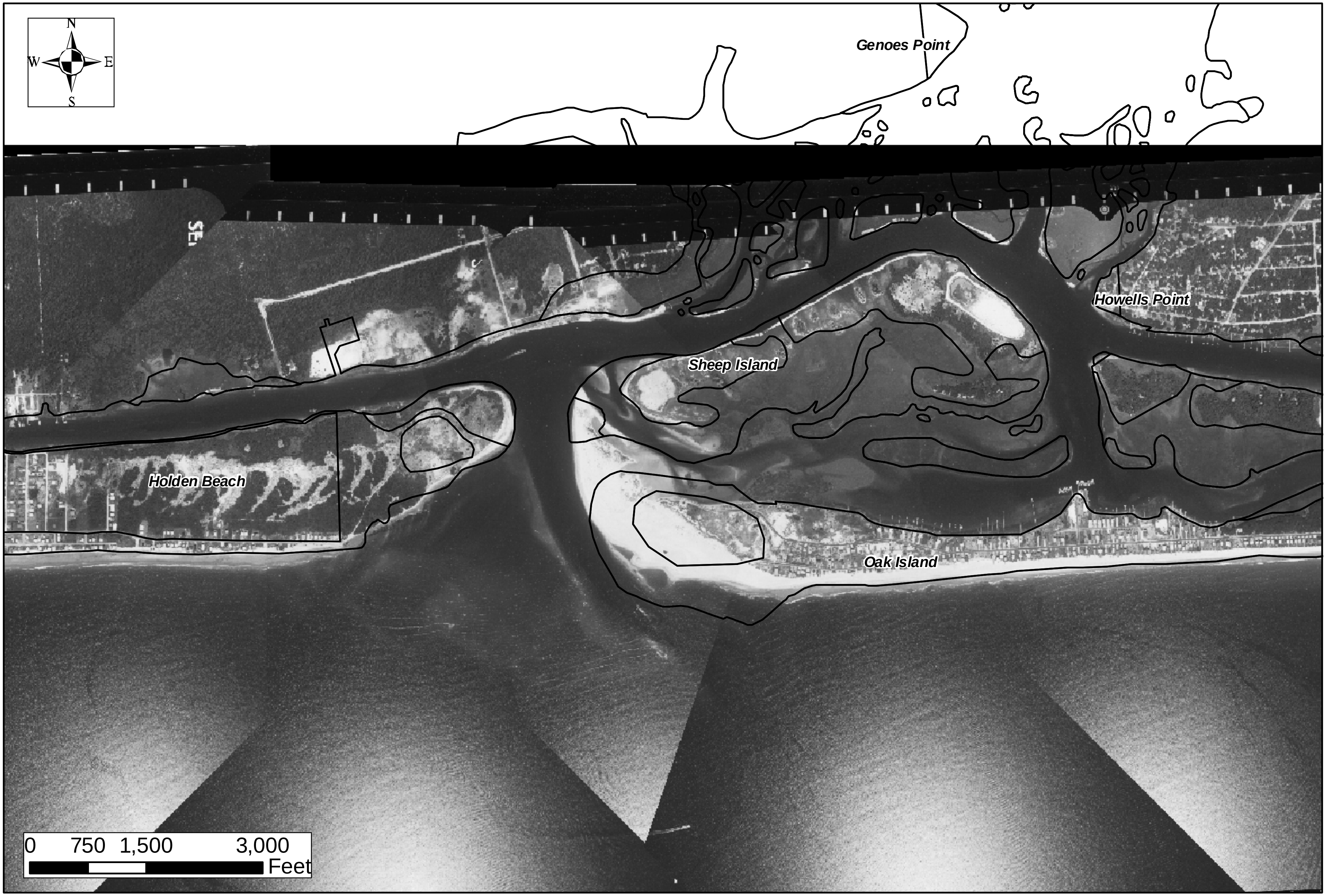


Figure A-5:
September 1988 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

APPLIED TECHNOLOGY & MANAGEMENT

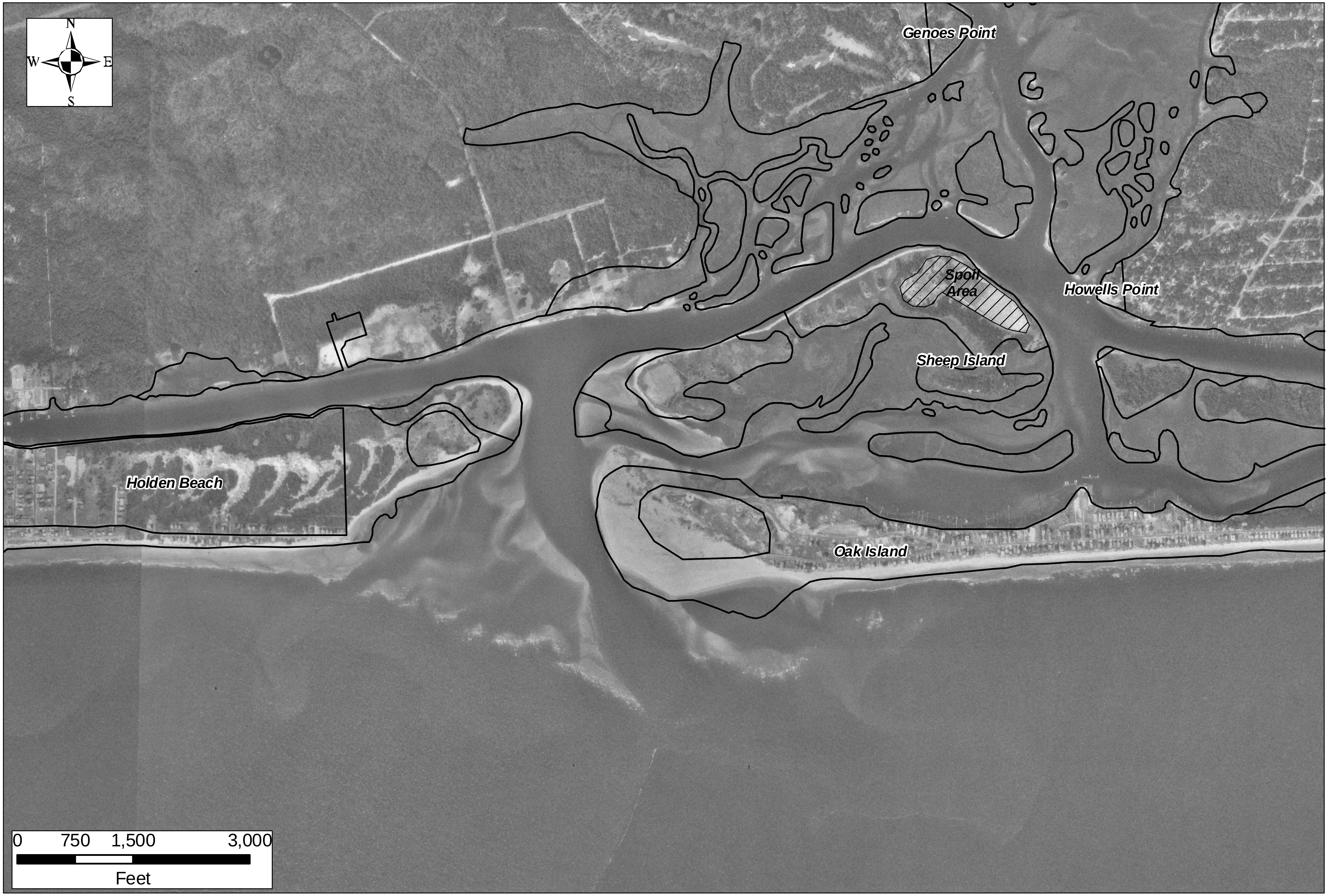


Figure A-6:
1993 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

APPLIED TECHNOLOGY & MANAGEMENT

Figure A-7:
2000 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

APPLIED TECHNOLOGY & MANAGEMENT

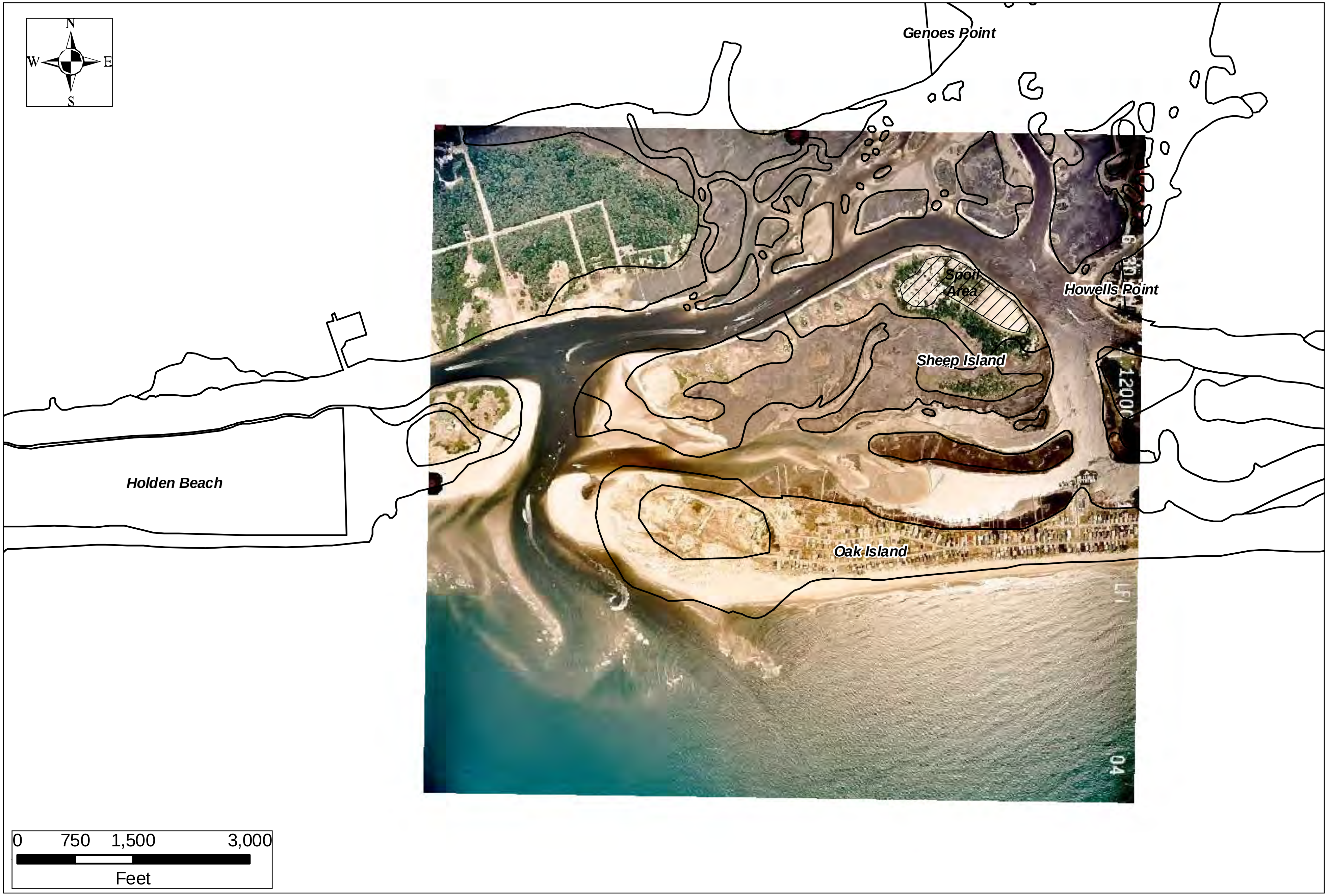


Figure A-8:
June 2001 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

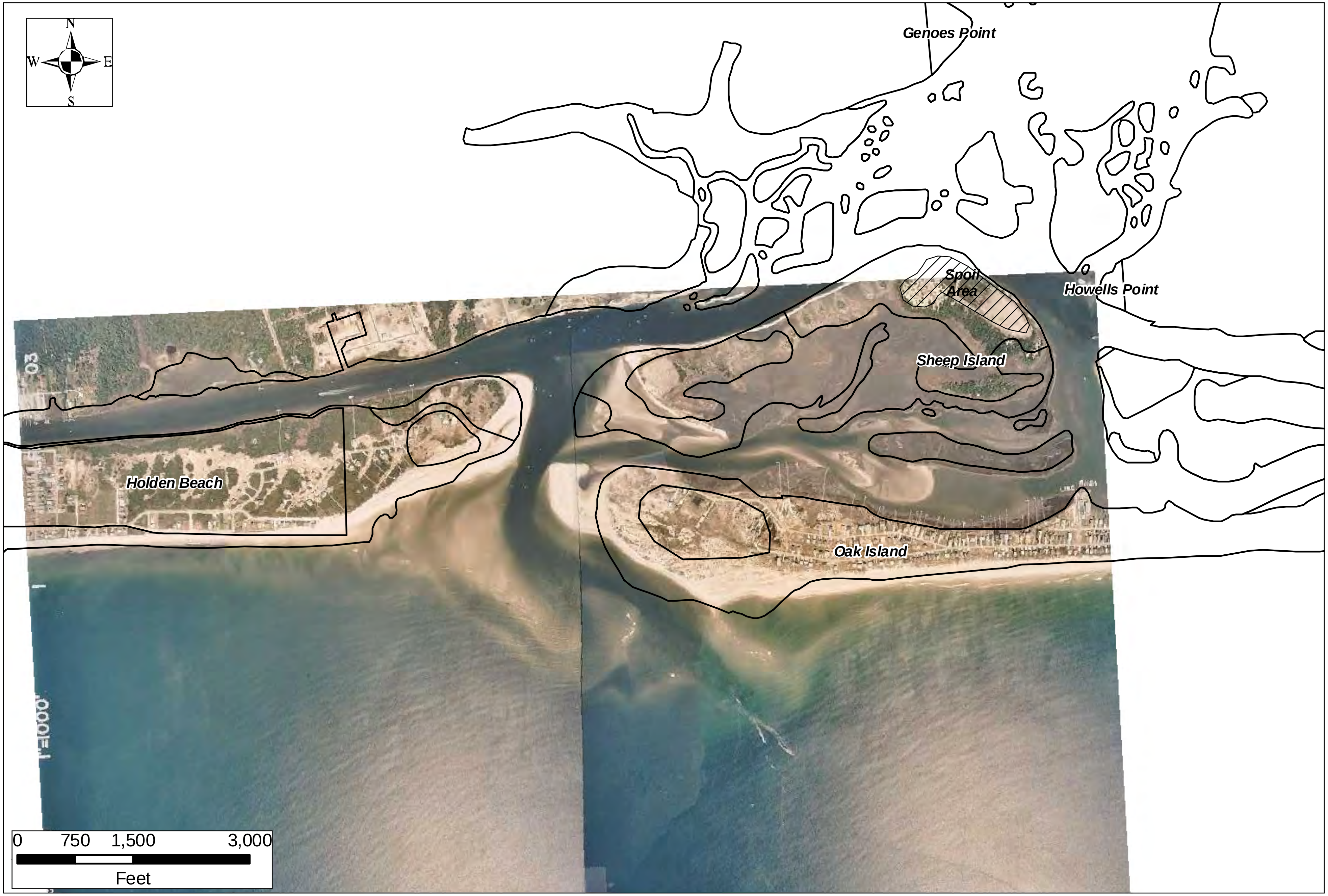


Figure A-9:
Sept 2001 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

ATM
APPLIED TECHNOLOGY & MANAGEMENT

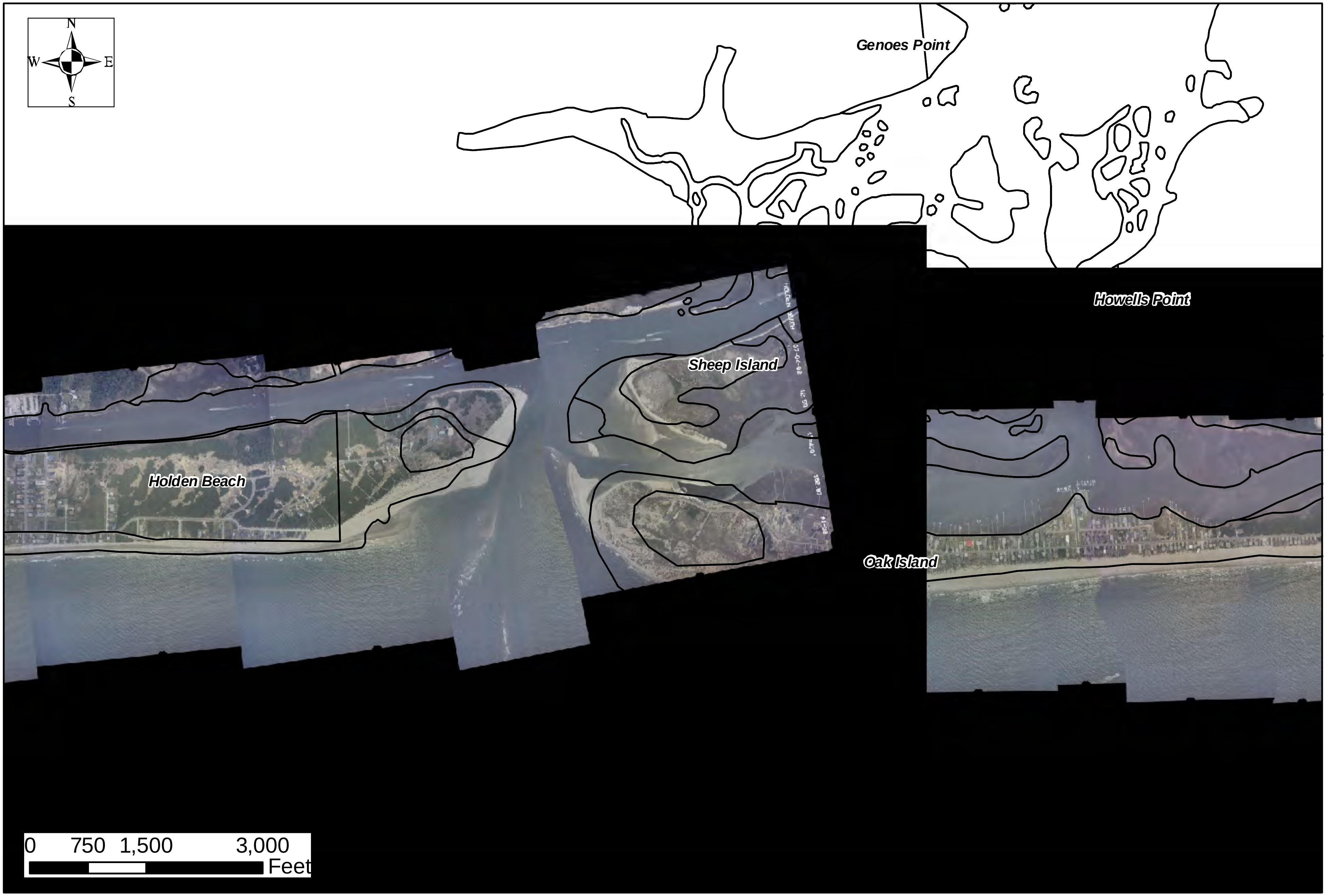


Figure A-10:
2002 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

Figure A-11:
May 2002 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

Figure A-12:
September 2002 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

APPLIED TECHNOLOGY & MANAGEMENT

Figure A-13:
2003 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

Figure A-14:
May 2003 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

ATM
APPLIED TECHNOLOGY & MANAGEMENT

Figure A-15:
August 2003 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

Figure A-16:
October 2003 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

Figure A-17:
2004 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

Figure A-18:
June 2004 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

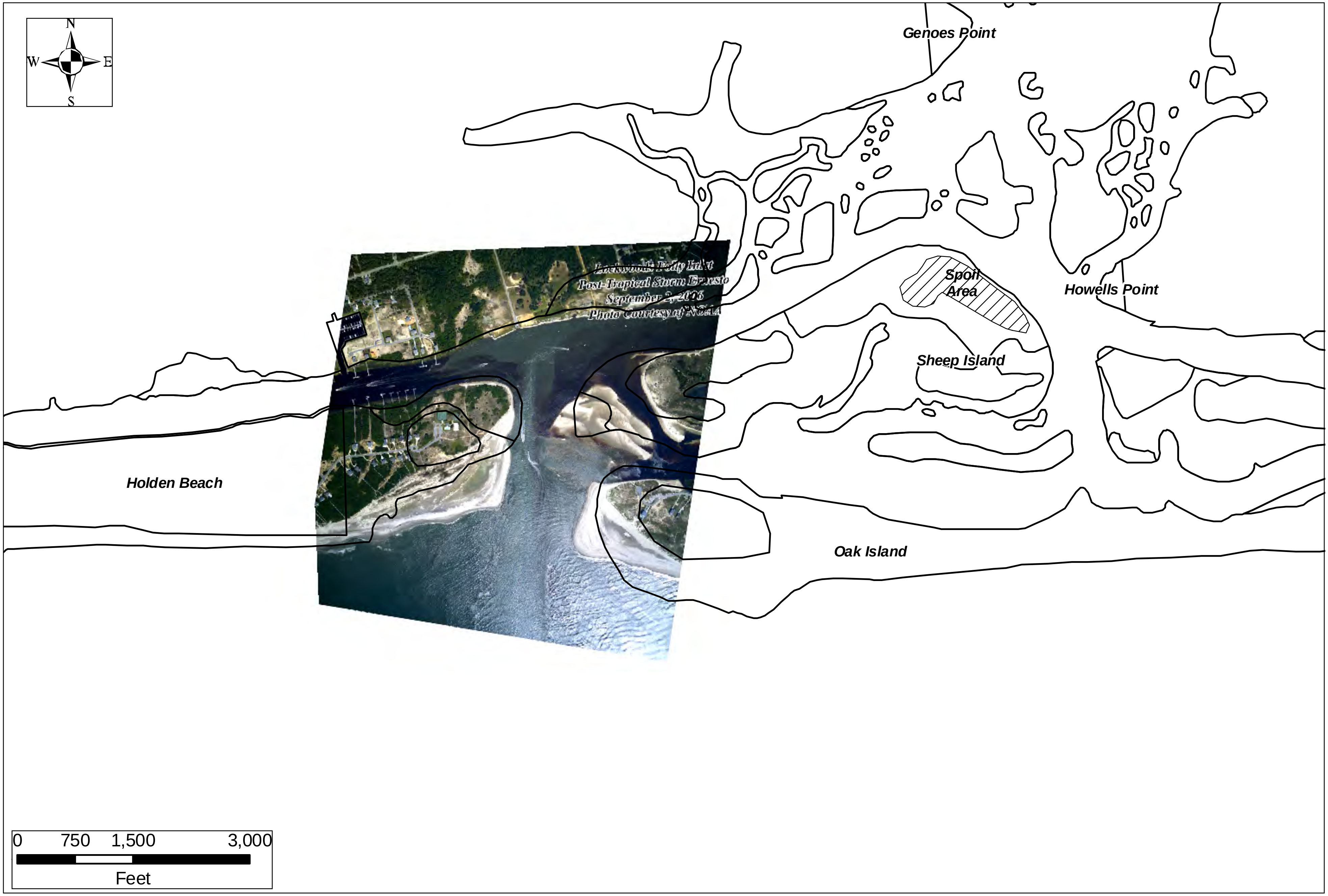


Figure A-19:
September 2005 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

Figure A-20:
2006 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

APPLIED TECHNOLOGY & MANAGEMENT

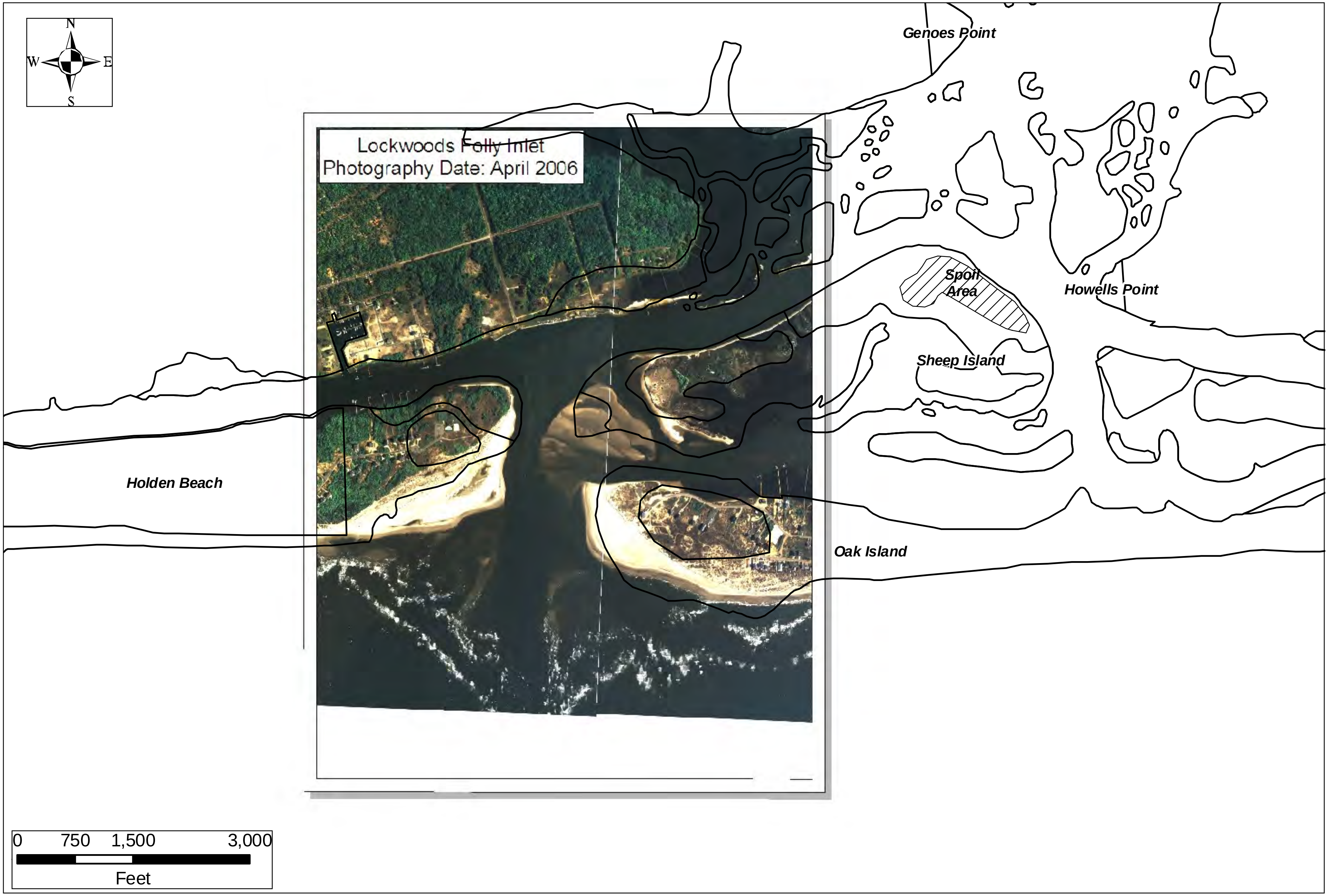


Figure A-21:
April 2006 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

ATM
APPLIED TECHNOLOGY & MANAGEMENT

Figure A-22:
2006 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

Figure A-23:
2008 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

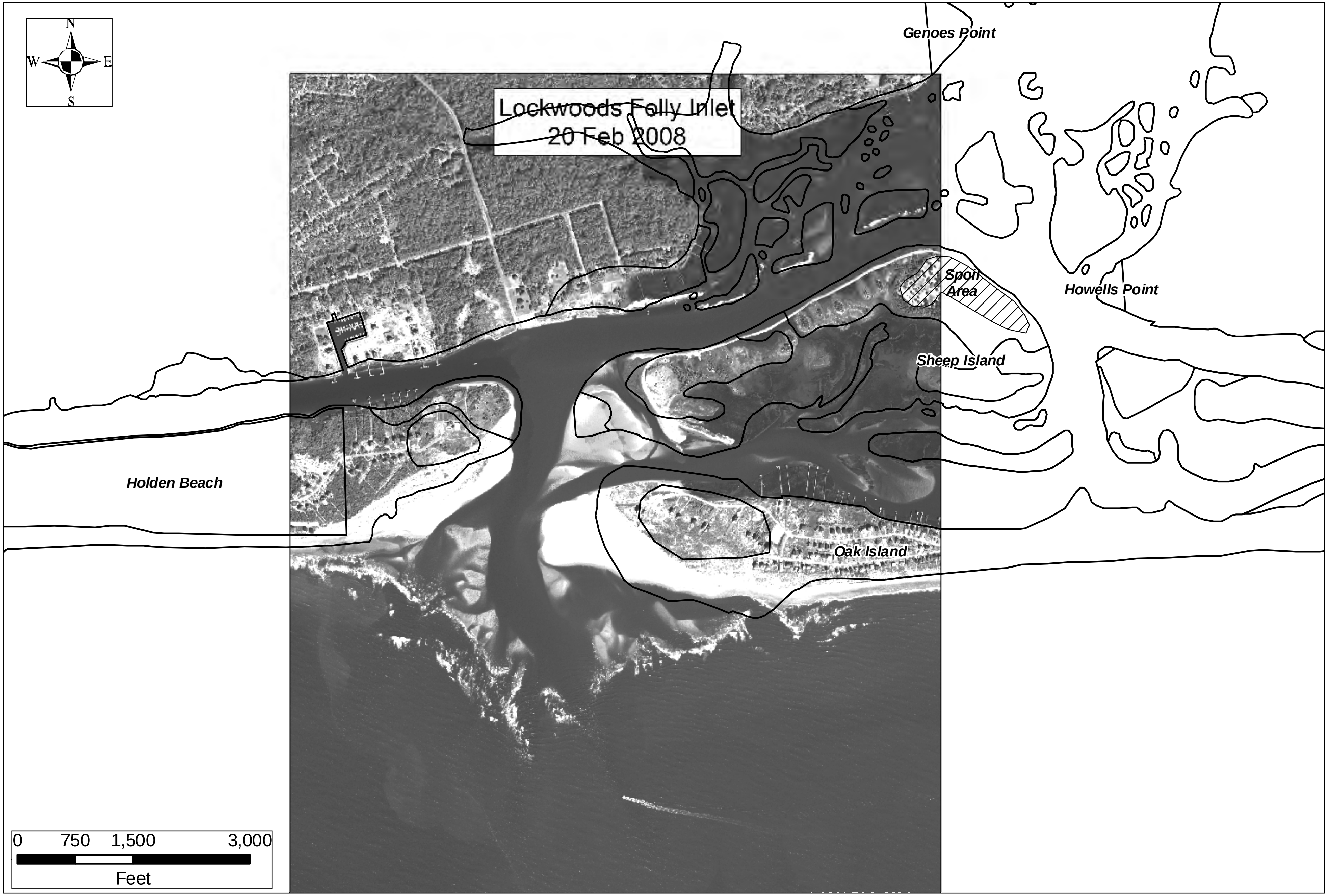


Figure A-24:
February 2008 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

Figure A-25:
2010 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

APPLIED TECHNOLOGY & MANAGEMENT

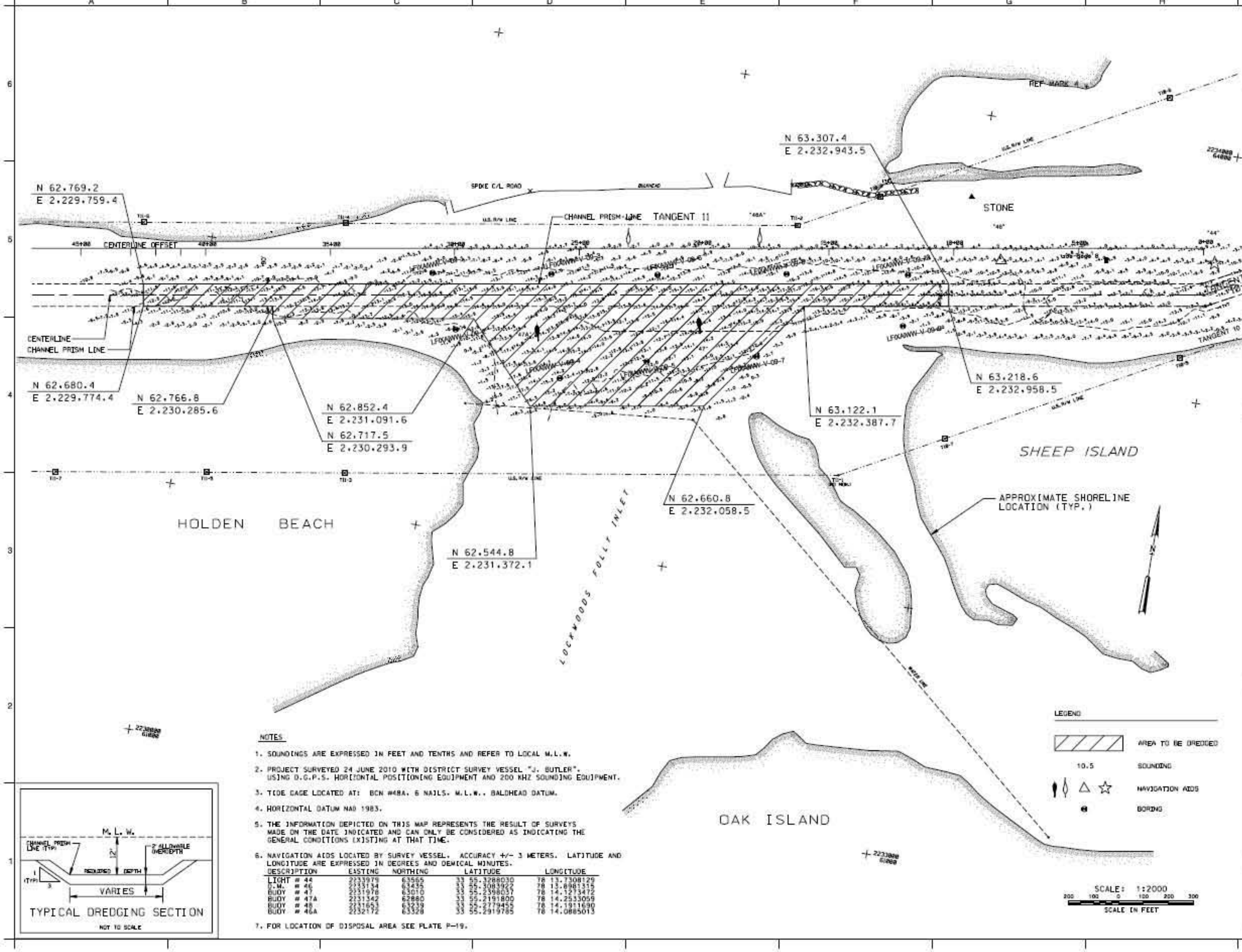
Figure A-26:
2011 Aerial with NOAA Electronic Navigation Chart (ENC) polylines

NOAA ENC data represents a compilation of datasets and is updated constantly.

APPLIED TECHNOLOGY & MANAGEMENT

Appendix B

Lockwoods Folly Inlet AIWW 2009 Vibracore Data



NOTES

1. SOUNDINGS ARE EXPRESSED IN FEET AND TENTHS AND REFER TO LOCAL M.L.W.

2. PROJECT SURVEYED 24 JUNE 2010 WITH DISTRICT SURVEY VESSEL "J. BUTLER". USING D.G.P.S. HORIZONTAL POSITIONING EQUIPMENT AND 200 KHZ SOUNDING EQUIPMENT.

3. TIDE GAGE LOCATED AT: BCN #48A, 6 NAILS. M.L.W., BALDHEAD DATUM.

4. HORIZONTAL DATUM NAD 1983.

5. THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULT OF SURVEYS MADE ON THE DATE INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME.

6. NAVIGATION AIDS LOCATED BY SURVEY VESSEL. ACCURACY +/- 3 METERS. LATITUDE AND LONGITUDE ARE EXPRESSED IN DEGREES AND DEMICAL MINUTES.

DESCRIPTION	EASTING	NORTHING	LATITUDE	LONGITUDE
LIGHT # 44	2233979	63565	33 55.3288030	78 13.7308129
D.M. # 46	2233134	63435	33 55.3083922	78 13.8981315
BUOY # 47	2231978	63010	33 55.2398037	78 14.1273472
BUOY # 47A	2231342	62880	33 55.2191800	78 14.2533059
BUOY # 48	2231653	63239	33 55.2779455	78 14.1911690
BUOY # 46A	2232172	63328	33 55.2919785	78 14.0885013

7. FOR LOCATION OF DISPOSAL AREA SEE PLATE P-19.

US Army Corps of Engineers
Wilmington District

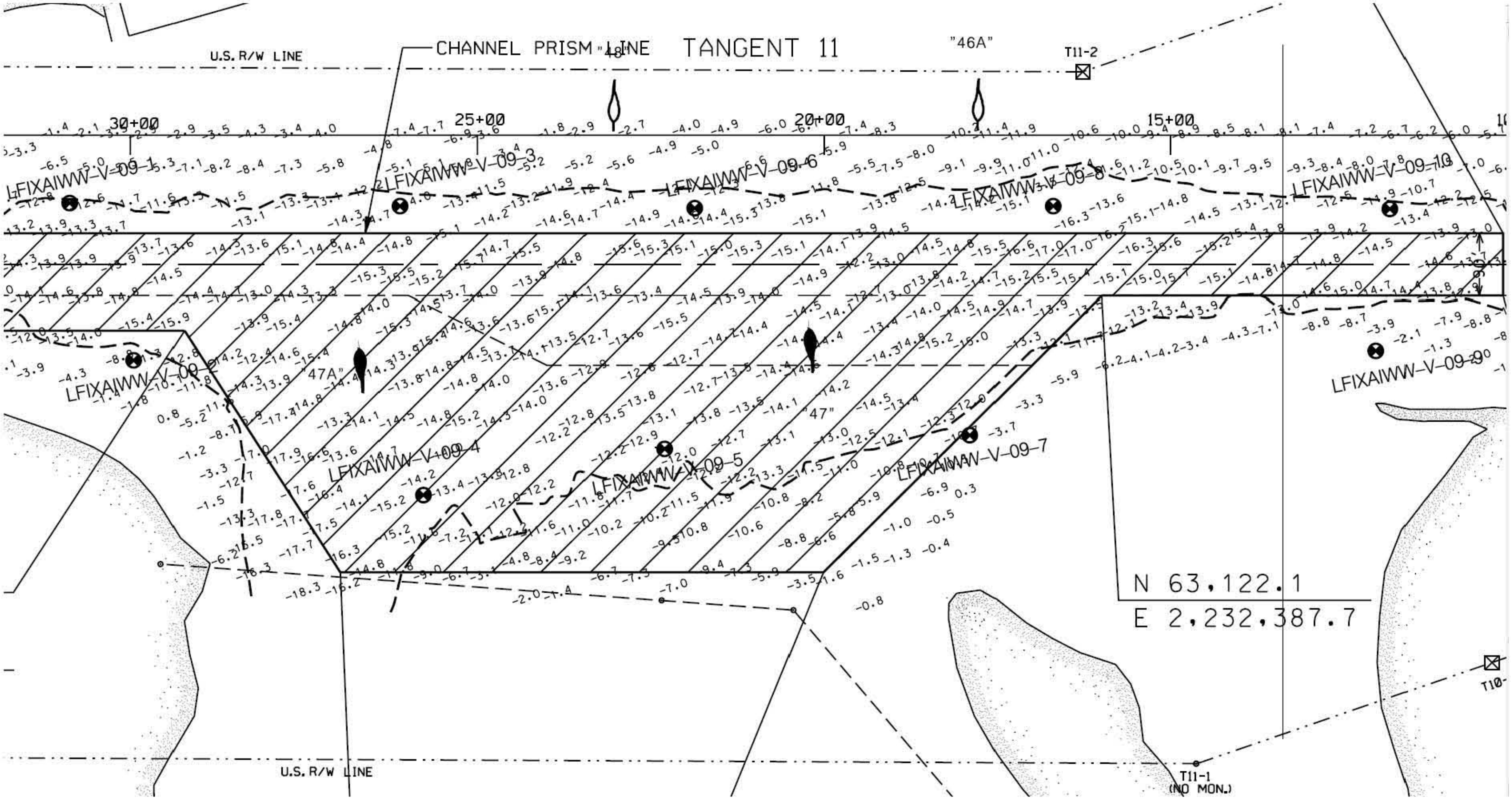
U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
WILMINGTON, NORTH CAROLINA

DESIGNED BY: GCR
REVIEWED BY: Chief, Design Section
CHK BY: CLD
DRAWING CODE: AIWW104-08-14
DATE: 21 JULY 2010
FILE NAME: loi-r-10.dgn

MAINTENANCE DREDGING
ATLANTIC INTRACOASTAL WATERWAY
THROUGH CHANNELS AND INLET CROSSINGS
NORTH CAROLINA

LOCKWOODS FOLLY INLET CROSSING
TANGENT 11

PLATE NUMBER
P-20
SHEET 20 OF 22



Zoom-in of vibracore boring locations

Boring Designation LFIXAIWW-V-09-1

DRILLING LOG

DIVISION: South Atlantic

INSTALLATION: Wilmington District

SHEET 1 OF 1 SHEETS

1. PROJECT: AIWW Cape Fear To Little River Tangent 11
2. HOLE NUMBER: LFIXAIWW-V-09-1 LOCATION COORDINATES: N 63,006.0 E 2,230,898.0
3. DRILLING AGENCY: USACE, Wilmington District
4. NAME OF DRILLER: Robie Page Crane Operator
5. DIRECTION OF BORING: ☒ VERTICAL ☐ INCLINED DEG FROM VERTICAL: --- BEARING:
6. THICKNESS OF OVERBURDEN (ft) 6.8
7. DEPTH DRILLED INTO ROCK (ft)
8. TOTAL DEPTH OF BORING (ft) 16.8
9. COORDINATE SYSTEM: State Plane HORIZONTAL: NAD83 VERTICAL: MLLW
10. SIZE AND TYPE OF BIT: 4" Dia. Vibracore
11. MANUFACTURER'S DESIGNATION OF DRILL: Vibracore Snell
12. TOTAL SAMPLES: DISTURBED 4 UNDISTURBED 4
13. TOTAL NUMBER CORE BOXES: N/A
14. ELEVATION GROUND WATER: 0.0
15. DATE BORING: STARTED 2/20/09 COMPLETED 2/20/09
16. ELEVATION TOP OF BORING: 0.0 (MLLW)
17. TOTAL CORE RECOVERY FOR BORING: N/A
18. SIGNATURE AND TITLE OF INSPECTOR: Larry Benjamin, USACE, Civil Engineer Technician

ELEV	DEPTH	Blows/ 0.5 ft	N_1	N_{60}	LEGEND	FIELD CLASSIFICATION OF MATERIALS (Description)	% REC	Samp No.	Laboratory						
									Gravel	Granular	Sand	Fines	#230	MC	ASTM Class
						0' to 6.8': Water. River Bottom at depth 6.8'									
-6.8	6.8					**6.8' to 13.4':** SP, Tan, Coarse, Poorly Graded Sand		1	0	0	99	1	1	25	SP
								2	1	0	97	2	2	27	SP
								3	0	0	98	2	2	24	SP
								4	0	0	97	3	3	30	SP
-13.4	13.4					**13.4' to 16.8':** No Recovery									
-16.8	16.8														

0.0 2.5 5.0 7.5 10.0 12.5 15.0

BOTTOM OF BOREHOLE AT 16.8 FT.

