NCDENR

North Carolina Coastal Resources Commission

FINAL REPORT
TERMINAL GROIN STUDY

March 1, 2010

Photo Courtesy of Carteret County Shore Protection Office

DIAL CORDY AND ASSOCIATES INC

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Executive Summary

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. Members of 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 and selection of study sites; and reviewed and commented on the study methodology and reports.

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 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 final two tasks were participation in the public input and meetings and the generation of a report for the CRC. 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.

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. In addition to the public hearings written comments could be submitted to the executive secretary of the CRC. The project website maintains a listing of these comments. 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.

Selection of Study Sites

- For this study, a *terminal groin* was defined as a structure built with the primary purpose to retain sand and not for navigation. It is a narrow, roughly shore-normal structure that generally only extends a short distance offshore.
- In consultation with the Science Panel, 25 sites with terminal structures along the Atlantic and Gulf coasts were initially considered. Five sites were then selected to be included in the study: Oregon Inlet, NC; Fort Macon, NC; Amelia Island, FL; Captiva Island, FL; and John's Pass, FL
- Only existing data was collected; no new data was acquired for this study.
- Uncertainties are associated with the data and should be recognized with any analyses.
- All five of the existing study sites have sand management activities (dredging, nourishment) as part of the overall project.

Physical Assessment

- Although terminal groins trap sand, they are dissimilar to a jetty, because once the terminal groin fills with sediment, additional sand bypasses the structure and enters the nearshore and / or the tidal inlet.
- Terminal groins are commonly built on either (or both) sides of inlets because in addition to the regional dominant longshore sediment transport system delivering sand preferentially to one side of an inlet, wave refraction around the ebb delta results in sand transport back toward the inlet along the downdrift shoreline.
- A 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.

- Dredging can have significant impacts on the inlet morphology and sedimentation processes of the ebb-tidal delta.
- 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.
- Quantitative analyses were performed for shoreline change; volumetric changes based on the shoreline changes; volumetric changes after subtracting out all beach nourishment and nearshore placement activities; and volumetric changes after subtracting out all beach nourishment and nearshore placement activities and then adding back in various scenarios for dredged material naturally bypassing the inlet.
- In all cases, the shorelines on the structure side of the inlet was eroding prior to construction of the terminal groin; and after construction, the shorelines on the structure side of the inlet were generally accreting.
- The data on the opposite side of the inlet does not display a clear trend (i.e. mixed accretion and erosion).
- After subtracting out all beach nourishment activities (but not accounting for dredging), the changes between pre- and post-construction periods on the terminal groin side show (note – "positive result" indicates an improvement; either reduced erosion, a change from erosion to accretion, or increased accretion; while "negative" indicates the converse):
    - There is a significant positive result over the first mile of shoreline (except for Amelia Island where this positive result only occurs over the first half mile);
    - For Oregon Inlet, Fort Macon, and Amelia Island there is a moderate negative result over the second mile and then much less of a change (either positive or negative) over the third mile;
    - For Oregon Inlet, further down the Pea Island shoreline, a positive result is present over the fourth mile and then minimal changes over the fifth and sixth miles;
    - On a cumulative basis, for Fort Macon and Oregon Inlet the positive results are significantly greater (about 150,000 cy / year) than any negative results over the shoreline reaches analyzed;
    - Amelia Island does not show a net positive result, but the adjustment in the post-nourishment shoreline that occurred during the very short post-construction analysis interval analyzed is likely the cause; and
    - For Captiva Island and John's Pass, the positive result is apparent over basically the entire three mile analysis length of shoreline with cumulative positive results amounting to 90,000 – 120,000 cy / year.

- After subtracting out all beach nourishment activities (but not accounting for dredging), the changes between pre- and post-construction periods show on the side opposite the terminal groin (note that no data was available for the Amelia Island study site):
  - Typically a minor to moderate negative result occurs over the first half to three-quarters of a mile. Whether this is the effect of terminal groin construction or other impacts such as increased dredging or migrating inlets, though, is not possible to definitively conclude.
  - For Captiva Island, John's Pass and Shackelford Banks the results turn positive after this initial distance with net cumulative positive results over the shoreline analyzed for Captiva Island and John's Pass and a negative result for Shackleford Banks.
  - At Oregon Inlet, the negative result continues for the second mile with minimal change over the third mile.
- Much like nourishment, the influence of dredging material from the inlet system must be accounted for when attempting to assess the impact of the terminal groins. These results show:

  One must assume about 25% of the material dredged from the inlet would have naturally reached Shackleford Banks for the negative pre- to post-construction change over the three-mile shoreline analysis interval to turn positive.

Environmental Assessment

- The environmental effects of a terminal groin structure alone could not be assessed for the sites without considering the associated beach nourishment activity.
- Potential effects of terminal groins in conjunction with shoreline management (i.e. beach nourishment) on natural resources vary according to the type of construction equipment used, the nature and location of sediment discharges, the time period of construction and maintenance in relation to life cycles of organisms that could be potentially affected, and the nature of the interaction of a particular species.
- The construction of a terminal groin, beach nourishment and dune construction prevents overwash and inlet migration thereby contributing to a loss of habitat for breeding and non-breeding shorebirds and waterbirds, including the piping plover.
- Terminal groins are typically used in combination with a long-term shoreline protection program (beach fill), in areas where pre-project shoreline conditions are generally degraded with limited potential sea turtle nesting activity.

- Based upon the historical nature of the terminal groins at Fort Macon, John's Pass (northern groin), and Redfish Pass; discernible trends 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 difficult if not impossible.
- While the use of control and/or regional sites strengthens the ability of a study to infer an impact from a detected change, one cannot infer an impact if there is no statistical evidence for a change (Mapstone 1995); and due to the lack of complete datasets and high levels of confidence in the quality of the data, statistical analysis was precluded.
- The current development and use of some of the selected 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, albeit sometimes on a limited basis.
- The terminal groins at Oregon Inlet and Amelia Island are more recent construction projects, and pre- and post-construction natural resource data readily available were evaluated (sea turtle and shorebird nesting data). 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.
- Anchoring the end of an island may curtail an inlet's natural migration patterns thereby minimizing the formation of sand flats;
- Fillet material should be compatible to minimize effects on benthic infauna recovery and upper trophic levels;
- Resources continue to use locations where terminal groins exist, however, if habitat succession occurs, species suitability may be affected.

Engineering Construction Techniques

- The five study sites all consist of rubble mound (rock) groins.
- 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.
- 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 shorter, mid to shallow-water groins; however, these materials tend to be cost-prohibitive. Timber and geotextile groins are less expensive alternatives and can be adapted to a variety of beach conditions, but also have limited applicability to shorter, shallow-water conditions.
- Concrete, steel, and timber structures have the advantage of being adjustable with the beach profile without having to rebuild or remodel the groin.
- Groin notching is an emerging technique that allows for adaptive management. 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.
- It appears that for shorter groins, the interruption to littoral transport is smaller compared to the overall magnitude of sediment transport and the muted impacts seen both updrift and downdrift of the inlet.
- There also seems to be a threshold that appears with both length and height to be crossed where adjacent impacts become more pronounced. While it is possible that dredging impacts may be responsible for this threshold crossing, it underlies the importance to considering the overall length of the structure in relation to the exterior man-made and natural processes that also drive sediment transport so that the structure's relative effects are minimized or eliminated.
- The permeability of the structure has a significant impact on adjacent shorelines. The Amelia Island structure has allowed material to bypass the structures to limit effects on downdrift shorelines and volumes. However, the structure has also had a limited impact on the updrift shoreline (mainly within the first 0.5 miles). The other structures have impermeable cores and appear to hold more sand for a greater distance updrift of the structure.

Economic Assessment

- The economic value at risk within the 30 year risk areas for developed shorelines varies greatly from about $27 million at Ocean Isle to over $320 million at Bald Head Island. It must be noted, though, that not all of these properties can be protected by a terminal groin.
- The economic value at current or imminent risk (as defined by the presence of sandbags for temporary protection) for developed shorelines varies from just under $3 million at North Topsail Beach to about $26 million at the north end of Figure Eight Island.
- Barrier island municipality tax bases range from $409 million for Caswell Beach to over $4.2 billion for Emerald Isle. The countywide tax bases range from $3.8 billion for Pender County to $29.1 billion for New Hanover County.
- The full value of residential property 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 soundfront location may transfer to nearby properties.
- Additional factors affecting the economic value of inlet areas were reviewed but not specifically quantified due to lack of data. Where possible, qualitative and case study information is provided for the following factors:
    - Beach Recreation Value
    - Shore / Surf / Beach Fishing
    - Primitive Area Hiking / Camping Value
    - Wetland Recreation Value
    - Value of Non-Game Wildlife in Beach and Coastal Wetland Areas
    - Value of Coastal Wetlands in Supporting Recreational Fishing
    - Value of Wetlands in Protecting Property from Hurricane Wind Damage
    - National Seashores and Refuges
    - State Parks

Initial Construction and Maintenance Costs

- Construction costs of terminal groins can vary greatly depending upon construction materials, length and beach profile.
- The construction costs (in 2009 dollars) of the five terminal groins analyzed range from less than $1 million for John's Pass and Captiva Island to about $24 million for Oregon Inlet.
- Four cost scenarios were developed:
    - Short, smaller cross-section groin (450 feet) on a flat-sloped beach
    - Short, smaller cross-section groin (450 feet) on a steep-sloped beach
    - Long, larger cross-section groin (1500 feet) on a flat-sloped beach
    - Long, larger cross-section groin (1500 feet) on a steep-sloped beach
- Rubble-mound terminal groins could range from about $1,230 per linear foot to $5,180 per linear foot.
- Geotextile Tube terminal groins could range from about $350 per linear foot to $660 per linear foot (short groin only; not recommended for longer groin)
- Steel or Concrete Sheet Pile or Timber terminal groins could range from about $4,000 per linear foot to $4,800 per linear foot. (Timber only recommended for short groin scenarios)
- Initial project costs including construction of the terminal groin, initial beach nourishment and permitting and design fees may range from about $3.5 million for a shorter groin to over $10 million for a larger one.
- Annual project costs including structure maintenance / repair, annual beach nourishment, and monitoring could be in the range of $0.7 million to over $2 million.
- Terminal groins are typically constructed as part of a broader beach management plan and may make nourishment adjacent to inlets feasible, but they do not eliminate the need for ongoing beach nourishment.
- These costs could vary substantially based on site conditions and design storm parameters.

Potential Locations

- The vast majority of the structures considered for this study were located at inlets with most of these adjacent to navigable, dredged channels.
- No terminal groins were identified as being located at the end of a non-inlet littoral cell.
- 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. These dredging activities may greatly outweigh any potential long-term shoreline changes resulting from the construction of a terminal groin.
- 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 may have the additional impact of "stabilizing" the location of a migrating inlet, such as the case at Oregon Inlet where this impact has also resulted in changes to the inlet cross-section – a general narrowing and deepening over time since terminal groin construction. Great care should be exercised when siting a terminal groin in this setting as the channel may shift and potential undermining of the groin may become a concern.
- Based on the existing sites and the literature review completed, the impacts of terminal groins on adjacent shorelines is difficult to identify if they exist at all if located adjacent to a highly managed, deeper-draft navigable inlet.
- The relative impact of these structures on adjacent areas is likely increased when sited next to natural or minimally managed shallow-draft inlets. For these locations, additional care and study (geologic setting, sediment budgets, etc.) is warranted to be sure that the terminal groin's impacts are acceptable or can be mitigated through minimal human activities (dredging and nourishment).

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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. Members of 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 and selection of study sites; and reviewed and commented on the study methodology 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. A list of the CRC, Science Panel and the CRC/CRAC steering committee are provided in Appendix A.

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

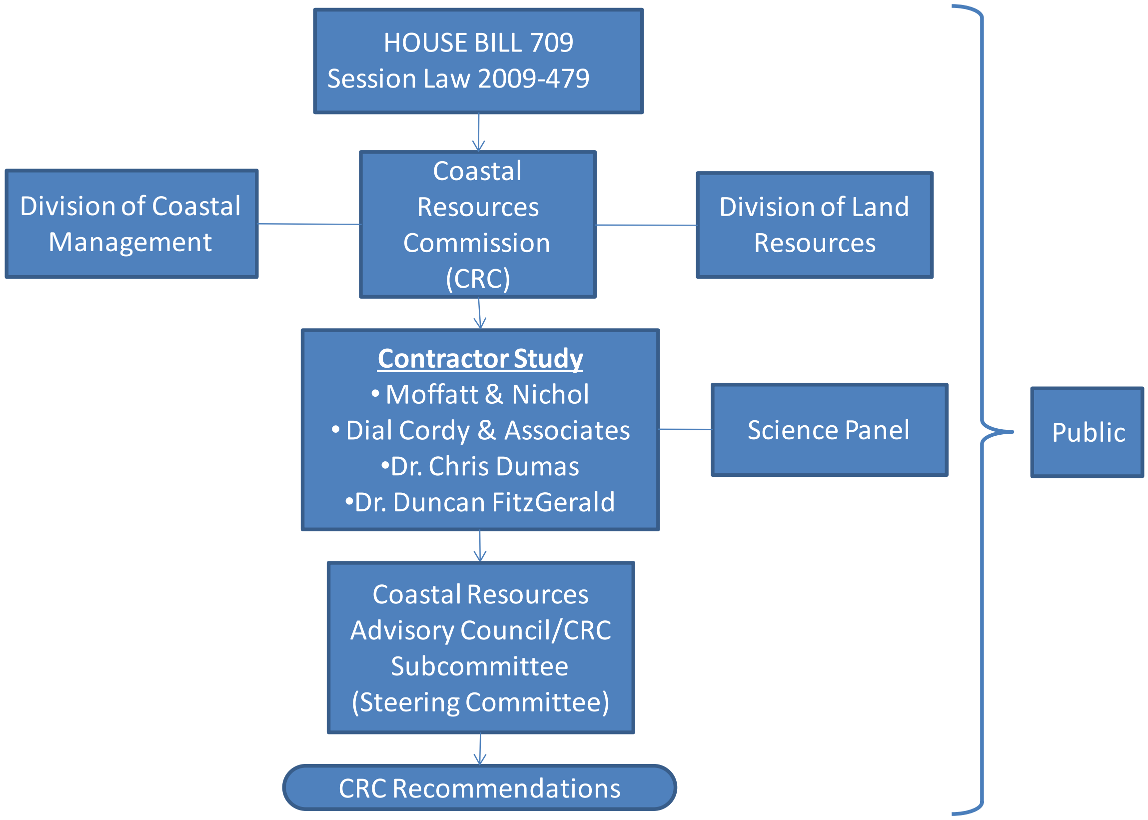


Figure I-1. Overall Project Structure

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 B.

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).

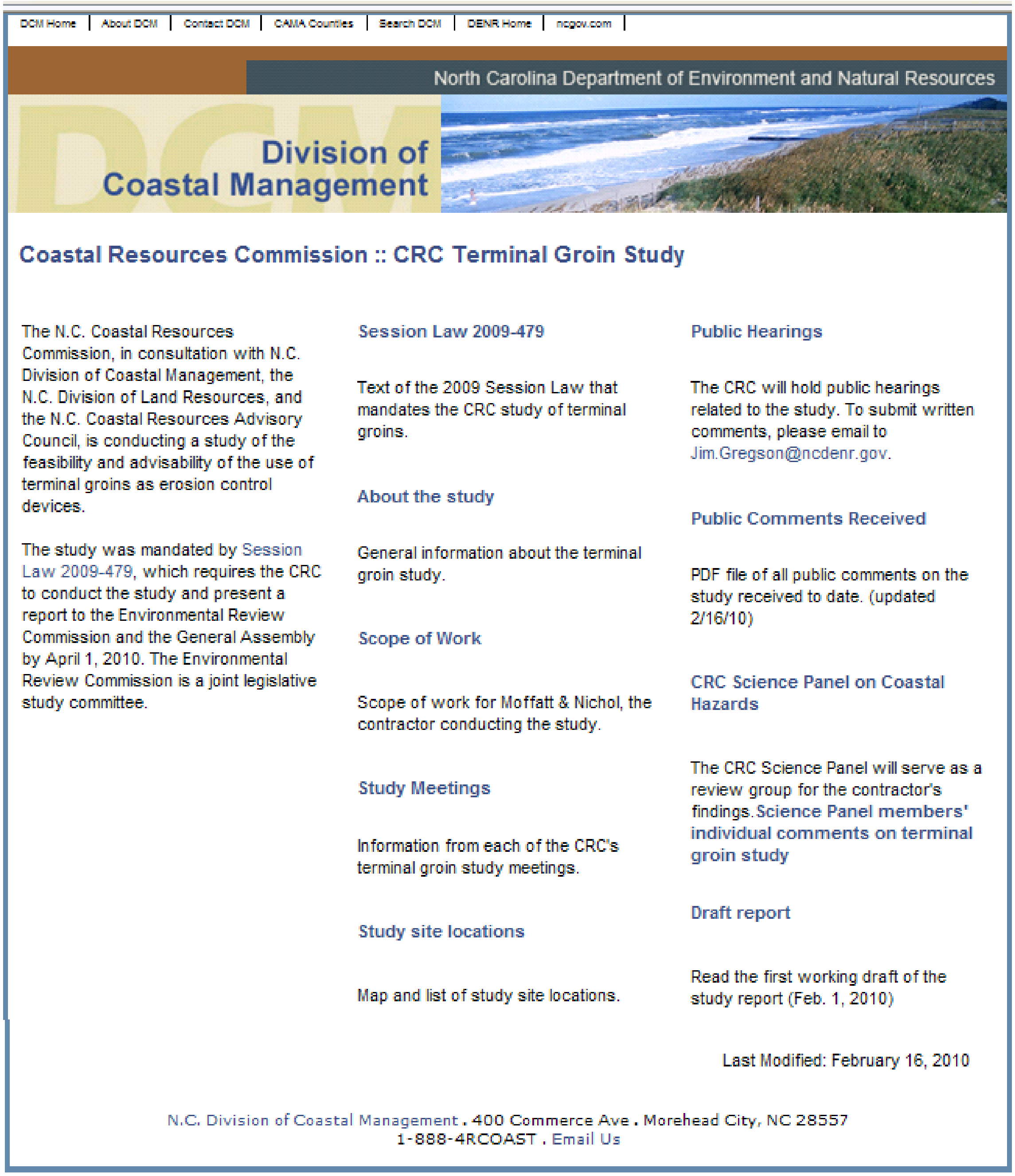


Figure I-2. Project Website

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 25, 2010 – 5 p.m.	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 (Figure I-3) with terminal structures 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.

Figure I-3. Potential Study Sites

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-4 illustrates the location of the selected study sites.

Figure I-4. Selected Study Sites

D. Limitations of Study

As with any study of this nature that has schedule and budgetary constraints, there are limitations with respect to the quantity and quality of available data and analysis procedures that should be understood. No new data collection efforts were undertaken for this study. Rather, available data (shoreline changes, nourishment and dredging activities, natural resources, etc.) were collected from as many sources as possible. Additionally, most of the data was originally collected for purposes other than determining the potential impact of a terminal groin.

The analysis procedures undertaken recognize the uncertainties associated with the underlying data, but detailed statistical analyses of the uncertainties were not performed. However, conclusions can still be drawn from the data and analyses as long as uncertainties are recognized. One cannot simply state in all cases that no conclusions can be made just because of underlying uncertainty (although in some cases this may be appropriate); as uncertainty will always exist in the analysis of coastal processes.

II. Physical Assessment

This section addresses the geological framework, physical processes, and human-induced changes that influence erosional-depositional sedimentation patterns at tidal inlets and along their adjacent shorelines. These processes are evaluated, both qualitatively and quantitatively, with respect to the impact of the terminal groin located at each of five selected 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. They extend into the nearshore zone and act as a dam to the longshore transport of sediment and 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 II-1). 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. 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.

Although most terminal groins are designed primarily to help stabilize a length of oceanfront shoreline, a sometimes 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 II-1. Terminal Groin at Saint Pete Beach, Florida

B. 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 II-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 II-1. Factors Affecting Terminal Groins

- Wave Energy Distribution and Wave Approach Along the Coast
- Rates and Directions of Longshore Sediment Transport
- Tide Ranges of the Ocean and Bay
- Wind Regime and Effects of Vegetation
- Effects of Major Storms
  - frequency and track
  - storm surge elevations
  - wave energy
  - erosion and depositional trends, including washovers
- Historical Morphological Changes of the Shoreline and Inlet System
- Bathymetric Changes of the Inlet and Nearshore
- Sand Circulation Patterns at Tidal Inlet
- Processes of Inlet Sediment Bypassing
- Geological Framework Controls on
  - inlet stability
  - nearshore sediment supplies
- Dredging History Including Disposal Sites
- 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 (Figure II-2). 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.

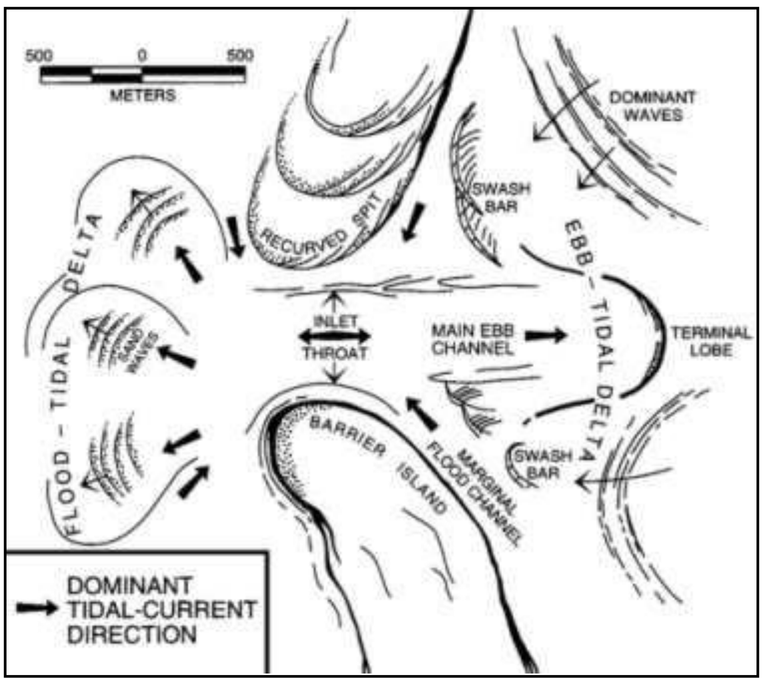


Image from Schrader, R.J., et. al. 2000.

Figure II-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 II-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 Methodology

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.

The geologic setting as well as shoreline 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 and volumetric changes in order to assess the effectiveness and impacts of the terminal groins from a physical perspective.

1. 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 available shoreline data was reviewed and the shorelines selected for analysis were those having data for three miles on both sides of the inlet and covering the longest time periods. The rates of shoreline change on each side of the inlet for a distance of three (or for one case, six) miles were computed for each site. Average rates were calculated for each time period for cumulative distances up to three (or for one case, six) miles and in intervals along the same segments for comparison of shoreline behavior. Three miles was selected as the comparison distance 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. However, six miles was chosen for Pea Island due to concerns expressed by the Science Panel about potential impacts in this region and the use of this distance in other monitoring studies of Pea Island.

Shoreline changes 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 (DCM), 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. While the closest available shoreline time periods were used, it should be noted there were some gaps in the time periods prior to and post groin construction. 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. Shoreline changes were calculated and compared relative to the inlet shoulder to allow comparison between time periods since the inlet position may have shifted. Tabular and graphical results are then presented for each site.

2. 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 impacts of nourishment and dredging, separate from the terminal groin. A standard rule of thumb is that 1 foot of shoreline change corresponds to 1 cubic yard of volumetric change (Herbich, 2000 and Kraus, 1998). However, site specific shoreline change to volume change estimates were made based on ratios developed from available profile data near each site. Figure II-3 illustrates an example of beach shoreline position change (taken as the mean high water line) to volume relationship that was calculated in the vicinity of each site using the available profile data. Available shoreline profiles, representative of the shoreline of surrounding area of each inlet, were reviewed at each site and selected to obtain the most reasonable average shoreline to volume change relationship using judgment to choose those profiles not surveyed near the time of storm or nourishment events. Profiles were taken out to near visual depth of closure where appropriate but were shortened in many instances to remove slight hydrographic errors along the seafloor which can result in large apparent changes if the profiles are extended to their fullest extents offshore.

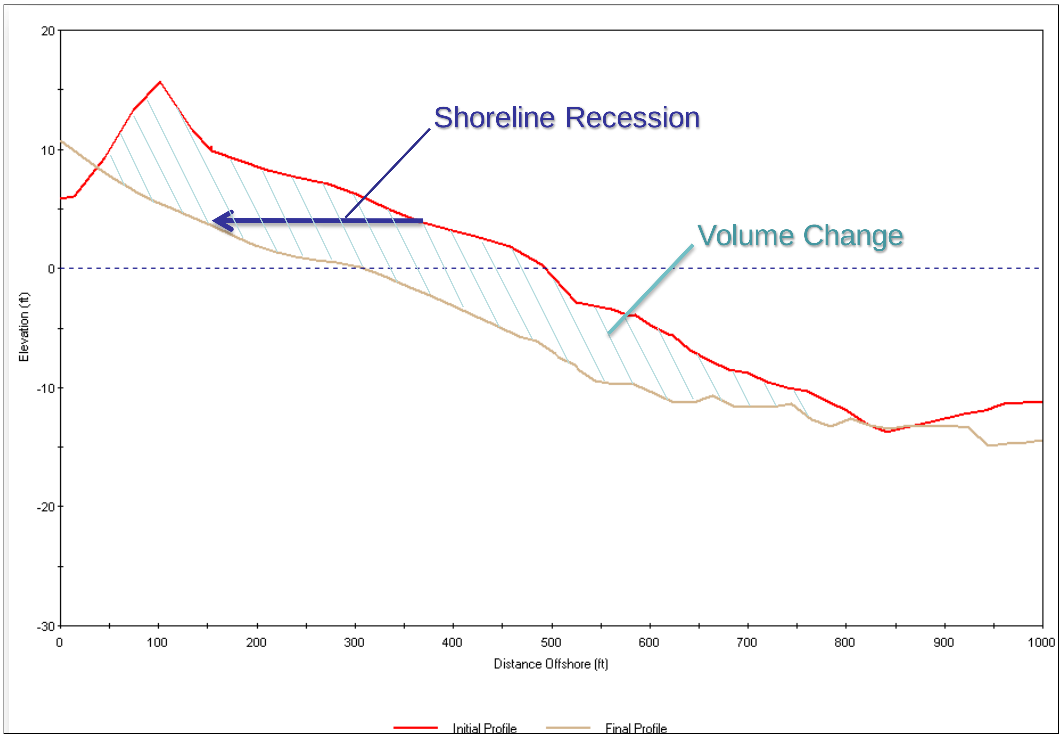


Figure II-3. Shoreline to Beach Volume Change Relationship

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 (see Figure II-4). 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.

ANALYSIS OVERVIEW

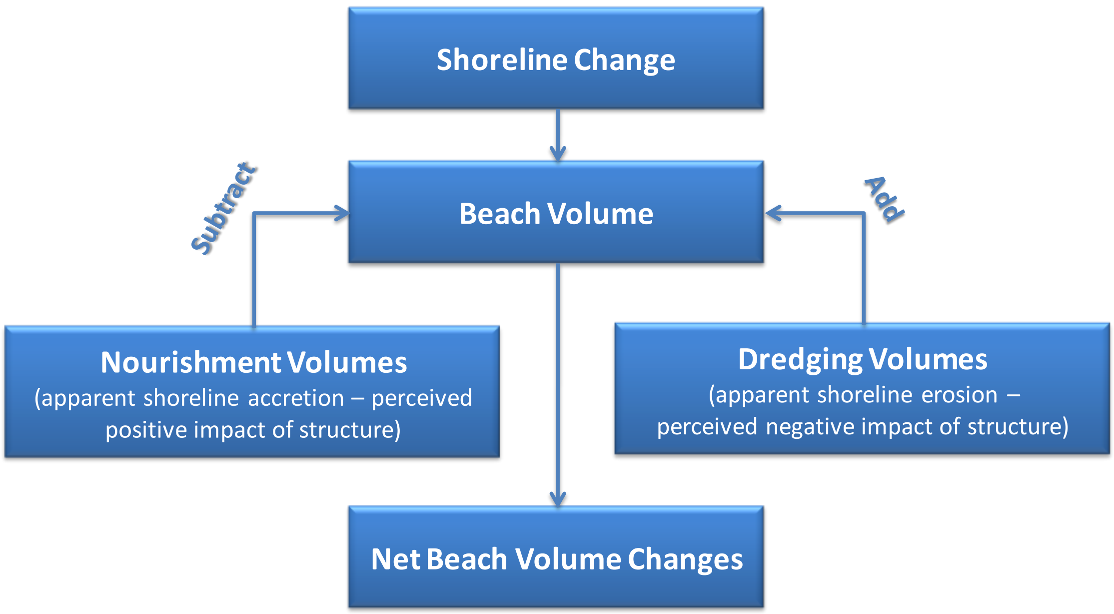


Figure II-4. Analysis Procedure

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. For comparison purposes data was presented in an average annual rate (cy/yr) over each time periods. Care was taken to note the date of the shorelines and the beach nourishment at the end of each time period so that the annual rates reflect the same time periods as the shorelines. 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.

D. Assessment of Oregon Inlet Terminal Groin

1. Qualitative Assessment

a) Site Description

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 II-5). It was opened by a hurricane in 1846 and then migrated south almost 4 km (2.5 miles) 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).

The inlet is high energy and has seen dynamic changes since its opening. 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-6). Information and data regarding the tidal, wave and storm environment at Oregon Inlet is presented in Appendix D.

b) Terminal Groin Construction

A 2.4 mile 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 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 3,125-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. The terminal groin was constructed to protect the southern end of the bridge and prevent further southerly migration of the tidal inlet.

