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North Carolina Coastal Resources Commission

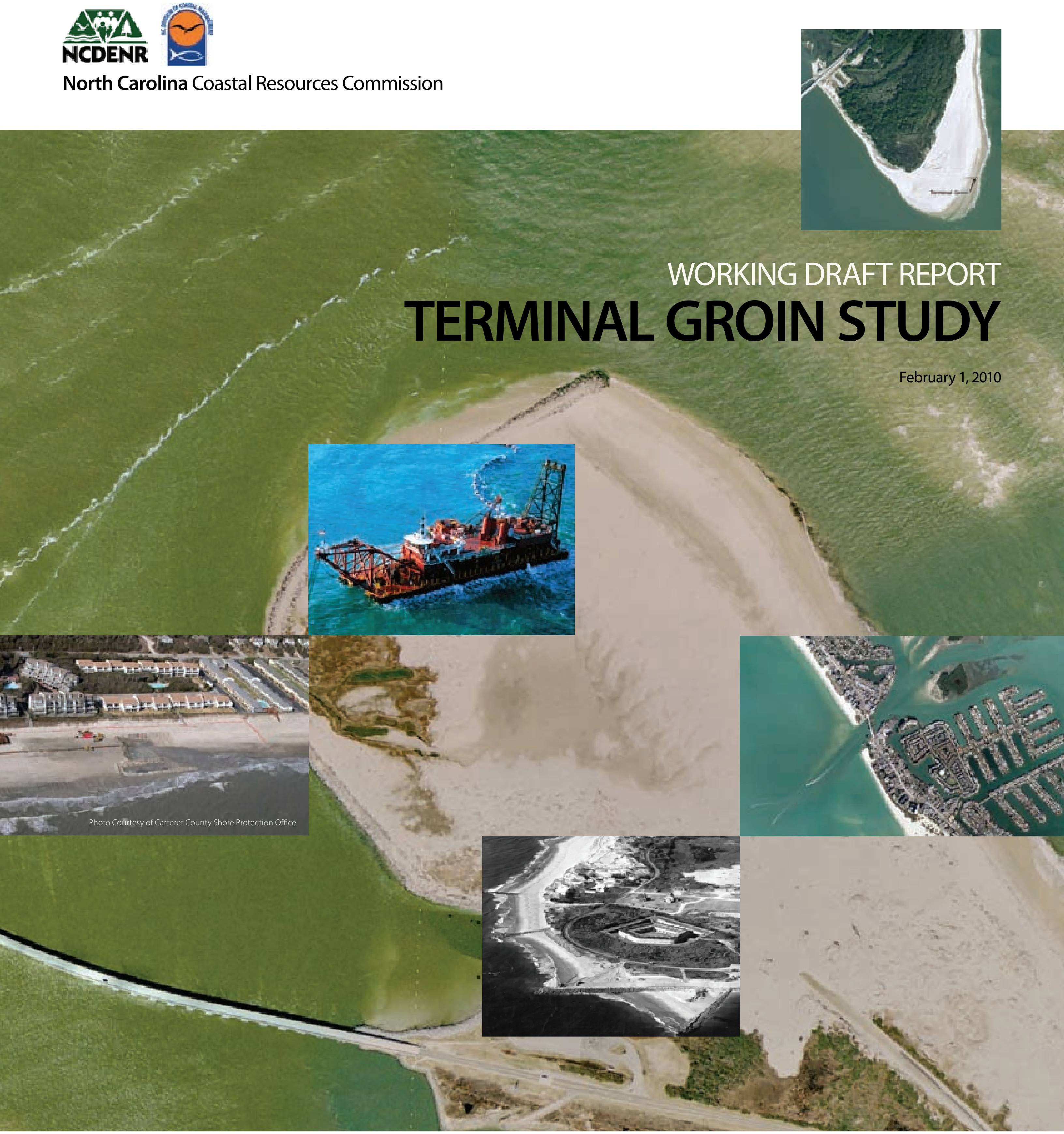

Photo Courtesy of Carteret County Shore Protection Office

WORKING DRAFT REPORT

TERMINAL GROIN STUDY

February 1, 2010

DIAL CORDY AND ASSOCIATES INC
Environmental Consultants

Coastal Economics & Business Services
Christopher F. Dumas, Ph.D.

DUNCAN FITZGERALD, PH.D.

moffatt & nichol

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I. Introduction

This report details the findings of the consultant team portion of the North Carolina Coastal Resources Commission Terminal Groin Study. The study was initiated by the legislature under House Bill 709 (HB709) and mandated by Session Law 2009-479. It directed the Coastal Resources Commission (CRC) in consultation with the Division of Coastal Management (DCM), Division of Land Resources, and the Coastal Resources Advisory Council (CRAC) to study the use and applicability of a terminal groin as an erosion control device. The CRC is to present a report to the Environmental Review Commission (ERC) and the General Assembly by April 1, 2010. The CRC through DCM has contracted with a consultant team to perform the technical review portion of the study.

This report focuses on the data gathering and analysis performed by the consultant team for this study. The team selected was led by Moffatt & Nichol (M&N) and supported by Dial Cordy & Associates (Environmental Consultants), Dr. Christopher Dumas (Professor of Economics, University of North Carolina, Wilmington), and Dr. Duncan FitzGerald (Professor of Department of Earth Sciences – Coastal Marine Geology, Boston University). The M&N team gathered data and performed analysis with respect to the tasks outlined in HB709. The Science Panel on Coastal Hazards, which advises the CRC and DCM with matters of scientific data pertaining to coastal topics and recommendations, provided input into the scoping of the study, selection of study sites, and peer review of the methods and reports.

Ultimately, the CRC will use the study as part of its charge to develop recommendations. This report is a fact gathering effort and does not advocate any policy with respect to the use of terminal groins. Policy recommendations and conclusions will be the responsibility of the CRC/CRAC.

The chart shown in Figure I-1 illustrates the overall project structure.

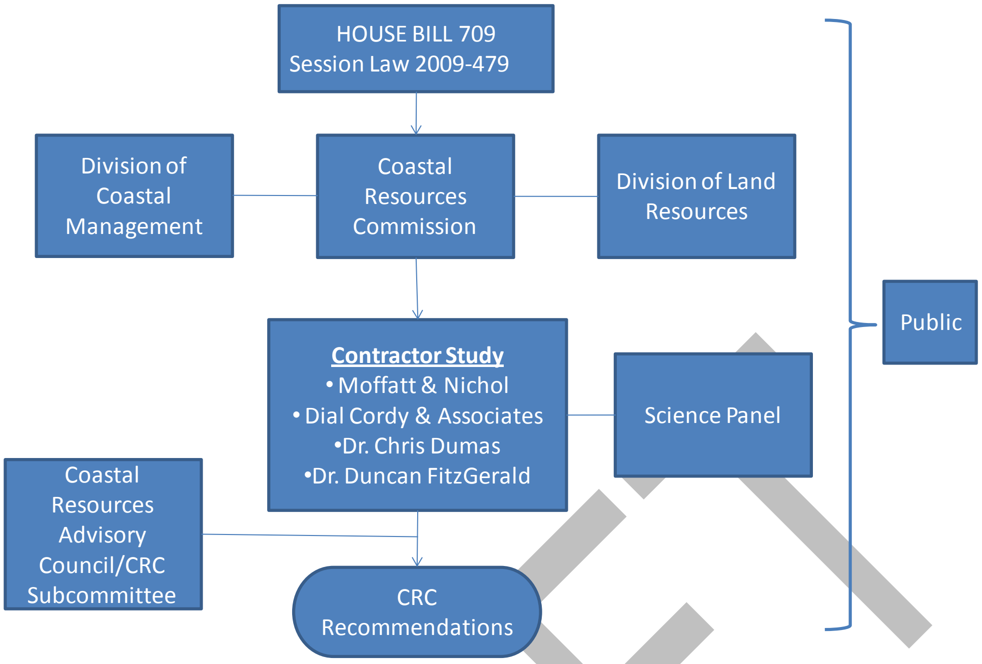


Figure I-1. Overall Project Structure

A. *Session Law 2009-479 / House Bill 709*

The General Assembly of North Carolina in Session Law 2009-479/House Bill 709 enacted an act to direct the Coastal Resources Commission (CRC) to study the feasibility and advisability of the use of a terminal groin as an erosion control device. A copy of the bill is included in Appendix A.

Section 2 stated that the CRC, in consultation with the Division of Coastal Management (DCM), the Division of Land Resources, and the Coastal Resources Advisory Commission (CRAC), shall conduct a study of the feasibility and advisability of the use of a terminal groin as an erosion control device.

The bill directs the CRC to consider:

(1) Scientific data regarding the effectiveness of terminal groins constructed in North Carolina and other states in controlling erosion. Such data will include consideration of the effect of terminal groins on adjacent areas of the coastline.
(2) Scientific data regarding the impact of terminal groins on the environment and natural wildlife habitats.
(3) Information regarding the engineering techniques used to construct terminal groins, including technological advances and techniques that minimize the impact on adjacent shorelines.
(4) Information regarding the current and projected economic impact to the State, local governments, and the private sector from erosion caused by shifting inlets, including loss of property, public infrastructure, and tax base.

(5) Information regarding the public and private monetary costs of the construction and maintenance of terminal groins.
(6) Whether the potential use of terminal groins should be limited to navigable, dredged inlet channels.

The study was divided into eight tasks. The first six tasks involved the gathering and analysis of information related to the six points of consideration in the legislation. The final two tasks were participation in the public input and meetings and the generation of a report for the CRC.

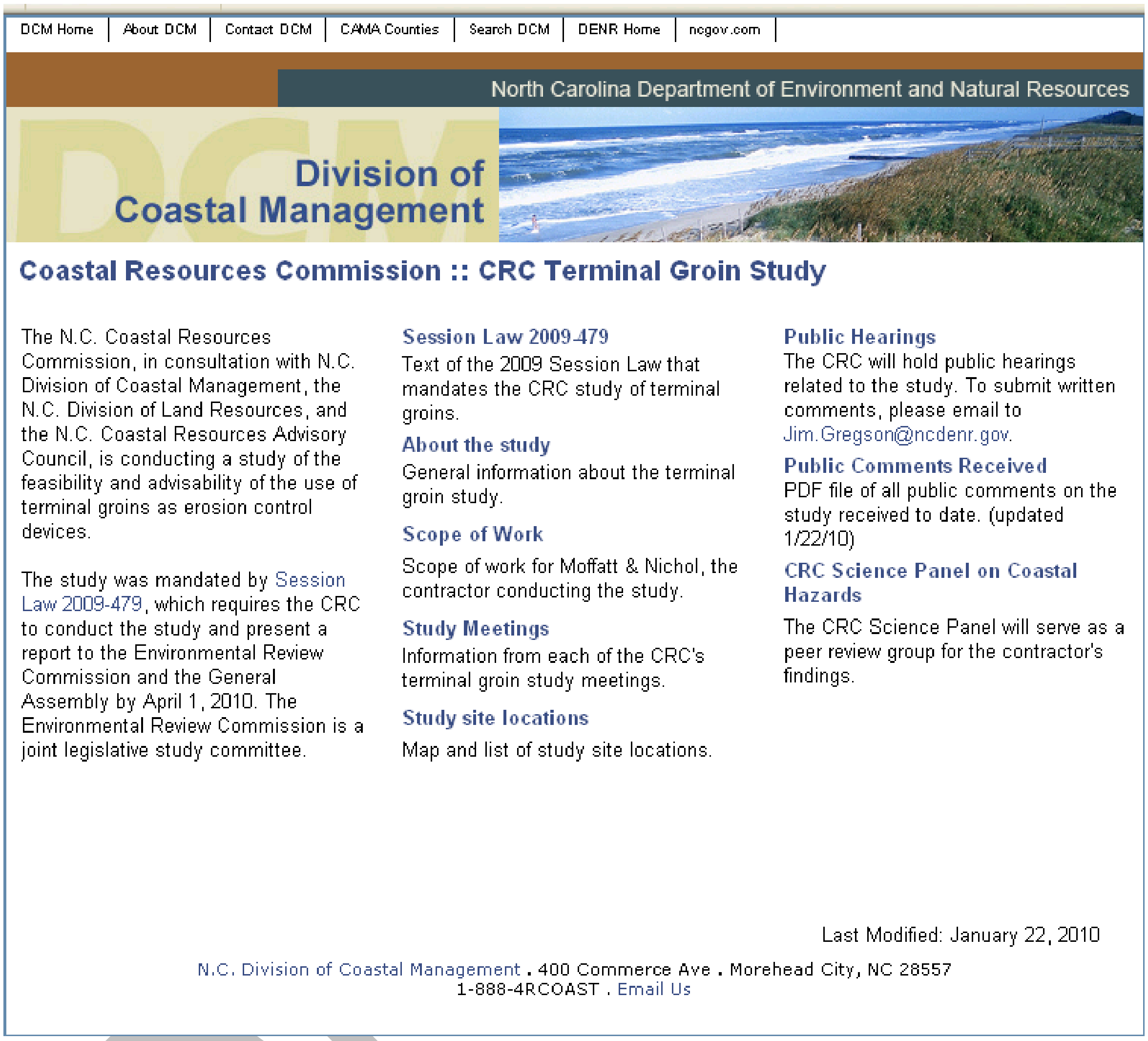
B. Public Consultation

Part of the objective of the study was to provide an open and transparent process. An important part of the overall study is the ability of the public to be informed and provide input. Presentations on the status of the study were made at the CRC Meetings, brief overviews provided at the public hearings, and active discussions on the data and analysis methods conducted at dedicated Science Panel Meetings, which were open to the public. A list of the associated meetings is provided in Table I-1.

Table I-1. Terminal Groin Study Meetings and Presentations

Meeting	Location	Date
Study Kick-off	New Bern	September 14, 2009
Science Panel Meeting	2728 Capitol Blvd., Raleigh	September 29, 2009
CRC Presentation	Atlantic Beach Sheraton	October 29, 2009
Science Panel Meeting	McKimmon Center, Raleigh	December 1, 2009
CRC Presentation	Hilton North Raleigh	January 13, 2010
Science Panel Meeting	2728 Capitol Blvd., Raleigh	January 19, 2010
--- Draft Report ---		February 1, 2010
Science Panel Meeting	2728 Capitol Blvd., Raleigh	February 8, 2010
Steering Committee Meeting to Develop Draft Recommendations for CRC	Cooperative Extension Office, New Bern	February 15, 2010
CRC Presentation	NH County Government Complex	February 17, 2010
--- Final Draft Report ---		March 1, 2010
Science Panel Meeting	2728 Capitol Blvd., Raleigh	March 12, 2010
Steering Committee Meeting to Develop Draft Recommendations for CRC	Cooperative Extension Office, New Bern	March 18, 2010
CRC Presentation	Sea Trail Plantation, Sunset Beach	March 25, 2010
--- CRC Report to ERC ---		April 1, 2010

Presentations, meeting minutes, public comments, and project information were regularly updated and maintained on a project website by DCM at www.nccoastalmanagement.net under the Terminal Groin Study heading in the ‘What’s New’ section (see Figure I-2).



Coastal Resources Commission :: CRC Terminal Groin Study

The N.C. Coastal Resources Commission, in consultation with N.C. Division of Coastal Management, the N.C. Division of Land Resources, and the N.C. Coastal Resources Advisory Council, is conducting a study of the feasibility and advisability of the use of terminal groins as erosion control devices.

The study was mandated by Session Law 2009-479, which requires the CRC to conduct the study and present a report to the Environmental Review Commission and the General Assembly by April 1, 2010. The Environmental Review Commission is a joint legislative study committee.

Session Law 2009-479
Text of the 2009 Session Law that mandates the CRC study of terminal groins.

About the study
General information about the terminal groin study.

Scope of Work
Scope of work for Moffatt & Nichol, the contractor conducting the study.

Study Meetings
Information from each of the CRC's terminal groin study meetings.

Study site locations
Map and list of study site locations.

Public Hearings
The CRC will hold public hearings related to the study. To submit written comments, please email to Jim.Gregson@ncdenr.gov.

Public Comments Received
PDF file of all public comments on the study received to date. (updated 1/22/10)

CRC Science Panel on Coastal Hazards
The CRC Science Panel will serve as a peer review group for the contractor's findings.

Last Modified: January 22, 2010

N.C. Division of Coastal Management . 400 Commerce Ave . Morehead City, NC 28557
1-888-4RCOAST . Email Us

Figure I-2. Project Website

The legislation directs the CRC to conduct at least three public hearings. Five hearings were scheduled during the study process at various locations generally corresponding with a CRC meeting. The list of public hearings is given in Table I-2.

Table I-2. Public Hearings

Public Hearing Location	Date and Time	In Conjunction with CRC Meeting
Sheraton Atlantic Beach	Oct. 29, 2009 - 5 p.m.	Yes
Kill Devil Hills Town Hall	Dec. 16, 2009 - 5 p.m.	No
North Raleigh Hilton, Raleigh	Jan. 13, 2010 - 4:30 p.m.	Yes
New Hanover County Government Complex, Wilmington	Feb. 17, 2010 - 5 p.m.	Yes
Sea Trail, Sunset Beach	March 24 or 25, 2010	Yes

In addition to the public hearings written comments could be submitted to the executive secretary of the CRC by email to jim.gregson@ncdenr.gov, or sent via mail to Jim Gregson, 400 Commerce Ave., Morehead City, N.C., 28557. The project website maintains a listing of these comments.

The study (this report) is to be submitted to the CRC by March 1, and the CRC is to report its findings and recommendations to the Environmental Review Commission and the General Assembly by April 1, 2010.

C. Selection of Study Sites

The initial list of potential study sites was developed by the study team with input from various individuals and concentrated on the Southeast due to environmental and other similarities. Northeastern sites were included only to be considered if necessary. Some 25 sites were part of the initial list along the Atlantic and Gulf coasts from New York to Florida. The objective was to select from this list a number of sites suitable for further analysis as part of the study. These selected sites would provide the basis for assessing the physical and environmental impacts of terminal groins in the study.

In consultation with the Science Panel, five sites were selected to be included in the study. These sites were selected based on three main criteria. First, whether the structure at the site fit the definition of a terminal groin; second, whether the site had similarity to potential North Carolina scenarios; and third, whether there was a reasonable expectation that a suitable quality and quantity of data was available for the location. For the purposes of this study, a terminal groin was defined as a structure built with the primary purpose to retain sand and not for navigation (jetty). Therefore, a terminal groin would be defined as a narrow, roughly shore- normal structure that generally extends only a short distance offshore.

Additionally, the sites were chosen to reflect a variety of structure and inlet size and characteristics. Most sites contain a single terminal groin, that is, a terminal groin not part of a groin field located adjacent to a tidal inlet. The general consensus and direction given by the Science Panel was to study only terminal groins adjacent to inlets. The House Bill had defined the study to include "the feasibility and advisability of the use of a terminal groin as an erosion control device at the end of a littoral cell or the side of an inlet" and defined a littoral cell is as "any section of coastline that has its own sediment sources and is isolated from adjacent coastal reaches in terms of sediment movement." The decision as to where a littoral cell begins or ends along a barrier island is extremely difficult to pinpoint and can shift. An inlet provides a clearly defined location and is generally the location of a terminal groin.

The five sites selected for the study and discussed in detail in this report are the terminal groins at Oregon Inlet and Fort Macon (Beaufort Inlet) in North Carolina, and Amelia Island, Captiva Island and John's Pass in Florida. Figure I-3 below illustrates the location of the selected study sites.

Figure I-3. Selected Study Sites

II. Coastal Engineering Assessment of the Effectiveness and Impacts of Terminal Groins

A. Overview

In order to assess the effectiveness and impacts of terminal groins, five study sites were selected along the southeastern Atlantic and Gulf coasts. This region was chosen since these coastal areas are most likely to be similar to North Carolina in terms of the physical setting and environmental influences. A coastal engineering assessment of the five study sites is discussed in this section of the report.

Data and analysis is presented for each site with respect to the physical environment, beach nourishment and sand placement activity, dredging of the adjacent inlet and shoreline change in order to assess the effectiveness and impacts of the terminal groins from a physical coastal engineering perspective. More detailed discussion of the structures and geology are presented in subsequent sections.

1. The Physical Environment

Waves, water levels, and storm activity cause sediment to move and help to shape the shoreline. Data on these physical parameters were gathered and are presented for each site.

Beaches, the transition zone between land and water, are susceptible to movement and reshaping by waves, winds, and currents. Waves play a major role in the shaping and evolution of beaches and inlets. Moving water suspends and transports sediment. The severity, frequency, and direction of incoming waves influence beach behavior and geometry. Waves can have short-term, seasonal, and long-term impacts on both the cross-shore and along-shore beach shape. Drastic changes in beach width and elevation can occur during a single hurricane, but it is the more frequent storm and wave events that generally drive the overall beach configuration. Winter storms and the associated higher wave activities typically pull sand offshore while gentler summer waves move the sand from the offshore bar back onto the beach. The typical angle of wave approach transports sand along the shoreline, and inlets interrupt the sand movement and form deltas due to the currents generated in the inlets by the rising and falling water levels of the tides. Understanding where the shoreline is eroding, and the angle at which waves typically arrive at the shore transporting sand along the coast and cause inlets to migrate is important. Wave data along the coast is available from long term wave hindcast modeling and from measurements at various wave buoys which have operated at various locations and for differing durations.

Wave hindcasts are numerical models which use historic wind and meteorological data to calculate or hindcast what the waves would have been at a particular location. The United States Army Corps of Engineers Wave Information Study (WIS) is an extensive hindcast model that provides wave information (height, period, and direction) for the 20 year period of 1980-99 at hundreds of offshore locations along the Atlantic and Gulf of Mexico coasts. This data is publicly available and can be downloaded from the USACE's website at http://www.frf.usace.army.mil/cgi-bin/wis/atl/atl_main.html.

Actual measurements of wave activity can be obtained from wave buoys from the National Data Buoy Center (NDBC) website at http://www.ndbc.noaa.gov/. The wave buoys are maintained by various operators and contain varying information from wave data to climatological data. Both real time and historical data can be downloaded.

In addition to wave activity, beaches and inlets are impacted by both temporal and spatial variations in the water level. Water level variations can be regular, such as the tides, or periodic, such as storm surge. Water level changes can also occur over long periods of time due to sea level rise (climate change or relative change due to land subsidence).

Along the North Carolina coast, tides are typically semidiurnal, having two high tides and two low tides each day of similar heights. Tides are currently actively measured at locations along the US coast by NOAA and the USACE. The NOAA tide stations data can be found at the NOAA Tides and Currents website (http://tidesandcurrents.noaa.gov/).

Shorter term water level fluctuations due to passing storms, both extratropical (northeasters) and tropical (tropical storms and hurricanes), can elevate water levels along the coast resulting in flooding and the penetration of waves further up the beach face reshaping it. These water levels influence the height of terminal groin structure and its effectiveness in trapping or holding sediment.

Storms can have a significant influence on the behavior of a shoreline and inlet. Increased water levels and high waves can move significant amounts of sediment over relatively short periods during a storm. The coast of North Carolina is affected annually by numerous storms. A tropical cyclone is a low pressure system that forms over warm water which may eventually become a tropical depression, tropical storm, or hurricane if conditions are favorable. A nor'easter (also known as an extratropical system) is similar to a tropical cyclone; the difference being that they typically develop during the winter season and form in the oceans outside of the tropics. For the coast of North Carolina, tropical storms, and especially hurricanes, can be a major episodic force in reshaping beaches, and inlets (including breaching new ones through the barrier islands). The National Oceanic and Atmospheric Administration (NOAA) maintains a GIS database including tracks for Atlantic and Pacific hurricanes and cyclones. Approximate storm location, date, wind speed, pressure, and category have been recorded for storms beginning in 1851. GIS shapefiles can be downloaded at NOAA's website. Noting the timing of major storms may help in understanding atypical shoreline or inlet behavior. Wave, water level and storm information relevant to each of the five study sites is presented.

2. Shoreline Change

Assessing the shoreline behavior and changes in the vicinity of the structures ultimately provides one of the best tools to assess the effectiveness and impact of the terminal groins. In order to quantify the impacts of terminal groins, shoreline changes were calculated in the vicinity of the terminal groins at each of the five study sites. Shoreline data for both pre- and post-construction of the terminal groins was collected where available. The rates of shoreline change on each side of the inlet for a distance of three miles were computed for each site. Average rates were calculated for each time period for cumulative distances up to three miles and in intervals along the same segments for comparison of shoreline behavior. Three miles was selected as the comparison difference based on availability of data for all sites and visual inspection of the shorelines that generally showed convergence of the shorelines at or before this distance from the inlet.

Changes in shoreline were analyzed in a geographic information system (GIS) by measuring differences in past and present shoreline locations. Shoreline locations are typically digitized from aerial photographs, charts, surveys and LiDAR. Shoreline positions for this study were obtained from available sources such as the North Carolina Division of Coastal Management, Department of Transportation, and the Florida Department of Environmental Protection. Historic shorelines comparisons were used as a basis for determining shoreline change rates. Pre- and post-structure shorelines were obtained which generally covered the longest available reasonable periods and extended at least three miles from the inlet shoulder and were entered into the GIS. Transects perpendicular to the shoreline were then cut every 50 m (164 ft) and the rate of change determined by measuring the distance between the shoreline/transect intersection points for pairs of historic shorelines pre- and post-terminal groin. The transect spacing of 50 m was selected based on the typical spacing used by DCM for their erosion rate calculations. Tabular and graphical results are then presented for each site.

3. Volumetric Changes, Beach Nourishment and Dredging Effects

Inlet regions and beaches are dynamic areas and factors such as beach nourishment and dredging impact the shoreline behavior. Since beach nourishment and dredging are typically quantified in terms of volumes (cubic yards of sand) the shoreline change rates were converted to equivalent beach volume changes to assess the impact of nourishment and dredging, separate from the terminal groin. Shoreline change to volume change estimates were made based on ratios developed from available profile data near each site.

Interpreting the impact of the terminal groin requires understanding the influence of placing sand on the beach (nourishment) and potentially removing sand from the system (dredging) on the observed shoreline change. Beach nourishment contributes to volume gains that are not attributable to the presence of the terminal groin. Another human activity that can have large effects on inlet and neighboring beach behavior is dredging of a channel through the inlet for navigation purposes. The channel typically cuts through the bar formations at the inlet and alters the flow and sediment transport patterns. Thus, dredging of sand from near the inlet removes sand from the beach system and results in beach volume loss that is not attributable to the presence of the terminal groin.

Data related to the volume of beach nourishment and dredging in the vicinity of the terminal groins were compiled for the analysis periods (Appendix C lists the engineering activities at each site). Where data was available, the influence of these activities was then assessed by subtracting the beach nourishment from the shoreline change volumes. The various dredging losses are illustrated by adding back the volume of sand attributable to dredging within the inlet system for each site. Sidecaster dredging was not included since the material is simply cast out of the navigation channel but typically remains within the inlet system.

B. Coastal Engineering Assessment of Selected Study Sites

1. Oregon Inlet

a) Site Description

Oregon Inlet was opened by a major hurricane in September 1846 and separates Bodie Island from Pea Island in the south. It is the only inlet between Hatteras Inlet some 40 miles to the southwest and the over 50 mile stretch to the end of Currituck Sound at the Virginia border. Currituck sound has no ocean inlet so Oregon Inlet is the only outlet for the enormous volume of sound waters along this nearly 100 mile portion of the North Carolina coast.

The inlet is high energy and has seen dynamic changes since its opening. Between 1846 and 1989, the inlet migrated approximately 2 miles south of its original location (Mallinson et al., 2008). The Herbert Bonner Bridge was constructed across the inlet in 1962 and since then numerous studies have been conducted on stabilizing the inlet. In an effort to help stabilize the inlet and protect the bridge and highway from inlet shifting and severe erosion, a terminal groin was built on the south side of the inlet between 1989 and 1991 (Figure II-1). The shoals and channels continue to shift and the north bank has continued southward spit growth causing Oregon Inlet to narrow and deepen (Mallinson et al., 2008). Changes in volume to the ebb-tidal delta appear to be cyclical and are related to the numerous storms that affect the area (Cleary and Marden, 1999).

Figure II-1. Oregon Inlet Terminal Groin

b) Physical Environment

Data on the waves, water levels, and storm activity are discussed in this section with the relationship to the geologic framework addressed in Section III of this report.

(1) Waves and Tides

For the Oregon Inlet site, the closest NDBC buoys and WIS stations were selected to represent wave conditions within the immediate area surrounding the Oregon Inlet terminal groin. These locations are shown in Figure II-2 along with nearby NOAA tidal gages. The closest tide gage is located at the Oregon Inlet Marina, which is inside the sound, not on the oceanside. The closest ocean tidal measurements are approximately 30 miles north at Duck, NC. Table II-1 presents the tidal datums for both gages.

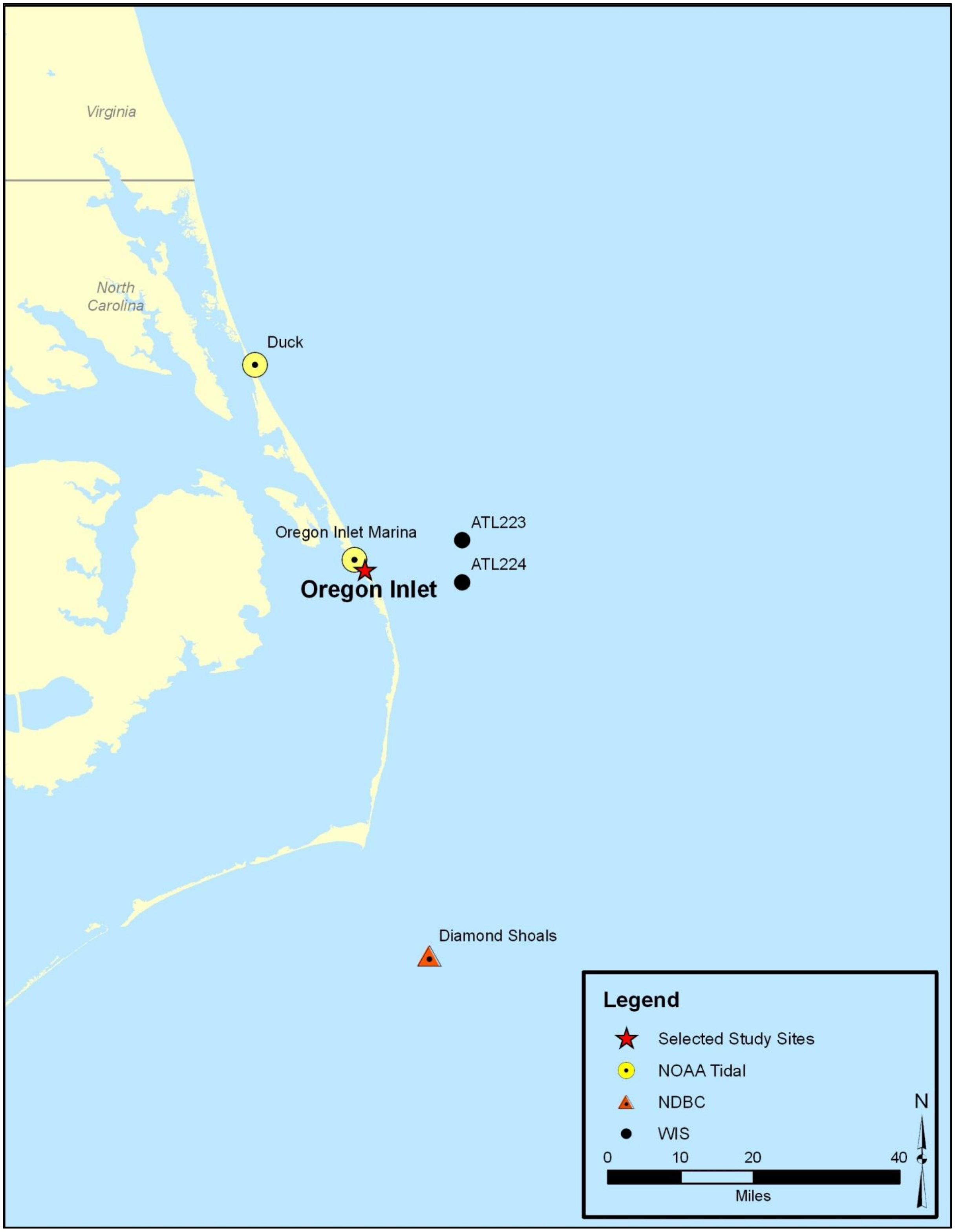


Figure II-2. Wave and Tidal Stations near Oregon Inlet

Table II-1. Tidal Gages near Oregon Inlet

Tidal Datum	Station	
	Oregon Inlet Marina (8652587)	Duck (8651370)
MHHW (ft)	1.17	3.69
MHW (ft)	1.02	3.37
DTL (ft)	0.59	1.84
MTL (ft)	0.57	1.75
MSL (ft)	0.58	1.77
MLW (ft)	0.13	0.14
MLLW (ft)	0.00	0.00
NAVD (ft)	0.66	2.19
Maximum (ft)	5.66	6.92
Max Date	1999/09/16	1999/08/30
Max Time	15:00	15:54
Minimum (ft)	-1.99	-2.66
Min Date	1996/03/10	1980/03/16
Min Time	21:48	12:54

Table II-2 and Table II-3 summarize the percent occurrences by wave height and direction for WIS stations ATL 223 and 224. Figure II-3 illustrates the average annual wave roses for both stations. The wave rose provides a graphical representation of the wave heights and directions from which the waves are coming.

Table II-2. WIS Percent Occurrence of Wave Heights

Wave Height (meters)	Percent Occurrence of Wave Height	
	Station ATL 223	Station ATL 224
0.00 – 0.49	8.0	8.4
0.50 – 0.99	38.9	39.5
1.00 – 1.49	26.0	26.8
1.5 – 1.99	13.0	12.9
2.00 – 2.49	7.1	6.8
2.50 – 2.99	3.5	3.0
3.00 – 3.49	1.7	1.3
3.50 – 3.99	0.9	0.6
4.00 – 4.49	0.4	0.3
4.50 – 4.99	0.2	0.1
5.00 - GREATER	0.3	0.2

Table II-3. WIS Percent Occurrence by Mean Wave Direction (From)

Direction Band & Center (deg)	Percent Occurrence of Mean Direction	
	Station ATL 223	Station ATL 224
348.75 – 11.24 (0.0)	8.8	8.2
11.25 – 33.74 (22.5)	8.8	9.6
33.75 – 56.24 (45.0)	10.1	11.0
56.25 – 78.74 (67.5)	11.0	12.2
78.75 - 101.24 (90.0)	10.1	10.5
101.25 - 123.74 (112.5)	8.9	8.4
123.75 - 146.24 (135.0)	8.2	7.6
146.25 - 168.74 (157.5)	8.0	7.6
168.75 - 191.24 (180.0)	9.1	9.3
191.25 - 213.74 (202.5)	4.5	5.0
213.75 - 236.24 (225.0)	1.3	1.3
236.25 - 258.74 (247.5)	0.8	0.5
258.75 - 281.24 (270.0)	0.8	0.5
281.25 - 303.74 (292.5)	1.3	0.9
303.75 - 326.24 (315.0)	2.3	2.2
326.25 - 348.74 (337.5)	6.0	5.0

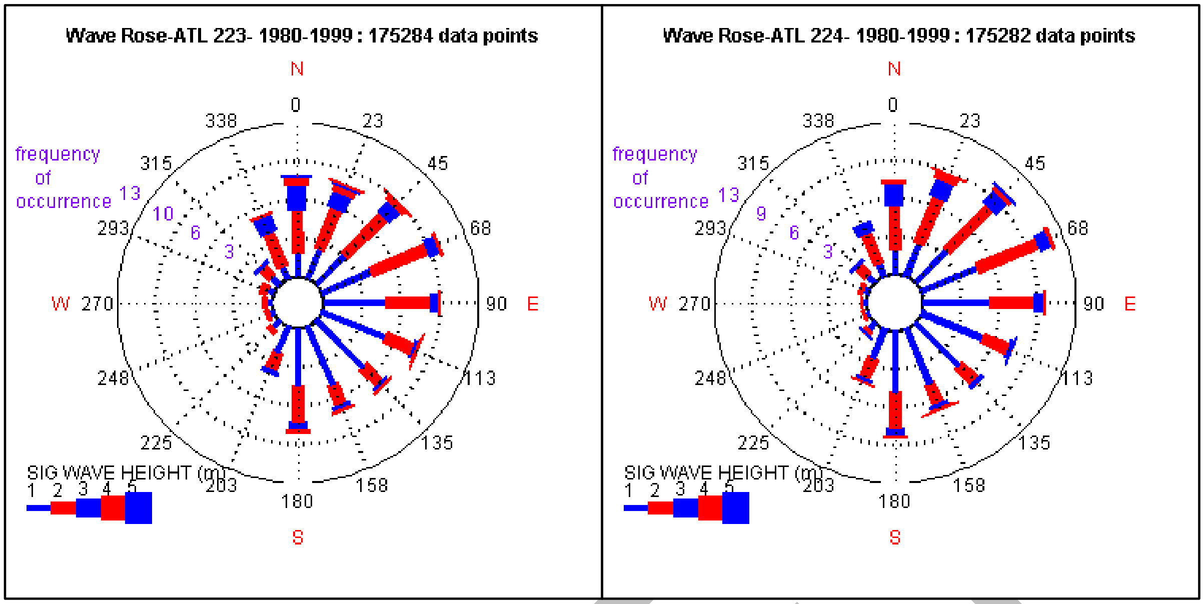


Figure II-3. Wave Roses (USACE WIS Hindcast)

A review of the WIS hindcast data yields the following observations:

- Almost 40% of the wave heights over the period 1980 – 1999 were between approximately 0.5 – 0.99 meters (1.6 – 3.2 feet).
- The typical direction of the waves was from northeast - southeast.
- The largest waves occur during the winter months (December – March) and are predominately from the north.

(2) Storms

The NOAA database of historical storms records approximate storm track, wind speed, pressure, and category for storms since 1851. Figure II-4 illustrates the hurricane tracks in the vicinity of Oregon Inlet and Table II-4 lists the extratropical storms, tropical storms, and hurricanes that have passed within 65 nautical miles between 1851 and 2008. Of these 98 storms, three have made landfall within 10 miles.

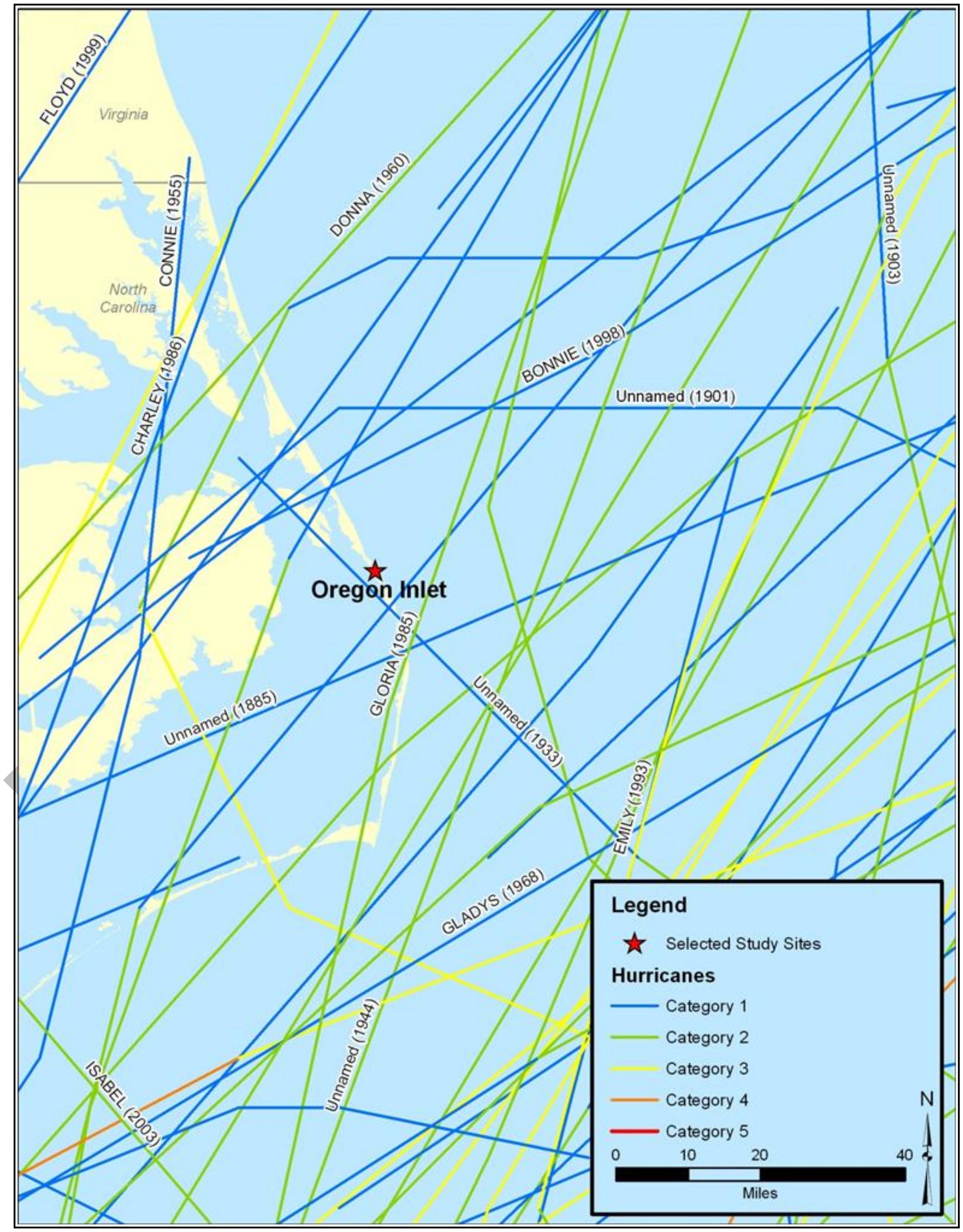


Figure II-4. Hurricanes in the Vicinity of Oregon Inlet

Table II-4. Oregon Inlet Storms (NOAA, 1951-2008)

YEAR	STORM NAME	MAXIMUM CATEGORY
1851	NOTNAMED	Tropical Storm
1852	NOTNAMED	Tropical Storm
1854	NOTNAMED	Tropical Storm
1856	NOTNAMED	Tropical Storm
1856	NOTNAMED	Tropical Storm
1857	NOTNAMED	Category 2
1858	NOTNAMED	Category 2
1861	NOTNAMED	Tropical Storm
1861	NOTNAMED	Tropical Storm
1861	NOTNAMED	Category 1
1863	NOTNAMED	Tropical Storm
1866	NOTNAMED	Category 1
1879	NOTNAMED	Category 3
1880	NOTNAMED	Category 1
1881	NOTNAMED	Tropical Storm
1882	NOTNAMED	Tropical Storm
1885	NOTNAMED	Category 1
1887	NOTNAMED	Extratropical
1888	NOTNAMED	Tropical Storm
1889	NOTNAMED	Tropical Storm
1893	NOTNAMED	Tropical Storm
1893	NOTNAMED	Tropical Storm
1893	NOTNAMED	Tropical Storm
1893	NOTNAMED	Tropical Storm
1894	NOTNAMED	Category 1
1894	NOTNAMED	Tropical Storm
1897	NOTNAMED	Tropical Storm
1897	NOTNAMED	Tropical Storm
1897	NOTNAMED	Tropical Storm
1899	NOTNAMED	Category 3
1900	NOTNAMED	Extratropical
1901	NOTNAMED	Category 1
1901	NOTNAMED	Tropical Storm
1907	NOTNAMED	Extratropical
1908	NOTNAMED	Category 1
1908	NOTNAMED	Category 1
1908	NOTNAMED	Tropical Storm
1910	NOTNAMED	Tropical Storm
1910	NOTNAMED	Extratropical
1912	NOTNAMED	Extratropical
1918	NOTNAMED	Tropical Storm
1924	NOTNAMED	Category 2
1925	NOTNAMED	Extratropical
1932	NOTNAMED	Tropical Storm
1933	NOTNAMED	Category 2
1933	NOTNAMED	Category 2
1934	NOTNAMED	Extratropical
1936	NOTNAMED	Category 2
1937	NOTNAMED	Tropical Storm
1938	NOTNAMED	Extratropical
1942	NOTNAMED	Extratropical
1944	NOTNAMED	Category 2
1945	NOTNAMED	Tropical Storm
1946	NOTNAMED	Tropical Storm
1946	NOTNAMED	Extratropical
1947	NOTNAMED	Extratropical
1953	BARBARA	Category 2
1954	CAROL	Category 2
1954	EDNA	Category 3
1955	CONNIE	Category 1
1955	IONE	Category 1
1956	FLOSSY	Extratropical
1958	HELENE	Category 3
1960	DONNA	Category 2
1962	ALMA	Category 1
1964	CLEO	Tropical Storm
1964	DORA	Tropical Storm
1964	ISBELL	Extratropical
1965	NOTNAMED	Extratropical
1967	DORIA	Tropical Storm
1968	GLADYS	Category 1
1970	ALMA	Extratropical
1971	DORIA	Tropical Storm
1972	AGNES	Tropical Storm
1981	BRET	Tropical Storm
1981	DENNIS	Tropical Storm
1984	DIANA	Tropical Storm
1985	GLORIA	Category 2
1986	CHARLEY	Category 1
1991	BOB	Category 2
1992	DANIELLE	Tropical Storm
1993	EMILY	Category 3
1995	ALLISON	Extratropical
1996	ARTHUR	Tropical Storm
1996	JOSEPHINE	Extratropical
1997	DANNY	Tropical Storm
1998	BONNIE	Category 1
1998	EARL	Extratropical
1999	FLOYD	Category 1
2000	HELENE	Tropical Storm
2002	GUSTAV	Tropical Storm
2002	KYLE	Tropical Storm
2004	ALEX	Category 2
2004	CHARLEY	Tropical Storm
2004	CHARLEY	Extratropical
2006	ALBERTO	Extratropical
2007	GABRIELLE	Tropical Storm
2007	BARRY	Extratropical
2008	CRISTOBAL	Tropical Storm

c) *Shoreline Change*

The shoreline impacts of the terminal groin at Oregon Inlet are assessed by examining the shoreline change prior to and after construction. Historical shoreline data was obtained from DCM and the NC Department of Transportation. The differences in shoreline position were calculated at 50 m transects along the shore for a distance of three miles to either side of the inlet. Shoreline data sets selected were chosen which extended three miles to either side of the inlet and to cover the pre-structure and post-structure time periods. Figure II-5 illustrates the shoreline data used in the analysis.

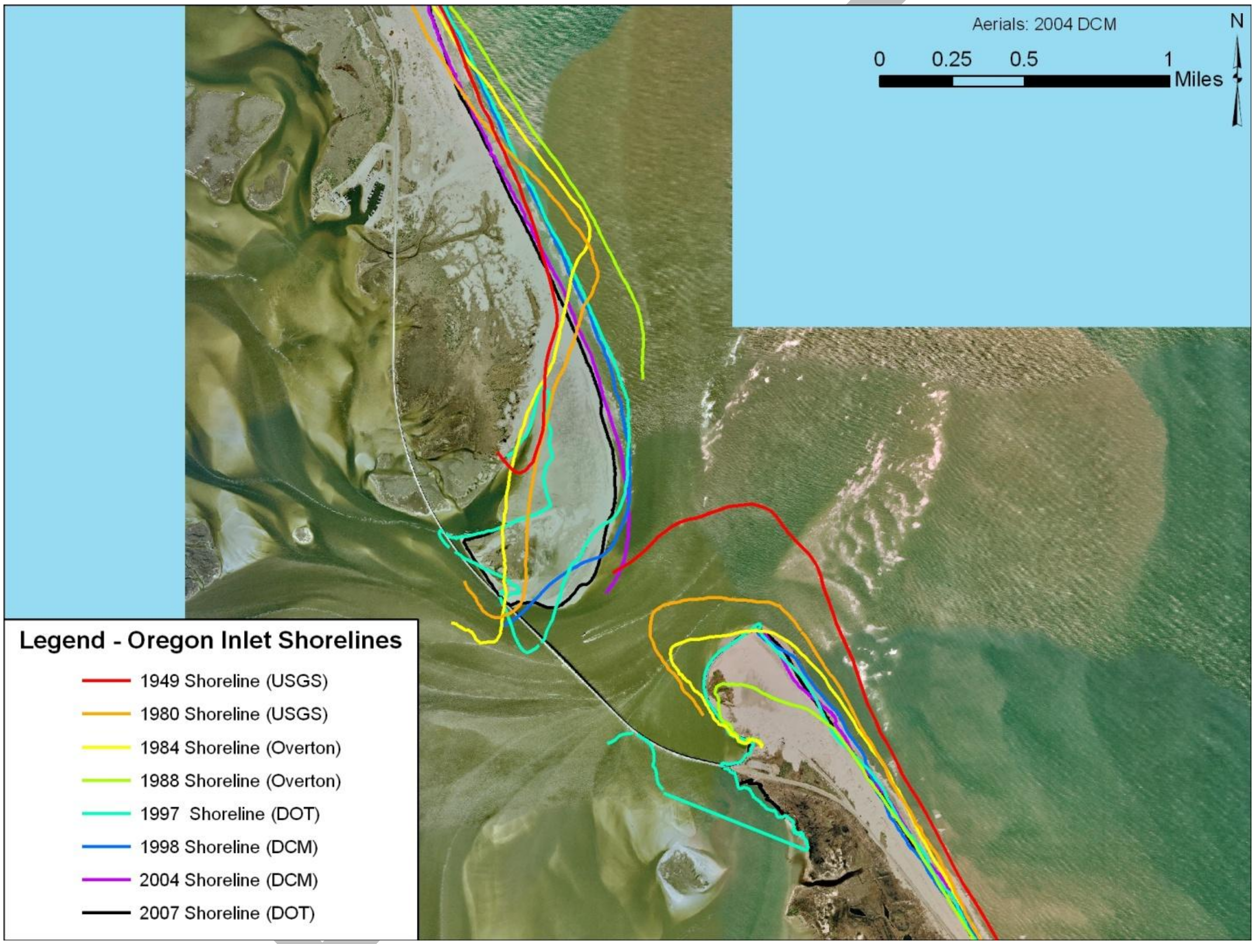


Figure II-5. Historic Shorelines – Oregon Inlet

Figure II-6 illustrates the calculation transects and the starting position of each shoreline comparison calculation period. The starting points were selected at the nearest inlet shoulder coincident portions of the shoreline for each calculation interval. These are not, however, coincident between periods due to shifting of the inlet. The starting transects labeled on Figure II-6 represent the zero position of the shoreline comparison for the time period noted. Results are reported with respect to the inlet shoulder for each given period. Pre-structure periods of 1949 to 1980 and 1984 to 1988 were selected since these periods represent the longest available pre-construction DCM shoreline interval and the period just prior to the structure construction after the start of significant hopper dredging activities at the inlet, respectively. The 1984 and 1988 shorelines are from the NCDOT monitoring reports prepared by Overton and Fisher at North Carolina State University. Post-construction shorelines for the periods of 1997 to 2007 (NCDOT) and 1998 to 2004 (DCM) were used for comparison. The terminal groin was constructed from 1989-91 with the fillet filling with sediment by 1992 and stabilizing by 1995.

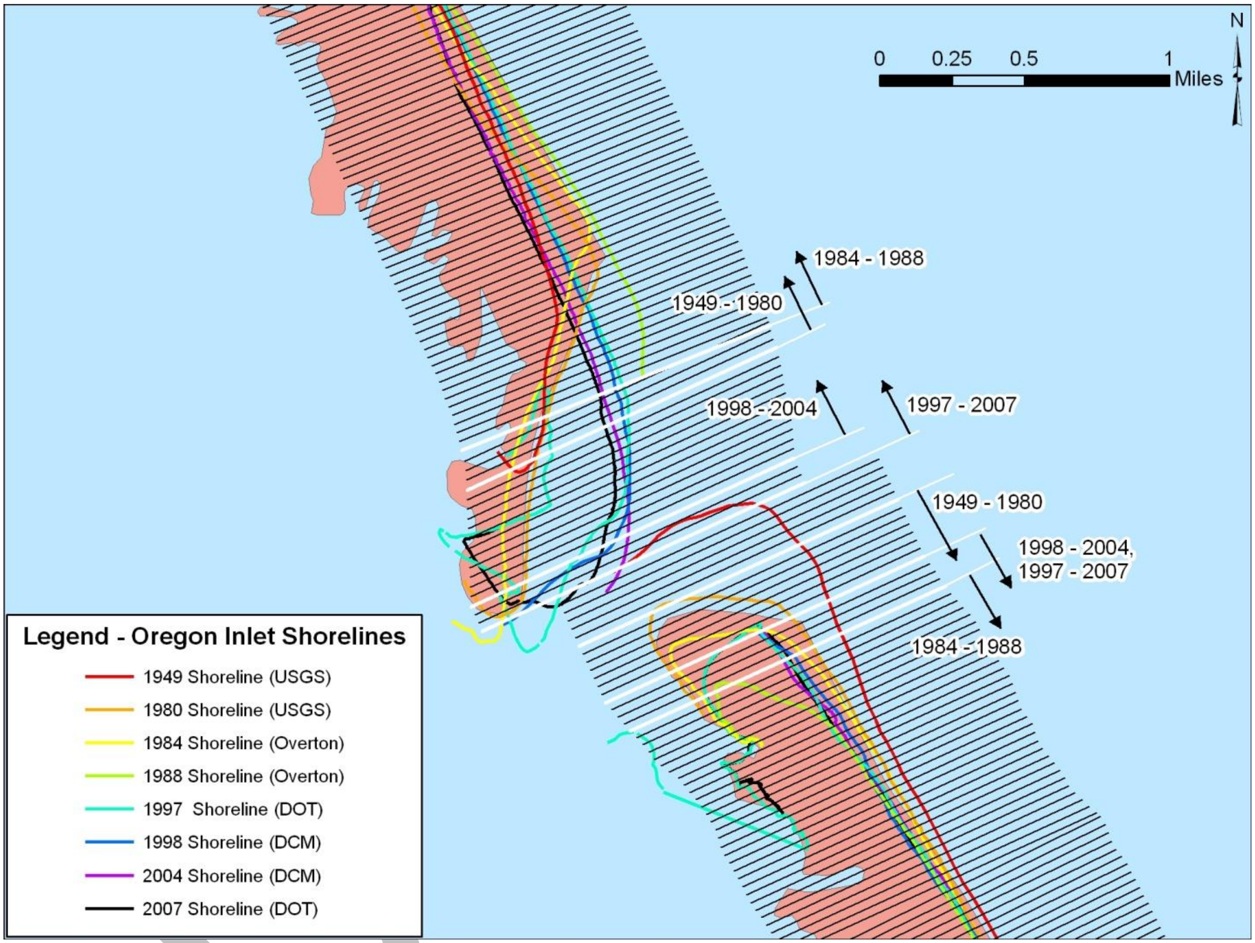


Figure II-6. Oregon Inlet Shoreline Change Calculation Transects

The results of the shoreline change calculations for the pre- and post-structure time periods are given in Table II-5. The table presents the calculation results for both the north side (Bodie Island) and south side (Pea Island and the location of the terminal groin) of Oregon Inlet. Values in red represent shoreline recession (erosion) and values in black represent shoreline advancement (accretion). The first six rows of the table present cumulative average shoreline change from the inlet shoulder to a total distance of three miles. The lower six rows provide the average shoreline change for each interval as indicated. Figure II-7 and Figure II-8 display the same data graphically.

Table II-5. Calculated Shoreline Change – Oregon Inlet

Distance from Inlet (mi)	1949-1980 North Average Change Rate (ft/yr)	1949-1980 South Average Change Rate (ft/yr)	1998-2004 North Average Change Rate (ft/yr)	1998 - 2004 South Average Change Rate (ft/yr)	1984 - 1988 North Average Change Rate (ft/yr)	1984 - 1988 South Average Change Rate (ft/yr)	1997-2007 North Average Change Rate (ft/yr)	1997-2007 South Average Change Rate (ft/yr)
0 - 0.25	3.1	100.7	3.2	18.3	499.6	228.9	33.2	3.8
0 - 0.5	9.5	62.8	16.0	19.4	381.6	161.0	0.7	2.4
0 - 0.75	15.3	46.4	24.9	14.0	267.9	132.0	15.1	0.1
0 - 1	14.9	37.0	29.6	5.9	213.3	109.5	22.0	1.5
0 - 2	2.1	22.6	42.5	0.1	132.2	66.4	31.9	2.4
0 - 3	2.9	19.7	38.8	3.7	117.8	52.3	26.8	1.0
0 - 0.25	3.1	100.7	3.2	18.3	499.6	228.9	33.2	3.8
0.25 - 0.5	16.0	24.8	35.3	20.6	263.7	93.2	31.8	1.0
0.5 - 0.75	26.8	13.8	42.7	3.2	40.4	73.9	46.6	5.1
0.75 - 1	14.0	8.5	43.5	18.5	49.4	42.1	42.9	5.9
1 - 2	10.8	8.2	55.5	5.8	51.1	23.4	41.8	3.3
2 - 3	18.7	14.1	29.3	11.3	117.8	24.1	16.4	7.7

*Red values represent shoreline recession (erosion) and black values represent shoreline advancement (accretion)

Prior to terminal groin construction, the shoreline to the south side of Oregon Inlet was eroding fairly rapidly (during both calculation time periods with the 1984-1988 being more than double the rate from 1949-1980). After the construction of the terminal groin, the south shoreline was still eroding but a much lower rate, and even accreting at some locations (intervals).

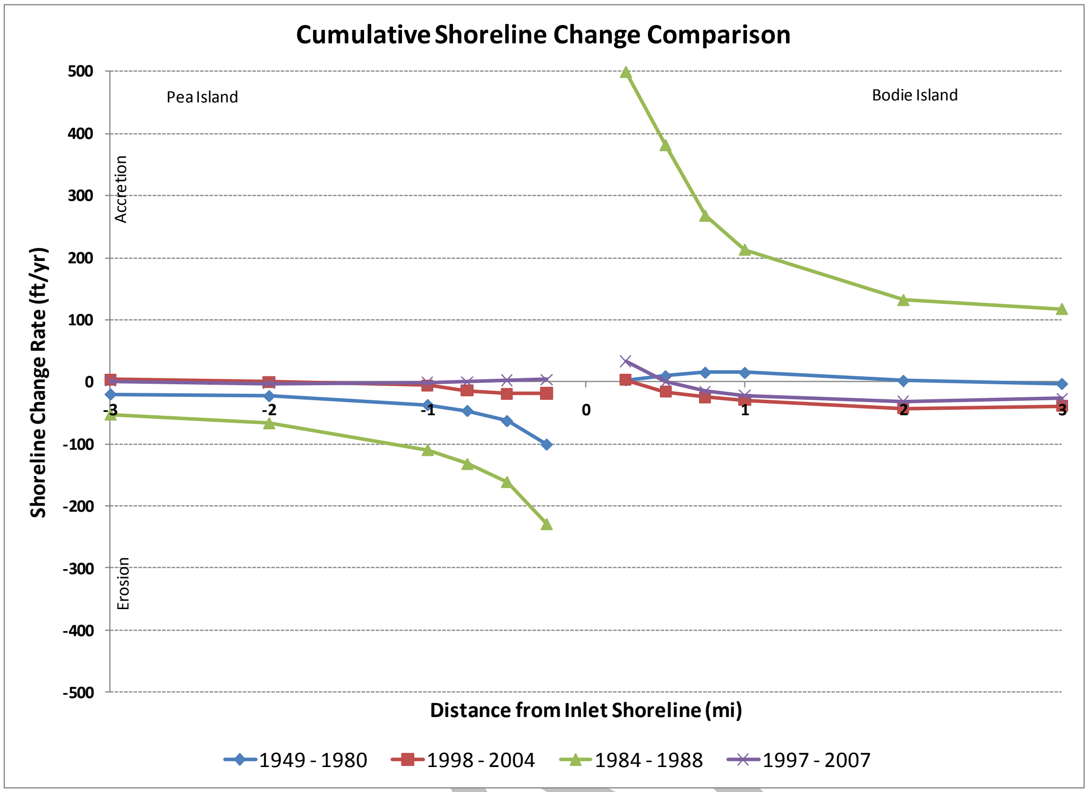


Figure II-7. Cumulative Shoreline Change – Oregon Inlet

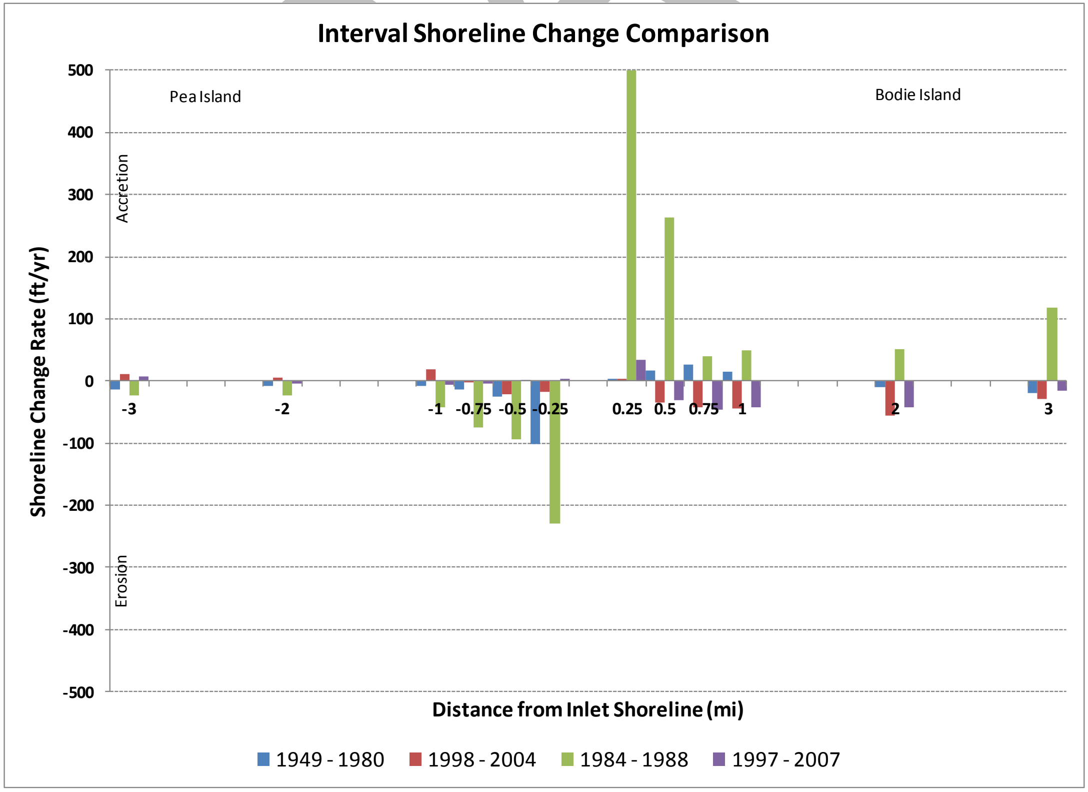


Figure II-8. Shoreline Change Interval Comparison – Oregon Inlet

d) Volumetric Changes, Beach Nourishment, and Dredging

The impact of the terminal groin in relation to other activities, particularly beach nourishment and dredging was assessed through volumetric comparison. The volume of beach material lost or gained was evaluated based on the shoreline change, nourishment and beach volumes placed, and quantities of material dredged from the inlet. The ratio of shoreline change to beach volume was developed based on available representative survey profiles collected by the US Army Corps of Engineers in 2004 and 2009 at the north end of the Pea Island (3 miles), south of the Oregon Inlet. The general rule that is typically applied for estimation is one foot of shoreline change equates to approximately one cubic yard of beach material volume per linear foot of beach. The ratio calculated for the area around Oregon Inlet was approximately 1.41 cubic yards of beach volume per linear foot for one foot of shoreline change. This matches well with other reported vales in other sources.

Table II-6 provides the volumetric beach change for the cumulative distances and intervals along each side of the inlet based on for the shoreline change presented previously. Beach volume losses are given in red and beach volume gains in black. These numbers are directly computed from the shoreline changes and include all impacts to the beach such as nourishment, since these are implicitly included in the shoreline measurements. Figure II-9 and Figure II-10 present the same information graphically.

Table II-6. Average Annual Beach Volume Changes – Oregon Inlet

Distance from Inlet (mi)	1949 - 1980 North Total Volume (cy/yr)	1949 - 1980 South Total Volume (cy/yr)	1998 - 2004 North Total Volume (cy/yr)	1998 - 2004 South Total Volume (cy/yr)	1984 - 1988 North Total Volume (cy/yr)	1984 - 1998 South Total Volume (cy/yr)	1997-2007 North Total Volume (cy/yr)	1997-2007 South Total Volume (cy/yr)
0 - 0.25	5,717	186,345	5,944	33,784	924,436	423,487	43,198	6,995
0 - 0.5	35,241	232,305	59,300	71,872	1,412,353	595,968	22,615	8,821
0 - 0.75	84,772	257,806	138,325	77,728	1,487,070	732,744	107,278	553
0 - 1	110,630	273,489	218,819	43,457	1,578,475	810,559	186,260	11,390
0 - 2	30,358	333,863	629,244	895	1,956,580	983,436	492,977	35,750
0 - 3	56,218	437,996	798,737	82,493	2,043,163	1,161,663	610,849	21,168
0 - 0.25	5,717	186,345	5,944	33,784	924,436	423,487	43,198	6,995
0.25 - 0.5	29,524	45,960	65,243	38,087	487,917	172,481	65,813	1,826
0.5 - 0.75	49,531	25,501	79,026	5,857	74,717	136,776	84,663	9,375
0.75 - 1	25,858	15,682	80,494	34,272	91,405	77,815	78,982	10,836
1 - 2	80,272	60,374	410,425	42,562	378,105	172,877	306,718	24,360
2 - 3	86,575	104,133	169,493	83,388	86,584	178,227	117,872	56,918

*Beach volume losses are given in red and beach volume gains in black.

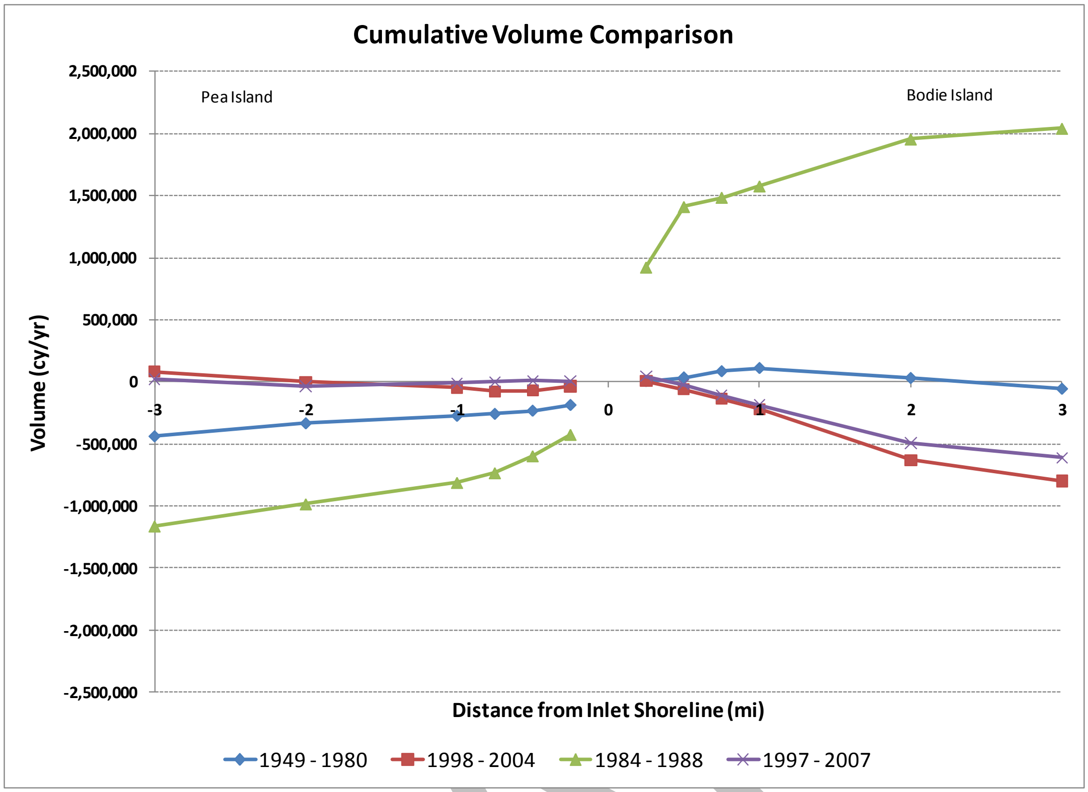


Figure II-9. Cumulative Beach Volume Change – Oregon Inlet

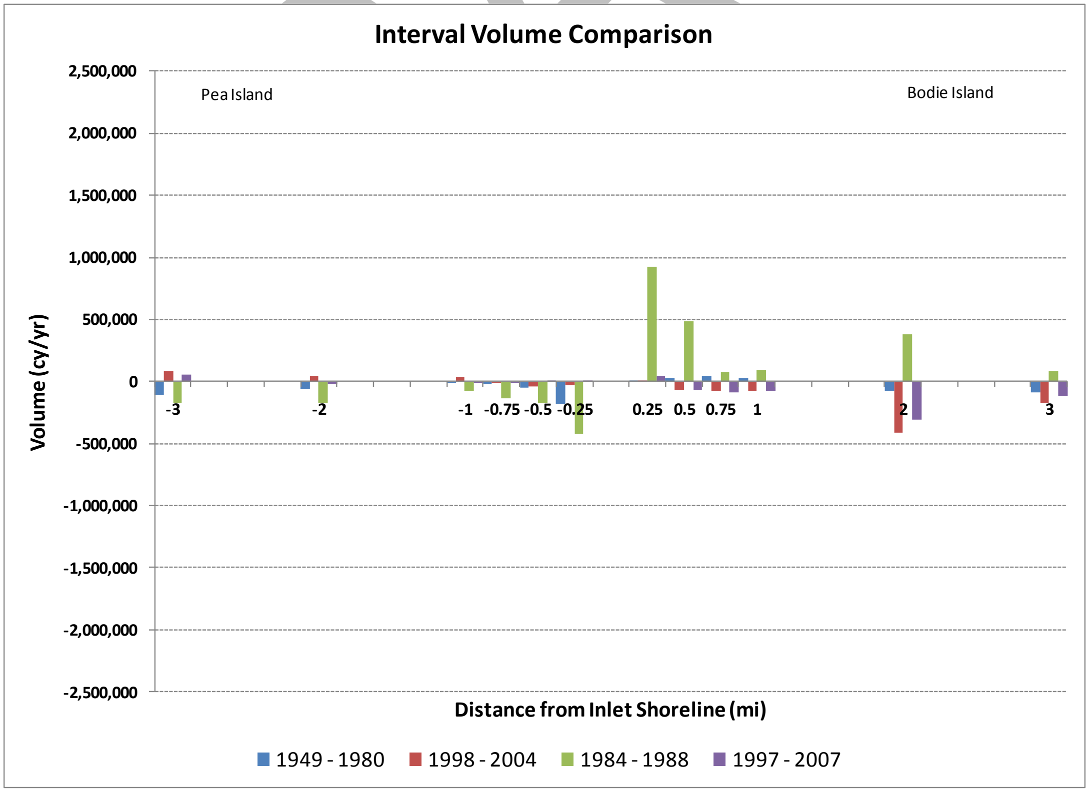


Figure II-10. Beach Volume Change Interval Comparison – Oregon Inlet

Since construction of the Oregon Inlet Terminal Groin, sand has been regularly placed along the Pea Island shoreline to the south of Oregon Inlet. The engineering activities log in Appendix C details the amounts, timing, and locations, when known, of beach nourishment activities. Most of this sand has come from the dredging of the navigation channel through the inlet and associated bar so some of it could be considered sand that should have naturally bypassed the inlet and been naturally put along the beach and is not an effect of the terminal groin structure per se. With the dominant sediment transport direction from the north to the south (based on numerous studies in the literature), intercepting material at the inlet by dredging interrupts the sand bypassing transport. This dredging impact will be discussed subsequently.

Nevertheless for comparison purposes in Table II-7, the beach nourishment material placed on the beach or disposed in the nearshore is subtracted from the volumes calculated based on shoreline change to arrive at volume changes net nourishment (as if the nourishment did not take place). Nourishment material was placed only along the south side of the inlet, only for the post construction periods, with amounts, on average of 708,839 cy/yr for the 1998 – 2004 period, and 452,474 cy/yr for the 1997 – 2007 period. The material amounts are total for the 3 miles extension. Figure II-11 and Figure II-12 present the same information graphically.

Table II-7. Volume Changes Net Nourishment – Oregon Inlet

Distance from Inlet (mi)	1949 - 1980 North Total Volume (cy/yr)	1949 - 1980 South Total Volume (cy/yr)	1998 - 2004 North Total Volume (cy/yr)	1998 - 2004 South Total Volume (cy/yr)	1984 - 1988 North Total Volume (cy/yr)	1984 - 1998 South Total Volume (cy/yr)	1997-2007 North Total Volume (cy/yr)	1997-2007 South Total Volume (cy/yr)
0 - 0.25	5,717	186,345	5,944	43,232	924,436	423,487	43,198	194
0 - 0.5	35,241	232,305	59,300	90,767	1,412,353	595,968	22,615	4,780
0 - 0.75	84,772	257,806	138,325	106,072	1,487,070	732,744	107,278	20,956
0 - 1	110,630	273,489	218,819	86,385	1,578,475	810,559	186,260	41,675
0 - 2	30,358	333,863	629,244	311,376	1,956,580	983,436	492,977	231,095
0 - 3	56,218	437,996	798,737	455,775	2,043,163	1,161,663	610,849	315,378
0 - 0.25	5,717	186,345	5,944	43,232	924,436	423,487	43,198	194
0.25 - 0.5	29,524	45,960	65,243	47,535	487,917	172,481	65,813	4,974
0.5 - 0.75	49,531	25,501	79,026	15,304	74,717	136,776	84,663	16,175
0.75 - 1	25,858	15,682	80,494	19,687	91,405	77,815	78,982	20,719
1 - 2	80,272	60,374	410,425	224,991	378,105	172,877	306,718	189,420
2 - 3	86,575	104,133	169,493	144,399	86,584	178,227	117,872	84,282

*Beach volume losses are given in red and beach volume gains in black.

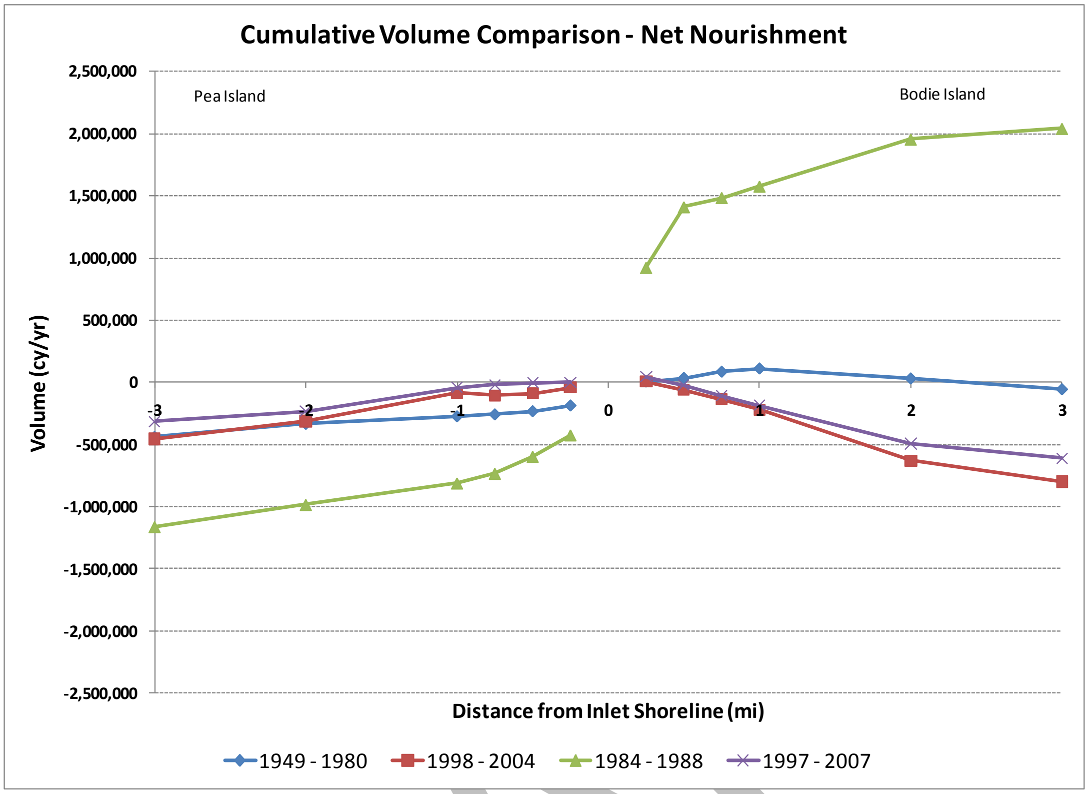


Figure II-11. Volume Changes Net Nourishment – Oregon Inlet

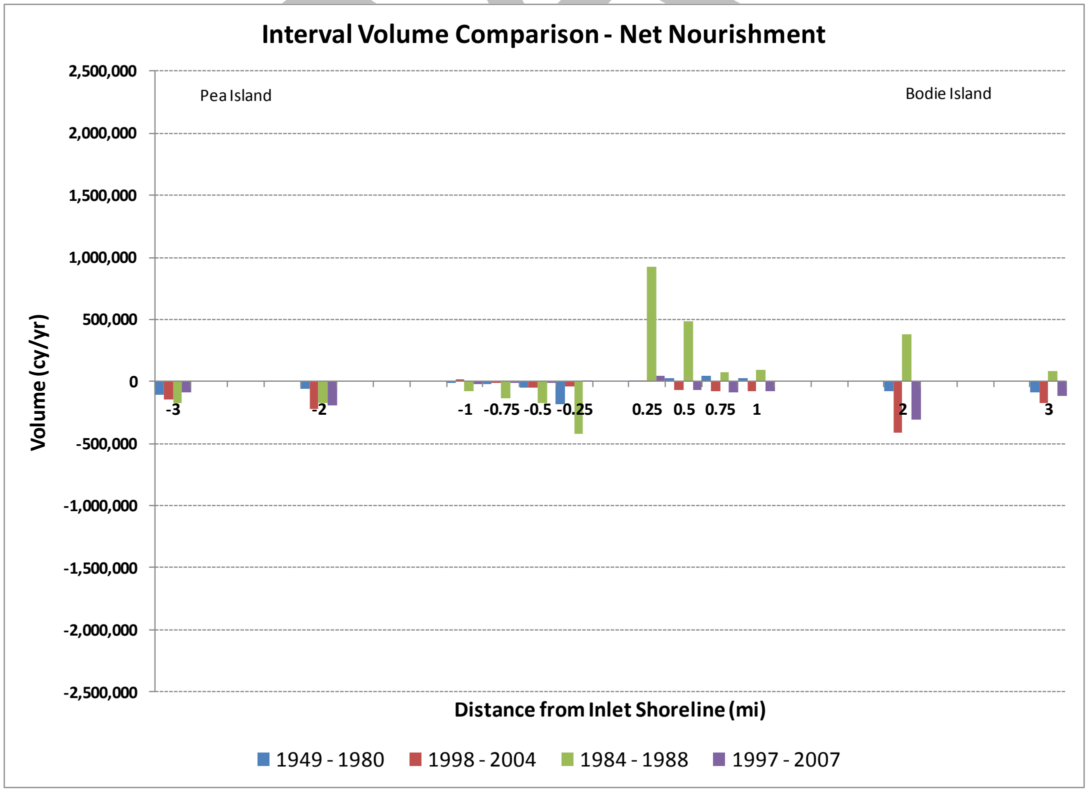


Figure II-12. Volume Changes Net Nourishment Interval Comparison – Oregon Inlet

Much like nourishment, the influence of dredging material needs to be accounted for when trying to assess the impact of the terminal groin. The impact of dredging at Oregon Inlet is significant due to the frequency of dredging of the navigation channel through the inlet and the disruption it causes to the sediment transport along the shoreline and past the inlet.

Dredging volumes (Table II-8) through the inlet and outer bar were calculated for the same time periods as the pre- and post-structure comparisons. While the details of the sediment transport and overall sediment budgets for the region vary, there is consensus that the dominant sediment transport in the region is to the south with gross annual transport rates well in excess of a million cubic yards. Detailed analysis of sediment budgets, though, is beyond the scope of this study. Table II-9 and Table II-10 present a means of generally quantifying the potential impacts of dredging by examining the change in beach volume under varying scenarios. The first scenario assumes none of the dredged material would have naturally reached the beaches (this is the case presented earlier net nourishment). The second scenario assumes 25% of the material dredged from the inlet system would have reached the beach naturally and the third scenario assumes 50%.

Table II-8. Dredging Volumes – Oregon Inlet

Distance from Inlet	1949 - 1980 Total Volume	1998 - 2004 Total Volume	1984 - 1988 Total Volume	1997 - 2007 Total Volume
(mi)	(cy/yr)	(cy/yr)	(cy/yr)	(cy/yr)
0 - 3	75,178	427,557	1,052,466	300,417

Table II-9. Volume Change Scenarios Net Nourishment and Dredging – North of Oregon Inlet

Distance from Inlet	Dredging Percentage Added to the North	1949 - 1980 North Total Volume	1998 - 2004 North Total Volume	1984 - 1988 North Total Volume	1997 - 2007 North Total Volume
(mi)	(%)	(cy/yr)	(cy/yr)	(cy/yr)	(cy/yr)
0 - 3	0%	56,218	798,737	2,043,163	610,849
0 - 3	25%	37,423	691,848	2,306,280	535,745
0 - 3	50%	18,629	584,959	2,569,396	460,641

*Beach volume losses are given in red and beach volume gains in black.

Table II-10. Volume Change Scenarios Net Nourishment and Dredging – South of Oregon Inlet

Distance from Inlet (mi)	Dredging Percentage Added to the South (%)	1949 - 1980 South Total Volume (cy/yr)	1998 - 2004 South Total Volume (cy/yr)	1984 - 1988 South Total Volume (cy/yr)	1997 - 2007 South Total Volume (cy/yr)
0 - 3	0%	437,996	455,775	1,161,663	315,378
0 - 3	25%	419,202	348,886	898,546	240,274
0 - 3	50%	400,407	241,997	635,430	165,169

*Beach volume losses are given in red and beach volume gains in black.

It can be seen that even assuming a small percentage of the dredged material would have naturally been transported to the beaches greatly alters apparent impacts of the terminal groin from examining only shoreline change and netting out all nourishment.

2. Fort Macon

a) Site Description

The Fort Macon terminal groin (Figure II-13) is located on Bogue Banks on the western side of Beaufort Inlet. Shackleford Banks, an undeveloped barrier island lies to the east of the inlet. Beaufort Inlet, located approximately 9 miles west of Cape Lookout, serves as the connection between the Atlantic Ocean and Morehead City Harbor, North Carolina's second major port. The inlet is utilized by commercial and recreational vessels and is one of two inlets in southeastern North Carolina which have been modified for deep draft commercial traffic.

Figure II-13. Fort Macon Terminal Groin

The terminal groin at Fort Macon was built to protect and preserve the fort from erosion. Fort Macon itself has a long history of being at risk from the Atlantic and shifting of Beaufort Inlet. Fort Macon was built between 1826 and 1834 to defend the inlet and harbor from seaborne attackers. By the very nature of its purpose, the fort was built close to the shoreline on a barrier island adjacent to a major inlet in an area prone to the natural forces that reshape shorelines (Paul Branch, http://www.clis.com/friends/default.htm). As early as 1831 wood pilings were laid at right angles to the beach to stop erosion near the fort and in 1840 Captain Robert E. Lee was sent to study the erosion problem at Fort Macon. He recommended that stone groins be constructed. By 1845 a total of six stone groins were built around the fort which protected the shore for almost 40 years (Paul Branch, http://www.clis.com/friends/default.htm). In 1906-11, the Army Corps of Engineers dredged the channel through Beaufort Inlet to a 20-foot depth, which today is dredged to 47-feet for navigation into Morehead City Harbor. Hurricane Hazel in October 1954 did considerable damage to the beach around the fort and erosion problems worsened. In 1961, a stone seawall and groin system was begun (Figure II-14). Later in 1968 the terminal groin was constructed by extending one of the existing groins. It was further extended in 1970 to its present size.

Figure II-14. Fort Macon Revetment-Groin Protection (1961)

Historic maps that date to the early part of the seventeenth century confirm the existence of the inlet. Since the Colonial period, the inlet has served as an entry to the port of Beaufort. Beaufort Inlet has remained in relatively the same location throughout its recorded history. The large tidal prism contributes to the stability of the inlet. Over the past 70 years, since the channel has been in a fixed position (1936), the inlet's cross-sectional area has fluctuated little although the inlet's minimum width has decreased (Cleary and Pilkey, 1996). During the same period, the average depth of the throat has increased as the navigation channel was deepened and widened. As a result the inlet's aspect ratio (width/depth) has decreased markedly since 1952 as the inlet constricted and deepened with dredging. Since dredging of the channel began, there has been a deepening and steepening of the profile and a generally lowering of the ebb-tidal delta platform.

b) *Physical Environment*

Data on the waves, water levels, and storm activity are discussed in this section with the relationship to the geologic framework addressed in Section III of this report.

(1) Waves and Tides

The closest NDBC buoys and USACE Wave Information Study hindcast points (WIS stations) near Fort Macon that represent wave conditions within the immediate area surrounding Beaufort Inlet and the terminal groin are shown in Figure II-15 along with nearby NOAA tidal gages. The closest operating tidal gage is located in Beaufort Inlet with another located on the ocean shore approximately 70 miles to the southwest at Wrightsville Beach. Table II-11 presents the tidal datums for both gages.

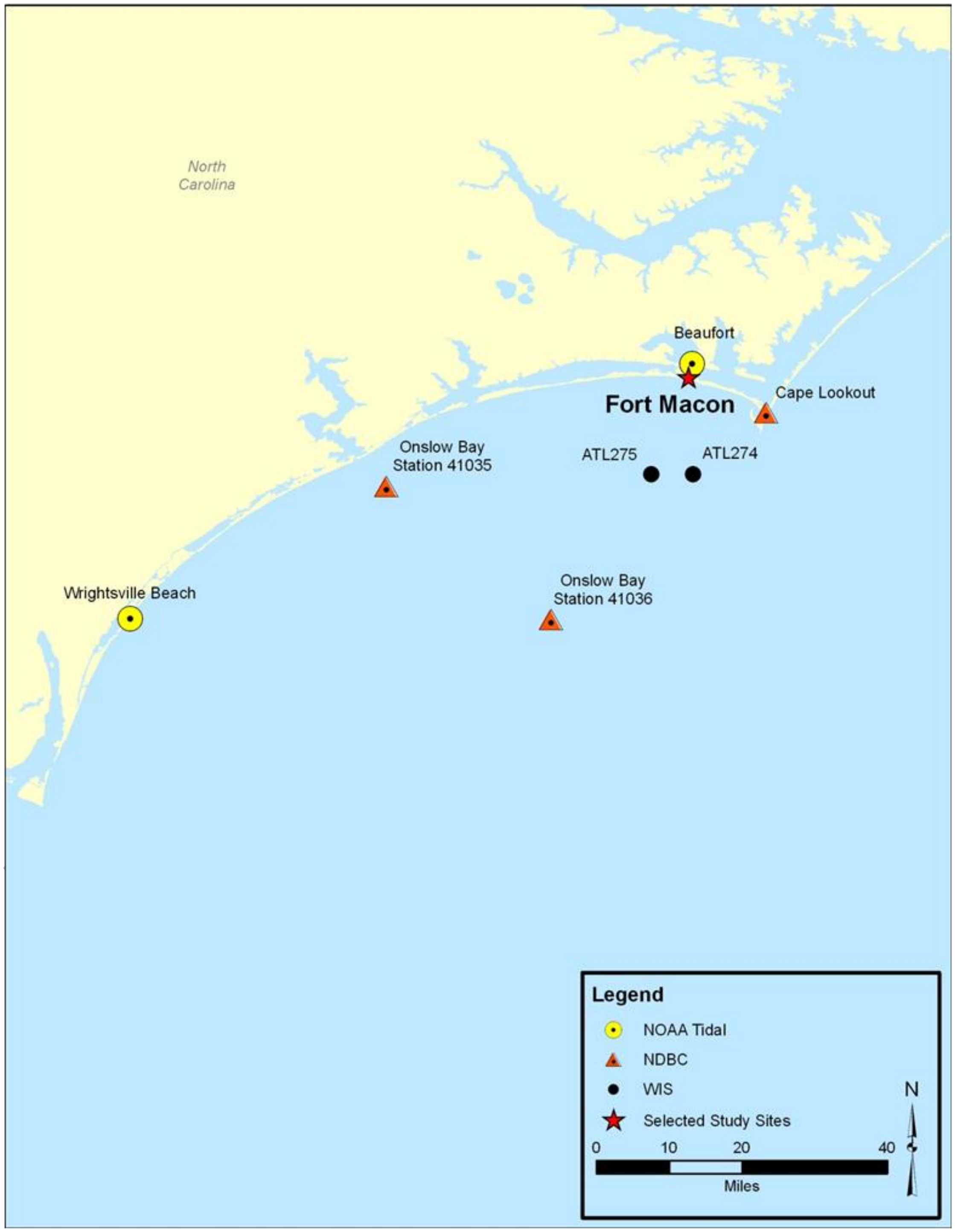


Figure II-15. Wave and Tidal Stations near Fort Macon (Beaufort Inlet)

Table II-11. Tidal Gages near Fort Macon

Tidal Datum	Station	
	Beaufort (8656483)	Wrightsville Beach (8658163)
MHHW (ft)	3.54	4.31
MHW (ft)	3.26	3.96
DTL (ft)	1.77	2.15
MTL (ft)	1.70	2.06
MSL (ft)	1.71	2.05
MLW (ft)	0.15	0.15
MLLW (ft)	0.00	0.00
NAVD (ft)	-	2.51
Maximum (ft)	6.29	7.08
Max Date	1999/09/16	2008/09/25
Max Time	9:12	20:54
Minimum (ft)	-1.92	-2.81
Min Date	1978/01/11	2007/04/16
Min Time	3:18	4:24

Table II-12 and Table II-13 summarize the percent occurrences by wave height and direction for WIS stations ATL 274 and 275. Figure II-16 illustrates the average annual wave roses for both stations. These wave roses provide a graphical representation of the wave heights and directions from which the waves are coming.

Table II-12. WIS Percent Occurrence of Wave Heights

Wave Height (meters)	Percent Occurrence of Wave Height	
	Station ATL 274	Station ATL 275
0.00 – 0.49	15.6	15.5
0.50 – 0.99	47.9	48.4
1.00 – 1.49	22.2	22.1
1.5 – 1.99	7.8	7.4
2.00 – 2.49	3.7	3.7
2.50 – 2.99	1.6	1.5
3.00 – 3.49	0.7	0.7
3.50 – 3.99	0.3	0.3
4.00 – 4.49	0.1	0.1
4.50 – 4.99	0.1	0.0
5.00 – GREATER	0.1	0.1

Table II-13. WIS Percent Occurrence by Mean Wave Direction (From)

Direction Band & Center (deg)	Percent Occurrence of Mean Direction	
	Station ATL 274	Station ATL 275
348.75 – 11.24 (0.0)	2.4	2.5
11.25 – 33.74 (22.5)	2.9	2.8
33.75 – 56.24 (45.0)	5.0	4.5
56.25 – 78.74 (67.5)	6.7	6.1
78.75 - 101.24 (90.0)	6.5	6.0
101.25 - 123.74 (112.5)	7.2	7.7
123.75 - 146.24 (135.0)	9.8	11.1
146.25 - 168.74 (157.5)	9.4	10.3
168.75 - 191.24 (180.0)	12.0	12.4
191.25 - 213.74 (202.5)	13.3	12.8
213.75 - 236.24 (225.0)	8.0	7.4
236.25 - 258.74 (247.5)	5.0	4.8
258.75 - 281.24 (270.0)	4.0	3.6
281.25 - 303.74 (292.5)	2.9	2.7
303.75 - 326.24 (315.0)	2.8	2.8
326.25 - 348.74 (337.5)	2.2	2.3

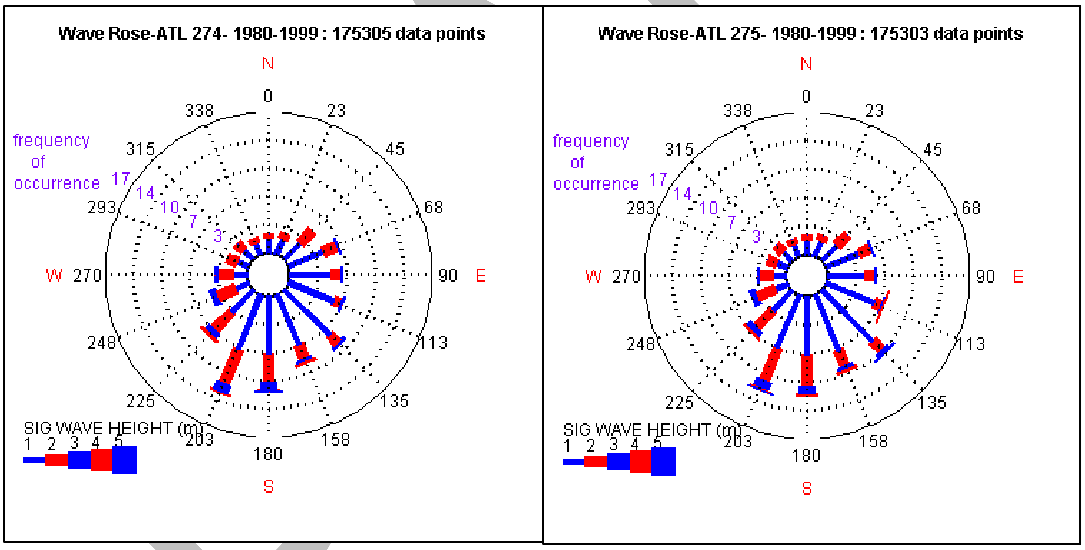


Figure II-16. Wave Roses (USACE WIS Hindcast)

A review of the WIS hindcast data yields the following observations:

- Almost 50% of the wave heights over the hindcast period (1980 – 1999) were between approximately 0.5 – 0.99 meters (1.6 – 3.2 feet).
- The typical direction of the waves was from south – southwest.
- However, from August to November the typical direction of the waves is from the east - southeast
- The largest waves occur during the winter months (December – March).

(2) Storms

The NOAA database of historical storms records approximate storm track, wind speed, pressure, and category for storms since 1851. Figure II-17 illustrates the hurricane tracks in the vicinity of Fort Macon and Table II-14 lists the extratropical storms, tropical storms, and hurricanes that have passed within 65 nautical miles between 1851 and 2008. Of these 117 storms, 9 have made landfall within 10 miles.

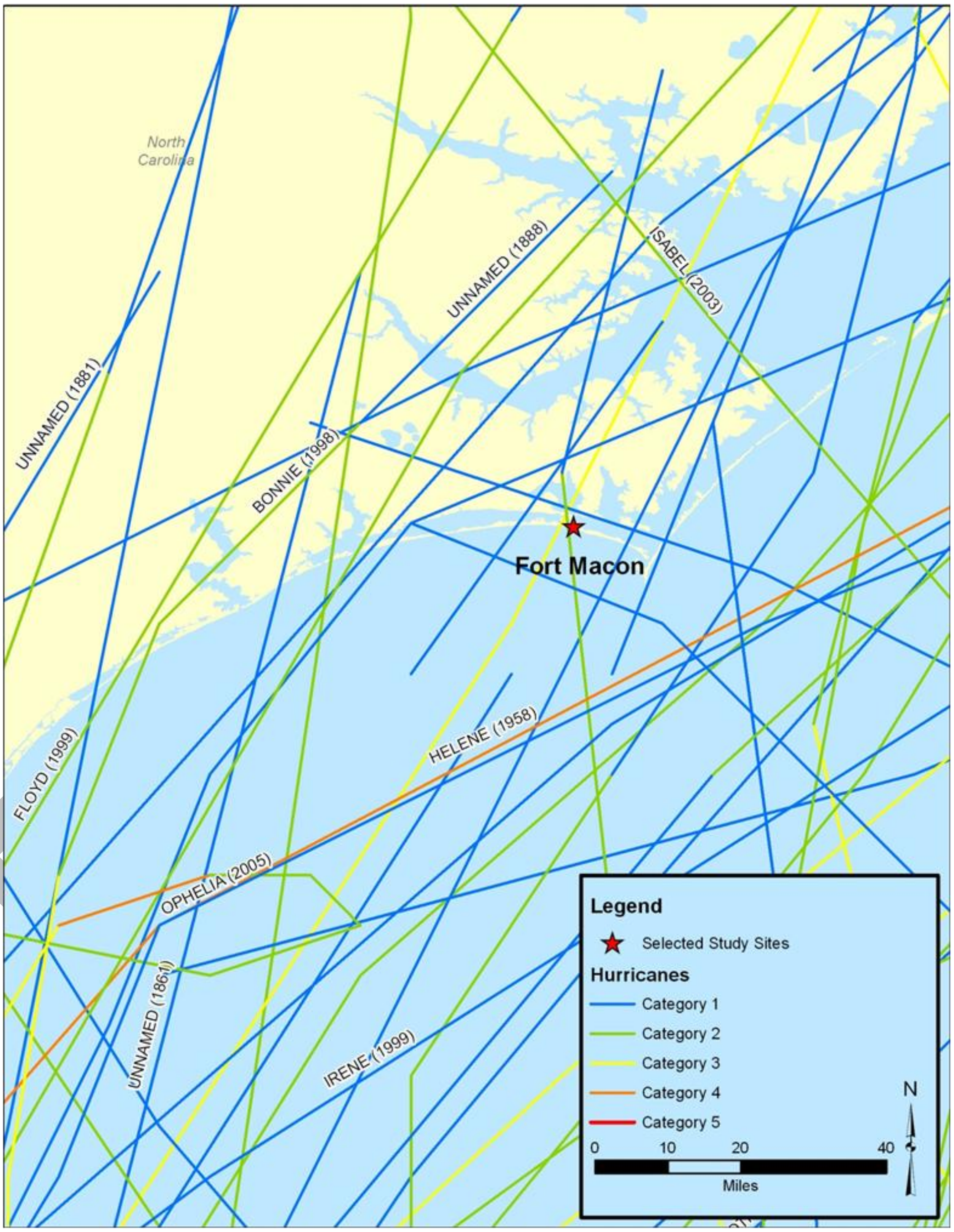


Figure II-17. Hurricanes in the Vicinity of Fort Macon

Table II-14. Fort Macon Storms (NOAA, 1951-2008)

YEAR	STORM NAME	MAXIMUM CATEGORY
1852	NOTNAMED	Tropical Storm
1852	NOTNAMED	Tropical Storm
1856	NOTNAMED	Tropical Storm
1856	NOTNAMED	Tropical Storm
1857	NOTNAMED	Category 2
1861	NOTNAMED	Category 1
1861	NOTNAMED	Category 1
1863	NOTNAMED	Tropical Storm
1868	NOTNAMED	Tropical Storm
1871	NOTNAMED	Tropical Storm
1871	NOTNAMED	Tropical Storm
1872	NOTNAMED	Tropical Storm
1873	NOTNAMED	Tropical Storm
1876	NOTNAMED	Category 1
1877	NOTNAMED	Tropical Storm
1878	NOTNAMED	Tropical Storm
1878	NOTNAMED	Category 2
1879	NOTNAMED	Category 3
1880	NOTNAMED	Category 1
1882	NOTNAMED	Tropical Storm
1882	NOTNAMED	Category 1
1885	NOTNAMED	Category 1
1885	NOTNAMED	Category 1
1887	NOTNAMED	Category 3
1887	NOTNAMED	Category 3
1887	NOTNAMED	Tropical Storm
1888	NOTNAMED	Tropical Storm
1889	NOTNAMED	Tropical Storm
1893	NOTNAMED	Tropical Storm
1893	NOTNAMED	Tropical Storm
1893	NOTNAMED	Tropical Storm
1893	NOTNAMED	Tropical Storm
1893	NOTNAMED	Tropical Storm
1894	NOTNAMED	Tropical Storm
1894	NOTNAMED	Tropical Storm
1897	NOTNAMED	Tropical Storm
1897	NOTNAMED	Tropical Storm
1899	NOTNAMED	Category 3
1899	NOTNAMED	Extratropical
1900	NOTNAMED	Extratropical
1901	NOTNAMED	Category 1
1901	NOTNAMED	Tropical Storm
1901	NOTNAMED	Tropical Storm
1904	NOTNAMED	Extratropical
1907	NOTNAMED	Tropical Storm
1907	NOTNAMED	Tropical Storm
1908	NOTNAMED	Category 1
1908	NOTNAMED	Category 1
1908	NOTNAMED	Tropical Storm
1908	NOTNAMED	Tropical Storm
1908	NOTNAMED	Tropical Storm
1908	NOTNAMED	Tropical Storm
1910	NOTNAMED	Tropical Storm
1910	NOTNAMED	Extratropical
1912	NOTNAMED	Extratropical
1913	NOTNAMED	Category 1
1918	NOTNAMED	Category 1
1924	NOTNAMED	Extratropical
1925	NOTNAMED	Extratropical
1928	NOTNAMED	Tropical Storm
1932	NOTNAMED	Tropical Storm
1933	NOTNAMED	Category 3
1934	NOTNAMED	Tropical Storm
1934	NOTNAMED	Category 1
1937	NOTNAMED	Tropical Storm
1938	NOTNAMED	Extratropical
1942	NOTNAMED	Tropical Storm
1944	NOTNAMED	Category 2
1945	NOTNAMED	Tropical Storm
1946	NOTNAMED	Tropical Storm
1949	NOTNAMED	Category 2
1953	BARBARA	Category 2
1953	FLORENCE	Extratropical
1954	CAROL	Category 2
1955	CONNIE	Category 2
1955	IONE	Category 3
1956	FLOSSY	Extratropical
1958	HELENE	Category 4
1960	BRENDA	Tropical Storm
1960	DONNA	Category 2
1962	ALMA	Tropical Storm
1964	DORA	Tropical Storm
1964	ISBELL	Category 1
1966	ALMA	Tropical Storm
1967	DORIA	Tropical Storm
1968	GLADYS	Category 1
1971	DORIA	Tropical Storm
1971	GINGER	Category 1
1972	AGNES	Tropical Storm
1975	AMY	Tropical Storm
1975	HALLIE	Tropical Storm
1981	DENNIS	Tropical Storm
1984	DIANA	Category 4
1985	GLORIA	Category 2
1985	KATE	Tropical Storm
1986	CHARLEY	Category 1
1995	ALLISON	Extratropical
1996	ARTHUR	Tropical Storm
1996	BERTHA	Category 2
1996	JOSEPHINE	Extratropical

YEAR	STORM NAME	MAXIMUM CATEGORY
1998	BONNIE	Category 2
1999	DENNIS	Tropical Storm
1999	FLOYD	Category 2
1999	IRENE	Category 1
2002	KYLE	Tropical Storm
2003	ISABEL	Category 2
2004	ALEX	Category 2
2004	CHARLEY	Tropical Storm
2005	OPHELIA	Category 1
2006	ALBERTO	Extratropical
2007	GABRIELLE	Tropical Storm
2007	BARRY	Extratropical
2008	CRISTOBAL	Tropical Storm

c) Shoreline Change

The shoreline impacts of the terminal groin at Fort Macon on the western side of Beaufort Inlet are assessed by examining the shoreline change prior to, and after, construction of the structure. Historical shoreline data was obtained from the NC Division of Coastal Management (DCM). The differences in shoreline position were calculated at 50 m (164 ft) transects along the shore for a distance of three miles to either side of the inlet. Shoreline data sets selected were chosen which extended three miles to either side of the inlet and to cover the pre-structure and post-structure time periods. Figure II-18 illustrates the shoreline data used in the analysis.

Figure II-18. Historic Shorelines – Fort Macon (Beaufort Inlet)

Figure II-19 illustrates the calculation transects and the starting position of each shoreline comparison calculation period. The starting points were selected at the nearest inlet shoulder coincident portions of the shoreline for each calculation interval. These are not, however, coincident between periods due to shifting of the inlet. Results are reported with respect to the inlet shoulder for each given period. The starting transects labeled on Figure II-19 represent the zero position of the shoreline comparison for the time period noted. A pre-structure period of 1933 to 1946 was used since this period represents the longest available pre-construction DCM shoreline interval. A post-construction period of 1971 to 2004 is used since the final extension of the terminal groin was completed in 1970.

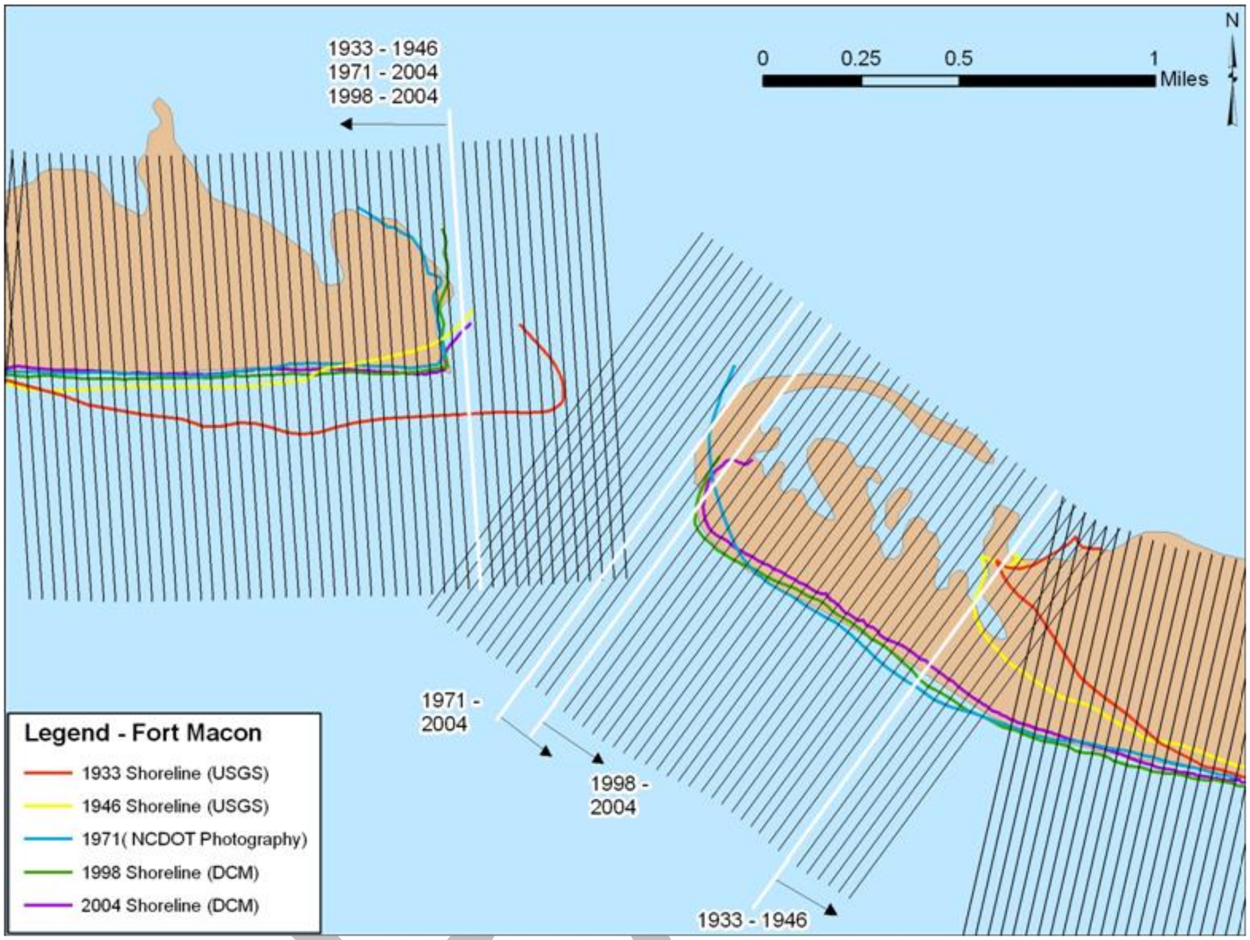


Figure II-19. Fort Macon (Beaufort Inlet) Shoreline Change Calculation Transects

The results of the shoreline change calculations for the pre- and post-structure time periods are given in Table II-15. The table presents the calculation results for both the west side (Fort Macon Terminal Groin Location) and east side (Shackleford Banks) of Beaufort Inlet. Values in red represent shoreline recession (erosion) and values in black represent shoreline advancement (accretion). The first six rows of the table present cumulative average shoreline change from the inlet shoulder to a total distance of three miles. The lower six rows provide the average shoreline change for each interval as indicated. Figure II-20 and Figure II-21 display the same data graphically.

Table II-15. Calculated Shoreline Change – Fort Macon

Distance from Inlet (mi)	1933 -1946 West Average Change Rate (ft/yr)	1933 - 1946 East Average Change Rate (ft/yr)	1971-2004 West Average Change Rate (ft/yr)	1971 - 2004 East Average Change Rate (ft/yr)
0 - 0.25	74.2	55.0	13.0	8.9
0 - 0.5	66.6	43.5	7.6	7.1
0 - 0.75	57.8	28.8	5.0	7.3
0 - 1	49.8	18.8	3.6	7.8
0 - 2	23.6	3.9	2.8	3.4
0 - 3	15.7	0.5	3.0	2.3
0 - 0.25	74.2	55.0	13.0	8.9
0.25 - 0.5	59.0	32.0	2.2	5.3
0.5 - 0.75	40.1	0.5	0.2	7.7
0.75 - 1	25.7	11.1	0.5	9.4
1 - 2	2.6	11.1	1.9	1.0
2 - 3	0.0	6.3	3.6	0.2

*Red values represent shoreline recession (erosion) and black values represent shoreline advancement (accretion)

Prior to terminal groin construction the shoreline to the west side of Beaufort Inlet was eroding. After the construction of the terminal groin, the western shoreline shows generally shows accretion along the three miles albeit with some limited areas of minor erosion. Prior to construction of the terminal groin, Shackleford Banks experienced accretion immediately adjacent to the inlet (likely due to inlet migration behavior) with erosion on the shore farther away. After construction of the terminal groin this pattern seems to have reversed itself.

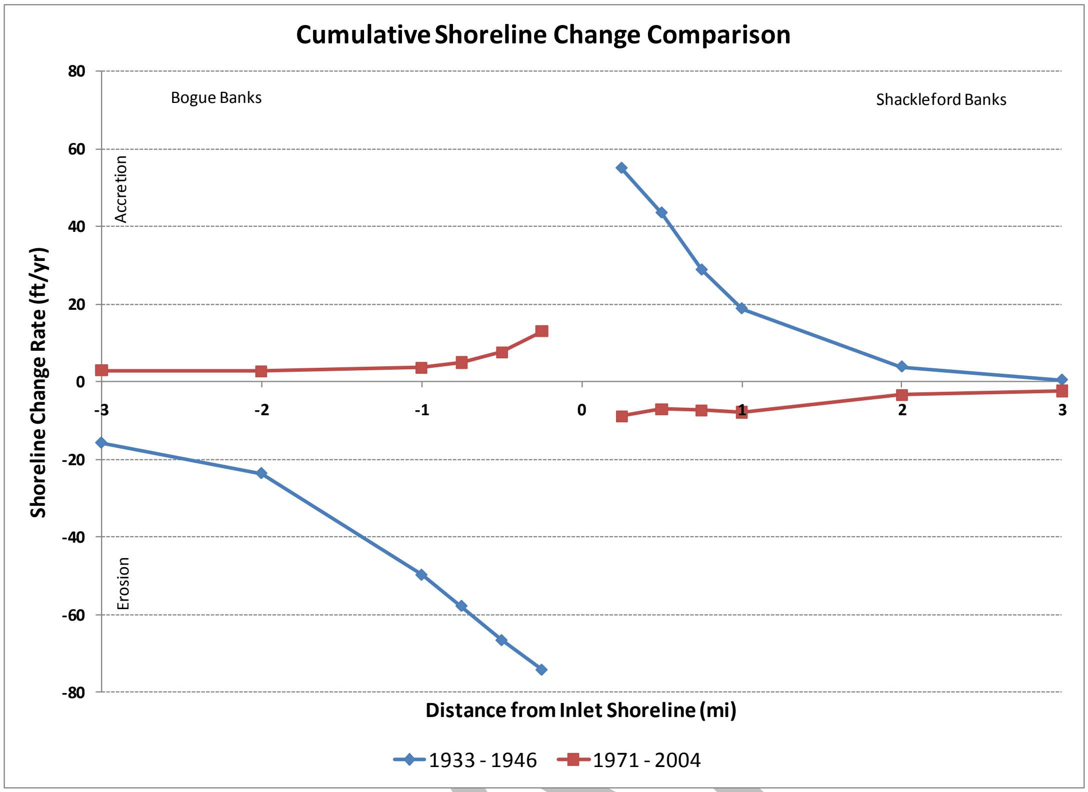


Figure II-20. Cumulative Shoreline Change – Fort Macon

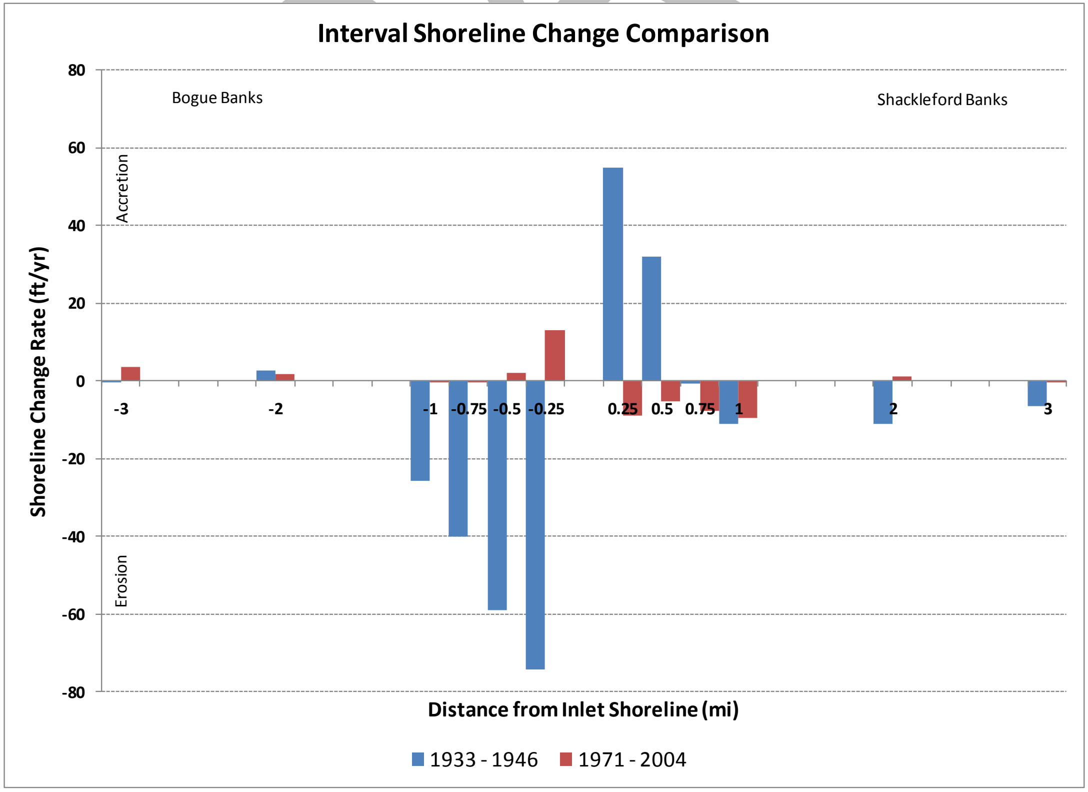


Figure II-21. Shoreline Change Interval Comparison - Fort Macon

d) Volumetric Changes, Beach Nourishment, and Dredging

The impact of the terminal groin in relation to other activities, particularly beach nourishment and dredging was assessed through volumetric comparison. The volume of beach material lost or gained was evaluated based on the shoreline change, nourishment and beach volumes placed, and quantities of material dredged from the inlet. The ratio of shoreline change to beach volume was developed based on available representative survey profiles collected by the Carteret County in 2003, 2004, 2005, 2008 and 2009 at the western side of the Beaufort Inlet (2 miles), and at the eastern side of the Inlet (Shackelford Banks, 1 mile). The general rule that is typically applied for estimation is one foot of shoreline change equates to approximately one cubic yard of beach material volume per linear foot of beach. The ratio calculated for the area around Fort Macon was approximately 1.01 cubic yards of beach volume per linear foot for one foot of shoreline change.

Table II-16 provides the volumetric beach change for the cumulative distances and intervals along each side of the inlet based on the shoreline change presented previously. Beach volume losses are given in red and beach volume gains in black. These numbers are directly computed from the shoreline changes and include all impacts to the beach such as nourishment. Figure II-22 and Figure II-23 present the same information graphically.

Table II-16. Average Annual Beach Volume Changes – Fort Macon

Distance from Inlet (mi)	1933 - 1946 West Total Volume (cy/yr)	1933 - 1946 East Total Volume (cy/yr)	1971 - 2004 West Total Volume (cy/yr)	1971 - 2004 East Total Volume (cy/yr)
0 - 0.25	98,414	72,948	17,297	11,783
0 - 0.5	176,629	115,382	20,197	18,772
0 - 0.75	229,835	114,658	19,921	29,027
0 - 1	263,955	99,926	19,308	41,469
0 - 2	250,254	41,117	29,190	36,101
0 - 3	250,326	7,499	41,845	36,905
0 - 0.25	98,414	72,948	17,297	11,783
0.25 - 0.5	78,215	42,433	2,900	6,989
0.5 - 0.75	53,206	723	276	10,255
0.75 - 1	34,120	14,732	613	12,442
1 - 2	13,701	58,808	9,883	5,368
2 - 3	71	33,619	12,655	804

*Beach volume losses are given in red and beach volume gains in black.

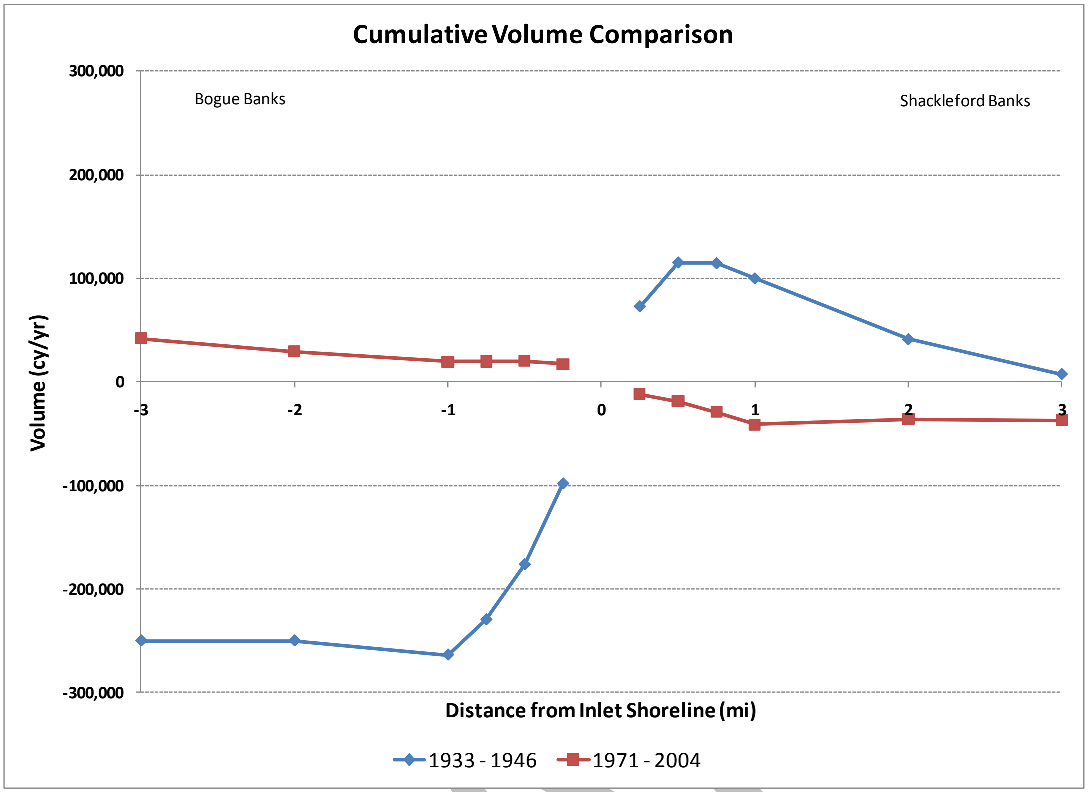


Figure II-22. Cumulative Beach Volume Change – Fort Macon

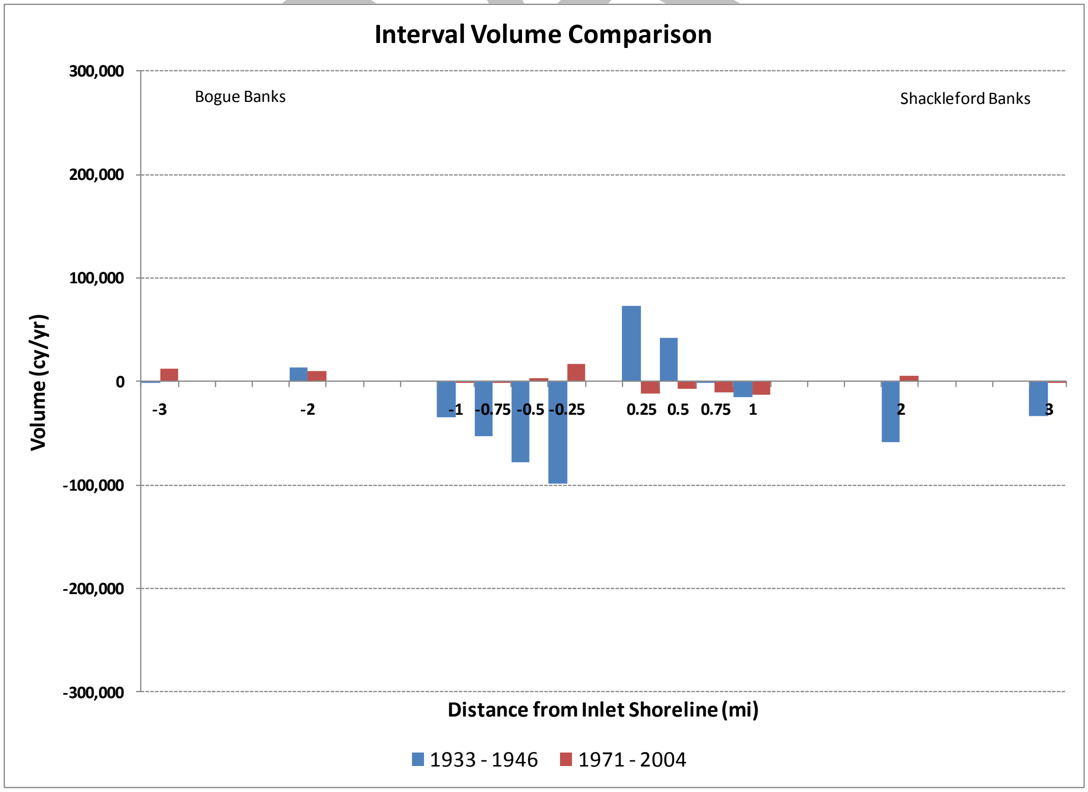


Figure II-23. Beach Volume Change Interval Comparison – Fort Macon

Since construction of the Fort Macon Terminal Groin, beach nourishment and sediment placement has occurred along the shoreline near the fort. The engineering activities log in Appendix C details the amounts, timing, and locations, when known, of beach nourishment activities. Since much of this material came from the Brandt Island dredge disposal area and was dredged from the inner harbor and channel it represents a net addition of material to the system and is not an effect of the terminal groin structure per se.

In Table II-17 this material is subtracted from the volumes calculated based on shoreline change to arrive at volume changes net nourishment. After terminal groin construction, on average 165,358 cy/yr of nourishment material has been placed on the west side of the inlet. Figure II-24 and Figure II-25 present the same information graphically.

Table II-17. Volume Changes Net Nourishment – Fort Macon

Distance from Inlet	1933 - 1946 West Total Volume	1933 - 1946 East Total Volume	1971 - 2004 West Total Volume	1971 - 2004 East Total Volume
(mi)	(cy/yr)	(cy/yr)	(cy/yr)	(cy/yr)
0 - 0.25	98,414	72,948	4,245	11,783
0 - 0.5	176,629	115,382	22,887	18,772
0 - 0.75	229,835	114,658	44,705	29,027
0 - 1	263,955	99,926	66,861	41,469
0 - 2	250,254	41,117	107,101	36,101
0 - 3	250,326	7,499	123,523	36,905
0 - 0.25	98,414	72,948	4,245	11,783
0.25 - 0.5	78,215	42,433	18,642	6,989
0.5 - 0.75	53,206	723	21,818	10,255
0.75 - 1	34,120	14,732	22,155	12,442
1 - 2	13,701	58,808	40,241	5,368
2 - 3	71	33,619	16,422	804

*Beach volume losses are given in red and beach volume gains in black.

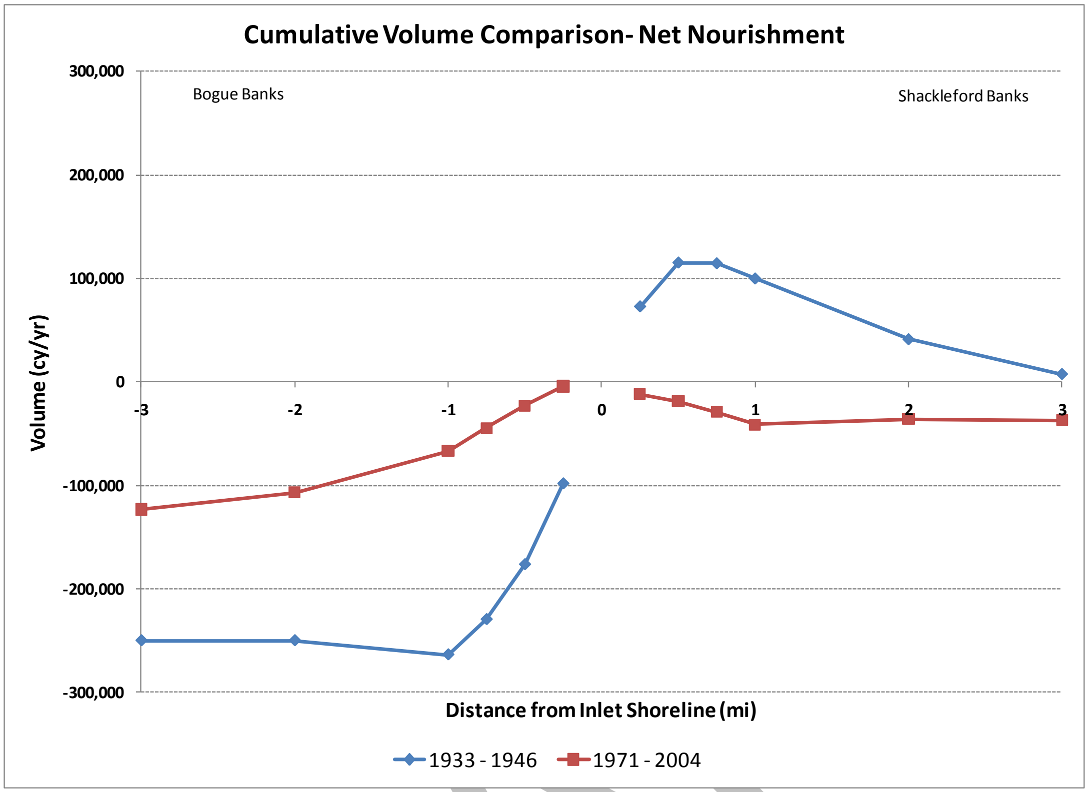


Figure II-24. Volume Changes Net Nourishment – Fort Macon

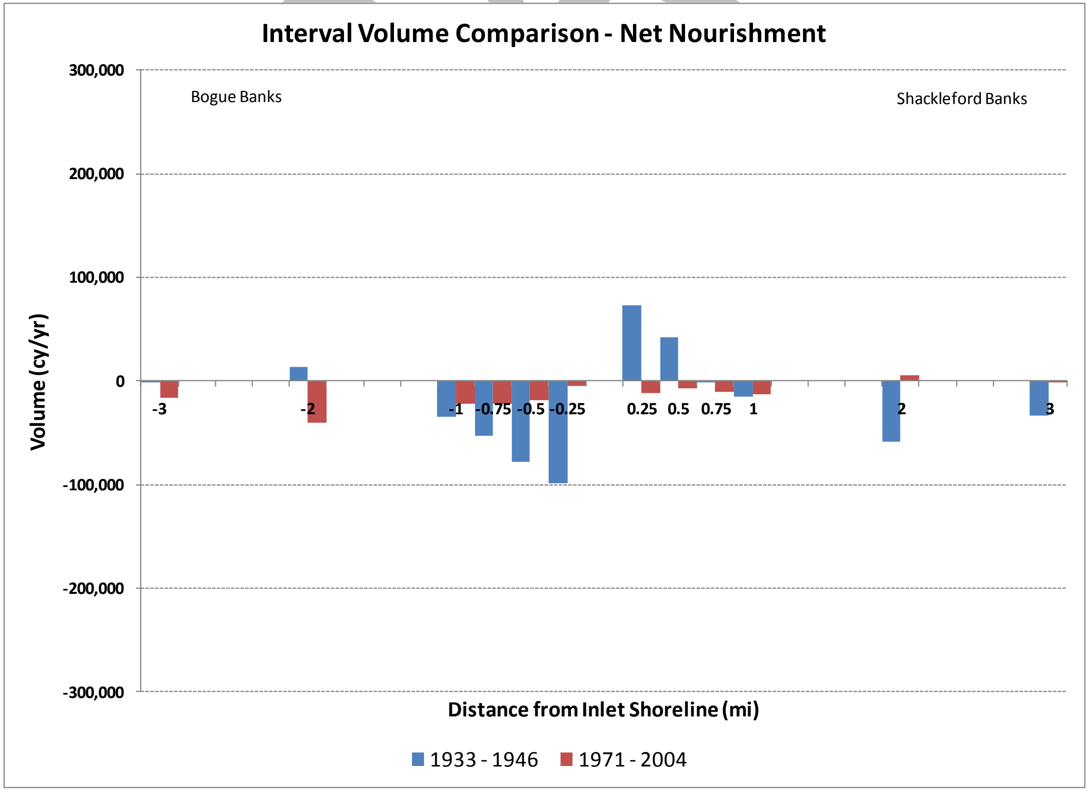


Figure II-25. Volume Changes Net Nourishment Interval Comparison – Fort Macon

Much like nourishment, the influence of dredging material and needs to be accounted for when trying to assess the impact of the terminal groin. The impact of dredging at the Fort Macon site is significant due to the deep draft navigation channel into Morehead City Harbor through Beaufort Inlet.

Past estimates involving changes in the volume of sediment stored in the 1854 ebb-tidal delta, indicated there was 48.97 million cy of material contained in the outer bar to depths of ~18 ft. Between 1854 and 1936, the ebb delta volume ranged from a low of 46.69 to a high of 56.63 million cy in 1874 (Cleary and Pilkey, 1996). Since major dredging operations began in the mid 1930s the volume of the ebb-tidal delta has steadily decreased from 48.26 million cy in 1936 to 31.65 million cy in 1974, a 34.2 % loss. Between 1974 and 2004 the outer bar volume has further decreased to 21.12 million cy. The net volume loss since 1936 was 27.14 million cy to depths of -18 ft. The most significant loss occurred within the Bogue Banks segment of the shoals on the western margin of the ebb channel.