NOTE:
SOILS ARE FIELD VISUALLY CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

REMARKS

ASTM

Time begin vibracoring: 1302 hrs

Soil described by Larry Benjamin, Civil Engr. Tech

NOTE: Top of hole is defined as surface of water and compensation is made for the tide such that top of Hole is 0.0' EL MLLW.

VIBRACORE BORING

From 0.0' to 10.0'
Ran 10.0' Rec: 6.6'

Top of vibracore soil sample is logged beginning at River Bottom.
When Run is greater than Recovery, the difference is depicted as Assumed Not Recovered.

Note: Soils Commercial Lab Classified in Accordance with ASTM - D2487

LAB CLASSIFICATION

Jar Number	Classification
1	SP
2	SP
3	SP
4	SP

Note: Hole Terminated at Predetermined Depth at 10.0'

ACE 1836-A (DRILLING LOG) LOCKWOOD FOLLEY INLET CROSSING-REV.GPJ ACE MVD WITH RAPID CPT 06-09-08.GDT 9/30/09

SPK FORM 1836-A
SEP 05

Boring Designation LFIXAIWW-V-09-1 SHEET 1 of 1

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING LFIXAIWW-V-09-1 SAMPLE 1
DEPTH 6.8 - 7.3 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0911
SAMPLE DESCRIPTION: Gray fine sand with few shells, SP

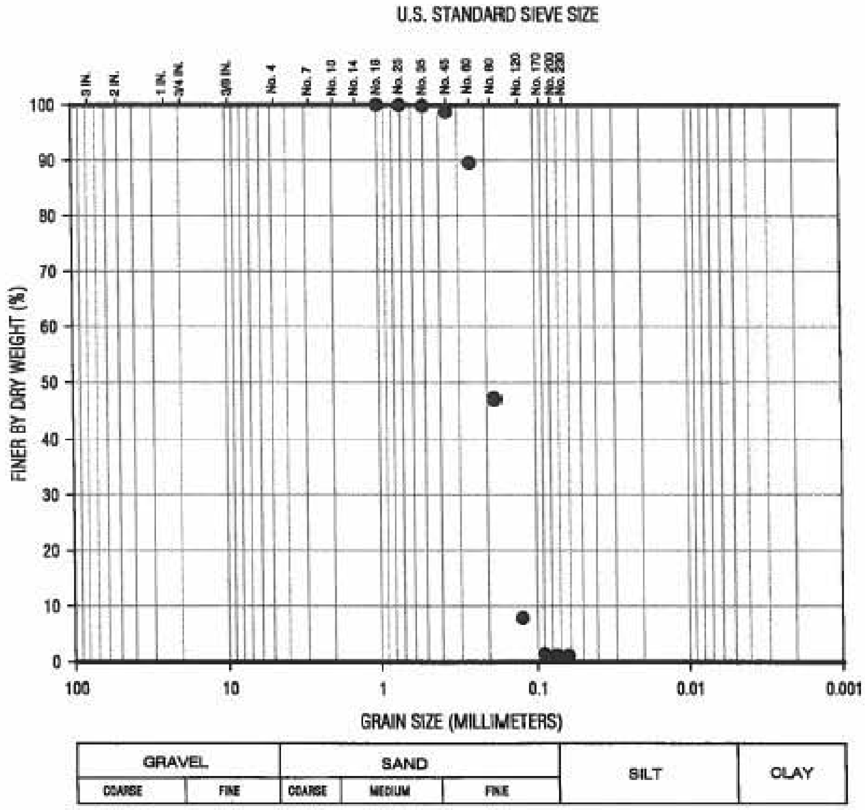
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 25.3
Wt. Dry Solids (grams): 160.72

Visually Estimated Shell Content(%): 10

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	100	100	100	100	100	99.9	99.7	98.7	89.5	47.1	7.9	1.4	1.1	1.1

Visually Estimated Shell Content (percent)

0	0	0	0	0	0	0	100	100	100	20	10	Shell Content <5% (Amount not visually estimated)			

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Checked By: Jcw Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-1** SAMPLE **2**
DEPTH 9.0 - 9.5 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0912
SAMPLE DESCRIPTION: Gray fine sand with trace organics and few shells, SP

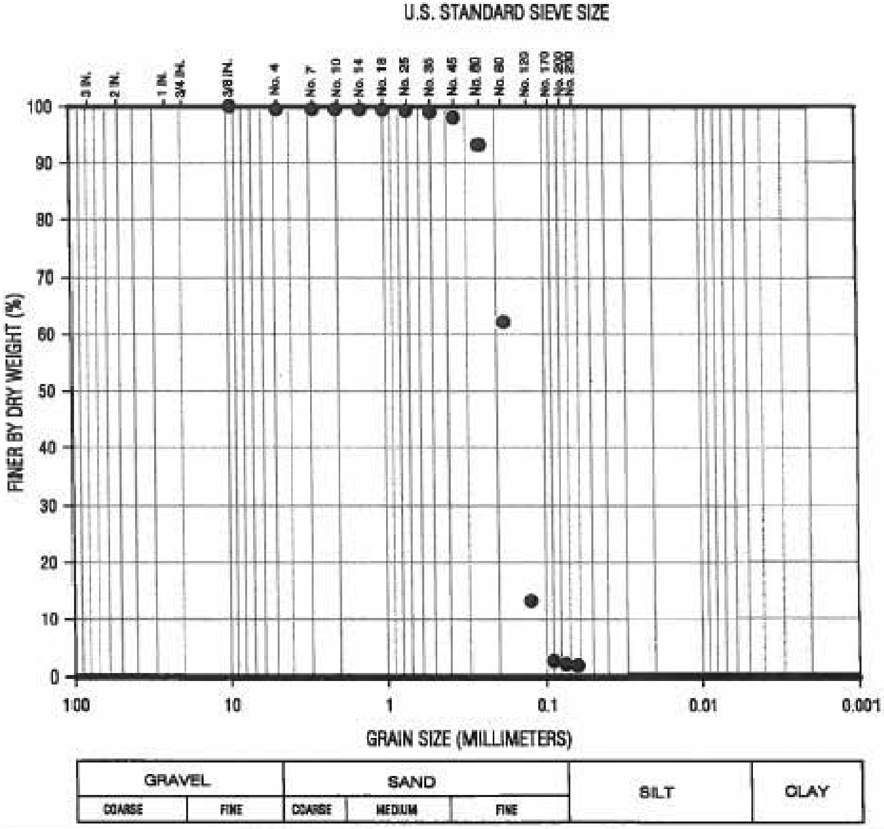
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 26.5
Wt. Dry Solids (grams): 162.07

Visually Estimated Shell Content(%): 10

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	99.5	99.4	99.4	99.4	99.4	99.2	98.9	98.0	93.2	62.2	13.2	2.6	2.0	1.8

Visually Estimated Shell Content (percent)

0	0	100	100	100	100	100	100	100	100	100	10	Shell Content <5% (Amount not visually estimated)			

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Checked By: jcw Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER
TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-1** SAMPLE **3**
DEPTH 11.0 - 11.5 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0913
SAMPLE DESCRIPTION: Gray fine sand with few shells, SP

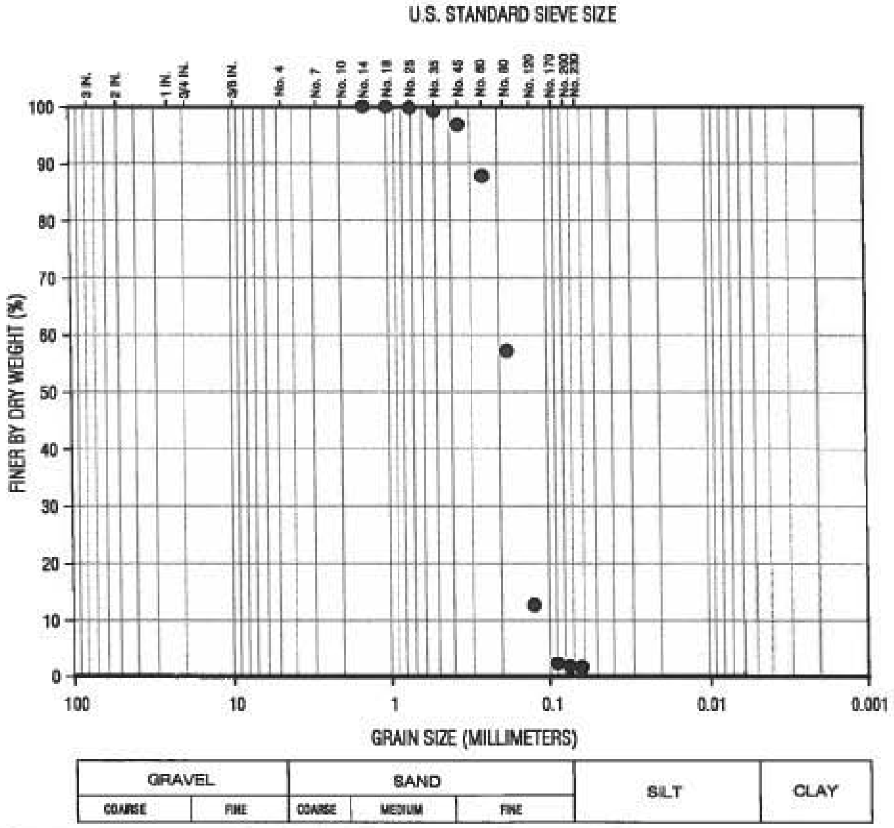
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 23.7
Wt. Dry Solids (grams): 186.49

Visually Estimated Shell Content(%): 5

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	100	100	100	100	99.9	99.8	99.2	96.8	87.8	57.1	12.7	2.2	1.7	1.5

Visually Estimated Shell Content (percent)

0	0	0	0	0	0	100	100	100	60	10	Shell Content <5% (Amount not visually estimated)

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Checked By: JCW Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-1** SAMPLE **4**
DEPTH 12.9 - 13.4 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0914
SAMPLE DESCRIPTION: Gray fine sand with trace shells, SP

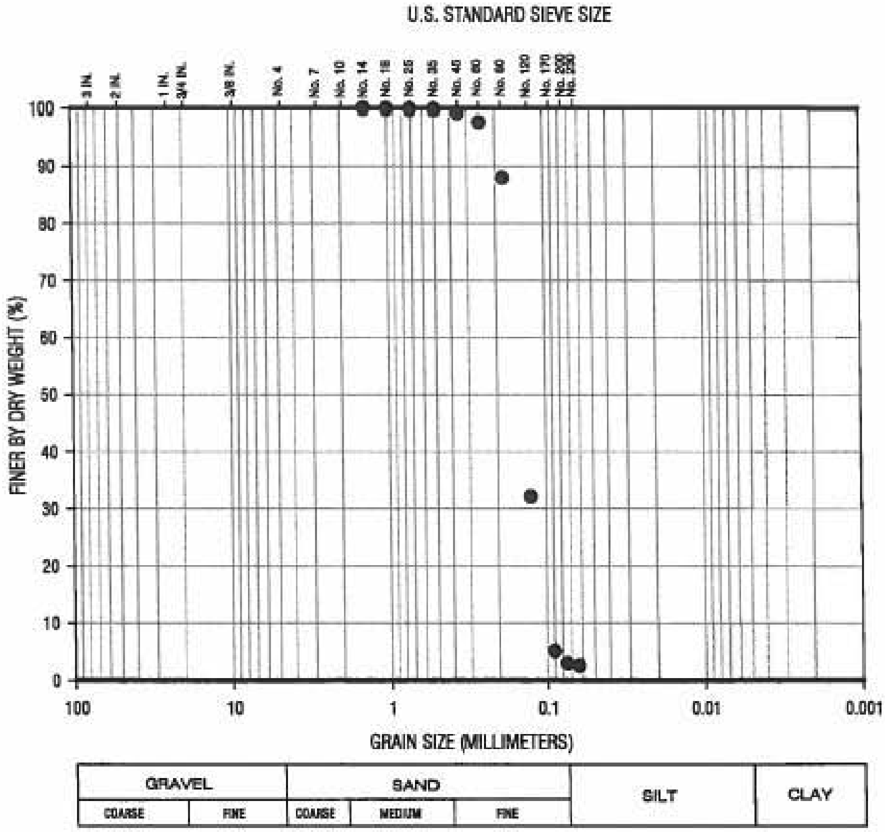
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 29.5
Wt. Dry Solids (grams): 159.03

Visually Estimated Shell Content(%): <5

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	100	100	100	100	99.9	99.8	99.7	99.2	97.7	88.0	32.2	5.1	3.0	2.6

Visually Estimated Shell Content (percent)

0	0	0	0	0	0	100	100	100	90	50	10	Shell Content <5% (Amount not visually estimated)

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Checked By: JCW Date: 10/26/09

[illegible]

Boring Designation LFIXAIWW-V-09-2

DRILLING LOG	DIVISION South Atlantic	INSTALLATION Wilmington District	SHEET 1 OF 1 SHEETS

1. PROJECT AIWW Cape Fear To Little River Tangent 11	9. COORDINATE SYSTEM State Plane	HORIZONTAL NAD83	VERTICAL MLLW
	10. SIZE AND TYPE OF BIT	4" Dia. Vibracore	
2. HOLE NUMBER LFIXAIWW-V-09-2 : LOCATION COORDINATES N 62,798.0 E 2,231,027.0	11. MANUFACTURER'S DESIGNATION OF DRILL Vibracore Snell		
3. DRILLING AGENCY USACE, Wilmington District	12. TOTAL SAMPLES	DISTURBED 3	UNDISTURBED 3
4. NAME OF DRILLER Robie Page Crane Operator	13. TOTAL NUMBER CORE BOXES	N/A	
5. DIRECTION OF BORING ☒ VERTICAL ☐ INCLINED DEG FROM VERTICAL --- BEARING	14. ELEVATION GROUND WATER	0.0	
	15. DATE BORING	STARTED 2/20/09	COMPLETED 2/20/09
6. THICKNESS OF OVERBURDEN (ft) 13.3	16. ELEVATION TOP OF BORING	0.0 (MLLW)	
7. DEPTH DRILLED INTO ROCK (ft)	17. TOTAL CORE RECOVERY FOR BORING	N/A	
8. TOTAL DEPTH OF BORING (ft) 19.8	18. SIGNATURE AND TITLE OF INSPECTOR Larry Benjamin, USACE, Civil Engineer Technician		

ELEV	DEPTH	Blows/ 0.5 ft	N_1	N_{60}	LEGEND	FIELD CLASSIFICATION OF MATERIALS (Description)	% REC	Samp No.	Laboratory Gravel	Granular	Sand	Fines	#230	MC	ASTM Class
						0' to 13.3': Water. River Bottom at depth 13.3'									
-13.3	13.3					**13.3' to 17.4':** SM, Dark Gray, Fine Silty Sand		1	0	0	64	36	34	70	SC
								2							
-17.4	17.4					**17.4' to 18.3':** MH, Dark Gray, Elastic Silt		3							
-18.3	18.3					**18.3' to 19.8':** No Recovery									
-19.8	19.8														

BOTTOM OF BOREHOLE AT 19.8 FT.

NOTE:
SOILS ARE FIELD VISUALLY CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

REMARKS

ASTM

Time begin vibracoring: 1315 hrs

Soil described by Larry Benjamin, Civil Engr. Tech

NOTE: Top of hole is defined as surface of water and compensation is made for the tide such that top of Hole is 0.0' EL MLLW.

VIBRACORE BORING

From 0.0' to 6.5'
Ran 6.5' Rec: 5.0'

Top of vibracore soil sample is logged beginning at River Bottom.
When Run is greater than Recovery, the difference is depicted as Assumed Not Recovered.

Note: Soils Commercial Lab Classified in Accordance with ASTM - D2487

LAB CLASSIFICATION

Jar Number	Classification
1	SC
2	-
3	-

Note: Hole Terminated at Refusal Depth at 6.5'

0.0
2.5
5.0
7.5
10.
12.
15.
17.

ACE 1836-A (DRILLING LOG) LOCKWOOD FOLLEY INLET CROSSING REV.GPJ ACE MVD WITH RAPID CPT 06-09-08.GDT 9/30/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: ----
BORING **LFIXAIWW-V-09-2** SAMPLE 1
DEPTH 13.3 - 13.8 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0921
SAMPLE DESCRIPTION: Dark gray clayey sand with trace organics and shells, SC

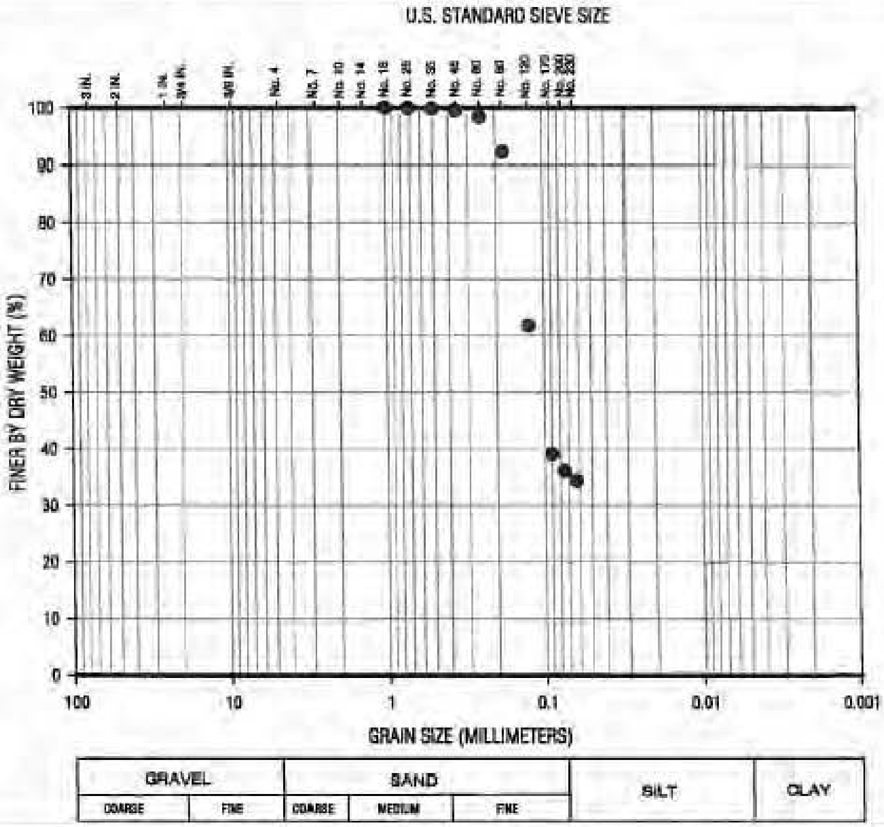
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 70.3
Wt. Dry Solids (grams): 130.23

Visually Estimated Shell Content(%): <5

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	100	100	100	100	100	99.9	99.8	99.5	98.3	92.2	61.7	39.0	36.1	34.4

Visually Estimated Shell Content (percent)

0	0	0	0	0	0	0	90	70	60	50	10	Shell Content <5% (Amount not visually estimated)

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Checked By: JCW Date: 10/26/09

Boring Designation LFIXAIWW-V-09-3

DRILLING LOG	DIVISION South Atlantic	INSTALLATION Wilmington District	SHEET 1 OF 1 SHEETS

1. PROJECT
AIWW Cape Fear To Little River Tangent 11

2. HOLE NUMBER: LFIXAIWW-V-09-3
LOCATION COORDINATES: N 63,081.0 E 2,231,368.0

3. DRILLING AGENCY
USACE, Wilmington District

4. NAME OF DRILLER
Robie Page Crane Operator

5. DIRECTION OF BORING
☒ VERTICAL
☐ INCLINED
DEG FROM VERTICAL: ---
BEARING:

6. THICKNESS OF OVERBURDEN (ft) 6.4

7. DEPTH DRILLED INTO ROCK (ft)

8. TOTAL DEPTH OF BORING (ft) 16.4

9. COORDINATE SYSTEM: State Plane
HORIZONTAL: NAD83
VERTICAL: MLLW

10. SIZE AND TYPE OF BIT 4" Dia. Vibracore

11. MANUFACTURER'S DESIGNATION OF DRILL
Vibracore Snell

12. TOTAL SAMPLES
DISTURBED: 4
UNDISTURBED: 4

13. TOTAL NUMBER CORE BOXES N/A

14. ELEVATION GROUND WATER 0.0

15. DATE BORING
STARTED: 2/20/09
COMPLETED: 2/20/09

16. ELEVATION TOP OF BORING 0.0 (MLLW)

17. TOTAL CORE RECOVERY FOR BORING N/A

18. SIGNATURE AND TITLE OF INSPECTOR
Larry Benjamin, USACE, Civil Engineer Technician

ELEV	DEPTH	Blows/ 0.5 ft	N_1	N_{60}	LEGEND	FIELD CLASSIFICATION OF MATERIALS (Description)	% REC	Samp No.	Laboratory Gravel	Granular	Sand	Fines	#230	MC	ASTM Class
						0' to 6.4': Water. River Bottom at depth 6.4'									
-6.4	6.4					**6.4' to 13'**: SP, Tan, Coarse, Poorly Graded Sand with Trace Shell Fragments		1	0	0	99	1	1	22	SP
								2	0	0	99	1	1	22	SP
								3	0	0	99	1	1	23	SP
								4	1	1	97	1	1	20	SP
-13.0	13.0					**13' to 16.4'**: No Recovery									
-16.4	16.4														

BOTTOM OF BOREHOLE AT 16.4 FT.

NOTE:
SOILS ARE FIELD VISUALLY CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

REMARKS

ASTM

Time begin vibracoring: 1336 hrs

Soil described by Larry Benjamin, Civil Engr. Tech

NOTE: Top of hole is defined as surface of water and compensation is made for the tide such that top of Hole is 0.0' EL MLLW.

VIBRACORE BORING

From 0.0' to 10.0'
Ran 6.5' Rec: 6.6'

Top of vibracore soil sample is logged beginning at River Bottom.
When Run is greater than Recovery, the difference is depicted as Assumed Not Recovered.

Note: Soils Commercial Lab Classified in Accordance with ASTM - D2487

LAB CLASSIFICATION

Jar Number	Classification
1	SP
2	SP
3	SP
4	SP

Note: Hole Terminated at Predetermined Depth at 10.0'

ACE 1836-A (DRILLING LOG) LOCKWOOD FOLLEY INLET CROSSING-REV.GPJ ACE MVD WITH RAPID CPT 06-09-08.GDT 9/30/09

SPK FORM 1836-A
SEP 05

Boring Designation LFIXAIWW-V-09-3 SHEET 1 of 1

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER
TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-3** SAMPLE **1**
DEPTH 6.4 - 6.9 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0931
SAMPLE DESCRIPTION: Light gray fine sand with little shells, SP

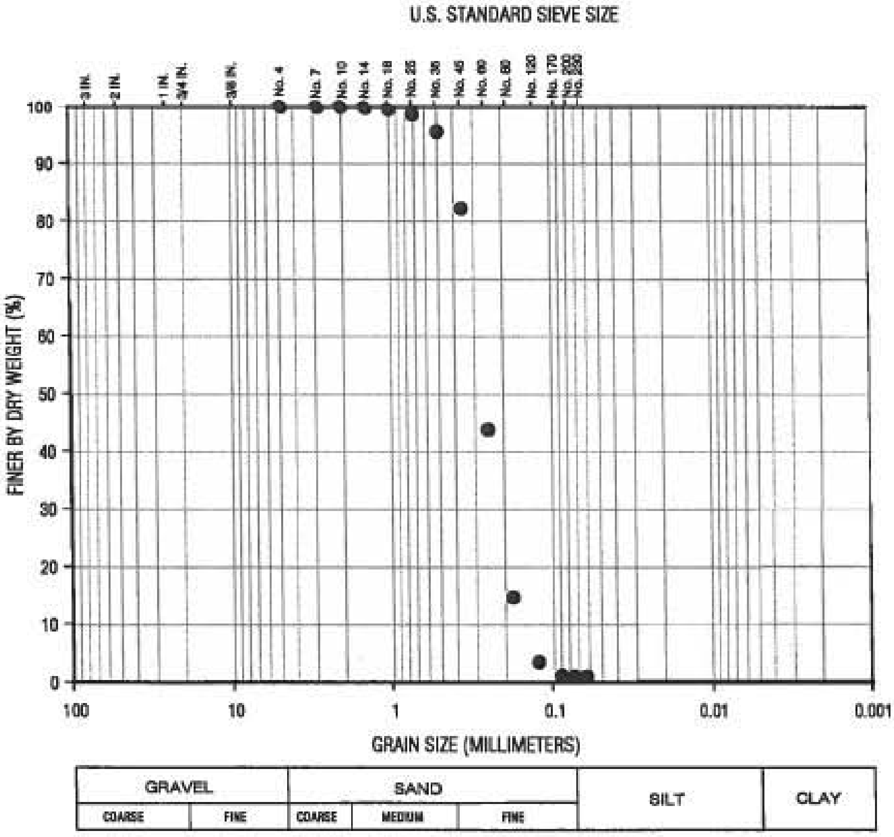
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 21.9
Wt. Dry Solids (grams): 174.90

Visually Estimated Shell Content(%): 15

Measured Carbonate Content [ASTM D 4373] as CaCO$_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	100	99.9	99.9	99.7	99.5	98.5	95.6	82.3	43.8	14.8	3.5	1.2	1.0	1.0
Visually Estimated Shell Content (percent)															
0	0	0	100	100	100	100	100	100	50	10	Shell Content <5% (Amount not visually estimated)				

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Checked By: Jcw
Date: 10/26/09

[illegible]

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER
TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-3** SAMPLE **2**
DEPTH 8.5 - 9.0 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0932
SAMPLE DESCRIPTION: Light gray fine sand with trace shells, SP

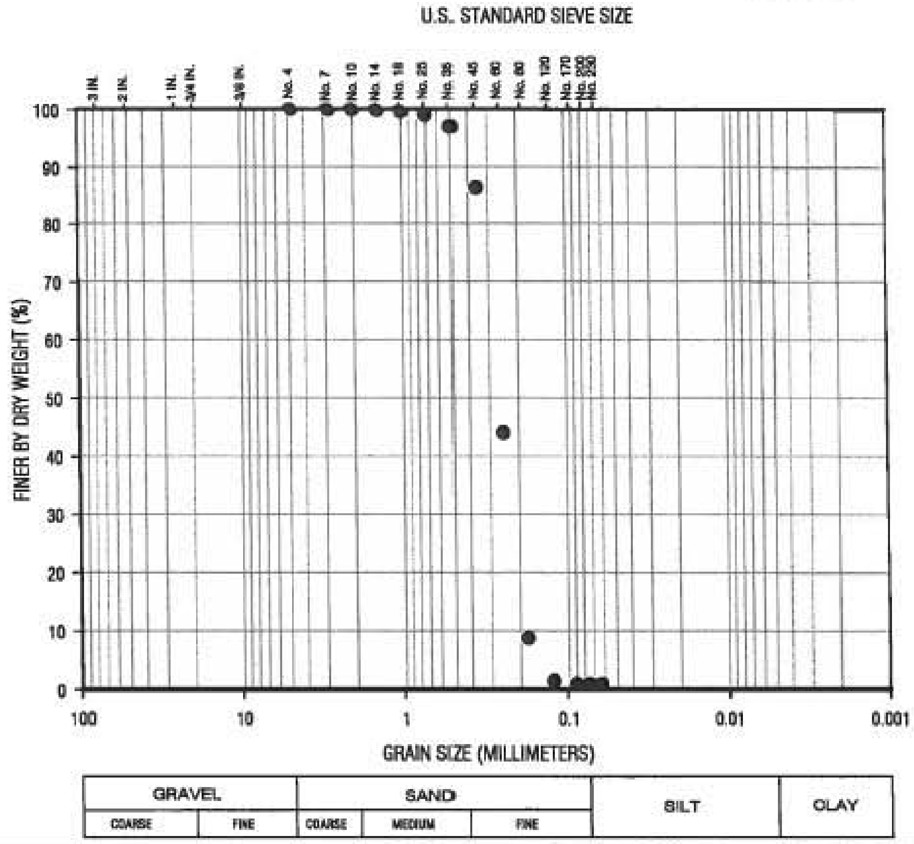
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other: ____

Moisture Content (%): 21.8
Wt. Dry Solids (grams): 190.42

Visually Estimated Shell Content(%): 10

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	100	99.9	99.9	99.8	99.6	98.9	96.9	86.4	44.0	8.8	1.4	1.0	0.9	0.9

Visually Estimated Shell Content (percent)

0	0	0	100	100	100	100	100	90	40	10	Shell Content <5% (Amount not visually estimated)

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Checked By: JCW Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING LFIXAIWW-V-09-3 SAMPLE 3
DEPTH 10.5 - 11.0 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0933
SAMPLE DESCRIPTION: Light gray fine sand with trace shell, SP

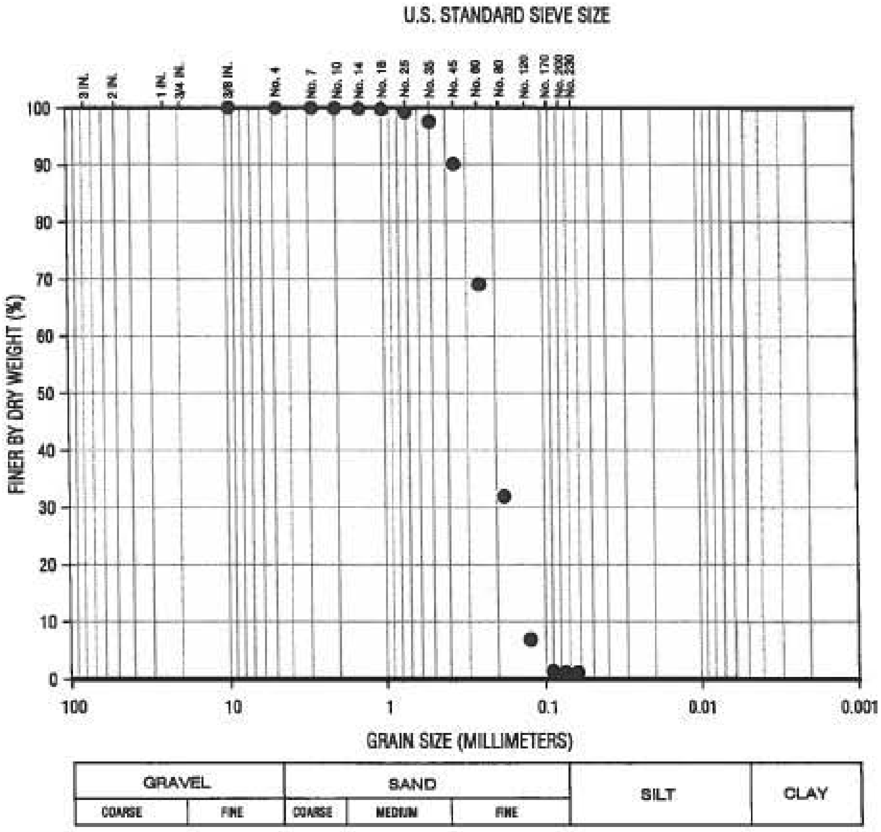
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 23.2
Wt. Dry Solids (grams): 182.48

Visually Estimated Shell Content(%): 10

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	99.9	99.9	99.9	99.8	99.6	99.2	97.4	90.0	68.9	31.9	6.9	1.4	1.2	1.1

Visually Estimated Shell Content (percent)

0	0	100	100	100	100	100	100	100	60	5	Shell Content <5% (Amount not visually estimated)

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Checked By: JCW
Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER
TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-3** SAMPLE **4**
DEPTH 12.5 - 13.0 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0934
SAMPLE DESCRIPTION: Gray sand with little shells, SP

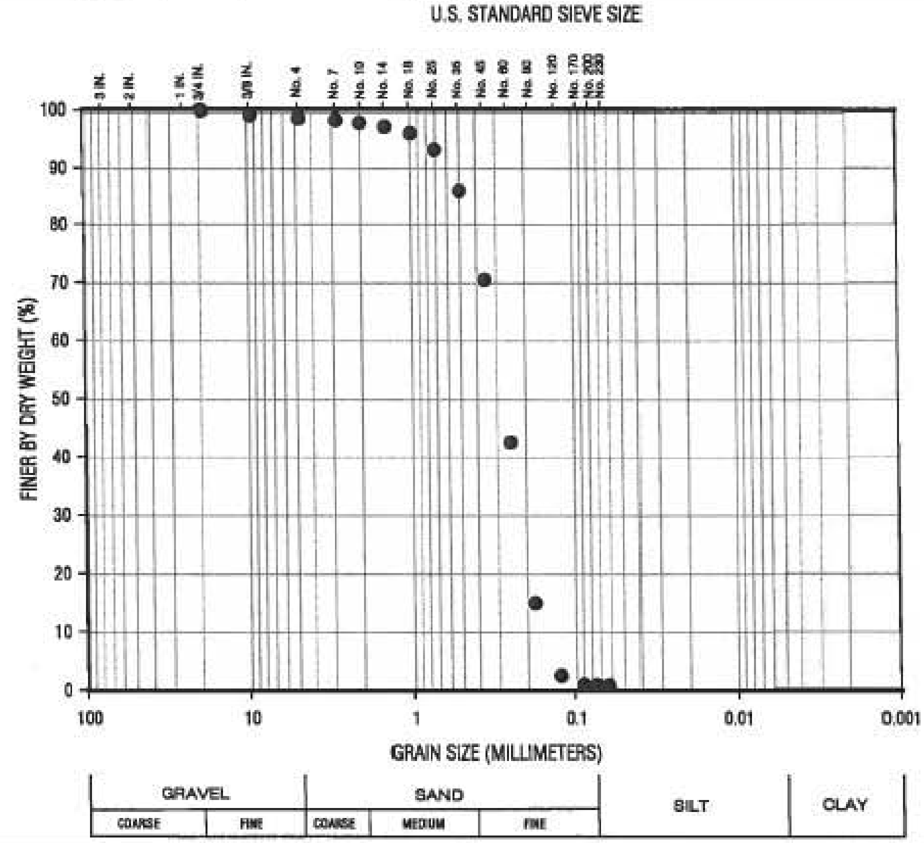
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 20.4
Wt. Dry Solids (grams): 177.55

Visually Estimated Shell Content(%): 15

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): 9.4



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	99.1	98.6	98.2	97.8	97.2	96.0	93.2	86.2	70.5	42.6	15.0	2.6	1.0	1.0	0.9

Visually Estimated Shell Content (percent)

0	100	100	100	100	100	100	100	70	30	Shell Content <5% (Amount not visually estimated)

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Checked By: JCW Date: 10/26/09

Boring Designation LFIXAIWW-V-09-4

DRILLING LOG	DIVISION South Atlantic	INSTALLATION Wilmington District	SHEET 1 OF 1 SHEETS

1. PROJECT
AIWW Cape Fear To Little River Tangent 11

2. HOLE NUMBER: LFIXAIWW-V-09-4
LOCATION COORDINATES: N 62,675.0 E 2,231,471.0

3. DRILLING AGENCY
USACE, Wilmington District

4. NAME OF DRILLER
Robie Page Crane Operator

5. DIRECTION OF BORING
☒ VERTICAL
☐ INCLINED
DEG FROM VERTICAL: ---
BEARING:

6. THICKNESS OF OVERBURDEN (ft) 7.6

7. DEPTH DRILLED INTO ROCK (ft)

8. TOTAL DEPTH OF BORING (ft) 17.6

9. COORDINATE SYSTEM: State Plane
HORIZONTAL: NAD83
VERTICAL: MLLW

10. SIZE AND TYPE OF BIT 4" Dia. Vibracore

11. MANUFACTURER'S DESIGNATION OF DRILL
Vibracore Snell

12. TOTAL SAMPLES
DISTURBED: 3
UNDISTURBED: 3

13. TOTAL NUMBER CORE BOXES N/A

14. ELEVATION GROUND WATER 0.0

15. DATE BORING
STARTED: 2/20/09
COMPLETED: 2/20/09

16. ELEVATION TOP OF BORING 0.0 (MLLW)

17. TOTAL CORE RECOVERY FOR BORING N/A

18. SIGNATURE AND TITLE OF INSPECTOR
Larry Benjamin, USACE, Civil Engineer Technician

ELEV	DEPTH	Blows/ 0.5 ft	N_1	N_{60}	LEGEND	FIELD CLASSIFICATION OF MATERIALS (Description)	% REC	Samp No.	Laboratory Gravel	Granular	Sand	Fines	#230	MC	ASTM Class
						0' to 7.6': Water. River Bottom at depth 7.6'									
-7.6	7.6					**7.6' to 12'**: SP, Tan, Coarse, Poorly Graded Sand with Trace Shell Fragments		1	3	1	95	1	1	21	SP
								2	1	2	97	1	1	22	SP
-12.0	12.0					**12' to 13.4'**: SP, Tan, Coarse, Poorly Graded Sand with Shell Fragments		3	0	1	98	1	1	21	SP
-13.4	13.4					**13.1' to 17.6'**: No Recovery									
-17.6	17.6														

BOTTOM OF BOREHOLE AT 17.6 FT.

NOTE:
SOILS ARE FIELD VISUALLY CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

REMARKS

ASTM

Time begin vibracoring: 1350 hrs

Soil described by Larry Benjamin, Civil Engr. Tech

NOTE: Top of hole is defined as surface of water and compensation is made for the tide such that top of Hole is 0.0' EL MLLW.

VIBRACORE BORING

From 0.0' to 10.0'
Ran 6.5' Rec: 5.5'

Top of vibracore soil sample is logged beginning at River Bottom.
When Run is greater than Recovery, the difference is depicted as Assumed Not Recovered.