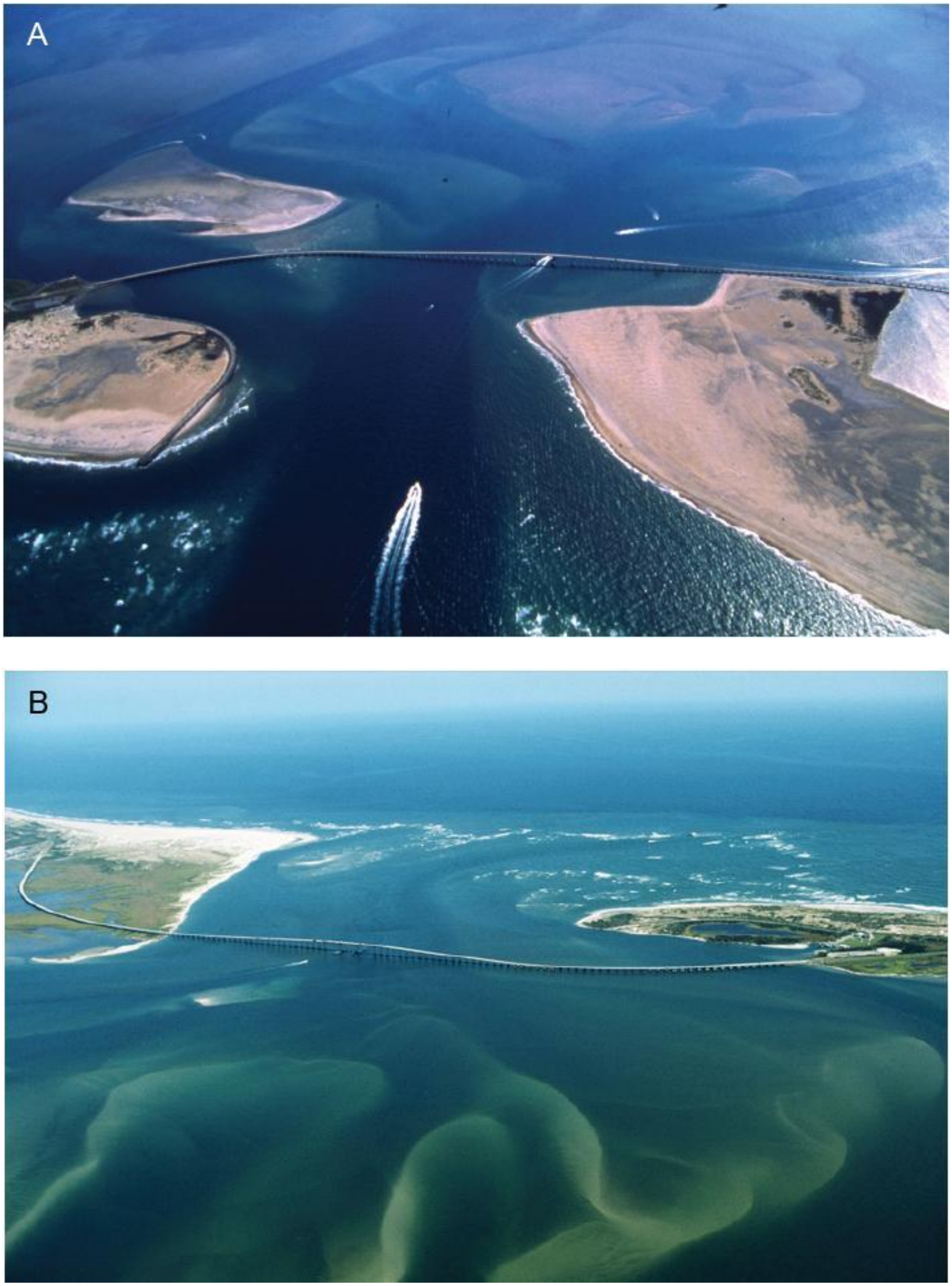


Figure II-5. Aerial Photographs of Oregon Inlet A. Looking Landward (Photograph from Ramanda, Nags Head) and B. Seaward (Photograph by D.A. Harvey)

A comparison of the 1991 post-construction shoreline with an August 2006 vertical aerial photograph (Figure II-7) 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.

c) 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 (3.3 feet) 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 (1.3 million cy/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). The cyclicity of these storms is likely a product of the North Atlantic Oscillation.

The high longshore transport rate explains the rapid southerly progradation of the Bodie Island spit that has forced the migration of Oregon Inlet. The recurved ridges comprising the spit end of Bodie Island (Figure II-8) 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 II-6. Oregon Inlet Terminal Groin & Revetment

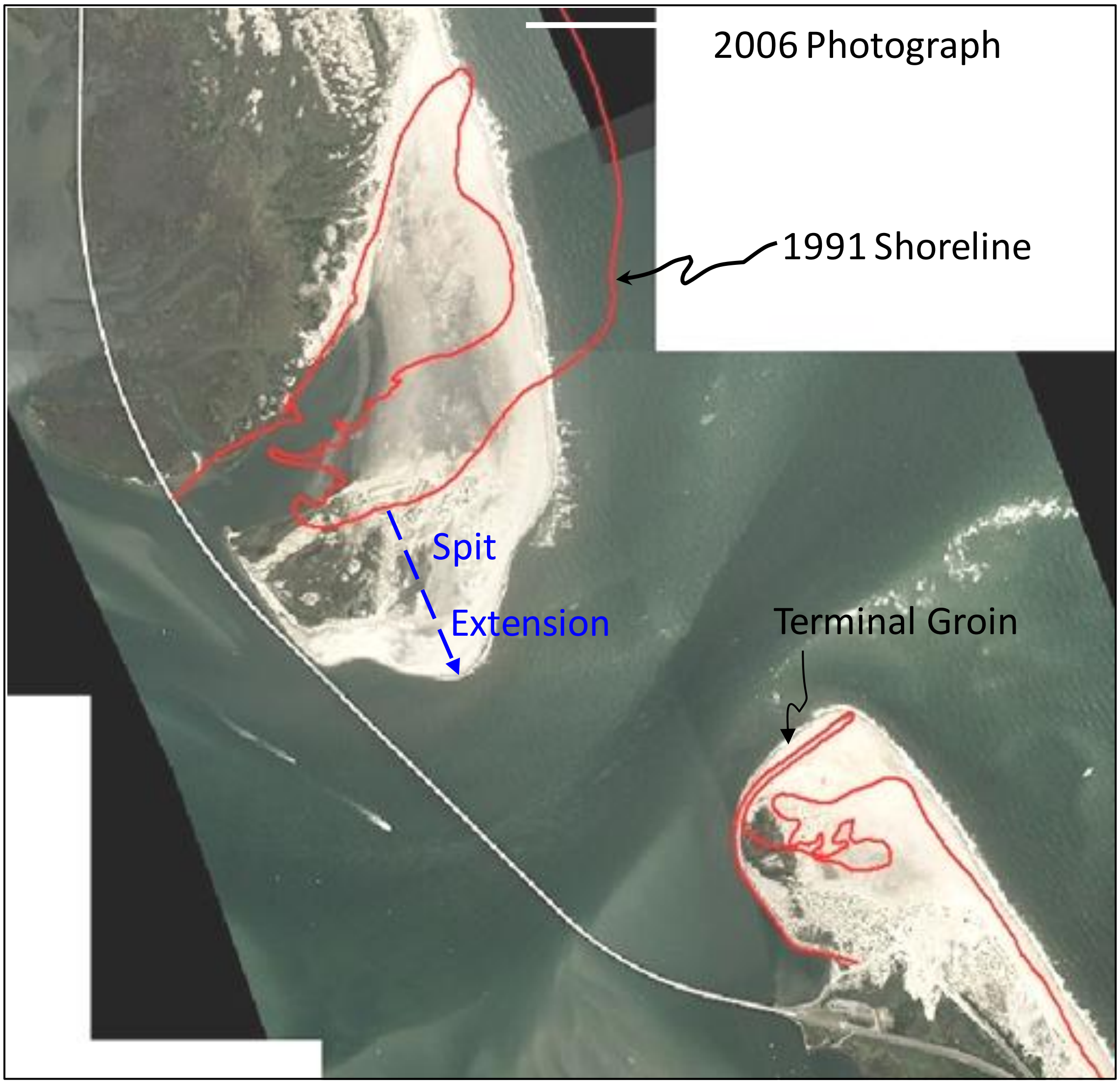


Figure II-7. Comparison of 1991 and 2006 Shorelines Along Bodie and Pea Islands

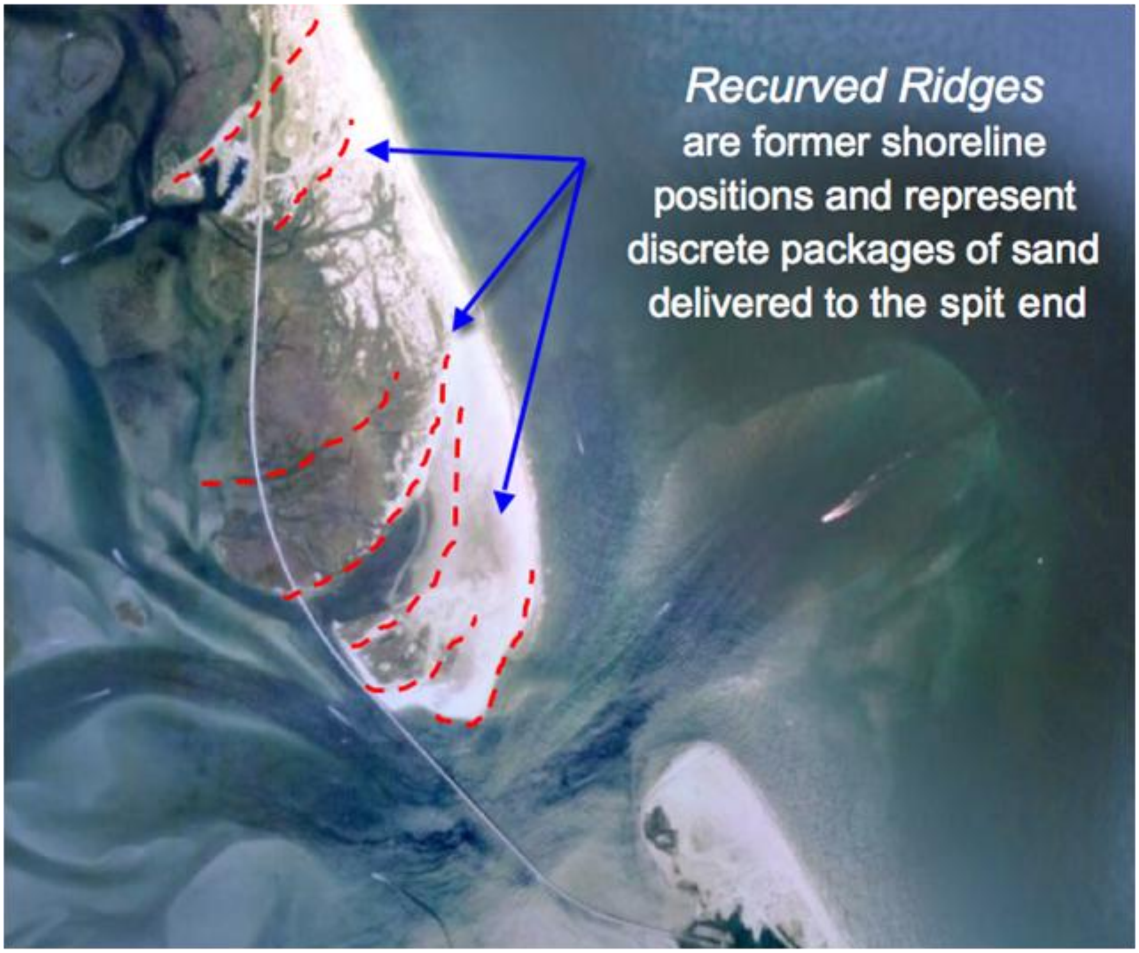


Figure II-8. Bodie Island Illustrating Recurved Ridges Comprising Spit End

d) 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 II-9. 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, the Bodie Island spit prograded southward about 400 m (1312 feet) and the channel thalweg (line connecting deepest depths along a channel) migrated southward by almost 300 m (984 feet) (Figure II-9A). From 1999 to 2001 a decrease in cross sectional area of the inlet (~1000 m^2 or 10764 sf), due to spit accretion and channel narrowing (~ 200 m or 656 feet), caused an increase in tidal current velocities resulting in channel scour and deepening of the thalweg by about 2 m (6.6 ft) (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 II-9B illustrates the subtidal progradation of the

Bodie Island 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.

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 II-10, 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.

e) Northern Pea Island

Wave refraction around the ebb-tidal delta is another important process at Oregon Inlet as shown in Figure II-11. 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 II-11). Currents generated by the flooding tides would have enhanced northerly sand transport along the tip of Pea Island.

This same morphology is observed in a 2001 photograph of the region (Figure II-12). 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.

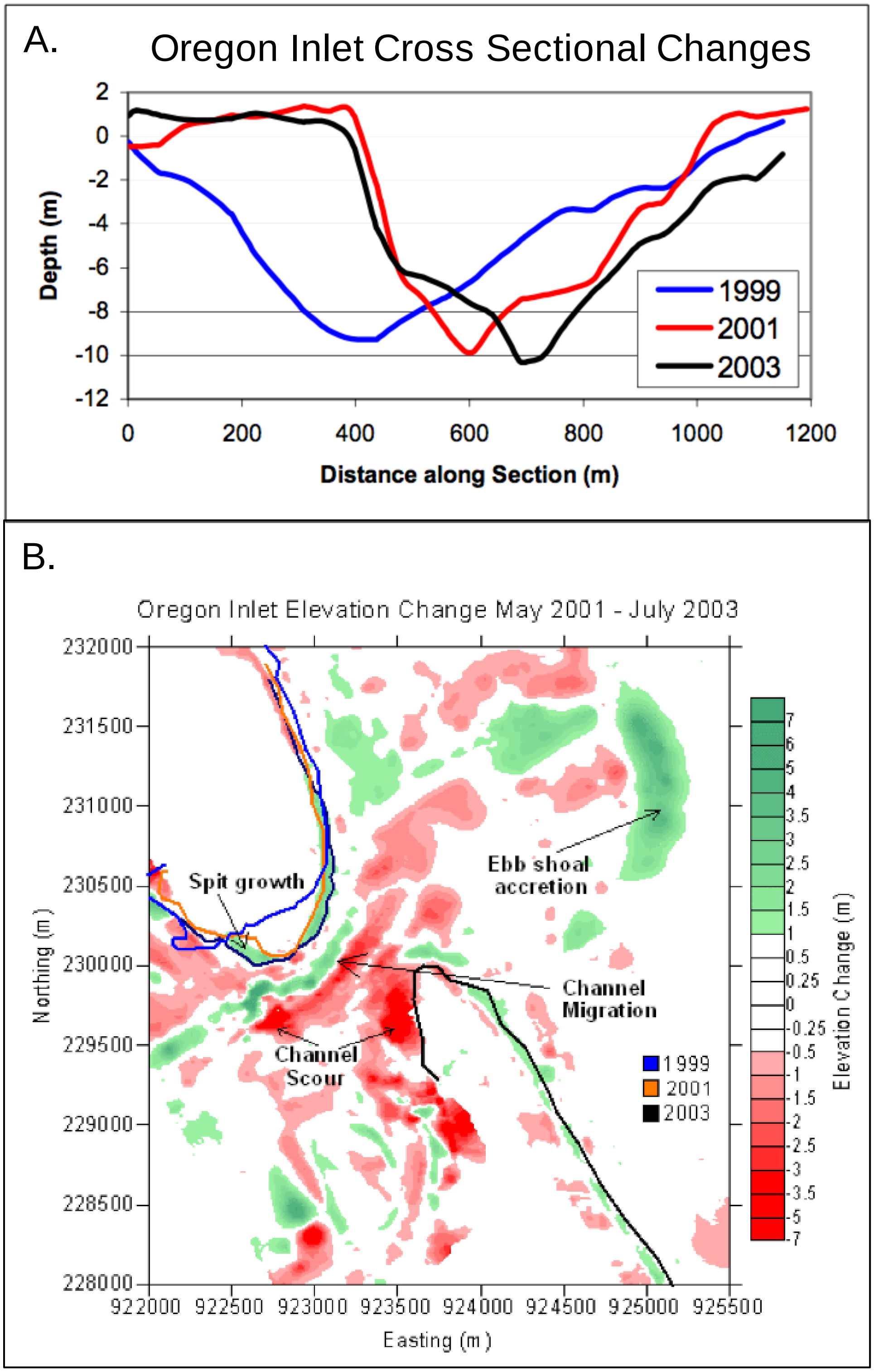


Figure II-9. Bathymetric Changes at Oregon Inlet Showing A. Cross-sectional Changes from 1999 to 2001 and B. Erosional-depositional Changes Over the 2001 – 2003 Period (Vandever and Miller, 2003)

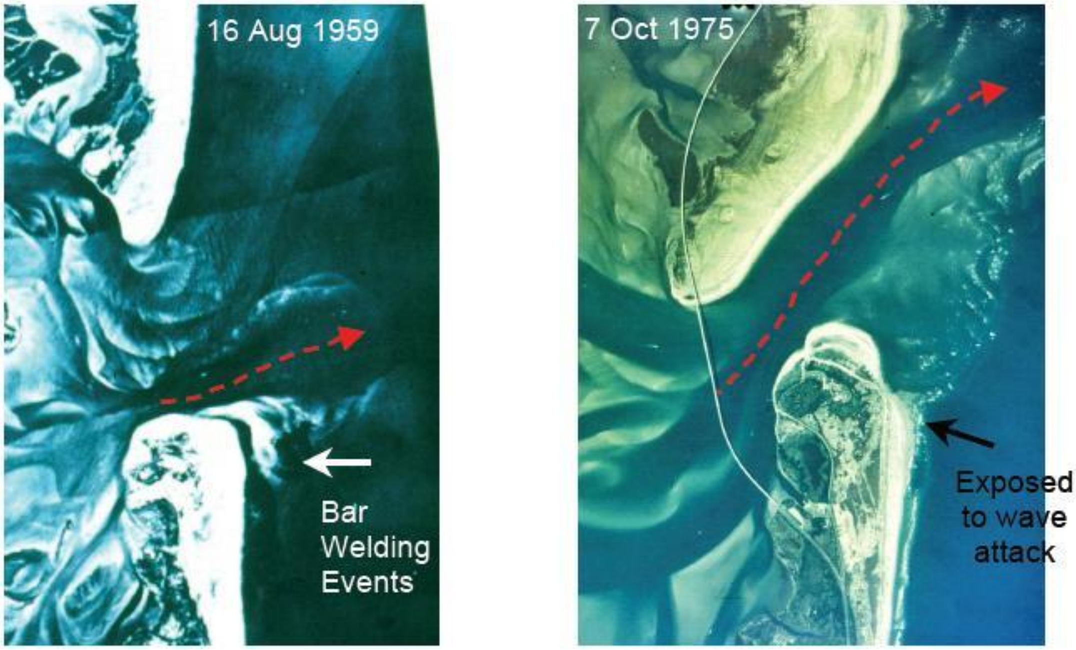


Figure II-10. Historical Aerial Photographs of Oregon Inlet Illustrating Different Ebb-tidal Delta Morphologies.
The overlap of the ebb delta dictates accretionary patterns along the adjacent beaches

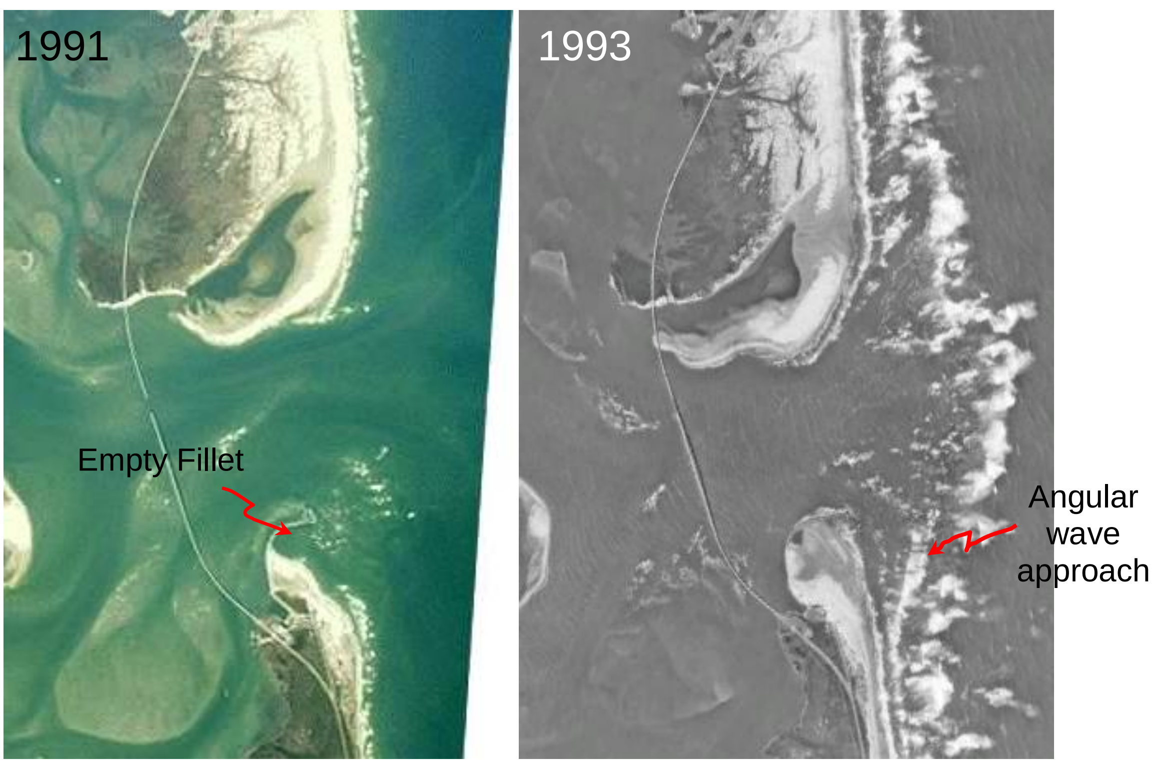


Figure II-11. Photographs of Northern Pea Island and Terminal Groin Area.
Note immediately following construction of the groin in 1991 the lack of sand in the fillet region. Two years later, it had mostly filled due to a nourishment project and from the natural northerly longshore transport of sand caused by wave refraction around the ebb delta

Figure II-12. 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 II-13. 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 II-13. Sequential Photographs of Oregon Inlet Depicting the Shoreline Changes Associated with Spit Accretion at Bodie Island and Southerly Migration of Oregon Inlet (Cleary, 2009)

The sequential photographs (Figure II-14) 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.

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.

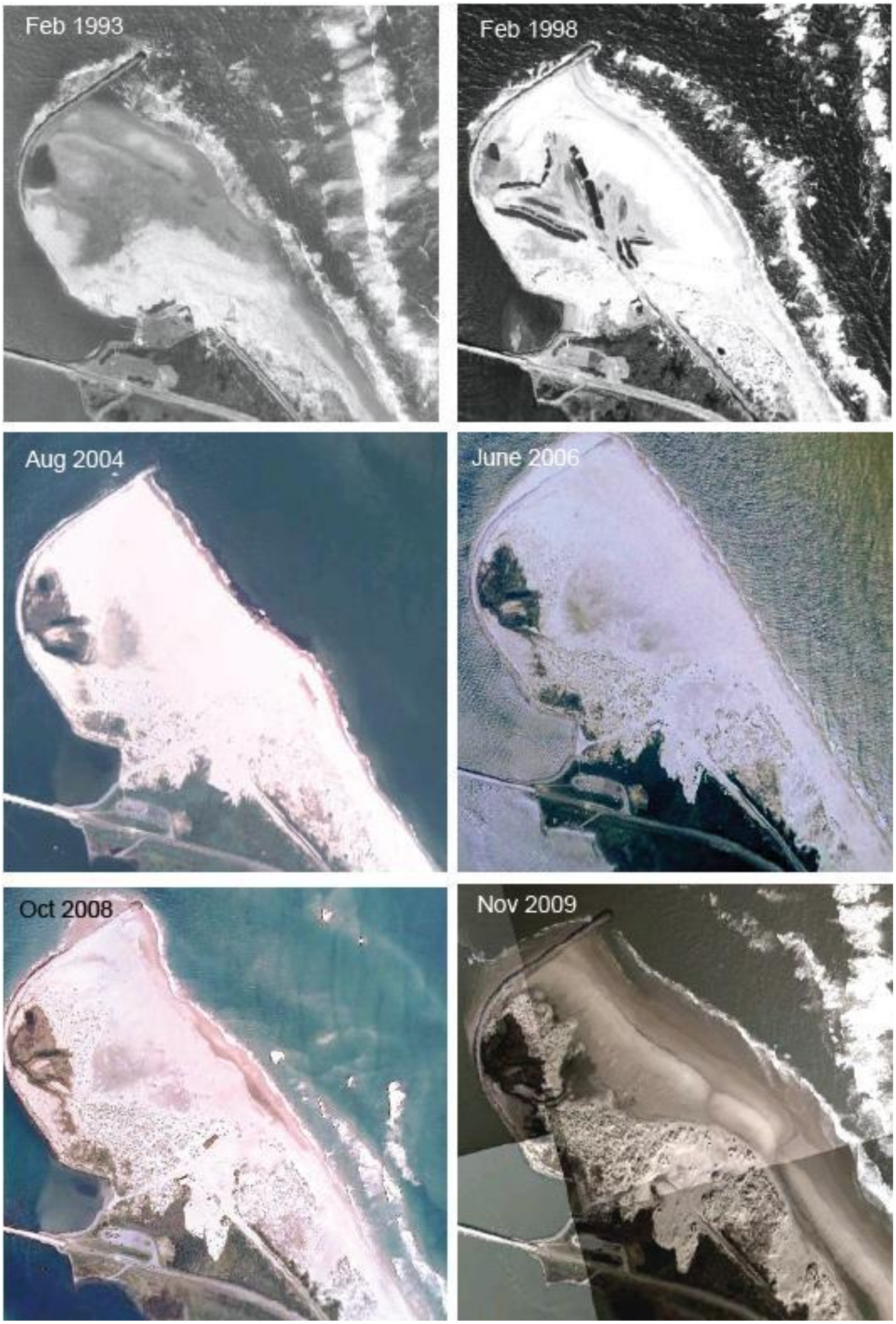


Figure II-14. Historical Changes of the Northern Pea Island Shoreline (downloaded from Google Earth)

f) 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.

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.

Dredging Oregon Inlet also 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 of sand to the downdrift barrier. This process is disrupted and sometimes completely terminated when a deep channel is dredged through the terminal lobe.

2. Quantitative Assessment

a) 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 (164 ft) transects along the shore for a distance of three miles to the north side of the inlet and six miles to the south. Shoreline data sets selected were chosen which extended over these areas and covered the pre-structure and post-structure time periods. Figure II-15 illustrates the shoreline data used in the analysis.

Figure II-16 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-16 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 (This period formed the basis of the ongoing DOT monitoring). 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.