Dredging volumes (Table II-18) through the inlet and outer bar were calculated for the same time periods as the pre- and post-structure comparisons. While the details of the sediment transport and overall sediment budgets for the region vary, there is some consensus that the dominant sediment transport in the region is to the west with an area of reversal just west of Beaufort Inlet such that sediment transport is generally toward the inlet. Detailed analysis of sediment budgets, though, is beyond the scope of this study. Table II-19 and Table II-20 present a means of generally quantifying the potential impacts of dredging by examining the change in beach volume under varying scenarios. The first scenario assumes none of the dredged material would have naturally reached the beaches (this is the case presented earlier net nourishment). The second scenario assumes 25% of the material dredged from the inlet system would have reached the beach naturally and the third scenario assumes 50%.

Table II-18. Dredging Volumes – Fort Macon

Distance from Inlet	1933 - 1946 Total Volume	1971 - 2004 Total Volume
(mi)	(cy/yr)	(cy/yr)
0 - 3	606,769	809,230

Table II-19. Volume Change Scenarios Net Nourishment and Dredging – West of Beaufort Inlet

Distance from Inlet	Dredging Percentage Added to the West	1933 - 1946 West Total Volume	1971 - 2004 West Total Volume
(mi)	(%)	(cy/yr)	(cy/yr)
0 - 3	0%	250,326	123,523
0 - 3	25%	98,633	78,784
0 - 3	50%	53,059	281,092

*Beach volume losses are given in red and beach volume gains in black.

Table II-20. Volume Change Scenarios Net Nourishment and Dredging – East of Beaufort Inlet

Distance from Inlet (mi)	Dredging Percentage Added to the East (%)	1933 - 1946 East Total Volume (cy/yr)	1971 - 2004 East Total Volume (cy/yr)
0 - 3	0%	7,499	36,905
0 - 3	25%	159,191	165,403
0 - 3	50%	310,884	367,710

*Beach volume losses are given in red and beach volume gains in black.

At Fort Macon it can be seen that even assuming a small percentage of the dredged material would have naturally been transported to the beaches greatly alters any apparent impacts of the terminal groin.

3. Amelia Island

a) Site Description

Amelia Island is the southernmost of the string of Sea Islands that stretch along the east coast of the United States from North Carolina to Florida. The Amelia Island terminal groin (Figure II-26) is located at the south end of the Amelia Island (Nassau County). Continuing south of the inlet is the Little Talbot Island (Duval County).

Figure II-26. Amelia Island Terminal Groin

An interesting morphological aspect occurs at the Nassau Sound where historically the tendency exists for the inlet to migrate northward, against the direction of predominant littoral drift, and against the direction of shoal/channel migration. This feature has increased the erosional pressure on the southern end of Amelia Island.

Two “leaky” rock structures were constructed, a 1,500-foot-long terminal groin and a 300-foot-long detached breakwater, as shown in Figure II-27. The structures were constructed to stabilize the shoreline in this area in order to protect the nearby maritime forest and ecosystem. These partially permeable and low structures were designed to reduce the alongshore transport rate of sand without adversely affecting various land forms in nearby Nassau Sound. The groin and breakwater were built leaky enough to permit some sand to continue to pass into the sound and along the downdrift shoreline.

Figure II-27. Amelia Island Terminal Groin and Breakwater

b) Physical Environment

Data on the waves, water levels, and storm activity are discussed in this section with the relationship to the geologic framework addressed in Section III of this report.

(1) Waves and Tides

The closest NDBC buoys and WIS stations near Amelia Island that represent wave conditions within the immediate area surrounding the terminal groin are shown in Figure II-28 along with nearby NOAA tidal gages. The closest operating tidal gage is located at the Nassau River entrance with a second nearby gage approximately 9 miles south at Mayport. Table II-21 lists the tidal datums for both gages.

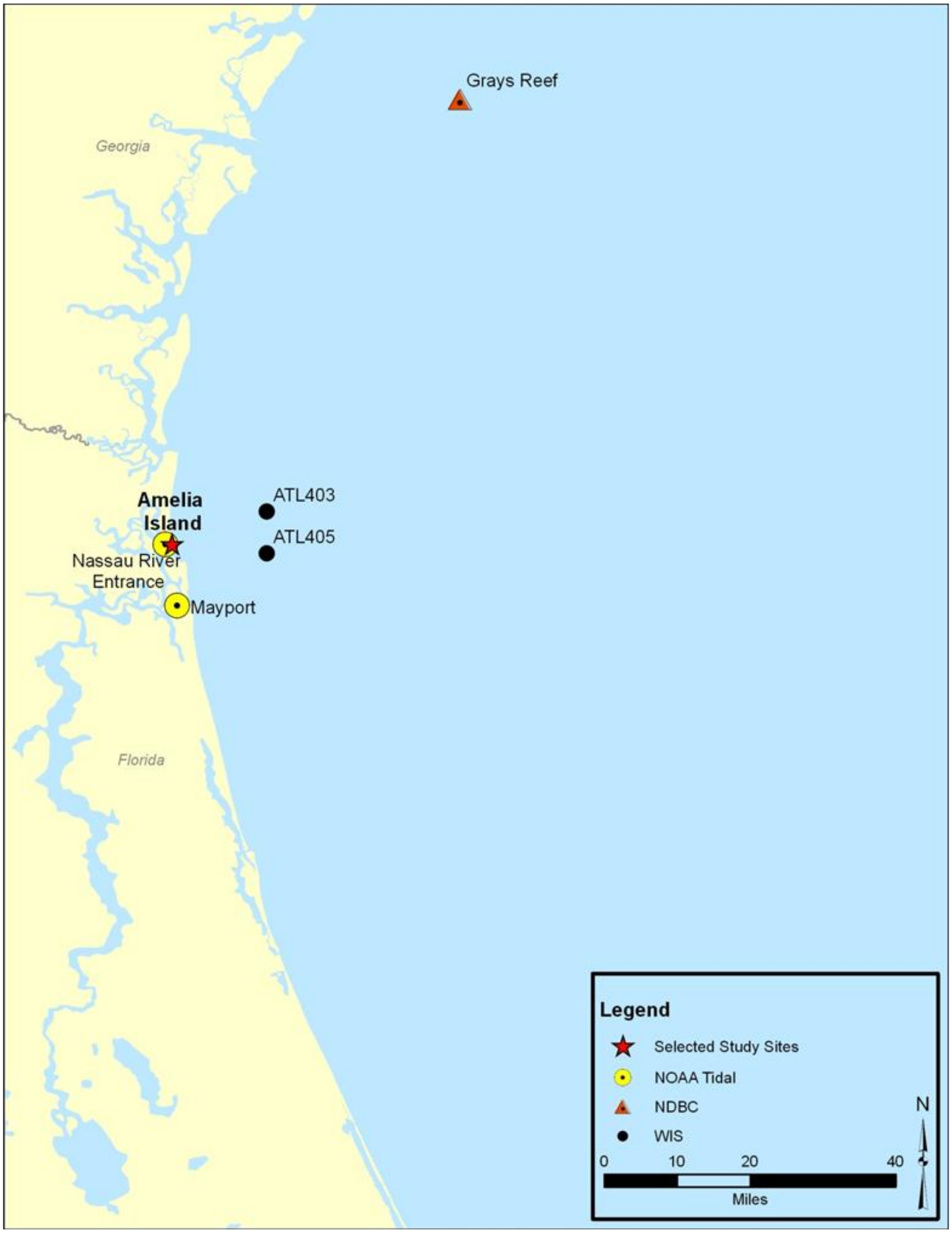


Figure II-28. Wave and Tidal Stations near Amelia Island

Table II-21. Tidal Gages near Amelia Island

Tidal Datum	Station	
	Mayport - Bar Pilots Dock (8720218)	Nassau River Entrance (8720135)
MHHW (ft)	4.99	5.69
MHW (ft)	4.72	5.35
DTL (ft)	2.5	2.85
MTL (ft)	2.44	2.77
MSL (ft)	2.46	2.7
MLW (ft)	0.15	0.19
MLLW (ft)	0	0
NAVD (ft)	-	3.18
Maximum (ft)	7.14	-
Max Date	20010917	-
Max Time	0.041667	-
Minimum 9ft)	-2.28	-
Min Date	19960218	-
Min Time	0.270833	-

Table II-22 and Table II-23 summarize the percent occurrences by wave height and direction for WIS stations ATL 403 and 405. Figure II-29 illustrates the average annual wave roses for both stations. These wave roses provide a graphical representation of the wave heights and directions from which the waves are coming.

Table II-22. WIS Percent Occurrence of Wave Heights

Wave Height (meters)	Percent Occurrence of Wave Height	
	Station ATL 403	Station ATL 405
0.00 – 0.49	9.7	9.4
0.50 – 0.99	49.5	49.1
1.00 – 1.49	26.1	26.2
1.5 – 1.99	9.9	10.1
2.00 – 2.49	3.1	3.4
2.50 – 2.99	1.1	1.2
3.00 – 3.49	0.4	0.4
3.50 – 3.99	0.1	0.2
4.00 – 4.49	0.0	0.1
4.50 – 4.99	0.0	0.0
5.00 - GREATER	0.0	0.0

Table II-23. WIS Percent Occurrence by Mean Wave Direction (From)

Direction Band & Center (deg)	Percent Occurrence of Mean Direction	
	Station ATL 403	Station ATL 405
348.75 – 11.24 (0.0)	3.3	3.4
11.25 – 33.74 (22.5)	4.9	5.2
33.75 – 56.24 (45.0)	7.6	8.2
56.25 – 78.74 (67.5)	13.4	15.0
78.75 - 101.24 (90.0)	22.1	22.7
101.25 - 123.74 (112.5)	25.8	24.7
123.75 - 146.24 (135.0)	8.9	7.9
146.25 - 168.74 (157.5)	4.5	4.3
168.75 - 191.24 (180.0)	3.1	2.8
191.25 - 213.74 (202.5)	1.1	1.0
213.75 - 236.24 (225.0)	0.6	0.6
236.25 - 258.74 (247.5)	0.5	0.5
258.75 - 281.24 (270.0)	0.6	0.5
281.25 - 303.74 (292.5)	0.8	0.7
303.75 - 326.24 (315.0)	1.2	1.1
326.25 - 348.74 (337.5)	1.5	1.5

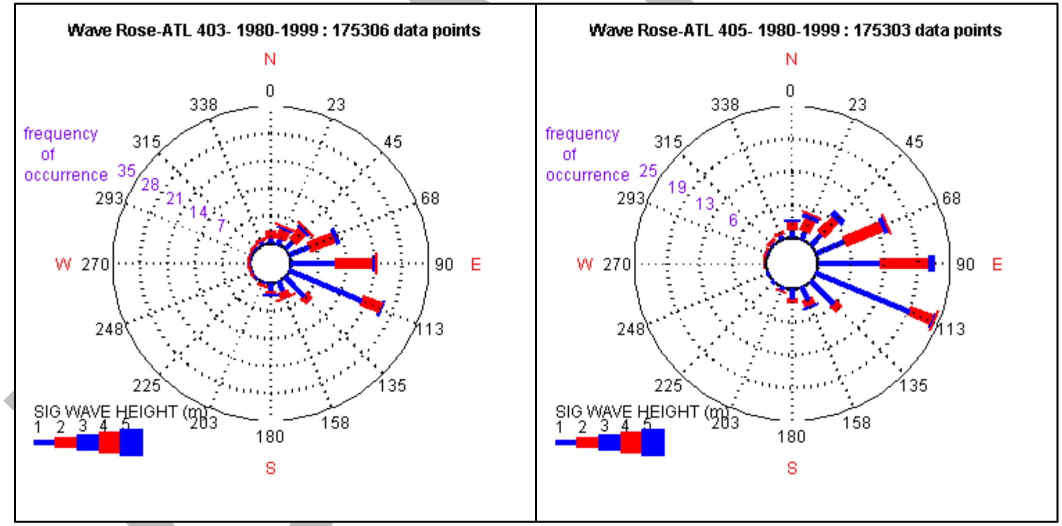


Figure II-29. Wave Roses (USACE WIS Hindcast)

A review of the WIS hindcast data yields the following observations:

- Almost 50% of the wave heights over the hindcast period (1980 – 1999) were between approximately 0.5 – 0.99 meters (1.6 – 3.2 feet).
- This region typically does not experience large wave heights over 2 meters (6.6 feet) – less than 5% of the total number of waves
- The typical direction of the waves was from east – east southeast.
- The largest waves occur during the winter months (December – March) and predominately from the northeast.

(2) Storms

The NOAA database of historical storms records approximate storm track, wind speed, pressure, and category for storms since 1851. Figure II-30 illustrates the hurricane tracks in the vicinity of Amelia Island and Table II-24 lists the extratropical storms, tropical storms, and hurricanes that have passed within 65 nautical miles between 1851 and 2008. Of these 83 storms, 4 have made landfall within 10 miles.

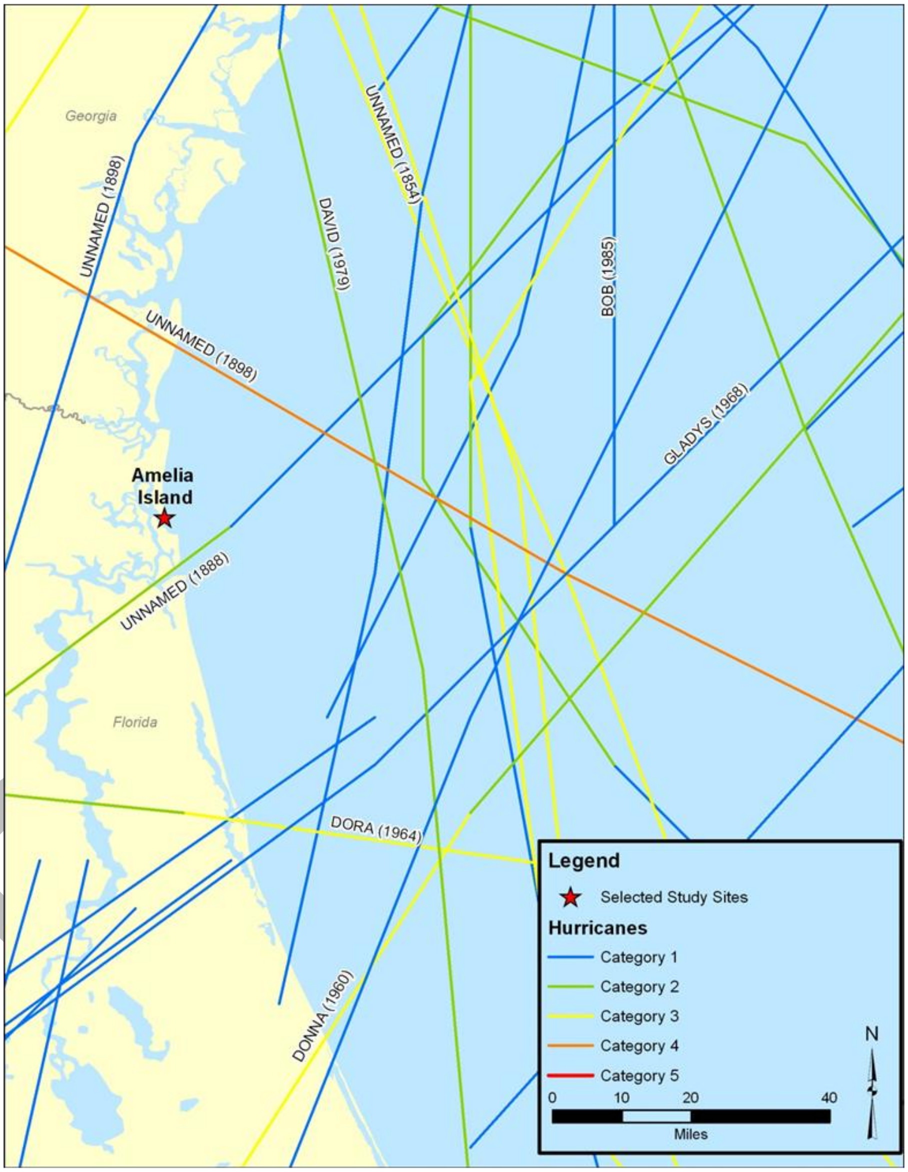


Figure II-30. Hurricanes in the Vicinity of Amelia Island

Table II-24. Amelia Island Vicinity Storms (NOAA, 1951-2008)

YEAR	STORM NAME	MAXIMUM CATEGORY
1853	NOTNAMED	Category 2
1854	NOTNAMED	Category 3
1867	NOTNAMED	Tropical Storm
1867	NOTNAMED	Tropical Storm
1867	NOTNAMED	Tropical Storm
1868	NOTNAMED	Tropical Storm
1871	NOTNAMED	Tropical Storm
1871	NOTNAMED	Tropical Storm
1871	NOTNAMED	Tropical Storm
1873	NOTNAMED	Tropical Storm
1874	NOTNAMED	Category 1
1877	NOTNAMED	Tropical Storm
1877	NOTNAMED	Tropical Storm
1878	NOTNAMED	Category 1
1878	NOTNAMED	Tropical Storm
1879	NOTNAMED	Tropical Storm
1880	NOTNAMED	Tropical Storm
1880	NOTNAMED	Category 1
1881	NOTNAMED	Category 2
1882	NOTNAMED	Tropical Storm
1884	NOTNAMED	Tropical Storm
1884	NOTNAMED	Tropical Storm
1885	NOTNAMED	Category 2
1885	NOTNAMED	Tropical Storm
1885	NOTNAMED	Tropical Storm
1885	NOTNAMED	Tropical Storm
1886	NOTNAMED	Tropical Storm
1888	NOTNAMED	Tropical Storm
1888	NOTNAMED	Category 2
1889	NOTNAMED	Tropical Storm
1893	NOTNAMED	Tropical Storm
1893	NOTNAMED	Category 3
1893	NOTNAMED	Category 3
1894	NOTNAMED	Category 1
1896	NOTNAMED	Category 3
1898	NOTNAMED	Category 4
1900	NOTNAMED	Tropical Storm
1906	NOTNAMED	Tropical Storm
1907	NOTNAMED	Tropical Storm
1910	NOTNAMED	Tropical Storm
1912	NOTNAMED	Tropical Storm
1912	NOTNAMED	Tropical Storm
1914	NOTNAMED	Tropical Storm
1915	NOTNAMED	Tropical Storm
1916	NOTNAMED	Tropical Storm
1916	NOTNAMED	Tropical Storm
1919	NOTNAMED	Tropical Storm
1919	NOTNAMED	Tropical Storm
1924	NOTNAMED	Tropical Storm
1926	NOTNAMED	Tropical Storm
1927	NOTNAMED	Tropical Storm
1928	NOTNAMED	Category 2
1932	NOTNAMED	Tropical Storm
1934	NOTNAMED	Tropical Storm
1936	NOTNAMED	Tropical Storm
1938	NOTNAMED	Tropical Storm
1944	NOTNAMED	Category 1
1945	NOTNAMED	Category 1
1945	NOTNAMED	Category 1
1945	NOTNAMED	Tropical Storm
1946	NOTNAMED	Tropical Storm
1946	NOTNAMED	Tropical Storm
1947	NOTNAMED	Tropical Storm
1947	NOTNAMED	Tropical Storm
1950	EASY	Tropical Storm
1953	NOTNAMED	Tropical Storm
1960	BRENDA	Tropical Storm
1960	DONNA	Category 3
1964	CLEO	Tropical Storm
1964	DORA	Category 3
1968	ABBY	Tropical Storm
1968	GLADYS	Category 1
1979	DAVID	Category 2
1981	DENNIS	Tropical Storm
1984	ISIDORE	Tropical Storm
1985	BOB	Category 1
1985	ISABEL	Tropical Storm
1988	CHRIS	Tropical Storm
1996	JOSEPHINE	Tropical Storm
2000	GORDON	Tropical Storm
2002	KYLE	Tropical Storm
2004	CHARLEY	Category 1
2005	TAMMY	Tropical Storm

c) Shoreline Change

The shoreline impacts of the terminal groin at south Amelia Island are assessed by examining the shoreline change prior to and after construction. Historical shoreline data was obtained from the Florida Department of Environmental Protection. The differences in shoreline position were calculated at 50 m transects along the shore for a distance of three miles to either side of the inlet. Shoreline data sets selected were chosen which extended three miles to either side of the inlet and to cover the pre-structure and post-structure time periods. Figure II-31 illustrates the shoreline data used in the analysis.

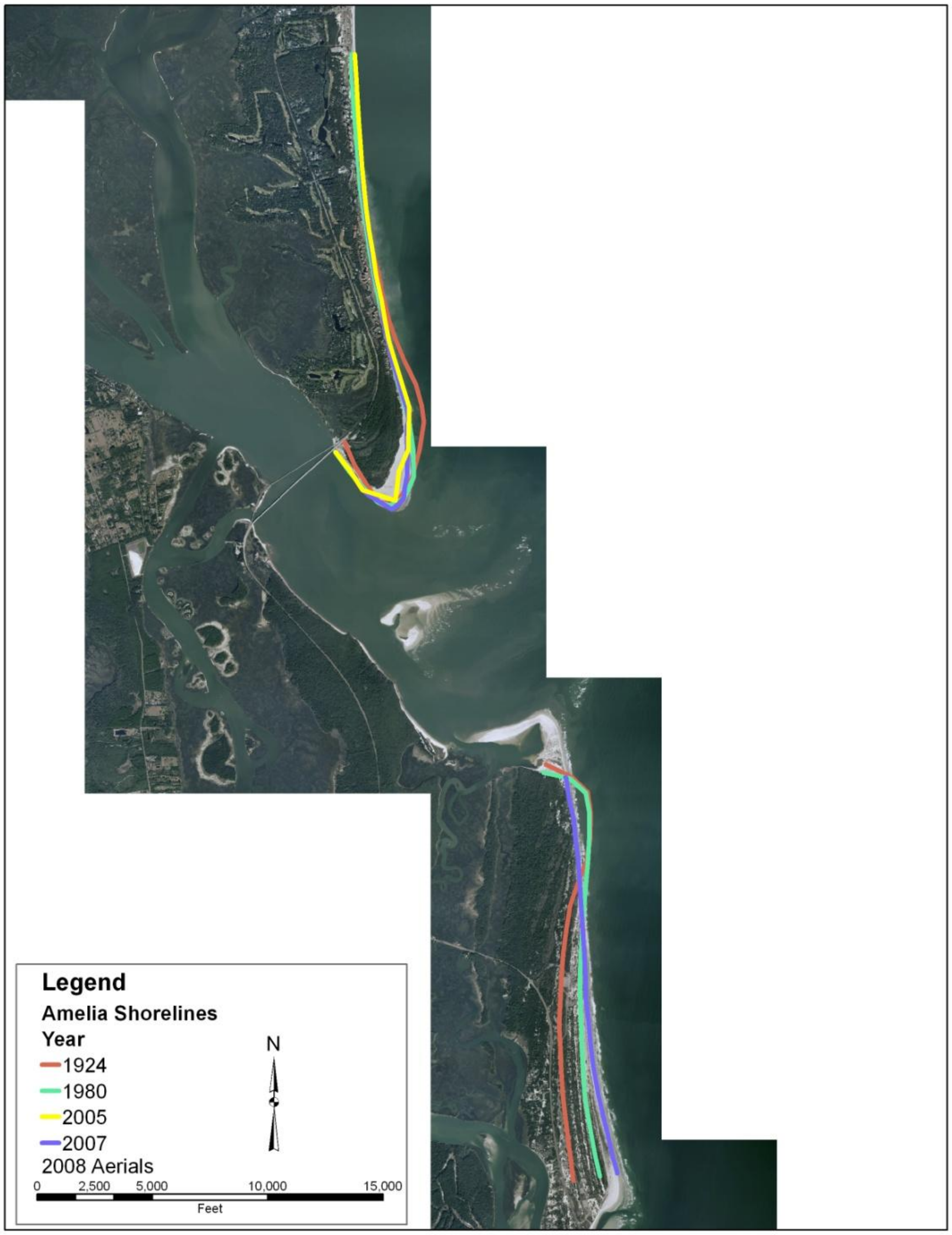


Figure II-31. Historic Shorelines – Amelia Island

Figure II-32 illustrates the calculation transects and the starting position of each shoreline comparison calculation period. A pre-structure period of 1924 to 1980 was used since this period represents the longest available pre-construction Florida Department of Environmental Protection shoreline interval. A post-construction period of 2005 to 2007 (short time frame) was used since the structure was finished in 2005. It has to be notes that there is not shoreline available for the south side of the inlet for the post construction time period.

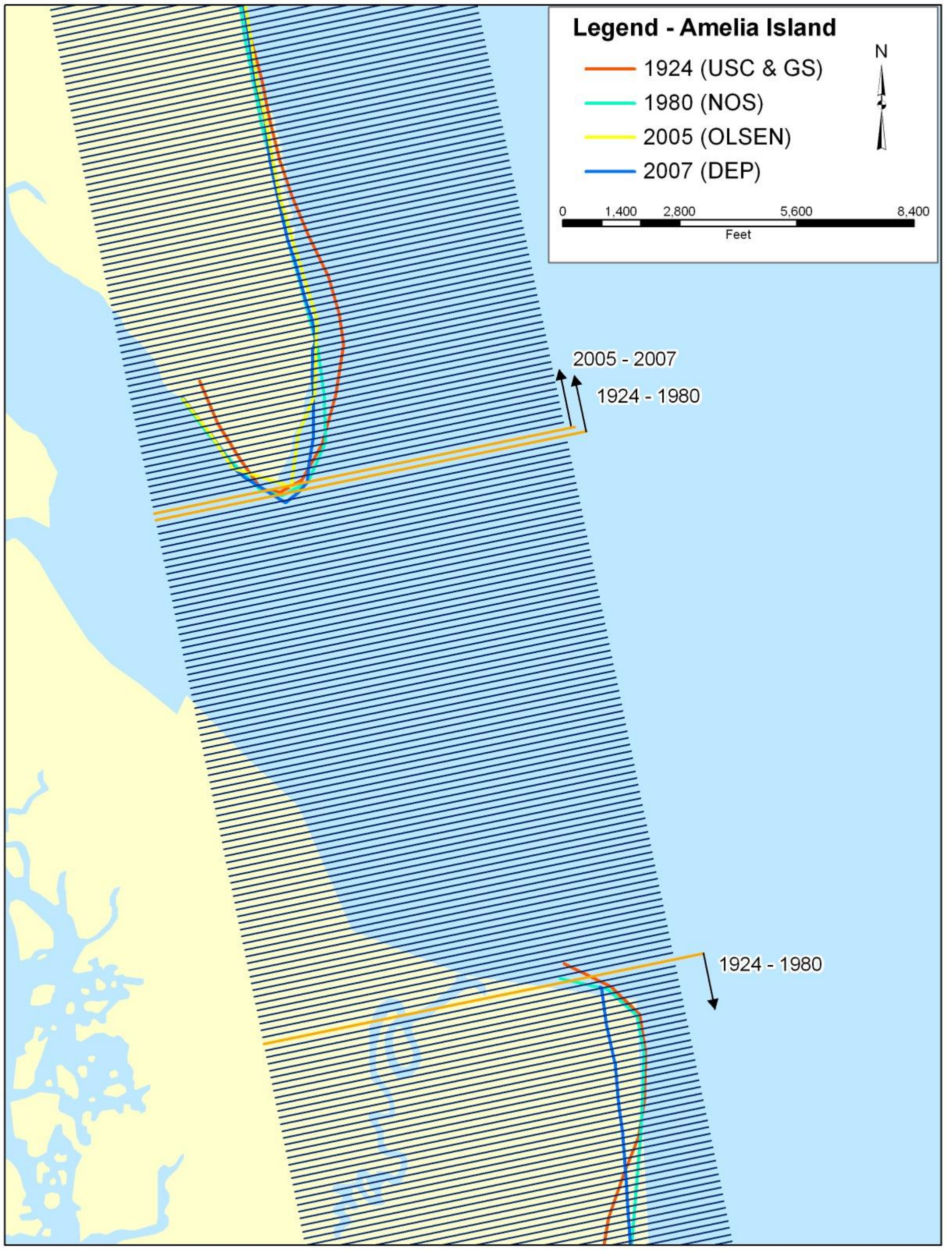


Figure II-32. Amelia Island Shoreline Change Calculation Transects

The results of the shoreline change calculations for the pre- and post-structure time periods are given in Table II-25. The table presents the calculation results for both the north side (Amelia

Island, Nassau County) and south side (Little Talbot Island, Duval County) of the Nassau River Inlet.

Values in red represent shoreline recession (erosion) and values in black represent shoreline advancement (accretion). The first six rows of the table present cumulative average shoreline change from the inlet shoulder to a total distance of three miles. The lower six rows provide the average shoreline change for each interval as indicated. Figure II-33 and Figure II-34 display the same data graphically.

Table II-25. Calculated Shoreline Change – Amelia Island

Distance from Inlet (mi)	1924 - 1980 North Average Change Rate (ft/yr)	1924 - 1980 South Average Change Rate (ft/yr)	2005 - 2007 North Average Change Rate (ft/yr)	2005 - 2007 South Average Change Rate (ft/yr)
0 - 0.25	3.2	3.2	190.7	N/A
0 - 0.5	0.6	2.1	112.9	N/A
0 - 0.75	4.0	1.5	64.3	N/A
0 - 1	6.0	0.1	34.0	N/A
0 - 2	5.6	6.9	3.0	N/A
0 - 3	4.1	10.3	3.2	N/A
0 - 0.25	3.2	3.2	190.7	N/A
0.25 - 0.5	4.8	0.8	35.1	N/A
0.5 - 0.75	11.2	0.2	33.0	N/A
0.75 - 1	12.4	5.1	56.8	N/A
1 - 2	5.2	13.9	28.1	N/A
2 - 3	1.0	17.2	15.5	N/A

[*] Red values represent shoreline recession (erosion) and black values represent shoreline advancement (accretion)

Prior to terminal groin construction the shoreline to the north side of the inlet was eroding. After the construction of the terminal groin, the north shoreline shows accretion along the first half mile and erosion on the following 2.5 miles. The accretion is high in the first half mile, so the cumulative values shows accretion along the first three miles of the south side of Amelia Island.

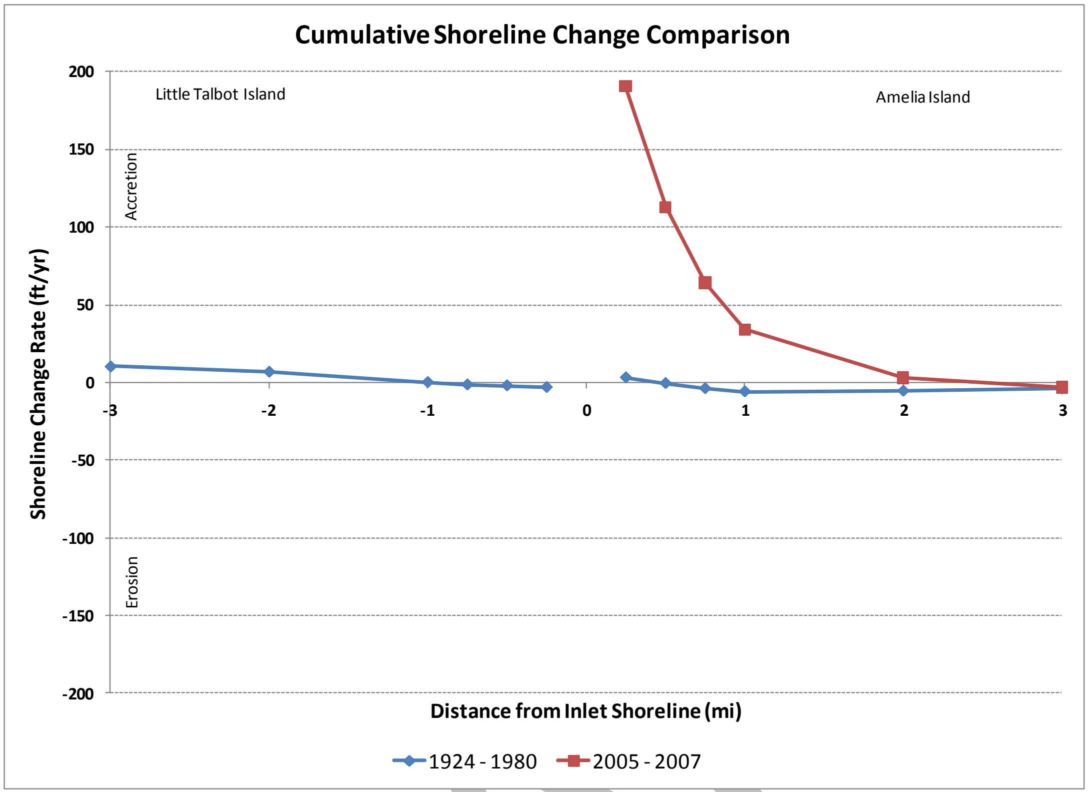


Figure II-33. Cumulative Shoreline Change – Amelia Island

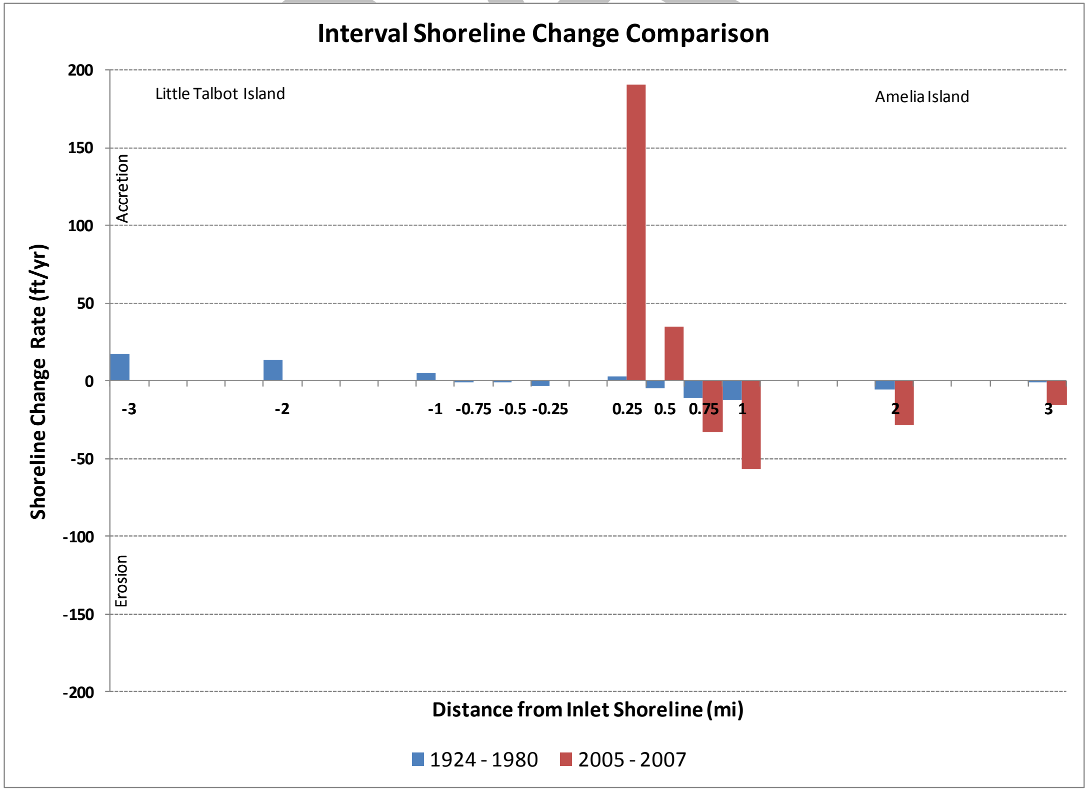


Figure II-34. Shoreline Change Interval Comparison – Amelia Island

d) Volumetric Changes, Beach Nourishment, and Dredging

The impact of the terminal groin in relation to other activities, particularly beach nourishment and dredging was assessed through volumetric comparison. The volume of beach material lost or gained was evaluated based on the shoreline change, nourishment and beach volumes placed and material dredged from the inlet and surroundings. The ratio of shoreline change to beach volume was developed based on available representative survey profiles collected by the Florida Department of Environmental Protection in 1990 and 2003 at Duval County (Little Talbot Island, up to 1.5 mile south of Inlet); and in 1981, 1998 and 2003 at Nassau County (Amelia Island, up to 1.5 mile north of Inlet). The general rule that is typically applied for estimation is one foot of shoreline change equates to approximately one cubic yard of beach material volume per linear foot of beach. The ratio calculated for the area around Amelia Island was approximately 1.25 cubic yards of beach volume per linear foot for one foot of shoreline change.

Table II-26 provides the volumetric beach change for the cumulative distances and intervals along each side of the inlet based on for the shoreline change presented previously. Beach volume losses are given in red and beach volume gains in black. These numbers are directly computed from the shoreline changes and include all impacts to the beach such as nourishment. Figure II-35 and Figure II-36 present the same information graphically.

Table II-26. Average Annual Beach Volume Changes – Amelia Island

Distance from Inlet (mi)	1924 - 1980 North Total Volume (cy/yr)	1924 - 1980 South Total Volume (cy/yr)	2005 - 2007 North Total Volume (cy/yr)	2005 - 2007 South Total Volume (cy/yr)
0 - 0.25	6,166	6,085	312,885	N/A
0 - 0.5	2,009	7,490	370,518	N/A
0 - 0.75	21,045	7,881	316,365	N/A
0 - 1	42,076	849	223,261	N/A
0 - 2	77,395	95,465	38,790	N/A
0 - 3	84,333	212,665	63,098	N/A
0 - 0.25	6,166	6,085	312,885	N/A
0.25 - 0.5	8,175	1,405	57,633	N/A
0.5 - 0.75	19,036	391	54,154	N/A
0.75 - 1	21,030	8,730	93,104	N/A
1 - 2	35,320	94,616	184,471	N/A
2 - 3	6,938	117,201	101,888	N/A

*Beach volume losses are given in red and beach volume gains in black.

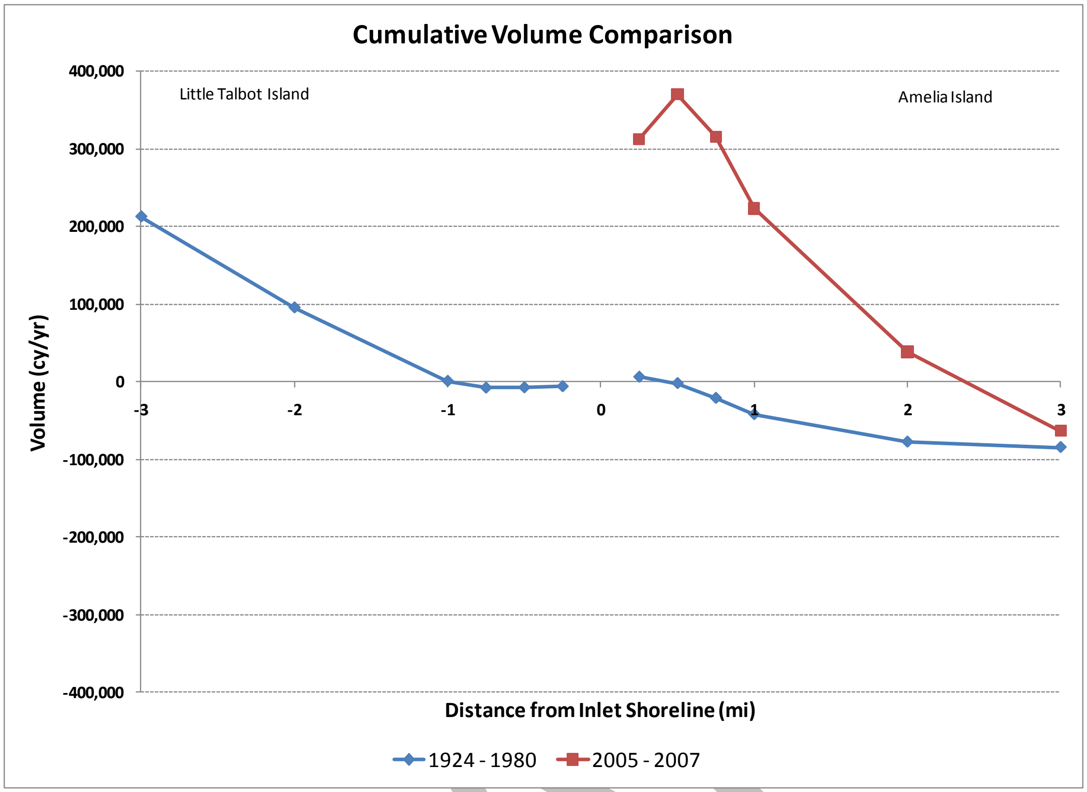


Figure II-35. Cumulative Beach Volume Change – Amelia Island

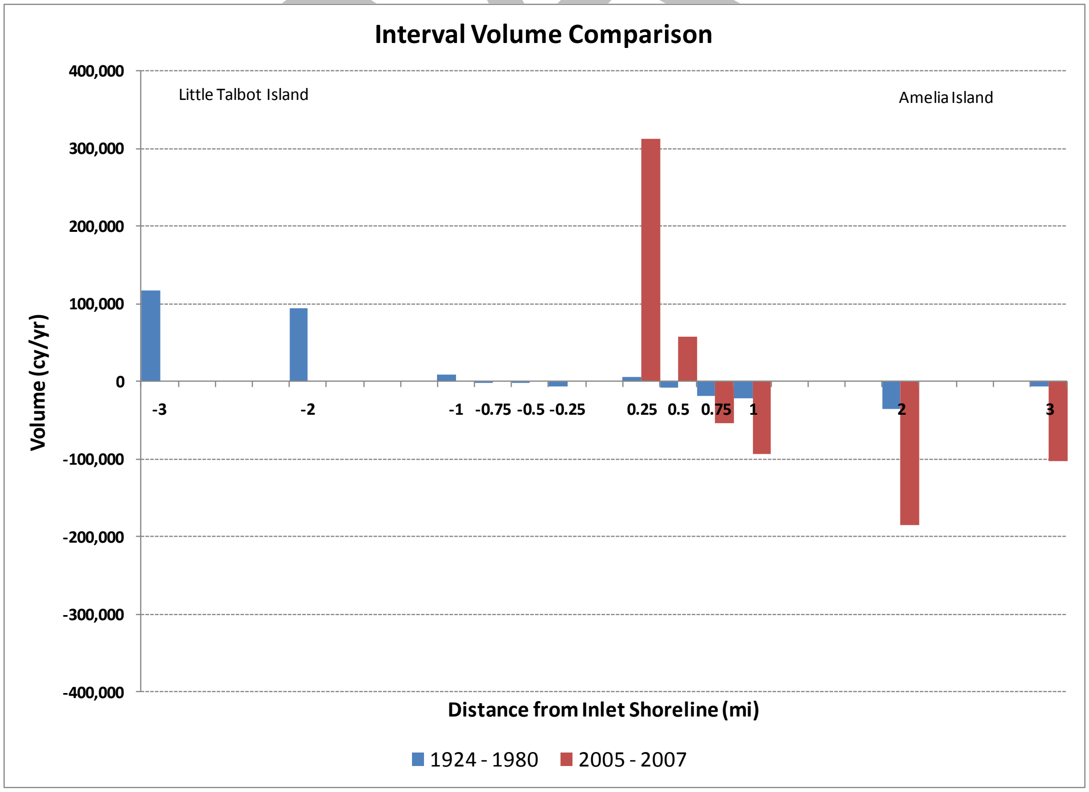


Figure II-36. Beach Volume Change Interval Comparison – Amelia Island

Since 1984, beach nourishment and sediment placement has occurred along the shoreline north of the Nassau River Inlet, specifically on Amelia Island. The engineering activities log in Appendix C details the amounts, timing, and locations, when known, of beach nourishment activities. Since it is known that most of the beach nourishment material came from the dredging of the Nassau Sound, it represents a net addition of material to the system and is not an effect of the terminal groin structure per se.

In Table II-27, this material is subtracted from the volumes calculated based on shoreline change to arrive at volume changes net nourishment. Prior to terminal groin construction, on average 161,488 cy/yr of nourishment material has been placed along the north side of the inlet, and 1,852 cy/yr has been placed along the south side (first quarter mile). 400,000 cy was placed between the terminal groin and the breakwater in the post-construction period (2005-07). Figure II-37 and Figure II-38 present the same information graphically.

Table II-27. Volume Changes Net Nourishment – Amelia Island

Distance from Inlet (mi)	1924 - 1980 North Total Volume (cy/yr)	1924 - 1980 South Total Volume (cy/yr)	2005 - 2007 North Total Volume (cy/yr)	2005 - 2007 South Total Volume (cy/yr)
0 - 0.25	5,946	5,868	312,885	N/A
0 - 0.5	1,937	7,222	303,851	N/A
0 - 0.75	20,294	7,600	183,031	N/A
0 - 1	40,573	818	23,261	N/A
0 - 2	74,631	92,055	161,210	N/A
0 - 3	81,321	205,070	263,098	N/A
0 - 0.25	5,946	5,868	312,885	N/A
0.25 - 0.5	7,883	1,355	9,034	N/A
0.5 - 0.75	18,356	377	120,820	N/A
0.75 - 1	20,279	8,418	159,770	N/A
1 - 2	34,058	91,237	184,471	N/A
2 - 3	6,690	113,015	101,888	N/A

*Beach volume losses are given in red and beach volume gains in black.

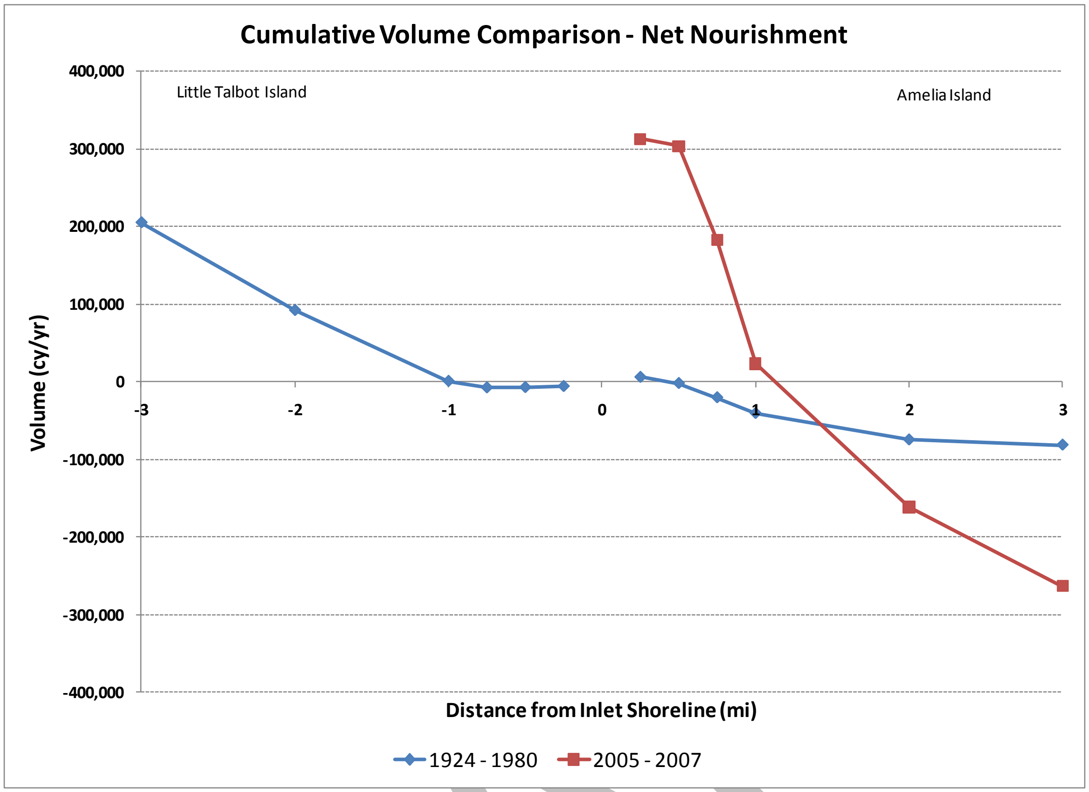


Figure II-37. Volume Changes Net Nourishment – Amelia Island

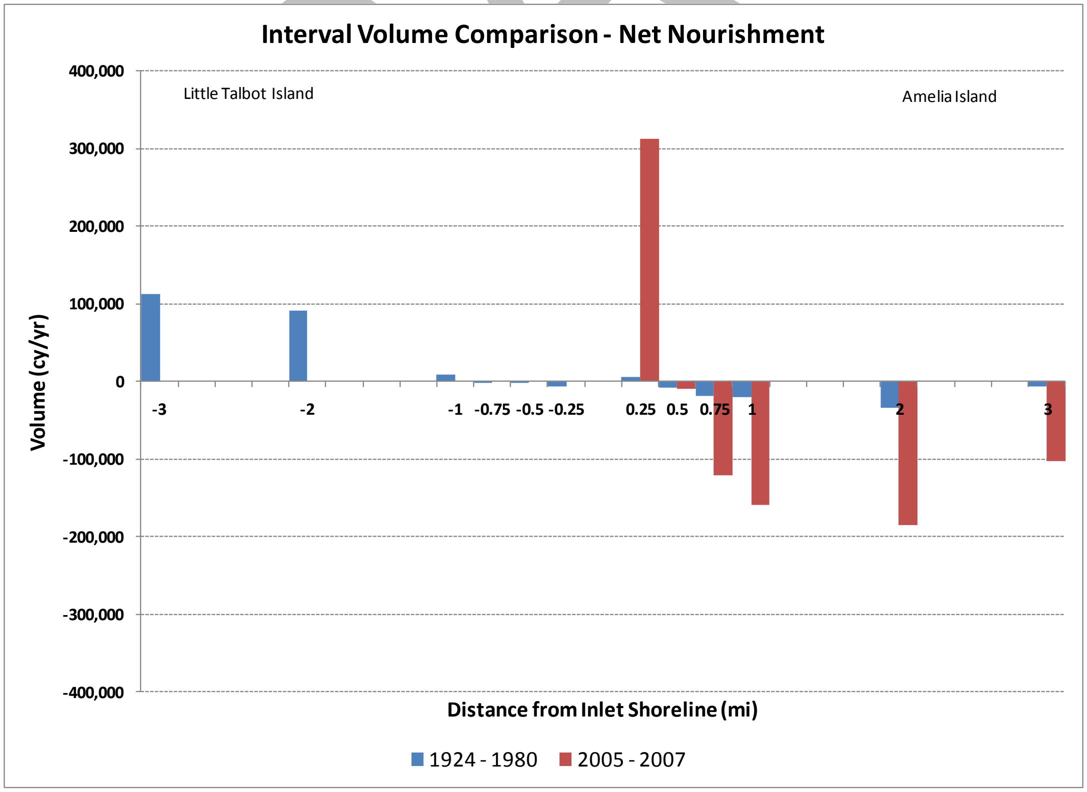


Figure II-38. Volume Changes Net Nourishment Interval Comparison – Amelia Island

As stated before, it is known that dredging has been conducted in the Nassau Sound with much of the material placed on the Amelia Island shoreline (mostly towards the south end). It is also known that dredging has been conducted at the channel of the St Mary's Inlet (north of Amelia Island). Knowing that the littoral drift in this area is predominately north to south, dredging material from the inlet north of Amelia Island could increase the erosion (shoreline retreat) along the Island.

4. Captiva Island

a) Site Description

Captiva Island is part of Lee County which is located on the lower western peninsula coast of Florida. The hurricane of 1921 created the Redfish Pass, which separates Captiva and North Captiva Islands. The Pine Island Sound separates Captiva Island from the mainland. The terminal groin is located at the north end of the Captiva Island, next to Redfish Pass (Figure II-39).

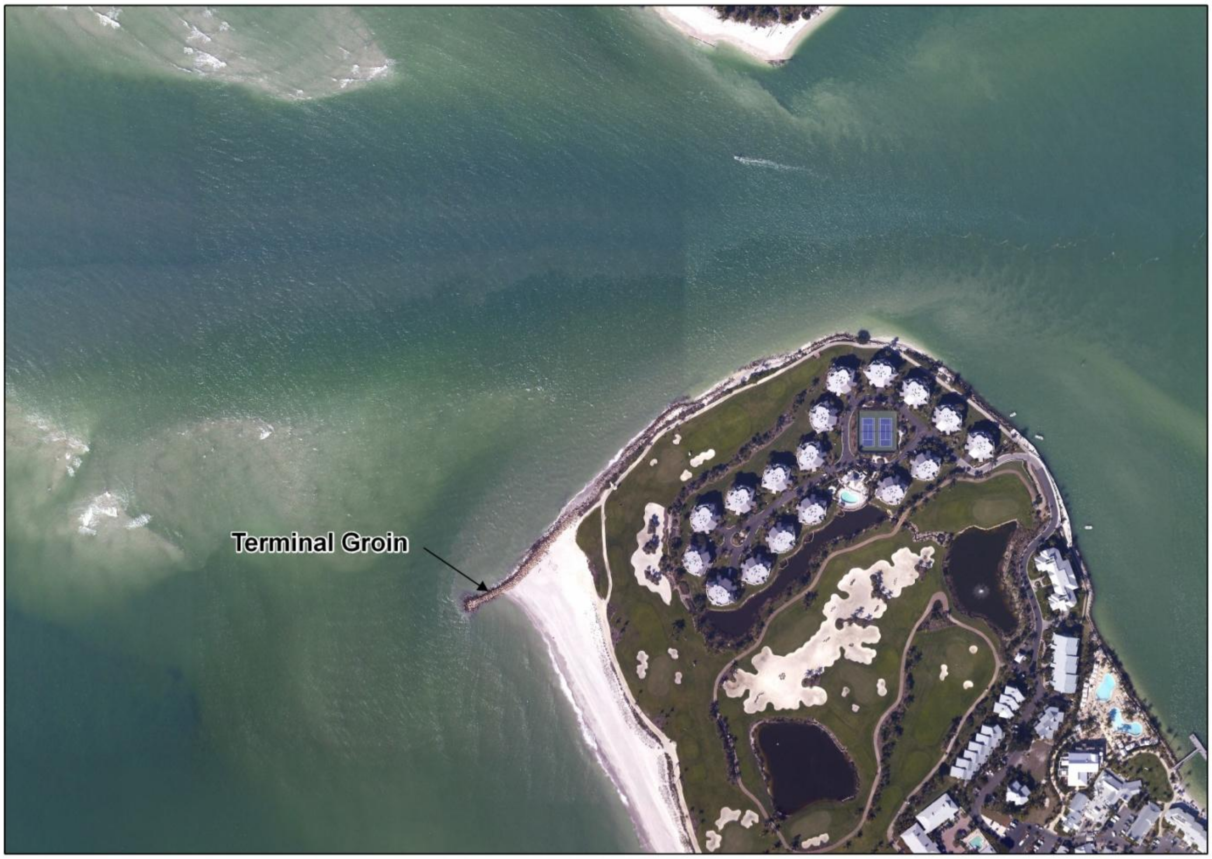


Figure II-39. Captiva Island Terminal Groin

Many groins and stabilization structures were constructed along Captiva Island in the early years, when this was a common practice; however most of them have been destroyed or removed. For example in 1961, 134 groins were constructed, and in 1962 two timber groins were built in the middle of the Island. Beach nourishment projects have eliminated the need of the groins, timber structures and segmented breakwaters that were constructed on the Island. The first beach nourishment project was built in 1961. The terminal groin at the north end of Captiva Island was constructed in 1977 and rehabilitated in 2006. Figure II-40 shows an aerial view of the Redfish Pass and the rehabilitation of the terminal groin in 2006 (Upper left figure is looking towards the north, and lower left figure is looking towards the Island).

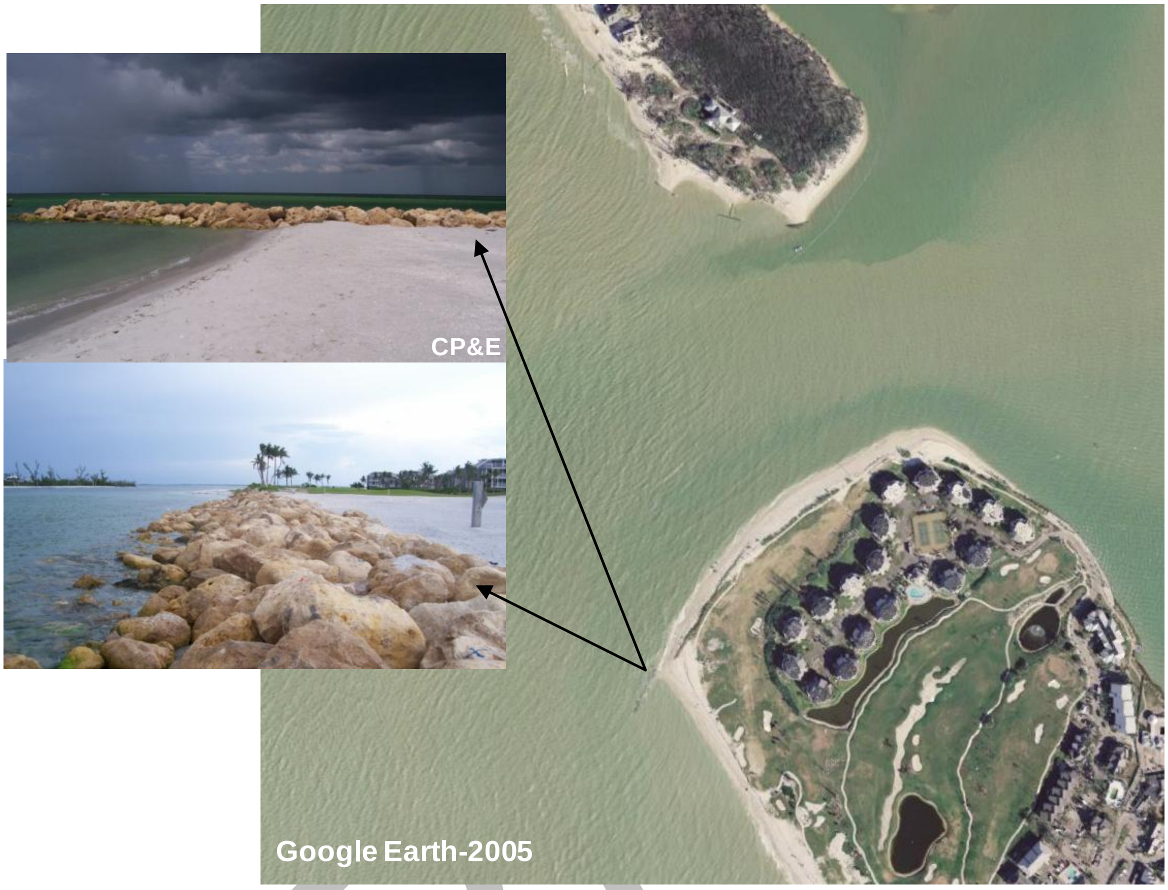


Figure II-40. Terminal Groin Rehabilitation

The Redfish Pass channel and the ocean bar shoal are regularly dredged to maintain the channel depth, which is subject to shoaling because of the strong tidal currents that transport and redeposit sediment from the beach facing the Gulf of Mexico. The inlet has a symmetrical north/south tide dominant ebb delta.

b) Physical Environment

Data on the waves, water levels, and storm activity are discussed in this section with the relationship to the geologic framework addressed in Section III of this report.

(1) Waves and Tides

The closest NDBC buoys and WIS stations near Captiva Island / Redfish Pass that represent wave conditions within the immediate area surrounding the terminal groin are shown in Figure II-41 along with nearby NOAA tidal gages. The NOAA tidal gage located at Fort Myers is the closest tidal gage to Captiva Island. This gage is located along the Caloosahatchee River, before its confluence with San Carlos Bay. The closest ocean-side tide gage is located approximately 37 miles south at Naples, Florida. Table II-28 lists the tidal datums for both gages.

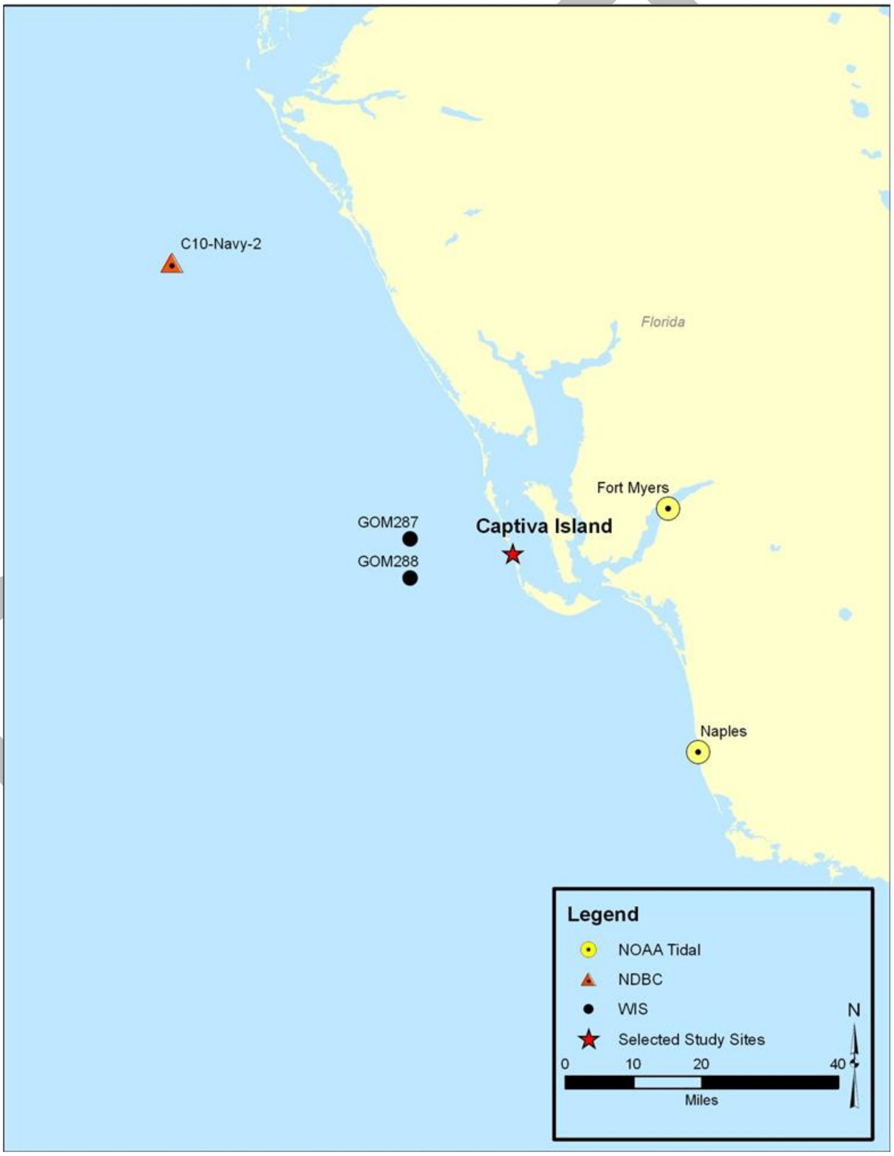


Figure II-41. Wave and Tidal Stations near Captiva Island

Table II-28. Tidal Gages near Captiva Island

Tidal Datum	Station	
	Fort Myers (8725520)	Naples (8725110)
MHHW (ft)	1.32	2.87
MHW (ft)	1.10	2.61
DTL (ft)	0.66	1.44
MTL (ft)	0.63	1.61
MSL (ft)	0.63	1.65
MLW (ft)	0.15	0.60
MLLW (ft)	0.00	0.00
NAVD (ft)	1.04	2.28
Maximum (ft)	4.72	5.98
Max Date	1988/11/23	1972/12/21
Max Time	4:48	23:54
Minimum (ft)	-2.86	-2.48
Min Date	1965/09/08	1988/03/15
Min Time	0:00	4:12

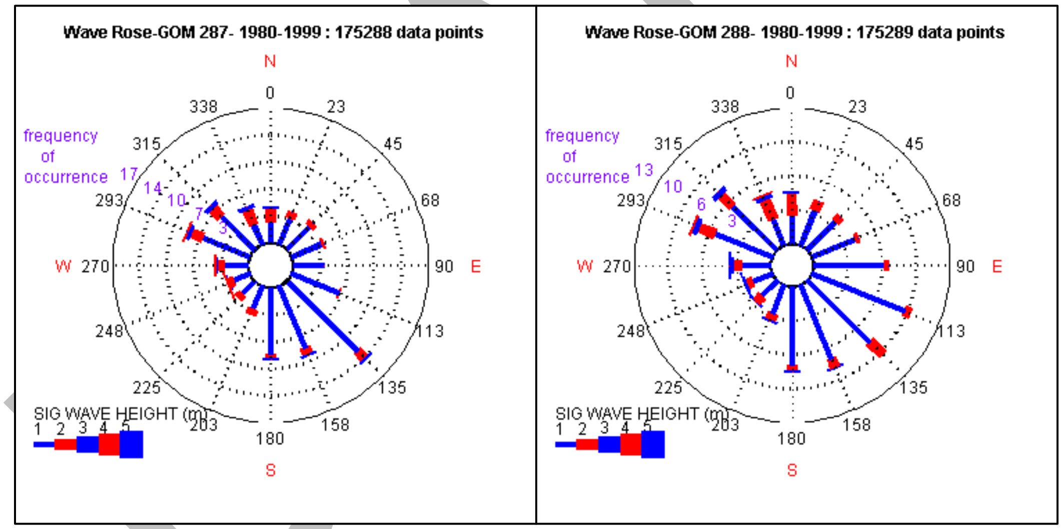
Table II-29 and Table II-30 summarize the percent occurrences by wave height and direction for WIS stations GOM 287 and 288. Figure II-42 illustrates the average annual wave roses for both stations. These wave roses provide a graphical representation of the wave heights and directions from which the waves are coming.

Table II-29. WIS Percent Occurrence of Wave Heights

Wave Height (meters)	Percent Occurrence of Wave Height	
	Station GOM 287	Station GOM 288
0.00 – 0.49	43.5	38.3
0.50 – 0.99	38.9	42.5
1.00 – 1.49	11.4	12.1
1.5 – 1.99	3.8	4.2
2.00 – 2.49	1.5	1.7
2.50 – 2.99	0.5	0.6
3.00 – 3.49	0.3	0.3
3.50 – 3.99	0.1	0.1
4.00 – 4.49	0.1	0.1
4.50 – 4.99	0.0	0.0
5.00 - GREATER	0.0	0.0

Table II-30. WIS Percent Occurrence by Mean Wave Direction (From)

Direction Band & Center (deg)	Percent Occurrence of Mean Direction	
	Station GOM 287	Station GOM 288
348.75 – 11.24 (0.0)	4.7	5.1
11.25 – 33.74 (22.5)	4.6	4.7
33.75 – 56.24 (45.0)	4.8	4.6
56.25 – 78.74 (67.5)	4.5	4.9
78.75 - 101.24 (90.0)	4.0	7.3
101.25 - 123.74 (112.5)	6.7	10.3
123.75 - 146.24 (135.0)	14.4	10.3
146.25 - 168.74 (157.5)	9.8	8.8
168.75 - 191.24 (180.0)	9.4	8.5
191.25 - 213.74 (202.5)	4.1	3.8
213.75 - 236.24 (225.0)	3.1	3.0
236.25 - 258.74 (247.5)	3.1	2.9
258.75 - 281.24 (270.0)	4.4	4.0
281.25 - 303.74 (292.5)	8.8	8.4
303.75 - 326.24 (315.0)	8.1	8.1
326.25 - 348.74 (337.5)	5.4	5.3


Wave Rose-GOM 287- 1980-1999 : 175288 data points

Wave Rose-GOM 288- 1980-1999 : 175289 data points

Figure II-42. Wave Roses (USACE WIS Hindcast)

A review of the WIS hindcast data yields the following observations:

- Over 40% of the wave heights over the hindcast period (1980 – 1999) were between approximately 0.5 – 0.99 meters (1.6 – 3.2 feet).
- This region typically does not experience large wave heights over 2 meters (6.6 feet) – less than 3% of the total number of waves
- The offshore wave direction is highly variable – the area experiences waves from all directions

(2) Storms

The NOAA database of historical storms records approximate storm track, wind speed, pressure, and category for storms since 1851. Figure II-43 illustrates the hurricane tracks in the vicinity of Captiva Island and Table II-31 lists the extratropical storms, tropical storms, and hurricanes that have passed within 65 nautical miles between 1851 and 2008. Of these 65 storms, 5 have made landfall within 10 miles.

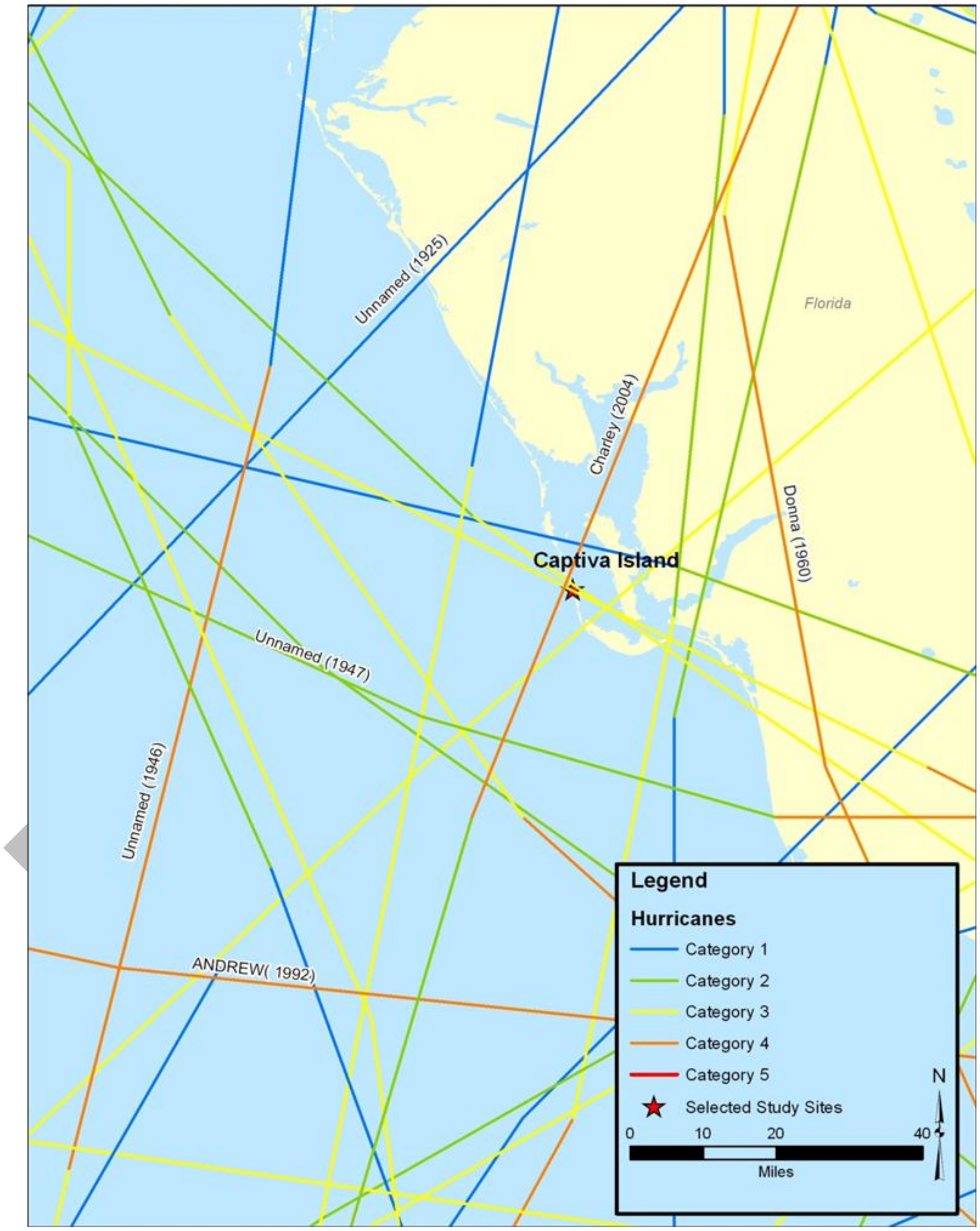


Figure II-43. Hurricanes in the Vicinity of Captiva Island

Table II-31. Captiva Island Vicinity Storms (NOAA, 1951-2008)

YEAR	STORM NAME	MAXIMUM CATEGORY
1858	NOTNAMED	Tropical Storm
1859	NOTNAMED	Tropical Storm
1861	NOTNAMED	Tropical Storm
1870	NOTNAMED	Category 1
1873	NOTNAMED	Category 3
1876	NOTNAMED	Category 2
1878	NOTNAMED	Tropical Storm
1878	NOTNAMED	Tropical Storm
1888	NOTNAMED	Category 3
1888	NOTNAMED	Tropical Storm
1891	NOTNAMED	Tropical Storm
1891	NOTNAMED	Tropical Storm
1894	NOTNAMED	Category 2
1895	NOTNAMED	Tropical Storm
1896	NOTNAMED	Tropical Storm
1897	NOTNAMED	Tropical Storm
1899	NOTNAMED	Tropical Storm
1901	NOTNAMED	Tropical Storm
1903	NOTNAMED	Category 1
1904	NOTNAMED	Tropical Storm
1904	NOTNAMED	Tropical Storm
1907	NOTNAMED	Tropical Storm
1909	NOTNAMED	Tropical Storm
1909	NOTNAMED	Tropical Storm
1910	NOTNAMED	Category 3
1916	NOTNAMED	Tropical Storm
1924	NOTNAMED	Category 2
1925	NOTNAMED	Category 1
1926	NOTNAMED	Category 4
1928	NOTNAMED	Tropical Storm
1929	NOTNAMED	Category 2
1932	NOTNAMED	Tropical Storm
1933	NOTNAMED	Tropical Storm
1934	NOTNAMED	Tropical Storm
1935	NOTNAMED	Category 4
1936	NOTNAMED	Tropical Storm
1936	NOTNAMED	Tropical Storm
1941	NOTNAMED	Category 3
1944	NOTNAMED	Category 3
1945	NOTNAMED	Tropical Storm
1945	NOTNAMED	Category 4
1946	NOTNAMED	Category 4
1946	NOTNAMED	Category 1
1947	NOTNAMED	Category 4
1951	HOW	Tropical Storm
1953	NOTNAMED	Tropical Storm
1953	HAZEL	Tropical Storm
1959	JUDITH	Tropical Storm
1960	DONNA	Category 4
1964	ISBELL	Category 3
1966	ALMA	Category 3
1968	ABBY	Tropical Storm
1969	JENNY	Tropical Storm
1981	DENNIS	Tropical Storm
1985	BOB	Tropical Storm
1988	KEITH	Tropical Storm
1990	MARCO	Tropical Storm
1992	ANDREW	Category 4
1994	GORDON	Tropical Storm
1998	MITCH	Tropical Storm
1999	HARVEY	Tropical Storm
2001	GABRIELLE	Tropical Storm
2004	CHARLEY	Category 4
2005	WILMA	Category 3
2006	ERNESTO	Tropical Storm
2008	FAY	Tropical Storm

c) Shoreline Change

The shoreline impacts of the terminal groin at Captiva Island are assessed by examining the shoreline change prior to and after construction. Historical shoreline data was obtained from the Florida Department of Environmental Protection. The differences in shoreline position were calculated at 50 m transects along the shore for a distance of three miles to either side of the inlet. Shoreline data sets selected were chosen which extended three miles to either side of the inlet and to cover the pre-structure and post-structure time periods. Figure II-44 illustrates the shoreline data used in the analysis.

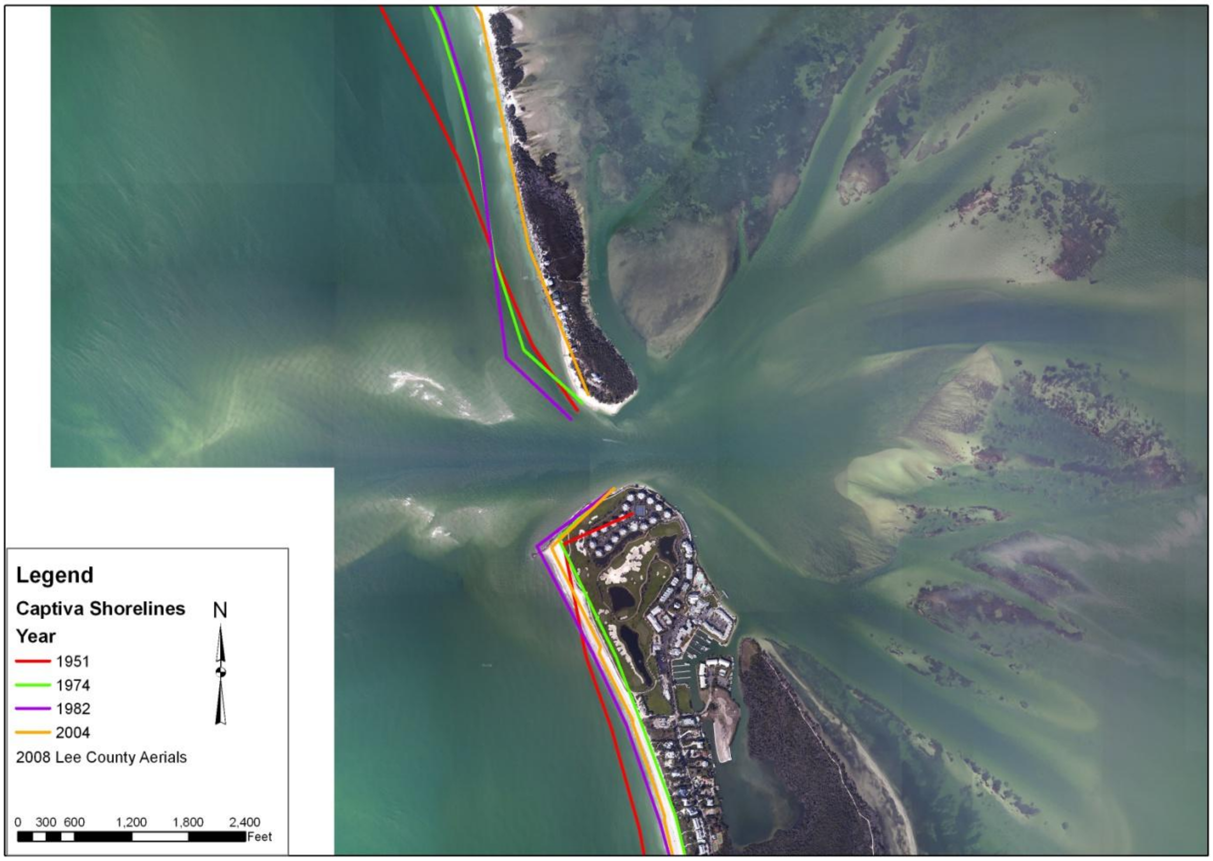


Figure II-44. Historic Shorelines – Captiva Island

Figure II-45 illustrates the calculation transects and the starting position of each shoreline comparison calculation period. A pre-structure period of 1951 to 1974 was used since this period represents the longest available pre-construction Florida Department of Environmental Protection shoreline interval. Post-construction period of 1982 to 2004 was used since the terminal groin was constructed in 1977.

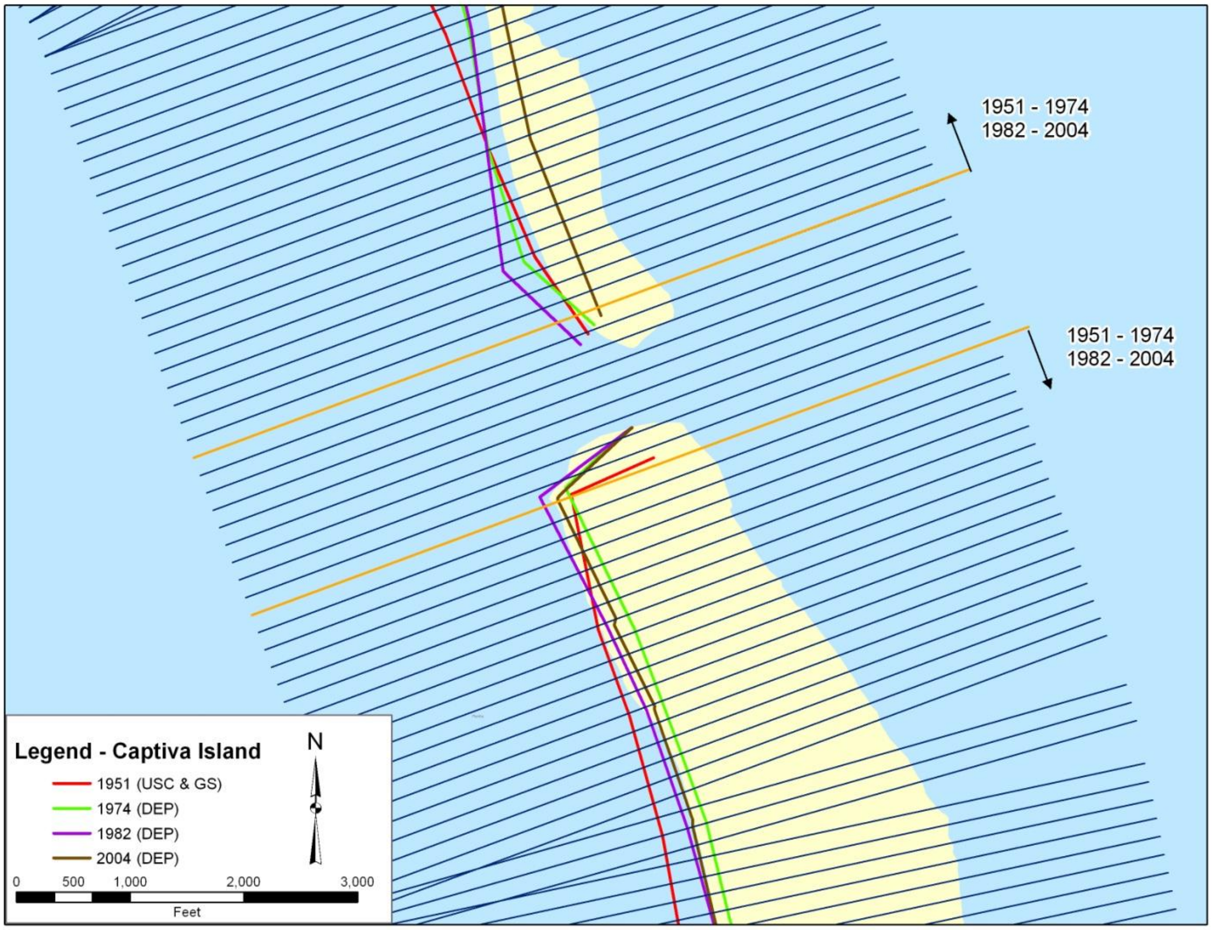


Figure II-45. Captiva Island Shoreline Change Calculation Transects

The results of the shoreline change calculations for the pre- and post-structure time periods are given in Table II-32. The table presents the calculation results for both the north side (North Captiva Island) and south side (Captiva Island terminal groin location) of Redfish Pass. Values in red represent shoreline recession (erosion) and values in black represent shoreline advancement (accretion). The first six rows of the table present cumulative average shoreline change from the inlet shoulder to a total distance of three miles. The lower six rows provide the average shoreline change for each interval as indicated. Figure II-46 and Figure II-47 display the same data graphically.

Table II-32. Calculated Shoreline Change – Captiva Island

Distance from Inlet (mi)	1951 -1974 North Average Change Rate (ft/yr)	1951 - 1974 South Average Change Rate (ft/yr)	1982 -2004 North Average Change Rate (ft/yr)	1982 - 2004 South Average Change Rate (ft/yr)
0 - 0.25	1.8	6.6	24.1	5.0
0 - 0.5	0.7	10.2	20.6	4.2
0 - 0.75	5.1	12.7	19.0	3.5
0 - 1	8.8	14.2	17.1	2.8
0 - 2	12.9	14.0	6.9	1.1
0 - 3	11.4	11.7	1.6	0.8
0 - 0.25	1.8	6.6	24.1	5.0
0.25 - 0.5	3.5	14.2	16.7	3.2
0.5 - 0.75	14.4	18.0	15.5	1.9
0.75 - 1	20.4	19.1	11.1	0.6
1 - 2	17.2	13.8	3.5	0.5
2 - 3	8.1	7.1	9.3	4.8

*Red values represent shoreline recession (erosion) and black values represent shoreline advancement (accretion)

Prior to terminal groin construction the shoreline to the south side of the inlet was eroding. After the construction of the terminal groin, the south side of the inlet was either eroding at a lower rate or accreting; thus showing net accretion for the cumulative of three miles. The north side shows an increase in erosion near the inlet but a net decrease over the first three miles.

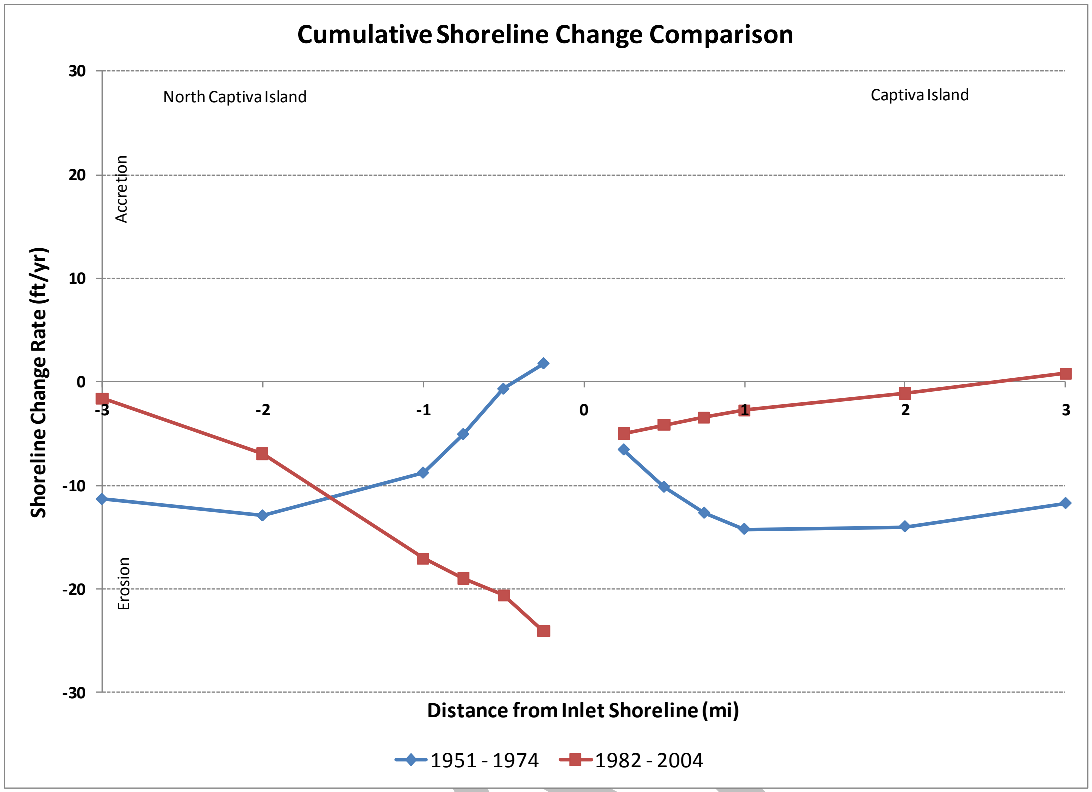


Figure II-46. Cumulative Shoreline Change – Captiva Island

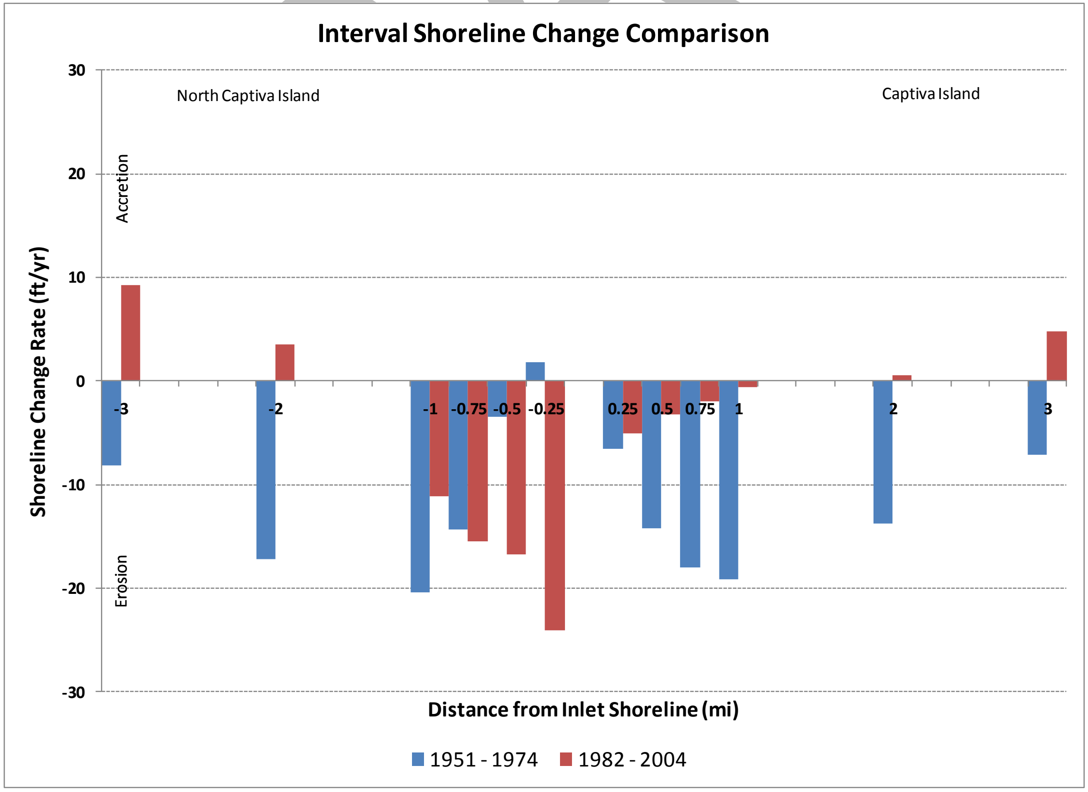


Figure II-47. Shoreline Change Interval Comparison – Captiva Island

d) Volumetric Changes, Beach Nourishment, and Dredging

The impact of the terminal groin in relation to other activities particularly beach nourishment and dredging was assessed through volumetric comparison. The volume of beach material lost or gained was evaluated based on the shoreline change, nourishment and beach volumes placed, and quantities of material dredged from the inlet. The ratio of shoreline change to beach volume was developed based on available representative survey profiles collected by the Florida Department of Environmental Protection in 1974, 1982, 1989 and 1994 at the north end of Captiva Island (1 mile), and the south end of North Captiva Island (1 mile). The general rule that is typically applied for estimation is one foot of shoreline change equates to approximately one cubic yard of beach material volume per linear foot of beach. The ratio calculated for the area around Redfish Pass was approximately 0.74 cubic yards of beach volume per linear foot for one foot of shoreline change.

Table II-33 provides the volumetric beach change for the cumulative distances and intervals along each side of the inlet based on the shoreline change presented previously. Beach volume losses are given in red and beach volume gains in black. These numbers are directly computed from the shoreline changes and include all impacts to the beach such as nourishment. Figure II-48 and Figure II-49 present the same information graphically.

Table II-33. Average Annual Beach Volume Changes – Captiva Island

Distance from Inlet (mi)	1951 -1974 North Total Volume (cy/yr)	1951 -1974 South Total Volume (cy/yr)	1982 -2004 North Total Volume (cy/yr)	1982 -2004 South Total Volume (cy/yr)
0 - 0.25	1,739	7,176	23,712	5,477
0 - 0.5	435	20,988	40,796	8,607
0 - 0.75	13,074	38,476	55,428	10,481
0 - 1	32,849	57,057	67,563	11,022
0 - 2	99,955	112,165	58,547	9,043
0 - 3	133,293	139,726	18,345	9,534
0 - 0.25	1,739	7,176	23,712	5,477
0.25 - 0.5	2,174	13,812	17,085	3,129
0.5 - 0.75	12,640	17,487	14,632	1,874
0.75 - 1	19,775	18,581	12,135	542
1 - 2	67,106	55,109	9,016	1,979
2 - 3	33,339	27,560	40,202	18,577

*Beach volume losses are given in red and beach volume gains in black.

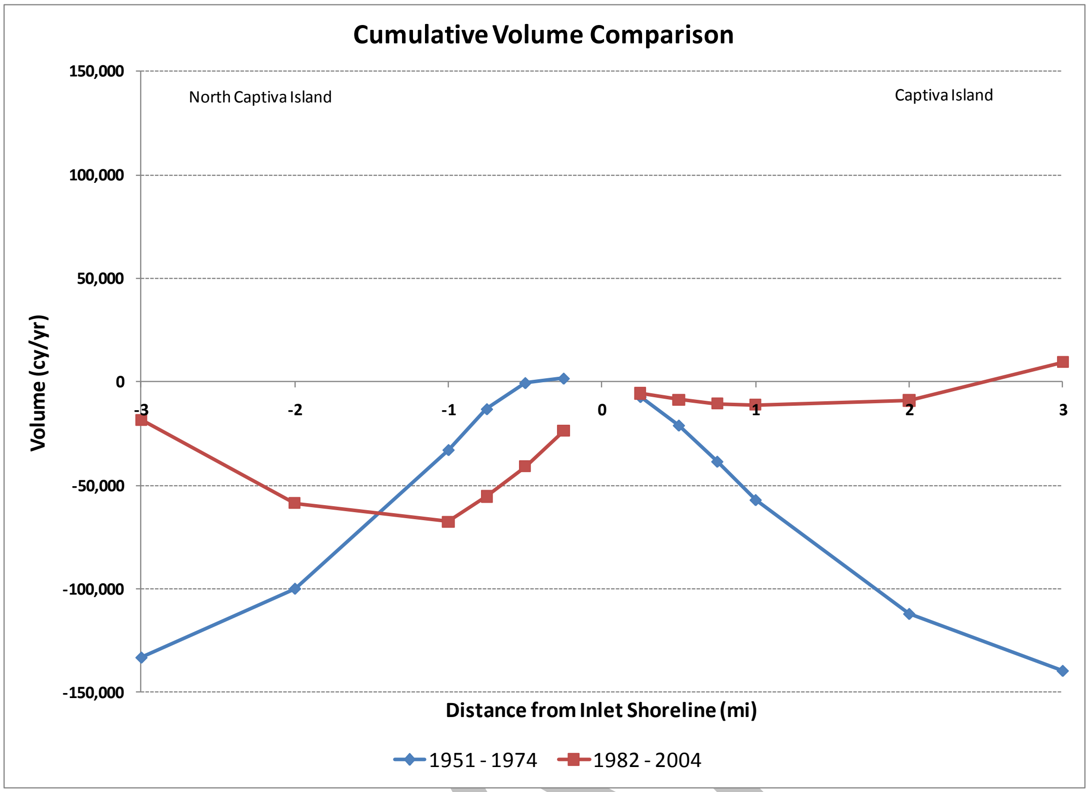


Figure II-48. Cumulative Beach Volume Change – Captiva Island

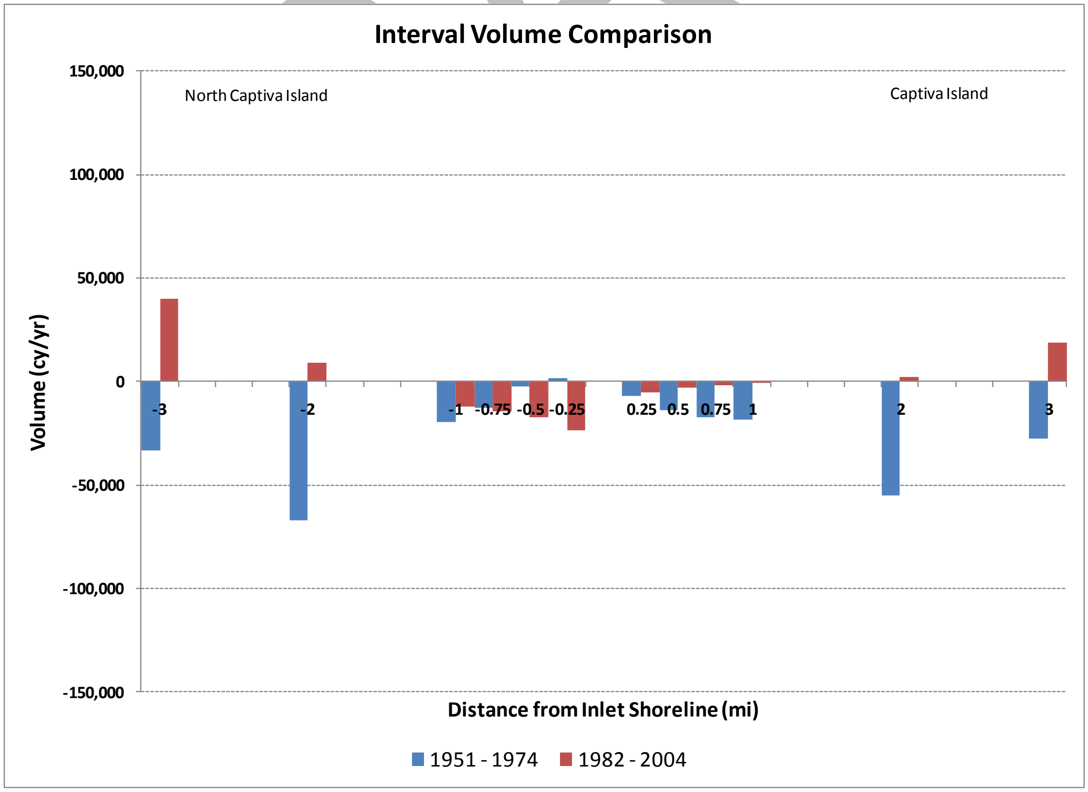


Figure II-49. Beach Volume Change Interval Comparison – Captiva Island

Before and after the construction of the Captiva Island Terminal Groin, beach nourishment and sediment placement has occurred along the shoreline south of Redfish Pass The engineering activities log in Appendix C details the amounts, timing, and locations, when known, of beach nourishment activities. The material used for beach nourishment is taken as a net addition of sediments to the system and is not an effect of the terminal groin structure per se.

In Table II-34 this material is subtracted from the volumes calculated based on shoreline change to arrive at volume changes net nourishment. Prior to terminal groin construction, on average 4,870 cy/yr nourishment material has been placed along the south side of the inlet; 55,023 cy/yr has been placed on the south side of the inlet post construction of the structure. Figure II-50 and Figure II-51 present the same information graphically.

Table II-34. Volume Changes Net Nourishment – Captiva Island

Distance from Inlet (mi)	1951 -1974 North Total Volume (cy/yr)	1951 -1974 South Total Volume (cy/yr)	1982 -2004 North Total Volume (cy/yr)	1982 -2004 South Total Volume (cy/yr)
0 - 0.25	1,739	7,618	23,712	10,062
0 - 0.5	435	21,872	40,796	17,777
0 - 0.75	13,074	39,802	55,428	24,236
0 - 1	32,849	58,825	67,563	29,363
0 - 2	99,955	115,484	58,547	45,725
0 - 3	133,293	144,595	18,345	45,489
0 - 0.25	1,739	7,618	23,712	10,062
0.25 - 0.5	2,174	14,254	17,085	7,715
0.5 - 0.75	12,640	17,929	14,632	6,459
0.75 - 1	19,775	19,023	12,135	5,127
1 - 2	67,106	56,659	9,016	16,362
2 - 3	33,339	29,111	40,202	236

*Beach volume losses are given in red and beach volume gains in black.

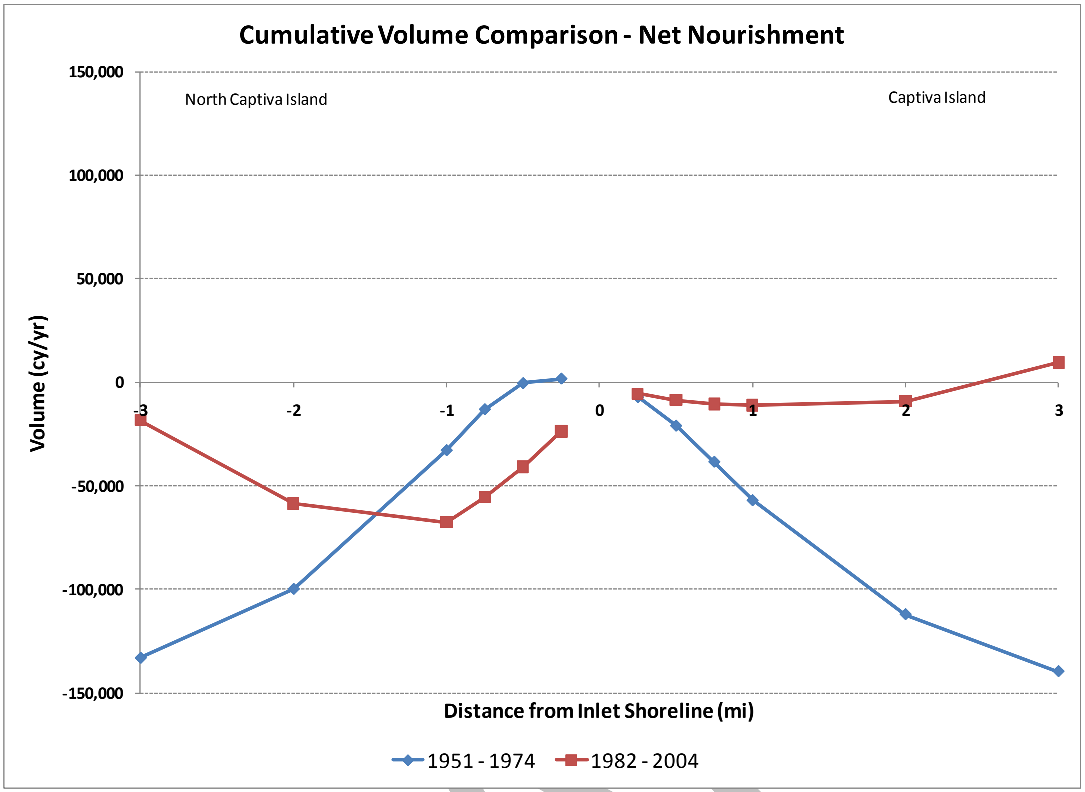


Figure II-50. Volume Changes Net Nourishment – Captiva Island

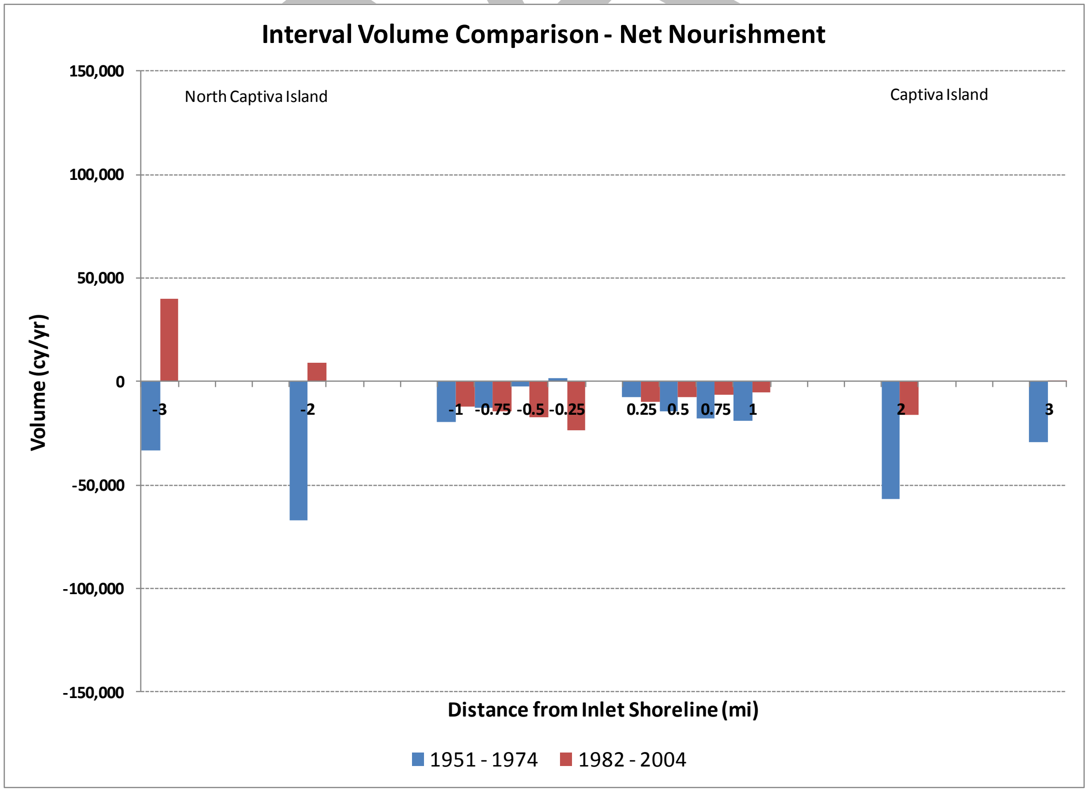


Figure II-51. Volume Changes Net Nourishment Interval Comparison – Captiva Island

Although detailed records of dredging in the Redfish Pass could not be located, it is known that the removal of the ocean bar shoal and maintenance of the inlet channel is performed and this may have an impact on the adjacent shorelines.

5. John’s Pass

a) Site Description

John’s Pass is located on the Gulf Coast of Florida just northwest of St. Petersburg and is between the barrier islands of Medeira Beach (Sand Key) to the north and Treasure Island to the South. It was created by a hurricane in 1848 and connects Boca Ciega Bay to the Gulf of Mexico. John’s Pass is a federal navigation project with maintenance dredging of the entrance channel conducted approximately every 8 years as needed (it is a well defined channel) with the dredged sand placed on the Treasure Island beaches. The ebb shoal has been used as a sand source for beach nourishment of Sand Key (DEP, 2000). John’s Pass is a tide dominated inlet with a large asymmetrical ebb tidal delta and a mature flood delta. The inlet is 590 feet wide at the throat with a mean depth of 16 feet (Mehta et al., 1976). The inlet has terminal groins on both the north and south sides (Figure II-52). The 460 feet long north terminal groin was constructed in 1961 and rehabilitated in 1988. The south terminal groin is 760 long and was constructed in 2000.

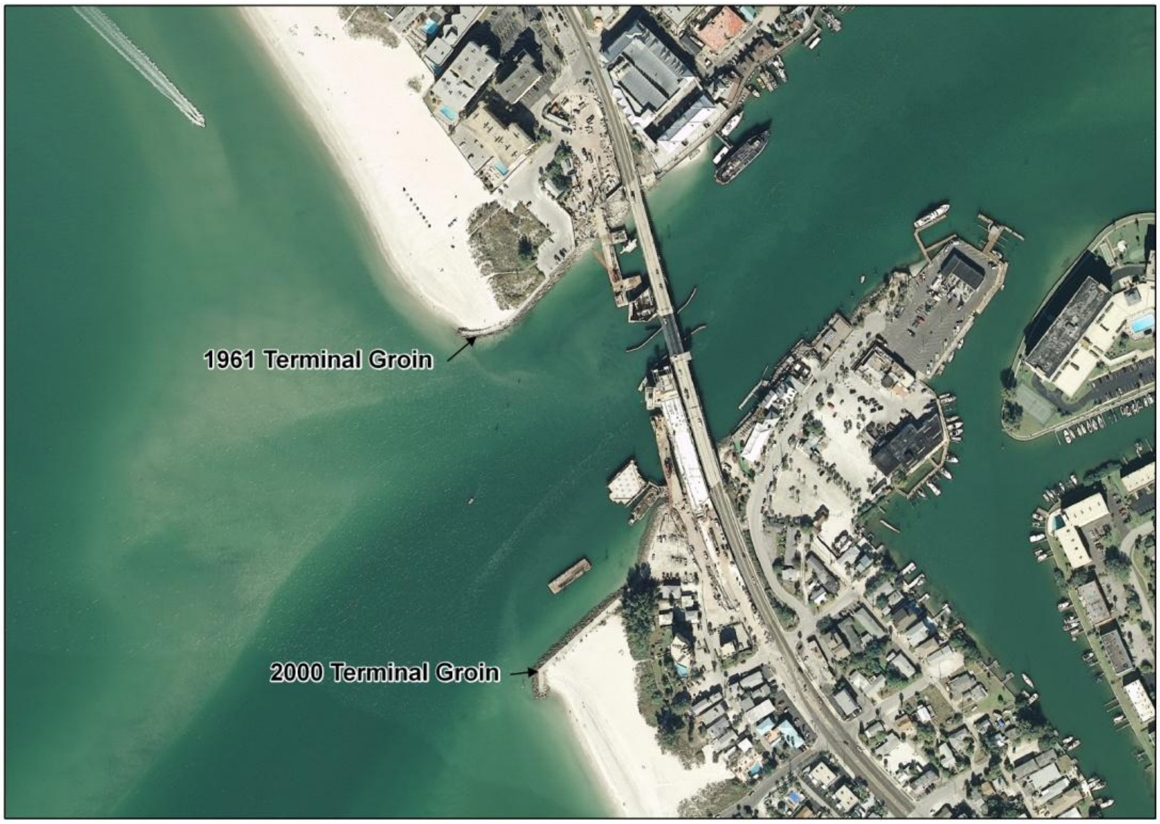


Figure II-52. John’s Pass Terminal Groins

b) Physical Environment

Data on the waves, water levels, and storm activity are discussed in this section with the relationship to the geologic framework addressed in Section III of this report.

(1) Waves and Tides

The closest NDBC buoys and WIS stations near John's Pass that represent wave conditions within the immediate area surrounding the terminal groins are shown in Figure II-53 along with nearby NOAA tidal gages. The NOAA tidal gage located at St. Petersburg, inside Tampa Bay is the closest tide gage to John's Pass. There is a second gage located in Tampa Bay approximately 16 miles south at Port Manatee, Florida. The closest ocean-side tide gage is located approximately 14 miles north at Clearwater Beach, Florida. Table II-35 lists the tidal datums for all three gages.

Figure II-53. Wave and Tidal Stations near John's Pass

Table II-35. Tidal Gages near John's Pass

Tidal Datum	Station		
	Clearwater Beach (8726724)	St. Petersburg (8726520)	Port Manatee (8726384)
MHHW (ft)	2.74	2.26	2.19
MHW (ft)	2.40	1.98	1.92
DTL (ft)	1.37	1.13	1.09
MTL (ft)	1.46	1.18	1.14
MSL (ft)	1.48	1.20	1.16
MLW (ft)	0.52	0.39	0.36
MLLW (ft)	0.00	0.00	0.00
NAVD (ft)	1.79	-	1.56
Maximum (ft)	6.79	6.26	4.48
Max Date	1993/03/13	1985/08/31	2004/09/06
Max Time	4:48	12:42	13:06
Minimum (ft)	-2.54	-2.47	-2.03
Min Date	1977/01/19	1972/01/16	2008/01/03
Min Time	8:06	0:00	11:36

Table II-36 and Table II-37 summarize the percent occurrences by wave height and direction for WIS stations GOM 268 and 269. Figure II-54 illustrates the average annual wave roses for both stations. These wave roses provide a graphical representation of the wave heights and directions from which the waves are coming.

Table II-36. WIS Percent Occurrence of Wave Heights

Wave Height (meters)	Percent Occurrence of Wave Height	
	Station GOM 268	Station GOM 269
0.00 – 0.49	37.6	35.7
0.50 – 0.99	41.8	41.2
1.00 – 1.49	11.7	13.9
1.5 – 1.99	5.0	5.3
2.00 – 2.49	2.4	2.4
2.50 – 2.99	0.9	0.9
3.00 – 3.49	0.4	0.4
3.50 – 3.99	0.1	0.1
4.00 – 4.49	0.0	0.0
4.50 – 4.99	0.0	0.0
5.00 - GREATER	0.0	0.0

Table II-37. WIS Percent Occurrence by Mean Wave Direction (From)

Direction Band & Center (deg)	Percent Occurrence of Mean Direction	
	Station GOM 268	Station GOM 269
348.75 – 11.24 (0.0)	6.2	6.0
11.25 – 33.74 (22.5)	6.4	6.5
33.75 – 56.24 (45.0)	5.4	5.8
56.25 – 78.74 (67.5)	7.0	6.9
78.75 - 101.24 (90.0)	6.7	6.4
101.25 - 123.74 (112.5)	5.4	6.0
123.75 - 146.24 (135.0)	6.9	7.9
146.25 - 168.74 (157.5)	9.6	9.5
168.75 - 191.24 (180.0)	6.6	6.1
191.25 - 213.74 (202.5)	5.3	5.0
213.75 - 236.24 (225.0)	3.9	3.7
236.25 - 258.74 (247.5)	3.7	3.5
258.75 - 281.24 (270.0)	6.2	5.8
281.25 - 303.74 (292.5)	8.7	8.6
303.75 - 326.24 (315.0)	6.9	7.0
326.25 - 348.74 (337.5)	5.3	5.3

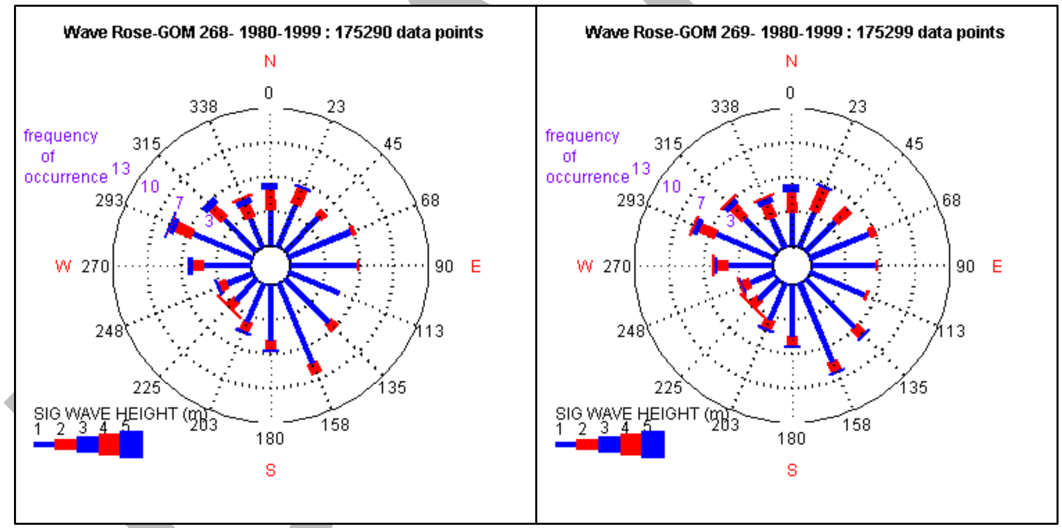


Figure II-54. Wave Roses (USACE WIS Hindcast)

A review of the WIS hindcast data yields the following observations:

- Over 40% of the wave heights over the hindcast period (1980 – 1999) were between approximately 0.5 – 0.99 meters (1.6 – 3.2 feet).
- This region typically does not experience large wave heights over 2 meters (6.6 feet) – less than 5% of the total number of waves
- The offshore wave direction is variable
- The largest waves occur during the winter months (December – March) and are predominately from the northwest.

(2) Storms

The NOAA database of historical storm records approximate storm track, wind speed, pressure, and category for storms since 1851. Figure II-55 illustrates the hurricane tracks in the vicinity of John’s Pass and Table II-38 lists the extratropical storms, tropical storms, and hurricanes that have passed within 65 nautical miles between 1851 and 2008. Of these 65 storms, only 2 have made landfall within 10 miles.

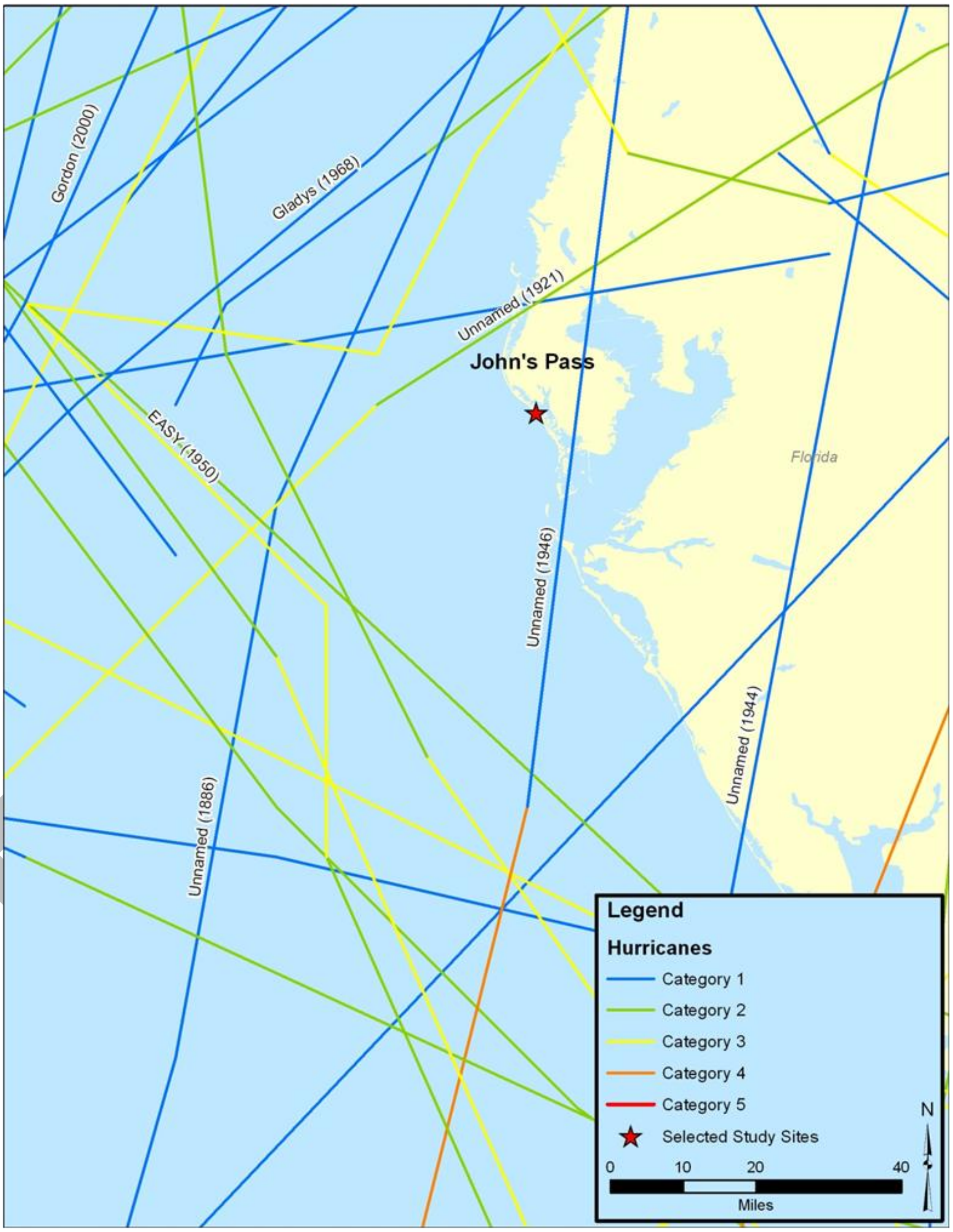


Figure II-55. Hurricanes in the Vicinity of John’s Pass

Table II-38. John's Pass Vicinity Storms (NOAA, 1951-2008)

YEAR	STORM NAME	MAXIMUM CATEGORY
1852	NOTNAMED	Category 1
1858	NOTNAMED	Tropical Storm
1859	NOTNAMED	Tropical Storm
1872	NOTNAMED	Tropical Storm
1873	NOTNAMED	Tropical Storm
1874	NOTNAMED	Category 1
1878	NOTNAMED	Category 2
1880	NOTNAMED	Tropical Storm
1880	NOTNAMED	Category 1
1886	NOTNAMED	Category 1
1887	NOTNAMED	Tropical Storm
1888	NOTNAMED	Category 1
1888	NOTNAMED	Tropical Storm
1892	NOTNAMED	Tropical Storm
1894	NOTNAMED	Category 2
1896	NOTNAMED	Category 3
1897	NOTNAMED	Tropical Storm
1898	NOTNAMED	Tropical Storm
1899	NOTNAMED	Category 1
1899	NOTNAMED	Tropical Storm
1901	NOTNAMED	Tropical Storm
1903	NOTNAMED	Tropical Storm
1904	NOTNAMED	Tropical Storm
1909	NOTNAMED	Tropical Storm
1910	NOTNAMED	Category 2
1916	NOTNAMED	Tropical Storm
1921	NOTNAMED	Category 3
1925	NOTNAMED	Category 1
1926	NOTNAMED	Category 3
1928	NOTNAMED	Tropical Storm
1928	NOTNAMED	Category 3
1929	NOTNAMED	Category 2
1930	NOTNAMED	Tropical Storm
1932	NOTNAMED	Tropical Storm
1933	NOTNAMED	Tropical Storm
1933	NOTNAMED	Category 3
1935	NOTNAMED	Category 3
1936	NOTNAMED	Tropical Storm
1937	NOTNAMED	Tropical Storm
1939	NOTNAMED	Tropical Storm
1940	NOTNAMED	Tropical Storm
1941	NOTNAMED	Category 2
1944	NOTNAMED	Category 3
1945	NOTNAMED	Category 1
1945	NOTNAMED	Tropical Storm
1945	NOTNAMED	Category 3
1946	NOTNAMED	Category 4
1947	NOTNAMED	Tropical Storm
1949	NOTNAMED	Category 3
1950	EASY	Category 3
1951	HOW	Tropical Storm
1960	DONNA	Category 4
1966	ALMA	Category 3
1968	ABBY	Tropical Storm
1968	GLADYS	Category 1
1984	ISIDORE	Tropical Storm
1988	KEITH	Tropical Storm
1990	MARCO	Tropical Storm
1995	ERIN	Category 1
1995	JERRY	Tropical Storm
2001	GABRIELLE	Tropical Storm
2004	CHARLEY	Category 4
2004	FRANCES	Category 1
2004	JEANNE	Category 2
2007	BARRY	Tropical Storm

c) Shoreline Change

The shoreline impacts of the terminal groins at John's Pass are assessed by examining the shoreline change prior to and after construction. Historical shoreline data was obtained from the Florida Department of Environmental Protection (DEP). The differences in shoreline position were calculated at 50 m transects along the shore for a distance of three miles to either side of the inlet. Shoreline data sets selected were chosen which extended three miles to either side of the inlet and to cover the pre-structure and post-structure time periods. Figure II-56 illustrates the shoreline data used in the analysis.

Figure II-56. Historic Shorelines – John's Pass

Figure II-57 illustrates the calculation transects and the starting position of each shoreline comparison calculation period. The starting points were selected at the nearest inlet shoulder coincident portions of the shoreline for each calculation interval. These are not, however, coincident between periods due to shifting of the inlet. Results are reported with respect to the inlet shoulder for each given period. The starting transects labeled on Figure II-57 represent the zero position of the shoreline comparison for the time period noted. A pre-structure period of 1873 to 1926 was used since this period represents the longest available pre-construction DEP shoreline interval. A post-construction period of 1974 to 2007 is used since the original north terminal groin was completed in 1961. No shoreline data was available for comparison on the south side of John's Pass after the 2000 construction of the southern terminal groin.

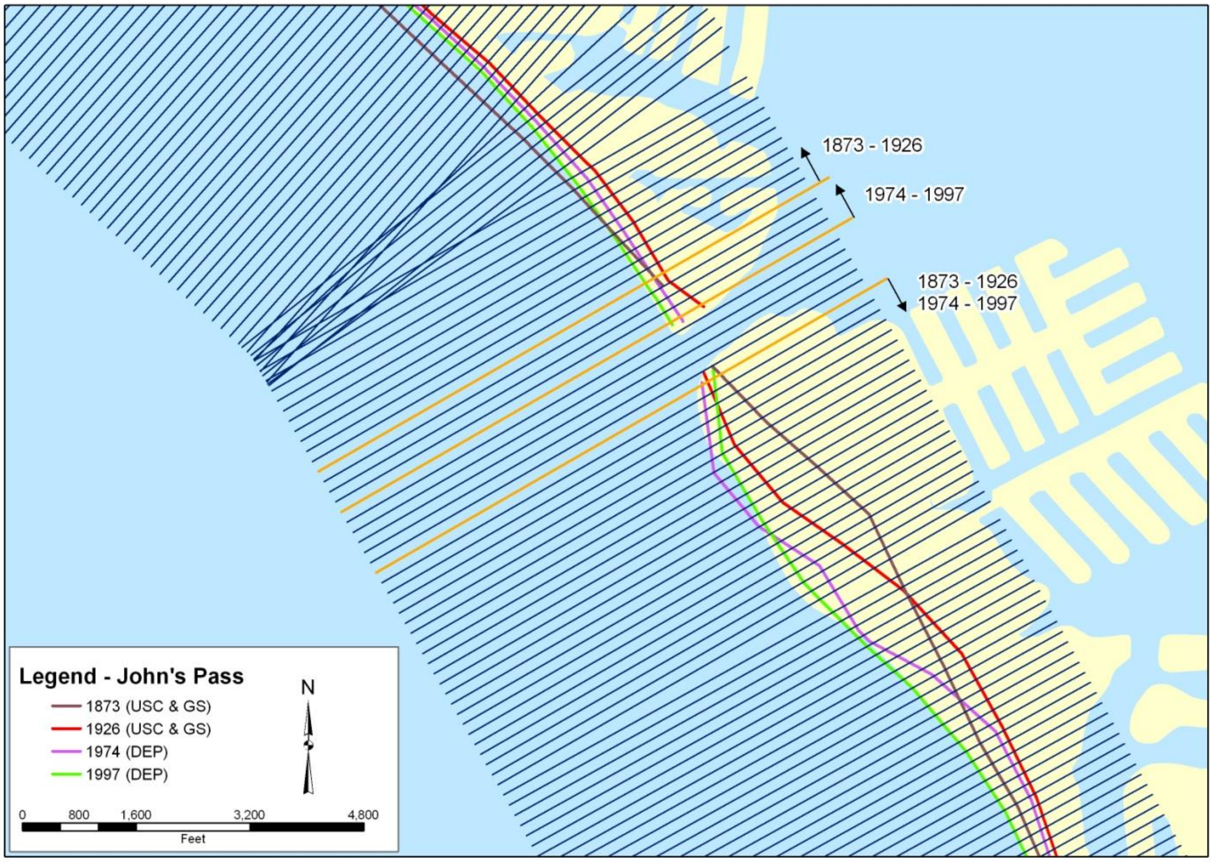


Figure II-57. John's Pass Shoreline Change Calculation Transects

The results of the shoreline change calculations for the pre- and post-structure time periods are given in Table II-39. The table presents the calculation results for both the north and south sides of John's Pass. Values in red represent shoreline recession (erosion) and values in black represent shoreline advancement (accretion). The first 6 rows of the table present cumulative average shoreline change from the inlet shoulder to a total distance of 3 miles. The lower 6 rows provide the average shoreline change for each interval as indicated. Figure II-58 and Figure II-59 display the same data graphically.

Table II-39. Calculated Shoreline Change – John's Pass

Distance from Inlet (mi)	1873-1926 North Average Change Rate (ft/yr)	1873-1926 South Average Change Rate (ft/yr)	1974 -1997 North Average Change Rate (ft/yr)	1974 - 1997 South Average Change Rate (ft/yr)
0 - 0.25	4.0	8.3	6.4	8.4
0 - 0.5	5.9	10.5	6.5	5.8
0 - 0.75	6.5	8.9	5.9	0.9
0 - 1	7.0	5.8	5.2	1.7
0 - 2	6.9	1.0	3.3	7.0
0 - 3	5.7	0.7	2.6	5.7
0 - 0.25	4.0	8.3	6.4	8.4
0.25 - 0.5	7.0	12.9	6.7	2.8
0.5 - 0.75	7.7	5.4	4.5	9.4
0.75 - 1	8.3	3.9	3.2	9.7
1 - 2	6.8	3.9	1.4	12.5
2 - 3	3.4	0.2	0.9	3.1

*Red values represent shoreline recession (erosion) and black values represent shoreline advancement (accretion)

Prior to construction of the north terminal groin, the shoreline to the north side of the inlet was eroding. After the construction of the terminal groin, the north side of the inlet shows accretion. The south side was accreting but after the construction of the north terminal groin shows erosion adjacent to the inlet but a net increase in accretion over the first three miles.

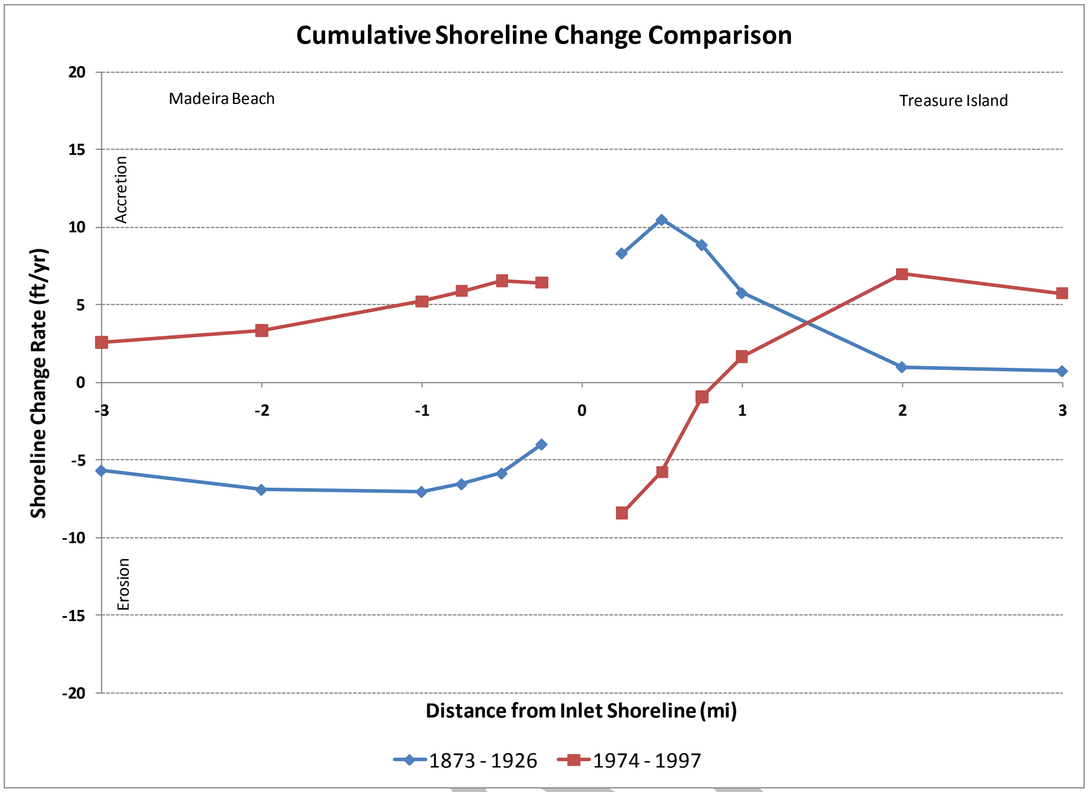


Figure II-58. Cumulative Shoreline Change – John's Pass

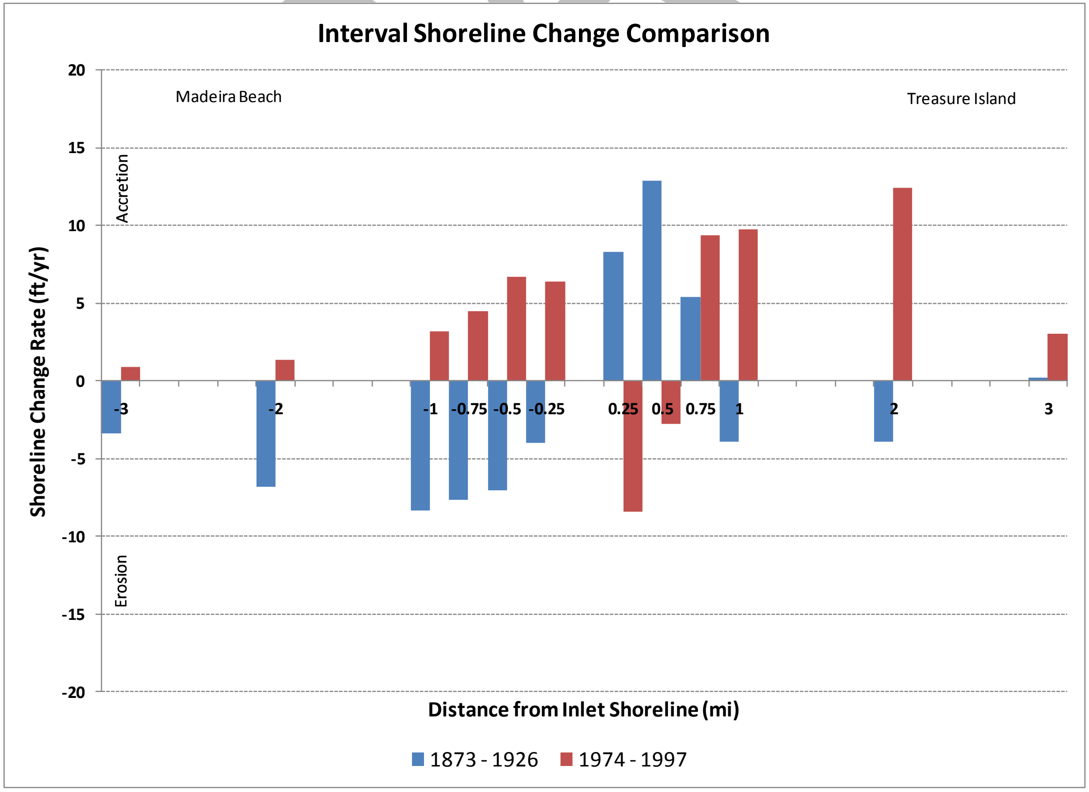


Figure II-59. Shoreline Change Interval Comparison - John's Pass

d) Volumetric Changes, Beach Nourishment, and Dredging

The impact of the terminal groin in relation to other activities, particularly beach nourishment and dredging was assessed through volumetric comparison. The volume of beach material lost or gained was evaluated based on the shoreline change, nourishment and beach volumes placed, and quantities of material dredged from the inlet. The ratio of shoreline change to beach volume was developed based on available representative survey profiles collected by the Florida Department of Environmental Protection in 1974, 1997 and 2003 at the north end of Treasure Island (up to 2 miles south of John's Pass), and at the south end of Madeira Beach (up to 2 miles north of John's Pass). The general rule that is typically applied for estimation is one foot of shoreline change equates to approximately one cubic yard of beach material volume per linear foot of beach. The ratio calculated for the area around John's Pass was approximately 0.91 cubic yards of beach volume per linear foot for one foot of shoreline change.