Note: Soils Commercial Lab Classified in Accordance with ASTM - D2487

LAB CLASSIFICATION

Jar Number	Classification
1	SP
2	SP
3	SP

Note: Hole Terminated at Predetermined Depth at 10.0'

0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5

ACE 1836-A (DRILLING LOG) LOCKWOOD FOLLEY INLET CROSSING-REV.GPJ ACE MVD WITH RAPID CPT 06-09-08.GDT 9/30/09

SPK FORM 1836-A
SEP 06

Boring Designation LFIXAIWW-V-09-4 SHEET 1 of 1

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER
TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 09/14/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-4** SAMPLE **1**
DEPTH 7.6 - 8.1 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0941
SAMPLE DESCRIPTION: Gray sand with little shells, SP

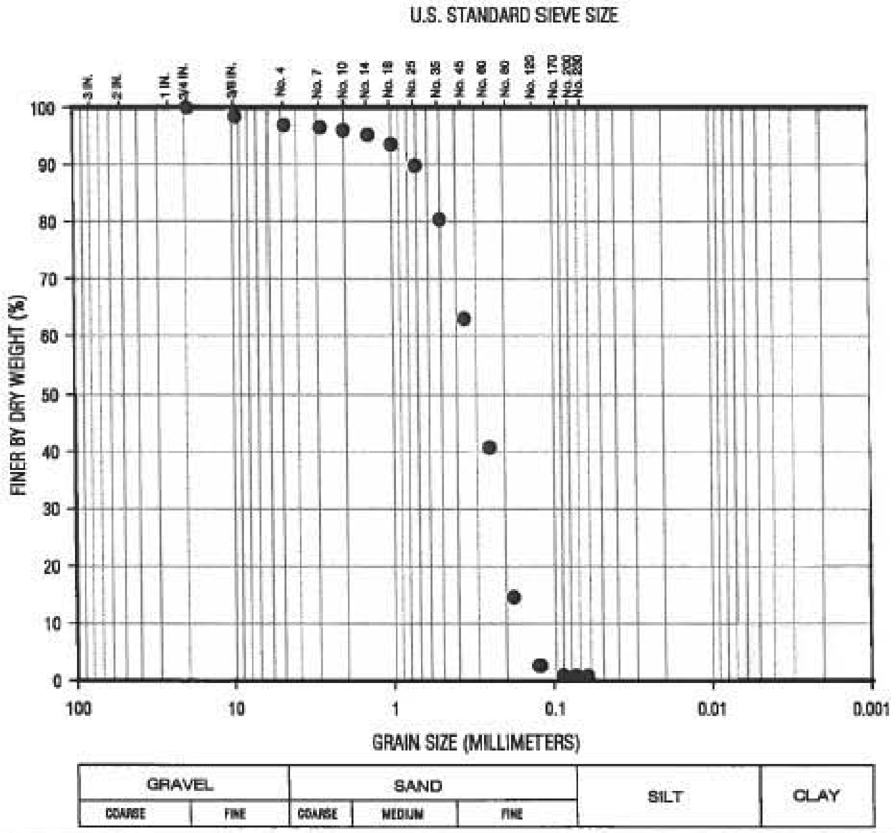
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 21.2
Wt. Dry Solids (grams): 180.69

Visually Estimated Shell Content(%): 15

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	98.4	96.8	96.5	96.0	95.1	93.5	89.8	80.3	63.0	40.7	14.6	2.7	1.0	0.9	0.9

Visually Estimated Shell Content (percent)

0	100	100	100	100	100	100	100	40	20	Shell Content<5% (Amount not visually estimated)					

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Checked By: JCW Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING LFIXAIWW-V-09-4 SAMPLE 2
DEPTH 9.5 - 10.0 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0942
SAMPLE DESCRIPTION: Gray sand with little shells, SP

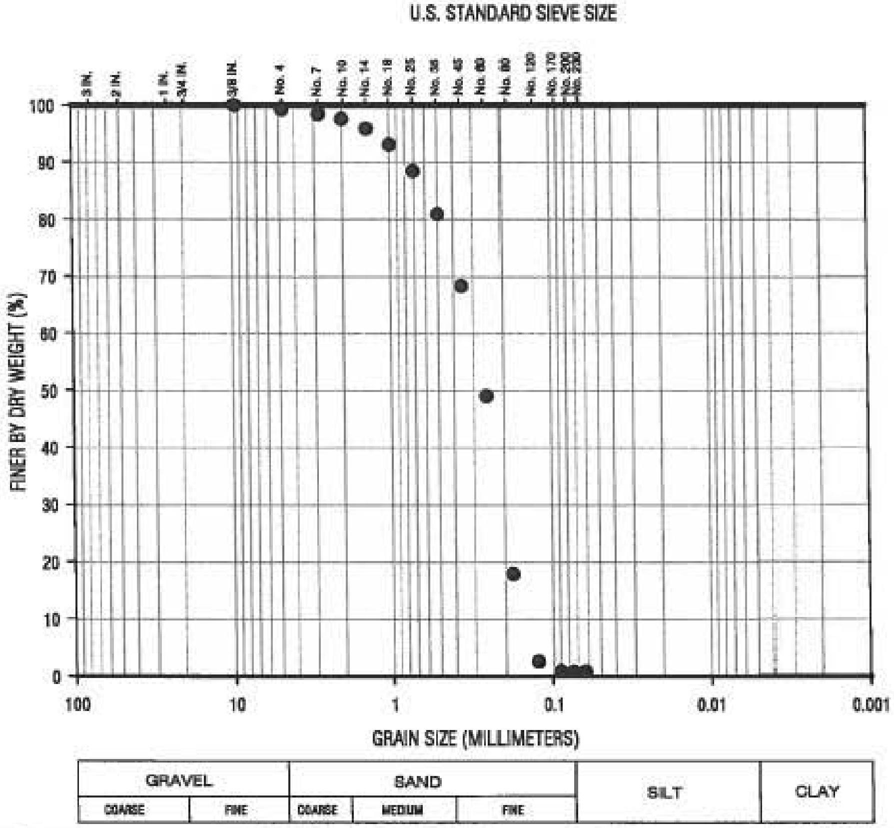
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 21.6
Wt. Dry Solids (grams): 178.62

Visually Estimated Shell Content(%): 20

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	99.2	98.4	97.6	95.9	93.1	88.5	80.9	68.3	49.1	17.9	2.7	1.0	0.9	0.9
Visually Estimated Shell Content (percent)															
0	0	100	100	100	100	100	90	50	20	5	Shell Content <5% (Amount not visually estimated)				

Checked By: JCW Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-4** SAMPLE **3**
DEPTH 11.5 - 12.0 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0943
SAMPLE DESCRIPTION: Gray sand with little shells, SP

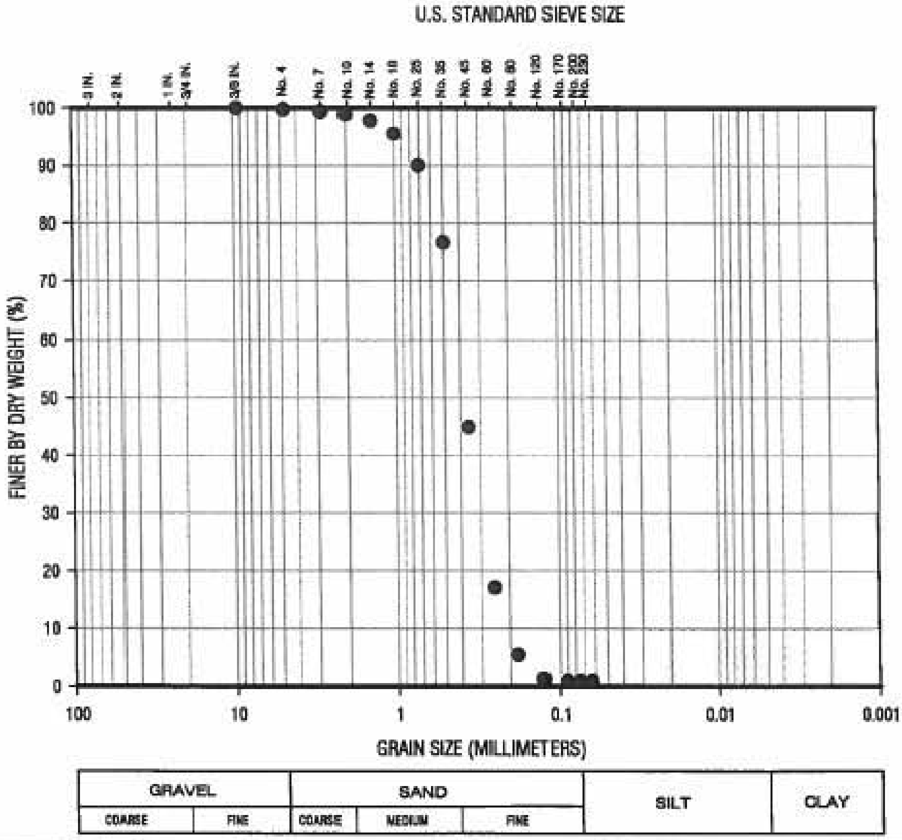
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 20.7
Wt. Dry Solids (grams): 191.32

Visually Estimated Shell Content (%): **20**

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	99.7	99.3	98.8	97.8	95.5	90.0	76.7	44.9	17.1	5.5	1.3	0.9	0.9	0.9

Visually Estimated Shell Content (percent)

0	0	100	100	100	100	100	100	50	10	Shell Content <5% (Amount not visually estimated)

Checked By: JCW Date: 10/26/09

DRILLING LOG

DIVISION South Atlantic

INSTALLATION Wilmington District

SHEET 1 OF 1 SHEETS

1. PROJECT AIWW Cape Fear To Little River Tangent 11

2. HOLE NUMBER LFIXAIWW-V-09-5 : LOCATION COORDINATES N 62,799.0 E 2,231,803.0

3. DRILLING AGENCY USACE, Wilmington District

4. NAME OF DRILLER Robie Page Crane Operator

5. DIRECTION OF BORING ☒ VERTICAL ☐ INCLINED : DEG FROM VERTICAL --- : BEARING

6. THICKNESS OF OVERBURDEN (ft) 2.3

7. DEPTH DRILLED INTO ROCK (ft)

8. TOTAL DEPTH OF BORING (ft) 12.3

9. COORDINATE SYSTEM State Plane : HORIZONTAL NAD83 : VERTICAL MLLW

10. SIZE AND TYPE OF BIT 4" Dia. Vibracore

11. MANUFACTURER'S DESIGNATION OF DRILL Vibracore Snell

12. TOTAL SAMPLES : DISTURBED 4 : UNDISTURBED 4

13. TOTAL NUMBER CORE BOXES N/A

14. ELEVATION GROUND WATER 0.0

15. DATE BORING : STARTED 2/20/09 : COMPLETED 2/20/09

16. ELEVATION TOP OF BORING 0.0 (MLLW)

17. TOTAL CORE RECOVERY FOR BORING N/A

18. SIGNATURE AND TITLE OF INSPECTOR Larry Benjamin, USACE, Civil Engineer Technician

ELEV	DEPTH	Blows/ 0.5 ft	N_1	N_{60}	LEGEND	FIELD CLASSIFICATION OF MATERIALS (Description)	% REC	Samp No.	Laboratory Gravel	Granular	Sand	Fines	#230	MC	ASTM Class
-2.3	2.3					**0' to 2.3':** Water. River Bottom at depth 2.3'									
-8.0	8.0					**2.3' to 8':** SP, Tan, Coarse, Poorly Graded Sand with Trace Shell Fragments		1 2 3	2 1 0	2 1 0	95 97 99	1 1 1	1 1 1		SP SP SP
-8.8	8.8					**8' to 8.8':** SP, Tan, Coarse, Poorly Graded Sand with Shell Fragments		4	7	1	91	1	1		SP
-12.3	12.3					**8.8' to 12.3':** No Recovery									

BOTTOM OF BOREHOLE AT 12.3 FT.

NOTE:
SOILS ARE FIELD VISUALLY CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

REMARKS

ASTM

Time begin vibracoring: 1404 hrs

Soil described by Larry Benjamin, Civil Engr. Tech

NOTE: Top of hole is defined as surface of water and compensation is made for the tide such that top of Hole is 0.0' EL MLLW.

VIBRACORE BORING

From 0.0' to 10.0'
Ran 6.5' Rec: 6.5'

Top of vibracore soil sample is logged beginning at River Bottom.
When Run is greater than Recovery, the difference is depicted as Assumed Not Recovered.

Note: Soils Commercial Lab Classified in Accordance with ASTM - D2487

LAB CLASSIFICATION

Jar Number	Classification
1	SP
2	SP
3	SP
4	SP

Note: Hole Terminated at Predetermined Depth at 10.0'

0.0
2.5
5.
7.
10.

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER
TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-5** SAMPLE **1**
DEPTH 2.3 - 2.8 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0951
SAMPLE DESCRIPTION: Gray sand with some shells, SP

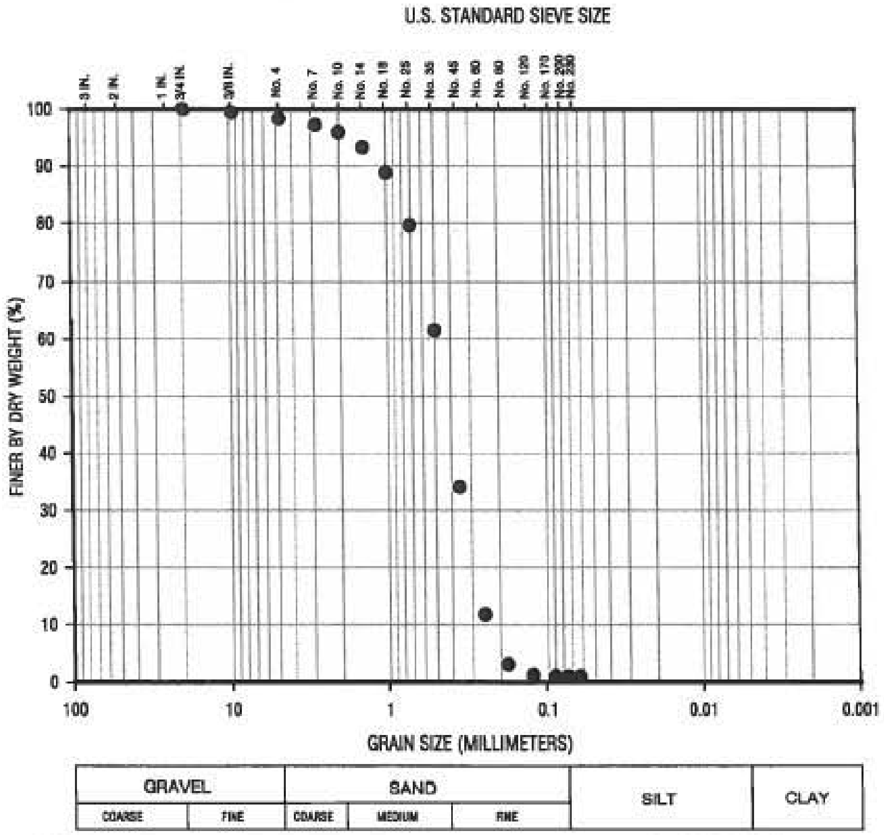
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other: ______

Moisture Content (%): 20.5
Wt. Dry Solids (grams): 176.28

Visually Estimated Shell Content(%): 35

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): 13.5



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	99.4	98.3	97.1	95.9	93.2	88.8	79.6	61.5	34.0	11.8	3.1	1.2	1.0	1.0	1.0

Visually Estimated Shell Content (percent)

0	100	100	100	100	100	100	100	50	20	10	Shell Content <5% (Amount not visually estimated)

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Checked By: JCW Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-5** SAMPLE **2**
DEPTH 4.5 - 5.0 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0952
SAMPLE DESCRIPTION: Gray sand with little shells, SP

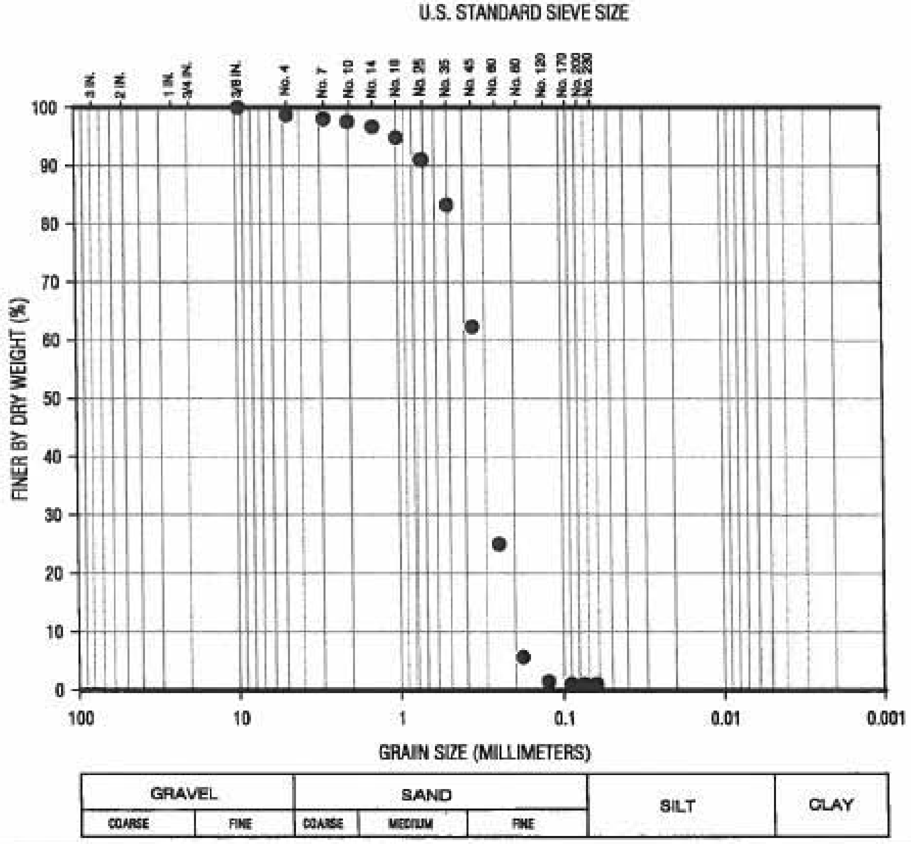
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 21.9
Wt. Dry Solids (grams): 183.72

Visually Estimated Shell Content(%): 20

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	98.6	98.0	97.5	96.6	94.8	91.0	83.2	62.3	25.0	5.6	1.5	1.1	1.0	1.0

Visually Estimated Shell Content (percent)

0	0	100	100	100	100	100	50	50	20	10	5	Shell Content <5% (Amount not visually estimated)			

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Checked By: JCW Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 09/14/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-5** SAMPLE **3**
DEPTH 6.5 - 7.0 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0953
SAMPLE DESCRIPTION: Gray fine sand with few shells, SP

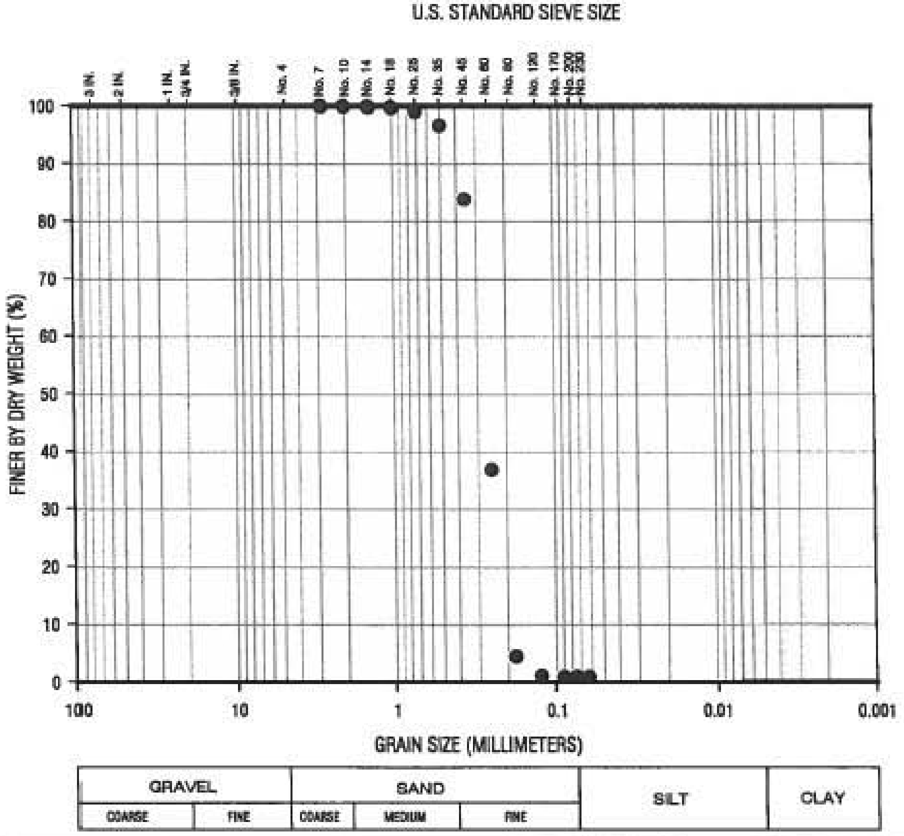
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 21.8
Wt. Dry Solids (grams): 184.42

Visually Estimated Shell Content(%): 15

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	100	100	99.9	99.8	99.6	99.0	96.6	83.9	36.9	4.6	1.2	1.1	1.1	1.0

Visually Estimated Shell Content (percent)

0	0	0	0	100	100	100	100	80	40	10	Shell Content <5% (Amount not visually estimated)				

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Checked By: JCW Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER
TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-5** SAMPLE **4**
DEPTH 8.3 - 8.8 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0954
SAMPLE DESCRIPTION: Gray sand with few shells, SP

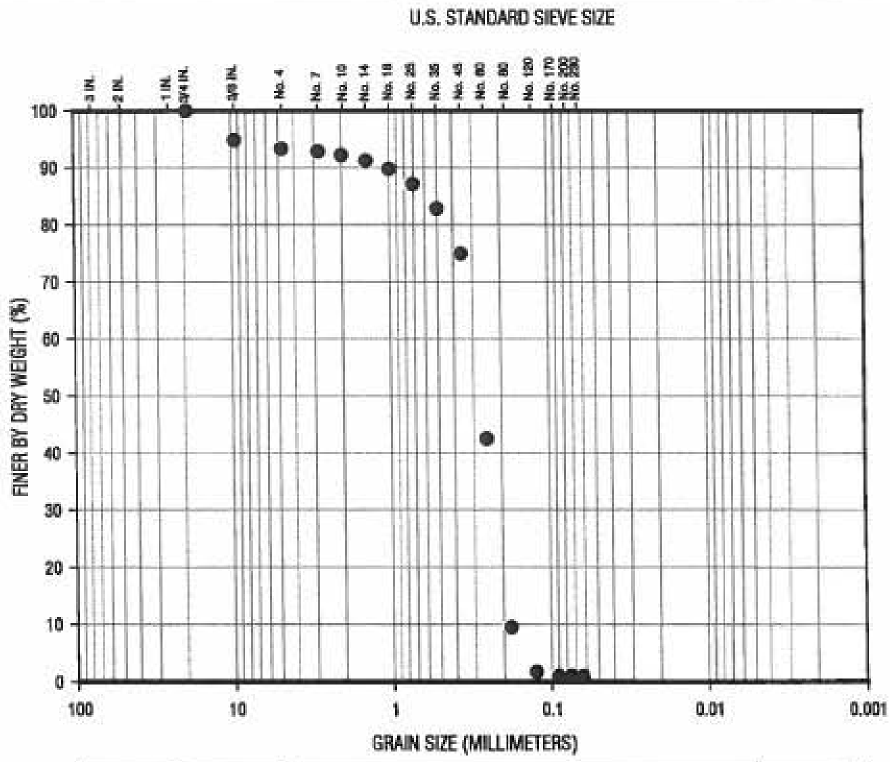
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 20.4
Wt. Dry Solids (grams): 432.65

Visually Estimated Shell Content(%): 10

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



GRAVEL		SAND			SILT	CLAY
COARSE	FINE	COARSE	MEDIUM	FINE		

Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	94.8	93.3	92.8	92.2	91.2	89.8	87.1	82.9	75.0	42.5	9.5	1.7	1.0	0.9	0.9
Visually Estimated Shell Content (percent)															
0	100	100	100	100	90	35	20	20	10	Shell Content <5% (Amount not visually estimated)					

The test data and all associated project information presented hereon shall be held in confidence and disclosed to other parties only with the authorization of the Client or Ardaman & Associates, Inc. Physical and electronic records of each project are kept for a minimum of 7 years. Test samples are kept in storage for at least 10 working days after mailing of the test report, prior to being discarded, unless a longer storage period is requested in writing and accepted by Ardaman & Associates, Inc.

Checked By: Date: 10/26/09

Boring Designation LFIXAIWW-V-09-6

DRILLING LOG

DIVISION
South Atlantic

INSTALLATION
Wilmington District

SHEET 1
OF 1 SHEETS

1. PROJECT
AIWW Cape Fear To Little River Tangent 11

2. HOLE NUMBER
LFIXAIWW-V-09-6

LOCATION COORDINATES
N 62,799.0 E 2,231,803.0

3. DRILLING AGENCY
USACE, Wilmington District

4. NAME OF DRILLER
Robie Page Crane Operator

5. DIRECTION OF BORING
☒ VERTICAL
☐ INCLINED

DEG FROM VERTICAL ---

BEARING

6. THICKNESS OF OVERBURDEN (ft) 5.4

7. DEPTH DRILLED INTO ROCK (ft)

8. TOTAL DEPTH OF BORING (ft) 15.4

9. COORDINATE SYSTEM
State Plane

HORIZONTAL
NAD83

VERTICAL
MLLW

10. SIZE AND TYPE OF BIT 4" Dia. Vibracore

11. MANUFACTURER'S DESIGNATION OF DRILL
Vibracore Snell

12. TOTAL SAMPLES

DISTURBED
4

UNDISTURBED
4

13. TOTAL NUMBER CORE BOXES N/A

14. ELEVATION GROUND WATER 0.0

15. DATE BORING

STARTED
2/20/09

COMPLETED
2/20/09

16. ELEVATION TOP OF BORING 0.0 (MLLW)

17. TOTAL CORE RECOVERY FOR BORING N/A

18. SIGNATURE AND TITLE OF INSPECTOR
Larry Benjamin, USACE, Civil Engineer Technician

ELEV	DEPTH	Blows/ 0.5 ft	N_1	N_{60}	LEGEND	FIELD CLASSIFICATION OF MATERIALS (Description)	% REC	Samp No.	Laboratory Gravel	Granular	Sand	Fines	#230	MC	ASTM Class
-5.4	5.4				≈	**0' to 5.4':** Water. River Bottom at depth 5.4'									
-12.6	12.6				⁘	**5.4' to 12.6':** SP, Tan, Coarse, Poorly Graded Sand with Trace Shell Fragments		1 2 3 4	0 0 0 3	0 0 0 2	99 99 99 94	1 1 1 2	1 1 1 1		SP SP SP SP
-15.4	15.4				⁘	**12.6' to 15.4':** No Recovery									

0.0
2.5
5.
7.
10.
12.
15.

BOTTOM OF BOREHOLE AT 15.4 FT.

NOTE:
SOILS ARE FIELD VISUALLY CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

REMARKS

ASTM

Time begin vibracoring: 1415 hrs

Soil described by Larry Benjamin, Civil Engr. Tech

NOTE: Top of hole is defined as surface of water and compensation is made for the tide such that top of Hole is 0.0' EL MLLW.

VIBRACORE BORING

From 0.0' to 10.0'
Ran 6.5' Rec: 7.2'

Top of vibracore soil sample is logged beginning at River Bottom.
When Run is greater than Recovery, the difference is depicted as Assumed Not Recovered.

Note: Soils Commercial Lab Classified in Accordance with ASTM - D2487

LAB CLASSIFICATION

Jar Number	Classification
1	SP
2	SP
3	SP
4	SP

Note: Hole Terminated at Predetermined Depth at 10.0'

ACE 1836-A (DRILLING LOG) LOCKWOOD FOLLEY INLET CROSSING-REV.GPJ ACE MVD WITH RAPID CPT 06-09-08.GDT 9/30/09

SPK FORM 1836-A
SEP 05

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER
TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-6** SAMPLE **1**
DEPTH 5.4 - 5.9 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0961
SAMPLE DESCRIPTION: Gray fine sand with few shells, SP

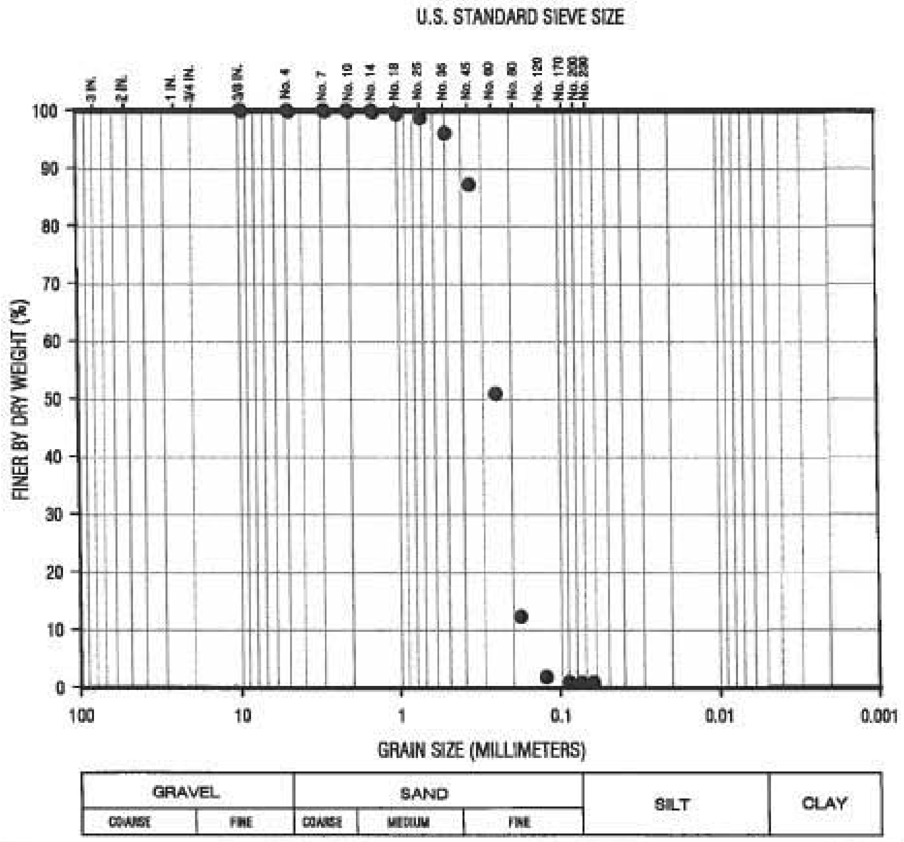
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 21.2
Wt. Dry Solids (grams): 189.67

Visually Estimated Shell Content(%): 5

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	99.9	99.9	99.9	99.8	99.5	98.7	96.1	87.2	50.9	12.3	1.9	1.0	1.0	1.0

Visually Estimated Shell Content (percent)

0	0	100	100	100	100	100	75	50	50	Shell Content <5% (Amount not visually estimated)

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Checked By: JCW Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER
TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-6** SAMPLE **2**
DEPTH 7.5 - 8.0 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0962
SAMPLE DESCRIPTION: Gray fine sand with trace shells, SP

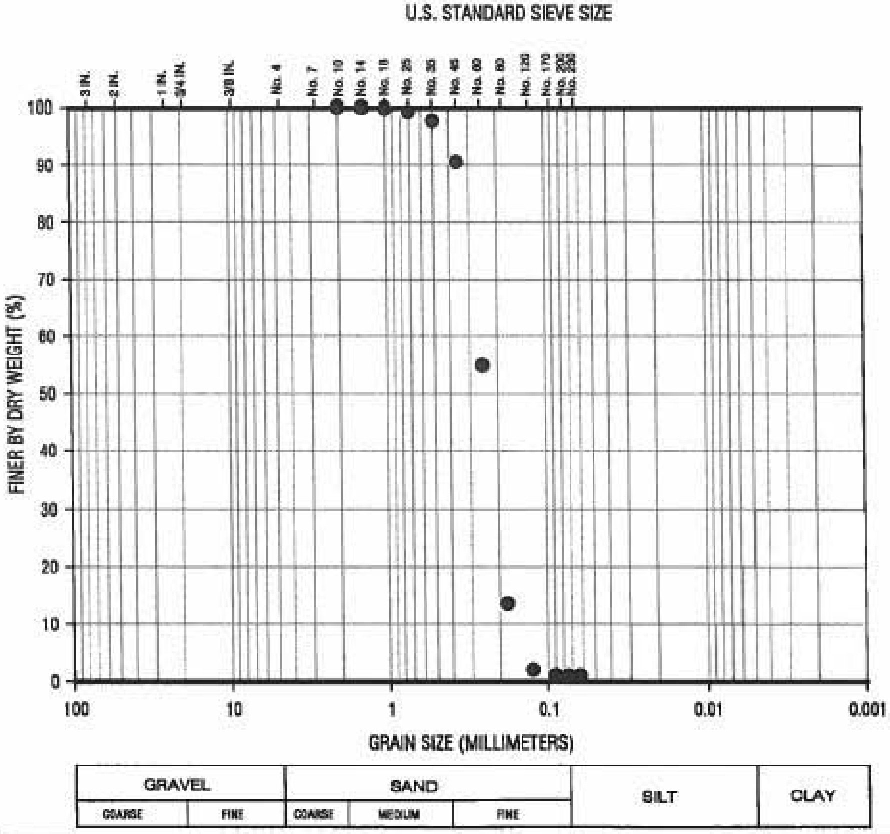
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis ☐ Other:

Moisture Content (%): 22.2
Wt. Dry Solids (grams): 186.12

Visually Estimated Shell Content(%): <5

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand					Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	100	100	100	99.9	99.7	99.3	97.7	90.6	54.9	13.6	2.0	1.1	1.1	1.1

Visually Estimated Shell Content (percent)

0	0	0	0	0	100	100	75	50	20	Shell Content <5% (Amount not visually estimated)

Checked By: JCW Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-6** SAMPLE **3**
DEPTH 9.5 - 10.0 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0963
SAMPLE DESCRIPTION: Gray fine sand with few shells, SP

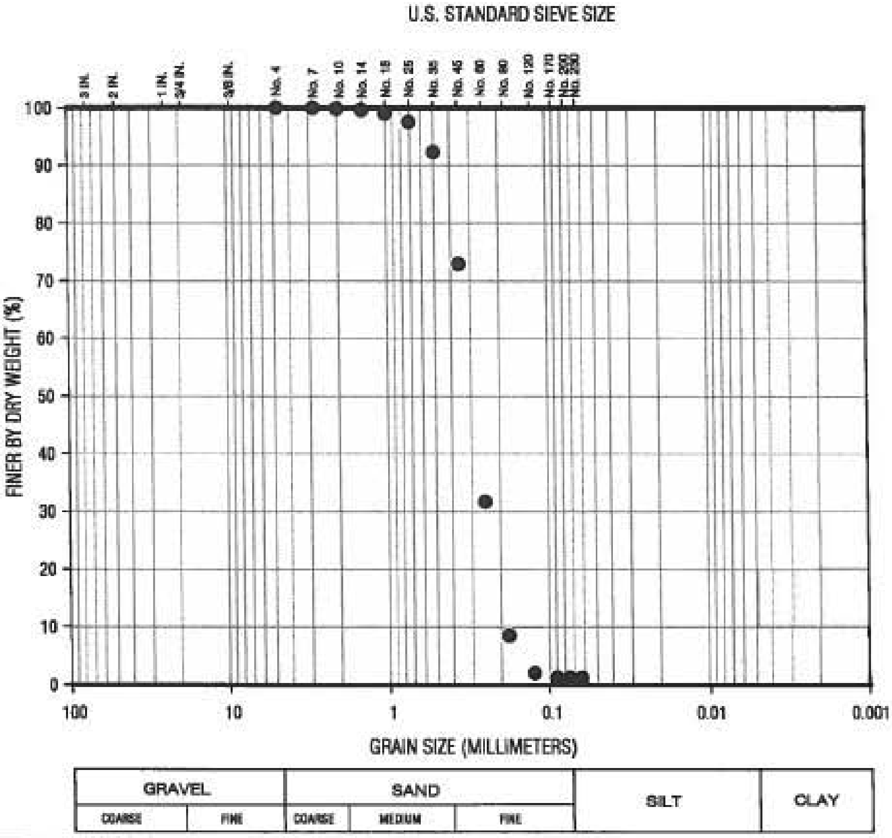
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 21.7
Wt. Dry Solids (grams): 177.57

Visually Estimated Shell Content(%): 5

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand					Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	100	99.9	99.8	99.5	99.0	97.5	92.3	72.9	31.7	8.5	2.0	1.2	1.2	1.2

Visually Estimated Shell Content (percent)

0	0	0	100	100	100	100	50	50	Shell Content <5% (Amount not visually estimated)

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Checked By: few

Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-6** SAMPLE **4**
DEPTH 11.5 - 12.0 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0964
SAMPLE DESCRIPTION: Gray sand with little shells, SP

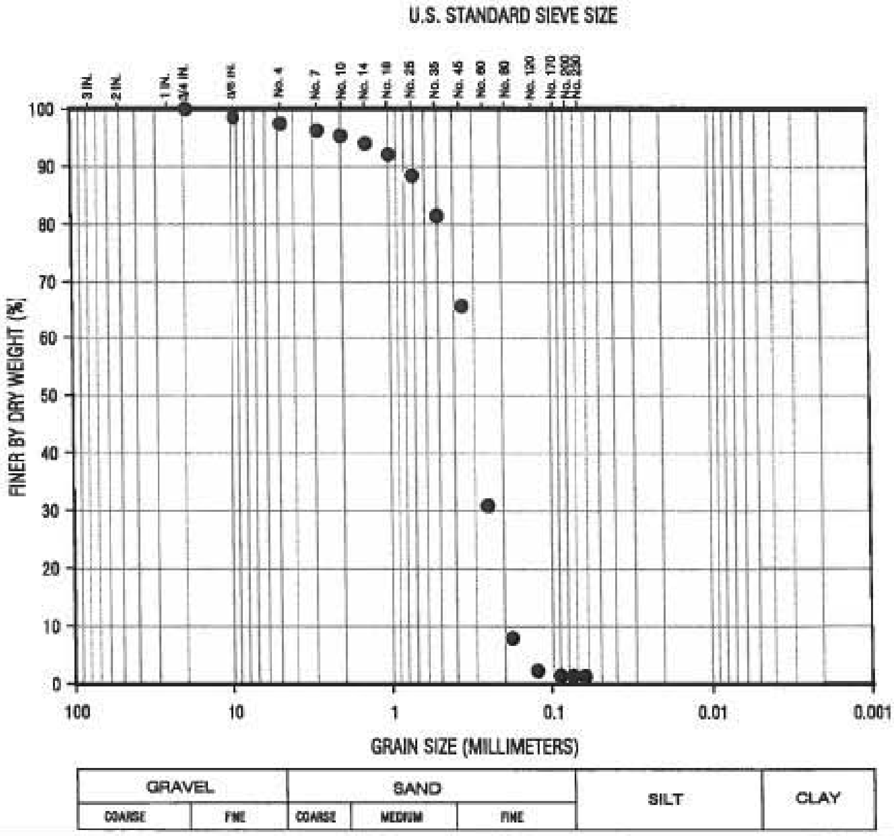
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 20.7
Wt. Dry Solids (grams): 357.52

Visually Estimated Shell Content(%): 25

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	98.5	97.4	96.3	95.3	94.0	92.1	88.5	81.5	65.5	30.9	8.0	2.4	1.5	1.5	1.4

Visually Estimated Shell Content (percent)

0	100	100	100	100	100	90	75	65	55	Shell Content <5% (Amount not visually estimated)

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Checked By: JCW Date: 10/26/09

Boring Designation LFIXAIWW-V-09-7

DRILLING LOG

DIVISION: South Atlantic

INSTALLATION: Wilmington District

SHEET 1 OF 1 SHEETS

1. PROJECT: AIWW Cape Fear To Little River Tangent 11

2. HOLE NUMBER: LFIXAIWW-V-09-7
LOCATION COORDINATES: N 62,892.0 E 2,232,234.0

3. DRILLING AGENCY: USACE, Wilmington District

4. NAME OF DRILLER: Robie Page Crane Operator

5. DIRECTION OF BORING: ☒ VERTICAL ☐ INCLINED
DEG FROM VERTICAL: ---
BEARING:

6. THICKNESS OF OVERBURDEN (ft): 0.8

7. DEPTH DRILLED INTO ROCK (ft):

8. TOTAL DEPTH OF BORING (ft): 10.8

9. COORDINATE SYSTEM: State Plane
HORIZONTAL: NAD83
VERTICAL: MLLW

10. SIZE AND TYPE OF BIT: 4" Dia. Vibracore

11. MANUFACTURER'S DESIGNATION OF DRILL: Vibracore Snell

12. TOTAL SAMPLES: DISTURBED 4 UNDISTURBED 4

13. TOTAL NUMBER CORE BOXES: N/A

14. ELEVATION GROUND WATER: 0.0

15. DATE BORING: STARTED 2/20/09 COMPLETED 2/20/09

16. ELEVATION TOP OF BORING: 0.0 (MLLW)

17. TOTAL CORE RECOVERY FOR BORING: N/A

18. SIGNATURE AND TITLE OF INSPECTOR: Larry Benjamin, USACE, Civil Engineer Technician

ELEV	DEPTH	Blows/ 0.5 ft	N_1	N_{60}	LEGEND	FIELD CLASSIFICATION OF MATERIALS (Description)	% REC	Samp No.	Laboratory Gravel	Granular	Sand	Fines	#230	MC	ASTM Class
-0.8	0.8					**0' to 0.8':** Water. River Bottom at depth 0.8'		1	1	3	95	1	1	19	SP
						0.8' to 7.8': SP, Tan, Coarse, Poorly Graded Sand with Trace Shell Fragments		2	2	4	94	1	1	17	SP
								3	1	0	98	1	1	22	SP
-7.8	7.8							4	1	0	96	3	3	24	SP
						7.8' to 10.8': No Recovery									
-10.8	10.8														

REMARKS

ASTM

Time begin vibracoring: 1426 hrs

Soil described by Larry Benjamin, Civil Engr. Tech

NOTE: Top of hole is defined as surface of water and compensation is made for the tide such that top of Hole is 0.0' EL MLLW.

VIBRACORE BORING

From 0.0' to 10.0'
Ran 6.5' Rec: 7.0'

Top of vibracore soil sample is logged beginning at River Bottom.
When Run is greater than Recovery, the difference is depicted as Assumed Not Recovered.

Note: Soils Commercial Lab Classified in Accordance with ASTM - D2487

LAB CLASSIFICATION

Jar Number	Classification
1	SP
2	SP
3	SP
4	SP

Note: Hole Terminated at Predetermined Depth at 10.0'

0.
2.
5.
7.
10.

BOTTOM OF BOREHOLE AT 10.8 FT.