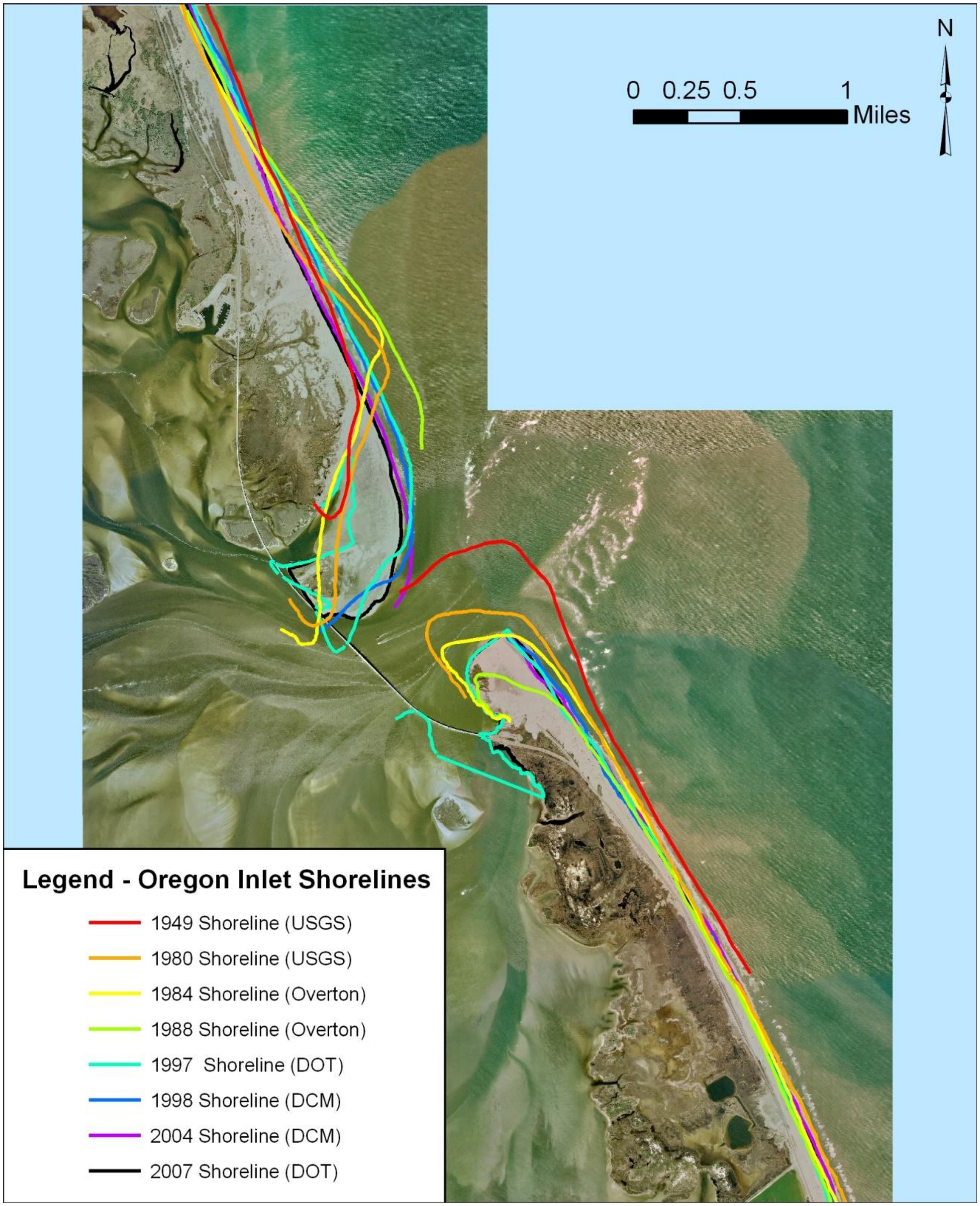


Figure II-15. Historic Shorelines – Oregon Inlet

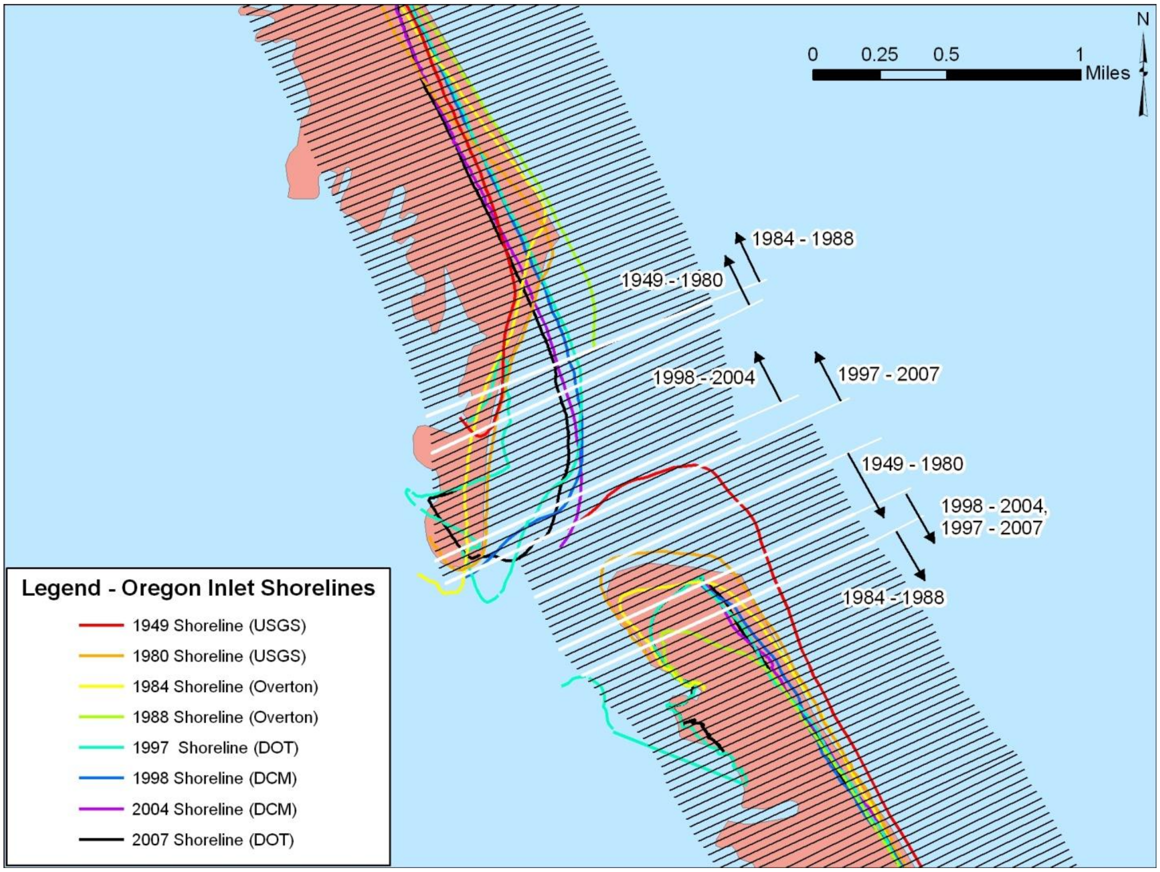


Figure II-16. Oregon Inlet Shoreline Change Calculation Transects

The results of the shoreline change calculations for pre- and post-structure time periods are given in Table II-2 and Table II-3 for Bodie Island and Table II-4 and Table II-5 for Pea Island (location of terminal groin). Values in red represent shoreline recession (erosion) and values in black represent shoreline advancement (accretion). The first table for each island presents the average shoreline change for each interval as indicated while the second table presents average shoreline change from the inlet shoulder to a total distance up to three miles for Bodie Island and six miles for Pea Island. Figure II-17 and Figure II-18 display the same data graphically.

Table II-2. Shoreline Change – Bodie Island (Intervals)

	Shoreline Change - Bodie Island (Intervals) (ft/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1949 - 1980	3.2	16.4	27.6	14.4	11.2	19.3
Pre: 1984 - 1988	489.4	258.3	39.6	48.4	50.0	33.3
Post: 1997 - 2007	33.5	32.1	47.0	43.2	42.2	16.6
Post: 1998 - 2004	3.2	34.8	42.1	42.9	54.7	24.3

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

Table II-3. Shoreline Change – Bodie Island (Total Average)

	Shoreline Change - Bodie Island (Total Average) (ft/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1949 - 1980	3.2	9.8	15.7	15.4	2.1	3.0
Pre: 1984 - 1988	489.4	373.9	262.4	208.9	129.5	115.4
Post: 1997 - 2007	33.5	0.7	15.2	22.2	32.2	27.0
Post: 1998 - 2004	3.2	15.8	24.6	29.2	41.9	36.1

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

Table II-4. Shoreline Change – Pea Island (Intervals)

	Shoreline Change - Pea Island (Intervals) (ft/yr)								
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**	**3 - 4**	**4 - 5**	**5 - 6**
Pre: 1949 - 1980	103.8	25.6	14.2	8.7	8.4	14.5	11.2	3.7	0.5
Pre: 1984 - 1988	224.2	91.3	72.4	41.2	22.9	23.6	28.2	20.9	14.9
Post: 1997 - 2007	3.8	1.0	5.1	5.9	3.3	7.8	7.0	2.2	2.3
Post: 1998 - 2004	18.0	20.3	3.1	18.3	5.7	11.1	11.1	7.6	2.0

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

Table II-5. Shoreline Change – Pea Island (Total Average)

	Shoreline Change - Pea Island (Total Average) (ft/yr)								
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**	**0 - 4**	**0 - 5**	**0 - 6**
Pre: 1949 - 1980	103.8	64.7	47.9	38.1	23.2	20.3	18.0	15.2	12.7
Pre: 1984 - 1988	224.2	157.8	129.3	107.3	65.1	51.2	45.5	40.6	36.3
Post: 1997 - 2007	3.8	2.4	0.1	1.6	2.4	1.0	2.5	1.5	1.7
Post: 1998 - 2004	18.0	19.2	13.8	5.8	0.1	3.7	5.5	2.9	2.8

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

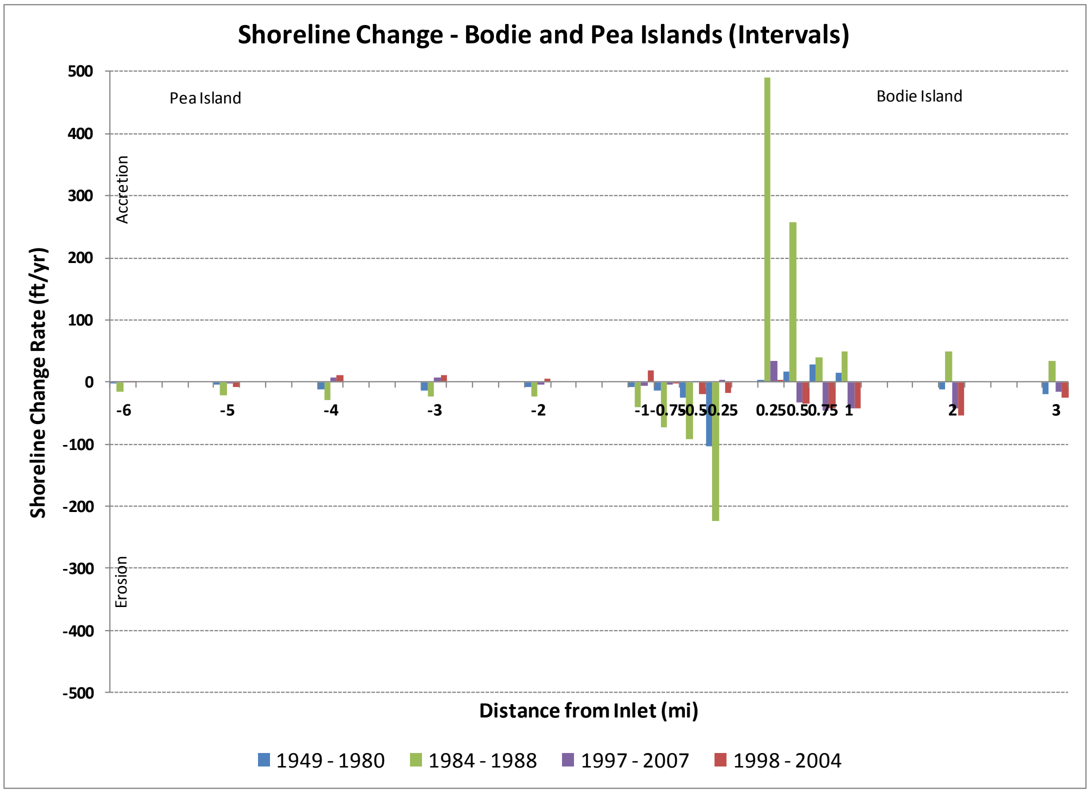


Figure II-17. Shoreline Change – Bodie and Pea Islands (Intervals)

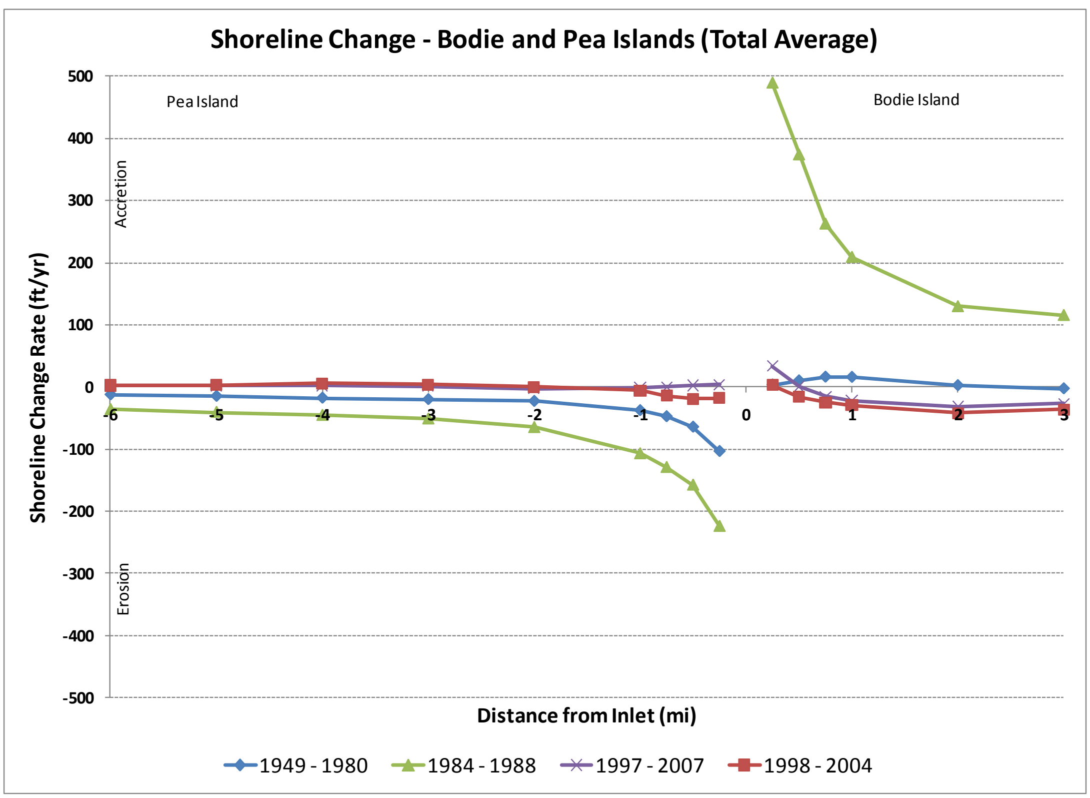


Figure II-18. Shoreline Change – Bodie and Pea Islands (Total Average)

b) Volumetric Changes

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 initially evaluated based on the shoreline change. 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 values in other sources.

Table II-6 and Table II-7 provide the volumetric beach change for the intervals and cumulative distances, respectively, along Bodie Island based on the shoreline change rates presented previously; while Table II-8 and Table II-9 present the volumetric beach change for the intervals and cumulative distances, respectively, along Pea Island. 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 and dredging, since these are implicitly included in the shoreline measurements. Figure II-19 and Figure II-20 present the same information graphically.

Table II-6. Beach Volume Changes – Bodie Island (Intervals)

	Volume Change - Bodie Island (Intervals) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1949 - 1980	5,926	30,601	51,339	26,802	83,202	143,577
Pre: 1984 - 1988	910,869	480,757	73,621	90,063	372,556	248,184
Post: 1997 - 2007	62,309	59,753	87,476	80,442	313,970	123,474
Post: 1998 - 2004	5,897	64,726	78,399	79,856	407,172	181,016

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

Table II-7. Beach Volume Changes – Bodie Island (Cumulative)

	Volume Change - Bodie Island (Cumulative) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1949 - 1980	5,926	36,527	87,866	114,668	31,466	66,594
Pre: 1984 - 1988	910,869	1,391,626	1,465,247	1,555,310	1,927,866	2,576,870
Post: 1997 - 2007	62,309	2,556	84,920	165,362	479,332	602,806
Post: 1998 - 2004	5,897	58,830	137,229	217,085	624,256	805,272

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

Table II-8. Beach Volume Changes – Pea Island (Intervals)

	Volume Change - Pea Island (Intervals) (cy/yr)								
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**	**3 - 4**	**4 - 5**	**5 - 6**
Pre: 1949 - 1980	193,147	47,638	26,432	16,255	62,578	107,934	83,320	27,196	3,585
Pre: 1984 - 1988	417,272	169,950	134,769	76,673	170,340	175,611	209,702	155,527	111,249
Post: 1997 - 2007	7,095	1,852	9,509	10,991	24,709	57,732	51,964	16,563	17,290
Post: 1998 - 2004	33,516	37,786	5,810	34,000	42,224	82,727	82,850	56,302	15,150

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

Table II-9. Beach Volume Changes – Pea Island (Cumulative)

	Volume Change - Pea Island (Cumulative) (cy/yr)								
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**	**0 - 4**	**0 - 5**	**0 - 6**
Pre: 1949 - 1980	193,147	240,785	267,217	283,472	346,049	453,984	537,303	564,499	568,085
Pre: 1984 - 1988	417,272	587,222	721,991	798,663	969,003	1,144,615	1,354,317	1,509,844	1,621,093
Post: 1997 - 2007	7,095	8,948	561	11,552	36,261	21,471	73,435	56,872	74,162
Post: 1998 - 2004	33,516	71,302	77,112	43,112	888	81,839	164,689	108,388	123,538

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

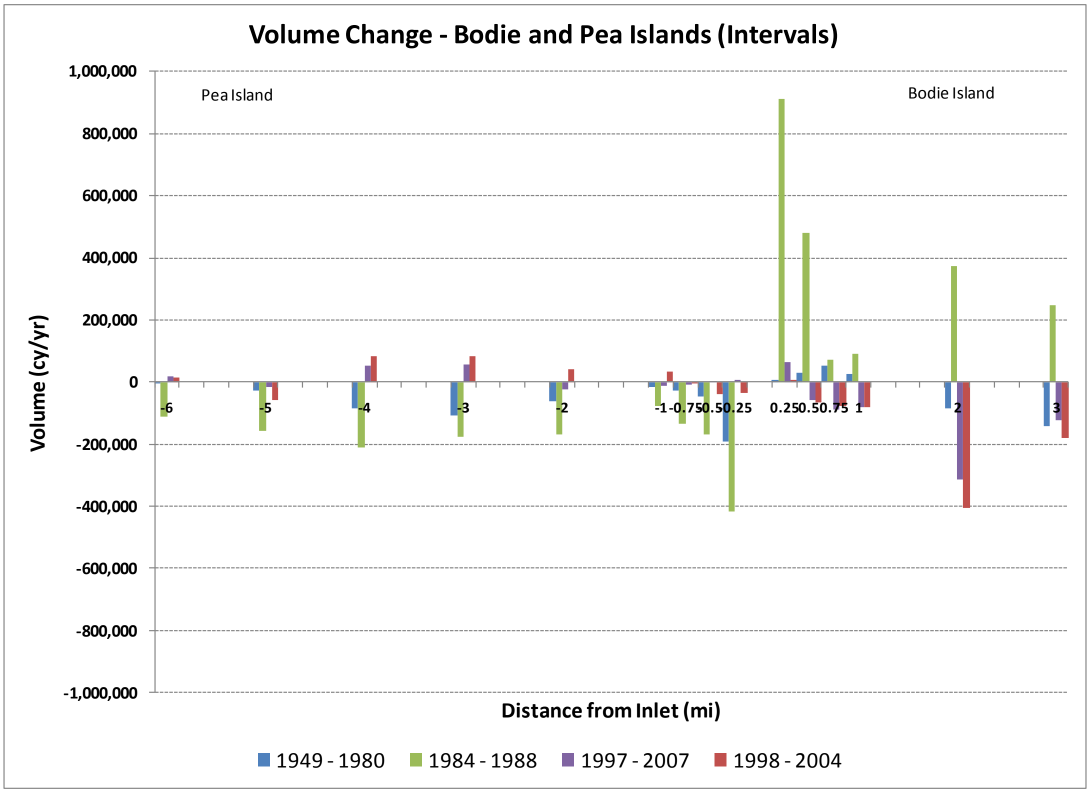


Figure II-19. Beach Volume Changes – Bodie and Pea Islands (Intervals)

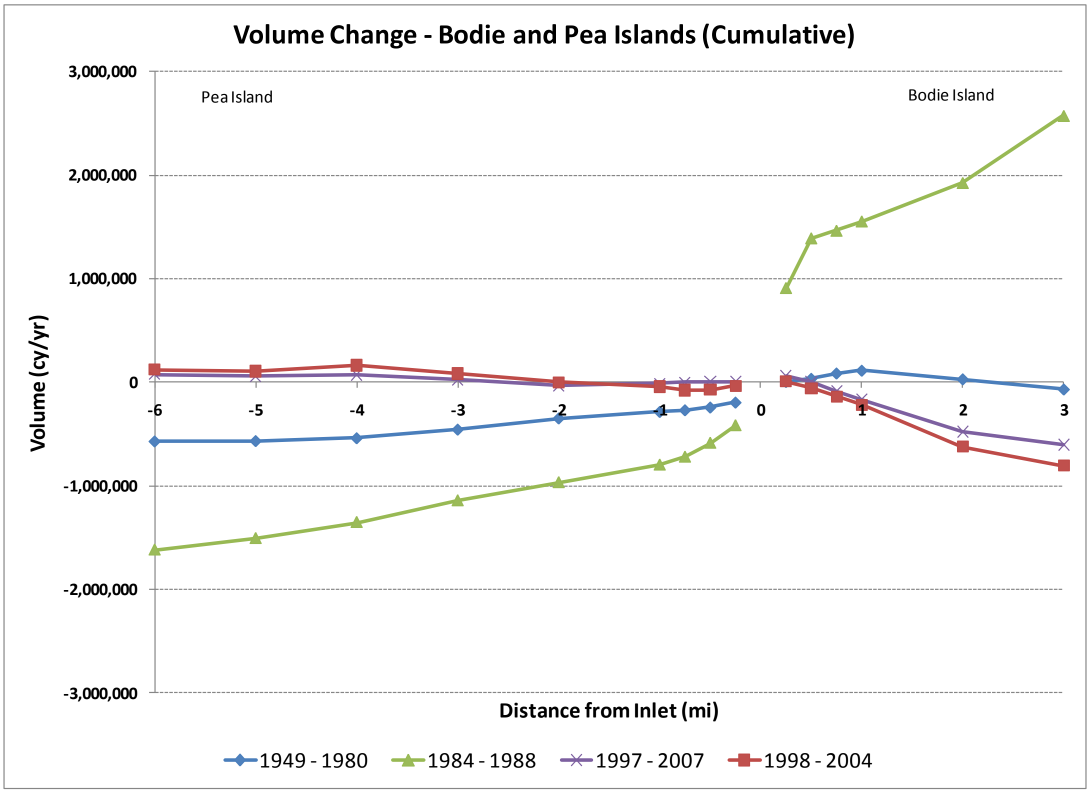


Figure II-20. Beach Volume Changes – Bodie and Pea Islands (Cumulative)

c) Volumetric Changes - Beach Nourishment & Nearshore Placement

Since construction of the Oregon Inlet Terminal Groin, sand has been regularly placed directly on the Pea Island shoreline or in the nearshore region. Table II-10 details the amounts, timing, and locations, when known, of beach nourishment and nearshore placement activities on Pea Island during the analysis periods. (The engineering activities log in Appendix C provides details for all activities). Table II-11 presents a summary of this data with respect to the amounts assumed placed on each analysis interval of shoreline for each of the analysis time periods. For material placed directly on the beach, the total volumes were pro-rated over the placement stations when known. In cases where the exact placement location was not known for the beach nourishment or the nearshore placement activities, the material was assumed to be distributed evenly over the six mile analysis area.

Table II-10. Beach Nourishment and Nearshore Placement – Pea Island

Year	Placement Location	Beach Nourishment Volume by Interval (cy)										Total Volume (cy)
		0 - 0.25	0.25 - 0.50	0.50 - 0.75	0.75 - 1.0	1.0 - 2.0	2.0 - 3.0	3.0 - 4.0	4.0 - 5.0	5.0 - 6.0	6.0 +	
1997	Pea Island (Nearshore)	11,321	11,321	11,321	11,321	45,284	45,284	45,284	45,284	45,284	0	**271,703**
1998	Pea Island (Nearshore)	10,841	10,841	10,841	10,841	43,364	43,364	43,364	43,364	43,364	0	**260,183**
1999	Pea Island (Nearshore)	13,705	13,705	13,705	13,705	54,820	54,820	54,820	54,820	54,820	0	**328,919**
2000	Pea Island (Unknown)	17,471	17,471	17,471	17,471	69,884	69,884	69,884	69,884	69,884	0	**419,305**
2000	Pea Island (Nearshore)	10,185	10,185	10,185	10,185	40,741	40,741	40,741	40,741	40,741	0	**244,445**
2001	Pea Island (sta 40 to 43 & sta 52 to 100)	0	0	0	30,822	482,884	0	0	0	0	0	**513,706**
2002	Pea Island (sta 80 to 151 and Nearshore)	0	0	0	0	244,284	488,568	0	0	0	0	**732,852**
2003	Pea Island (sta 66 to 188)	0	0	0	0	343,181	343,181	343,181	0	0	0	**1,029,543**
2003	Pea Island (Nearshore)	4,485	4,485	4,485	4,485	17,939	17,939	17,939	17,939	17,939	0	**107,631**
2004	Pea Island (sta 45 to 115 excluding 70 to 90)	0	0	0	0	308,224	308,224	0	0	0	0	**616,448**
2005	Pea Island (Nearshore)	7,173	7,173	7,173	7,173	28,693	28,693	28,693	28,693	28,693	0	**172,156**

Table II-11. Beach Nourishment and Nearshore Placement – Pea Island

Period	Beach Nourishment Volume by Interval (cy/yr)										Total Volume (cy/yr)
	0 - 0.25	0.25 - 0.50	0.50 - 0.75	0.75 - 1.0	1.0 - 2.0	2.0 - 3.0	3.0 - 4.0	4.0 - 5.0	5.0 - 6.0	6.0 +	
Pre: 1949 - 1980	0	0	0	0	0	0	0	0	0	0	**0**
Pre: 1984 - 1988	0	0	0	0	0	0	0	0	0	0	**0**
Post: 1997 - 2007	7,518	7,518	7,518	10,600	167,930	144,070	64,390	30,072	30,072	0	**469,689**
Post: 1998 - 2004	8,098	8,098	8,098	12,501	229,331	195,246	81,418	32,392	32,392	0	**607,576**

Most of this sand came from the dredging of the navigation channel through the inlet and the associated bar, so much of it could be considered sand that would have naturally bypassed the inlet and ended up along the beach naturally. 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 this sand bypassing transport.

Nevertheless for comparison purposes in Table II-12 and Table II-13 for Bodie Island and Table II-14 and Table II-15 for Pea Island, the total 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 without nourishment (as if the nourishment or nearshore disposal did not take place). Figure II-21 and Figure II-22 present the same information graphically.

Table II-12. Volume Changes Without Nourishment – Bodie Island (Intervals)

	Volume Change w/o Nourishment - Bodie Island (Intervals) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1949 - 1980	5,926	30,601	51,339	26,802	83,202	143,577
Pre: 1984 - 1988	910,869	480,757	73,621	90,063	372,556	248,184
Post: 1997 - 2007	62,309	59,753	87,476	80,442	313,970	123,474
Post: 1998 - 2004	5,897	64,726	78,399	79,856	407,172	181,016

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

Table II-13. Volume Changes Without Nourishment – Bodie Island (Cumulative)

	Volume Change w/o Nourishment - Bodie Island (Cumulative) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1949 - 1980	5,926	36,527	87,866	114,668	31,466	66,594
Pre: 1984 - 1988	910,869	1,391,626	1,465,247	1,555,310	1,927,866	2,576,870
Post: 1997 - 2007	62,309	2,556	84,920	165,362	479,332	602,806
Post: 1998 - 2004	5,897	58,830	137,229	217,085	624,256	805,272

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

Table II-14. Volume Changes Without Nourishment – Pea Island (Intervals)

	Volume Change w/o Nourishment - Pea Island (Intervals) (cy/yr)								
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**	**3 - 4**	**4 - 5**	**5 - 6**
Pre: 1949 - 1980	193,147	47,638	26,432	16,255	62,578	107,934	83,320	27,196	3,585
Pre: 1984 - 1988	417,272	169,950	134,769	76,673	170,340	175,611	209,702	155,527	111,249
Post: 1997 - 2007	423	5,666	17,027	21,592	192,638	86,338	12,427	46,635	12,782
Post: 1998 - 2004	41,614	45,884	13,908	21,499	187,107	112,519	1,432	88,694	17,242

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

Table II-15. Volume Changes Without Nourishment – Pea Island (Cumulative)

	Volume Change w/o Nourishment - Pea Island (Cumulative) (cy/yr)								
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**	**0 - 4**	**0 - 5**	**0 - 6**
Pre: 1949 - 1980	193,147	240,785	267,217	283,472	346,049	453,984	537,303	564,499	568,085
Pre: 1984 - 1988	417,272	587,222	721,991	798,663	969,003	1,144,615	1,354,317	1,509,844	1,621,093
Post: 1997 - 2007	423	6,089	23,115	44,707	237,345	323,683	336,110	382,745	395,528
Post: 1998 - 2004	41,614	87,498	101,406	79,908	267,015	379,534	378,102	466,796	484,038

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

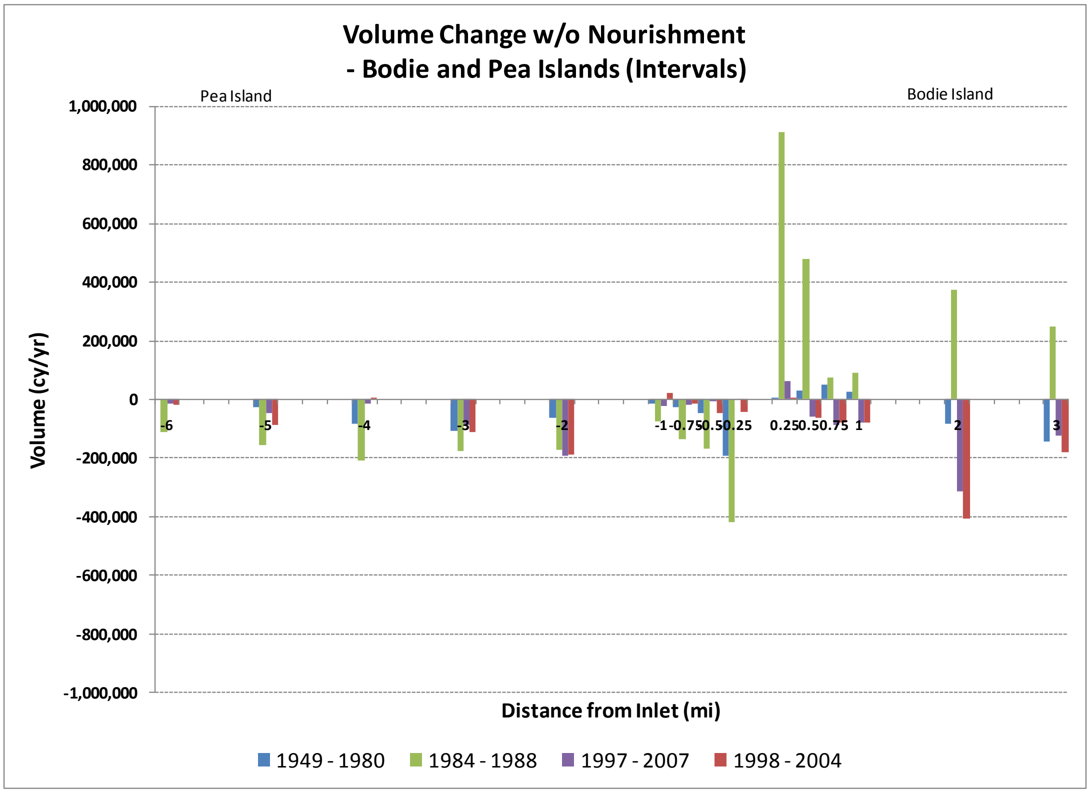


Figure II-21. Volume Changes Without Nourishment – Bodie and Pea Islands (Intervals)

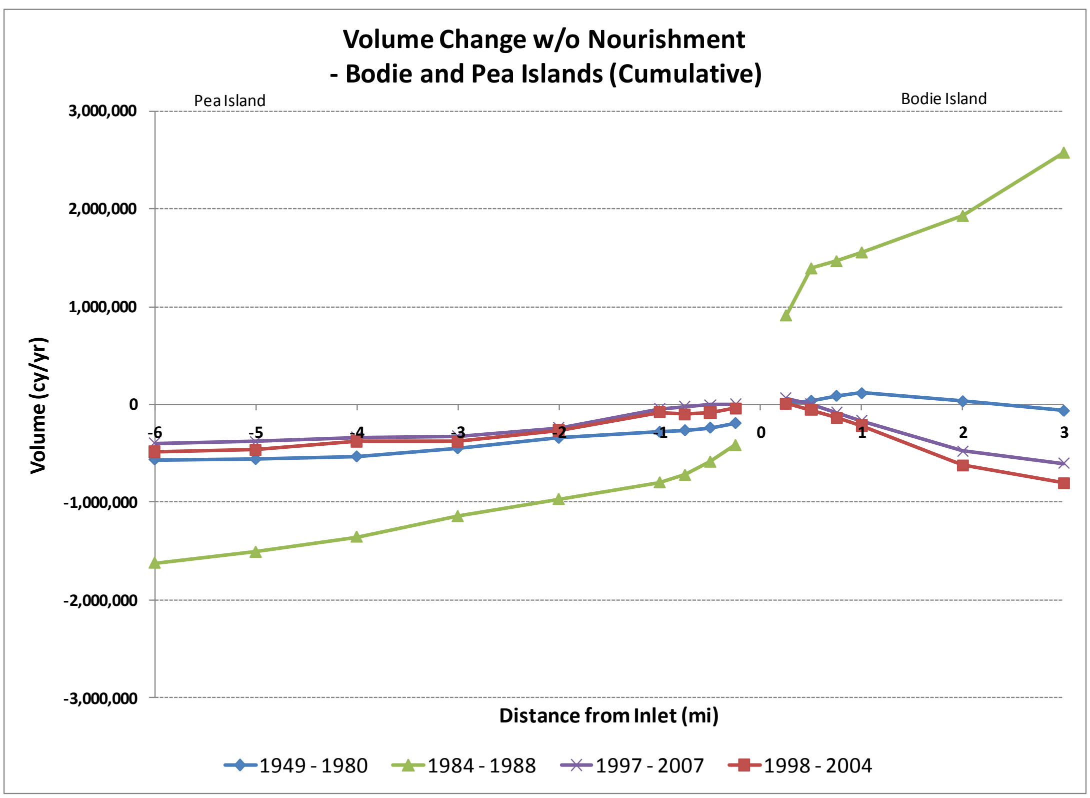


Figure II-22. Volume Changes Without Nourishment – Bodie and Pea Islands (Cumulative)

d) Volumetric Changes - Dredging

Much like nourishment, the influence of dredging material from the inlet system must 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.