Table II-40 provides the volumetric beach change for the cumulative distances and intervals along each side of the inlet based on the shoreline change presented previously. Beach volume losses are given in red and beach volume gains in black. These numbers are directly computed from the shoreline changes and include all impacts to the beach such as nourishment. Figure II-60 and Figure II-61 present the same information graphically.

Table II-40. Average Annual Beach Volume Changes – John's Pass

Distance from Inlet (mi)	1873-1926 North Total Volume (cy/yr)	1873-1926 South Total Volume (cy/yr)	1974 -1997 North Total Volume (cy/yr)	1974-1997 South Total Volume (cy/yr)
0 - 0.25	2,972	11,175	8,638	11,309
0 - 0.5	11,366	26,600	16,620	14,623
0 - 0.75	20,524	33,057	21,983	3,456
0 - 1	30,477	28,371	25,760	8,155
0 - 2	62,878	9,630	32,350	67,708
0 - 3	79,550	10,451	36,499	81,448
0 - 0.25	2,972	11,175	8,638	11,309
0.25 - 0.5	8,395	15,425	7,982	3,314
0.5 - 0.75	9,157	6,457	5,362	11,168
0.75 - 1	9,953	4,685	3,777	11,610
1 - 2	32,401	18,741	6,590	59,553
2 - 3	16,672	821	4,149	13,740

*Beach volume losses are given in red and beach volume gains in black.

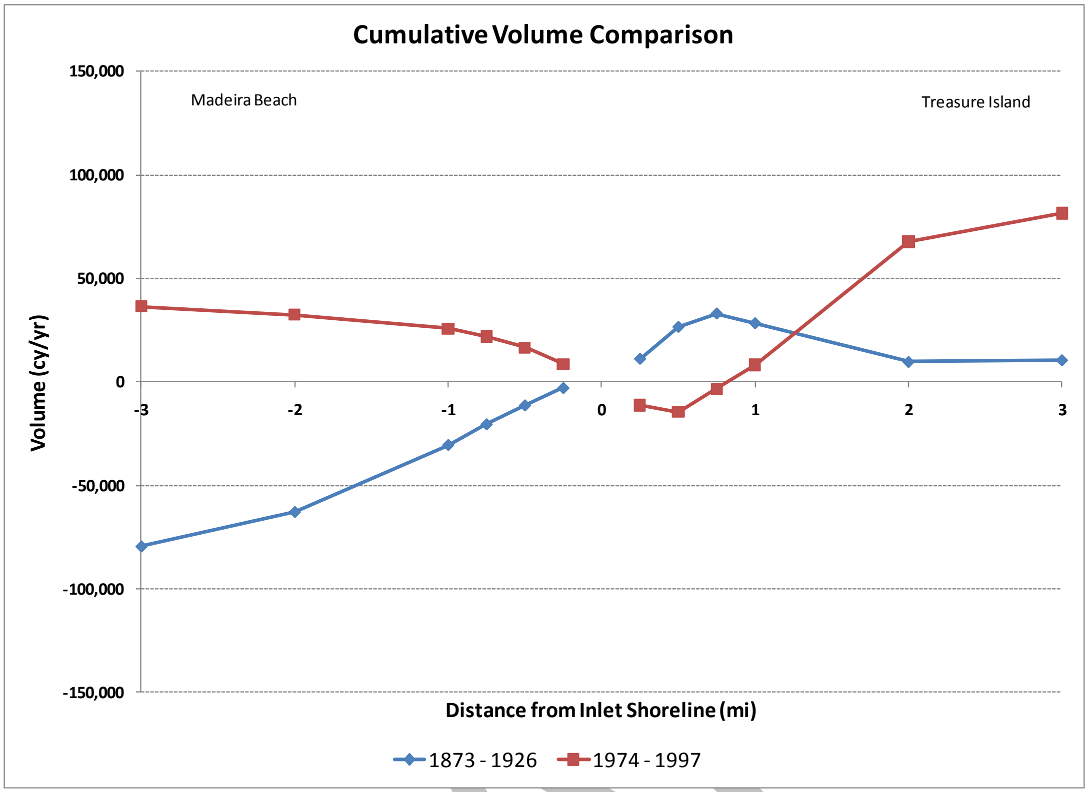


Figure II-60. Cumulative Beach Volume Change – John's Pass

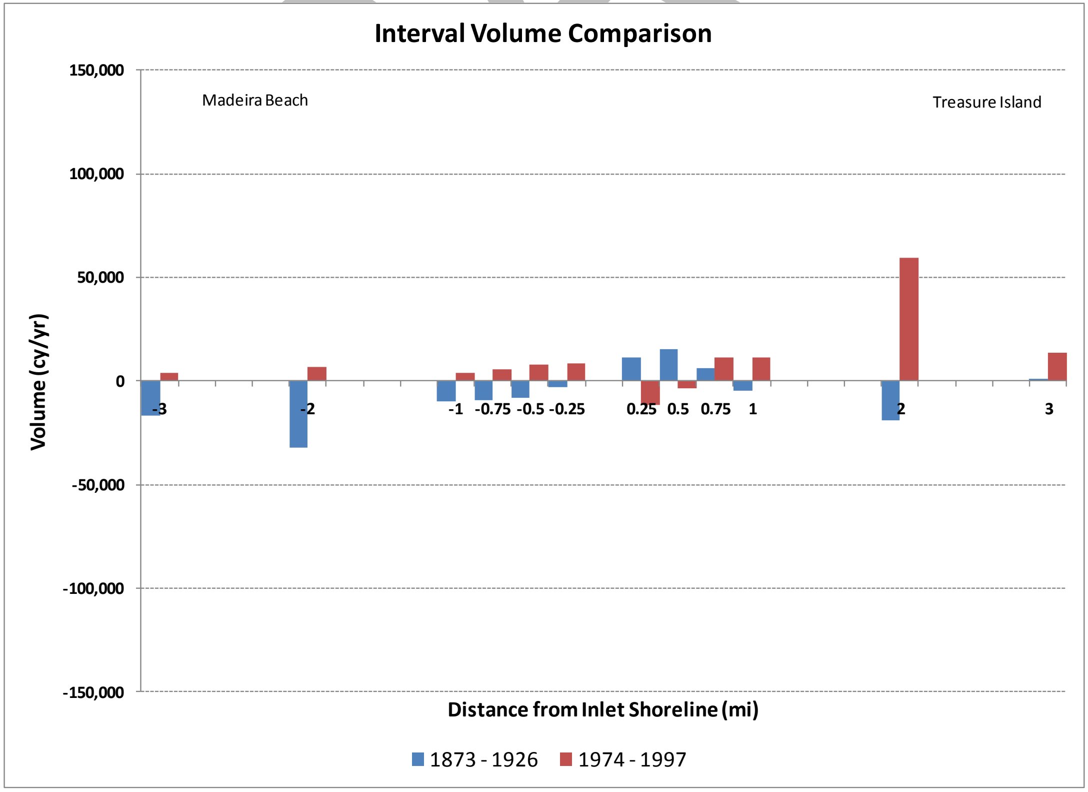


Figure II-61. Beach Volume Change Interval Comparison – John's Pass

Since construction of the terminal groins, beach nourishment has occurred along the shoreline near John's Pass. The engineering activities log in Appendix C details the amounts, timing, and locations, when known, of beach nourishment activities. Any material that was not dredged from the inlet itself represents a net addition of material to the system and is not an effect of the terminal groin structure per se.

In Table II-41 this material is subtracted from the volumes calculated based on shoreline change to arrive at volume changes net nourishment. After terminal groin construction, on average 39,102 cy/yr nourishment material has been placed along the south side of the inlet. Figure II-62 and Figure II-63 present the same information graphically.

Table II-41. Volume Changes Net Nourishment – John's Pass

Distance from Inlet (mi)	1873-1926 North Total Volume (cy/yr)	1873-1926 South Total Volume (cy/yr)	1974 -1997 North Total Volume (cy/yr)	1974-1997 South Total Volume (cy/yr)
0 - 0.25	2,972	11,175	8,638	13,573
0 - 0.5	11,366	26,600	16,620	19,151
0 - 0.75	20,524	33,057	21,983	10,247
0 - 1	30,477	28,371	25,760	901
0 - 2	62,878	9,630	32,350	43,629
0 - 3	79,550	10,451	36,499	42,346
0 - 0.25	2,972	11,175	8,638	13,573
0.25 - 0.5	8,395	15,425	7,982	5,578
0.5 - 0.75	9,157	6,457	5,362	8,904
0.75 - 1	9,953	4,685	3,777	9,346
1 - 2	32,401	18,741	6,590	44,530
2 - 3	16,672	821	4,149	1,283

*Beach volume losses are given in red and beach volume gains in black.

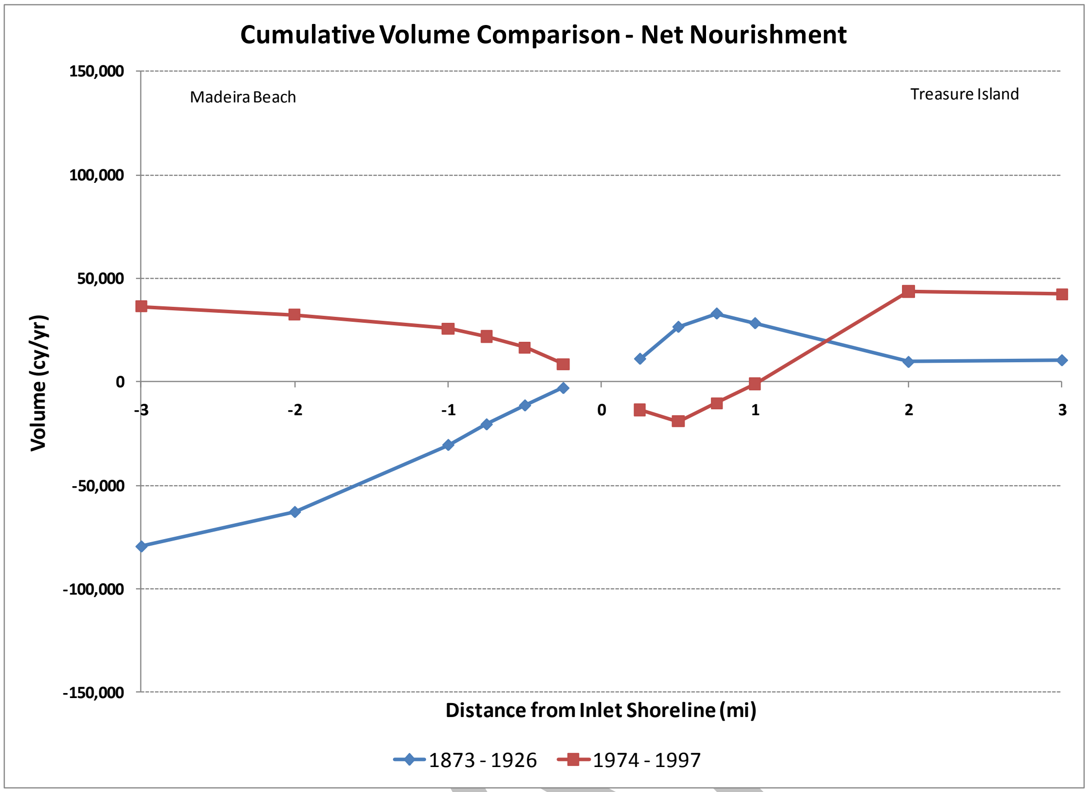


Figure II-62. Volume Changes Net Nourishment – John's Pass

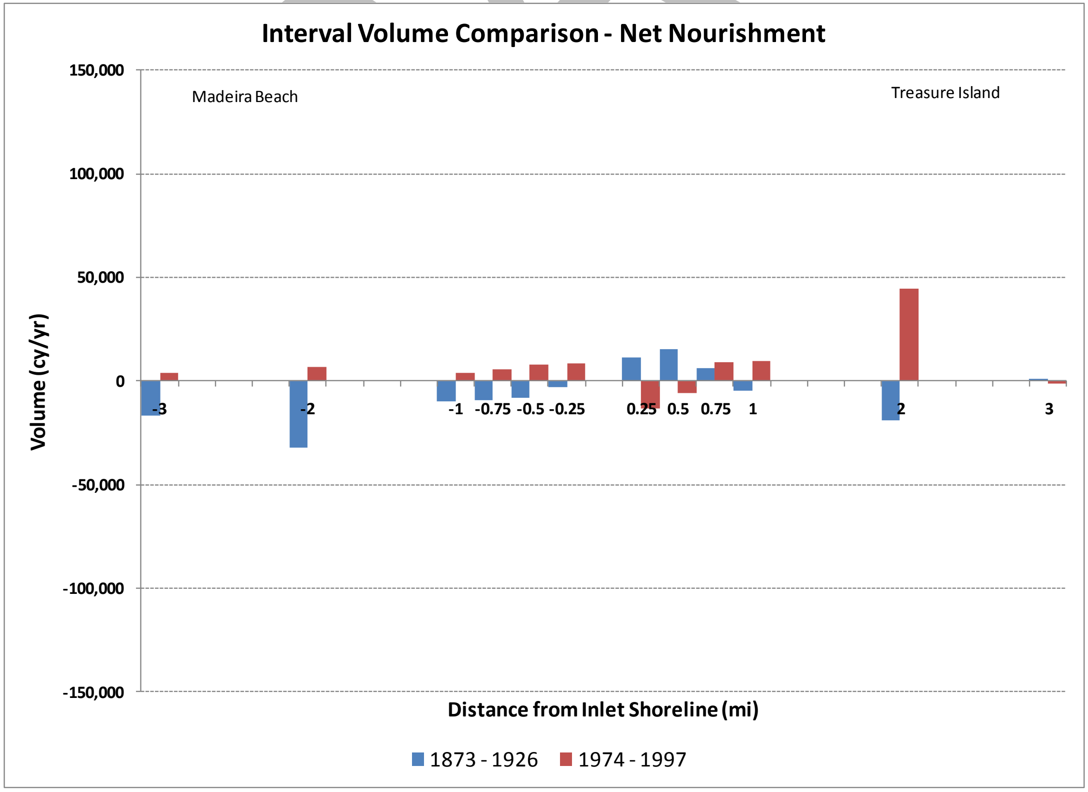


Figure II-63. Volume Changes Net Nourishment Interval Comparison – John's Pass

Much like nourishment, the influence of dredging material needs to be accounted for when trying to assess the impact of the terminal groin. While the channel is not dredged frequently, the potential impact should be accounted for as it is not an impact of the terminal groins per se. It is also interesting to note that on occasion sand was taken from the delta complex as a sand source for other nourishment projects.

Dredging volumes (Table II-42) through the inlet were calculated for the same time periods as the pre- and post-structure comparisons. The dominant sediment transport in the region is to the south. Detailed analysis of sediment budgets, though, is beyond the scope of this study. Table II-43 and Table II-44 present a means of generally quantifying the potential impacts of dredging by examining the change in beach volume under varying scenarios. The first scenario assumes none of the dredged material that was removed from the system would have naturally reached the beaches (this is the case presented earlier net nourishment). The second scenario assumes 25% of the material dredged from the inlet system would have reached the beach naturally and the third scenario assumes 50%.

Table II-42. Dredging Volumes – John's Pass

Distance from Inlet	1873-1926 Total Volume	1974 -1997 Total Volume
(mi)	(cy/yr)	(cy/yr)
0 - 3	0	12,435

Table II-43. Volume Change Scenarios Net Nourishment and Dredging – North of John's Pass

Distance from Inlet	Dredging Percentage Added to the North	1873-1926 North Total Volume	1974 -1997 North Total Volume
(mi)	(%)	(cy/yr)	(cy/yr)
0 - 3	0%	79,550	36,499
0 - 3	25%	79,550	39,608
0 - 3	50%	79,550	42,717

*Beach volume losses are given in red and beach volume gains in black.

Table II-44. Volume Change Scenarios Net Nourishment and Dredging – South of John's Pass

Distance from Inlet	Dredging Percentage Added to the South	1873-1926 South Total Volume	1974 -1997 South Total Volume
(mi)	(%)	(cy/yr)	(cy/yr)
0 - 3	0%	10,451	42,346
0 - 3	25%	10,451	45,455
0 - 3	50%	10,451	48,563

*Beach volume losses are given in red and beach volume gains in black.

C. Overall Findings, Comparisons, and Summary

The five study sites cover a range of physical wave and tidal conditions for inlets along the southeastern and Gulf coasts of the United States. Table II-45 summarizes some of the data presented.

Table II-45. Some Characteristics of the Five Study Sites

Study Site	Average Tidal Range (MHHW – MLLW)	Average Offshore Significant Wave Height*	Average Offshore Peak Wave Period*	Adjacent Inlet Width	Number of Storms** between 1851 - 2008 (within 65 nm)
Oregon Inlet	2.43 ft	3.9 ft	7 s	2,800 ft	98
Fort Macon	3.93 ft	3.3 ft	5 s	3,700 ft	117
Amelia Island	5.34 ft	3.3 ft	7 s	10,300 ft	83
Captiva Island	2.10 ft	2.3 ft	4 s	700 ft	65
John's Pass	2.40 ft	2.3 ft	4 s	600 ft	65

*From 1980-99 WIS Hindcast (Typically 15-20 m depth)
** From NOAA data includes hurricanes, tropical and extratropical storms

The terminal groins at the five selected study sites have been constructed from 1961 to 2005 and vary in length from the longest being over 3,000 feet at Oregon inlet to the shortest of 350 feet at Captiva Island (Table II-46).

Table II-46. Terminal Groins

Study Site	Terminal Groin Structure Information		
	Year Constructed	Length (ft)	Crest Height (ft – MTL)
Oregon Inlet	1989 - 1991	3,125^{d}	8-9.5
Fort Macon	1961, 1965, 1970^{a}	1,530	4.5
Amelia Island	2004 – 2005	1,500	4.7
Captiva Island	1977, 2006^{b}	350	---
John's Pass	North: 1961, 1987^{c} South: 2000	North – 460 South – 400	2.7-5.2

[a] Fort Macon Terminal Groin was constructed in 3 stages with the final extension completed in 1970.
[b] Captiva Island Terminal Groin was reconstructed in 2006.
[c] The North Terminal Groin at John's Pass was reconstructed in 1987.
[d] Includes section parallel to shore backside.

For each of the sites, shoreline change rates were calculated on both sides of the associated inlet for the available shoreline periods prior to, and after, the construction of the terminal groins. Table II-47 summarizes this data for the 3 mile stretch of shoreline on each side of the inlet. For Oregon Inlet, two values are presented since two different pre- and post-terminal groin time periods were analyzed as discussed previously. The data show that in all cases the shoreline was eroding prior to construction of the terminal groin (on the structure side of the inlet) and that after the construction of the terminal groin the shorelines were generally accreting. The data on the opposite side of the inlet does not display a clear trend. It should be noted again that this shoreline change is purely the difference between the shorelines and includes the impacts of beach nourishment and dredging that have occurred in each area and so do not solely represent the impacts of the terminal groins. Thus, factors such as beach nourishment and dredging that impact the shoreline behavior must be taken into account for a full evaluation.

Table II-47. Comparison of the Shoreline Change Rates

Study Site	Average Shoreline Change Rates Along 3 miles (ft/yr)			
	Terminal Groin Side of Inlet		Opposite Side of Inlet	
	Pre – Construction	Post – Construction	Pre – Construction	Post – Construction
Oregon Inlet	19.7 / 24.1**	3.7 / 1.0 ***	2.9 / 117.8 **	38.8 / 26.8 ***
Fort Macon	15.7	3.0	0.5	2.3
Amelia Island	3.5	3.2	8.8	N/A
Captiva Island	11.8	0.8	11.4	1.6
John's Pass – North Structure	5.7	2.6	0.7	5.7

*Red values represent shoreline recession (erosion) and black values represent shoreline advancement (accretion)

** Pre construction years: 1949 – 1980 / 1984 – 1988

*** Post construction years: 1998 – 2004 / 1997 - 2007

Since beach nourishment and dredging are typically quantified in terms of volumes (cubic yards of sand), the shoreline change rates were converted to equivalent beach volume changes to assess the impact of nourishment and dredging, separate from the terminal groin. Shoreline change to volume change estimates were made based on ratios developed from available profile data near each site. The ratio calculated for each of sites in cubic yards of beach volume per linear foot for one foot of shoreline change is given in Table II-48.

Table II-48. Shoreline Change to Beach Volume Ratios

Study Site	Volumetric Change Rate (cy/ft)
Oregon Inlet	1.41
Fort Macon	1.01
Amelia Island	1.25
Captiva Island	0.74
John's Pass	0.91

The volume of beach material lost or gained was evaluated based on the shoreline change, nourishment and beach volumes placed, and quantities of material dredged from the inlet.

Table II-49 shows the total average annual amount of beach nourishment volume added to the sites (over 3 miles along both sides of the inlet). Table II-50 provides a summary of the beach volume changes where the beach nourishment material placed on the beach, or disposed in the nearshore, is subtracted from the volumes calculated based on shoreline change to arrive at volume changes net nourishment.

Table II-49. Total Annual Beach Nourishment

Study Site	Beach Nourishment Volume within 3 Miles from Inlet (cy/yr)	
	Terminal Groin side of Inlet	
	Pre – Construction	Post – Construction
Oregon Inlet	0 / 0*	708,839 / 452,474**
Fort Macon	0	165,368
Amelia Island	0	163,340
Captiva Island	4,870	55,023
John's Pass– North Structure	0	39,102

* Pre construction years: 1949 – 1980 / 1984 – 1988
** Post construction years: 1998 – 2004 / 1997 - 2007

Table II-50. Volume Changes Net Nourishment

Study Site	Volume Change within 3 Miles from Inlet (cy/yr)			
	Terminal Groin side of Inlet		Opposite Side of Inlet	
	Pre – Construction	Post – Construction	Pre – Construction	Post – Construction
Oregon Inlet	437,996 / 1,161,663**	455,775 / 315,378***	56,218 / 2,043,163**	798,737 / 610,849***
Fort Macon	250,326	123,523	7,499	36,905
Amelia Island	81,321	263,098	205,070	N/A
Captiva Island	144,595	45,489	133,293	18,345
John's Pass– North Structure	79,550	36,499	10,451	42,346

[*] Beach volume losses are given in red and beach volume gains in black.
** Pre construction years: 1949 – 1980 / 1984 – 1988
*** Post construction years: 1998 – 2004 / 1997 - 2007

In all cases except Amelia Island (and one case of Oregon Inlet), there is an average annual increase in beach volumes post terminal groin construction on the terminal groin side of the inlet. On the opposite side of the inlet the trends are mixed.

Much like nourishment, the influence of dredging material needs to be accounted for when attempting to assess the impact of the terminal groins. Table II-51 summarizes the dredging records obtained at each site for the same pre- and post-terminal groin construction periods.

Table II-51. Dredging Summary

Study Site	Pre – Construction Dredged Volume (cy/yr)	Post – Construction Dredged Volume (cy/yr)
Oregon Inlet	75,178 / 1,052,466 *	427,557 / 300,417 **
Fort Macon	606,769	809,230
Amelia Island	N/A	N/A
Captiva Island	N/A	N/A
John's Pass	0	12,435

* Pre construction years: 1949 – 1980 / 1984 – 1988
** Post construction years: 1998 – 2004 / 1997 - 2007

Table II-52 and Table II-53 present a means of generally quantifying the potential impacts of dredging by examining the change in beach volume under varying scenarios. The first scenario assumes 25% of the material dredged from the inlet system would have reached the beach naturally and the second scenario assumes 50%. With the exception of the opposite (north) side of Oregon Inlet a net benefit is shown in all cases.

Table II-52. Volume Change Scenario Net Nourishment and Dredging – 25% Scenario

Study Site	Volume Change within 3 Miles from Inlet (cy/yr)			
	Terminal Groin side of Inlet		Opposite Side of Inlet	
	Pre – Construction	Post – Construction	Pre – Construction	Post – Construction
Oregon Inlet	419,202 / 898,546*	348,886 / 240,274**	37,423 / 2,306,280*	691,848 / 535,745**
Fort Macon	98,633	78,784	159,191	165,403
Amelia Island	N/A	N/A	N/A	N/A
Captiva Island	N/A	N/A	N/A	N/A
John's Pass–North Structure	79,550	39,608	10,451	45,455

* Pre construction years: 1949 – 1980 / 1984 – 1988
** Post construction years: 1998 – 2004 / 1997 - 2007

Table II-53. Volume Change Scenario Net Nourishment and Dredging - 50% Scenario

Study Site	Volume Change within 3 Miles from Inlet (cy/yr)			
	Terminal Groin side of Inlet		Opposite Side of Inlet	
	Pre – Construction	Post – Construction	Pre – Construction	Post – Construction
Oregon Inlet	400,407 / 635,430*	241,997 / 165,169**	18,629 / 2,569,396*	584,959 / 460,641**
Fort Macon	53,059	281,092	310,884	367,710
Amelia Island	N/A	N/A	N/A	N/A
Captiva Island	N/A	N/A	N/A	N/A
John's Pass–North Structure	79,550	42,717	10,451	48,563

* Pre construction years: 1949 – 1980 / 1984 – 1988

** Post construction years: 1998 – 2004 / 1997 - 2007

III. Geologic Assessment

This section addresses the geological framework, physical processes, and human-induced changes that influence erosional-depositional sedimentation patterns at the five tidal inlet sites and along their adjacent shorelines. These processes are evaluated as to their impact on the terminal groin located at each of the study sites.

A. Function of a Terminal Groin

Terminal groins are structures built at the end of littoral cells to reduce shoreline erosion and conserve sand along the end of beach or barrier, usually consisting in part of nourishment sand. Like most groins, they are normally constructed of 1 to 4-ton boulders that are fitted together to increased their stability against storm wave attack. They extend into the nearshore zone and act as a dam to the longshore transport of sediment. They are usually constructed at the downdrift end of a barrier on the updrift side of a tidal inlet. However, due to wave refraction around the ebb tidal delta, which causes sand to enter the channel from both sides of the inlet, terminal groins have been built on both sides of an inlet. Jetties are built to prevent sand in the littoral zone from entering the inlet channel and to help maintain navigation depths of dredged channels. Although terminal groins trap sand, they are dissimilar to a jetty, because once the terminal groin fills with sediment (beach accretes to the end of the groin and is called a *fillet*), additional sand bypasses the structure and enters the nearshore and/or the tidal inlet (Figure III-1). Commonly, terminal groin construction is done in combination with beach nourishment so that the groin does not capture existing sand reservoirs. During high wave energy events, the beach along the fillet often erodes and the sand is mobilized. Once depositional wave conditions return and the normal longshore transport system is reestablished, the fillet is reconstructed.

Terminal groins are commonly built at the end of the barrier and extend along the entire length of the tidal inlet. Although most terminal groins are designed primarily to help stabilize a length of oceanfront shoreline, a sometime overlooked consequence when the structure is built on the downdrift side of the inlet, is the stabilization of the inlet by preventing migration of the inlet channel. The groin inhibits erosion of the side of the channel by tidal currents and thus the inlet is not allowed to migrate.

Figure III-1. Terminal Groin at Saint Pete Beach, Florida

The proper design of a terminal groin permits the longshore transport of sand around and over the structure once the beach has accreted to the end of the groin. During high wave energy events, sand is often transported over the structure. Usually beach nourishment is done in conjunction with groin construction so that sand will not be removed from the normal littoral transport system.

B. Impact of Geological Framework and Physical Processes

Numerous processes affect terminal groins because of their location at the ends of barriers next to tidal inlets. These factors are listed in Table III-1 and discussed in the text below. Some of the processes have day-to-day effects on terminal groins, such as wave energy and tidal currents, whereas others exert a seasonal or yearly influence (major storms, dredging activity), and still others that have a very long-term impact (sea-level rise).

Table III-1. Factors Affecting Terminal Groins

1. Wave energy distribution and wave approach along the coast
2. Rates and directions of longshore sediment transport
3. Tide ranges of the ocean and bay
4. Wind regime and effects of vegetation
5. Effects of major storms
    a. frequency and track
    b. storm surge elevations
    c. wave energy
    d. erosion and depositional trends, including washovers
6. Historical morphological changes of the shoreline and inlet system
7. Bathymetric changes of the inlet and nearshore
8. Sand circulation patterns at tidal inlet and processes of inlet sediment bypassing
9. Geological framework controls on inlet stability and nearshore sediment supplies.
10. Dredging history including disposal sites
11. Sea level trends

1. Wave Energy and Longshore Sediment Transport

The volume of sand delivered to the fillet region is dependent on sand availability and wave energy, which in turn is a function of deepwater wave energy, direction of wave approach, and wave shoaling characteristics as the wave propagates toward the beach. The wave regime dictates the dominant longshore transport direction, but transport reversals commonly accompany storms or changes in the configuration of the ebb-tidal delta.

2. Tides and Tidal Currents

Marginal flood channels associated with ebb deltas and tidal inlets also influence the transport of sand in the vicinity of terminal groins. These channels are often located just offshore of the beach and thus, flood and ebb currents in these channels can enhance or retard wave-induced sand transport rates along the adjacent beach, respectively. The strength of tidal currents at the inlet is a function of tidal range, which is largest during spring tides and smallest during neap tides. Large tidal ranges produce steep water surface slopes, strong tidal currents, and greatest potential sediment transport. During neap tides the converse is true. Tidal and wave-generated currents control the circulation of sand at tidal inlets and processes that allow sand to bypass the inlet from the updrift barrier to the downdrift barrier. It is important to note that regardless of the net longshore transport direction along the coast and the dominant pathways of inlet sediment bypassing, sand commonly moves onshore from the ebb delta to the beach in the form of landward migrating bar complexes. Depending on the size of the inlet, these bars can add 10,000 to more than 100,000 cubic yards of sand to the beach. Sand also moves onshore independent of bars.

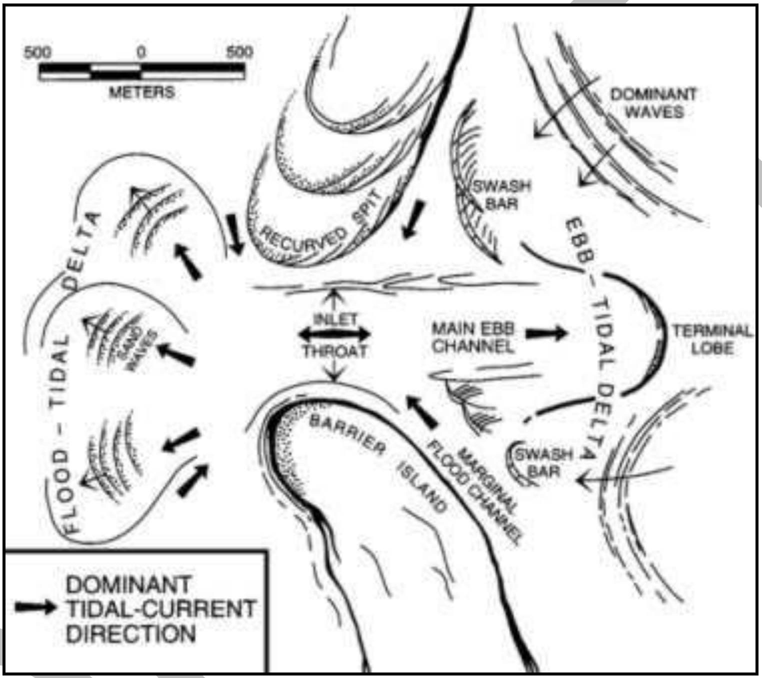


Image from Schrader, R.J., et. al. 2000.

Figure III-2. Inlet Geologic Features

3. Effects of Storms at Inlets

Ebb-tidal currents move sand that is delivered to the inlet via longshore sediment transport seaward to the ebb delta, whereas the flooding currents transport sand into backbarrier channels and to flood-tidal deltas (see Figure III-2). This process is enhanced during storms when meteorological tides steepen the water surface slope and strengthen tidal currents flowing into the backbarrier. During these periods, storm waves also increase longshore transport rates and the delivery of sand to the inlet. This increased sand supply coupled with the strong flood currents enhances sand movement into the backbarrier, as evidenced by the enlargement of flood tidal deltas and shoaling of tidal waterways during storms. Movement of sediment into the backbarrier represents a long-term sequestration of sand from the littoral zone, which will not become part of the active inlet and nearshore system until the shoreline transgresses to this backbarrier site.

4. Storm Effects on Barriers

The North Carolina coast is impacted by hurricanes and tropical storms on almost a yearly basis, although their occurrence is cyclic having decadal frequencies. Extra-tropical northeast storms occur much more frequently, but generally have weaker winds that produce smaller storm surges and lower wave heights than hurricanes. The Florida coast is influenced primarily by hurricanes and tropical storms. The major impact of storms is beach erosion, dune scarping, barrier overwashing, and sand transport into the backbarrier. Occasionally, major storms can breach a barrier forming a permanent or ephemeral tidal inlet. Salt spray driven onshore during intense storms can stunt or kill vegetation. Under certain circumstances washovers can deposit sand in the supratidal and interior portions of the barrier increasing the elevation of the barrier. Likewise, overwash fans deposited along the lagoon side of the barrier enlarge the footprint of the barrier and aid in its landward migration.

5. Interpretation of Historical Data Bases

The effects of major storms as well as long-term morphological changes of the shoreline in the vicinity of the terminal groin area can be interpreted using sequential vertical aerial photographs, maps, coastal charts, topographic and bathymetric surveys, and other historical data sets. These resources allow an assessment of how the shoreline adjacent to the terminal groin responds to different forcings, such as the orientation of the main ebb channel and configuration of the ebb-tidal delta. For example, it can be ascertained if the preferential overlap of the ebb delta along the terminal groin shoreline protect this region and lessen storm erosion as well as deliver sand to this beach in the form of landward migrating bar complexes. Alternatively, does this same shoreline erode when the ebb delta shifts and overlaps the opposite shoreline? These trends are important because the effects of the terminal groin may be masked by larger-scale sedimentation patterns dictated by the tidal inlet.

6. Geological Framework

The geological framework of the region can impart a strong signature on the physical processes affecting erosional-depositional patterns along terminal groin shorelines. The ability of a tidal inlet to migrate downdrift in the dominant longshore transport direction depends on the ability of the ebb and flood tidal currents to erode the downdrift bank of the inlet from the beach to the base of the channel. Some inlets are stabilized with engineering structures, such as jetties and terminal groins, while others are naturally stable due to the stratigraphy of the channel bank. If the inlet throat (narrowest and deepest section of the inlet normally occurring where the barriers constrict the channel) erodes into bedrock or resistant sediments, such as consolidated clay, limestone, cemented sandstone, or other indurated sedimentary lithologies, migration of the channel may be prevented or severely impeded. Moreover, it has been shown by numerous scientists working along the North Carolina coast that the shelf stratigraphy is tied closely to the present sand reservoirs along the coast and inner shelf regions (Riggs et al, 1995).

Also important are the paleo-drainage patterns of rivers that debouched sediment onto the continental shelf during lower stands of sea level. It is the reworking of these deposits and contribution of erodible sand from the Tertiary sedimentary bedrock that provided the sand resources responsible for building the North Carolina barrier island chains. It should also be noted that shoreline erosion rates often closely correlate with the stratigraphy of the shoreface and units underlying the barrier sediments. Barriers overlying sandy units (i.e., inlets fills, fluvial deposits) are less resistant to erosion when compared to barriers overlying compact estuarine and lagoonal mud (Riggs et al, 1995).

7. Dredging and Sediment Disposal

Major sand accumulations are found at tidal inlets and in backbarrier regions in the form of flood and ebb-tidal deltas, tidal channel deposits, and point bars. Frequently, these sand reservoirs are excavated during the dredging of channels to improve navigation. One of the side benefits of these projects is a source of sand to nourish eroding beaches. However, dredging projects can also alter the hydrodynamics of tidal inlets and backbarrier channels, changing the relative strength of flood versus ebb-tidal current, leading to the redistribution of sand deposits and morphological changes. Because natural channels are usually in equilibrium with the water they convey during the rise and fall of the tides, dredging a wider and deeper channel disturbs this equilibrium. One common consequence of dredging is the creation of a sediment sink whereby sand that is moving through the system accumulates in the deepened channel, resulting in shoaling and the need for maintenance dredging. This condition has important implications to the tidal inlet, the longshore transport system, and sand reservoirs comprising this coastal region. Unless the dredged sand is put back onto the beach, the removal of sand from the channel represents a permanent and continual (in the case of maintenance dredging) loss of sand from the coastal system.

Dredging a tidal inlet also has the potential of decreasing the frictional resistance in the channel, leading to less attenuation of the tidal wave as it propagates into the backbarrier. This enlargement of the channel dimensions can increase the tidal range in the backbarrier producing a larger bay tidal prism (volume of water entering and exiting the inlet during a half tidal cycle). The major impacts of the increasing tidal exchange are stronger tidal currents and greater sand transport potential. As tidal prism increases the ebb tidal delta will grow in volume at the expense of sand that normally bypasses the inlet and nourishes the downdrift barrier. This situation is exacerbated when the main ebb channel is continually over-dredged beyond its equilibrium dimensions. Under these circumstances, the ebb delta never achieves an equilibrium volume leading to little sand bypassing the inlet. The condition is further worsened, if the main ebb channel is dredged through the terminal lobe (outer bar of the ebb delta). This incision of the outer delta into two halves greatly diminishes the ability of tide and wave-generated currents to transfer sand across this chasm and complete the transfer of sand around the inlet.

8. Sea-Level Rise

There is growing certainty that global sea-level rise (SLR) is accelerating, however, there is no consensus on the response of coastal marshes to these changing conditions. The common model of marsh response to SLR predicts increased vertical accretion through enhanced plant productivity and higher rates of inorganic deposition. This relationship fails when organic production and inorganic accumulation cannot keep pace with the rate of SLR, culminating in the submergence of the marsh platform. If North Carolina platform marshes are not able build vertically at the same rate that sea level rises, then they will be converted to intertidal and subtidal environments, which will lead to increased tidal exchange through the tidal inlets. As described above, enlarging tidal prisms will grow the size of ebb-tidal deltas, leading to the sequestration of sand offshore and erosion of onshore beaches and barriers. At the same time, the overall deepening of the backbarrier due to SLR produces accommodation space for sand that is transported landward during storms. Thus, SLR can create a backbarrier sediment sink that can further diminish the barrier sand reservoirs.

A second potential loss of sediment to the barrier system due to SLR is the sand transported offshore caused by a deepening of the nearshore. The disequilibrium of the nearshore profile generated by SLR results in sand being left offshore during storms and not being transported back onshore during fair weather conditions. It should be noted that these processes attributed to SLR occur slowly and their net effects may take decades to be measured.

C. Assessment of the Five Selected Study Sites

1. Oregon Inlet

Oregon Inlet is the only permanent tidal inlet along the North Carolina coast north of Cape Hatteras and is one of four inlets that exchanges tidal waters between Pamlico Sound and the Atlantic Ocean (Figure III-3). It was opened by a hurricane in 1846 and then migrated south almost 4 km by 1989 (Riggs et al, 2009). Oregon Inlet separates Bodie Island to the north and Pea Island to the south, both of which are storm-dominated barriers and have had long histories of storm overwashing, barrier breaching, inlet formation, and shoreline recession. The dynamic evolution of these barriers is manifested in numerous relic flood delta, overwash fans, recurved spit and beach ridge complexes, and tidal inlet scars (Fisher, 1967; Riggs et al, 2009).

a. Terminal Groin Construction

A 3.9-km long bridge (Bonner Bridge) connecting Bodie Island to Pea Island was completed in 1963. By the 1980's the southerly migration of Oregon Inlet resulted in a deepening of tidal channels beneath the bridge, which exposed support pilings costing millions of dollars in road construction and bridge repairs. Eventually erosion of downdrift Pea Island threatened to separate the end of the bridge from the island, so to prevent this foreseeable disaster, a 3125-foot long rubble-mound revetment and terminal groin were constructed at the northern end of Pea Island. The revetment wrapped around to the backside of the island and terminated at the Coast Guard facility. The groin projected slightly northward into the inlet and extended seaward to a position parallel to the northern end of Pea Island (Figure III-4). The terminal groin was constructed to protect the southern end of the bridge and prevent further southerly migration of the tidal inlet. A comparison of the 1991 post-construction shoreline with an August 2006 vertical aerial photograph reveals that between these two surveys Bodie Island prograded approximately 0.5 km (1640 feet) southward and that a combination of dredge sand disposal and natural sand deposition filled the region between the terminal groin and the adjacent beach on Pea Island.

b. Longshore Transport and Bodie Spit Accretion

This region experiences the highest wave energy along the East Coast of the United States with a significant wave height of 1 m and significant period of 9 seconds (Leffler et al, 1996). The dominant southerly longshore transport of sand in this region, which has been estimated to be as high as 1,000,000 m^3/yr (Inman and Dolan, 1989), is driven by the passage of extratropical northeasterly storms, which were intense between 1932-1962 and very mild during the 1963-1971 period (Riggs et al, 2009). Likewise, from 1982 to 1995 the region averaged 34 storms per year, which was followed by a very mild period from 1997 to 2002 of only 13 storms per year (Riggs and Ames, 2009). This cyclicity of these storms is likely a product of the North Atlantic Oscillation.

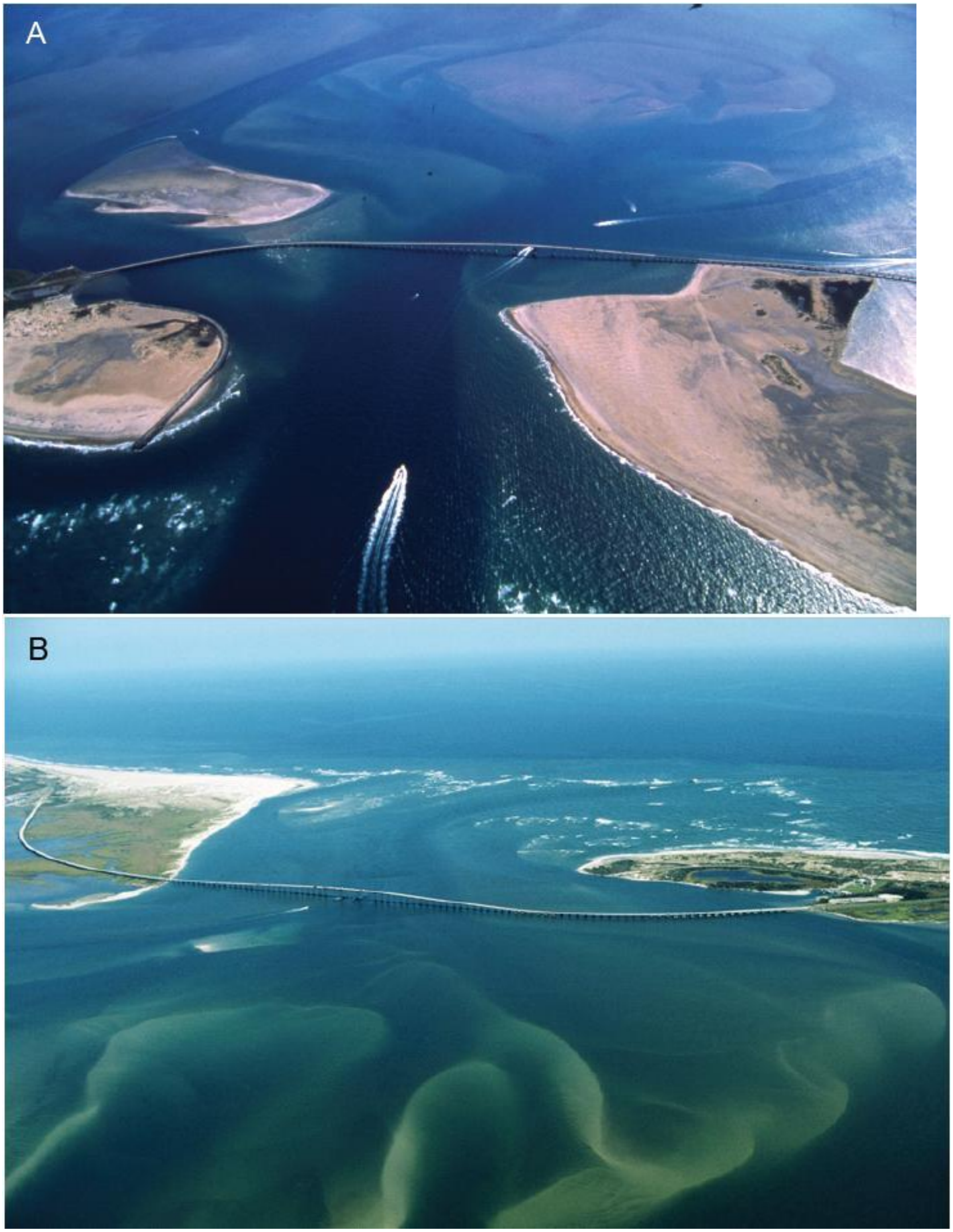


Figure III-3. Aerial Photographs of Oregon Inlet A. Looking Landward (Photograph from Ramanda, Nags Head) and B. Seaward (Photograph by D.A. Harvey)

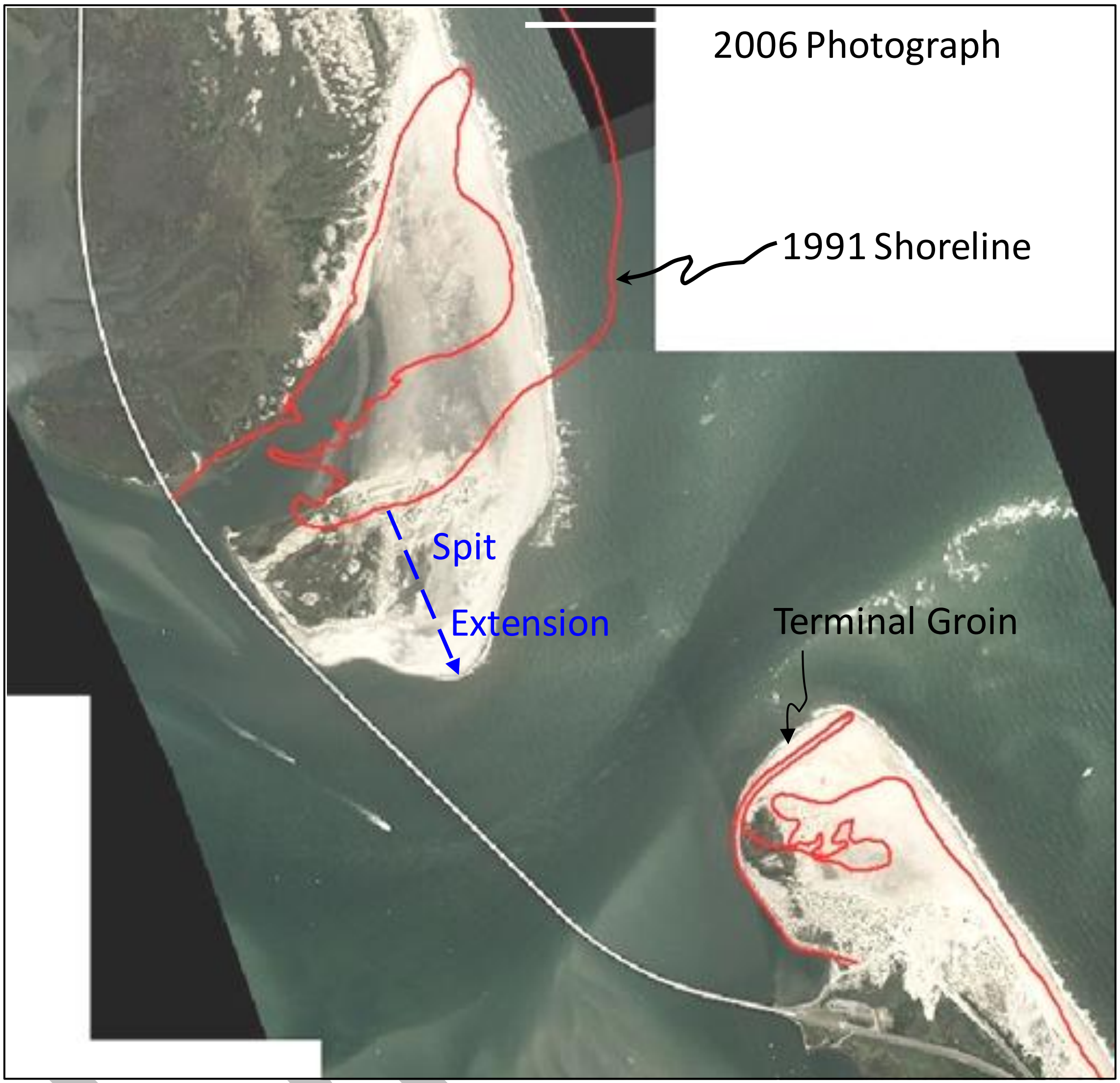


Figure III-4. Comparison of 1991 and 2006 Shorelines Along Bodie and Pea Islands

The high longshore transport rate explains the rapid southerly progradation of Bodie Island spit that has forced the migration of Oregon Inlet. The recurved ridges comprising the spit end of Bodie Island (Figure III-5) are a product of waves refracting into the inlet. More importantly, they represent packages of sand being delivered to the inlet and are associated with individual, or a set of closely spaced, high intensity storms. They demonstrate that the longshore transport of sand is largely a function of storm frequency and intensity and emphasize that this region of North Carolina is a storm-dominated coast.

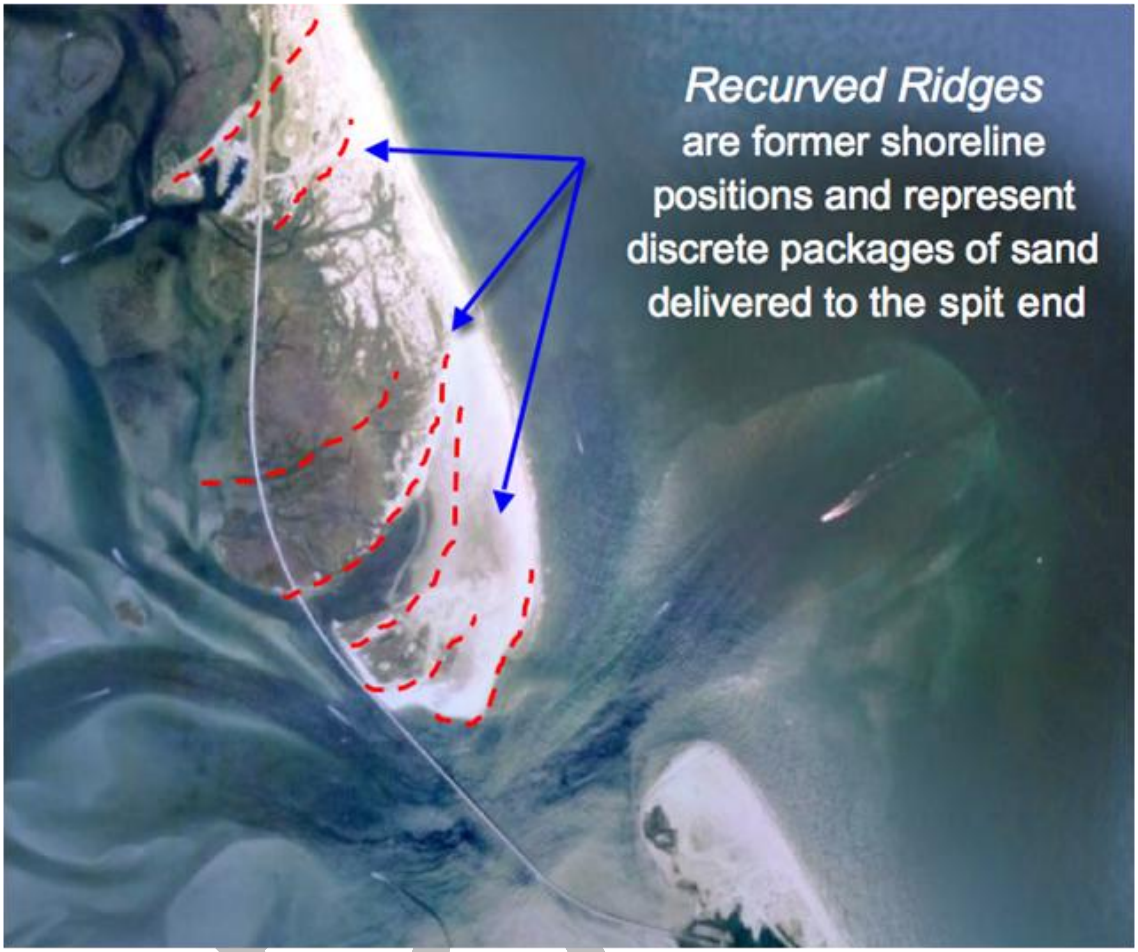


Figure III-5. Bodie Island Illustrating Recurved Ridges Comprising Spit End

c. Oregon Inlet

Migrational and sedimentation trends of Oregon Inlet were studied using topographic and bathymetric time series collected by the U.S. Army Corps of Engineers and analyzed by Vandever and Miller (2003). Shoreline topographic surveys of Bodie and Pea Islands and bathymetric surveys of the tidal inlet, ebb-tidal delta, and backbarrier area immediately landward of the inlet were conducted in 1999, 2001, and 2003. Comparisons of these datasets are shown in Figure III-6. Although the northern end of Pea Island was largely stabilized in 1991 by completion of the terminal groin, Bodie Island continued to encroach into Oregon Inlet. Note that between 1999 and 2003 Bodie spit prograded southward about 400 m and the channel thalweg (line connecting deepest depths along a channel) migrated southward by almost 300 m (Figure III-6A). From 1999 to 2001 a decrease in cross sectional area of the inlet (~1000 m^2), due to spit accretion and channel narrowing (~ 200 m), caused an increase in tidal current velocities resulting in channel scour and deepening of the thalweg by about 2 m (Vandever and Miller, 2003). During the same period, the symmetrical channel cross section became more V-shaped and slightly asymmetric. The bathymetric difference map in Figure III-6B illustrates the subtidal progradation of Bodie spit into the channel and a shift of the channel thalweg southward. Bathymetric changes in the ebb-tidal delta region reflect the narrowing and seaward extension of the main ebb channel, which resulted in a growth and seaward displacement of the terminal lobe (outer bar of the ebb-tidal delta). The point to emphasize here is that the longshore transport system, Bodie spit evolution, tidal inlet hydraulics, ebb-delta sedimentation trends, and erosional-depositional changes to the northern tip of Pea Island (terminal groin region) are all intimately interconnected. A perturbation to one part of the system affects the processes and morphology of others.

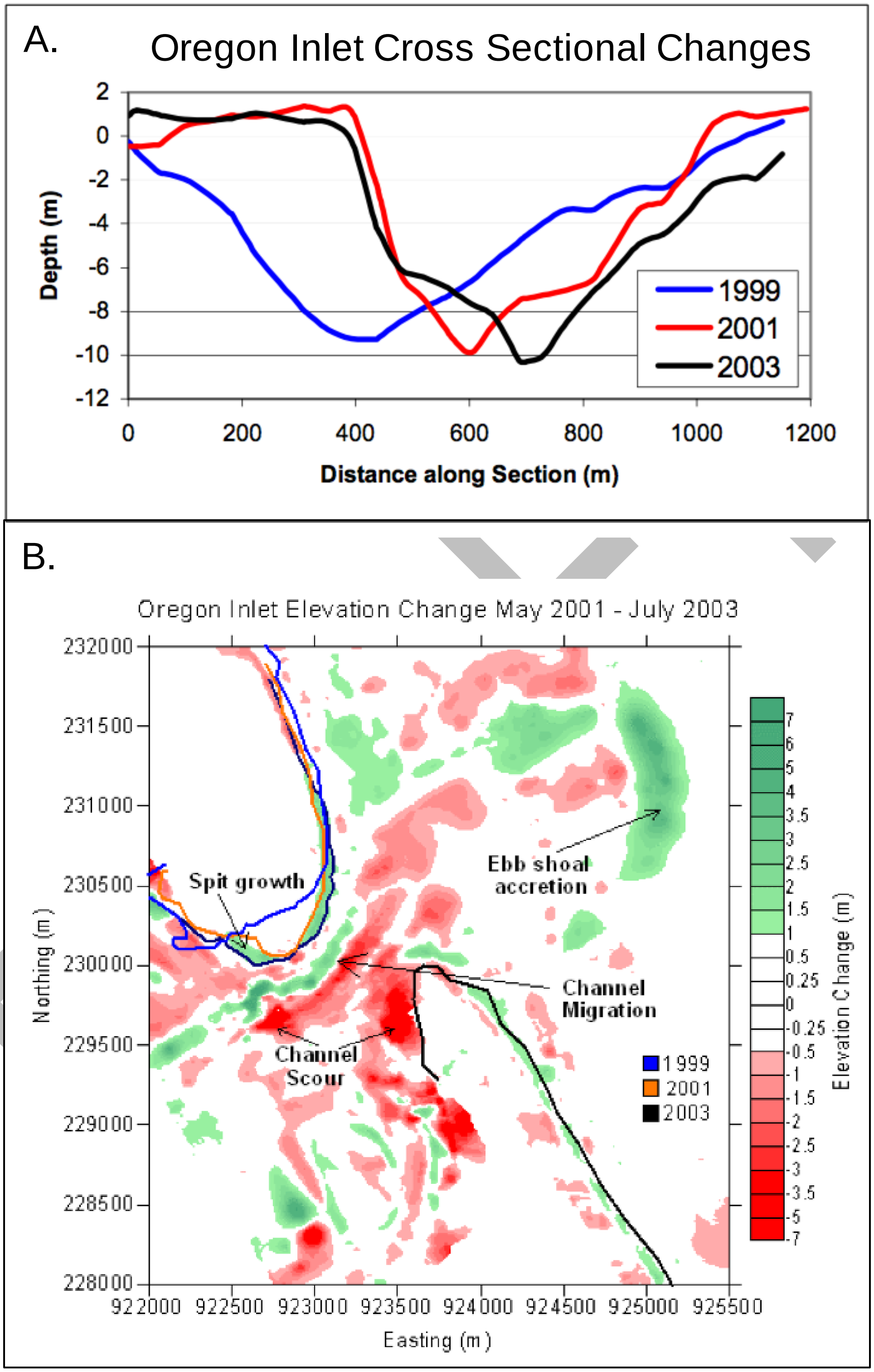


Figure III-6. Bathymetric Changes at Oregon Inlet Showing A. Cross-sectional Changes from 1999 to 2001 and B. Erosional-depositional Changes Over the 2001 – 2003 Period (Vandever and Miller, 2003)

As discussed in the previous section on geological framework and physical processes, the configuration of the ebb-tidal delta at Oregon Inlet strongly controls sedimentation processes in the vicinity of the terminal groin. The orientation of the main ebb channel dictates the asymmetry of the ebb-tidal delta and overlap of the updrift or downdrift inlet shorelines. As seen in Figure III-7, in 1959 the main ebb channel was oriented straight out the inlet and the ebb-tidal delta fronted the downdrift northern end of Pea Island. In this configuration, swash bars migrated onshore adding sand to the northern shoreline. Conversely, in 1975 the main channel was situated along the updrift Bodie Island Shore and Bodie Island was the beneficiary of landward bar-welding events and the northern of Pea Island was exposed to storm waves and erosion.

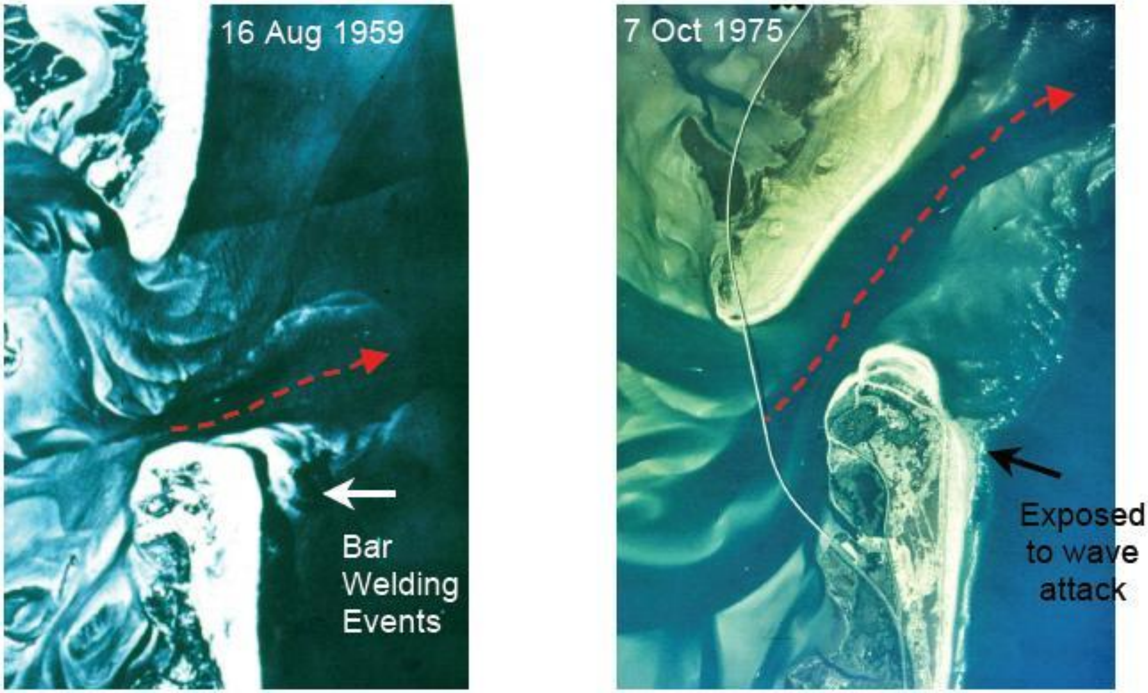


Figure III-7. Historical Aerial Photographs of Oregon Inlet Illustrating Different Ebb-tidal Delta Morphologies. The overlap of the ebb delta dictates accretionary patterns along the adjacent beaches

d. Northern Pea Island

Wave refraction around the ebb-tidal delta is another important process at Oregon Inlet as shown in Figure III-8. An aerial view of Pea Island in 1991 shows the terminal groin extending into the inlet and the fillet region containing little sand. However, swash bars can be seen immediately offshore of the groin and these may have moved onshore and contributed sand to the beach. By 1993, the groin had trapped sufficient sediment (through beach nourishment and natural processes) so that the fillet region was mostly filled with sand. The 1993 photograph reveals a relatively wide tidal inlet and an ebb delta that is pushed close to the inlet mouth. Note that waves are breaking at a steep angle to the beach, indicating that at this time sand was moving northward along the beach toward the groin (Figure III-8). Currents generated by the flooding tides would have enhanced northerly sand transport along the tip of Pea Island.

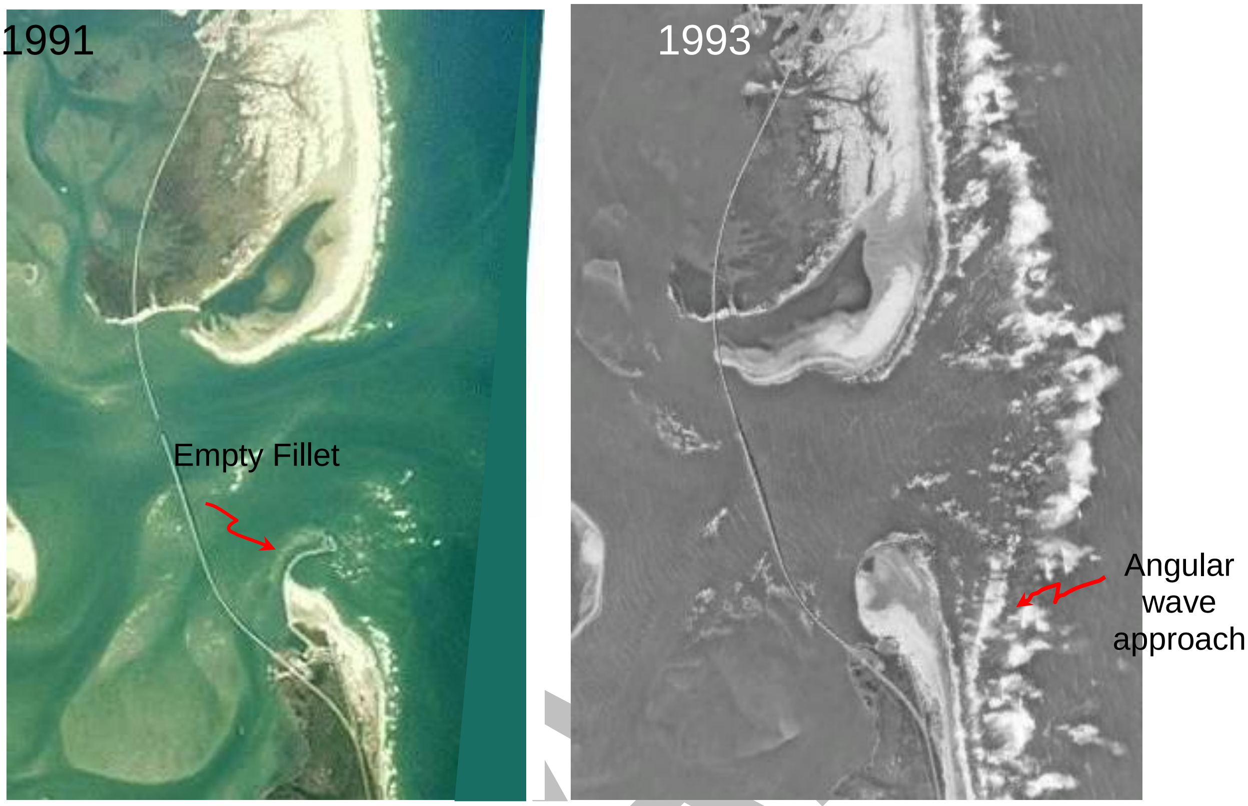


Figure III-8. Photographs of Northern Pea Island and Terminal Groin Area. Note immediately following construction of the groin in 1991 the lack of sand in the fillet region. Two years later, it had mostly filled due to a nourishment project and from the natural northerly longshore transport of sand caused by wave refraction around the ebb delta

This same morphology is observed in a 2001 photograph of the region (Figure III-9). This photograph demonstrates that after the beach accretes to the end of the groin, additional longshore transport of sand toward the inlet moves around the groin (as well as over and through the groin during elevated tides and high wave energy events) and is deposited along the inlet shoreline. It should also be noted that sand is also sequestered at the northern end of Pea Island as a consequence of storm overwash into the fillet region. Beach sand blown into the back dunal area also adds to the sand reservoir in this region.

Figure III-9. 2001 Aerial Photograph of Oregon Inlet Showing Wave Refraction Around Ebb Delta Producing Northerly Transport Along Pea Island Feed Sand to the Fillet Region. Note the sand that has moved past the groin and constructed a beach along the inlet shore

The evolution of northern Pea Island prior to the construction of Bonner Bridge through 2006 is shown in Figure III-10. Before emplacement of the terminal groin in 1991, northern Pea Island was characterized by long-term retreat due to inlet migration; however, there were also short-lived periods of northerly spit progradation. The bulge in the beach in the 2006 photograph is evidence of the onshore movement of sand from the ebb delta, probably in the form of landward migrating swash bars. At tidal inlets where the ebb delta has achieved an equilibrium volume of sand as dictated by its tidal prism, sand entering the tidal inlet via the longshore transport system bypasses the inlet and nourishes the downdrift beach and barrier system with sand. This supply of sand is not constant and the volume and rate varies as function of the following:

1. Storm frequency and magnitude
2. Spit construction or erosion
3. Dredging activity
4. Changes in tidal prism and equilibrium ebb-tidal delta volume
5. Inlet migration

Figure III-10. Sequential Photographs of Oregon Inlet Depicting the Shoreline Changes Associated with Spit Accretion at Bodie Island and Southerly Migration of Oregon Inlet (Cleary, 2009)

Long-term shoreline changes along northern Pea Island are presented in **Error! Reference source not found.**. In response to the southerly migration of Oregon Inlet, northern Pea Island retreated both landward and southward. After the terminal groin was completed in 1991, the shoreline was relatively stable with progradation and retreat of 0 to 60 m along a 2 km stretch of shore south of the inlet. A more detailed view of shoreline changes in the vicinity of the groin is shown in Figure III-12 covering the period between 1993 and 2009.

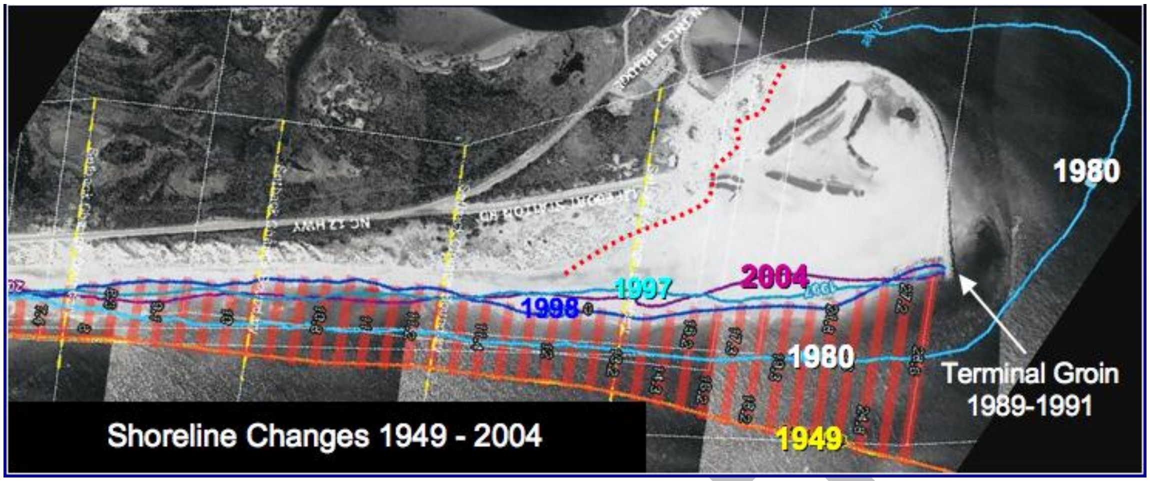


Figure III-11. Long-term Shoreline Changes of Northern Pea Island. The shoreline has been more stable since emplacement of the terminal groin (Cleary, 2009)

The sequential photographs illustrate that although the most shoreline variability occurs in the vicinity of the terminal groin, there appears to be no long-term trends. When the beach extends to the end of the groin, sand is transported around the structure and builds a beach along the inlet shoreline. Loss of the beach near the groin is most likely a product of storm erosion.

e. Quantitative Shoreline Measurements

Quantitative shoreline data for northern Pea Island are provided in Figure III-13 and were derived from shape-files downloaded from North Carolina Coastal Management Division and analyzed by Cleary (2009). This data set is deemed appropriate for assessing the influence of the terminal groin on the downdrift shoreline, because it covers the period before and after the groin construction and there are six transects, evenly spaced, that extends about 1.5 miles from the Oregon Inlet. Transect 1 is located about 1500 ft from the terminal groin and each succeeding transect is then located 1,250 ft to the south. The data demonstrate that between 1849 and 1997 that the entire shoreline underwent net erosion, although there were two stations that experienced minor accretion during different time periods (Transect T-3, 1942-1980, +5.5 ft/yr; Transect T-6, 1980-1997, +1.6 ft/yr; Figure III-13). The transect closest to the inlet (T-1) had most erosion (1896 ft) during this time period, which is understandable given that this transect is closest to southerly migrating Oregon Inlet. Middle transect T-3 underwent the least amount of erosion, but still retreated 1181 ft.

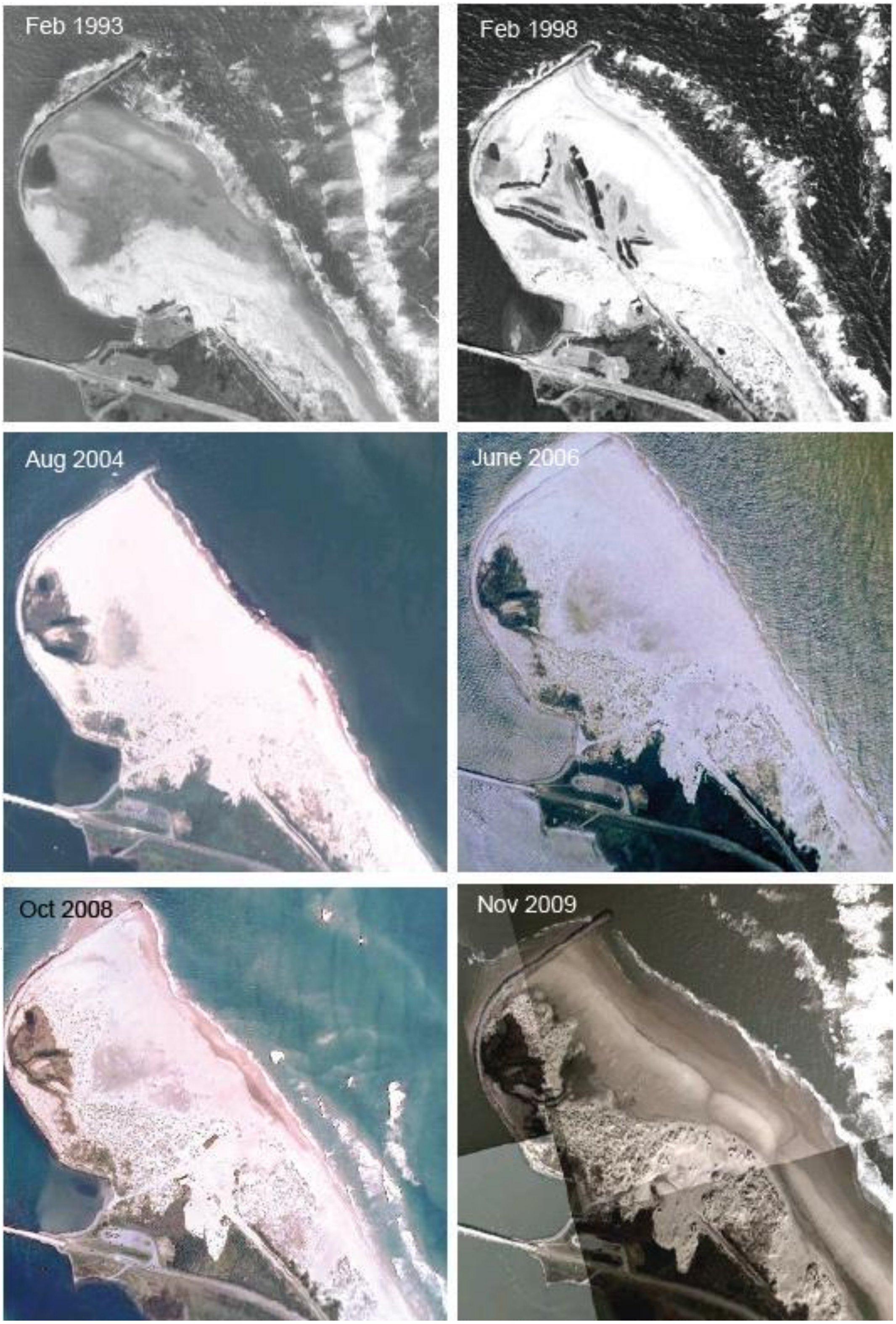


Figure III-12. Historical Changes of the Northern Pea Island Shoreline (downloaded from Google Earth)

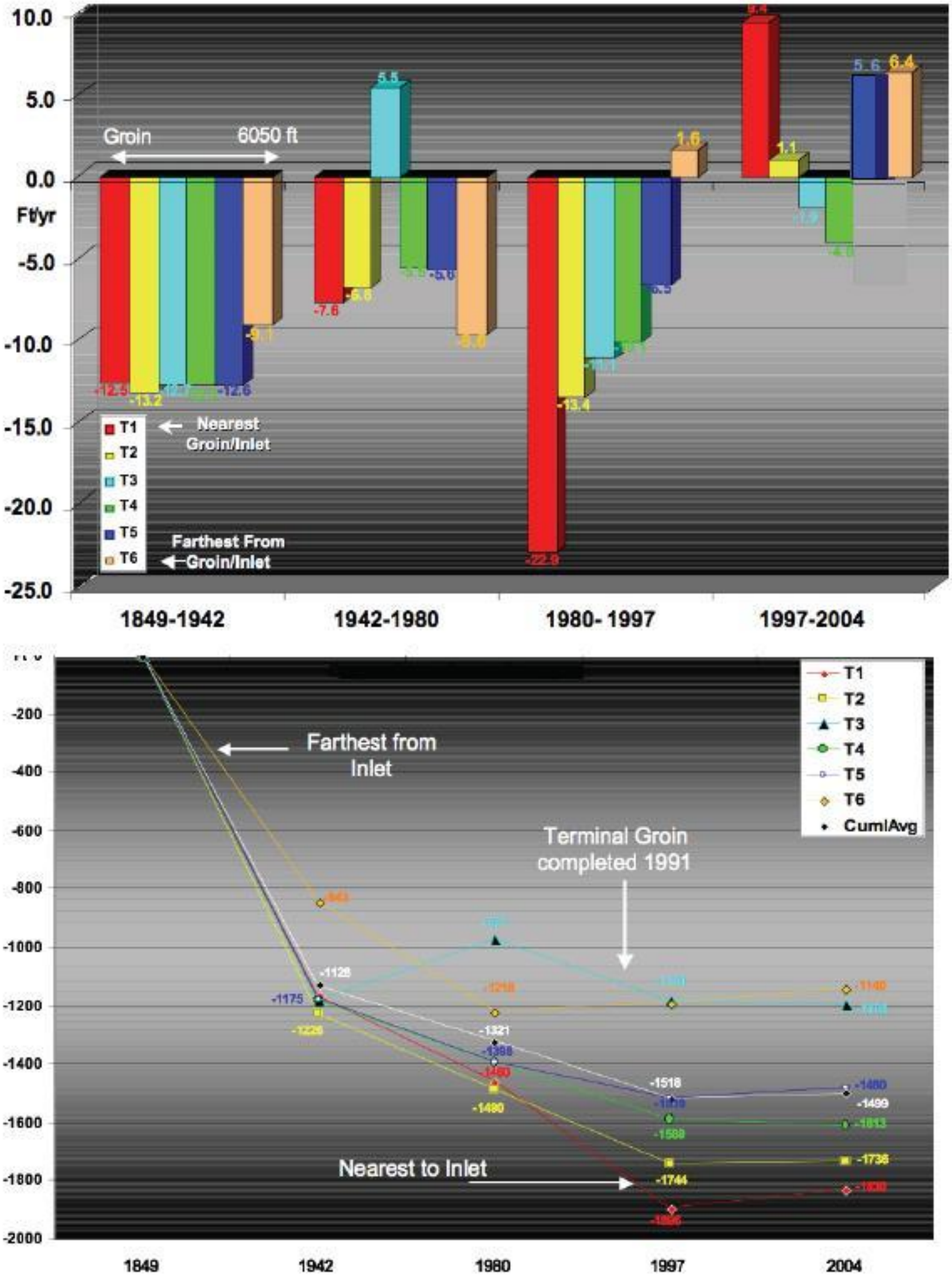


Figure III-13. Shoreline Changes along the Northern Mile of Pea Island. Data for these graphs were derived from North Carolina Division of Costal Management shapefile (Cleary, 2009)

The average shoreline erosion for all the stations was 1518 feet. The pervasive erosion that characterized northern Pea Island reflected the long-term retreat of this coast (Riggs et al, 2009) as well as the migrational history of Oregon Inlet. As the inlet migrated to the south, the longshore transport of sand was sequestered in the recurved ridges of southerly prograding Bodie Island spit. Additional sand was lost from the littoral system due to the landward transport sediment through Oregon Inlet that led to the formation of flood-tidal deltas, tidal creek point bars, and intertidal and subtidal shoals. The sand deposited in the updrift spit and in the backbarrier was not entirely compensated by erosion of the downdrift inlet shoreline and thus northern Pea Island experienced a sand deficit and it eroded. This erosional trend changed after the construction of the terminal groin. Between 1997 and 2004, the two stations closest to the inlet and the two furthest away from the terminal groin experienced accretion ranging from +1.1 to 9.4 ft/yr. Conversely, the two middle stations, T-3 and T-4, underwent erosion of -1.9 and 4.0 ft/y, respectively. The cumulative average for all six transects was a net seaward advancement of the shoreline of 19 feet for the post- groin construction period (Figure III-13, Cleary, 2009).

f. General Pea Island Shoreline Changes

A long-term shoreline monitoring study of Pea Island has been funded by NCDOT since the 1990 covering the northern 6.5 miles of the barrier, resulting is a series of reports (Overton and Fisher, 2005; Overton, 2007; Fisher, Overton, and Jarrett, 2004). Using the data from these reports Riggs and Ames (2009) have produced a summary diagram showing shoreline trends for three overlapping time periods including: 1949 to 1998, 1984 to 1988, and 1989 to 2003 (Figure III-14). The 1949 to 1998 shoreline trend encompasses the longest time period and shows much lower erosion rates than does the much shorter time frame between 1984 and 1988. The highly eroding nature of Pea Island, particularly at the very northern end, during 1984-1988 period was probably due to a decrease in the volume of sand bypassing Oregon Inlet. Note the large spit that formed at the end of Bodie Island during the 1984-1989 time span (Figure III-15). The sediment trapped in this accreting spit certainly would have decreased the delivery of sand to the inlet and thus, the availability of sand to nourish the downdrift barrier. As shown Figure III-12and Figure III-13 and discussed above, the very northern end of the Pea Island accreted following the construction of the terminal groin, which was to be expected. It is remarkable that much of Pea Island has continued to erode despite a large and ongoing beach nourishment effort.

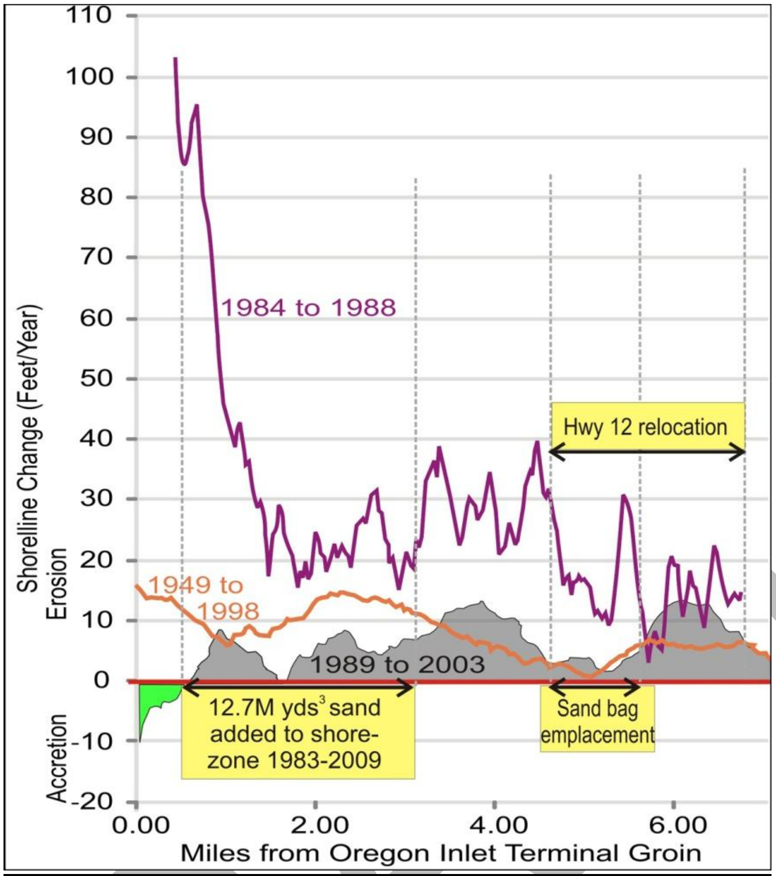


Figure III-14. Shoreline Changes for Three Overlapping Time Periods (Riggs and Ames, 2009)

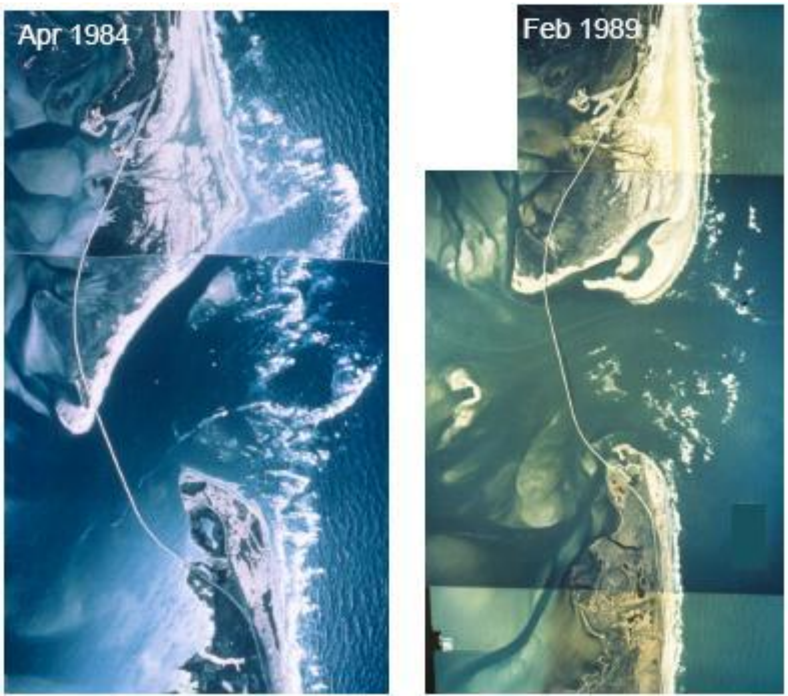


Figure III-15. Aerial Photographs Illustrating Extensive Spits Growth at Bodie Island between 1984 and 1989

g. Dredging and Beach Nourishment

Another major factor influencing erosional-depositional patterns along northern Pea Island is the dredging activity at the inlet, which includes maintaining a 14-foot navigation channel at the inlet and through the outer portion of the ebb-tidal delta as well as the channel beneath the navigation span of Bonner Bridge. The USACE is only able to maintain the authorized 14-foot depth of the channel, on average about 25% of the time (Bill Dennis personal communication 2008). Prior to 1989, dredged sediment was largely disposed offshore in deep water.

The quantity and disposal locations of sediment derived from dredging of the channels and ebb delta between August 31, 1989 and November 3, 2005 are listed in Table III-2. A second compilation of dredging activity at Oregon Inlet has been assembled by Riggs and Ames (2009) and is given in Table III-3. Most of the differences between the volumes listed in Table III-2 and Table III-3 are due to the longer period of record used by Riggs and Ames (2009) and their inclusion of sediment mined from the backbarrier storage site and transferred to Pea Island. Regardless of the differences, the important point demonstrated by both tables is that the normal longshore supply of sediment to Pea Island has been and continues to be significantly augmented through beach and nearshore sand nourishment.

Table III-2. Dredging Volumes and Disposal Sites for 1989 – 2005 (based on USACE data)

August 31, 1989 through November 3, 2005. **Disposal Method/Location**	**Quantity (cubic yards)**
Offshore	522,799
Nearshore of PINWR (1.5 miles south,16-20 ft water depth)	2,100,390
Piped to PINWR Beaches	4,914,920
Placed on a Disposal Island	167,258
Total	**7,705,367**
Total possible to affect PINWR	**7,015,310**

A study of the nourishment sand along PINWR between 1990 and 2002 was made by Dolan et al (2004), and they concluded that the sediment placed on the beach during this period was finer-grained and contained significantly greater quantities of heavy minerals than the native sand. They state: "During the past 12 years of bypassing sand from Oregon Inlet to PINWR, there has been a significant decrease in sand size in the swash-zone of the beach, from 1.16 mm in 1990 to 0.55 mm in 2002. We are convinced that this is due to the introduction of finer sand that is dredged out of the inlet and placed on PINWR."

Table III-3. Chronicle of Dredging at Oregon Inlet and Beach Nourishment along Pea Island (Riggs and Ames, 2009)

2006 - 2009*	= ~1.9 million cubic yds in 2 pipeline dredge ops and deposited at milepost 1 to 3 on Pea Island
1989 - 2005***	= ~3.7 million cubic yds in 10 pipeline dredge ops & deposited at milepost 1 to 3 on Pea Island
2006 - 2007*	= ~1.2 million cubic yds in 4 hopper dredge ops & deposited in the nearshore off milepost 1 to 3 of Pea Island
1993 - 2005***	= ~ 2.0 million cubic yds in 10 hopper dredge ops & deposited in the nearshore at milepost 1 to 3 of Pea Island
1983 - 1988**	= ~3.2 million cubic yds in 10 hopper dredge ops & deposited in the nearshore of milepost 1 to 3 of Pea Island
1996 - 1997**	= ~0.5 million cubic yds mined from fillet to build dune ridges at milepost 4 to 5 on Pea Island
1992 - 1993**	= ~0.2 million cubic yds mined from fillet to build dune ridges at milepost 4 to 5 on Pea Island
Total = ~12.7 million cubic yds	
Sources:	* Estimates from Pea Island Wildlife Refuge
	** NC Dept. of Transportation
	*** US Army Corps of Engineers

Much of the dredged material at Oregon Inlet sand comes from the channel region inside of the inlet where current velocities are reduced and finer grain sizes reside compared to the inlet proper. The backbarrier is generally a region of lower energy and thus, the grain sizes here are usually finer-grained than those found at nearby beaches. The finer grain size of the nourishment sand would be less stable than the native sand and would more easily erode, especially during storms. It should also be noted that nourishment projects calling for sand to be pumped into the nearshore are far less successful than projects placing sand directly onto the beach. The sand bar that is created in the nearshore zone is much less stable than sand put on a beach and can be easily transported down shore by wave energy, particularly during storms.

As discussed in an earlier section of this report, dredging Oregon Inlet affects the sand bypassing capabilities of the inlet and ebb-tidal delta system and very likely diminishes the natural (net) transfer of sand from Bodie Island to Pea Island. Dredging and deepening the main ebb channel create a natural sediment sink, whereby sand is deposited until the former equilibrium channel depth is reestablished. In some instances, dredging the main inlet channel into the backbarrier reduces tidal friction and produces larger tidal ranges in the backbarrier bays. This process will increase the inlet tidal prism, leading to a larger volume of sand sequestered on the ebb delta. Any enlargement of the ebb delta volume removes sand from the onshore barriers reservoirs. In addition, dredging the inlet channel into the backbarrier allows larger storm waves to propagate and transport sand onto flood delta and other intertidal and subtidal shoals.

A final impact of dredging involves bisecting the terminal lobe of ebb tidal delta (outer bar). Despite draining and filling large bays and sounds, Oregon Inlet is wave-dominated due to its micro-tidal range and relatively large wave energy. This type of inlet has a shallow bar that defines the seaward extent of the ebb-tidal delta. Breaking waves along this bar are responsible for transporting sand along the periphery of the delta in a continuous feeding sand to the downdrift barrier. This process is disrupted and sometimes completely terminated when a deep channel is dredged through the terminal lobe.

h. Hurricanes and Northeasters

A final major impact to the shoreline history of northern Pea Island is the occurrence and frequency of major storms. Although hurricanes are more intense in terms of storm surge and maximum wave height than northeast storms, they are relatively fast moving storms and commonly impact a shoreline for a shorter duration. Still, hurricanes are the agents of the greatest change, although a season with numerous extratropical storms may have a strong cumulative effect of causing extensive shoreline retreat. For example, on 18 September 2003, Hurricane Isabel (Category 2) tracked from the southern Atlantic and made landfall along the Outer Banks producing > 2-m high storm surge and wave heights > 12.1 m were measured at the Field Research Facility in Duck, North Carolina. The hurricane cause extensive erosion, overwash, and a new tidal inlet between Hatteras and Frisco, North Carolina, unofficially named Isabel Inlet. Between 1851 and 2008, 98 major storms have passed within 65 nautical miles of Nags Head, see Figure III-16, (located 12 nautical miles north of Pea Island) and three have made a direct landfall within 10 nautical miles. It is a reasonable assumption that the frequency and magnitude of intense storms have a major influence on the sedimentation history and especially the retreat of the barrier shoreline.

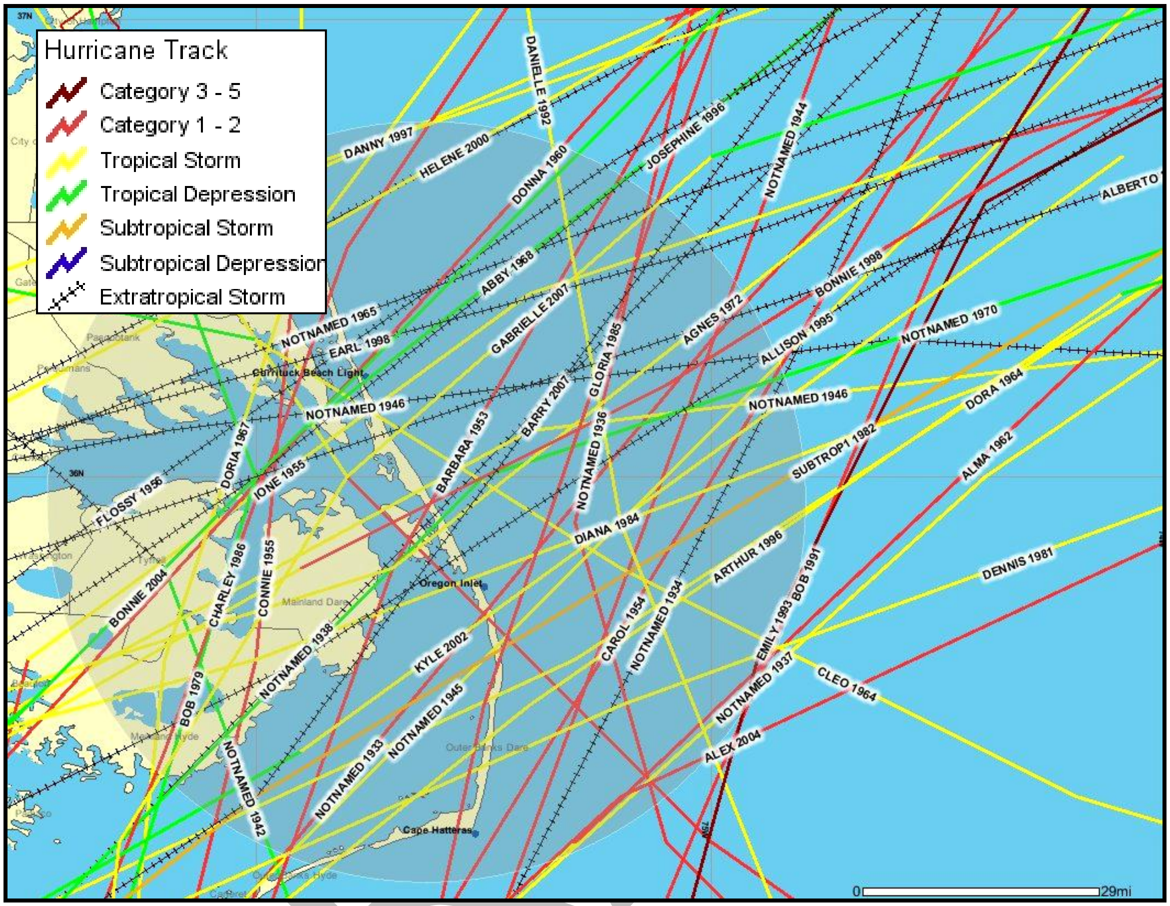


Figure III-16. Storm Tracks That Have Passed Within 65 Nautical Miles of Nags Head, NC

i. Summary

Northern Pea Island (PINWR) is impacted by numerous processes that have collectively led to an eroding barrier that is susceptible to overwash and possible future breaching. The key factors that have produced this state include: sequestration of sand at Bodie Island and Oregon Inlet, human impacts, and major storms. Construction of the terminal groin stabilized the northern end of Pea Island and prevented Oregon Inlet from migrating southward. Several data sets including historical aerial photograph and shoreline change maps (Figure III-10 - Figure III-13) demonstrate that the northern 1.5 miles of the beach have been stable since emplacement of the terminal groin. Wave refraction around the southern portion of the ebb-tidal delta produces a sediment transport reversal resulting in sand delivery to the northern end of the Pea Island. This northerly movement of sand is the primary process that replenishes the fillet groin following high wave energy erosional events. There is ample evidence showing that when the beach builds near the end of the groin, sand is transported around the groin building a narrow beach or entering the inlet channel.

The terminal groin contributes little to the long-term erosion of the PINWR shoreline south of the fillet region. The enduring retreat of this shoreline is due to a deficit of sediment delivered to the beach, despite a constant nourishment program. During periods of spit building at Bodie Island, the natural process of sand bypassing Oregon Inlet is drastically reduced. Instead of sand entering the inlet via longshore transport, the sand builds recurved ridges and extends the length of Bodie spit. Continuous dredging at the inlet creates sediment sinks, which further diminishes the volume of sand moving around the inlet. Moreover, it has been shown that much of the dredged sand used to nourish PINWR is finer-grainer than the native sand and is susceptible to storm erosion. A major storm impacts this part of coast on average once every year and half. The frequency and magnitude of storms likely have had a strong imprint on PINWR's shoreline history.

The most important impact of the terminal groin to PINWR has been its stabilization of Oregon Inlet. If the groin were not constructed, Oregon Inlet would have continued migrating south and lengthened Bodie Island at the expense of Pea Island (Bonner Bridge and navigation issues not considered in this scenario). Some sand would have been permanently lost to backbarrier during the inlet's southward march, lessening sand delivery to Pea Island.

2. Fort Macon

Beaufort Inlet is located west of Cape Lookout along the east-west oriented coast between Shakleford Banks on the east and Bogue Banks on the west. The earliest records of this region show the existence of Beaufort Inlet and adjacent barrier system since at least 1708 (USACE, 1970). Fort Macon, situated on the eastern tip of Bogue Banks, was constructed in the early 19th century and the fort, including 400 acres of land, was acquired by the state of North Carolina in 1926. Almost immediately after its construction, the fort was endangered by erosion and 11 groins were built to protect, which were continually reconstructed through 1908. During the 1953-1958 period, the groins were again reconstructed and 100,000 yd^3 of sand was placed between the groins. On the opposite of the Beaufort Inlet, several groins were built in 1882, to stabilize the western end of Shakleford Banks.

The terminal groin at Fort Macon, alternatively referred to as a jetty, is 1670 feet long and extends from Fort Macon Point seaward along a transect parallel to the inlet channel. Groin construction was begun in 1961 and by 1965 the seaward 1130 feet was completed to a 9-foot elevation. At that time, 92,800 yd^3 of sand was placed along the barrier between 1.3 and 0.5 miles west of the groin. In 1970, an addition 100,000 yd^3 of sand was added to the shore. It was reported that the newly constructed groin acted as a barrier to the easterly longshore transport of sand, but that some sand leaked through the groin and by 1968, sand was freely bypassing the structure. Presumably, this was because the beach had accreted to the end of the groin.

a. Physical Processes

Wave data derived from NOAA’s National Data Buoy Center and from USACE’s Wave Information Study show that the dominant waves come from the southerly quadrant with a slight southwesterly bias, having heights between 0.5 and 1.5 m, 70% of the time. There are no reliable net longshore transport rates for this section of coast, however, it has been estimated that sand moves in a westerly direction toward along Shackleford Banks and also toward the inlet along the eastern end of Bogue Banks. A nodal point exist west of the inlet where sand moves toward the west end of Bogue Banks. Long-term historical records documenting the inlet prior to stabilization demonstrate that the main channel migrated from a southwest to a southeast orientation, which is consistent with a bidirectional longshore transport system (Figure III-17). Beaufort Inlet experiences semidiurnal tides with a mean range of about of 1.0 m. This stretch of shore is particularly susceptible to storms that travel northward up the coast making a landfall west of Cape Lookout. From 1851 to 2008, 117 storms have passed within 65 nautical miles and nine hurricanes (tropical storms) have made landfall within 10 miles of Fort Macon (Figure III-18).

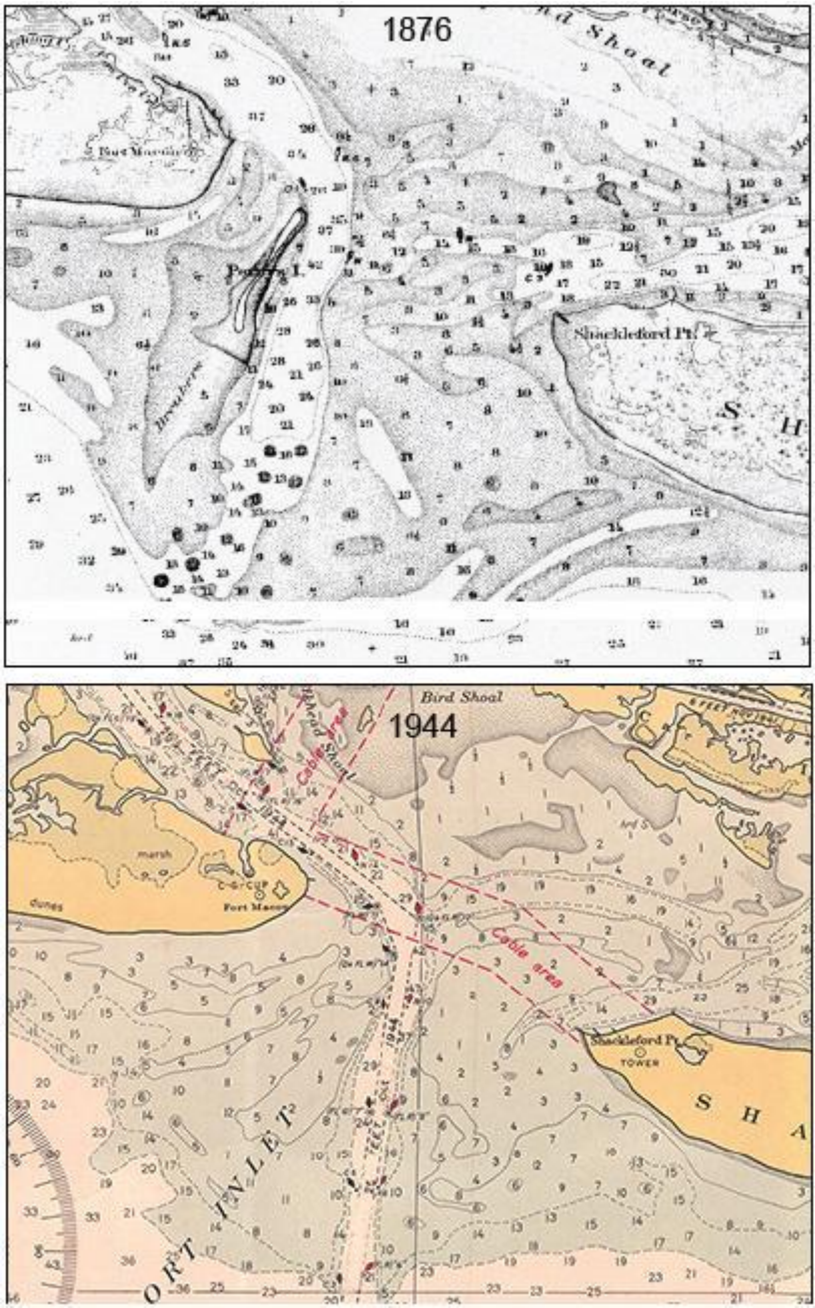


Figure III-17. Historical Coastal Charts of Beaufort Inlet in 1876 and 1994

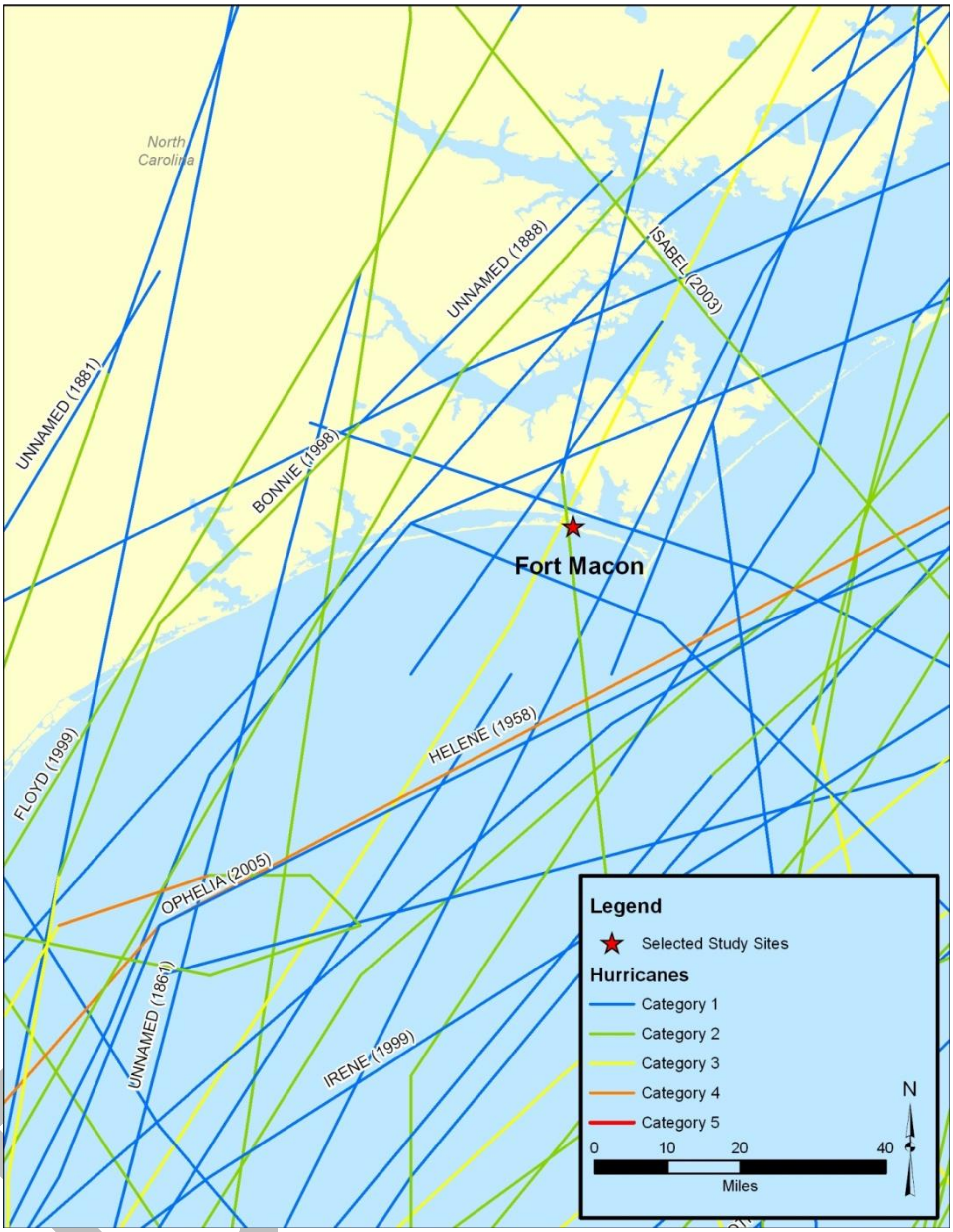


Figure III-18. Plot of Hurricanes in the Vicinity of Fort Macon between 1851 and 2008

b. Early Dredging Activity

The shifting nature of the inlet entrance and corresponding variable channel conditions resulted in dredging of the natural inlet channel to maintain a 20-foot navigation channel. By 1933, a Federal dredging project deepened the navigation channel to 30 feet (Figure III-19), which was deepened again to 35 feet by 1960.

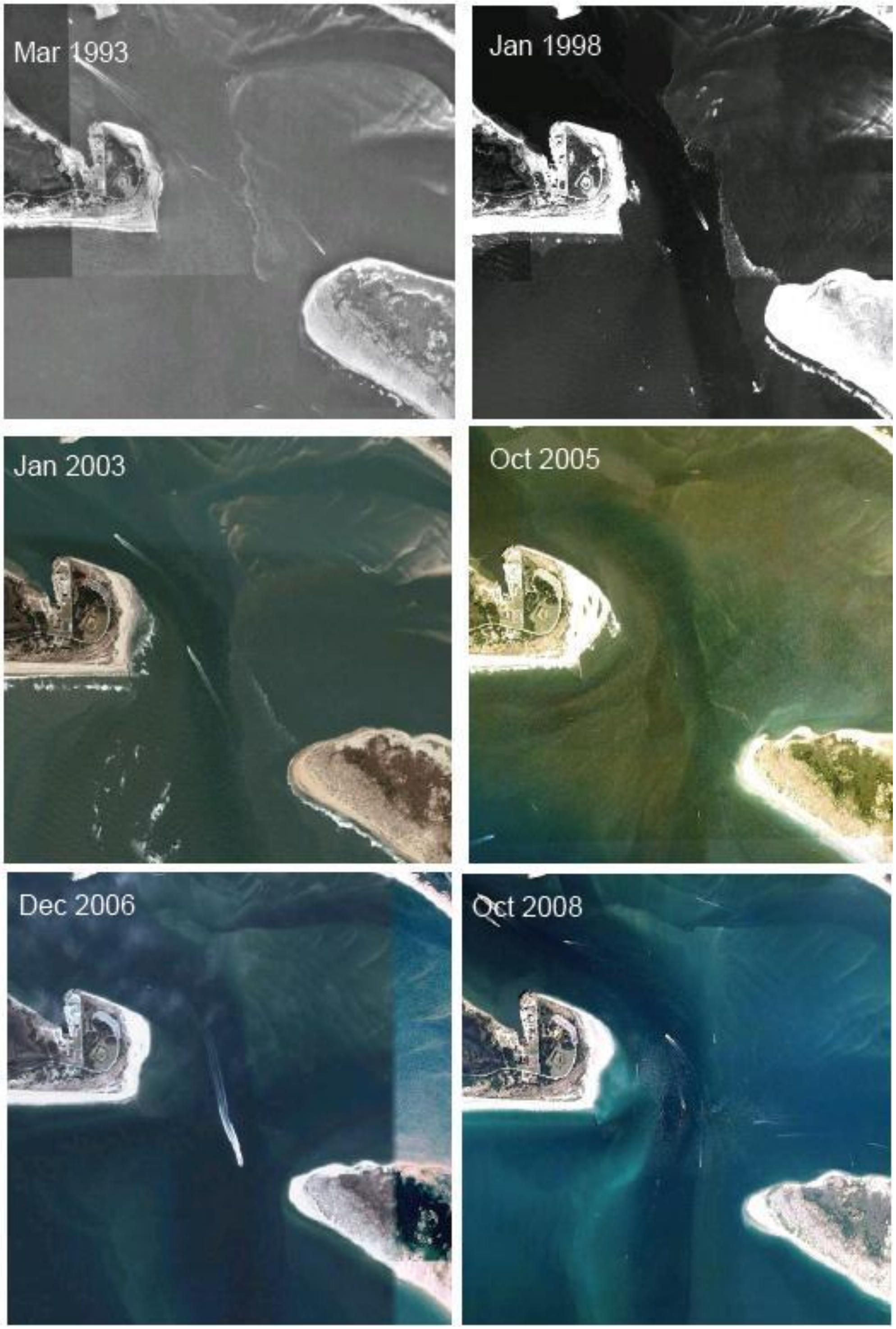


Figure III-19. Aerial Photographs Showing Shoreline Changes in the Vicinity of Fort Macon Terminal Groin. Note the shoreline progradation inside the inlet (2005) and west of the terminal groin (taken from Google Earth)

c. Sedimentation Trends

It is seen in the historical documentation that since building the groin in 1965, the shoreline has accreted to the end of the structure (Figure III-19). The groin was built to an elevation of approximately nine feet above mean low water and that despite this height, progradation of the beach to near the end of the groin has allowed sediment to be transported around the structure (Figure III-20). During storms and periods of high wave activity, it is likely that sand would have been transported over the structure toward the inlet as well. This process has led to the formation of a sizeable beach (width = 50 to 200 m) along the entire length of the inlet shoreline. Undoubtedly, this process continues to the present time, because as evidenced in October of 2008 (Figure III-19) the beach extends to near the end of the terminal groin and there is a robust beach adjacent to the inlet.

Figure III-20. Photographs Illustrating Progradation of the Beach West of the Groin and Along Inlet Shore. Dashed line indicates extent of groin beneath the beach

d. Historical Shoreline Trends

Shoreline changes within 6050 feet of the inlet and terminal groin are shown in a series of figures for the period between 1851 and 2004 (Figure III-21) and 1933 to 2004 (Figure III-22) (Cleary, 2009). The initial period of record (1851 to 1946) shows that the shoreline experience large-scale excursions, which was probably a result of shifts in the position of the main ebb channel and attendant configurational changes of the ebb-tidal delta (Wells and McNinch, 2001). The northern end of Bogue Banks was highly progradational from 1851 to 1933, but highly erosional between 1933 and 1946. This variable period of shoreline change was prior to emplacement of the terminal groin, but did span several dredging projects. More recent and more quantitative shoreline changes of northern Bogue Banks are shown in Figure III-22. These data were derived from shape-files downloaded from North Carolina Coastal Management Division and analyzed by Cleary (2009). The data exhibited in Figure III-22 are for six (near evenly spaced) stations that extend from the groin (T-1) to a position 6050 feet (T-6) west along beach. Shoreline change data for each of these stations are given for seven different time periods beginning in 1933 and ending in 2004.

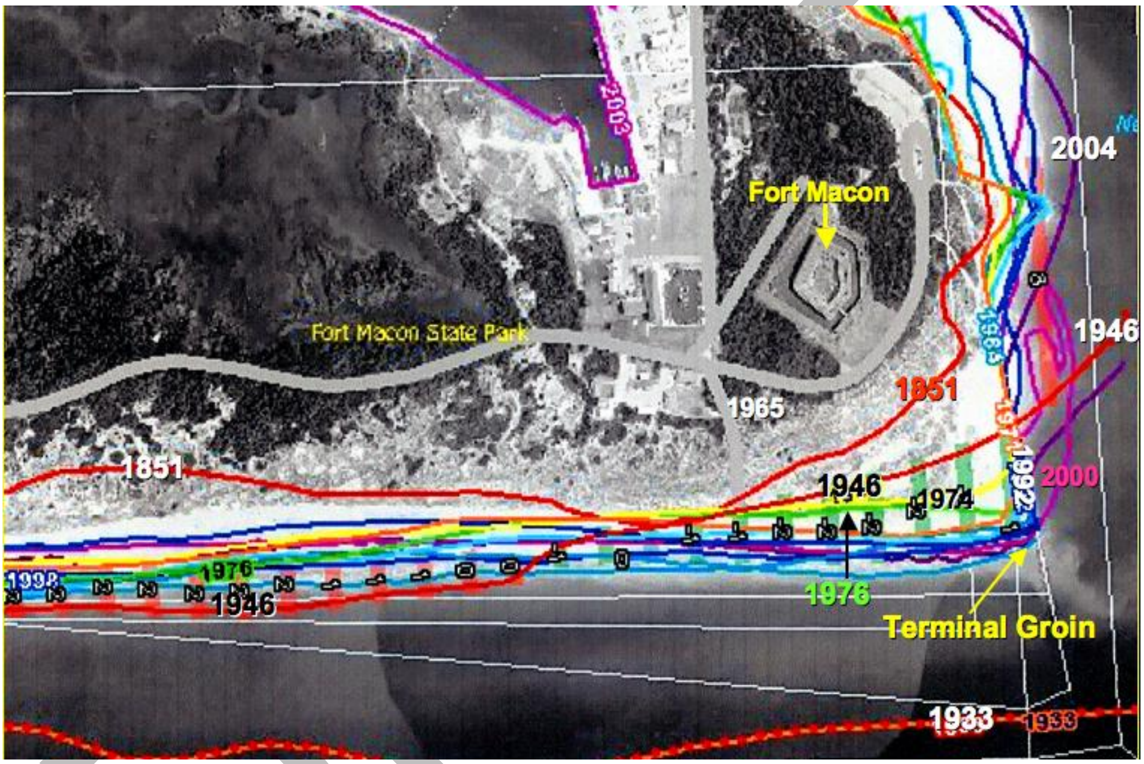


Figure III-21. Compilation of Historic Shorelines in the Vicinity of Fort Macon Terminal Groin (Cleary, 2009). Note the degree of shoreline progradation from 1851to 1933 followed by shoreline retreat from 1933 to 1946.

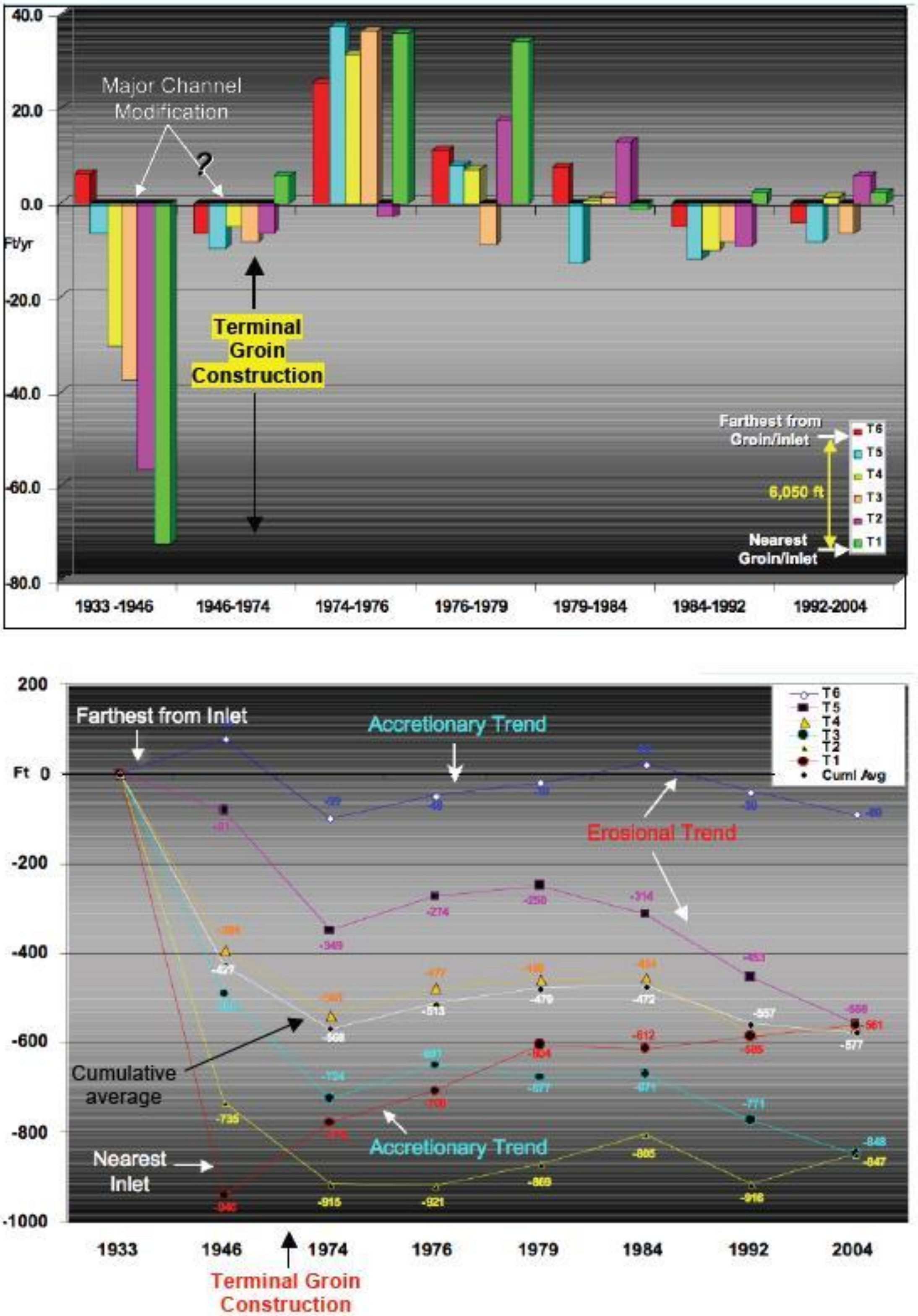


Figure III-22. Shoreline Change History for Northern Bogue Banks in the Vicinity of the Groin (Cleary, 2009)

For the first two time periods (1933-1946; 1946-1974), the six stations show very similar trends of erosion with two exceptions. Station #6, furthest from the inlet, experienced accretion between 1933 and 1946 and Station #1, closest to the terminal groin, was progradational between 1946 and 1974. It is of interest to note that during the 1933-1946 period the amount of erosion decreased away from the inlet. This erosional trend continued through the 1946-1974 period, excepting Station #1, which was depositional. For the 1974-1979 period all stations experienced progradation. During the 20 most recent years (1984-2004 period) all stations were erosional, again except for Station #1 next to the groin that accreted 51 feet. In fact, following a severe erosional period in which it eroded 940 feet during the 13 years from 1933 to 1946, Station #1 prograded 379 feet during the 1946-2004 period. Most of this accretion occurred following the construction of the terminal that was completed in 1965.

Other trends are also noteworthy, as they demonstrate shoreline patterns in relationship to the proximity of the terminal groin. For example, since the terminal lobe was built (period covering 1974-2004), Stations #1 and #2 have gained 217 (7.2 ft/yr) and 68 feet (3.2 ft/yr) of beach width, respectively. Two stations have retreated slightly (Stations #6 – 10 feet, 0.3 ft/yr; #4 -37, 1. ft/yr) and two stations have undergone greater degrees of erosion (Stations #5 -209, 7.0 ft/yr; #3 -124, 4.1 ft/yr). A final plot in Figure III-22 shows the cumulative shoreline change since 1965 (terminal groin construction). This plot uses the combined values of the six stations as a proxy for the entire 6050 feet of beach west of the groin. Between 1974 and 2004, there has been an average retreat of 11 feet or 0.4 ft/yr for the 30-year period. Prior to emplacement of the terminal groin (1933 to 1974 period), the shoreline segment lost an average of 568 feet or 13.9 ft/yr.

e. Dredging and Disposal History

Disposal of dredged materials in the ocean has been associated with the Morehead City Harbor Federal navigation project since 1910. Harbor improvements can be divided into: 1) dredging within inner harbor and 2) Beaufort Inlet ocean bar channels. Dredging in the inner harbor areas has been performed with a hydraulic cutterhead dredge with dredged material disposal being upland, on the beach or offshore. The entrance channel to the inlet is typically shallowest in the distal portion of ebb delta (sometimes called the outer bar) and this is the region that is most commonly dredged. Dredging of the outer channel has been done using a hopper dredge and disposed in the ocean. The entrance channel was gradually deepened from 20 to 30 feet and widened from 300 to 400 feet in 1933, and increased to 42 feet deep and 450 feet wide in 1978. In 1994, the bar channel was dredged to its present dimensions of 47 feet deep and 450 to 600 feet wide (USACE, 1997).

Since 1970, approximately 19.9 million cubic yards of dredged materials have been disposed of in the ocean off Beaufort Inlet (Table III-4). Between 1987 and 1996, approximately 7.9 million cubic yards of dredged materials from project channels was placed within the ODMDS. Between 1970 and 1996, the average annual volume of dredged material placed in the ocean was about 0.7 million cubic yards.

Beginning in 1995, some of the sediment removed during maintenance dredging of the Morehead City navigation channels was placed in a nearshore disposal area off Bogue Banks on the west side of the ebb delta along the 25 foot contour (Figure III-23). The purpose of the nearshore disposal site was to provide sand to the nearshore and ebb-tidal delta. The ebb delta at Beaufort Inlet was decreasing in volume and to counteract this trend, sediment was placed along the periphery of the delta to feed sand into the shallower portion of the delta. In 1995, of the 815,000 cubic yards of sediment dredged at the inlet and from the Morehead navigational channels, 173,000 cubic yards were placed in the nearshore disposal area while the rest (642,000 cubic yards) was placed in the ODMDS. In 1996, all of the sediment (657,000 cubic yards) that was dredged from the navigation channels was placed in the nearshore disposal site. Initial bathymetric surveys and modeling studies performed in 1997 showed that the 25-foot depth contour may be too deep for shoaling waves to transport the sand onshore. Disposing of the sediment into shallower would require different equipment and would be far more costly (EPA & USACE, 1997).

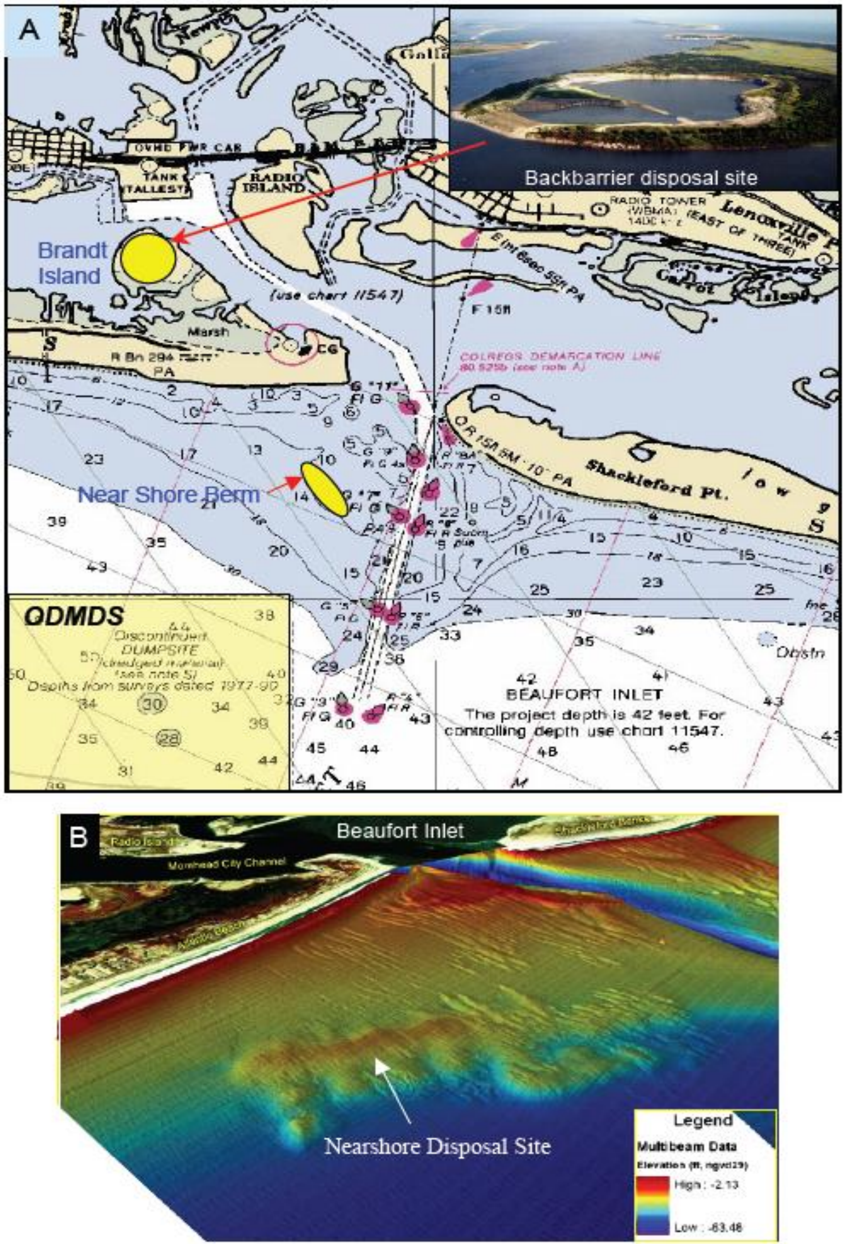
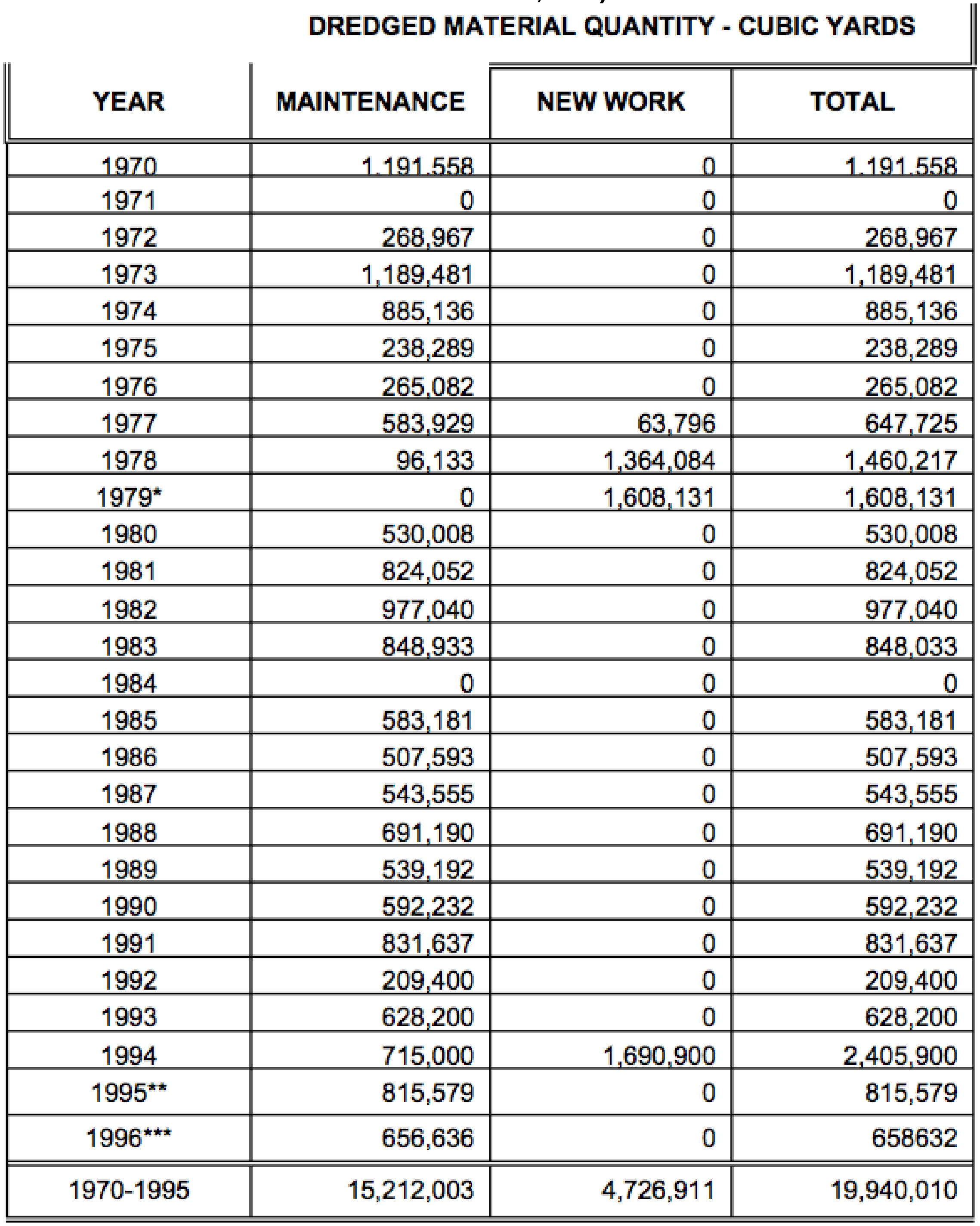


Figure III-23. A. Dredge Disposal Sites Used in Maintaining Navigation Channels for Morehead City and Beaufort Inlet. B. DEM Showing Build-up of Sand at Nearshore Site

Table III-4. Compilation of Dredging Data for Morehead City Navigational Channels (from EPA & USACE, 1997)



	DREDGED MATERIAL QUANTITY - CUBIC YARDS		
YEAR	MAINTENANCE	NEW WORK	TOTAL
1970	1,191,558	0	1,191,558
1971	0	0	0
1972	268,967	0	268,967
1973	1,189,481	0	1,189,481
1974	885,136	0	885,136
1975	238,289	0	238,289
1976	265,082	0	265,082
1977	583,929	63,796	647,725
1978	96,133	1,364,084	1,460,217
1979*	0	1,608,131	1,608,131
1980	530,008	0	530,008
1981	824,052	0	824,052
1982	977,040	0	977,040
1983	848,933	0	848,033
1984	0	0	0
1985	583,181	0	583,181
1986	507,593	0	507,593
1987	543,555	0	543,555
1988	691,190	0	691,190
1989	539,192	0	539,192
1990	592,232	0	592,232
1991	831,637	0	831,637
1992	209,400	0	209,400
1993	628,200	0	628,200
1994	715,000	1,690,900	2,405,900
1995**	815,579	0	815,579
1996***	656,636	0	658632
1970-1995	15,212,003	4,726,911	19,940,010

f. Dredging and Ebb-tidal Delta Changes

Progressively dredging Beaufort Inlet to deeper and deeper depths has had several major consequences to the tidal inlet, ebb-tidal delta, and adjacent shorelines. As chronicled above, the main channel has been dredged since 1933 from an initial depth of 20-30 feet to the present control depth of 45 feet along with a substantial widening of the channel (Figure III-24). One of the primary and far-reaching results of the dredging has been a decrease in the frictional resistance of tidal flow into and out the tidal inlet. The larger channel dimensions have produced increased tidal exchange between the ocean and the backbarrier system, resulting in a larger equilibrium inlet cross-sectional area. Using empirical data, Olsen and Associates (2006) have estimated that since dredging began in 1933 to 2004 the cross sectional of the inlet throat increased by 1.3 to 1.7 times, which was due to the increasing tidal prism.