NOTE:
SOILS ARE FIELD VISUALLY CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

ACE 1836-A (DRILLING LOG) LOCKWOOD FOLLEY INLET CROSSING-REV.GPJ ACE MVD WITH RAPID CPT 06-09-08.GDT 9/30/09

SPK FORM 1836-A
SEP 05

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER
TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-7** SAMPLE **1**
DEPTH 0.8 - 1.3 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0971
SAMPLE DESCRIPTION: Gray sand with little shells, SP

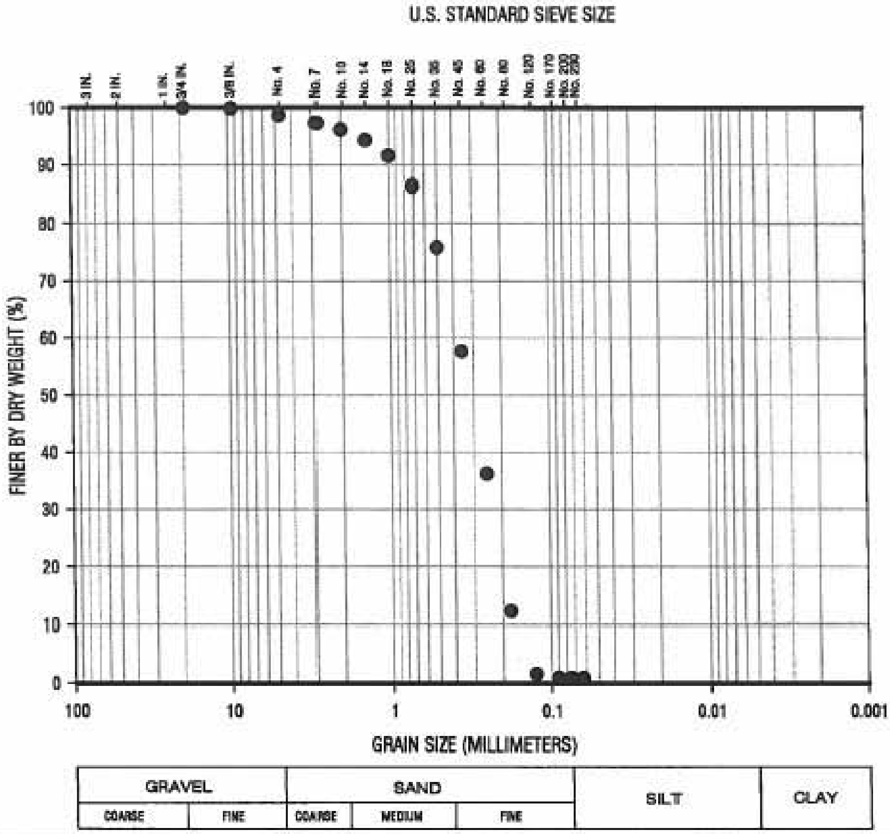
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 18.8
Wt. Dry Solids (grams): 400.63

Visually Estimated Shell Content(%): 15

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	99.8	98.6	97.3	96.1	94.3	91.6	86.4	75.8	57.6	36.2	12.3	1.6	0.9	0.9	0.9

Visually Estimated Shell Content (percent)

0	100	100	100	100	100	85	20	20	10	Shell Content <5% (Amount not visually estimated)

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Checked By: JCW Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING LFIXAIWW-V-09-7 SAMPLE 2
DEPTH 3.0 - 3.5 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0972
SAMPLE DESCRIPTION: Gray sand with little shells, SP

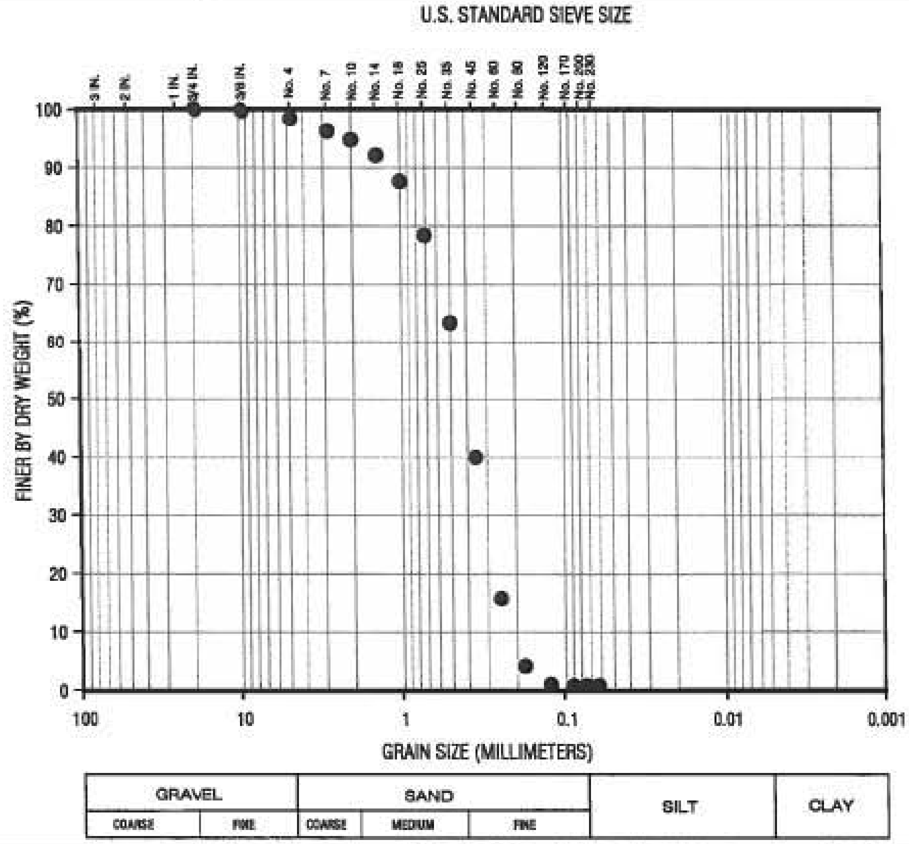
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 17.4
Wt. Dry Solids (grams): 360.87

Visually Estimated Shell Content(%): 15

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): 14.1



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	99.7	98.4	96.3	94.8	92.0	87.6	78.4	63.4	40.0	15.8	4.2	1.0	0.9	0.9	0.8

Visually Estimated Shell Content (percent)

0	100	100	100	100	90	75	50	Shell Content <5% (Amount not visually estimated)

Checked By: JCW Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING LFIXAIWW-V-09-7 SAMPLE 3
DEPTH 5.0 - 5.5 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0973
SAMPLE DESCRIPTION: Gray fine sand with trace shells, SP

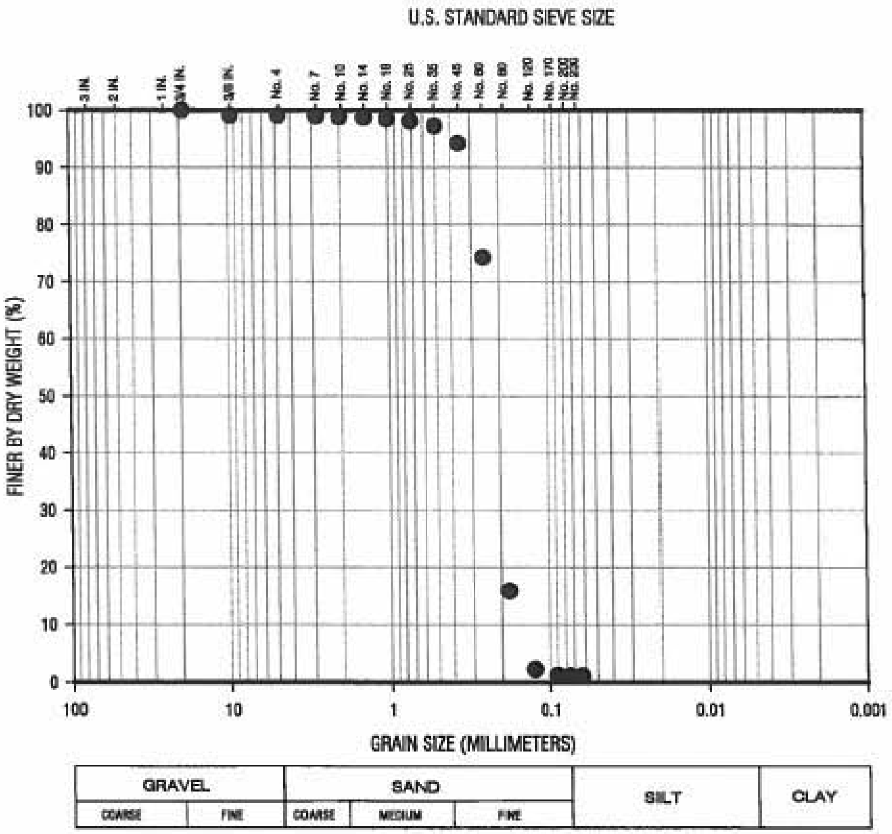
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 22.3
Wt. Dry Solids (grams): 367.93

Visually Estimated Shell Content(%): <5

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	99.0	99.0	98.9	98.8	98.7	98.4	98.1	97.2	94.2	74.2	15.9	2.2	1.1	1.1	1.0

Visually Estimated Shell Content (percent)

0	100	100	100	100	100	90	40	50	Shell Content <5% (Amount not visually estimated)

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Checked By: JCW

Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING LFIXAIWW-V-09-7 SAMPLE 4
DEPTH 7.0 - 7.5 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0974
SAMPLE DESCRIPTION: Gray fine sand with trace shells, SP

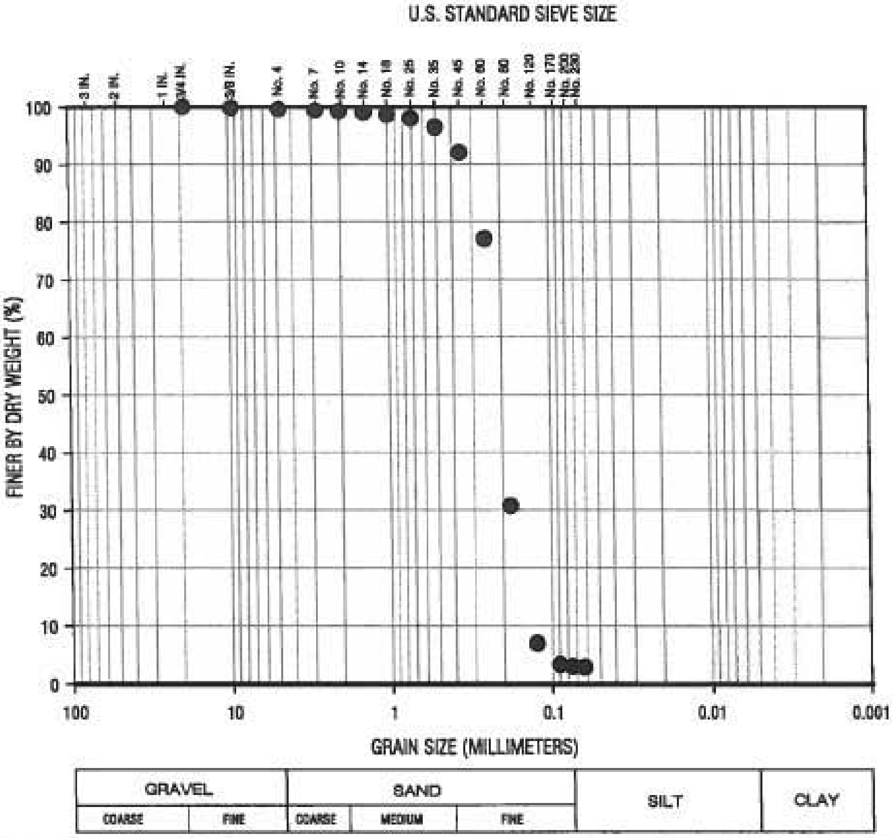
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other: ____

Moisture Content (%): 23.5
Wt. Dry Solids (grams): 335.26

Visually Estimated Shell Content(%): <5

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	99.8	99.5	99.4	99.2	98.9	98.6	97.9	96.4	92.0	77.1	30.8	6.9	3.3	2.9	2.8

Visually Estimated Shell Content (percent)

0	100	100	100	100	100	90	40	50	Shell Content <5% (Amount not visually estimated)

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Checked By: Jcw Date: 10/26/09

Boring Designation LFIXAIWW-V-09-8

DRILLING LOG

DIVISION South Atlantic	INSTALLATION Wilmington District		SHEET 1 OF 1 SHEETS
1. PROJECT AIWW Cape Fear To Little River Tangent 11	9. COORDINATE SYSTEM State Plane	HORIZONTAL NAD83	VERTICAL MLLW
	10. SIZE AND TYPE OF BIT 4" Dia. Vibracore		
2. HOLE NUMBER LFIXAIWW-V-09-8	LOCATION COORDINATES N 63,238.0 E 2,232,297.0	11. MANUFACTURER'S DESIGNATION OF DRILL Vibracore Snell	
3. DRILLING AGENCY USACE, Wilmington District	12. TOTAL SAMPLES	DISTURBED 3	UNDISTURBED 3
4. NAME OF DRILLER Robie Page Crane Operator	13. TOTAL NUMBER CORE BOXES N/A		
	14. ELEVATION GROUND WATER 0.0		
5. DIRECTION OF BORING ☒ VERTICAL ☐ INCLINED	DEG FROM VERTICAL ---	BEARING	
	15. DATE BORING	STARTED 2/20/09	COMPLETED 2/20/09
6. THICKNESS OF OVERBURDEN (ft) 11.2	16. ELEVATION TOP OF BORING 0.0 (MLLW)		
7. DEPTH DRILLED INTO ROCK (ft)	17. TOTAL CORE RECOVERY FOR BORING N/A		
8. TOTAL DEPTH OF BORING (ft) 21.2	18. SIGNATURE AND TITLE OF INSPECTOR Larry Benjamin, USACE, Civil Engineer Technician		

ELEV	DEPTH	Blows/ 0.5 ft	N_1	N_{60}	LEGEND	FIELD CLASSIFICATION OF MATERIALS (Description)	% REC	Samp No.	Laboratory							REMARKS
									Gravel	Granular	Sand	Fines	#230	MC	ASTM Class	
-11.2	11.2					0' to 11.2': Water. River Bottom at depth 11.2'										
						11.2' to 15': SP, Tan, Coarse, Poorly Graded Sand		1	0	0	99	1	1	24	SP	
-15.0	15.0							2	0	0	99	1	1	24	SP	
-16.4	16.4					15' to 16.4': SP, Tan, Coarse, Poorly Graded Sand with Shell Fragments		3								
-21.2	21.2					16.4' to 21.2': No Recovery										

ASTM

Time begin vibracoring: 1438 hrs

Soil described by Larry Benjamin, Civil Engr. Tech

NOTE: Top of hole is defined as surface of water and compensation is made for the tide such that top of Hole is 0.0' EL MLLW.

VIBRACORE BORING

From 0.0' to 10.0'
Ran 6.5' Rec: 5.2'

Top of vibracore soil sample is logged beginning at River Bottom.
When Run is greater than Recovery, the difference is depicted as Assumed Not Recovered.

Note: Soils Commercial Lab Classified in Accordance with ASTM - D2487

LAB CLASSIFICATION

Jar Number	Classification
1	SP
2	SP
3	-

Note: Hole Terminated at Predetermined Depth at 10.0'

0.0
2.5
5.
7.
10.
12.5
15.
17.
20.

BOTTOM OF BOREHOLE AT 21.2 FT.

NOTE:
SOILS ARE FIELD VISUALLY CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

ACE 1836-A (DRILLING LOG) LOCKWOOD FOLLEY INLET CROSSING-REV.GPJ ACE MVD WITH RAPID CPT 06-09-08.GDT 9/30/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER
TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-8** SAMPLE 1
DEPTH 11.2 - 11.7 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0981
SAMPLE DESCRIPTION: Gray fine sand with few shells, SP

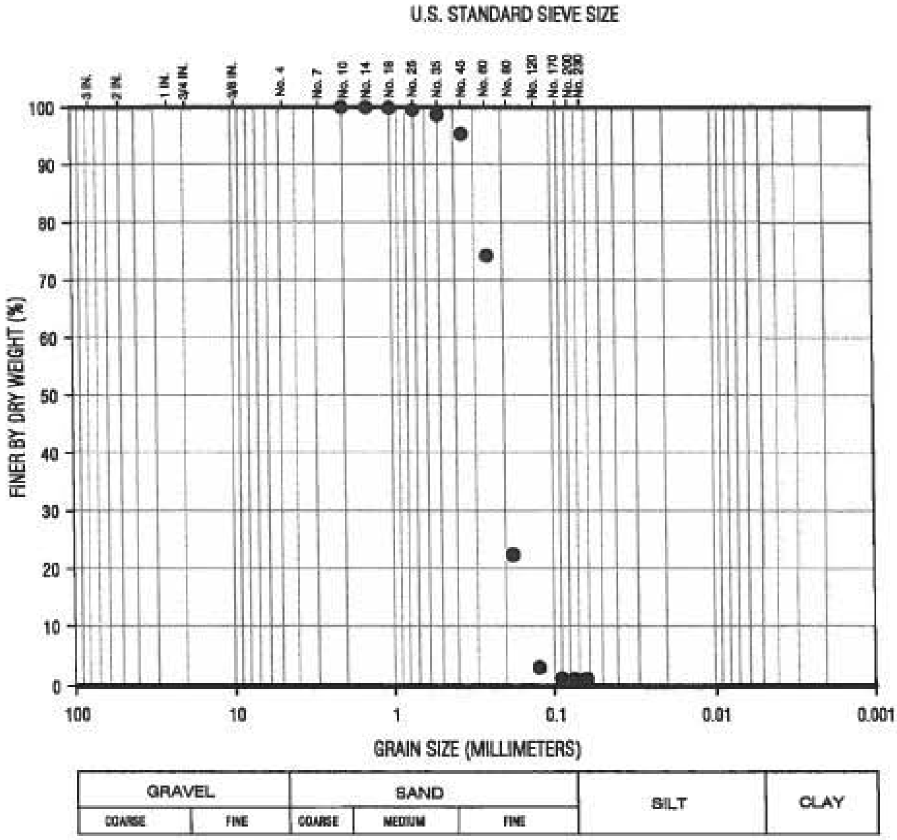
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 23.5
Wt. Dry Solids (grams): 178.46

Visually Estimated Shell Content(%): 5

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	100	100	100	99.9	99.8	99.5	98.6	95.3	74.1	22.3	3.1	1.2	1.1	1.1
Visually Estimated Shell Content (percent)															
0	0	0	0	0	100	100	100	50	50	20	Shell Content <5% (Amount not visually estimated)				

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Checked By: JCW Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING LFIXAIWW-V-09-8 SAMPLE 2
DEPTH 13.0 - 13.5 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0982
SAMPLE DESCRIPTION: Gray fine sand with trace shells, SP

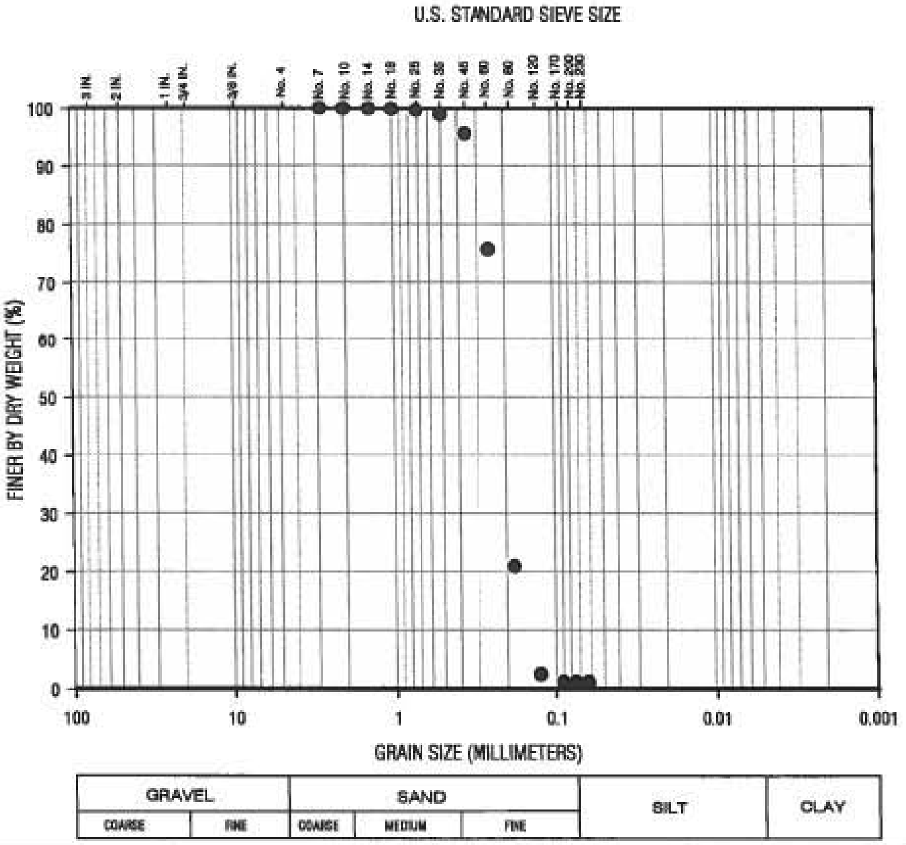
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 23.5
Wt. Dry Solids (grams): 181.17

Visually Estimated Shell Content(%): <5

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	100	100	99.9	99.9	99.8	99.6	98.8	95.5	75.6	20.9	2.4	1.1	1.1	1.1

Visually Estimated Shell Content (percent)

0	0	0	0	100	100	100	90	50	20	Shell Content <5% (Amount not visually estimated)

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Checked By: JCW Date: 10/26/09

Boring Designation LFIXAIWW-V-09-9

DRILLING LOG

DIVISION South Atlantic

INSTALLATION Wilmington District

SHEET 1 OF 1 SHEETS

1. PROJECT AIWW Cape Fear To Little River Tangent 11

2. HOLE NUMBER LFIXAIWW-V-09-9 : LOCATION COORDINATES N 63,238.0 E 2,232,297.0

3. DRILLING AGENCY USACE, Wilmington District

4. NAME OF DRILLER Robie Page Crane Operator

5. DIRECTION OF BORING ☒ VERTICAL ☐ INCLINED : DEG FROM VERTICAL --- : BEARING

6. THICKNESS OF OVERBURDEN (ft) 0.4

7. DEPTH DRILLED INTO ROCK (ft)

8. TOTAL DEPTH OF BORING (ft) 10.4

9. COORDINATE SYSTEM State Plane : HORIZONTAL NAD83 : VERTICAL MLLW

10. SIZE AND TYPE OF BIT 4" Dia. Vibracore

11. MANUFACTURER'S DESIGNATION OF DRILL Vibracore Snell

12. TOTAL SAMPLES : DISTURBED 4 : UNDISTURBED 0

13. TOTAL NUMBER CORE BOXES N/A

14. ELEVATION GROUND WATER 0.0

15. DATE BORING : STARTED 2/20/09 : COMPLETED 2/20/09

16. ELEVATION TOP OF BORING 0.0 (MLW)

17. TOTAL CORE RECOVERY FOR BORING N/A

18. SIGNATURE AND TITLE OF INSPECTOR Larry Benjamin, USACE, Civil Engineer Technician

ELEV	DEPTH	Blows/ 0.5 ft	N_1	N_{60}	LEGEND	FIELD CLASSIFICATION OF MATERIALS (Description)	% REC	Samp No.	Gravel	Granular	Sand	Fines	#230	MC	ASTM Class
-0.4	0.4					**0' to 0.4'**: Water. River Bottom at depth 0.4'		1	11	5	77	1	1	18	SP
-3.0	3.0					**0.4' to 3'**: SP, Tan, Coarse, Poorly Graded Sand with Shell Fragments									
-4.6	4.6					**3' to 4.6'**: MH, Dark Gray, Elastic Silt with Trace Shell Fragments		2	1	1	55	44	39	55	SC
-9.0	9.0					**4.6' to 9'**: SM, Dark Gray, Fine Silty Sand with Shell Fragments		3 4	14 0	3 0	67 88	15 12	14 11	32 37	SC SP-SM
-10.4	10.4					**9' to 10.4'**: No Recovery									

0.0
2.5
5.0
7.5
10.0

BOTTOM OF BOREHOLE AT 10.4 FT.

NOTE:
SOILS ARE FIELD VISUALLY CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

REMARKS

ASTM

Time begin vibracoring: --- hrs

Soil described by Larry Benjamin, Civil Engr. Tech

NOTE: Top of hole is defined as surface of water and compensation is made for the tide such that top of Hole is 0.0' EL MLLW.

VIBRACORE BORING

From 0.0' to 10.0'
Ran 6.5' Rec: 8.6'

Top of vibracore soil sample is logged beginning at River Bottom.
When Run is greater than Recovery, the difference is depicted as Assumed Not Recovered.

Note: Soils Commercial Lab Classified in Accordance with ASTM - D2487

LAB CLASSIFICATION

Jar Number	Classification
1	SP
2	SC
3	SC
4	SP-SM

Note: Hole Terminated at Predetermined Depth at 10.0'

ACE 1836-A (DRILLING LOG) LOCKWOOD FOLLEY INLET CROSSING-REV.GPJ ACE MVD WITH RAPID CPT 08-09-08.GDT 10/26/09

SPK FORM 1836-A
SEP 05

Boring Designation LFIXAIWW-V-09-9 SHEET 1 of 1

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER
TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-9** SAMPLE **1**
DEPTH 0.4 - 0.9 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0991
SAMPLE DESCRIPTION: Gray sand with some shells, SP

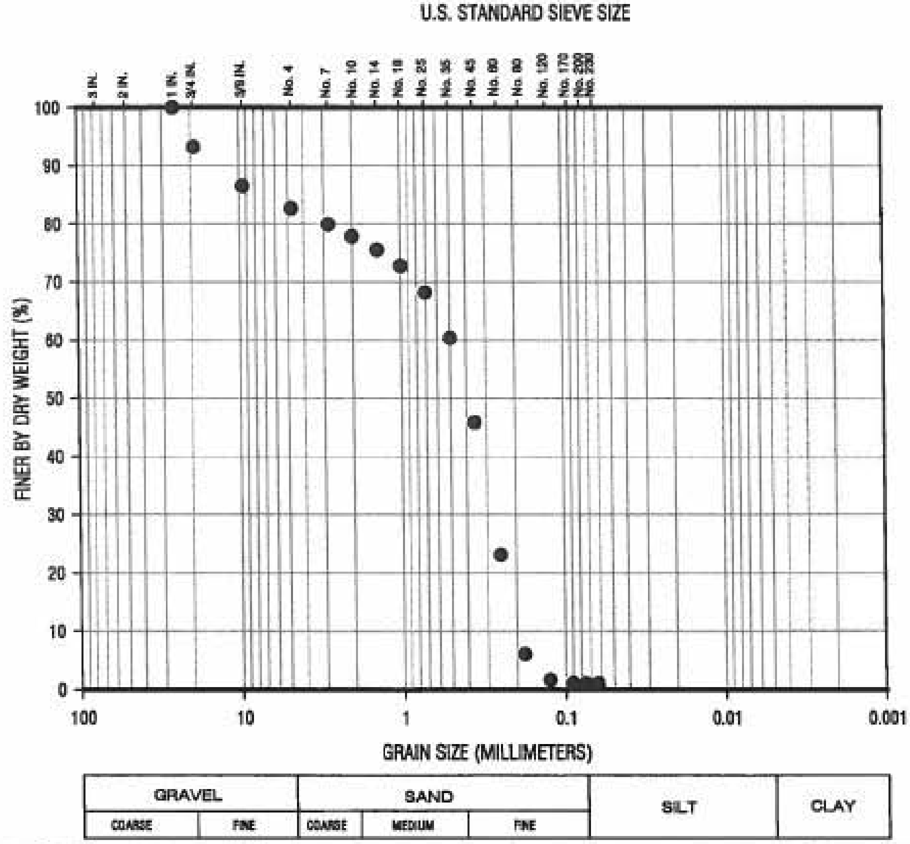
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 17.7
Wt. Dry Solids (grams): 612.72

Visually Estimated Shell Content(%): 45

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): –



Percent Finer (dry wt. basis)

Gravel				Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
1"	3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	93.2	86.5	82.6	79.9	77.8	75.5	72.7	68.2	60.4	45.8	23.1	6.1	1.7	1.1	1.1	1.0
Visually Estimated Shell Content (percent)																
0	100	100	100	100	100	100	60	50	70	60	Shell Content <5% (Amount not visually estimated)					

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Checked By: JCW

Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER
TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-9** SAMPLE **2**
DEPTH 3.0 - 3.5 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0992
SAMPLE DESCRIPTION: Dark gray clayey fine sand with trace shells, SC

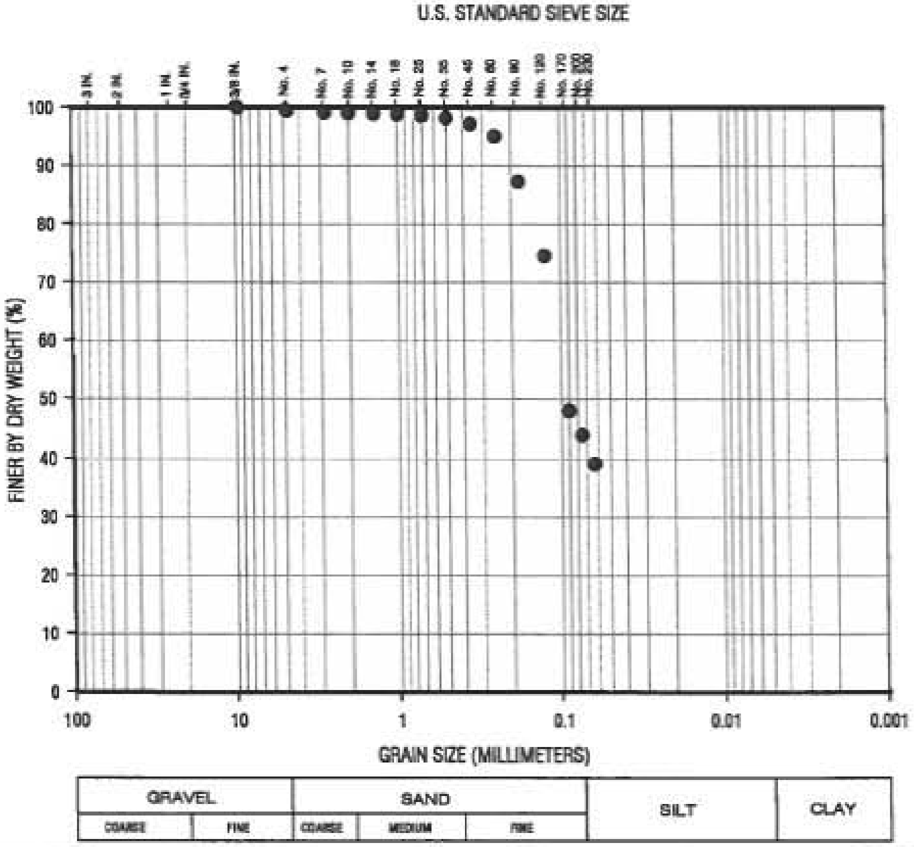
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 54.5
Wt. Dry Solids (grams): 297.59

Visually Estimated Shell Content(%): <5

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	99.5	99.1	99.0	98.9	98.8	98.6	98.2	97.2	95.0	87.2	74.5	47.9	44.1	39.1

Visually Estimated Shell Content (percent)

0	0	100	100	100	100	100	30	Shell Content <5% (Amount not visually estimated)

Checked By: JCW Date: 10/26/09

[illegible]

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-9** SAMPLE **3**
DEPTH 4.6 - 5.1 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0993
SAMPLE DESCRIPTION: Dark gray clayey sand with little shells, SC

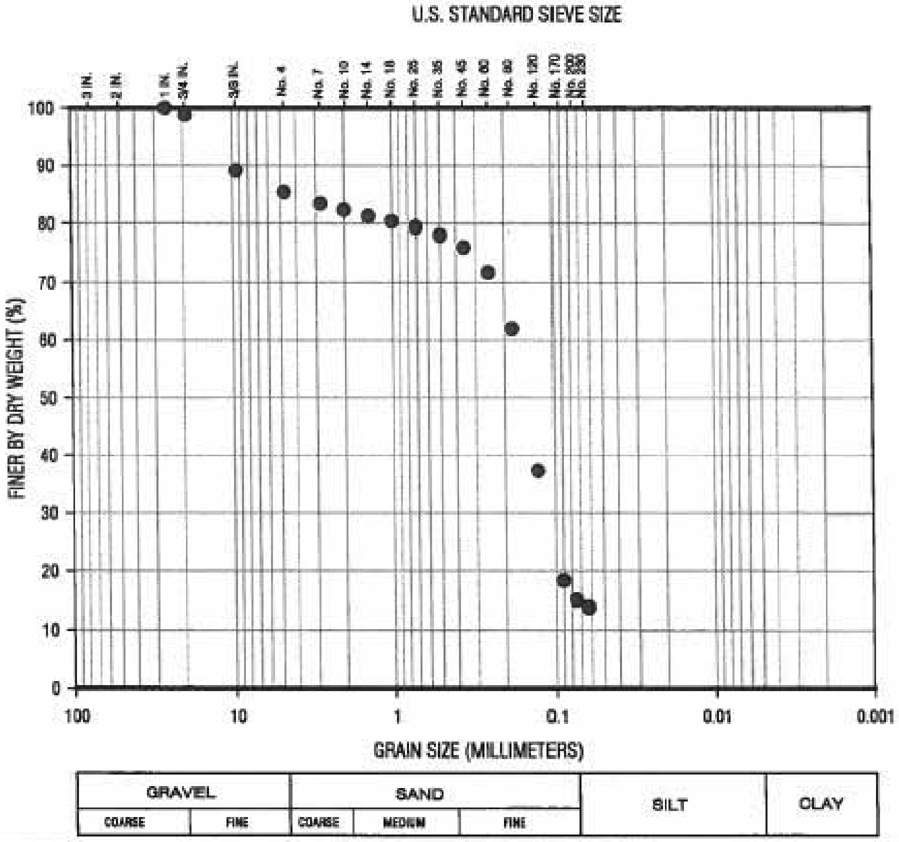
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 32.3
Wt. Dry Solids (grams): 494.56

Visually Estimated Shell Content(%): 25

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel				Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
1"	3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	98.7	89.1	85.4	83.4	82.3	81.2	80.4	79.4	78.1	76.1	71.7	62.0	37.4	18.4	15.1	13.8
Visually Estimated Shell Content (percent)																
0	100	100	100	100	100	100	100	80	70	70	Shell Content <5% (Amount not visually estimated)					

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Checked By: JCW Date: 10/26/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-9** SAMPLE **4**
DEPTH 7.0 - 7.5 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV0994
SAMPLE DESCRIPTION: Dark gray fine sand with silt and trace shells, SP-SM

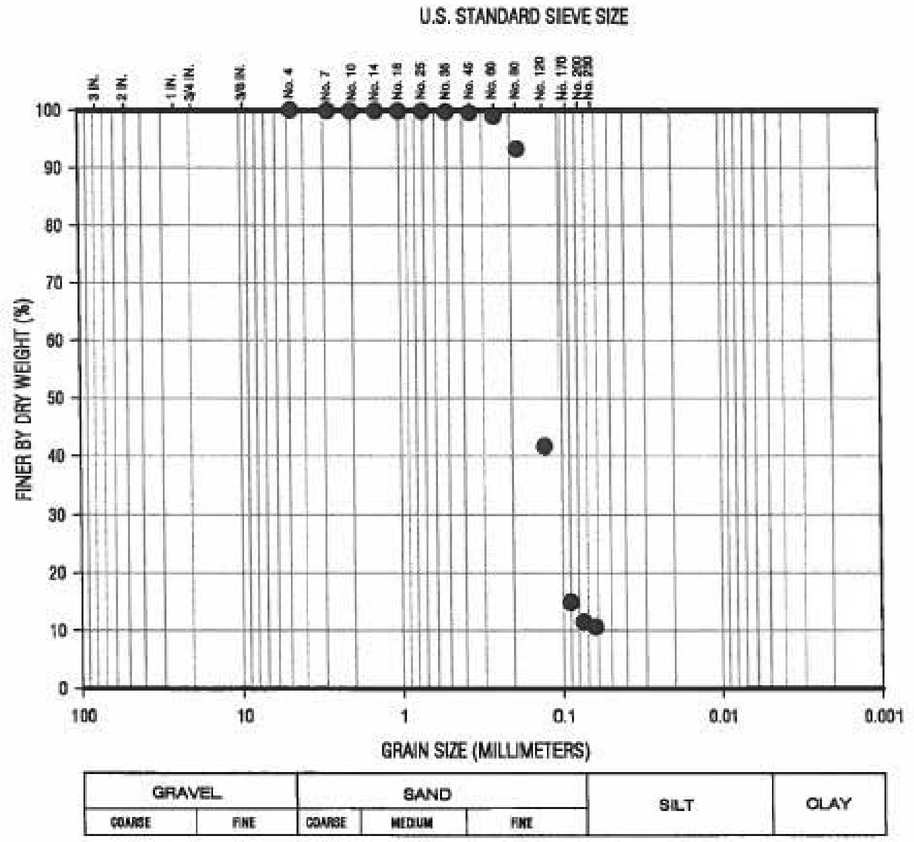
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 36.9
Wt. Dry Solids (grams): 169.83

Visually Estimated Shell Content(%): < 5

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand					Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	100	100	99.9	99.8	99.8	99.8	99.8	99.7	99.5	99.0	93.2	41.6	14.9	11.5	10.6

Visually Estimated Shell Content (percent)

0	0	0	100	100	75	Shell Content <5% (Amount not visually estimated)

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Appendix C

Additional CMS Modeling

APPENDIX C – ADDITIONAL MODELING RUNS

2009 MODEL RUNS

This report describes 2009 model runs where the 10 model alternative cases listed in Section 7.2.4 were simulated for 190 days, running from June 1, 2009 to December 8, 2009. This period was chosen due to its lack of nourishment/dredging projects and the availability of bathymetric survey data coinciding with the start and near-end dates of simulations (for model verification). Additionally, this 190-day period coincides with more easterly net transport conditions, therefore “downdrift” (i.e., into the inlet) effects are more noticeable. Due to the model complexity and a maximum time step of 10 minutes (to account for tidal variation and its effects on sediment transport), yearlong model runs typically required 2 to 3 days to complete. Therefore, the 10 model runs were also chosen to run on the 190-day period to allow for the inclusion of many alternatives. The 190-day period was compared with 1-year runs in terms of sediment transport trends as well as with GENESIS-T runs during the same time period. Sediment transport during this period was shown to be generally representative of typical conditions. Note that while the modeling was run in comparison with absolute measurements, it is important that results are analyzed in a relative manner, for comparative purposes.

Case 1: Baseline (No-Action)

The baseline case is run under existing conditions and is referred to as the no-action case. By comparing alternative model results to the no-action case, the relative magnitude and extent of possible impacts with respect to sediment transport and morphology can be better understood. Figure C-1 shows the simulated results of the no-action case.

The modeled inlet morphology shows the inlet channel training up along the Holden Beach shoreline. This effect has been noted in research (Cleary, 2008) and U.S. Army Corps of Engineers (USACE) survey data. The bend widener area of the Atlantic Intracoastal Waterway (AIWW) also shows significant infilling (relative to authorized depths). This can move the channel thalweg closer to the Holden Beach shoreline.

Figure C-2 presents morphology change of the baseline no-action condition. The plot shows sediment erosion and deposition patterns, similar to Figure C-1. Relatively large changes are exhibited in Figure C-2. While these patterns show agreement with measured data, the relative comparison between alternatives will prove most useful in evaluating alternatives.

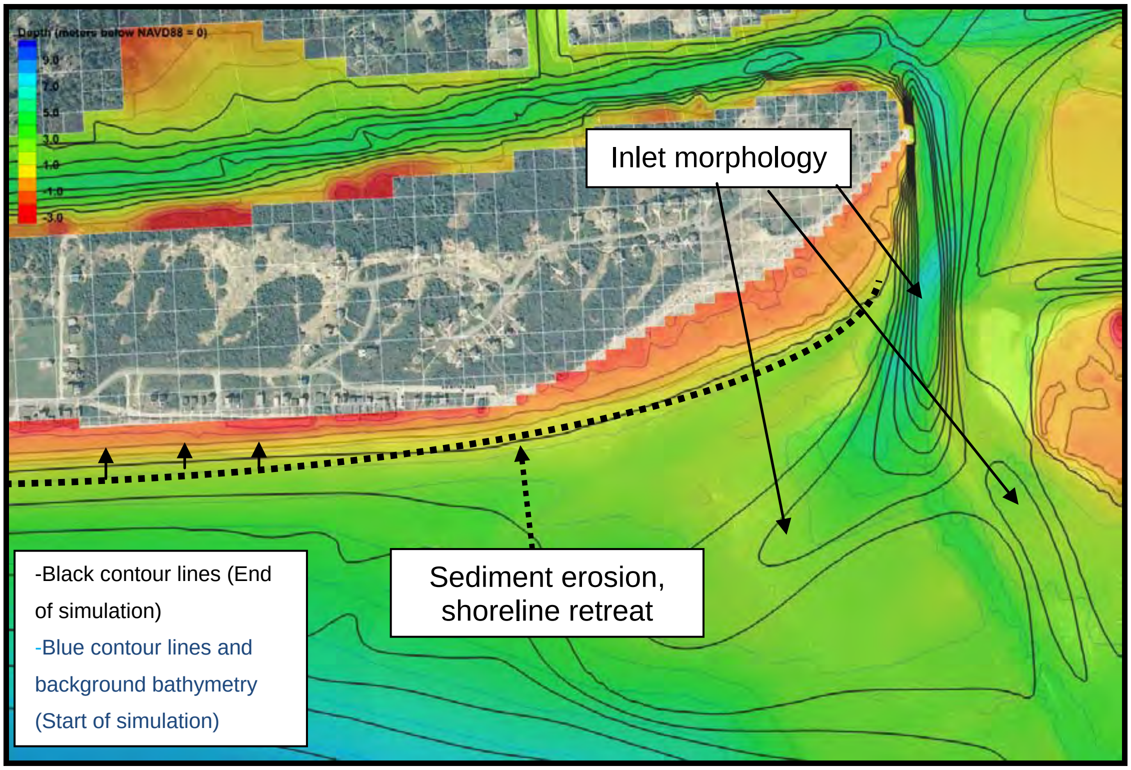


Figure C-1. Baseline "No-Action" Case before and after 190-Day Simulation. Note erosion and shoreline retreat along eastern Holden Beach.

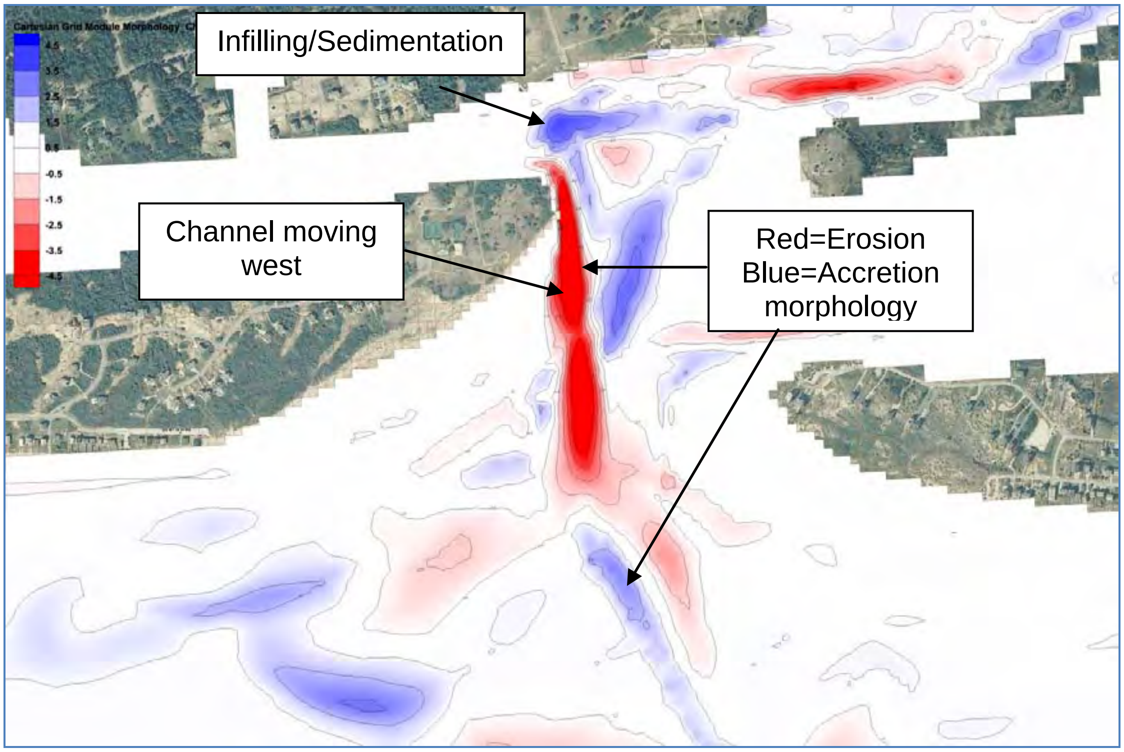


Figure C-2. Morphology Change over 190-Day Time Span for the No-Action Alternative in the Vicinity of LWF Inlet.