Table II-16 details the amounts, timing, and locations, when known, of dredging activities that removed material from within the inlet system during the analysis time periods. (The engineering activities log in Appendix C provides details for all activities).

Sidecast dredging and any dredging that occurred in channels within Pamlico Sound were not included in this analysis since these activities did not remove material that might otherwise have bypassed the inlet and naturally ended up on the adjacent shorelines. Table II-17 presents a summary of this data with respect to the amounts dredged during each analysis time period.

Table II-16. Dredging Volumes – Oregon Inlet

Year	Dredging Location	Total Volume (cy)	Year	Dredging Location	Total Volume (cy)
1960	Oregon Inlet	62,991	1987	Oregon Inlet	41,400
1961	Oregon Inlet	20,013	1988	Oregon Inlet	274,166
1962	Oregon Inlet	109,166	1988	Oregon Inlet	213,791
1963	Oregon Inlet	76,868	1997	Oregon Inlet	271,703
1964	Oregon Inlet	12,800	1998	Oregon Inlet	260,183
1965	Oregon Inlet	188,142	1999	Oregon Inlet	328,919
1967	Oregon Inlet	215,232	2000	Oregon Inlet	419,305
1968	Oregon Inlet	211,430	2001	Oregon Inlet	513,706
1969	Oregon Inlet	132,036	2002	Oregon Inlet	732,829
1970	Oregon Inlet	40,531	2003	Oregon Inlet	107,631
1971	Oregon Inlet	132,149	2004	Oregon Inlet	147,871
1972	Oregon Inlet	302,206	2004	Oregon Inlet	37,775
1984	Oregon Inlet	270,467	2004	Oregon Inlet	15,660
1984	Oregon Inlet	24,418	2004	Oregon Inlet	1,460
1984	Oregon Inlet	480,739	2005	Oregon Inlet	15,710
1985	Oregon Inlet	456,321	2006	Oregon Inlet	16,645
1985	Oregon Inlet	283,507	2006	Oregon Inlet	21,625
1985	Oregon Inlet	521,442	2007	Oregon Inlet	1,030
1986	Oregon Inlet	219,322	2007	Oregon Inlet	17,080
1986	Oregon Inlet	258,750	2007	Oregon Inlet	25,665
1986	Oregon Inlet	266,450	2007	Oregon Inlet	7,150
1987	Oregon Inlet	365,906	2007	Oregon Inlet	62,220
1987	Oregon Inlet	533,183			

Table II-17. Dredging Volumes – Oregon Inlet

Period	Total Volume (cy/yr)
Pre: 1949 - 1980	75,178
Pre: 1984 - 1988	841,972
Post: 1997 - 2007	273,106
Post: 1998 - 2004	366,477

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-18 and Table II-19 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 without nourishment). The additional scenarios assume 25%, or 50% of the material dredged from the inlet system would have reached the beach naturally.

Table II-18. Volume Change Scenarios Including Dredging Effects – Bodie Island (3 miles)

	Dredging Effects - Bodie Island (cy/yr)		
Dredging Percentage Added	0%	25%	50%
Pre: 1949 - 1980	66,594	47,800	29,005
Pre: 1984 - 1988	2,576,870	2,787,363	2,997,856
Post: 1997 - 2007	602,806	534,530	466,253
Post: 1998 - 2004	805,272	713,653	622,034

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

Table II-19. Volume Change Scenarios Including Dredging Effects – Pea Island (6 miles)

	Dredging Effects - Pea Island (cy/yr)		
Dredging Percentage Added	0%	25%	50%
Pre: 1949 - 1980	568,085	549,290	530,495
Pre: 1984 - 1988	1,621,093	1,410,600	1,200,107
Post: 1997 - 2007	395,528	327,251	258,975
Post: 1998 - 2004	484,038	392,419	300,800

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

3. 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.

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 a sediment sink, which further diminishes the volume of sand moving around the inlet.

Construction of the terminal groin stabilized the northern end of Pea Island and prevented Oregon Inlet from migrating southward. 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 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.

Prior to terminal groin construction, the Pea Island shoreline was eroding fairly rapidly during both calculation time periods with the 1984-1988 period (when intensive hopper dredging and offshore disposal occurred) being more than double the rate from 1949-1980. After the construction of the terminal groin, the south shoreline was still eroding but at a much lower rate, and even accreting at some locations (intervals). It must be noted, though, that these shorelines include the effects of beach nourishment and dredging activities.

For the 1949-1980 time period, the Bodie Island shoreline was acretionary in the first mile but erosional in the next two miles; while for the post-construction time periods, the shoreline was generally erosional, at higher rates, except at its tip.

Significant beach nourishment, nearshore placement and dredging activities have occurred. Since the terminal groin was constructed, millions of cubic yards of material have been placed on the beach or in the nearshore region and dredged from the inlet system during the analysis time period.

Once all beach nourishment and nearshore placement activities are subtracted out, the volumetric analysis (comparing to the longer term 1949-1980 time period) shows that after construction of the terminal groin, the average erosion was significantly reduced over the first mile; moderately increased over the second mile; remained about the same of the third mile; moderately decreased again over the fourth mile and was relatively stable over the 5th and 6th miles. The average erosion, though, over these six miles, did decrease significantly. Futhermore, it should be noted that significant questions exist as to whether the material placed in the nearshore is ever actually moved onto the beach or whether it is placed too far offshore, in too deep of water, to achieve any positive benefits.

Bodie Island has the same volumetric trends as the shoreline change since no nourishment has occurred on this side of the inlet.

However, given the large volumes of material dredged from the inlet system, it can be seen that even assuming a small percentage of the dredged material would have naturally been transported to the Pea Island beach could significantly reduce or eliminate any apparent negative impacts in some of the pertinent intervals within the six mile analysis area.

E. Assessment of Fort Macon Terminal Groin

1. Qualitative Assessment

a) Site Description

The Fort Macon terminal groin (Figure II-23) 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-23. 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-24). 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-24. 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.

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 II-25). Information and data regarding the tidal, wave and storm environment at Beaufort Inlet is presented in Appendix D.

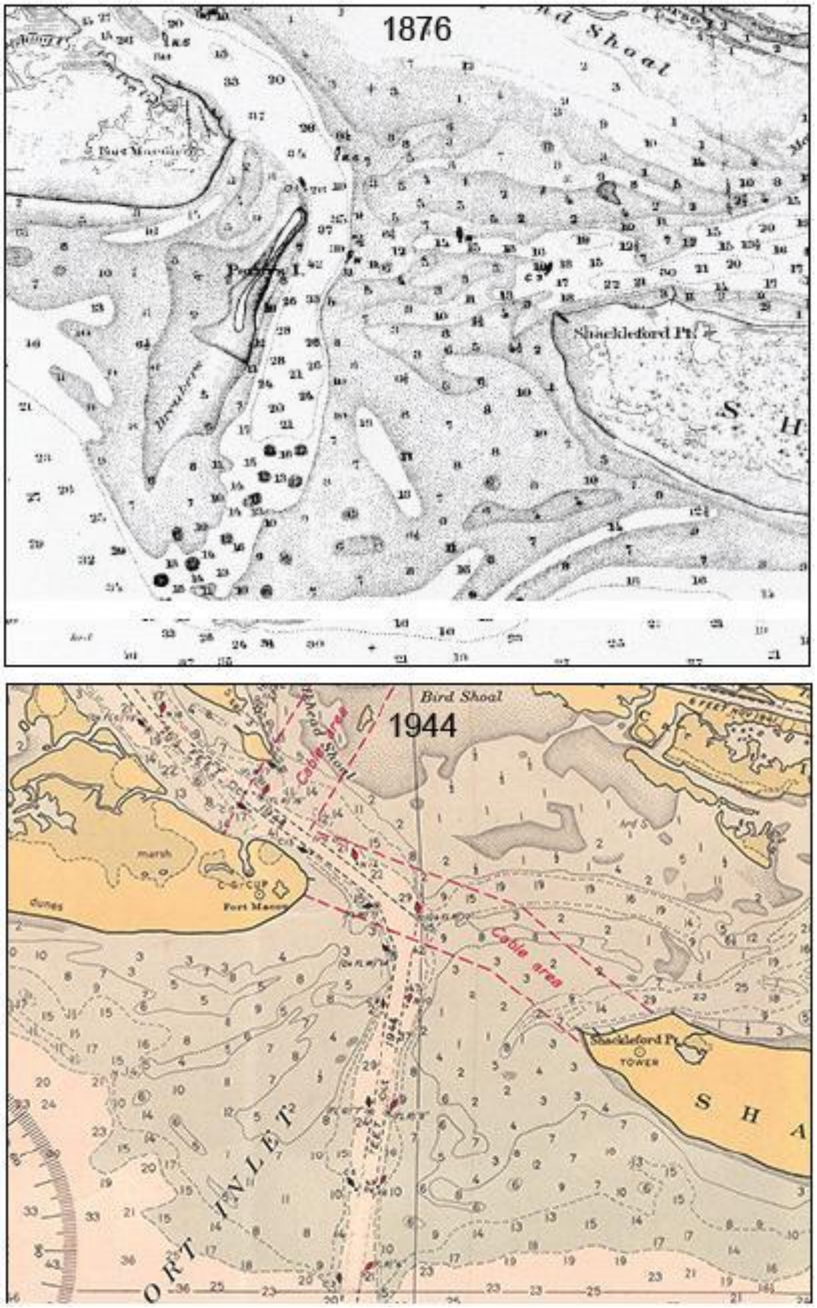


Figure II-25. Historical Coastal Charts of Beaufort Inlet in 1876 and 1994

b) 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 II-26). 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 II-27). 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 II-26) the beach extends to near the end of the terminal groin and there is a robust beach adjacent to the inlet.

c) Historical Shoreline Trends

Shoreline changes near the inlet and terminal groin are shown in Figure II-28 for the period between 1851 and 2004 (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.

d) Dredging and Disposal History

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, which was deepened again to 35 feet by 1960.

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).

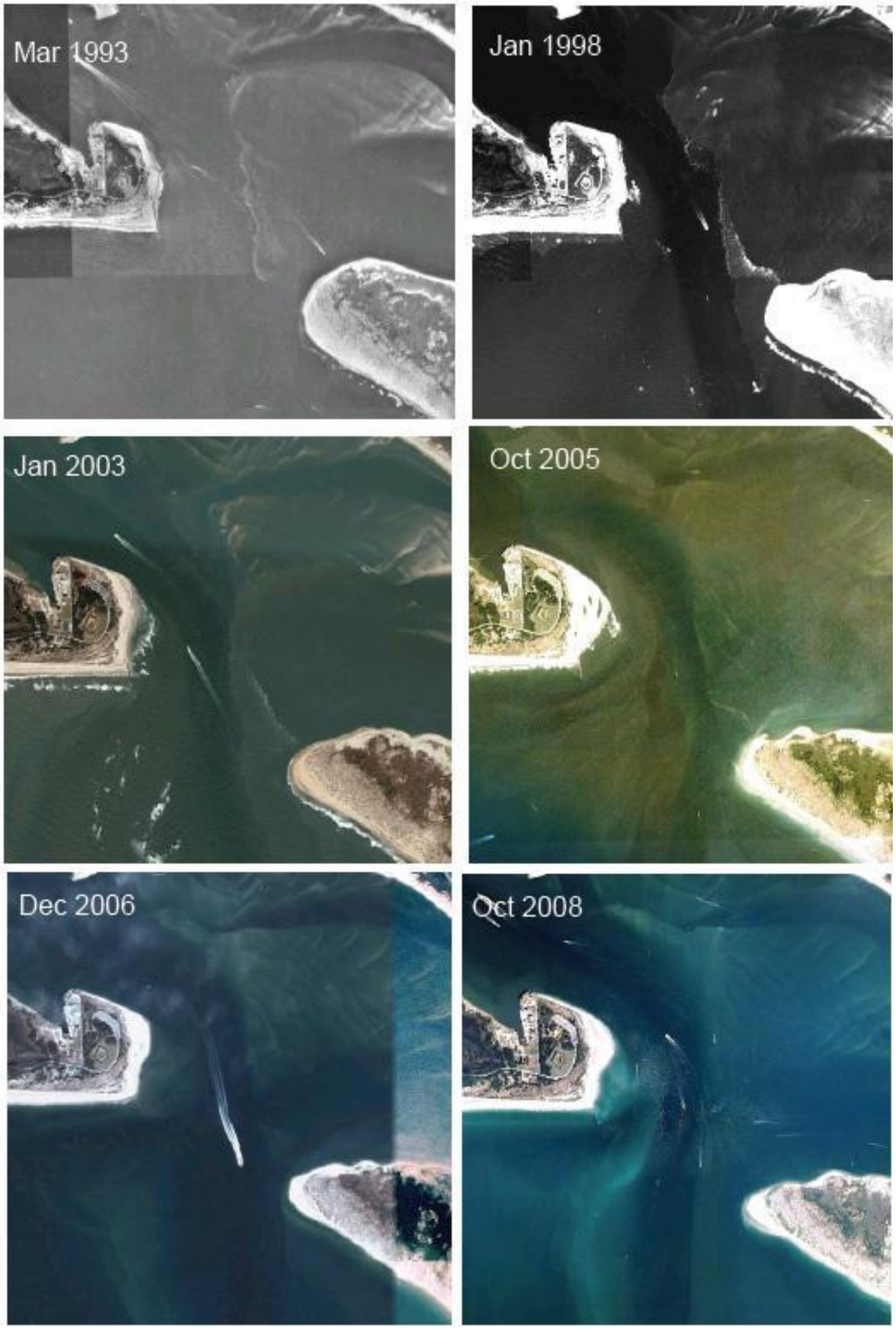


Figure II-26. Aerial Photographs Showing Shoreline Changes in the Vicinity of Fort Macon Terminal Groin.
Note the shoreline progradation inside the inlet (2005) and west of the terminal groin (taken from Google Earth)

Figure II-27. Photographs Illustrating Progradation of the Beach West of the Groin and Along Inlet Shore.
Dashed line indicates extent of groin beneath the beach

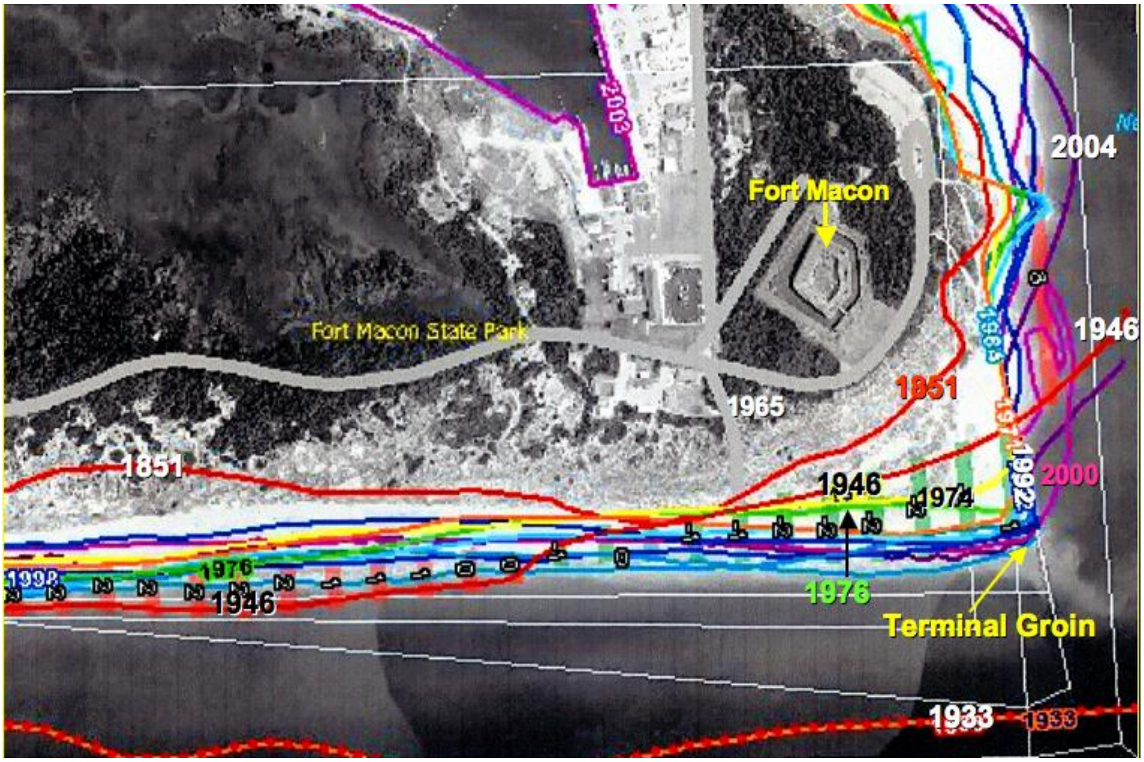


Figure II-28. Compilation of Historic Shorelines in the Vicinity of Fort Macon Terminal Groin (Cleary, 2009).

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 II-29). 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 sediment dredged at the inlet and from the Morehead navigational channels, about 20% was placed in the nearshore disposal area while the rest was placed in the ODMDS. In 1996, all of the sediment 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).

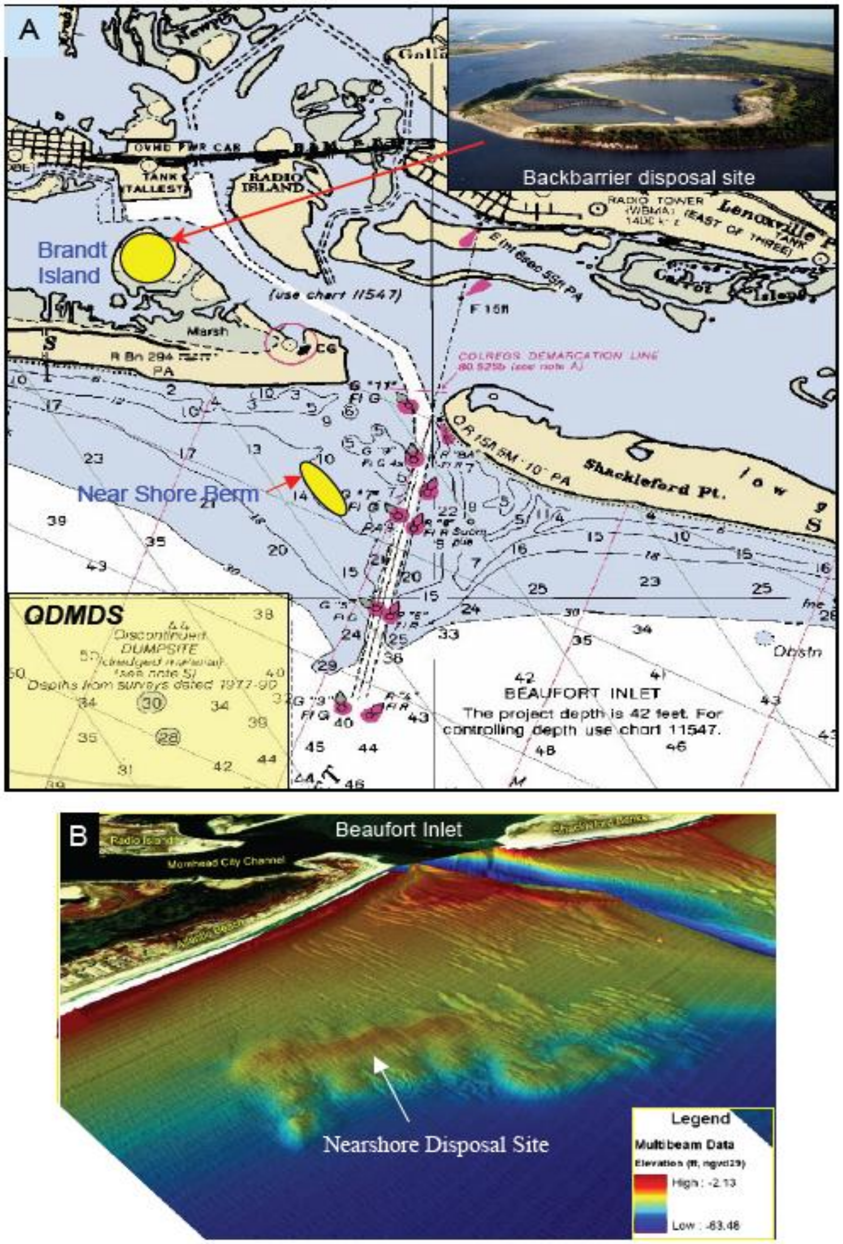


Figure II-29. A. Dredge Disposal Sites Used in Maintaining Navigation Channels for Morehead City and Beaufort Inlet. B. DEM Showing Build-up of Sand at Nearshore Site

e) 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 II-30). 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, it 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.

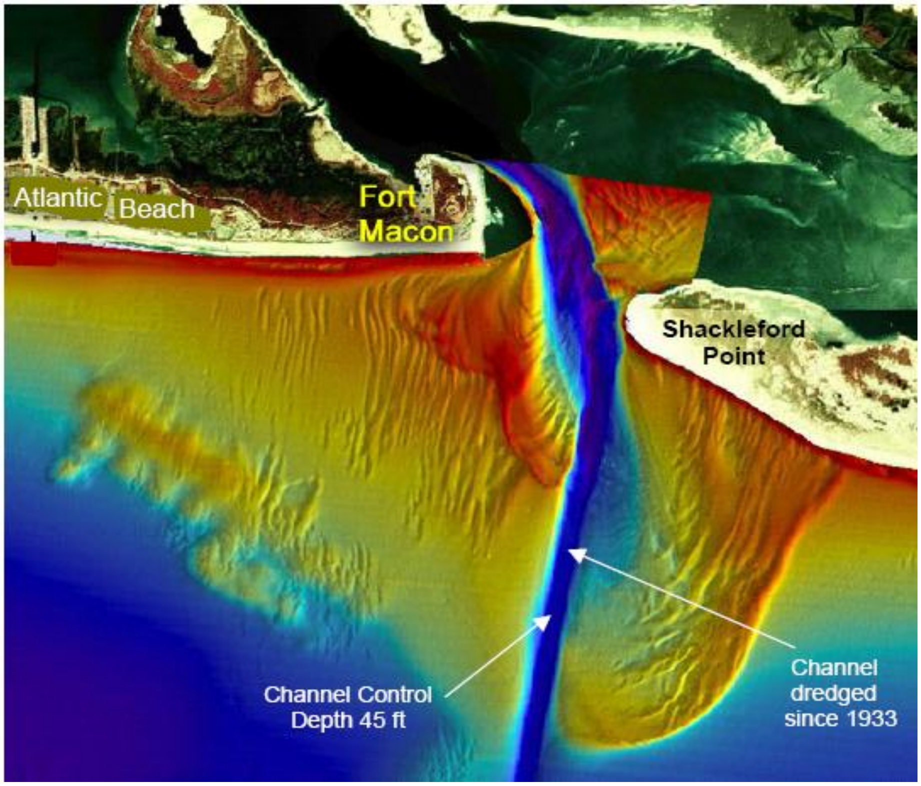


Figure II-30. Digital Elevation Model Illustrating the Relief of the Ebb-tidal Delta. Note that the main channel has been dredged since 1933 and is presently maintained to a depth of 45 feet.

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 or 6.6 fps) are about twice as strong as flood currents (spring tides, velocity = 1.0 m/s or 3.3 fps) (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 II-31. 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 II-30 and Figure II-31).

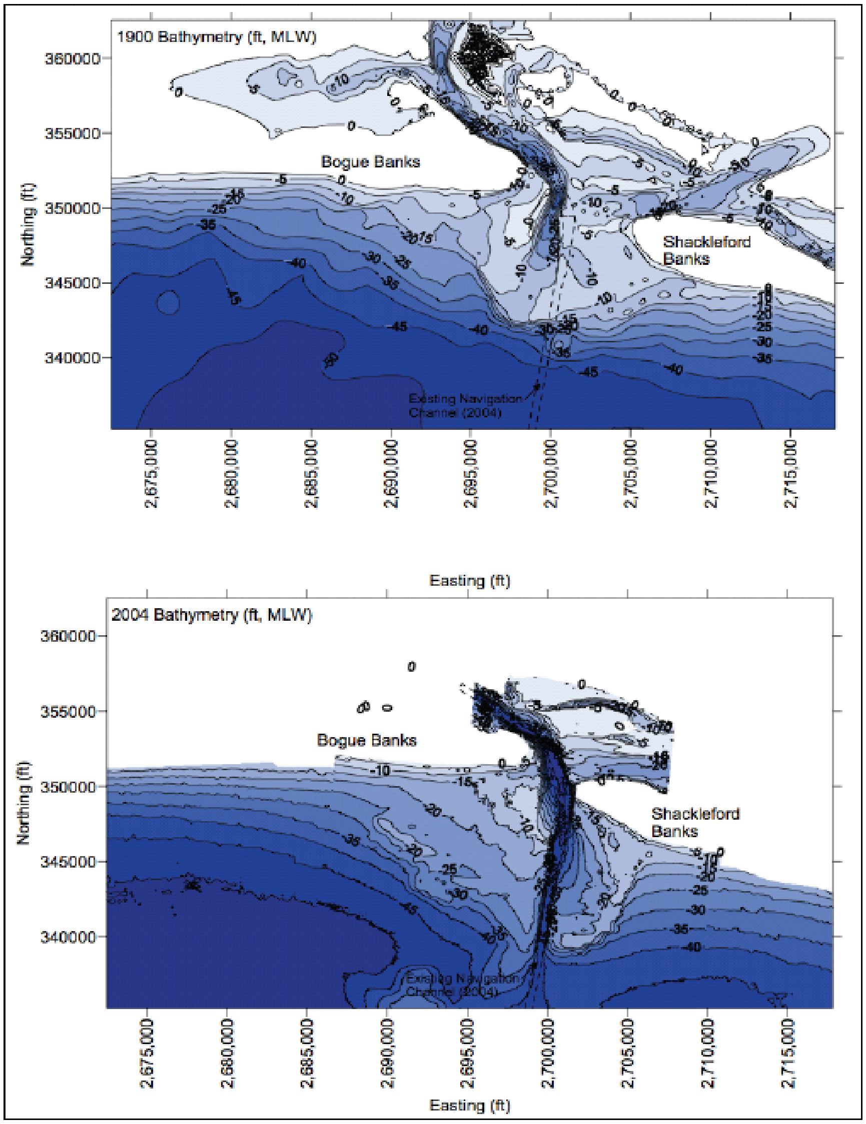


Figure II-31. Comparison of Bathymetry between ca. 1900 and 2004 (Olsen, 2004)

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 II-31 that 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 II-31) indicates that the ebb delta affords far less protection for the inlet shoreline during storms than it had in 1900.

2. Quantitative Assessment

a) 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-32 illustrates the shoreline data used in the analysis.