The larger tidal prism also creates a greater equilibrium sized ebb-tidal delta. This condition has led to an ebb delta that would increase in volume, if sand were abundant. However, just the opposite is true; high rates of dredging are depleting the delta of sand. Since 1933, its has been estimated that ebb-tidal delta has lost 26.6 million cubic yards of sediment. During this interval, sedimentation trends on the west side of the ebb delta changed from a gain of +265,500 cy/yr prior to dredging to an average loss of -304,200 cy/yr from 1933 to 2004. The east side lost far less sand; prior to dredging it was losing about -32,700 cy/yr and since that time the loss increased to -70,700 cy/yr (Olsen and Associates, 2004). The main ebb channel is being dredged far beyond the dimensions necessary to convey its tidal flow. This situation explains why the channel has become a sand sink and why it must be continuously dredged to maintain the 45-foot navigation channel. The sand removed from the channel during dredging and placed beyond wave base (i.e. ODMDS), or at some other site where it is stable or transported away from the inlet, represents a permanent loss of sand from the system. It is reasonable to believe that the gradual decrease in volume of the ebb-tidal delta since 1933 (26.6 million cubic yards) is due to a mass balance deficit. More sand was removed from the delta through dredging than was delivered to the delta via longshore transport along both barrier shorelines.

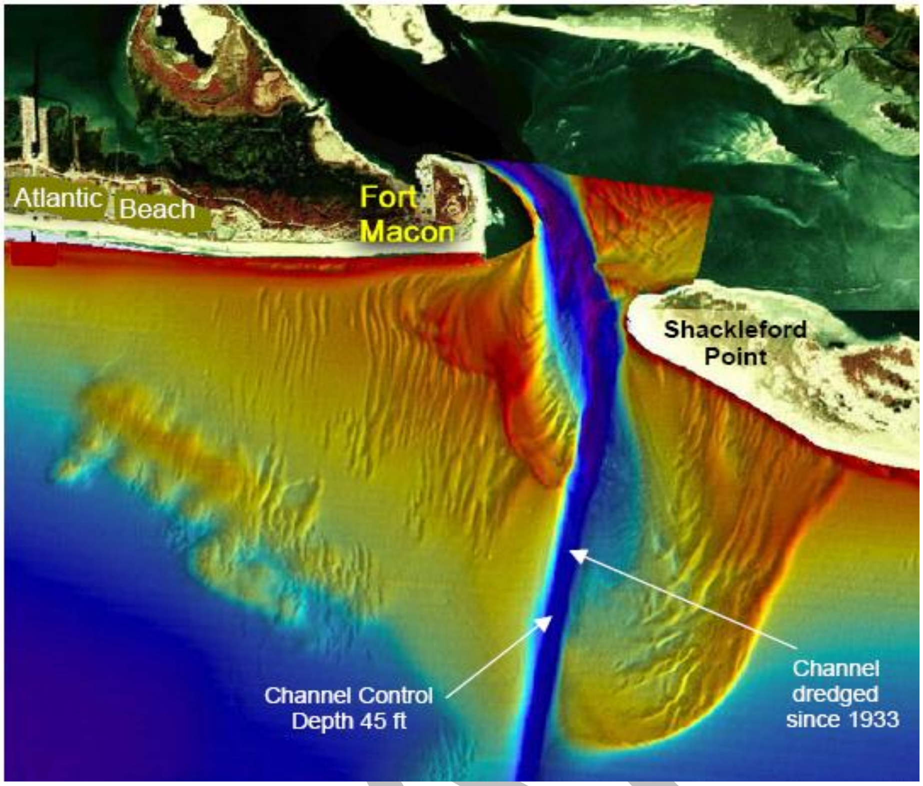


Figure III-24. Digital Elevation Model Illustrating the Relief of the Ebb-tidal Delta. Note that the main channel has been dredged since 1933 and is presently maintained to a depth of 45 feet.

Moreover, increased ebb tidal flow issuing from Beaufort Inlet has extended the delta further offshore into deeper water and changed the planform of the delta. The inlet is tide-dominated and ebb current velocities (spring tides, velocity = 2.0 m/s) are about twice as strong as flood currents (spring tides, velocity = 1.0 m/s) (Seim, 2002). This strong ebb current asymmetry in combination with the long-term increase in tidal prism has led to the gradual transport of sand offshore, elongating the delta and extending the terminal lobe (outer bar) into deeper water. A comparison of tidal inlet shoreline and ebb-tidal delta bathymetry are presented in Figure III-25. In 1900, the inlet was relatively wide (compared to today), the ebb delta was symmetrically disposed along the Shackleford Banks and Bogue Banks shorelines, and the terminal lobe was defined by the 15-foot contour. The 2004 map, which depicts conditions following a long period of channel dredging, shows an inlet that is very different compared to the 1900 map. By 2004, most of the ebb delta fronts Bogue Banks, the inlet has narrowed, primarily due to spit extension from Shackleford Banks, and the terminal lobe is now defined by the 40-foot contour. Most importantly, the delta has been cut into two separate halves by the 45-foot dredged channel (Figure III-24 and Figure III-25).

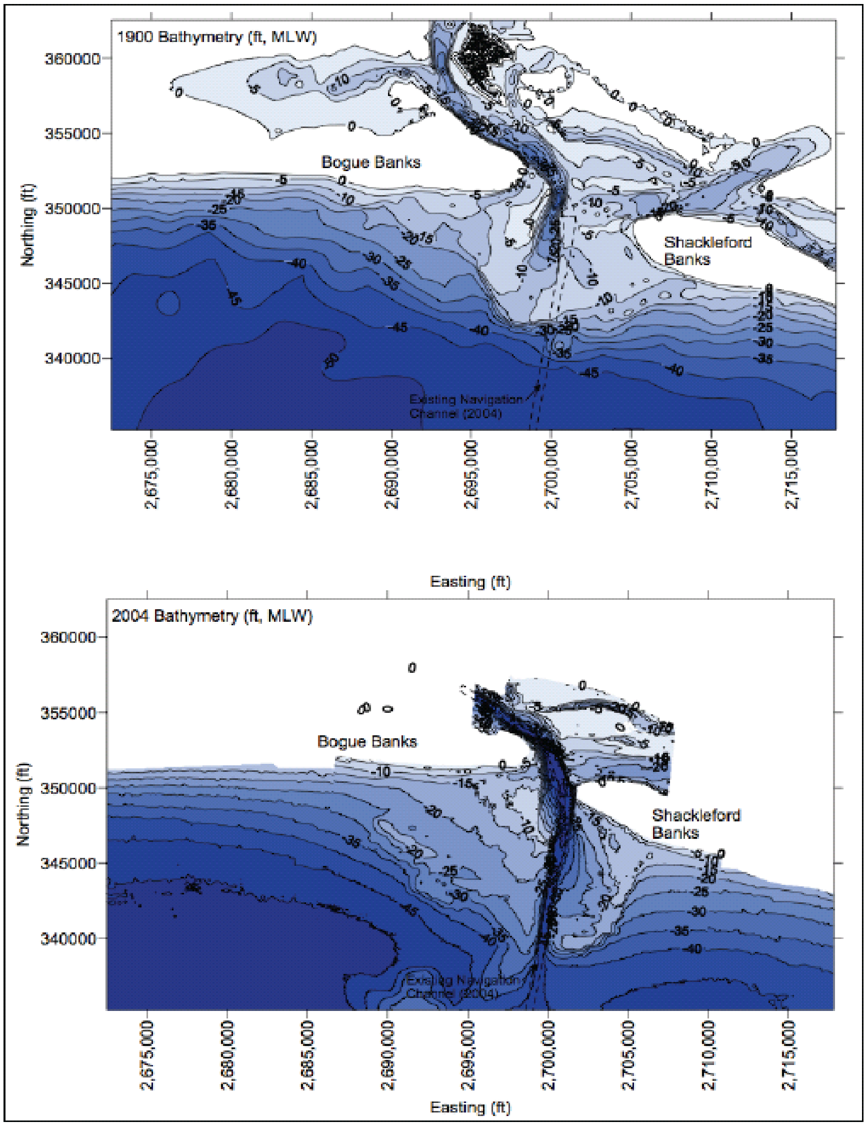


Figure III-25. Comparison of Bathymetry between ca. 1900 and 2004 (Olsen, 2004)

The incision through the middle of the terminal lobe has significantly disrupted the processes of inlet sediment bypassing, whereby sand moves from one side of the inlet to the other side. This transferal process involves moving the sand that is delivered to the inlet and main ebb channel via longshore transport, to the terminal lobe. Here, flood tidal and wave-induced currents move some of this sand along the periphery of the delta toward the downdrift shoreline. Shoaling and breaking waves also transport sand directly across the swash platform to the onshore beach, sometimes in the form of landward migrating swash bars. The terminal lobe (outer bar) is the bridge between the two halves of the ebb delta on either side of the main ebb channel. The 45-foot navigation channel has severed the terminal lobe and truncated the inlet sediment bypassing process.

The long-term loss of sand to the ebb delta (26.6 million cubic yards; Olsen and Associates, 2006) has steepened the overall gradient of the swash platform. Note in

Figure III-25 that the between 1900 and 2004 the 15-foot contour significantly migrated onshore on both sides of the main channel. The steepening of the gradient of the swash platform reduces the ability of the delta to attenuate wave energy, particularly during storms. Prior to 1900, large storm waves broke along the periphery of the ebb delta, reformed with smaller heights and less energy, and eventually broke again along the inlet shoreline. The 2004 bathymetric map (Figure III-25) indicates that the ebb delta affords far less protection for the inlet shoreline during storms than it had in 1900.

g. Summary

Construction of the terminal groin between 1961 and 1965 at the very northern end of Bogue Banks at Beaufort Inlet has protected the Fort Macon area from erosion and possible dismantlement during major storms that impact this region frequently. The groin has also stabilized the northern end of Bogue Banks that had previously had a history of westerly retreat (1851) and easterly progradation (1933) (Figure III-21). Through beach nourishment and natural processes the shoreline immediately adjacent to the terminal groin prograded seaward to near the end of the structure by the late 1970's. Six monitoring stations extending 6050 feet west of the terminal groin all exhibited accretion between 1974 (first survey after groin construction) and 1979. After 1979, some of the stations underwent erosion and others experienced net accretion, but their cumulative trend has been one of very slight accretion (9 feet, Figure III-22).

Vertical aerial photographs of northern Bogue Banks show that the beach has maintained a position near the end of the terminal groin since 1993 and that sand has been moving eastward around and over the groin, building a beach along the inlet shoreline. These photographs demonstrate that once the fillet had filled with sand, the groin no longer impeded the flow of sand into the inlet.

Dredging in the backbarrier of Beaufort Inlet (Morehead City navigation channels) and the main ebb channel through the ebb delta, which includes the terminal lobe (Engineers call the "outer bar"), has significantly changed the morphology and sedimentation processes of the ebb-tidal delta. Deepening and widening of the inlet channel decreased flow resistance, which increased tidal exchange between the ocean and backbarrier and ultimately the inlet tidal prism. Dredging in the backbarrier creates a sediment sink, which coupled with increased flood tidal flow into the backbarrier results in a siphoning of sediment from the inlet and the need for a continuous maintenance program. Likewise, dredging of a 45-foot navigation channel through the inlet has produced a sand sink in main channel of the ebb delta, a permanent incision of the ebb delta and terminal lobe, and a complete disruption of the natural processes of inlet sediment bypassing.

Long-term dredging of the inlet at a rate several times the sand delivery via longshore transport has depleted the ebb delta of 26.6 million cubic meters of sand since 1933. In turn, the ebb delta has steepened as evidenced by the landward migration of the 15 and 10-foot contours between 1933 and 2004 (Figure III-25). Collectively, the impacts of dredging have created a sediment sink at the delta that draws sand away from the adjacent shorelines and toward the inlet. Additionally, the steeper gradient of the delta, due to the loss of sand and increased tidal prism, has resulted in less attenuation of wave energy during storms and more susceptibility of shoreline erosion. The nearshore disposal site, used since 1995, appears to be in too deep of water for waves and flood currents to move sand onshore.

Erosional and depositional processes along the shorelines east and west of Beaufort Inlet will continue to be primarily affected by hurricane impacts and dredging activities.

3. Florida Inlets

This section of the report deals with terminal groins along the Florida Gulf Coast, including sites at both sides of John's Pass and at the north end of Captiva Island, and one site along Florida's northern Atlantic Coast at the southern end of Amelia Island (Figure III-26). The Florida Gulf Coast is a low energy environment having relatively small waves and a microtidal range and thus, morphological changes and net sedimentation trends are largely a product of infrequent major storms. For example, John's Pass was formed during an 1848 hurricane, and hurricanes and tropical storms account for the greatest degree of morphological change and shoreline erosion along these shores. Thus, the influence of terminal groins on sedimentation processes on the nearby barrier shorelines at the three study sites is complicated due to hurricane impacts, the presence of other coastal structures, and the common practice of beach nourishment.

a. Physical Environment

The Gulf Coast experiences deepwater waves between 0.5 and 1.0 m more than 40% of the time and waves greater than 2 m less than 5% of the time. The spring tidal range in the Gulf study areas is 0.84 m. In northern Florida on the Atlantic coast, deepwater waves are between 0.5 to 1.0 m about 50% of the time and 2-m waves occur less than 5% of the time. The average mean and spring ranges for Amelia Island are approximately 1.6 m and 1.8 m, respectively. Between 1851 and 2008, 65 hurricanes and tropical storms has impacted the Gulf Coast sites and 83 have hit the Amelia Island site, but very few of these have made a direct landfall near the sites (4 for Amelia and Captiva Islands and 2 for John's Pass).

Figure III-26. Location of Terminal Groin Study Sites in Florida

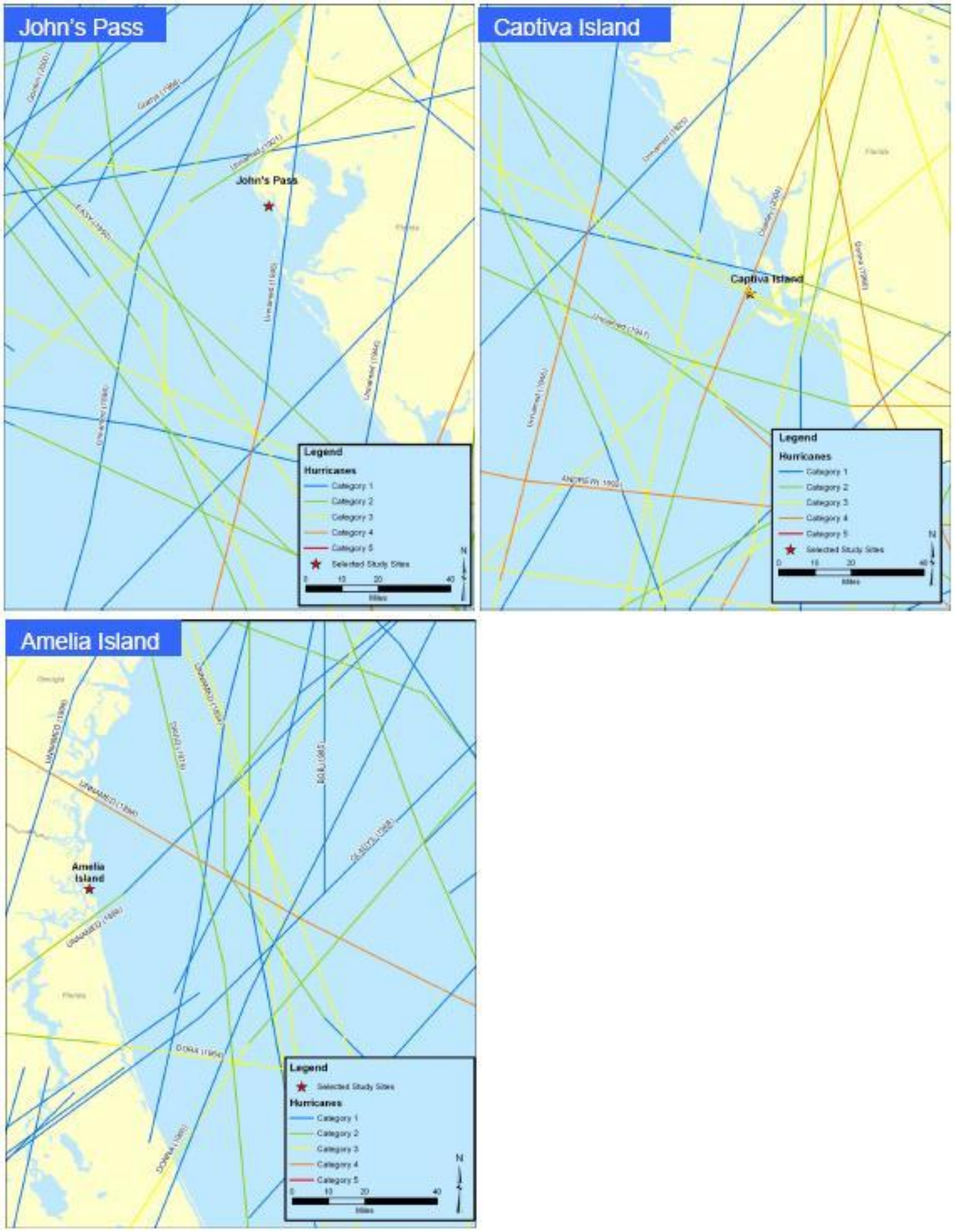


Figure III-27. Hurricane Tracks for the Three Study Sites (NOAA Databases)

Although all three sites have been frequented by numerous hurricanes and tropical storms, there have been very few hurricanes that make landfall at these sites. Therefore, large storm surges and extreme wave energy are uncommon. Still, historically hurricanes have had a major imprint on these shores resulting in major washover events, barrier breaching and tidal inlet formation, and significant erosional impacts.

b. Amelia Island

Amelia Island is one of the sea islands comprising the Georgia Bight barrier island chain. These islands are wide and long and composed of a system of tightly spaced beach-ridge systems, representing former shoreline positions. The barriers abut deep, large tidal inlets referred to as sounds and separated from the mainland by expansive marshes and tidal channels. The recurved ridges at the southern end of Amelia Island indicate the barrier has had a long history of southerly progradation and that the net longshore sand transport direction is to the south. The entire southern half-mile of the island comprises the George Crady Bridge Fishing Pier State Park. This area contains one very large terminal groin that extends onto the spit platform of Nassau Sound and a second smaller structure that was built just north of the George Crady Bridge at the south end of Amelia Island.

The long-term erosion rate along the southern end of Amelia Island averages almost 5 m/yr (Byrnes and Hiland, 1995) and more recent data indicate that the shoreline has retreated more than 300 m since 1957 (Olsen and Bodge, 2006). From 1964 to 2001, numerous measures were undertaken to combat the erosion including the placement of millions of cubic meters of sand for beach nourishment and the construction of groins. Finally, in 2002 a comprehensive beach management plan was implemented. Phase 1 consisted of the placement of 1.6 million cubic meters of sand along the southern beach. Some of this sand was transported by waves to the end of the island providing a spit platform upon which three engineering structures were constructed (Figure III-28). Phase 2 consisted of:

1. A 93-m long offshore breakwater constructed at the "hinge point" of the ocean-facing beach where concentrated shoreline erosion was occurring.
2. A 465-m long rock-mound terminal groin anchored in the supratidal zone was built approximately 760 m south of the breakwater.
3. A 40-m long terminal groin constructed along the backside of the barrier.

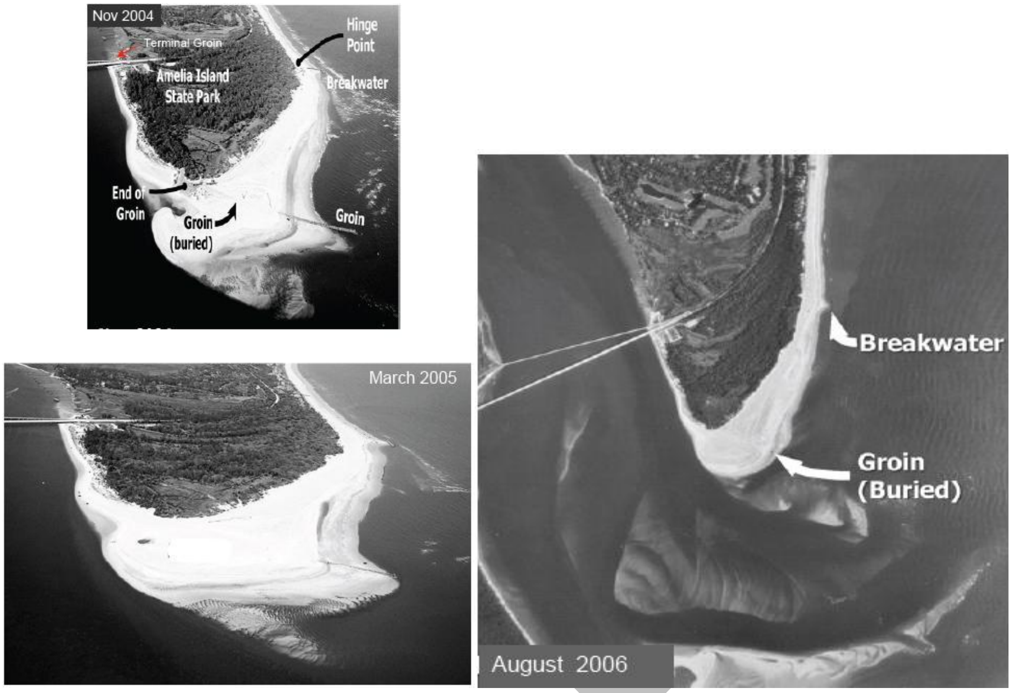


Figure III-28. Oblique Aerial Photographs of the Southern End of Amelia Island Illustrating the Results of the Beach Nourishment and Emplacement of Coastal Structures (Olsen and Bodge, 2006)

Figure III-29. Photgraphs Showing Before and After the Construction of the Backside Terminal Groin (Olsen, 2008)

The terminal groin at the southern end of Amelia Island was built to reduce the loss of sand from a 5.6 km updrift beach restoration project without adversely affecting the sediment transport required to maintain the downdrift, inlet-facing shoreline. The structure was designed to be leaky and allow sand to move over and around the structure during the passage of northeast storms. The second, much smaller rock groin was built just north of bridge to prevent large volumes of sand from moving freely into the backbarrier marsh system and to provide protection to the bridge and other Park infrastructure. It was built to trap sand (unleaky), but since the groin does not extend completely across the intertidal beach, some sand continues to bypass the seaward terminus of the structure.

During the summer of 2006, an additional 230-300,000 cubic meters of sand was placed between the breakwater and terminal groin by the USACE (Jacksonville District). The sand was sourced from maintenance dredging in the nearby Nassau Sound segment of the Intracoastal Waterway west of the bridge. Various stages during the construction of the three structures and results of the beach nourishment are presented in Figure III-28 and Figure III-29. By November 2004, the detached breakwater and long terminal groin were in place and the beach was responding to wave processes. Note that south of the breakwater reformed waves were breaking at a high angle to the beach transporting sand southward. The beach is scalloped on the updrift side of the groin, but sand is actively being transport past the leaky groin as evidenced by the bulge in beach immediately west of the groin and the spit-like feature building into the backbarrier. By March 2005 more sand had in-filled the shoreline around the groin, but the updrift beach appeared to have retreated slightly. By August 2006, after completion of the second nourishment project, the beach appeared robust and the groin is mostly buried with sand.

As shown in Figure III-29, the small terminal groin has impounded sand since its construction and has stabilized the shorefront seaward of the fishing pier and bridge. By 2008, sand is moving past the groin as evidenced by the northerly deflection of the tidal creek extending from the backside marsh and into the adjacent sound.

A sequential set of vertical aerial photographs depicting conditions at the end of Amelia Island is presented in Figure III-30 for the period between 1994 and 2008. Several points of interest can be gleaned from these photographs:

1. Continuous retreat of the vegetated dune and back-dunal areas along the ocean facing beach and backside of the southern barrier.

2. Parking lot and bridge construction between 1994 and 1999.

3. Extensive progradation of the beach along the southern tip of the island following completion of groin construction and beach nourishment.

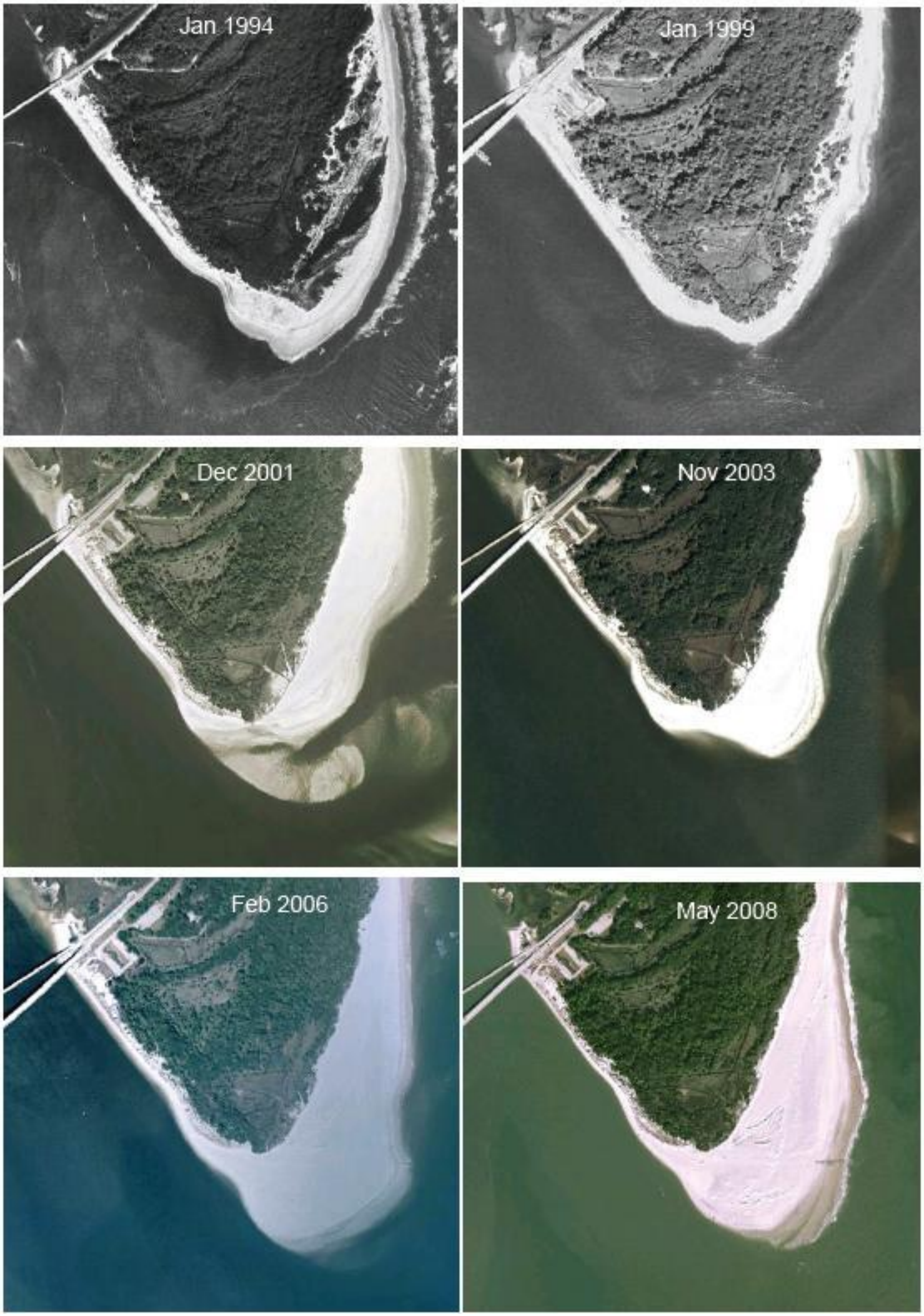


Figure III-30. Sequential Vertical Aerial Photographs of Amelia Island between 1994 and 2008 (from Google Earth)

The shoreline changes to the end of Amelia Island and bathymetric changes to the Nassau Sound have been quantified by Olsen and Associates (2008) and are presented in Figure III-31 - Figure III-33. Figure III-31 provides a visual depiction of the shoreline changes and Figure III-32 presents the actual values of retreat and progradation of the beach for 27 profiles along the study area. As seen in Figure III-31, there is widespread variability both spatially and temporally in the amount and direction of shoreline change. However, some general trends can be discerned from the data. After the major nourishment project was completed in 2002, the southern tip of the island underwent net progradation (until at least 2008), Contrastingly, after the initial sand nourishment, the ocean-facing beach eroded although there was progradation following the 2006 summer nourishment project. The backside of the island has been the most stable and undergone the least amount of change compared to the entire project area.

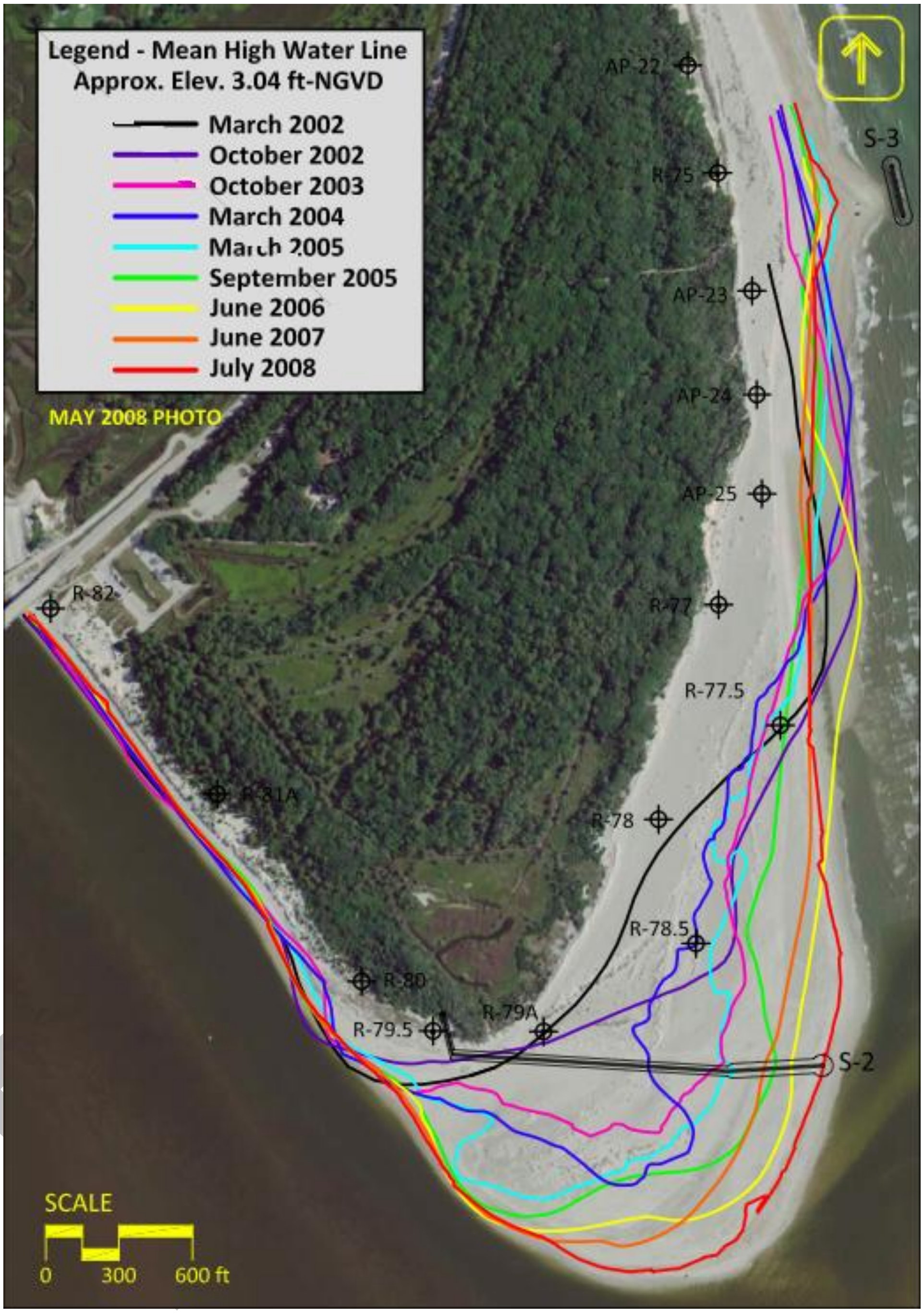


Figure III-31. Shoreline Changes on Southern Amelia Island between 2002 and 2008
Note that the southern tip of the barrier prograded to the south. This extension of the spit was facilitated, in part, from sand eroded from the beach directly north and transported south. (Olsen, 2008)

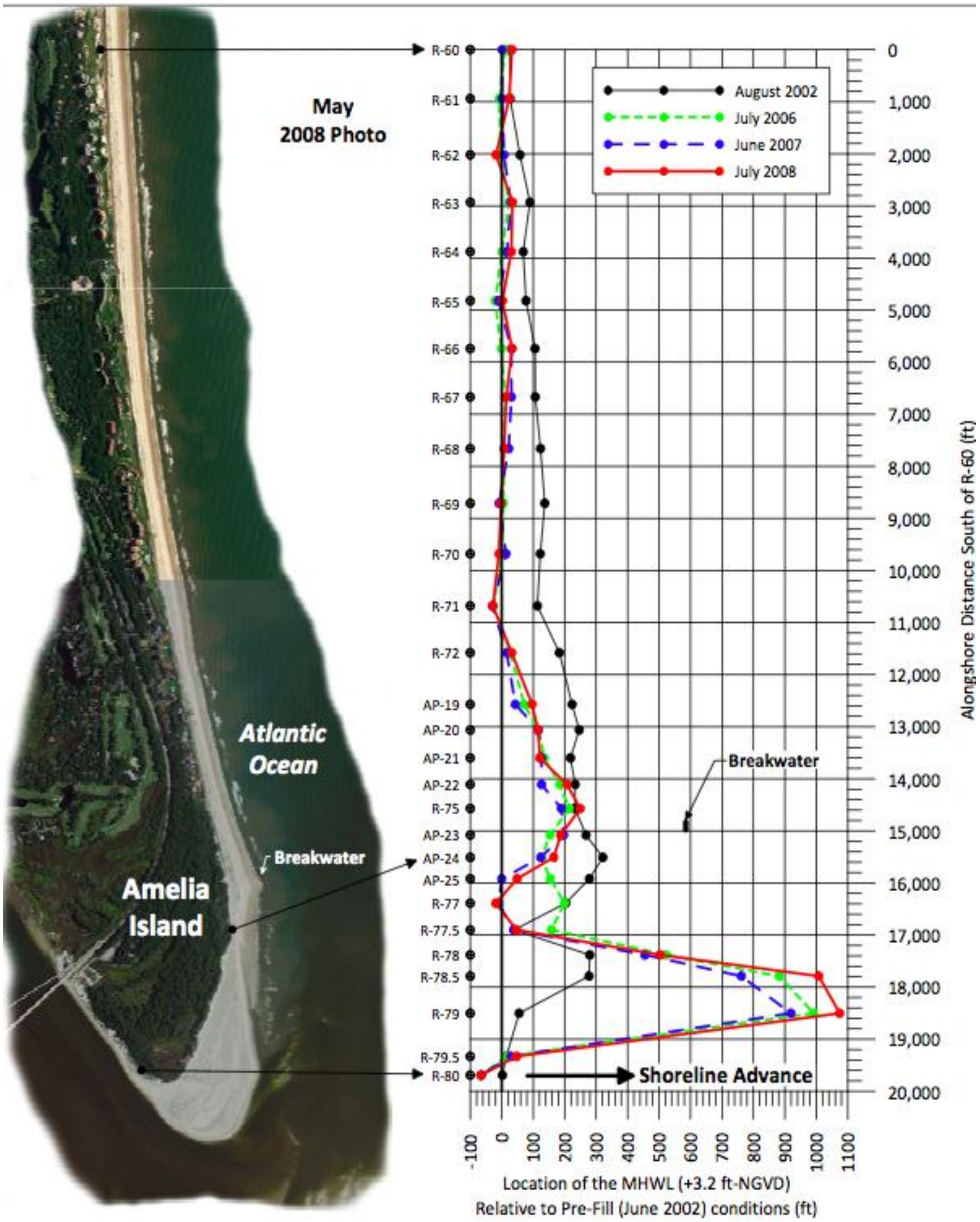


Figure III-32. Quantitative Shoreline Trends of Southern Amelia Island (Olsen, 2008)

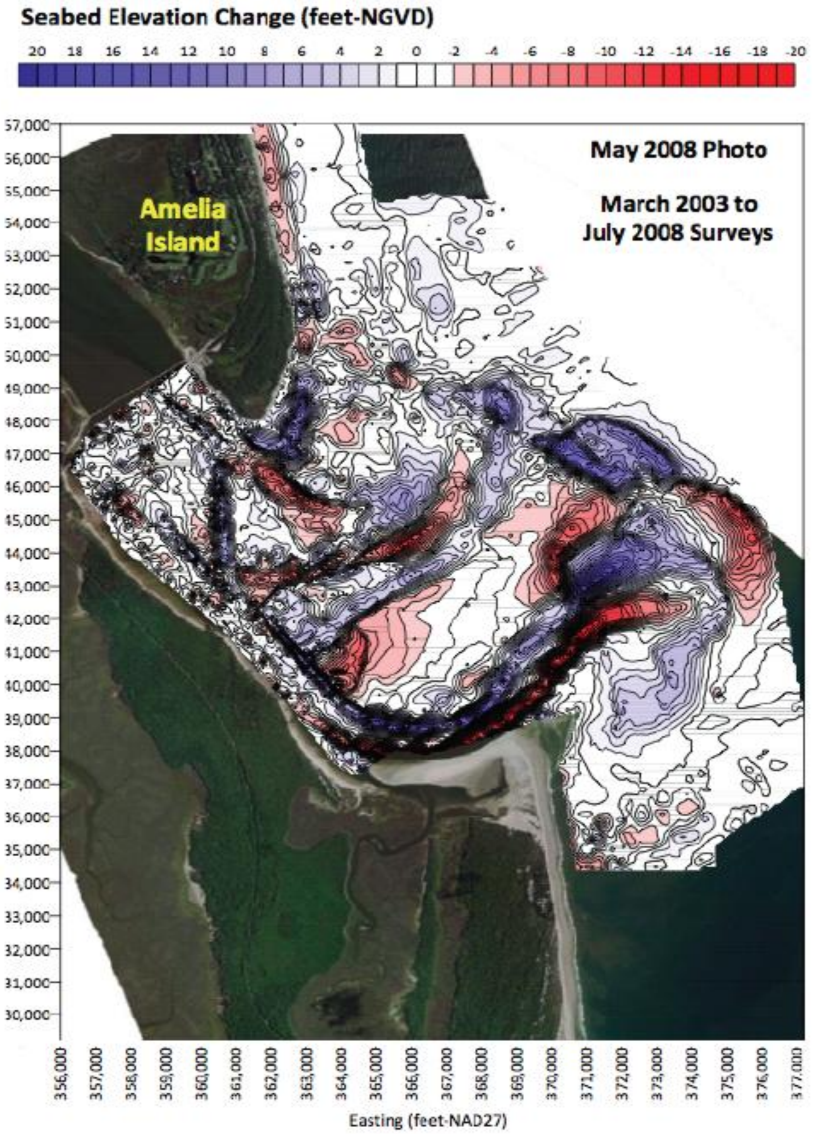


Figure III-33. Bathymetric Changes of Nassau Sound Determined from Repetitive Bathymetric Surveys from 2003 - 2008 (Olsen, 2008)

Figure III-32 demonstrates the entire shoreline north of the breakwater eroded after 2002, but the amount of erosion lessened to the north. The largest amount of shoreline progradation occurred near the terminal groin where there was almost 320 m of beach added to the shore. The greatest amount of erosion has occurred south of the breakwater where the shoreline has retreated 40 to 60 m. The detached breakwater is impounding sand that otherwise would be transported southward.

Figure III-33 is a bathymetric difference map of Nassua Sound indicating red for erosion and blue for deposition (from Olsen and Associates, 2008) for the period between 2003 and 2008. The figure suggests that the major nourishment projects have not only produced accretion along the Amelia Island beaches, but some of this sand has been reworked by waves and delivered to Nassau Sound. This tidal inlet is composed of a series of deep channels separated by shallow interfluves. The increase in sand delivery to the inlet from Amelia Island during the project period has caused deposition within the interfluves forcing a southerly migration of the channels.

c. Captiva Island

Captiva Island is situated along Florida's southernmost barrier chains and flanked by Redfish Pass at its northern end and the intermittently-opened Blind Pass at its southern end. Redfish Pass was opened during a 1921 hurricane connecting Pine Island Sound to the Gulf of Mexico. The hurricane that opened Blind Pass separated Captiva from Sanibel Island to the south. The opening of Redfish Pass captured a significant portion of the tidal prism of Blind Pass and consequently it has had a history of periodic closure. The inlet permanently closed in 2000 except for a brief opening by Hurricane Charley in 2004. It was dredged open in 2009.

Captiva Island is an 8-km long barrier that had been categorized as a "critically eroding beach" by the Florida Department of Environmental Protection's Bureau of Beaches and Coastal Systems (FL-EPA 2008). Redfish Pass is approximately 220 m wide and has well-developed ebb and flood tidal deltas (Figure III-34).

In response to the long-term erosion problems along Captiva Island, construction of a terminal groin at the north end of the island, adjacent to Redfish Pass, was begun in 1977 and completed in 1981 (Figure III-35). The ebb-tidal delta of Redfish Pass was dredged to nourish Captiva Island in 1981, 1988 and 1989 (Table III-5). During the summer of 2006, the groin at the northern end of Captiva Island was extended 100 feet seaward for the purpose of capturing more the sand that otherwise would be moving northward into Redfish Pass. The island was nourished again in 1996 using sand from an offshore borrow area.

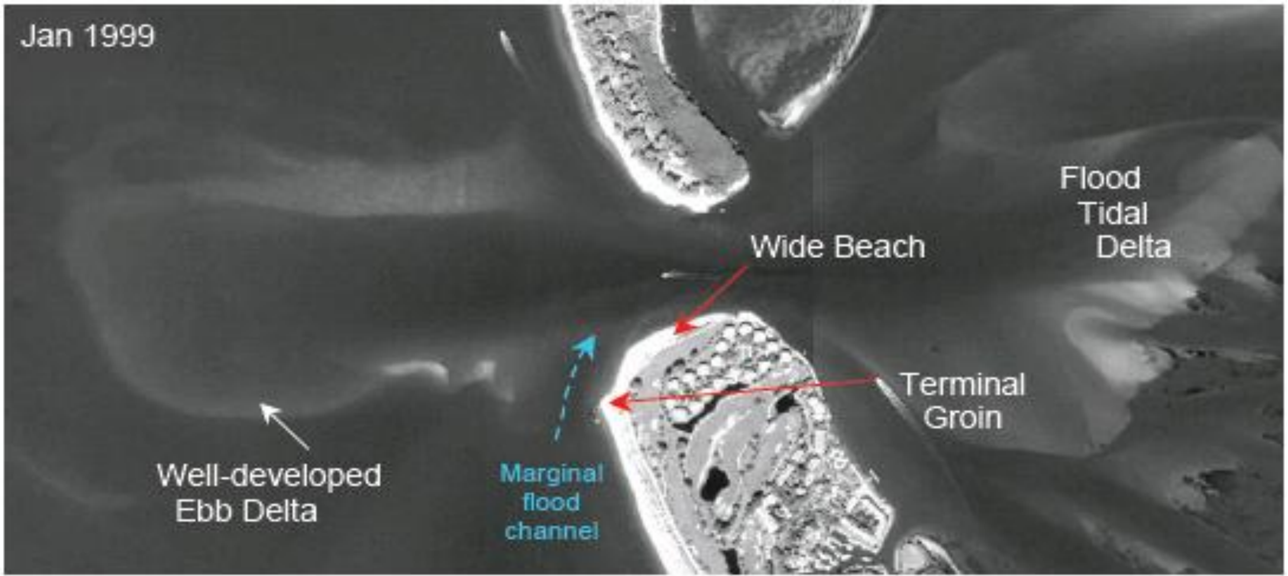
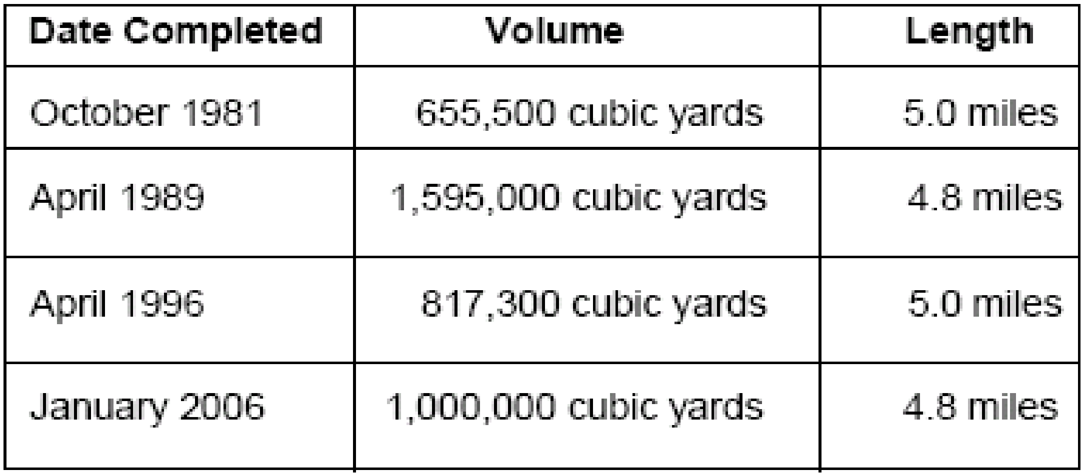


Figure III-34. View of the Ebb-tidal Delta That Has Been Used as a Source of Sand for Nourishing the Beach Along Captiva Island (from Google Earth)

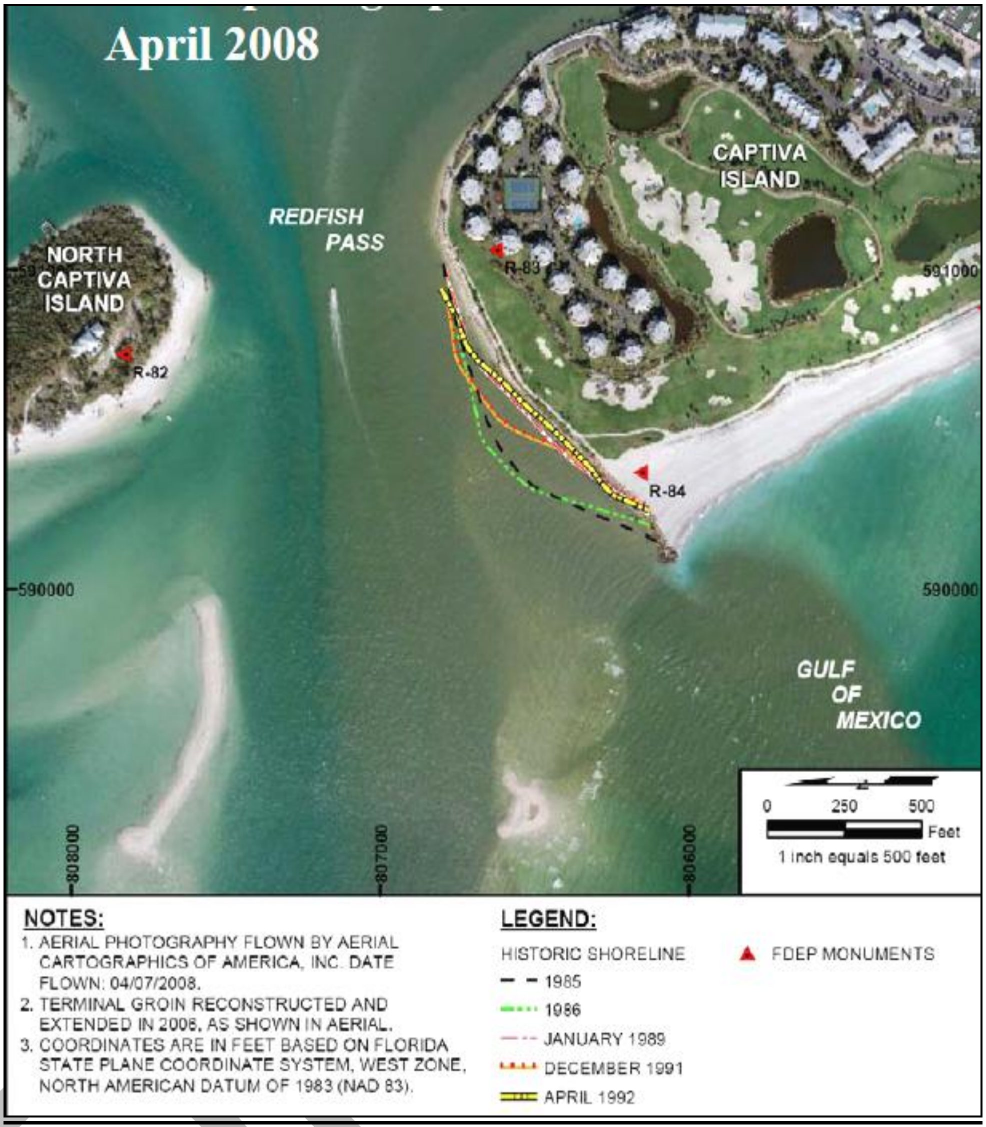
Figure III-35. View of the Terminal Groin at Redfish pass (from Google Earth)

Table III-5. Captiva Beach Restoration Project (FL-EPA, 2008)



Date Completed	Volume	Length
October 1981	655,500 cubic yards	5.0 miles
April 1989	1,595,000 cubic yards	4.8 miles
April 1996	817,300 cubic yards	5.0 miles
January 2006	1,000,000 cubic yards	4.8 miles

As seen in Figure III-34 and Figure III-35, the beach along northern Captiva Island has built to near the end of the terminal groin. This condition coupled with the existence of the marginal flood channel just offshore from the beach indicates that sand moves around the structure building a beach along the inlet shoreline. Historically, this beach north of the terminal groin and inside the inlet varies in width from 0 to 30 meters. The presence or absence of the beach has been related to storm activity and configurational changes of the ebb-tidal delta allowing the beach to be exposed to variable wave climate. Shoreline change data for the region inside the inlet indicate a period of erosion from 1985 to 1992 and a gradual retreat of the beach (Figure III-36). Also note that the 1992 and 2008 shorelines are in similar locations. Additional shoreline changes in the vicinity of the groin for the 1994 – 2007 period are presented in Figure III-37. In all of the photographs the beach extends to near the end of the groin, especially prior to lengthening the groin by 100 feet in 2006. The beach inside the inlet is relatively narrow in 1994 and 2003, but much wider in 1999 and 2006. In 2004 Hurricane Charley made landfall along northern North Captiva Island causing extensive damage and breaching of the barrier forming a new tidal inlet in the middle of the North Captiva. Along northern Captiva Island the beach inside the inlet was completely destroyed during the hurricane (Figure III-38).



NOTES:

1. AERIAL PHOTOGRAPHY FLOWN BY AERIAL CARTOGRAPHICS OF AMERICA, INC. DATE FLOWN: 04/07/2008.
2. TERMINAL GROIN RECONSTRUCTED AND EXTENDED IN 2006, AS SHOWN IN AERIAL.
3. COORDINATES ARE IN FEET BASED ON FLORIDA STATE PLANE COORDINATE SYSTEM, WEST ZONE, NORTH AMERICAN DATUM OF 1983 (NAD 83).

Figure III-36. Shoreline Changes of Beach Inside Redfish Pass
Note that between 1985 and 1992, the shoreline receded (FL-EPA, 2008)

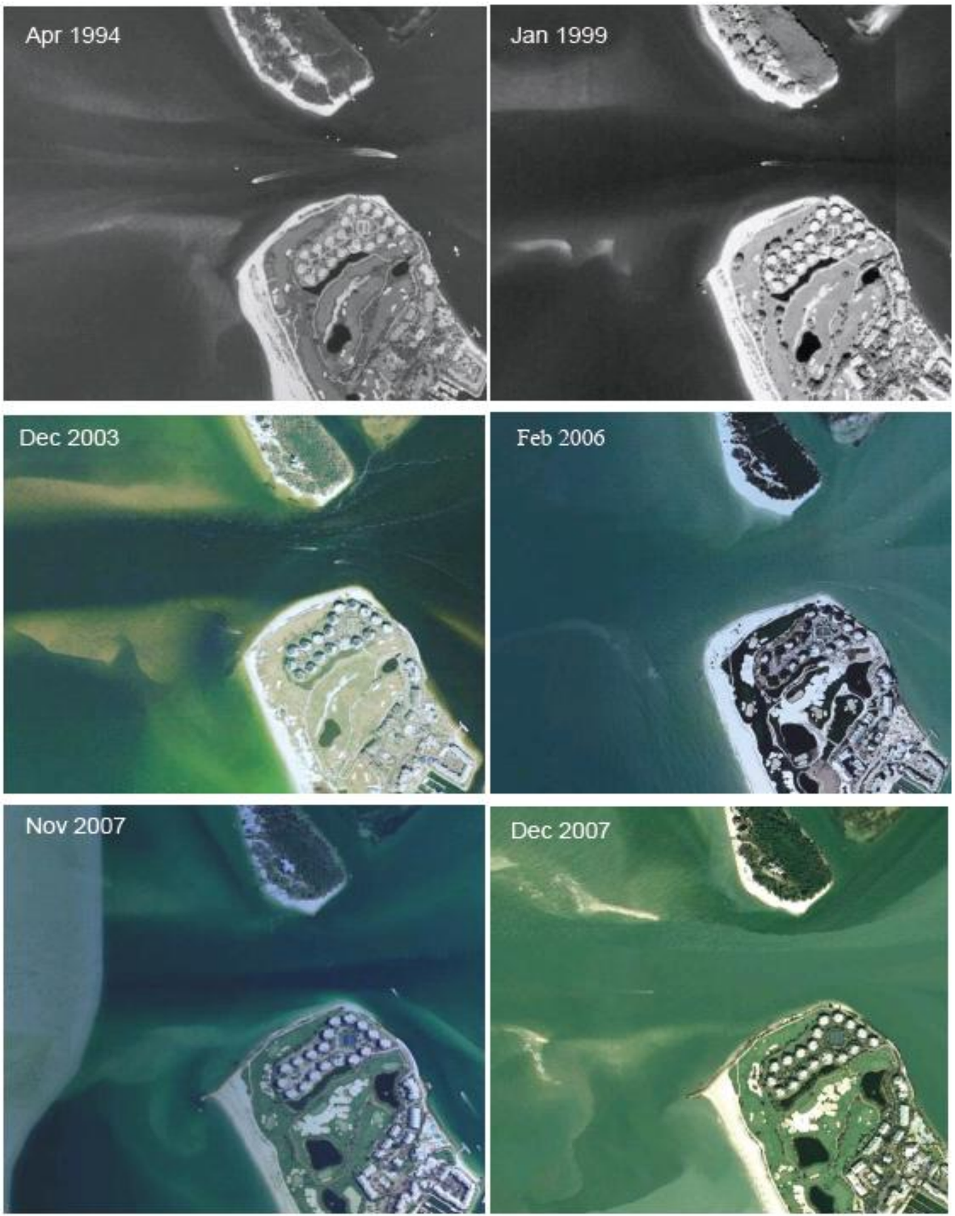


Figure III-37. Sequential Vertical Aerial Photographs of Captiva Inlet between 1994 and 2007 (from Google Earth)

Figure III-38. Comparison of Photographs Taken Before and Immediately After the Passage of Hurricane Charley Showing Beach Erosion Inside the Inlet

In January of 2006, 1,000,000 cubic meters of sand was added to Captiva Island, which substantially widened the beach and rebuilt the beach inside the inlet (see February 2006 in Figure III-37). By the end of 2007, the beach had mostly disappeared (2007 December, Figure III-37), which may have been the result of less sand bypassing the longer terminal groin. Alternatively, the disappearance of the beach may have been due to erosion caused by the passage of Tropical Storm Barry that made landfall north of this region in June 2007. From February 2007 to March 2008 the entire barrier experienced an average shoreline change of -3.2 feet. Next to the terminal groin the shoreline accreted 52 feet during 2008.

d. John’s Pass

John’s Pass is located between Medeira Beach to the north and Treasure Island on the south. The inlet is 150 m across and has a cross-sectional area of 883 m^2 and a spring tidal prism of $6.0x10^6$ m^3 (Mehta et al., 1975). The inlet is ebb-dominant having maximum ebb-tidal currents (143 cm/s) that exceed flood-tidal velocities (115 cm/s). Davis and Gibeaut (1990) found a net southerly longshore transport rate of 38,200 m^3/yr at John’s Pass and Tidwell (2005) found a rate of 35,000 m^3/yr in the vicinity of Blind Pass.

Severe erosion along Madeira Beach led to the installation of 37 groins in 1957 and a similar groin field was built along southern Treasure Island in 1959 (Elko and Davis, 2000). The terminal groin on the north side of John’s Pass was constructed in 1961 to trap the southerly longshore movement of sand at the southern end of Madeira Beach. Between 1957 and 1974, Madeira Beach prograded several 10s of meters (Figure III-39).

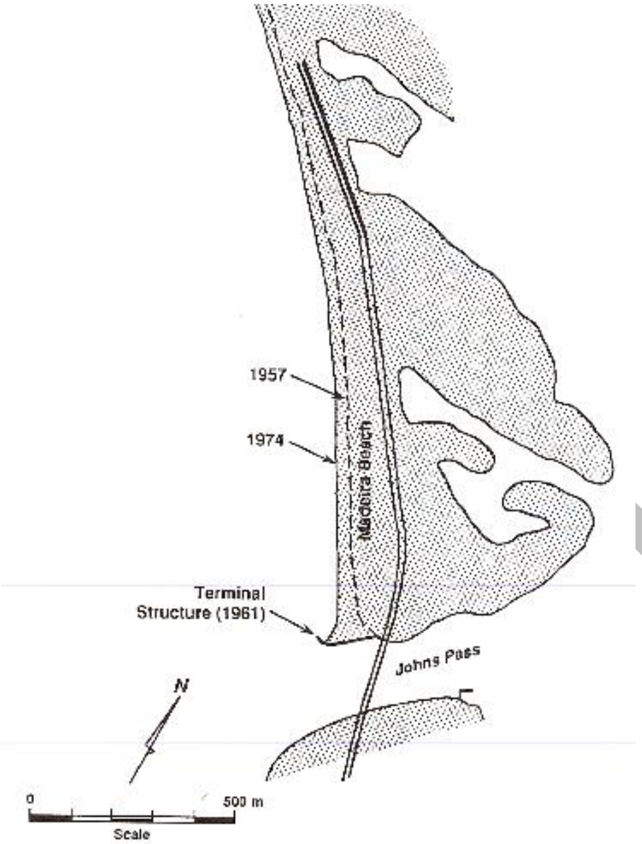


**Figure III-39. Shoreline Changes Along Mederia Beach between 1957 and 1974
Note that the terminal groin at the north side of John's Pass was built in 1961**

John's Pass is a federally maintained waterway and is dredged to a minimum depth of 3 m and width of 46 m (USACE, 2004). Dredging of the inlet channel began in the early 1960's with a combined 131,500 m^3 from John's Pass and Blind Pass. The sand was placed 600 m offshore along the northern 0.6 km of Treasure Island. By the early 1970's, this sand had been reworked by waves into a large, landward-migrating cuspate bar that eventually welded to the beach forming the O'Brien's lagoon. The lagoon was artificially filled in the late 1970s. The time interval between dredgings is infrequent (about every five years) due the strong ebb currents that provided a natural flushing of the inlet channel. The terminal groin at the northern end of Treasure Island, abutting the inlet's southside, was constructed in 2000 to help maintain the beach nourishment projects at the northern end of the island and minimize sand transport in John's Pass (Florida EPA, 2008).

The hydrodynamics of John's Pass have responded to several natural and anthropogenic forcings, which in turn have affected the inlet tidal prism and geometry and size of the ebb-tidal delta. Both John's Pass and the next inlet to the south, Blind Pass, are connected to the same bay tidal prism. Mehta et al. (1976) have shown that a southerly migration of Blind Pass decreased its hydraulic conductivity to Boca Ciega Bay leading to a capture of greater tidal prism by John's Pass. Offsetting this trend has been the land-building projects in the bay, which have decreased bay area by 28%, thereby reducing the tidal prism (Krock, 2005). Finally, continued dredging of the ebb delta outer bar has decreased the volume of the ebb-tidal delta, accentuated its asymmetry, and cut the delta in two. Note in Figure III-40 the gradual decrease in size of the ebb-delta that reflected the land-building activity in Boca Ciega Bay that began in the late 1950s, particularly in the vicinity of the inlet. The ensuing decrease in tidal prism decreased the equilibrium size of the ebb-tidal delta volume. This condition was followed by long-term dredging activity in the inlet channel and outer bar of the tidal delta. These changes to the ebb delta would have diminished the ability of the inlet to bypass sand from Medeira Beach to northern Treasure Island and certainly exacerbated the periodic erosional conditions along the downdrift inlet shoreline.

A vertical aerial photograph in Figure III-41 shows the conditions that were present at John's Pass in 2008. At this time the beach had accreted to end of the terminal groin, and in fact there was a bulge in the beach north of the groin. Just offshore of the beach and a part of the ebb-tidal delta, a well-developed marginal flood channel extends along the beach and into the main channel. Flood and wave-generated currents transport sand in this channel into the inlet channel (red arrow in Figure III-41). Also seen in this photograph is evidence of the longshore movement of sand at the end of the beach and around the terminal groin. The photograph shows a stream of sand flowing around the groin and into main channel (blue arrow in Figure III-41). This appears to be sand that is moving as part of the southerly littoral transport system, which may be enhanced by flood-tidal currents in the adjacent marginal-flood channel.

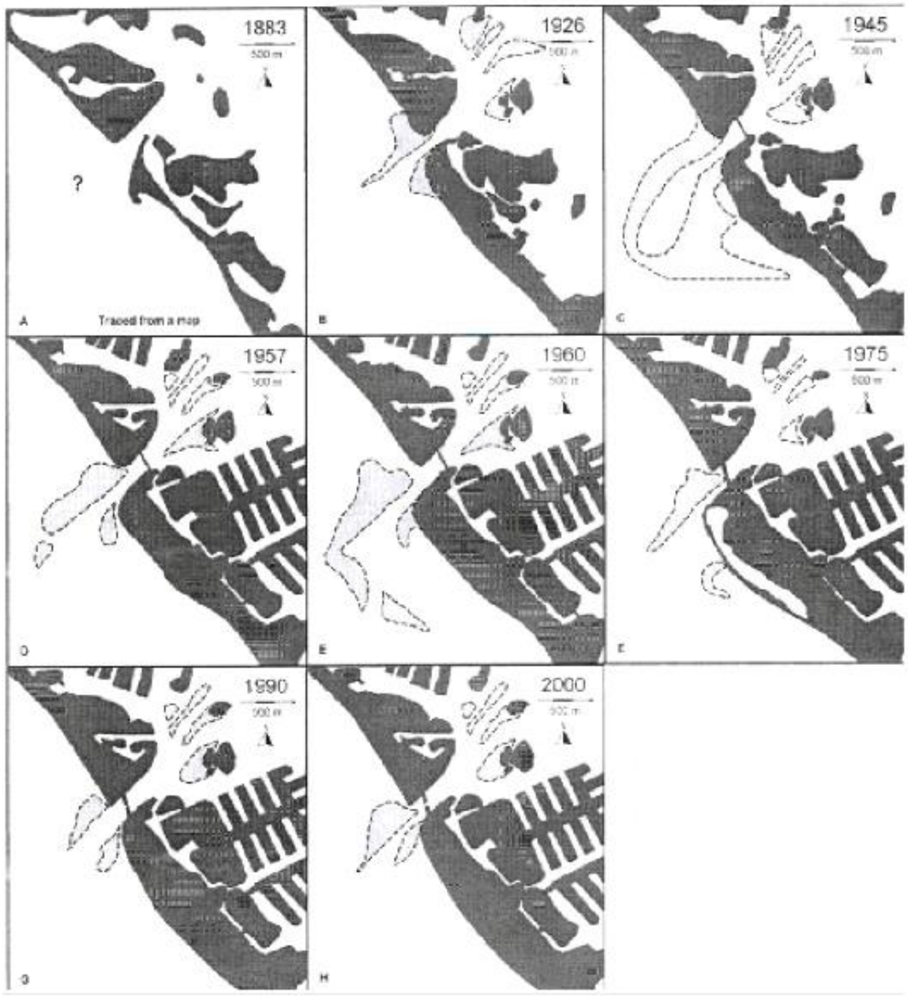


Figure III-40. Historical Morphological Changes of John's Pass from 1883 to 2000 (Davis & Vinther, 2002)

Note gradual decrease in size to the ebb-tidal delta.

Figure III-41. Vertical Aerial Photograph of the Terminal Groin at the North Side of John's Pass

On the opposite side of the inlet, a wide beach flanks the terminal groin, although edge effects are present at the end of the structure (Figure III-42). This type of scalloped shoreline is common around stone structures at the mouth of tidal inlets and estuaries and is a product of wave refraction processes. The shallow nature of the nearshore at the end of the groin and extending into the inlet channel is an indication that sand is entering the waterway (blue arrow in Figure III-42).

Figure III-42. Vertical Aerial Photograph of the Terminal Groin at the South Side of John's Pass at the Northern End of Treasure Island (from Google Earth)

A composite set of historical aerial photographs are presented in Figure III-43, depicting morphological changes at John’s Pass from 1995 to 2008. Several points are apparent:

1. The fillets at both terminal groins are filled with sand.
2. The northern side of the ebb delta is shallower and better developed than the southern side of the delta.
3. The northern part of the delta exhibits a well-developed channel-margin linear bar that defines the main ebb channel.
4. The ebb delta elongates with time, as especially seen by the northern channel margin linear bar.
5. The terminal groin constructed at the south side of the inlet has resulted in straighter more uniform shoreline.
6. The northern Treasure Island shore undergoes periods of widening and narrowing. These changes are consistent along the entire shore, but are not reflected along Maderia Beach.
7. The terminal groins do not appear to adversely affect the updrift and downdrift shoreline as evidence by the erosional-depositional historical trends.

Figure III-43. Sequential Vertical Aerial Photographs of John's Inlet between 1995 and 2008 (from Google Earth)

a. Summary – Florida Inlets

Terminal groins have been investigated along the Florida coast including two at John's Pass on either side of the inlet channel, one at the north end of Captiva Island, and a long terminal groin at the end of Amelia Island. At all these sites the inlet channel has been dredged and the onshore beaches in the vicinity of the terminal groins have been nourished periodically with sand. Hurricanes have had major impacts along the west coast sites of Florida, even though they seldom make a direct landfall near the inlets. The northern Florida site along the Atlantic Ocean is affected both by hurricanes and northeasters.

The historical photographs, shoreline change data, dredging accounts, and other records indicate that the terminal groins stabilize the entrance of the inlet and prevent its migration. The beaches in the vicinity of the terminal groins have historically almost always extended to near the end of groin, which is a product of natural processes as well as beach nourishment. Evidence that sand bypasses these structures includes the construction of beaches inside the inlet, existence of subtidal bars trending into the inlet channel, development of marginal flood channels, historical shoaling and closure of tidal inlets, landward migrating swash bars welding to the downdrift inlet shoreline, and anecdotal accounts.

The shoreline in the vicinity of the terminal does not appear to behave substantially differently than the beaches further away, with the exception that the beaches next to these structures undergo less shoreline retreat during storm events and longer-term erosional periods than the adjacent updrift and downdrift beaches.

D. Overall Findings and Summary

Terminal groins have been investigated at five locations: two sites in North Carolina and three locations in Florida. These sites encompass a range of physical settings and sedimentological conditions. Other than the pre-existing geological factors that have shaped the coast's inner shelf, barrier and backbarrier morphology and sediment abundance, the framework geology of these regions is of secondary importance in comparison to the present-day factors affecting erosional and depositional processes at the project locations. Rising sea level influences the entire coastal zone and is not preferentially changing sedimentation processes at terminal groin sites. Rather, the rate of sea-level rise will dictate the response of the coast to inundation, the fate of backbarrier marshes, and the redistribution of sand reservoirs. It is also true that any hardened structure, such as a groin, does not have the capacity of moving landward with migrating barriers. Over the short-term, the evolution of barrier coasts is primarily a product of storms, sediment supply, and inlet processes. When considering terminal groins, the data analyzed in this study indicate that tidal inlet dynamics, storm impacts, dredging and beach nourishment, and day-to-day wave processes are the chief factors affecting the sedimentation patterns and sand distribution at the ends of barriers.

Tidal inlet processes impart a strong signature on the adjacent shoreline, which is usually commensurate with the size of the inlet. The North Carolina and northern Florida Atlantic coast sites contain relatively large tidal inlets (width = 0.7 -1.2 km), while John's Pass and Redfish Pass are small tidal inlets (width = 220 - 240 m).

Terminal groins are typically constructed at the downdrift end of littoral transport cells. They are also commonly built on both sides of inlets or in some instances on the updrift side of a tidal inlet because in addition to the regional dominant longshore transport system delivering sand preferentially to one side of an inlet (updrift inlet shoreline), wave refraction around the ebb delta results in sand transport back toward the inlet along the downdrift inlet shoreline. Flood tidal currents flowing toward the inlet in marginal flood channels aid in this process. Thus, although the dominant longshore transport direction is south along Bodie Island, a terminal groin built at the north end of Pea Island traps sand moving back toward the inlet. Likewise, the regional sand transport regime along the central Florida Gulf Coast is south. Still, terminal groins have been constructed along the downdrift inlet shorelines of John' Pass and Redfish Pass because they trap sand moving northward.

Ebb-tidal deltas are major sand reservoirs and changes in their volume (controlled by tidal prism) affect the transfer of sand between the ebb shoal and the adjacent shore. Slight changes in their volumes can significantly influence erosional-depositional processes along inlet beaches. Ebb-tidal deltas are also the subtidal sand bridges between adjacent barrier islands that allow sand to bypass the inlet. When a deep channel is cut through the ebb delta, such as at Beaufort Inlet, the sediment transferal process is terminated or significantly diminished. Erosion ensues along the downdrift barrier because the sediment supply to the beach has been halted. Moreover, at inlets having functioning sediment bypassing systems, the configuration of the ebb delta (overlap of the ebb delta along the inlet shorelines) controls where sand moves onshore from delta to the inlet shoreline. For example, at Redfish Pass changes in the alignment of the main ebb channel and configuration of the ebb shoal have been linked to periods of erosion at the northern shoreline of Captiva Island. Likewise, the pattern of wave refraction and sheltering effects imparted by the ebb delta of Nassau Sound have been shown to control the direction and rate of longshore sand transport at the southern end of Amelia Island.

All of the study sites have been strongly affected by storms, and in fact four out of the six inlets were formed by storms during historic times, including Oregon Inlet, John’s Pass, and Redfish Pass. In addition, historical data reveal that storms, especially hurricanes, have the greatest impact on barriers in the project areas, particularly in terms of erosion and shoreline change. Given this assessment, the least amount of shoreline erosion occurs along terminal groin shorelines, with the exception of beaches that form on the inlet side of the terminal groin. These beaches were often eroded during storms, probably due to the elevated tidal currents resulting from the storm surge as well as from the increased wave activity. It is also apparent that terminal groin fillets fill with sand quickly following storm activity.

Dredging has significantly impacted the entire project area, causing both beneficial and deleterious effects. Much of the nourishment sand that has been placed on the beaches in the vicinity of the terminal groins has been derived from maintenance dredging of channels, both at the inlet and in backbarrier, as well as from opportunity dredging projects. Although these dredging programs provide navigable waterways and beneficial sand sources, they also create sediment sinks because the deepened and widened channels are no longer in hydraulic equilibrium with tidal exchange through these channels. The long-term dredging activities at Beaufort and Oregon Inlets have produced sediment sinks at the inlet and in backbarrier channels, which have drastically reduced the volume of sand bypassing the inlets and nourishing the downdrift barrier shorelines. In addition, as deltas have become depleted with sand, such as at Beaufort Inlet, the slope of the ebb shoal has steepened, allowing greater energy, particularly during storms, to impact the inlet shorelines. Finally, dredging of the inlet channel has exacerbated the sequestration of sand at ebb deltas due to the increased hydraulic conductivity that has produced larger tidal prisms and larger equilibrium volume of the ebb shoals.

Terminal groins at the project sites have had little effect on the regional sand transport regime. Once the beaches prograded to near the end of the structure, either by natural longshore transport or through beach nourishment projects, wave processes have transported sand around and over the groins into the tidal inlet. There is abundant evidence demonstrating that sand moves past the groins, including the formation of beaches inside the inlet, existence of subtidal bars trending into the inlet channel, the presence of flood-oriented sandwaves in marginal flood channels, historical shoaling and closure of inlets, as well as mass balance considerations.

The major impact of terminal groins at the study sites is that they stabilized the location of the inlet channel preventing the inlet from migrating. In New England and elsewhere around world, many tidal inlets are anchored next to bedrock headlands. At these sites, the beach along the bedrock side of the inlet is typically stable, whereas the unanchored side of the inlet experiences much greater shoreline change. Terminal groins act like large major bedrock outcrops, anchoring the end of the barrier and stabilizing the nearby beach.

IV. Environmental Assessment of the Potential Impacts of Terminal Groins

A. Overview of Environmental Considerations

Oceanfront and inlet shorelines are dynamic features that experience continual movement by short-term (boat wakes, storms, tides, etc.) and long-term (sea level rise) processes. As described by Nordstrom (2000), the expanding use of the coast by human populations characteristically involves a gradual intensification of urban development in the littoral zone, with the ultimate consequence that coupled surf-beach-dune systems must be managed. As coastal populations encroach on oceanfront and inlet shorelines, coastal states formulate policies and management plans to deal with shoreline erosion. This management process attempts to balance between the need to provide protection to the public from coastal hazards with the need to maintain the integrity of the natural system.

Beaches adjacent to tidal inlets are often subject to the most dynamic shoreline changes associated with accelerated erosion. These beaches experience much larger scale fluctuations in their shoreline compared to beaches away from inlets [American Shore and Beach Preservation Association (ASBPA) 2008; Jarrett 2007]. These changes are primarily associated with shifts in the position and orientation of the main bar channel that connects the sounds with the ocean; as well as, the entrapment of littoral material in the inlet (Jarrett 2007). Many coastal inlets, such as Beaufort Inlet, have shoal systems that can hold significant quantities of sand, sometimes in the millions of cubic yards (cy) (Personal communication, B. Cleary, University of North Carolina at Wilmington, November 2009). When the channel (thalweg) migrates, the location of the ebb-tidal shoal also changes. This causes wave patterns around the inlet to change, with often significant movement of the adjacent ocean shoreline position (Cleary 1996). Homes, roads, and infrastructure can be damaged or destroyed if the result of this process is severe erosion.

Hard structures including seawalls, bulkheads, and groins are effective in stabilizing uplands and protecting existing structures, but do not prevent the erosion of adjoining beaches, which narrow and may eventually disappear (Pilkey and Wright 1988; Watts 1987). Therefore, hard stabilization measures have been increasingly replaced by beach nourishment operations, which replace sediments lost through natural or human induced erosion with sand removed from a borrow site. Repeated nourishment is often necessary to keep pace with erosion. For example, 88 percent of nourished beaches along the Atlantic coast require replenishment within five years of the initial nourishment (Leonard et al. 1990). More frequent beach nourishment and nourishment of more beaches may be expected under increasing rates of sea level rise (Peterson et al. 2000a). North Carolina has been under the influence of relative sea level rise at a rate of 1.0 to 1.5 feet per century for the last 60 years. However, one approach to extending the life of beach nourishment projects is through the use of stabilization structures [National Oceanic and Atmospheric Administration (NOAA) 2009]; although shoreline stabilization projects can sufficiently alter the habitat such that it loses some of its natural functions (Clark 1974).

According to NOAA Coastal Services Center (2009), the major concern with the use of stabilization structures is their potential adverse effects on the adjacent shorelines. For example, prior to our present understanding of coastal processes; stabilization structures in the form of groins were the preferred approach to controlling beach erosion. However, since groins function by trapping sand within the littoral system, they may have an associated adverse effect on the downdrift shoreline (Personal communication, R. Young, Western Carolina University, November 2009). The recognition of this effect was the impetus for the gradual evolution of beach erosion control toward nourishment. Jarrett (2008) indicated though that a closer look at the United States Army Corps of Engineers (USACE) manual provides a more relevant statement on the potential effect of terminal groins: "Groins on the updrift side of inlets can benefit nearby beach nourishment projects by controlling (or gating) the amount entering (lost) to the inlet. Terminal groins fill quickly and do not have major effects on ebb tidal shoals, and normal inlet sand-passing processes."

As the NOAA Coastal Services Center indicates (2009), it is well known that structures have an effect on the nearshore processes that shape the plan form and profile of a beach. Structures affect the nearshore waves and current, slowing wave energy in the case of breakwaters and trapping sand in the case of groins, thus influencing the sand movement along the shoreline of the beach system. Structures may be used to beneficially influence a beach nourishment project by modifying the forces that cause rapid or accelerated losses from the beach and thus increase overall project performance. For example, structures can be used with beach nourishment in certain locations to slow the background erosion rate. Stabilization structures used to prolong the life of a beach nourishment project can be effective in reducing sand losses from a segment of shoreline and thereby used to control erosion hotspots (NOAA 2009).

Beach erosion control structures can be categorized generally in three groups (Sorenson 1997) (a) structures that are attached and are perpendicular to the shoreline, (b) structures that are parallel to the shoreline and are offset seaward from the shore and (c) structures that are parallel to the shoreline and located on the visible beach. Type (a) structures are the focus of this document, i.e. terminal groins.

The use of hardened structures as a shoreline erosion response measure for ocean and inlet shorelines is prohibited by the State of North Carolina; although, they are currently permitted in estuarine shorelines (NCDCM 2006). Prior to 2003, the hardened structure prohibition was controlled by regulations enacted by the N.C. Coastal Resources Commission (CRC) in response to the North Carolina Coastal Area Management Act (CAMA). In 2003, the N.C. State Legislature passed a law (Session Law 2003-427, § 113A-115.1) specifically prohibiting the construction of breakwaters, bulkheads, groins, jetties, revetments, seawalls, and similar structures in response to ocean and inlet shoreline erosion.

This terminal groin study as mandated by Session Law 2009-479 requires the CRC, in consultation with N.C. Division of Coastal Management (NCDCM), the N.C. Division of Land Resources (NCDLR), and the N.C. Coastal Resources Advisory Council (CRAC), to evaluate the feasibility and advisability of the use of terminal groins as erosion control devices in North Carolina. As described by ASBPA (2008), terminal groins are often placed near inlets and sometimes are confused with jetties. Terminal groins placed at inlets can limit the loss of sand into the inlet and moderate large-scale fluctuations of the shoreline near the inlet. The principal purpose of a terminal groin at an inlet is to retain sand on the beach directly updrift of the inlet;

whereas, the purpose of a jetty is to help maintain navigation channel depth and location. A terminal groin, once filled to a designed capacity, will allow sand moving in the littoral zone to flow past the structure; although, the terminal groin will still cause some reduction in the net movement of sand at its location.

House Bill 709 directs the CRC to consider all of the following:

- Scientific data regarding the effectiveness of terminal groins constructed in North Carolina and other states in controlling erosion. Such data will include consideration of the effect of terminal groins on adjacent areas of the coastline.
- Scientific data regarding the effect of terminal groins on the environment and natural wildlife habitats.
- Information regarding the engineering techniques used to construct terminal groins, including technological advances and techniques that minimize the effect on adjacent shorelines.
- Information regarding the current and projected economic effect to the state, local governments and the private sector from erosion caused by shifting inlets; including loss of property, public infrastructure, and tax base.
- Information regarding the public and private monetary costs of the construction and maintenance of terminal groins.
- Whether the potential use of terminal groins should be limited to navigable, dredged inlet channels.

This section presents a review of readily available environmental data regarding terminal groins' potential effect on the environment and natural wildlife habitats. The projects evaluated and included herein are based primarily upon the response of shorelines to such structures, the federal/state agencies assessing the projects' environmental effects, and the experience of the coastal engineering firm conducting the shoreline protection projects.

1. Site Selection

A total of 26 inlet locations along the East and Gulf coasts were reviewed by the CRC Science Panel during the 29 September 2009 meeting. The following five terminal groin locations were chosen for evaluation:

Pea Island, Oregon Inlet, North Carolina;
Fort Macon, Beaufort Inlet, North Carolina;
Captiva Island, Redfish Pass, Florida
South Amelia Island, Nassau Sound, Florida;
Treasure Island, John's Pass, Florida; and

The CRC Science Panel discussed during the 29 September 2009 meeting that in the event data was limited for the five sites chosen for full evaluation; alternative sites may need to be considered (NCDCM 2009). Based on limited data, representative projects at adjacent inlets were evaluated to provide additional scientific data in order to analyze the effects of terminal groins. Additional data for inlets within the vicinity of the study sites were also collected during the data acquisition phase.

2. Technical Approach of Analysis

A review of past scientific, engineering, and publicly accessible information and data related to the five terminal groin projects chosen in North Carolina and Florida was conducted. Environmental resources discussed include the benthic resources, shorebirds and waterbirds, fisheries, coastal habitats and associated biota, and federally protected species. Readily available information was identified from web-based literature searches and over 140 contacts were made with applicable state/local and federal agencies, coastal engineering firms, non-profit organizations, and libraries (Appendix D). Table IV-1 provides a breakdown of representatives contacted for environmental information. Information identified was reviewed for its usefulness in assessing natural resource effects from construction and maintenance of the selected terminal groin locations.

Table IV-1. Enumerated list of representatives contacted for environmental data and/or information as it relates to terminal groins.

Representatives	North Carolina	Florida
State/Local Agency	17	33
Federal Agency	26	21
Non-profit Organization[a]	8	11
For-profit Organization[b]	23	13
Individual[c]	2	0
Total	**76**	**78**

[a] Non-profit organization (501c3) category includes Audubon Chapters, Conservation organizations, etc.

[b] For-profit organization category includes universities, consulting firms, etc.

[c] Individual category includes persons that have retired from state and federal agencies, experts in their field and conducting their own research, etc.

In general, the historical nature of the selected study sites resulted in limited availability of pre- and post-construction resource monitoring data, required mitigation, and operation and maintenance requirements.

3. General Environmental Effects

In the last several years, public and state agencies along the east coast have been moving away from hardened coastal protection structures (e.g. seawalls) towards soft solutions (e.g. nourishment). Desired methods aim to enhance/maintain a natural coastline system while still providing coastal infrastructure protection and the tourism industry opportunities. In addition, hybrid solutions that combine hard and soft coastal protection methods (e.g. a combination of submerged breakwaters, nourishment and dune stabilization) are becoming more common in order to meet sustainability issues, such as limited sources of beach compatible material (Mead 2005). The changing methodologies of coastal protection have been driven by a society that is well aware of the environmental and infrastructure values that beaches provide.

Terminal groin structures are frequently located within estuarine and coastal systems; however, only a limited amount of information exists on the biological effects of such structures [Coastal Engineering Research Center (CERC) 1981]. Coastal structures may result in changes in wave and current patterns, sedimentation patterns, and habitat types. These changes in turn may affect aquatic biological communities (CERC 1984).

Most coastal protection projects, whether they include hard or soft structures, are of particular environmental concern due to their magnitude, timing, and the sensitivity of high value resources within a project area. Protection of high quality environmental resources found within project areas and borrow areas is typically required during project construction and renourishment. Beach renourishment and associated borrow site effects are being increasingly scrutinized by resource agencies, and compensatory mitigation and monitoring may be required. Discussion of the environmental considerations and the significant resources with respect to terminal groin locations is summarized below.

a) Coastal and Marine Resources Effects

Tidal inlets provide tidal conveyance from open bodies of water to more sheltered lagoons, estuaries, or bays. As evident in a model study of Boca Ciega Bay, John's Pass, and Blind Pass (Becker and Ross 1999), inlets are often in a state of flux due to a variety of forcing influences which control their shape and stability. Such inlet areas, as designated by the CAMA, are important Areas of Environmental Concern (AEC). Many AECs have also been designated as Significant Natural Heritage Areas (SNHA) by the North Carolina Natural Heritage Program (NCNHP), as well as essential fish habitat (EFH) by the National Marine Fisheries Service (NMFS). Environmental factors such as tides, longshore transport, freshwater input, and wave climate influence inlet configurations (O'Brien 1976) and therefore have immediate and direct effects on biological resources within the system. In order to provide a concise summary of coastal resources, such as biological resources (i.e. birds and shellfish beds), sensitive shorelines (i.e. marshes and tidal flats), submerged habitats (i.e. seagrasses) and human resources; the NOAA Environmental Sensitivity Index (ESI) map portal program was utilized (NOAA 2008; Personal communication, K. Taylor, NC Geologic Survey, October 2009). Each site includes a coastal classification map, a habitat map depicting the major sensitive habitats, and a species map which represents major habitat range.

The State of Florida classifies water bodies in accordance with water quality criteria established per Chapter 62-302 of the Florida Administrative Code (FAC) and under authority of Section 403.061 of the Florida Statutes. Water Quality classifications are arranged in order of the degree of protection required, ranging from Class I with the most stringent protection to Class V with the least protection. Section 403.061(27), Florida Statutes, grants Florida Department of Environmental Protection (FDEP) the power to: Establish rules which provide for a special category of water bodies within the state, to be referred to as "Outstanding Florida Waters", which shall be worthy of special protection because of their natural attributes. In 1975, Florida enacted the Aquatic Preserve Act. This ensured assignment and protection of aquatic preserves throughout the state for the enjoyment of future generations. Currently, Florida has 41 aquatic preserves, encompassing almost two million acres. All but four of these submerged lands are located along Florida's 8,400 miles of coastline in the shallow waters of marshes and estuaries (FDEP 2009).

Dredging and placement of beach quality sand and the construction of terminal groins have the potential to affect biological resources in a variety of ways. The potential for adverse effects from beach restoration may result from actions of the dredging equipment (i.e. suction, sediment removal, hydraulic pumping of water and sediment); physical contact with dredging equipment and vessels; physical barriers imposed by the presence of dredging equipment (i.e. pipelines); and placement of dredged material on the beach within a proposed construction template (i.e. covering, suffocation) (USACE 2008a). Although beach placement of material and associated construction operations (i.e. operation of heavy equipment, pipeline route, etc.) may adversely affect some species and their habitat; the resulting constructed beach profile promotes restoration of important habitat that has been lost or degraded as a result of erosion. The placement of rock to construct a terminal groin would result in a loss of benthic organisms, and possibly limit numbers of macroinvertebrates and juvenile/larval fish. The placement of rock may also result in the permanent loss of intertidal and nearshore subtidal habitat; however, this loss may be negligible when compared to the total amount of intertidal habitat within a specific project area.

The loss of these habitats would be replaced by rocky, hardbottom material that would add diversity to the bottom habitat (USACE 2008a); thus providing a new habitat type that can be utilized by certain groups of invertebrates, juvenile/larval fish, and birds. Potential effects vary according to the type of equipment used, the nature and location of sediment discharged, the time period in relation to life cycles of organisms that would potentially be affected, and the nature of the interaction of a particular species with the dredging activities.

b) Benthic Resources

A seafloor with physical properties ranging from dense muds to well-cemented limestone including adequate elevation changes may be considered hardbottom or live bottoms. Such hardened or semi-hardened seafloor areas generally support a high diversity of benthic or sessile flora and fauna. Such areas are rich in biological activity and considered EFH (Boss et al. 1999). 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 (Personal communication, M. Sramek, NOAA NMFS, February 2010).

Benthic macroinvertebrates and infaunal species have limited mobility, and some are sensitive to physical and chemical environmental changes. Thus, benthic infauna can be useful indicators of a wide range of natural and anthropogenic stresses. Many benthic species depend upon variable particle sizes and available interstitial pore space in the substrate. Most species are found in the upper 3.3 feet of the substrate due to available oxygen content and aeration properties, although some larger species may live deeper (USFWS 2002). The type of benthic taxa found dominating the bays and sounds of North Carolina include bivalves, polychaetes, and amphipods. Dominant benthic indicator species researched in relation to coastal projects include mole crabs (*Emerita talpoida*), coquina clams (*Donax variabilis, D. parvula*), some amphipods (almost all Haustoriids), and polychaetes (mostly *Capitella capitata* and *Scolelepis squamata*), all of which can be found in North Carolina's intertidal beaches (Peterson et al. 2006, 2000a, 2000b; Street et al. 2005; USFWS 2002).

Based on a four-year analysis of the effects of inlet migration at Emerald Isle, NC; Carter (2008) concluded that benthic communities are rarely in equilibrium and can vary significantly in their distribution and biotic composition. In addition, natural ecosystem processes and physical variations make it difficult for researchers to distinguish between natural and anthropogenic disturbances (Grober 1992). Important considerations when evaluating potential effects to the benthic community include: the ability of the community to recolonize the area after a disturbance, restoration of some measure of community parameters (e.g., species richness and diversity), and the functional property of the community to higher trophic levels (i.e., resident and migratory fish and shorebirds).

As described by Wilber (2003), the placement of sand on the beach buries, at least temporarily, existing benthic habitat; which would reduce the availability of infauna to benthic feeders. The long-term effects of beach nourishment on the benthic infauna and surface sediments of Panama City beaches were investigated by Culter and Mahadevan (1982), resulting in a well-known fact that species composition and faunal densities vary seasonally. Species diversity was lowest in the swash zone and sandbar and highest offshore. Based on benthic community analyses and sediment parameters, no significant differences were found between nourishment borrow sites and surrounding areas, and in the nearshore areas where beach nourishment was conducted. No long-term adverse effects from beach nourishment were detected in the Florida or North Carolina studies (Culter and Mahadevan 1982; Carter 2008).

In cases where sediment texture is substantially changed due to the placement of a higher fraction of fine sediments on the beach, recovery of benthic infaunal communities may be delayed (Reilly and Bellis 1983; Peterson et al. 2000a). Where there is a high correspondence between the fill site and ambient beach sediments (e.g. Nelson 1993; Van Dolah et al. 1994; Hackney et al. 1996; Jutte et al. 1999; Burlas et al. 2001), infaunal recolonization is more rapid and potential limitations to benthic food availability are reduced. Temporary effects on intertidal macrofauna in the immediate vicinity of the beach construction activities are expected as a result of discharges of material on the beach. Any reduction in the numbers and/or biomass of intertidal macrofauna may have localized limiting effects on surf-feeding fishes and shorebirds due to a reduced food supply. In such instances, these animals may be temporarily displaced to other locations. Effects to these areas could be minimized by consideration of shorebird nesting and feeding habits and potentially re-seeding of coquina clams, an important food source.

Comprehensive environmental assessments of coastal engineering projects evaluate beneficial, as well as detrimental effects. 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. However, few studies have examined the utilization patterns of these structures as shelter, foraging, spawning, or nursery habitat by fish and invertebrate populations. Consequently, a lack of documentation of beneficial effects of rubble-mound structures exists (CERC 1984); although Knot et al. and Van Dolah et al. (1984) sampled the macrobenthic communities of the intertidal and nearshore sub-tidal environments at Murrells Inlet, SC, and a comparison of species abundance between years and among localities (updrift and downdrift) suggested no widespread effects attributable to jetty construction. It has long been known that desirable reef habitat is created whenever new surfaces are introduced into nearshore areas; however, the actual changes and the derived benefits have not been adequately described (CERC 1980).

c) Fish and Fisheries

Inlets are important corridors (or bottlenecks) through which many fish must successfully pass to complete their life cycles (Street et al. 2005; Roberts et al. 1995). Larval fish diversity in North Carolina's inlets is very high. Sixty-one larval species have been found in Oregon Inlet; Atlantic croaker (*Micropogonias undulatus*) and summer flounder (*Paralichthys dentatus*) were particularly abundant (Hettler and Barker 1993). Other species included bluefish (*Pomatomus saltatrix*), black sea bass (*Centropristus striata*), gray snapper (*Lutjanus griseus*), several flounder species, pigfish (*Verro oxycephalus*), pinfish (*Lagodon rhombodies*), spotted seatrout (*Cynoscion nebulosus*), weakfish (*C. regalis*), spot (*Leiostomus xanthurus*), kingfish (*Menticirrhus americanus*), red drum (*Sciaenops ocellatus*), striped mullet (*Mugil cephalus*), and butterfish (*Peprilus* sp.). Effects on larval transport due to the presence of a terminal groin would likely occur, but the level of effect would depend on several factors; such as the species' spawning areas, egg types (demersal or buoyant), and the larval stage when the structural encounter occurred (Personal communication, M. Sramek, NOAA NMFS, February 2010). As described by Street et al. (2005); Beaufort, Ocracoke, and Oregon Inlets also support significant larval fish passage, although Oregon Inlet may be especially important due to the great distance between it and adjacent inlets, its orientation along the shoreline, and the direction of prevailing winds. Oregon Inlet provides the only opening into Pamlico Sound north of Cape Hatteras for larvae spawned and transported from the Mid-Atlantic Bight.

As defined by Street et al. (2005), water column habitat is “the water covering a submerged surface and its physical, chemical, and biological characteristics.” Differences in the chemical and physical properties of the water affect the biological components of the water column including fish distribution. Water column properties that may affect fisheries’ resources include temperature, salinity, dissolved oxygen (DO), total suspended solids, nutrients (nitrogen, phosphorus), and chlorophyll *a* (SAFMC 1998). Other factors, such as depth, pH, water velocity and movement, and water clarity, also affect the distribution of aquatic organisms.

Surf zone habitats have been viewed as harsh environments that are difficult to effectively sample (Schaefer 1967; Lasiak 1984), which may account for the relative lack of information regarding the dependence of young fish on this habitat type. The importance of surf zone habitat as a nursery area for juvenile fish along the high-energy beaches of the eastern United States and northern Gulf of Mexico is becoming increasingly evident (Ross et al. 1987; Lazzari et al. 1999; Layman 2000; Able et al. 2009). Increases in coastal development and erosion control measures, along with a greater emphasis on defining and protecting critical fish habitats, have all contributed to a growing interest in how beach restoration projects affect surf-zone fish communities.

As described by Wilber (2003), beach nourishment may affect surf zone finfish through reductions in benthic prey and shelter availability, and the disruption of fish distribution patterns. The beach placement of sand buries, at least temporarily, existing benthic habitat, which would reduce the availability of infauna to benthic feeders. Another potential effect arises when hard-substrate habitats, such as groins, are partially or totally buried by sediments, which may reduce the value of these structures as foraging and shelter sites (Wilber 2003). Additionally, the physical disturbance caused by dredging and the pumping of sand onto the beach may affect fish distribution patterns. High suspended sediment concentrations can negatively affect the physiology and feeding behavior of visually orienting estuarine fish (reviewed in LaSalle et al. 1991; Wilber and Clarke 2003).

Localized fish abundance and distribution patterns have been significantly associated with the presence of rock groins, with greater fish captures and higher species richness at areas nearest groins. The presence of rock groins may increase the sampling efficiency near these structures, resulting in more abundant and species-rich catches. Alternatively, 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).

d) Shorebirds and Waterbirds

The dynamic coastal processes that characterize inlet and barrier beach systems create habitats which support various bird species such as the federally listed piping plover (*Charadrius* *melodus*). According to NC Wildlife Resources Commission (NCWRC) (2009), the barrier islands and associated inlets on which many waterbirds depend are being severely altered by attempts to stabilize beaches. If habitat is to be retained for migrating, wintering, and breeding waterbirds; it is imperative that coastal habitat is managed. Habitats associated with inlets are particularly valuable to coastal birds (Harrington 2008) and as such, should be afforded extra protection. According to the US Shorebird Conservation Plan (Brown et al. 2001), data from several shorebird inventory programs in North American in the past two decades strongly suggest that populations of the majority of species are declining, some at rates exceeding 5 percent per year. The plan also states that coastal development and human activities in coastal zones have grown a great deal and have reduced intertidal habitats, prey base, and have usurped high tide resting areas used by shorebirds (NCWRC 2009; Lamonte et al. 2006). Populations of many colonial waterbird species are also showing declines. Coastal development, coastal protection, dredging, and human disturbance are listed as actions that can significantly affect the ability of coasts and intertidal waters to sustain waterbirds (Kushlan et al. 2002).

As described by the USACE (2009), many habitats used by birds in Florida are affected by large-scale beach management activities such as shoreline protection through beach nourishment, dune building and planting, or removal of wrack from beaches. Florida's coastal bird habitats are also affected by inlet management through activities such as jetty construction or inlet bypassing. The effects of coastal sediment management on birds have rarely been studied in Florida (USACE 2009). Consequently, despite a large amount of coordinated (and uncoordinated) coastal bird surveys (Sprandel et al. 1997; Douglass and Coburn 2002; Ferland and Haig 2002; Lamonte et al. 2006; Gore et al. 2007) the year-round distribution, abundance, and habitat associations of Florida's shoreline-dependent birds is still poorly known. These data gaps challenge Florida's management of coastlines for birds. Limited coordinated data to assess recommendations for one species may conflict with the needs of another. Similarly, it is problematic to propose management recommendations that would positively affect the entire community of shoreline-dependent birds when neither the community, nor the habitat needs, have been adequately described. Effects of various coastal management activities on shoreline-dependent birds (e.g., coastal engineering, beach management activities) can be only partially addressed (relative to the limited number of species or seasons where data have been collected).

A great variety of birds in the South Atlantic Bight use terminal groins as loafing or roosting sites (Personal communication, D. Allen, NCWRC, October 2009). However, 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 and purple sandpipers are also occasionally abundant in flocks of 40 to 50 (Personal communication, R. Newman, Fort Macon State Park, October 2009). 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).

Beach-nesting birds that utilize dry beach overwash habitats include terns (Laridae spp.), black skimmers (*Rhychops niger*), Wilson's plovers (*Charadrius wilsonia*), piping plovers, and American oystercatchers (*Haematopus palliates*). These species nest on bare sand and shell with little or no vegetation and will change nesting areas in response to changing environmental conditions, such as increased vegetation. Waterbirds use group dynamics to select suitable nesting areas. This grouping creates nesting, resting, and foraging areas with large colonies that can include multiple species of waterbirds (CPE 2009). This is one reason why it's important that these birds have a number of suitable nesting, foraging, and roosting sites along the coast.

4. Federally Threatened and Endangered Species Effects

Any potential effects on federally listed threatened and endangered species would be limited to those species that occur in habitats present in the project areas (Table IV-2). Updated lists of threatened and endangered (T&E) species for the five study sites (Carteret and Dare Counties, North Carolina; and Nassau, Lee, and Pinellas Counties, Florida) were obtained from the NMFS (Southeast Regional Office, St. Petersburg, FL) (http://sero.nmfs.noaa.gov/pr/pdf/North%20Carolina.pdf; http://sero.nmfs.noaa.gov/pr/pdf/Species%20List/South%20Atlantic.pdf) and the United States Fish and Wildlife Service (USFWS) (Field Office, Raleigh, NC) (http://www.fws.gov/raleigh/es_tes.html) websites. These lists were combined to develop the following composite list of T&E species that could be present within the areas of evaluation based upon their geographic range. However, the actual occurrence of a species in the area would depend upon the availability of suitable habitat, the season of the year relative to a species' temperature tolerance, migratory habits, and other factors.

a) Mammals

(1) West Indian Manatee

The West Indian manatee (*Trichechus manatus*) was listed as an endangered species in 1967 [under a law that preceded the Endangered Species Act (ESA) of 1973], and then a federally protected species under the ESA. The manatee is also protected under the Marine Mammal Protection Act of 1972 (USFWS 2007b). Manatees primarily feed on aquatic vegetation, but can be found feeding on fish, consuming between four and nine percent of their body weight in a single day (USFWS 2007b). Sheltered areas such as bays, sounds, coves, and canals are important areas for resting, feeding, and reproductive activities (Humphrey 1992). The West Indian manatee can be found occupying the coastal, estuarine, and some riverine habitats from Virginia to the Florida Keys, the Caribbean Islands, Mexico, Central America, and northern South America (Garcia-Rodriguez et al. 1998; USFWS 2007b).

Table IV-2. Threatened and endangered species potentially present within the selected study sites.

Species Common Names	Scientific Name	Federal Status
MAMMALS		
West Indian manatee	*Trichechus manatus*	Endangered
North Atlantic right whale	*Eubaleana glacialis*	Endangered
Humpback whale	*Megaptera novaeangliae*	Endangered
BIRDS		
Piping plover	*Charadrius melodus*	Threatened
Roseate tern	*Sterna dougallii dougallii*	Threatened

REPTILES		
Green sea turtle	*Chelonia mydas*	Threatened
Hawksbill turtle	*Eretmochelys imbricata*	Endangered
Kemp's ridley sea turtle	*Lepidochelys kempii*	Endangered
Leatherback sea turtle	*Dermochelys coriacea*	Endangered
Loggerhead sea turtle	*Caretta caretta*	Threatened
FISH		
Shortnose sturgeon	*Acipenser brevirostrum*	Endangered
Gulf sturgeon	*Acipenser oxyrinchus desotoi*	Threatened
Smalltooth sawfish	*Pristis pectinata*	Endangered
VASCULAR PLANT		
Seabeach amaranth	*Amaranthus pumilus*	Threatened

Status	**Definition**
Endangered	A taxon "in danger of extinction throughout all or a significant portion of its range."
Threatened	A taxon "likely to become endangered within the foreseeable future throughout all or a significant portion of its range."

Manatees have been sighted in North Carolina most frequently from June through October when water temperatures are warmest (above 71.6 ºF) (USFWS 2007b; USFWS 2007c); however, manatees may also overwinter in North Carolina where the discharge from power plants supports warm water temperatures, though the occurrences are atypical (USACE 2006).

(2) Humpback Whale and North Atlantic Right Whale (NARW)

These whale species occur temporally off the coast of North Carolina and Florida. Of all the whale species known to occur in the Atlantic, only the North Atlantic right whale (NARW) (*Eubaleana glacialis*) and the humpback whale (*Megaptera novaeangliae*) routinely come close to inshore waters. Humpback whales were listed as "endangered" throughout their range on 2 June 1970 under the ESA and are considered "depleted" under the Marine Mammal Protection Act. Humpback whales are often found in protected waters over shallow banks and shelf waters for breeding and feeding. They migrate toward the poles in summer and toward the tropics in winter and are in the vicinity of the North Carolina coast during seasonal migrations, especially between December and April. Since 1991, humpback whales have been seen in nearshore waters of North Carolina with peak abundance in January through March (NMFS 2003). Based on an increased number of sightings and stranding data, the Chesapeake and Delaware Bays and the U.S. mid-Atlantic and southeastern states, particularly along Virginia and North Carolina coasts, have become increasingly important habitat for juvenile humpback whales (Wiley et al. 1995).

The frequency with which NARWs occur in offshore waters in the southeastern U.S. remains unclear (NMFS 2003). While it usually winters in the waters between Georgia and Florida, the NARW can, on occasion, be found in the waters off North Carolina (Georgia Department of Natural Resources 1999). NARWs swim very close to the shoreline and are often noted less than a mile offshore (Schmidly 1981). NARWs have been documented along the North Carolina coast, as close as 820 feet from the beach, between December and April with sightings being most common from mid to late March (USACE 2008b). Sighting data provided by the NARW Program of the New England Aquarium indicates that 93 percent of all North Carolina sightings between 1976 and 1992 occurred between mid-October and mid-April (Slay 1993). The occurrence of NARWs in North Carolina waters is usually associated with spring or fall migrations. Due to their occurrence in the nearshore waters, offshore vessel movements could result in an encounter with humpback and NARW species. However, with regards to the construction and maintenance of terminal groins, these whale species would not likely be affected. Designated Critical Habitat for the NARW is located in coastal waters of northeastern Florida, yet beyond the effect of marine structures [Coastal Planning and Engineering, Inc. (CPE) 2008].

b) Shorebirds and Waterbirds

Piping Plover

The piping plover is federally listed under the ESA, as amended with three separate breeding populations in North America: 1) the Atlantic Coast population (threatened), 2) the Northern Great Plains population (threatened), and 3) the Great Lakes population (endangered). Piping plovers are also listed as threatened throughout their wintering range (USFWS 1996a). The Atlantic Coast population breeds along the east coast of North America, from the Canadian Maritime Provinces to North Carolina. The Northern Great Plains population can be found breeding from southern Alberta to Manitoba and south to Nebraska. The Great Lakes population breeds along the shorelines of the Great Lakes. All three populations migrate to the coastal shorelines of the South Atlantic, Gulf of Mexico, and the beaches of the Caribbean Islands to winter (USFWS 2006).

Factors that affect distribution, abundance, and survival of the federally-threatened piping plover on the wintering grounds are poorly understood (Cohen et al. 2008). Wintering plovers on the Atlantic Coast prefer wide beaches in the vicinity of inlets (Nicholls and Baldassarre 1990; Wilkinson and Spinks 1994). At inlets, foraging plovers are associated with moist substrate features such as intertidal flats, algal flats, and ephemeral pools (Nicholls and Baldassarre 1990; Wilkinson and Spinks 1994). Because tide and weather variation often cause plovers to move among habitat patches, a complex of patches may be important to local wintering populations (Johnson and Baldassarre 1988; Drake et al. 2001). As described in Cohen (2008), inlet stabilization with rock jetties and channel dredging for navigation alter the dynamics of sediment transport and affect the location and movement rate of barrier islands (Camfield and Holmes 1995), which might in turn affect the availability of plover habitat.

Roseate Tern

As described by the South Atlantic Fisheries Management Council (SAFMC) (1999), the roseate tern (*Sterna dougallii dougallii*) is distributed worldwide in a variety of coastal habitats. The North American subspecies is divided into two separate breeding populations, one in the northeastern U.S. and Nova Scotia, and one in the southeastern U.S. and Caribbean. Wintering areas are concentrated along the north and northeastern coasts of South America. It is not known if these two populations winter in proximity to each other. The roseate tern was listed as endangered in northeastern North America and threatened in the Caribbean and Florida in 1987 in response to nesting habitat loss, competition from expanding gull populations, and increased predation. Strictly a coastal species, this bird is usually observed foraging in nearshore surf. In the winter, the roseate tern is pelagic in its habits. Open sandy beaches isolated from human activity are optimal nesting habitat for the roseate tern.

c) Sea Turtles

Five species of sea turtles are known to occur off North Carolina and Florida beaches: the green sea turtle (*Chelonia mydas*), loggerhead sea turtle (*Caretta caretta*), leatherback sea turtle (*Dermochelys coriacea*), hawksbill sea turtle (*Eretmochelys imbricate*), and Kemp's ridley sea turtle (*Lepidochelys kempii*). Sea turtles prefer to nest on wide sloping beaches or near the base of the dunes (Kikukawa et al. 1999). In order for nesting to be successful, the following conditions must be met: the supratidal beach must be wide enough to allow nesting; access must be unobstructed (i.e. fencing, seawalls); sand compaction must allow for nest excavation; and the nesting area must be high enough in elevation to preclude tidal inundation throughout the nesting season. Sand composition, color, and grain size can affect the incubation time, gender, and hatching success of turtle hatchlings (Street et al. 2005; Personal communication, H. Hall, USFWS, November 2009).

The potential for future armoring encompasses the primary nesting beaches for sea turtles along the east coast of North Carolina, as well as the southeast and southwest coasts of Florida (Schroeder and Mosier 2000; Mosier 1998). The use of hard structures both parallel and perpendicular to the shoreline can lead to habitat loss for nesting sea turtles and according to USFWS (2008), the data on effects of groins on sea turtle mortality are insufficient to make a threat determination. Hard structures can both directly and indirectly affect sea turtles. Direct affects include: (1) prevention of access to suitable nesting sites, (2) abandonment of nesting attempts due to interaction with the structure, and (3) interference with proper nest cavity construction and nest covering. Furthermore, shore parallel hard structures such as T-head and other composite groins can (4) impede and/or trap nesting females and hatchlings, (5) concentrate predators, and (6) alter current regimes and longshore sediment transport. Indirect effects include: (1) the permanent loss of nesting habitat or escarpment formation as a result of beach profile and width alteration; (2) increase in clutch mortality as a result of frequent inundation and/or exacerbated erosion, and (3) increase in hatchling and adult female energy expenditure in attempts to overcome structures.

As discussed in Section IV-A, hard structures can be shore parallel, shore perpendicular, long, short, high, low, permeable, and impermeable. Depending on the design, hard structures can physically block a nesting female from accessing a more suitable higher nesting elevation. In a study conducted by Mosier (2000) of three nesting beaches on the east coast of Florida, 86 percent of nesting females that encountered a hard structure during emergence returned to the water without nesting as a result of the inability to access higher elevation nesting habitat. Nests that are laid in low elevation environments are vulnerable to wash out, and nest incubation environments may be altered resulting in nest loss or decreased nest success.

According to Lucas et al. (2004) in a study designed to assess sea turtle response to beach attributes (i.e. hard structures), turtles emerged onto portions of the beach where anthropogenic structures threatened to block access to optimal nesting habitat; however, upon encountering the structures, turtles abandoned the nesting sequence. This study indicated that only the most seaward structures affected sea turtle nesting. Depending on the design of shore perpendicular structures such as straight and composite groins (i.e. T-head), the structure may act as an impediment or a trap (Foote et al. 2003) to nesting females and/or hatchlings (Davis et al. 2002). Stem features of the groin may be exposed above the beach surface or may be buried by accreting sand. This results in potential impediments to the nesting process either during nest site selection or during nest digging, thus resulting in potential false crawls or false digs and subsequent increase in energy expenditure.

In most cases, groins are used as design components in combination with beach fill, in “critical erosion” or hot spot areas. Therefore, pre-project nesting conditions are generally degraded with limited sea turtle crawl activity. According to Davis et al. (2002), depending on the quantity of added beach fill, the rate of sediment accumulation, and the groin crest elevations; hatchlings may potentially be trapped by the groin both in the water and/or on the beach. The resultant increased energy expenditure to traverse around a structure depletes the critical “frenzy” energy reserves of hatchlings necessary to reach the safety of offshore developmental areas. Furthermore, predator concentration, including bird and fish species, may occur within the vicinity of high relief hard structures. As hatchlings become trapped by the structure during egress offshore, the period of time that they are most vulnerable to predation increases, resulting in increased losses (Davis et al. 2002).

d) Fish

Shortnose Sturgeon

The shortnose sturgeon (*Acipenser brevirostrum*) was listed as endangered on 11 March 1967 and has remained on the endangered species list since enactment of the ESA in 1973. Historically, shortnose sturgeon inhabited most major rivers on the Atlantic coast of North America south of the Saint John River in Canada. However, NMFS currently recognizes 19 distinct population segments: New Brunswick, Canada (1), Maine (2), Massachusetts (1), Connecticut (1), New York (1), New Jersey/Delaware (1), Maryland/Virginia (1), North Carolina (1), South Carolina (4), Georgia (4), and Florida (2) (Kynard 1997; NMFS 1998a).

Shortnose sturgeons are found in rivers, estuaries, and the sea along the east coast of North America, but populations are confined mostly to natal rivers and estuaries (Vladykov and Greeley 1963). Their southerly distribution historically extended to the Indian River, Florida (Evermann and Bean 1898). The species appears to be estuarine anadromous in the southern part of its range, but in some northern rivers it is "freshwater amphidromous", i.e., adults spawn in freshwater but regularly enter saltwater habitats during their life (Kieffer and Kynard 1993). Adults in southern rivers forage at the interface of fresh tidal water and saline estuaries and enter the upper reaches of rivers to spawn in early spring (Savannah River: Hall et al. 1991; Altamaha River: Heidt and Gilbert 1979; Flouronoy et al. 1992; Rogers and Weber 1995; Ogeechee River: Weber 1996). Shortnose sturgeon appear to spend most of their life in their natal river systems, only occasionally entering the marine environment; therefore, effects to this species from terminal groin construction and maintenance is not likely.

Gulf Sturgeon

The gulf sturgeon (*Acipenser oxyrinchus desotoi*) is a federal and state listed threatened species [Florida Fish and Wildlife Conservation Commission (FFWCC) 2004]. Gulf sturgeons are anadromous fish inhabiting coastal rivers from Louisiana to Florida, where critical habitat has been designated by USFWS for this species. Typically, adult fish move to spawning grounds in the rivers from February through April, and then move out of the rivers into the Gulf of Mexico and its estuaries and bays between September and November, where they feed and spend the winter (NMFS 2009). The effects from a terminal groin on this species is not likely.

Smalltooth Sawfish

When the U.S. Distinct Population Segment (DPS) of smalltooth sawfish (*Pristis pectinata*) was listed as endangered under the ESA on 1 April 2003, it became the first elasmobranch on the Endangered Species List. Smalltooth sawfish were once widespread throughout Florida and were commonly encountered from Texas to North Carolina. Currently, smalltooth sawfish can only be found with any regularity in south Florida between the Caloosahatchee River and the Florida Keys. Based on the contraction in range and anecdotal data, it is likely that the population is currently at a level less than five percent of its size at the time of European settlement (NMFS 2006).

The smalltooth sawfish is a tropical marine and estuarine elasmobranch with a circumtropical distribution. The current center of abundance for smalltooth sawfish in the United States is in the Ten Thousand Islands and the Florida Bay region of the Everglades National Park (Carlson et al. 2007). Shallow estuarine (and sometimes freshwater) areas appear to be especially important for juvenile sawfish; however, recent data from sawfish encounter reports and satellite tagging indicate that mature animals regularly occur in waters in excess of 165 feet (ft) (Simpfendorfer 2002). The preferred substrate types range from mud, sand, seagrass, limestone, rock, coral reef, to sponge. This species also has strong associations with mangroves, seagrass, and inshore bars or banks of rivers (Carlson et al. 2007).

As described by CPE (2008), the smalltooth sawfish has been mostly extirpated in more northern counties of south Florida; and so it is not likely to be found within the sites evaluated in this study.

e) Vascular Plants

(1) Seabeach Amaranth

Barrier islands are dynamic environments, with topographic and vegetation profiles dictated by the interaction of plant growth habits and physical processes such as wind-driven sand, salt spray, and wave-driven erosion and accretion (Myers and Ewel 1990). High temperatures, strong winds, and varying wet and dry conditions typical of a dune environment along a barrier island system provide unique conditions for plant species with specific adaptations. Sand dunes and vegetation that comprise the dune system are important to the coastline since they provide storm surge protection, recreation, and wildlife habitat.

Seabeach amaranth (*Amaranthus pumilus*) was listed as threatened on 7 April 1993 under the ESA of 1973. Before its listing, seabeach amaranth had experienced a reduction in range, population size, and population numbers. Seabeach amaranth is an annual plant that grows on the dunes of Atlantic Ocean beaches. Historically, this species was found from Massachusetts to South Carolina. According to USACE surveys between 1992 and 2004 (unpublished data), its distribution is now limited to North and South Carolina with some populations on Long Island, New York (USACE 2006). Flowering begins as soon as plants have reached sufficient size, sometimes as early as June, but more often beginning in July and continuing until the death of the plant in late fall. Seed production commences in July or August and peaks in September during most years, but continues until the death of the plant (USFWS 1993; USFWS 1996b; USFWS 2007a).

The primary habitat of seabeach amaranth consists of overwash flats at accreting ends of islands and lower foredunes and upper strands of non-eroding barrier island beaches. Seabeach amaranth may form small temporary populations in other habitats, including sound-side beaches, blowouts in foredunes, and sand and shell material placed as beach nourishment or dredged material (USFWS 1993; USFWS 2007a). The plant is typically found at elevations from 0.6 ft to 4.9 ft above mean high tide (Weakly and Bucher 1992). Seabeach amaranth is an effective sand binder, building dunes where it grows. A single large plant may be capable of creating a dune up to 23.6 inches high, containing 71 to 106 cubic ft of sand, although most are smaller (Weakley and Bucher 1992). Seabeach amaranth appears to function in a relatively natural and dynamic manner, allowing it to occupy suitable habitat as it becomes available (USFWS 1993).

5. Water Quality Effects

The construction of a terminal groin potentially produces temporary localized effects to ambient water quality during and proximal to the structural construction and fill areas [Dial Cordy and Associates (DC&A) 2003]. Turbidity is a major impact of groin construction (USACE 1976a). As confirmed by the Captiva Erosion Prevention District (CEPD 2002), short-term environmental effects, primarily elevated turbidity levels in the water column also occur as a result of beach nourishment. Should turbidity levels become problematic, best management practices to be considered could include the washing of stone prior to placement or the use of turbidity curtains. Water quality effects anticipated during and immediately following construction of a terminal groin may also have short-term effects to EFH. As described by Dolan (1999), the majority of larval fish migrates along the coast within the inshore longshore transport system and therefore could be negatively affected if turbidity levels increase significantly.

Resuspension of toxic materials can also occur, as can some noise, air, and water pollution. Compared to jetties and breakwaters, these physical effects should be less because groins are relatively small structures (Mulvihill et al. 1980).

A frequently cited environmental concern related to beach nourishment operations involves short- and long-term effects of suspended sediments, either during the actual filling process or over an indefinite period as the new beach profile responds to prevailing physical forces (USACE 2001). During the filling process, concerns are generally associated with the presence of very high concentrations of suspended sediments and plumes of turbid water in the vicinity of the sediment discharge. Several factors can contribute to the magnitude of re-suspension and spatial extent of plumes, including prevalent meteorological and sea state conditions, granulometry of the fill sediments (e.g., % silts or clays), and mode of placement (e.g., hydraulic pipeline or vessel pump-out).

6. Anthropogenic Effects (Recreation/Aesthetics/Public Access)

Short-term effects to recreational shoreline uses include limiting and/or blocking access to the beach front during the construction of a terminal groin, initial restoration of the beach (berm and dune), and each periodic renourishment. CEPD (2002) concluded that armor and seawalls could provide a significant degree of protection to upland structures, but would result in a reduction of recreational beaches. However, generally speaking, terminal groin locations become popular recreational fishing areas (Personal communication, M. Sramek, NOAA NMFS, February 2010).

A terminal groin is typically a permanent hard structure that can have long-term permanent effects on recreational fishermen by requiring recreational boats or beach vehicles to slow down or alter courses. However, according to USACE (2008a), prior to the initiation of construction, it is “Standard Operating Procedure” for the USACE to coordinate with the US Coast Guard to ensure that new permanent structures, such as terminal groins, are placed on appropriate maps and are equipped with appropriate navigation aids, if needed. As seen at Oregon Inlet, the construction of a terminal groin has offered alternative locations for recreational fishing, thereby offsetting potential negative effects associated with navigation. According to the USACE (2008a), fishing from a terminal groin is highly discouraged and not-supported by the USACE because fishing from and walking on stone groins is known to be unsafe, potentially resulting in bodily injury. However, periodic renourishment may ensure the long-term existence of the sandy beach, berm, and dune; thus preserving future recreational uses such as sunbathing, walking, birding, and surf-fishing. The presence of a terminal groin in concert with a shoreline protection plan may provide long-term infrastructure protection, shoreline benefits, and beach access to public recreational facilities.

The construction of a terminal groin structure may have potential direct and long-term effects on aesthetic and scenic resources by visually effecting view sheds of the surrounding coastal and marine region (USACE 2008b). Visual effects can be from shoreward- and waterward-facing perspectives. The terminal groin may have an adverse effect of trapping floating debris and trash, creating an unwanted view and potentially effecting marine species from debris ingestion and entanglement. Additionally, the construction of a terminal groin has the potential to affect buried cultural resources. In more recent construction locations, remote sensing efforts for cultural resources were performed and the results aid in the design and placement of the terminal groin footprint.

B. Assessment of the Five Study Sites

Readily available scientific, engineering, regulatory, and publicly accessible information and data related to the five terminal groin locations chosen by the CRC Science Panel were collected and reviewed. The potential environmental effects from the construction and maintenance of the selected terminal groins on the marine benthic community, shorebird use, fisheries, coastal habitat and associated biota, and protected species (marine reptiles, marine mammals, shorebirds) are provided below.

1. Oregon Inlet

a) General Site Description

Oregon Inlet was created by a hurricane on 8 September 1846. The inlet separates Bodie Island to the north and Pea Island/Hatteras Island to the south (Figure IV-1). For the purpose of this report, Pea Island/Hatteras Island will be referred to as the Pea Island National Wildlife Refuge (PINWR). As with most natural tidal inlets, Oregon Inlet has had a history of dynamic change and migration since its opening, having migrated more than two miles south of its original location. This highly turbulent area requires the USACE to spend approximately five million dollars per year for maintenance dredging of the Oregon Inlet channel. The USACE is only able to maintain the authorized 14-foot channel depth, on average about 25 percent of the time (Personal communication, B. Dennis, USACE – Wilmington District, November 2009).

Figure IV-1. Oregon Inlet Terminal Groin

Because of the constantly shifting features of Oregon Inlet (Figure IV-2), the existing Herbert C. Bonner Bridge has been a maintenance issue for the North Carolina Department of Transportation (NCDOT) since it was constructed in 1962. Between April 1988 and March 1989, the erosion at the northern end of PINWR occurred at a rate of 1,150 ft/year. During one severe “nor’easter” in March 1989, the northern end of PINWR eroded 350 to 400 feet southward. This series of storms created the potential of destroying the southern abutment of the Bonner Bridge and severing the land transportation link between Bodie Island and PINWR.

NCDOT data from 2002 showed an average daily traffic of 5,400 vehicles per day with the highest daily traffic volume being 14,270 vehicles on Saturday, July 6 (NCDOT 2008). To ensure the Highway 12 transportation corridor was not lost, the USACE utilized engineering and design analysis of navigation jetties for Oregon Inlet in conjunction with the Manteo Shallowbag Bay project (NCDOT 1989) to design a terminal groin for the northern end of PINWR. The terminal groin was designed to be a portion of and incorporated into the jetties if and when they were constructed. The terminal groin construction was financed by the Federal Highway Administration with any maintenance and monitoring to be completed by the NCDOT.

The terminal groin at Oregon Inlet is located on the southern side of the inlet along the north end of the PINWR (Figure IV-1). The project consists of a terminal groin 3,125 feet long, starting at the US Coast Guard Station bulkhead. The groin extends from the bulkhead in a northwest direction, curving 90 degrees towards the northeast, and then straightening out again to be perpendicular with the inlet shoreline of PINWR.

Source: USACE - Wilmington District, 2001

Figure IV-2. 2001 Oregon Inlet Aerial Photograph

The above inlet alignment places the groin near the position that the north point of PINWR occupied in April 1985. An accretion fillet was designed to impound sediment transported alongshore towards the inlet in order to provide enough wave sheltering for protection of the southern Bonner Bridge abutment. Once filled, the areal extent of this fillet was planned to be 60 acres. The groin was designed to withstand a still water level of eight feet above mean sea level (msl) and waves between 9 and 15 feet. The groin ranges in width between 110 to 170 feet at the base and 25 feet at the landward end to 39 feet at the seaward end. The design elevation ranged between 8 and 9.5 feet above msl (NCDOT 1989). Toe protection on the inlet side of the groin is provided by a 43-foot wide single layer of armor stone on top of a layer of core material (NCDOT 1989). Construction began in 1989 and was completed in October 1991 at a cost of $13.4 million dollars (1989 dollars).

The freestanding nature of the terminal groin in a position mimicking the 1985 shoreline relied on the natural coastal processes to deposit sediment along its landward (southern) side. For example, sediment transported towards the structure would begin to occupy the fillet until its design capacity was exceeded, at which point sediment would be transported around the end of the structure and towards the inlet. Therefore, the terminal groin and associated fillet is a temporary interruption of the sediment pathways with normal restoration of sediment pathways once the terminal groin fillet is impounded to designed capacity (NCDOT 1989).

Several environmental documents have been prepared in conjunction with the construction and maintenance of the Oregon Inlet terminal groin. Through finalization of these documents, including those of USFWS, a determination was made that the terminal groin and beach nourishment would not significantly affect any part of the natural environment and that sand management would have a positive effect on the natural environment. Accordingly, it was determined that the preparation of an Environmental Impact Statement for the construction of a terminal groin would not be required (USFWS 1989). Additional supporting documents developed included:

An Environmental Assessment (EA) that summarizes two (2) alternatives and subsequent environmental effects for these actions (June 1989); EA developed by the NCDOT (1 May 1989); and USFWS's Biological Opinions (26 May 1989 and 19 June 1989)

(1) Aesthetics

In general, the northern end of Hatteras Island and southern end of Bodie Island have a low vertical profile with slightly rolling terrain and scattered vegetation (Figure IV-2). As described by the NCDOT (2008), sandy beaches are along the oceanfront and inlet side of the islands. Salt marsh and mudflats are on the sound side of the island. Other than the marsh on the sound side of the island and the general undeveloped character of the island, there are no unique physical features related to landform or vegetation. Man-made vertical elements are present on both the Hatteras Island and Bodie Island sides of Oregon Inlet.

On the Hatteras Island side of Oregon Inlet, a public-use parking lot is on the east side of NC 12 with the terminal groin and the top of the (former) US Coast Guard Station being visible. On Bodie Island, there is a campground on the east side of NC 12. The US Coast Guard Station, a large radio tower, and Oregon Inlet Marina are on the west side of NC 12. The Bonner Bridge structure is a prominent visual feature on both sides of Oregon Inlet. The man-made feature contrasts with the natural characteristics of the island. Salt marsh and mudflats are on the soundside of the islands with emergent wetland vegetation such as needlerush (*Juncus roemerianus*) and smooth cordgrass (*Spartina alterniflora*). The terrain generally is flat with some dunes bordering the beach area. Low shrubs and grasses are more prevalent further inland (NCDOT 2008).

(2) Recreation

The undeveloped and protected character of the area provides a setting for recreational activities such as surf fishing, bird watching, and shell collecting. NCDOT (2008) discussed two publicly owned recreation areas within the project area: the Cape Hatteras National Seashore (CHNS) and the PINWR. CHNS and PINWR lands and the waters of the Atlantic Ocean and Pamlico Sound that border the CHNS, the PINWR, and Hatteras Island as a whole are used for a variety of recreational activities. Activities within the project area include: surf and inlet fishing, surfing, wind and kite boarding, birding, hiking, and cycling along NC 12.

The heaviest recreational fishing effort in the vicinity of the PINWR is in the surrounding sound system from October through April (USFWS 2008). Fishing pressure on the PINWR is relatively low and is a reflection of the isolation of the area and limited access, rather than low catch quotas. During 2007, there were an estimated 2,000 fishing visits to the PINWR (NCDOT 2008).