In addition to depth contour and morphology change plots, volume change comparisons are also conducted in the following subsections for a more quantitative comparison.

Case 2: Short Groin and Nourishment Alternative

The short groin combined with a 60,000 cubic yards (cy) nourishment was simulated for this alternative. Figure C-3 compares the eastern end of Holden Beach at the end of the 190-day simulations of the no-action case and short-groin-and-nourishment alternative. Similar to the no-action and previous alternatives, some erosion occurs along parts of the shoreline. However, the nourishment significantly extends the beachfront in the project area, and the short groin traps sediment along the western front, forming a sand fillet.

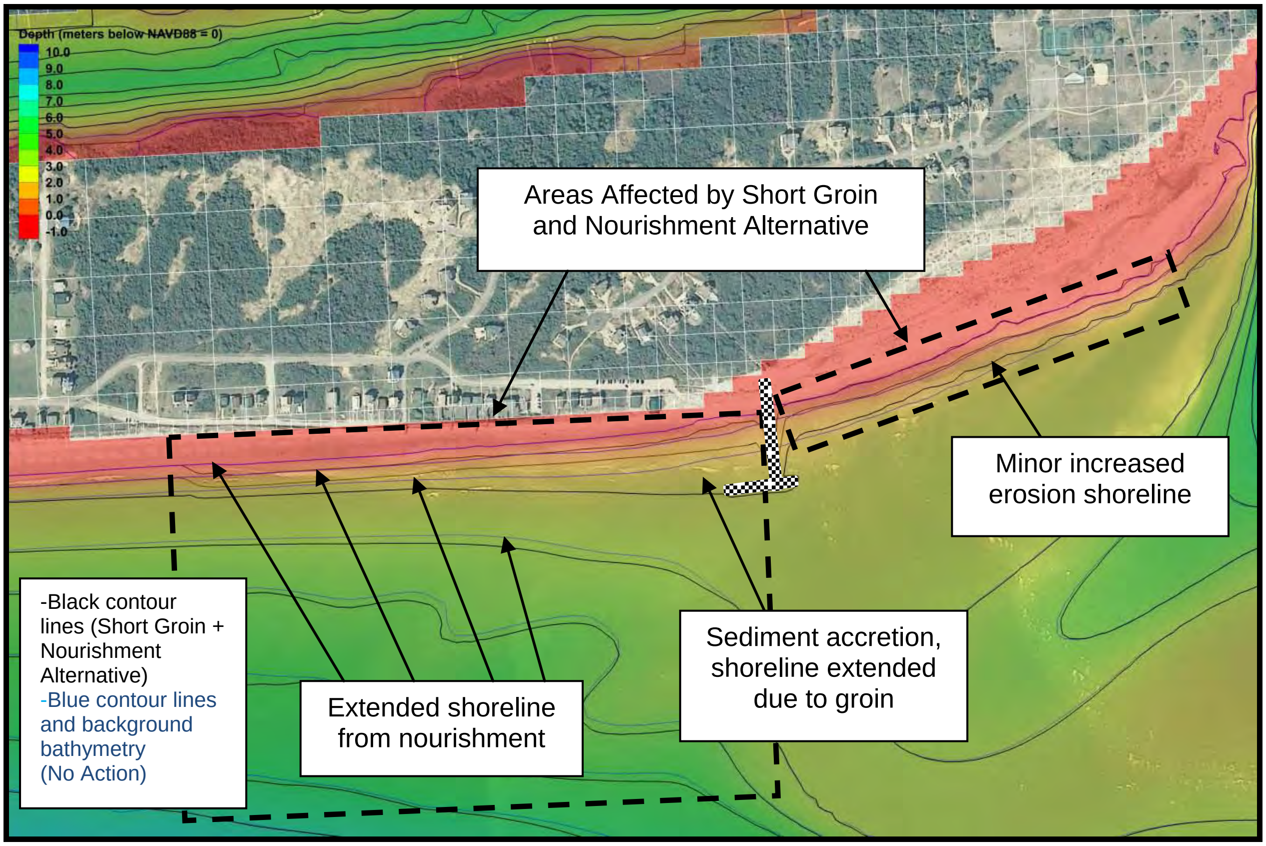


Figure C-3. Resulting Shoreline and Bathymetry after 190-Day Simulations. No-action versus short groin and nourishment alternative.

Figure C-4 presents morphology change comparing the final time step of this alternative relative to the final time step of the no-action alternative. The most significant changes for the short groin and 60,000 cy nourishment remain localized at the end of the 190-day run (as anticipated). Negligible changes occur to the inlet and elsewhere. An additional model run was conducted that included the Lockwoods Folly (LWF) AIWW inlet crossing (LWFIX) borrow area. The morphology change (compared to no-action) is presented in Figure C-5. The dredging of the LWFIX borrow area results in larger morphology changes in the project area than the groin and nourishment alternative.

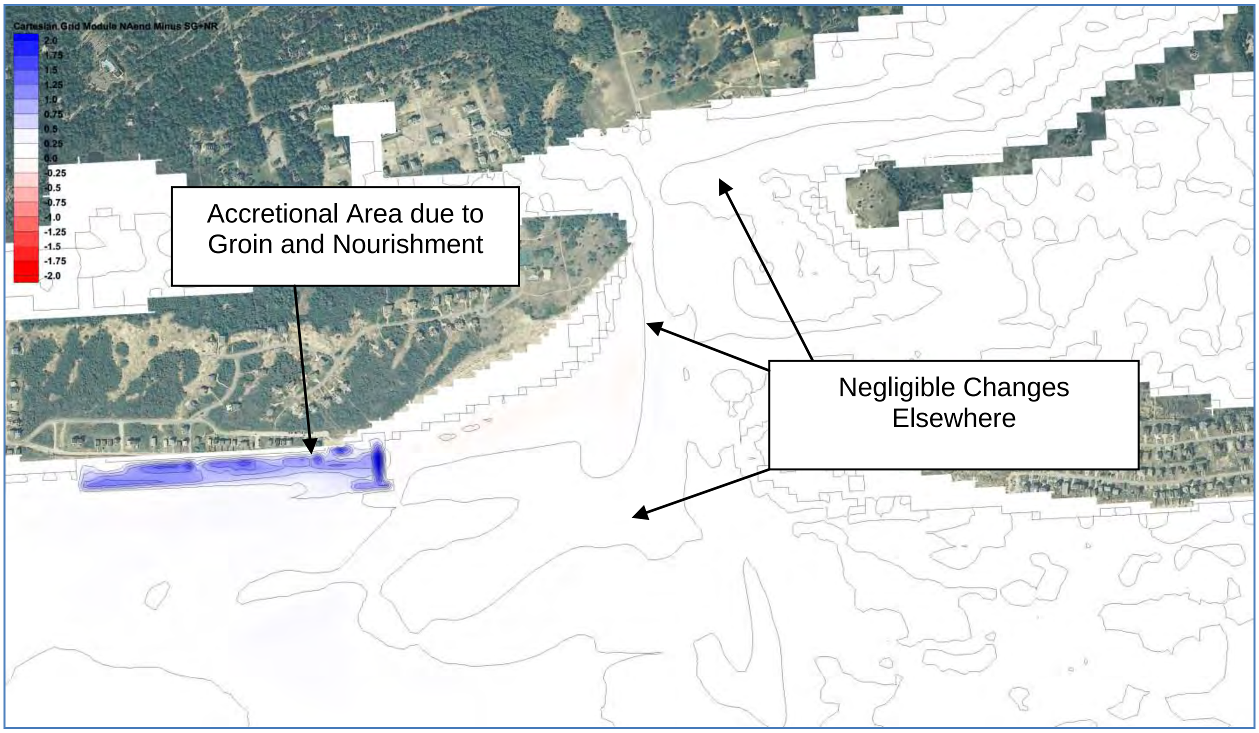


Figure C-4. *The Short Groin and 60,000 cy Nourishment Depth Change Relative to No-Action.*

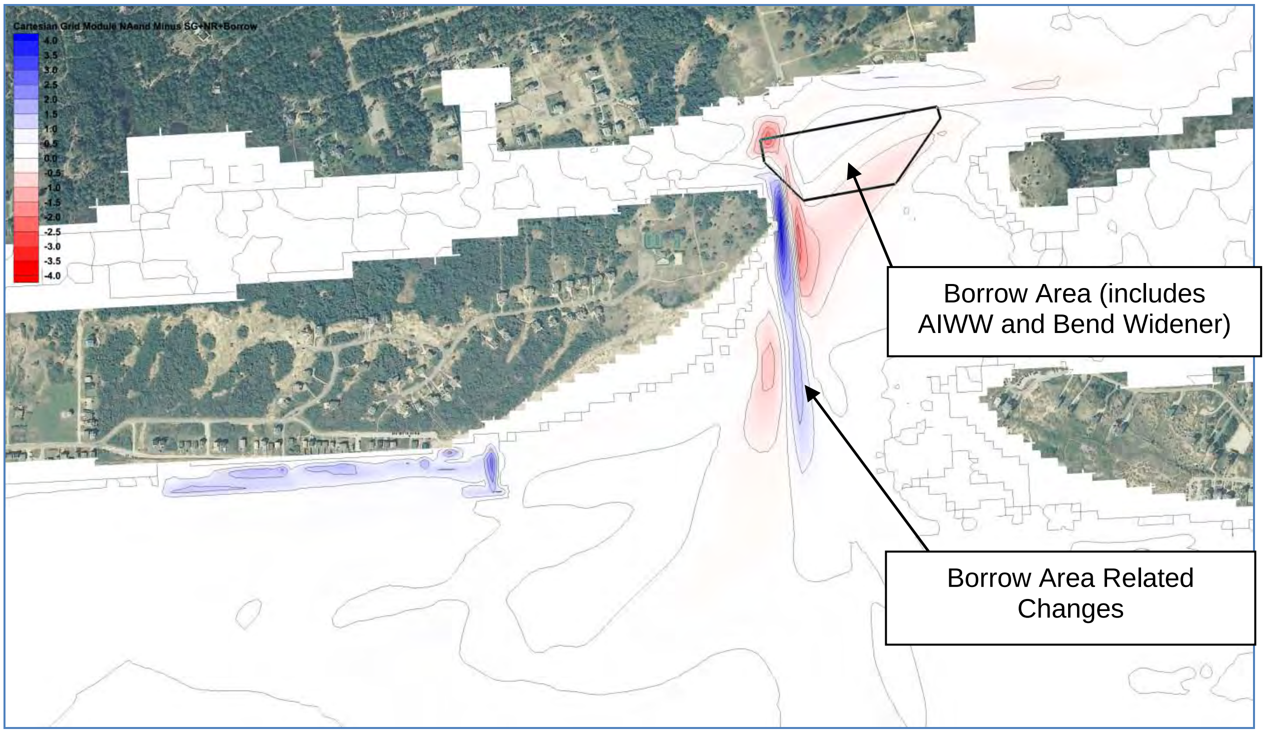


Figure C-5. The Short Groin and 60,000 cy Nourishment and Borrow Area Depth Change Relative to No-Action. Note change in color scale.

Case 3: Long Groin and Nourishment Alternative

The long groin combined with a 90,000 cy nourishment alternative was also considered. The combined groin-and-beach-nourishment alternative was modeled using the same methods as the short-groin-and-nourishment alternative. Figure C-6 compares the eastern end of Holden Beach at the end of the 190-day simulations of the no-action case and the long-groin-and-nourishment alternative. The nourishment significantly extends the beachfront in the project area, and the long groin traps sediment along the western front, extending the 1-meter (m) contour shoreline approximately 140 m (460 feet). The morphology of the small area directly east of the groin and the inlet channel is slightly affected.

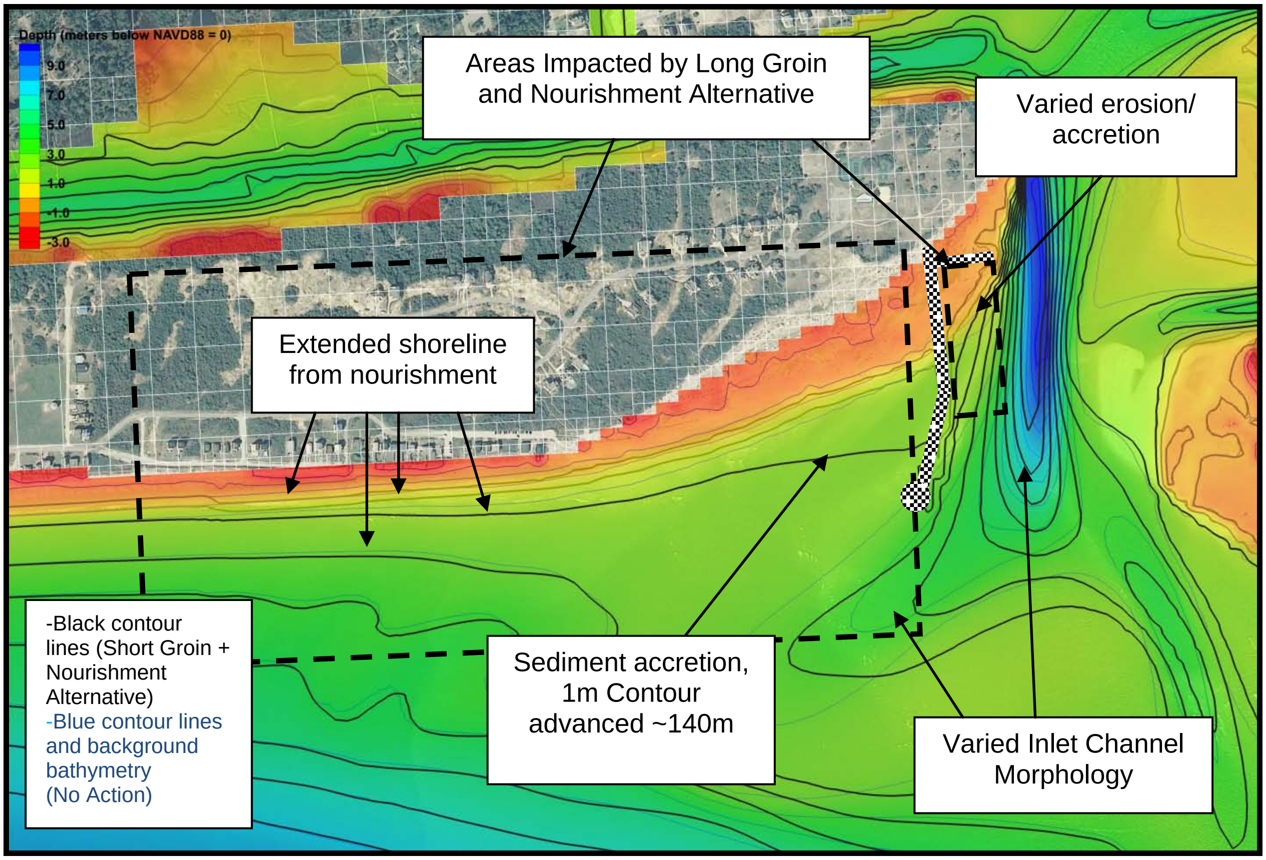


Figure C-6. Resulting Shoreline and Bathymetry after 190-Day Simulations. No-action versus long groin and nourishment alternative.

The channel can be seen training up to the groin in Figure C-7 (morphology change). This effect (i.e., the migration of the channel thalweg toward a long groin/jetty structure) has been identified by Kieslich (1981) and others. A "spur" feature (similar to the Fort Macon terminal groin) was included in the long-groin design to minimize this effect.

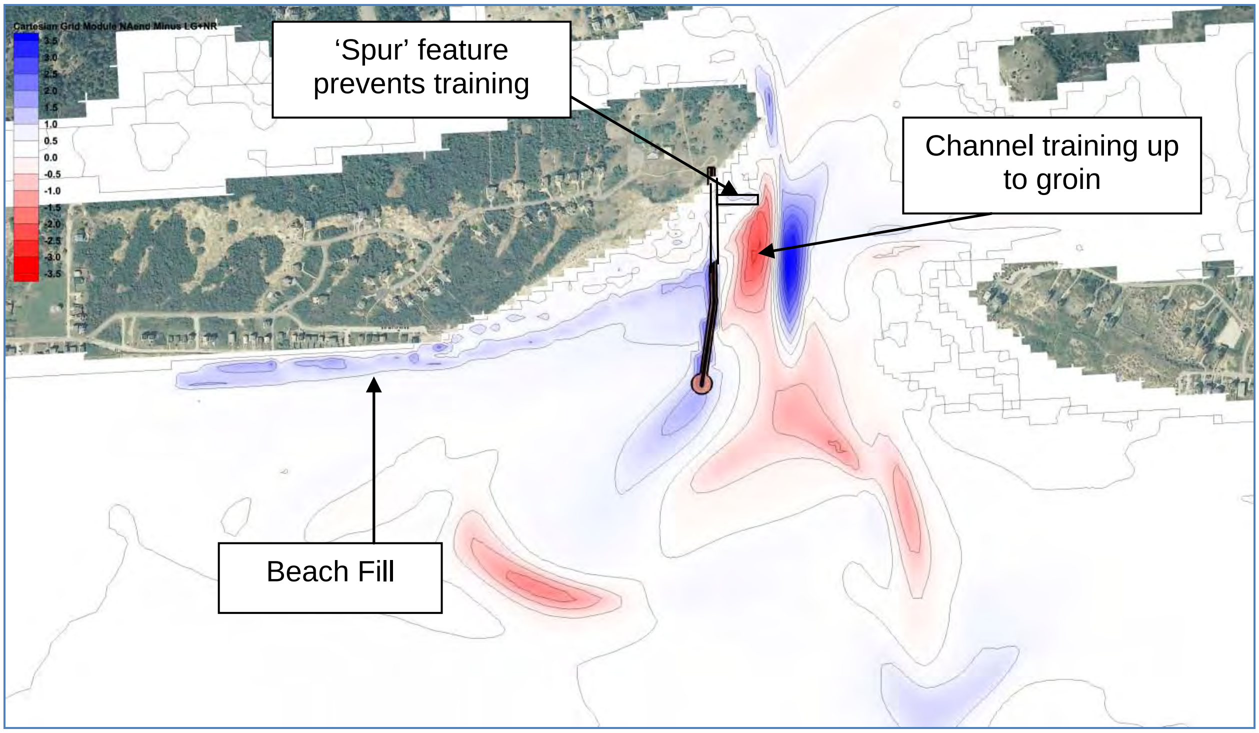


Figure C-7. Nourishment and Long Groin Alternative versus No-Action (blue=accretion, red=erosion)

Case 4: 60,000 cy Nourishment-Only Alternative

One proposed alternative is a nourishment-only alternative. This would involve a beach nourishment on the eastern portion of Holden Beach, similar to the historical LWFIX projects that the USACE has conducted. It would place approximately 30 cy/ft of beach-compatible sand along approximately 2,000 ft of shoreline (total of 60,000 cy). The nourishment alternative was modeled by extending the existing beach profile seaward about 40 ft along the nourished beachfront and then verified by performing a volume calculation. This altered bathymetry represents the estimated beach profile after the nourished beach has reached equilibrium (tapers are included). Figure C-8 compares the eastern end of Holden Beach at the end of the 190-day simulations of the no-action case and nourishment-only alternative. Figure C-9 presents morphology change of this alternative with the no-action. As expected, the nourishment alternative extends the beachfront in the project vicinity.

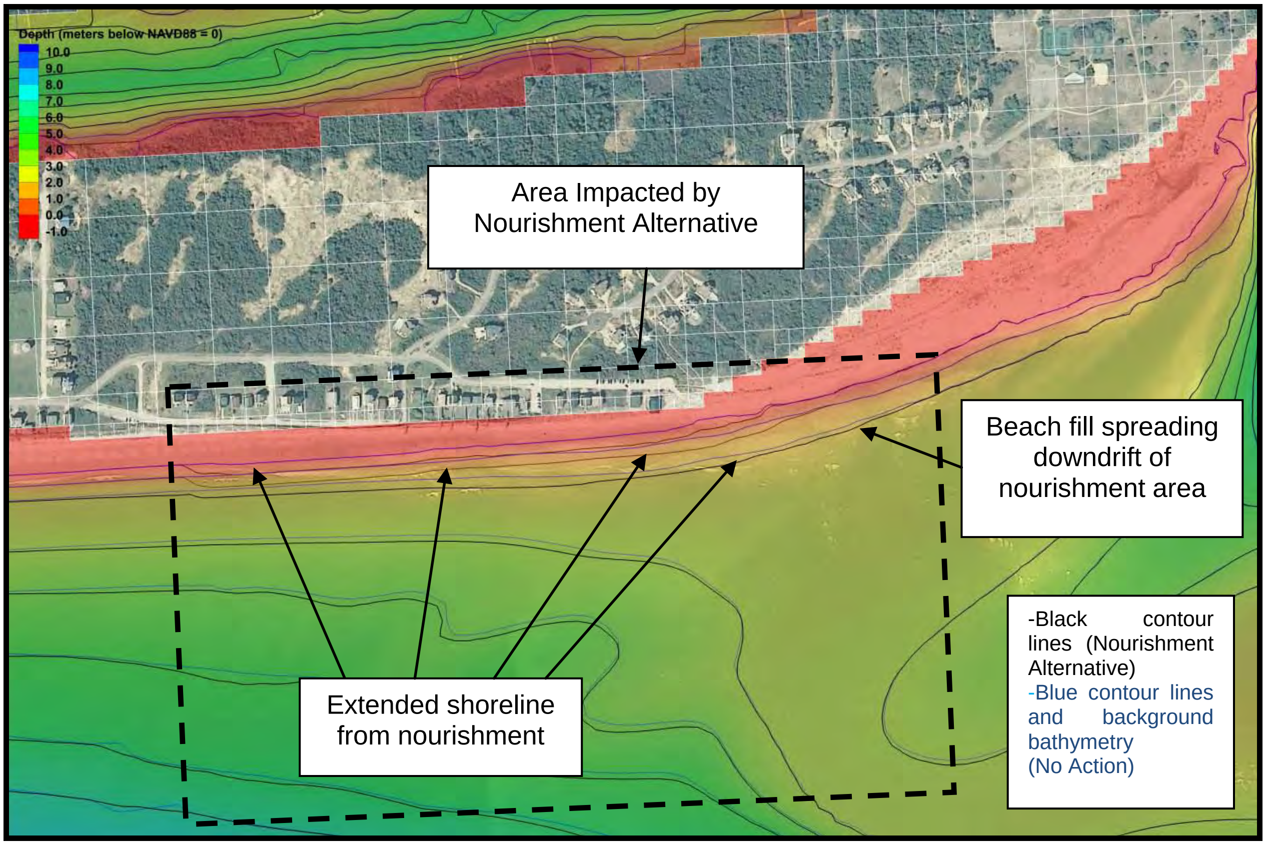


Figure C-8. *Resulting Shoreline and Bathymetry after 190-Day Simulations. No-action versus nourishment only alternative.*

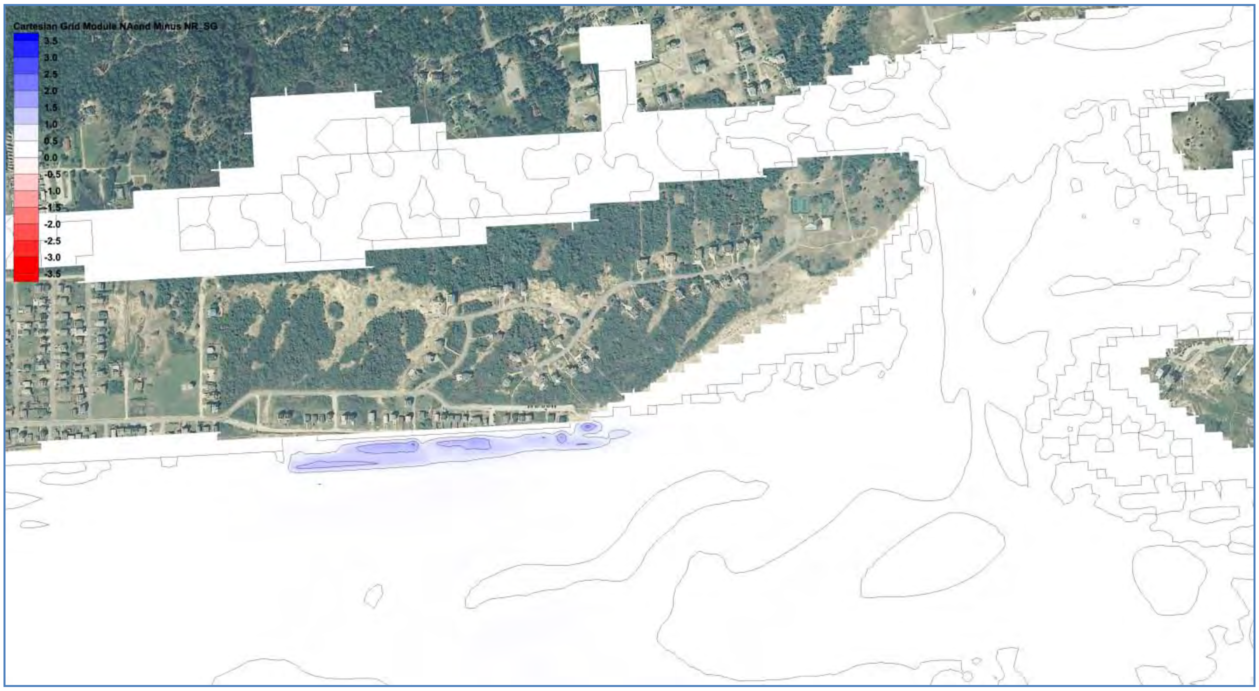


Figure C-9. *60,000 cy Nourishment versus No-Action Morphology Change*

Case 5: 90,000 cy Nourishment Only Alternative

The 90,000 cy nourishment-only alternative places an average of about 23 cy/ft of beach-compatible sand along approximately 4,000 ft of shoreline (total of about 90,000 cy). This nourishment placement is identical to the fill placement that accompanies the long groin in Case 3. The nourishment alternative was modeled by extending the existing beach profile seaward about 40 ft along the nourished beachfront. This altered bathymetry represents the estimated beach profile after the nourished beach has reached equilibrium. Figure C-10 compares the eastern end of Holden Beach at the end of the 190-day simulation for the no-action case and nourishment-only alternative. While erosion occurs under both circumstances, it can be seen that the nourishment alternative will significantly extend the beachfront in the project vicinity. For example, the 1-m contour shoreline is extended approximately 10 m (33 ft). However, note that the same nourishment volume in conjunction with the long groin extended the 1-m contour shoreline approximately 140 m (460 ft) in the same location. Figure C-11 presents morphology change of this alternative with the no-action. The beach fill has remained within the general project area.

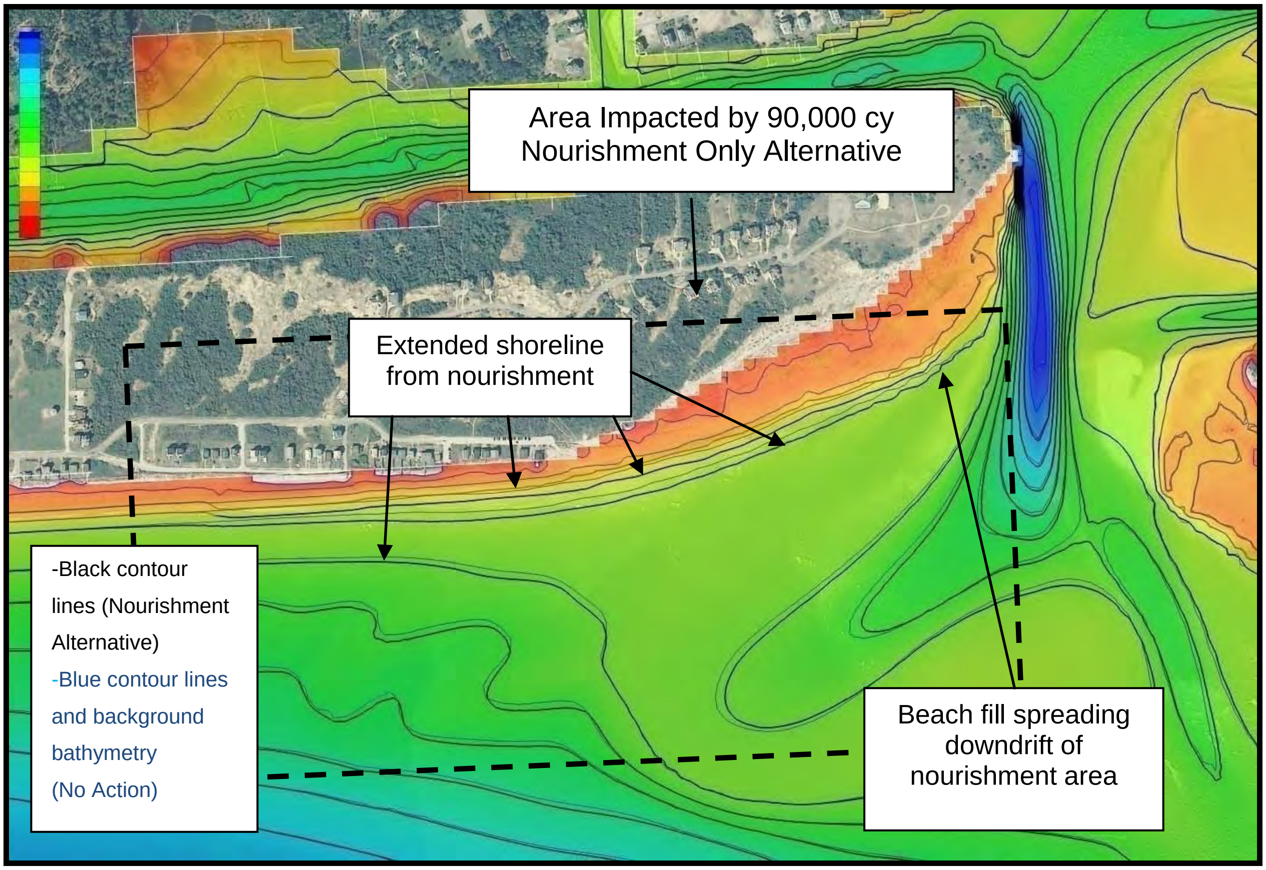


Figure C-10. Resulting Shoreline and Bathymetry after 190-Day Simulations. No-action versus the 90,000 cy nourishment only alternative.

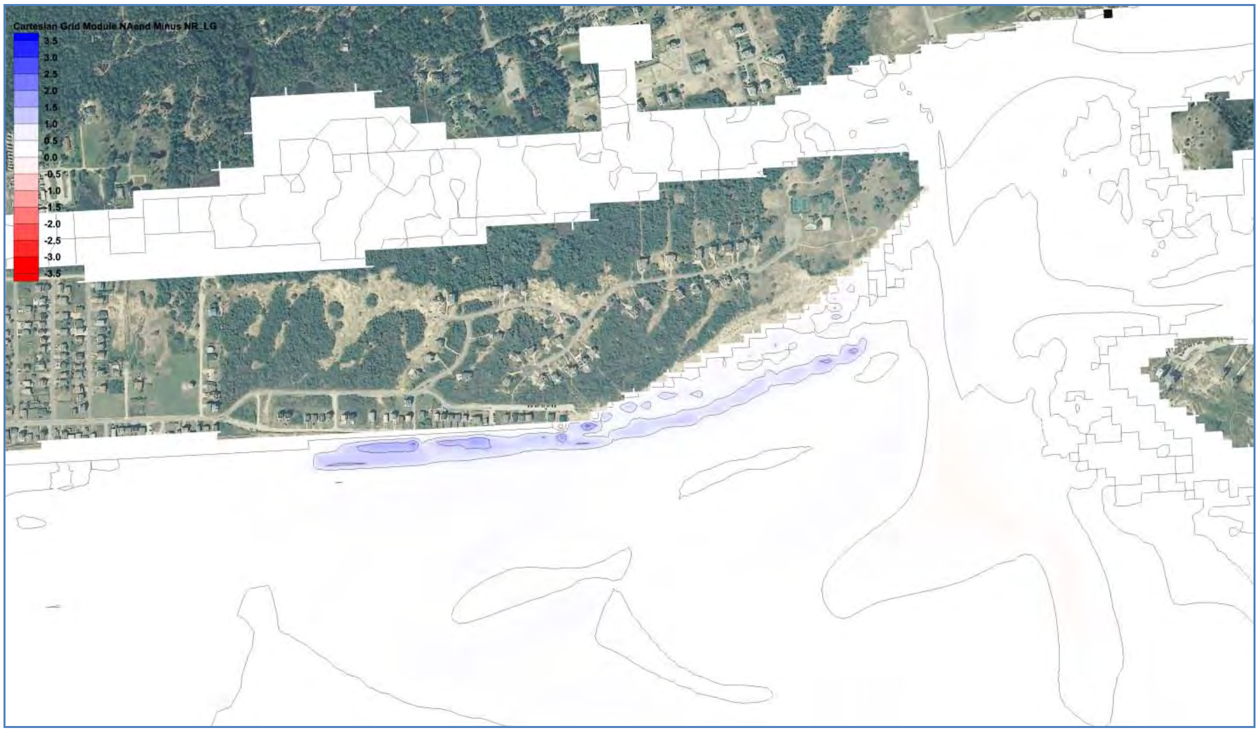


Figure C-11. 90,000 cy Nourishment versus No-Action Morphology Change.

Case 6: Short Groin Alternative

While not a proposed alternative, a short-groin-only simulation was run to assess its affect without a beach nourishment. This could be considered the maximum effect of the groin under extremely erosive conditions (possibly at the end of a nourishment cycle). Figure C-12 compares the eastern end of Holden Beach at the end of the 190-day simulations of the no-action case and short-groin alternative. The short-groin alternative performs as expected. Sediment is trapped on its western front, significantly extending the beachfront in the area, with only a minor increase in erosion on the eastern shoreline.

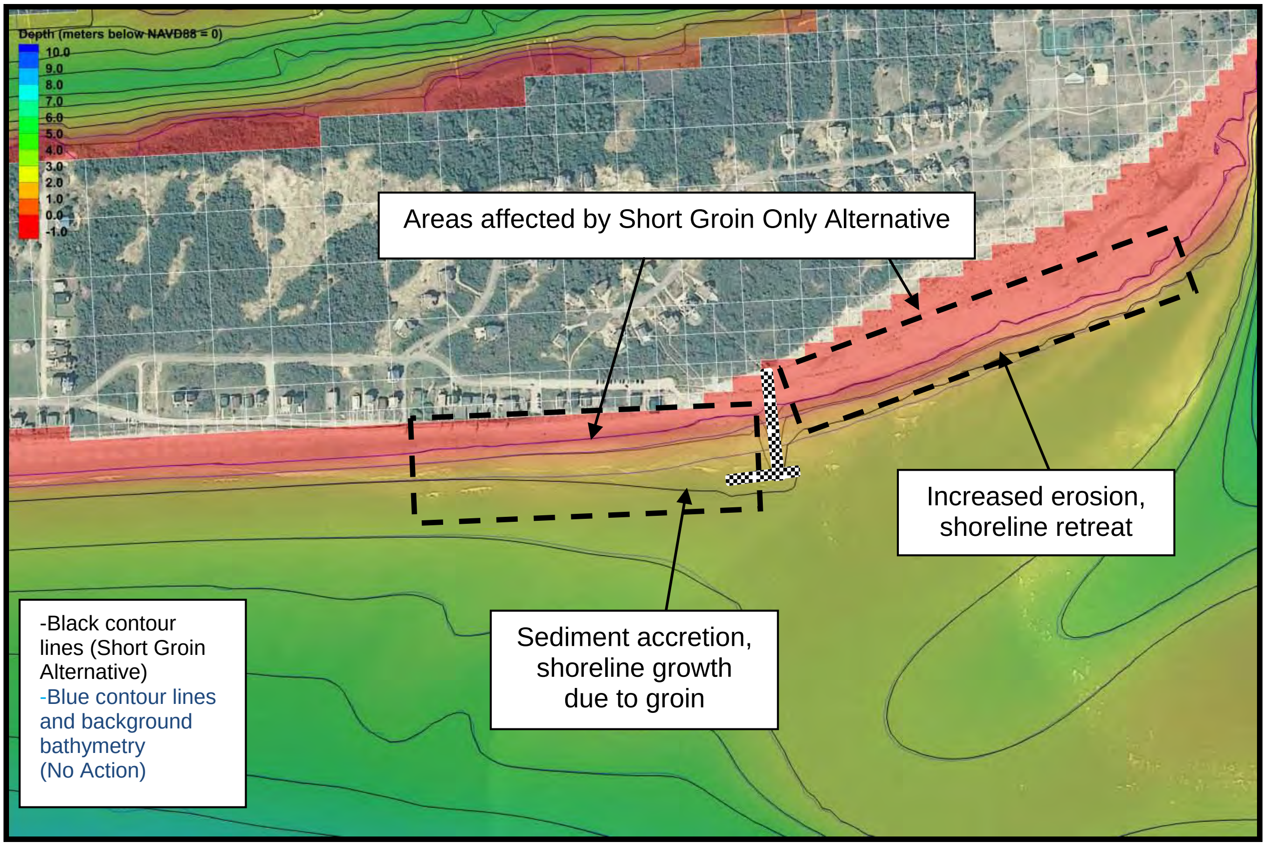


Figure C-12. Resulting Shoreline and Bathymetry after 190-Day Simulations. No-action versus short groin only case.

Figure C-13 presents morphology change and exhibits some channel realignment closer to the Holden Beach shoulder. Figure C-14 presents sediment transport vector roses at the Holden Beach east location comparing the short groin only, as well as the short-groin-plus-nourishment alternatives to baseline conditions. Sediment transport is relatively similar for the alternatives pictured. The “inner” sediment transport vectors show an expected decrease in easterly transport. The “outer” sediment transport vectors are generally the largest for the alternatives that includes a nourishment component. Increased sediment transport is expected following a beach nourishment until the fill material equilibrates.

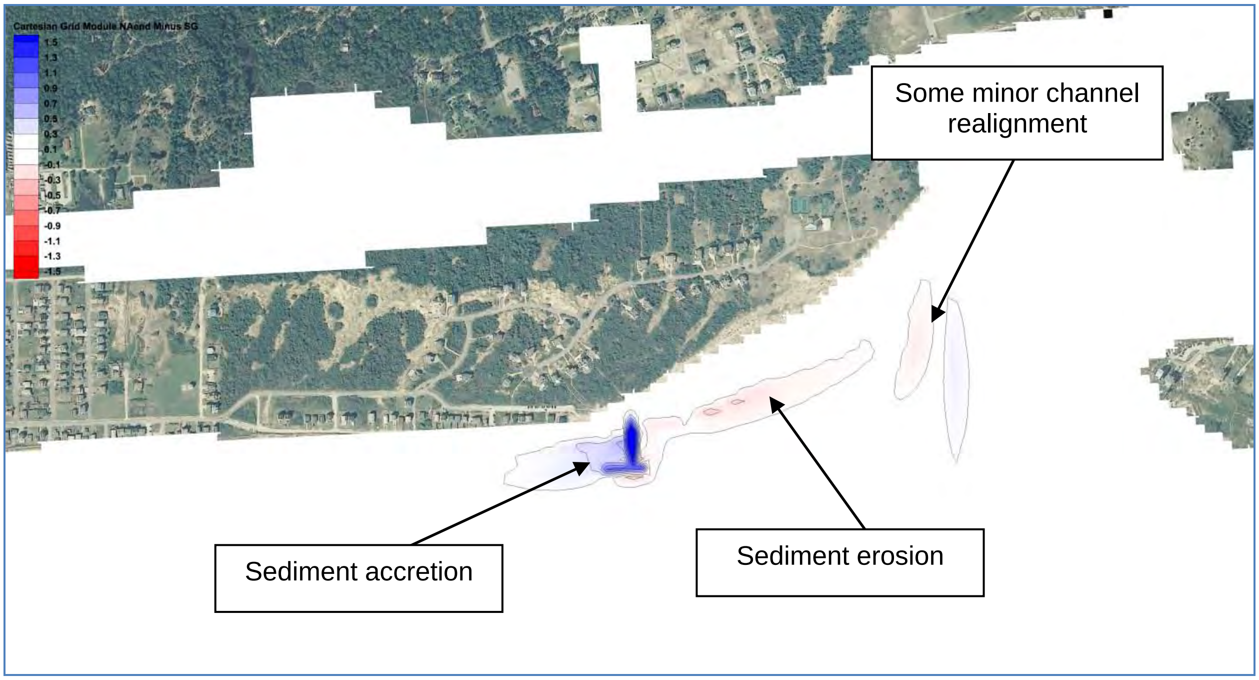


Figure C-13. Short Groin Only versus No-Action Morphology Change. Note color contour scale. Changes are minor, however this groin only alternative is having an effect.