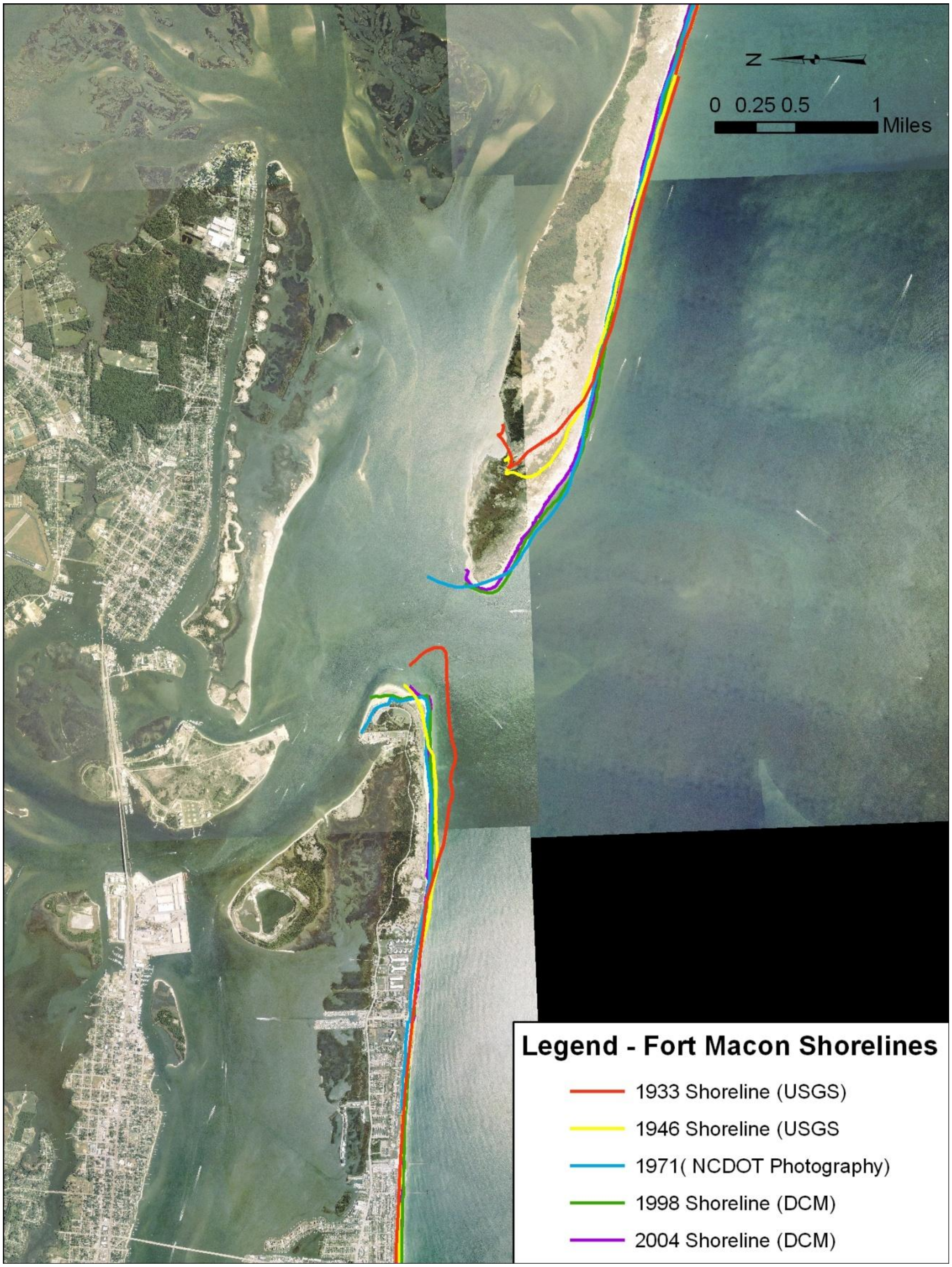


Figure II-32. Historic Shorelines – Fort Macon (Beaufort Inlet)

Figure II-33 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-33 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.

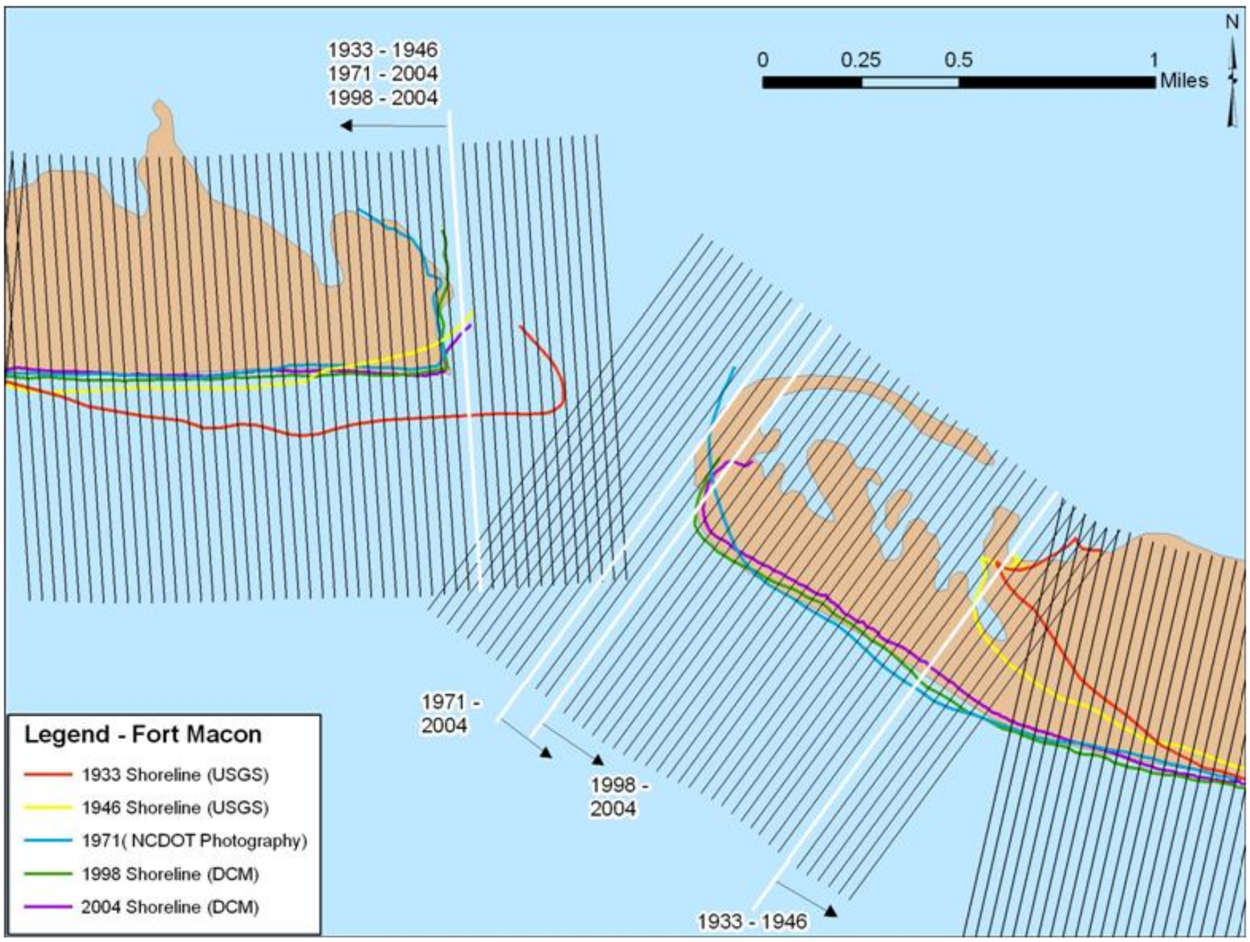


Figure II-33. Fort Macon (Beaufort Inlet) Shoreline Change Calculation Transects

The results of the shoreline change calculations for the pre- and post-structure time periods are given in Table II-20 and Table II-21 for Shackleford Banks and Table II-22 and Table II-23 for Fort Macon (location of terminal groin). Values in red represent shoreline recession (erosion) and values in black represent shoreline advancement (accretion). The first table for each island presents the average shoreline change for each interval as indicated while the second table presents average shoreline change from the inlet shoulder to a total distance up to three miles. Figure II-34 and Figure II-35 display the same data graphically.

Table II-20. Shoreline Change – Shackleford Banks (Interval)

	Shoreline Change - Shackleford Banks (Intervals) (ft/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1933 - 1946	54.3	31.6	0.5	11.0	11.0	6.3
Post: 1971 - 2004	8.9	5.3	7.8	9.4	1.0	0.2

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

Table II-21. Shoreline Change – Shackleford Banks (Total Average)

	Shoreline Change - Shackleford Banks (Total Average) (ft/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1933 - 1946	54.3	43.0	28.5	18.6	3.8	0.5
Post: 1971 - 2004	8.9	7.1	7.3	7.9	3.4	2.3

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

Table II-22. Shoreline Change – Fort Macon (Interval)

	Shoreline Change - Fort Macon (Intervals) (ft/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1933 - 1946	73.3	58.3	39.6	25.4	2.6	0.0
Post: 1971 - 2004	13.1	2.2	0.2	0.5	1.9	3.7

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

Table II-23. Shoreline Change – Fort Macon (Total Average)

	Shoreline Change - Fort Macon (Total Average) (ft/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1933 - 1946	73.3	65.8	57.1	49.2	23.3	15.5
Post: 1971 - 2004	13.1	7.7	5.0	3.7	2.8	3.0

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

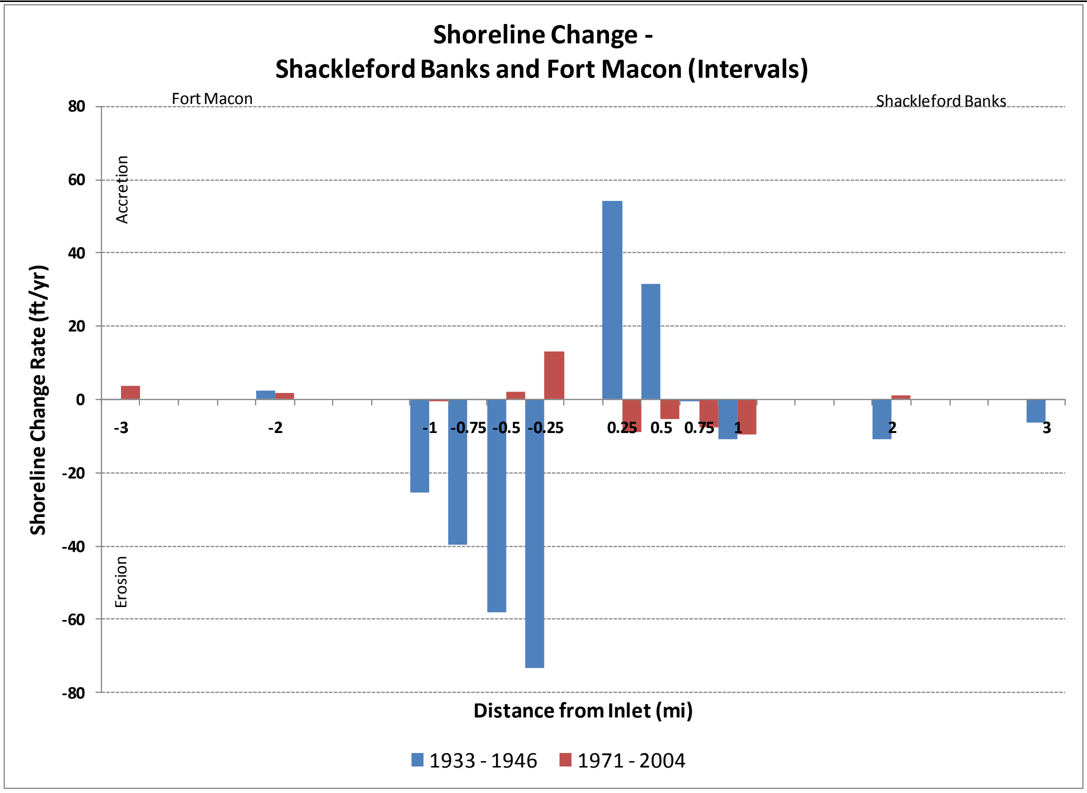


Figure II-34. Shoreline Change – Shackleford Banks and Fort Macon (Intervals)

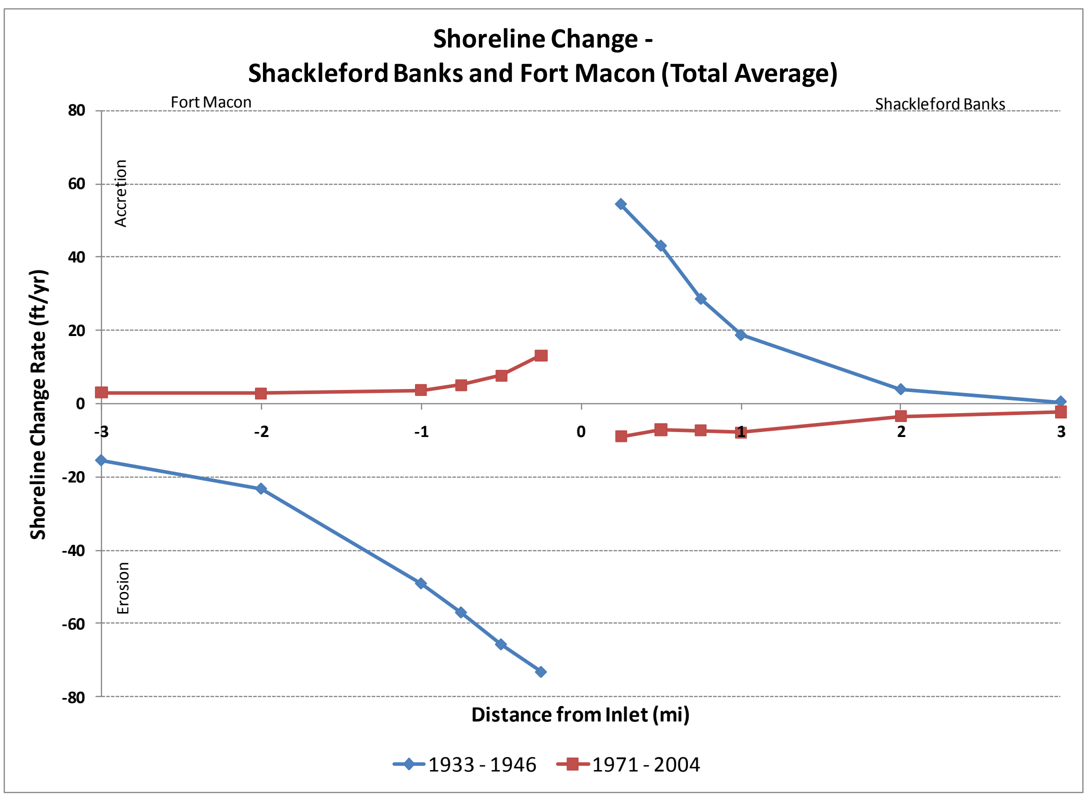


Figure II-35. Shoreline Change – Shackleford Banks and Fort Macon (Total Average)

b) Volumetric Changes

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 initially evaluated based on the shoreline change. 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 (Shackleford 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-24 and Table II-25 provide the volumetric beach change for the intervals and cumulative distances, respectively, along Shackleford Banks based on the shoreline change rates presented previously, while Table II-26 and Table II-27 present the volumetric beach change for the intervals and cumulative distances, respectively along Fort Macon. 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 and dredging, since these are implicitly included in the shoreline measurements. Figure II-36 and Figure II-37 present the same information graphically.

Table II-24. Beach Volume Changes – Shackleford Banks (Intervals)

	Volume Change - Shackleford Banks (Intervals) (cy/yr)					
Distance from Inlet (mi)	0 - 0.25	0.25 - 0.5	0.5 - 0.75	0.75 - 1	1 - 2	2 - 3
Pre: 1933 - 1946	72,446	42,142	718	14,631	58,404	33,387
Post: 1971 - 2004	11,912	7,066	10,367	12,579	5,427	812

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

Table II-25. Beach Volume Changes – Shackleford Banks (Cumulative)

	Volume Change - Shackleford Banks (Cumulative) (cy/yr)					
Distance from Inlet (mi)	0 - 0.25	0 - 0.5	0 - 0.75	0 - 1	0 - 2	0 - 3
Pre: 1933 - 1946	72,446	114,588	113,869	99,238	40,835	7,447
Post: 1971 - 2004	11,912	18,978	29,345	41,924	36,497	37,309

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

Table II-26. Beach Volume Changes – Fort Macon (Intervals)

	Volume Change - Fort Macon (Intervals) (cy/yr)					
Distance from Inlet (mi)	0 - 0.25	0.25 - 0.5	0.5 - 0.75	0.75 - 1	1 - 2	2 - 3
Pre: 1933 - 1946	97,737	77,677	52,840	33,886	13,607	71
Post: 1971 - 2004	17,486	2,932	279	620	9,991	19,495

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

Table II-27. Beach Volume Changes – Fort Macon (Cumulative)

	Volume Change - Fort Macon (Cumulative) (cy/yr)					
Distance from Inlet (mi)	0 - 0.25	0 - 0.5	0 - 0.75	0 - 1	0 - 2	0 - 3
Pre: 1933 - 1946	97,737	175,414	228,254	262,139	248,532	248,603
Post: 1971 - 2004	17,486	20,418	20,139	19,519	29,510	47,778

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

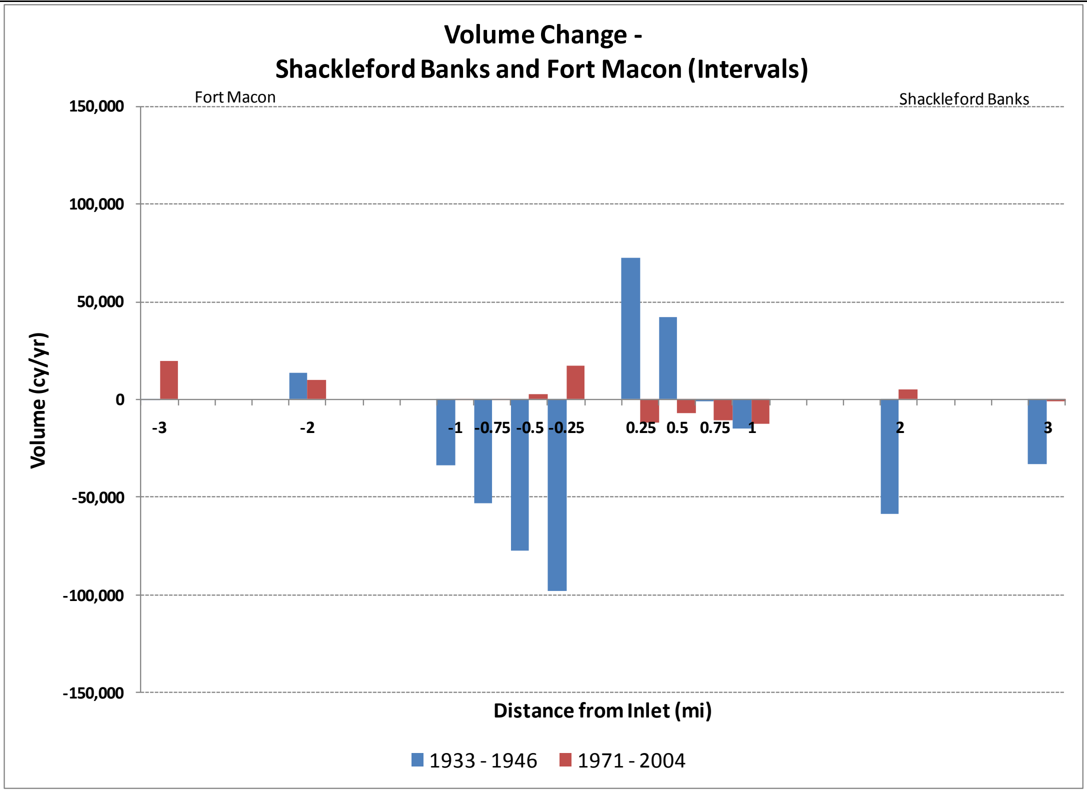


Figure II-36. Beach Volume Changes – Fort Macon (Intervals)

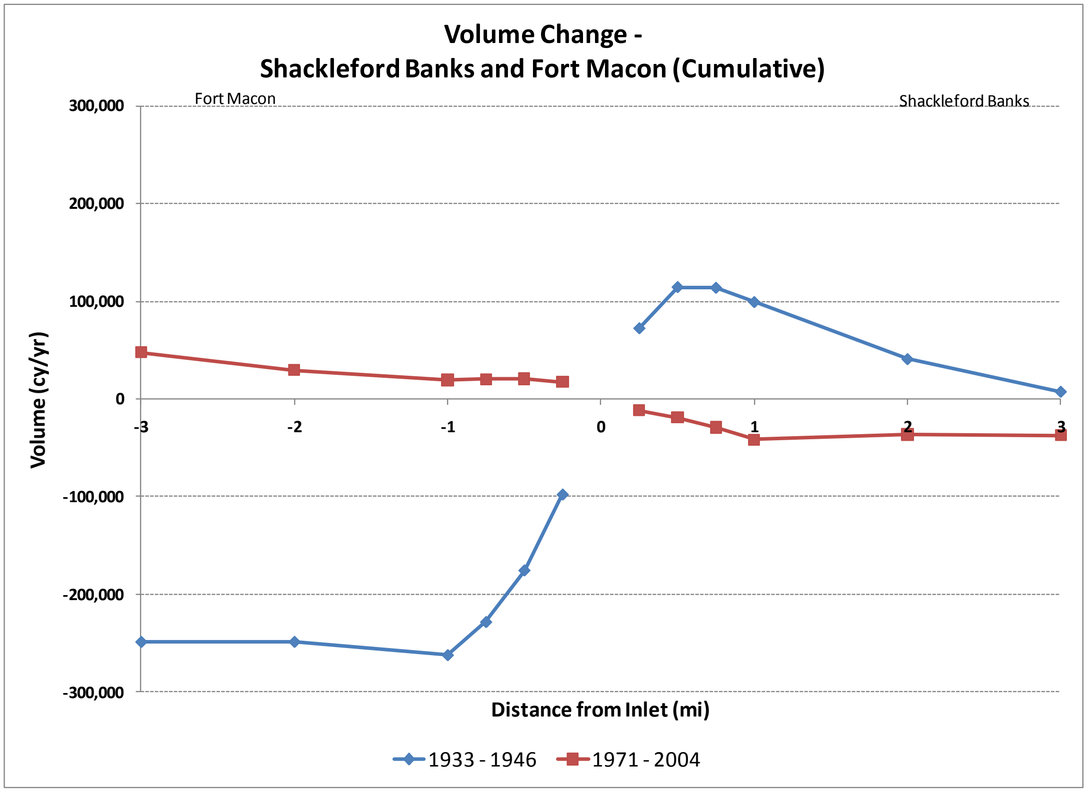


Figure II-37. Beach Volume Changes – Fort Macon (Cumulative)

c) Volumetric Changes – Beach Nourishment

Since construction of the Fort Macon Terminal Groin, beach nourishment and sediment placement has occurred along the shoreline near the fort. Table II-28 details the amounts, timing, and locations, when known, of beach nourishment activities at Fort Macon during the analysis time periods. (The engineering activities log in Appendix C provides details for all activities).

Table II-28. Beach Nourishment – Fort Macon

Year	Placement Location	Extent (ft)	Beach Nourishment Volume by Interval (cy)							Total Volume (cy)
			0 - 0.25	0.25 - 0.50	0.50 - 0.75	0.75 - 1.0	1.0 - 2.0	2.0 - 3.0	3.0 +	
1973	Beach Nourishment	5,043	126,067	126,067	126,067	126,067	0	0	0	504,266
1979	Beach Nourishment	11,797	147,467	147,467	147,467	147,467	589,870	0	0	1,179,739
1986	Beach Nourishment (Atlantic Beach)	39,129	130,269	130,269	130,269	130,269	521,075	521,075	2,605,375	4,168,600
1994	Beach Nourishment	24,737	109,613	109,613	109,613	109,613	438,454	438,454	876,907	2,192,268
2002	Beach Nourishment	-	26,169	26,169	26,169	26,169	104,674	0	0	209,348

Table II-29 presents a summary of this data with respect to the amounts assumed placed on each analysis interval of shoreline for each of the analysis time periods. For material placed directly on the beach, the total volumes were pro-rated over the placement stations when known. In cases where the exact placement location was not known, the material was assumed to be distributed evenly over the placement extents beginning at the terminal groin.

Table II-29. Beach Nourishment – Fort Macon

Period	Beach Nourishment Volume by Interval (cy/yr)							Total Volume (cy/yr)
	0 - 0.25	0.25 - 0.50	0.50 - 0.75	0.75 - 1.0	1.0 - 2.0	2.0 - 3.0	3.0 +	
Pre: 1933 - 1946	0	0	0	0	0	0	0	0
Post: 1971 - 2004	16,351	16,351	16,351	16,351	50,123	29,077	105,524	250,128

In Table II-30 and Table II-31 for Shackleford Banks, and Table II-32 and Table II-33 for Fort Macon, the total beach nourishment material placed on the beach is subtracted from the volumes calculated based on shoreline change to arrive at volume changes without nourishment (as if the nourishment did not take place). Figure II-38 and Figure II-39 present the same information graphically.

Table II-30. Volume Changes Without Nourishment – Shackleford Banks (Intervals)

	Volume Change w/o Nourishment - Shackleford Banks (Intervals) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1933 - 1946	72,446	42,142	718	14,631	58,404	33,387
Post: 1971 - 2004	11,912	7,066	10,367	12,579	5,427	812

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

Table II-31. Volume Changes Without Nourishment – Shackleford Banks (Cumulative)

	Volume Change w/o Nourishment - Shackleford Banks (Cumulative) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1933 - 1946	72,446	114,588	113,869	99,238	40,835	7,447
Post: 1971 - 2004	11,912	18,978	29,345	41,924	36,497	37,309

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

Table II-32. Volume Changes Without Nourishment – Fort Macon (Intervals)

	Volume Change w/o Nourishment - Fort Macon (Intervals) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1933 - 1946	97,737	77,677	52,840	33,886	13,607	71
Post: 1971 - 2004	1,135	13,419	16,630	16,971	40,132	9,582

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

Table II-33. Volume Changes Without Nourishment – Fort Macon (Cumulative)

	Volume Change w/o Nourishment - Fort Macon (Cumulative) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1933 - 1946	97,737	175,414	228,254	262,139	248,532	248,603
Post: 1971 - 2004	1,135	12,284	28,914	45,885	86,017	96,826

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

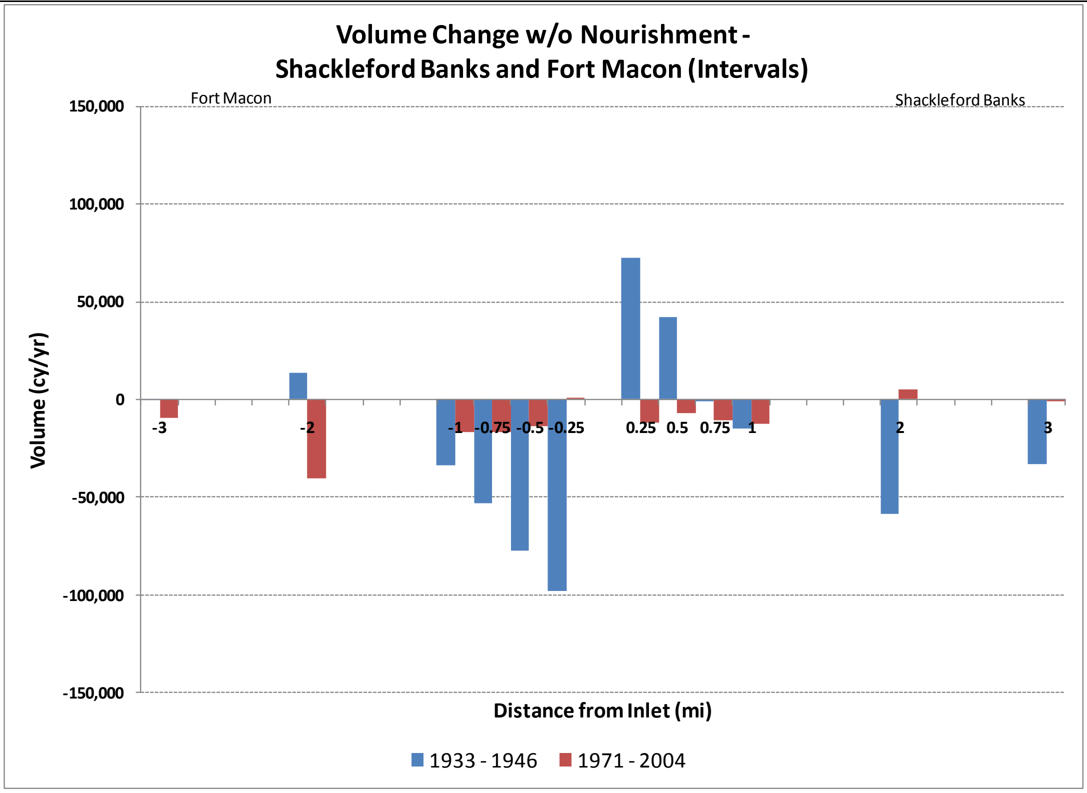


Figure II-38. Volume Changes w/o Nourishment – Shackleford Banks and Fort Macon (Intervals)

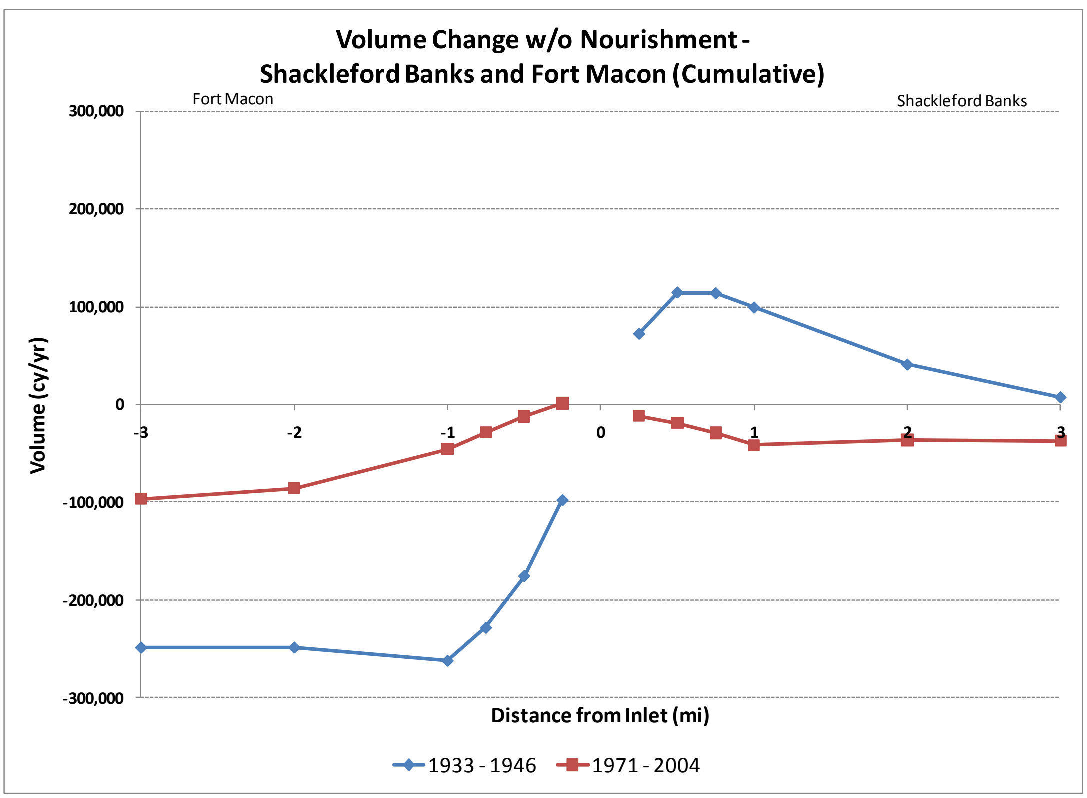


Figure II-39. Volume Changes w/o Nourishment – Shackleford Banks and Fort Macon (Cumulative)

d) Volumetric Changes - Dredging

Much like nourishment, the influence of dredging material from the inlet system must 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.