(3) Public Access

The General Management Plan and Amended EA for CHNS [National Park Service (NPS) 1984] and the Draft Revised Statement for Management (NPS 1991) serve as the NPS plans for the CHNS. The two current management documents provide for the preservation of the cultural resources and the flora, fauna, and natural physiographic conditions, while allowing appropriate recreational use and public access to the oceanside and soundside shores. Included in these plans are provisions for controlling off-road vehicles, providing for accessible oceanside and soundside sites, allowing natural seashore dynamics to occur, controlling exotic vegetation, preparing natural and cultural resource studies, and cooperating with state and local governments to achieve mutual planning objectives. PINWR officials intend to maintain some type of public access within the PINWR, including access to the (former) US Coast Guard Station.

b) Natural Resources

Habitats on the Outer Banks are highly ephemeral in nature because of the high level of natural disturbance present in barrier island ecosystems. Plants and wildlife such as seabeach amaranth and piping plovers have evolved to specialize in these habitats. The USFWS is responsible for the natural resources management within the PINWR (Personal communication, D. Stewart, USFWS, November 2009). As a first priority, federal law and regulation require the PINWR manager to ensure that all uses of the PINWR are compatible with Executive Order 7864 and the National Wildlife PINWR System Improvement Act of 1997, and that any allowed use of the PINWR be compatible with the mission (“wildlife first”) and purpose of the PINWR. A loss of ocean overwash habitat is a direct result of overstabilization; resulting from the placement and maintenance of the terminal groin (Personal communication, D. Stewart, USFWS, February 2010). The primary purpose of the PINWR is to be a breeding ground for migratory birds and other wildlife. The PINWR is a Section 4(f) resource (NCDOT 2008). In addition, it is a significant publicly owned recreation area and also a significant historic site eligible for inclusion in the National Register of Historical Places (NRHP). The PINWR provides habitat for a wide variety of wildlife (NCDOT 2008). Extensive marine and estuarine systems exist within the vicinity of the Pea Island terminal groin (Figure IV-3), and the sand and mudflats on the south end of Bodie Island attract many shorebirds.

Figure IV-3. Coastal Classification of Habitat for Oregon Inlet, NC

Allowing natural barrier island change, which has been prevented in the project area by the presence of NC 12 and human dune building for many decades, would allow the formation of ephemeral habitats that are essential to maintaining the natural ecological character of a barrier island. Overwash fans, new inlets, and low sloping beaches may be formed that serve as habitat for resting, feeding, and nesting of avian species (NCDOT 2008). As described by USFWS (2008); Oregon Inlet dredging, Bonner Bridge, and NC Highway 12 maintenance and protection have influenced the loss of acreage by subduing and altering natural processes such as overwash. The Pea Island terminal groin and impact area consist of approximately 55 acres as evaluated in 2007, thus restoring and stabilizing the tip of Pea Island (USFWS 2008; Personal communication B. Dennis, USACE, November 2009). When coupled with the placement of fill material, positive impacts on the shoreline have been measured along a reach extending approximately 8,000 ft south of the terminal groin. This area was experiencing catastrophic erosion during the five years prior to construction. For the remaining 8,000 ft to the south, no generalized trend in the shoreline response was evident (Dennis and Miller 1993). Although the USACE confirmed positive impacts on shoreline change in the vicinity of the terminal groin, Dolan (2001b) confirmed that changes in the configuration of the beaches and the distribution of sediment grains sizes and mineral content would have an important impact with respect to swash zone fauna, bird and turtle nesting success, and ghost crab distribution. Although the sand from the Oregon Inlet dredging is considered to be of "beach quality," it was more often than not significantly different in size and heavy mineral content from the lower beach-face or swash zone of the native beaches. These differences lead to significant alterations of the beach configuration and therefore had indirect affects to the habitat of the organisms that live in these areas (Dolan 2001b).

(1) Seabeach Amaranth

Habitat for the federally threatened seabeach amaranth does occur in the vicinity of the terminal groin at Oregon Inlet; however, a search of the NCNHP database and the USACE's recent survey results disclosed no current or historical records of the species for the PINWR area (Personal communication, H. LeGrand, NCNHP, October 2009; Personal communication, D. Piatkowski, USACE, November 2009). This species was not documented on Bodie Island flats prior to 2004, despite previous surveys over multiple years (NCDOT 2008). According to NCDOT (2008), the NPS located a single seabeach amaranth on the Bodie Island flats on 6 July 2004.

(2) Sea Turtles

As shown in Figure IV-4, the NOAA ESI database includes habitat for the green sea turtle and loggerhead sea turtle for the Oregon Inlet area. Sea turtle nesting data from the PINWR within five miles south of Oregon Inlet dates back to 1990 (Figure IV-5).

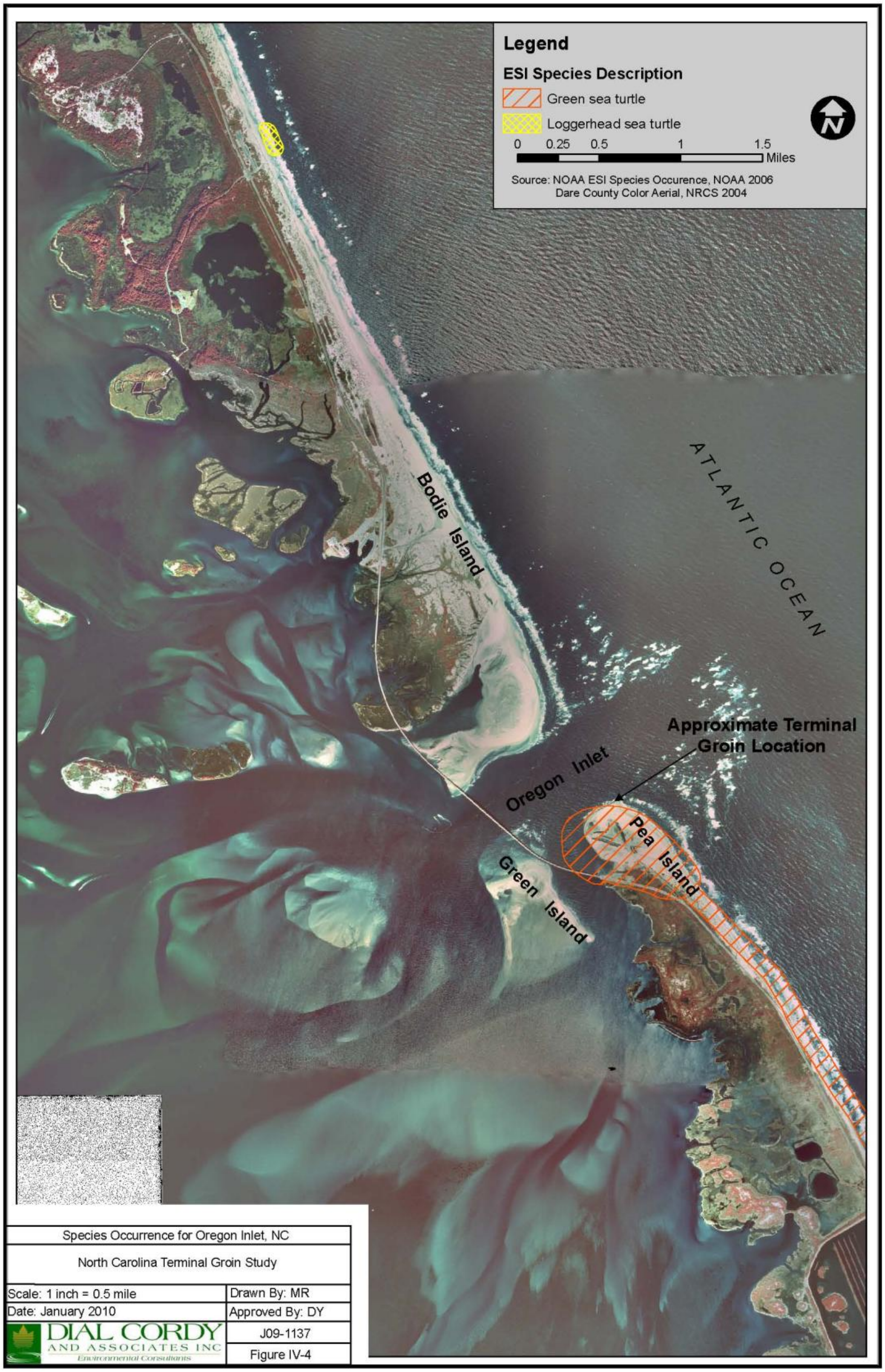


Figure IV-4. Species Occurrence for Oregon Inlet, NC

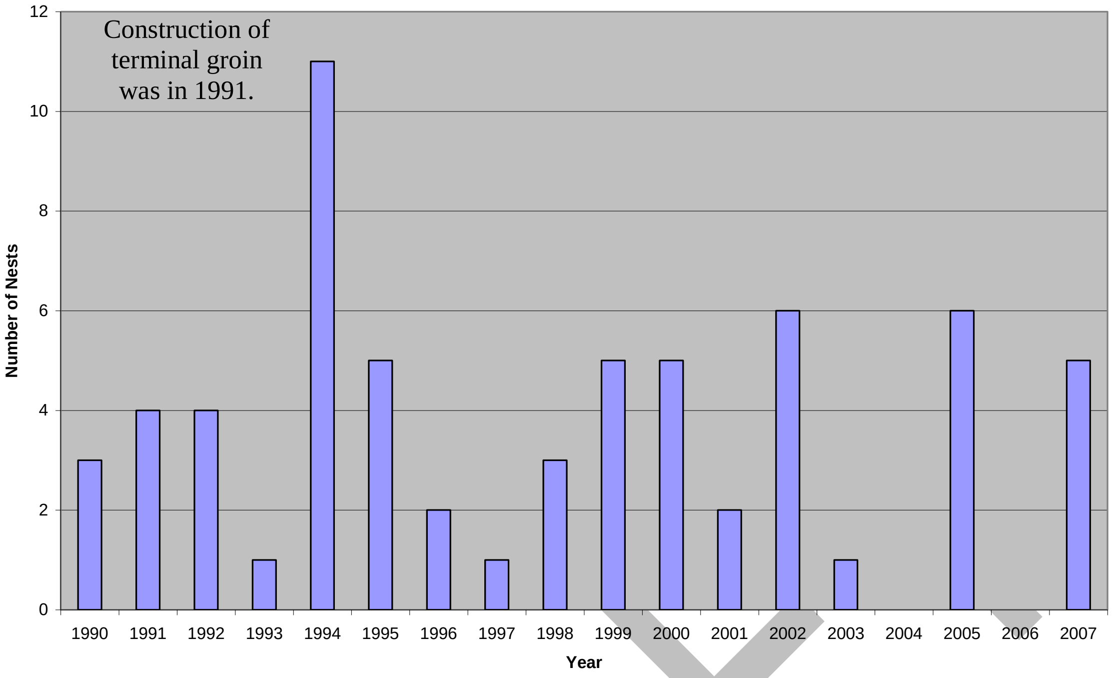


Figure IV-5. Loggerhead Sea Turtle Nesting Data from PINWR

The PINWR has an average of 10 to12 nests per year although on average, 3.4 loggerhead nests have been recorded within five miles south of Oregon Inlet annually over the course of the last 19 years. The number of loggerhead nests recorded from 1990 through 1993 ranged from one to four. The highest annual total was recorded in 1994, when a total of 11 nests were confirmed. Over the next three years, the number of nests steadily declined, reaching a low of one nest in 1997. The number of nests increased to three in 1998, and five nests were recorded each year in 1999 and 2000. Since 2000, the number of annual nests has ranged from zero to six, with an annual average of 2.5 nests. No nests were recorded in three out of the last five years (2004, 2006, and 2008).

Sea turtle nesting densities on the south side of Oregon Inlet have been significantly higher than densities on the north side of the inlet. Between 1990 and 2000, a total of 43 nests were recorded within the area five miles south of the inlet. In contrast, a total of 12 nests were recorded during this period within the area five miles north of the inlet. The NCWRC tracks sea turtle nesting within sea turtle management zones, which consist of one mile increments measured along the North Carolina coastline (Table IV-3 and Table IV-4). Oregon Inlet falls between Management Zone 57 to the north and Management Zone 58 to the south. On Pea Island, sea turtle nesting within one mile of the inlet (Zone 58) has been relatively low, with a total of 4 nests recorded between 1990 and 2000. During the same period, nesting densities further south were substantially higher and evenly distributed, with a range of 7 to 12 nests in the next 4 management zones (Zones 59 – 62). In comparison, nesting densities on Bodie Island ranged from 1 to 4 within the five management zones immediately north of the inlet (Zones 53 - 57) (USACE 2001).

The first green sea turtle known to nest on PINWR was in 1993 (USFWS 2008). One of the nests on the PINWR during the 2007 nesting season was identified as a green sea turtle nest.

Table IV-3. Sea turtle management zones south of Oregon Inlet.

Year	**Sea Turtle Management Zones**				
	58	**59**	**60**	**61**	**62**
1990	0	0	1	0	1
1991	0	3	0	0	1
1992	1	1	0	0	2
1993	0	0	0	1	0
1994	0	5	2	1	3
1995	2	0	1	2	0
1996	0	1	0	1	0
1997	1	0	0	0	0
1998	0	0	3	0	0
1999	0	1	2	0	2
2000	0	1	0	2	2
Total	**4**	**12**	**9**	**7**	**11**

Table IV-4. Sea turtle management zones north of Oregon Inlet.

Year	**Sea Turtle Management Zones**				
	53	**54**	**55**	**56**	**57**
1990	0	0	1	0	1
1991	1	0	0	0	0
1992	1	0	1	0	0
1993	0	0	0	0	0
1994	0	0	0	1	0
1995	0	1	2	0	0
1996	0	0	0	0	0
1997	0	0	0	0	0
1998	1	1	0	0	0
1999	0	1	NA	NA	NA
2000	NA	NA	NA	NA	NA
Total	**2**	**1**	**4**	**1**	**1**

As described by USFWS (2008), Pea Island has a severe beach erosion problem, resulting in a narrow beach and frequent overwash. In 1994, PINWR personnel determined that the best management strategy to optimize survival of turtle hatchlings was to move nests to a turtle safe-zone. Subsequent to that decision, guidelines specific to coastal processes and conditions at the PINWR were developed to facilitate the appropriate relocation of turtle nests. Likely nesting turtles avoid inlet areas with or without terminal groins. Without pre-groin turtle nesting data, conclusions on the terminal groin's effects on nesting turtles is limited (Personal communication, D. Stewart, USFWS, February 2010).

(3) Seagrass

Extensive seagrass (also known as submerged aquatic vegetation or SAV) beds occur near Oregon Inlet and throughout shallow portions of Pamlico Sound (Figure IV-6) (Personal Communication, D. Field, NOAA, February 2010). These seagrass beds form a complex and important ecosystem. Submerged beds of eelgrass (*Zostera marina*), shoalgrass (*Halodule wrightii*), and widgeon grass (*Ruppia maritima*) exist together and separately. Seagrasses can occur in isolated patches and as extensive beds. The importance of seagrass systems to estuarine ecology has been widely recognized (Thayer et al. 1975, 1979, 1981; Zieman 1975; Thayer and Phillips 1977; Fonseca et al. 1979; McRoy and Helfferich 1980; Ferguson et al. 1981; Zimmerman and Minello 1984; Weinstein 1985).

Numerous studies have documented seagrass habitats as important nursery areas for many fish species (Adams 1976; Thayer et al. 1979; Weinstein and Heck 1979; Miller and Dunn 1980; Stoner 1980; Homziak et al. 1982; Epperly and Ross 1986; Kenworthy et al. 1988; McMichael and Peters 1989; Noble and Monroe 1990). The North Carolina Division of Marine Fisheries (NCDMF) data was generated from boat surveys conducted between 1995 and 2001. The dynamic nature of the area around Oregon Inlet results in ephemeral habitats, particularly in shallow water and shoreline areas. A survey conducted by NCDOT in the fall of 2007 found that only 25 percent of the SAV habitat contained SAV. SAV can be affected by a variety of factors including light availability, water temperature, sediment composition, wave energy, tidal range, and a variety of other factors. These factors may influence the location and the amount of SAV from year to year. See Figure IV-6 for Seagrass Habitat locations.

Figure IV-6. Seagrass Habitat for Oregon Inlet, NC

(4) Shorebirds and Waterbirds

Shorebird species have been monitored within the Oregon Inlet system for many decades (Dinsmore et al. 1998; Personal communication, D. Stewart, USFWS, November 2009). For purposes of this study, shorebird data, provided by PINWR in the form of annual narrative reports, recorded during 1950, 1960, and 1970 were compared with data collected during 2006 and 2007 (Table IV-7) (USFWS 2007d, 2008). Selected species that were evaluated include American oystercatcher, black skimmer, common tern (*Sterna hirundo*), least tern (*Sterna antillarum*), gull-billed tern (*Sterna nilotica*), Caspian tern (*Hydroprogne caspia*), and red knot (*Calidris canutus*). It should be noted that the units of measurement that were used to estimate shorebird utilization changed between 1960 and 1970.

In 1950 and 1960, the total number of individuals within the PINWR boundaries was estimated (USFWS 1951, 1961). In 1970, 2006, and 2007, the estimated species days use (average population X number of days present) of the PINWR was recorded (USFWS 1971, 2007d, 2008). As shown in Figure IV-7 estimates for 1950 include 500 black skimmers, 400 common terns, 1,000 least terns, and 150 red knots.

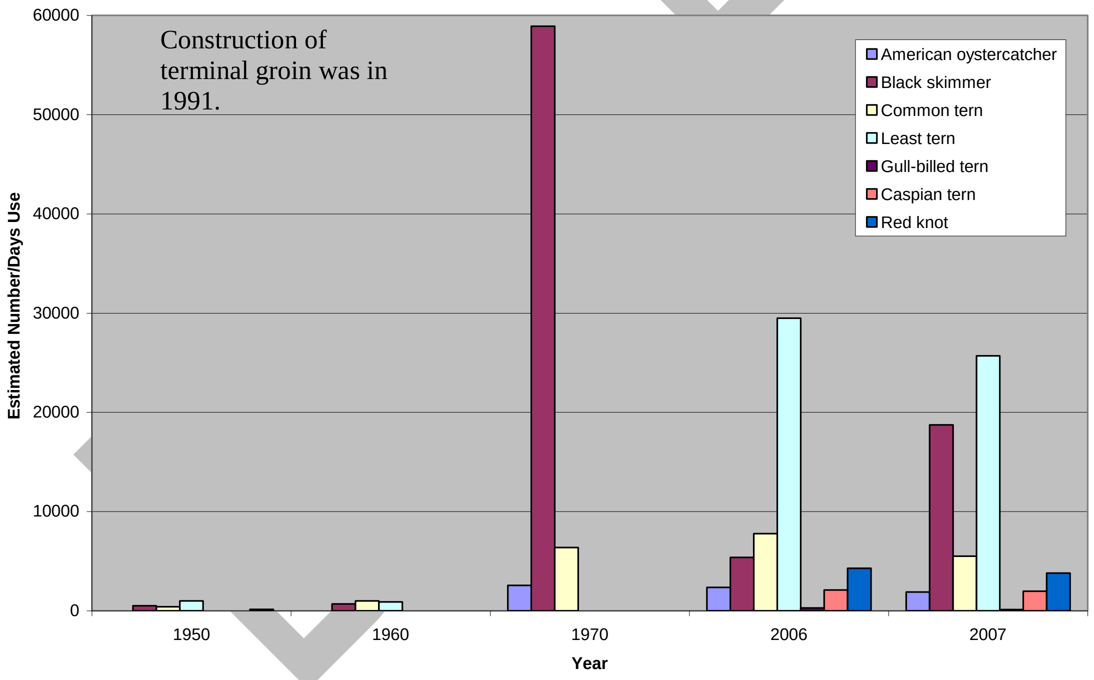


Figure IV-7. Shorebird Survey Data in the Vicinity of Oregon Inlet

Estimates for 1960 included 700 black skimmers, 1,000 common terns, and 900 least terns. Based on observations in 1970, the number of days use for black skimmers was estimated at 58,900 days. American oystercatchers (2,560 days use) and common terns (6,370 days use) were the only other species recorded during 1970. The 1970 total for all three species was 67,830 days use. During 2006 and 2007, all of the selected species were observed within the PINWR. Least terns were the most common species, with an estimated 29,486 days use in 2006 and 25,694 days use in 2007. The estimated number of days use for black skimmers declined to

5,387 days in 2006, followed by an increase to 18,727 days in 2007. With the exception of the black skimmer, the estimated number of days use for all species declined between 2006 and 2007. However, due to the large increase in the black skimmer population, the total number of days use for all species increased from 52,185 in 2006 to 57,924 in 2007, with peak numbers of 428 in September 2007. As described by USFWS (2008), black skimmers and least terns were observed nesting behind the terminal groin during 2007.

The pre-construction historical bird data as described above suggests the immediate groin location was not highly used. Following construction, a large sandflat developed behind the groin where shorebirds and colonial waterbirds nested (and still nest to some extent). As shown in Figure IV-8 and Figure IV-9 (comparison of 1991 aerial to 2009 aerial), some of this area is still kept in good bare sand condition by overwash from the ocean during storms, but much of the area is becoming or retaining heavy vegetation.

In fact, the number of piping plovers that use the site during migration and winter has declined as the vegetation has encroached into the site (Personal communication, D. Allen, NCWRC, October 2009). Terns, oystercatchers, and piping plovers depend on overwash habitats that are being converted to vegetated dune communities as a result of the terminal groin (Personal communication, D. Stewart, USFWS, February 2010).

Source: NCDOT, 1991

Figure IV-8. 1991 Oregon Inlet Aerial Photograph

Source: Dare County Color Aerial, NRCS 2009

Figure IV-9. 2009 Oregon Inlet Aerial Photograph

Federally Threatened Species

Piping Plover

Oregon Inlet serves primarily as a wintering area for the piping plover. Areas on either side of Oregon Inlet have been designated as critical habitat for wintering piping plovers. Successful nesting has been documented on Pea Island in the area just south of the terminal groin. Recent nesting attempts on Bodie Island have been unsuccessful, presumably due to predation and disturbance (USACE 2001). Annual piping plover data were obtained for Bodie Island, Pea Island, and Oregon Inlet Shoals (Figure IV-10 and Figure IV-11).

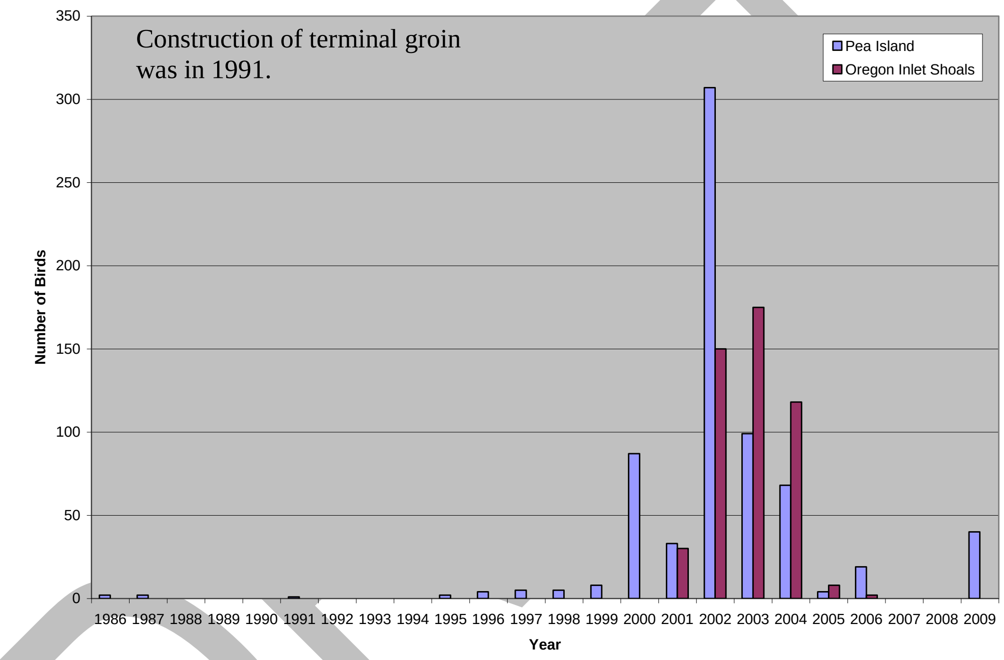


Figure IV-10. Annual Piping Plover Observations in the Vicinity of Pea Island

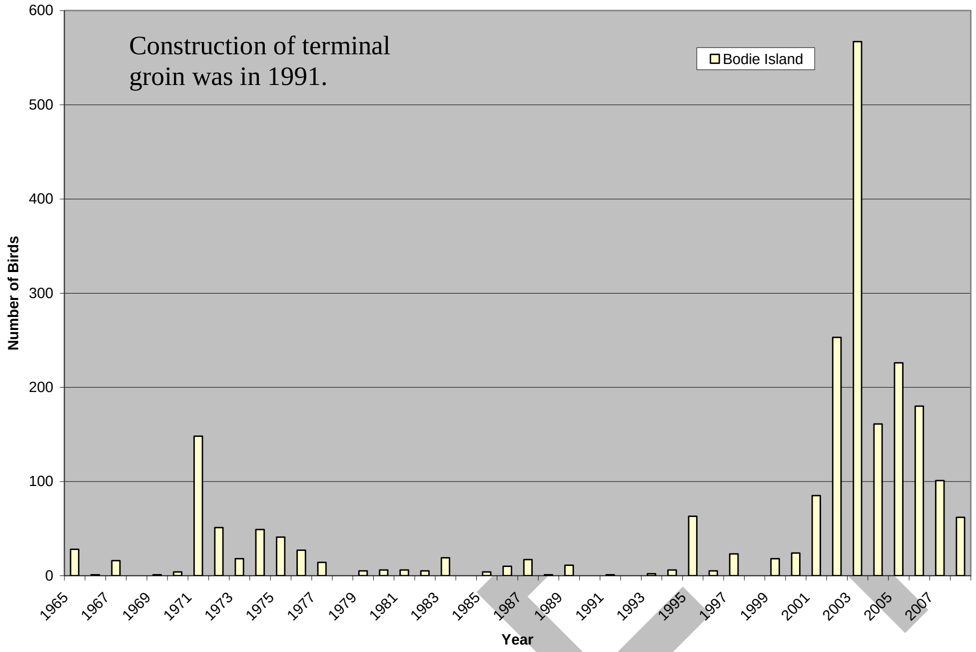


Figure IV-11. Annual Piping Plover Observations in the Vicinity of Bodie Island

Prior to 2001, annual piping plover observations on Bodie Island (just north of Oregon Inlet) were relatively low, with an annual average of 18 individuals observed from 1965 through 2000. The period of 2001 through 2003 was marked by a sharp increase in piping plover observations on Bodie Island. Annual observations during this period increased sharply to 85 individuals in 2001 and peaked at 567 individuals in 2003. Subsequent to 2003, annual piping plover observations on Bodie Island steadily declined, reaching a low of 62 individuals in 2008. Pea Island piping plover records date to 1986. Prior to 2000, annual piping plover observations on Pea Island were relatively low, with an annual range of 0 to 8 individuals and an annual average of 2 individuals observed from 1986 through 1999. In 2000, observations on Pea Island increased sharply to 87 individuals. Annual observations subsequently declined to 33 individuals in 2001, and increased sharply to 307 individuals in 2002. Pea Island observations declined steadily over the next three years, reaching a low of 4 individuals in 2005. Annual observations increased to 19 individuals in 2006; however, no piping plovers were reported from Pea Island during 2007 or 2008. In 2009, a total of 40 individuals were observed on Pea Island. Piping plover records for Oregon Inlet Shoals date to 2001, when a total of 30 individuals were observed. Observations increased to 150 individuals in 2002 and reached a peak of 175 individuals in 2003. The number of individuals observed on Oregon Inlet Shoals in 2004 remained relatively high at 118; however, observations declined sharply to 8 individuals in 2005 and 2 individuals in 2006. No piping plovers were reported from Oregon Inlet Shoals during 2007 or 2008. Fluctuations in annual observations at all three sites (i.e., Pea Island, Oregon Inlet Shoals, and Bodie Island) followed a similar pattern from 2000 through 2008. This common pattern is characterized by sharp increases in the number of annual observations from 2000 through 2003, followed by sharp declines from 2004 through 2008. .

Based on Cohen et al.'s (2008) study, piping plover habitat use at Oregon Inlet is strongly influenced by tidal stage. When water levels are low, exposing the intertidal areas of the sound islands, plovers prefer sound islands over both the ocean and sound sides of the barrier islands. Piping plovers in Alabama also prefer sand flat islands at low water levels (Zivojnivich and Baldassarre 1987). Other studies have shown that where wintering shorebird habitat availability depends on the tide, habitat selection is a function of safety at roost sites (Rogers et al. 2006), foraging habitat quality (Burger et al. 1977; Smith and Nol 2000; van Gils et al. 2006), and the distances between roosts and foraging areas (Dias et al. 2006; van Gils et al. 2006). As described by USFWS (2008) and depicted in Figure IV-8 and Figure IV-9, habitat behind the terminal groin has undergone succession due to wind and water-borne sand, and it is no longer as suitable for piping plover nesting and foraging habitat. Since the piping plover is primarily a winter resident at Oregon Inlet, the major threat to this species in the vicinity of the inlet is the degradation of beach foraging habitat (USACE 2001). Although, the construction of the terminal groin resulted in the formation of about a 50-acre fillet; thus, restoring and stabilizing the tip of Pea Island (Dennis and Miller 1993), and therefore providing valuable habitat in the years following construction for piping plovers (Figure IV-10).

Intense human disturbance in shorebird winter habitat can be functionally equivalent to habitat loss if the disturbance prevents birds from using an area (Goss-Custard et al. 1996), and can lead to roost abandonment and local population decline (Burton et al. 1996). In Cohen et al.'s (2008) study, piping plovers commonly roosted on the ocean beach south of Oregon Inlet and rarely roosted on the ocean beach north of the inlet, despite the fact that the southern beach was 2.1 and 4.5 times farther than the two most frequently-used foraging sites. The northern beach was used by off-road vehicles (ORVs) while the southern beach had only limited pedestrian traffic.

Most of the sound islands, such as Oregon Inlet Shoal (or Green Island) (Figure IV-8 and Figure IV-9) used by plovers were artificially created by the USACE, suggesting that constructed sand flats can successfully mitigate habitat loss due to other beach and inlet management activities or recreational disturbance, and may be useful in habitat restoration projects in general. However, in the case of Sand Shoal, no shorebird data has been collected by NCWRC since it washed away years ago due to the dynamic nature of Oregon Inlet (Personal communication, D. Allen, NCWRC, October 2009). Due to reoccurring habitat changes, birds will rotate between PINWR (behind the terminal groin) and the sound islands in which NCWRC indicated that most of the artificially created islands would not have been affected by the terminal groin except for Green Island, a natural shoal island (Personal communication, D. Allen, NCWRC, October 2009).

Plovers use engineered islands in which the most recent sand deposition ranged from 28 years to < ten years, suggesting that restoration efforts could have short- and long-term benefits (Cohen et al. 2008). Comparing NCDOT aerials as the terminal groin was constructed (1991, Figure IV-8) and after (2009, Figure IV-9), the loss of vegetation habitat is evident; however, the additional dune and sand created flats may provide plover and other shorebirds supplemental habitat.

(5) Fish and Fisheries

As described by Street et al. (2005); Beaufort, Ocracoke, and Oregon Inlets also support significant larval fish passage, although Oregon Inlet may be especially important due to the great distance between it and adjacent inlets, its orientation along the shoreline, and the direction of prevailing winds. Oregon Inlet provides the only opening into Pamlico Sound north of Cape Hatteras for larvae spawned and transported from the Mid-Atlantic Bight.

Oregon Inlet serves as an important passageway for the larvae of many commercially and economically important species. Larval fishes hatch in the open ocean, migrate inshore, pass through Oregon Inlet, and enter important nursery areas in the sounds. Passage through the inlet is a critical life cycle requirement for many species (USACE 2001). Oregon Inlet has very high larval fish diversity. Hettler and Barker (1993) documented 61 larval fish species that utilize the inlet. Different species utilize the inlet at different times of the year, and utilization is continuous throughout the year (Hettler and Barker 1993). Research indicates that larval fish in the ocean migrate westward until they encounter the shoreline and then move along the shoreline until they encounter the inlet. Consequently, shoreline structures that impede this lateral movement may have significant effects on transport through the inlet (USACE 2001).

The estuarine and ocean waters adjacent to the terminal groin support a great diversity of fish and shellfish species (NCDOT 1989). Seasonal variations in abundance and occurrence of fish and shellfish species are common, resulting from seasonal cycles of water temperature and the migratory patterns of species. As described by NCDOT (1989), common sport and commercial species found in the area include Atlantic croaker, spot, weakfish, spotted seatrout, bluefish, red drum, summer flounder, blue crab (*Callinectes sapidus*), and penaeid pink, white, and brown shrimp (*Farfantepenaeus duorarum*, *Lilopenanaeus setiferus*, and *Farfantepenaeus aztecus*); respectively.

As described in Street et al. (2005), a jetty's construction effect on fisheries has been discussed and reviewed at length by the scientific community in association with the proposed construction of a dual jetty system at Oregon Inlet (USACE 1999a). In the latest EIS (USACE 1999a), the Fish and Wildlife Coordination Act Report concluded that the Oregon Inlet project should not be constructed because of, among other concerns, the effect of jetties on larval fish passage. Miller (1992) and Settle [NMFS, unpublished (unpub.) data], in reviewing the potential effects of a dual jetty system at Oregon Inlet, estimated that successful passage of winter-spawned, estuarine-dependent larvae through Oregon Inlet could be reduced significantly. Although there are conflicting opinions on the magnitude of fisheries effects of a dual jetty system at Oregon Inlet, there is valid concern that construction of the structures would prevent some portion of ocean-spawned larvae from reaching estuarine nursery areas (USACE 1999a). Construction or lengthening of jetties, particularly where inlets occur infrequently along the coast (such as Oregon Inlet), could lower successful fish recruitment and fishery productivity (Kapolnai et al. 1996; Churchill et al. 1997; Blanton et al. 1999).

Joyner et al. (1998) conducted a study of the post-stabilization morphology of Oregon Inlet to determine the relationship between the growth of the Bodie Island spit to the north and the resulting bathymetric changes in the inlet. This study provided insight as to the expected changes in configuration of the main inlet channel as the southern migration of Bodie Island spit approached the terminal groin along northern PINWR. Accretion of the spit on Bodie Island and the location of the terminal groin were responsible for a change in location and orientation of the main channel section. Channel deepening also occurred and in order to maintain a constant cross-sectional area, a narrowing inlet must become deeper to accommodate the same discharge volume (also known as tidal prism). The data shows that this has happened since the terminal groin was constructed. According to Joyner et al. (1998), Oregon Inlet exhibited changes as expected with the stabilization of a single side of a tidal inlet. An inlet's morphological changes may affect larval and fish transport. According to Street et al. (2005), the construction of new or expanded jetties or groins along North Carolina's ocean shoreline should not be allowed until field research has been completed to assess the effect of jetties on successful larval passage through inlets into estuaries, particularly in Pamlico Sound where inlets are limited.

(6) Benthic Resources

In association with the construction of the terminal groin and placement of Oregon Inlet maintenance dredged material on Pea Island, the USFWS has monitored infauna along the PINWR's shoreline since the early 1990s. Effects on mole crabs, coquina clams, polychaetes (marine worm), and ghost crabs (*Ocypode quadrata*) have been routinely monitored. In a 1 September 1994 report, preliminary monitoring results showed mole crab and coquina numbers were significantly reduced following shoreline placement of Oregon Inlet maintenance dredged material. Ghost crab numbers did not seem affected and the marine worm numbers increased (Dolan 1994).

In a 10 September 2001 report, swash zone organisms including mole crabs, coquina clams, polychaetes, and amphipods were monitored assessing dredged material placement along PINWR down drift of the terminal groin. Hopper dredge plants placed Oregon Inlet maintenance material in an inshore zone at water depths between 12 and 18 feet. The numbers of organisms immediately onshore of the placement areas were reduced; however, the sediment volume placed during 2000 through 2001 was not enough to significantly inhibit the beach face organisms for an extended period of time (Dolan 2001a).

A "Summary of Results of Dredging and Sand Bypassing" dated 20 October 2001 compared effects from both hopper nearshore placement and direct pipeline placement of maintenance dredged material from Oregon Inlet on downdrift shorelines from Pea Island's terminal groin (Dolan 2001b). Although the terminal groin limits natural sand bypassing, artificial sand placement on Pea Island has probably mitigated some of these impacts (Personal communication, H. Hall, USFWS, February 2010). Within the past 20 years, approximately six million cubic yards of maintenance dredged material have been bypassed from the inlet to Pea Island by shallow-draft hopper dredges and by direct pipeline placement. Shallow placement by hopper dredges reduced the sediment budget sand losses; yet altered the onshore beaches sediment characteristics. Direct pipeline placement provided maximum effect on erosion, but with the highest potential for biological effects. Beach-face fauna are covered for extended periods of time and pipeline discharges directed into the upper reaches of the shoreline dislocate ghost crabs and shorebirds (Dolan 2001b).

The underlying effects on the infaunal communities within a terminal groin fill is directly related to the fill material size, the volume of material placed, and the seasonal material placement (Personal communication, H. Hall, USFWS, February 2010). Mole crabs and coquina clams stay within the swash zone but move up and down the beach through wave action transport. Mole crabs vibrate lower limbs creating a "quicksand" condition allowing ease of burrowing. If placed material is too well sorted, contains a surplus of heavy minerals, too coarse, or too fine;

the mole crabs' ability to burrow is compromised or deterred (Dolan 1999). These infauna species are also responsive to ambient water and air temperatures. On PINWR, they appear in early April, peak in late summer, and hibernate for the winter off the beach-face and in the nearshore zone. The placement of terminal groin fill in late summer may affect the populations' yearly cycle, possibly carrying over to the spring re-emergence. The health of these macroinvertebrates is also tied to water quality. If the terminal groin's fill material has an elevated percentage of silts and clays (resulting in higher surf zone turbidity levels), these filter feeding organisms' swash zone distribution and offshore wintering characteristics may be significantly affected (Dolan 1999). PINWR places sand on the beach in a manner that mimics a cuspate pattern. These intermittent placements create a series of undisturbed and disturbed placement zones (Personal communication, D. Stewart, USFWS, February 2010).

Scarps may refer to hardbottom areas which are amply hardened and distinguish themselves in elevation from adjacent seafloor contours. Few of these elevation distinguished features were found in a survey conducted in 1998, adjacent to Bodie Island, north of Oregon Inlet (Boss et al. 1999).

A sessile community has likely developed on the terminal groin's structural components. Site specific studies supporting this inference were not found; however, a comparison was made to the natural coquina outcropping in southern North Carolina as to possible species that may take residence on the subtidal elements of Oregon Inlet's terminal groin. Such potential species included sea lettuce (*Ulva lactuca*), hollow green weeds (*Enteromorhpa* sp.), sea anemone (*Bunodosoma cavernata*), oysterdrill (*Urosalpinx cinerea*), calcareous tube worm (*Eupomotus dianthus*), and various polychaetes and crabs (USACE 2001).

Live hardbottom habitat has not been documented along or near Bodie or Pea Island shorelines adjacent to Oregon Inlet although hardbottom has been documented offshore of Oregon Inlet (Moser and Taylor 1995; SEAMAP 2001; Personal communication, A. Deaton, NCDMF, February 2010). As noted in NCDOT (2008), no live/hardbottom habitat is designated in the vicinity of Oregon Inlet by the SAFMC. Hardbottom outcroppings within depths potentially affected by the terminal groin or associated beneficial use of dredged sand have not been recorded.

2. Fort Macon, Beaufort Inlet, North Carolina

a) General Site Description

Beaufort Inlet is one of the most managed inlets in North Carolina (Figure IV-12). When discussing environmental resources and potential effects, the number of ongoing projects in this area should to be considered. As shown in Figure IV-13, a late 1970's photograph looking east to west towards Beaufort Inlet depicts a historical rock structure on Shackleford Banks. The structure is landlocked as the inlet migrated to the west in the last 50 years (Moslow and Heron 1994). The State Port at Morehead City has a navigational channel approximately 45 feet deep through Beaufort Inlet. The beaches along Fort Macon State Park periodically receive dredged material disposal from maintenance dredging of the navigation channels, most recently during 2007 (Personal communication, R. Rudolph, Carteret County Shoreline Protection Office, March

2009). The US Coast Guard has a base on the north side of Fort Macon State Park; the shoreline of this base is stabilized with riprap, groins, and bulkheads.

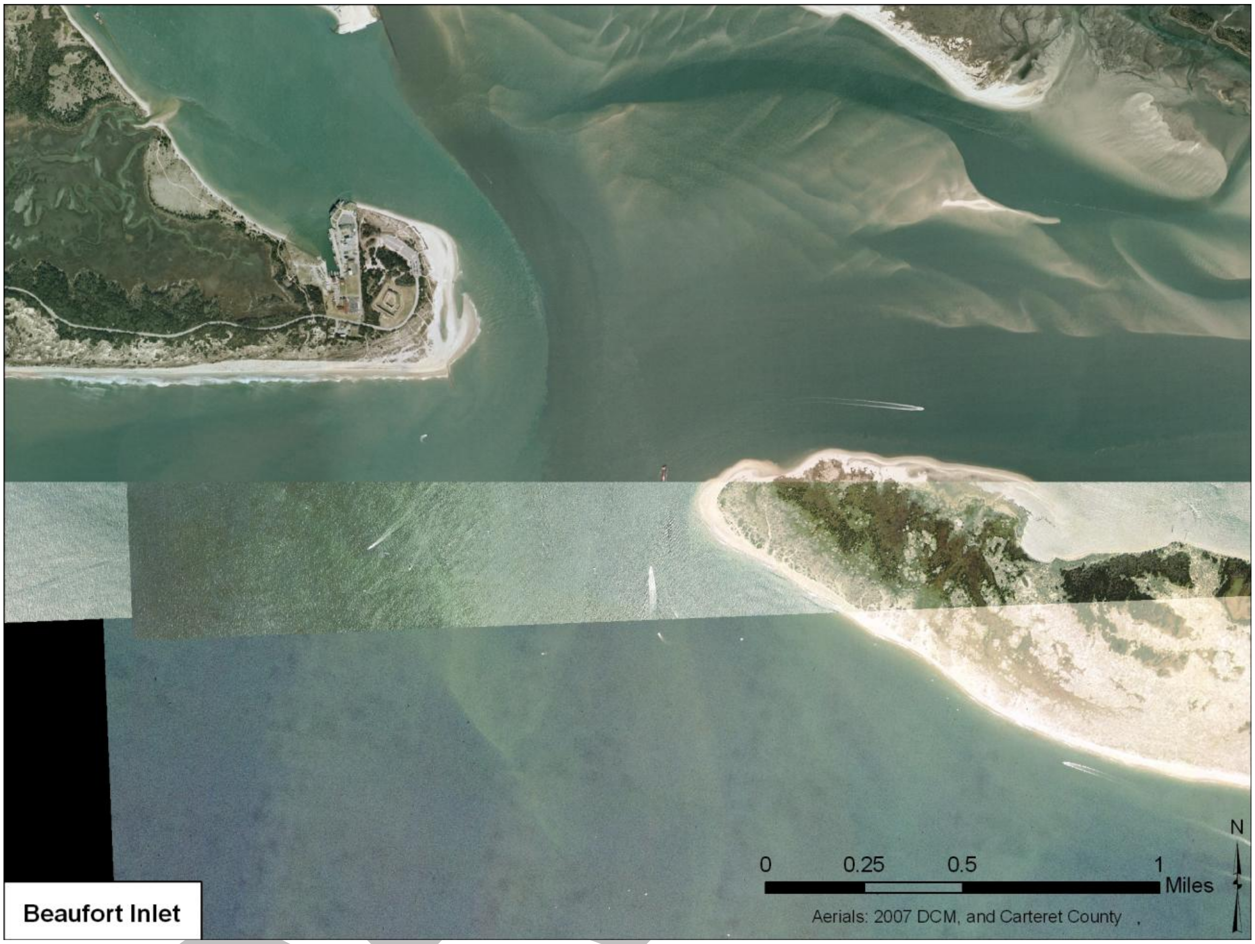


Figure IV-12. Beaufort Inlet

Interior islands have been created by dredged material and/or artificially stabilized. The shoreline at the State Port is entirely bulk-headed and large sections are a result of dredged material fill including significant portions of Radio and Brandt Islands. According to Hay and Sutherland (1988), there are two small jetties near Beaufort Inlet. The Radio Island jetty was built prior to 1939 to prevent the shoaling of Bulkhead Channel leading to Beaufort Harbor. Early surveys suggest that the Shackleford jetty was constructed near the turn of the century in an early attempt to stabilize Beaufort Inlet. Neither of these structures is more than 980 feet in length (Figure IV-13).

Figure IV-13. Hard Structure Located on Western End of Shackelford Banks
Source: Cape Lookout National Seashore, Michael Rikard

Prior to the principal navigation improvements from 1876 through 1933, Bogue Banks was advancing eastward toward the inlet, and Shackleford Banks was retreating eastward away from the inlet. After 1936, the shoreline processes reversed. Bogue Banks retreated rapidly back toward its 1876 location, and efforts were made to stabilize its eastern shoreline by small groins and structures built to protect Fort Macon (circa 1950s). Shackleford Banks advanced westward, approaching its current location by 1974. Over the next 30 years, from 1974 to 2004,the Bogue Banks shoreline recovered slightly as a result of beach fill placement from inner-harbor dredging. The sand spit at Fort Macon advanced along and into the western bank of the navigation channel inside the inlet throat, and Shackleford Banks advanced into the eastern bank of the channel at the inlet throat.

As described by the Carteret County Shore Protection Office (2002), the Morehead City Harbor Federal Navigation Project involves maintenance dredging of Beaufort Inlet that separates Shackleford and Bogue Banks, located to the east and west of the inlet, respectively. There have been several prior studies in the study area and adjacent waters by the USACE Wilmington District (USACE 1976b, 2003).

Approximately 10,012,600 cubic yards of dredged material has been placed west of the terminal groin from Fort Macon to Atlantic Beach (Carteret County Shore Protection Office 2002). In a 1993 consistency position letter, the NCDCM requested the USACE to modify the project to include alternatives that would preferably dispose dredged material on the ocean beach or shallow active nearshore area. In order to fulfill the requirements set forth in this correspondence, the USACE constructed a nearshore berm complex located along the 25-foot bathymetric contour that was anticipated to reintroduce beach-quality sand into the littoral draft feeding Bogue Banks. The nearshore berm was initially constructed in 1996 and has been used for dredge disposal since that time (Figure IV-14). In the 2001 Section 111 Feasibility Report, the USACE noted that material placed at the nearshore site has exhibited little movement.

Figure IV-14. Existing and Proposed Nearshore Disposal Locations for Beaufort Inlet
Source: USACE – Wilmington District (2009)

(1) Aesthetics

Aesthetic effects of the terminal groin and subsequent placement of dredged material have been both positive and negative. Beach placement temporarily affects aesthetics due to the presence of heavy equipment, pipelines, and incompatible material on the beach. The placement of poor quality material resulted in elevated turbidity in the surf zone. Noise and combustion exhaust created by the operation of the dredge and other equipment resulted in minor increases in noise and air pollution (USACE 2003). However, not all placement events were of questionable quality, the terminal groin has protected Fort Macon as designed; and upon completion of most beneficial placement events, the aesthetics and recreational use of the beach have been enhanced due to the wider beach.

(2) Recreation/Public Access

Fort Macon State Park is located at the east end of Bogue Banks overlooking Beaufort Inlet, just south of Brandt Island. This park is North Carolina's most visited park, with approximately 1.4 million visitors each year (Fort Macon State Park 2000). Fort Macon State Park was opened in 1936 as the state's first functioning park. Facilities include a seaside bathhouse, restrooms, refreshment stand, designated fishing and swimming areas, picnic tables, outdoor grills, and a short nature trail. Bird and wildlife viewing are popular activities at the park. Recreational resources of statewide significance are centered on Fort Macon and the beach (Fort Macon State Park 2000). The restored 19th-century fort provides historical educational opportunities that are not available elsewhere in North Carolina, and the park's diverse coastal environment also provides a broad range of educational opportunities. These areas are utilized by tourists and local residents throughout the year.

b) Natural Resources

As described by USFWS (2002), the Beaufort Inlet area has been characterized as a significant resource. The NCNHP has delineated several SNHA within the area, including the Rachel Carson National Estuarine Research Reserve (NERR) to the northeast and Shackleford Banks to the east.

The Fort Macon Registered Natural Heritage Area covers 350 acres and encompasses the entire park with the exception of the areas that are developed with recreational facilities or the fort itself (Fort Macon State Park 2000). The natural area provides a good example of a typical sea-to-sound barrier island community developed over the various geological and topographical features of the island.

The Fort Macon State Park profile (2000) consists of a continuous line of dunes which in turn supports a dune grass natural community dominated by sea oats (*Uniola paniculata*) and seaside little bluestem (*Schizachyrium littorale*). The interior portion supports a maritime shrub natural community which is a dense thicket of coastal red cedar (*Juniperus virginiana*), stunted live oak (*Quercus virginiana*) and loblolly pine (*Pinus taeda*), yaupon (*Ilex vomitoria*) and wax myrtle (*Myrica cerifera*). There are small pockets of maritime forest with similar species but a taller canopy. The sound side of the park has a salt marsh dominated by saltmarsh cordgrass.

Tidal inlets including Beaufort Inlet have also been designated as Habitat Areas of Particular Concern (HAPC) for red drum, penaeid shrimp and the snapper-grouper complex by the SAFMC (NCDMF 2000). The USFWS has designated critical habitat for overwintering piping plovers at the Rachel Carson NERR and Shackleford Banks (2002). Shackleford Banks forms the southernmost portion of Cape Lookout National Seashore (CLNS) and has also been designated a Wilderness Area. The United States Congress has designated Fort Macon State Park and portions of Beaufort Inlet as covered by the Coastal Barrier Resources Act (CBRA) or within a CBRA zone, coincident with the boundaries of the NERR and CLNS. Figure IV-15 depicts the numerous coastal resources present within the vicinity of Beaufort Inlet and the Fort Macon terminal groin.

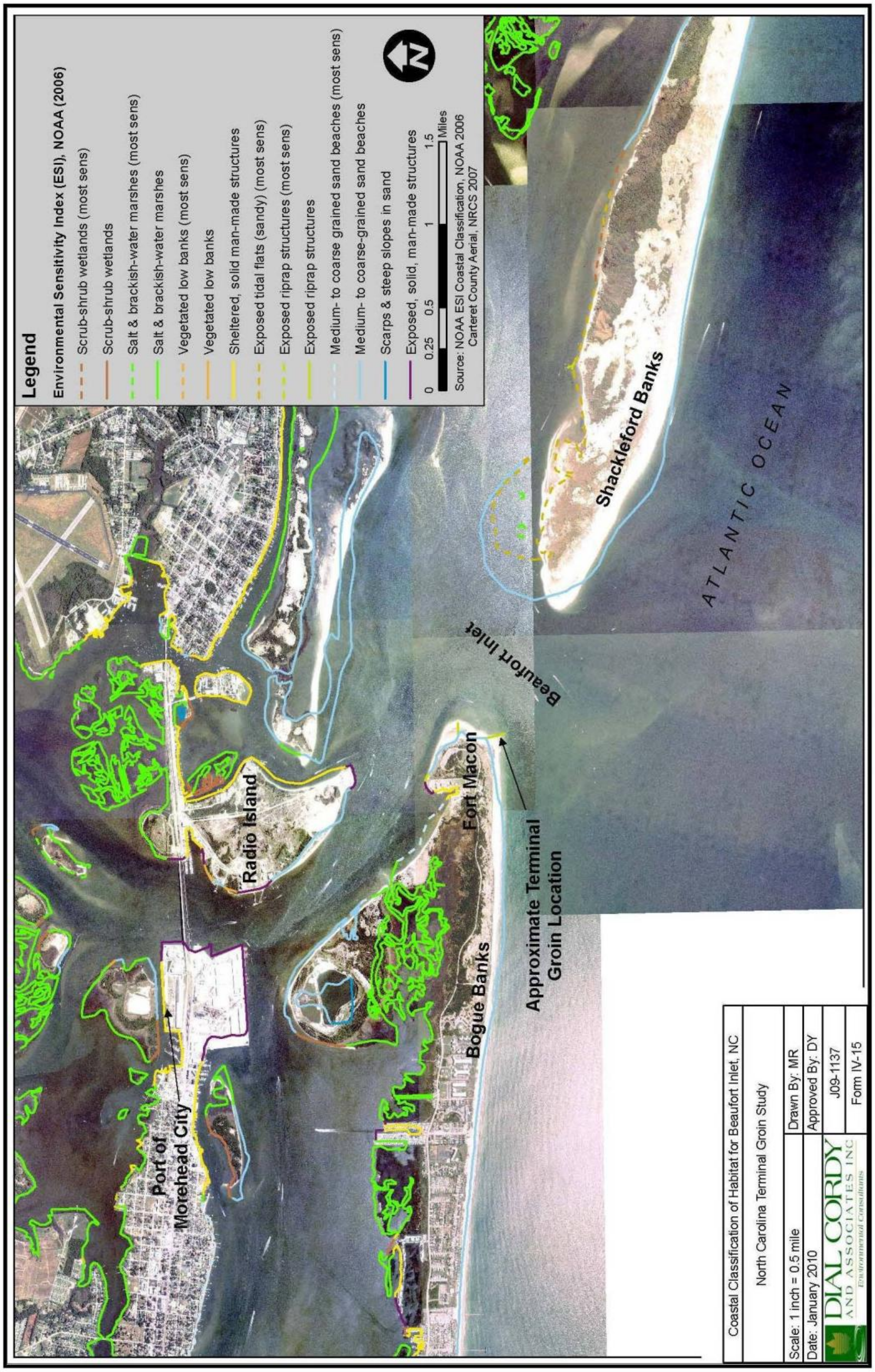
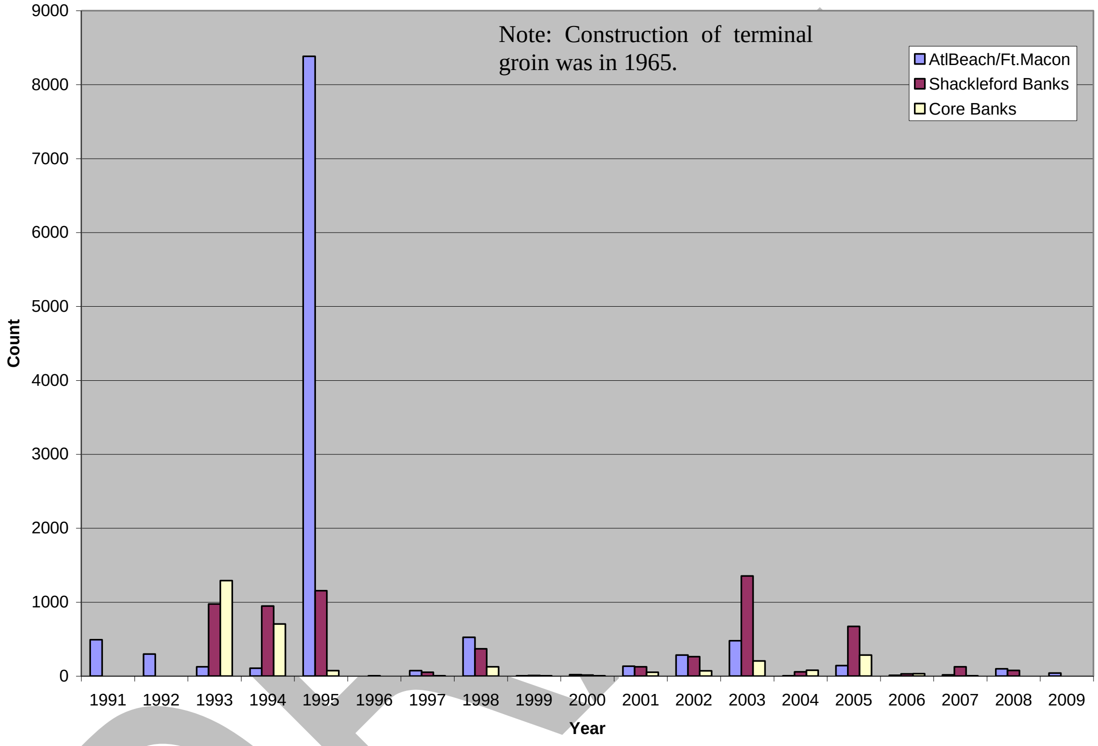


Figure IV-15. Coastal Classification of Habitat for Beaufort Inlet, NC

(1) Seabeach Amaranth

Seabeach amaranth on Fort Macon/Atlantic Beach has been monitored since 1991 (Figure IV-16). The number of plants observed on Fort Macon/Atlantic Beach declined steadily from 490 plants in 1991 to 106 plants in 1994. The population increased sharply in 1995, with a total of 8,382 plants observed. No plants were observed in 1996, and only 74 were observed in 1997. The population increased to 525 plants in 1998, followed by a decline to four plants in 1999. Over the next four years, the population increased steadily, reaching a high of 479 plants in 2003. Since 2003, the annual number of plants has ranged from 4 to 142.



Note: Construction of terminal groin was in 1965.

Figure IV-16. Seabeach Amaranth Plants for the Beaufort Inlet Area

Seabeach amaranth plants on Shackleford Banks have been monitored since 1993. A total of 975 plants were observed in 1993. Numbers remained relatively high over the next two years, with 948 plants observed in 1994 and 1,155 plants observed in 1995. The population declined to three plants in 1996, and only 51 plants were observed in 1997. The population increased to 369 plants in 1998, followed by a decline to nine plants in 1999. Over the next four years, the population increased steadily, reaching a high of 1,354 plants in 2003. Since 2003, the annual number of plants has ranged from 30 to 671.

As a comparison to an unmanaged barrier island, Core Banks survey data was included in this evaluation. Seabeach amaranth at Core Banks have been monitored since 1993. A total of 1,290 plants were observed in 1993. Numbers remained relatively high in 1994, with a total of 704 plants observed. The population declined sharply over the next three years, with 75 plants observed in 1995, one plant observed in 1996, and two plants observed in 1997. The population increased to 125 plants in 1998, followed by a decline to two plants in 1999. Over the next four years, the population increased steadily, reaching a high of 206 plants in 2003. Since 2003, the annual number of plants has ranged from zero to 284.

Fluctuations among the three populations, shown in Figure IV-16, exhibit similar patterns over the course of the monitoring period. All of the populations experienced significant declines between 1995 and 1996, and the number of plants in all three populations remained low in 1997. All three populations experienced significant increases in 1998. All three populations declined sharply in 1999, remained low in 2000, and increased steadily over the course of the following three years (2001-2003). All three populations experienced sharp declines in 2004, followed by significant increases in 2005 and subsequent declines in 2006.

Seabeach amaranth experiences a great deal of natural population variability from one year to the next. These natural fluctuations can be attributed to a number of factors; such as erosion, storms, and seed dispersal. Habitat loss due to hurricanes may have contributed to the dramatic decline in seabeach amaranth numbers from 1997 to 2000 as evidenced by the post-hurricane data from Hurricane Fran (1996) and Hurricane Floyd (1999) (USACE 2006).

(2) Seagrass

In 1981, visible SAV in Core and Bogue sounds covered 19,458 acres [8.4 million square feet (ft^2)] within a total water area of 104,840 acres (19 percent SAV coverage; Carraway and Priddy 1983). However, acreage for these areas may be underestimated, particularly in low salinity riverine areas, since aerial photography at the scale utilized (1:24,000) may not be able to detect some SAV due to the relatively small patch size and high turbidity of the water (Street et al. 2005). In contrast, considerable SAV loss may have occurred in Morehead City when the port access channels were originally dredged, given that nearby, similar yet undredged areas within Bogue Sound support SAV. As indicated by Street et al. (2005), because almost all of the eastern shoreline of Core Sound and the southern shoreline of Back Sound are undeveloped (Shackleford and Core Banks), the seagrass beds in that area have not been highly effected by channel dredging, marinas, or docks. As seen in Figure IV-17, seagrass is not present in Beaufort Inlet; however, it is present on the sound side of Fort Macon and within the inner part of Carrot Island, approximately 1.2 miles away from the inlet (Personal communication, D. Field, NOAA, February 2010; Personal communication, S. Chappell, NCDMF, February 2010).

Figure IV-17. Seagrass Habitat for Beaufort Inlet, NC

(3) Sea Turtles

The Sea Turtle Monitoring Project, initiated in 2002 by NCWRC, was designed to observe and record sea turtle nesting activity on the island of Bogue Banks (Hollowman and Godfrey 2006). The project area included the ocean-facing beaches on Bogue Banks with the Atlantic Beach/Fort Macon State Park area evaluated in this study (Figure IV-18). As a comparison to an ocean-facing beach that has not been nourished, Shackelford Banks and Core Banks sea turtle nesting data were also included in the analysis. Sea turtle nesting activities on Bogue Banks included research data relative to the effects of beach nourishment on sea turtle nesting: sand compaction, sand temperature, and nest temperature throughout the sea turtle nesting seasons.

The study of the effects of beach renourishment on sea turtle nesting was initiated following concern that the material placed on the beach during nourishment may be different from what originally existed on the nesting beaches (Holloman and Godfrey 2006). The differences in sediment may have negative effects on sea turtle reproduction. For instance, characteristics such as sand compaction and sand temperature directly affect sea turtle nests. Sex determination in hatchlings is dependent upon the temperature at which nests incubate: higher temperatures yield greater numbers of females while cooler temperatures result in more male hatchlings (Wibbels 2003). Although, as discussed by Street et al. (2005), soft stabilization offers an alternative to hard stabilization that has less severe habitat effects and some positive effects. For example, wider beaches from properly constructed beach nourishment projects can enhance sea turtle nesting habitat.

Figure IV-18. Species Occurrence for Beaufort Inlet, NC

Given that darker colors absorb more solar radiation, sediment used as beach fill could result in warmer nests if turtles lay their eggs in darker nourished sand (Hays et al. 2001). North Carolina is roughly the northern boundary of sea turtle nesting in the southeastern United States. North Carolina sand temperatures are cooler than those of more southerly states, thereby producing relatively more male hatchlings than more southerly states (Mrosovsky et al. 1984; Mrosovsky and Provancha 1992). Other potential effects include the possibility that dark sediment could create nest temperatures that are too hot for successful incubation or that the nourished material is too compact for successful nest construction. Although Fort Macon was not included in the study initiated in 2000 by the NCWRC (Personal communication, M. Godfrey, NCWRC, November 2009), it was concluded that sand temperatures in nourished areas were warmer than non-nourished areas (Hollowman and Godfrey 2006).

Regular monitoring of sea turtle nesting activity has been conducted on Shackelford Banks since 1990 (Figure IV-19). On average, 10 nests have been recorded annually over the course of the last 19 years. No obvious trends in nesting activity are evident over the course of the 19 year monitoring period. Highly productive years include 1993 (20 nests), 1995 (16 nests), 1997 (13 nests), 1998 (21 nests), 2003 (16 nests), 2005 (16 nests), and 2008 (15 nests). Regular monitoring of sea turtle nesting activity at Fort Macon State Park has been conducted since 1985 (Figure IV-19). On average, 3.5 nests have been recorded annually over the course of the last 24 years. During the period of 1985 through 1993, the number of annual nests ranged from one to 13, with an annual average of five nests. No nests were recorded in 1994, 1995, or 1996.

During the period of 1997 through 2008, the annual number of nests ranged from zero to six, with an annual average of three nests. As depicted in Figure IV-19, other than the lack of nesting activity from 1994 through 1996, no obvious trends in nesting activity are evident over the course of the 24-year monitoring period.

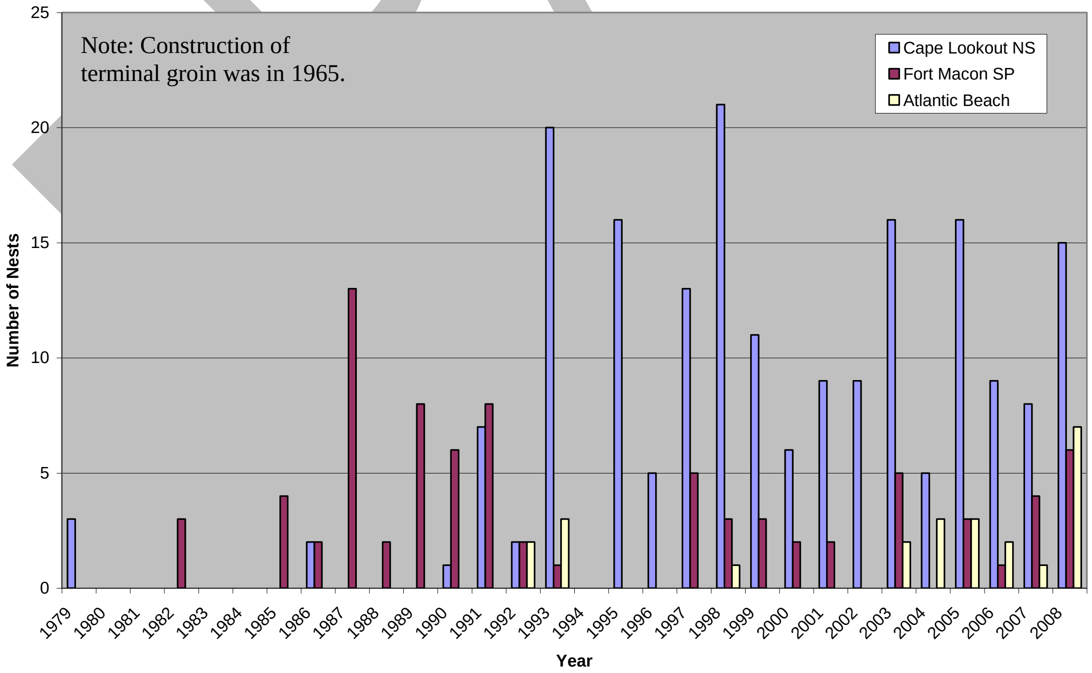


Figure IV-19. Sea Turtle Nesting Activity for the Beaufort Inlet Area

Although historical data for sea turtle nesting was obtained, it is difficult to analyze as Fort Macon State Park relocates most of the nests due to the high number of tourists (Personal communication, M. Godfrey, NCWRC, November 2009). However, in the case of Fort Macon State Park, the high number of visitors has likely had little effect on whether or not a female sea turtle will nest, since the park is closed to the public after sunset. On the other hand, human effect may be disturbing female nesting sea turtles in Atlantic Beach, which tends to be rather "busy" at night during the nesting season (Personal communication, M. Godfrey, NCWRC, November 2009).

(4) Shorebirds and Waterbirds

Tidal shoals that are sub-aerial during low tides are valuable foraging and roosting habitat for migratory shorebirds and colonial waterbirds (USFWS 2002). Some of these shoals are supra-tidal even at high tide and provide additional habitat to numerous species of shorebirds and colonial waterbirds species. In 1998, the Beaufort Inlet system encompassed approximately 463 acres of shoals and inlet shoulders available to shorebirds and colonial waterbirds (Figure IV-20). This was the fifth largest flood tidal shoal system in North Carolina with only Cape Fear River, New Drum, Oregon, and Ocracoke Inlets exceeding it. Overall, Beaufort Inlet provided the sixth largest inlet complex in North Carolina in terms of habitat available to migratory shorebirds and waterbirds in 1998 (USFWS 2002).

The inlet shorelines on both Beaufort Inlet and Shackleford Banks have supported bird nesting habitat for black skimmer, common tern, gull-billed tern, and least tern (Figure IV-20); NCWRC, unpublished data). During migratory periods, thousands of birds are commonly found in and around Beaufort Inlet. Birds commonly seen in Beaufort Inlet during the winter months include common loon (*Gavia immer*), double-crested cormorants (*Phalacrocorax auritus*), red-breasted mergansers (*Mergus serrator*), northern gannets (*Morus bassanus*), Bonaparte's gulls (*Larus philadelphia*), great blue heron (*Ardea herodias*), and black-crowned night-herons (*Nycticorax nycticorax*). Willets (*Tringa semipalmata*), ruddy turnstone (*Arenaria interpres*), sanderlings (*Calidris alba*) and various gull species are often found along the beaches of Fort Macon State Park during the winter (Personal communication, R. Newman, Fort Macon State Park, October 2009). Avian use of the inlet shoreline at Fort Macon State Park can attract birds not regularly seen at North Carolina inlets [e.g., purple sandpiper (*Calidris maritima*), scoters (Anatidae sp.), eiders (Anatidae sp.), and ducks] because of several rock structures (Fussell 1985). Most commonly during the summer, the western side of Beaufort Inlet supports willets, ruddy turnstone, black-bellied plover (*Pluvialis squatarola*), sanderlings, gulls, and terns. Spring and fall migratory periods bring red knot, whimbrel (*Numenius phaeopus*), western sandpiper (*Calidris mauri*), scoters, common loon, red-throated loon, heron, egret, and white ibis (*Eudocimus albus*) (Fussell 1985). Gull-billed terns, black skimmers, and terns have nested in the past at Beaufort Inlet (Personal communication, D. Allen, NCWRC, October 2009).

Figure IV-20. 1998 Aerial Photograph of Beaufort Inlet, NC

Waterbirds regularly seen at the Rachel Carson NERR are black tern, common tern, sandwich tern, black skimmer, cormorant (Family Phalacrocoracidae), glaucous gull (*Larus hyperboreus*), Iceland gull (*Larus glaucoides*), lesser black-backed gull (*Larus fuscus*), Bonaparte's gull, little gull (*Hydrocoloeus minutus*), brown pelican (*Pelecanus occidentalus carolinensis*), black-crowned night-heron, and white ibis (Fussell 1985). Within the inlet itself, Radio Island and the Rachel Carson NERR both generate diverse bird watching. At the Rachel Carson NERR, which Fussell (1985) refers to as the Bird Shoal Complex for its avian diversity, common shorebird species include American oystercatcher, semipalmated plover (*Charadrius semipalmatus*), ruddy turnstone, willet, whimbrel, greater yellowlegs (*Tringa melanoleuca*), short-billed dowitcher (*Limnodromus griseus*), marbled godwit (*Limosa fedoa*), dunlin (*Calidris alpine*), red knot, long-billed curlew (*Numenius americanus*), western sandpiper, semipalmated sandpiper, sanderling, piping plover, black-bellied plover, and Wilson's plover.

Wilson's plover nesting surveys were conducted by Park Service personnel on CLNS from 2006 through 2009 (Figure IV-21). The annual number of nesting pairs on Shackleford Banks ranged from 14 to 32. The number of nesting pairs increased from 14 in 2006 to 32 in 2008, followed by a decrease to 18 nesting pairs in 2009. During this same period, the number of nesting pairs on North and South Core Banks were generally two to three times greater than the number of pairs on Shackleford Banks. The number of nesting pairs on North and South Core Banks increased steadily from 28 in 2006 to 64 in 2009. Nesting surveys for the least tern, black skimmer, common tern, and gull-billed tern were conducted by Park Service personnel on Shackleford Point in 1992, 1993, and 1995 (Figure IV-22). The total number of nests for all species increased from 277 in 1992 to 592 in 1993, followed by a decrease to 60 nests in 1995. American oystercatcher nesting activity has been monitored on CLNS since 1995 (Altman 2008); however, surveys conducted prior to 2003 did not include Shackleford Banks, and survey results from 2003 onward do not differentiate between Shackleford Banks and North/South Core Banks. The number of nests has remained steady over the course of the monitoring period (Figure IV-23), with an annual average of 81 nests.

Lack of historic natural resource data hinders drawing conclusions on the effects of the construction and operation of the terminal groin on natural resources. However, the inlet shoreline adjacent to the Fort Macon terminal groin does not appear to be suitable for either colonial nesters or shorebirds based on preliminary analysis of historical aerial photographs and available historical shorebird and colonial waterbird data. Colonial waterbirds and shorebirds depend on ephemeral habitats while stabilization of inlet shoreline usually causes vegetational growth that results in unsuitable habitat (Personal communication, D. Allen, NCWRC, October 2009), and not having historical pre-construction bird surveys makes it difficult to conclusively say the terminal groin alone is the cause of loss of suitable habitat.

Annual least tern and Wilson's plover observations at Fort Macon State Park were recorded by the park ranger between 1994 and 2009 (Figure IV-24). The numbers of annual observations were highly variable over the course of this period. An annual average of 44 least terns were observed from 1994 through 2000. No least tern observations were recorded in 2001 and 2002. Least tern observations declined steadily from 168 in 2003 to 5 in 2008, followed by a sharp increase to 281 in 2009. Wilson's plover observations remained low throughout the period of record. An annual average of three Wilson's plovers was observed between 1996 and 2000. No

Wilson's plover observations were recorded in 2001 and 2002, and an annual average of 11 Wilson's plovers were observed between 2003 and 2009.

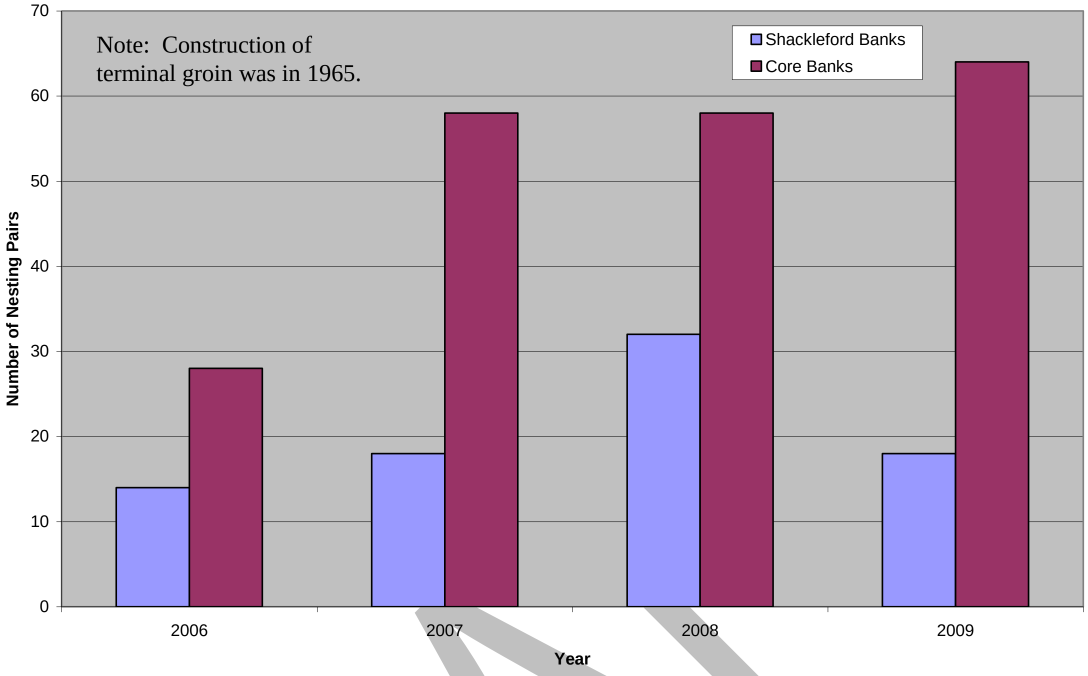


Figure IV-21. Wilson's Plover Nesting Survey Data (CLNS)

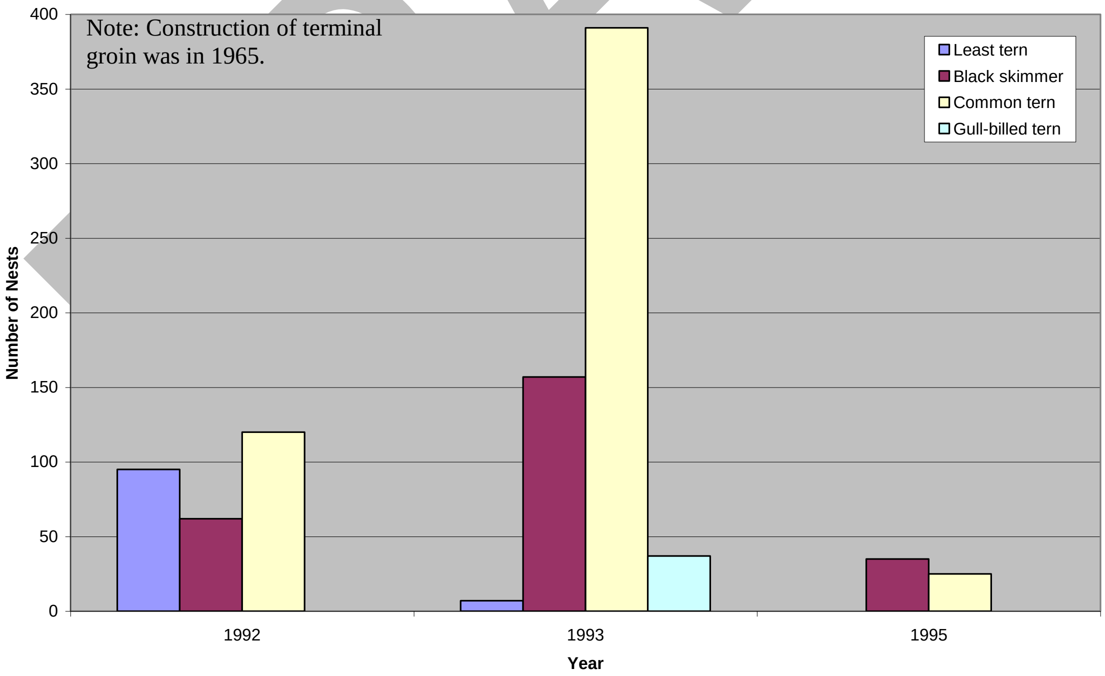


Figure IV-22. Nesting Surveys For The Least Tern, Black Skimmer, Common Tern, and Gull-Billed Tern (Shackleford Point)

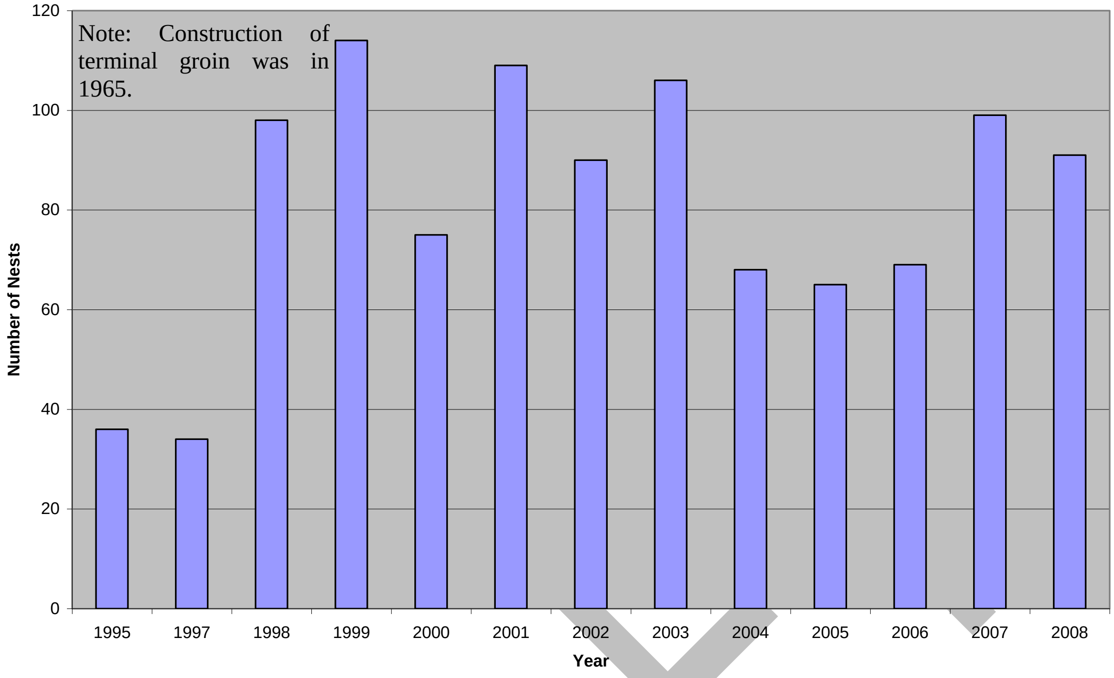


Figure IV-23. American Oystercatcher Nesting Activity (CLNS)

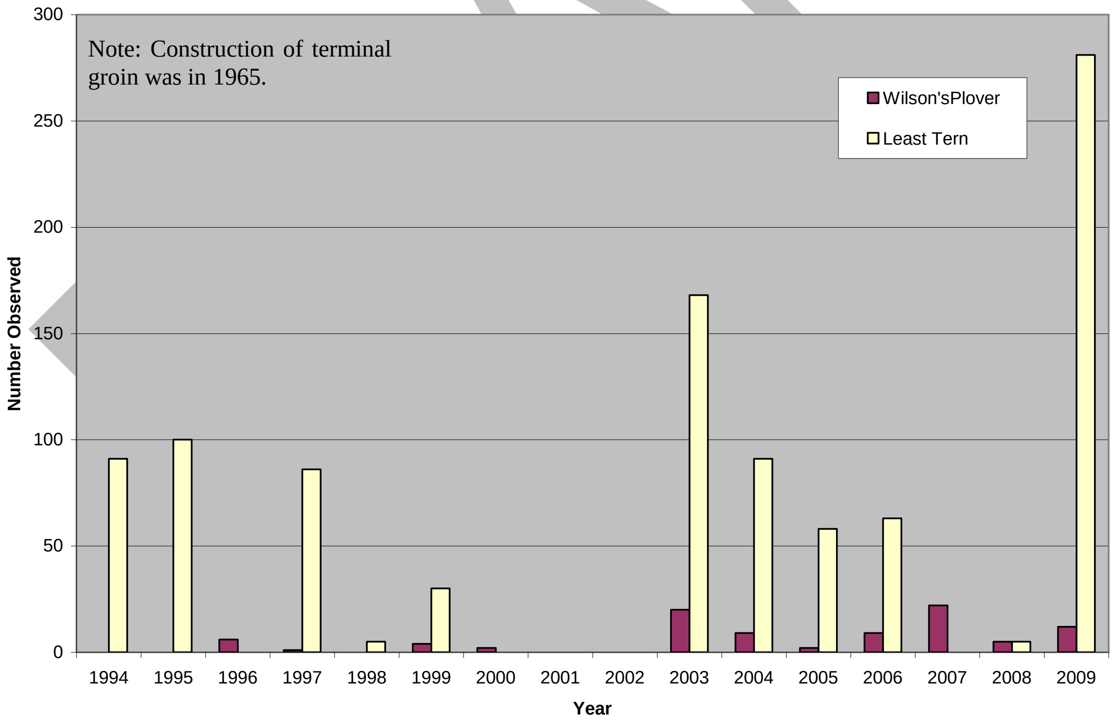


Figure IV-24. Annual Least Tern and Wilson's Plover Observations (Fort Macon State Park)

Federally Threatened Species

Piping Plover

Annual piping plover data were obtained for Shackleford Banks West, Fort Macon, and North/South Core Banks (Figure IV-25 and Figure IV-26). The earliest records for Shackleford Banks West date to 1970; however, pre-2000 records are limited to 3 individuals in 1970, 4 individuals in 1980, 1 individual in 1989, and 1 individual in 1996. In 2000, a total of 25 individuals were observed on Shackleford Banks West. The number of observations subsequently increased to 72 individuals in 2001. Over the next 5 years, the number of annual observations on Shackleford Banks West steadily declined, culminating with a low of 6 individuals in 2006. The number of observations increased to 38 individuals in 2007 and subsequently declined to 14 individuals in 2008. There have been few recorded observations of piping plovers at Fort Macon. Fort Macon records are limited to one individual in 1996 and 3 individuals in 2006. Piping plover records for North and South Core Banks date to 1983 (Figure IV-26). Prior to 2000, annual piping plover observations on the Core Banks were relatively low, with an annual average of 19 individuals observed during the period of 1983 through 1999. The period of 2000 through 2008 was marked by a steady increase in piping plover observations. Annual observations on the Core Banks increased from 57 individuals in 2000 to 241 individuals in 2008. On average, 125 individuals were observed on the Core Banks during the period of 2000 through 2008. In comparison, an average of 33 individuals was observed on Shackleford Banks West during the period of 2000 through 2008.

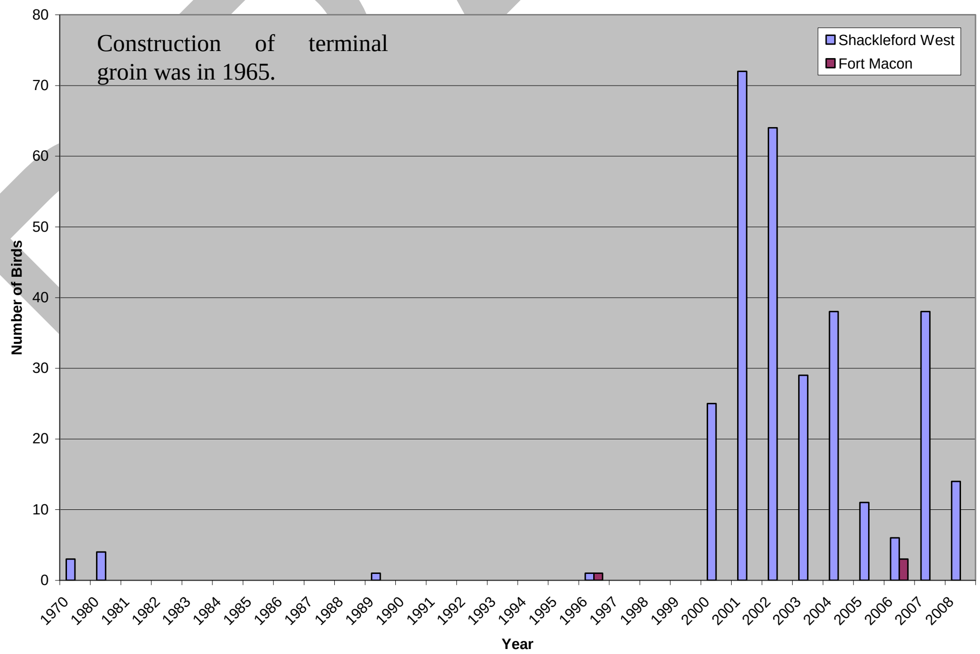

Construction of terminal groin was in 1965.

Figure IV-25. Annual Piping Plover Observations for Fort Macon and Shackleford Banks, NC

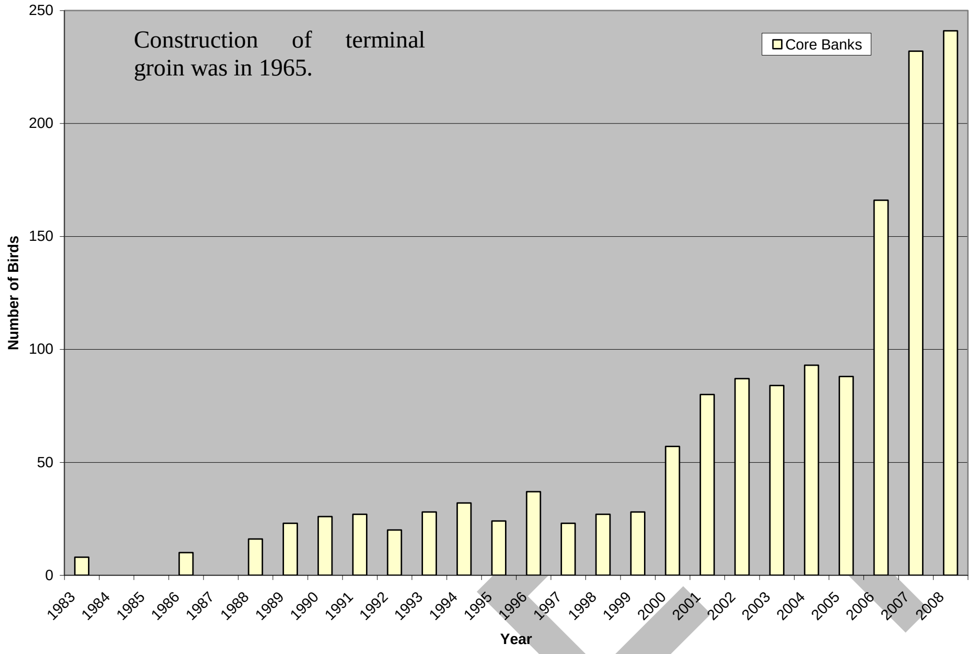


Figure IV-26. Annual Piping Plover Observations for Core Banks, NC

Roseate Tern

The roseate tern is a rare coastal migrant from late March to mid-May and from late July to October (Potter et al. 1980). The nest of this colonial ground-nesting seabird is generally a depression on open sand with shells or grasses, usually on the upper beach or dune areas. This species nested near Core Banks in Carteret County in 1973 (Potter et al. 1980) but has not been known to nest in the area since this sighting.

Based on discussions with NCWRC, it is difficult to draw many conclusions from available data with respect to the terminal groin at Fort Macon considering pre-construction data is unavailable. However, based on a review of historical aerial photographs it is clear that the area around the Fort Macon terminal groin has not been very suitable for either nesting colonial waterbirds or shorebirds since the groin was built (Personal communication, D. Allen, NCWRC, October 2009). It is known that these inlet shoreline dependent birds depend on ephemeral habitats, and stabilization of these areas typically causes vegetation to grow which makes these sites unsuitable for these birds (Personal communication, D. Allen, NCWRC, October 2009).

(5) Fish and Fisheries

The Newport River Estuary is an important nursery area for larval fish, and Beaufort Inlet serves as a passageway for the larvae as they migrate inshore [North Carolina State Ports Authority (NCSPA) 2001]. Patterns of larval transport seem to be tied to the inlet's flow characteristics. In other words, the majority of incoming larvae are transported to the east toward the estuaries behind Shackleford Banks and to the center toward Beaufort and the Beaufort channel. Approximately 90 percent of incoming larvae are entrained and directed up estuary to either Shackleford Banks or Beaufort Channel (Bulkhead Channel), while 10 percent of larvae are transported through the Morehead City Channel into Bogue Sound and the Newport River Estuary (Blanton et al. 1999; Churchill et al. 1999; NCSPA 2001).

Research conducted by scientists at the NOAA laboratory in Beaufort has documented 129 different species of larval fish in and around Beaufort Inlet to date, finding larvae present during every month of the year. Peters et al. (1995) and Peters and Settle (1994) documented species' utilization and temporal trends of larval fish transport through Beaufort Inlet. Table IV-5 depicts the time periods during which various larval species immigrated through the inlet. Over 52 taxa that included 29 species were identified. Menhaden (*Brevoortia* sp.), spot, Atlantic croaker, and pinfish dominated the majority of the samples. Darkened boxes indicate higher larval abundance.

Table IV-5. Peak larval abundance of seven important fish species near Beaufort Inlet.

Species	**Month**						
	Sep	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Menhaden						▨	▨
Summer flounder						▨	▨
Southern flounder						▨	▨
Spot					▨	▨	▨
Pinfish				▨	▨	▨	▨
Gulf flounder			▨	▨	▨	▨	▨
Atlantic croaker	▨	▨	▨	▨	▨	▨	▨

Source: Peters et al. 1995

Larvae passing downwind and outside the narrow withdrawal zone pass seaward of the inlet shoals and, given the right conditions, will be transported into the next available inlet downstream. The strong asymmetrical tidal flow within Beaufort Inlet also creates cross-channel salinity and temperature gradients during flood tide periods, when larvae are most apt to migrate to estuarine waters (Churchill et al. 1999). As described by NCSPA (2001), salinity and temperature levels measured with *in situ* current meters in the eastern and central sections of the inlet resembled those of shelf water, providing relatively stable water conditions for incoming larvae. However, salinity and temperature measurements in the western section of Beaufort Inlet fluctuate more than those of the eastern and central sections. These fluctuations are a result of the relatively high amount of freshwater input coming from the Newport River which passes through the channel and moves toward the inlet mouth (Kirby-Smith and Costlow 1989). This input creates a mixture of continental shelf and estuarine plume water moving through the channel out of Beaufort Inlet and into the Atlantic Ocean (Churchill et al. 1999a; Luettich et al. 1999). The mixed water could potentially result in unfavorable conditions for larvae migrating through the western section of the inlet. Larvae may attempt to avoid the flow along the western section reducing the amount of larvae transported into the channel.

Hardened structures can potentially interfere with the passage of larvae and early juveniles from offshore spawning grounds into estuarine nursery areas (Street et al. 2005; Kapolnai et al. 1996;

Churchill et al. 1997; Blanton et al. 1999). Approximately 60 species of larval fish and 34 species of juvenile and adult fish have been documented moving through Beaufort Inlet, Ocracoke Inlet, and Oregon Inlet in the winter and an even greater number of species during the summer months (Hettler and Barker 1993; Peters et al. 1995). Successful transport of larvae from fish spawning on the continental shelf through the inlet occurred within a narrow zone parallel to the shoreline and was highly dependent on along-shore transport processes (Blanton et al. 1999; Churchill et al. 1999; Hare et al. 1999).

Effects may be greatest in coastal areas like the Outer Banks, where there are few inlets. Offshore spawning, estuarine-dependent species that might be effected by hardened structures include many of North Carolina's most important commercial and recreational fish species such as menhaden, spot, Atlantic croaker, shrimp, gag grouper (*Myceteroperca microlepis*), black sea bass, and flounders. Moreover, the areal loss of beach at hardened shorelines is often managed by implementing nourishment projects, possibly having additional effects on the subtidal bottom. In addition to causing erosion on downdrift beaches and accelerating the need for beach nourishment projects, marine structures obstruct fish passage through adjacent inlets (Blanton et al. 1999).

Commercial fishery landings from the Newport River/Beaufort Inlet area is a million dollar industry, with an average of 683,550 pounds for an annual value of $1,065,455 from 1994 to 2001 (Street et al. 2005). Over two dozen fishery species have been commercially harvested each year from this system. Blue crab, shrimp, hard clams, Eastern oyster (*Crassostrea virginica*), mullet, and southern flounder (*Paralichthys lethostigma*) are the largest annual catches by weight from the Newport River and Beaufort Inlet area (NCDMF, unpublished data). The tidal shoal system within Beaufort Inlet also provides spawning habitat for blue crab and red drum.

(6) Benthic Resources

The noticeable differences between the natural and artificial beaches of the project area persist in the wet beach, or the area subject to daily tidal flux. This ecological niche is subject to wave action, which creates alternating periods of subaqueous and subaerial conditions. The fauna adapted to this environment are concentrated in the top 2 to 4 inches [Personal communication, Dr. C.H. Peterson, University of North Carolina (UNC) Chapel Hill, October 2009] and are sensitive to the grain size, geomorphology, and swash energy of the intertidal zone (Alexander et al. 1993; Donoghue 1999). Therefore, the fauna are patchily distributed depending upon the specific physical and hydrologic characteristics at any given location along and across the beach (Bowman and Dolan 1985; Donoghue 1999; Lindquist and Manning 2001). Along Bogue Banks, the wet beach infauna is dominated by polychaete worms, coquina clams, and mole crabs (Diaz 1980; Lindquist and Manning 2001; Peterson et al. 2000a; Peterson and Manning 2001; Reilly and Bellis 1978). Predators foraging on the infauna include shorebirds such as sanderlings and willets and surf zone fish including Florida pompano (*Trachinotus carolinus*) and Gulf kingfish (*Menticirrhus littoralis*) (Lindquist and Manning 2001; Peterson et al. 2000a; Peterson and Manning 2001). The native wet beaches of Bogue Banks often have depressed infaunal populations due to beach scraping and beach fill activities relative to pre-project levels (Peterson et al. 2000a; Peterson and Manning 2001; Reilly and Bellis 1978). The dune face adjacent to the beach provides habitat for ghost crabs and other invertebrate species. This ecological community has been disrupted by beach scraping, or bulldozing, along the majority of the island's beaches. The scraping has degraded the biological community naturally found in the dune scarp and dune toe, suppressing the abundance and distribution of fauna such as ghost crabs (Conaway 2000; Peterson et al. 2000a; Peterson and Manning 2001).

In 1994, quantitative sampling of benthic invertebrates was conducted within the Beaufort Inlet ebb tidal delta (Peterson et al. 1995). Sampling was conducted within a planned dredged material disposal area on the west side of Beaufort Inlet and in a control area on the east side of the inlet. In order of abundance, the most common organisms in the core samples were polychaetous annelids, bivalve molluscs, crustaceans (amphipods), echinoderms, and nematodes. Sampling results indicate a strong association between polychaete/amphipod density and water depth. Polychaete density increased with depth, whereas the density of amphipods decreased with depth. Core sample densities were similar to those found in other North Carolina estuaries and lagoons where demersal predation is a dominant ecological factor. Larger epifauna and infauna represented in the scrape samples included sand dollars, olive shells, brown shrimp, and other taxa. The densities of lager epifauna and infauna were generally lower at the deepest depth stratum; however, the relationship between depth and patterns of abundance varied in a complex fashion among transects. Variation in sampling results between the treatment and control areas indicate that the two sides of the inlet are not symmetrical with regard to environmental processes or benthic community composition. Peterson et al. (1995) postulate that the differences are due to differences in water circulation patterns and sedimentation.

Additional baseline sampling of benthic invertebrates was conducted in the same areas in 1996 (Peterson et al. 1996). In order of abundance the most common benthic organisms in the core samples were polychchaetous annelids, bivalve molluscs, and crustaceans (amphipods). Core sample densities were again similar to those found in other North Carolina estuaries and lagoons where demersal predation is a dominant ecological factor. Sampling again indicated that the two sides of the inlet are not symmetrical with regard to environmental processes or benthic community composition.

In conjunction with the development of the Morehead City Harbor Dredged Material Management Plan (DMMP), Wilmington District USACE is investigating opportunities to expand the existing nearshore ocean disposal area off Bogue Banks (west of Beaufort Inlet) and create a new nearshore ocean disposal area off Shackleford Banks (east of Beaufort Inlet). Prior to the placement of any maintenance material into the existing/expanded nearshore ocean disposal area off Bogue Banks and the new nearshore area off Shackleford Banks; the characterization of the marine benthic macroinvertebrate community and associated sediment particle size, followed by analysis of community parameters via statistical treatment was required. The results of this 2009 characterization study will be available in early 2010 (Personal communication, D. Piatkowski, USACE Wilmington District, February 2010). Figure IV-14, provided by the USACE Wilmington District, shows the location of these existing and proposed nearshore disposal sites.

The deposition of dredge material from navigational channel maintenance on estuarine or coastal dredge disposal sites, ebb tidal deltas, or other areas of subtidal bottom results in increased turbidity, temporary reduction in and slow recovery of the abundance and diversity of benthic invertebrates (SAFMC 1998).

(7) Cultural and Hardbottom Resources

Fort Macon State Park is managed by the state and contains high archaeological value as an historic military defense site in coastal North Carolina. Beaufort Inlet has more recently received scientific attention as a shipwreck believed to be Blackbeard's Queen Anne's Revenge has been discovered on the southwestern portion of the inlet's ebb tidal delta. Other shipwrecks adjacent to Beaufort Inlet are currently being investigated for archaeological significance and recovery.

A recent hardbottom and cultural resources survey was conducted by the USACE in the fall of 2009 within the vicinity of the nearshore disposal area offshore of Fort Macon as well as the proposed offshore site near Shackelford Banks' western end. The surveys were conducted as part of on-going efforts by the USACE to expand nearshore disposal options associated with maintenance dredging of Beaufort Inlet (Figure IV-27). The purpose of this work is to assess the presence and/or absence of both cultural and hardbottom resources within the USACE's proposed nearshore disposal areas (i.e. off Bogue Banks and Shackleford Banks) for the Morehead City Harbor DMMP. The data collected from this work is required in order to establish baseline conditions and subsequently refine the nearshore disposal area use plan to avoid effects to significant cultural and environmental resources from dredging activities. Preliminary results indicate no hardbottom resources are present within the investigation areas shown in Figure IV-27 (Personal communication, D. Piatkowski, USACE Wilmington District, February 2010). Other studies by Moser and Taylor (1995), including data on hardbottom locations in North Carolina waters (i.e., within 3 nautical miles of shore), have confirmed no hardbottom resources within the nearshore area of the Fort Macon terminal groin.

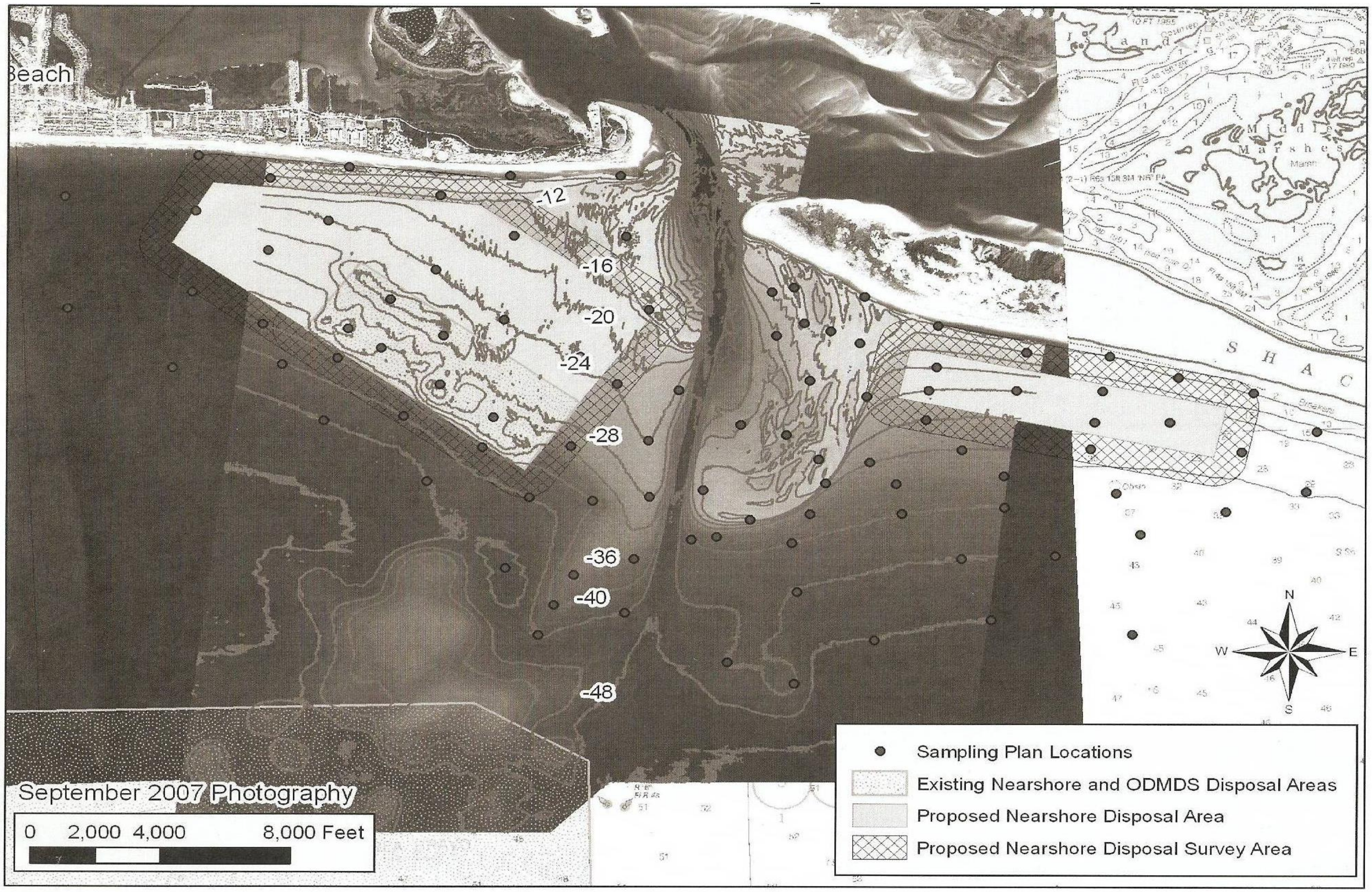


Figure IV-27. Location of Hardbottom and Cultural Resource Surveys Offshore of Beaufort Inlet

In the 2009 cultural resources survey, the USACE confirmed through magnetometer, side-scan sonar, and sub-bottom profile surveys significant magnetic and/or sonar anomalies that might represent cultural resources; however, the sources and exact locations have not been identified as of yet.

3. Amelia Island, Nassau Sound, Florida

a) General Site Description

As described by Olsen (1993); Nassau Sound is a natural, unmaintained entrance connecting the Nassau River, South Amelia River, and the Atlantic Intracoastal Waterway (AIWW) with the Atlantic Ocean. Nassau Sound separates Amelia Island to the north from Little Talbot Island to the south (Figure IV-28).

From 1993 to 2003, the southern terminus of Amelia Island had receded to such a degree that the historical sandy spit formation associated with the Amelia Island State Park (AISP) had been completely lost. The AISP is located in northeast Florida, in eastern Nassau County. In order to stabilize south Amelia Island, a two phase construction project plan was formulated. An EA performed for Phase I was completed in September 2001 (DC&A 2001a). Phase I, constructed in the summer of 2002, stabilized the beach area by dredging and placing approximately two million cubic yards of material within the eroded area (Olsen Associates, Inc. 2003). Phase II of the stabilization plan involved the construction of terminal structures at the south end of Amelia Island to provide a physical “template” which would preclude the nourished shoreline from receding back to its 2002 pre-nourishment configuration. As described in DC&A (2003), the synthesis of these two projects would provide long-term benefits that otherwise would not be accomplished with just one or the other. The long-term benefits of these two projects include the erosion reduction of Amelia Island’s south end and the continued protection of the recreational beach, wildlife nesting areas, and landward natural communities.

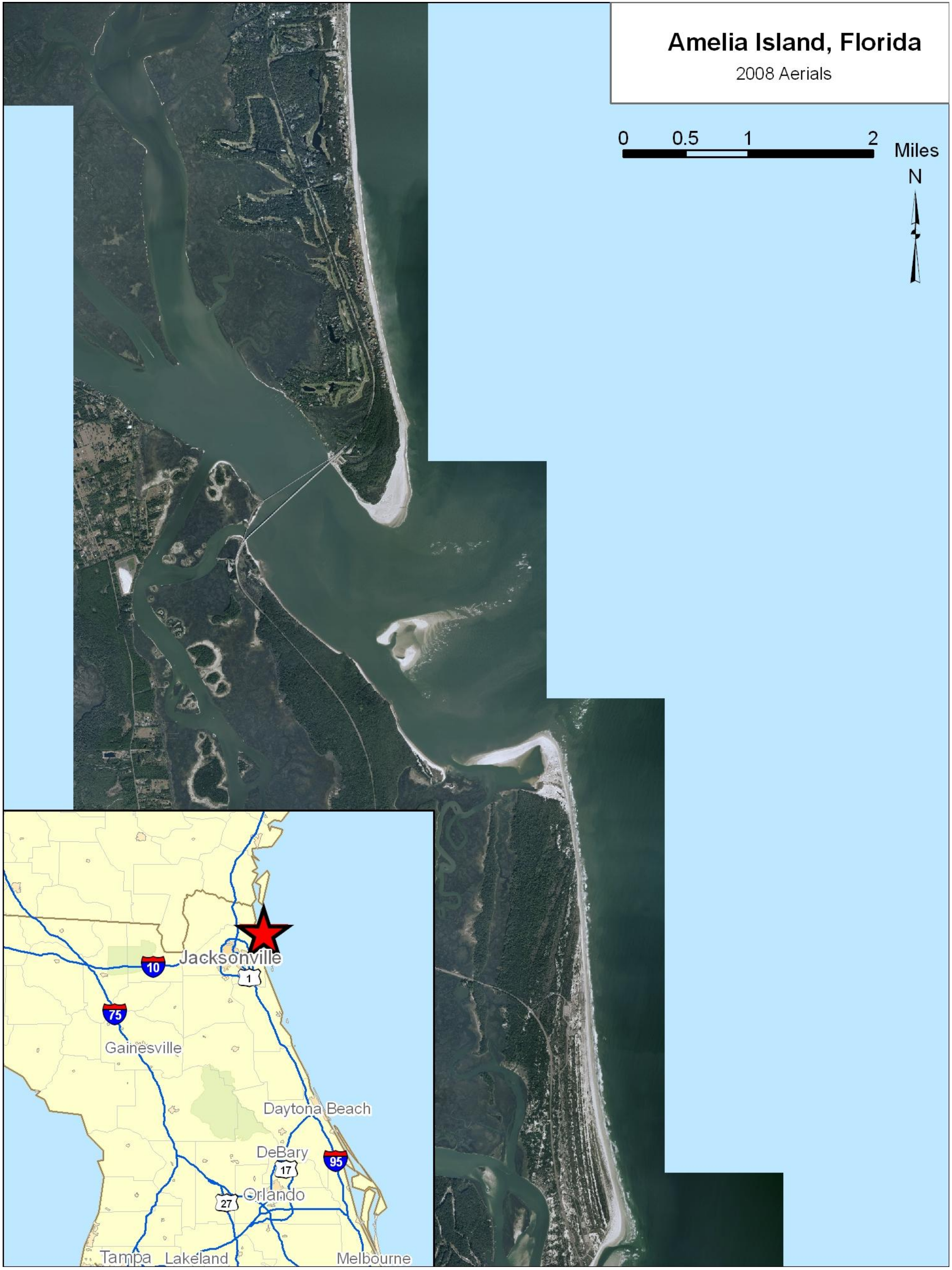


Figure IV-28. Amelia Island, Florida

Inlet migration had placed increased erosion pressure on the southern end of Amelia Island prompting coastal engineering actions intended to protect valuable resources along the AISP and adjacent to privately held lands northward. Without the Phase I renourishment project, the sandy beach would have experienced further effects not only to public recreational use, but would continue to degrade both the shoreline and the maritime forest to a point that wildlife species would not have been able to utilize the area for nesting, foraging, and roosting. Long-range beach management decisions by both public and private interests were implemented to help resolve the erosion problem. Phase II was proposed to increase the longevity of the restored beach area and surrounding communities (DC&A 2003).

Following a series of beach nourishment projects along a two mile stretch of beaches to the north of the inlet (1994 and 2002), a 465-foot long leaky terminal groin was installed in 2004 (Olsen Associates, Inc. 2000, 2008). The groin was meant to stabilize the beach without adversely affecting the sediment transport required to maintain the downdrift inlet-facing shoreline. The groin was purposely developed to be low and leaky to allow passage of some littoral drift. Because the intertidal shoreline would be located well seaward of the requisite groin curve, the curve is anticipated to be wholly buried by sand most or all of the time. The curved landward connection was included to prevent a tidal channel from flanking the groin: i.e., from cutting a channel between the groin and the upland in the event of a severe storm or by strong currents/erosion from the west. The structure is sited as close as practicable to the southern end of the island's existing vegetation and high water shoreline.

In 2006, the groin system was reported meeting or exceeding its goals. The groin promoted the formation of a large spit downdrift protecting the inlet-facing shoreline and the beach above has been maintained (Olsen Associates, Inc. 2008).

The principal objectives of this project were to ensure the long-time maintenance of a suitably wide shoreline and the protection of adjacent maritime forest from erosion and inundation caused by typical (seasonal) wave conditions and high frequency storm events (DC&A 2003). Phase I of the south Amelia Island stabilization project was necessary to address an emergency condition; whereby, chronic inlet-related shoreline erosion was threatening the upland maritime forest and associated environmental resources located predominately within AISP. Phase I provided a reliable template to secure the project site while awaiting the second construction phase. The goal of Phase II was to supplement Phase I renourishment efforts with structures that would provide continued stability of the project site. Deemed successful, the project has adequate nesting/foraging/roosting areas for sea turtle and least tern use, while at the same time increasing the shoreline width for continued reliable, public recreational use (Olsen Associates, Inc. 2008).

(1) Aesthetics

Although aesthetics were not evaluated by DC&A (2003), based on a general review of aerial photography, the visual environment of AISP did not significantly change from pre-construction to post-construction of Phase II.

(2) Recreation

Within the AISP, all upland uses are either recreational or for conservation purposes. Northward of the AISP and within the Phase II project area, all upland uses are residential (single-family or multi-family). The shoreline immediately adjacent to the terminal structure is open to the public. In the AISP, a small attendance fee is collected (generally on the honor system). That fee did not change due to the project, and is applied to costs associated with maintaining the Park facilities.

The AISP is an important fishing destination for citizens of both Nassau and Duval Counties. The waters offshore of the project site and surrounding areas are used primarily by recreational boating traffic (DC&A 2003). Small recreational boats comprise the majority of crafts within Nassau Sound. Commercial boat traffic does traverse the area, but generally occurs outside of the immediate project area in order to avoid the Nassau Sound shoals. Recreational diving in the immediate area is extremely limited due to the strong currents, shallow depths and dark water/limited visibility (Olsen Associates, Inc. 2002).

Effects to navigation associated with the terminal groin were proposed to be minimal (DC&A 2003). Small craft utilizing the area would need to avoid the terminal structures and breakwater. Design plans indicate that the structures would be visible above the mean high water line. Therefore, the structures would be seen by boaters and avoided. Since commercial boat traffic does not utilize the near-shore area within the project boundaries, navigation for these vessels does not pose a problem.

(3) Public Access

Amelia Island contains a total of 14 miles of oceanfront beach. The majority of the beach contains private, residential houses west of the primary dune. However, AISP and Fort Clinch State Park (Fort Clinch) provide public access for recreational use of the shoreline. Additionally, public access to the South Amelia beaches is provided at several designated areas. All of the publicly owned access areas, especially the AISP and Fort Clinch are popular destinations for local citizens and visitors to use for multi-purpose recreation.

During Phase II shoreline stabilization activities, the use of the beach was restricted temporarily. The restrictions were implemented to protect the public's safety from the machinery, equipment and equipment staging areas. As soon as construction was completed, the beach was reopened to the public. The engineered system’s construction allowed for continued stabilization of the beach and associated recreational activities (DC&A 2003).

b) Natural Resources

Nassau Sound has existed as a natural inlet system for at least as long as historic charts indicate (Olsen Associates, Inc. 2001). Natural forces such as tides, currents, and waves continually interact within the project area, as well as the surrounding landscapes. These events continue to help characterize physical features of the Nassau Sound area. Although unstabilized, Nassau Sound has been affected over the last century as a direct result of man-induced activities that include two Department of Transportation bridges, the excavation of the Atlantic Intracoastal Waterway, and the construction of navigation projects at the Saint (St.) Mary’s River entrance and the St. Johns River entrance (Figure IV-29).

(1) Vegetation

The Florida Department of Transportation’s Florida Land Use, Cover and Forms Classification System (FLUCCS) was utilized to describe the natural communities within the Phase II project boundaries. Three major communities identified include: coastal scrub, live oak, and saltwater marsh (Figure IV-29). An additional community, the nearshore open sand/benthic habitat, is described under Section 2.3.2.5 - Benthic Resources.

As described by DC&A (2003), construction of the stabilization structures would provide increased protection of the vegetative communities. Completion of the Phase I beach renourishment provided initial protection of the coastal scrub and live oak communities. The stabilization structures furthered the measures being taken to protect the vegetative communities.

Accumulation of sand at the landward end of the terminal structure was proposed to stabilize the existing dune and vegetation by significantly reducing the erosion and overwash that occurs in existing conditions. Expansion of the vegetation across the new sand accumulation was expected, and is consistent with that observed along the accretional, inboard end of structures such as is observed at the north sides of St. Lucie Inlet, Port Canaveral, St. Augustine, and St. Johns River Entrance (Olsen Associates, Inc. 2003).

The terminal groin located west of the A1A bridge was proposed to help protect salt marsh and therefore, provide habitat protection for the diamondback terrapin (*Malaclemys terrapin*) and other species that utilize that habitat (DC&A 2003).

Based on a preliminary evaluation of aerial photographs pre- and post-construction of the terminal groin, no significant changes have been observed in vegetation communities (Olsen Associates, Inc. 2008).

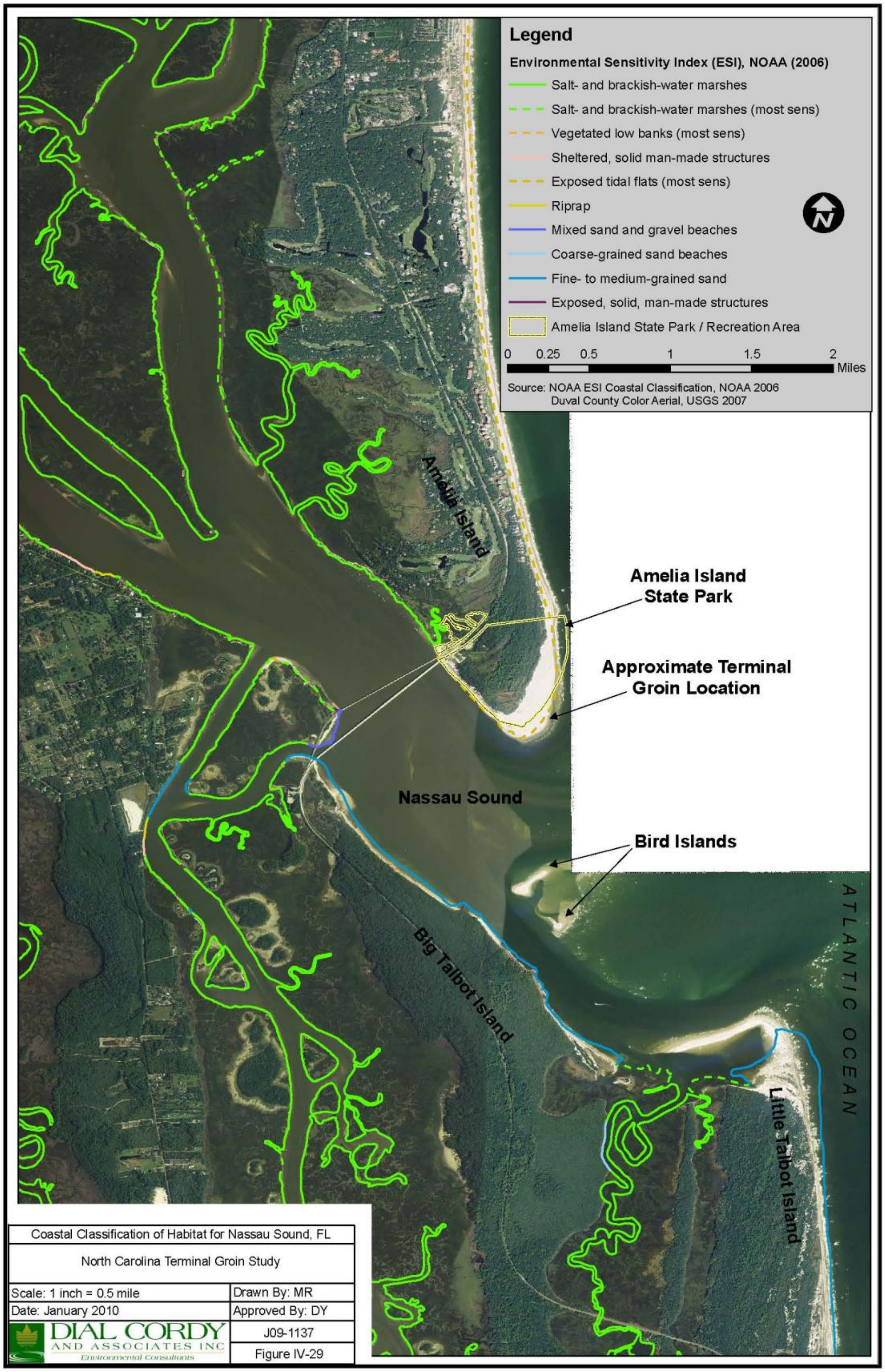


Figure IV-29. Coastal Classification of Habitat for Nassau Sound, FL

(2) Sea Turtles

Loggerhead sea turtles use the habitats offshore of Nassau County to varying degrees during different stages of their life cycle. During the summer months, hatchlings utilize this habitat as a corridor to deeper waters farther off the coast. Juvenile and sub-adult sea turtles may utilize the offshore habitats as a foraging area, while adult sea turtles are present year-round with seasonally high abundances during the breeding season. The green sea turtle follows similar life cycles as the loggerhead sea turtle, although their abundance in the project area is greatly reduced or rare. Green sea turtles utilize the habitats offshore of Nassau County to varying degrees during different stages of their life cycle. During the summer months, hatchlings utilize this habitat as a corridor to deeper waters farther off the coast. Juvenile and sub-adult green sea turtles may utilize the offshore habitats as a foraging area, while adults are sporadically present year-round with their greatest occurrence during the breeding season.

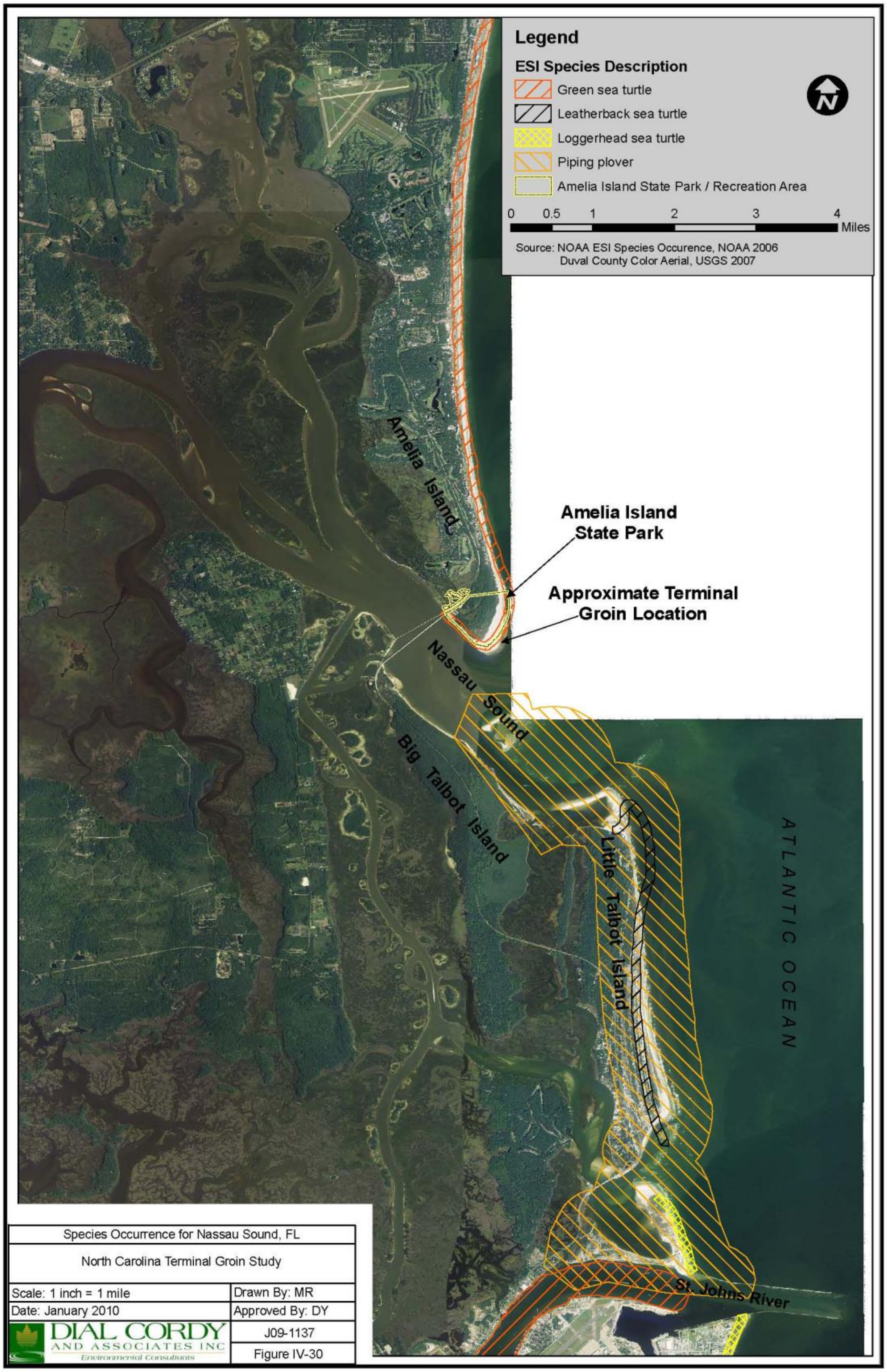


Figure IV-30. Species Occurrence for Nassau Sound, FL

The loggerhead sea turtle is the most common sea turtle nesting on Amelia Island (Figure IV-30). Loggerhead sea turtles nest on ocean beaches, with nests typically positioned between the high tide line and the dune front. Relatively narrow, steeply sloped, coarse-grained beaches are the preferred nesting habitat (NMFS and USFWS 2008). The green sea turtle nesting habits are similar to the loggerhead sea turtle, although green sea turtle nesting is uncommon within Nassau County. Over the course of 12 years, the nest records ranged from 0 to 4 per year (average = 0.8) [Florida Marine Research Institute (FMRI) 2000]. According to USFWS (2001b), a total of 10 nests were recorded for green sea turtles on Amelia Island between 1988 and 1999 with 2 nests occurring within the area that received nourishment. There are no records of green sea turtles nesting within the Phase II project area (USFWS 2004). The leatherback sea turtle, a relatively uncommon visitor to Amelia Island, was recorded to nest three times on Amelia Island, with one (1) nest occurring within the re-nourished area between 1988 and 1999. There are no records of leatherback sea turtles nesting within the project area of Phase II (USFWS 2004).

Sea turtle nesting data for Amelia Island, AISP, and Little Talbot Island State Park were obtained from the FFWCC (Personal Communication, B. Brost, FFWCC, February 2010), the Fish and Wildlife Research Institute (http://research.myfwc.com/features/category_sub.asp? id=2309), the USACE Sea Turtle Data Warehouse (http://el.erdc.usace.army.mil/seaturtles/), and the Florida Shore Protection and Sea Turtle Management System:
(http://el.erdc.usace.army.mil/flshore/refs.cfm?County=None).

Sea turtle nesting data for Amelia Island dates back to 1986 (Figure IV-31). On average, 74 nests were recorded annually from 1986 through 2005. The annual number of nests was relatively low from 1986 through 1989, with a range of 31 to 57 nests. Numbers fluctuated widely from 1990 through 1999, with a low of 30 nests recorded during 1993 and a peak of 120 nests recorded during 1999. The number of nests declined steadily over the next three years, reaching a low of 51 in 2002. There was a resurgence of nesting activity in 2003, when an all-time high of 121 nests was recorded.

The number of nests declined sharply to 46 in 2004, followed by an increase to 70 in 2005. Other than the steady decline between 1999 and 2003, no obvious trends in nesting activity are evident over the course of the monitoring period. Additional data specific to AISP spans the period of 2004 through 2008 (Figure IV-31). On average, three nests have been recorded annually over the course of the five-year monitoring period. Nesting data for Little Talbot Island State Park spans the period of 2004 through 2008 (Figure IV-31). On average, 26 nests have been recorded annually over the course of the five-year monitoring period. The number of nests recorded ranged from 2 to 43. Due to inconsistent monitoring protocols and the lack of historical monitoring data for AISP, it is difficult to draw conclusions regarding the effects of the terminal groin on sea turtle nesting (Personal Communication, M. Simmons, Biologist, AISP, February 2010).

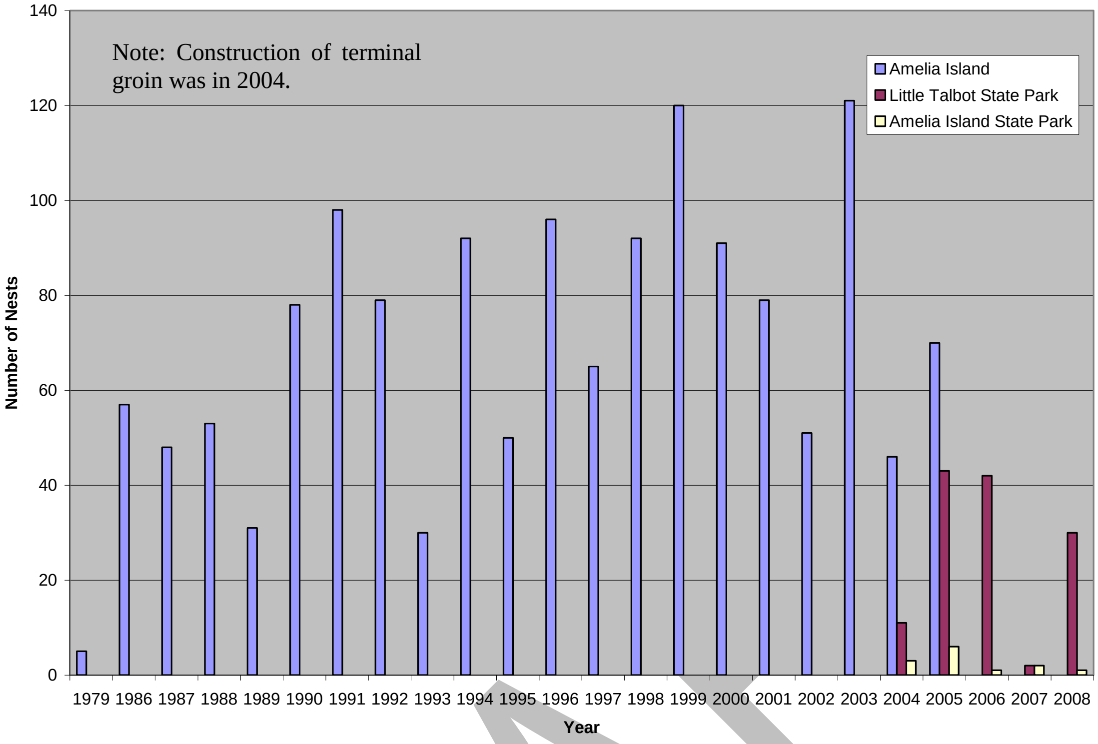


Figure IV-31. Sea Turtle Nesting Data from Amelia Island and Little Talbot State Park

Based on the Biological Opinion of the USFWS (2001a and 2004), the Shoreline Stabilization project affected only one mile of the approximately 1,400 miles of available sea turtle nesting habitat in the southeastern United States. Research has shown that the principal effect of such shoreline stabilization projects on sea turtle reproduction is a reduction in nesting success, and this reduction is most often limited to the first year following project construction (USFWS 2004). Research has also shown that the effects of a shoreline stabilization project on sea turtle nesting habitat are typically short-term because an affected beach will be reworked by natural processes in subsequent years, and beach compaction will decline.

Nests laid on nourished beaches generally hatch successfully (Nelson and Dickerson 1988) as Herren (1999) found no significant difference in hatching success in the nourished area in the first or second season after the Sebastian Inlet, Florida, sand transfer nourishment. Although Ecological Associates, Inc. (EAI) (1999) found lower overall hatch success on nourished beaches following construction compared to controls; the differences were not statistically different. The EAI study did show changes in incubation environment, but these changes did not affect the hatching success. These changes, along with changes in beach sediment composition did not affect hatching success in the EAI study. Both the Herren and EAI studies point to erosional losses of nests laid low on the newly constructed berms as the primary source of effect. A proper relocation program, if needed, could largely eliminate this source of effect.

(3) Shorebirds and Waterbirds

The permit for Phase II construction of this South Amelia Island Shore Stabilization Structures Project was issued 27 August 2003. Because of concerns raised during the evaluation of the permit application, an extensive monitoring program and the Shorebird Management Plan (SMP) were included as requirements in the permit. The primary concern raised was the potential effects the structure might have on the sediment transport system, which affects the sediment balance of the islands and shoals in Nassau Sound, collectively known as the "Bird Islands." These islands and shoals have historically provided critical nesting, resting, and feeding habitat for a variety of shorebird and seabird species. Based on pre- and post-survey data within Nassau Sound, the Bird Islands have not experienced a change in total acreage (Personal communication, A. Browder, Sr. Engineer, Olsen Associates).

As described in the SMP (DC&A 2003), no significant adverse effects to shorebird or seabird populations were expected to occur during the construction phase of the project. Although, based on the Biological Opinions of USFWS (2001a, 2004), construction of the terminal structure was expected to have a minor affect; i.e., reduction in the amount of littoral sand transport into Nassau Sound, until the system stabilizes six months following construction. This project was expected to have the potential to result in the temporary loss of a minor, possibly insignificant portion of the Nassau Sound/Bird Island shoal and spit complex.