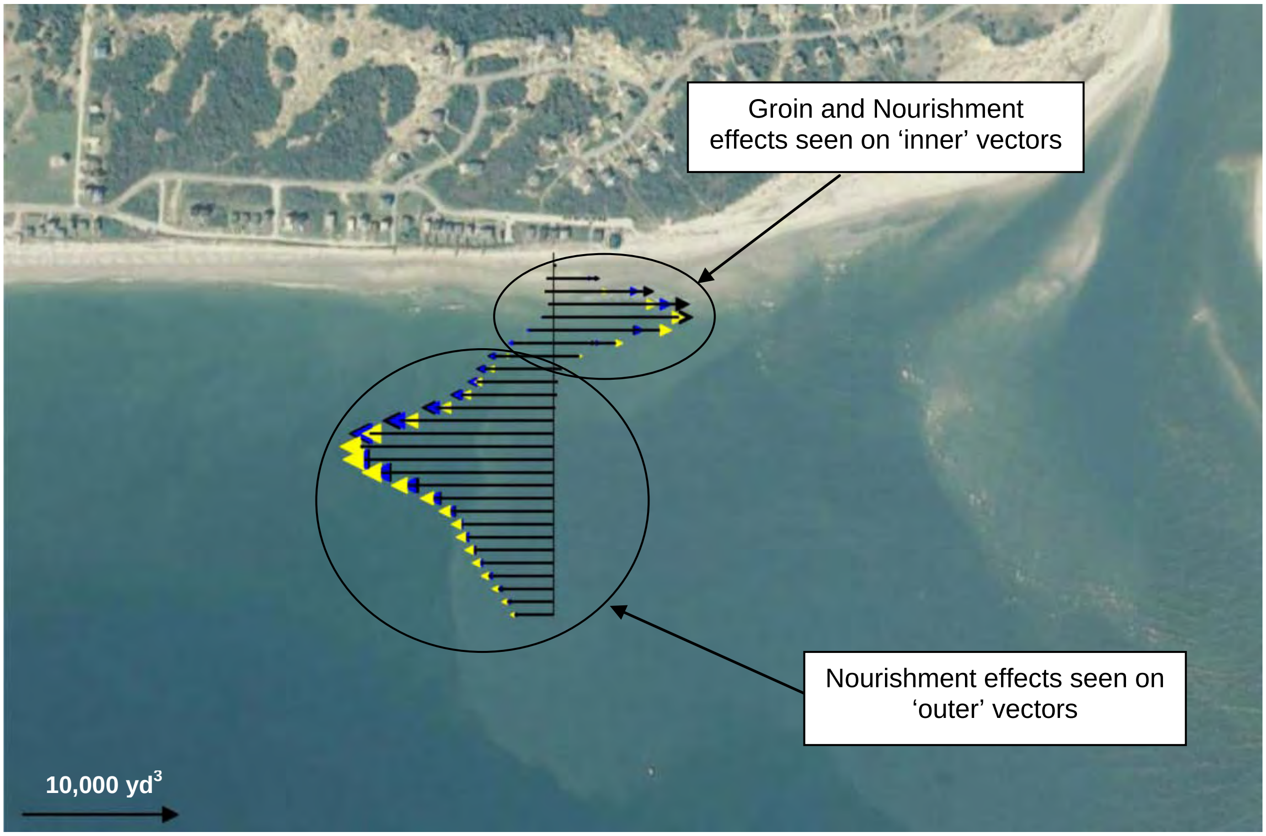


Figure C-14. 2009 190-Day No-Action (BLACK), Short Groin Only (BLUE), Short Groin and Nourishment (YELLOW) Sediment Transport Roses at HB East Transect

Case 7: Long Groin-Only Alternative

Similar to Case 6, the long groin was also modeled without an accompanying beach nourishment. The long groin is similar to the Fort Macon terminal groin structure [refer to the Work Plan (ATM, 2011) for more information]. Figure C-15 compares the eastern end of Holden Beach at the end of the 190-day simulations of the no-action case and long-groin alternative. While erosion occurs under both circumstances, the long groin alternative performs as expected. Sediment is trapped on its western front, significantly extending the beachfront in the area, with only a minor increase in erosion on the eastern shoreline. Inlet morphology is affected also, which can be seen in the morphology change in Figure C-16. As expected, the channel is "training up" to the side of groin. As previously mentioned, the spur feature has minimized the channel migration along the shoreline sections of the structure; however, the training effect is occurring on the seaward end of the structure.

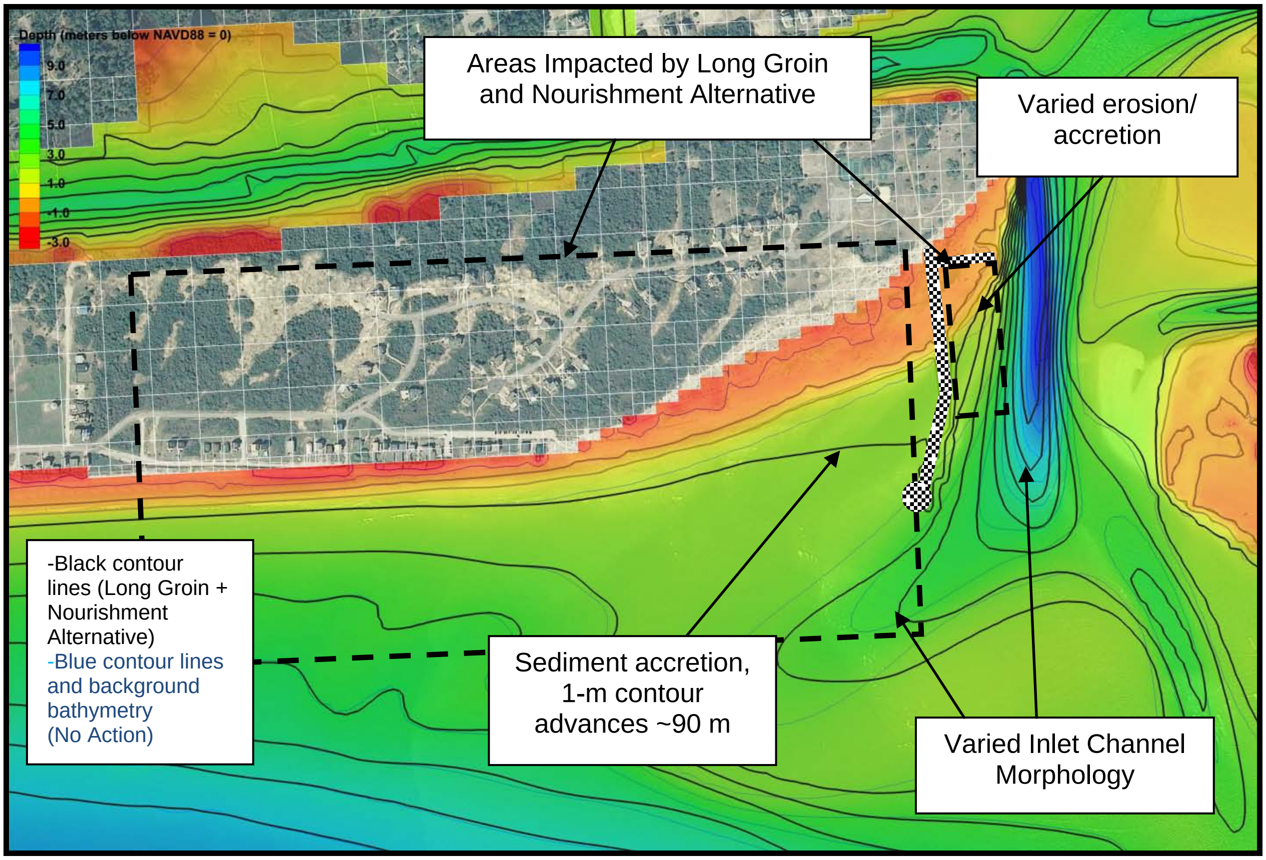


Figure C-15. Resulting Shoreline and Bathymetry after 190-Day Simulations. No-action versus long groin only alternative.

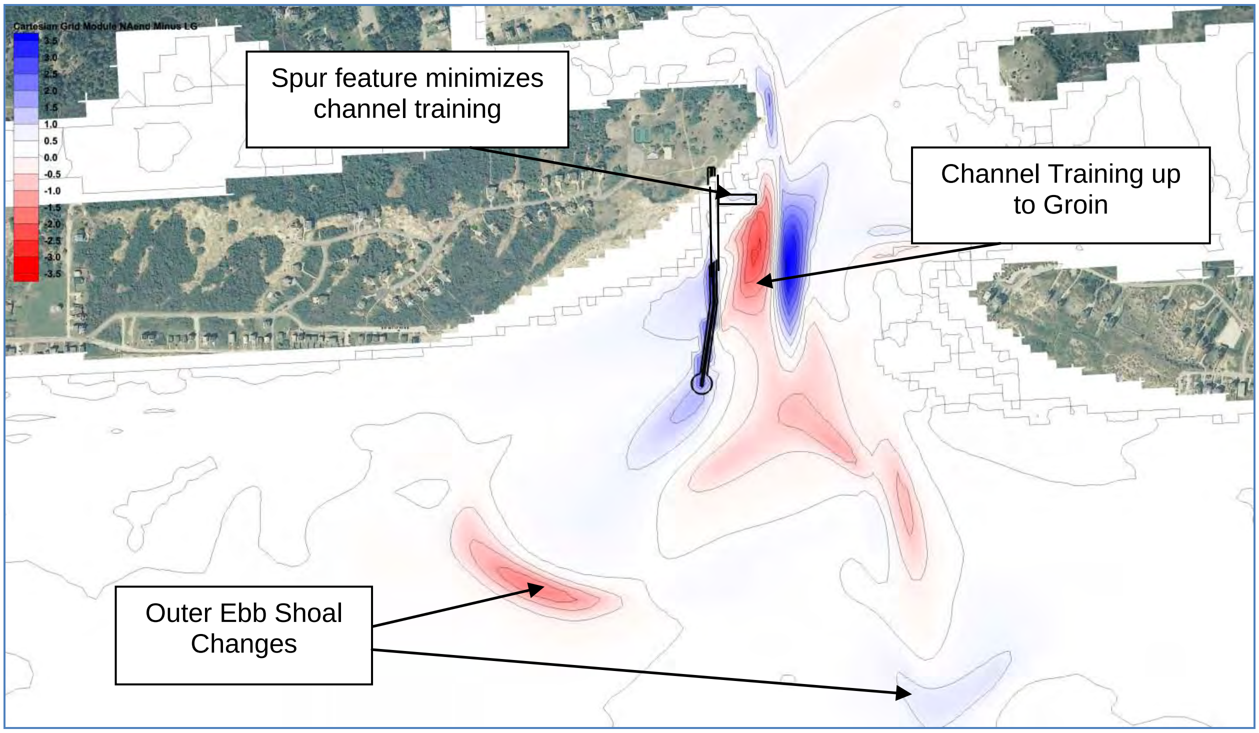


Figure C-16. No-Action versus Long Groin Only Morphology Change (red=erosion, blue=accretion).

The 1-m contour shoreline advances approximately 90 m (295 ft) just west of the long groin (i.e., in the fillet region of the groin). Therefore, this alternative is effectively trapping sediment on the updrift.

As seen in Figure C-16, some additional changes are exhibited along the outer ebb shoal due to the long-groin-only alternative. Figure C-17 presents sediment transport vector roses at the Holden Beach east location comparing the long-groin-only, as well as the long-groin-plus-nourishment alternatives to baseline conditions. Sediment transport is relatively similar for the alternatives pictured. In general, the nourishment simulations essentially shift the transport vectors seaward, in addition to increasing sediment transport for the "outer" vectors.

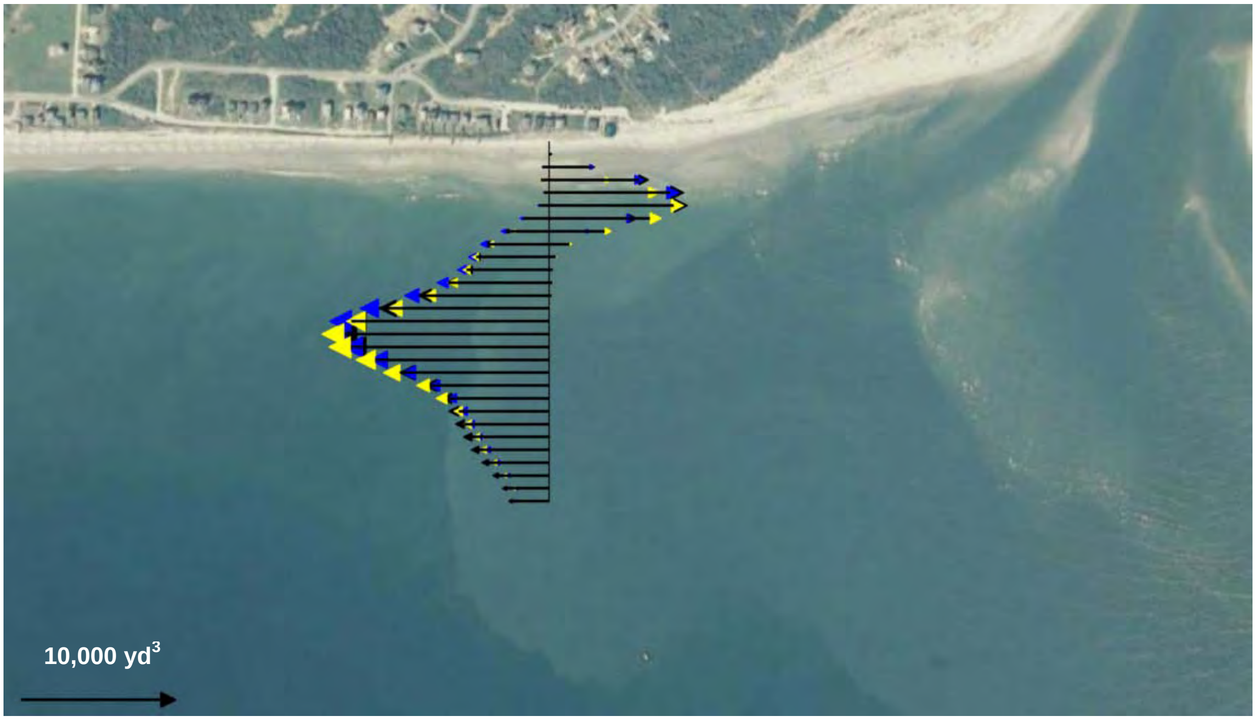


Figure C-17. 2009 190-Day No-Action (BLACK), Long Groin Only (BLUE), and Long Groin + Nourishment (YELLOW) Sediment Transport Roses

<u>Case 8: Central Reach Nourishment</u>

The Central Reach nourishment was also simulated to assess effects to the east end of Holden Beach. The Central Reach nourishment proposes to place up to 1,310,000 cy of material from Station 40+00 to Station 260+00 (approximately 22,000 ft). Sand spreading is anticipated to benefit adjacent eastern and western shorelines. As seen in Figure C-18, some sand spreading has occurred over the model run period.

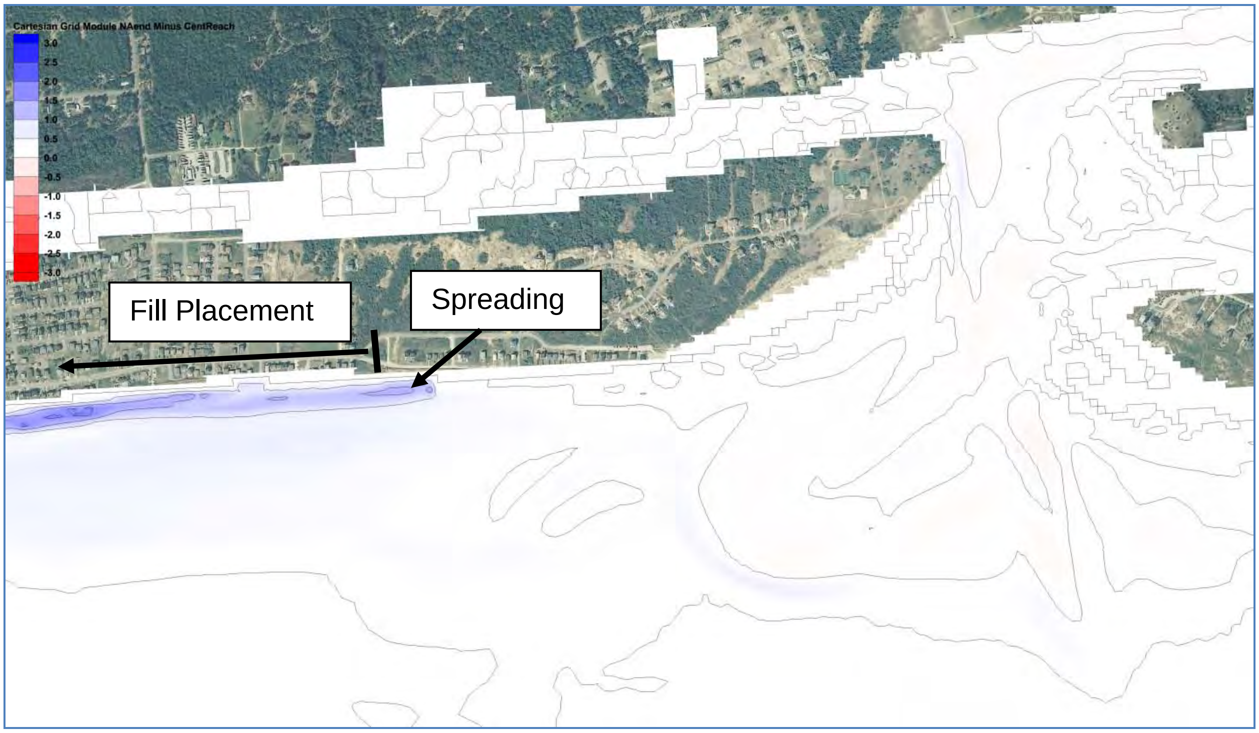


Figure C-18. Central Reach Nourishment versus No-Action Morphology Change

<u>Case 9: Channel Relocation Alternative</u>

The LWF Inlet between Holden Beach and Oak Island has been historically positionally stable. Therefore, the inlet relocation alternative only involved the relocation of the dredged outer channel connecting the main inlet to deeper waters. As previously mentioned, this alternative represents an *inlet channel relocation* as opposed to a complete *inlet relocation* (e.g., Mason Inlet relocation). Figure C-19 shows the initial bathymetry of the relocated outer channel versus existing conditions for the 2009 survey. The proposed dredged channel was oriented approximately 90 degrees to the existing channel and connects similar depth contours. The proposed dredged channel is about 150 wide by 8 ft mean low water (MLW) deep (conforming to existing USACE outer channel dimensions). Figure C-20 compares the resulting bathymetries after 190-day simulations. The inlet relocation affects the shoal morphology and results in an accretion of sediment and shoreline growth along a small stretch of shoreline (about 200 ft) on eastern Holden Beach.

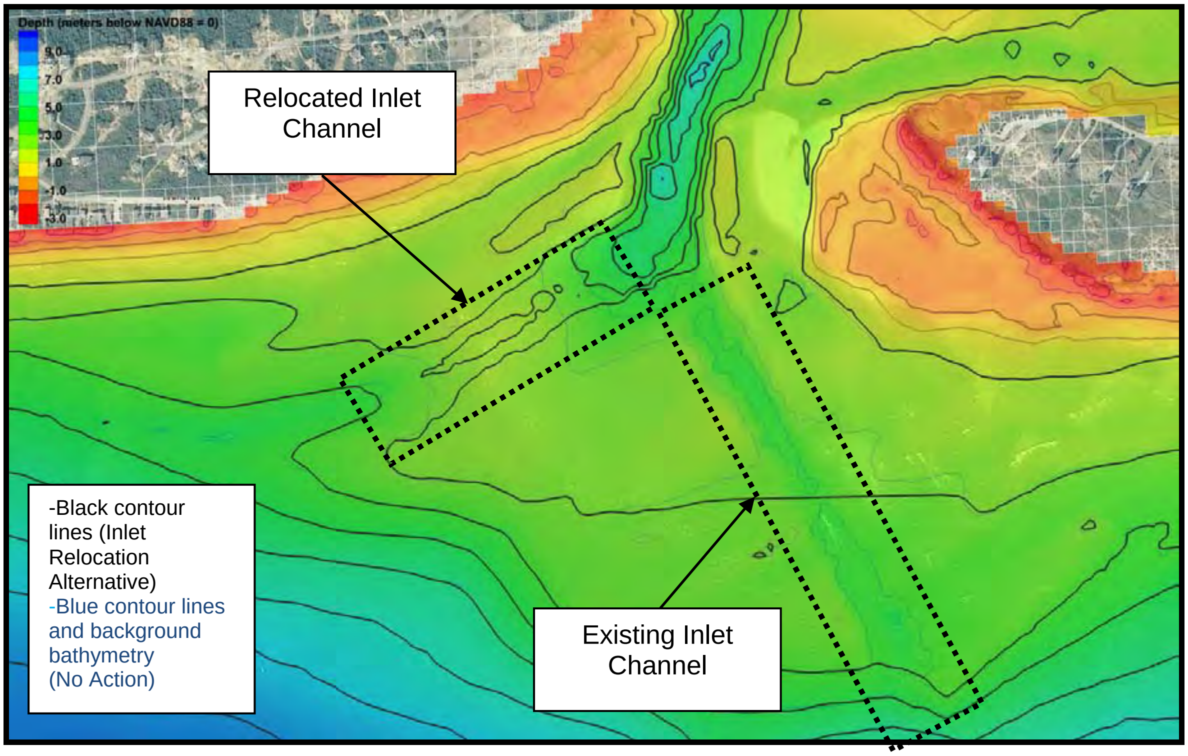


Figure C-19. Initial Bathymetry of No-Action versus Inlet Relocation Alternative

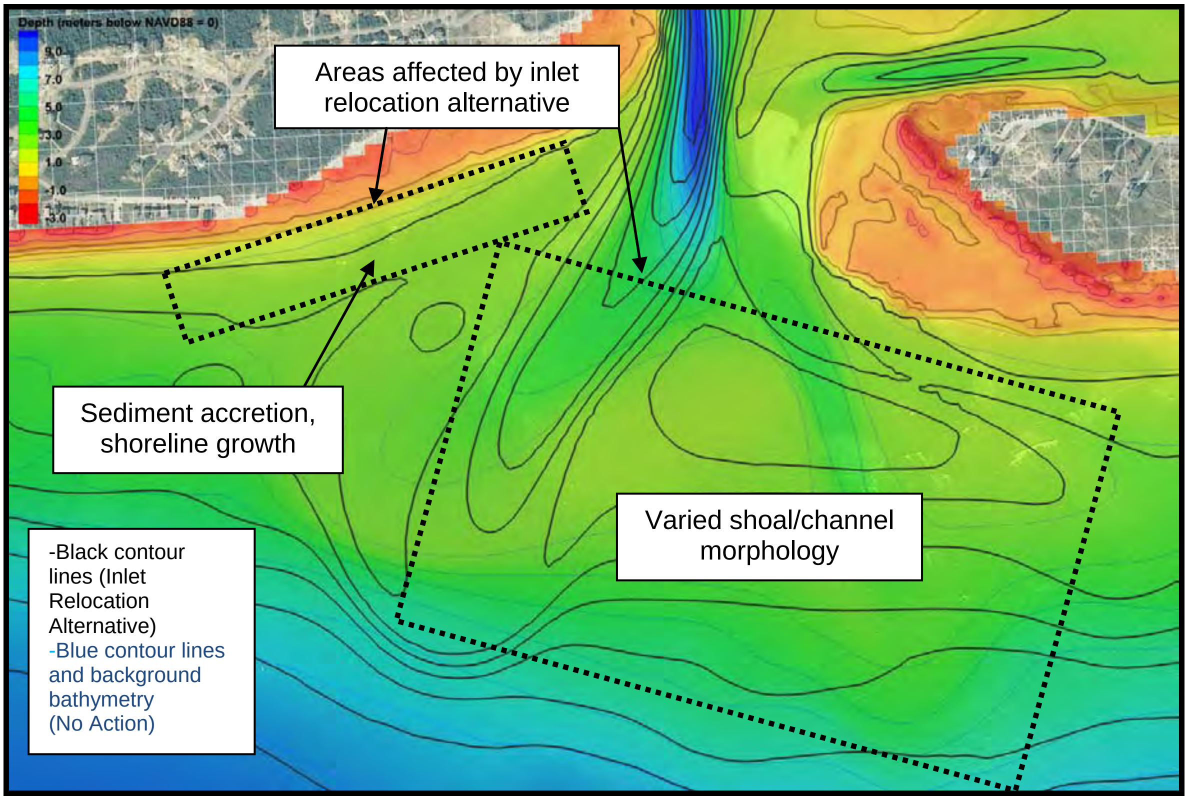


Figure C-20. Resulting Shoreline and Bathymetry after 190-Day Simulations. No-action versus inlet relocation alternative.

Figure C-21 presents morphology change results for this alternative. As shown, the inlet relocation alternative has an effect on a relatively large area of the ebb shoal. The inlet is migrating and is ephemeral in nature. This agrees with USACE outer channel dredging, which is performed ideally every 3 months (when funding is available) to maintain safe navigation conditions. Negligible benefits are exhibited to the east end shoreline as well as to the west end of Oak Island.

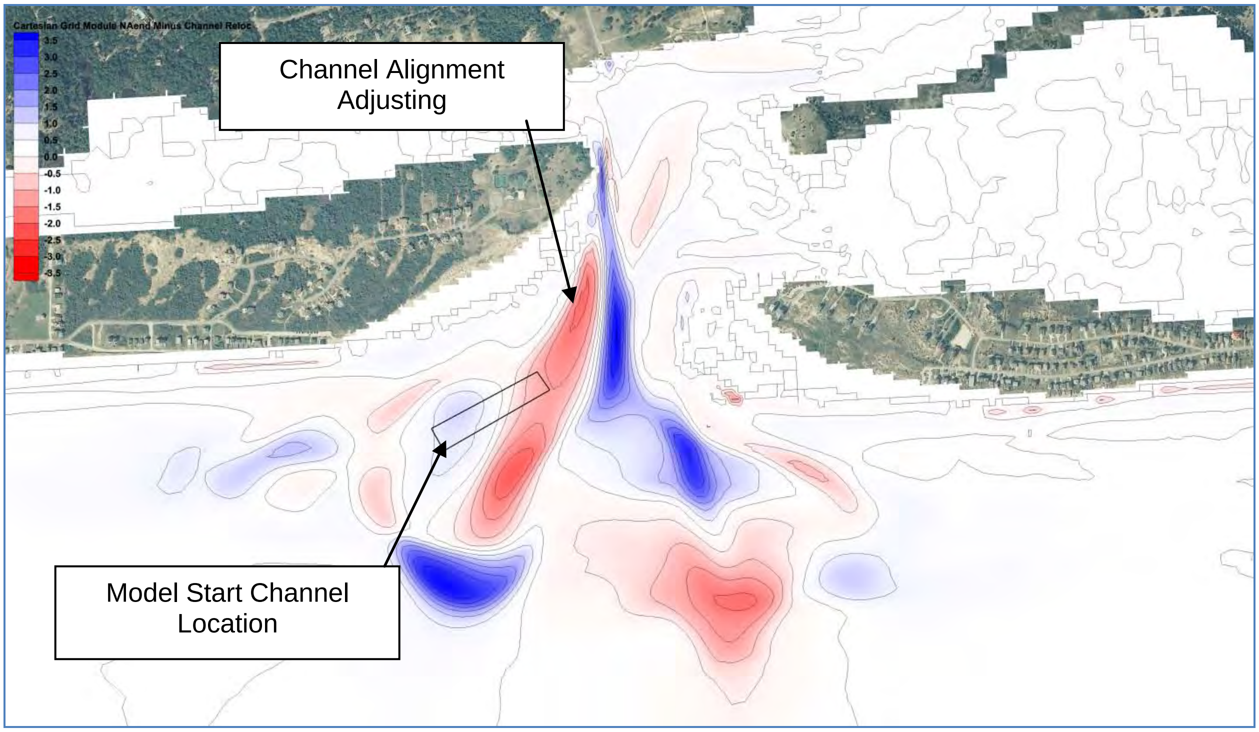


Figure C-21. Inlet Relocation Morphology Change

<u>Case 10: Short Groin, Nourishment , Channel Relocation and LWFIX Borrow Area</u>

In an effort to combine the results of the previous modeling into a comprehensive alternative, the following model alternative includes the short groin, 60,000 cy nourishment, channel relocation and the AIWW borrow area. Figure C-22 presents morphology change for this alternative relative to no-action and relatively positive results are exhibited. The nourishment and groin are performing as anticipated, whereas the LWFIX borrow area has eased the “pinching” effect that occurs when the bend widener is not dredged. The channel relocation shows some effect, although infilling and natural channel migration have already occurred by the end of the simulation.

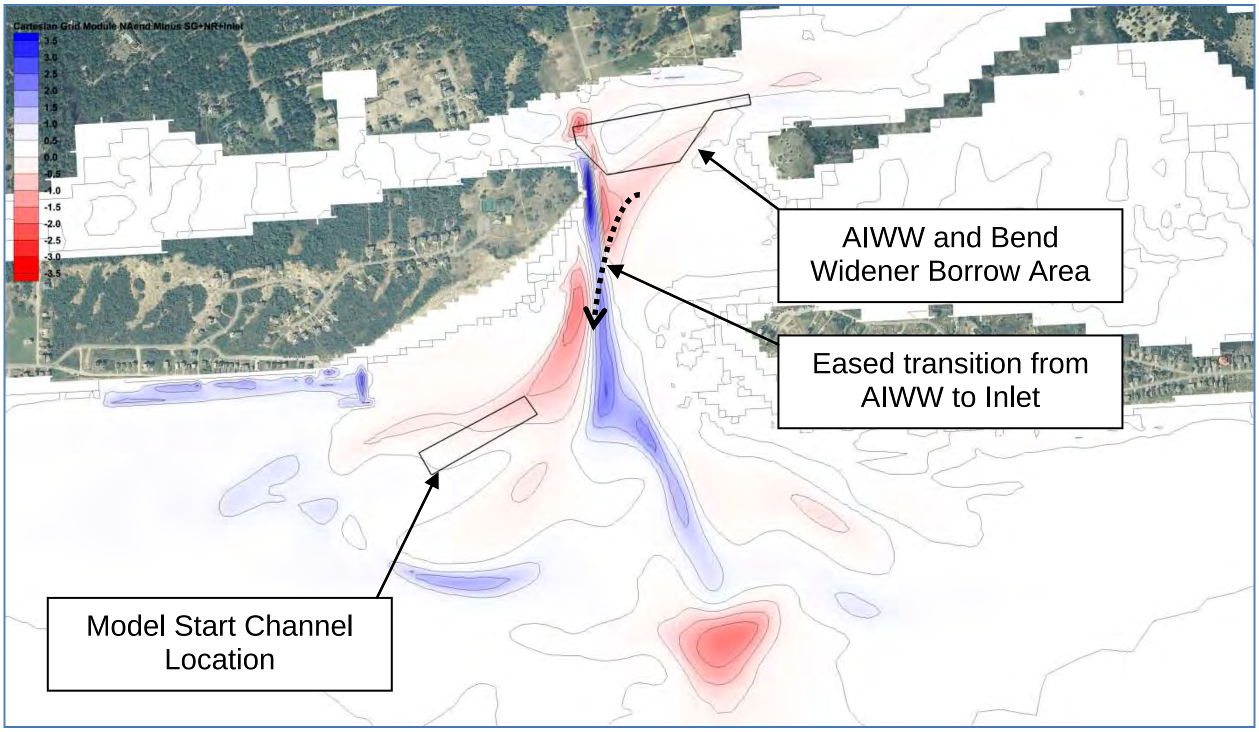


Figure C-22. Short Groin, 60,000 cy Nourishment, Channel Relocation, and LWFIX Borrow Area

Relative Impacts of 2009 CMS Simulated Alternatives

The 2009 CMS model simulations revealed two areas of Holden Beach that were significantly affected by the nourishment, short-groin, and short-groin-and-nourishment alternatives (see Figure C-23). Area 1 extends over about 2,700 ft of shoreline and includes the nourished beachfront (when applicable) and updrift shoreline west of the short groin (when applicable). Area 2 covers about 1,700 ft of shoreline and includes the downdrift shoreline east of the short groin (when applicable).

Similarly, the CMS simulations revealed two areas of Holden Beach that were affected by the long-groin-only and long-groin-and-nourishment alternatives (Figure C-23). Area 3 covers about 4,300 ft of shoreline and includes the nourished beachfront (when applicable) and updrift shoreline west of the long groin. Area 4 covers about 400 ft of shoreline and includes the downdrift shoreline east of the long groin and edges of the inlet channel.

Depending on the modeled alternative, all areas experienced a number of effects, including increased or decreased erosion, shoreline accretion due to sediment trapping, shoreline accretion due to nourishment activity, and other varied morphology changes.

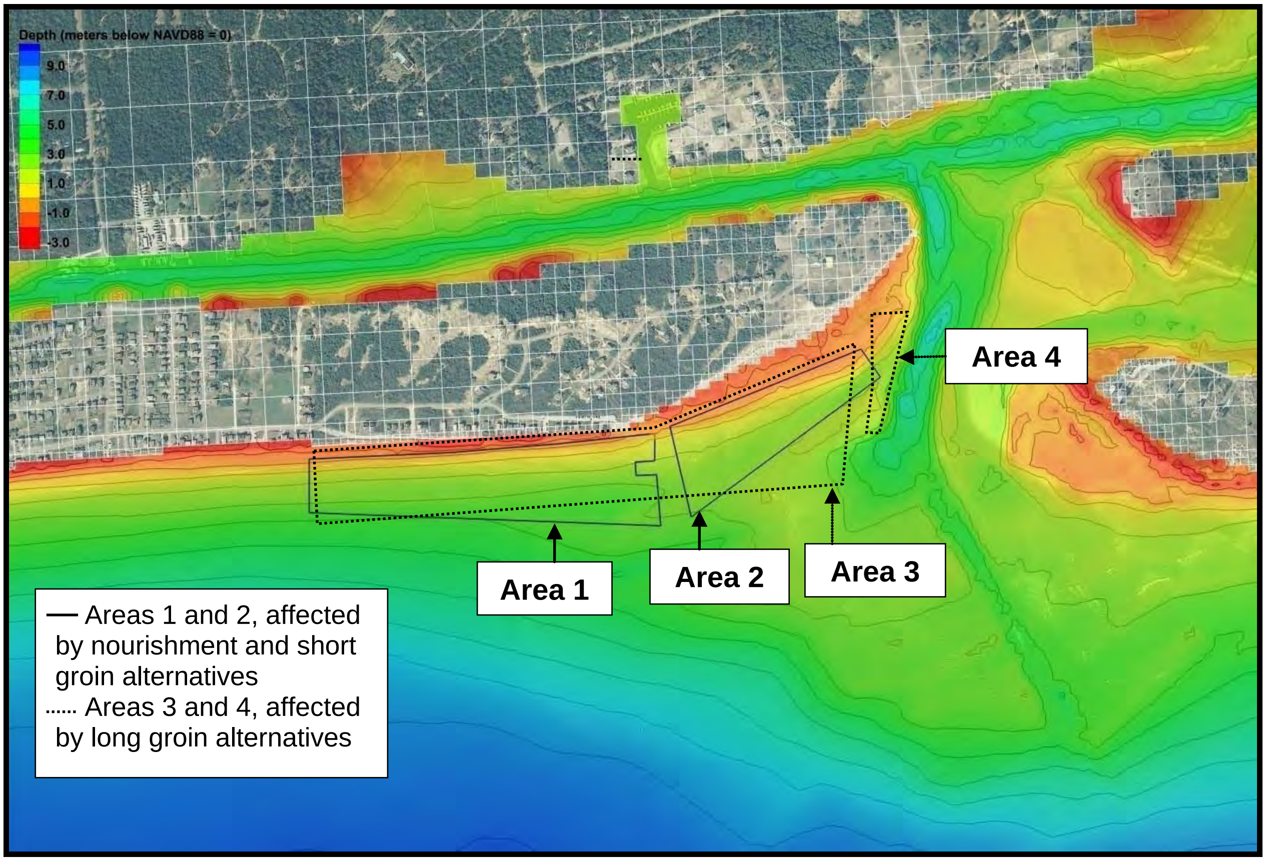


Figure C-23. Areas Considered for Relative Impact Comparison.

Morphology change in the areas was assessed to compare relative impacts of the alternatives. Volume calculations were performed to determine the initial and final sand volumes in the areas relative to the no-action baseline condition. Table C-1 presents the results of the relative impact assessment for Areas 1 and 2. The magnitude of sediment loss is affected differently in each area by the varying alternatives. For example, the short groin only alternative (SG) results in accretion in Area 1 and erosion in Area 2, relative to the no-action alternative. As expected with this alternative, sections of shoreline in Area 1 also grow seaward due to updrift sediment trapping by the groin, whereas Area 2 experiences some shoreline erosion from a lack of available sediment. The inclusion of nourishment along Area 1 has obvious benefits for this reach of shoreline.

Table C-1. Relative Impact Assessment Results from 190-Day Simulations, Areas 1 and 2

Alternative	Area 1 Volume Change (cy)	Area 2 Volume Change (cy)
60,000 cy Nourishment Only	55,029	1,451
Short Groin Only	9,004	-8,032
Groin and Nourishment	64,033	-6,518
Channel Relocation	-11,479	-1,099
Central Reach Nourishment	31,035	65
Groin, Nourishment, Channel Relocation, LWFIX Borrow Area	60,939	-15,408

As seen in Table C-1, the short groin by itself traps approximately 9,000 cy of material over approximately 2,700 feet (when compared with no-action results). The groin and nourishment alternative benefit the updrift shoreline by approximately 23.7 cy/ft, while some downdrift impacts are still exhibited (-6,518 cy). The sediment downdrift impacts of the short groin are approximately 8,000 cy over 190 days. Therefore, an approximate annual downdrift impact of the short groin is 16,000 cy. This is a conservative estimate because 1) the groin is modeled as impermeable, and 2) the 190-day model simulation occurs from June to December, when more westerly transport is seen due to increased south-southwest wind-wave conditions.

Figures C-24 and C-25 present morphological changes relative to Areas 1 and 2. In general, the channel relocation alternative (Figure C-24) induces the most change within the ebb shoal/inlet system. While there is some accretion in the nearshore of Area 2, erosion is exhibited overall for Areas 1 and 2.

The short groin exhibits relatively local effects. Figure C-25 presents the short groin, a 60,000 cy nourishment, the channel relocation, and the LWFIX borrow area. Changes with each component can be separated with modeling. No significant synergistic effects are exhibited. In comparing Figures C-24 and C-25, the inlet channel relocation component exhibits the largest effect on the ebb shoal system.

As seen in Figure C-25, the LWFIX/bend widener borrow area has a significant effect by easing the “pinching” of the channel thalweg alongshore of Holden Beach. This effect can also be seen in Figure C-26, which presents results of 2012 USACE survey data.

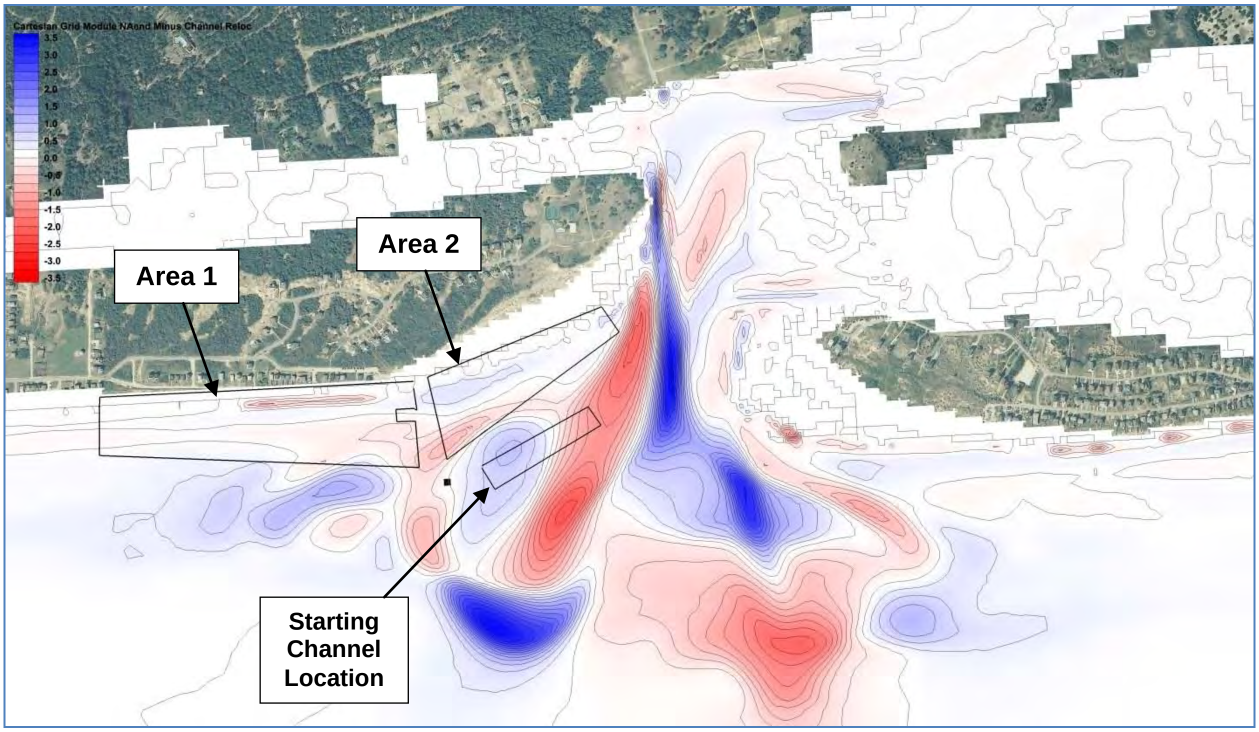


Figure C-24. Morphology Change of Channel Relocation Relative to Areas 1 and 2. Area 1 exhibits overall erosion while Area 2 exhibits some accretion near the shoreline and erosion in deeper water.