It should be noted that past estimates involving changes in the volume of sediment stored in the 1854 ebb-tidal delta, indicated there was 48.97 million cubic yards 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, and the most significant loss occurred within the Bogue Banks segment of the shoals on the western margin of the ebb channel.

Table II-34 details the amounts, timing and locations, when known, of dredging activities that removed material from within the inlet system during the analysis time periods. (The engineering activities log in Appendix C provides details for all activities). Any dredging that occurred within the inner harbor was not included in this analysis since these activities did not remove material that might otherwise have bypassed the inlet and naturally ended up on the adjacent shorelines. Table II-35 presents a summary of this data with respect to the amounts dredged during each analysis time period.

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-36 and Table II-37 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 without nourishment). The additional scenarios assume 25% or 50% of the material dredged from the inlet system would have reached the beach naturally.

Table II-34. Dredging Volumes – Beaufort Inlet

Year	Dredging Location	Total Volume (cy)	Year	Dredging Location	Total Volume (cy)
1933	Outer Bar Channel	156,300	1980	Outer Bar Channel	294,610
1935	Outer Bar Channel	763,100	1981	Outer Bar Channel	824,052
1936	Outer Bar Channel	3,460,100	1982	Outer Bar Channel	977,040
1937	Outer Bar Channel	268,300	1983	Outer Bar Channel	848,933
1938	Outer Bar Channel	205,700	1984	Outer Bar Channel	1,098,259
1939	Outer Bar Channel	473,800	1985	Outer Bar Channel	583,181
1940	Outer Bar Channel	918,100	1986	Outer Bar Channel	367,681
1942	Outer Bar Channel	299,200	1987	Outer Bar Channel	534,555
1943	Outer Bar Channel	91,900	1988	Outer Bar Channel	691,190
1944	Outer Bar Channel	584,900	1989	Outer Bar Channel	539,192
1945	Outer Bar Channel	520,800	1990	Outer Bar Channel	592,232
1946	Outer Bar Channel	145,800	1991	Outer Bar Channel	11,959
1971	Outer Bar Channel	913,800	1991	Outer Bar Channel	831,637
1972	Outer Bar Channel	783,700	1993	Outer Bar Channel	837,573
1973	Outer Bar Channel	952,900	1994	Outer Bar Channel	2,606,922
1974	Outer Bar Channel	401,600	1996	Outer Bar Channel	656,646
1975	Outer Bar Channel	238,289	1997	Outer Bar Channel	191,872
1975	Outer Bar Channel	190,397	1998	Outer Bar Channel	1,163,563
1976	Outer Bar Channel	74,685	1999	Outer Bar Channel	1,040,919
1976	Outer Bar Channel	583,929	2000	Outer Bar Channel	1,701,659
1977	Outer Bar Channel	96,133	2001	Outer Bar Channel	886,136
1978	Outer Bar Channel	1,364,069	2003	Outer Bar Channel	886,136
1978	Outer Bar Channel	1,608,131	2004	Outer Bar Channel	801,000
1978	Outer Bar Channel	530,008			

Table II-35. Dredging Volumes – Beaufort Inlet

Period	Total Volume (cy/yr)
Pre: 1933 - 1946	563,429
Post: 1971 - 2004	785,429

Table II-36. Volume Change Scenarios Without Nourishment and Dredging – Shackleford Banks (3 miles)

	Dredging Effects - Shackleford Banks (cy/yr)		
Dredging Percentage Added	**0%**	**25%**	**50%**
Pre: 1933- 1946	7,447	148,304	289,162
Post: 1971 - 2004	37,309	159,048	355,405

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

Table II-37. Volume Change Scenarios Without Nourishment and Dredging – Fort Macon (3 miles)

	Dredging Effects - Fort Macon (cy/yr)		
Dredging Percentage Added	**0%**	**25%**	**50%**
Pre: 1933- 1946	248,603	107,746	33,111
Post: 1971 - 2004	96,826	99,531	295,889

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

3. 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 and stabilized the eastern end of Bogue Banks that had previously had a history of westerly retreat (1851) and easterly progradation (1933). 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.

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. 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.

Prior to terminal groin construction, the Fort Macon shoreline was eroding fairly rapidly over the first mile and was relatively stable over the next two miles. After the construction of the terminal groin, the shoreline is relatively stable or accretionary with significant accretion immediately adjacent to the terminal groin. It must be noted, though, that these shorelines include the effects of beach nourishment and dredging activities.

Shackleford Banks was highly accretionary in the first half-mile for the 1933-1946 time period, but was mostly erosional over the next 2.5 miles. After construction of the terminal groin, the shoreline was erosional over the first mile and then relatively stable over the next two miles.

Significant beach nourishment and dredging activities have occurred at Fort Macon and Beaufort Inlet. Since the terminal groin was constructed, millions of cubic yards of material have been placed on the beach or in the nearshore region and dredged from the inlet system during the analysis time period.

Once all the beach nourishment activities are subtracted out, the volumetric analysis shows for Fort Macon that after construction of the terminal groin, the average erosion was significantly reduced over the first mile; moderately increased over the second mile; and was relatively stable in the third mile. The average erosion, though, over these three miles, did decrease significantly.

Shackleford Banks has the same volumetric trends as the shoreline change since no nourishment has occurred on this side of the inlet.

However, given the very large volumes of material dredged from the inlet system, it can be seen that even assuming a small percentage of the dredged material would have naturally been transported to either Fort Macon or Shackleford Banks could significantly reduce or eliminate any apparent negative impacts in some of the pertinent intervals within the three mile analysis area.

F. Assessment of Amelia Island Terminal Groin

1. Qualitative Assessment

a) Site Description

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. 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. Continuing south of the inlet is the Little Talbot Island (Duval County). Information and data regarding the tidal, wave and storm environment at Amelia Isalnd is presented in Appendix D.

b) Terminal Groin

From 1964 to 2001, numerous measures were undertaken to combat the erosion including the placement of millions of cubic yards 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 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 the terminal groin and an offshore breakwater were constructed.

The Amelia Island terminal groin (Figure II-40) is located at the south end of the Amelia Island (Nassau County). 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-41. 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.

During the summer of 2006, additional 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.

Figure II-40. Amelia Island Terminal Groin

Figure II-41. Amelia Island Terminal Groin and Breakwater

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 (Table II-39). 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 (Table II-40).

A sequential set of vertical aerial photographs depicting conditions at the end of Amelia Island is presented in Figure II-42 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.

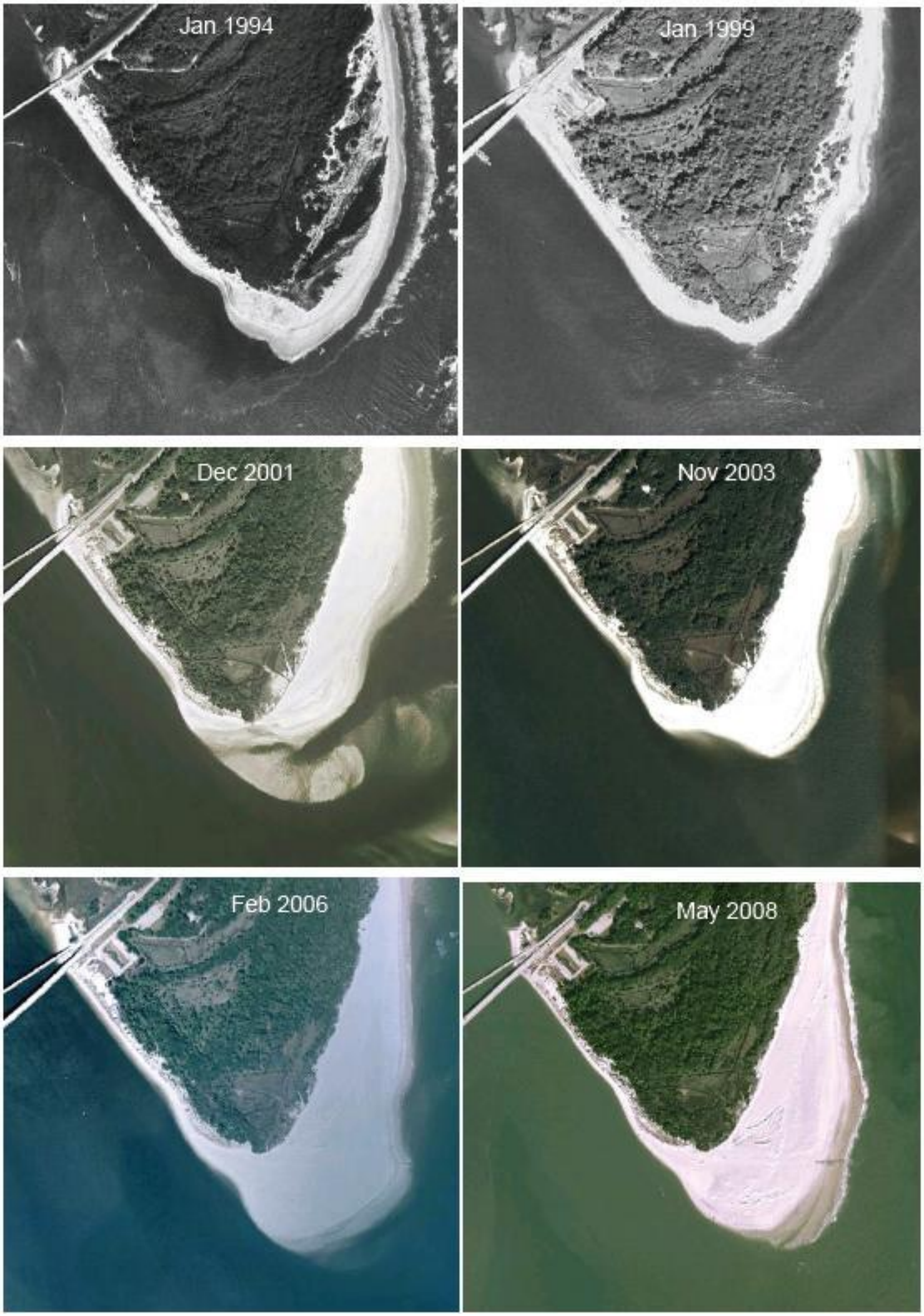


Figure II-42. Sequential Vertical Aerial Photographs of Amelia Island between 1994 and 2008 (from Google Earth)

c) Shoreline Changes

The shoreline changes to the end of Amelia Island have been quantified by Olsen and Associates (2008) and are presented in Figure II-43. As seen, 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.

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 while the greatest amount of erosion has occurred south of the breakwater as the detached breakwater is impounding sand that otherwise would be transported southward.

d) Bathymetric Changes

Figure II-44 is a bathymetric difference map of Nassau 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.

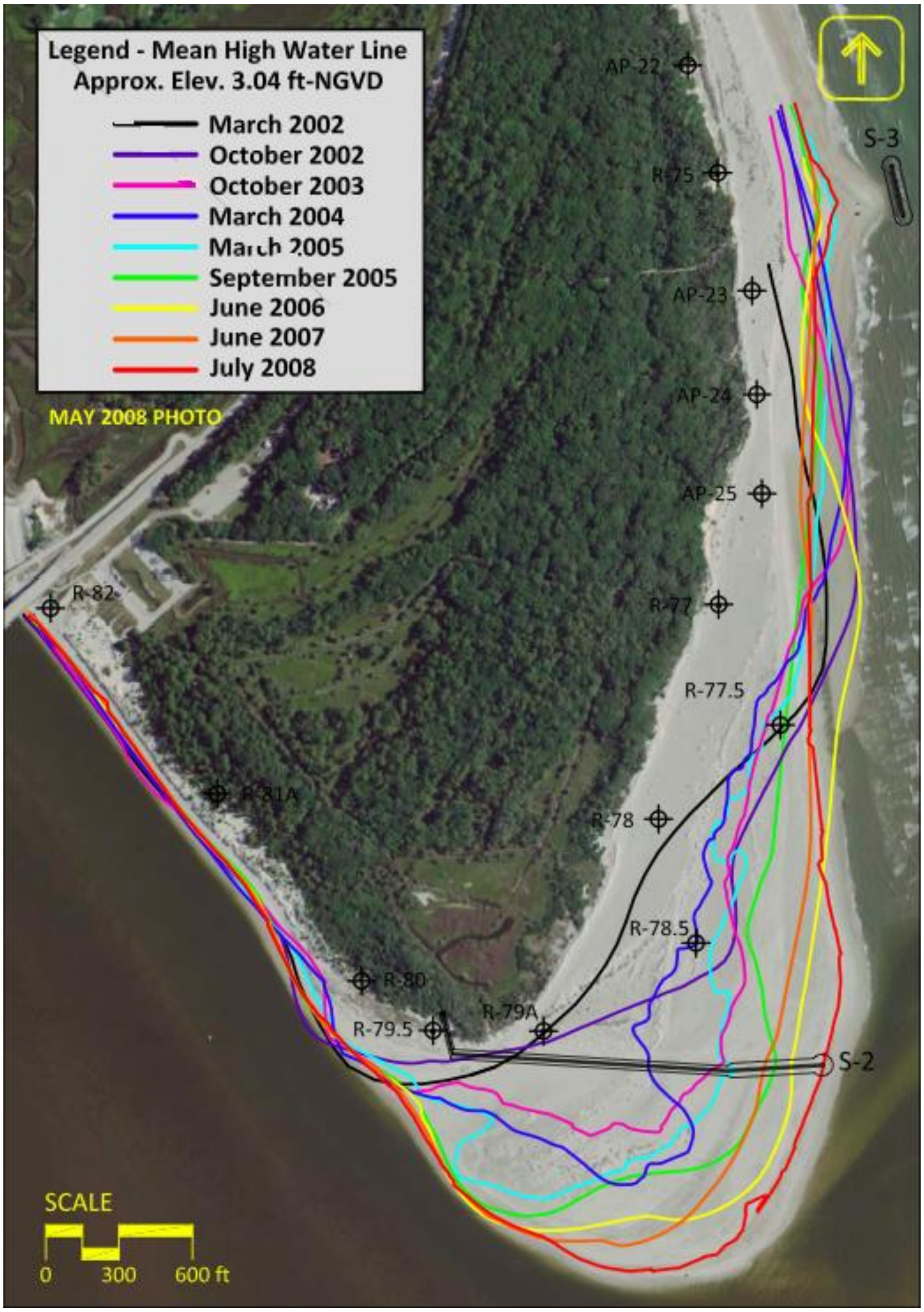


Figure II-43. Shoreline Changes on Southern Amelia Island between 2002 and 2008
Note that the southern tip of the barrier prograded to the south. This extension of the spit was facilitated, in part, from sand eroded from the beach directly north and transported south. (Olsen, 2008)

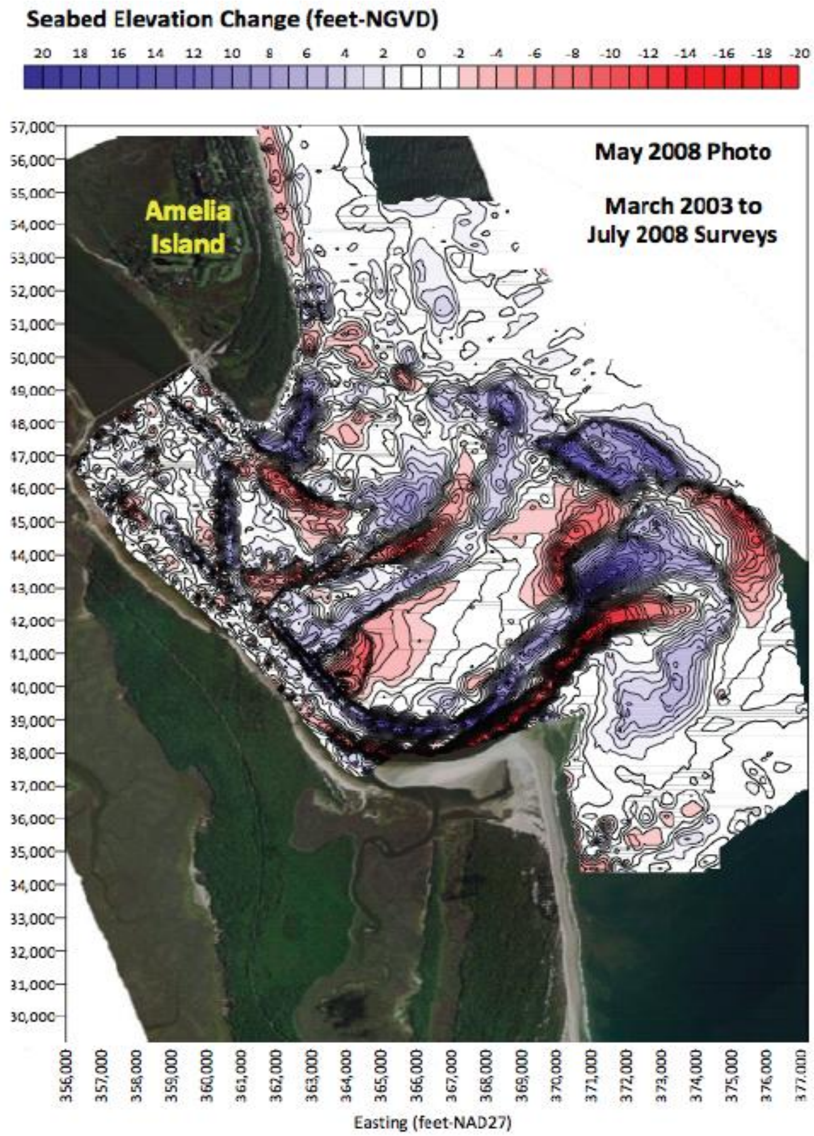


Figure II-44. Bathymetric Changes of Nassau Sound Determined from Repetitive Bathymetric Surveys from 2003 - 2008 (Olsen, 2008)

2. Quantitative Assessment

a) 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 (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-45 illustrates the shoreline data used in the analysis.

Figure II-46 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 noted that shoreline data is not available for the south side of the inlet for the post construction time period.

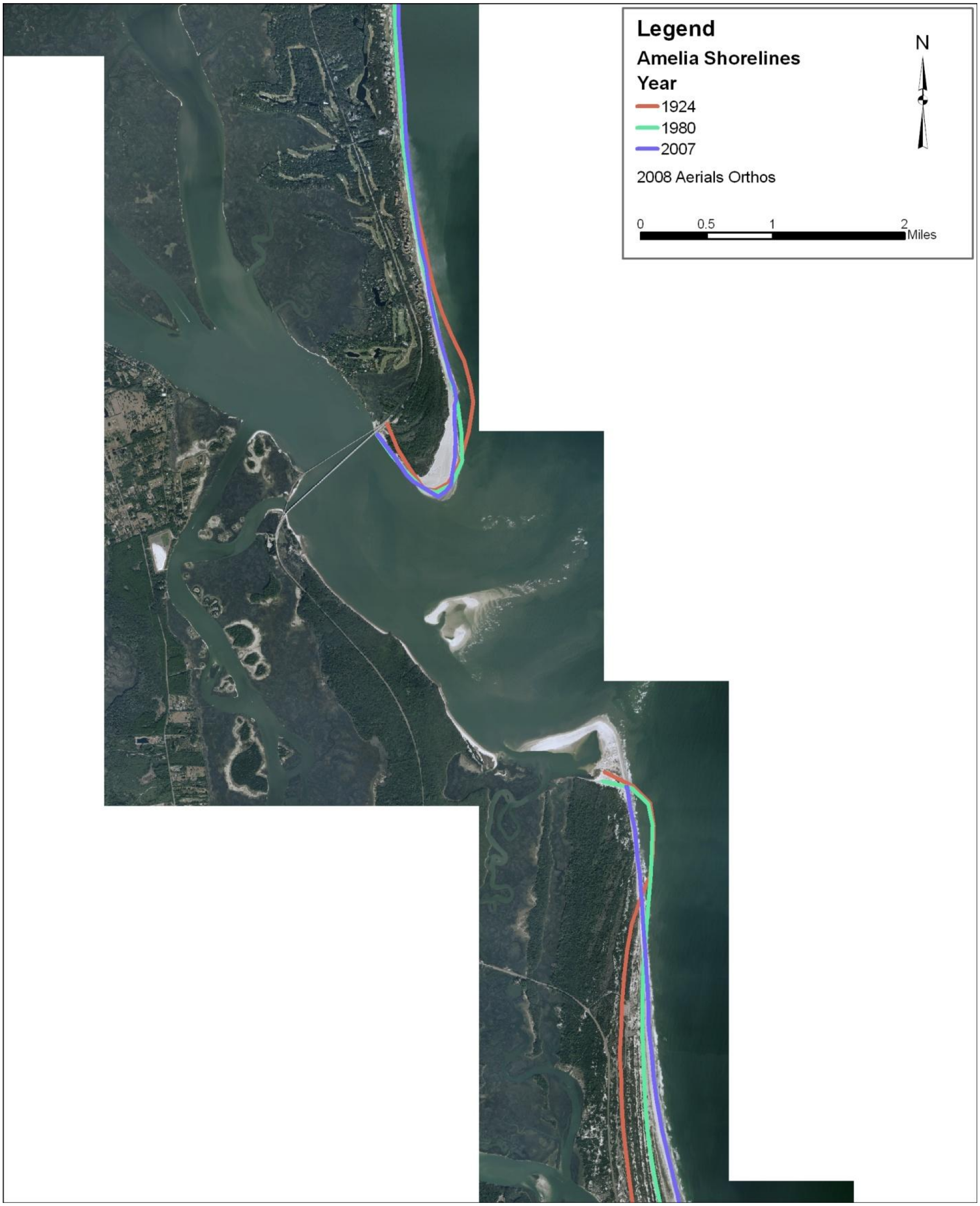


Figure II-45. Historic Shorelines – Amelia Island

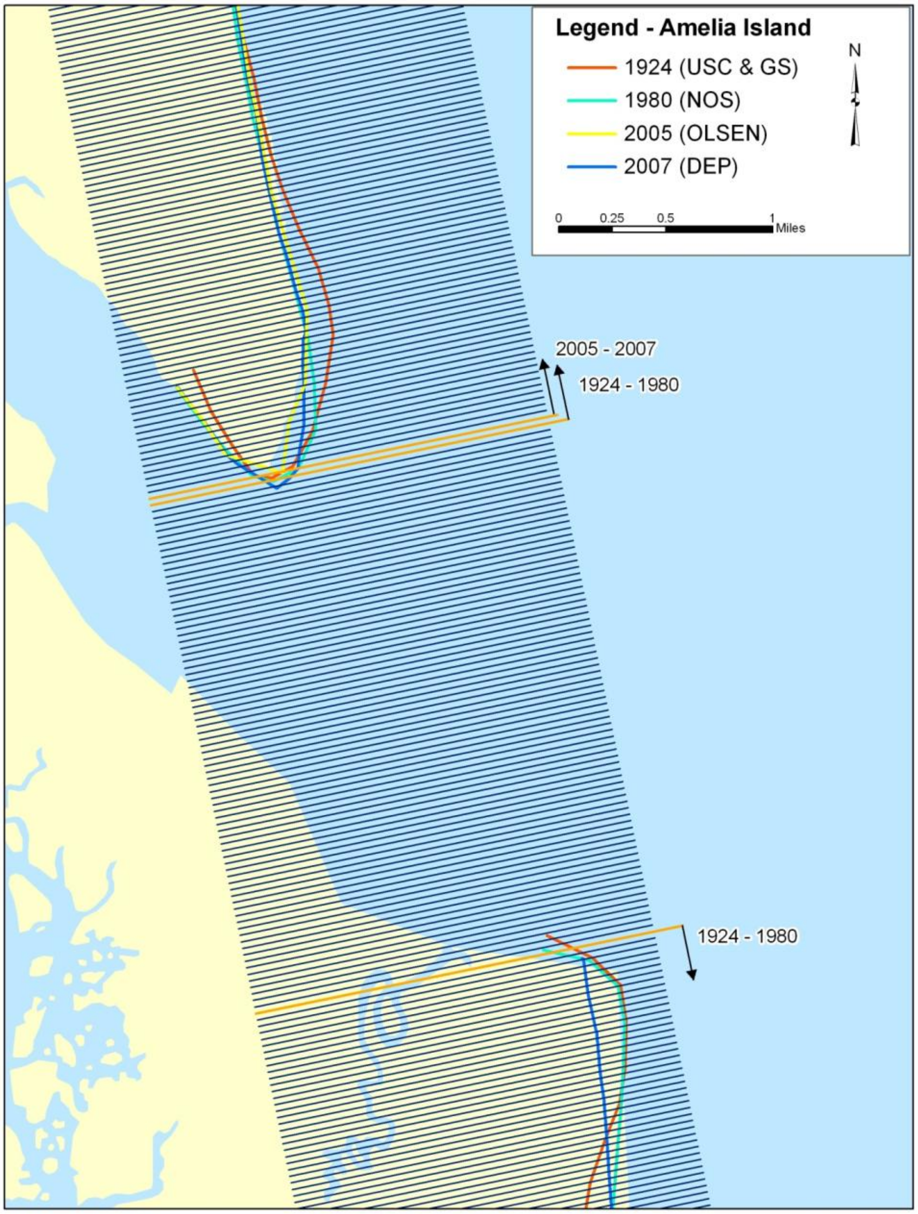


Figure II-46. Amelia Island Shoreline Change Calculation Transects

The results of the shoreline change calculations for the pre- and post-structure time periods are given in Table II-38 and Table II-39 for Amelia Island (location of terminal groin) and Table II-40 and Table II-41 for Little Talbot Island. Values in red represent shoreline recession (erosion) and values in black represent shoreline advancement (accretion). The first table for each island presents the average shoreline change for each interval as indicated while the second table presents average shoreline change from the inlet shoulder to a total distance up to three miles. Figure II-47 and Figure II-48 display the same data graphically.