Historical Shorebird Use—Pre-Construction Survey Results

A total of ten species of shorebirds have been documented nesting within the area (Table IV-6). The FDEP - Division of Recreation and Parks staff has systematically surveyed known shorebird nesting areas to document breeding activities since 1988. Historically, nesting by shorebirds on south Amelia Island occurred almost entirely at the southern tip of the island, within the boundary of AISP. Nesting on Little Talbot Island has been largely restricted to nesting by least terns, concentrated on the north end, though some nesting by other species has occurred on both the north and south ends. As described in the SMP (2004), Wilson's plovers have consistently nested on both islands, but their nests may be harder to detect since they form loose, less visible, colonies. American oystercatchers, another more solitary nester, have more commonly nested on Little Talbot Island, though in low numbers.

Table IV-6. Shorebird species confirmed to nest in the Nassau Sound area, with known nesting locations indicated.

Common Name	Scientific Names	Locations		
		Little Talbot Island	Nassau Sound Shoals	Amelia Island
Wilson's plover	*(Charadrius Wilsonia)*	X	X	X
Killdeer	*(Charadrius vociferus)*			X
American oystercatcher	*(Haematopus palliates)*	X	X	X
Willet	(*Catoptrophorus semipalmatus*)		X	
Laughing gull	(*Larus atricilla*)		X	
Gull-billed tern	(*Sterna nilotica*)		X	
Royal tern	(*Sterna maxima*)		X	
Sandwich tern	(*Sterna sandvicensis*)		X	
Least tern	(*Sterna antillarum*)	X	X	X
Black skimmer	(*Rynchops niger*)		X	X

Source: Amelia Island State Park Shorebird Management Plan

The FDEP records for other shorebird species date back to 1997; however, there are few records prior to 2003 for Amelia Island and few records prior to 2002 for Little Talbot Island and the Bird Islands. Due to the lack of data, the evaluation of non-nesting shorebird records for Amelia Island was limited to 2003 onwards, and the evaluation of non-nesting shorebird records for Little Talbot Island and the Bird Islands was limited to 2002 onwards. Selected species that were evaluated included the American oystercatcher, black skimmer, Caspian tern, common tern, gull-billed tern, least tern, red knot, roseate tern, and Wilson's plover.

On Amelia Island, the total number of individuals representing all of the selected species increased from 783 in 2003 to 1,828 in 2004 (Figure IV-32). The total number of individuals declined to 952 in 2005 and 540 in 2006. Numbers remained steady at 571 in 2007, followed by an increase to 1,251 individuals during 2008. Least terns were the most abundant species, with an average of 315 individuals observed annually over the course of the six-year monitoring period (2003 through 2008). Other abundant species included black skimmers (annual average of 288), Caspian terns (annual average of 158), and red knots (annual average of 99). Of the selected species, nesting by least terns, Wilson's plovers, and black skimmers has been documented on Amelia Island (Figure IV-33). Since 2002, a total of 706 nests have been recorded on Amelia Island. Least terns account for the majority of the nests, with a total of 581 nests recorded from 2002 through 2007. Records for other species include 100 black skimmer nests in 2006 and 25 Wilson's plover nests from 2003 through 2007.

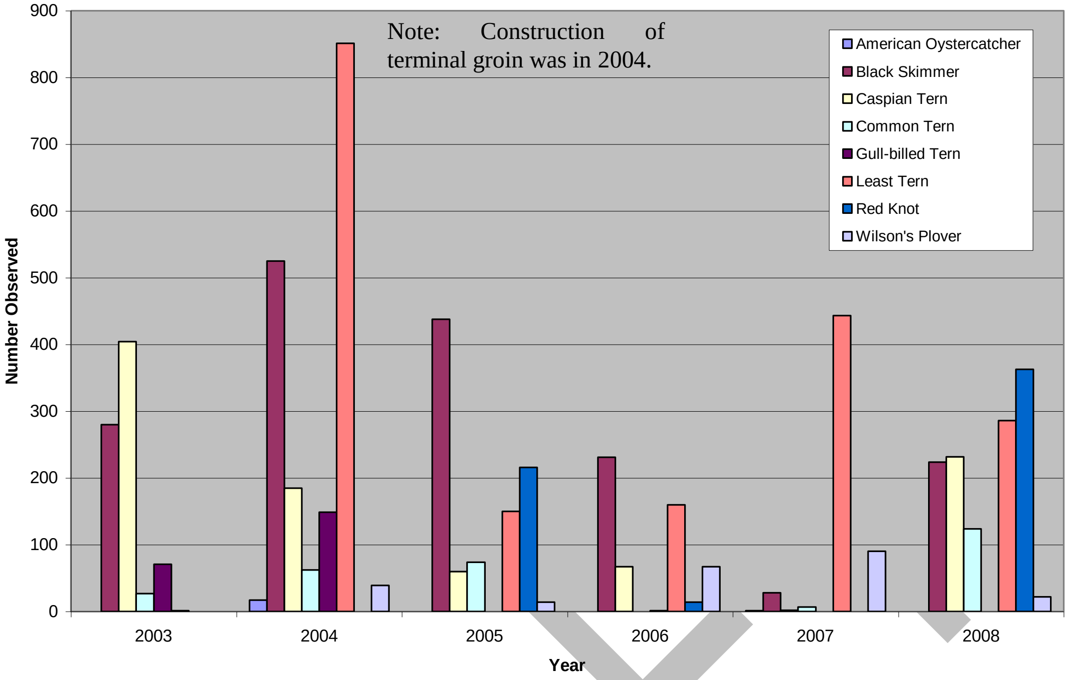


Figure IV-32. Amelia Island State Park Non-Nesting Shorebird Observations

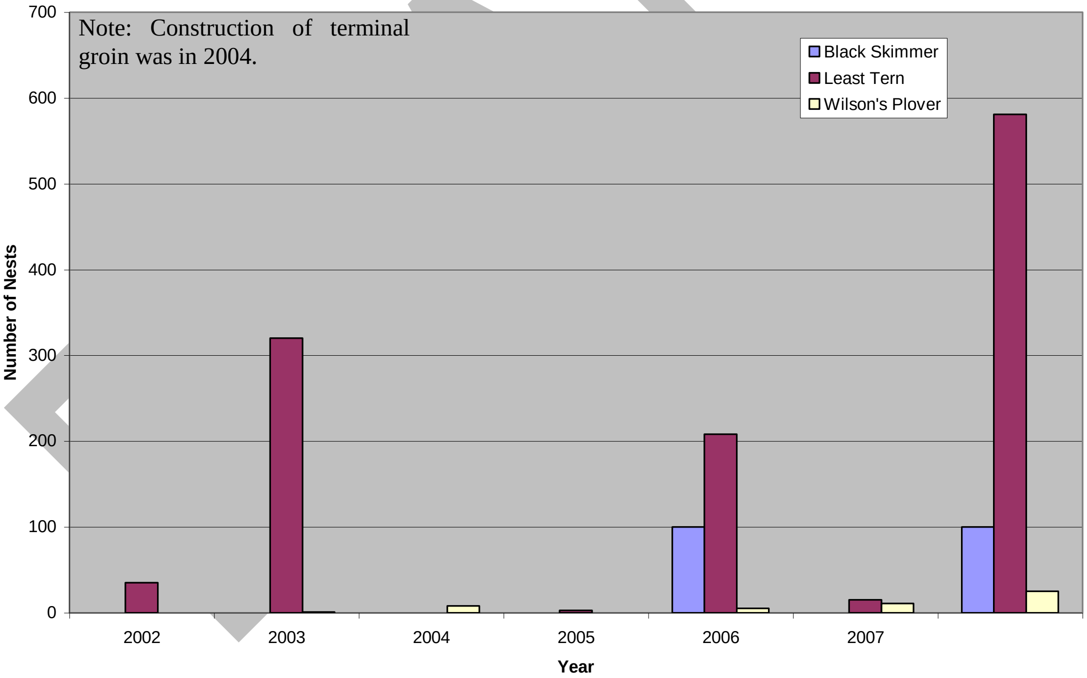
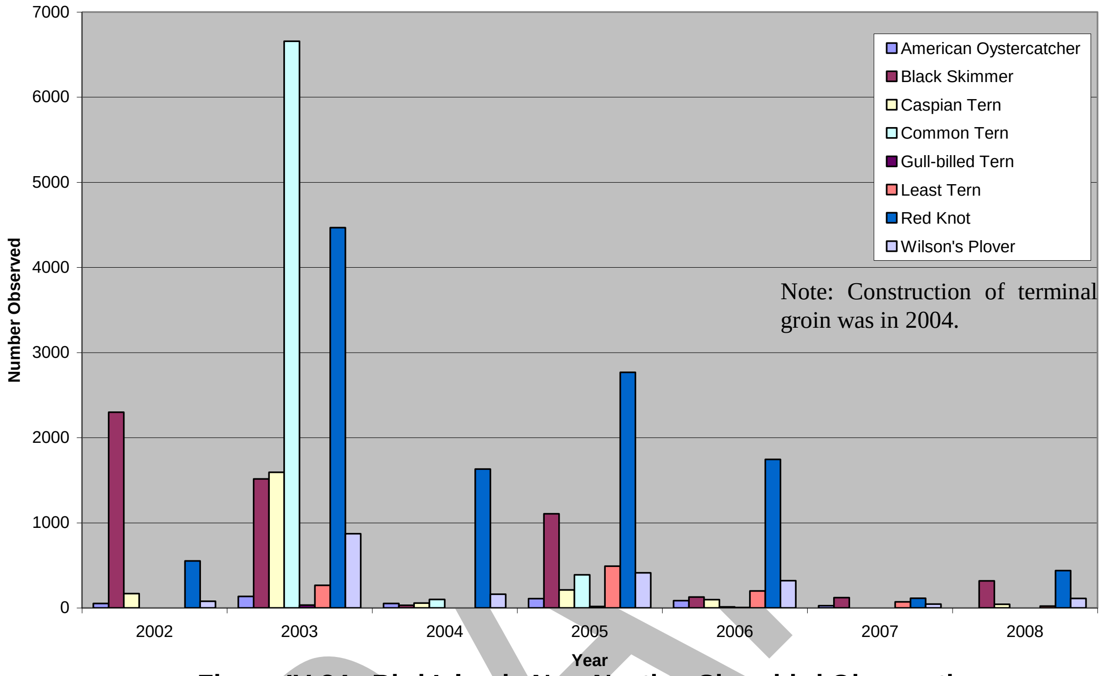


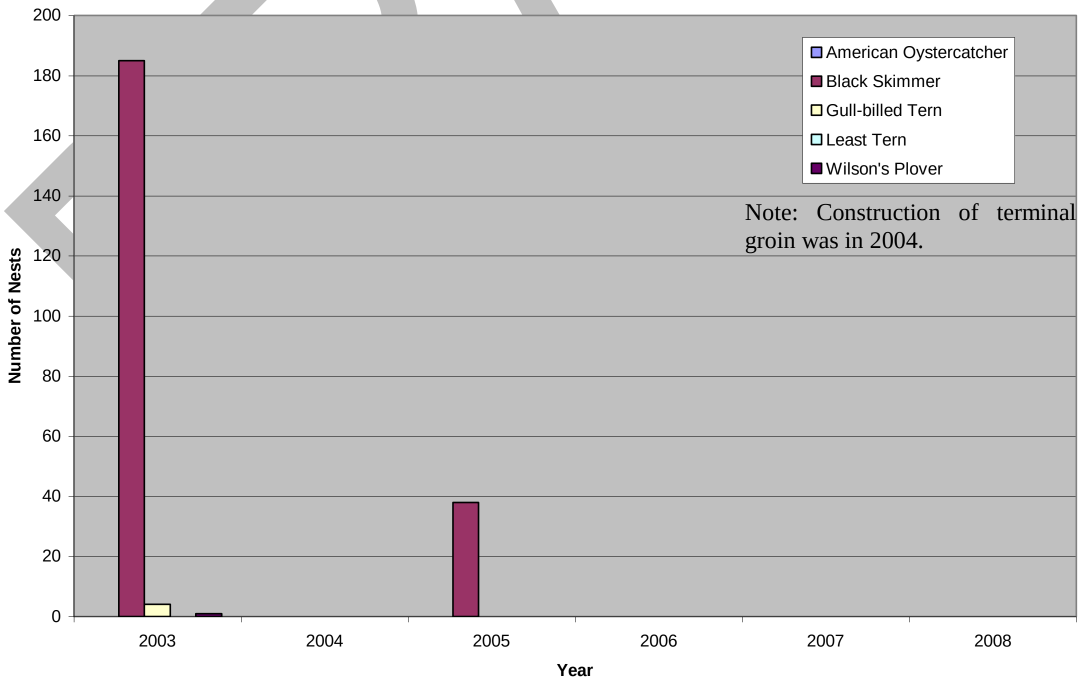
Figure IV-33. Amelia Island Nesting Shorebird Observations

On the Bird Islands, the total number of individuals representing all of the selected species increased from 3,261 in 2002 to 15,697 in 2003 (Figure IV-34). The total number of individuals declined to 2,150 in 2004, increased to 5,579 in 2005, and declined to 2,765 in 2006. Total numbers declined further to 396 in 2007 and remained relatively low at 937 in 2008. Red knots were the most abundant species, with an average of 1,861 individuals observed annually over the course of the seven-year monitoring period (2002 through 2008). Other abundant species included common terns (annual average of 1,193), black skimmers (annual average of 537), Caspian terns (annual average of 334), and least terns (annual average of 174). Nesting records for the Bird Islands include 185 black skimmer nests in 2003, four gull-billed tern nests in 2003, one Wilson's plover nest in 2003, and 38 black skimmer nests in 2005 (Figure IV-35).



Note: Construction of terminal groin was in 2004.

Figure IV-34. Bird Islands Non-Nesting Shorebird Observations



Note: Construction of terminal groin was in 2004.

Figure IV-35. Bird Islands Nesting Shorebird Observations

On Little Talbot Island, the total number of individuals representing all of the selected species increased from 1,015 individuals in 2002 to 1,259 individuals in 2003 (Figure IV-36). The total number of individuals declined to 421 in 2004, increased to 1,463 in 2005, and declined to 927 in 2006. Total numbers declined further to 314 in 2007, followed by an increase to 1,262 in 2008. Red knots were the most abundant species, with an average on 409 individuals observed annually over the course of the seven year monitoring period (2002 through 2008). Other abundant species included roseate terns (annual average of 121), black skimmers (annual average of 80), common terns (annual average of 52), and Caspian terns (annual average of 48). Of the selected species; nesting by least terns, Wilson's plovers, and American oystercatchers has been documented on Little Talbot Island (Figure IV-37). Since 1997, a total of 95 nests have been recorded on Little Talbot Island. A total of 57 least tern nests were recorded from 1997 through 2002; however, no additional least tern nests have been observed since 2002. Of the 57 least tern nests, 31 were recorded in 1997 and 21 were recorded in 2002. A total of 36 Wilson's plover nests were observed from 1997 through 2007. Of the 36 Wilson's plover nests, 20 were recorded in 2002 and nine were recorded in 2007.

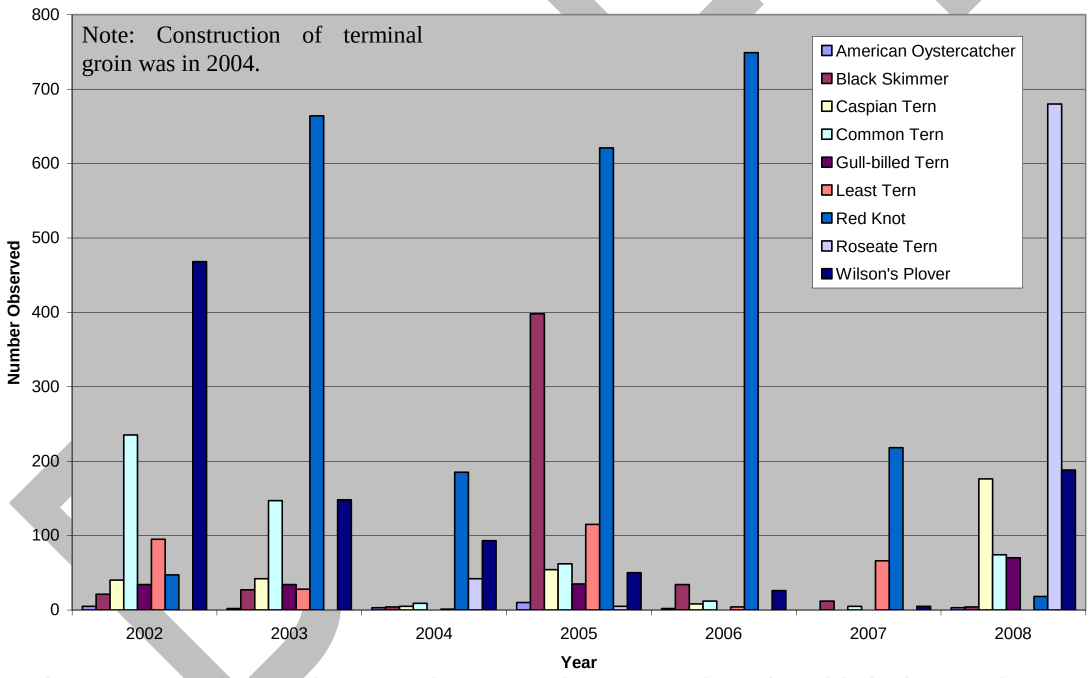


Figure IV-36. Little Talbot Island State Park Non-Nesting Shorebird Observations

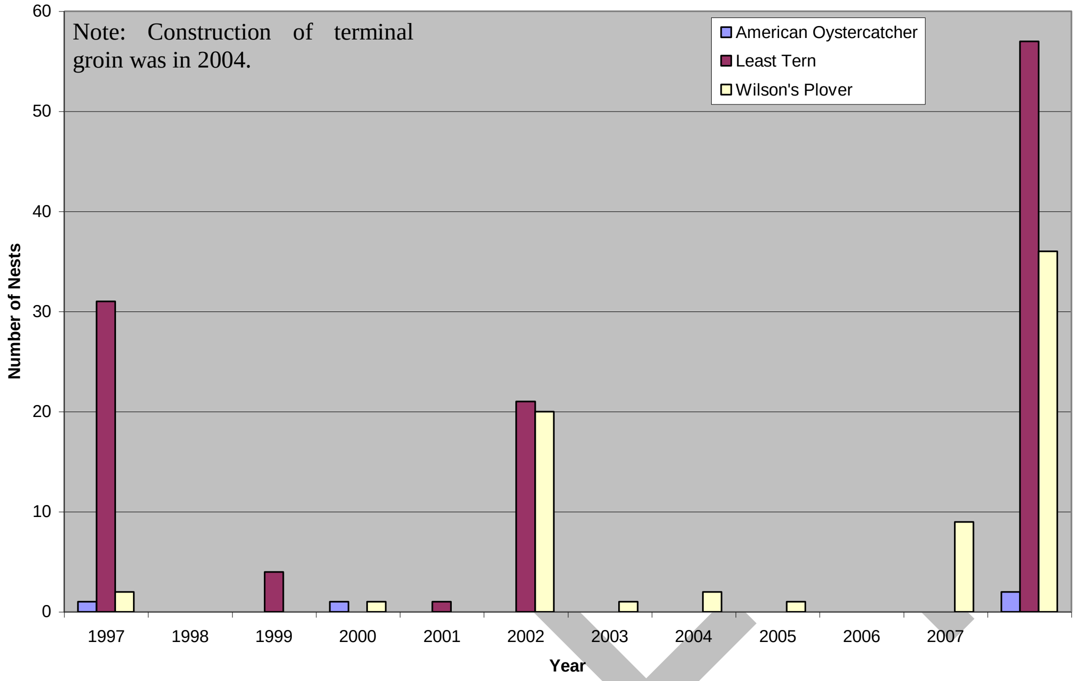


Figure IV-37. Little Talbot Island State Park Nesting Shorebird Observations

Federally Threatened Species

Least Tern

The least tern is listed by the state of Florida as a threatened species and is protected federally under the Migratory Bird Treaty Act [Florida Game and Freshwater Fish Commission (FGFWFC) 1997]. The AISP is designated by the state as Critical Wildlife Habitat for least terns (Personal communication, M. Simmons, AISP, November 2009; DC&A 2003). However, prior to Phase I renourishment efforts, lack of suitable beach habitat precluded this species from utilizing this protected area. The southern portion of Little Talbot Island State Park contains a least tern nesting area (Personal communication, M. Simmons, AISP, November 2009). Least terns attempted to nest along the beach at the northern end of Little Talbot Island State Park in 2001, but nest inundation from higher than normal tide events destroyed nests and nest contents (Lach 2001). Continued above-average tides hindered successful re-nesting efforts in those areas during that year's nesting season. These failures typify that lack of suitable, expansive beach habitat can greatly reduce nest success.

Since 1988, least terns have rarely succeeded in fledging offspring in their traditional colony sites on the north end of Little Talbot Island and the south end of Amelia Island. However, in 2002 beach renourishment activities resulted in a widened beach profile at the south end of Amelia Island and least terns attempted to establish a nesting colony there, though that attempt was abandoned. In 2003, least terns returned to that site and formed a large and very successful colony for the first time since the 1980s; an estimated 125 pairs nested and produced approximately 75 fledglings.

Piping Plover

Although Little Talbot Island is designated by the state as Critical Wintering Habitat for the piping plover, AISP, including the northern limits of project boundaries, does not have this designation (Figure IV-30). The piping plover has not been reported within the AISP, although a few sightings of this species have been made south of the project area (DC&A 2003). Since piping plovers consistently use this portion in relatively high numbers, it would be expected that a significant adverse change to the habitat could have a similar effect on those birds (USFWS 2004). Activities on-site may cause some birds to shift preferred nesting sites. Because FL-Unit 35 extends further south to the St. Johns River, and the birds are also known to utilize that area, the unit's size and the documentation of birds using other unaffected areas within the unit helps reduce those potential effects (USFWS 2004).

Annual piping plover observations on Little Talbot Island and the Bird Islands have been recorded by the FDEP since 2001 (Figure IV-38). On average, 153 piping plovers have been observed annually since 2001. The number of annual observations increased from three in 2001 to 181 in 2002 and 329 in 2003. Annual piping plover observations subsequently declined to 200 in 2004, and remained steady in 2005 and 2006. The annual average for the period of 2004 through 2006 was 218 individuals. Piping plover observations subsequently declined to 28 in

2007 and remained low at 53 individuals in 2008. FDEP data do not include any records of piping plovers on Amelia Island.

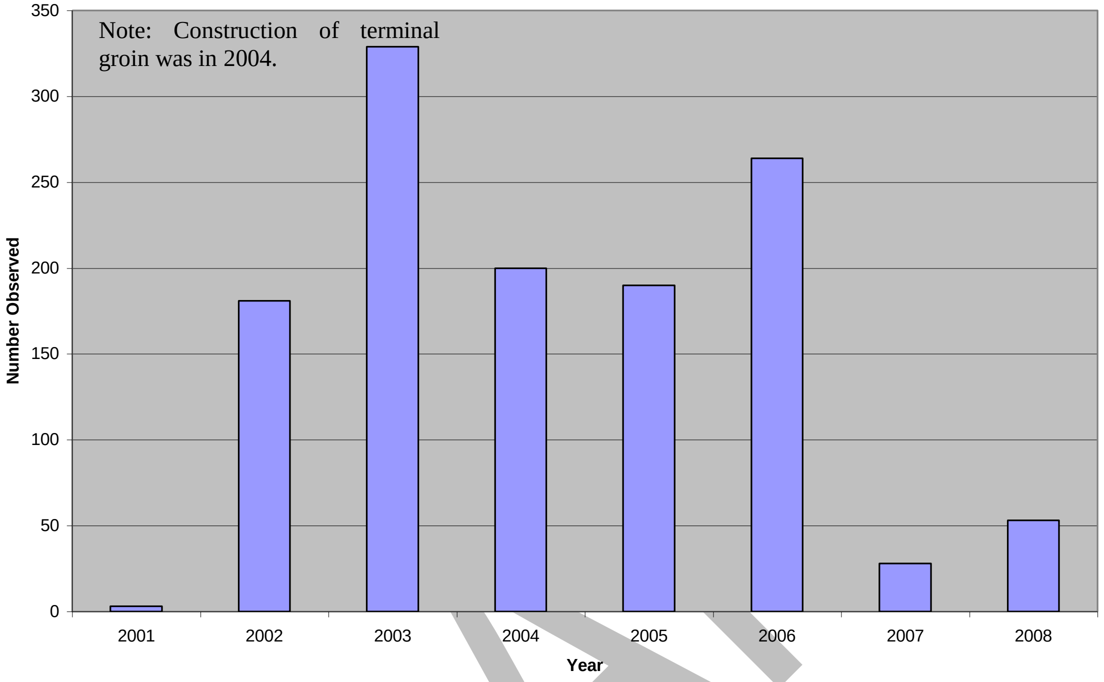


Figure IV-38. Piping Plover Observations for Little Talbot Island and Bird Islands, Nassau Sound

<u>Nesting on the Nassau Sound Islands</u>

The Nassau Sound islands have historically supported some of the largest and most diverse shorebird nesting colonies in northeast Florida. Shorebird nesting efforts were highest in the 1970s and 1980s when thousands of black skimmers, gull-billed terns, royal terns (*Thalasseus maximus*), least terns, and sandwich terns (*Thalasseus sandvicensis*) nested on the islands. Smaller numbers of American oystercatchers, Wilson's plovers, and laughing gulls (*Leucophaeus atricilla*) have also been recorded nesting on the islands. Monitoring of shorebird nesting on the Nassau Sound islands has occurred on and off for at least the past 30 years. Nesting surveys were conducted from 1974 through 1977 by Dr. Robert W. Loftin and students from the University of North Florida (Loftin 1978).

Nesting data from 2000 through 2004 indicate that black skimmers and gull-billed terns successfully nested and produced chicks on Nassau Sound islands, though at reduced numbers compared to the 1970s and 1980s. Estimating the number of nesting pairs has been difficult since the colonies were not entered during the surveys to prevent disturbance (Personal communication, M. Simmons, AISP, November 2009). Typically about 200 black skimmers and a dozen gull-billed terns nested on the Nassau Sound islands each year during this period (SMP). However, overwash of the nesting areas during storm events and spring tides has been a persistent problem for nesting colonies on the islands. Based on pre- and post-survey data within

Nassau Sound, the Bird Islands have not experienced a change in total acreage (Personal communication, A. Browder, Sr. Engineer, Olsen Associates).

Nesting on Amelia Island, North of the State Park

In 1994, a beach nourishment project was carried out along southern Amelia Island. Sand was pumped onto approximately three miles of the beach from just south of American Beach southward to about the northern border of the state park. In 1995, least terns first nested on that re-nourished beach, at the southern end near the south Amelia public beach access. Numbers of nests increased each year until 1999, when approximately 150 pairs nested there. In 2000, no least terns attempted to nest in any part of the re-nourished area of the Amelia Island beach until June/July. Then, only about 50 pairs began nesting in the southern area, probably as a second nesting attempt. Numbers of least terns nesting in this area remained low through 2004, when it was estimated that 50 to 75 least terns nested there (Personal communication, M. Simmons, AISP, November 2009). Observations have indicated that least terns nesting in this area have been successful incubating eggs to hatching and rearing the young to fledging, but fledging rates are not known.

Permit provisions were expected to provide suitable nesting sites outside the construction area. To ensure no adverse effects occurred, the permit for Phase II of the South Amelia Island Stabilization Project required post-construction surveys and monitoring and an annual report discussing the performance of the beach fill and the structures, especially any adverse effects that might be attributable to the structures. Due to inconsistent monitoring protocols and the lack of historical monitoring data for Amelia Island State Park, it is difficult to draw conclusions regarding the effects of the terminal groin on shorebird use (Personal communication, M. Simmons, Biologist, AISP, February 2010).

(4) Fish and Fisheries

The SAFMC (1998) has designated the water column and intertidal flats within the project area as EFH. The nearshore bottom area has also been designated as Essential Fish Habitat-Habitat Areas of Particular Concern (EFH-HAPC) (SAFMC 1998).

Several different species inhabit the intertidal flats and water column. As reported by USACE (1984), species that inhabit these habitats include red drum, spotted seatrout, bluefish, Atlantic croaker, kingfish, and mullet (*Mugil* sp.). Continental Shelf Associates (1993) conducted trawls in the region and identified bay anchovy (*Anchoa mitchilli*) as the dominant species collected. Drum (Family Sciaenidae) were the second most abundant fish collected. Table IV-7 represents species that were identified within the project area or could potentially be observed in and around the project area.

Table IV-7. Fish species within and adjacent to the Nassau Sound.

Common Name	Scientific Name
Bay anchovy	*Anchoa mitchilli*
Black drum	*Pozonias cromis*
Bluefish	*Pomatomus saltatrix*
Croaker	*Micropogan undulates*
Mullet	*Mugil* sp.
Pompano	*Trachinotus carolinus*
Southern flounder	*Paralichthyr lethostigma*
Spanish mackerel	*Scomberomorus maculates*
Spotted seatrout	*Cynoscion nebulosus*
Red drum	*Scianenops ocellata*
Kingfish	*Menticirrhus americanus*

As discussed in the EA, temporary effects that were projected to occur include displacement of fish during placement of rock associated with the construction of the terminal groin as well as temporary elevation in turbidity levels (DC&A 2003). Long-term effects of the structure would be beneficial to fish by providing significant structure currently absent within the project area.

c) Benthic Resources

Based on a review of available literature for this site, biologically active hardbottom habitat does not exist within the project area. The benthic communities present on or near the beaches and in the offshore borrow area are associated with sandy sediments.

A dominant invertebrate found along the shoreline of Nassau County is the Atlantic coquina clam (USACE 1999b). Biological communities in the highly dynamic intertidal swash zone must cope with being aerially exposed during normal tidal cycles as well as being subjected to the high energy of the ocean waves. Typically, these organisms have low species diversity because of the harshness of the environmental conditions present. However, animals that are able to successfully adapt to these dynamic conditions are faced with very little competition from other organisms. Because of this lack of competition and adaptability to the dynamic conditions found along the project area, coquina clams are able to numerically dominate the biological community (Edgren 1959).

Receding waves tend to wash amphipods and isopods out of their burrows and suspend these organisms into the water column where they serve as an important food source for a variety of nearshore fish. A variety of polychaete worms that are also adapted to this highly dynamic and stressful environment can be found within the intertidal zone of the Nassau County beaches. These intertidal organisms also provide an important food source for foraging shore and wading birds. Highly visible decapod crustaceans of the Nassau County supralittoral zone include the ghost crab, mole crab, and Atlantic fiddler crab (*Uca pugilator*). These organisms are highly motile and burrow into the moist sand to retard water evaporation from their bodies during aerial exposure (Barnes 1974). As described in DC&A (2003), the nearshore benthic community was comprised of approximately 59 acres. Post-construction monitoring was not a permit requisite for this resource.

4. Captiva Island

a) General Site Description

Redfish Pass is a relatively young, hydraulically stable tidal inlet (CEPD 2002). The pass separates North Captiva Island from Captiva Island and connects Pine Island Sound to the Gulf of Mexico. Redfish Pass is reported to have cut through the barrier island during a severe tropical storm in 1921. The pass is about 900 feet wide and recent surveys indicate depths up to 20 feet (CEPD 2002) (Figure IV-39).

Figure IV-39. Captiva Island, Florida

The extensive shoal system (ebb and flood tidal shoals) that has formed as a result of the pass contains about eight million cubic yards of material. This material has been trapped from the longshore transport between adjacent shores. The Redfish Pass Inlet Management Plan (IMP) investigated the effect of the pass on Captiva Island and found it to be approximately 32,000 cubic yards per year (CPE 1995). Studies since then have indicated higher estimated effects.

The erosion problem along the gulf-shore of Captiva and Sanibel Islands stems from a sand deficiency principally caused by inlet effects from Redfish Pass and Blind Pass (CEPD 2002). Since the CEPD was established in 1959 by an Act of the Florida Legislature, several types of structures and beach fill have been constructed in attempt to remedy the situation. Prior corrective actions identified in the 1996 Design Memorandum and still existing in the project areas are summarized below:

Date	**Shore Protection Structure**
1961	Placement of 107,000 cubic yards of beach fill from bay side of the island.
1962-63	Installation of two timber groins along the center of the island.
1972	Initial construction of terminal rock groin at Blind Pass.
1977	Initiation of terminal rock groin at Redfish Pass.
1981	Placement of 655,000 cubic yards of initial fill and completion of terminal groin at north end of Captiva Island (Redfish Pass).
Uncertain	6,200-ft rock revetment and 850-ft concrete wall constructed on Captiva Island.
1988-89	Placement of 1,594,522 cubic yards of fill along 4.5 miles of Captiva Island and a 100-ft extension of the terminal groin at south end of Captiva Island (Blind Pass).
1991	Private seawall constructed 1/3 of a mile south of Blind Pass.
1993	240-ft rock revetment on Sanibel Island (near R-111) to protect road.

Many of the rock structures described above by CEPD (2002) are buried and deemed to not affect the future construction activities. The two main structures in existence are the terminal groins at Redfish Pass and Blind Pass.

Based on the Redfish IMP, the Redfish Pass groin was refurbished and extended during the summer of 2006. The refurbishing of the existing Redfish Pass groin located on the northern end of Captiva Island was required to economically maintain the design cross-section within the region south of the groin. The refurbishing of the groin limited the possibility of abrupt movement of material from the project area into Redfish Pass. According to CEPD (2002), since the completion of the 1996 project, the project area shoreline has receded an average of 28 feet in the Captiva segment of the project. During this period, the most severe shoreline recession, 139 feet, has occurred near Redfish Pass.

(1) Aesthetics

Captiva Island possesses visually pleasing attributes including the waters of the Gulf of Mexico and the existing natural appearing beach. The white sand contains fragments of shells, which tend to give the beach a golden tint (CPE 1995). The beaches of Captiva, although eroded, are famous for the shells that are sought by visitors. The island is developed residentially along the majority of its length. Hotels and condominiums are present in some areas of South Seas Plantation and intermittently along the rest of Captiva Island. There is a vegetated dune along the entire length of Captiva Island in which some sections are adjacent to the Captiva-Sanibel Road, which is the only route to mainland Florida (CPE 1995).

(2) Recreation

Common water related activities in southwest Florida include fishing, sailing, kayaking, snorkeling, and recreational diving. In Lee County, listed dive shops and dive boat operations are concentrated in the Ft. Myers area. Based on 1999 data provided by the Bureau of Marine Fisheries Management, there are more than 40 artificial reefs in Lee County (CEPD 2002).

FMRI reported 39,000 registered vessels for Lee County in 2000. There were over 3,500 personal pleasure watercraft boats registered and more than 300 personal watercraft rentals in 2000. Sailing, kayaking, and canoeing are popular water activities on Captiva and Sanibel Islands with guided tours or private rentals available. Redfish Pass provides recreational boating access through a relatively deep channel that has not required maintenance dredging

(3) Public Access

As described in the Joint Coastal Permit Application for the Captiva and Sanibel Islands Renourishment Project (CEPD 2002), the project area consisted of both publicly and privately owned property. Of the 4.9-mile project length on Captiva Island, 5,562 linear feet provide direct public benefit. The largest Gulf front parcel on Captiva Island is the 5,010-foot segment of public road that traverses adjacent to the beach and is the main Hurricane evacuation route.

Turner Park, adjacent to Blind Pass provides a public beach and parking. The remaining public properties are road ends. Public access is available at seven access points on Captiva Island with two public parking lots. The entire project area has been developed. Resort and beach recreation development is prevalent in the northern segment of Captiva Island with the remainder being primarily single-family residences. State Road 867 parallels the shoreline for a distance of approximately one mile and a rubble revetment was constructed to protect the roadway.

b) Natural Resources

Redfish Pass, which has a history of slow migration and tidal shoaling, greatly influences the surrounding estuarine and marine environment (CPE 1993). The presence of the pass allows for the mixing of gulf and estuarine waters. The tides that occur at the pass greatly influence the currents, water quality, salinity, and temperature regimes within the pass and the surrounding estuarine waters. The pass also provides migratory marine-estuarine species with ready access to their spawning and nursery grounds (Figure IV-40).

Figure IV-40. Coastal Classification of Habitat for Redfish Pass, FL

Captiva is in an area of overlap between subtropical marine species and temperate marine species (CEPD 1995). Many of the sessile tropical species are at the northern limit of their range and are under some natural stress during the winter months because of lowered temperatures and the increased turbidities brought on by storms. Many motile forms, such as fish, migrate in and out of the area with the seasons. During the warmer summer months, tropical species predominate, while during the cooler winter months, temperate species are relatively more abundant.

The natural resources surrounding Redfish Pass are comprised of three major resource classifications (CPE 1993). These include the beach and dune system, and upland areas; the estuarine wetlands; and the nearshore Gulf of Mexico. As depicted in Figure IV-41 (1991 snapshot) and Figure IV-42 (2006 snapshot), the habitat surrounding Redfish Pass has remained relatively stable.

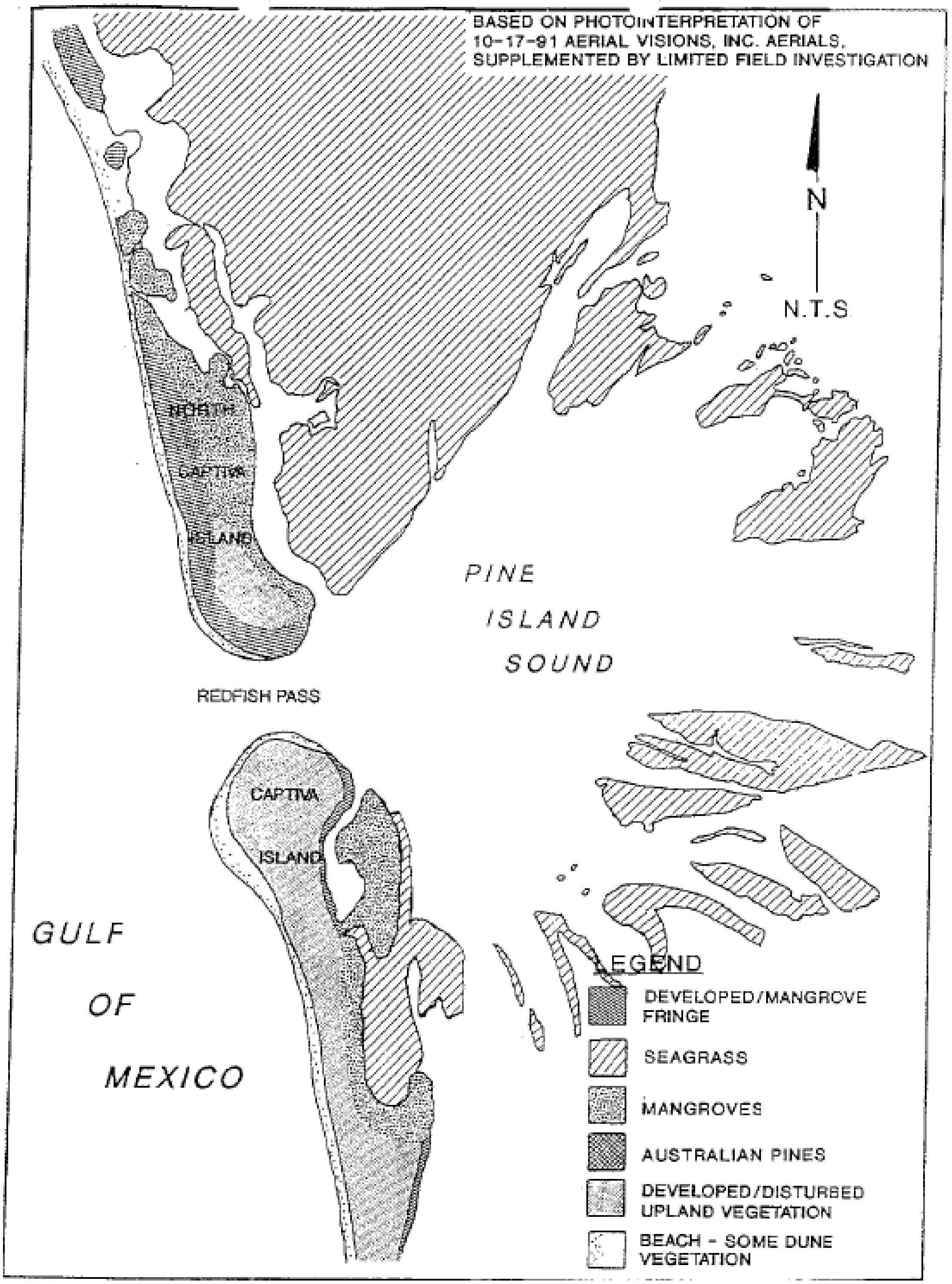


Figure IV-41. Coastal Habitats of Redfish Pass (1991)

Figure IV-42. Seagrass and Mangrove Habitat for Redfish Pass, FL

Based on discussions with Lee County's Operations Manager for Marine Services, shoreline protection efforts alone may have possibly worked; however, the additional sand placement events needed to maintain the shoreline would have likely had adverse indirect effects on fisheries and SAV within Redfish Pass as a result of sand transport. Additionally, without the construction of the terminal groin, there would have been a significant increase in cost to shoreline protection efforts due to an increase in the frequency of sand placement events. Without both the terminal groin and fill project elements, the degrading habitat would have lessened the opportunity for nesting birds and sea turtles (Personal communication, S. Boutella, Operations Manager for Marine Services, Lee County, February 2010). As confirmed by the Sanibel-Captiva Conservation Wildlife Habitat Management Office, the groin and fill area at Redfish Pass does not appear to be of an immediate concern to the local resource agencies (Personal communication, B. Smith, Director, February 2010).

(1) West Indian Manatee

Lee County is considered one of the most important counties for manatees on the west coast of Florida due to the large expanses of warm, shallow water that contains seagrass; the presence of warm water refugia; and ready access to freshwater resources (FDEP 2005). Lee County waters host a large number of manatees that travel south and north, to and from the waters of southern Collier County and the Everglades.

Manatees extensively use the seagrass beds, tidal creeks, canals and marine basins in Pine Island Sound, Matlacha Pass, and San Carlos Bay (Figure IV-43). Manatees may frequently move north along the bayside coasts of the barrier islands such as Sanibel, Captiva, Northern Captiva, and Cayo Costa. Lee County, along with the FDEP, completed a comprehensive Manatee Protection Plan (MPP) in 2004. In addition, both county and state governments have passed some basic manatee protection speed zone rules in portions of the county including the Caloosahatchee River. A more comprehensive rule was developed and includes slow speed zones from April 1st through November 15th in Pelican Bay (between Cayo Costa and Punta Blanca Islands) as well as within Safety Harbor on North Captiva Island. These speed zones reflect the need for manatee protection during the warmer months of the year when manatees are more likely to be found along the barrier island chain.

(2) Sea Turtles

As described by Foote (2003), erosion control structures are proposed to absorb wave energy and minimize sand scouring thus providing a sandy beach for humans, for property protection, and for sea turtle nesting habitat. If the structures perform successfully and adequate sand remains within the project area it is probable that sea turtles will nest near the erosion control structures. The beaches in proximity to Redfish Pass provide nesting habitat for the Atlantic loggerhead sea turtle (Figure IV-43). Other sea turtles reported to occur in the vicinity of Redfish Pass include the green, hawksbill, Kemp's ridley, and the leatherback sea turtles. Prior to the 1988 Captiva Island beach restoration project, continuing beach erosion and the construction of shoreline protection structures had resulted in the loss of most of the sea turtle nesting habitat south of Redfish Pass (LeBuff 1990). Following the 1988 Captiva Island beach restoration project, LeBuff (1990) confirmed both the number of nests and nesting success increased. Studies prior to the beach project documented an average of 19 nests/year for the five-mile beach, with an average nesting success of 36.5 percent. In contrast, according to CPE (1993), the average number of nests from 1988 to 1991 was 56.8 nests or a 199 percent increase over pre-restoration averages.

Figure IV-43. Species Occurrence for Redfish Pass, FL

Sea turtle nesting data for Captiva Island dates back to 1986 (Figure IV-44). On average, 94 nests were recorded annually from 1986 through 2009. The number of nests on Captiva Island increased steadily from 28 nests in 1986 to 141 nests in 1995. The number of nests declined over the next two years, before increasing sharply to 177 nests in 1998. The number of nests remained high over the next two years, with 142 nests in 1999 and 179 nests in 2000. The number of nests generally declined over the course of the next seven years, reaching a low of 54 nests in 2007.

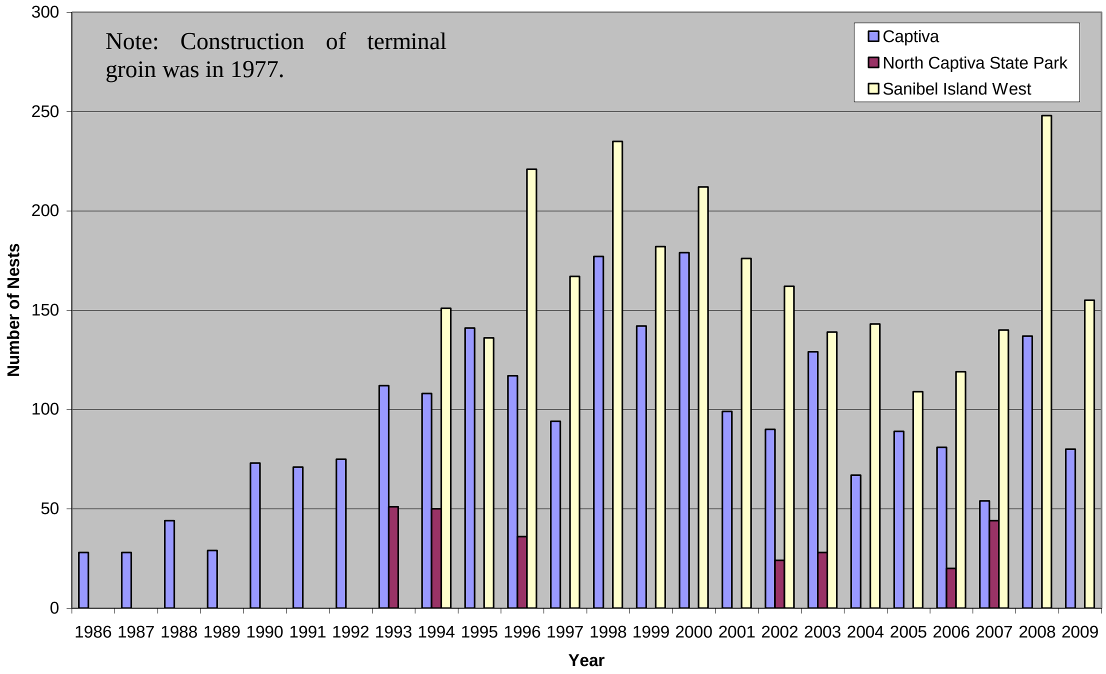


Figure IV-44. Sea Turtle Nesting Data from Captiva Island, North Captiva State Park, and Sanibel Island West

Sea turtle nesting data for Sanibel Island West dates back to 1994 (Figure IV-44). On average, 168 nests have been recorded annually over the course of the last 16 years. A total of 151 nests were recorded during 1994. The number of nests declined slightly to 136 nests in 1995, followed by an increase to 221 nests in 1996. The number of nests reached a peak in 1998, when a total of 235 nests were recorded. The number of nests gradually declined over the next seven years, reaching a low of 109 nests in 2005. The number of nests increased over the next three years, reaching an all-time high of 248 nests in 2008.

Nesting data for North Captiva Island State Park is intermittent. The available data set includes 1993, 1994, 1996, 2002, 2003, 2006, and 2007 (Figure IV-44). The number of nests recorded ranged from 20 to 51. The average number of nests recorded was 36.

To date there is little available data regarding sea turtle hatchling reactions/interactions with offshore emergent breakwaters or shoreline T–groins, such as the three T-groin structures located on the north side of Redfish Pass (North Captiva Island). There are currently few similar structures along the west Florida shoreline. These Gulf coast structures can be found at 1) at Marco Island in Collier County, 2) in Naples, north of Gordon Pass, Collier County, and 3) at North Captiva Island, at the north side of Redfish Pass in Lee County. Monitoring has shown that the existing structures on the west coast have improved beach stability leading to additional nesting habitat (Personal communication, K. Humiston, Humiston & Moore Engineers). No adverse effects, except for one female sea turtle becoming entrapped in the groin, have been documented. Only limited nesting has occurred near the existing structures. Additionally there has been minimal monitoring effort to evaluate the failure or success of the hatchling migration from the shoreline to and/or beyond these structures. Sea turtle nesting on Captiva Island has historically been very low. Consequently, it is not possible to detect changes associated with the terminal groin [Personal communication, A. Bryant, Sanibel Captiva Conservation Foundation (SCCF), February 2010].

(3) Shorebirds and Waterbirds

Many species of birds are known to forage in the project area, particularly on North Captiva Island (CPE 1993). Shorebirds, including gulls, terns, sandpipers, plovers and stilts, use the intertidal beach for foraging; while other birds, such as the eastern brown pelican and the double-crested cormorant, forage in the nearshore waters (Continental Shelf Associates 1987). Table IV-8 lists some of the most common bird species reported in the vicinity of Redfish Pass.

In 2009, a USACE sponsored bird survey for Lee County was conducted (Lott et al. 2009). Redfish Pass between North Captiva Island and Captiva Island was included within the survey area. The north and south sides of the pass were surveyed separately. Captiva Island has an elevated area on the inlet beach that larids and shorebirds use for roosting. Species diversity was low as only nine species were observed over three visits: the great egret, snowy egret, black-bellied plover, willet, ruddy turnstone, sanderling, laughing gull, royal tern, and sandwich tern. All observations were either on intertidal or shallow-water substrates, and no wrack line was present. The disturbances were low at this site relative to other surveyed areas. During the three surveys; no vehicles, no dogs, and no parked boats were observed.

Based on irregular surveys, Captiva Island has less shorebird diversity and abundance as compared to Sanibel (Personal communication, B. Smith, Director of Sanibel-Captiva Conservation Wildlife Habitat Management Office, February 2010). Although shorebirds and waterbirds are not regularly surveyed on Captiva in the vicinity of Redfish Pass, there is a monitoring program associated with Blind Pass on Sanibel Island, approximately five miles south of Redfish Pass. There are four species of listed shorebirds that have been historically known to nest on Sanibel Island, approximately five miles from Redfish Pass, which include: least tern, snowy plover (*Charadrius alexandrinus*), Wilson's plover, and black skimmer (Loflin 2005). In the last eight years, the previously small nesting population of black skimmers has, for an unknown reason, ceased nesting activities on Sanibel Island. A small historical nesting colony that included all four species nested in the dunes landward of part of the nourishment area (just west of Silver Key), but none of these species returned to nest at this site in recent years; probably due to a steadily increasing density of native coastal vegetation including sea oats, salt grass, marsh elder, sea blight, railroad vine, and inkberry at this former tidal pass location.

Table IV-9 presents the number of nesting pairs of each species found during monitoring by the SCCF on all Sanibel Island beaches in 2002 through 2003. SCCF has the only comprehensive shorebird monitoring and protection program for the island.

No shorebird nesting is known to have occurred within or immediately adjacent to the proposed nourishment project locations from 2002 through 2005 (Loflin 2005). A recently active colony of approximately 15 pairs of least terns and seven pairs of snowy plovers was located approximately 1,200 feet from the east end of the proposed project location.

Table IV-8. Common bird species within the vicinity of Redfish Pass.

Common Name	Scientific Name
American robin	*Turdus migratorius*
Black skimmer	*Rynchops niger*
Blue jay	*Cyanocitta cristata*
Boat-tailed grackle	*Quiscalus major*
Carolina wren	*Thyrothorus ludovicianus*
Common barn-owl	*Tyto alba*
Common flicker	*Colaptes auratus*
Common grackle	*Quiscalus quiscula*
Common ground-dove	*Columbina passerina*
Common yellowthroat	*Geothlypis trichas*
Eastern screech-owl	*Otus asio*
European starling	*Sturnus vulgaris*
Fish crow	*Corvus ossifragus*
Gray catbird	*Dumetella carolinensis*
Gray kingbird	*Tyrannus dominicensis*
Great crested flycatcher	*Myiarchus crinitus*
Great horned owl	*Bubo virginianus*
House sparrow	*Passer domesticus*
Laughing gull	*Larus atricilla*
Mangrove cuckoo	*Coccyzus minor*
Mourning dove	*Zenaida macroura*
Northern cardinal	*Cardinalis cardinalis*
Northern mockingbird	*Mimus polyglottos*
Pileated woodpecker	*Dryocopus pileatus*
Prairie warbler	*Dendroica discolor*
Red-bellied woodpecker	*Melanerpes carolinus*
Red-winged blackbird	*Agelaius phoeniceus*
Ring-billed gull	*Larus delawarensis*
Royal tern	*Sterna maxima*
Rufous-sided towhee	*Pipilo erythrophthalmus*
Sanderling	*Calidris alba*
Sandwich tern	*Sterna sandvicensis*
Short-billed dowitcher	*Limnodromus griseus*
Smoth-billed ani	*Crotophaga ani*
White-eyed vireo	*Vireo griseus*
White-winged dove	*Zenaida asiatica*
Willet	*Catoptrophorus semipalmatus*

Table IV-9. Number of shorebird nests on Sanibel Island in 2002 and 2003.

Species	2002	2003
Snowy plover	27	31
Least tern	50	50
Wilson’s plover	6	8
Black skimmer	0	0

In addition to the nesters, numerous resident or itinerant shorebirds have been recorded as utilizing Sanibel's beaches for feeding, resting, or overnight accommodations on a year-round basis. These species are joined by numerous additional ones during spring and fall migration and a subset of these use the beaches as over-wintering habitat. The piping plover is occasionally observed among the migrants and over-wintering species, although Sanibel and Captiva Islands were not designated as critical habitat for this species during a recent evaluation by the USFWS (Figure IV-43). There was a proposed critical overwintering habitat for piping plovers covering Captiva Island and Sanibel Island; however, due to the lack of use by piping plover in this specific area, this unit has been deleted from the finalized Federal Register (USFWS 2001b). The CEPD received a Joint Coastal Permit from the FDEP in 2002 and a dredge and fill permit from the USACE to undertake a beach nourishment project on both Captiva and Sanibel Islands. As the areas to be nourished were undergoing moderate to severe erosion and did not support shorebird nesting, the project was expected to enhance and benefit shorebird foraging, resting, and nesting habitat. It was anticipated by Loflin (2005), should any shorebirds unexpectedly begin nesting activities before or during construction within the project area; construction activities, especially heavy equipment operation, would disturb the birds. In addition, shorebirds that utilized the shoreline in the project area or immediately adjacent to it during construction for foraging, resting, and nesting would be disturbed and forced to utilize other shorelines. In addition to natural coastal processes, the distribution and quality of bird habitat on Florida’s coasts are strongly affected by human disturbance or coastal engineering (Lamonte et al. 2006).

(4) Water Quality

Redfish Pass falls within a coastal waterbody segment [Waterbody Identification (ID) 2092D] that has been assessed under Florida’s Impaired Waters Rule (Chapter 62-303, F.A.C) and determined to not be in violation of any water quality standards except for mercury in fish tissue (most marine waters in Florida are impaired for mercury) and dissolved oxygen (Personal communication, J. Nelson, FDEP South District Office, October 2009). An important caveat is that no causative pollutant has been established for dissolved oxygen and the water quality stations reporting the impairment are not located in the vicinity of the terminal groin at Redfish Pass. No long-term water quality station exists within the vicinity of Redfish Pass (Personal communication, J. Nelson, FDEP South District Office, October 2009); however, as described by the CEPD (2002) the placement of dredged material on the beach would have no long-term effect on water quality. A temporary localized increase in turbidity was expected as fine-grained material present in the nourishment sands was washed from the sediments. However, no significant increase was expected in nutrients, contaminants, or other parameters since the dredged material was primarily sand that would settle quickly through the water column.

(5) Fish and Fisheries

The offshore gulf waters provide habitat for adult and juvenile fishes (CPE 1993). Estuarine-dependent species which use the offshore and pass waters for spawning include red drum, spotted seatrout, snook (*Centropomus undecimalis*), Atlantic croaker, southern flounder, Florida pompano, striped mullet, Gulf menhaden (*Brevoortia patronus*), tarpon (*Megalops atlanticus*), and bonefish (*Albula vulpes*) (Continental Shelf Associates, Inc. 1987). Reef fishes in the area include red grouper (*Epinephelus morio*), jewfish (*Epinephelus itajara*), gag grouper, scamp (*Mycteroperca phenax*), red snapper (*Lutjanus campechanus*), and mangrove snapper (*Lutjanus griseus*) (Continental Shelf Associates, Inc. 1987).

The coastal waters offshore of Captiva and North Captiva Islands also contain a wide variety of commercial and sport fishes. A review of recent marine fishes annual landings' summaries indicates that significant commercial fisheries for mullet, red grouper, spotted sea trout, blue crab and pink shrimp (*Farfantepenaeus duorarum*) exist in Lee County (CPE 1993). Although some commercially valuable fishes do frequent the waters adjacent to Redfish Pass, commercial fisheries in the vicinity of Redfish Pass are generally limited to seasonal mullet fisheries (CPE 1993). No known commercial concentrations of scallops or shrimp exist in the immediate area of Redfish Pass.

Many commercial fishermen utilize Lee County coastal waters, fishing a wide array of gear for various economically important species. Table IV-10 summarizes commercial values of several species harvested in Lee County for the period between 1992 through 1998 (Lee County 2005).

Tarpon, grouper, red drum, and snook are among the many popular fish caught in Lee County. Local fishing guides provide full-day or half-day fishing tours for several of these species. Snook are caught off the local beaches; whereas, redfish are abundant on the grass flats, inlets, and in the backwaters of Pine Island Sound accessible through Redfish Pass. Most of the fish associated with the nearshore littoral zone offshore Captiva and Sanibel Islands are highly motile and capable of escaping temporary effects.

(6) Benthic Resources

As evaluated by CPE (1993, 1995), aerial photographs and field investigations of the project area shoreline confirmed no significant hardbottom formations exist in proximity to Redfish Pass. The gulf floor surrounding Redfish Pass consists of unconsolidated sediments, primarily sand. According to CEPD (2002), the extension and refurbishing of the terminal groin at Redfish Pass created new areas of nearshore habitat. The original groin covered approximately 0.15 acre of land in vicinity of the intertidal zone and was to be increased to 0.65 acre upon refurbishment. The area to be covered was characterized by sandy bottom with no known hardbottom or seagrass beds. The groin extension provided an additional 0.5 acre of substrate available for habitation by nearshore communities such as crabs, sea urchins, and numerous other gastropod species. During the data collection phase of the study, post-construction monitoring data regarding potential hardbottom and/or seagrass effects due to the extension of the groin at Redfish Pass were not ascertained.

Table IV-10. Commercial values of fish species harvested in Lee County for the period between 1992 through 1998.

Species	1992	1993	1994	1995	1996	1997	1998
Grouper	$1,028,430	$1,007,230	$938,472	$797,017	$927,747	No Data	No Data
Lobster, Spiny	$29,634	$20,564	$27,293	$39,328	$6,288	$13,982	$14,835
Shrimp	$4,291,249	$8,286,381	$8,233,486	$11,524,218	$12,958,319	$12,802,009	$15,940,420
Snapper	$242,723	$232,057	$178,324	$104,331	$71,728	$46,760	$60,164
Stone Crabs	$243,230	$466,080	$500,786	$1,105,251	$1,953,834	$603,951	$739,452
Blue Crabs					$1,941,168	$1,118,088	$1,554,594
TOTALS	**$5,835,266**	**$10,012,312**	**$9,878,361**	**$13,570,145**	**$17,859,084**	**$14,584,790**	**$18,309,465**

Source: Data from FDEP-FMRI

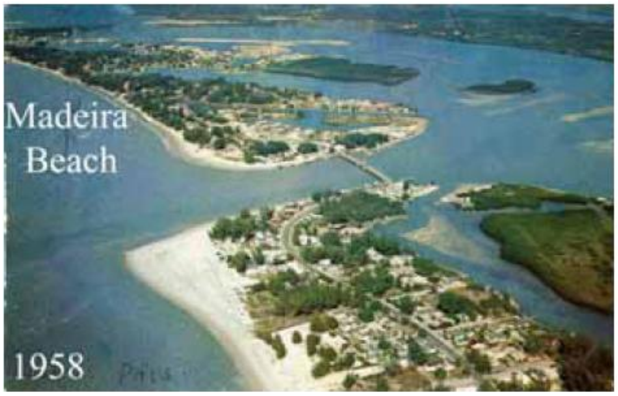
As described by the CEPD (2002), the placement of dredged material on the beach was proposed to have no long-term effect on water quality. A temporary localized increase in turbidity was expected as fine-grained material present in the nourishment sands was washed from the sediments. However, no significant increase was expected in nutrients, contaminants or other parameters since the dredged material was primarily sand which would settle quickly through the water column to the bottom.

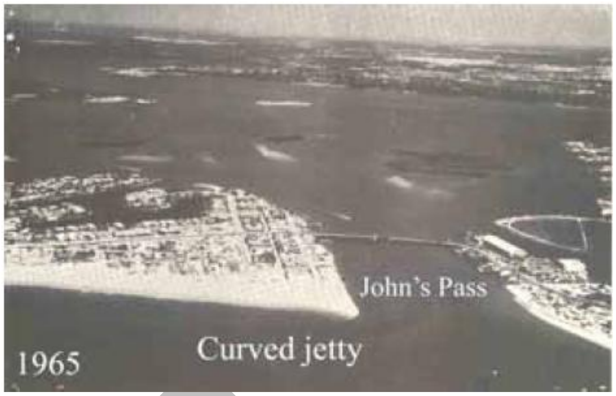
The placement of dredged material on the beach and in the littoral zone was proposed to effect benthic communities occupying the project areas. However, populations of benthic organisms were anticipated to reestablish within six to 12 months after placement occurred (CEPD 2002). Beach nourishment, borrow area dredging, and rehabilitation of marine structures were anticipated to temporarily disrupt some phytoplankton and zooplankton populations. Increased turbidity in the water column was expected to temporarily reduce light penetration, which could have affected primary production by the phytoplankton. However, due to the nature of the materials to be utilized, the effects would have been short-term in nature (Culter and Mahadevan 1982). As concluded by CEPD (2002), no long-term effect on the biological productivity of the nearshore littoral zone was expected.

5. Treasure Island, John's Pass, Florida

a) General Site Description

John's Pass, approximately 2,100 feet long and 600 feet wide, is located on the west coast of Florida and separates Sand Key on the north from Treasure Island to the south (Vincent 1992). Created by a hurricane in 1848, John's Pass connects Boca Ciega Bay to the Gulf of Mexico. The community immediately to the north is Madeira Beach, which prior to the construction of the terminal structure on the south end of Sand Key was experiencing a chronic erosion problem (Dean 1993). A tide-dominated inlet, John's Pass has extensive ebb- and flood-tidal deltas (Davis and Gibeaut 1990) and a federally maintained navigation channel. In an attempt to alleviate the chronic erosion problem, a field of adjustable groins was constructed in 1957 and the terminal structure on the north side of John's Pass shown in Figure IV-45 was constructed in 1961 (Pinellas County Department of Environmental Management 2008). The 1958 postcard, below left, looks north at John's Pass prior to construction of the curved terminal groin. Note the inlet's shoreline has been hardened by seawalls.





In 1961, the City of Madeira Beach constructed the 460-ft curved terminal groin on north side of John's Pass and nourished the beach, as shown in this 1965 photo, above right. Federally-authorized dredging of John's Pass began in 1966. In 2000, Pinellas County constructed another terminal groin on the south side of John's Pass, as shown in the photograph below.

Figure IV-45. John’s Pass, Florida

Treasure Island beaches have been actively managed since 1969, and southern Long Key beaches have been managed since 1980 (CPE 1992). Both beach reaches are on a four-year nourishment cycle (Pinellas County Department of Environmental Management 2008). In 2000, dredge material from John's Pass and Blind Pass were used to renourish Treasure Island and Long Key Beaches.

Treasure Island and Long Key beaches experienced severe erosion following the 2005 hurricane season. As a result, an emergency beach nourishment project took place in 2006 using material from Egmont Shoal (Pinellas County 2009; DC&A 2009). The current project activities under consideration combine the scheduled maintenance beach nourishment activities with scheduled channel maintenance dredging activities associated with John's Pass (2010) and Blind Pass (2009).

Natural events such as storms and hurricanes act to erode beaches and redistribute sands, contributing to the rate at which beaches erode. Management of these beach resources is a collaborative effort between county, state, and federal entities. Florida's inlet operation and maintenance has altered shoreline sediment transport and deposition necessitating shoreline management of these adjacent beaches.

(1) Aesthetics

Equipment utilized during construction activities are visible on the beaches of Pinellas County and detract from the landward and waterward view shed. These visual and public convenience effects were temporary and move with project progress.

(2) Recreation

According to the FDEP (2008), Florida depends on its 825 miles of sandy beaches fronting the Atlantic Ocean, Gulf of Mexico, and Straits of Florida for the enjoyment of its residents and tourists. Beaches and dunes in Pinellas County are some of the county's most valuable natural resources. These resources provide habitat, storm protection, public access, and the base for the tourism industry. Pinellas County has 35 miles of beaches on the Gulf coast of Florida that are valued for their recreational value. Pinellas County residents as well as tourists utilize these beaches year-round.

The economic benefit from visitors to these recreational resources is reflected in the number of visitors and the revenue that they bring to the county. Motel, hotel, and condominium visitation data for 2007 showed 5,300,220 visitors stayed in Pinellas County and spent over $3 billion (Pinellas County 2007). In 2007 and 2008, approximately $750,000 was collected each year through the tourist development tax (Pinellas County 2008).

(3) Public Access

The earliest permanent settlement in Pinellas County avoided the string of barrier islands along the Gulf Coast. Inaccessible and mosquito-ridden, the barriers were bypassed for more suitable home sites on the mainland. The county's barrier islands have in most cases been transformed into linear cities and towns with very little undeveloped land remaining.

According to the Pinellas County beach access guide, there are 127 parking spaces identified within the Madeira Beach Park located just north of John's Pass (Pinellas County Department of Public Works 2009). The Madeira Beach Park also includes restrooms, showers, and walkovers to the beach. Access to the beach front south of John's Pass is limited, as there are eight parking spaces located approximately 500 feet from the inlet. Treasure Island Park, including 151 parking spaces with numerous facilities, is located south of John's Pass.

b) Natural Resources

John's Pass is located within the Pinellas County Aquatic Preserve, established 21 March 1972 and designated as an Outstanding Florida Water on 1 March 1979. The submerged lands of the preserve include sand and mudflats, seagrass beds, and oyster reefs. The estuarine shoreline is protected by mangroves. As described by FDEP (2006), management concerns with aquatic preserves in highly urbanized areas include recreational issues (boating activities), runoff and dredging, loss of habitat due to shoreline hardening and adjacent upland development, and effects to water quality due to an increased load of nutrients. See Figure IV-46 for classification of habitat and development areas.

(1) Sea Turtles

Vertebrate species that utilize the offshore habitats of Pinellas County include many threatened and endangered species. The Gulf of Mexico is within the range of five species of sea turtle, the West Indian manatee, and up to 28 cetacean species. Of these, four species of sea turtle, the manatee, and one cetacean [bottlenose dolphin (*Tursiops truncatus*)] occur within the study area.

Four species of sea turtle commonly occur within the area around Pinellas County [Meylan et al. 1999; Environmental Protection Agency (EPA) 1981]. These are the loggerhead, green, Kemp's ridley, and the hawksbill. Loggerhead sea turtles represent most of the sea turtles present in the Tampa Bay area. Data collected on sea turtle nesting in the area shows that the majority are loggerhead sea turtle nests (Figure IV-47 and Figure IV-48). Stranding records within the Pinellas County area also confirmed that loggerhead sea turtles are the most numerous species.

As shown in Figure IV-48, regular monitoring of sea turtle nesting activity has been conducted on north Pinellas County beaches since 1988. On average, 67 nests have been recorded on the north Pinellas County beaches. The number of nests recorded from 1988 through 1995 was relatively low, with an annual average of 48 nests. Annual nesting records from 1996 through 2005 were significantly higher, with an average of 82 nests.

As recorded by the FFWCC, regular monitoring of sea turtle nesting activity has also been conducted on the middle region of Pinellas County beaches since 1988 (Personal communication, B. Brost, FFWCC, February 2010). On average, 50 nests have been recorded annually for this region of Pinellas County beaches. The number of nests recorded from 1988 through 1994 was relatively low, with an annual average of 37 nests. The number of nests recorded from 1995 through 2005 was significantly higher, with an average of 58 nests.

(2) Shorebirds and Waterbirds

Shorebirds that are known to nest on Pinellas County Beaches include American oystercatcher, black skimmer, laughing gull, Caspian tern, least tern, royal tern, sandwich tern, snowy plover, Wilson’s plover, and willet (Hodgson et al. 2009; FFWCC Shorebird/Seabird Monitoring Website http://myfwc.com/ shorebirds/).

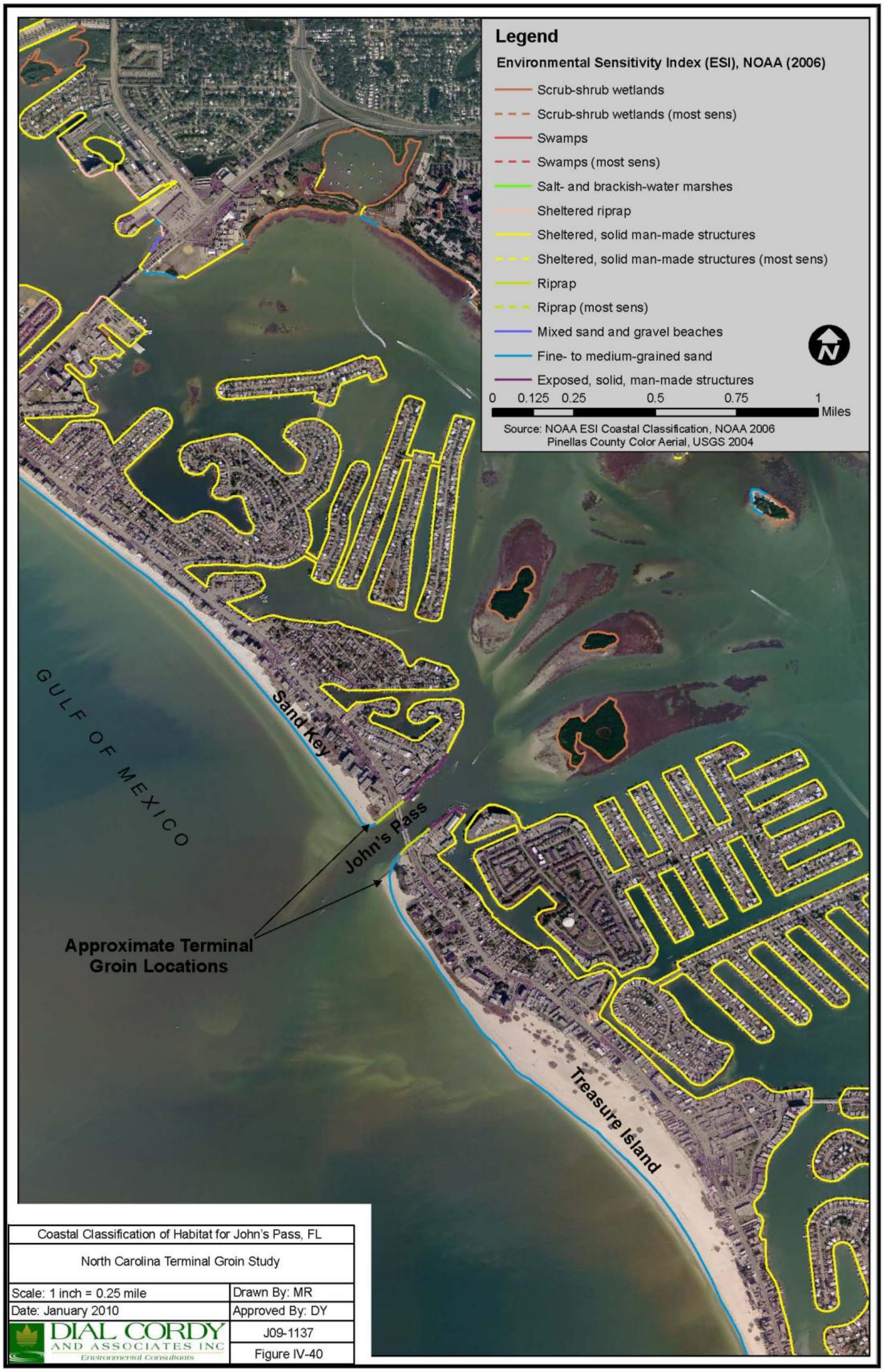


Figure IV-46. Coastal Classification of Habitat for John's Pass, FL

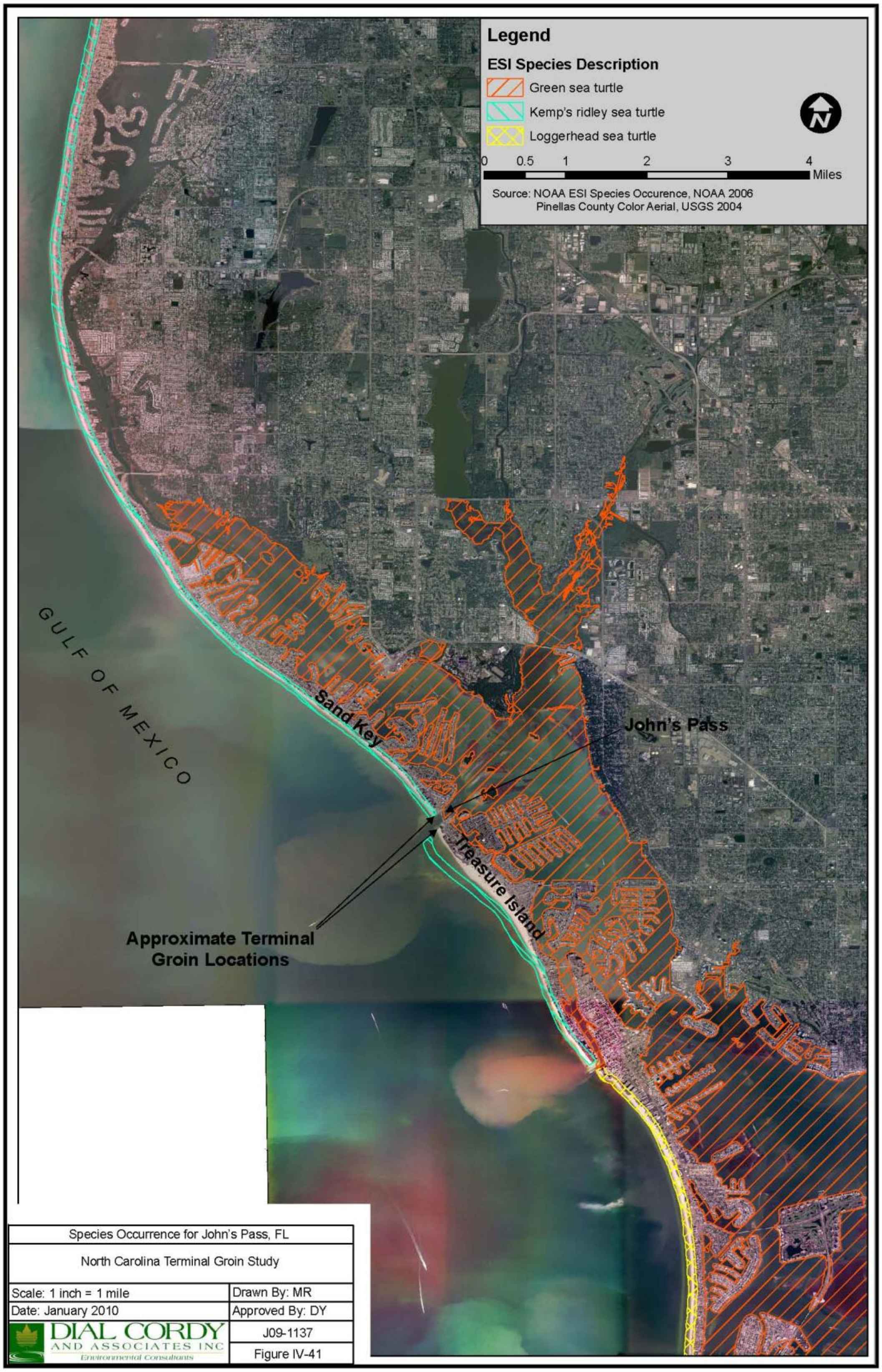


Figure IV-47. Species Occurrence for John's Pass, FL

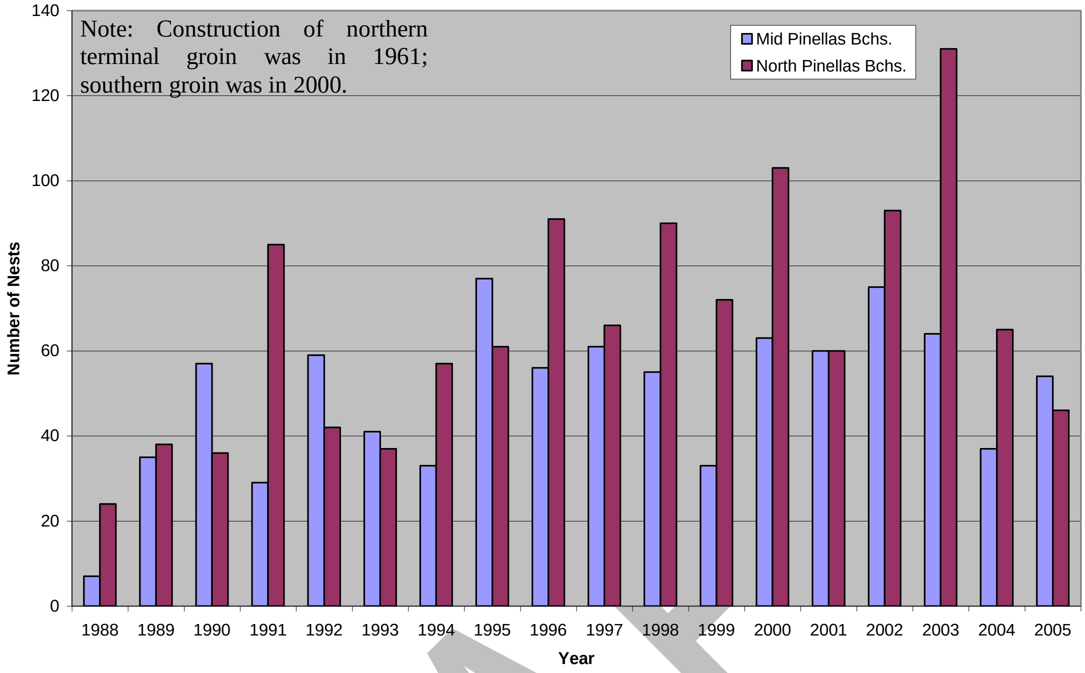

Note: Construction of northern terminal groin was in 1961; southern groin was in 2000.

Figure IV-48. Sea Turtle Nesting Data for Mid and North Pinellas Beaches

In 2007 and 2008, Audubon of Florida's Florida Coastal Islands Sanctuaries Program conducted direct nesting censuses of known colonial waterbird colonies in the Tampa Bay watershed and Pinellas County. Census sites included three sites in John's Pass: Little Bird Key, Bird Rookery Key, and Eleanor Island (Hodgson et al. 2009).

As described by DC&A (2009), the area evaluated in proximity to John's Pass consists of suitable habitat for wintering piping plover; however, no piping plover critical habitat is designated within the project area. In addition, this region experiences greater human activity during the winter season. Therefore, the likelihood of piping plover utilizing the beach habitat in the project area is low. Due to limited availability, shorebird data was not accessible for review.

(3) Seagrasses

SAV considered as EFH for juvenile fish species, within Boca Ciega Bay and John's Pass are associated with tidal flats and shoal areas surrounding mangrove islands or along the shoreline. There are four main species of SAV in the area; shoalgrass, manatee grass (*Syringodium filiforme*), widgeon grass, and turtle grass (*Thalassia testudinum*). Figure IV-49 depicts the presence of seagrass and unvegetated tidal flats within John's Pass. Seagrasses are present around the mangrove islands east and south of the channel. Seagrass patches are also associated with the portions of the area's shoreline and canals. No seagrass is known to occur along the outer pass channel or ebb shoals (DC&A 2009).

Source: Southwest Florida Water Management District, SWFWMD 2006
Pinellas County Color Aerial, USGS 2004

Figure IV-49. Seagrass and Tidal Flats for John's Pass, FL

Source: Southwest Florida Water Management District, SWFWMD 2006
Seminole, FL Digital Ortho Quad, FDEP 1999

Figure IV-50. Habitat Change for John's Pass, FL from 1999 to 2006.

There appears to be a significant reduction in unvegetated tidal flats along with a significant increase in SAV (Figure IV-50) when comparing 1999 to 2006 Southwest Florida Water Management District (SWFWMD) data. The maintained channel dimensions, flow characteristics, meteorological conditions and water quality/water clarity attributes are the likely precursors to the expansion of SAV.

(4) Fish and Fisheries

Assessments of marine resources within the project area were conducted in 2001 and 2002 (DC&A 2001, 2002), and more recently in association with an EA for dredging of the ebb shoal with beach placement (DC&A 2009). Dominant biological community types were documented within and adjacent to the proposed ebb shoal borrow areas, pipeline corridors, and nearshore areas. Surveys of the ebb tidal shoal areas and the Pass-a-Grille channel were also performed (DC&A 2001b, 2002). Marine habitats identified during the offshore surveys included hardbottom, shell hash, and open sand habitat. The biological communities associated with these different bottom types and the water columns have been identified as EFH in accordance with the amendment to the Fishery Management Plans of the [Gulf of Mexico Fishery Management Council (GMFMC) 1998].

Since John's Pass is located within the Pinellas County Aquatic Preserve, turbidity elevation is restricted at the limit of the mixing zone during dredging operations. Therefore turbidity within the mixing zone will be less than 29 nephelometric turbidity units (NTUs) above background. This limits adverse effects to hardbottom.

Fishes off of the Pinellas County coast are comprised of both demersal and pelagic species, many of which utilize the pass for passage between inshore and offshore waters either for foraging or with maturation. Many of the species present within this area are of commercial importance and addressed under the NMFS GMFMC Management Plan (GMFMC 1998). The fish assemblages in the area offshore of Pinellas County Florida and the Gulf of Mexico have been studied many times in the past. These studies have included reports which characterize the offshore and nearshore assemblages of fishes (Moe and Martin 1965; Saloman and Naughton 1979), cold stress of fishes on reef areas (Gilmore et al. 1978), growth and reproduction (Schirripa and Burns 1997; Bullock et. al 1996), and the effects of fishing activities and predation (Pierce et al. 1998; Nelson and Bortone 1996).

Pelagic species also occur throughout the Gulf of Mexico in the nearshore and offshore waters. Major coastal pelagic families include Rachycentridae (cobia), Mugilidae (mullets), Pomatomidae (bluefish), Caranagidae (jacks), Scombridae (tunas and mackerels), Engraulidae (anchovies), and Carahahinidae (requiem sharks). Many of these pelagic species form large schools (e.g. jacks, mullet, mackerel, etc.), while others travel singly or in small groups (e.g. cobia). Distribution of these species can vary seasonally and usually depends on water column attributes that vary seasonally.

Moe and Martin (1965) collected over 2,300 individual fishes from 41 species during sampling conducted at nine separate locations offshore of Pinellas County. Fishes observed during diver and video surveys on or near hardbottom habitats offshore of Pinellas County (DC&A 2002) include a total of 17 species from 15 families. Most species observed included small demersal species common to hardbottom areas. The most common species observed were wrasses (Labridae); in particular the slippery dick (*Halichoeres bivittatus*). Other common fishes included searobins (*Prionotus* sp.), and menhaden. Anecdotal observations of pelagic fishes during the survey included large schools of baitfish (Engraulidae and Clupeidae), sharks (Carahahinidae), mackerel (Scombridae), and a nurse shark (*Ginglymostoma cirratum*).

In Pinellas County, a gulf sturgeon was most recently documented near Redington Beach in 1992 (USFWS 1995). Gulf sturgeon have not been documented in the vicinity of John's Pass or Blind Pass, possibly because these inlets do not provide access to freshwater rivers required by the gulf sturgeon. Gulf sturgeon may use the project area for foraging during winter months when they are known to be in the Gulf of Mexico.

(5) Benthic Resources

Although John's Pass is not specifically monitored for water quality through the Pinellas County water quality monitoring program (Pinellas County Department of Environmental Management 2009), John's Pass is considered non-impaired coastal waters. An older study (Myers et al. 2000) provided water quality data for the area including south Boca Ciega Bay, which includes John's Pass, and indicated the water quality to be good. The benthic community can serve as an excellent indicator of water quality, and Grabe (1998) describes Boca Ciega Bay as diverse and heterogeneous, and that less than 15 percent of the benthic habitat of the bay is classified as degraded.

Lyons and Collard (1974) characterized the shallow shelf habitat offshore of Pinellas County as an area with sediments dominated by quartz sand and carbonates with exposed rock substrate. This substrate provides habitat for scleractinian, molluscan, crustacean and other invertebrate species. Previous studies have identified species common to habitats offshore of Pinellas County (EPA 1981; CZR 1991; Child 1992; Posey et. al 1996). The species listed in these previous studies compares closely to species observed during the 2002 survey conducted by DC&A (2002). In total, over 40 dominant invertebrate species were observed from the diver and video surveys. According to DC&A (2002), there are many more cryptic and less obvious species present within these complex habitats (Table IV-11).

Table IV-11. Invertebrates within and adjacent to John's Pass.

Common Name	Scientific Name
Echinoderms	
Beaded Sea Star	*Astropecten articulatus*
Orange-Ridged Sea Star	*Echinaster spinulosus*
Rock-boring Urchin	*Echinometra lucunter*
Common Comet Star	*Linckia guildingii*
Banded Sea Star	*Luidia alternata*
Striped Sea Star	*Luidia clathara*
Sea Star	*Luidia* sp.
Variegated Urchin	*Lytechinus variegates*
Mollusks	
Lightning Whelk	*Busycon contrarium*
Tritons trumpet	*Charonia variegata*
Penshell	*Pinna carnea*
Florida Horse Conch	*Pleuroploca gigantean*
Scleractin Corals	
Tube Coral	*Ciadocora arbuscula*
Cactus Coral	*Isophyllia sinuosa*
Rose Coral	*Manicina aereolata*
Branching Fire Coral	*Millepora alcicornis*
Boulder Star Coral	*Montastrea annularis*
Robust Ivory Tree Coral	*Oculina robusta*
Hidden Cup Coral	*Phyllangia americana*
Mushroom Coral	*Scolymia lacera*
Starlet Coral	*Siderastrea* sp.
Knobby Star Coral	*Solenastrea hyades*
Blushing Star Coral	*Stephanocoenia mitchelinii*
Octocorals	
Warty Sea Rod	*Eunicea calyculata*
Shelf-knob Sea Rod	*Eunicea succinea*
Colorful Sea Whip	*Leptogorgia virgulata*
Orange Spiny Sea Rod	*Muricea elongata*
Delicate Spiny Sea Rod	*Muricea laxa*
Giant Slit-Pore Sea Rod	*Plexaurella nutans*
Sea Plume	*Pseudoterogorgia* sp.
Yellow Sea Whip	*Pterogorgia citrina*
Sponges	
Erect Rope Sponge	*Amphimedon compressa*
Brown Variable Sponge	*Anthosigmella varians*
Dark Volcano Sponge	*Calyx podatypa*
Brown Bowl Sponge	*Cribrochalina vasculum*
Ball Sponge	*Ircinia* sp.
Branching Tube Sponge	*Pseudoceratina crassa*
Loggerhead Sponge	*Spheciospongia vesparium*
Giant Barrel Sponge	*Xestospongia muta*
Crustaceans	
Florida Stone Crab	*Menippe mercenaria*
Tunicates	
Colonial tunicates	*Clavelina* sp.
Condominium Tunicate	*Eudistoma* sp.
Overgrowing Tunicates	Family Didemnidae

Source: DC&A 2002

The nearshore hardbottom was previously delineated in 2001 by Sea Systems Corp. with side scan sonar and again in August 2005 (DC&A) with towed camera investigations spaced along regular intervals throughout the project area. Comprehensive documentation of the hardbottom resources within 1,000 feet of the shoreline could not be assured with the aforementioned methodology. On 7-10 October 2005, CPE biologists verified and mapped the nearshore hardbottom edge resources within the project area using self contained underwater breathing apparatus (SCUBA).

The most obvious feature of the hardbottom habitats in the eastern Gulf of Mexico includes the octocorals, sponges, and scleractinian corals. Eight species of octocorals, eleven species of scleractinian (hard) corals, and eight species of sponges were identified. Sediments within the area consist of sand to shelly sand that supports benthic invertebrate communities. In an EPA (1981) study, dominant species in these habitats included sand dollars (*Encope emarginata*) and marine worms (*Luidia* sp.). Similar species were observed during the DC&A (2002) study. Benthic sampling conducted during past surveys also shows that polychaetes, oligochaetes, pycnogonids, bivalves, and arthropods are the dominant taxa collected in these habitats (CZR 1991; Child 1992; Posey et al. 1996).

Although these species may be found offshore north and south of John's Pass, it was determined that John's Pass ebb tidal shoal (152.1 acres) consisted of primarily sand, with no documentation of seagrass or hardbottom (DC&A 2002).

c) Cultural Resources

Based upon the results of the April 2009 cultural resources survey in the area of John's Pass and Blind Pass borrow areas, as well as previous survey results, no cultural resources are believed to be present within the two borrow areas surveyed (SEARCH 2009; Hall 2000a, b).

C. Summary and Conclusion

As described by Defeo et al. (2009), society's response to beach erosion and shoreline retreat relies heavily on engineering interventions that place armoring structures on beaches (Nordstrom 2000; Charlier et al. 2005; Griggs 2005a, b). Hard structures that include walls constructed of stone, concrete, wood, steel, or geotextiles have been used for centuries as a coastal defense strategy (Charlier et al. 2005), but this protection is not achieved without ecological costs. The effects of coastal structures may cause significant habitat changes, with attendant ecological effects (Sobocinski 2003; Martin et al. 2005; Dugan and Hubbard 2006; Bertasi et al. 2007) that can be difficult to detect in the short term (Jaramillo et al. 2002). As eroding beaches become narrower after structures are constructed, the reduced habitat can directly lower the diversity and abundance of biota, especially in the upper intertidal zone (Sobocinski 2003; Dugan and Hubbard 2006; Dugan et al. 2008). This, in turn, can also be detrimental to higher trophic levels (e.g., coastal avifauna) that may be affected by both reduced habitat area and declining intertidal prey resources. This phenomenon is reflected by observations of significantly lower numbers and fewer species of birds on hardened shorelines compared with non-hardened segments of beaches, as seen at Beaufort Inlet (i.e., Fort Macon versus Shackelford Banks).

The North Carolina 2009 General Assembly (House Bill 709) authorized the CRC, in consultation with the NCDCM, the NCDLR, and the CRAC, to determine the feasibility and advisability of the use of a terminal groin as an erosion control device. The structure's function would be to limit or control sediment passage into an inlet channel. Five terminal groin locations were chosen for evaluation; Pea Island, Oregon Inlet, NC; Fort Macon, Beaufort Inlet, NC; South Amelia Island, Nassau Sound, FL; Treasure Island, John's Pass, FL; and Captiva Island, Redfish Pass, FL. Readily available data was compiled and reviewed to provide an overview of the documented environmental effects of marine structures, specifically terminal groins.

Based upon the historical nature of the terminal groins at Fort Macon, John's Pass (northern groin), and Redfish Pass; conclusive results of the effects of these terminal groins on the natural resources is somewhat limited. Lacking pre-construction data makes an empirical determination of post-construction effects at these sites somewhat subjective. The current development and use of these sites precludes unrestricted utilization by the site's natural resources. Sea turtles, avian species, and marine species, however, continue to make use of these managed sites.

The terminal groins at Oregon Inlet and Amelia Island are more recent construction projects, and pre- and post-construction natural resource data were evaluated. The more recent data collected since construction, indicates an increase in public interest/participation, and funding for monitoring of these resources. Although shorebirds and sea turtles utilize both locations, neither significant trends nor adverse effects were discernable from the available data. The resources present at both the Amelia Island and Fort Macon terminal groin locations were compared to undisturbed neighboring barrier islands where data indicated resources were more prevalent, as expected.

On the Atlantic coast, groins can be used to increase the longevity and augment the stability of replenished beaches (Leonard et al. 1990; Bodge 2003). 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 construction. Improperly used, they can exacerbate beach erosion (Bodge 2003).

Under particular conditions, it may be possible to limit adverse effects with terminal structures without detrimental effects to the adjacent shorelines (Dean 1993). The height of the groin depends on the degree to which it is desirable for sand to overtop the groin and replenish the downdrift beach. The minimum height is about the same height as the beach berm height. Lower groins that follow the profile of the existing beach help stabilize the native beach sand, but impounds very little of the longshore transport (USACE 1981).

Terminal groins may serve to reduce the frequency of renourishment events, which in turn may minimize long-term cumulative effects on the natural resources.

Because of the diversity and commercial importance of such hardbottom areas, appropriate effort should be employed ensuring avoidance of such habitats while assessing potential groin locations, borrow sources, and/or shoreline and adjacent shoreline sand placement templates.

D. Compliance Recommendations

The use of a terminal groin at an inlet has the potential of creating adverse environmental effects. These potential effects can be avoided or minimized through the use of site specific design parameters, construction methods, and construction materials. A minimized design should allow natural resources to adapt to the engineered system while providing an adequate level of shoreline stabilization. The following compliance recommendations may be considered if terminal groin legislation is approved in North Carolina, and if natural or cultural resources are potentially present within a project location.

- Perform site specific design analysis
- Perform site specific hydraulic/shoreline/inlet modeling
- Minimize structural geometry (height, width, and length)
- Minimize design fill template
- Maximize littoral bypass
- Maximize tidal flow passage
- Assess fill template material (compatibility, volume availability, and source location)
- Conduct pre- and post-construction shoreline profile surveys
- Conduct site specific pre-construction analysis (seasonal resource/construction windows, dredge plant selection and material placement technique, waterside and landside site access corridors, prewashed structural components, construction turbidity minimization, and beach access coordination during construction/maintenance)
- Design in-situ structural modification capabilities to include potential full scale removal/replacement
- Design for minimal debris entrapment
- Assess trends in resources and project performance by analyzing aerial imagery prior to and after construction
- Perform seasonal turtle nest relocations and hatchling rearing, as applicable
- Map and assess benthic resources in close proximity to the groin/fill area prior to and following construction
- Perform avian surveys prior to and following construction

- Perform sea beach amaranth surveys prior to and following construction, as applicable
- Map and assess significant cultural resources within or adjacent to the terminal groin/fill template

V. Engineering Construction Techniques to Limit Potential Impacts

A. Overview of Approach

Several factors contribute heavily to a terminal groin's performance, as well as its potential impacts on adjacent shorelines. Length, height, permeability, type of material, and groin configuration are all factors that affect a terminal groin's behavior. Groins that are too long, too high, or impermeable may overly impede the longshore drift. Groins that are too short, too low, or too permeable may be ineffective at impeding any longshore drift, rendering them effectively useless.

To complete this study on engineering techniques that may be used to limit potential impacts, an inventory of the five (5) study sites and their structural characteristics was completed. A summary table of each site and their calculated impacts on adjacent shorelines (from Section 1) was also reported. Plots of these resulting impacts versus various groin heights, lengths, widths, and porosities were completed. Lastly, a literature review of engineering construction techniques used to limit terminal groin impacts was performed.

B. Characteristics of the Five Study Site Structures

The five study sites all consist of rubble mound (rock) groins. John's Pass and Captiva Island groins are short groins, with lengths less than 500 feet. Amelia Island and Fort Macon both have lengths over 1,500 feet. Amelia Island is also an example of a permeable groin. Oregon Inlet has the longest selected groin at over 3,000 feet long.

1. Oregon Inlet

The erosion control measures at Oregon Inlet include a 3,125-foot long groin and a 625-foot long revetment. The elevation of the groin ranges between 8 and 9.5 feet (MSL), with the higher elevation at the head (seaward end) of the groin. The base of the groin ranges from 110 to 228 feet wide; and the crest width ranges from 15 to 39 feet wide. The groin has toe protection on both sides, with lengths varying from 10.5 to 43 feet. The rock sizes increase towards the head of the groin. Figure V-1 shows the 2007 aerials, and Table V-1 summarizes the structural information for the Oregon Inlet terminal groin.

Figure V-1. Oregon Inlet Terminal Groin

Table V-1. Oregon Inlet Terminal Groin Structural Information

Terminal Groin Parameter	Value
-Length	3,125 ft
-Elevation	8 – 9.5 ft MSL
-Width	Crest: 15 – 39 ft / Base: 110 – 228 ft
-Stone Size (Station: 6+25 – 17+25)	
Armor	Type 'A-II' Stone 2.5 – 4.5 Ton 50% > 3.5 Ton
Under layer	Type 'U-II' Stone 500 – 1000 lbs 75% > 750 lbs
Foundation	Type 'F-I' Stone 0.5 – 110 lbs
-Stone Size (Station: 17+50 – 29+25)	
Armor	Type 'A-III' Stone 7 – 10 Ton 50% > 9.0 Ton
Under layer	Type 'U-III' Stone 1500 – 2000 lbs 75% > 2000 lbs
Foundation	Type 'F-I' Stone 0.5 – 110 lbs
Revetment Parameter	**Value**
- Length	625 ft

Construction for the groin began in 1989 and was completed in October 1991. The groin extends from the bulkhead at the US Coast Guard station in a northwest direction, curving 90 degrees towards the northeast, and straightening out to be perpendicular with the natural inlet shoreline. The groin was designed anticipating the channel moving towards the structure by adding a 12-meter wide scour apron along the inlet toe. The free-standing nature of the terminal groin in a position mimicking the 1985 shoreline relied on the natural coastal processes to deposit sediment along its landward (southern) side. Figure V-2 shows a typical cross-section for the terminal groin (taken from Oregon Inlet Plan Drawings)

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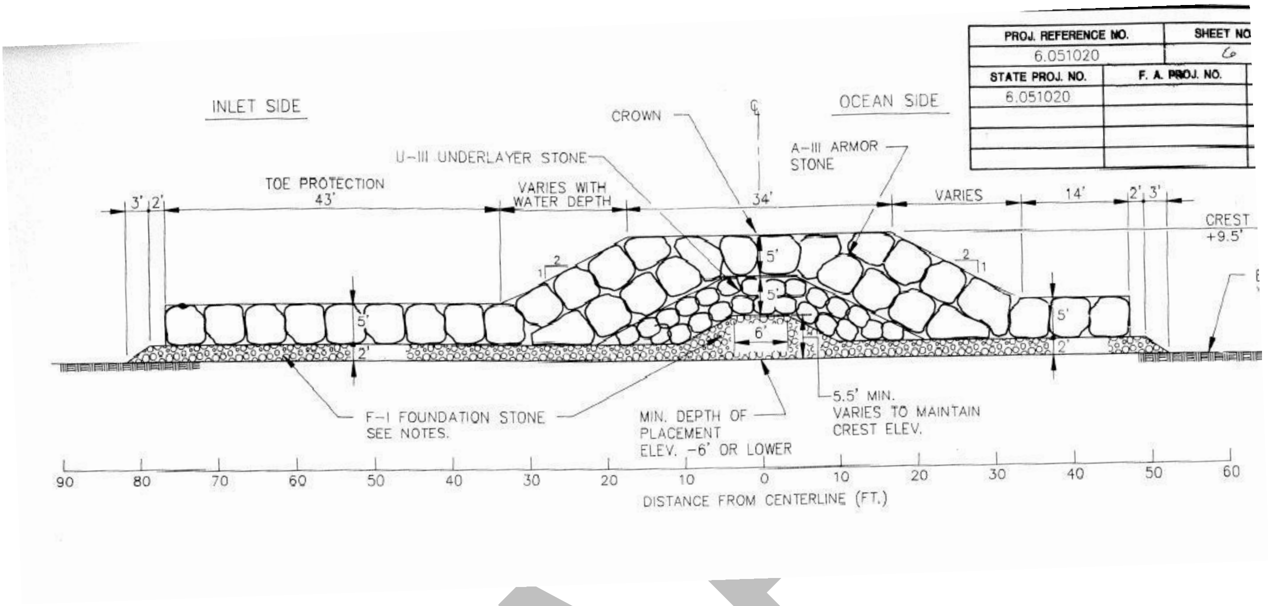


Figure V-2. Oregon Inlet Terminal Groin Typical Cross-Section

2. Fort Macon

This terminal groin is constructed of rock with a total length of 1,530 feet and a crest elevation of 6 feet (MLW). The crest width is 10 feet, with a base width ranging from 58 to 66 feet. The foundation or bedding stone used ranged in size up to 12”, while the core consists of stone ranging in size from 12” – 24”. Over top of the core is the underlayer stone (2000 lb avg), while the armor layer used ranges in size from 7.5 – 12.5 tons. Table V-2 summarizes the structural information for the Fort Macon terminal groin. Figure V-3 illustrates the typical cross-section from the 1986 groin extension permit plans.

Table V-2. Fort Macon Terminal Groin Structural Information

Terminal Groin Parameter	Value
Length	1,530 ft
Crest Elevation	6 ft MLW
Width	Crest: 10 ft / Base: 58 ft – 66 ft
Stone Size[1]	
Armor	Type ‘A’ Stone, 15 ton/LF (7.5-12.5 ton) 75% - 10 ton min
Under layer	Type ‘C’ Stone, 10 ton/LF (2000 lbs avg) 50% +-
Core	Type ‘D’ Stone, 11 Ton/LF (12” – 24’’) 50% > 6’’
Bed	Type ‘E’ Stone, 4 Ton/LF (<12’’)

[1] Voids used for design computation: Type ‘A’ 40%, Type ‘C’ 35%, Type ‘D’ 30%, and Type ‘E’ 30%.

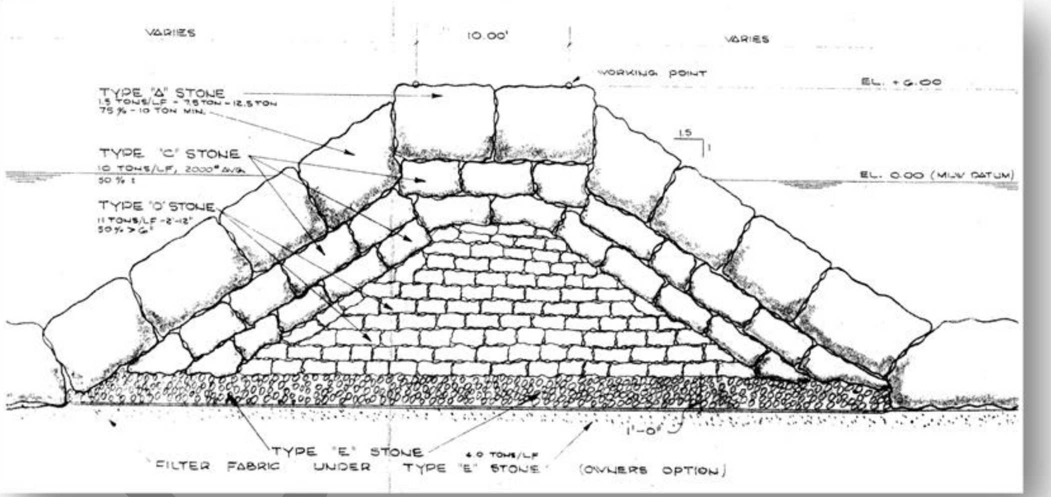


Figure V-3. Fort Macon Terminal Groin Typical Cross-Section

Figure V-4 shows the layout of the Fort Macon terminal groin, revetment, and seawall, where construction was completed in three phases. The first phase began in 1961 with the construction of the seawall, revetment, and a portion of the terminal groin that was built to a length of only 720 feet due to budget constraints. This portion of the groin was built to an elevation of 6 feet and excluded the structure’s top armor layer. The revetment (250 feet) and seawall (530 feet) were constructed along the dune bank starting just north of the present-day Fort Macon parking lot in a southeastern direction.

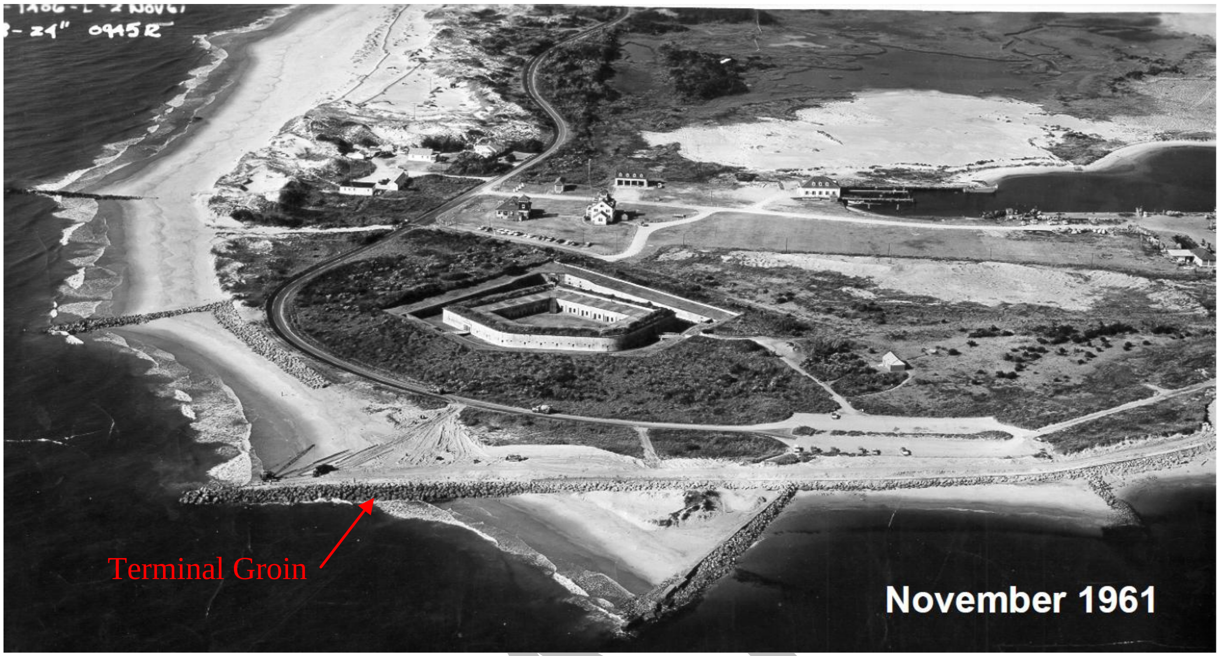


Figure V-4. Fort Macon Terminal Groin (1961)

Phase two began in 1965 and extended the groin by an additional 410 feet oceanward. An additional groin was constructed west of the revetment due to extensive erosion on the sound side of the island, which was impacting the US Coast Guard station.

Phase three began in August 1970. It extended the terminal groin by an additional 400 feet to bring the total length to 1,530 feet. A 480-foot long stone groin was built near the bathhouse in an effort to stabilize beach fill placed in the area. The total erosion control measures include a revetment, seawall, a terminal groin, and seven more groins in the vicinity of Fort Macon.

3. Amelia Island

The terminal groin and detached breakwater located at Amelia Island were constructed between 2004 and 2005 on the southern end of Amelia Island. The groin length is approximately 1,500 feet long, with a crest elevation of 5.2 feet (NGVD). The crest width ranges from 6 to 15 feet. Due to environmental concerns, the groin used only armor stones to maximize permeability. The armor stone ranges from 0.4 to 7 tons. A Tensar rock-filled mattress was utilized as the foundation. Table V-3 summarizes the structural information for the terminal groin. Figure V-5 illustrates the typical cross-sections for Amelia Island terminal groin (taken from Olsen Permit Drawings).

Table V-3. Amelia Island Terminal Groin Structural Information

Terminal Groin Parameter	Value
- Length	1,500 ft
- Elevation	5.2 ft (NGVD)
- Width	Crest: 6 – 15 ft / Base: 22 – 76 ft
- Stone Size	
Armor (Section C-C')	Stone 2 – 3 Ft (0.4 – 1.5 Ton)
Armor (Sections D-D' & E-E')	Stone 3 – 5 Ft (1.4 – 7 Ton)

The structural stabilization on the southern end of Amelia Island consisted of the terminal groin described above and a 93-meter long detached breakwater. Both structures were designed to maximize permeability and allow passage of some sediment through the groin structure. The groin was designed to be long enough to stabilize the southern shore of the Amelia Island State Park; however due to environmental concerns downdrift, it was not designed long enough to benefit the shoreline further updrift. The breakwater was constructed near the northernmost boundary of the State Park, approximately 800 meters updrift of the groin, to help stabilize the updrift shoreline. Both structures were designed in accordance with the predicted elevations of high water that occur during the fall and winter months, and to be overtopped.

A unique design feature of the terminal groin was development of a sand spit on the downdrift side. The purpose of this spit is to maintain the natural littoral environment along the sound-side shoreline. The groin structure should ideally provide a template for land formation and updrift stability, while at the same time allow a large percentage of the local inlet-directed littoral transport to pass through the structure (Olsen, 2006). As of the last monitoring report in 2008, the project has performed above expectations. Since construction, an additional 400,000 cubic yards of fill were placed between the breakwater and terminal groin in 2006. After accounting for the placed sand, approximately 715,000 cubic yards of shoreline have been lost since 2002. This volume includes localized losses immediately south of the breakwater. However, at the approximate northern limit of the detached breakwater, the +8 foot contour (top of berm elevation) is approximately 180 feet seaward of its 2002 location; and immediately adjacent to the terminal groin, the mean high water level is approximately 1,070 feet seaward of its eroded pre-construction location. Recent aerial photography indicates that the terminal groin is completely inundated with sand and is essentially non-activated (Olsen, 2008). Figure V-6 shows the Amelia Island terminal groin as of 2008.

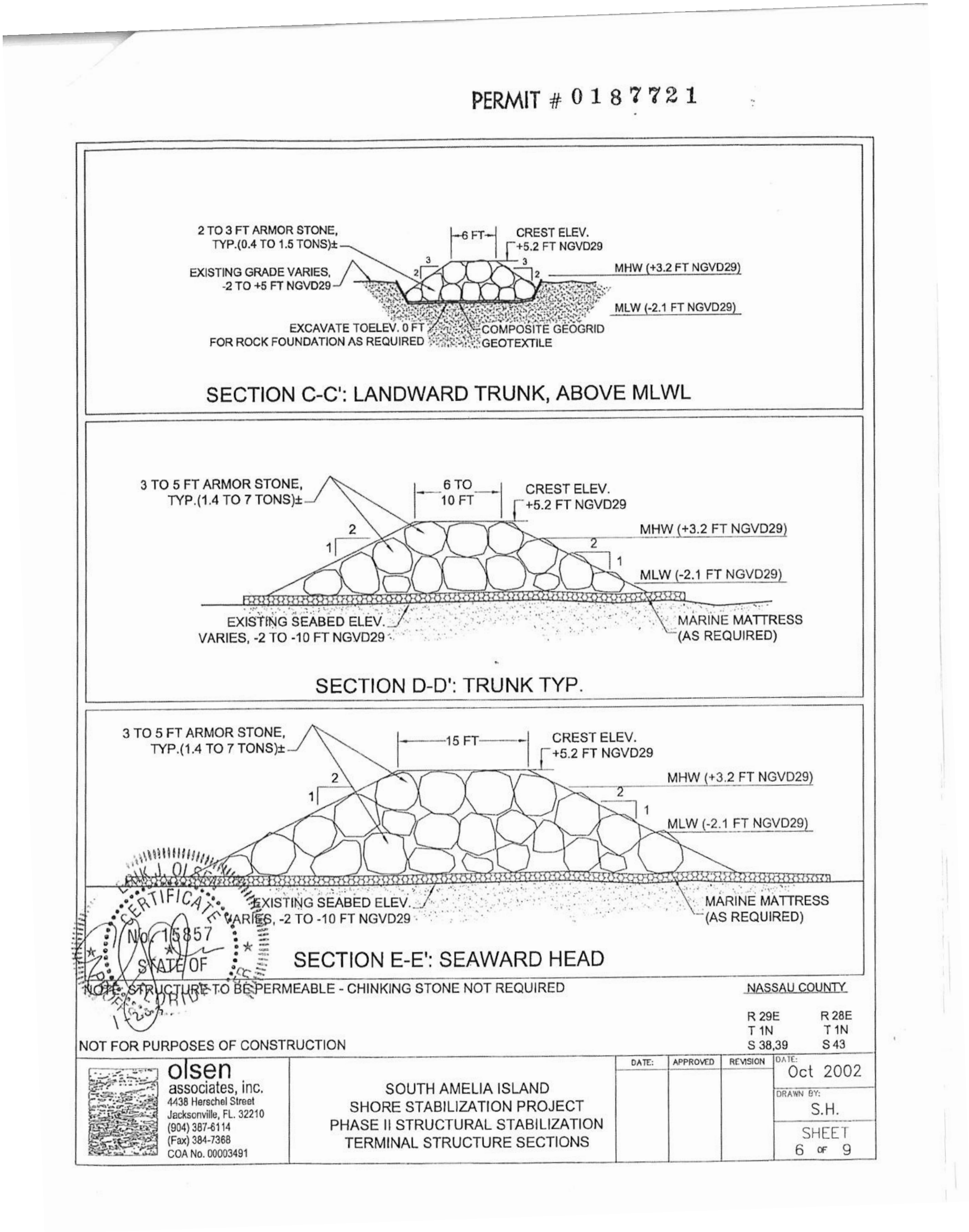


Figure V-5. Amelia Island Terminal Groin Cross-Sections

Figure V-6. Amelia Island Terminal Groin

4. Captiva Island

The rock groin was constructed between 1977 and 1981 at the north end of Captiva Island at Redfish Pass. The terminal groin is 350 feet long with a 1,500-foot revetment along the Gulf beach at the north end of Captiva Island.

Hurricane Charley, in 2004, severely damaged the groin. Between 2005 and 2006, beach nourishment and groin rehabilitation increased the stability of the beach. The groin reconstruction was completed in 2006 with 9,036 tons of limestone boulders and a total length of 340 feet. The new armor layer unit sizes ranged between 2 to 7 tons (Hagerup, 2006 & Coastal Planning & Engineering, Inc., 2008). Figure V-7 shows the 2006 reconstructed groin. Figure V-8 shows the Captiva Island terminal groin in 2008.

Figure V-7. 2006 Terminal Groin at Captiva Island

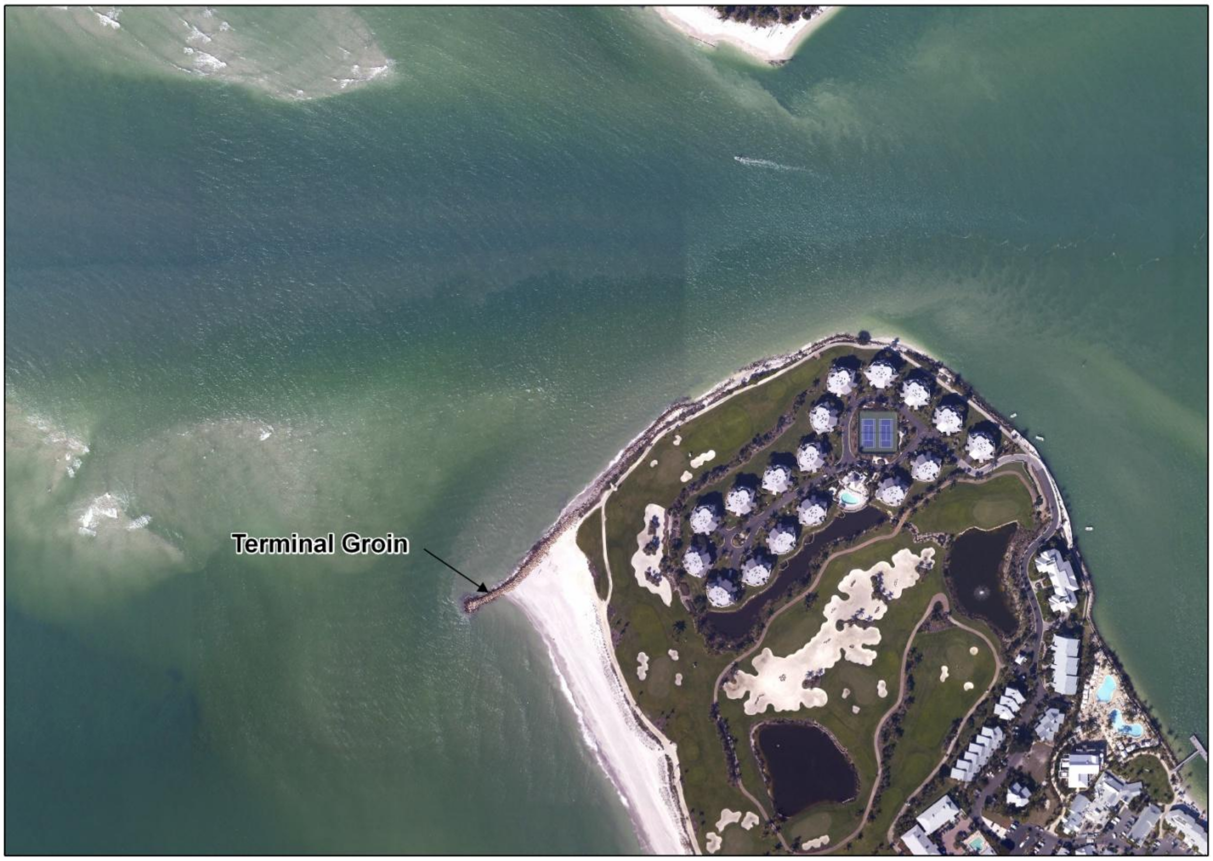


Figure V-8. Captiva Island Terminal Groin

5. John's Pass

The terminal groin constructed at the south end of Madeira Beach at John's Pass is 460 feet long. The crest elevation ranges between 3.2 and 5.7 feet (NGVD). The crest width is between 12 to 22 feet. The groin utilizes three different types of stone for the bedding, core, and armor layers. Table V-4 summarizes the structural information for the terminal groin. Figure V-9 illustrates a typical cross-section for the terminal groin (taken from the 1986 groin extension permit).

Table V-4. John's Pass Terminal Groin Structural Information

Terminal Groin Parameter	Value
- Length	460 ft
- Elevation	3.2 – 5.7 ft (NGVD)
- Width	Crest: 12 – 22 ft / Base: 72 – 162 ft
- Stone Size	
Armor	Stone: 1.0 Ton
Core	Stone: 0.1 Ton
Bedding	Stone: 15 – 50 lbs

A few years before the groin was constructed, the beach had thirty-seven 200-foot long groins that were originally designed to be adjustable; however, since they were made of concrete, this made the groins almost impossible to adjust. The southern portion of Madeira Beach (also known as Sand Key) continued to experience severe erosion; to the point where the beach ceased to exist in some areas.

The 460-foot curved terminal groin was constructed in 1961 on the north side of John's Pass. Its intended purpose was to block the swash channel along the southernmost part of the shore, force the longshore flow seaward, and cause some seaward movement of the shoreline in the immediate vicinity north of the groin (City of Madeira Beach, 1960).

In 2000, Pinellas County constructed a second terminal groin on the southern side. Figure V-10 shows both terminal groins at John's Pass.

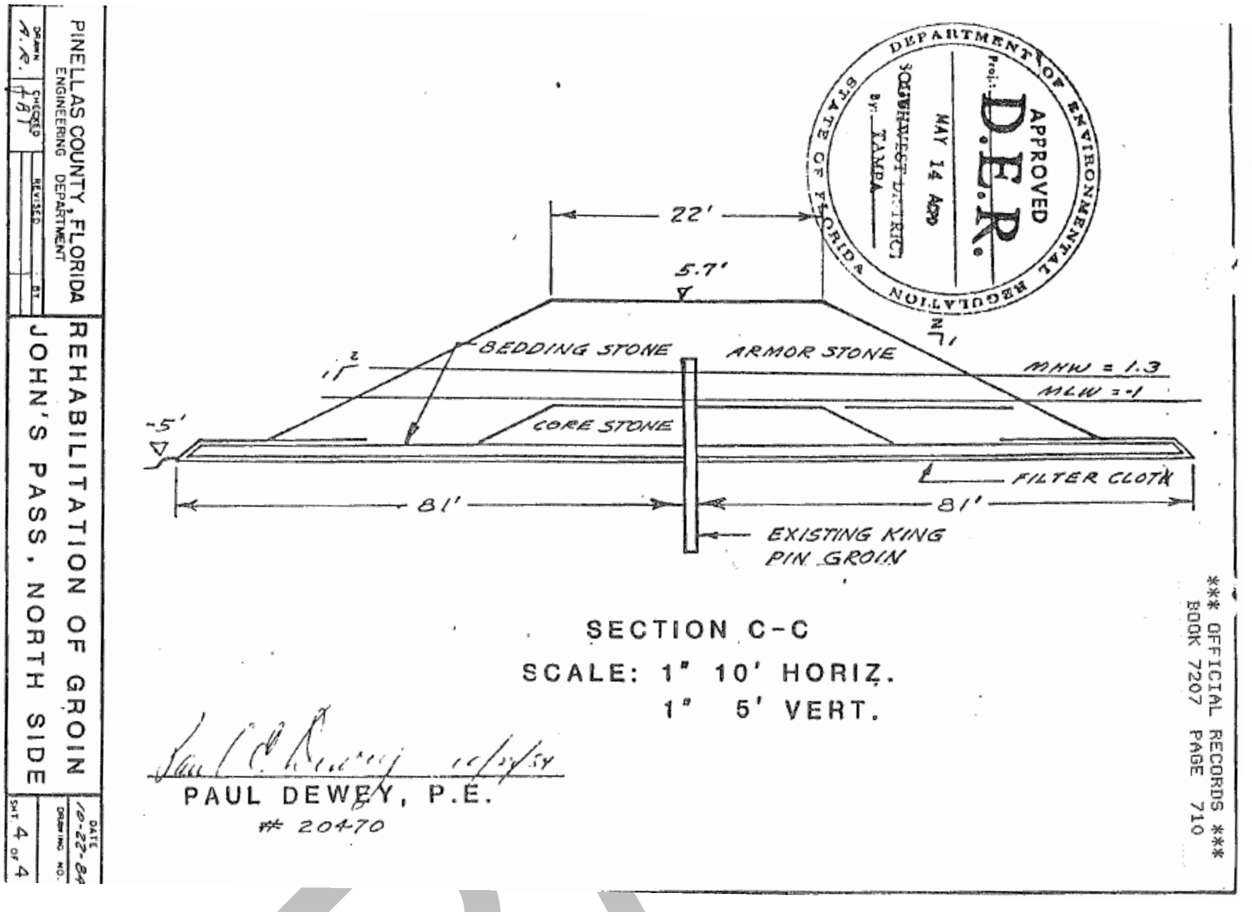


Figure V-9. John's Pass Terminal Groin Typical Cross-Section

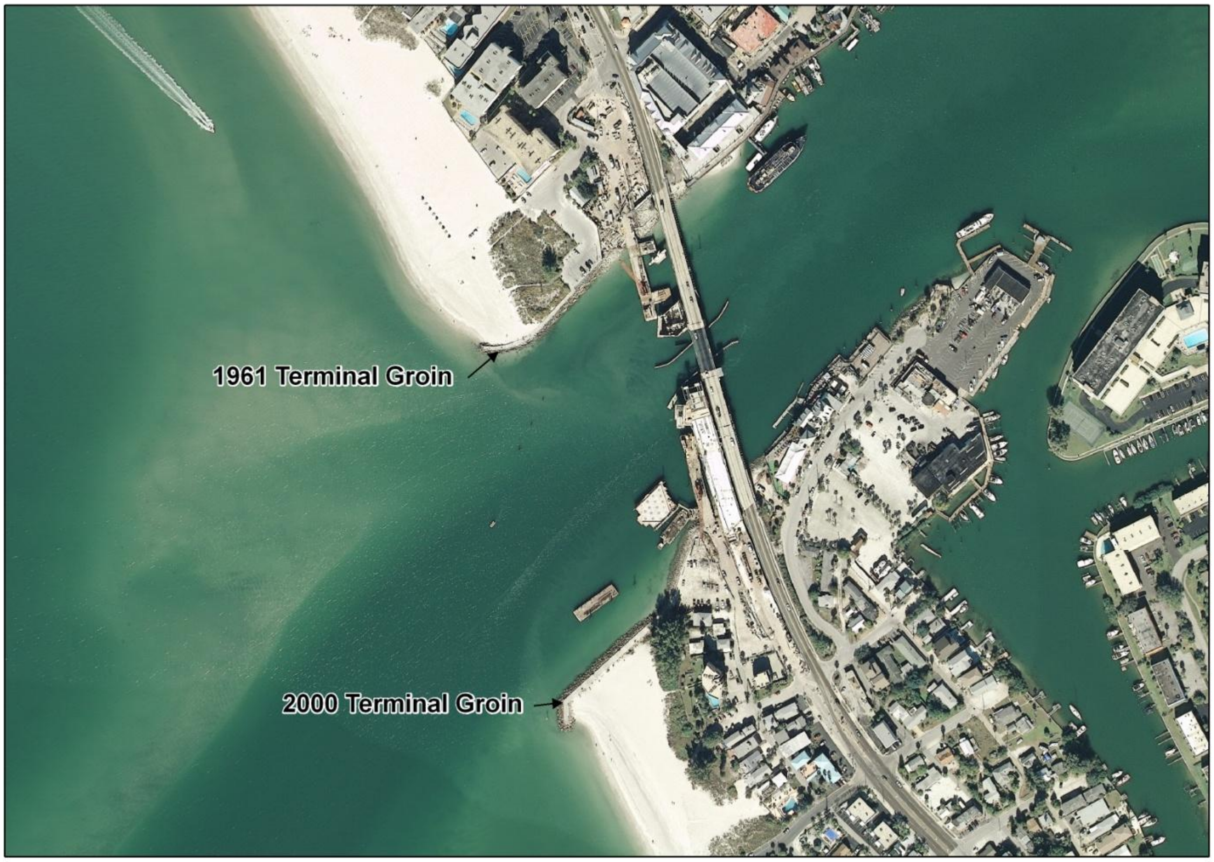


Figure V-10. John's Pass Terminal Groins

6. Analysis of Existing Sites

As part of a parametric study to investigate the effects of groin length, elevation, and porosity on the adjacent shorelines, the results from the shoreline and volumetric analyses completed as part of the coastal engineering assessment were plotted against these factors for the five sites. Given the variability of the behaviors noted during the coastal engineering assessment, it was decided that the factors would be plotted against the cumulative results over the 3 mile length for which calculations were completed.

a) Groin Length

The first factor investigated as part of the parametric study was groin length. For each of the five sites, the difference between pre and post conditions were computed for the following over a distance of 3 miles: the shoreline change, overall volume change, and the volume change with nourishment netted out. These factors were then plotted against groin length for both sides of the inlet. Please note that the effective length (perpendicular to shoreline orientation) of the Oregon Inlet terminal groin was estimated to be approximately 1500 ft) and that the time periods of 1949-1980 (pre) and 1997-2007 (post) were used for this analysis of Oregon Inlet. Figure V-11 through Figure V-13 show the results below for the rates on the side of the inlet with the groin. Figure V-14 through Figure V-16 shows the rates on the opposite side of the groin.