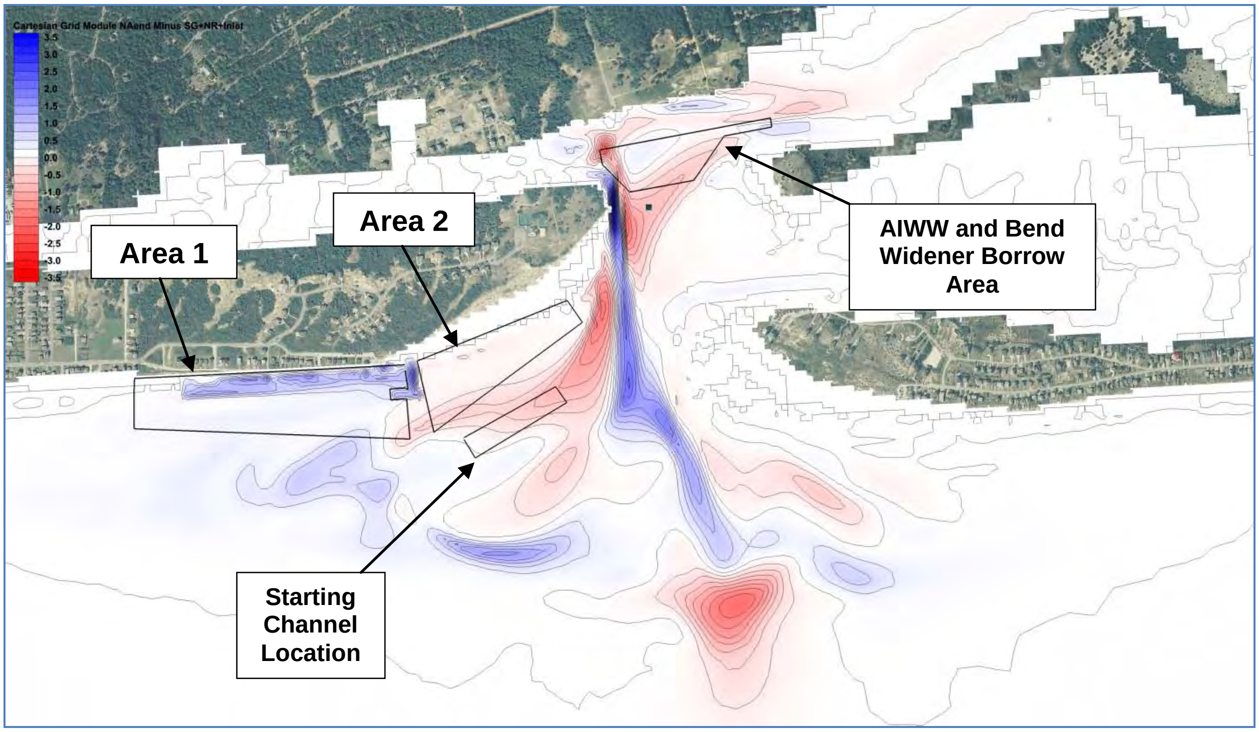


Figure C-25. Morphology Change of Short Groin, 60,000 cy Nourishment, Channel Relocation, and Inlet Borrow Area versus No-Action. As expected, Area 1 exhibits accretion. Area 2 exhibits some erosion, although this is also due to the channel relocation.

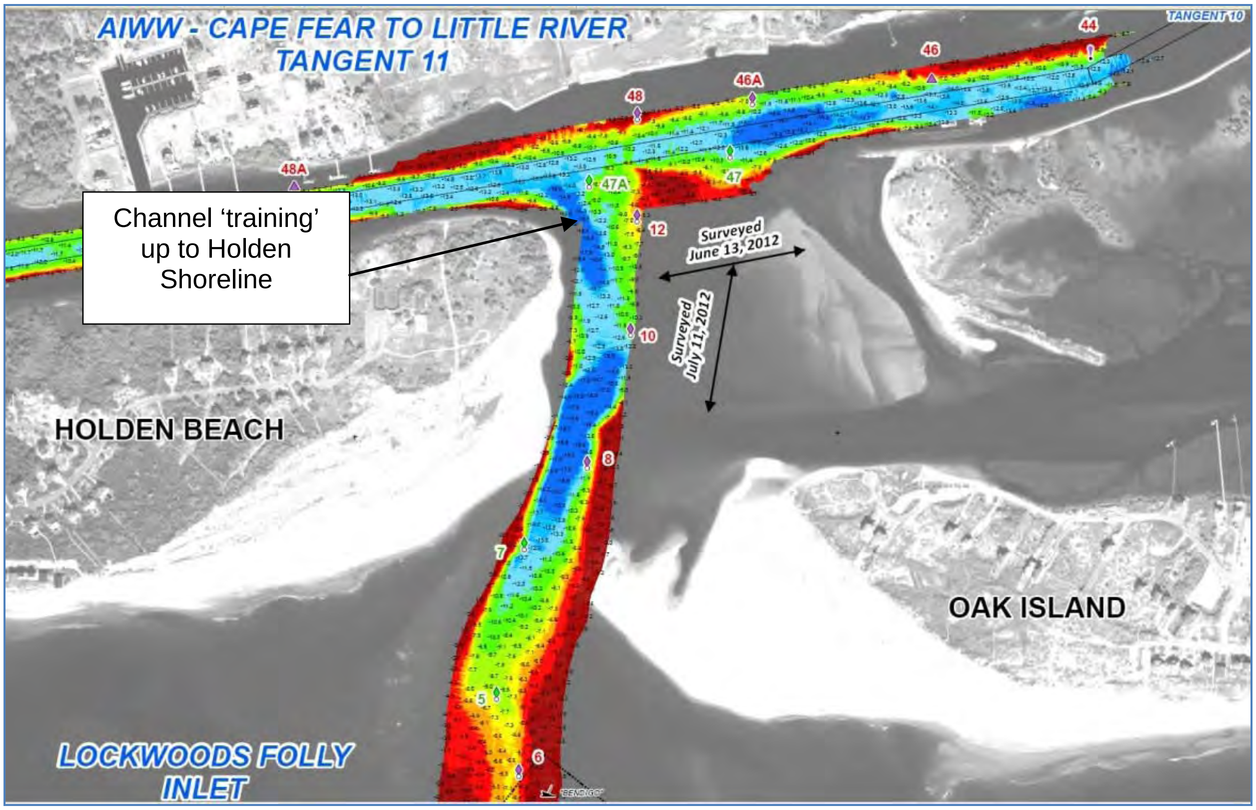


Figure C-26. June/July 2012 Survey of LWF and the AIWW. Channel seen to be 'training' up to Holden Beach, which is also exhibited in the modeling.

Table C-2 presents volume changes in Areas 3 and 4, which are for assessing long groin alternatives relative to no-action baseline conditions. The long groin by itself traps approximately 46,000 cy over 4,300 ft during the 190-day simulation. Downdrift losses attributed to the long groin only alternative are approximately 16,000 cy. In terms of downdrift effects in Area 4, a negligible amount of nourishment sand is bypassed during the simulation (15,677 cy for groin-only versus 15,336 cy for groin-and-nourishment). An approximate annual downdrift impact of the long groin is 32,000 cy/yr. As mentioned with the short groin downdrift effects, this is a conservative assumption because the groin is modeled as impermeable during a period of more easterly sediment transport.

Table C-2. Relative Impact Assessment Results from 190-day Simulations, Areas 3 and 4.

Alternative	Area 3 Volume Change (cy)	Area 4 Volume Change (cy)
90,000 cy Nourishment	87,327	509
Long Groin Only	45,963	-15,677
Long Groin and Nourishment	131,887	-15,336
Channel Relocation	-18,674	-18,687
Central Reach Nourishment	30,607	238

LONG TERM SEDIMENT TRANSPORT ANALYSES, SUITES 1-2

Regional sediment transport was further investigated for the long-term simulations. Tables C-3 and C-4 and Figures C-27 and C-28 show the results of the annualized sediment transport. While the results of each alternative differ slightly (contributing to the positive local impacts discussed in the previous two sections), regional sediment transport system remains largely unaffected.

Table C-3. Annualized Sediment Transport, Suite 1.

	Annualized Net Sediment Transport, cy/yr		
"Original"	Observation Profile		
Alternative	Holden Beach	Inlet	Oak Island
NA	-262,331	75,496	-42,206
NR	-266,076	65,688	-43,612
SGNR	-267,585	64,364	-43,373
LGNR	-269,187	95,038	-40,261

**Positive values indicate eastern transport (or into LWF Inlet).*
Negative values indicate western transport (or out of LWF Inlet)

Table C-4. Annualized Sediment Transport, Suite 2.

"New"	Annualized Net Sediment Transport, cy/yr		
	Observation Profile		
Alternative	Holden Beach	Inlet	Oak Island
NA	-262,331	75,496	-42,206
NR	-265,294	61,345	-43,456
SGNR	-265,375	67,056	-43,452

** Negative values indicate Western transport (or out of LWF Inlet)*

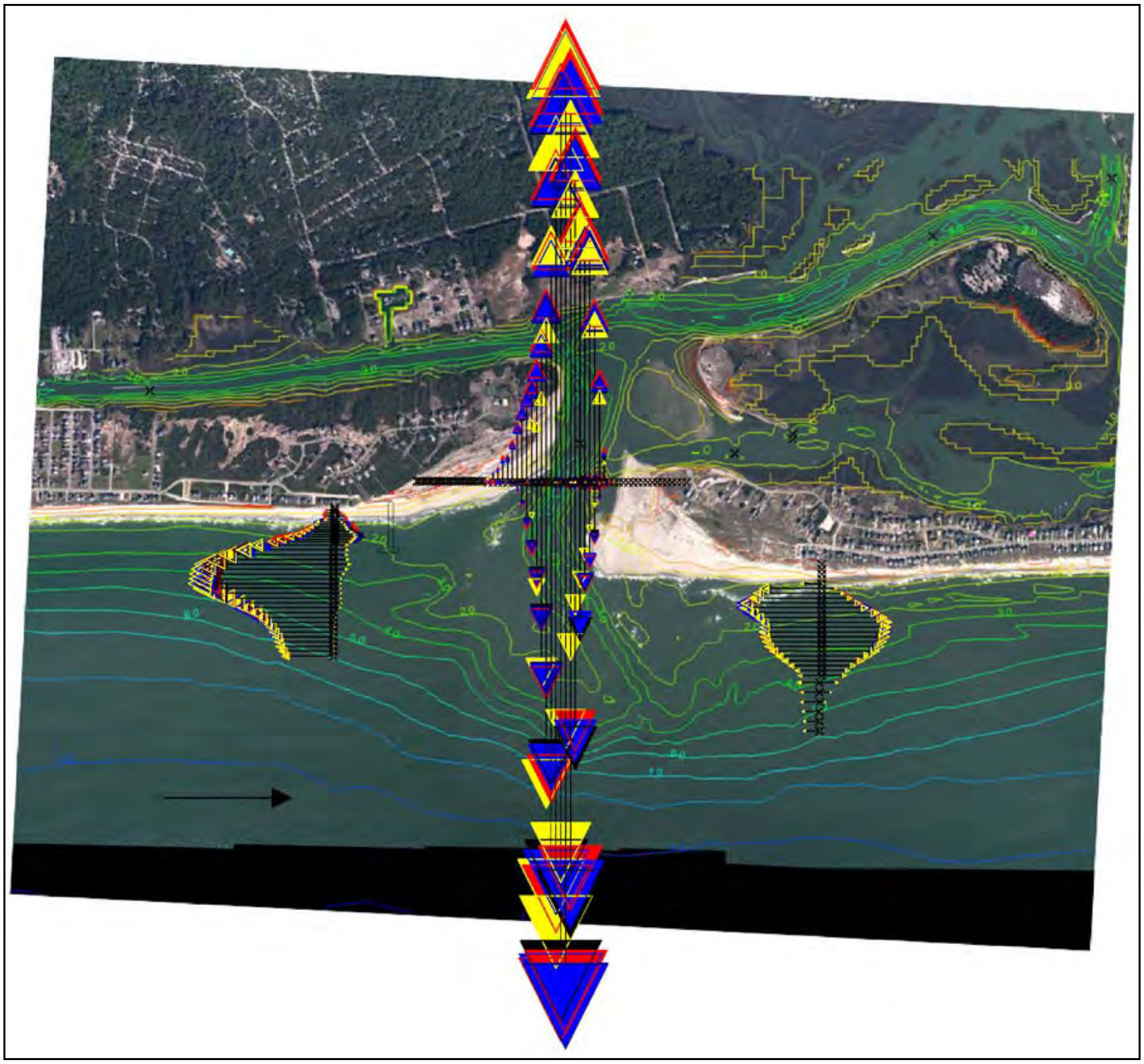


Figure C-27. Gross Sediment Transport, Suite 1. Red(no-action), Black(nourishment-only), Blue(short groin/nourishment), Yellow(long groin/nourishment).

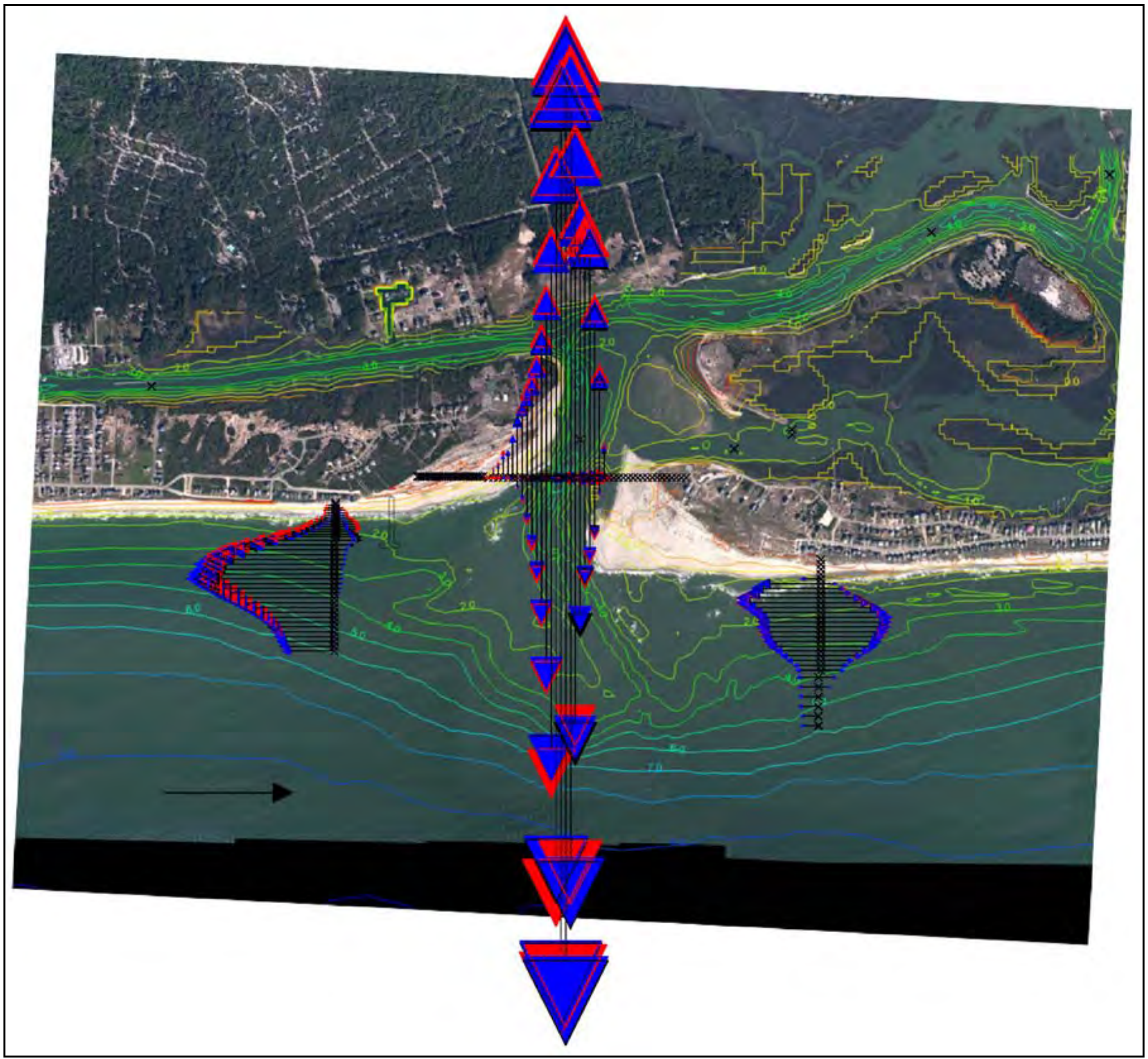


Figure C-28. Gross Sediment Transport, Suite 2. Red(NA), Black(NR), Blue(SGNR).

REFERENCES

Applied Technology and Management, Inc. (ATM). 2011. Holden Beach Terminal Groin Work Plan. Prepared for Town of Holden Beach.

Cleary, W., 2008. Overview of Oceanfront Shorelines: Cape Lookout to Sunset Beach, NC. Report prepared for Moffat & Nichol.

Kieslich, J.M. 1981. Tidal Inlet Response to Jetty Construction. GITI Report 19, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

USACE survey data obtained via email from USACE Wilmington Navigation Branch. Data sets generally span 2000 to 2013.

DRILLING LOG

DIVISION South Atlantic

INSTALLATION Wilmington District

SHEET 1 OF 1 SHEETS

1. PROJECT AIWW Cape Fear To Little River Tangent 11

2. HOLE NUMBER LFIXAIWW-V-09-10 : LOCATION COORDINATES N 63,315.0 E 2,232,777.0

3. DRILLING AGENCY USACE, Wilmington District

4. NAME OF DRILLER Robie Page Crane Operator

5. DIRECTION OF BORING ☒ VERTICAL ☐ INCLINED : DEG FROM VERTICAL --- : BEARING

6. THICKNESS OF OVERBURDEN (ft) 13.3

7. DEPTH DRILLED INTO ROCK (ft)

8. TOTAL DEPTH OF BORING (ft) 23.3

9. COORDINATE SYSTEM State Plane : HORIZONTAL NAD83 : VERTICAL MLLW

10. SIZE AND TYPE OF BIT 4" Dia. Vibracore

11. MANUFACTURER'S DESIGNATION OF DRILL Vibracore Snell

12. TOTAL SAMPLES : DISTURBED 2 : UNDISTURBED 2

13. TOTAL NUMBER CORE BOXES N/A

14. ELEVATION GROUND WATER 0.0

15. DATE BORING : STARTED 2/20/09 : COMPLETED 2/20/09

16. ELEVATION TOP OF BORING 0.0 (MLLW)

17. TOTAL CORE RECOVERY FOR BORING N/A

18. SIGNATURE AND TITLE OF INSPECTOR Larry Benjamin, USACE, Civil Engineer Technician

ELEV	DEPTH	Blows/ 0.5 ft	N_1	N_{60}	LEGEND	FIELD CLASSIFICATION OF MATERIALS (Description)	% REC	Samp No.	Laboratory Gravel	Granular	Sand	Fines	#230	MC	ASTM Class
						0' to 13.3': Water. River Bottom at depth 13.3'									
-13.3	13.3					**13.3' to 16.7':** SP, Tan, Coarse, Poorly Graded Sand with Shell Fragments		1	15	6	75	4	4	24	SP
								2							
-16.7	16.7					**16.7' to 23.3':** No Recovery									
-23.3	23.3														

REMARKS

ASTM

Time begin vibracoring: 1505 hrs

Soil described by Larry Benjamin, Civil Engr. Tech

NOTE: Top of hole is defined as surface of water and compensation is made for the tide such that top of Hole is 0.0' EL MLLW.

VIBRACORE BORING

From 0.0' to 10.0'
Ran 6.5' Rec: 3.4'

Top of vibracore soil sample is logged beginning at River Bottom.
When Run is greater than Recovery, the difference is depicted as Assumed Not Recovered.

Note: Soils Commercial Lab Classified in Accordance with ASTM - D2487

LAB CLASSIFICATION

Jar Number	Classification
1	SP
2	-

Note: Hole Terminated at Predetermined Depth at 10.0'

0.0 2.5 5.0 7.5 10.0 12. 15. 17. 20. 22.

BOTTOM OF BOREHOLE AT 23.3 FT.

NOTE:
SOILS ARE FIELD VISUALLY CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

ACE 1836-A (DRILLING LOG) LOCKWOOD FOLLEY INLET CROSSING-REV.GPJ ACE MVD WITH RAPID CPT 06-09-08.GDT 9/30/09

ARDAMAN & ASSOCIATES, INC. GEOTECHNICAL TESTING LABORATORY
PARTICLE-SIZE ANALYSIS TEST REPORT

CLIENT: USACE, WILMINGTON DISTRICT
PROJECT: AIWW CAPE FEAR TO LITTLE RIVER
TANGENT 11
FILE NO.: 09-142
DATE SAMPLE RECEIVED: 06/24/09
DATE TEST SET-UP: 06/24-29/09
DATE REPORTED: 07/13/09

INCOMING SAMPLE NO.: -----
BORING **LFIXAIWW-V-09-10** SAMPLE 1
DEPTH 13.3 - 13.8 ☒ ft; ☐ m
LABORATORY IDENTIFICATION 09142/LFIXAIWWV09101
SAMPLE DESCRIPTION: Dark gray sand with some shells, SP

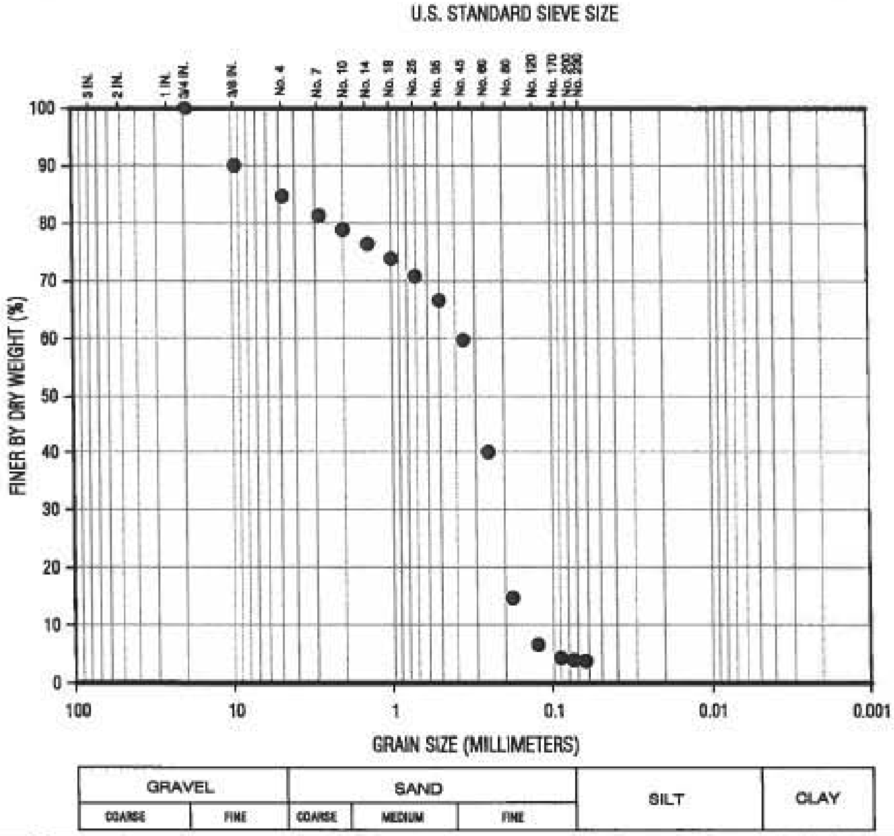
TEST PROCEDURES

ASTM Standard D 422: ☒ Sieve Analysis
☐ Other:

Moisture Content (%): 24.0
Wt. Dry Solids (grams): 529.38

Visually Estimated Shell Content(%): 30

Measured Carbonate Content [ASTM D 4373] as $CaCO_3$ (%): --



Percent Finer (dry wt. basis)

Gravel			Coarse Sand		Medium Sand				Fine Sand						Silt/Clay
3/4"	3/8"	No. 4	No. 7	No. 10	No. 14	No. 18	No. 25	No.35	No. 45	No. 60	No. 80	No. 120	No. 170	No. 200	No. 230
100	90.0	84.6	81.3	78.9	76.4	73.9	70.8	66.6	59.7	39.9	14.6	6.6	4.3	3.9	3.7

Visually Estimated Shell Content (percent)

0	100	100	100	100	100	70	55	15	5	Shell Content <5% (Amount not visually estimated)

The test data and all associated project information presented hereon shall be held in confidence and disclosed to other parties only with the authorization of the Client or Ardaman & Associates, Inc. Physical and electronic records of each project are kept for a minimum of 7 years. Test samples are kept in storage for at least 10 working days after mailing of the test report, prior to being discarded, unless a longer storage period is requested in writing and accepted by Ardaman & Associates, Inc.

Checked By: JCW Date: 10/26/09

Appendix D

Draft Inlet Management Plan

DRAFT INLET MANAGEMENT PLAN
LOCKWOODS FOLLY INLET, NC

1.0 INTRODUCTION

The Town of Holden Beach (herein referred to as the "Town") has proposed the construction of a terminal groin and a concurrent 150,000 cubic yard (cy) beach nourishment at the east end of Holden Beach, adjacent to Lockwoods Folly (LWF) Inlet, as part of its ongoing beach management activities. Projects involving terminal groins are required to include an inlet management plan to monitor impacts on coastal resources, among other things. Specifically, Senate Bill 110 § 113A-115.1(e)(5) calls for:

> "A plan for the management of the inlet and the estuarine and ocean shorelines immediately adjacent to and under the influence of the inlet. The inlet management plan shall do all of the following relative to the terminal groin and its accompanying beach fill project:
>
> a. Describe the post-construction activities that the applicant will undertake to monitor the impacts on coastal resources.
> b. Define the baseline for assessing any adverse impacts and the thresholds for when the adverse impacts must be mitigated.
> c. Provide for mitigation measures to be implemented if adverse impacts reach the thresholds defined in the plan.
> d. Provide for modification or removal of the terminal groin if the adverse impacts cannot be mitigated."

2.0 PHYSICAL MONITORING

2.1 EXISTING MONITORING

As part of its ongoing beach management plan, the town of Holden Beach routinely monitors the shoreline from Shallotte Inlet to LWF Inlet with annual bathymetric surveys dating back to 2000. These surveys encompass LWF Inlet and ebb shoal areas. Beginning with the April 2012 survey, an additional six transects were included on western Oak Island "in order to more closely monitor inlet-related effects and establish more consistent baseline data" (Holden Beach Annual Monitoring Report, ATM, 2012). Figure D-1 shows an overview of the latest Town survey from April 2012. The U.S. Army Corps of Engineers (USACE) also performs routine bathymetric surveys of LWF Inlet, the Atlantic Intracoastal Waterway (AIWW) inlet crossing (LWFIX), and the bend widener section of the AIWW inlet crossing (see Figures D-2 and D-3).

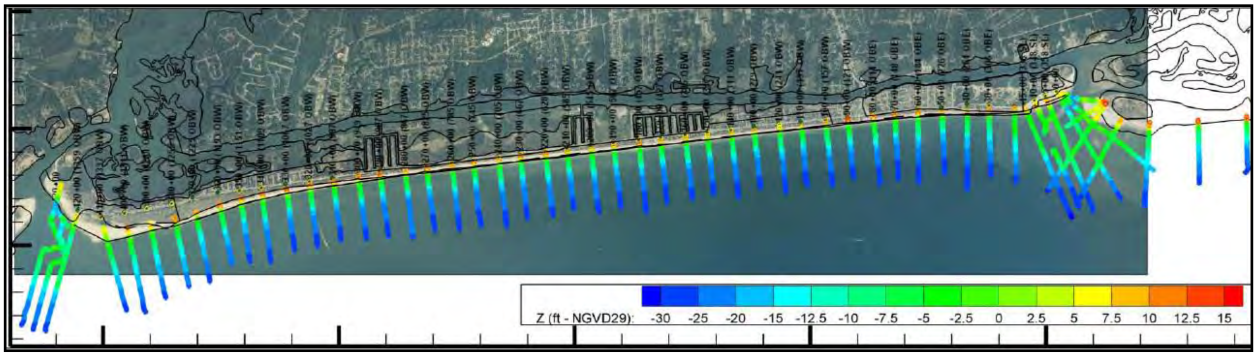


Figure D-1. Town of Holden Beach Annual Bathymetric Survey, April 2012 (2008 Aerial).

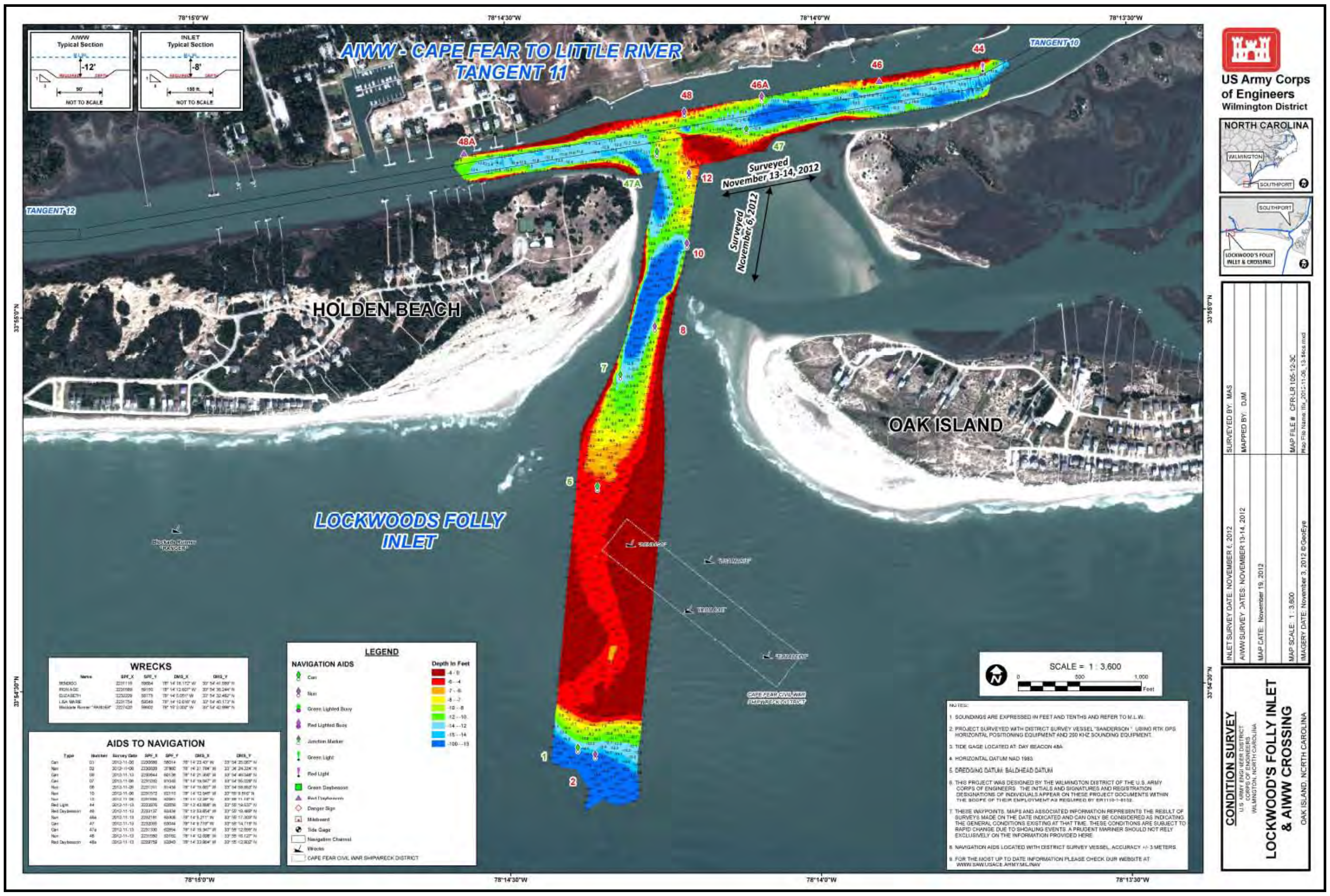


Figure D-2. USACE LWF Inlet, AIWW Inlet Crossing, and Bend Widener November 2012 Survey (source: Wilmington USACE Navigation Branch).

Additional physical monitoring beyond the ongoing efforts by the Town of Holden Beach and USACE will be necessary to fully observe any potential project-related effects to surrounding areas as part of the inlet management plan.

2.2 PROPOSED BEACH FILL AND INLET AREA MONITORING

Pre-project and post-project beach profile surveys will be performed at the 16 control reference transects depicted in Figure D-3. These transects coincide with ongoing annual survey transects performed by the Town of Holden Beach. Figure D-3 also shows zones of special interest within the inlet area specific to potential groin impacts. The proposed transects cover all areas except for the flood shoal, AIWW inlet crossing, and bend widener. The USACE routinely surveys the AIWW inlet crossing and bend widener. The latest surveys available will be used as the pre-project conditions for these areas. Additional surveying will occur to accurately define conditions of the flood shoal.

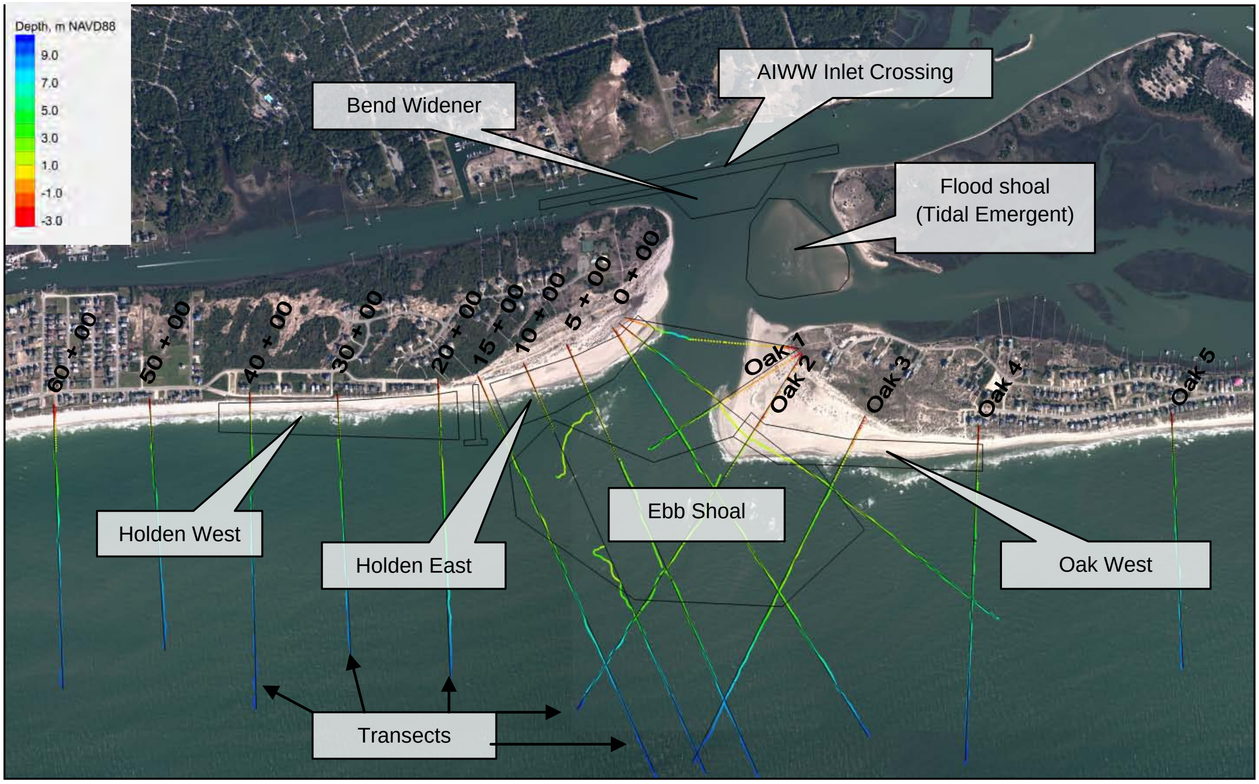


Figure D-3. Pre- and Post-Project Physical Monitoring Transects and Zones. Survey transects shown are from 2012; the aerial is from 2011.

Immediate pre-project and immediate post-project and annual surveys thereafter will be performed from the primary dune (or equivalent) to a minimum elevation of -25 ft referenced to the North American Vertical Datum of 1988 (NAVD88). This elevation typically occurs within 2,500 ft from the shoreline. All survey lines will be terminated if a distance of 2,500 ft is reached prior to the target depth. Landside spot elevations will be measured at a maximum of 25 ft intervals, with higher density in areas of significant features such as escarpments or any notable change in elevation. Hydrographic soundings (vessel survey portion) will be reported at a minimum of approximately 25 ft intervals. All profiles will be surveyed approximately along and parallel to the monitoring transects as shown on Figure D-3 (note latest survey transect at station 10+00 shown was disrupted by a shoal/sandbar). These transects can extend landward or seaward as needed to meet established minimum depths. Due to the natural migratory nature of LWF Inlet, survey transect extents may vary from survey to survey. Annual surveys will also include “flood shoal” surveys extended to wading depth (i.e., no vessel survey component), with spot measurements at a maximum of 25-ft grid spacing with higher density in areas of significant features such as escarpments, or any notable change in elevation.

Semi-annual profile surveys will be extended to wading depth only (i.e., no vessel survey component). Surveys will include the primary dune (or equivalent) and extend to -6 ft NAVD88 (i.e., wading depth at low tide).

2.3 BEACH PROFILE AND INLET AREA MONITORING SCHEDULE

A pre-construction survey will be performed within 4 weeks prior to the commencement of beach fill placement. This survey will document the baseline conditions immediately prior to construction. Similarly, an immediate post-construction survey will be performed within approximately 4 weeks following completion of beach fill and groin construction. It is assumed that beach nourishment will occur either before or concurrent with groin construction. This will more easily allow the groin to be constructed from land. Table D-1 presents the proposed surveying timeline for the inlet management plan.

Semi-annual surveys are proposed to occur in the first through fifth years following construction. The ongoing annual survey schedule will resume in Year 6 of the project and continue into the foreseeable future. Annual surveys will include transects along all of Holden Beach shown in Figure D-1 as part of the Town’s ongoing monitoring.

Table D-1. Physical Monitoring Survey Schedule

Survey*	Timeline	Beach Survey Extents
Pre-Project Survey	within 4 weeks of project initiation	Dune to -25 ft NAVD88+Flood Shoal
Post-Project Survey	within 4 weeks of project completion	Dune to -25 ft NAVD88
Semi-annual	6 months post-project	Dune to -6 ft NAVD88
Annual	1 yr post-project	Dune to -25 ft NAVD88+Flood Shoal
Semi-annual	1.5 yr post-project	Dune to -6 ft NAVD88
Annual	2 yr post-project	Dune to -25 ft NAVD88+Flood Shoal
Semi-annual	2.5 yr post-project	Dune to -6 ft NAVD88
Annual	3 yr post-project	Dune to -25 ft NAVD88
Semi-annual	3.5 yr post-project	Dune to -6 ft NAVD88
Annual	4 yr post-project	Dune to -25 ft NAVD88+Flood Shoal
Semi-annual	4.5 yr post-project	Dune to -6 ft NAVD88
Annual	5 yr post-project	Dune to -25 ft NAVD88+Flood Shoal
Semi-annual	5.5 yr post-project	Dune to -6 ft NAVD88
Annual (ongoing)	Ongoing surveys resume annually	Dune to -25 ft NAVD88+Flood Shoal

*The most recent available USACE AIWW inlet crossing, bend widener, and LWF inlet surveys will be used in conjunction with annual surveys. All annual surveys will include survey of flood shoal.

The most recent available USACE AIWW inlet crossing, bend widener, and LWF Inlet surveys will be used in conjunction with this monitoring schedule. The USACE typically surveys these areas several times a year. However, if USACE surveys have not occurred within 4 months of the annual survey, these areas will be surveyed during the Town's survey collection effort. This additional surveying area is presented in Figure D-4.

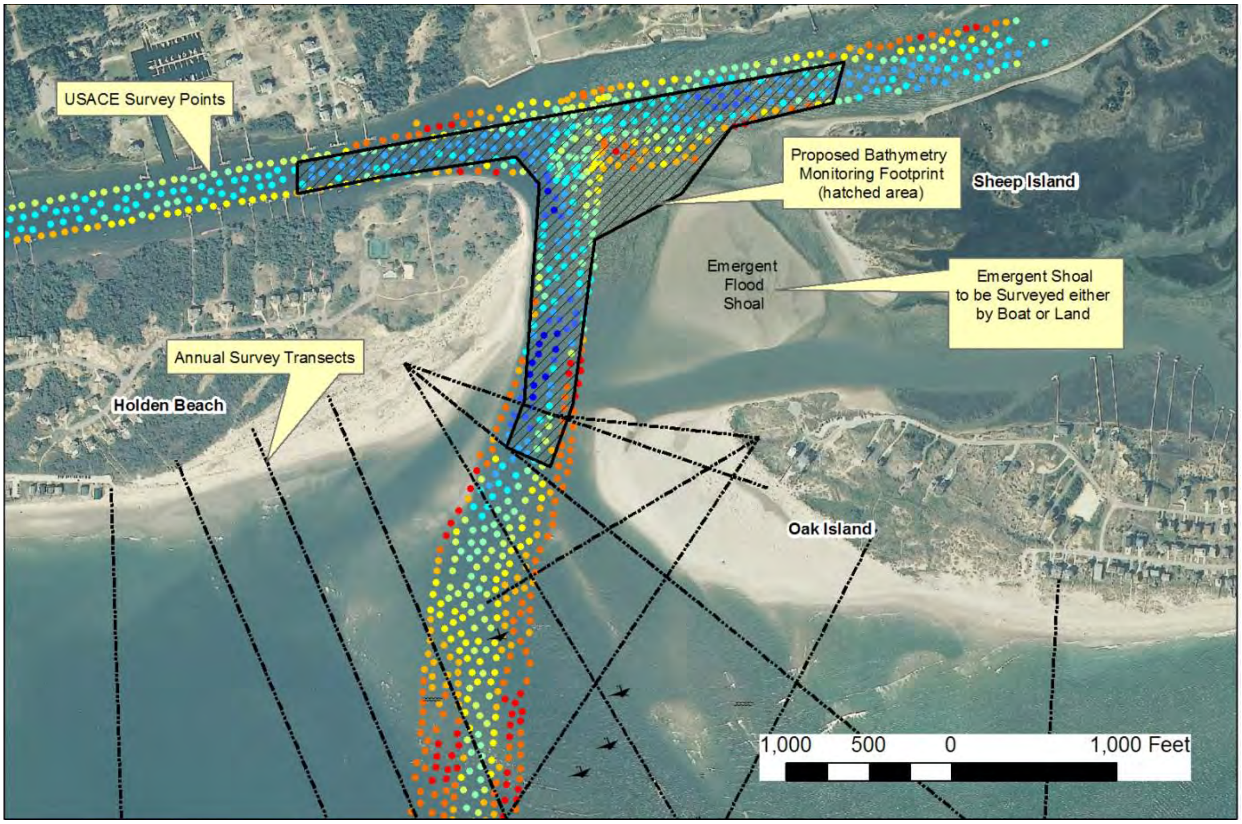


Figure D-4. Proposed Bathymetric Data Collection, if No Recent USACE Survey Data are Available. Bathymetry footprint may vary based on shoaling/navigable depths.