Table II-38. Shoreline Change – Amelia Island (Intervals)

	Shoreline Change - Amelia Island (Intervals) (ft/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1924 - 1980	3.7	3.9	10.6	12.5	5.5	1.0
Post: 2005 - 2007	163.4	54.7	26.7	48.9	24.9	11.4

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

Table II-39. Shoreline Change – Amelia Island (Total Average)

	Shoreline Change - Amelia Island (Cumulative) (ft/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1924 - 1980	3.7	0.1	3.6	5.8	5.6	3.9
Post: 2005 - 2007	163.4	105.5	59.5	31.5	2.9	2.5

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

Table II-40. Shoreline Change – Little Talbot Island (Intervals)

	Shoreline Change - Little Talbot Island (Intervals) (ft/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1924 - 1980	3.4	0.9	0.4	4.2	13.6	17.2
Post: 2005 - 2007	N/A	N/A	N/A	N/A	N/A	N/A

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

Table II-41. Shoreline Change – Little Talbot Island (Total Average)

	Shoreline Change - Little Talbot Island (Cumulative) (ft/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1924 - 1980	3.4	2.2	1.6	0.1	6.8	10.2
Post: 2005 - 2007	N/A	N/A	N/A	N/A	N/A	N/A

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

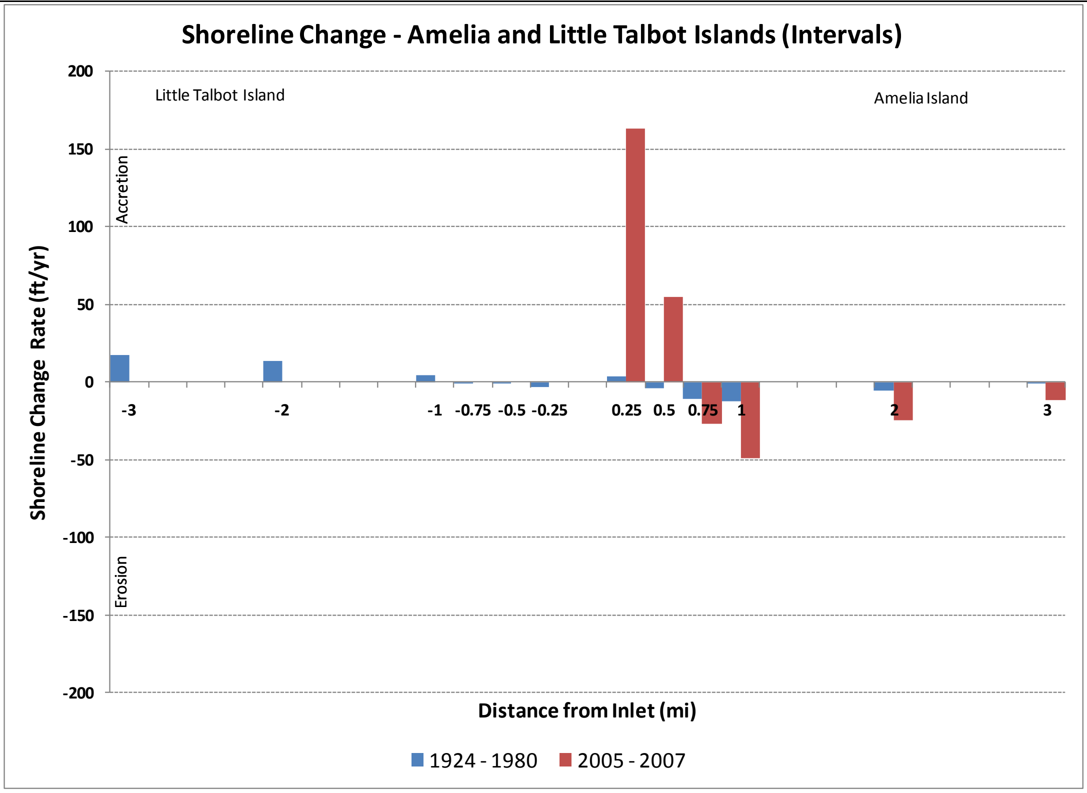


Figure II-47. Shoreline Change – Amelia and Little Talbot Islands (Intervals)

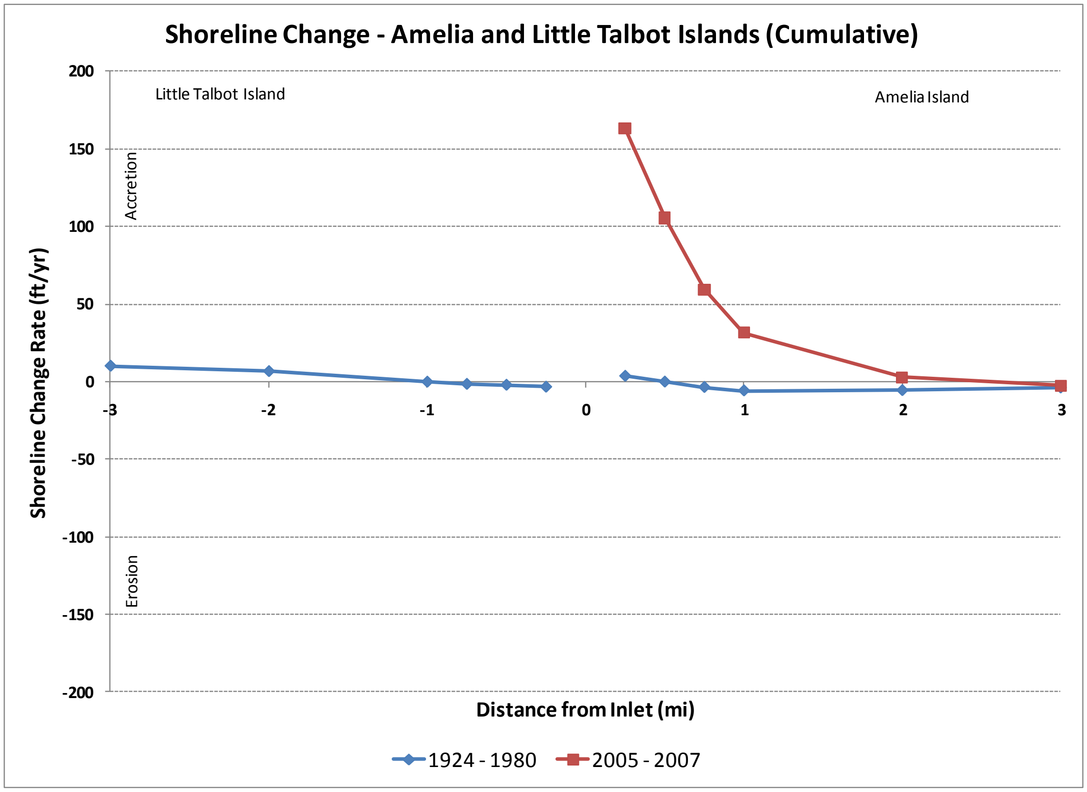


Figure II-48. Shoreline Change – Amelia and Little Talbot Islands (Total Average)

b) Volumetric Changes

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 initially evaluated based on the shoreline change. 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 in Duval County (Little Talbot Island, up to 1.5 mile south of Inlet); and in 1981, 1998 and 2003 in 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-42 and Table II-43 provide the volumetric beach change for the intervals and cumulative distances, respectively, along Amelia Island based on for the shoreline change rates presented previously; while Table II-44 and Table II-45 present the volumetric beach change for the intervals and cumulative distances, respectively, along Little Talbot Island. 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 and dredging since these are implicitly included in the shoreline measurements. Figure II-49 and Figure II-50 present the same information graphically.

Table II-42. Beach Volume Changes – Amelia Island (Intervals)

	Volume Change - Amelia Island (Intervals) (cy/yr)					
Distance from Inlet (mi)	0 - 0.25	0.25 - 0.5	0.5 - 0.75	0.75 - 1	1 - 2	2 - 3
Pre: 1924 - 1980	6,088	6,390	17,474	20,697	36,001	6,806
Post: 2005 - 2007	269,622	90,333	44,102	80,698	164,048	75,307

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

Table II-43. Beach Volume Changes – Amelia Island (Cumulative)

	Volume Change - Amelia Island (Cumulative) (cy/yr)					
Distance from Inlet (mi)	0 - 0.25	0 - 0.5	0 - 0.75	0 - 1	0 - 2	0 - 3
Pre: 1924 - 1980	6,088	303	17,777	38,475	74,476	77,702
Post: 2005 - 2007	269,622	348,002	294,417	207,949	37,996	49,449

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

Table II-44. Beach Volume Changes – Little Talbot Island (Intervals)

	Volume Change - Little Talbot Island (Intervals) (cy/yr)					
Distance from Inlet (mi)	0 - 0.25	0.25 - 0.5	0.5 - 0.75	0.75 - 1	1 - 2	2 - 3
Pre: 1924 - 1980	5,650	1,462	685	6,872	90,051	113,374
Post: 2005 - 2007	N/A	N/A	N/A	N/A	N/A	N/A

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

Table II-45. Beach Volume Changes – Little Talbot Island (Cumulative)

	Volume Change - Little Talbot Island (Cumulative) (cy/yr)					
Distance from Inlet (mi)	0 - 0.25	0 - 0.5	0 - 0.75	0 - 1	0 - 2	0 - 3
Pre: 1924 - 1980	5,650	7,112	7,797	924	89,126	202,501
Post: 2005 - 2007	N/A	N/A	N/A	N/A	N/A	N/A

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

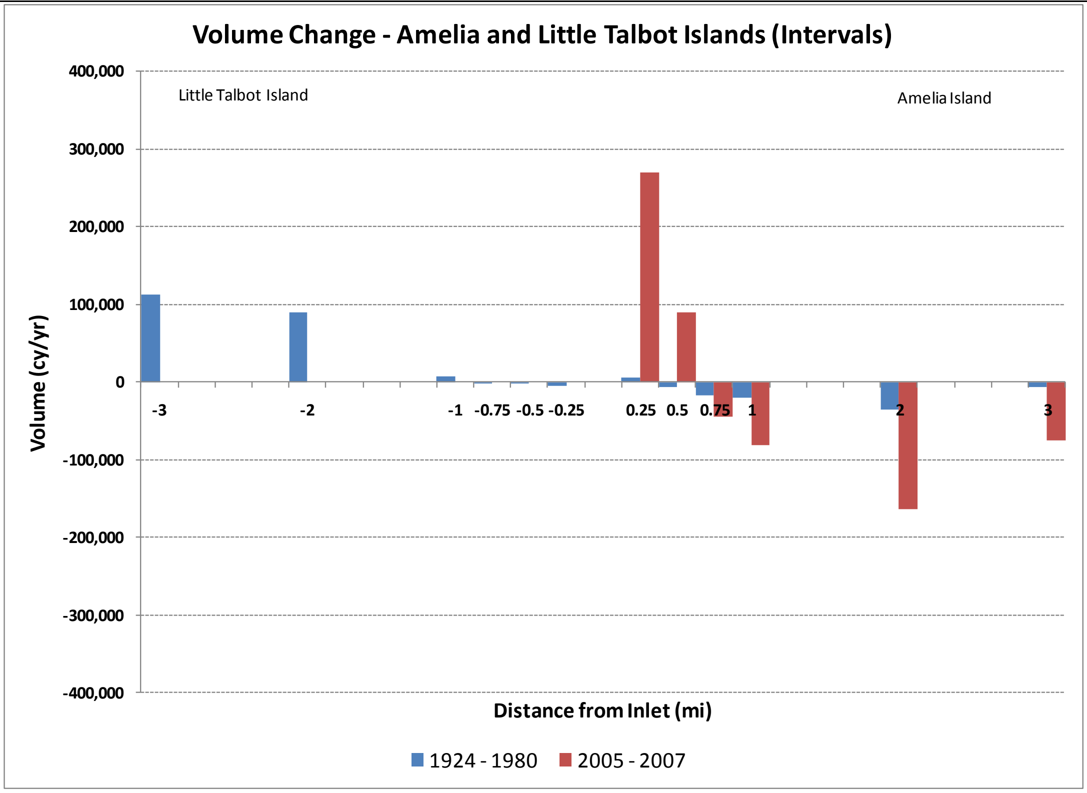


Figure II-49. Beach Volume Changes – Amelia and Little Talbot Islands (Intervals)

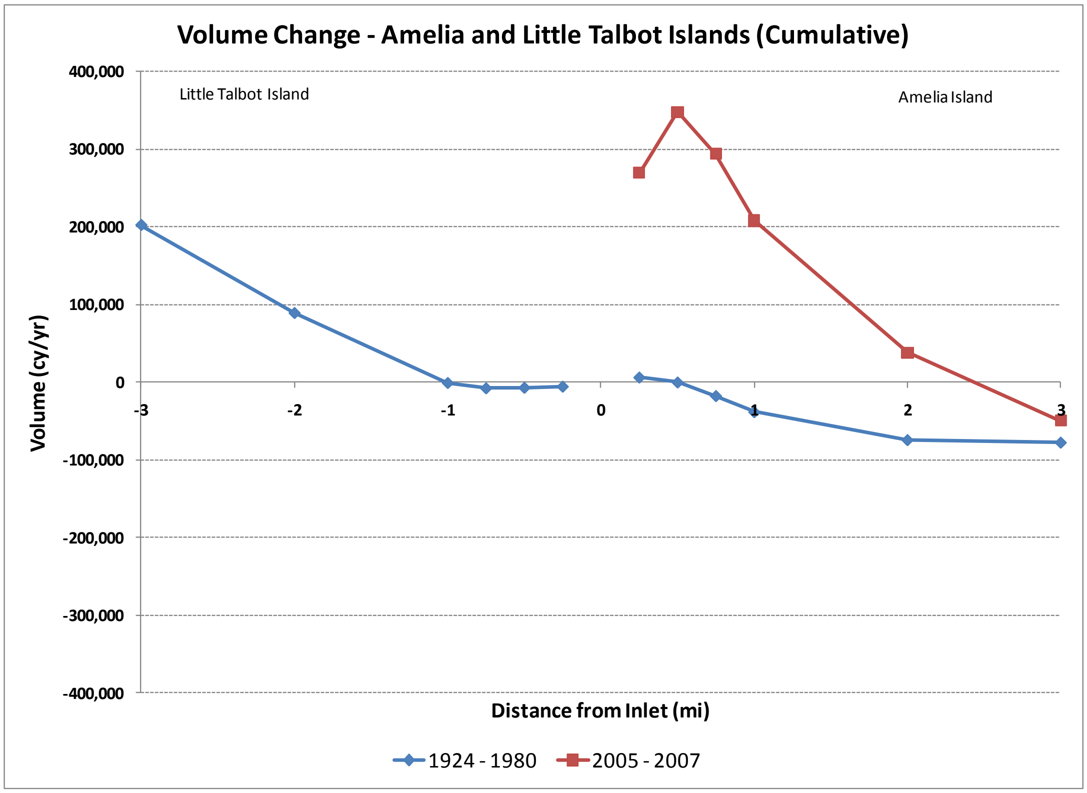


Figure II-50. Beach Volume Changes – Amelia and Little Talbot Island (Cumulative)

c) Volumetric Changes - Beach Nourishment

Since 1984, beach nourishment and sediment placement has occurred along the shoreline north of the Nassau River Inlet, specifically on Amelia Island. Table II-46 details the amounts, timing, and locations, when known, of beach nourishment activities on Amelia Island during the analysis time periods. (The engineering activities log in Appendix C provides details for all activities). Table II-47 presents a summary of this data with respect to the amounts assumed placed on each analysis interval of shoreline for each of the analysis time periods. For material placed directly on the beach, the total volumes were pro-rated over the placement stations, when known.

Table II-46. Beach Nourishment – Amelia Island

Year	Placement Location	Beach Nourishment Volume by Interval (cy)							Total Volume (cy)
		0 - 0.25	0.25 - 0.50	0.50 - 0.75	0.75 - 1.0	1.0 - 2.0	2.0 - 3.0	3.0 +	
2006	Beach Nourishment (R-76 to R-79)	0	133,333	133,333	133,333	0	0	0	400,000

Table II-47. Beach Nourishment – Amelia Island

Period	Beach Nourishment Volume by Interval (cy/yr)							Total Volume (cy/yr)
	0 - 0.25	0.25 - 0.50	0.50 - 0.75	0.75 - 1.0	1.0 - 2.0	2.0 - 3.0	3.0 +	
Pre: 1924 - 1980	0	0	0	0	0	0	0	0
Post: 2005 - 2007	0	66,667	66,667	66,667	0	0	0	200,000

In Table II-48 and Table II-49 for Amelia Island, and Table II-50 and Table II-51 for Little Talbot Island, the total beach nourishment material placed on the beach is subtracted from the volumes calculated based on shoreline change to arrive at volume changes without nourishment (as if the nourishment did not take place). Figure II-51 and Figure II-52 present the same information graphically.

Table II-48. Volume Changes Without Nourishment – Amelia Island (Intervals)

	Volume Change w/o Nourishment - Amelia Island (Intervals) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1924 - 1980	6,088	6,390	17,474	20,697	36,001	6,806
Post: 2005 - 2007	269,622	23,666	110,769	147,365	164,048	75,307

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

Table II-49. Volume Changes Without Nourishment – Amelia Island (Cumulative)

	Volume Change w/o Nourishment - Amelia Island (Cumulative) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1924 - 1980	6,088	303	17,777	38,475	74,476	77,702
Post: 2005 - 2007	269,622	281,335	161,084	7,949	162,004	249,449

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

Table II-50. Volume Changes Without Nourishment – Little Talbot Island (Intervals)

	Volume Change w/o Nourishment - Little Talbot Island (Intervals) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1924 - 1980	5,650	1,462	685	6,872	90,051	113,374
Post: 2005 - 2007	N/A	N/A	N/A	N/A	N/A	N/A

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

Table II-51. Volume Changes Without Nourishment – Little Talbot Island (Cumulative)

	Volume Change w/o Nourishment - Little Talbot Island (Cumulative) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1924 - 1980	5,650	7,112	7,797	924	89,126	202,501
Post: 2005 - 2007	N/A	N/A	N/A	N/A	N/A	N/A

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

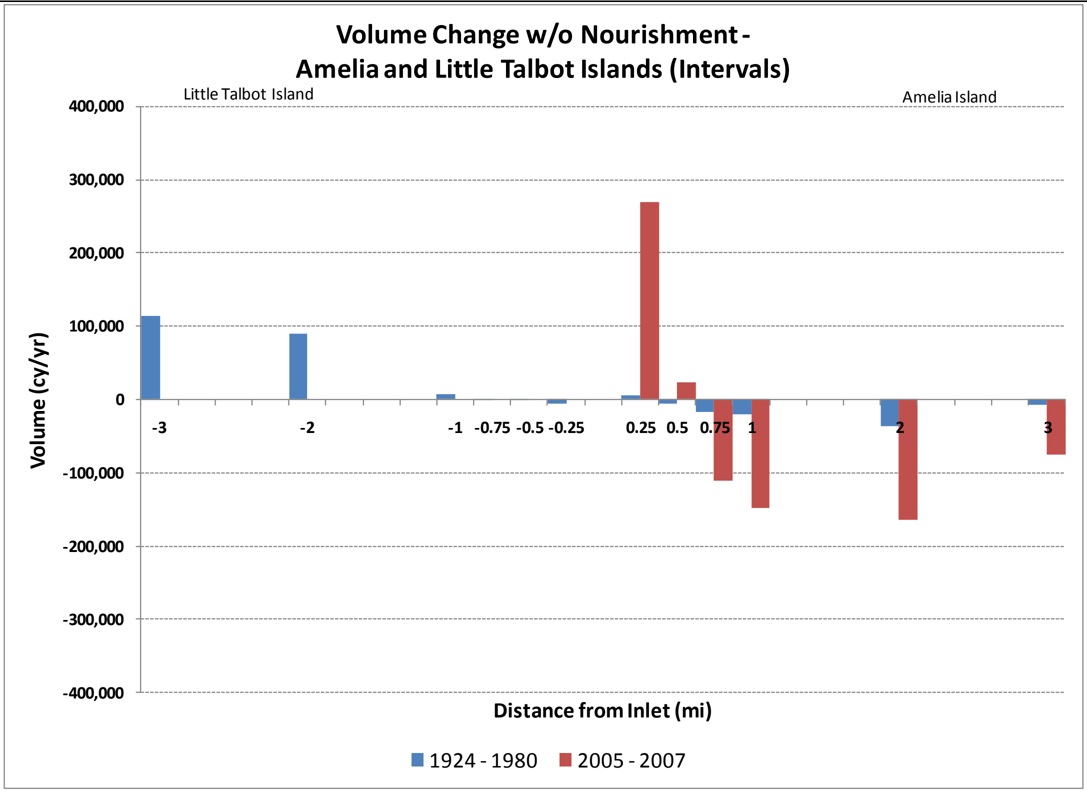


Figure II-51. Volume Changes w/o Nourishment – Amelia and Little Talbot Islands (Intervals)

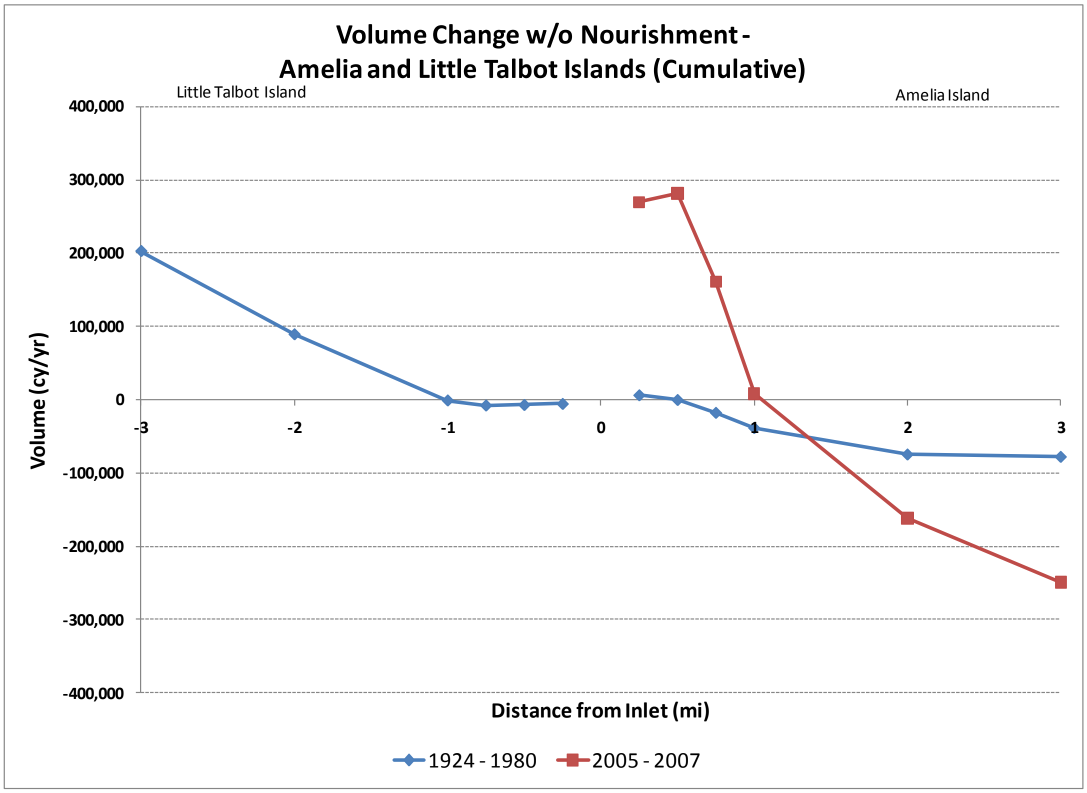


Figure II-52. Volume Changes w/o Nourishment – Amelia and Little Talbot Islands (Cumulative)

d) Volumetric Changes - Dredging

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). However, the quantities and timing of these dredging activities is not known and thus a quantitative analysis of the possible effects of this dredging cannot be made.

It is also known that significant dredging has been conducted in the channel of the St Mary's Inlet (north of Amelia Island) which is flanked by two large jetties. Knowing that the littoral drift in this area is predominately north to south, the frequency and timing of dredging material from this inlet north of Amelia Island could also have a direct correlation to erosion rates (shoreline retreat) along the Island.

3. Summary

The construction of the terminal groin at Amelia Island has occurred relatively recently, thus making any definitive conclusions about its performance difficult at best, as the shoreline has not had time to equilibrate to the new structures and a recent large nourishment. It is apparent, though, that the "leaky" rock terminal groin does allow material to pass over / through it as evidenced by the spit-like feature building to its south.

Prior to terminal groin construction, the Amelia Island shoreline was eroding over most of the first three miles, except for the first quarter mile. After the construction of the terminal groin, the shoreline has accreted substantially over the first half mile, but erosion is evident over the next 2.5 miles. This trend is even more evident once the beach nourishment is subtracted out. However, it should be noted that a significant beach nourishment placement occurred during this short, two-year post-construction time period used for analysis and these changes may simply be indicative of the shoreline adjusting to an equilibrium state.

Little Talbot Island experienced erosion over its first three-quarter mile interval with accretion beyond prior to construction. Unfortunately, no post-construction shoreline data was available.

G. Assessment of Captiva Island Terminal Groin

1. Qualitative Assessment

a) Site Description

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 and separating Captiva and North Captiva Islands. 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. Blind Pass 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 720 feet wide and has well-developed ebb and flood tidal deltas (Figure II-55). 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.

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. Information and data regarding the tidal, wave and storm environment at Captiva Island is presented in Appendix D.

a) Terminal Groin

The terminal groin is located at the north end of the Captiva Island, next to Redfish Pass (Figure II-53) and was constructed in 1977 and rehabilitated in 2006. Figure II-54 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).

As seen in Figure II-55 and Figure II-56, 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 100 feet. 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.

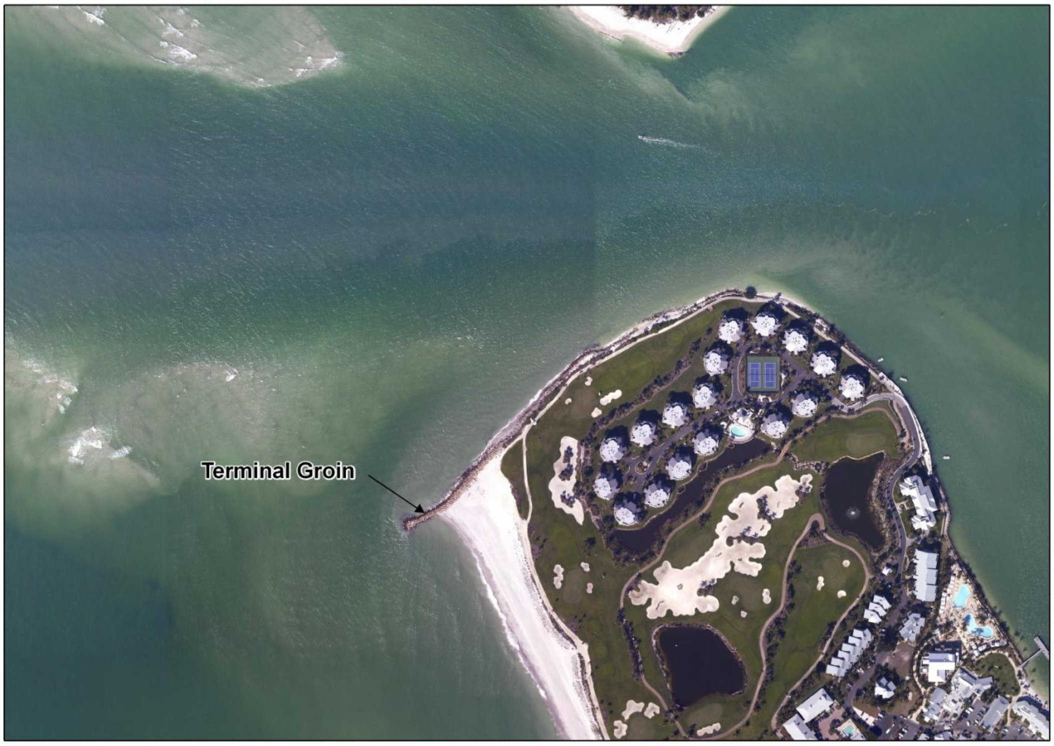


Figure II-53. Captiva Island Terminal Groin

Figure II-54. Terminal Groin Rehabilitation

Figure II-55. 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 II-56. View of the Terminal Groin at Redfish pass (from Google Earth)

a) Shoreline Changes

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 II-57). 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 II-58. 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 II-59).