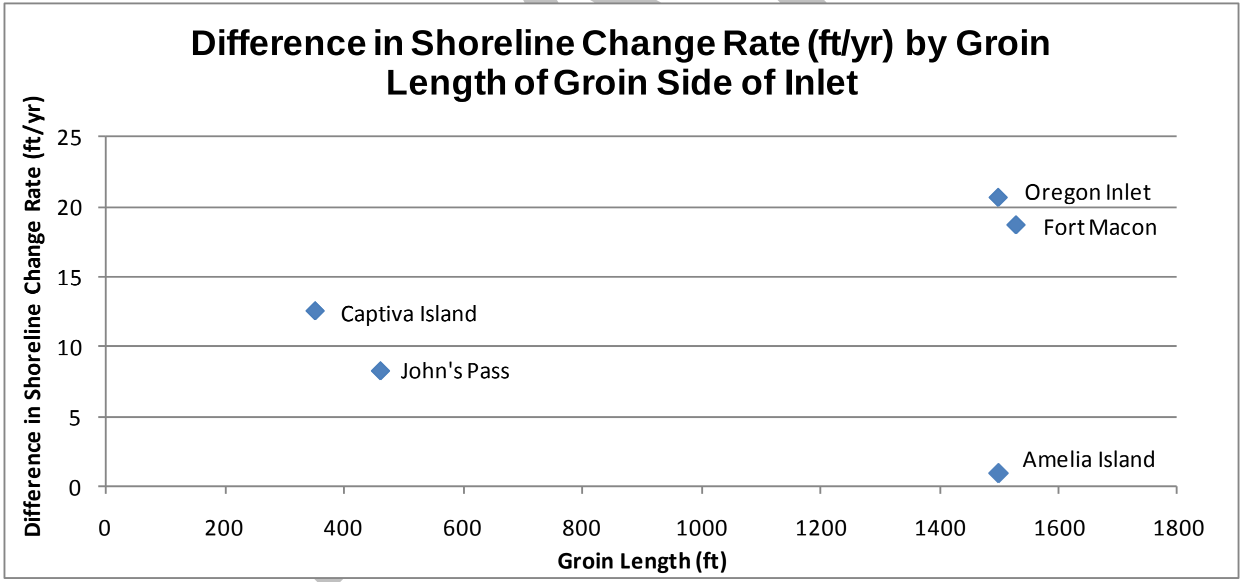


Figure V-11. Difference in Shoreline Change Rate (ft/yr) by Groin Length (ft)

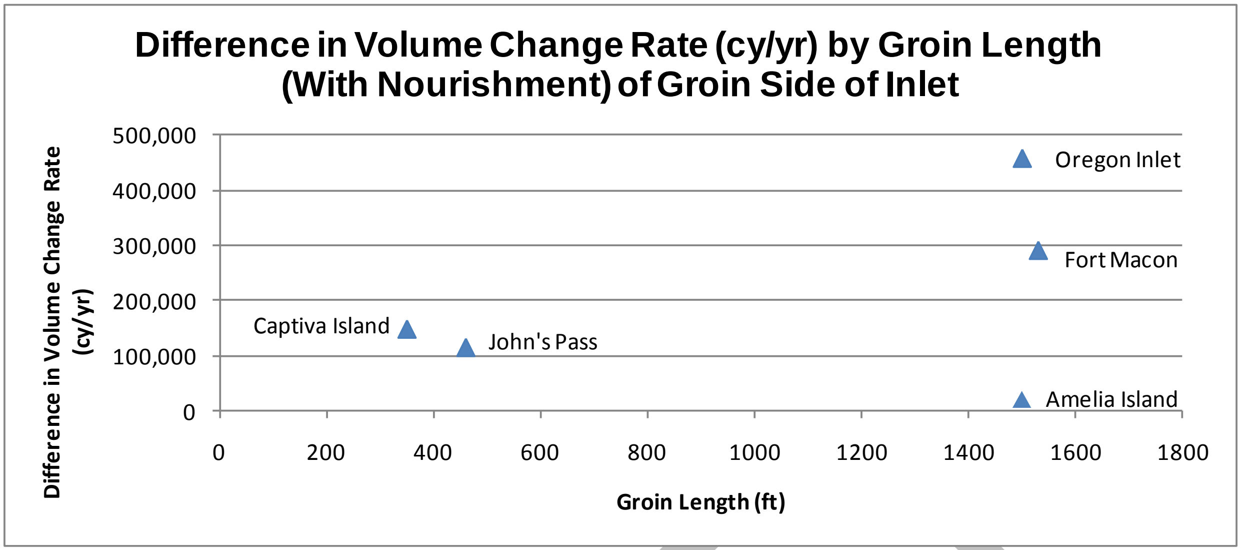


Figure V-12. Difference in Volume Change Rate (cy/yr) by Groin Length (ft) - With Nourishment

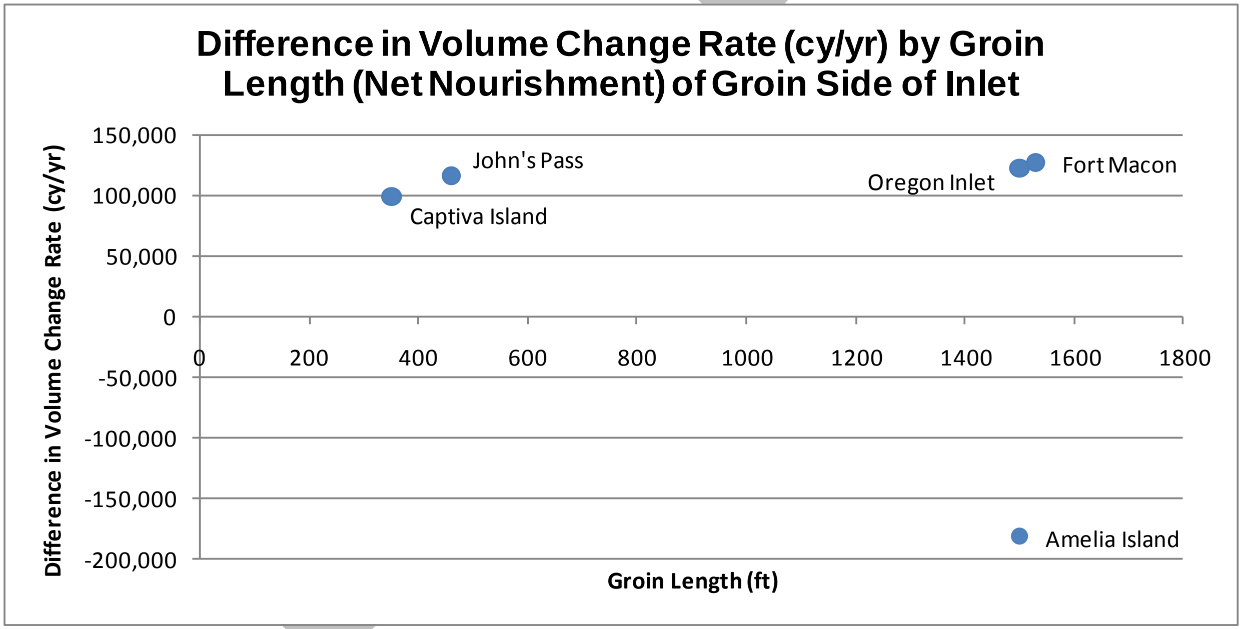


Figure V-13. Difference in Volume Change Rate (cy/yr) by Groin Length (ft) - Net Nourishment

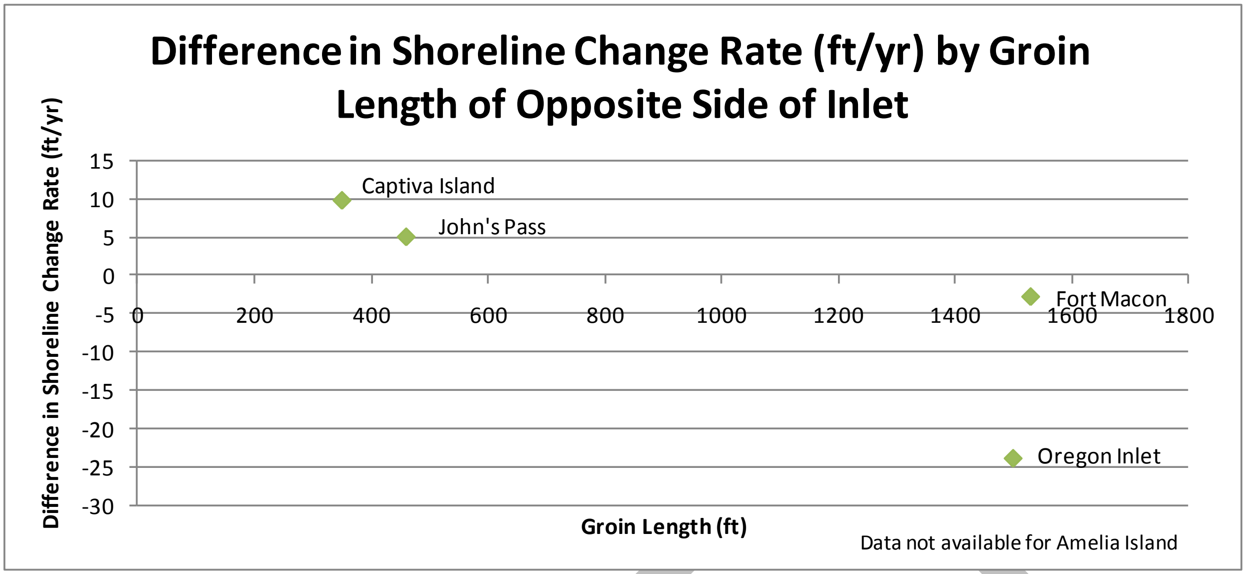


Figure V-14. Difference in Shoreline Change Rate (ft/yr) by Groin Length (ft)

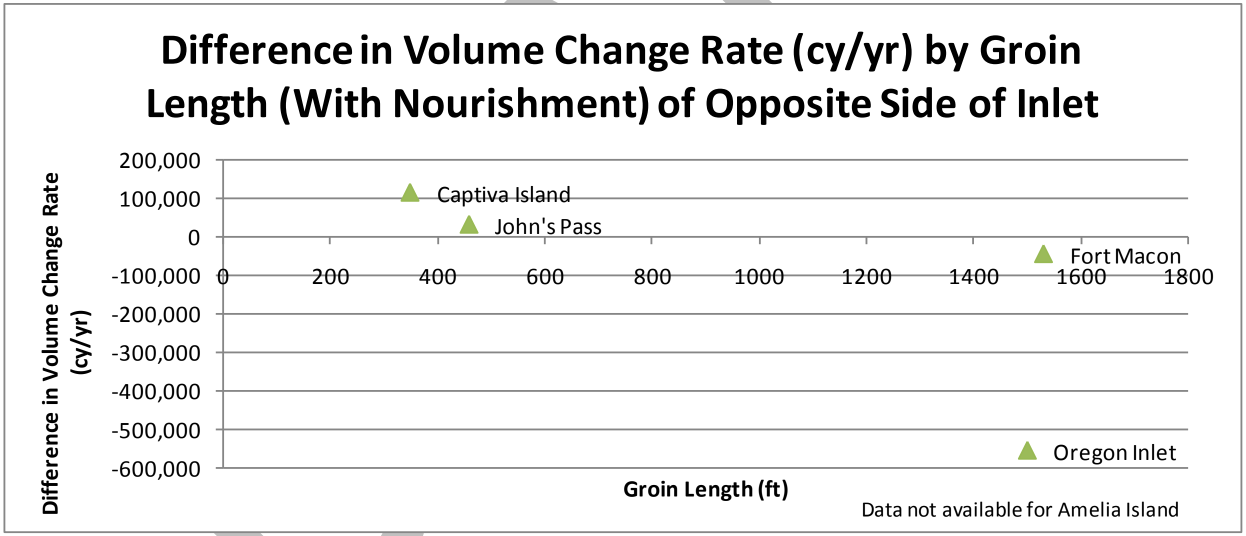


Figure V-15. Difference in Volume Change Rate (cy/yr) by Groin Length (ft) - With Nourishment

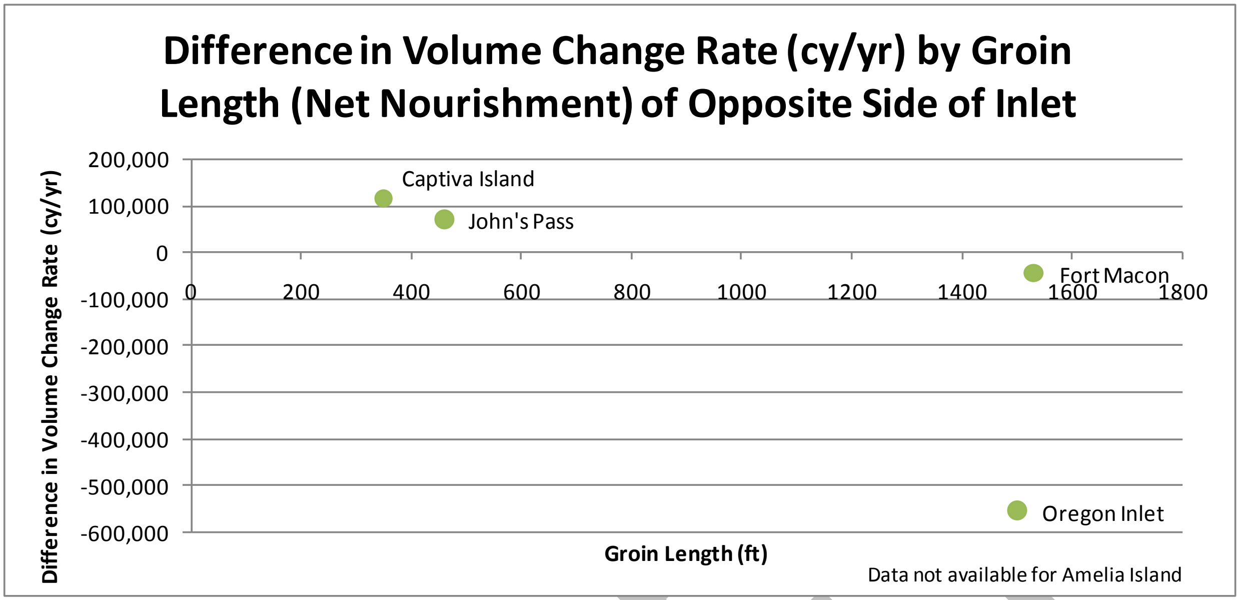


Figure V-16. Difference in Volume Change Rate (cy/yr) by Groin Length (ft) - Net Nourishment

As can be seen in the above graphs, on the structure side of the inlet, the shoreline change rate is lessened more over a 3 mile length with a longer groin than with a shorter one. When looking at the volume changes, it is very interesting to note that there appears to be a point of diminishing returns with length especially once the nourishment impacts are netted out. Based on these limited datasets, it appears that an asymptote of 100,000 – 120,000 cy is reached and no further benefit may be realized once a system equilibrates. It is also interesting to note how the “leaky” structure at Amelia Island appears to be working with no strong total accretional behavior along the first 3 miles of the groin side of the inlet. Lastly, it should be noted that the volume change rates listed above do not have the impacts of dredging netted out.

When investigating the opposite side of the inlet, it appears that negative impacts appear once the structure reaches a certain length. However, it is important to note that these values were not adjusted for the dredging impacts which are substantial at the longer groin sites (Oregon Inlet, Fort Macon-Beaufort Inlet). Nonetheless, at the shorter sites where dredging volumes are not high, it would appear that the structure does not have a negative effect on the opposite side of the inlet. While only two data points, it reveals the importance of the scale of these structures in relation to the other sediment transport drivers.

b) Groin Elevation

The next factor investigated as part of the parametric study was groin elevation. For each of the five sites, the shoreline change, overall volume change, and the volume change with nourishment netted out was plotted against groin elevation (relative to mean tide level) for both sides of the inlet. Figure V-17 through Figure V-19 show the results below for the rates on the side of the inlet with the groin. Figure V-20 through Figure V-22 show the rates on the opposite side of the groin.

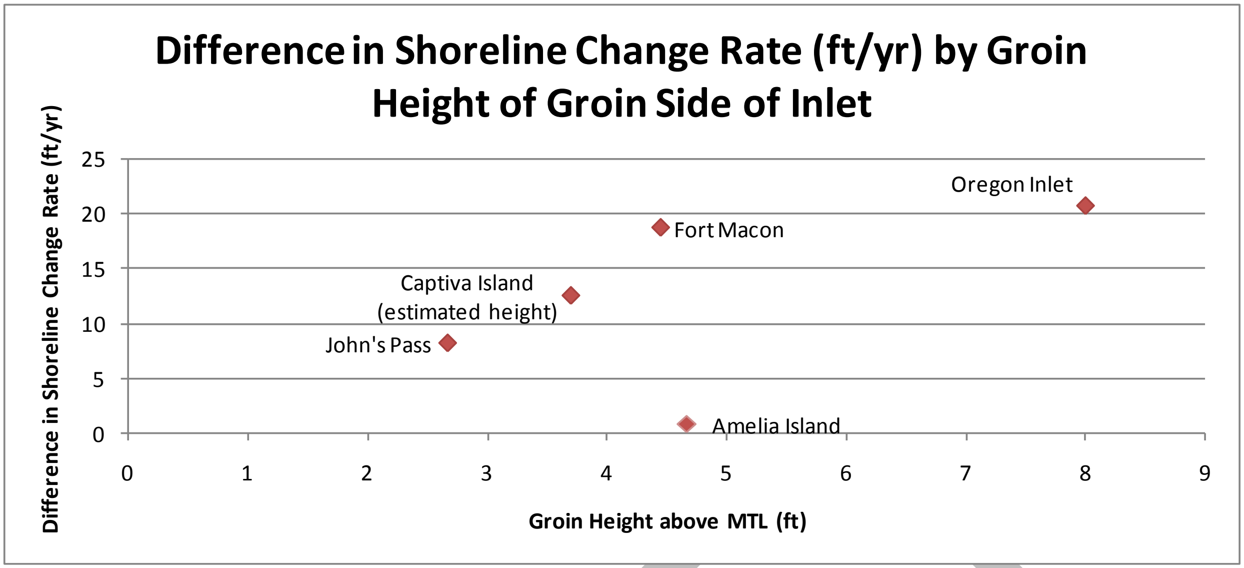


Figure V-17. Difference in Shoreline Change Rate (ft/yr) by Groin Height (ft)

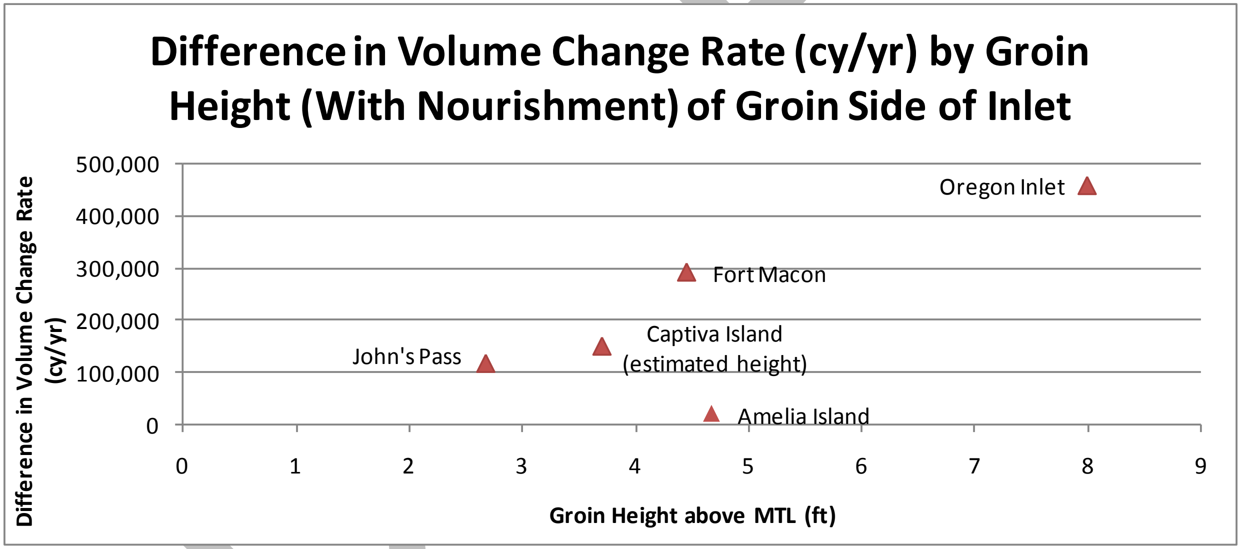


Figure V-18. Difference in Volume Change Rate (cy/yr) by Groin Height (ft) – With Nourishment

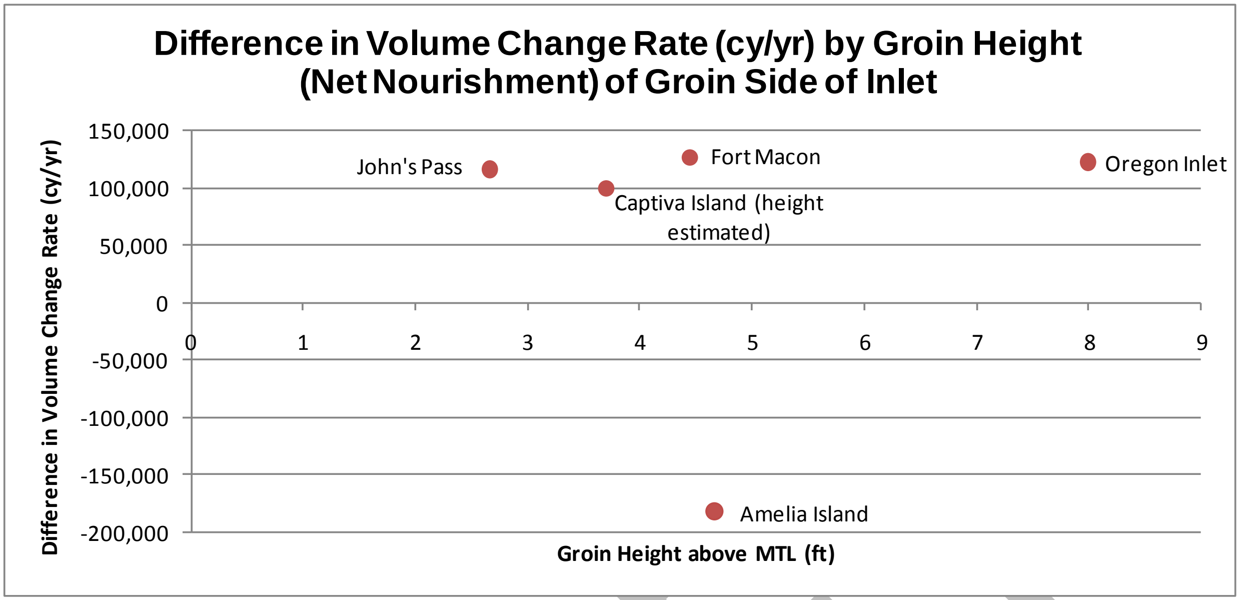


Figure V-19. Difference in Volume Change Rate (cy/yr) by Groin Height (ft) - Net Nourishment

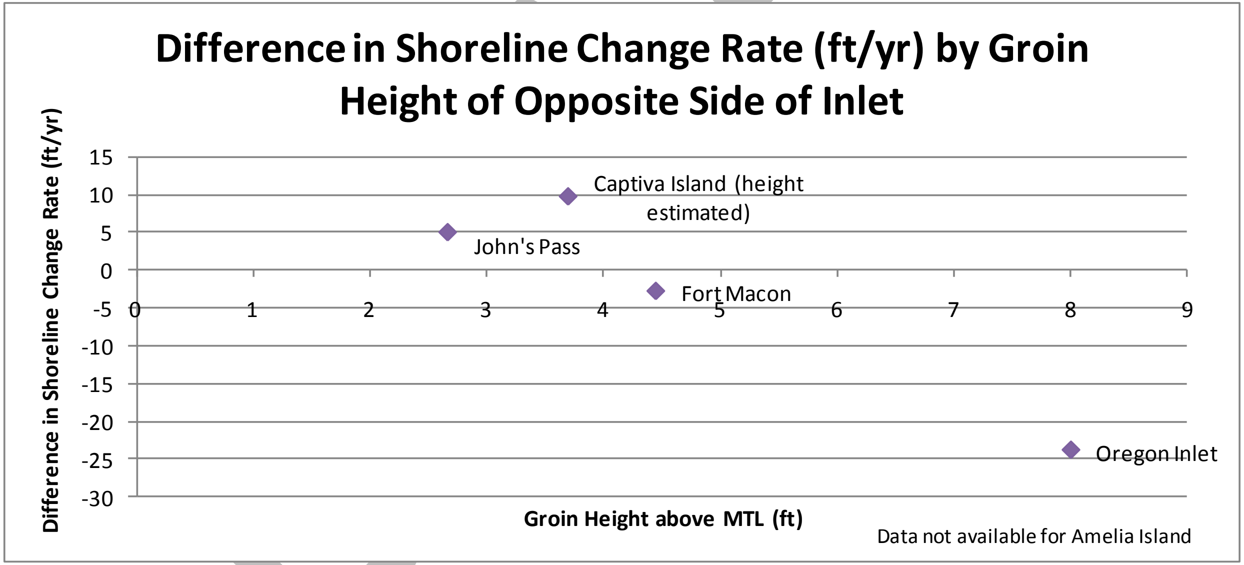


Figure V-20. Difference in Shoreline Change Rate (ft/yr) by Groin Height (ft)

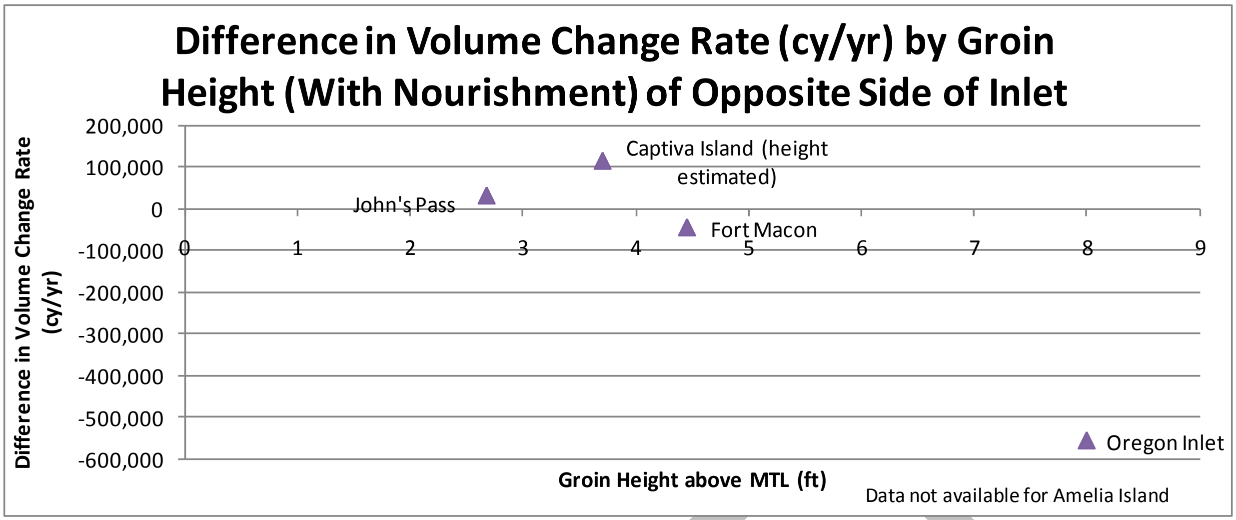


Figure V-21. Difference in Volume Change Rate (cy/yr) by Groin Height (ft) - With Nourishment

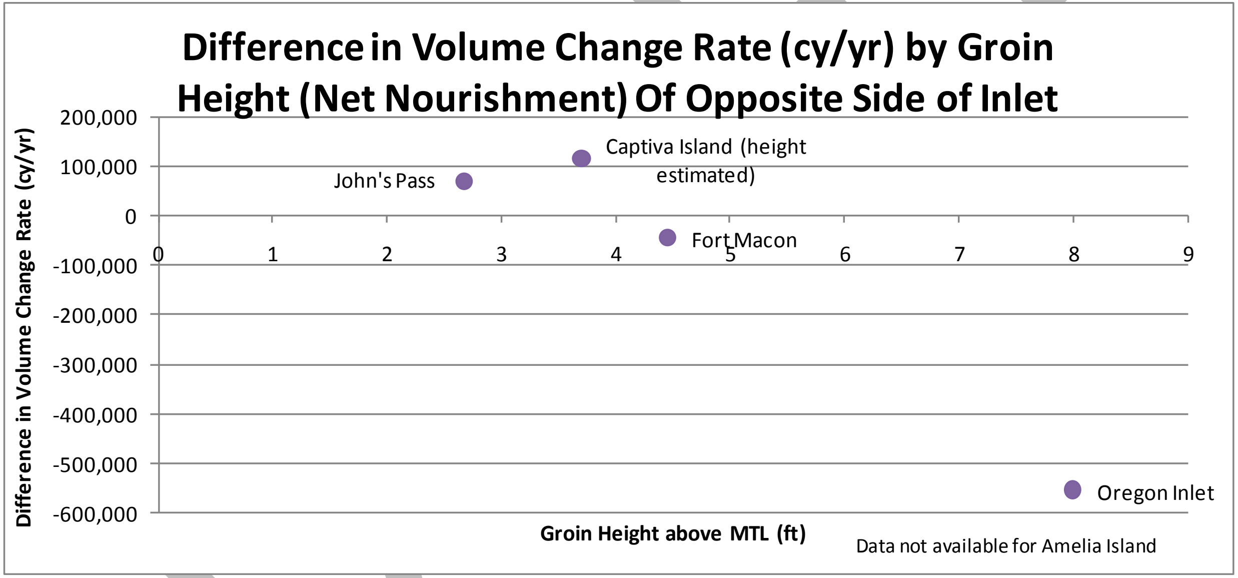


Figure V-22. Difference in Volume Change Rate (cy/yr) by Groin Height (ft) - Net Nourishment

As can be seen in the above graphs, on the structure side of the inlet, the shoreline change rate is lessened more over a 3 mile length with a higher groin than with a lower one which makes intuitive sense. When looking at the volume changes, it is very interesting to note that there appears to be a point of diminishing returns with height especially once the nourishment impacts are netted out.

When investigating the opposite side of the inlet, it appears that negative impacts appear once the structure reaches a certain height. However, it is important to note that these values were not adjusted for the dredging impacts which are substantial at the higher groin sites (Oregon Inlet, Fort Macon-Beaufort Inlet). However, at the lower sites where dredging volumes are not high, it would appear that the structure has no negative effect on the opposite side of the inlet. While only two data points, it reveals the importance of the scale of these structures in relation to the other sediment transport drivers.

c) Groin Porosity

The last factor investigated as part of the parametric study was groin porosity. Since all of the terminal groins (except Amelia) were built with dense core, the above graphs were also investigated by looking at the results for Amelia. Based on the above graphs, the results for Amelia show almost no impact on shorelines. In fact, the volume changes were negative (but likely due to the recent nourishment equilibration) over the 3 miles. Only by looking at the detailed results was it determined that the "leaky" structure showed shoreline change benefits within the first 0.5 – 0.75 miles updrift of the terminal groin.

C. Literature Review and Discussion of Approaches to Minimize Impacts

As previously mentioned, a groin's performance depends greatly on its dimensions and type of materials used. A great deal of consideration should be utilized when developing potential terminal groin designs, as each factor is site-specific. While much of the discussion below is taken from design guidance for groin structures, it is also relevant and germane to the design of terminal groins.

1. Length

The length of the groin needs to be sufficient to retain the required beach width, by reducing a proportion of the longshore transport under normal conditions. Since extending a groin across the entire surf zone is costly and a total reduction in longshore transport would deprive downdrift beaches, compromise in groin length is a necessary design consideration (Perdok, 2003).

The longshore sediment transport is dependent on groin length relative to the surf zone width. If the surf zone extends beyond the groin (i.e., a short groin), most of the transport bypasses the groin, carried in the accelerating flow near the groin head. Thus a shorter groin will lead to less erosion downdrift of the groin, but capture less sediment updrift. If the groin extends past the surf zone (i.e., longer groins), the groin blocks nearly all sediment transport. A longer groin will trap more sediment updrift of the groin; but starve the downdrift beaches of sediment, leading to more erosion (Johnson, 2004 & Aminti, 2007). Studies have shown that the impacts of the groin downdrift are dependent on the length of the groin; however, most impacts will be noticeable within 3 miles of the groin. Monitoring done at Oregon Inlet shows the impacts are noticeable for a maximum of 5 km (~3 miles) downdrift of the groin (Overton, 2004).

U. Perdok states, "*In practice, it is proven effective to construct groins beyond the breaker line of the summer wave climate at mean high tide, as this is the season when wave climate builds up* *the beaches. When a wider beach is desired, the groin should be constructed to a length related to the future breaker line*." To avoid outflanking at the upper end of the beach, the groin should be placed far enough back into the beach to allow for the occasional drop in beach levels (Perdok, 2003).

2. Height

Groin height is of great importance in reducing currents and sediment transport across the groin. However, excessive height can lead to a focusing of flow which can lead to scour at the head of the structure. Excessive height can also increase wave reflection. Groin height contributes to a reduction of wave energy along the shoreline, as it causes waves to break further offshore (Poff, 2001). In a series of models studying the effects of groins on the surrounding beach environment, H. Johnson states, "*Groin height should account for wave overtopping and the resultant sediment transport that occurs over or behind the structure.*" Results show that in storm conditions, low groins are unlikely to trap any significant amount of sediment (Johnson, 2004).

The top level of a groin will determine the maximum potential beach depth updrift of the groin. The structure should be designed for any combination of beach levels on either side of the groin between the local scour level and the desired maximum beach depth (Fleming, 1993).

In most situations, it is preferable for the groin to protrude just above the beach level, with adjustments that can be made as the beach level changes. This will allow for some sediment to be transported over the structure and will reduce wave reflections from the groin. Most of the sediment will be trapped, as the largest concentration of sediment travels along the bottom of the groin. Ideally, groin height will vary with beach level; however, in practice, it is not economically feasible to continuously adjust the height. Studies have found that seasonal adjustments restricting groin heights to a level approximately 0.5 – 0.75 meters above beach levels will improve groin function. An alternative to continuously adjusting groin height is periodic beach nourishment to maintain beach levels. A groin profile that matches the beach profile will reduce near-shore longshore currents, but minimize local increases in velocities along the groin (Perdok, 2003). A typical terminal groin profile is shown in Figure V-23 (USACE, 2002).

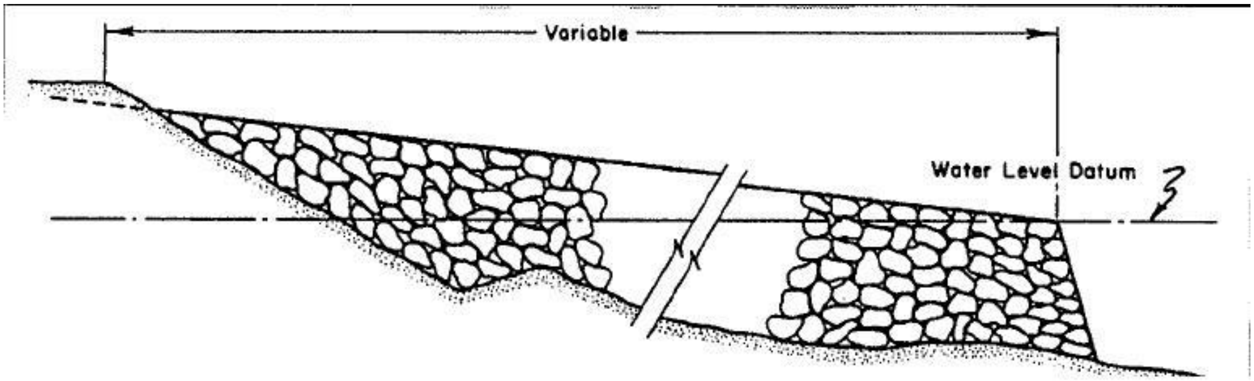


Figure V-23. Typical Terminal Groin Profile

In some situations, a submerged groin is suitable to meet project goals. Not only are submerged groins about one-third of the cost of emerged groins, they can be just as effective as their emerged counterparts. As previously stated, most of the sediment transport occurs along the bottom of the groin, so submerged groins are capable of trapping sediment. A submerged groin also has the benefit of beach aesthetics, as the groin will generally follow the beach profile. Several examples of submerged groins have been utilized successfully along the coasts of Spain and Italy (Pena, 2007 & Aminti, 2007).

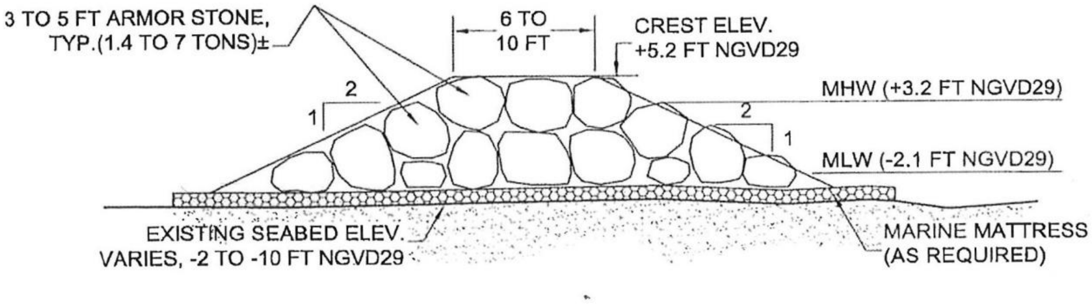
3. Permeability

Groins can be designed to be either permeable or impermeable depending on their intended purpose. Permeable groins do not impound sand directly, like impermeable groins. Permeable groins influence the water column's ability to retain and transport sediments by reducing the velocities through the groin.

Permeable groins can also affect wave energy by allowing waves to penetrate the groin. Permeable groins can behave as oblique breakwaters and can significantly alter the wave climate along the shore. A 10% groin permeability results in a 50% reduction of wave height when waves approach parallel to the groin (Poff, 2001 & USACE, 2002).

Permeable groins do allow sediment to be transported through the structure. They reduce longshore currents; however, they will trap less sediment than their impermeable counterparts. By trapping less sediment, they will cause less downdrift erosion problems.

The Amelia Island terminal groin is a functional example of a permeable groin. Due to environmental concerns downdrift, the groin at Amelia Island was intentionally designed to have a large degree of permeability. Post 2-year monitoring reports indicate that the groin and its detached breakwater are functioning properly and have exceeded expectations (Olsen, 2006 & 2008). It has retained enough sediment to help stabilize the shoreline updrift of the groin without causing harmful effects to important bird nesting habitats downdrift. Figure V-24 illustrates the difference between Amelia Island (permeable groin) and a typical rubble mound groin.



Amelia Island Typical Cross-Section

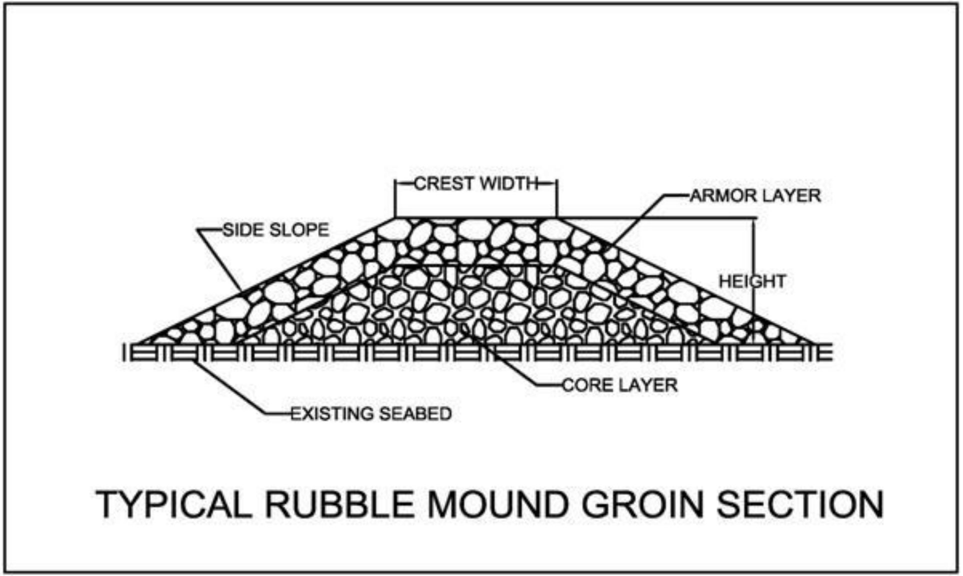


Figure V-24. Permeable Groin vs. Typical Groin

A typical rubble mound configuration can be made more permeable by lowering the height of the core layer to below mean sea level. This will allow additional sediment transport through the larger, more porous, armor layer. The disadvantage of lowering the core layer is that the groin is unable to absorb excessive wave energy as effectively. Also, typically the cost will increase as the volume of armor stone increases (Ehrlich, 1982).

The major benefits of permeable groins include lower construction and maintenance costs, reduction in both tidal and wave induced currents, decreased longshore sediment transport, decreased intensity of rip currents along the updrift side, more uniform shorelines, and reduced erosion on the leeward side of the groin (Poff, 2001).

Some disadvantages of permeable groins include increased channel shoaling from substantial sediment transport through the groin, possible higher dredging costs, and loss of beach material. Also, impermeable groins have predictable locations for abrasion, where permeable groin performance is generally less predictable (Perok, 2003 & USACE, 1986).

4. Configuration

Most groins are straight structures, perpendicular to the shoreline. However, other possible shapes include: T-, L-, and Y-shaped groins, inclined, dogleg, and tuned T-shaped. Some examples of these are shown in Figure V-25. T-shaped groins are similar to near-shore breakwaters when the T end is above mean sea level. T-head and L-shaped groins include a shore-parallel head section that acts to diffract wave energy before it reaches the shoreline.

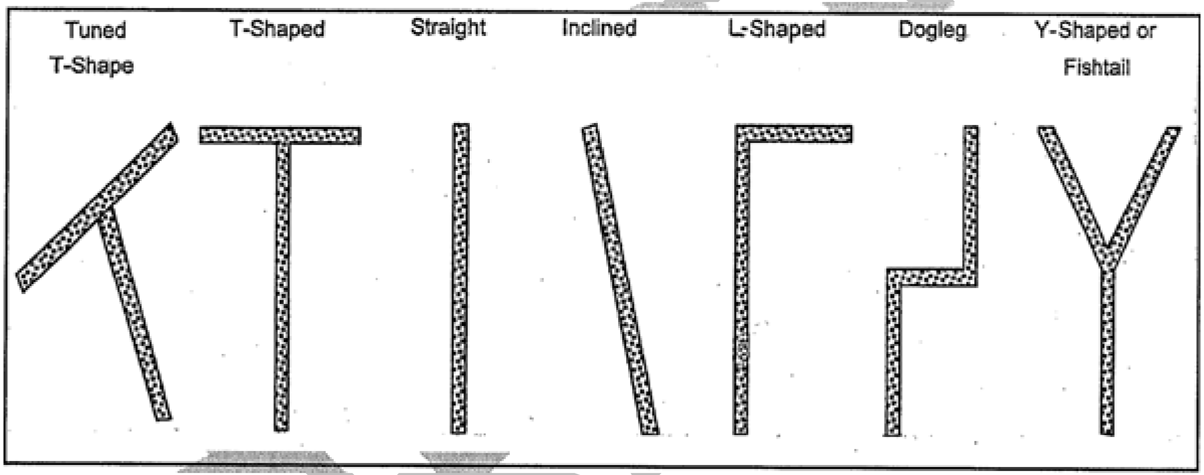


Figure V-25. Possible Groin Configurations (taken from USACE Coastal Engineering Manual, 2002)

T-head groins can be an improvement over standard groins since they reduce the occurrence of rip currents adjacent to the groin and block the offshore movement of sand adjacent to the groin. The USACE Coastal Engineering Manual states, "*T-head and L-shaped groins are best suited for protecting limited coastal reaches where the mobilizing forces include tidal currents, as well as wave-generated currents and where the objectives are more focused on stabilization of the shoreline, rather than increasing beach width*" (USACE, 2002). Inclined groins may reduce rip currents along the updrift side when inclined in the direction of net sediment transport.

5. Material

The type of materials used in marine structures depends on the required lifespan and costs associated with the structure. Generally, due to the costs associated with these structures, the expected lifespan can be between 25 to 50 years. The design needs to determine the durability of a groin in the aggressive marine environment, while ensuring maintenance costs are kept to a minimum.

a) Rock

The most common material used in terminal groin construction is rock. Rock (or rubble mound) groins generally have a core of smaller, graded stone with an armor layer of larger stone overlaying the core. Generally rock groins have a trapezoidal cross section (either with or without toe protection) and are dependent on weight for their stability. Rock groins have degrees of permeability depending on the size stones used.

In most cases, rock must be hand-placed. The armor layer should have a degree of interlocking to protect the groin from loads associated with marine structures (Latham, 1993). Rock groins can also present a safety hazard if people climb on top of the groin. However, rock groins tend to be very durable when designed and built correctly.

b) Concrete Panels and Armor Units

Concrete groins may be constructed using precast blocks, fillable cells, interlocking shapes (concrete armor units), or sheet piles. Typically, concrete units reinforced with steel are used. Figure V-26 illustrates an example of concrete sheet piles.

Sea water, which is rich in chlorides and sulphates, can corrode the reinforcement. Deterioration can also occur from alkali aggregate reactivity. Admixtures should be added to the concrete to counteract these effects; however, care should be taken when selecting the admixtures so they do not adversely affect the performance of the concrete.

Concrete armor units are man-made concrete objects designed to resist the action of waves on coastal structures. The armor units are applied in a single layer. The performance of these units greatly depends on accurate positioning of the individual blocks to enable the full interlocking potential. Specific placing must be strictly maintained during construction to ensure stability of the armor layer. Breakage can occur if the units are not installed properly (Boorman, 1996; Bunker, 1996; & USACE, 2002). Figure V-27 shows some examples of different concrete armor units.

Figure V-26. Example of Concrete Sheet Piles

Figure V-27. Examples of Concrete Armor Units

c) Steel

Steel groins may be comprised of sheet pilings, H-piling, waling, and sheeting; or a combination of all of the above. Steel sheeting, pilings, and sheeting are fairly quick and simple to install with pile drivers or vibratory equipment. Factory-produced materials can be delivered onsite with known properties, making quality control more reliable than other building materials. Steel has high strength and stiffness, with good ductility; however, it readily corrodes in a marine environment. Steel must be coated with an epoxy finish to keep it from corroding in saltwater. Steel groins can also have concrete fascias and caps to prevent corrosion (Spragg, 1993). Figure V-28 illustrates an example of a steel sheet pile terminal groin.

Figure V-28. Example of Steel Sheet Pile Terminal Groin

d) Timber

A potential low-cost material available for construction is timber. Timber groin configurations can have single or multiple rows of pilings. Timber groins can also have planks between the pilings which can be removed easily to vary the height of the groin with the beach level, making the groin adjustable in different beach conditions without having to rebuild or remodel the groin. Timber groins are relatively easy to construct, have a smaller footprint, and are more aesthetically pleasing than some of their counterparts (Perdok, 2003).

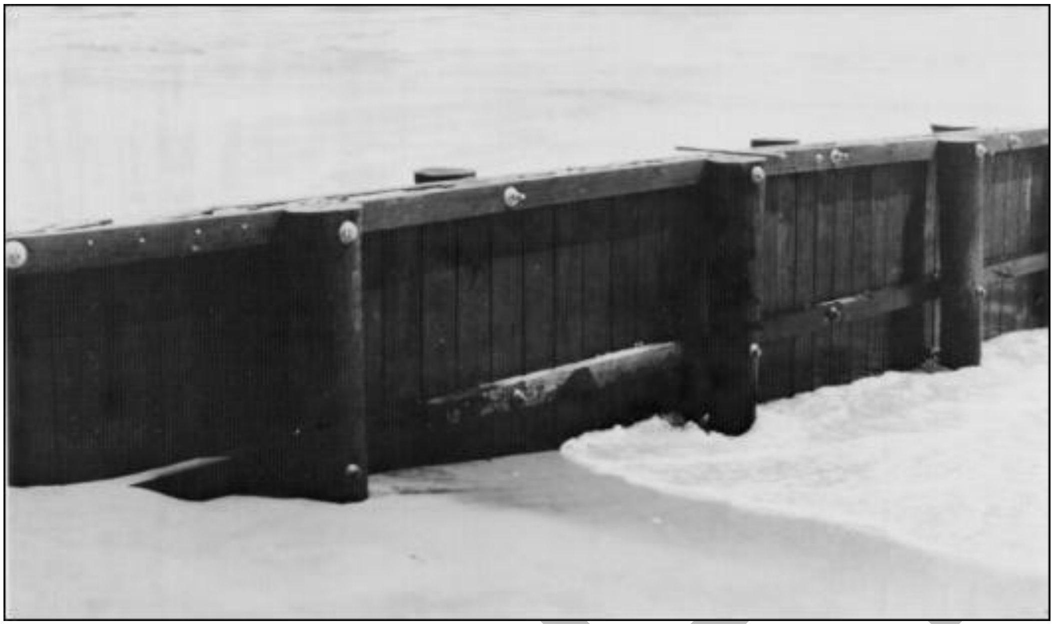


Figure V-29. Example of a Timber Groin

Timber does have several disadvantages, including, attack from physical damage, fungal decay, rotting, and marine borers. Timber also has a very limited structural application; that is where applied loads are low. Timber cannot withstand the same forces that rock, steel, or concrete groins can, and should not be used for construction of deep water groins (Spragg, 1993).

e) Geotextile

Geotextile tubes are a relatively inexpensive alternative to other building materials. There are numerous types of tubes and bags that can be filled with sand and stacked on top of one another to construct the groin. Figure V-30 shows an example of a geotextile tube.

Geotextiles made of polyester tend to perform better than polypropylene due to its better creep resistance and greater long-term strength. Polyester yarns are easier to sew, resulting in tighter seams. Also polyester fabrics tend to swell when wet, thereby decreasing the opening size and allowing for better sediment capture.

The major disadvantage to geotextiles is the ease of tearing or puncturing of the fabric during and after construction. Geotextiles also tend to degrade in UV light. Repairing damaged portions of geotextile tubes usually requires replacing or rebuilding the damaged sections. Patching geotextiles has proven ineffective in the past; however new technologies such as chemical seaming and HDPE covers may prove to be viable options to repair punctures and tears (Heilman, 2003). Another disadvantage to geotextile groins is, like timber, they cannot withstand larger loads and should not be used for deep water groins.

Figure V-30. Example of a Geotextile Tube

6. Alternative Techniques

When long groins have detrimental effects on the downdrift beaches, groin notching can be an alternative to removal of the groin. Groin notching, or removal and lowering of a portion of the groin just seaward of the beachfill design template, is designed to help maintain a straighter shoreline and provide the needed littoral transport downdrift of the groin. Another advantage to groin notching over removal is leaving existing marine habitats intact (Bocamazo, 2003).

Notched groins have recently undergone laboratory and field tests conducted by the US Army Corps of Engineers (USACE). Trial notched groins have been implemented by USACE along the southern New Jersey shore. Tentative conclusions show that notches in the swash zone are the most efficient. However, notching a groin in the swash zone may not be successful depending on how and at what rate sediment typically moves along the shore. Notches located in the surf zone are less efficient and can create strong rip currents which are hazardous to swimmers. Surf zone notches may actually move sediment further from shore (USACE, 2002).

D. Overall Findings and Summary

Terminal groin design is very site-specific. The length, height, and permeability of the groin will determine how effective the groin is at trapping sediment updrift of the groin and the overall impact of the groin on sediment transport. Long groins that are built above the seasonal high water level or are completely impermeable will most effectively block sediment. However, short groins with high permeability may not block enough sediment to be effective. Terminal groins should be just long enough to retain the required beach width, without causing an undue reduction in sediment transport downdrift.

Ideally, the groin height should be limited to just above beach level. Adjustable heights to nourishment volumes and design berm heights are also beneficial. The design groin height should also account for wave overtopping and the desired amount of sediment transmission over the structure.

Groin permeability has to weight the disruption of sediment transport with the potential for increased dredging costs if the structure is adjacent to a navigable channel.

Material types have also shown to have an effect on sediment transport rates and shoreline behavoir. Rock is generally the most widely used building material since it is readily available and highly durable. Concrete and steel are suitable building materials for larger, deep-water groins; however, these materials tend to be cost-prohibitive. Timber and geotextile groins are cheaper alternatives and can be adapted to a variety of beach conditions. Both have the advantage of being adjustable with the beach profile without having to rebuild or remodel the groin. However, both of these materials cannot withstand the loads experienced with deep-water groins and should not be used.

Groin notching is an emerging technique to rehabilitate long groins that have caused negative effects downdrift. Notching allows for sediment to bypass the groin where it would normally be trapped. This may prove to be a cost-effective alternative to groin removal.

These findings from the literature were confirmed when evaluating the five study sites. As reported in the analyses above, it appears that for shorter groins, the interruption to littoral transport is small compared to the overall magnitude of sediment transport since no negative impacts can be seen on the updrift or downdrift side of the inlet. There also seems to be a threshold that appears to be crossed once the effective length of the structure goes beyond 1,500 feet (at least for these five sites). While it is likely true that dredging impacts are responsible for this threshold crossing, it underlies the importance to considering the overall length of the structure in relation the exterior man-made and natural processes that also drive sediment transport so that the structure's impacts on the system are minimized.

The elevation of the structure is also an important consideration and appears to have a threshold limit where additional height does not buy additional benefit to updrift shorelines without causing undue impacts downdrift.

Finally, the porosity of the structure has a significant impact on adjacent shorelines. Based on the results above, one can see that the Amelia Island structure has had no adverse impact on downdrift shorelines and volumes. However, the structure has also had a limited impact on the three mile updrift shoreline. In looking at the details, it appears that the updrift benefit of the Amelia Island terminal groin dies off between 0.5 – 0.75 miles. The other structures have impermeable cores and appear to hold more sand for a greater distance updrift of the structure.

VI. Economic Assessment

A. Overview of Economic Considerations

The potential economic impact to State, local governments, and private sector from erosion due to shifting inlets was assessed. Using the best available information, properties at risk within the State's Proposed Inlet Hazard Areas were identified. Given 30 years is a typical mortgage duration and other costal risks are often calculated over this time period, a 30-year risk time period was used in the economic assessment.

1. Inlets Considered

The purpose of the economic assessment component of the study was to assess the economic value located within the proposed 30-year risk areas (30YRAs) adjacent to the following North Carolina inlets that are defined by Inlet Hazard Areas:

* Beaufort Inlet
* Bogue Inlet
* New River Inlet
* New Topsail Inlet
* Rich Inlet
* Mason Inlet
* Masonboro Inlet
* Carolina Beach Inlet
* Cape Fear Inlet
* Lockwoods Folly Inlet
* Shallotte Inlet
* Tubbs Inlet

In addition, Oregon Inlet is considered as a special case. While not defined as an Inlet Hazard Area (due to not having development immediately on either side), Oregon Inlet is traversed by a major bridge that is at risk from erosion and inlet migration.

* Oregon Inlet

2. 30-Year Risk Areas (30YRAs)

The 30YRAs were defined by lines on aerial photo maps provided by the North Carolina Division of Coastal Management. The maps are based on aerial photos from 2003-2009. Any land existing seaward of the lines is assumed to be at risk in the next 30 years. The current location of the line at each inlet can be seen in Section B. It should be noted that the proposed 30-year risk areas (30YRAs) are based on proposed 30-year risk lines that are still in draft form and being developed by DCM and a Science Panel subcommittee. These lines were agreed upon to use in this assessment since they represent the best currently available data.

3. Types of Economic Value Considered

The 30YRAs support several types of economic value, including property and infrastructure value, recreation value, and environmental (wildlife preserve, scenic view, etc.) value. Given the time constraints of this study, it was decided to focus on the following components of economic value:

* Residential property
* Commercial property
* Government property
* Road infrastructure
* Waterline infrastructure
* Sewer infrastructure
* Recreation and environmental value

Detailed assessment of environmental value is beyond the scope of this study. However, a brief review of studies that attempt to assess these values is provided in a separate section (Section C) to give some indication of their potential magnitude.

a) Property Value

County online Geographic Information System (GIS) property parcel databases were consulted to determine the property parcel numbers, types (residential, commercial, or government) and locations within the 30YRAs.

* GIS Brunswick County, NC. http://gis.brunsco.net/

* New Hanover County, NC -- GIS Maps.
http://www.nhcgov.com/AgnAndDpt/INFO/GIS/Pages/GISMaps.aspx

* Pender County, NC -- GIS maps.
http://www.pendercountync.gov/Government/Departments/InformationTechnologyServices/GISServices/OnLineGISDisclaimer.aspx

* Onslow County, NC -- GIS Maps.
http://maps.onslowcountync.gov/gomaps/map/Index.cfm

* GIS Carteret County, NC. http://carteret.connectgis.com/

Property parcel information was available for each side of each inlet, enabling disaggregation of results by inlet side. Some inlets face east, producing "north side" and "south side" results; other inlets face south, producing "east side" and "west side" results.

Some county GIS systems provided property value data as well as geographic data, while some did not. For those systems that did not, online county property tax records were used to determine property values via property parcel identification numbers. The property values obtained were the assessed property values as of the most recent assessment as made available through the county online GIS systems or from online property tax systems when the GIS systems contained no value information. For properties last assessed prior to 2009, some adjustments would customarily be made to account for the effects of inflation on property values; this adjustment typically increases property values. However, the economic crisis of 2008-2009 resulted in some reduction in most property values in the study region since the last assessment. As a detailed parcel-by-parcel accounting for these factors is beyond the scope of this study, we simply use the most recent assessed value as our measure of property value.

The property values provided by the county GIS systems were usually divided into three components: land value, structure/building value, and "other" value (e.g., outbuildings, common areas, etc.). Where possible, the values of these components are reported separately and then totaled. Some counties did not list "other" value.

For parcels with multiple residential units (e.g., duplexes and condos), property values were obtained for each residential unit in the parcel.

Many of the parcels in the 30YRAs were residential beach houses/cottages. In many locations, these houses are arrayed in rows parallel to the shore. If a house is lost to inlet migration, some or all of the value of the inlet/oceanfront location would be expected to transfer to houses located on the next row away from the inlet/ocean, increasing their market value. On the other hand, loss of the intervening row of houses may increase the perception of erosion risk for the remaining houses, decreasing their market values. A detailed assessment of these "value transfer effects" is beyond the scope of this study; instead, we simply present the existing values of the structures in their current locations. However, a brief review of studies that attempt to assess these effects is provided in a separate section below to give some indication of their potential magnitude.

b) Road Infrastructure Value

The length (feet) of road infrastructure within each 30YRA was determined using the county online GIS measuring tools. There are many types of road construction. For the purposes of this study, it is assumed that roads are typical 2-lane roads with 2-foot paved shoulders but without curbs, gutters, parking or sidewalks. This may not be accurate for all locations (for example, the road on the north end of Wrightsville beach has a bike lane on each side; however, this road was not in the 30YRA), but is typical for beach island roads in the study area. Road infrastructure was valued at current replacement cost. North Carolina Department of Transportation Construction Cost Estimates for 2008 were used to determine the typical cost of constructing such roads: $3 million per mile, or $568 per foot. The length of road within each 30YRA was multiplied by $568 per foot to obtain the replacement cost value of road infrastructure.

c) Water Line Infrastructure Value

Coastal municipality Coastal Area Management (CAMA) plans were consulted to determine the locations and types of water line infrastructure within the 30YRAs. These plans typically contain maps of water and sewer infrastructure locations. In general, water lines run along all streets in the 30YRSs. As a result, the length (feet) of road infrastructure within each 30YRA was multiplied by an average per-foot cost of constructing typical, terminal water lines in coastal areas of $55/foot, based on discussions with engineers in the Cape Fear Public Utility Authority and Wrightsville Beach public works department.

d) Sewer Infrastructure Value

Coastal municipality Coastal Area Management (CAMA) plans were consulted to determine the locations and types of sewer line infrastructure within the 30YRAs. In general, sewer lines run along all streets in the 30YRAs. As a result, the length (feet) of road infrastructure within each 30YRA was multiplied by an average per-foot cost of constructing typical, terminal sewer lines in coastal areas. Discussions with engineers in the Cape Fear Public Utility Authority and Wrightsville Beach planning department produced an estimate of $150/foot.

B. Economic Impact of Shifting Inlets

1. Economic Value At Inlets

The economic impact of a particular inlet shifting within the 30YRAs was tabulated for each North Carolina inlet included in this economic study (excluding Oregon Inlet). Table VI-1 through Table VI-12 present components of economic value within the 30YRAs for each side of each inlet (excluding Oregon Inlet). Figure VI-1 through Figure VI-12 shows the 30 year risk line used for the economic evaluation at each inlet (excluding Oregon Inlet).

Following the figures and tables is a special discussion of economic value at risk to shifting of Oregon Inlet.

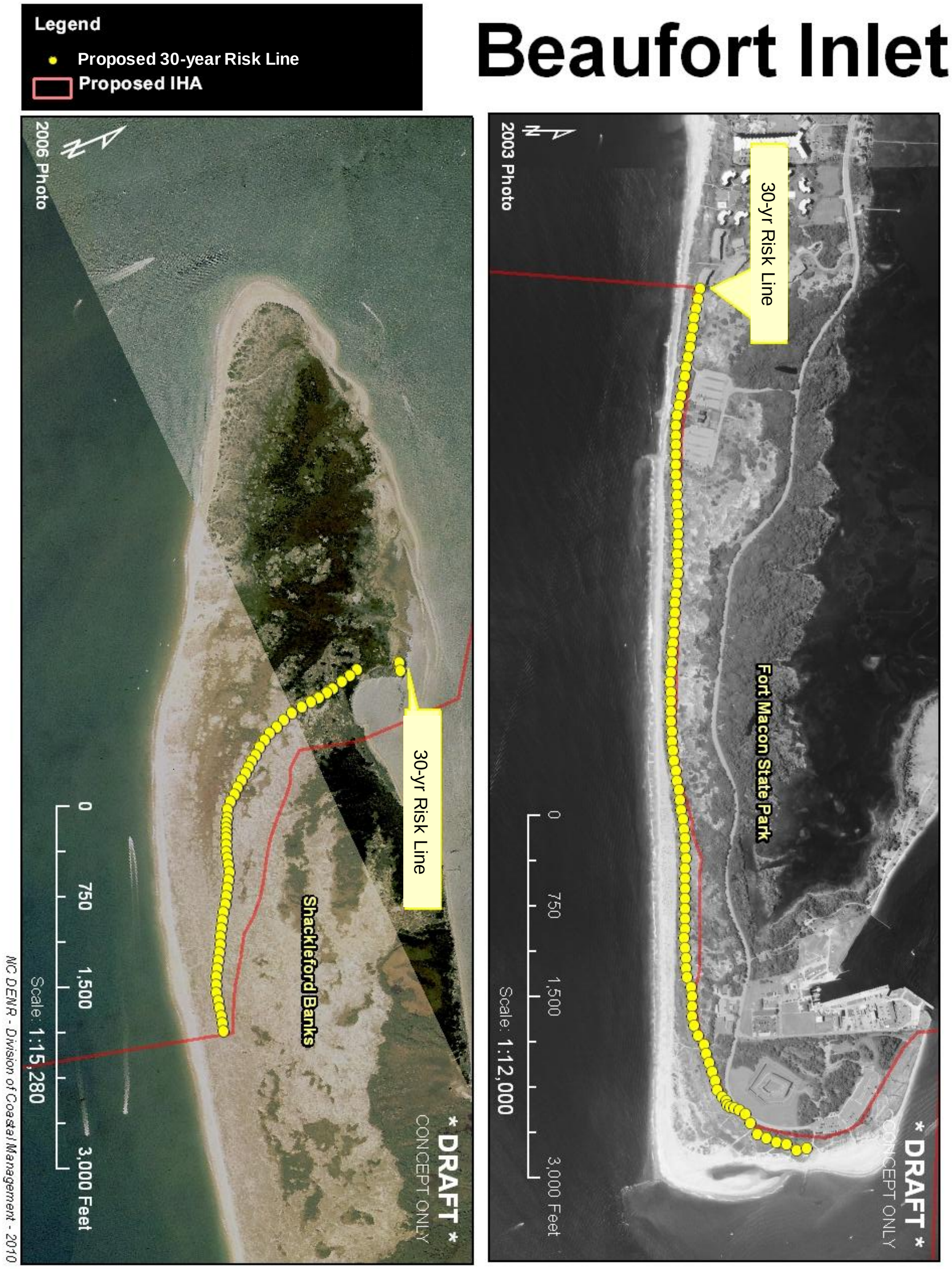


Figure VI-1. 30-yr Risk Line at Beaufort Inlet

Table VI-1. Economic Value at Risk Within 30-yr Risk Lines at Beaufort Inlet

Value Type	West Side of Inlet (Ft Macon State Park side)	East Side of Inlet (Shackleford Banks Side)
Residential Property Value		
Number of Parcels	None w/n 30-yr Risk Lines.	None (undeveloped island)
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Commercial Property Value		
Number of Parcels	None w/n 30-yr Risk Lines.	None (undeveloped island)
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	~90% public beach area (~9000ft in length) in Ft. Macon State Park	None (undeveloped island)
Land Value	-----	-----
Structure Value	5% loss of paved parking at Ft. Macon State Park	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	2-lane road w. 2' paved shoulders (no curb, gutter, parking or sidewalk)	None (undeveloped island)
Length (ft)	300	-----
Replacement Cost / ft	$568	-----
Total Value	$170,000	-----
Waterline Infrastructure Value		
Type	Typical	None (undeveloped island)
Length (ft)	300	-----
Replacement Cost / ft	$55	-----
Total Value	$17,000	-----
Sewer Infrastructure Value		
Type	None known. (Park on package system outside 30-yr risk line.)	None (undeveloped island)
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
GRAND TOTAL VALUE	**$187,000**	**None (undeveloped island)**

Figure VI-2. 30-yr Risk Line at Bogue Inlet

Table VI-2. Economic Value at Risk Within 30-yr Risk Lines at Bogue Inlet

Value Type	West Side of Inlet (Bear Island side)	East Side of Inlet (Emerald Island Side)
Residential Property Value		
Number of Parcels	None (undeveloped island)	63 single family 33 condo units
Land Value	-----	$54,920,000
Structure Value	-----	$33,460,000
Other Value	-----	$1,070,000
Total Value	-----	$89,450,000
Commercial Property Value		
Number of Parcels	None (undeveloped island)	None known.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None (undeveloped island)	None known.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	None (undeveloped island)	2-lane road w. 2' paved shoulders (no curb, gutter, parking or sidewalk)
Length (ft)	-----	5818
Replacement Cost / ft	-----	$568
Total Value	-----	$3,304,624
Waterline Infrastructure Value		
Type	None (undeveloped island)	Typical
Length (ft)	-----	5818
Replacement Cost / ft	-----	$55
Total Value	-----	$319,990
Sewer Infrastructure Value		
Type	None (undeveloped island)	Typical
Length (ft)	-----	5818
Replacement Cost / ft	-----	$150
Total Value	-----	$872,700
GRAND TOTAL VALUE	**None (undeveloped island)**	**$93,947,314**

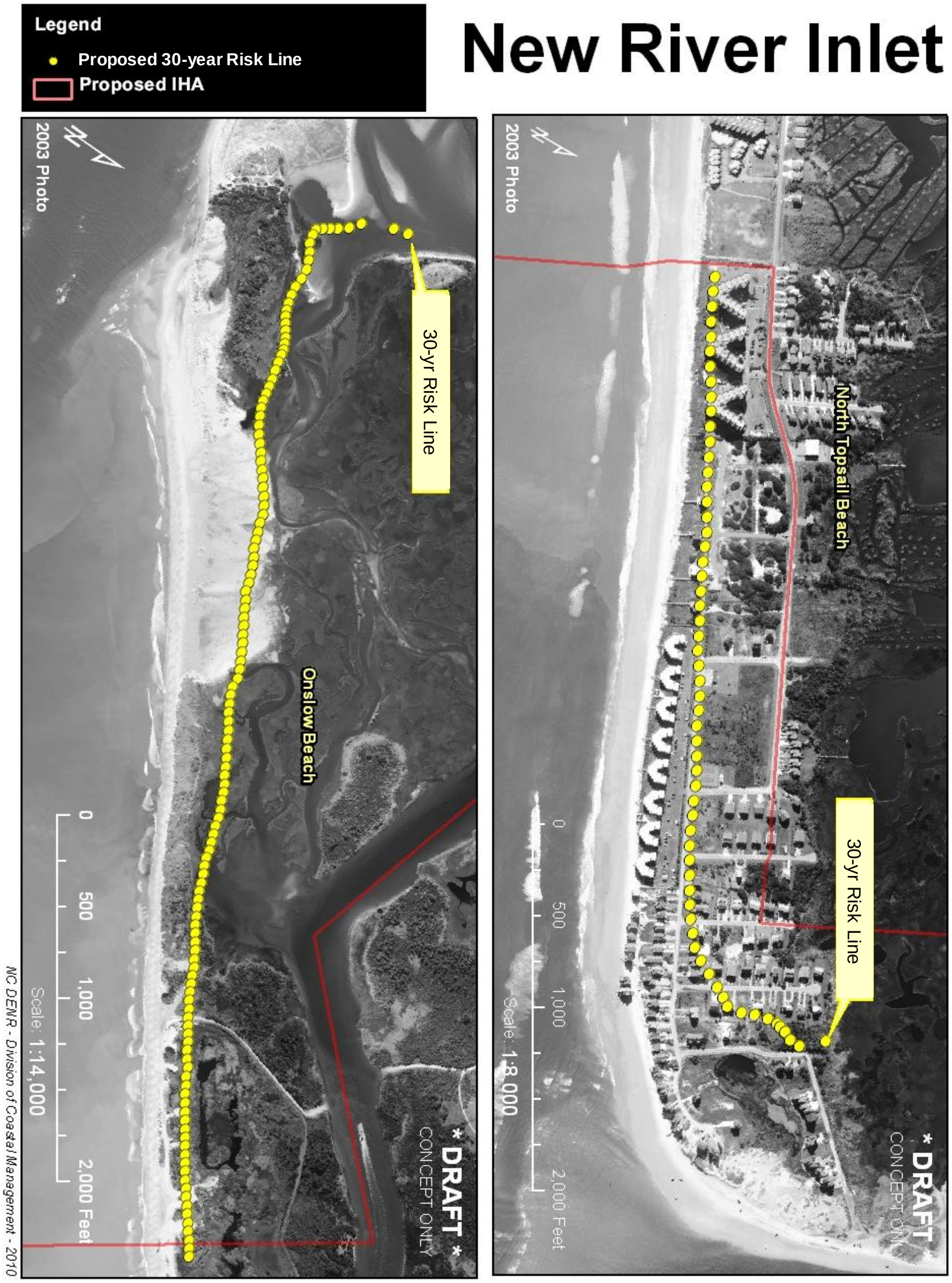


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Figure VI-3. 30-yr Risk Line at New River Inlet

Table VI-3. Economic Value at Risk Within 30-yr Risk Lines at New River Inlet

Value Type	North Side of Inlet (Onslow Beach side)	South Side of Inlet (North Topsail Beach Side)
Residential Property Value		
Number of Parcels	None (undev. military land)	136 residential single fam. 240 condo units
Land Value	-----	$24,773,765
Structure Value	-----	$41,666,597
Other Value	-----	$377,331
Total Value	-----	$66,817,693
Commercial Property Value		
Number of Parcels	None (undev. military land)	None known.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None (undev. military land)	None known.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	None (undev. military land)	2-lane road w. 2' paved shoulders (no curb, gutter, parking or sidewalk)
Length (ft)	-----	4480
Replacement Cost / ft	-----	$568
Total Value	-----	$2,545,455
Waterline Infrastructure Value		
Type	None (undev. military land)	Typical
Length (ft)	-----	4480
Replacement Cost / ft	-----	$55
Total Value	-----	$246,400
Sewer Infrastructure Value		
Type	None (undev. military land)	Typical
Length (ft)	-----	4480
Replacement Cost / ft	-----	$150
Total Value	-----	$672,000
GRAND TOTAL VALUE	**None (undev. military land)**	**$70,281,548**

Figure VI-4. 30-yr Risk Line at New Topsail Inlet

Table VI-4. Economic Value at Risk Within 30-yr Risk Lines at New Topsail Inlet

Value Type	North Side of Inlet (Topsail Beach side)	South Side of Inlet (Lea Hutaff Island Side)
Residential Property Value		
Number of Parcels	148 single-family residences 36 condo units	None (undeveloped island)
Land Value	$19,122,000	-----
Structure Value	$14,157,000	-----
Other Value	-----	-----
Total Value	$33,279,000	-----
Commercial Property Value		
Number of Parcels	None known.	None (undeveloped island)
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None known.	None (undeveloped island)
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 (undeveloped island)
Length (ft)	4575	-----
Replacement Cost / ft	$568	-----
Total Value	$2,599,000	-----
Waterline Infrastructure Value		
Type	Typical	None (undeveloped island)
Length (ft)	4575	-----
Replacement Cost / ft	$55	-----
Total Value	$252,000	-----
Sewer Infrastructure Value		
Type	Typical	None (undeveloped island)
Length (ft)	4575	-----
Replacement Cost / ft	$150	-----
Total Value	$686,000	-----
GRAND TOTAL VALUE	**$36,816,000**	**None (undeveloped island)**

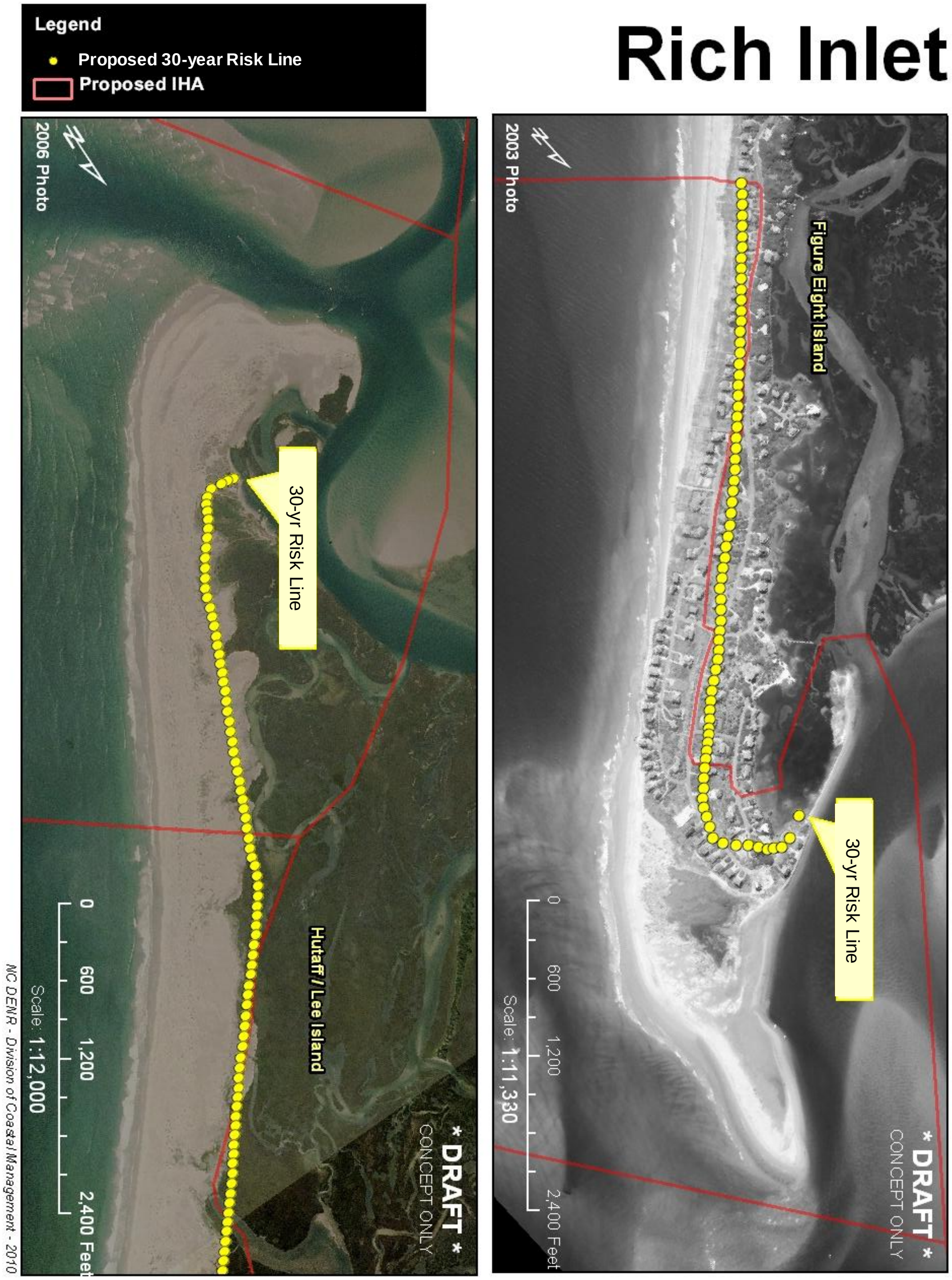

Figure VI-5. 30-yr Risk Line at Rich Inlet

Table VI-5. Economic Value at Risk Within 30-yr Risk Lines at Rich Inlet

Value Type	North Side of Inlet (Lea Hutaff Island side)	South Side of Inlet (Figure Eight Island Side)
Residential Property Value		
Number of Parcels	None (undeveloped island)	89 single-family residences
Land Value	-----	$99,043,000
Structure Value	-----	$64,143,000
Other Value	-----	-----
Total Value	-----	$163,186,000
Commercial Property Value		
Number of Parcels	None (undeveloped island)	None known.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None (undeveloped island)	None known.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	None (undeveloped island)	2-lane road w. 2' paved shoulders (no curb, gutter, parking or sidewalk)
Length (ft)	-----	5149
Replacement Cost / ft	-----	$568
Total Value	-----	$2,926,000
Waterline Infrastructure Value		
Type	None (undeveloped island)	Typical
Length (ft)	-----	5149
Replacement Cost / ft	-----	$55
Total Value	-----	$283,000
Sewer Infrastructure Value		
Type	None (undeveloped island)	Typical
Length (ft)	-----	5149
Replacement Cost / ft	-----	$150
Total Value	-----	$772,000
GRAND TOTAL VALUE	**None (undeveloped island)**	**$167,168,000**

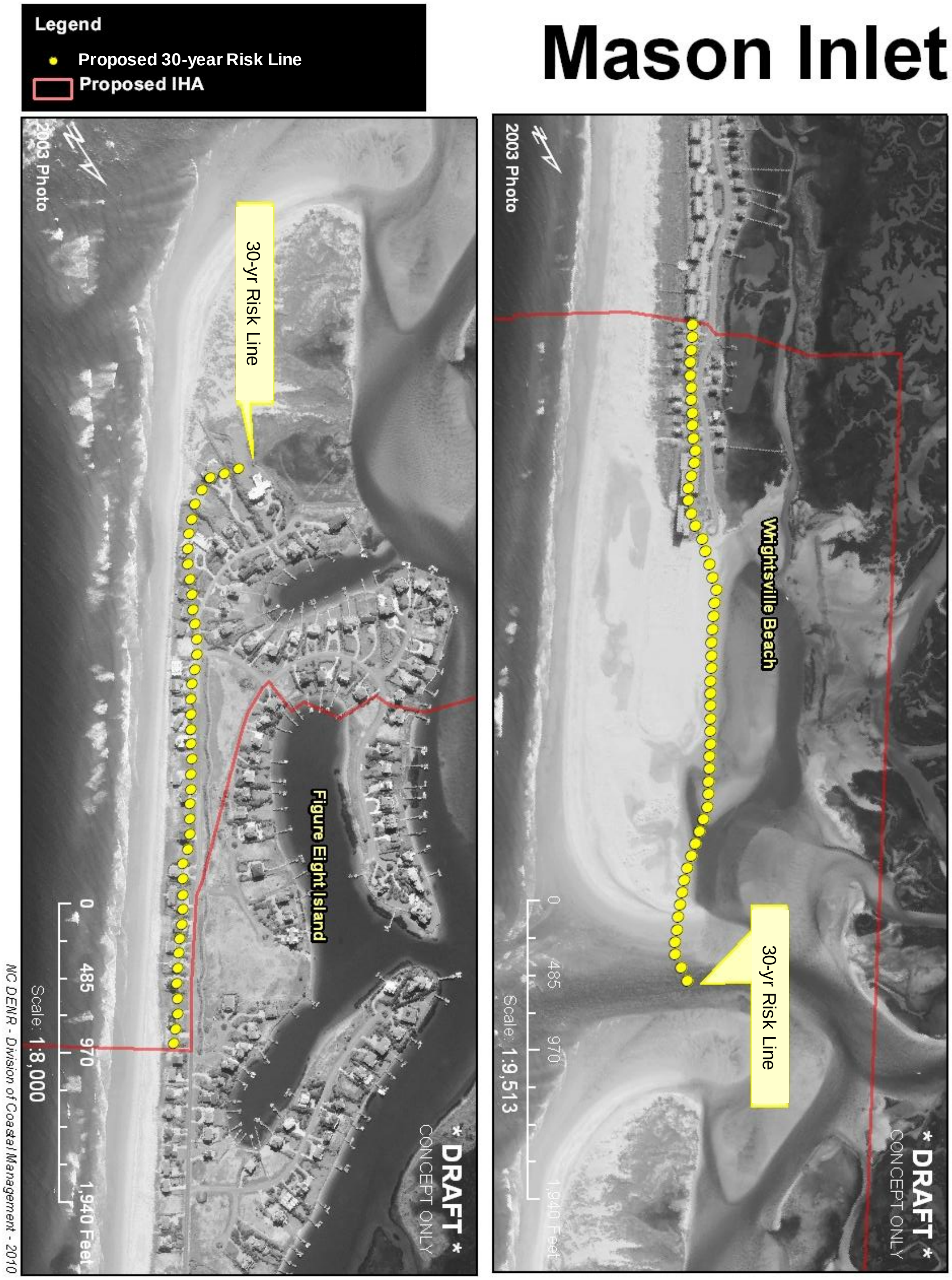

Figure VI-6. 30-yr Risk Line at Mason Inlet

Table VI-6. Economic Value at Risk Within 30-yr Risk Lines at Mason Inlet

Value Type	North Side of Inlet (Figure Eight Island side)	South Side of Inlet (Wrightsville Beach Side)
Residential Property Value		
Number of Parcels	25	14 single-family 1 condo resort w. 168 resid. units
Land Value	$30,364,488	$30,869,445
Structure Value	$16,044,453	$53,840,582
Other Value	-----	-----
Total Value	$46,408,941	$84,710,027
Commercial Property Value		
Number of Parcels	None known.	2 units in condo resort
Land Value	-----	(value included under residential)
Structure Value	-----	(value included under residential)
Other Value	-----	-----
Total Value	-----	(value included under residential)
Government Property Value		
Number of Parcels	None known.	None known.
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)	2-lane road w. bike lanes each side (no curb, gutter, parking or sidewalk)
Length (ft)	250	0
Replacement Cost / ft	$568	$568
Total Value	$142,000	-----
Waterline Infrastructure Value		
Type	Typical	Typical
Length (ft)	250	0
Replacement Cost / ft	$55	$55
Total Value	$14,000	-----
Sewer Infrastructure Value		
Type	Typical	Typical
Length (ft)	250	0
Replacement Cost / ft	$150	$150
Total Value	$38,000	-----
GRAND TOTAL VALUE	**$46,602,941**	**$84,710,027**

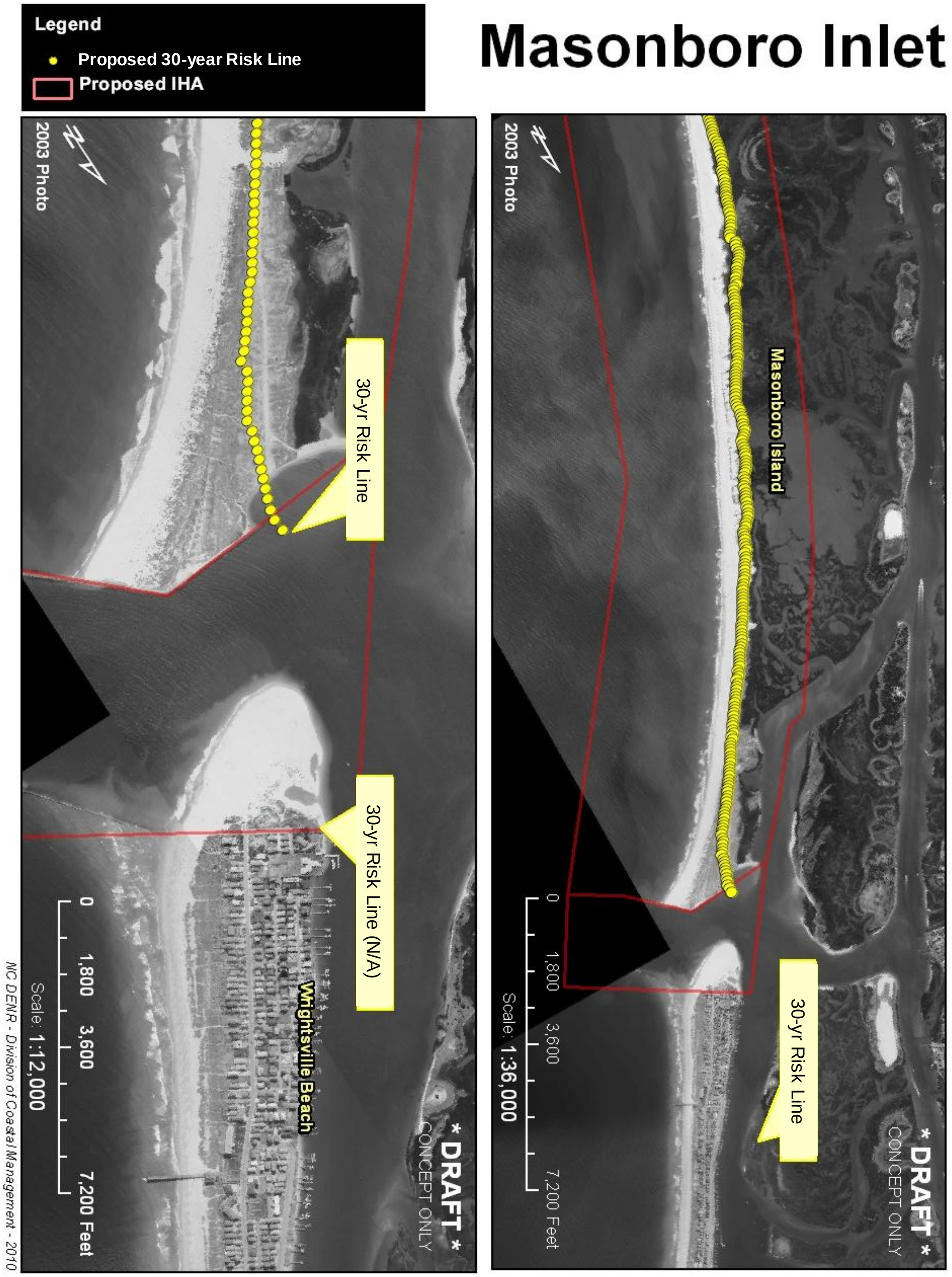

Figure VI-7. 30-yr Risk Line at Masonboro Inlet

Table VI-7. Economic Value at Risk Within 30-yr Risk Lines at Masonboro Inlet

Value Type	North Side of Inlet (Wrightsville Beach side)	South Side of Inlet (Masonboro Island Side)
Residential Property Value		
Number of Parcels	None w/n 30-yr Risk Lines.	None (undeveloped island)
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Commercial Property Value		
Number of Parcels	None w/n 30-yr Risk Lines.	None (undeveloped island)
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None w/n 30-yr Risk Lines.	None (undeveloped island)
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	None w/n 30-yr Risk Lines.	None (undeveloped island)
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Waterline Infrastructure Value		
Type	None w/n 30-yr Risk Lines.	None (undeveloped island)
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Sewer Infrastructure Value		
Type	None w/n 30-yr Risk Lines.	None (undeveloped island)
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
GRAND TOTAL VALUE	**None w/n 30-yr Risk Lines.**	**None (undeveloped island)**

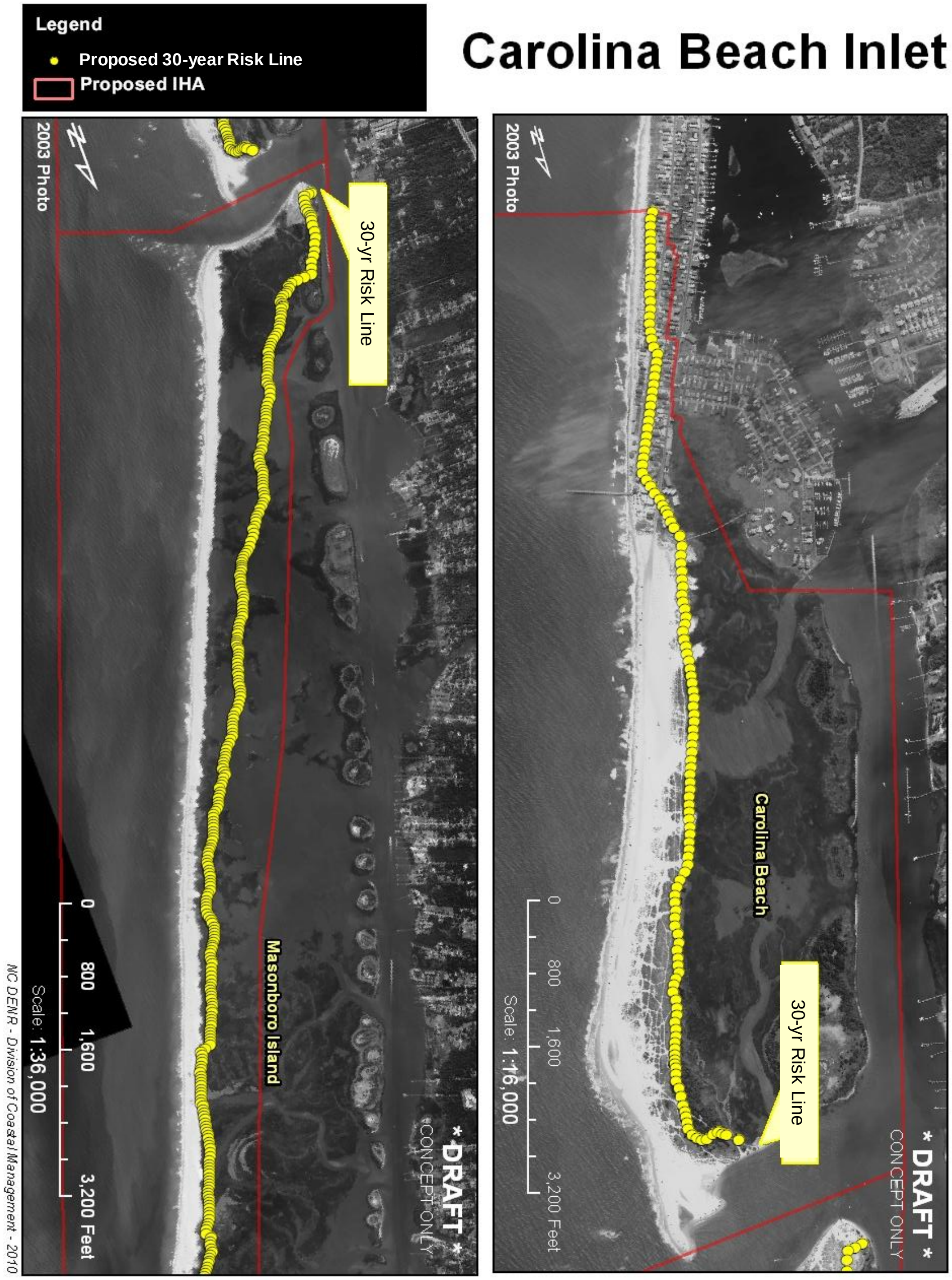

Figure VI-8. 30-yr Risk Line at Carolina Beach Inlet

Table VI-8. Economic Value at Risk Within 30-yr Risk Lines at Carolina Beach Inlet

Value Type	**North Side of Inlet (Masonboro Island side)**	**South Side of Inlet (Carolina Beach Side)**
Residential Property Value		
Number of Parcels	None (undeveloped island)	39
Land Value	-----	$28,753,000
Structure Value	-----	$5,976,000
Other Value	-----	$0
Total Value	-----	$34,729,000
Commercial Property Value		
Number of Parcels	None (undeveloped island)	1 (Carolina Beach Fishing Pier)
Land Value	-----	(included in residential totals)
Structure Value	-----	(included in residential totals)
Other Value	-----	-----
Total Value	-----	(included in residential totals)
Government Property Value		
Number of Parcels	None (undeveloped island)	None known.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	None (undeveloped island)	2-lane road w. 2' paved shoulders (no curb, gutter, parking or sidewalk)
Length (ft)	-----	2076
Replacement Cost / ft	-----	$568
Total Value	-----	$1,180,000
Waterline Infrastructure Value		
Type	None (undeveloped island)	Typical
Length (ft)	-----	2076
Replacement Cost / ft	-----	$55
Total Value	-----	$114,000
Sewer Infrastructure Value		
Type	None (undeveloped island)	Typical
Length (ft)	-----	2076
Replacement Cost / ft	-----	$150
Total Value	-----	$311,000
GRAND TOTAL VALUE	**None (undeveloped island)**	**$36,334,000**

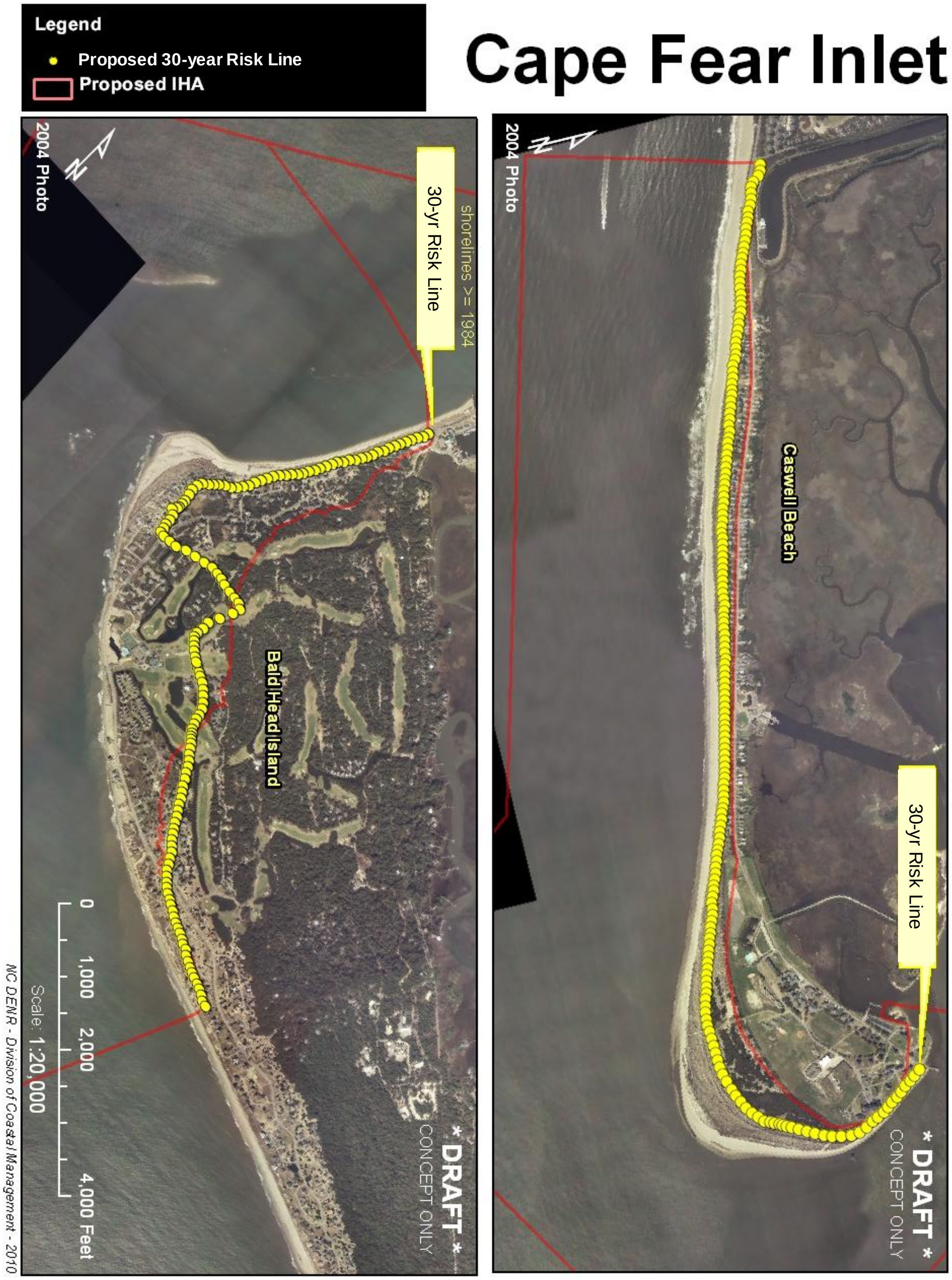

Figure VI-9. 30-yr Risk Line at Cape Fear Inlet

Table VI-9. Economic Value at Risk Within 30-yr Risk Lines at Cape Fear Inlet

Value Type	West Side of Inlet (Caswell Beach side)	East Side of Inlet (Baldhead Island Side)
Residential Property Value		
Number of Parcels	100 residential	323 residential
Land Value	$84,014,000	$195,274,000
Structure Value	$19,327,000	$114,625,000
Other Value	$877,000	$833,000
Total Value	$104,218,000	$310,732,000
Commercial Property Value		
Number of Parcels	1 (Progress Energy)	2 (Bald Head Island Club)
Land Value	$4,650,000	$963,000
Structure Value	$0	-----
Other Value	$5000	$525,000
Total Value	$4,655,000	$1,488,000
Government Property Value		
Number of Parcels	1 (Town of Caswell Beach) 1100 Caswell Beach Rd.	None known.
Land Value	$8,280,000	-----
Structure Value	$0	-----
Other Value	$0	-----
Total Value	$8,280,000	-----
Road Infrastructure Value		
Type	2-lane road w. 2' paved shoulders (no curb, gutter, parking or sidewalk)	2-lane road w. 2' paved shoulders (no curb, gutter, parking or sidewalk)
Length (ft)	1032	11990
Replacement Cost / ft	$568	$568
Total Value	$586,000	$6,813,000
Waterline Infrastructure Value		
Type	Typical	Typical
Length (ft)	1032	3750
Replacement Cost / ft	$55	$55
Total Value	$57,000	$659,000
Sewer Infrastructure Value		
Type	Typical	Typical
Length (ft)	1032	3750
Replacement Cost / ft	$150	$150
Total Value	$155,000	$1,799,000
GRAND TOTAL VALUE	**$117,951,000**	**$321,491,000**

Figure VI-10. 30-yr Risk Line at Lockwoods Folly Inlet

Table VI-10. Economic Value at Risk Within 30-yr Risk Lines at Lockwoods Folly Inlet

Value Type	West Side of Inlet (Holden Beach side)	East Side of Inlet (Oak Island Side)
Residential Property Value		
Number of Parcels	150	102
Land Value	$21,080,000	$93,700,000
Structure Value	$5,640,000	$15,470,000
Other Value	$511,000	$730,000
Total Value	$27,240,000	$109,900,000
Commercial Property Value		
Number of Parcels	None known.	None known.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	2 (Town of Holden Bch.)	2 (Town of Long Beach) 2 (Town of Oak Island)
Land Value	-----	$5.22 million (Long Beach) $237,000 (Oak Island)
Structure Value	-----	-----
Other Value	-----	-----
Total Value	No assessed value.	$5,460,000
Road Infrastructure Value		
Type	2-lane road w. 2' paved shoulders (no curb, gutter, parking or sidewalk)	2-lane road w. 2' paved shoulders (no curb, gutter, parking or sidewalk)
Length (ft)	8908	3750
Replacement Cost / ft	$568	$568
Total Value	$5,060,000	$2,130,000
Waterline Infrastructure Value		
Type	Typical	Typical
Length (ft)	8908	3750
Replacement Cost / ft	$55	$55
Total Value	$490,000	$206,000
Sewer Infrastructure Value		
Type	Typical	Typical
Length (ft)	8908	3750
Replacement Cost / ft	$150	$150
Total Value	$1,340,000	$563,000
GRAND TOTAL VALUE	**$34,130,000**	**$118,259,000**

Figure VI-11. 30-yr Risk Line at Shallotte Inlet

Table VI-11. Economic Value at Risk Within 30-yr Risk Lines at Shallotte Inlet

Value Type	**West Side of Inlet (Ocean Isle side)**	**East Side of Inlet (Holden Beach Side)**
Residential Property Value		
Number of Parcels	85	193
Land Value	$16,934,000	$229,097,000
Structure Value	$7,866,000	$41,912,000
Other Value	$269,000	$2,846,000
Total Value	$25,069,000	$273,855,000
Commercial Property Value		
Number of Parcels	None known.	None known.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None known.	None known.
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)	2-lane road w. 2' paved shoulders (no curb, gutter, parking or sidewalk)
Length (ft)	2818	5685
Replacement Cost / ft	$568	$568
Total Value	$1,601,000	$3,230,000
Waterline Infrastructure Value		
Type	Typical	Typical
Length (ft)	2818	5685
Replacement Cost / ft	$55	$55
Total Value	$155,000	$313,000
Sewer Infrastructure Value		
Type	Typical	Typical
Length (ft)	2818	5685
Replacement Cost / ft	$150	$150
Total Value	$423,000	$853,000
GRAND TOTAL VALUE	**$27,248,000**	**$278,251,000**

Figure VI-12. 30-yr Risk Line at Tubbs Inlet

Table VI-12. Economic Value at Risk Within 30-yr Risk Lines at Tubbs Inlet

Value Type	West Side of Inlet (Sunset Beach side)	East Side of Inlet (Ocean Isle Side)
Residential Property Value		
Number of Parcels	None w/n 30-yr Risk Lines.	15 single family, 24 condo units
Land Value	-----	$26,290,000
Structure Value	-----	$9,113,000
Other Value	-----	$564,000
Total Value	-----	$35,966,000
Commercial Property Value		
Number of Parcels	None w/n 30-yr Risk Lines.	None known.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None w/n 30-yr Risk Lines.	None known.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	None w/n 30-yr Risk Lines.	2-lane road w. 2' paved shoulders (no curb, gutter, parking or sidewalk)
Length (ft)	-----	740
Replacement Cost / ft	-----	$568
Total Value	-----	$420,000
Waterline Infrastructure Value		
Type	None w/n 30-yr Risk Lines.	Typical
Length (ft)	-----	740
Replacement Cost / ft	-----	$55
Total Value	-----	$41,000
Sewer Infrastructure Value		
Type	None w/n 30-yr Risk Lines.	Typical
Length (ft)	-----	740
Replacement Cost / ft	-----	$150
Total Value	-----	$111,000
GRAND TOTAL VALUE	**None w/n 30-yr Risk Lines.**	**$36,538,000**

The issues involved in assessing the economic value at risk due to shifting of Oregon Inlet are different from those associated with the other North Carolina inlet, and so Oregon Inlet is considered here as a special case. In the case of Oregon Inlet, the benefits of a terminal groin depend on the scenario assumed for Bonner Bridge, which spans the inlet and connects Bodie Island in the north with Hatteras Island in the south. Bonner Bridge is near the end of its service life. Several alternatives for Bonner Bridge repair, relocation, or extension have been considered by highway planners (NCDOT 2008b). The current Preferred Alternative consists of a new bridge over Oregon Inlet (west of the existing Bonner Bridge) and the construction of additional bridges within the highway NC 12 easement from Oregon Inlet to the town of Rodanthe as needed to retain NC 12 in light of both ongoing shoreline erosion and the potential for island breaches in the area. The Preferred Alternative is designated as the "Parallel Bridge Phased Approach/Rodanthe Bridge Alternative." It is assumed here that the current Preferred Alternative is implemented, and economic value is assessed with and without a terminal groin under this assumption.

Currently, a terminal groin is in position. The terminal groin must remain in position to protect the Hatteras Island end of the new Parallel bridge that will replace Bonner Bridge until a smaller bridge is built to the south, connecting the new Parallel bridge with NC 12 farther south. The smaller bridge is the northern-most (closest to Oregon Inlet, within the Canal Zone area) Phase II bridge of the Preferred Alternative Plan. Once the smaller bridge is constructed, the terminal groin could be removed. The cost of constructing the smaller bridge is estimated to be between $131 and 194 million (2006 dollars). In effect, maintaining the terminal groin for one year allows delay of the construction of the smaller bridge for one year. If it is assumed that:

(1) constructing the smaller bridge costs $162.5 million (the midpoint of the cost estimate range) in 2009 (assuming that any inflation in construction costs that occurred between 2006 and 2008 was offset by deflation in construction costs during the recession of 2008-2009), and

(2) discount rate of 5% (the discount rate used by NCDOT in the Bonner Bridge alternatives study) is appropriate,

then the costs savings arising from delaying construction of the smaller bridge by t years is:

$$(\$162.5 \text{ million}) - [(\$162.5 \text{ million})/(1+0.05)^{t}].$$

For example, if the terminal groin is maintained for 5 years, the costs savings arising from delayed construction of the smaller bridge for 5 years is $35.18 million. If the terminal groin is maintained for 30 years, the cost savings is $124.90 million. These are not annual cost savings but rather the total cost savings of delaying bridge construction for the indicated number of years. The cost savings arise from being able to invest and earn interest on the money that otherwise would have been spent on constructing the smaller bridge. For every year that bridge construction is delayed, interest can be earned.

Interest rates and corresponding discount rates have been unusually low since the financial crisis of 2008-2009. If these lower rates persist, then the 5% discount rate may be inappropriately large. If a 2% discount rate is used instead, then the costs savings arising from delayed construction of the smaller bridge are smaller. For example, delaying bridge construction for 5 years results in a savings of $15.32 million. If the terminal groin is maintained for 30 years, the cost savings is $72.79 million with a 2% discount rate.

Against these savings must be netted the costs of maintaining the existing terminal groin.

2. Tax Values

The property tax base and property tax revenues originating from within each 30YRA were determined based on the residential and commercial property values located within each 30YRA and the property tax rates applicable within each 30YRA. Applicable property tax rates were obtained from the North Carolina Department of Revenue, Policy Analysis and Statistics Division, as given in the document "Property Tax Rates and Latest Year of Revaluation for North Carolina, Counties and Municipalities, Fiscal Year 2007-2008, Final Report," dated June 2008. The property tax rates used in this analysis are the rates that were in effect during the 2007-2008 fiscal tax year. Rates include county, city, and school district tax rates, but not fire district, or some special district tax rates. The rates are expressed in units of dollars of tax per $100 of assessed property value. The assessed residential and commercial property values identified in this study were summed to obtain estimates of property tax base. State and federal properties are exempt from property tax. Some undeveloped parcels have very low assessed property tax valuations. Assessed property tax base values for each 30YRA were divided by $100 and then multiplied by the applicable tax rate to estimate property tax revenues originating from within each 30YRA. The total assessed tax value (tax base) summed across all 30YRAs for the fiscal 2007-2008 tax year was $1.412 billion, and the estimated property tax revenues originating from within this area was $6.75 million. Table VI-13 presents the tax assessment findings for each of the 30YRAs.

Table VI-13. Property Tax Values, Property Base Tax, and Property Tax Revenue Located Within 30YRAs

Inlet	County	Location	Tax Rate per $100 Assessed Value	Assessed Residential Property Value	Assessed Commercial Property Value	Assessed Property Tax Base	Property Tax Revenue
Beaufort	Carteret	Ft. Macon	exempt	exempt	exempt	exempt	exempt
Beaufort	Carteret	Shackleford Banks	exempt	exempt	exempt	exempt	exempt
Bogue	Carteret	Emerald Isle	0.297	$89,450,000	0	$89,450,000	$265,667
Bogue	Onslow	Hammocks Beach	exempt	exempt	exempt	exempt	exempt
New River	Onslow	North Topsail Beach	0.663	$66,817,693	0	$66,817,693	$443,001
New River	Onslow	Onslow Beach (south end)	exempt	exempt	exempt	exempt	exempt
New Topsail	Pender	Lea-Hutaff Isle (north end)	1.03	undeveloped	undeveloped	~$0	~$0
New Topsail	Pender	Topsail Beach	1.03	$33,279,000	0	$33,279,000	$342,774
Rich	New Hanover	Figure Eight Isle (north end)	0.42	$163,186,000	0	$163,186,000	$685,381
Rich	Pender	Lea-Hutaff Isle (south end)	1.03	undeveloped	undeveloped	~$0	~$0
Mason	New Hanover	Figure Eight Isle (south end)	0.42	$46,408,941	0	$46,408,941	$194,918
Mason	New Hanover	Wrightsville Beach (north end)	0.4834	$84,710,027	(incl. in resid.)	$84,710,027	$409,488
Masonboro	New Hanover	Masonboro Isle (north end)	exempt	exempt	exempt	exempt	exempt
Masonboro	New Hanover	Wrightsville Beach (south end)	0.4834	$0-in 30YRA	$0-in 30YRA	$0-in 30YRA	$0-in 30YRA
Carolina Beach	New Hanover	Carolina Beach	0.595	$34,729,000	(incl. in resid.)	$34,729,000	$206,638
Carolina Beach	New Hanover	Masonboro Isle (south end)	exempt	exempt	exempt	exempt	exempt
Cape Fear	Brunswick	Bald Head Isle	0.585	$310,732,000	$1,488,000	$312,220,000	$1,826,487
Cape Fear	Brunswick	Caswell Beach (east end)	0.455	$104,218,000	$4,655,000	$108,873,000	$495,372
Lockwoods Folly	Brunswick	Holden Beach (east end)	0.374	$27,240,000	0	$27,240,000	$101,878
Lockwoods Folly	Brunswick	Oak Isle (west end)	0.4695	$109,900,000	0	$109,900,000	$515,981
Shallotte	Brunswick	Holden Beach (west end)	0.374	$273,855,000	0	$273,855,000	$1,024,218
Shallotte	Brunswick	Ocean Isle Beach (east end)	0.385	$25,069,000	0	$25,069,000	$96,516
Tubbs	Brunswick	Ocean Isle Beach (west end)	0.385	$35,966,000	0	$35,966,000	$138,469
Tubbs	Brunswick	Sunset Beach (east end)	0.42	$0-in 30YRA	$0-in 30YRA	$0-in 30YRA	$0-in 30YRA
	TOTALS			**$1,405,560,661**	**$6,143,000**	**$1,411,703,661**	**$6,746,788**

Note:
Property tax rates are those in effect for 2007-2008 tax year.
Rates include county, city, and school district tax rates, but not fire district, or some special district tax rates.

C. Discussion of other factors that influence economics

1. Recreation and Environmental Value

Beach and wetland areas located within the 30 YRAs considered in this study support recreation and environmental values.

Beach areas provide locations for walking, shell collecting, sunbathing, swimming, surfing, birdwatching and fishing. Wetland areas provide kayaking, canoeing, and birdwatching opportunities as well as important habitat for juvenile fish and shellfish that support recreational and commercial fishing. Wetland areas may also improve coastal water quality through uptake of excess nutrients in the water and reduce the magnitude and severity of coastal erosion processes by absorbing wave energy.

The types and relative importance of supported values typically depend on whether the area is located on the ocean-facing, inlet-facing, or mainland-facing shore of the barrier island and on whether the area is adjacent to substantial residential and commercial development or is located on an undeveloped island or adjacent to a nature preserve.

A brief review of the economic values of beach and wetland areas is provided below, followed by a brief discussions of the undeveloped and nature preserve areas located within the 30 YRAs.

a) Beach Recreation Value

Recently, Bin et al. (2005) provided estimates of consumer surplus value for beach recreation in North Carolina. Consumer surplus is the value to the recreationist of the recreation experience itself, value beyond the expenditures made in order to gain access to the experience. The authors estimated consumer surplus per visitor for a day of beach recreation using the single-site multiple regression travel cost method. Onsite visitation data for seven North Carolina beaches were collected between July and November of 2003. One model pertained to beach visitors that make single day trips to the beach, while the other was for visitors that stay onsite overnight. Depending upon the site, the estimated net benefits of a day at a beach in North Carolina ranged between $11 and $80 for those users making day trips and between $11 and $41 for those users staying overnight. In a separate study, Bin et al. (2007) estimated consumer surplus values per trip for day trips and overnight trips to Carteret, Pender, Onslow, New Hanover and Brunswick County beaches based on data provided in Herstine et al. (2005). The average estimates of consumer surplus value are $55 per day trip and $65 per overnight trip. These values are similar to other estimates of consumer surplus per beach trip for North Carolina beach trips (e.g., Bin et al. 2005, Whitehead et al. 2008).

b) Shore/Surf/Beach Fishing

Beaches also support consumer surplus value arising from pier and shore/surf/beach fishing. Whitehead et al. (2009) examine the impacts of eroding beaches on shore fishing value in North Carolina based on survey data from 2005-2006. The frequency of trips, average respondent travel cost to each site and the three-year historic average catch at each site were developed for 22 manmade fishing sites (piers and jetties) and the 28 beach and inlet fishing sites in North Carolina. Sixty-two percent of the anglers fish from manmade structures (piers and jetties), with thirty-eight percent fishing directly on the beach. In addition to surf fishing sites on ocean-facing beaches, the north shore of Oregon Inlet, the south shore of Beaufort inlet at Ft. Macon State Park, and the north shore of New River Inlet on Topsail Island were found to be very popular shore fishing locations. The most popular target species were: spot, flounder, kingfish, seatrout, bluefish, striped bass, Spanish mackerel, red drum and king mackerel. A large number of consumer surplus estimates were developed from the model including the potential lost economic value from loss of access to fishing sites, changes in catch rates, and changes in beach width. For example, the change in consumer surplus per trip from a change in the catch rate of one fish per hour at each site is $4.04. The change in consumer surplus per trip from an increase in beach width of 10 meters is $2.97. These estimates of consumer surplus loss assume that pier fishing locations are still available; that is, these estimates measure reduction in value from losing access to favorite fishing sites, under the assumption that other, substitute fishing sites are still available.

c) *Primitive Area Hiking/Camping Value*

Bowker, J.M. (2006) explores the economic value of recreation activities in primative/wilderness areas using data from the National Survey on Recreation and the Environment and GIS databases. These areas would be similar to undeveloped barrier islands such as Masonboro, Lea-Hutaff, and perhaps Hammocks Beach/Bear islands. Results indicate that although U.S. per-capita participation in such recreation is projected to decrease, based on changing demographics, total visitation will increase, driven by increases in population and household income.

d) *Wetland Recreation Value*

In a review article of the wetlands valuation literature, Brander et al. (2006) find that wetlands are highly productive ecosystems, providing a number of goods and services that are of value to people. The open-access nature and the public-good characteristics of wetlands often result in these regions being undervalued in decisions relating to their use and conservation. The authors examined over 190 wetland valuation studies worldwide, providing 215 value observations, in order to present a more comprehensive meta-analysis of the valuation literature. In North America, saltwater/brackish water wetlands had a mean value of around $2000/hectare/year and a median value of $200/hectare/year (1995 dollars), with values varying depending on location and functions. In another review article of 39 wetland valuation studies, Woodward and Wui (2001) conclude that the variation in value estimates across locations is large, and site-specific studies are often needed to determine value. In the Woodward and Wui study, the component values of wetlands as nursery areas supporting recreational and commercial fisheries and as locations for birdwatching recreation were large relative to other components of value.

Bergstrom, et al. (1990) studied the recreation value of 3.25 million acres of wetlands along the south-eastern coast of Louisiana in 1985-1986, including values arising from waterfowl hunting and recreational fishing, shrimping and crabbing. An estimated 1.81 million recreation person-days per year supported an estimated $27.36 million in consumer surplus per year, or $360/year per wetland recreationist (1986 dollars).

In a recent study of the willingness of Mississippi state taxpayers to pay for restoration of barrier islands adversely affected by hurricanes, Petrolia and Kim (2009) found that average willingness to pay was $35 per taxpaying household, based on conservative assumptions and a random sample survey of 3000 Mississippi households.

e) Value of Non-Game Wildlife in Beach and Coastal Wetland Areas

There is evidence that North Carolina households place value on the non-game wildlife residing in coastal beach and wetland areas. Whitehead (1993) evaluated the value of coastal and marine non-game wildlife based on data from a 1991 survey of North Carolina households and found mean willingness to pay of $10.98 (1991 dollars) per household to support a "Loggerhead Sea Turtle Preservation Fund" and $14.74 per household to support a "Coastal Nongame Wildlife Preservation Fund."

f) Value of Coastal Wetlands in Supporting Recreational Fishing

In a study of the economic value on the contribution of saltwater marsh in supporting recreational fishing in Florida, Bell (1997) estimated that an acre of wetlands supported between $80-$526/year in consumer surplus for saltwater recreational anglers. This study only considered recreational fishing for species that depend on saltwater marsh habitat for part of their life cycle. The study used the relationship between acres of saltwater marsh in southern states from Virginia to Texas and recreational saltwater fishing trips, catch, and value to produce the marsh value estimates.

g) Value of Wetlands in Protecting Property from Hurricane Wind Damage

Farber (1987) examined the value on wetlands in reducing wind damage to property. The study estimated a storm wind damage function for the Louisiana gulf coast, where inland distance of a location and wetlands traversed by a hurricane were among the factors considered. Estimates were made of the increase in expected wind damage to property from the loss of intervening wetlands. The discounted value of the loss of a one mile strip of wetlands along Louisiana's gulf coast was estimated to be between $1.1 million and $3.7 million in 1980 dollars, using discount rates of 8% and 3%, respectively.

h) Pea Island National Wildlife Refuge

Pea Island National Wildlife Refuge is located in Dare County on the north end of Hatteras Island, adjacent to Oregon Inlet (http://www.fws.gov/peaisland/). Portions of the refuge would be at risk of loss should the existing terminal groin be removed. The 5,834 acre refuge is approximately 13 miles long (north to south) and ranges from a quarter mile to 1 mile wide (from east to west). Refuge is comprised of ocean beach, dunes, upland, fresh and brackish water ponds, salt flats, and salt marsh. The refuge is home more than 365 species; wildlife list has 25 species of mammals, 24 species of reptiles, and 5 species of amphibians. Concentrations of ducks, geese, swans, wading birds, shore birds, raptors, neotropical migrants are seasonally abundant on refuge. Endangered and threatened species include: peregrine falcons, loggerhead sea turtles, and piping plovers. Shelling, beachcombing, and walking along the shoreline are popular activities. Eco-tourists include canoeists and kayakers, beachcombers, surf and sound anglers, and nature photographers. Refuge has 790 acres of manageable waterfowl and waterbird impoundments. Pea Island National Wildlife Refuge is known as a "Bird Watchers Paradise." Two wildlife trails that are open year round. Hunting is not allowed on the refuge, but it offers access to both the Atlantic Ocean and Pamlico Sound for saltwater fishing. The Coastal Wildlife Refuge Society (the refuge support group) operates a gift shop in the Visitor Center.

i) Fort Macon State Park

Fort Macon State Park is located in Carteret County on the eastern end of Bogue Banks, on the west side of Beaufort Inlet (http://www.ncparks.gov/Visit/parks/foma/main.php). A Civil War fort situated at the eastern end of the 424-acre has been restored and is a major regional tourist attraction. Picnic facilities in the park include outdoor grills, drinking water, picnic tables, shelters and restrooms. Although the fort area itself is not in the 30 YRAs, large portions of the beach recreation area are at risk.

Large beaches line the inlet and ocean-facing sides of the park. A seaside bathhouse and refreshment stand are open Memorial Day through Labor Day. The bathhouse facility has showers, changing rooms, concession stand and toilets. Lifeguards are on duty from Memorial Day through Labor Day. Because of strong water currents, wading, swimming and surfing are not allowed on the inlet beaches. Fish are abundant in the inlet and the ocean, and fishing is allowed year-round. Common species include flounder, bluefish, spot, croaker, sheepshead and whiting. In addition, Fort Macon is a great place for bird watching in all seasons.

j) Hammocks Beach State Park/ Bear Island

Hammocks Beach State Park is located on undeveloped Bear Island and Huggins Island, on the south side of Bogue Inlet (http://www.ncparks.gov/Visit/parks/habe/main.php). Bear Island is an 892-acre barrier island, roughly 3.5 miles long by .5 mile wide. Shrub thickets, maritime forests, large dunes and sand ridges dominate the landscape.

Between mid-May and late August, loggerhead sea turtles, a threatened/endangered species, come ashore at night to nest above the high-tide line. Hammocks Beach is also a haven for migratory shore birds, such as herons and egrets, who feed in tidal marshes and rest on the beach in the spring and fall. Bottlenose dolphins are often seen swimming offshore.

Although there are no residents on Bear Island, some recreational infrastructure has been established, including a Bathhouse, Restrooms, Picnic Area, Outdoor Showers, and a small Concession Canteen with large covered porch. These facilities are open from Memorial Day through Labor Day. A portion of the beach is a designated swimming area. There are lifeguards on duty in the designated swimming area most days from Memorial Day through Labor Day. Fishing at Hammocks Beach is a favorite pastime in all seasons but is particularly good in the fall. Puppy drum, flounder, trout and blue fish are frequent catches on Bear Island.

Primitive campsites are located near the beach and the inlet. Fourteen family campsites accommodate six people and two tents each. Three group campsites, available to affiliated groups only, accommodate up to 12 persons each. Campsites are open year round.

A passenger ferry provides transportation to Bear Island for a modest fee. The island is also accessible by private boat or marine taxi service. Canoeists and kayakers may reach Bear Island and explore the marsh by way of a designated canoe trail. Markers placed along the route indicate points of interest along the way.

k) Lea Hutaff Island

Located north of Wilmington between Figure Eight Island and Topsail Island, Lea-Hutaff Island is a 5,641-acre undeveloped barrier island that provides primitive recreation opportunities (http://iba.audubon.org/iba/viewSiteProfile.do?siteId=346&navSite=state). One of North Carolina's few remaining relatively pristine barrier islands, Lea-Hutaff is an important sanctuary for wildlife and a peaceful recreation area for people.

In the spring and summer loggerhead sea turtles nest here, and thousands of shorebirds stop off during long migrations. This narrow strip of sand has been designated a state-significant Important Bird Area by Audubon North Carolina. More than 4,000 acres of tidal marsh and creeks serve as primary nursery areas for fish, shrimp and crabs, and support thousands of birds throughout the year.

Both Lea and Hutaff islands are privately owned. National Audubon Society and the NC Coastal Land Trust are currently negotiating with landowners to acquire Lea Island. Audubon North Carolina has a cooperative agreement to protect and manage Hutaff Island and Audubon staff posts and patrols tern and skimmer colonies on both islands and monitors birds throughout the year.

l) Masonboro Island

Masonboro Island is the largest undisturbed barrier island along the southern part of the North Carolina coast and is located between Masoboro Inlet and Carolina Beach Inlet (http://www.nccoastalreserve.net/About-The-Reserve/Reserve-Sites/Masonboro-Island/59.aspx). The Masonboro Island component is the largest site within the North Carolina National Estuarine Research Reserve System. The 8.4 mile long island encompasses approximately 5,046 acres, 87 percent of which are covered with marsh and tidal flats. The remaining 619 acres are composed of beach uplands and dredge material islands. Masonboro Island is an essentially pristine barrier island and estuarine system and supports important biological research as well as primitive beach recreation, fishing, and kayaking/canoe activities. The Masonboro Island site can only be reached by boat. There are public and private boat ramps in and near Wrightsville Beach and Carolina Beach. Boats usually land on the beaches along the north and south sound side of the island. Trails allow visitors to walk across the island to access the beach. Visitors may also walk down the undisturbed ocean beach for miles, a rare, unique, and therefore valuable experience. Camping is allowed on the island.

2. Transfer of Property Values to Remaining Structures Following Erosion Losses

The full value of residential property located within the 30YRAs as presented in the tables of this study may not be lost in the event that the properties themselves are lost to shifting inlets, as some of the property value associated with oceanfront or sound front location may transfer to nearby properties. While detailed assessment of this potential effect is beyond the scope of this study, a recent study of the components of coastal North Carolina property values provides some information on the possible size of the effect.

Bin et al. (2007) estimated the potential impacts of sea level rise on coastal North Carolina property values using a hedonic multiple regression model framework. Since the pioneering work by Rosen (1974), hedonic property models have been used extensively to study real estate values. Palmquist (2004) provides a useful summary of the hedonic property models. These models assume that a unit (parcel) of real property is a bundle of attributes (location, number of bedrooms, ocean view, etc.). The market price of property, which is observable, represents the total value of the combination of attributes. Residential homes are composite goods that contain different types and quantities of attributes. By observing how property values change as the levels of various attributes change, the incremental contribution of each attribute to total parcel value can be estimated.

Numerous studies have applied hedonic property value models to estimate the impacts on property values of hazard risks such as flood hazards (MacDonald, Murdoch, and White 1987; MacDonald, et al. 1990; Bin and Polasky 2004), erosion hazards (Kriesel, Randall, and Lichtkoppler 1993; Landry, Keeler, and Kriesel 2003), and wind hazards (Simmons, Kruse, and Smith 2000). As would be expected, prior studies have found that proximity to shoreline has a strong positive effect on property values. Milon, Gressel, and Mulkey (1984) estimated a large positive value from being close to the shore. They found that property values declined 36% in moving 500 feet from the Gulf of Mexico. Other studies have also found positive values for water proximity (Shabman and Bertelson 1979; Earnhart 2001).

Bin et al. used assessed values as the dependent variable in their hedonic regression study of North Carolina coastal property values. Property values were regressed on structural, location, and environmental attributes of properties within one mile of the coastline in

Dare, Carteret and New Hanover Counties, NC. The hedonic regression results provide estimates of the relative importance of each property attribute in determining overall property values. Separate hedonic regression models were estimated for residential and non-residential properties. The primary results were robust across several alternative model specifications, and the results reported below are from the specification that provided the best overall model fit.

The Bin et al. study results related to the value of the water frontage component of property value provide information on the portion of overall property value that might be transferred to properties farther back from shore in the event a shorefront property is lost. In the Bin et al. study, water frontage raises property values by about 55% for ocean frontage and 35% for sound frontage for New Hanover county residential parcels (n=39,546 real estate transactions, $R^2 = 0.86$). That is, for every $1 million in ocean front residential property value, $354,840 of the $1 million is due to ocean front location, and $645,160 is due to other characteristics of the property. In the event that the property were lost to shifting inlets, the $645,160 would be lost, but some of the $354,840 of water frontage value would transfer to other property parcels on the "next row back" from the ocean (if a next row were present). The full $354,840 amount might not transfer to parcels on the "next row back" because (1) the "next row" parcels might be different from the lost parcels in acreage, structure characteristics, etc., and (2) loss of the first row parcels might indicate increased future risk of loss for the "next row" parcels, decreasing the market value of the "next row" parcels.

Results were similar for the other two NC counties in the Bin et al. study. For Dare County residential parcels, water frontage raises property values by about 73% for ocean frontage and 32% for sound frontage (n=25,870 real estate transactions, $R^2 = 0.71$). For Carteret County residential parcels, water frontage raises property values by about 67% for ocean frontage and 50% for sound frontage (n=27,789 real estate transactions, $R^2 = 0.69$).

In their investigation of erosion risk, Landry, Keeler, and Kriesel (2003) find a substantial discount for those properties in close proximity to high erosion hazard areas. The market value of homes in high erosion areas were reduced by $9,269. Dorfman, Keeler, and Kriesel (1996) examine shoreline protection schemes along the Lake Erie coast, focusing on the impact of hardened structures placed offshore to prevent bluff erosion. They find that housing values capitalize the value of erosion protection; erosion protection structures increase average property value by $16,261 by decreasing probability of erosion loss to a low level (0.05%).

Estimation of willingness to pay from hedonic property price models can be complicated by correlation of housing characteristics. Correlation is found in housing data when two or more characteristics tend to move in the same or opposite directions. For example, houses with large square footage will tend to have more bedrooms and vice-versa—a positive correlation. If too much correlation exists in housing characteristic data, the separate effect of characteristics on housing value cannot be identified. Correlation can be a problem in coastal housing data. Bin and Kruse (2006) find that houses in flood zones on the coast tend to sell for more than other houses. However, these homes tend to be oceanfront and/or have superior ocean view (a confounding positive correlation between flood risk and amenities). As such, it can be difficult to separate the effect of flood zone and view amenities in coastal housing markets. Bin, Crawford, Kruse, and Landry (2006) use a novel approach to solve this identification problem. Many previous papers have used ocean frontage as a property attribute. They argue that ocean frontage primarily conveys benefits in terms of access and amenities. Instead of controlling for ocean-frontage, they use distance from the water to account for benefits of access, and use a GIS-derived viewscape measure to account for benefits associated with coastal ocean view. Viewscape is a three-dimensional measure of ocean view that is designed to capture the view amenities associated with a property, taking into account man-made and natural obstructions to view and how these obstructions change over time (i.e. from year-to-year). Importantly, the viewscape measure varies independently of risk, allowing researchers to disentangle spatially integrated attributes. The authors find that increasing ocean view by one degree increases housing value by $995. For their access measure, they find that a 10 foot decrease in distance to the beach increases housing value by $853. Location in a flood zone decreases housing value, on average, by $36,000.

To summarize the main point of this section, the full property values located within the 30 year risk line areas identified in this study likely would not be lost should the properties themselves be lost to shifting inlets, as a portion of the property value would likely transfer to nearby properties. Even if only half of the oceanfront amenity value as estimated in the Bin et al. study were to transfer to nearby properties, this would represent a transfer on the order of 17-21% of current values. That is, on the order of 17-21% of current property values in the 30 year risk line areas may transfer to nearby properties in the event the current properties are lost to shifting inlets.

D. Overall Findings and Summary

The economic impact of erosion due to shifting inlets ranges widely by inlet and even side of inlet. Some inlets have higher development with property and infrastructure with values in excess of $100 Million while others are undeveloped within the areas at risk. While this assessment provides a means to estimate the economic impact to the State from erosion due to shifting inlets it is important to remember that not all property and infrastructure within the 30-year risk lines could necessarily be protected by a terminal groin. Additional factors such as recreation and environmental economic values and the potential transfer of value as properties are lost and others become oceanfront can be important in assessing the full economic impacts of erosion near inlets.

VII. Initial Construction and Maintenance Costs of Terminal Groins

This section documents the state of knowledge regarding the initial and maintenance costs associated with terminal groin structures. As part of the cost study, a literature review of the existing five (5) study sites was completed to estimate their initial construction and maintenance costs. The selected terminal groins' plan sheets were used to determine a cost per linear foot of groin. Unit costs were estimated by knowledge of existing nearby projects as well as estimates within *RS Means*. These unit costs were used with the structure lengths and dimensions to develop opinions of probable costs for the five (5) study sites. These estimates were checked against their reported construction costs (when known) escalated to 2009 dollars. These unit costs were then used to estimate a potential range of costs for varying lengths and slopes for potential terminal groins in North Carolina.

A. Overview of Costs and Key Factors

Groins are simple coastal structures that often require minor maintenance once the initial construction is complete. Initial construction and maintenance costs are mainly dependent on structure dimensions and type of material. Other factors such as availability of selected materials, transport, labor, and equipment costs also factor in the costs.

B. Development of Terminal Groin Unit Costs

A number of different building materials can be used in the construction of terminal groins as well as allowing for the need for adjustments and potential removal. Materials used in construction will vary with the intended purpose of the groin. As previously mentioned, unit costs for each material were estimated using nearby projects as well as estimates within *RS Means*. The unit costs were used with varying structure lengths and dimensions to develop a range of probable linear foot costs for each type of material. Figure VII-1 and Figure VII-2 show various structure depths which may be experienced along North Carolina shorelines and lead to the various unit costs per linear foot that were developed.

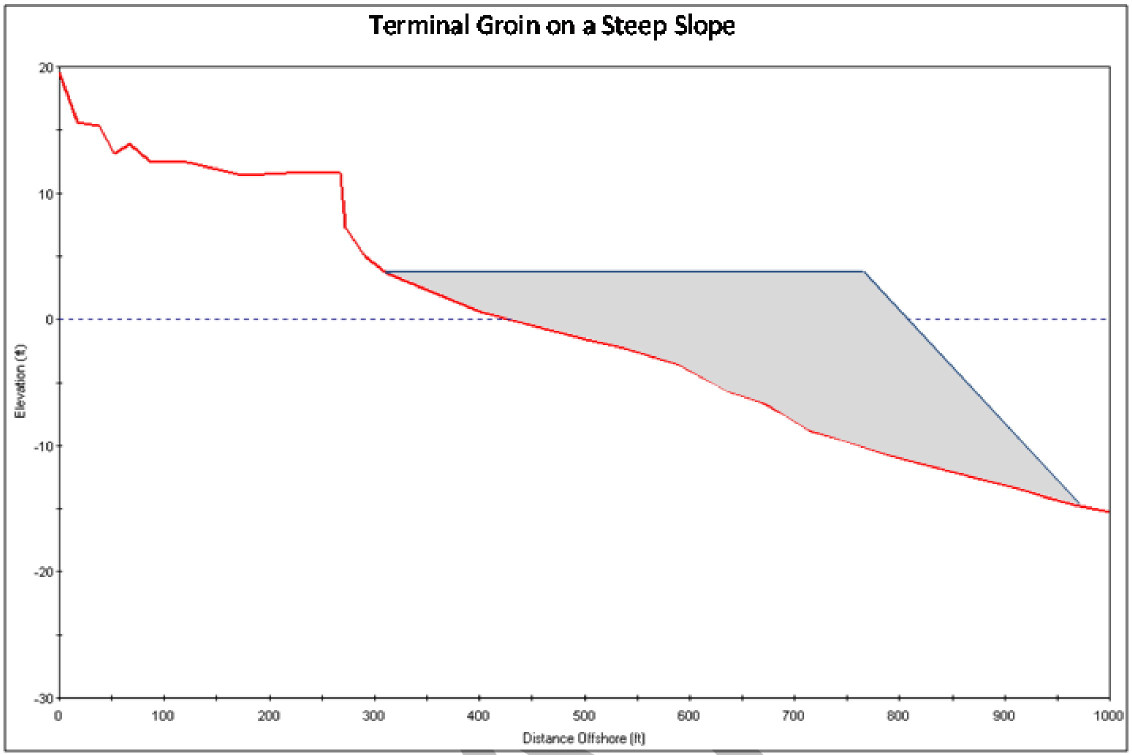

Figure VII-1. Terminal Groin Length along a Steep Slope

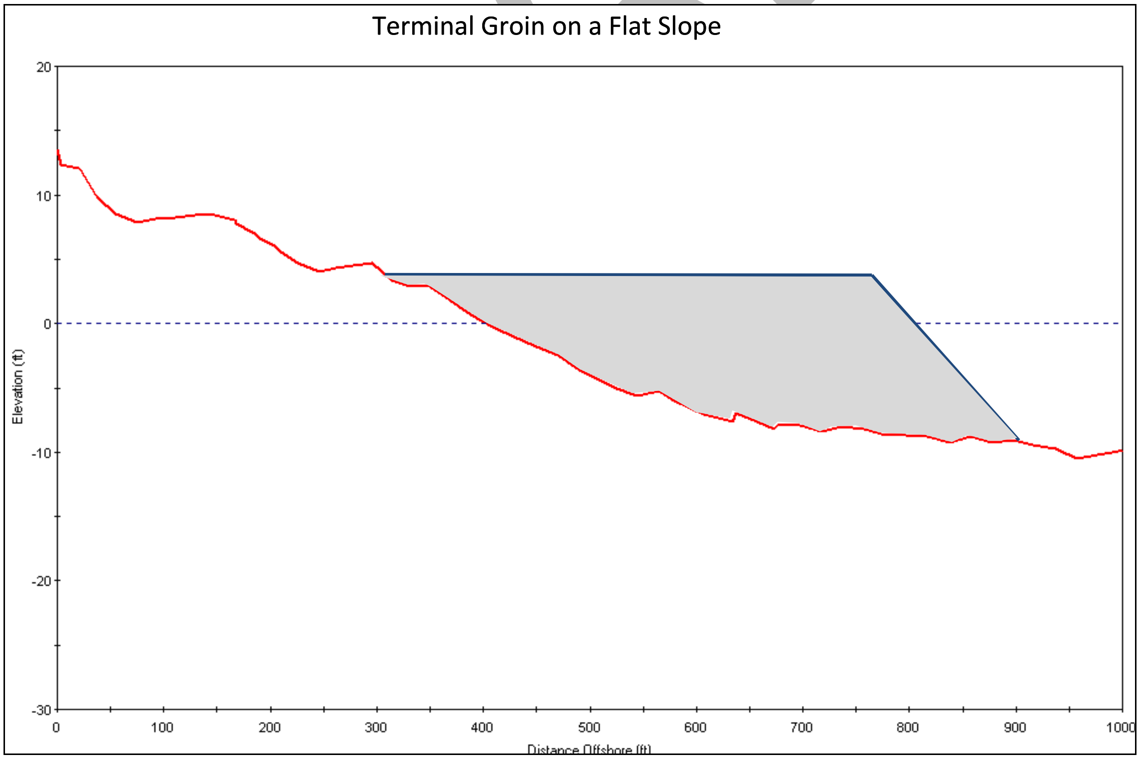

Figure VII-2. Terminal Groin Length along a Flat Slope

1. Rock

Generally, the most common type of material used for terminal groin structures is rock. Rock (or rubble mound) groins usually have a core of smaller, graded stone with an armor layer of larger stones overlying the core. The cost of stone varies with size. Generally, the material cost for a rubble mound groin may vary between $1,200 (for a small-stone groin that is 8-foot high with a 20-foot wide crest and 2:1 side slopes) and $6,500 per linear foot (for a large-stone groin that is 22-feet high with a 30-foot wide crest and 2:1 side slopes). Figure VII-3 shows an example of a typical cross-section for rubble mound groins. It should be noted that permeable groins may be designed without a core layer or a core layer built to a certain elevation to allow sand to pass through the structure.