2.4 AERIAL PHOTOGRAPHY

Aerial photographs of the study area that include the survey transects in Figure D-3 will be obtained twice a year in the first 2 years after groin construction. During Years 3 through 5 following construction, aerial photographs will be taken once per year. At the end of 5 years, the applicant will coordinate with regulatory agencies to determine whether additional annual aerial photographs are required.

2.5 SURFICIAL SEDIMENT SAMPLING

Surface beach sediment samples will be collected along two transects within the project construction limits and along three transects outside of the project footprint during survey events from pre-construction to 2 years post-construction. These locations are identified in Figure D-3 as Station 60+00 (west control), Oak 3 (east control), 20+00/30+00 (project), and 10+00 (inlet control). Samples at each of these transect profiles will be collected at three cross-shore locations. The sample locations correspond approximately to the +6 ft, +3 ft, and -3 ft elevation contours referenced to NAVD88. Sediment samples will be analyzed using standard ASTM procedures for grain size distribution, percent fines, color, and visually for shell content. In addition, these samples will be used in support of biological monitoring discussed in subsequent sections.

2.6 PHYSICAL MONITORING DATA ANALYSIS

The monitoring data collected will be analyzed to determine volume and shoreline changes in the project area and the adjacent beaches, and to assess project performance. The following analyses will be performed, at a minimum:

- Beach profile comparison plots: The current survey for each profile will be graphically compared to the previous survey(s).
- Shoreline change analysis: The shoreline (typically the mean high water line) positions between consecutive surveys will be compared, plotted, and analyzed for mean and extreme changes.
- Volume change analysis: Project placement volumes will be compared with volume remaining in the active profile at the time of each survey. Estimates of cross-shore and longshore sediment volume changes will be calculated and compared with each subsequent survey, to the extent possible.
- Sediment grain size distribution: Sediment samples will be analyzed and compared to the composite mean grain size of the native beach material.
- Storm events: Any significant storm events that affect the project beach will be described based on available local meteorological data.
- Performance assessment: An overall project performance assessment will be based on the design goals and current state of the project determined through the data collection and analysis efforts described above.

3.0 BIOLOGICAL MONITORING

The following macro-invertebrate monitoring plan is proposed to monitor the subsequent effects of the beach fill and terminal groin project on selected burrowing macro-invertebrate species that have been shown to be indicators of the ecological response of the beach system. The Town’s biological sampling program currently includes the coquina or bean clam (*Donax variabilis* and *Donax parvula*), mole crab (*Emerita talpoida*), and ghost crab (*Ocypode quadrata*), which are three often-used indicators of beach ecological health (Greene, 2002).

The bean clam and mole crab primarily inhabit the swash zone, whereas the ghost crab primarily inhabits the dune area. The purpose of the monitoring plan is to provide statistical data to evaluate any effects of the biological system within the project area footprint to control areas. A standard Before After Control Impact (BACI) protocol will be implemented.

The proposed biological monitoring program will build upon the existing program. The Town completed a similar biological monitoring survey in 2010 as part of its post-nourishment monitoring plan for the beach nourishment completed in 2009. This survey included transects 30+00 and 60+00, transects also proposed in this monitoring plan. This existing data will be helpful in statistical analysis and biological assessment.

3.1 BIOLOGICAL MONITORING METHODS

Primary components of the monitoring plan will consist of collecting sampling cores within the intertidal region to monitor mole crab and bean clam abundances. In addition, recovery of the ghost crab will be observed by the number of active ghost crab burrow holes on the upper portion of the beach. Monitoring will be conducted along two transects (Figure D-3) within the project reach (20+00 and 30+00) and along three transects outside the project footprint, one to the west (60+00), one on the inlet shoulder (10+00) and one to the east (Oak 3). Surficial sand samples will also be obtained at the same transects to correlate macro-invertebrate recovery with sediment characteristics.

3.1.1 MOLE CRAB AND BEAN CLAM

Sampling cores for mole crab and bean clam will be collected at three stations along each transect; three cores at the mid-tide level, three cores at the low tide mark, and three cores taken in shallow water. From a timing perspective, sample collection shall occur as close to low tide as possible. Cores will be obtained using a cylindrical core with inside diameter of 10 centimeters (cm) and a depth of 15 cm. Samples will be passed through a 0.5 millimeter (mm) stainless steel sieve to separate sediment from infauna. Biological samples will be photographed and measured, then returned to the sampling location.

3.1.2 GHOST CRAB

Active ghost crab burrow hole counts will be performed along the upper portion of each transect, between the mid-tide mark and the toe of dune. Swaths 4 meter (m) wide will be laid out along each transect and active burrow holes will be identified by the observation of fresh ghost crab tracks around each hole. From a timing perspective, ghost crab counts shall occur as close to low tide as possible.

3.1.3 SURFICIAL SEDIMENT SAMPLES AND COMPATIBILITY

Five physical factors predominantly control the distribution and abundance of biota in the intertidal zone: wave energy, bottom type (substrate), tidal exposure, temperature, and salinity (Dethier and Schoch, 2000; Ricketts and Calvin 1968). Surface beach samples will be obtained to correlate any potential invertebrate effects with the placed material. Surface beach sediment samples will be collected as described in Section 2.5.

3.2 BIOLOGICAL MONITORING DATA ANALYSIS

Statistical comparison between species abundances (mole crab and bean clam) and burrow hole counts (ghost crab) within the project reach and within the control areas will occur to assess any potential effects of the project on the macro-invertebrate community. Sampling will be conducted immediately prior to construction, within 60 days following completion of construction, and again at 6 months post-construction. A 1-year and 2-year post construction sampling survey will also occur while additional surveys following the 2-yr post-construction event may be required, depending on previous results. The following analyses will be performed, at a minimum:

- Macro-invertebrate abundances comparison plots: A comparison between macro-invertebrate abundances within the project reach versus the control areas for each species. Comparisons to previous sampling events where applicable.
- Sediment compatibility analysis: Statistical native and fill grain size analyses will be performed.

4.0 MONITORING REPORT

A monitoring report summarizing the physical and biological data collected and the analyses described in Sections 2 and 3 will be submitted to the Town and regulatory agencies within 90 days of completion of each field survey. The report will also include an assessment of post-project macro-invertebrate recovery and overall project performance. The first report will be completed following project construction and will include pre- and immediate post-construction survey data.

5.0 POST-PROJECT ANALYSIS AND MITIGATION

Mitigation work required due to documented adverse impacts resulting from groin construction may include renourishment of the beach adversely affected by the groin; reconfiguration, notching or shortening of the groin; and/or complete removal of the groin. The exact form of mitigation required will depend on the location, type, and extent of the adverse impact. When mitigation work is required, it will be completed as soon as possible after the permitting agencies determine need for the action, typically within 3 months. However, a longer time may be allocated to avoid impacts during sea turtle nesting season or other natural resources concerns. The Town has independently maintained a regular source of funding [i.e., the Beach Preservation/Access & Recreation/Tourism (BPART) Fund] for, among other things, its beach management activities. This fund has regularly financed the Town's nourishments and accompanying projects for the past decade. If it is required, the BPART fund would be available to finance any mitigation. The subsequent sections describe the methodology for determining adverse impacts, establishing thresholds required for mitigation, and the mitigation methods and alternatives.

5.1 EFFECTS OF LOCKWOODS FOLLY INLET

According to the [North Carolina Beach and Inlet Management Plan (NC BIMP)], between 1858 and 1938, LWF Inlet migrated westward approximately 2,300 ft to its present location (NC BIMP, 2011). Cleary and Marden (2001) estimate that the midpoint of LWF Inlet has migrated approximately 500 ft west since 1938. Several other studies have analyzed the movement of LWF Inlet over the last century, including Cleary (1996, 2008) and CSE (2009). The North Carolina Department of Environment and Natural Resources (NCDENR) also developed a shoreline analysis using historical aerials shown in Figure D-5. As Cleary (1996) states, "Although the inlet has been locationally stable, there has been considerable morphologic change within the inlet, its shoals and along adjacent shorelines." A chronic erosion trend exists along the east end of Holden Beach, up to 2 kilometers (km) from LWF Inlet. The approximate influence of LWF Inlet is 2 km in both the eastern (Oak Island) and western (Holden Beach) directions (Cleary, 1996; Cleary, 1998).

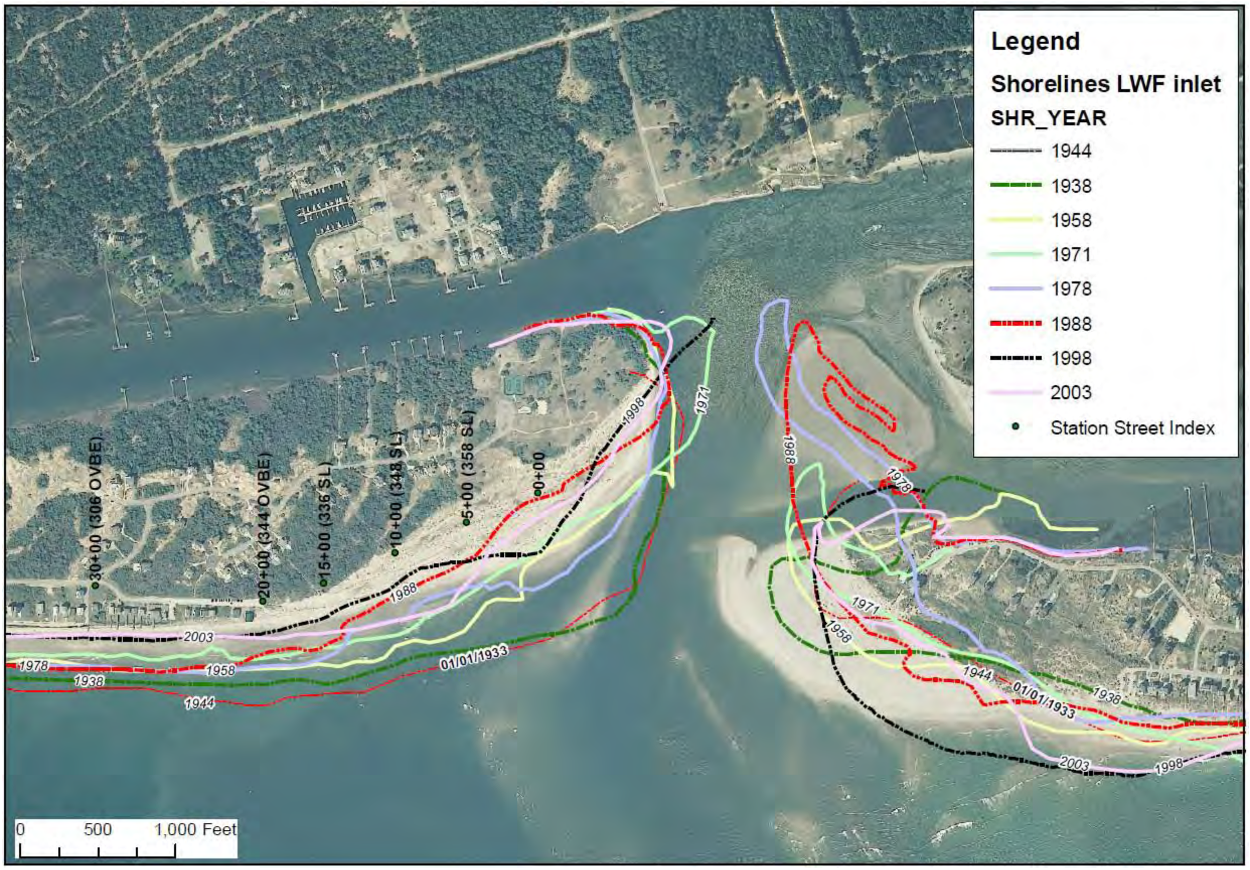


Figure D-5. Historical Shoreline Change of Lockwoods Folly Inlet Area.

Lockwoods Folly Inlet outer channel orientation/alignment has also been documented to affect shoreline erosion intensity (Cleary, 1996; 2008). The USACE Navigation Branch conducts outer channel dredging and follows deep water. Over the last century, channel alignment has been closer to the Oak Island shoreline, which has been cited as favorable for Oak Island, while increased erosion occurs on Holden Beach. This effect results from the alignment affecting wave propagation and flood channels.

Concerning inlet area shoreline morphology, Cleary (1996) states:

> Within 100 m of LWF Inlet, the Holden Beach shoreline has eroded 260 meters during the past 58 years, at an average of 4.5 meters per year. For a brief period during the late 1970s, accretion took place along this reach due to reorientation of the ebb channel, but today erosion continues along much of the eastern margin of the island.
>
> The most dramatic changes to Long Beach [Oak Island] have occurred within 400 meters of the inlet. Since 1938, this area has experienced an average net accretion of 1 meter per year, though it was plagued by serious erosion in the 1970s and 1980s. Almost 100 meters of shoreline eroded between 1974 and 1986, at an average of 8 meters per year. During this time, the flood channel was positioned along the Long Beach shoulder, causing rapid erosion, but since 1986 the shoreline has built up again by 185 meters.

Warren and Richardson (2010) performed a statistical shoreline analysis (standard deviation of shoreline position and average rate of shoreline change) that identified Transect 530 as the point along the oceanfront where LWF Inlet processes were no longer dominant [see Figure D-6 for North Carolina Division of Coastal Management (NCDCM) and Town stationing]. Figure D-7 shows the same analysis for Oak Island. The 2011 setback factors (SBF) as determined by DCM are also presented in Figures D-6 and D-7. Note that the western Oak Island SBF is 2 ft, which is the state minimum and generally denotes stable/accretional shoreline conditions for the period of analysis (1944 to 2009).

Figure D-6. Current and Proposed IHA Boundaries. 2011 setback factors (SBF) and 2004 erosion rates also pictured.

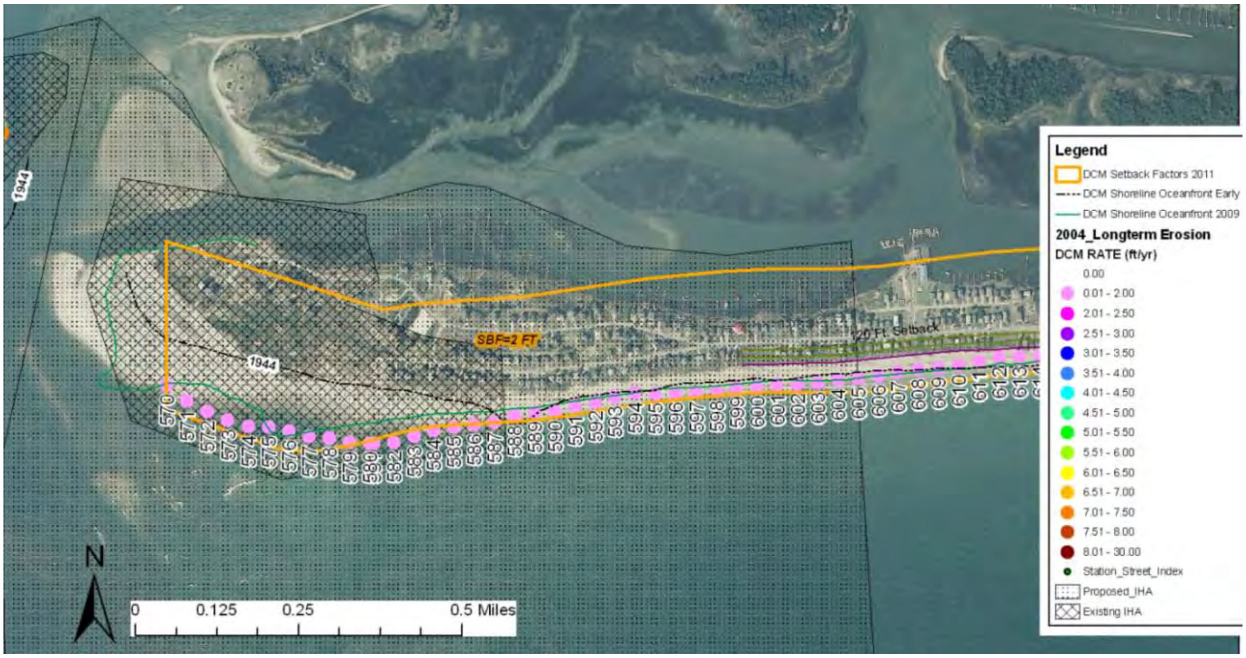


Figure D-7. Oak Island Existing Inlet Hazard Area (IHA) and Proposed IHA. The IHA areas indicate areas of inlet influence.

Terminal groins, as with all groins, typically hold sand on the updrift side (forming a “fillet”), with potential affects to downdrift beaches under extremely erosional conditions. In a regional net transport sense, Holden Beach is downdrift of the proposed eastern end terminal groin. However, locally (where the net transport is to the east), the inlet throat itself is downdrift of any groin placed along the inlet margin (see Figure D-8).

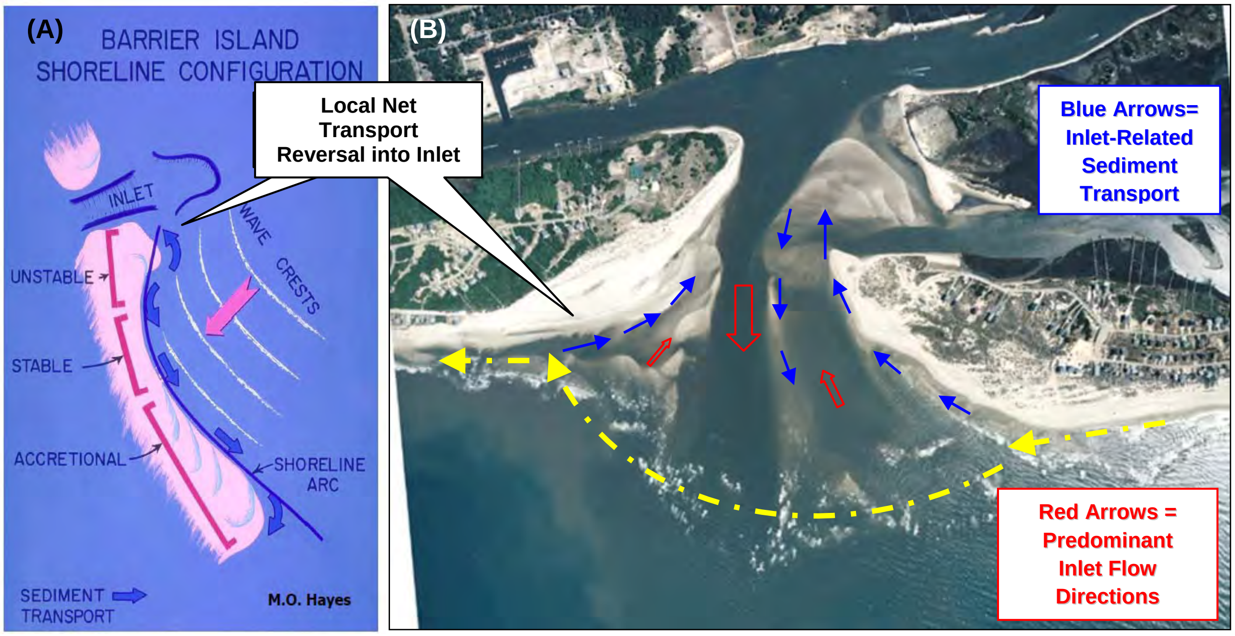


Figure D-8. (A) Generalized Net Sand Transport near an Inlet (Source: Hayes). Note that net transport reverses to the south of the inlet. (A) very closely resembles (B), typical net transport trends at LWF Inlet and on Holden Beach.

5.2 HURRICANE AND STORM EFFECTS

Hurricanes are typically the most extreme episodic events to affect shorelines in the region. For example, in 2008, Hurricane Hanna significantly affected the Holden Beach shoreline. Hanna made landfall approximately 20 miles west of Holden Beach on September 6, 2008. This subjected the Holden Beach shoreline to the most intense northeast quadrant conditions due to the counter-clockwise storm rotation. As a result, the entire area suffered damage; however, the east end exhibited more erosion than the rest of the island. Table D-2 presents losses per linear foot along the east end from Hurricane Hanna. Up to 21.2 cubic yards per foot (cy/ft) was lost at Station 20+00, while the Central Reach shoreline lost an average of 8 cy/ft. Figure D-9 presents a post-Hanna photo on the east end, showing significant dune and upper beach erosion. Dune unit volumes [above 7 feet referenced to the National Geodetic Vertical Datum (ft NGVD)] on the east end have averaged approximately 6 cy/ft, according to surveys ranging from 2000 through 2012.

Table D-2. Unit Volume Change due to Hurricane Hanna

Station	Unit Volume Change (cy/ft) due to Hurricane Hanna
15+00	-1.6
20+00	-21.2
30+00	-5.3
40+00	-12.3

Figure D-9. Post Hurricane Hanna Image Showing Dune Losses on the East End of Holden Beach (~Station 25+00).

5.3 SHORT-TERM CHANGE (STATION 10+00)

In an effort to characterize short-term change in the locally downdrift zone of the inlet management area (Station 10+00, see Figure D-3), available survey data from Holden Beach surveys were analyzed from 2000 to 2012. Fifteen transects were available at this location for analysis, however, they varied in survey extents (i.e., how far landward and seaward they extend). As a result, only 14 of these transects had sufficient data for a volume calculation of the upper beach down to -8 ft NAVD88. The surveyed transects are presented in Figure D-9.

Data were analyzed using BMAP (Beach Morphology Analysis Package) software and analyzed by volume change down to -9 ft NAVD88 and to MHW contour change (+1.8 ft NAVD88). Table D-3 presents tidal datums for the project site, using the Yaupon Beach, Oak Island NOAA station. Volume and MHW shoreline changes from consecutive surveys are presented in Figures D-10 and D-11. Extreme variability is exhibited from survey to survey. Surveys were taken at variable intervals, where many intervals were less than a year. Surveys also vary by season. The post-Hurricane Irene survey (note extreme MHW erosion in Figure D-11 between May and September 2011) was not included in volume calculations due to survey extents.

Table D-3. Project Site Tidal Datums

NOAA Station: Yaupon Beach, Oak Island	Feet (NAVD88=0)
MHHW	2.2
MHW	1.8
NAVD88	0.0
MSL	-0.5
MTL	-0.6
NGVD29	-1.1
MLW	-2.9
MLLW	-3.1

Table D-4 shows MHW and volume change statistics for Station 10+00. Variation seen from consecutive surveys is large, where a standard deviation for annualized MHW change is 109.3 ft/yr. A standard deviation for annualized volume change is 47.9 cy/ft/yr. Due to the variation, a moving average consisting of three consecutive surveys is included in Figures D-10 and D-11 to smooth individual survey variation. A similar method of using three consecutive surveys for smoothing is proposed for threshold analysis, described in the following section.

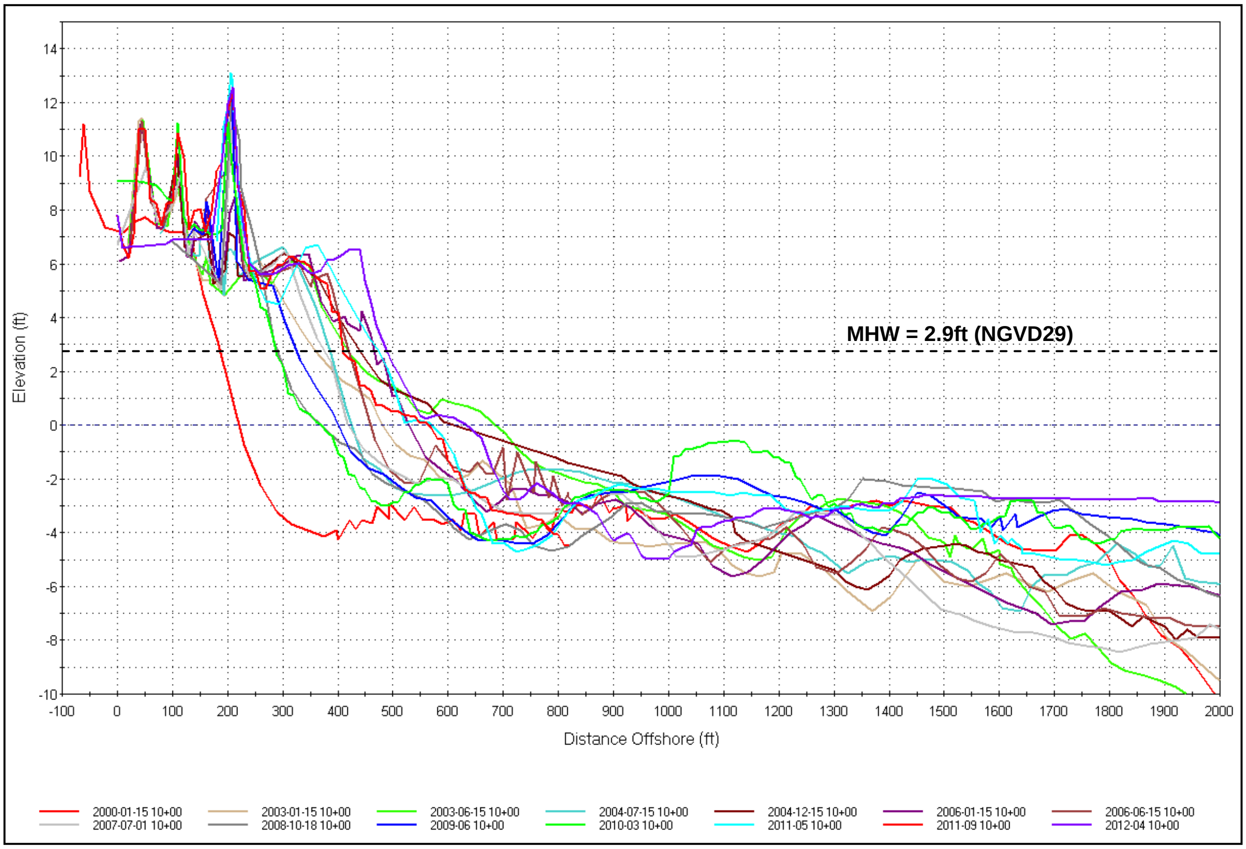


Figure D-10. Station 10+00 Survey Profiles, elevations are feet NGVD29.

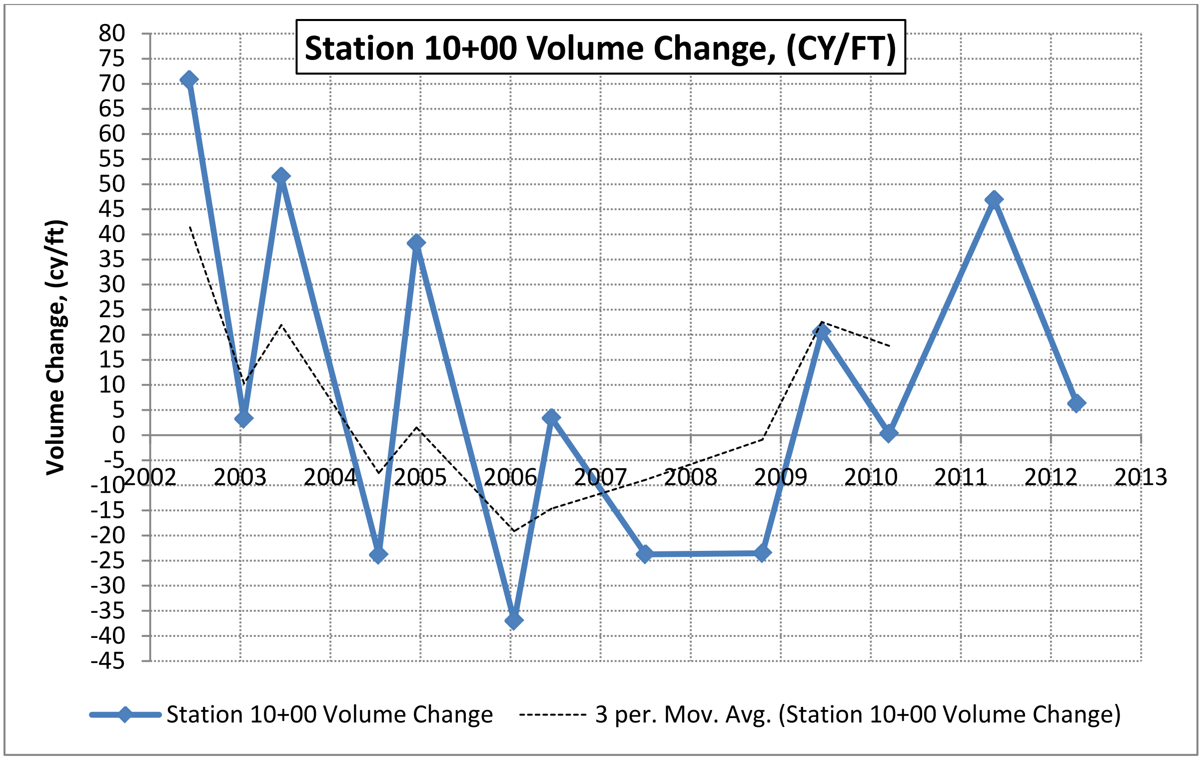


Figure D-11. Station 10+00 Unit Volume Change (cy/ft). A 3 point moving average is also plotted.

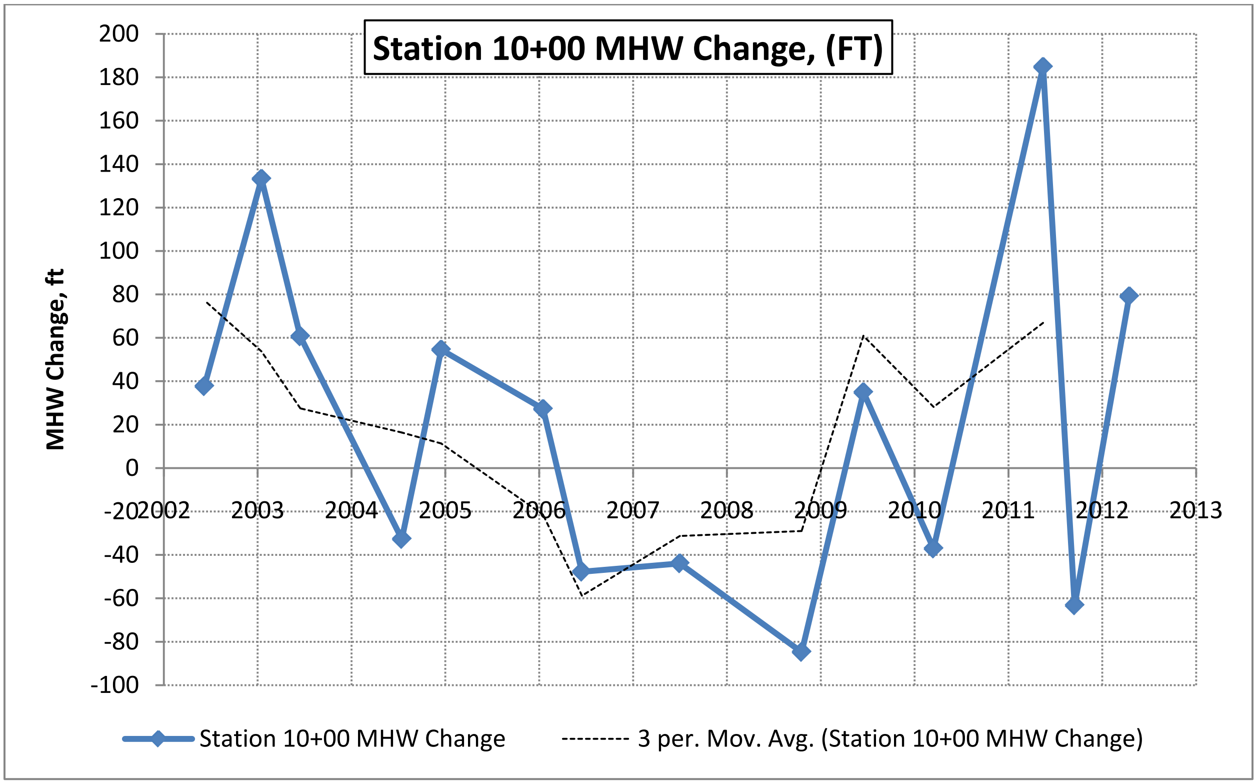


Figure D-12. Station 10+00 MHW Change (MHW=+2.9ft NGVD29). A 3 point moving average is also plotted.

Table D-4. Station 10+00 MHW and Volume Change Statistics

	MHW Change (ft)	Annualized (ft/yr)	Volume Change (cy/ft)	Annualized (cy/ft/yr)
Minimum	-84.8	-187.9	-37.0	-34.1
Mean	21.6	28.1	10.2	18.5
Maximum	184.8	219.1	70.8	124.6
St. Dev.	78.2	117.9	33.5	46.1

5.4 THRESHOLDS

The information presented in Sections 5.1 through 5.3 indicates that the naturally occurring processes of the inlet channel and shoal migration may overshadow the effects of the proposed groin. Previous studies and the physical history of the project site also reveal a profoundly dynamic morphological environment, specifically within the inlet area and along adjacent shorelines.

While in a regional sense Holden Beach is downdrift of the terminal groin, locally, the sediment transport is directed into LWF Inlet. Since the chief concern of potential terminal groin impacts is downdrift of the structure, it is proposed that Station 10+00 be the monument used for establishing a trigger.

NCDENR DCM long-term shoreline erosion rates at Station 10+00 are 7 ft per year (Figure D-5); however the trigger methodology must also take into account short-term shoreline/volume change rates as well because of the frequency of the surveys. Volume change rates (cy/ft/yr) are favored over shoreline change rates (ft/yr) due to the potential for specific shorelines (e.g., MHW, MLW, etc.) to change rapidly under seasonal and storm conditions.

In general, there will be three layers to the methodology for evaluation of potential post-project impacts: 1) comparison of post-project volume change rates to historical (i.e., background) erosion rates, using recent (2000-2012) statistical variations as a guide; 2) comparison of LWF Inlet dynamics and effect on nearby shorelines, and 3) comparison of post-project volume change rates within the monitoring area to adjacent shoreline reach post-project and historical change rates. The third comparison is anticipated to be needed if significant nor'easter(s), tropical system(s), or an extended period of higher wave activity occurs where shorelines over the entire region experience higher than typical erosion rates. More discussion on these components is presented in the following paragraphs.

1. At Station 10+00, survey data can vary significantly from survey to survey, depending on the season and recent wave activity, among other influences. The NCDENR DCM long-term shoreline erosion rate of 7 ft/yr can be equated to a baseline volume loss of 7 cy/ft/yr. Based on the standard deviation of 46.1 cy/ft/yr in Section 5.3, mitigation will be required if an annualized volumetric erosion rate of 53 cy/ft/yr (baseline + annualized standard deviation) is exceeded for three consecutive surveys due to presence of the groin. The statistical method of including the mean (baseline) +/- one standard deviation is commonly used to encompass 68 percent of

possible outcomes, assuming a normally distributed variable (e.g., shoreline change). Outcomes outside of this 68 percent can be considered outliers, or abnormal results (e.g., potential groin effects). This volumetric change will be measured over approximately 960 feet, from 188 ft to 1,148 ft at Station 10+00 as shown in Figure D-13. This zone includes the current dune to approximately -6 ft NGVD88 and was chosen to avoid the majority of inlet/shoal migration influences.

2. Comparison of the configuration of LWF Inlet is of critical importance in assessing groin and nourishment effects. This analysis will use aerial photography and bathymetric data to develop an overview of the LWF Inlet system. Bathymetric data will be summarized by zones (see Figure D-3). Due to LWF Inlet complexities and annual/seasonal variations, no quantitative mitigation zone thresholds are proposed for the project; however, analysis will occur to evaluate potential project effects. Zone volume changes will also be compared to changes as developed for sediment budgets (e.g., 2008 OCTI sediment budget – Figure D-14). Note that volume change within the LWFIX borrow area zone and groin-adjacent zones will be directly related to future nourishment planning/scheduling.

3. In addition to post-project comparisons to historical rates, nor'easters and tropical storms impacts can also affect individual monitoring events, therefore, relative comparisons (between downdrift and control beaches) are needed. The wading-depth surveys do save on costs; however, they do not include the entire active beach profile, and measurements are vulnerable to cross-shore adjustments/variability.

Mitigation may not be required following catastrophic or significant storm events (i.e., with a return period of 5 years or greater). Note that the Federal Emergency Management Agency (FEMA) typically uses the 5-year return period for beach-related storm mitigation; although they will respond to most events where the Governor declares a state of emergency.

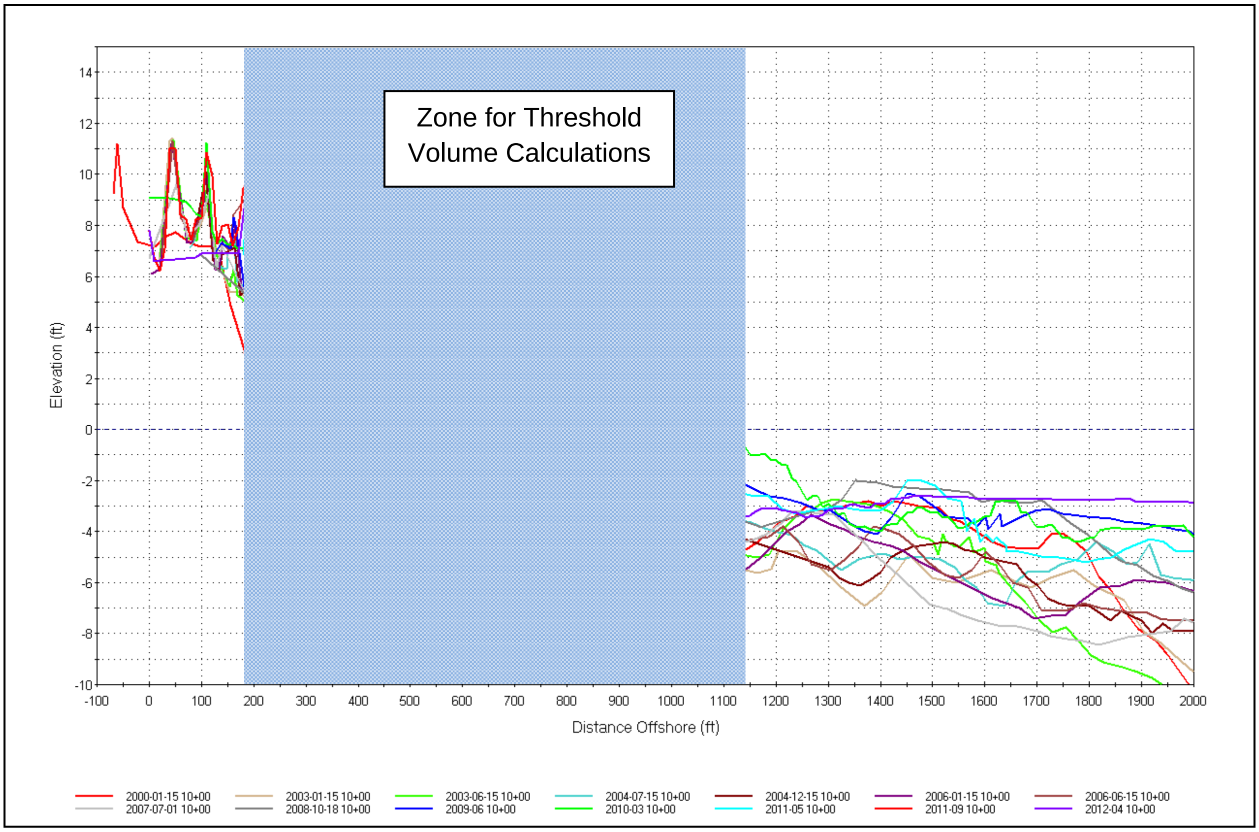


Figure D-13. Station 10+00 Zone for Threshold Volume Calculations, elevations are feet NGVD29.

Figure D-14. LWF Inlet sediment budget as developed by OCTI (2008). All values are 1,000 cubic yards (cy) (e.g., 290=290,000 cy). Black arrows indicate sediment transport in/out of cells. dV=annual volume change, P=annual placement, R=annual removal, Res=annual residual.

6.0 SUMMARY

The Town of Holden Beach remains committed to the successful long-term health of the shoreline in and surrounding the project area. As a result, it will adhere to all monitoring and mitigation as required by regulatory agencies to ensure the success of the proposed project. In this respect, the Town will monitor the project site as well as the inlet management area to document project performance and any potential deviations from what is anticipated to occur. The Town will place nourishment sand when needed and will work in concert with any nourishment activities by the USACE to maintain the health of the project and surrounding inlet management area once the groin has been installed. The Town's inlet management plan will necessarily be adaptive to respond to any issues or concerns that arise over the long term. The proposed monitoring in this document forms the basis of this long-term management plan.

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