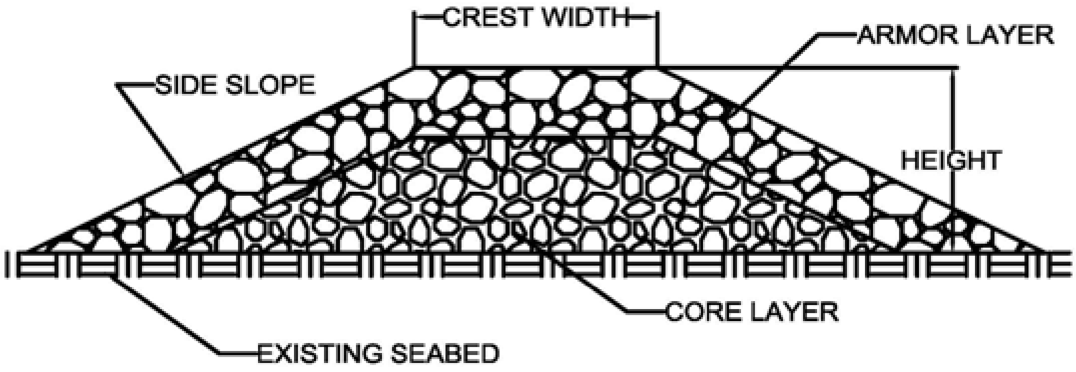

Figure VII-3. Rubble Mound Construction

2. Concrete and Steel

Concrete and steel sheet piles are more expensive options that may also be utilized. Concrete groins can also be constructed of precast blocks, fillable cells, or interlocking shapes (concrete armor units). Concrete armor unit costs vary greatly depending on the manufacturer.
For a tied back concrete sheet pile groin, the unit cost is approximately $4,600 per linear foot up to a height of 16 feet. Typically, concrete groins would not be used for greater heights. Figure VII-4 illustrates an example of concrete sheet piles.

Figure VII-4. Example of Concrete Sheet Piles

Steel groins may be as simple as a line of sheet piling, or a combination of H-piling, waling, and sheeting. Steel groins with sheeting can be adjusted in the field by removing or adding panels to optimize the groin performance. Steel groins usually must be coated with epoxy finish to prevent deterioration from salt water or use concrete fascia and caps. A steel groin with concrete fascia and cap is approximately $4,000 per linear foot for groins up to 16 feet in height. Steel groins can be reinforced for use in greater depths of water; however, this is typically cost prohibitive to use for depths greater than 20 feet. Figure VII-5 illustrates an example of a steel sheet pile groin.

Figure VII-5. Example of Steel Sheet Pile Terminal Groins

3. Timber

Timber is another viable option for construction material. Generally, timber groins have pilings in single or multiple rows. Timber groins can also have planks between the pilings which may be adjusted depending on the required height for the groin. However, timber cannot withstand the same loads that rock, steel, or concrete groins can withstand; therefore it should not be used for longer groins in deeper water. Typically, a timber groin would only be considered for water depths less than 10 feet. A timber pile groin's cost could range from approximately $4,000 to $5,000 per linear foot. Figure VII-6 illustrates an example of a timber groin with planks and pilings (taken from the Federal Highway Administration website).

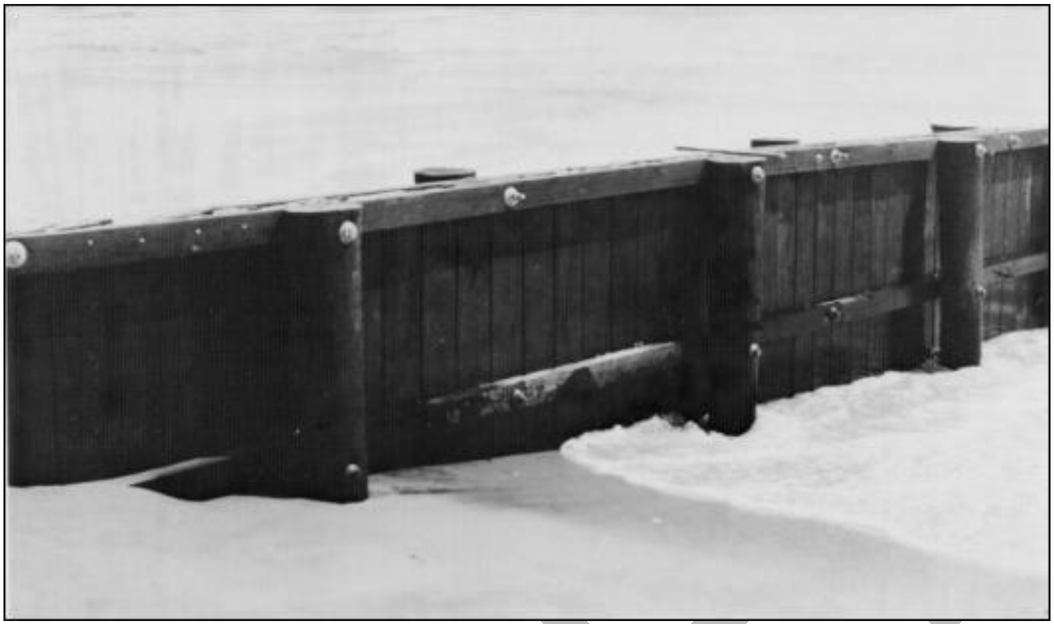

Figure VII-6. Example of a Timber Groin

4. Geotextile

Geotextile tubes are an inexpensive alternative to some of the other building materials. There are numerous types of bags and tubes that can be filled with sand and stacked on top of one another to construct the groin. These types of structures have been utilized in the past at Bald Head Island and other locations. Like timber, the geotextile tubes should not be utilized for longer groins in deeper water, since they cannot withstand the larger loads associated with long groins. Generally, a geotextile groin is approximately $250 (~5-6 ft in height) to $1,000 (~12-15 ft in height) per linear foot.

C. Cost Evaluation of Five (5) Selected Study Sites

An evaluation of the five selected existing terminal groins was performed to estimate the construction cost of the groins if they were built in 2009. The material unit prices were taken from previous estimates for nearby projects within the past year and *RS Means*.

1. Fort Macon

The Fort Macon terminal groin was constructed between 1961 and 1970. The final length is 1,530 feet long and the crest elevation is 6 feet (MLW). At the deepest portion, the groin is estimated to be approximately 14 feet above the sea floor. The crest width is 10 feet wide; while the base ranges from 58 to 66 feet wide. The groin utilizes 4 types of stone ranging from 1-foot stones for the bedding and core layers to 12.5-ton stone for the armor layer. Figure VII-7 shows the typical cross section for the Fort Macon terminal groin. Table VII-1 shows a summary of the estimated cost information for the Fort Macon terminal groin. No initial construction cost information was available for the terminal groin itself. However, using the typical cross section in the plans, the unit cost is determined to be $1,900 per linear foot, and the opinion of probable cost in 2009 dollars for the terminal groin is $2.9 million.

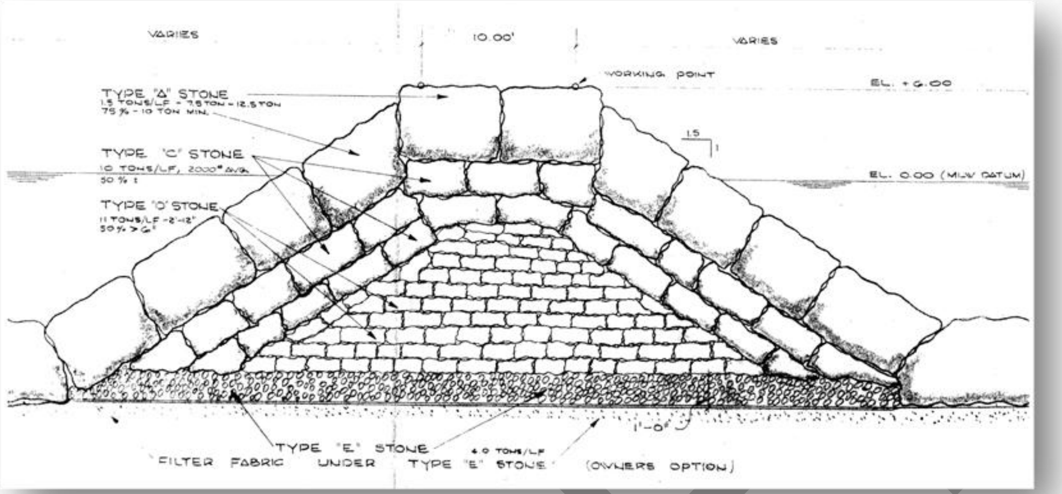

Figure VII-7. Typical Cross Section for Fort Macon Terminal Groin

Table VII-1. Fort Macon Terminal Groin Estimated Costs

Length	1,530 ft
Height	Up to 1 - 14 ft
Unit Cost	$1,900/LF
Total Estimated Cost	**$2.9M**

2. Oregon Inlet

The terminal groin and revetment at Oregon Inlet was completed in 1991. At the time, the construction cost for the groin was $13.4 million. The groin extends from the bulkhead in a northwest direction, curving 90 degrees towards the northeast, and straightening out to be perpendicular with the natural inlet shoreline. The total length of the groin is 3,125 feet. The crest elevation ranges from 8 to 9.5 feet (MSL). At its deepest portion, the groin is estimated to be 25.5 feet high. The crest width ranges from 15 to 39 feet wide; the base width ranges from 110 to 228 feet wide. The groin has toe protection on both sides, with lengths varying from 10.5 to 43 feet. The groin utilizes five different sizes of stone. The foundation stone ranges from 0.5 to 110 lbs. The under layer stone ranges from 500 to 2000 lbs. The armor layer stone ranges from 2.5 to 10 tons. Figure VII-8 illustrates a typical cross-section for the Oregon Inlet terminal groin. Using the cross sections given in the plans, the unit cost is determined to be $8,410 per linear foot. The total estimated cost for the terminal groin alone is $26.3 million, which compares well with the escalated actual initial construction cost of $28.2 million (albeit this includes the revetment cost). Table VII-2 shows theses estimated costs for the Oregon Inlet terminal groin.

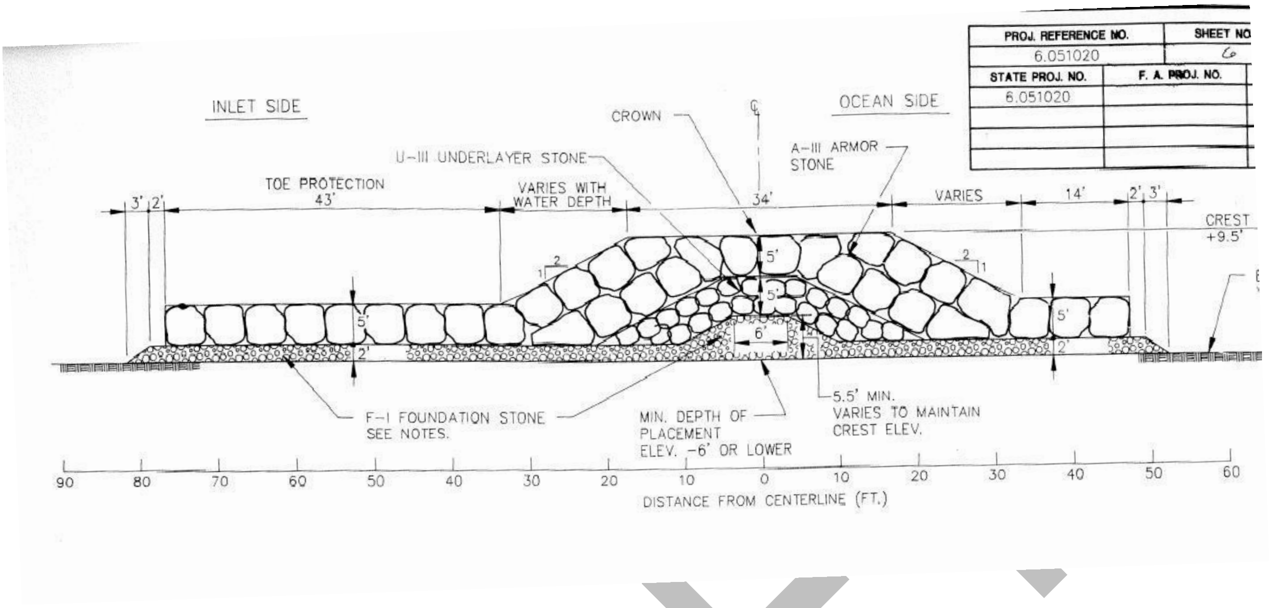

Figure VII-8. Oregon Inlet Typical Cross-Section

Table VII-2. Oregon Inlet Terminal Groin Estimated Costs

Length	3,125 ft
Height	14 – 25.5 ft
Unit Cost	$8,410/LF
Total Estimated Cost	$26.3M
1989 Construction Costs (includes revetment)*	$13.4
2009 Construction Costs (includes revetment)**	$24.2M

*reported by USACE
**assumes annual escalation of 3%

3. Amelia Island

The terminal groin at Amelia Island was constructed between 2004 and 2005 on the southern end of Amelia Island. Due to environmental concerns, the groin was designed and built utilizing only armor stone to maximize permeability. The approximate cost to build the groin was $3 million, in 2006 dollars. The groin length is approximately 1,500 feet long, and the crest elevation is 5.2 feet (NGVD). At the deepest portion, the groin height is estimated to be 15.2 feet high. The crest width ranges from 6 to 15 feet. The armor stone ranges from 0.4 to 7 tons. Figure VII-9 shows the cross-sections for the Amelia Island terminal groin. Table VII-3 summarizes the cost information for the Amelia Island terminal groin. Using the typical cross sections provided in the plans, the unit cost is determined to be $2,260 per linear foot. The total estimated cost for Amelia Island terminal groin is $3.4 million, which compares well with the actual escalated construction cost of $3.3 million.

Table VII-3. Amelia Island Terminal Groin Estimated Costs

Length	1,500 ft
Height	7.2 - 15.2 ft
Unit Cost	$2,260/LF
Total Estimated Cost	$3.4M
2006 Construction Costs	$3.0M
2009 Construction Costs*	$3.3M

*assumes annual escalation of 3%

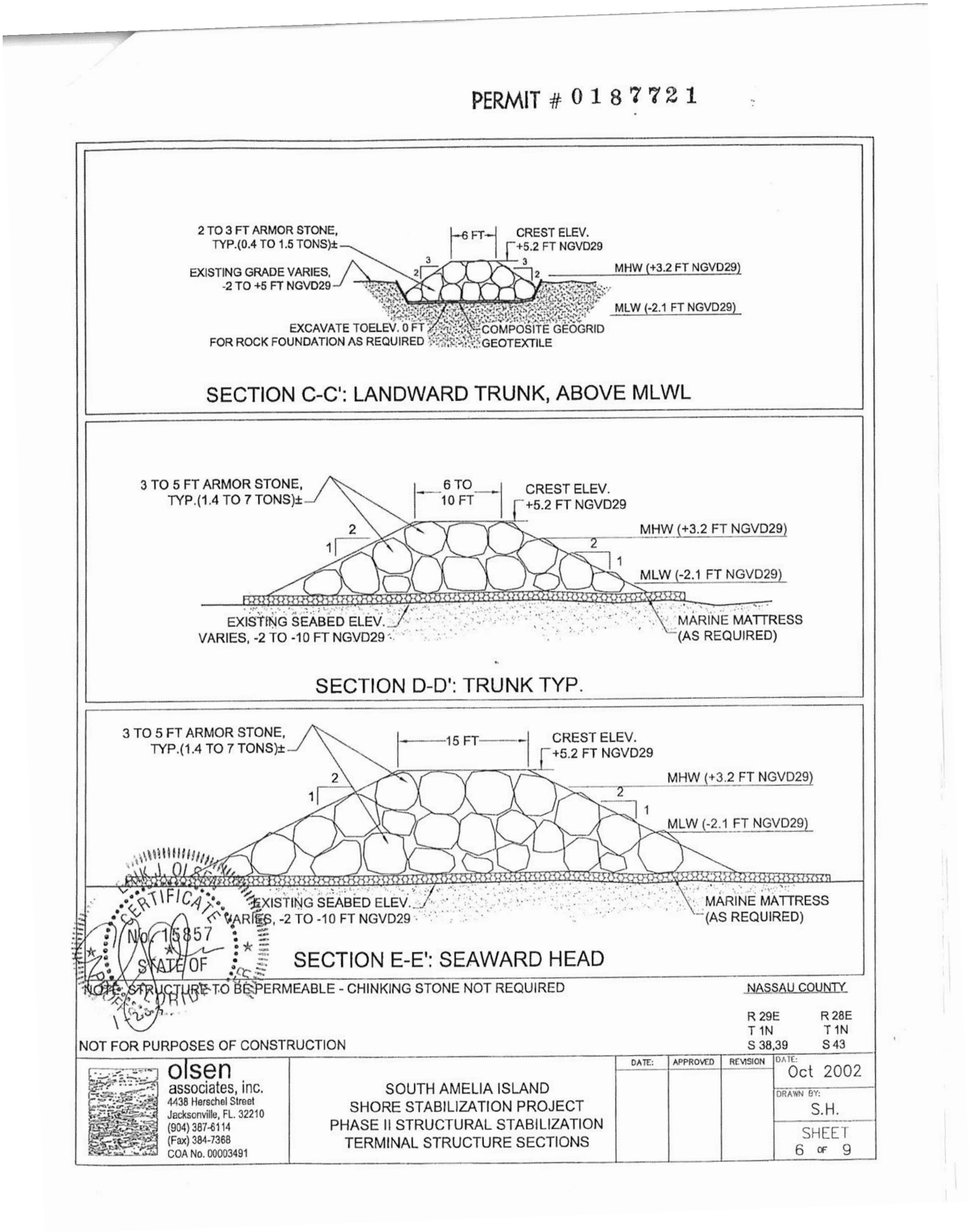

Figure VII-9. Amelia Island Terminal Groin Typical Cross-Section

4. John’s Pass

A terminal groin was constructed at the south end of Madeira Beach at John’s Pass in 1961. The groin extends 460 feet. The crest elevation ranges from 3.2 to 5.7 feet (NGVD). At the deepest portion, the groin is estimated to be 15 feet above the sea floor. The crest width ranges from 12 to 22 feet. The groin utilizes three different types of stone. The bedding stone ranges from 15 to 50 lbs. The core stone averages 0.1 tons; and the armor stone averages 1 ton. No detailed initial construction cost information was available (reported to be less than $300k). However, utilizing the typical cross sections provided in the plans, the estimated unit cost is $1,925 per linear foot. The total estimated 2009 cost for John’s Pass is $890,000. Table VII-4 shows the cost information for the northern John’s Pass terminal groin. This per linear foot cost matches well with the terminal groin constructed in 2000 along the opposite side of the inlet. The cost for this 760 ft long structure was $1.4 million (2000 dollars) which equates to $1,840 per linear foot.

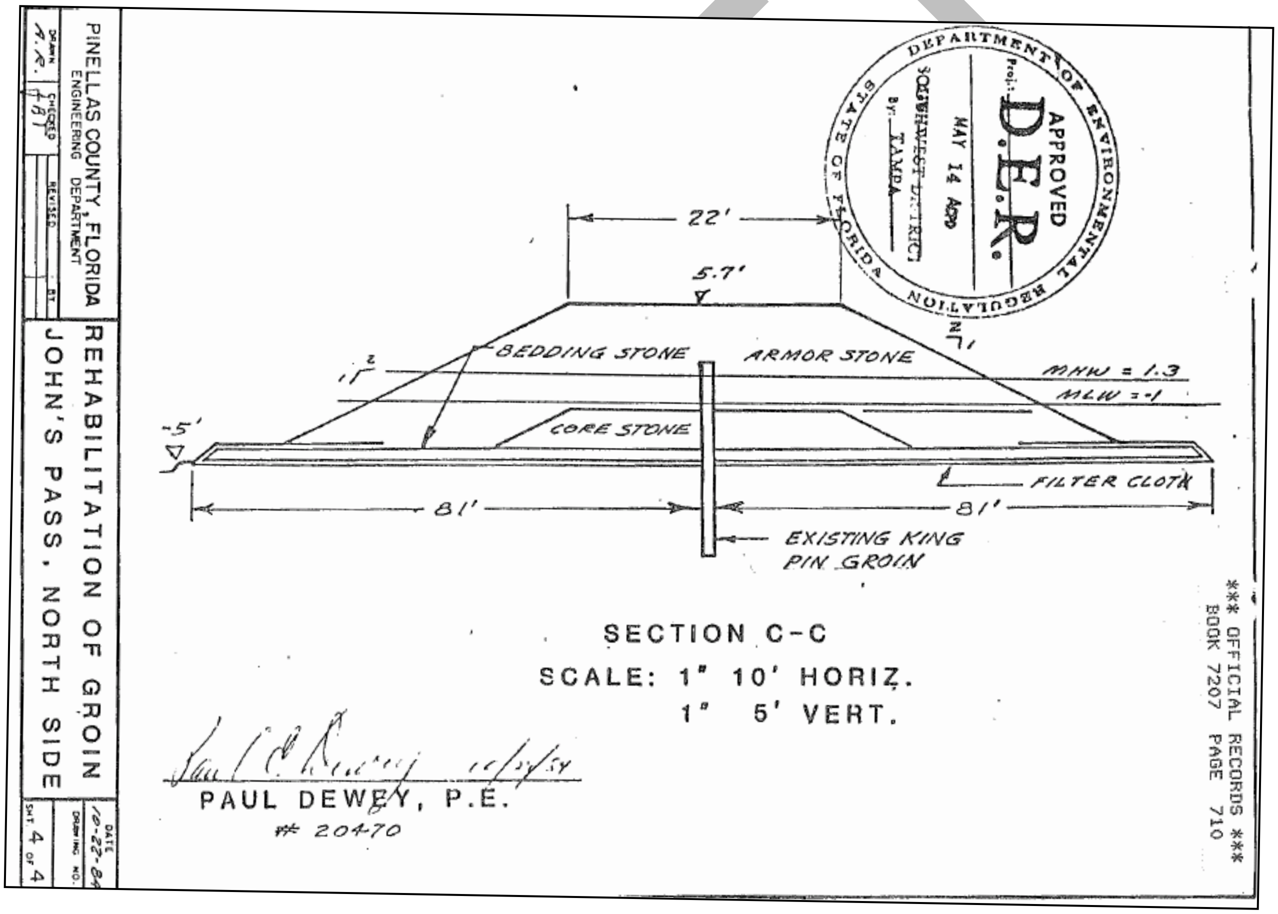

Figure VII-10. Typical Cross-Section for John's Pass Terminal Groin

Table VII-4. John's Pass Terminal Groin Estimated Costs

Length	460 ft
Height	Up to15 ft (~10 ft avg)
Unit Cost	$1,925/LF
Total Estimated Cost	**$890K**

5. Captiva Island

A rock groin was constructed in 1977 at the north end of Captiva Island at Redfish Pass. The terminal groin is 350 feet long. Typical cross sections could not be located for this groin, nor any initial construction cost data. For the estimated cost analysis, a typical cross section similar to John's Pass was used. The unit cost is assumed to be the same as John's Pass of $1,925 per linear foot, and the total 2009 estimated cost for the groin is $670,000. Table VII-5 summarizes the cost information for Captiva Island terminal groin.

Table VII-5. Captiva Island Terminal Groin Estimated Costs

Length	350 ft
Height	Up to 15 ft* (~10 ft avg)
Unit Cost	$1,925/LF*
Total Estimated Cost	**$670K**

* Assumed same cross-sectional area as John's Pass

D. Potential Range of Initial Construction Costs for North Carolina Terminal Groins

Two scenarios were analyzed using these unit costs. A relatively short trapezoidal groin (450 feet long) was placed along typical North Carolina shoreline slopes. A crest elevation was set to 4.0 feet (MLW), with a crest width of 20 feet. The average groin height ranged from 8 to 12 feet. Side slopes were set to 2:1. Figure VII-11 illustrates the typical cross section for this scenario. Figure VII-12 and Figure VII-13 show some typical beach slopes for this scenario. Table VII-6 shows the ranges of anticipated unit and total costs for the above scenario. Based on these scenarios, a typical short rock terminal groin initial construction cost may range from $550,000 - $1 million, while a short timber, steel or concrete groin initial construction cost may range from $1.8 – 2.0 million. A short geotextile groin may cost less than $300,000, but please note that these types of structures would have limited applicability given their likelihood of failure in deeper water and active swash zones.

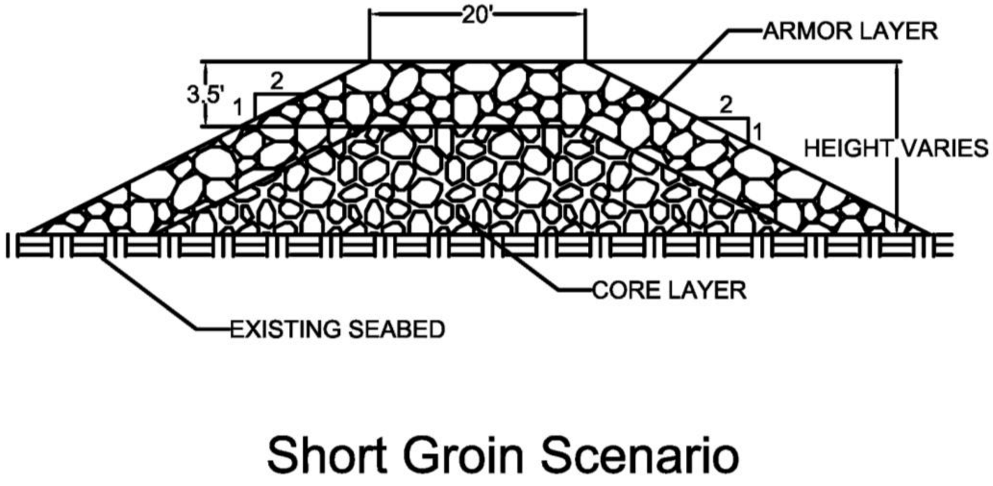

Figure VII-11. Typical Cross Section for Short Groin Scenario

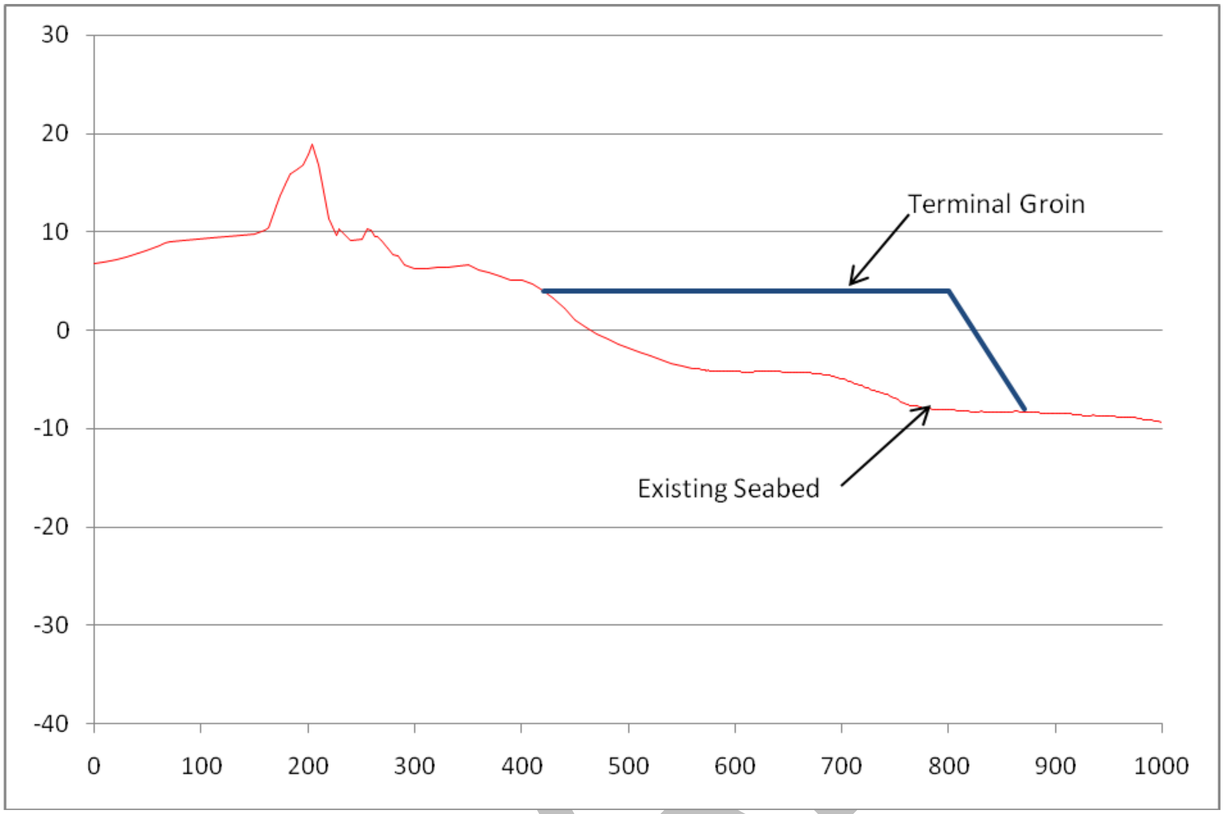

Figure VII-12. Short Groin along a Flat-Sloped Beach

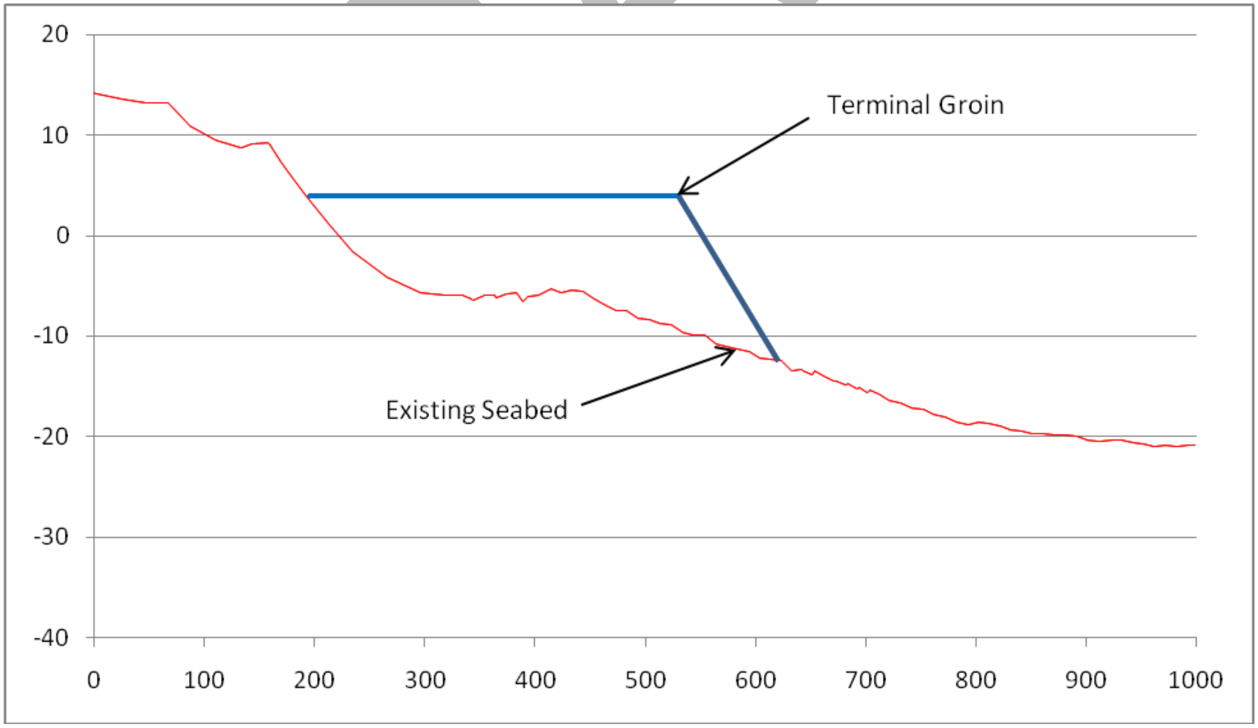

Figure VII-13. Short Groin along a Steep-Sloped Beach

Table VII-6. Short Groin Scenario Unit Costs

Length	450	450
Average Height	8	12
Rubble Mound (small stone)		
Unit Cost	$1230/LF	$1930/LF
Total Cost	$554K	$869K
Rubble Mound (large stone)		
Unit Cost	$1440/LF	$2260/LF
Total Cost	$648K	$1.0M
Geotextile Tubes		
Unit Cost	$350/LF	$660/LF
Total Cost	$160K	$300K
Steel Sheet Piles w/ concrete fascia & cap		
Unit Cost	$4000/LF	$4300/LF
Total Cost	$1.8M	$1.9M
Concrete sheet piles (tied back)		
Unit Cost	$4600/LF	$4800/LF
Total Cost	$2.1M	$2.2M
Timber piles		
Unit Cost	$4000/LF	N/A*
Total Cost	**$1.8M**	**N/A***

*Reaching upper limit of allowable use

The second scenario analyzed a longer groin (1,500 feet) placed on typical North Carolina slopes. The crest elevation remained set at 4 feet (MLW); however the width was widened to 30 feet due to the increased exposure to wave energy. The average groin height ranges from 12 to 19 feet; and the side slopes are set to 2:1. The figure below illustrates the typical cross-section for the long groin scenario. Figure VII-15 and Figure VII-16 show examples of this groin along various North Carolina beaches.

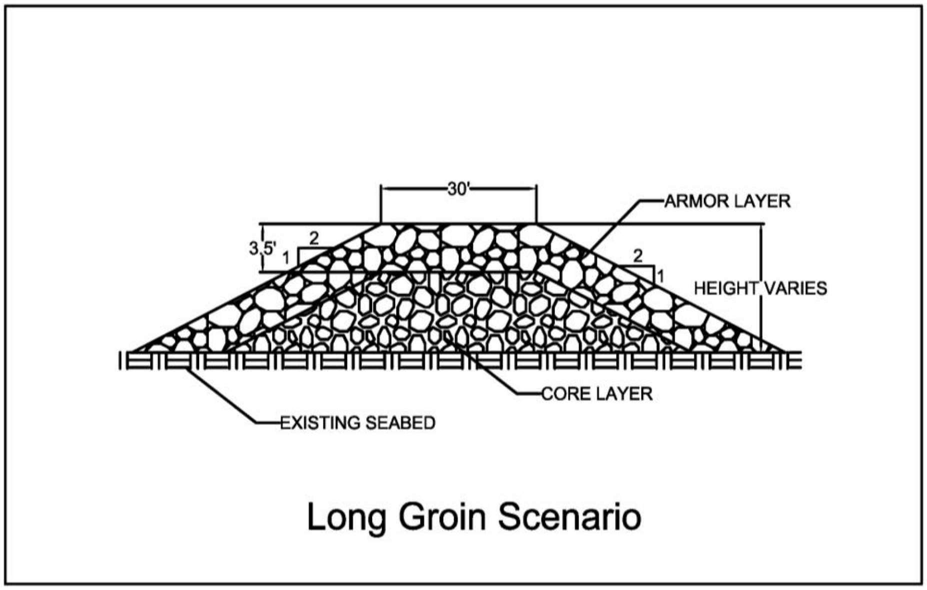

Figure VII-14. Typical Long Groin Scenario Cross Section

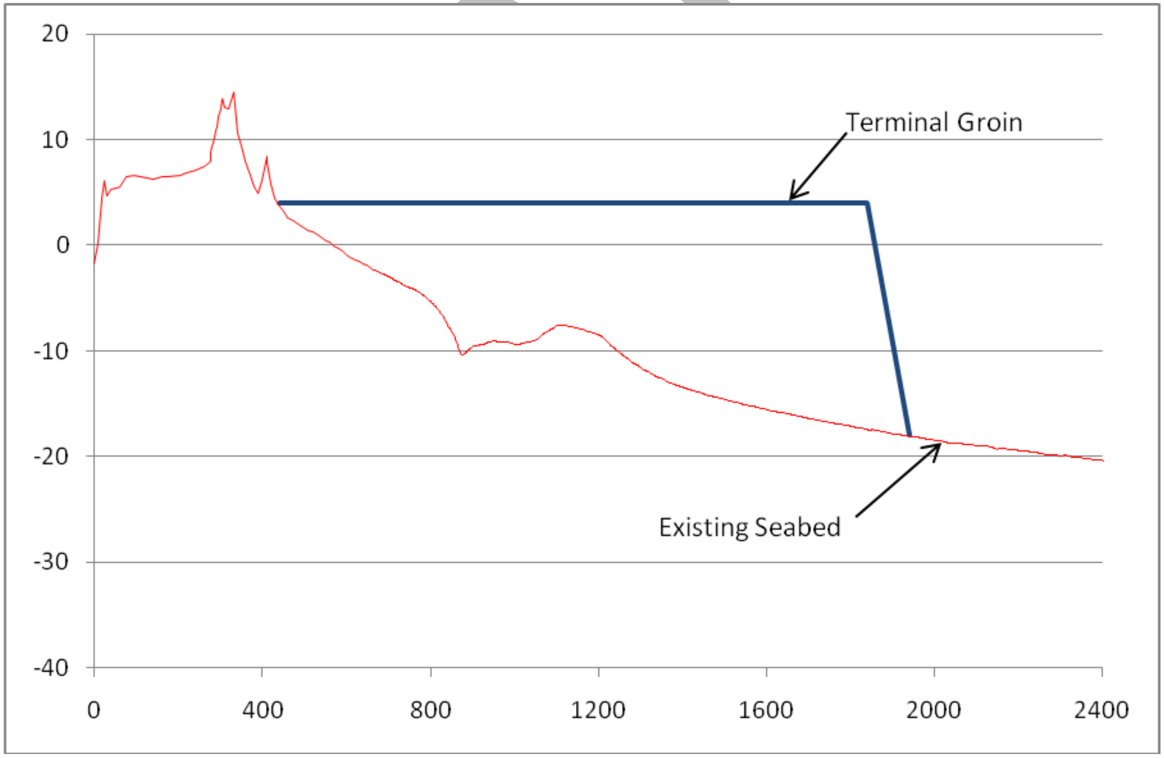

Figure VII-15. Groin Cross Section on a Flat-Sloped Beach

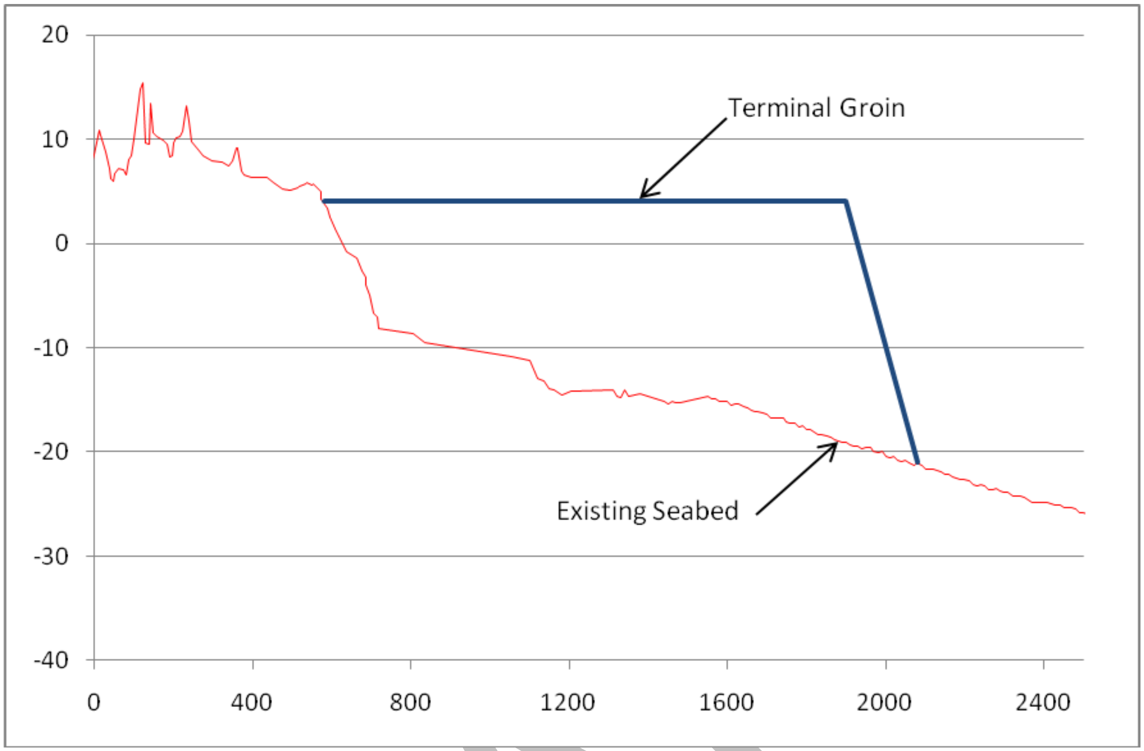

Figure VII-16. Groin Cross Section on a Steep-Sloped Beach

Table VII-7 shows the ranges of anticipated unit and total costs for the above scenario. Based on the scenario, a typical long terminal groin initial construction cost may range from $4 - $8 million.

Table VII-7. Long Groin Scenario Unit Costs

Length	1500 ft	1500 ft
Average Height	12 ft	19 ft
Rubble Mound (small stone)		
Unit Cost	$2,640/LF	$4,460/LF
Total Cost	$4.0M	$6.7M
Rubble Mound (large stone)		
Unit Cost	$3,090/LF	$5,180/LF
Total Cost	$4.6M	$7.8M
Geotextile Tubes*		
Unit Cost	N/A	N/A
Total Cost	N/A	N/A
Steel Sheet Piles w/ concrete fascia & cap		
Unit Cost	$4,300/LF	$4,500/LF
Total Cost	$6.5M	$6.8M
Concrete sheet piles (tied back)**		
Unit Cost	$4,800/LF	N/A
Total Cost	$7.2M	N/A
Timber piles*		
Unit Cost	N/A	N/A
Total Cost	N/A	N/A

*Should not be used for longer groins
**Should not be used for water depths greater than 15 feet

E. *Potential Range of Maintenance Costs for North Carolina Terminal Groins*

1. Structure Maintenance Costs

As an estimate of maintenance costs, it was observed that a couple of the older structures in Florida have required rehabilitation after a 15 – 20 year time period, and the costs appeared to be roughly equivalent to the initial construction costs based on the tonnage reported. This would equate to a 5-10% annual maintenance cost (please note that maintenance costs for Oregon Inlet have been very small by comparison so this is likely a conservative estimate). With increased storminess and the possibility of accelerated sea level rise (3.28 ft/century), the annualized maintenance costs (at a planning level) should be in the range of 10-15%, based on typical North Carolina offshore slopes.

2. Beach Nourishment Costs

Since initial beach nourishment will also be likely required for these structures, these costs should be included. Based on a rough estimate of the initial fillet that may be required for various structure lengths, an estimated 100,000 cubic yds of fill would be required for a short groin (0.5 x 450 ft wide x 3000 ft long x 4 ft deep) and 300,000 cubic yds of fill for a long groin (0.5 x 1500 ft wide x 3000 ft long x 4 ft deep). Using a cost of $12/yd, the initial beach nourishment costs would range between $1.2 and $3.6 million.

3. Other Costs

There are additional costs not included in the above estimates, including: permitting, design, monitoring, and possible removal of the groin. Permitting and engineering design costs are estimated to be between 15 – 25% of the initial construction costs. Monitoring costs would likely range from $100,000 (2 surveys/year) – $500,000 (multiple surveys and environmental monitoring) per year for a few years, depending on agency requirements. Given the State's longstanding ban on structures, it is expected that the monitoring requirements during the first few years would be substantial.

Should unexpected negative impacts to existing marine environments occur, groin removal may be necessary. For structural members like steel, concrete piles, timber, or geotextile groins an average cost for removal is $1000 per linear foot. For rock or concrete armor groins, the cost of removal is approximately $250-500 per linear foot (depending on section).

F. Overall Findings and Summary

An estimate for initial construction and maintenance costs of the existing five (5) study sites was completed. The selected terminal groin plan sheets (when available) were utilized to develop costs per linear foot of groin. Table V-8 summarizes the estimated costs for each of the five selected sites.

Table VII-8. Summary of Estimated Costs for 5 Selected Sites

Site Location	
Fort Macon	
Unit Cost	$1,900/LF
Total Cost	$2.9M
Oregon Inlet	
Unit Cost	$8,410/LF
Total Cost	$26.3M
Amelia Island	
Unit Cost	$2,260/LF
Total Cost	$3.4M
John's Pass	
Unit Cost	$1,925/LF
Total Cost	$890K
Captiva Island	
Unit Cost	$1,925/LF
Total Cost	$670K

The unit costs developed were used to estimate a range of costs for varying lengths and slopes for potential terminal groins along the North Carolina coast. The two scenarios developed utilized a short groin (450 feet long) and a long groin (1500 feet long) placed on typical North Carolina shoreline slopes. Table VII-9 summarizes the range of anticipated costs for the developed scenarios.

Table VII-9. Estimated Costs for Potential North Carolina Groins

Length	450 ft	450 ft	1500 ft	1500 ft
Average Height	8 ft	12 ft	12 ft	19 ft
Rubble Mound (small stone)				
Unit Cost	$1,230/LF	$1,930/LF	$2,640/LF	$4,460/LF
Total Cost	$554K	$869K	$4.0M	$6.7M
Rubble Mound (large stone)				
Unit Cost	$1,440/LF	$2,260/LF	$3,090/LF	$5,180/LF
Total Cost	$648K	$1.0M	$4.6M	$7.8M
Geotextile Tubes*				
Unit Cost	$350/LF	$660/LF	N/A	N/A
Total Cost	$160K	$300K	N/A	N/A
Steel Sheet Piles w/ concrete fascia & cap				
Unit Cost	$4,000/LF	$4,300/LF	$4,300/LF	$4,500/LF
Total Cost	$1.8M	$2.2M	$6.5M	$6.8M
Concrete sheet piles (tied back)**				
Unit Cost	$4,600/LF	$4,800/LF	$4,800/LF	N/A
Total Cost	$2.1M	$2.2M	$7.2M	N/A
Timber Piles*				
Unit Cost	$4,000/LF	N/A	N/A	N/A
Total Cost	$1.8M	N/A	N/A	N/A

*Should not be used for longer groins
**Likely not used for water depths greater than 15 feet

Based on the average initial construction costs reported above for the short and long terminal groin scenarios (short groin = ~ $1 million, and long groin = ~$6 million), the total costs for the structures including maintenance are shown in Table V-10.

Table VII-10. Total Structure Costs

Initial Costs	Cost	Short (450')	Long (1500')
Initial Cost (LS)	--	$1,000,000	$6,000,000
Initial Beach Nourishment (LS)	--	$1,200,000	$3,600,000
Permitting and Design	20.0%	$200,000	$1,200,000
Total Initial Costs	**Total**	**$2,400,000**	**$10,800,000**

Removal ($/LF)	$500	$225,000	$750,000

Annual Costs			
Annual Maintenance ($/yr)	12.5%	$125,000	$750,000
Annual Monitoring (LS/yr)		$300,000	$300,000
Total Annual Maintenance Costs	**Total**	**$425,000**	**$1,050,000**

VIII. Potential Locations of Terminal Groins

This section discusses the potential locations where terminal groins may be considered. As part of this determination, a literature review of existing sites of terminal groins was completed.

A. Literature Review of Existing Terminal Groin Sites

One of the first steps completed for this study was the documentation of terminal groin sites along the East and Gulf Coasts (Figure VIII-1). After an exhaustive review of the literature and multiple contacts with leading coastal experts, the following list of terminal structures was developed (Table VIII-1).

Figure VIII-1. Potential Study Sites

Table VIII-1. Potential Study Site Locations

Potential Study Site	Terminal Groin	Adjacent to Dredged Inlet	Comments
Rockaway, NY	✓	✓	
Coney Island, NY	✓	✓	Structure offset 3000’ from edge of island
Ocean City Inlet		✓	Jetties
Willoughby Spit	✓	✓	
Chesapeake Beach	?		Mid-beach structure
Oregon Inlet	✓	✓	
Buxton (Cape Hatteras Lighthouse)	?		Several historic groins to protect lighthouse
Fort Macon	✓	✓	
Shell Island (removed)	✓		Sandbags
Folly Beach	✓	✓	
Hunting Island	✓		Proposed (not built)
Hilton Head	✓	✓	
Tybee Island (north)	✓	✓	
Tybee Island (south)	✓	✓	
Amelia Island	✓	✓	
St. Lucie Inlet	✓	✓	
Jupiter Inlet	✓	✓	Structures on both sides of inlet
Baker’s Haulover Inlet	✓	✓	Structures on both sides of inlet
Bonita Beach	✓		
Captiva Island	✓	✓	
Boca Grande Lighthouse	✓	✓	
Blind Pass	✓	✓	Structures on both sides of inlet
John’s Pass	✓	✓	Structures on both sides of inlet
Clearwater Pass	✓	✓	Structures on both sides of inlet
Honeymoon Island	✓	✓	

After reviewing the above list, it was apparent that the vast majority of structures were located at inlets with most of these adjacent to navigable, dredged channels. Only a few were not located at the end of an island. However, it is important to note that for the ones not located at the end of an island, their placement location was typically due to jurisdictional and / or project sponsor constraints. Such an example is the terminal groin located on the west end of the Coney Island, NY beach renourishment project which was located between a public beach and a private community that originally decided not to participate in the federal beach renourishment project. During the literature review, no terminal groin structures were identified as being located at the “end of a non-inlet littoral cell;” most likely since such a location would be difficult, if not impossible to identify, due to the high variability of waves and current patterns which ultimately dictate sediment transport magnitudes and directions. For example, the historic groins at Cape Hatteras are very near the end of a littoral cell, and even in that case, it is apparent that there are downdrift impacts. Variability in wave, tides and other conditions preclude a realistic, accurate, fixed location of a littoral cell in the middle of an island along the North Carolina coast. Fixed mid-island littoral cells may exist along coastlines with rock headlands, embayments, and other fixed features but those conditions do not exist in North Carolina currently.

In addition, the project team was also informed by Senator Basnight's office that the original intent of the legislation was to only study sites located next to inlets. For this reason and the practical limitations listed above, the study only considered terminal groin structures located next to inlets.

Additionally, difficulties in selecting structures that could truly be considered "terminal groins" as defined by this study were encountered. This was due to the historical desire to prevent sediment from entering the navigable channels where structures were located. Thus, since these structures had navigation as either their primary purpose, or in conjunction with maintaining an adjacent beach nourishment project, they were typically much longer, higher, and / or impermeable structures that are most properly classified as "jetties," not terminal groins.

Furthermore, several structures were lengthened over time to improve their ability to prevent sediment from entering navigation channels. In other words, the initial structure was built; sand accreted to near the end of the structure; sand began bypassing around / over the structure; increasing amounts of sediment began entering the navigation channel; and then the structure was lengthened to prevent the sediment movement. Hence, these structures, too, would be classified as jetties, not terminal groins.

With the constraints listed above the study team and Science Panel selected the list of five (5) sites that were utilized as potential analogs to potential applications in North Carolina. The five sites all exhibited a range of wave, tide and hydrodynamic forcings that might be experienced in North Carolina as shown in Table VIII-2

Table VIII-2. Environmental Conditions at Five Selected Study Sites

Study Site	Average Tidal Range (MHHW – MLLW)	Average Offshore Significant Wave Height*	Average Offshore Peak Wave Period*	Adjacent Inlet Width
Oregon Inlet	2.43 ft	3.9 ft	7 s	2,800 ft
Fort Macon	3.93 ft	3.3 ft	5 s	3,700 ft
Amelia Island	5.34 ft	3.3 ft	7 s	10,300 ft
Captiva Island	2.10 ft	2.3 ft	4 s	700 ft
John's Pass	2.40 ft	2.3 ft	4 s	600 ft

*From 1980-99 WIS Hindcast (Typically 15-20 m depth)

The sites also provided a range of inlet management practices, ranging from Fort Macon having the most extreme level of inlet management (dredging) that has been well documented in other sections of the report, to the smaller, less managed inlets in Florida.

Related to the level of inlet management, the five sites also appear to provide the study with a wide range of sediment transport conditions given the historical shoreline behaviors, beach nourishment and dredging activities, and the estimates of ebb and flood delta volumes.

B. Siting Lessons Learned from Five Study Sites

With respect to the structures discussed previously in this report and their locations, some general observations can be made. First, it is clear from the analysis in Section II and Table VIII-3 that the amount of material dredged can have a very significant impact which may greatly outweigh any potential long-term shoreline changes resulting from the construction of a terminal groin.

Table VIII-3. Dredging Summary

Study Site	Pre – Construction Dredged Volume (cy/yr)	Post – Construction Dredged Volume (cy/yr)
Oregon Inlet	75,178 / 1,052,466 *	427,557 / 300,417 **
Fort Macon	606,769	809,230
Amelia Island	N/A	N/A
Captiva Island	N/A	N/A
John's Pass	0	12,435

* Pre construction years: 1949 – 1980 / 1984 – 1988

** Post construction years: 1998 – 2004 / 1997 - 2007

This is to be expected, though, as dredging of navigable inlets creates a sediment "sink." This sink may reduce the amount of sediment that is naturally transported across the inlet resulting in negative impacts to the adjacent shorelines. Thus, any minimal negative impacts that a terminal groin might have on the shorelines on the opposite side of the inlet may be overshadowed by the influence of the inlet dredging; and the greater amount of material dredged, the smaller the relative potential impact of the terminal groin.

For this study, the most substantial (longer, higher and / or less permeable) terminal groins were typically found where the greatest amount of dredging activity occurs. While this may be obvious, it is worth stating that the more significant the dredging activities, the potentially greater the impacts on adjacent shorelines; the greater the potential need for more nourishment and / or more substantial stabilization structures.

By relation, it is also apparent that the level of inlet management that is already being completed will have a significant impact on the level of system perturbation that the terminal groin structure will have. For example, as shown previously, the terminal groin's impacts on adjacent shorelines are minimal when compared to dredging when dredging volumes and needs are substantial. Conversely, if a terminal groin is being considered for a natural inlet, or one with minimal intervention, the terminal groin's potential impacts will likely be much more noticeable and apparent on adjacent shorelines, and much more care and design optimization would be required to ensure minimal impacts to adjacent areas.

It is also important to note that all five of the study sites do currently requirement regular beach nourishments as part of the shoreline management within the area. It does appear that the terminal groins have likely lessened nourishment needs at the sites.

With respect to locating a terminal groin on the updrift or downdrift side of an inlet, it is interesting to note that both sides were represented among the five structures selected for this study. While an initial thought might be that a terminal groin should be located on the updrift side of an inlet in order to capture sediment, it must be noted that sediment typically moves in both directions along a shoreline depending upon the incident wave activity, and significant reversals in sediment transport direction often occur near an inlet due to the presence of the ebb shoals and other inlet features which transform the waves as they approach the shoreline.

Locating a terminal groin on the "net" downdrift side of inlet, though, may have the additional impact of "stabilizing" the location of a migrating inlet, such as the case at Oregon Inlet. For example, at Oregon Inlet, this impact has also resulted in changes to the inlet cross-section – a general narrowing and deepening over time since terminal groin construction.

IX. Summary of Findings

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To be included in Final Report after peer review and comments by the Science Panel.

X. References

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Appendix A

Session Law 2009-479
House Bill 709

GENERAL ASSEMBLY OF NORTH CAROLINA
SESSION 2009

SESSION LAW 2009-479
HOUSE BILL 709

AN ACT TO IMPOSE A MORATORIUM ON CERTAIN ACTIONS OF THE COASTAL RESOURCES COMMISSION RELATED TO TEMPORARY EROSION CONTROL STRUCTURES AND TO DIRECT THE COASTAL RESOURCES COMMISSION TO STUDY THE FEASIBILITY AND ADVISABILITY OF THE USE OF A TERMINAL GROIN AS AN EROSION CONTROL DEVICE.

The General Assembly of North Carolina enacts:

SECTION 1.(a) Definitions and Concepts. – The following definitions and concepts apply to Sections 1 of this act and its implementation:

(1) "Temporary erosion control structure" means a sandbag structure placed above mean high water and parallel to the shore.

(2) A community is considered to be actively pursuing a beach nourishment or inlet relocation project under any of the following circumstances:

- a. The community has a current and valid Coastal Area Management Act permit for the project.
- b. The community has been identified by a U.S. Army Corps of Engineers' Beach Nourishment Reconnaissance Study, General Reevaluation Report, Coastal Storm Damage Reduction Study, or an ongoing feasibility study by the U.S. Army Corps of Engineers.
- c. The community has received a favorable economic evaluation report on a federal project or is in the planning stages of a project that (i) has been designed by the U.S. Army Corps of Engineers or persons meeting applicable State occupational licensing requirements and (ii) has been initiated by a local government or community working toward the identification and adoption of a mechanism to provide the necessary local or State funds to construct the project.

SECTION 1.(b) Moratorium Established. – Notwithstanding Article 7 of Chapter 113A of the General Statutes and rules adopted pursuant to Article 7, there is hereby established a moratorium on certain actions of the Coastal Resources Commission related to temporary erosion control structures. The Commission shall not order the removal of a temporary erosion control structure that has been permitted under Article 7 of Chapter 113A of the General Statutes in a community that is actively pursuing a beach nourishment project or an inlet relocation project on or before the effective date of this act.

SECTION 1.(c) Exceptions. – The moratorium on certain actions by the Coastal Resources Commission related to temporary erosion control structures shall not prohibit the Commission from undertaking any of the following actions:

(1) Granting permit modifications to allow the replacement, within the originally permitted dimensions, of temporary erosion control structures that have been damaged or destroyed.

(2) Requiring the removal of temporary erosion control structures installed in violation of Article 7 of Chapter 113A of the General Statutes and rules adopted pursuant to Article 7.

(3) Requiring that a temporary erosion control structure that has been modified in violation of Article 7 of Chapter 113A of the General Statutes and rules adopted pursuant to Article 7 be brought back into compliance with permit conditions.

(4) Requiring the removal of a temporary erosion control structure that no longer protects an imminently threatened road and associated right-of-way or an imminently threatened building and associated septic system.

SECTION 2.(a) Study. – The Coastal Resources Commission, in consultation with the Division of Coastal Management, the Division of Land Resources, and the Coastal Resources Advisory Commission, shall conduct a study of the feasibility and advisability of the use of a terminal groin as an erosion control device at the end of a littoral cell or the side of an inlet to limit or control sediment passage into the inlet channel. For the purpose of this study, a littoral cell is defined as any section of coastline that has its own sediment sources and is isolated from adjacent coastal reaches in terms of sediment movement.

SECTION 2.(b) Specific Considerations. – In conducting the study, the Commission shall specifically consider all of the following:

(1) Scientific data regarding the effectiveness of terminal groins constructed in North Carolina and other states in controlling erosion. Such data will include consideration of the effect of terminal groins on adjacent areas of the coastline.

(2) Scientific data regarding the impact of terminal groins on the environment and natural wildlife habitats.

(3) Information regarding the engineering techniques used to construct terminal groins, including technological advances and techniques that minimize the impact on adjacent shorelines.

(4) Information regarding the current and projected economic impact to the State, local governments, and the private sector from erosion caused by shifting inlets, including loss of property, public infrastructure, and tax base.

(5) Information regarding the public and private monetary costs of the construction and maintenance of terminal groins.

(6) Whether the potential use of terminal groins should be limited to navigable, dredged inlet channels.

SECTION 2.(c) Public Input. – In conducting the study, the Commission shall hold at least three public hearings where interested parties and members of the general public will have the opportunity to present views and written material regarding the feasibility and advisability of the use of a terminal groin as an erosion control device at the end of a littoral cell or the side of an inlet to limit or control sediment passage into the inlet channel.

SECTION 2.(d) Report. – No later than April 1, 2010, the Commission shall report its findings and recommendations to the Environmental Review Commission and the General Assembly.

SECTION 3. This act is effective when it becomes law. Section 1 of this act expires September 1, 2010.

In the General Assembly read three times and ratified this the 11th day of August, 2009.

s/ Walter H. Dalton
President of the Senate

s/ Joe Hackney
Speaker of the House of Representatives

s/ Beverly E. Perdue
Governor

Approved 1:21 p.m. this 26th day of August, 2009

Appendix B

Committee Lists

Coastal Resources Commission :: Members

Members as of October 1, 2009				
Member	**Address**	**Telephone**	**Expertise**	**Term Ends**
Bob Emory (Chair)	112 Cameila Road New Bern, NC 28562	252-633-7417 (o) 252-638-8587 (h)	Coastal forestry	6/30/10
Joan L. Weld (Vice Chair)	352 Bear Branch Drive Currie, NC 28435	910-283-4521	State or national conservation organization	6/30/10
Charles B. Bissette Jr.	204 Coventry Rd. Morehead City, NC 28557	252-728-4191 (o)	Coastal Engineering	6/30/12
Renee Cahoon	P.O. Box 714 Nags Head, NC 27959	252-441-5358 (o) 252-441-4847 (h)	Local government	6/30/10
Veronica Carter	1102 Veranda Court Leland, NC 28451	910-371-1784 (H) 910-409-8457 (C)	At-large	6/30/12
Charles M. Elam	2880 Slater Rd. Suite 200 Morrisville, NC 27560	919-678-1071 (o)	Coastal land development financing	6/30/12
Dr. James R. Leutze	601 South College Rd. Wilmington, NC 28403	910-962-7662 (o) 910-256-6020 (h)	At-large	6/30/12
Ed Mitchell		252-634-3373 (o)	Coastal land development	6/30/12
Jerry L. Old	1669 Tulls Creek Road Moyock, NC 27958	252-435-6366 (o) 252-232-3925 (h)	Local government	6/30/12
William R. Peele III	6767 Hwy. 264 East Washington, NC 27889	252-975-6687 (o) 252-923-0053 (h)	Coastal agriculture	6/30/12
Vacant			Sports fishing	6/30/10
Melvin M. Shepard Jr.	194 Charles Creek Road Sneads Ferry, NC 28460	910-327-1231 (o) 910-327-7401 (h)	Marine-related business	6/30/12
David Webster	652 Chowning Place Wilmington, NC 28409	910-962-3756 (o)	Marine ecology	6/30/10
Robert O. "Bob" Wilson	The Rowboat Co. 858 Williamson Road Mooresville, NC 28117	704-663-3478 (o)	At-large	6/30/10
Lee Wynns	404 E. River St. P.O. Box 6 Colerain, NC 27924	252-356-4684 (h) 252-356-4387 (o)	Commercial fishing	6/30/10

Science Panel on Coastal Hazards

Dr. Margery Overton, Chair	Department of Civil, Construction, and Environmental Engineering N.C. State University
Steven Benton	Division of Coastal Management (retired) Raleigh
Dr. William Cleary	Center for Marine Science University of North Carolina at Wilmington
Tom Jarrett, P.E.	U.S. Army Corps of Engineers (Retired)
Dr. Charles "Pete" Peterson	Institute of Marine Sciences University of North Carolina at Chapel Hill
Dr. David John Mallinson	East Carolina University
Dr. Stan Riggs	Department of Geology East Carolina University
Spencer Rogers	North Carolina Sea Grant Wilmington
Dr. Antonio B. Rodriguez	Institute of Marine Sciences University of North Carolina at Chapel Hill
Dr. Gregory Williams	U.S. Army Corps of Engineers Wilmington
William Birkemeier	Field Research Facility, ERDC/CHL US Army Corps of Engineers
Dr. Elizabeth Judge Sciaudone, PE	N.C. State University
Dr. Robert S. Young	Department of Geosciences Western Carolina University

Last Modified: September 15, 2009

Terminal Groin Study
CRC/CRAC Subcommittee Members:

- Bob Emory
- Jim Leutze
- Melvin Shepard
- Veronica Carter
- Charles “Boots” Elam
- Dara Royal
- Spencer Rogers
- Anne Deaton
- Tracy Skrabal
- Bill Morrison

Appendix C

Engineering Activity Logs

ENGINEERING ACTIVITIES LOG FOR OREGON INLET

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
1	1950	Dredging	USACE begins dredging to maintain a 14' X 400' channel through Oregon Inlet				
2	1960	Dredging	Oregon Inlet - Hyde (dredge)	62,991			
3	1961	Dredging	Oregon Inlet - Hyde (dredge)	24,013			
4	1962	Dredging	Oregon Inlet - Hyde (dredge)	109,186			
5	1963	Dredging	Oregon Inlet - Hyde (dredge)	76,868			
6	1964	Dredging	Oregon Inlet - Hyde (dredge)	12,800			
7	1964	Dredging	Oregon Inlet - Merrit (dredge)	7,800			
8	1965	Dredging	Oregon Inlet - Hyde (dredge)	188,142			
9	1965	Dredging	Oregon Inlet - Merrit (dredge)	95,404			
10	1966	Dredging	Oregon Inlet - Hyde (dredge)	88,489			
11	1966	Dredging	Oregon Inlet - Merrit (dredge)	98,244			
12	1967	Dredging	Oregon Inlet - Hyde (dredge)	215,232			
13	1968	Dredging	Oregon Inlet - Hyde (dredge)	211,430			
14	1968	Dredging	Oregon Inlet - Merrit (dredge)	85,704			
15	1969	Dredging	Oregon Inlet - Hyde (dredge)	132,036			
16	1969	Dredging	Oregon Inlet - Merrit (dredge)	70,000			
17	1970	Dredging	Oregon Inlet - Hyde (dredge)	40,531			
18	1970	Dredging	Oregon Inlet - Merrit (dredge)	74,790			
19	1970	Dredging	Oregon Inlet - Schweizer (dredge)	55,424			
20	1971	Dredging	Oregon Inlet - Hyde (dredge)	132,149			
21	1972	Dredging	Oregon Inlet - Hyde (dredge)	302,206			
22	1972	Dredging	Oregon Inlet - Merrit (dredge)	22,944			
23	1973	Dredging	Oregon Inlet - Merrit (dredge)	19,995			
24	1973	Dredging	Oregon Inlet - Schweizer (dredge)	40,450			

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
25	1974	Dredging	Oregon Inlet - Merrit (dredge)	55,100			
26	1974	Dredging	Oregon Inlet - Schweizer (dredge)	164,672			
27	1975	Dredging	Oregon Inlet - Schweizer (dredge)	182,068			
28	1976	Dredging	Oregon Inlet - Schweizer (dredge)	372,473			
29	1977	Dredging	Oregon Inlet - Schweizer (dredge)	312,485			
30	1978	Dredging	Oregon Inlet - Merrit (dredge)	9,045			
31	1978	Dredging	Oregon Inlet - Schweizer (dredge)	349,082			
32	1979	Dredging	Oregon Inlet - Schweizer (dredge)	415,000			
33	1980	Dredging	Oregon Inlet - Schweizer (dredge)	438,000			
34	April, 1963	Bridge Opening	The 2.4-mile Bonner Bridge opens				
35	1980	Dredging	Oregon Inlet - Schwiezer (dredge)	438,000			
36	1981	Dredging	Oregon Inlet - Currituck (dredge)	27,225			
37	1981	Dredging	Oregon Inlet - Schwiezer (dredge)	550,250			
38	1981	Dredging	Oregon Inlet - Merrit (dredge)	115,605			
39	1982	Dredging	Oregon Inlet - Schwiezer (dredge)	665,080			
40	1982	Dredging	Oregon Inlet - Merrit (dredge)	279,265			
41	1983	Dredging	Oregon Inlet - Mermentau (dredge)	146,251			
42	1983	Dredging	Oregon Inlet - Schwiezer (dredge)	514,160			
43	1983	Dredging	Oregon Inlet - Merrit (dredge)	221,019			
44	1983	Dredging	Oregon Inlet - Fry (dredge)	152,986			
45	1984	Dredging	Oregon Inlet - Mermentau (dredge)	270,467			
46	1984	Dredging	Oregon Inlet - Mermentau (dredge)	24,418			
47	1984	Dredging	Oregon Inlet - Schweizer (dredge)	356,327			
48	1984	Dredging	Oregon Inlet - Merrit (dredge)	85,498			
49	1984	Dredging	Oregon Inlet - Fry (dredge)	162,835			

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
50	1984	Dredging	USACE initiates a large scale hopper dredge of Oregon Inlet				
51	1984	Dredging	Oregon Inlet - Mermentau (dredge)	480,739			
52	1985	Dredging	Oregon Inlet - Mermentau (dredge)	456,321			
53	1985	Dredging	Oregon Inlet - Northerly Island (dredge)	283,507			
54	1985	Dredging	Oregon Inlet - Schweizer (dredge)	377,790			
55	1985	Dredging	Oregon Inlet - Merrit (dredge)	305,446			
56	1985	Dredging	Oregon Inlet - Northerly Island (dredge)	521,442			
57	1986	Dredging	Oregon Inlet - Northerly Island (dredge)	744,522			
58	1987	Dredging	Oregon Inlet - Mermentau (dredge)	365,906			
59	1987	Dredging	Oregon Inlet - Mermentau (dredge)	533,183			
60	1987	Dredging	Oregon Inlet - Currituck (dredge)	41,400			
61	1988	Dredging	Oregon Inlet - Mermentau (dredge)	274,166			
62	1988	Dredging	Oregon Inlet - Northerly Island (dredge)	213,791			
63	1989	Dredging	Oregon Inlet - Atchafalaya (dredge)	290,000			
64	1989	Dredging	Oregon Inlet - Atchafalaya (dredge)	159,000			
65	1989	Dredging	Oregon Inlet - Currituck (dredge)	77,638			
66	1990	Dredging	Oregon Inlet Ocean Bar	292,020			
67	1990	Beach Nourishment	Dredging near Bonner Bridge; placed on tip of Pea Island	254,955	2,000	127	Vicinity of Bonner Bridge
68	1989 - March 1991	Groin Construction	The project consisted of a terminal groin and revetment (3,125 and 625 ft long) starting at the US Coast Guard Station; the groin ranges in width btw 110 to 170 ft at the base and 25 ft at the landward end to 39 ft at the seaward end; the groin was designed to withstand a still water level of 8 ft above MSL and wave btw 9 and 15 ft.				
69	April - November, 1991	Beach Nourishment	USACE places fill on to the PINWE beach	470,000			
70	1991	Dredging	Oregon Inlet Ocean Bar	230,779			Placed Offshore
71	1991	Dredging	Oregon Inlet - Northerly Island (dredge)	182,894			
72	1991	Dredging	Oregon Inlet - Currituck (dredge)	149,503			

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
73	1991	Dredging	Oregon Inlet - S	480,926			
74	1991	Dredging	Oregon Inlet - Merrit (dredge)	61,243			
75	November, 1991	Beach Nourishment	Placed on Pea Island (sta 60 to 100)	184,300	4,000	46	Navigation Span
76	April, 1991	Beach Nourishment	Placed on Pea Island (sta 45 to 55 & sta 85 to 100)	282,600	2,500	113	Oregon Inlet Navigation Span
77	September, 1992	Beach Nourishment	Placed on Pea Island	157,600	1,000		Oregon Inlet Navigation Channel
78	1991 - 1997	Surveys	FRF's Oregon Inlet Monitoring Program surveys extended 6 km north and south of the inlet; survey lines spaced at 300 m intervals and extended offshore to the 9 m depth contour				
79	September, 1992	Beach Nourishment	Placed on Pea Island (sta 80 to 134)	1,078,000	5,400	200	Oregon Inlet Navigation Span
80	1992	Dredging	Oregon Inlet - ADCO (dredge)	94,331			
81	1992	Dredging	Oregon Inlet - Georgia (dredge)	900,592			
82	1992	Dredging	Oregon Inlet - Schweizer (dredge)	602,896			
83	1992	Dredging	Oregon Inlet - Merrit (dredge)	88,802			
84	October, 1993	Beach Nourishment	Placed on Pea Island (sta 80 to 105)	433,235	2,500	173	Oregon Inlet Navigation Span and Ocean Bar
85	1993	Dredging	Oregon Inlet - Currituck (dredge)	18,485			
86	1993	Dredging	Oregon Inlet - Schweizer (dredge)	585,690			
87	1994	Dredging	Oregon Inlet - Merrit (dredge)	55,596			
88	1995	Beach Nourishment	Placed on Pea Island	203,191	2,000	102	
89	November, 1995	Beach Nourishment	Placed on Pea Island (sta 79 to 80)	65,231			Orgeon Inlet Ocean Bar
90	December, 1995	Beach Nourishment	Placed on Pea Island (Nearshore)	168,400			Orgeon Inlet Ocean Bar
91	1995	Dredging	Oregon Inlet - Schweizer (dredge)	577,891			
92	1995	Dredging	Oregon Inlet - Atchafalaya (dredge)	250,000			
93	1995	Dredging	Oregon Inlet	233,631			
94	1996	Beach Nourishment	Placed on Pea Island	500,217			
95	August, 1996	Beach Nourishment	Placed on Pea Island (Nearshore)	271,004			Oregon Inlet Navigation Span and Ocean Bar
96	1996	Dredging	Oregon Inlet - Mermentau (dredge)	271,004			

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
97	1996	Dredging	Oregon Inlet - Currituck (dredge)	13,110			
98	September, 1997	Beach Nourishment	Placed on Pea Island (Nearshore)	271,703			Oregon Inlet Navigation Span and Ocean Bar
99	1997	Dredging	Oregon Inlet	271,703			
100	October, 1998	Beach Nourishment	Placed on Pea Island (Nearshore)	260,183			Oregon Inlet Navigation Span and Ocean Bar
101	1998	Dredging	Oregon Inlet	260,183			
102	1999	Beach Nourishment	Placed on Pea Island (Nearshore)	328,919			Oregon Inlet Navigation Span and Ocean Bar
103	1999	Dredging	Oregon Inlet	328,919			
104	2000	Beach Nourishment	Placed on Pea Island	419,305			
105	October, 2000	Beach Nourishment	Placed on Pea Island (Nearshore)	244,445			Oregon Inlet Navigation Span and Ocean Bar
106	2000	Dredging	Oregon Inlet	419,305			
107	November, 2001	Beach Nourishment	Placed on Pea Island (sta 40 to 43 & sta 52 to 100)	513,706			Oregon Inlet Navigation Span
108	2001	Dredging	Oregon Inlet	513,706			
109	October, 2002	Beach Nourishment	Placed on Pea Island (Nearshore & sta 80 to 151)	732,852			Oregon Inlet Navigation Span and Ocean Bar
110	2002	Dredging	Oregon Inlet	732,829			
111	October, 2003	Beach Nourishment	Placed on Pea Island (sta 66 to 188)	1,029,543			Oregon Inlet Navigation Span
112	2003	Beach Nourishment	Placed on Pea Island (Nearshore)	107,631			Oregon Inlet Ocean Bar
113	2003	Dredging	Oregon Inlet	107,631			
114	2003	Dredging	Oregon Inlet - Merrit (dredge)	50,840			
115	July - November, 2004	Beach Nourishment	Placed on Pea Island (Nearshore & sta 45 to 115 - not 70 to 90)	616,448			Oregon Inlet Navigation Span and Ocean Bar
116	2004	Dredging	Oregon Inlet	147,871			
117	2004	Dredging	Oregon Inlet - Currituck (dredge)	54,895			
118	November, 2005	Beach Nourishment	Placed on Pea Island (Nearshore)	172,155			Oregon Inlet Ocean Bar
119	2005	Dredging	Oregon Inlet - Currituck (dredge)	15,710			
120	2005	Dredging	Oregon Inlet - Fry (dredge)	242,930			
121	2006	Dredging	Oregon Inlet - Currituck (dredge)	38,270			

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
122	2006	Dredging	Oregon Inlet - Fry (dredge)	200,480			
123	2006	Dredging	Oregon Inlet - Merrit (dredge)	255,540			
124	2007	Dredging	Oregon Inlet - Currituck (dredge)	113,145			
125	2007	Dredging	Oregon Inlet - Fry (dredge)	241,870			
126	2007	Dredging	Oregon Inlet - Merrit (dredge)	702,466			
127	November, 2008	Beach Nourishment	Placed on Pea Island (sta 45 to 110)	791,829			Oregon Inlet Navigation Span and Ocean Bar
128	October, 2009	Beach Nourishment	Placed on Pea Island (sta 45 to 150)	1,183,144			Oregon Inlet Navigation Span and Ocean Bar

ENGINEERING ACTIVITIES LOG FOR FORT MACON

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
1	1829 - 1834	Fort Construction	Fort Macon Construction				
2	1911	Dredging	Navigational Improvements to Beaufort Inlet begin; Channel dredged to 300-ft wide				
3	1927	Dredging	Outer Bar Channel	311,300			
4	1928	Dredging	Outer Bar Channel	156,900			
5	1929	Dredging	Outer Bar Channel	209,400			
6	1930	Dredging	Outer Bar Channel	166,300			
7	1932	Dredging	Outer Bar Channel	56,100			
8	1933	Dredging	Outer Bar Channel	156,300			
9	1935	Dredging	Outer Bar Channel	763,100			
10	1936	Dredging	Outer Bar Channel deepened to -30 ft and 400-ft wide; channel location becomes fixed				
11	1936	Dredging	Morehead City Harbor Channel Maintenance	2,367,900			
12	1936	Dredging	Outer Bar Channel	3,460,100			
13	1937	Dredging	Morehead City Harbor Channel Maintenance	215,900			
14	1937	Dredging	Outer Bar Channel	268,300			
15	1938	Dredging	Morehead City Harbor Channel Maintenance	55,700			
16	1938	Dredging	Outer Bar Channel	205,700			
17	1939	Dredging	Morehead City Harbor Channel Maintenance	35,000			
18	1939	Dredging	Outer Bar Channel	473,800			
19	1940	Dredging	Morehead City Harbor Channel Maintenance	262,700			
20	1940	Dredging	Outer Bar Channel	918,100			
21	1942	Dredging	Outer Bar Channel	299,200			
22	1943	Dredging	Morehead City Harbor Channel Maintenance	10,000			
23	1943	Dredging	Outer Bar Channel	91,900			
24	1944	Dredging	Morehead City Harbor Channel Maintenance	727,600			

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
25	1944	Dredging	Outer Bar Channel	584,900			
26	1945	Dredging	Morehead City Harbor Channel Maintenance	141,800			
27	1945	Dredging	Outer Bar Channel	520,800			
28	1946	Dredging	Morehead City Harbor Channel Maintenance	193,900			
29	1946	Dredging	Outer Bar Channel	145,800			
30	1947	Dredging	Morehead City Harbor Channel Maintenance	119,400			
31	1947	Dredging	Outer Bar Channel	48,800			
32	1948	Dredging	Morehead City Harbor Channel Maintenance	174,800			
33	1948	Dredging	Outer Bar Channel	542,900			
34	1949	Dredging	Outer Bar Channel	1,103,000			
35	1950	Dredging	Morehead City Harbor Channel Maintenance	101,800			
36	1950	Dredging	Outer Bar Channel	637,900			
37	1951	Dredging	Outer Bar Channel	616,800			
38	1952	Dredging	Outer Bar Channel	504,600			
39	1953	Dredging	Morehead City Harbor Channel Maintenance	230,500			
40	1953	Dredging	Outer Bar Channel	312,200			
41	1954	Dredging	Outer Bar Channel	797,100			
42	1955	Dredging	Morehead City Harbor Channel Maintenance	166,000			
43	1955	Dredging	Outer Bar Channel	719,200			
44	1956	Dredging	Outer Bar Channel	564,200			
45	1957	Dredging	Morehead City Harbor Channel Maintenance	177,600			
46	1957	Dredging	Outer Bar Channel	1,039,500			
47	1958	Dredging	Outer Bar Channel	866,800			
48	1959	Dredging	Morehead City Harbor Channel Maintenance	196,600			
49	1959	Dredging	Outer Bar Channel	977,400			

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
50	1960	Dredging	Morehead City Harbor Channel Maintenance	130,000			
51	1960	Dredging	Outer Bar Channel	589,400			
52	1961	Beach Nourishment			7656		
53	1961	Seawall, Revetment, Partial Groin Construction	Due to financial constraints, the groin was only built to a length of 720 ft at an elevation of 6 ft and excluded the structure's top armor layer. The revetment (250 ft) and seawall (530 ft) were constructed along the dune bank starting just north of the present-day Fort Macon parking lot in a southeastern direction				
54	1961	Dredging	Morehead City Harbor Channel Maintenance	1,336,000			
55	1961	Dredging	Outer Bar Channel	1,869,200			
56	1962	Dredging	Outer Bar Channel	898,600			
57	1963	Dredging	Outer Bar Channel	584,800			
58	1963	Dredging	Morehead City Harbor Channel Maintenance	509,200			
59	1964	Dredging	Outer Bar Channel	407,800			
60	1965	Groin Extention & Construction; Beach Nourishment	Groin extended an additional 410 ft oceanward; Additional groin was constructed west of the revetment due to extensive erosion on the back, or sound side, of the island and its impact to the US Coast Guard station. Beach fill was also placed on the beach between the present day bathhouse and boardwalk region and the terminal groin	93,000			
61	1965	Dredging	Outer Bar Channel	655,000			
62	1965	Dredging	Morehead City Harbor Channel Maintenance	253,300			
63	1966	Dredging	Outer Bar Channel	691,800			
64	1967	Dredging	Outer Bar Channel	966,000			
65	1967	Dredging	Morehead City Harbor Channel Maintenance	178,000			
66	1968	Dredging	Outer Bar Channel	708,600			
67	1968	Dredging	Morehead City Harbor Channel Maintenance	72,100			
68	1969	Dredging	Outer Bar Channel	401,800			
69	1970	Dredging	Morehead City Harbor Channel Maintenance	431,300			
70	1970	Dredging	Outer Bar Channel	853,900			Disposal: ODMDS

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
71	1970 (aug)	Groin Extention & Construction; Beach Nourishment	Groin extended an additional 400 ft to a total length of 1,530 ft; A stone groin (480 ft long) was built near the bathhouse in an effort to stabilize the beach fill placed in the area of the bathhouse and boardwalk	100,000			
72	1971	Dredging	Outer Bar Channel	913,800			
73	1972	Dredging	Outer Bar Channel	783,700			
74	1973	Beach Nourishment		1,189,481	5043	235.8677375	State Port (Morehead City Harbor)
75	1973	Dredging	Outer Bar Channel	952,900			
76	1974	Dredging	Morehead City Harbor Channel Maintenance	557,400			
77	1974	Dredging	Outer Bar Channel	401,600			Disposal: ODMDS
78	1975	Dredging	Outer Bar Channel - Gerig	238,289			Disposal: ODMDS
79	1975	Dredging	Outer Bar Channel - Goethals	190,397			Disposal: ODMDS
80	1976	Dredging	Outer Bar Channel - Davison	74,685			Disposal: ODMDS
81	1976	Dredging	Outer Bar Channel - Gerig	583,929			Disposal: ODMDS
82	1977	Dredging	Outer Bar Channel - Macfarland	96,133			Disposal: ODMDS
83	1978	Dredging	Outer Bar Channel - Landfitt	1,364,069			Disposal: ODMDS
84	1978	Dredging	Outer Bar Channel - Sensibar	1,608,131			Disposal: ODMDS
85	1978	Dredging	Morehead City Harbor Channel Maintenance	164,893			
86	1978	Dredging	Morehead City Harbor Channel Maintenance - Pullen	1,179,739			
87	1978	Dredging	Outer Bar Channel - Landfitt	530,008			Disposal: ODMDS
88	1979	Beach Nourishment	USACE Maintenance Dredge of Morehead City Inner Harbor	1,179,739	11797	100.0033059	Morehead City Inner Harbor
89	1980	Dredging	Outer Bar Channel	294,610			
90	1981	Dredging	Outer Bar Channel - Dodge Island	824,052			Disposal: ODMDS
91	1981	Dredging	Morehead City Harbor Channel Maintenance - Hampton Roads	589,566			
92	1982	Dredging	Morehead City Harbor Channel Maintenance - Hampton Roads	22,865			
93	1982	Dredging	Outer Bar Channel - Manhattan	977,040			Disposal: ODMDS
94	1983	Dredging	Morehead City Harbor Channel Maintenance - Hampton Roads	263,609			Disposal: ODMDS

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
95	1983	Dredging	Outer Bar Channel - Dodge Island	848,933			Disposal: ODMDS
96	1984	Dredging	Outer Bar Channel	1,098,259			
97	1985	Dredging	Outer Bar Channel - Sugar Island	583,181			Disposal: ODMDS
98	1985	Dredging	Morehead City Harbor Channel Maintenance - Clinton	153,625			
99	1986	Beach Nourishment	USACE Maintenance Dredge of Morehead City Inner Harbor and Brandt Island Pump out; placed on Atlantic Beach	4,168,600	39129	106.5347952	Morehead City Inner Harbor / Brandt Island
100	1986	Dredging	Morehead City Harbor Channel Maintenance - Jim Bean	3,912,894			
101	1986	Dredging	Outer Bar Channel	367,681			
102	1986	Dredging	Morehead City Harbor Channel Maintenance	255,743			
103	1987	Dredging	Morehead City Harbor Channel Maintenance - Enterprise	351,588			
104	1987	Dredging	Outer Bar Channel - Sugar Island	534,555			Disposal: ODMDS
105	1988	Dredging	Outer Bar Channel - Dodge Island	691,190			Disposal: ODMDS
106	1989	Dredging	Outer Bar Channel - Atchafalaya	539,192			Disposal: ODMDS
107	1989	Dredging	Morehead City Harbor Channel Maintenance	269,178			
108	1990	Dredging	Outer Bar Channel - Cherokee	592,232			Disposal: ODMDS
109	1991	Dredging	Outer Bar Channel	11,959			
110	1991	Dredging	Morehead City Harbor Channel Maintenance	143,747			
111	1991	Dredging	Outer Bar Channel Eagle	831,637			Disposal: ODMDS
112	1993	Dredging	Outer Bar Channel	837,573			Disposal: ODMDS
113	November 1993 - February 1994	Beach Nourishment	USACE Maintenance Dredge of Morehead City Inner Harbor	2,192,268	24,737 (total)		Morehead City Inner Harbor
114	November 1993 - February 1994	Beach Nourishment	USACE Brandt Island Pump Out	2,472,132	24,737 (total)		Brandt Island
115	1994	Dredging	Morehead City Harbor Channel Maintenance	4,664,416			
116	1994	Dredging	Outer Bar Channel	2,606,922			Disposal: ODMDS
117	1995	Dredging	Morehead City Harbor Channel Maintenance	815,579			Disposal: ODMDS
118	1996	Dredging	Outer Bar Channel	656,646			Disposal: ODMDS
119	1997	Dredging	Morehead City Harbor Channel Maintenance	739,584			

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
120	1997	Dredging	Outer Bar Channel	191,872			Disposal: ODMDS
121	1998	Dredging	Outer Bar Channel	1,163,563			
122	1998	Dredging	Morehead City Harbor Channel Maintenance	18,233			
123	1999	Dredging	Outer Bar Channel	1,040,919			
124	1999	Dredging	Morehead City Harbor Channel Maintenance	350,042			
125	June & September, 1999	Survey	CSE surveys for Carteret County				
126	2000	Dredging	Outer Bar Channel	1,701,659			
127	June, 2000	Survey	CSE surveys for Carteret County				
128	February, 2002	Beach Nourishment	USACE Maintenance Dredge of Morehead City Inner Harbor	209,348			Morehead City Inner Harbor
129	December, 2003	Survey	CSE surveys for Carteret County				
130	2004	Dredging	Morehead City Harbor Channel Maintenance	2,940,507			Disposal: ODMDS
131	2004	Dredging	Morehead City Harbor Channel Maintenance	1,577,052			Disposal: ODMDS
132	June, 2004	Survey	CSE surveys for Carteret County				
133	November 2004 - February 2005	Beach Nourishment	USACE Brandt Island Pump Out; placed on Atlantic Beach	2,390,000	22,543 (total)		
134	2005	Dredging	Morehead City Harbor Channel Maintenance	906,716			Disposal: ODMDS
135	January - March, 2005	Beach Nourishment	USACE Maintenance Dredge of Morehead City Inner Harbor	530,729	12,500 (total)		Morehead City Inner Harbor
136	May, 2005	Survey	CSE surveys for Carteret County				
137	May, 2006	Survey	CSE surveys for Carteret County				
138	May, 2007	Survey	CSE surveys for Carteret County				
139	2007	Beach Nourishment	Morehead City Inner Harbor Maintenance Dredging (Range C, Bulkhead Channel)	211,000			Morehead City Inner Harbor (Range C Bulkhead Channel)

ENGINEERING ACTIVITIES LOG FOR AMELIA ISLAND

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
1	1964	Revetment Construction	In response to erosion damage from Hurricane Dora (1964), emergency Federal funds were appropriated for construction of granite stone revetments along approximately 1.1 miles of American Beach		5808		
2	1970's	Beach Scraping	Amelia Island Plantation (AIP) conducted beach scraping along its shoreline. The effort consisted of seasonal scraping of sand from the intertidal beach zone and subsequent placement at the dune toe				
3	1980	Beach Scraping	Permitted beach scraping was conducted between monuments R-64 and r-68. The project was undertaken by the AIP and constructed in a manner consistent with previous scraping efforts	32,000			
4	January - March, 1984	Beach Nourishment	Between January and March, the AIP placed material via truck haul from the Atlantic Intracostal Waterway (AIWW) dredge spoil disposal site within the Amelia Island State Recreation Area (AISRA) located at the southern end of Amelia Island	76,000	7,200	11	AIWW dredge spoil
5	1984	Beach Nourishment	As an emergency response to the Thanksgiving Day Storm of 1984, an additional 5,500 cy of sand were trucked in from the AIWW spoil site and placed at various locations where breaching of the AIP dune system was considered imminent	5,500			AIWW dredge spoil
6	1987	Beach Nourishment	As part of a larger island-wide 1.42 mcy beach fill project, 515,000 cy of material were placed by the USACE along a 1.3 mile each of shoreline between R-48 and R-55. The material was obtained from new work dredging of the St. Mary's Entrance required to provide navigational access for the US Navy's submarines. The disposal project was undertaken as a result of a 1986 Memorandum of Understanding between the US Navy and the State of Florida	515,000	6,864	75	St. Mary's Entrance
7	1987	Nearshore Disposal	USACE placed 2.13 mcy of material in a nearshore disposal site located between R-33 and R-55. The material placed was obtained from the new work dredging of St. Mary's Entrance. The material was placed seaward of the -18 ft (MLW) contour, and primarily in deeper water *-20 to -35 ft, MLW)	2,130,000			St. Mary's Entrance
8	1988	Beach Nourishment	USACE placed material along approximately 1 mile of shoreline between R-55 and R-60. The material was originally placed in the USACE nearshore disposal site by hopper dredge, then later moved onshore by means of a cutterhead dredge. The volume actually placed on the beach is a matter of dispute. The dredging contractor was paif for the placement of 1.083 mcy of fill, intended to extend over the 12,000-ft reach of shoreline between R-54 and R-65. Actual placement of material occurred along approximately 5,000 ft of shoreline between R-55 and R-60. This resulted in an approximate 60% shortfall in project length relative to the original design. Anecdotal visual inspection indicated that much of the material was fine sands and clay, which in all probability resulted from over-dredging of the specified nearshore rehandling site.	750,000	5,280	142	
9	1989	Beach Nourishment	AIP placed beach fill material along its shoreline. The material was trucked in from an AIWW dredge spol disposal site located west of the Amelia River	50,000			AIWW (west of Amelia River) dredge spoil
10	1991	Beach Nourishment	AIP placed beach fill, from an upland source, along its shoreline as part of a continuing dune protection project	12,000			

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
11	Winter, 1992/1993	Erosion Control	For purposes of "holding the line" until a comprehensive shore-protection solution could be developed, some 10,000 ft of 60" diameter sand-filled geotextile tubes were installed along the existing dune line to protect development.				
12	1993	Beach Nourishment	USACE beach fill along South American Beach extending south to about R-62	300,000			
13	1994	Beach Nourishment	SAISS-MSBU constructed a comprehensive beach restoration project along the southernmost 17,000 feet of Amelia Island's shoreline. The project placed fill between monuments R-62 and R-78. The borrow area for the site was 800-ft wide by 7,500-ft long and located between 3,000 and 3,900 feet offshore of the southern end of the island on the margins of the Nassau Sound ebb shoal platform	2,600,000			Offshore of southern end of island on Nassau Sound ebb shoal platform
14	August - November, 1995	Temporary Terminal Groin	Consists of four groins placed perpendicular to the shoreline, spaced about 500 ft apart in a tapered configuration. The groins were constructed of 70" diameter, sand-filled geotextile tubes (LONGARD) and numerous smaller support tubes. The landward terminus of each groin was installed below grade withing the 1994 beach fill				
15	October, 1996	Terminal Groin Repair	The southernmost groin, G-4, was vandalized in October, resulting in deflation of a 50-ft section of the geotextile groin. The gap was closed through the placement of several small tube sections				
16	May - September, 1997	Beach Nourishment	Between May and September, USACE placed fill along 4,500 ft of shoreline between monuments R-77.5 and R-73.5. The sand was obtained from maintenance dredging of the AIWW through Nassau Sound. Fill was placed within the groin field as well as along the beach 1,000 ft north and 2,000 ft south of the structures	300,000	4,500	67	AIWW dredge spoil through Nassau Sound
17	2000	Terminal Groin Repair	All four groins have been routinely vandalized, resulting in substantial structural damage and sand loss. The seaward terminus of each groin required major reconstruction during which the decision was made to truncate each structure, thereby creating the current groin configuration. Additional stablizing bags were also added to groin, G-4, at this time. In October, groin, G-3, was rendered ineffective				
18	November - December, 2000	Flood Protection	Approximately 2,000 ft of shore-parallel sand-filled geotextile tubes were placed along segments of the AISRA to reduce flooding of the maritime forest in areas where the dune had been lost to chronic erosion.				
19	May - September, 2001	Beach Nourishment	USACE placed fill along 4,500 ft of shoreline between monuments R-77.5 and R-73.5. The sand was obtained from maintenance dredging of the AIWW through Nassau Sound. Fill was placed within the groin field as well as along the beach 1,000 ft north and 2,000 ft south of the structures	300,000	4,500	67	AIWW dredge spoil through Nassau Sound
20	June, 2002	Survey	Pre-construction (2002 Shore Stabilization Project)				
21	2002	Groin Removal / Beach Nourishment	Phase 1 of the South Amelia Island Shore Stabilization Project was constructed between monuments R-79 and R-60 along Amelia Island State Park and northward thereof. Prior to construction, all shore-parallel and shore-perpendicular geotextil structures are removed	1,800,000			
22	August, 2002	Survey	Post-Construction (2002 Shore Stabilization Project)				

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
23	May, 2003	Survey	9-Months Post Construction (collected independently by FDEP)				
24	October, 2003	Survey	14-Months Post Construction				
25	March, 2004	Survey	19-Months Post Construction				
26	2004/2005	Breakwater / Groin Construction	Phase 2 of the South Amelia Island Shore Stabilization Project was constructed consisting of 3 engineered rubble mound erosion control structures, a detached breakwater and two groins, including a "leaky" terminal groin at the south end of the island in an east-west orientation				
27	March, 2005	Survey	31-Months Post Construction				
28	September, 2005	Survey	37-Months Post Construction				
29	2006	Beach Nourishment	USACE placed fill onto the south Amelia Island beaches between the detached breakwater and the terminal groin, or between monuments R-76 to R-79	400,000			
30	July, 2006	Survey	47-Months Post Construction				
31	June, 2007	Survey	58-Months Post Construction				
32	July, 2008	Survey	Condition surveys for each structure including adjacent beaches; beach profiles from R-55 to R-82; including half-stations between R-73 and R-82; Bathymetric surveys of Nassau Sound (including borrow areas)				

ENGINEERING ACTIVITIES LOG FOR CAPTIVA ISLAND

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
1	1960s - 1970s	Seawalls & Revetment Construction	Extensive Seawalls and Revetments are placed				
2	1961	Groin Construction & Beach Nourishment	134 Groins are constructed on Captiva Island; fill placed along Captiva Island	107,000			
3	1966	Groin Construction	2 timber groins are constructed at the middle of captiva Island				
4	November - December, 1973	Beach Nourishment	Fill placed on Captiva Island	5,000			
5	July, 1976	Jetty Construction	The recently constructed jetty is deemed to be a navigation hazard				
6	1977	Groin Construction	A 350-ft rock groin is constructed at the north end of Captiva Island at Redfish Pass; a 1,500 foot long rubble rock revetment is constructed at the Gulf beach at the north end of Captiva Island				
7	1981	Beach Nourishment	Fill placed on South Seas Resort	655,000			
8	1988	Groin Construction & Beach Nourishment	Fill placed on Captiva Island & Blind Pass Groin constructed	1,600,000			
9	1991	Beach Nourishment	Fill placed on SO. Seas Plantation				
10	1996	Beach Nourishment	Fill placed along Captiva Island	821,000			
11	2005 - 2006	Beach Nourishment	Fill placed on Captiva Island	1,017,000			
12	July, 2006	Groin Reconstruction & Extention	Redfish Pass Groin reconstructed and extended				
13	April, 2008	Beach Nourishment	Fill placed on Captiva Island	100,000			

ENGINEERING ACTIVITIES LOG FOR JOHN'S PASS

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
1	1926	Bridge Construction	Pinellas County constructed bridges across Blind Pass & Johns Pass and built a road on Treasure Island				
2	1934	Groin Construction	Two 150-ft groins are built on the Veteran's Administration Beach at Madeira Beach				
3	1957	Groin Construction	The City of Madeira Beach builds a groin field of 37 groins over its entire frontage. These groins were constructed of timber piles with adjustable timber and concrete panels				
4	1960	Groin Construction	The City of Treasure Island installs a groin field of 56 groins on the southern frontage of Treasure Island. 94,000 cy of material is dredged from Johns Pass and placed on the outer bar of Johns Pass (20,000 ft offshore)	94,000			
5	1961	Jetty Construction & Beach Nourishment	A 460-ft curved jetty is installed on the north side of Johns Pass, and fill is placed on the beach north of Johns Pass	30,000			
6	1964	Beach Nourishment	Fill placed on Sunset Beach (Treasure Island)	10,000			Dredge from Blind Pass
7	1966	Dredging	Channel Maintenance	77,650			
8	1966	Revetment Construction	A 920-ft long revetment is placed along the south bank of Johns Pass				
9	1969	Bridge Construction	New bridge over Johns Pass is completed				
10	1969	Beach Nourishment	Fill placed on Treasure Island	790,000	1,000	790	Dredge from Blind Pass
11	1971	Beach Nourishment	Fill placed on Treasure Island	75,000	1,600	47	Dredge from Johns Pass
12	1972	Beach Nourishment	Fill placed on Treasure Island	150,000	1,400	107	
13	1974	Survey	Beach Profile Surveys for Treasure Island				
14	1976	Groin Construction & Beach Nourishment	USACE begins construction of 2 impermeable sheet pile groins and the third periodic nourishment of Treasure Island beaches north of Blind Pass. The groin at the southern end of Treasure Island is 360-ft long and the 2nd groin (2,300 ft north of the first) is 285-ft long	404,849			
15	1976	Beach Nourishment & Groin Extention	Fill placed on southern portion of Treasure Island; Groin extended and stabilized at south end of island	380,000	7,920	48	offshore borrow area
16	December, 1978	Beach Nourishment	Fill placed on southern Treasure Island	32,000			Dredge from Blind Pass
17	1979	Dredging	Channel Maintenance	80,000			
18	1981	Dredging	Channel Maintenance	70,000			
19	1983	Dredging	Channel Maintenance	80,000			
20	1983	Beach Nourishment	Fill placed on Treasure Island	220,000			
21	1986	Emergency Beach Nourishment	Repairs to Treasure Island	549,000			

No	Date	Project Type	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
22	1988	Beach Nourishment	Initial Fill placed on North Redington Beach				
23	1987	Groin Rehabilitation	Rehabilitation of Groin at Johns Pass completed				
24	1991	Dredging	Channel Maintenance	56,000			
25	June, 1996	Beach Nourishment	Fill placed on Sunset Beach (Treasure Island) & northern 2,400 feet of Long Key	252,950			Egmont Shoal
26	2000	Dredging	Channel Maintenance	390,000			
27	2000	Groin Construction	Terminal groin constructed on the south side of John's Pass				
28	May, 2000	Beach Nourishment	Fill placed along the northern 2,400 feet of Long Key & Sunset Beach (Treasure Island)	358,900	2,400	150	Blind Pass & Johns Pass
29	August, 2000	Beach Nourishment	Fill placed along Sunset Beach (Treasure Island) between monuments DNR-136 and DNR-141	40,000			Blind Pass & Johns Pass
30	September, 2004	Beach Nourishment	Fill placed along southern third of Treasure Island between monuments DNR-136 and DNR-141. Following Hurricane Jeanne, additional fill was placed along Sunset Beach to complete segment and repair damages due to the storm	225,422	5,100	44	
31	February, 2006	Survey	Beach Profile Surveys done for Long Key & Treasure Island				
32	August, 2006	Beach Nourishment	Fill placed on Sunshine Beach & Sunset Beach (Treasure Island)	184,272			Egmont Shoal
33	December, 2006	Survey	Beach Profile Surveys done for Long Key & Treasure Island				
34	August, 2007	Survey	Beach Profile Surveys done for Long Key & Treasure Island				
35	October, 2008	Survey	Beach Profile Surveys done for Long Key & Treasure Island				
36	2009	Dredging	Channel Maintenance	375,000			

Appendix D

Environmental Sources and Contacts

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
Aaron Adams	Fisheries Specialist	Mote Marine Laboratory		aadams@mote.org	10/13/09	fisheries data for Pine Sound
Adam Fauth	IT Specialist	Pea Island National Wildlife Refuge	252-473-1131	Adam_Fauth@fws.gov	11/30/09	receive files for annual narrative reports on ftp site
Adam Gelber	Program Manager - Ecological Science	PBS&J	305-514-3387	agelber@pbsj.com	11/23/2009, 1/14/10	SAV data for FL projects
Alan Shirey		USACE Charleston	843-329-8166	alan.d.shirey@usace.army.mil	9/10 email	emailed response 9/10 No monitoring to his knowledge on Hunting Island
Albert E. Browder, Ph.D., P.E.	Senior Engineer/ Vice-President	Olsen Associates	904-387-6114 ext 15	abrowder@olsen-associates.com	12/4/09	Nassau Sound Inlet Management Plan
Amanda Bryant	Biologist	Sanibel-Captiva Conservation Foundation	239-472-3984	abryant@sccf.org	12/4/09	sea turtle data for Captiva and Sanibel
Amanda Hardy	Biologist	Amelia Island Plantation	904-321-5082	nelsonc@aipfl.com	1/14/10	pre- and post-construction monitoring data for Amelia Island
	Assistant Director	Pinellas County Envir. Mngt.	727-464-4633	asquires@pinellascounty.org	10/26/09	permits for Johns Pass
Andy Coburn	Associate Director	Program for the Study of Developed Shorelines, Western Carolina Univeristy		acoburn@wcu.edu	11/2/09	natural resource information relative to terminal groins
Angela Mangiameli	Conservation Biologist	Audubon North Carolina	910-686-7527	amangiameli@audubon.org	10/11/09	request bird data for NC inlets
Ann Hodgson	Gulf Coast Ecosystem Science Coordinator	Audubon, Florida Coastal Islands Sanctuaries Program	813--623-6826	Ahodgson@audubon.org	1/7/10	Requested shorebird data for Johns Pass

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
Ann Marie Lauritsen	Biologist	USFWS Jacksonville	904-525-0661	annmarie_lauritsen@fws.gov	10/28/09	biological information on Johns Pass and Amelia Island
Anne Deaton	Habitat Specialist	NC Division of Marine Fisheries	252-726-7021	Anne.Deaton@ncdenr.gov	11/19/09	Coastal Habitat Protection Plan - updated version
Annette Nielsen	Environmental Specialist II	Charlotte Harbor Preserve State Park-FL DEP	941-575-5861	annette.nielsen@dep.state.fl.us	10/13/09	Redfish Pass and Stump Pass info
Audra Livergood	Habitat Restoration Specialist	NMFS - NOAA Habitat Conservation Division	954-356-7100	audra.livergood@noaa.gov	11/2/09	biological monitoring data for FL
Beth Brost	Biological Scientist II	Florida Fish and Wildlife Conservation Commission	727-896-8626 ext 1914	beth.brost@myfwc.com	12/4/09	historical sea turtle data for FL
Beth Irlandi	Assistant Professor of Oceanography	Department of Marine and Environmental Systems, Florida Institute of Technology	321-674-7454	irlandi@fit.edu	11/23/09	biological monitoring data for FL
Beverlee Lawrence	Project Manager/Biologist	USACE - Jacksonville District	904-232-1904	beverlee.a.lawrence@usace.army.n	11/3/09	Amelia Shore Stabilization Project
Bill Birkemeier	Washington DC liaison	USACE - Coastal & Hydraulics Laboratory	252-261-6840 ext 229	William.Birkemeier@usace.army.mi	11/7/09	background on CHL's studies
Bill Dennis	Coastal Engineer	USACE - Wilmington District	910-251-4780	william.a.dennis@usace.army.mil	11/4/09	Final Supplemental EIS on Manteo (Shallowbag) Bay
Bill Kirby Smith		Duke Univ. Marine Lab		wwks@duke.edu	12/1/09	marine ecology
Blaire Witherington	Research Scientist	Florida Fish and Wildlife Conservation Commission Fish and Wildlife Research Institute	321-674-1801		1/14/10	Effects of ocean inlets on sea turtle nesting
Bob Brantley	Coastal Engineering Manager	FL DEP	850-413-7803	Robert.brantly@dep.state.fl.us		included in email chain from C.Hand 9/10-9/11
Bob Joseph	Park Manager	Talbot Island State Park	904-251-2320	robert.joseph@dep.state.fl.us	11/30/09	pre- and post-construction monitoring data for Amelia Island
Bob Wasno	Marine Agent	Florida Sea Grant College Program	461-7518	wasnorm@leegov.com	11/23/09	biological monitoring data for Redfish Pass and/or Blind Pass

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
Bonnie Bendell	Coastal Engineer	NC Division of Coastal Management	919-733-2293 ext 256	Bonnie.Bendell@ncdenr.gov	11/19/09	NC estuarine policy on groins
Bonnie Strawser	Visitor Services Manager	Alligator River/Pea Island National Wildlife Refuges	252-473-1131 ext 230	Bonnie_Strawser@fws.gov	11/24/09	Pea Island data - ftp site
Brad Smith	Director	Sanibel / Captiva Conservation Wildlife Habitat Management Office	239-472-3984 ext. 200		11/25/2009, 1/14/10	biological monitoring data for Redfish Pass and/or Blind Pass
Brandon Howard	Biologist	USACE - Jacksonbille District	561-472-3527	brandon.howard@saj02.usace.army	11/23/09	biological monitoring data for FL
Brent Stufflebeam	Student Aide	USACE - Fort Myers Regulatory Division	239-334-1975 ext 26	brent.a.stufflebeam@usace.army.m	11/19/09	regulatory permits for Redfish Pass
Britta Muiznieks	biologist	Cape Hatteras National Seashore	252.995.3740	Britta_Muiznieks@nps.gov	10/15/09	breeding and non-breeding data for the N side of the inlet (Bodie Island Spit)
Carolyn Currin, PhD	Marine Scientist and Microbiologist	NMFS - NOAA Office of Habitat Protection	252-728-8749	carolyn.currin@noaa.gov	11/2/09	fisheries data for study sites
Chad Lach	Manager	Florida State Parks	941-964-0375	chad.lach@dep.state.fl.us	11/25/09	biological monitoring data for Captiva
Charlotte Hand	JCP Compliance Officer	FL DEP	850-414-7716	Charlotte.hand@dep.state.fl.us	9/11/09	received email 9/10 regarding turtles and permit compliance for projects
Chase Gatlin	GIS Specialist	Cape Hatteras National Seashore	252-995-6968		11/9/09	GIS data for Oregon Inlet - Bodie Island spit
Chris Canfield	ED & VP	NC Audubon	919-929-3899	CCANFIELD@audubon.org	10/6/09	
Chris Freeman	Senior Coastal Geologist	Geodynamics	252-247-5785	chris@geodynamicsgroup.com	11/5/09	shoreline change data for Fort Macon
Christina Nelson		Amelia Island Plantation	904-321-5082	nelsonc@aipfl.com	11/30/2009, 1/14/10	pre- and post-construction monitoring data for Amelia Island
Chuck Schnepel	Regulatory Chief	USACE Tampa Bay	813-769-7071	chales.a.schnepel@usace.army.mil	10/29/09	regulatory documents on Johns Pass
Clarence Coleman		Federal Highways Administration			11/10/09	Bonner Bridge EIS
Craig Ten Brink	Wildlife Biologist	Threatened & Endangered Species-Marine Corps Base Camp Lejeune	910-451-7228	craig.tenbrink@usmc.mil	10/9/09	phone call to determine if USMC has analyzed terminal groins in mgmt

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
Cynthia Scott	Administrative Support Supervisor	Pinellas Co. Dept. of Env. Management		csscott@co.pinellas.fl.us	10/17/09	Johns Pass permit
Dan Rittschoff, PhD	Associate Professor of Zoology	Duke Univ. Marine Lab		RITT@duke.edu	11/13/09	habitat change for Shackelford Banks and Bird Shoal
Dave Kandz		Audubon of Florida		conservation@stpeteaudubon.org	11/23/2009, 1/14/10	shorebird nesting data for Redfish Pass and Johns Pass
David Allen	Wildlife Diversity Supervisor	NC Wildlife Resources Commission	252-448-1546	allend@coastalnet.com	10/5/09	forwarded C. Canfield's message (included Sam Cooper and Greg Massey)
David Bernhart		National Marine Fisheries Service, SE Regional Office	727-570-5312	david.bernhart@noaa.gov	11/23/09	SAV data for FL projects
David Eggleston, PhD		NC State University, Center for Marine Sciences and Technology		david_eggleston@ncsu.edu	12/1/09	marine biology
Dennis Stewart	biologist	Pea Island National Wildlife Refuge	252-473-1131 ext 231	dennis_stewart@fws.gov	10/16/09	PINWR data
Donald Deis	Senior Scientist	PBS&J	904-363-8442	ddeis@pbsj.com	11/23/09	seagrass data for FL
Don Fields	Principal Investigator	NOAA Center for Coastal Fisheries and Habitat Research	252-728-8770	don.field@noaa.gov	12/1/09	SAV data for NC study sites
Doug Piatowski	Biologist	USACE, Wilmington	910-251-4908	Douglas.Piatkowski@usace.army.m	10/8/09	NC Inlet - USACE info
Elizabeth Gillen		FL DEP Fort Meyers	239-332-6975	elizabeth.gillen@dep.state.fl.us	10/14/09	Redfish Pass permit requirements
Ellen McCarron	Assistant Director	Office of Coastal and Aquatic Managed Areas	850-245-2110	Ellen.McCarron@dep.state.fl.us	10/7/09	Bird rookery monitoring and Charlotte Harbor Volunteer Water Quality Monitoring Network
Emily Rice	Assistant Waterbird Biologist	NCWRC	252-393-6585	emily.rice@ncwildlife.org	10/12/09	request bird data for NC inlets
Eric Gasch	Biologist - Environmental Planning	USACE - Jacksonville District	904-232-3140	eric.k.gasch@saj02.usace.army.mil	10/29/09	regulatory documents relative to terminal groins

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
Erik Olsen	President	Olsen Associates	904-387-6114	eolsen@olsen-associates.com	9/9/09	emailed 9/09. Received response 9/09
Erin Rasnake		FL DEP		Erin.Rasnake@dep.state.fl.us	10/7/09	requested biological data for Redfish Pass via email
Eve Haverfield		Turtle Time Inc.	239-851-1338		11/25/09	sea turtle nesting data for Pinellas County and Lee County
Frank Yelverton	Lead Biologist, Environmental Resources Section	USACE, Wilmington	910-251-4640	frank.yelverton@usace.army.mil	10/8/09	NC Inlet - USACE info
Fritz Rohde	Fishery Biologist	NMFS - NOAA	252-728-5090	fritz.rohde@noaa.gov	10/1/09	fisheries and benthic data for NC
Harry LeGrand	Naturalist	NC Natural Heritage Program DENR Division of Natural Resources Planning and Conservation	919-715-8697		11/6/09	vegetation data for dune habitats at inlets
Heather Strafford	Manager	Charlotte Harbor Aquatic Preserves	850-245-2110	Heather.Stafford@dep.state.fl.us	10/7/09	Bird rookery monitoring and Charlotte Harbor Volunteer Water Quality Monitoring Network
Hope Sutton	Stewardship Coordinator	NC National Estuarine Research Reserve	910-962-2998	suttonh@uncw.edu	11/9/09	sea turtle data for Shackelford Banks
Howard Hall	Fish and Wildlife Biologist	USFWS - Ecological Services	919 856-4520 ext 27	howard_hall@fws.gov	10/8/09	fisheries and benthic data for NC; BO for Oregon Inlet
Hugh Heine	Biologist	USACE - Wilmington District	910-251-4070	hugh.heine@usace.army.mil	11/4/09	nearshore hardbottom data for Beaufort Inlet
Jackie Keiser	Project Manager	USACE Jacksonville	904-232-3915	Jacqueline.J.Keiser@saj02.usace.	10/5/09	
Jackie Ott	GIS Specialist	NC National Estuarine Research Reserve	910-962-2324	ottj@uncw.edu	10/13/09	GIS Data for Oregon Inlet and Beaufort Inlet
Jaime Collazo, PhD	Biology Professor	NC State University	919-515-8837	jaime_collazo@ncsu.edu	11/9/09	breeding and non-breeding data for the N side of the inlet (Bodie Island Spit)
WD Higginbotham	City Manager	Madeira Beach, Fl	727.391.9951	jmadden@ci.madeira-beach.fl.us	12/18/2009, 1/14/10	environmental documents for John's Pass
Jason Powell		Cape Hatteras National Seashore	252-473-4018		11/9/09	archival data for Cape Hatteras National Seashore

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
Jeff Howe	Fish and Wildlife Biologist	USFWS S. FL. Ecological Services Office	772-562-3909 ext 283	jeffrey_howe@fws.gov	10/25/09	Service Biological Opinion on marine structures
Jennifer Nelson	Environmental Administrator	Florida Department of Environmental Protection South District Office	239-332-6975	Jennifer.Nelson@dep.state.fl.us	10/7/09	water quality data for Redfish Pass
Jill Huntington	Coastal Management Specialist	GA DNR/Coastal Management	912-264-7218	jill_huntington@dnr.state.ga.us	9/9/09	Left message. No response 9/09 E. Olsen has monitoring data for Tybee Island project
Joanne Steenhuis	Senior Environmental Specialist	NCDENR - NC Division of Water Quality	910-796-7306	Joanne.Steenhuis@ncdenr.gov	10/13/09	401 Certification for Oregon Inlet
Jocelyn Karazsia	Fishery Biologist	NMFS - NOAA Protected Species Section	561-616-8880 ext 207		11/2/2009, 1/14/10	
Johathan Cohen, PhD	Research Scientist	Virginia Tech	540-231-9069	jocohen1@vt.edu	10/14/09	non-breeding piping plovers at Oregon Inlet
John Fussell	ornithologist		252-240-1046	jfuss@clis.com	10/7/09	request bird data for NC inlets
Jon Altman	Biologist	Cape Lookout National Seashore	252-728-2250	jon_altman@nps.gov	11/9/09	sea turtle data for Shackelford Banks
Joy Hazell	Agent	Florida Sea Grant College Program	239-533-7518	jhazell@ufl.edu	11/30/09	fish data for Redfish Pass
Judy Ott	Program Scientist	Charlotte Harbor National Estuary Program	239-338-2556 ext 230	jott@swfrpc.org	10/8/2009, 1/14/10	biological information on aquatic preserve and background info on Redfish Pass, Blind Pass, and Stump Pass
Katherine McGlade		NC Coastal Federation	203 962 3046	katherinem@nccoast.org	12/1/09	Pea Island data - infauna graphs
Kathy Rooker	Administrator	Lee County	239-472-2472	mycepd@gmail.com	10/15/09	biological monitoring reports for Captiva
Kenneth Dugger	Section Chief, Supervisory Biologist	USACE - Jacksonville District	904-232-1686	Kenneth.R.Dugger@usace.army.mi	11/25/09	biological monitoring reports
Ken Taylor	Chief	N.C. Geological Survey	919-733-2423 ext 401	kenneth.b.taylor@ncdenr.gov	10/1/09	

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
Kevin Conner	Coastal Engineer	USACE-Wilmington District	910-251-4867		11/4/09	discussion of Beaufort Inlet ebb tidal delta deflation
Kristie Anders	Educational Director	SCCF	239-472-2329	kanders@sccf.org	10/14/09	Redfish Pass background
Larry Cahoon, PhD	oceanographer	UNCW	910-962-3000	cahoon@uncw.edu	10/7/09	general information for NC inlets
Lee Edmiston	Director	Office of Coastal and Aquatic Managed Areas FL DEP Tallahassee	850-245-2110	Lee.Edmiston@dep.state.fl.us	10/7/2009, 1/14/10	Bird rookery monitoring and Charlotte Harbor Volunteer Water Quality Monitoring Network
Loren D. Coen, PhD	Director	Sanibel-Captiva Conservation Foundation Marine Laboratory	239-395-3115	lcoen@sccf.org	10/6/2009, 1/14/10	biological information on Redfish Pass and Captiva Island
Lynn Leonard	Professor of Geology	UNCW		lynnl@uncw.edu	11/3/09	data on Redfish Pass based on journal article
Maia McGuire	Marine Agent	Florida Sea Grant College Program	824-4564	mpmcguire@ifas.ufl.edu	11/23/09	biological monitoring data for Amelia Island
Margery Overton, PhD	Civil, Construction and Envrionmental Engineering Professor	NC State University	919-515-7682	overton@ncsu.edu	11/2/09	natural resource information relative to terminal groins
Mark Evans		USACE	904-232-2028	mark.r.evans@usace.army.mil	11/3/09	Amelia Shore Stabilization Project
Mark Fonesca, PhD	Supervisory Ecologist	NMFS - NOAA NOS/CCFHR	252-728-8729	mark.fonseca@noaa.gov	11/2/2009, 1/14/10	fisheries data for study sites
Mark Ladeon		Beaches & Shore Resource Center - Lee County	850-487-7723	mark.leadon@dep.state.fl.us	11/12/09	FL inlet management documents
Mark Sramek	Fishery Biologist	NMFS - NOAA Protected Species Section	727-824-5311	Mark.Sramek@noaa.gov.	10/30/2009, 1/14/10	Gulf Coast information
Mark Thompson		NMFS - NOAA Habitat Conservation Division	850-234-5061	mark.thompson@noaa.gov	11/23/09	biological monitoring data for FL
Martin Posey, PhD	Department Chair	UNCW - Biology Department	910-962-3470	poseym@uncw.edu	11/4/09	infaunal data for Oregon and Beaufort Inlet

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
Marty Seeling	Biological Administrator	Beaches and Coastal Systems permitting - FL DEP	850-487-4471, extension 104., 850-414-7728	martin.seeling@dep.state.fl.us	09/09/2009, 10/14/2009, 1/14/10	Sent email with permit info 9/09, email sent 9/10 regarding monitoring; NEPA documents on FL study sites
Mary Saunders	Project Manager	USACE - Jacksonville District		mary.l.saunders@usace.army.mil	12/24/09	Captiva biological monitoring reports
Matthew Godfrey, PhD	Sea Turtle Biologist	NC Wildlife Resources Commission	252-728-1528	matt.godfrey@ncwildlife.org	10/5/09	request sea turtle trend data (included Molly Ellwood, Rudi Rudolph, Jean Beasley, Doug Piatowsky) and other biological data
Michael Hensley	Manager	Lovers Key State Park	239-463-4588		11/25/09	biological monitoring data
Michael Piehler, PhD		UNC Chapel Hill		mpiehler@email.unc.edu	12/1/09	nearshore habitat/ water column processes
Michael Rikard	Resource Management Specialist	Cape Lookout National Seashore	252-728-2250 ext 3012	Michael_Rikard@nps.gov	11/11/09	Shoreline change data for Shackelford Banks
Mike Anderson	Manager of Sea Turtle Nesting	Clearwater Marine Aquarium	727-441-1790 ext 224	manderson@cmaquarium.org	11/11/09	sea turtle nesting data for Pinellas County
Mike Giles	Cape Fear COASTKEEPER	NC Coastal Federation	910-790-3275	capefearcoastkeeper@nccoast.org	10/23/09	terminal groin data for NC
Mike Maxemow	Public Works Director					
Mike Mullens	Board of Director	Captiva Erosion and Protection Division	239-472-2472	mycepd@gmail.com	11/25/09	biological monitoring data for Captiva
Mike Nowicki	Project Manager and Engineer	USACE - Jacksonville District, Regulatory Division	904-232-2171	Michael.F.Nowicki@usace.army.mil	10/29/09	environmental planning documents relative to terminal groins
Mike Simmons	Environmental Specialist I	Talbot Island State Park	904 251-2815	Michael.T.Simmons@dep.state.fl.us	11/12/09	shorebird data for Amelia Island State Park
Mindy Brown		Charlotte Harbor Aquatic Preserves	341-575-5861			bird data for Captiva
Molly Ellwood	Southeast Permit Coordinator	NC Wildlife Resources Commission	910-796-7240	molly.ellwood@ncwildlife.org	10/5/09	recommendations for biological contacts
Nancy Douglas		FWC	863-647-4000 ext 1137		12/4/09	shorebird data for Pinellas and Lee Counties

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
Nancy White	Director	UNC Coastal Studies Institute, ECU	252-475-3663	nmwhite@csi.northcarolina.edu	12/1/09	biological data relevant to terminal groins
Nicole Elko, PhD	President	Elko Coastal Consulting	727-439-4774	nelko@pinellascounty.org	8/09 (call message), 9/8 (call message), 9/9 (email)	Nicole no longer works for Pinellas county. Andrew Squires responded via email 9/09.
Pace Wilbur	Atlantic Branch Supervisor, Fishery Biologist	NMFS - NOAA Habitat Conservation Division	843-953-7200	pace.wilber@noaa.gov	11/2/09	fisheries data for study sites
Paden Woodruff	Environmental Administrator	FL DEP Beach Erosion Control Program	850-922-7703	Paden.Woodruff@dep.state.fl.us	9/9/09	contactted by email and forwarded to M. Seeling 9/09
Paula Gillikin	Rachel Carson Site Manager	NC Coastal Reserve & National Estuarine Research Reserve	252.838.0886	paula.gillikin@ncdenr.gov	10/16/09	information on habitat alterations and/or other anectodal sightings for Bird Shoals.
Paula Johnson	Project Manager	USACE - Jacksonville District	904-232-2503	Paula.R.Johnson@usace.army.mil		
Penny Hall	biologist	Florida Fish and Wildlife Conservation Commission	727-896-8626	penny.hall@myfwc.com	11/23/09	SAV data for FL projects
Pete Peterson, PhD	Scientist	University of North Carolina at Chapel Hill	252) 726-6841	CPeters@email.unc.edu	10/6/09	request biological data for NC terminal groins - fisheries/benthic
Phil Payonk	Chief, Environmental Resources Section	USACE, Wilmington	910 251-4589	philip.m.payonk@usace.army.mil	9/22/09	
Ping Wang, PhD		University of S. Florida	813-974-9170	pwang@chuma1.cas.usf.edu	9/10/09	email 9/10
Randy Newman	Park Ranger	Fort Macon State Park	(252) 726-3775	randy.newman@ncdenr.gov	11/3/09	background on Fort Macon terminal groin
Richard D. Bartleson, Ph.D.	Research Scientist	Sanibel-Captiva Conservation Foundation Marine Lab	239-395-4617	rbartleson@sccf.org	10/6/2009, 1/14/10	requested biological data for Redfish Pass via phone
Richard Fischer, PhD	Certified Wildlife Biologist	U.S. Army Engineer Research & Development Center	502-315-6707	Richard.A.Fischer@usace.army.mil	11/13/09	natural resource information relative to terminal groins for Oregon Inlet

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
Rob Young	Director	Program for the Study of Developed Shorelines, Western Carolina Univeristy		ryoung@wcu.edu	11/2/09	natural resource information relative to terminal groins
Robert Ginsburg, PhD	professor of marine geology	RSMAS, University of Miami, FL	305 421 4875	rginsburg@rsmas.miami.edu	10/7/09	request for hardbottom information in selected FL sites
Robert Neal		Lee County	239-533-8566		10/6/09	Gaspiralla Island information - USACE GRR/EIS
Robin Trindell, PhD	Biological Administrator	Florida Fish and Wildlife Conservation Commission	850-922-4330	Robbin.Trindell@fwc.state.fl.us	9/10/09	email 9/10; replied 9/10
Roland Ottolini	Supervisor	Lee County	239-533-5533	rottolini@leegov.com	10/14/2009, 1/14/10	Redfish Pass - inlel management details
Ron Sechler	Fishery Biologist	NMFS - NOAA	252-728-5090	ron.sechler@noaa.gov	10/1/09	fisheries and benthic data for NC
Sam Cooper	Environmental Scientist	CZR Incorporated	910-392-9253	scooper@czr-inc.com	10/5/09	bird survey information for Oregon Inlet and Beaufort Inlet
Sara Winslow		NC Division of Marine Fisheries	252-264-3911	sara.winslow@ncmail.net	10/8/09	fisheries and benthic data for NC
Scott Chappell	GIS Specialist	NC Division of Marine Fisheries	252-808-8071	scott.chappell@ncdenr.gov	12/1/09	SAV data for NC study sites
Sidney Maddock	Conservation Biologist	Audubon North Carolina	252-996-0234	smaddock@audubon.org	10/10/2009, 1/14/10	request bird data for NC inlets
Spencer Rogers		North Carolina Sea Grant	910-962-2491	rogerssp@uncw.edu	9/11/09	
Stan Riggs	Coastal and Marine Geologist	East Carolina University	328-6015	riggss@ecu.edu	12/1/09	contacts for biological data
Steve Benton	Retired	Science Hazard Panel	919-231-2885	sbenton45@earthlink.net	11/6/09	environmental data for NC inlets
Steve Boutelle	Operations Manager, Marine Services	Lee County	239-533-8128	boutelsj@leegov.com	1/14/10	general operation of Redfish Pass terminal groin
Steve Everhart	District Manager	NC Division of Coastal Management	910-796-7215	Steve.Everhart@ncdenr.gov	11/9/09	sea turtle data
Steve Keehn	Coastal Engineer	Coastal Planning & Engineering, Inc.	561-391-8102	skeehn@coastalplanning.net	10/5/2009, 1/14/10	Redfish and Johns Pass data
Steve Ross	Research Associate Professor	University of NC at Wilmington	910-395-3905	rosss@uncw.edu	11/15/09	fisheries data for NC

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
Steve Underwood	Assistant Director of Policy & Planning	NC Division of Coastal Management	919-733-2293 ext 224	Steve.Underwood@ncdenr.gov	11/17/09	environmental data on rubble structures
Susan Blass		USACE - Jacksonville District		Susan.M.Blass@saj02.usace.army.	11/9/09	Redfish Pass NEPA documents
Susan Cohen	Program Manager	MCB Camp Lejeune, NC	910-451-7900	susan.cohen@usmc.mil	10/28/09	barrier island dynamics
Tampa Audubon Chapter				president@tampaaudubon.org	11/25/09	shorebird nesting data for Johns Pass
Tancred Miller	Coastal Policy Analyst	NC Division of Coastal Management	252-808-2808	Tancred.Miller@ncdenr.gov	11/17/09	Biological and Estuarine Working Group
Todd Miller	Executive Director	NC Coastal Federation	252 393-8185	toddm@nccoast.org	9/29/09	terminal groin data for NC
Tom Jarrett	professional engineer	Coastal Planning & Engineering of North Carolina	910-392-0453	tjarrett@coastalplanning.net	10/5/09	information on the construction timeframe of NC terminal groins
Tori Deal	JCP Compliance	FL DEP	850-414-7731	Tori.Deal@dep.state.fl.us	9/11/09, 9/14, 9/14, 9/17	Providing permits and engineering files on FL groin projects
Tracy Rice		Terwilliger Consulting, Inc.	610-693-1147	tracymrice@yahoo.com	11/2/09	threats to sandy beach ecosystems
Tracy Skrabal	Coastal Scientist & Southeast Regional Manager	NC Coastal Federation	910-790-3275	tracys@nccoast.org	9/29/09	terminal groin data for NC
Troy Alphin	lab manager	UNCW - Center for Marine Science	910-962-2395	alphint@uncw.edu	11/4/09	infaunal data for Oregon and Beaufort Inlet
Tunis McElwain				Tunis.W.McElwain@usace.army.mil	11/18/09	regulatory permits for Redfish Pass
USACE Florida Shore Protection and Sea Turtle Management System	NA	NA	NA	http://el.erdc.usace.army.mil/flsho	NA	literature on FL sea turtle nesting
USACE Turtle Warehouse Data	NA	NA	NA	http://el.erdc.usace.army.mil/seatu	NA	literature on FL sea turtle nesting
Vincent George	Project Manager and Planning Consultant	Bureau of Beaches and Coastal Systems	850-413-7783	vincent.george@dep.state.fl.us	11/6/2009, 1/14/10	Redfish Pass Inlet Management Plan - CPE study ('93)

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
Walker Golder	Bird Ecologist	Audubon		wgolder@audubon.org	10/5/09	forwarded C. Canfield's message (included Andy Wood and Angela Mangiamelli) - follow up
Wilson Laney		USFWS - South Atlantic Division	919-515-5019	Wilson_laney@fws.gov	10/8/09	fisheries and benthic data for NC

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Photo Courtesy of Carteret County Shore Protection Office

1616 East Millbrook Road, Suite 160
Raleigh, North Carolina 27609
P 919.781.4626   F 919.781.4869
www.moffattnichol.com