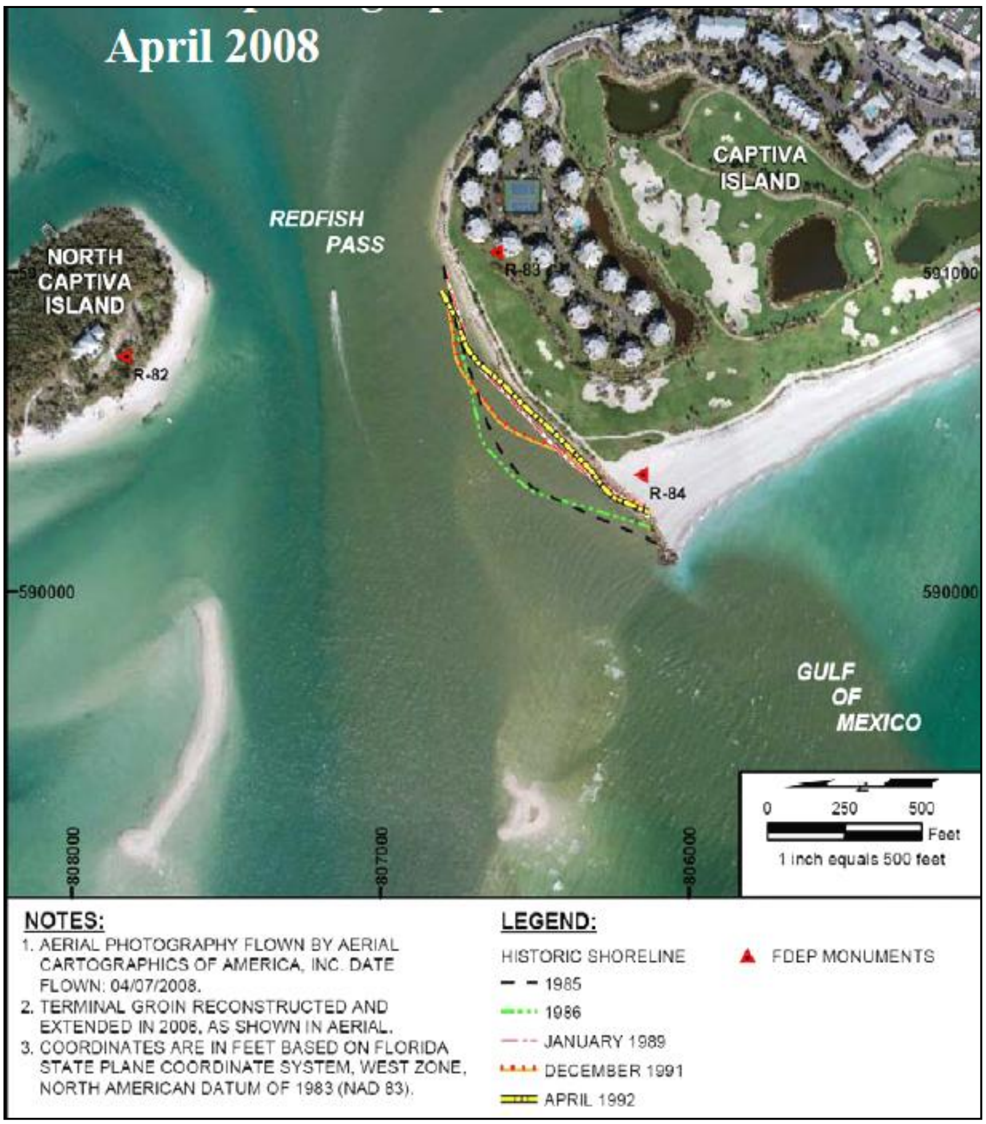


Figure II-57. Shoreline Changes of Beach Inside Redfish Pass
Note that between 1985 and 1992, the shoreline receded (FL-EPA, 2008)

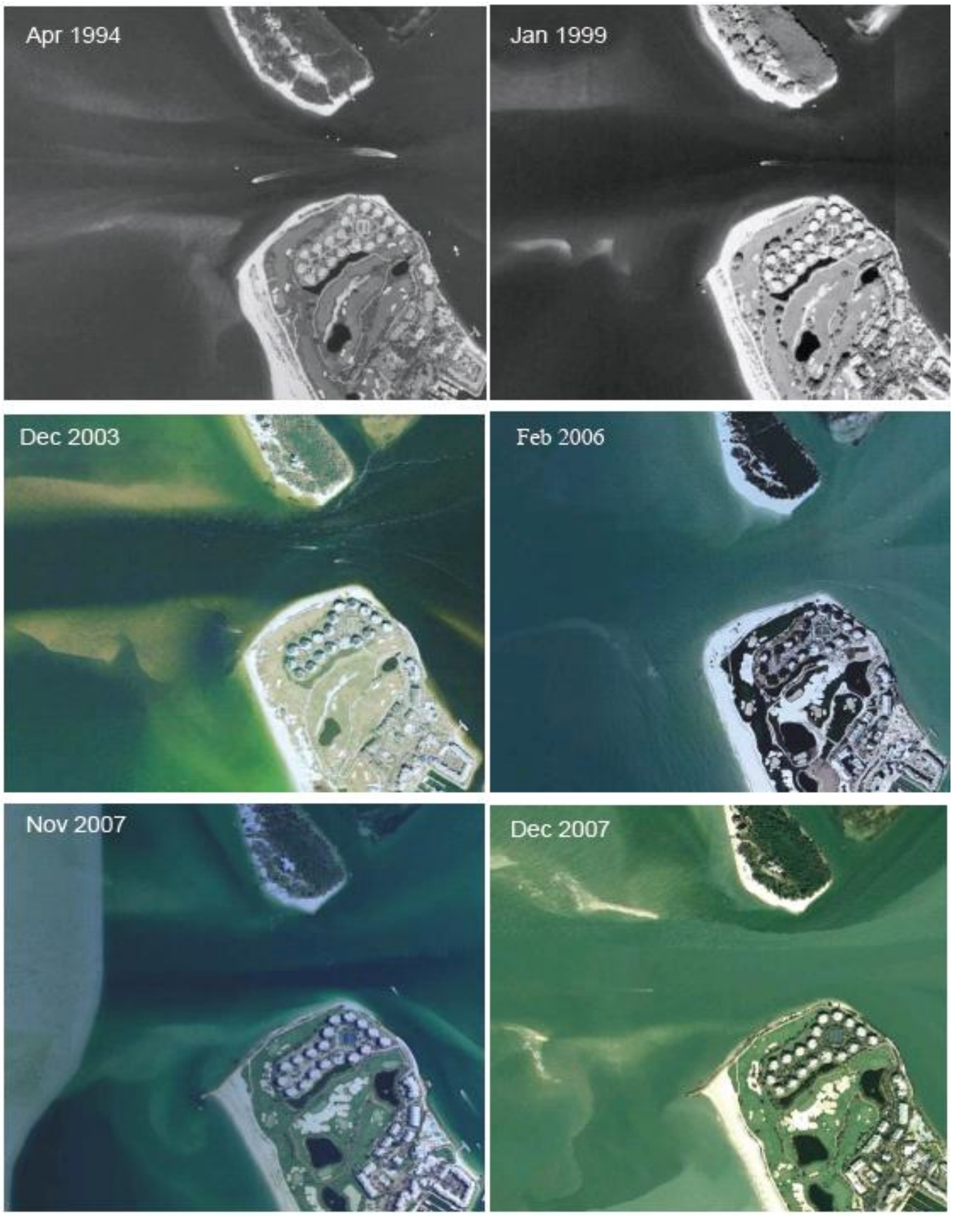


Figure II-58. Sequential Vertical Aerial Photographs of Captiva Inlet between 1994 and 2007 (from Google Earth)

Figure II-59. Comparison of Photographs Taken Before and Immediately After the Passage of Hurricane Charley Showing Beach Erosion Inside the Inlet

In January of 2006, sand was added to Captiva Island, which substantially widened the beach and rebuilt the beach inside the inlet (see February 2006 in Figure II-58). By the end of 2007, the beach had mostly disappeared (2007 December, Figure II-58), 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.

2. Quantitative Assessment

a) 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 (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-60 illustrates the shoreline data used in the analysis.

Figure II-61 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.

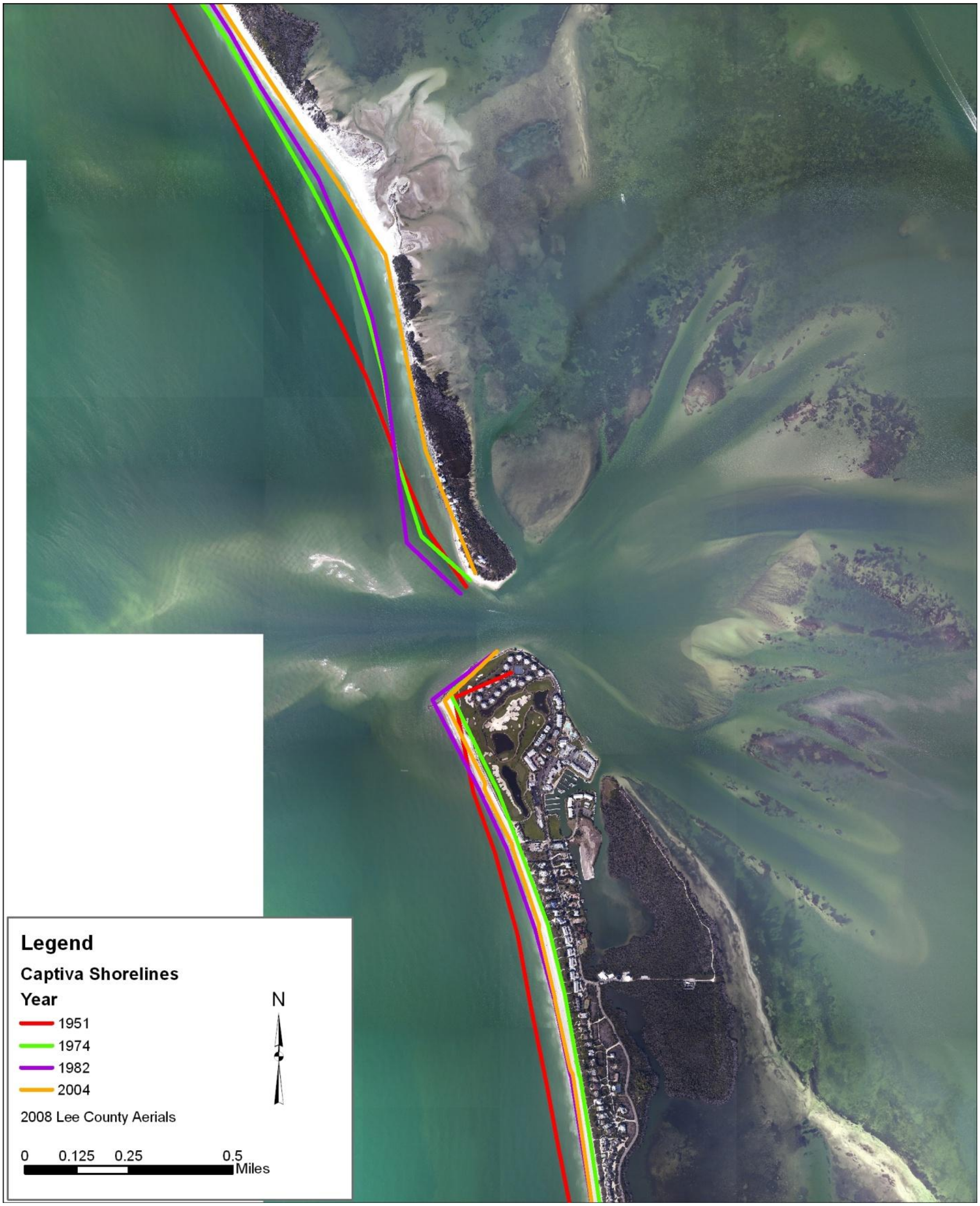


Figure II-60. Historic Shorelines – Captiva Island

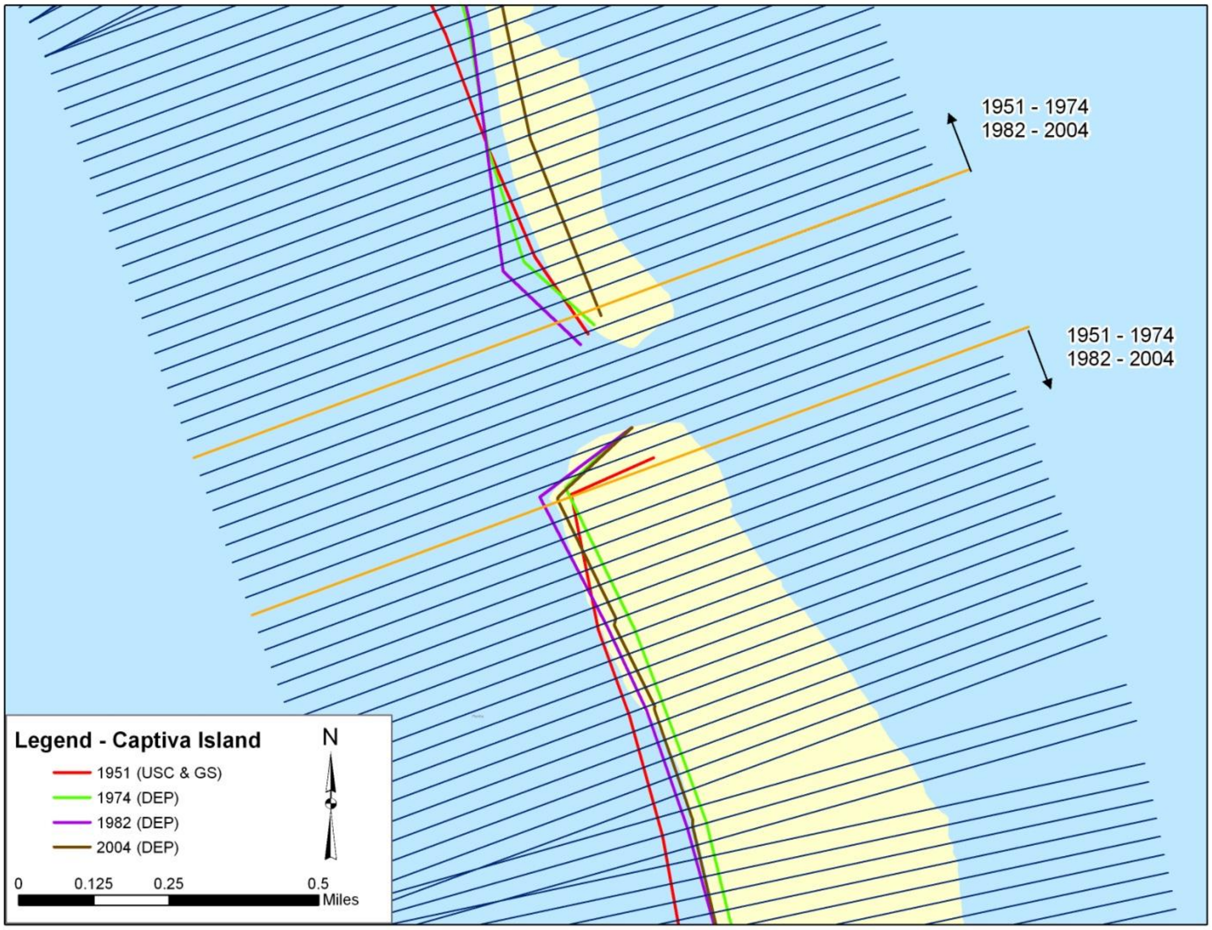


Figure II-61. Captiva Island Shoreline Change Calculation Transects

The results of the shoreline change calculations for the pre- and post-structure time periods are given in Table II-52 and Table II-53 for Captiva Island (location of the terminal groin) and Table II-54 and Table II-55 for North Captiva Island. Values in red represent shoreline recession (erosion) and values in black represent shoreline advancement (accretion). The first table for each island presents the average shoreline change for each interval as indicated while the second table presents average shoreline change from the inlet shoulder to a total distance up to three miles. Figure II-62 and Figure II-63 display the same data graphically.

Table II-52. Shoreline Change – Captiva Island (Intervals)

	Shoreline Change – Captiva Island (Intervals) (ft/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1951 - 1974	5.7	13.9	17.6	19.3	14.2	7.4
Post: 1982 - 2004	5.2	3.2	2.2	0.5	0.4	4.4

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

Table II-53. Shoreline Change – Captiva Island (Total Average)

	Shoreline Change – Captiva Island (Total Average) (ft/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1951 - 1974	1.8	0.2	4.5	8.5	12.9	11.4
Post: 1982 - 2004	24.0	20.6	18.7	17.1	7.4	1.5

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

Table II-54. Shoreline Change – North Captiva Island (Intervals)

	Shoreline Change – North Captiva Island (Intervals) (ft/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1951 - 1974	1.8	2.2	13.0	20.4	17.3	8.6
Post: 1982 - 2004	24.0	17.3	14.8	12.3	2.3	10.2

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

Table II-55. Shoreline Change – North Captiva Island (Total Average)

	Shoreline Change – North Captiva Island (Total Average) (ft/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1951 - 1974	5.7	9.8	12.4	14.1	14.1	11.9
Post: 1982 - 2004	5.2	4.2	3.5	2.8	1.2	0.7

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

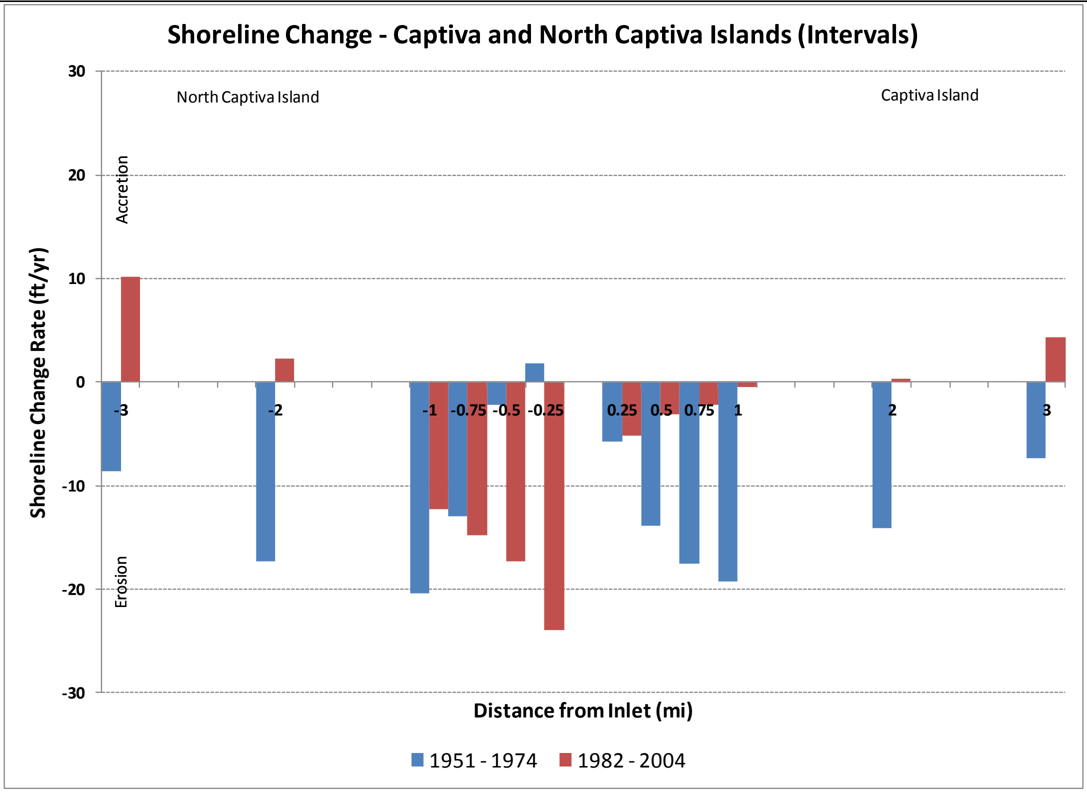


Figure II-62. Shoreline Change – Captiva and North Captiva Islands (Interval)

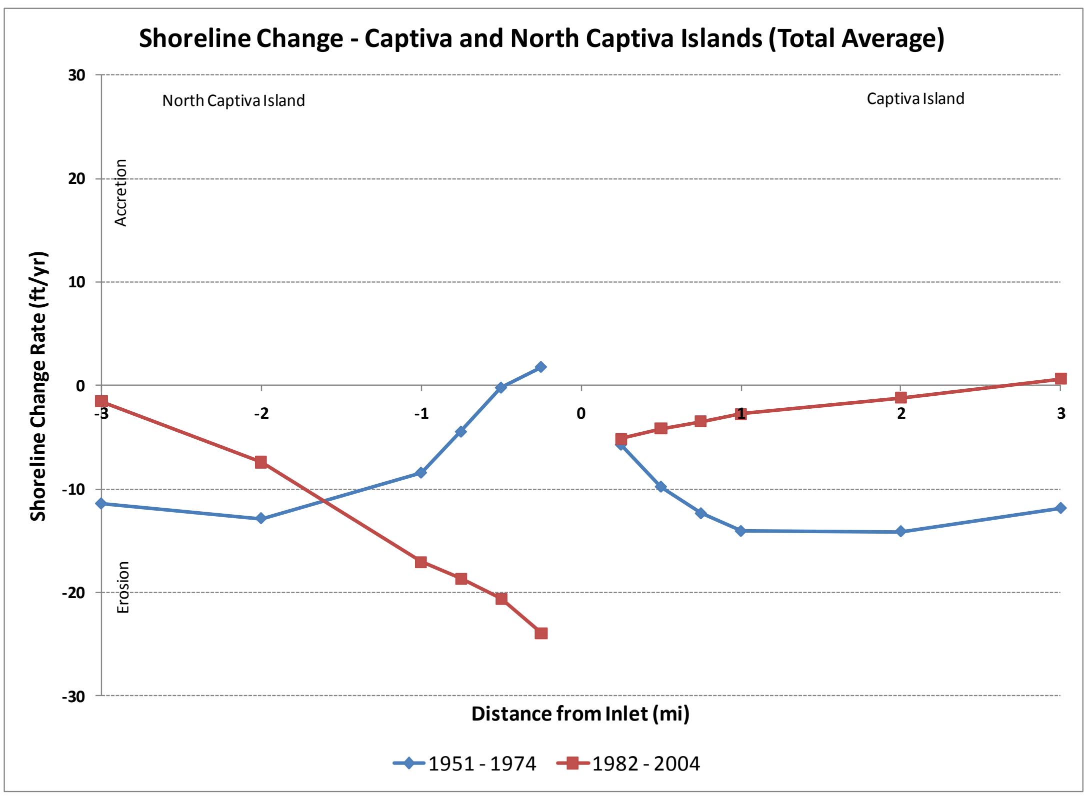


Figure II-63. Shoreline Change – Captiva and North Captiva Islands (Total Average)

b) Volumetric Changes

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 initially evaluated based on the shoreline change. 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-56 and Table II-57 provide the volumetric beach change for the intervals and cumulative distances, respectively, along Captiva Island based on the shoreline change rates presented previously; while Table II-58 and Table II-59 present the volumetric beach change for the intervals and cumulative distances, respectively, along North Captiva Island. 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 and dredging, since these are implicitly included in the shoreline measurements. Figure II-64 and Figure II-65 present the same information graphically.

Table II-56. Beach Volume Changes – Captiva Island (Intervals)

	Volume Change – Captiva Island (Intervals) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1951 - 1974	5,615	13,557	17,149	18,807	55,303	28,783
Post: 1982 - 2004	5,051	3,080	2,109	523	1,400	17,046

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

Table II-57. Beach Volume Changes – Captiva Island (Cumulative)

	Volume Change – Captiva Island (Cumulative) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1951 - 1974	5,615	19,172	36,321	55,128	110,431	139,214
Post: 1982 - 2004	5,051	8,131	10,241	10,763	9,363	7,683

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

Table II-58. Beach Volume Changes – North Captiva Island (Intervals)

	Volume Change – North Captiva Island (Intervals) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1951 - 1974	1,749	2,186	12,714	19,890	67,498	33,534
Post: 1982 - 2004	23,407	16,865	14,444	11,979	8,900	39,686

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

Table II-59. Beach Volume Changes – North Captiva Island (Cumulative)

	Volume Change – North Captiva Island (Cumulative) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1951 - 1974	1,749	437	13,151	33,041	100,539	134,073
Post: 1982 - 2004	23,407	40,272	54,716	66,695	57,795	18,109

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

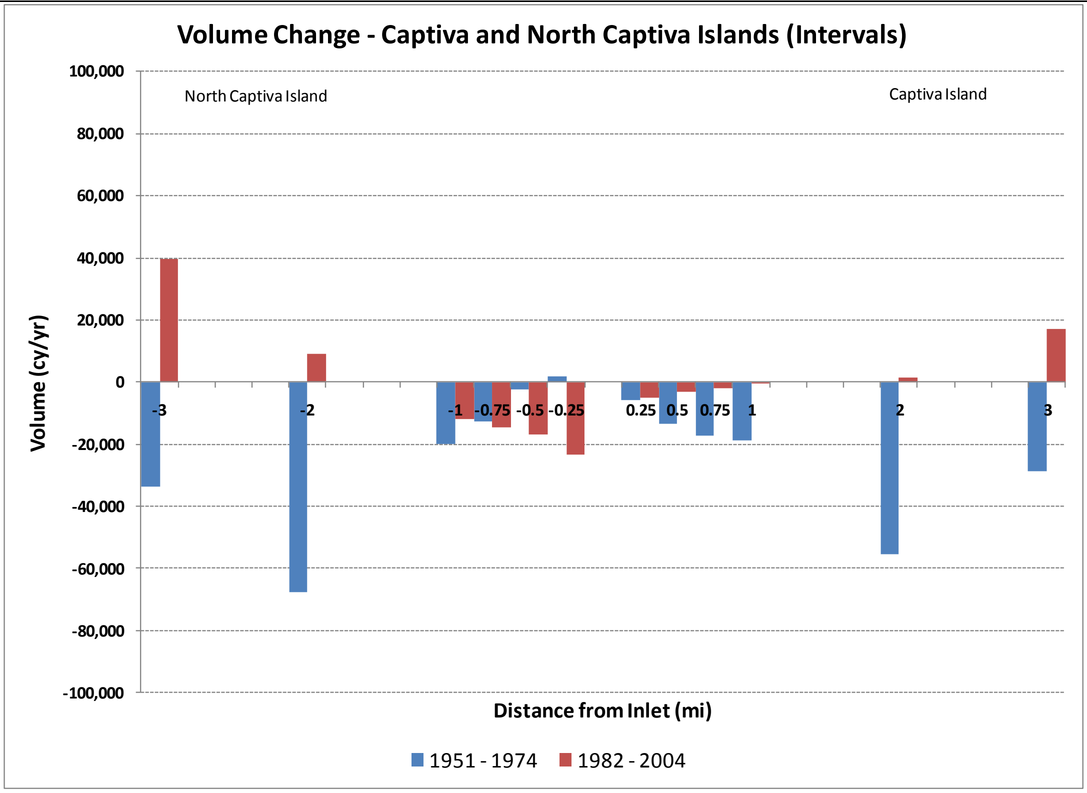


Figure II-64. Beach Volume Change – Captiva and North Captiva Islands (Intervals)

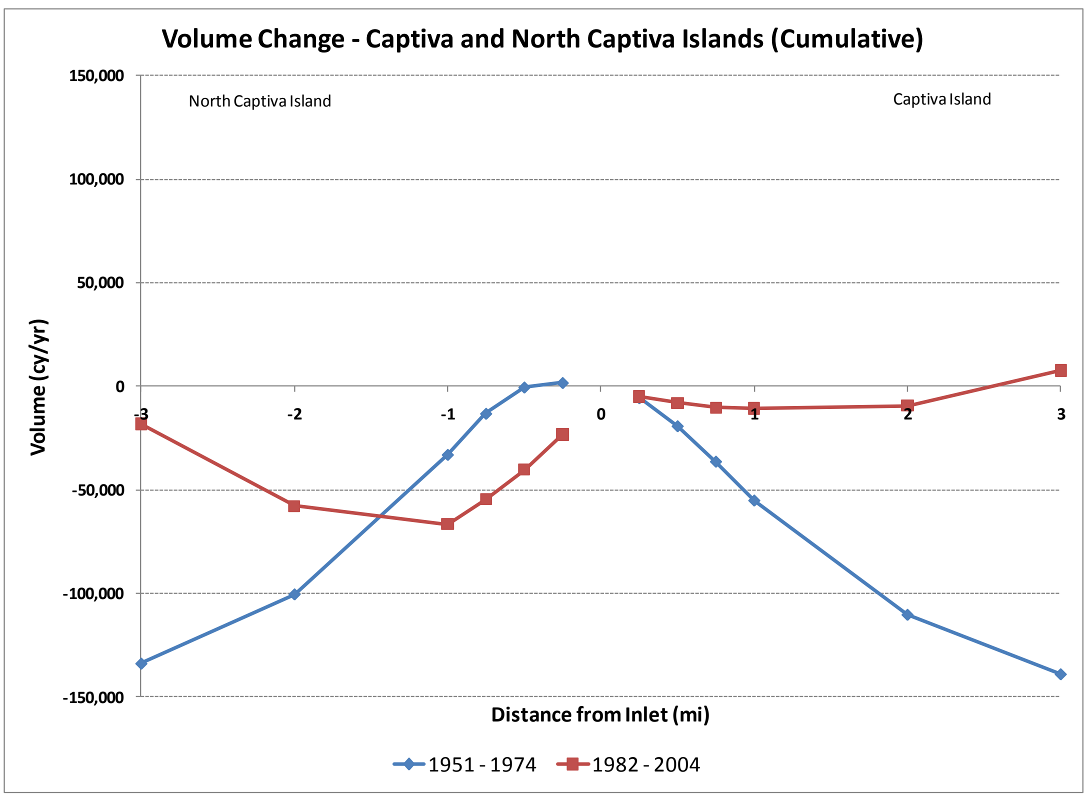


Figure II-65. Beach Volume Change – Captiva and North Captiva Islands (Cumulative)

c) Volumetric Changes – Beach Nourishment

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. Table II-60 details the amounts, timing, and locations, when known, of beach nourishment activities along Captiva Island during the analysis time periods. (The engineering activities log in Appendix C provides details for all activities). Table II-61 presents a summary of this data with respect to the amounts assumed placed on each analysis interval of shoreline for each of the analysis time periods. For material placed directly on the beach, the total volumes were pro-rated over the placement stations when known. In cases where the exact placement location was not known, the material was assumed to be placed evenly over the three mile analysis area.

Table II-60. Beach Nourishment – Captiva Island

Year	Placement Location	Beach Nourishment Volume by Interval (cy)							Total
		0 - 0.25	0.25 - 0.50	0.50 - 0.75	0.75 - 1.0	1.0 - 2.0	2.0 - 3.0	3.0 +	Volume
1961	Captiva Island	8,917	8,917	8,917	8,917	35,667	35,667	0	107,000
1973	South Seas Resort	1,250	1,250	1,250	1,250	0	0	0	5,000
1988	Captiva Island	80,000	80,000	80,000	80,000	320,000	320,000	640,000	1,600,000
1996	Captiva Island	34,208	34,208	34,208	34,208	136,833	136,833	410,500	821,000

Table II-61. Beach Nourishment – Captiva Island

Period	Beach Nourishment Volume by Interval (cy/yr)							Total Volume
	0 - 0.25	0.25 - 0.50	0.50 - 0.75	0.75 - 1.0	1.0 - 2.0	2.0 - 3.0	3.0 +	(cy/yr)
Pre: 1951 - 1974	442	442	442	442	1,551	1,551	0	4,870
Post: 1982 - 2004	5,191	5,191	5,191	5,191	20,765	20,765	47,750	110,045

In Table II-62 and Table II-63 for Captive Island, and Table II-64 and Table II-65 for North Captiva Island, the total beach nourishment material placed on the beach is subtracted from the volumes calculated based on shoreline change to arrive at volume changes without nourishment (as if the nourishment did not take place). Figure II-66 and Figure II-67 present the same information graphically.

Table II-62. Volume Changes Without Nourishment – Captiva Island (Intervals)

	Volume Change w/o Nourishment – Captiva Island (Intervals) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1951 - 1974	6,057	13,999	17,591	19,249	56,854	30,334
Post: 1982 - 2004	10,243	8,271	7,301	5,714	19,365	3,719

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

Table II-63. Volume Changes Without Nourishment – Captiva Island (Cumulative)

	Volume Change w/o Nourishment – Captiva Island (Cumulative) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1951 - 1974	6,057	20,056	37,647	56,896	113,750	144,083
Post: 1982 - 2004	10,243	18,514	25,815	31,529	50,893	54,613

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

Table II-64. Volume Changes Without Nourishment – North Captiva Island (Intervals)

	Volume Change w/o Nourishment – North Captiva Island (Intervals) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1951 - 1974	1,749	2,186	12,714	19,890	67,498	33,534
Post: 1982 - 2004	23,407	16,865	14,444	11,979	8,900	39,686

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

Table II-65. Volume Changes Without Nourishment – North Captiva Island (Cumulative)

	Volume Change w/o Nourishment – North Captiva Island (Cumulative) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1951 - 1974	1,749	437	13,151	33,041	100,539	134,073
Post: 1982 - 2004	23,407	40,272	54,716	66,695	57,795	18,109

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

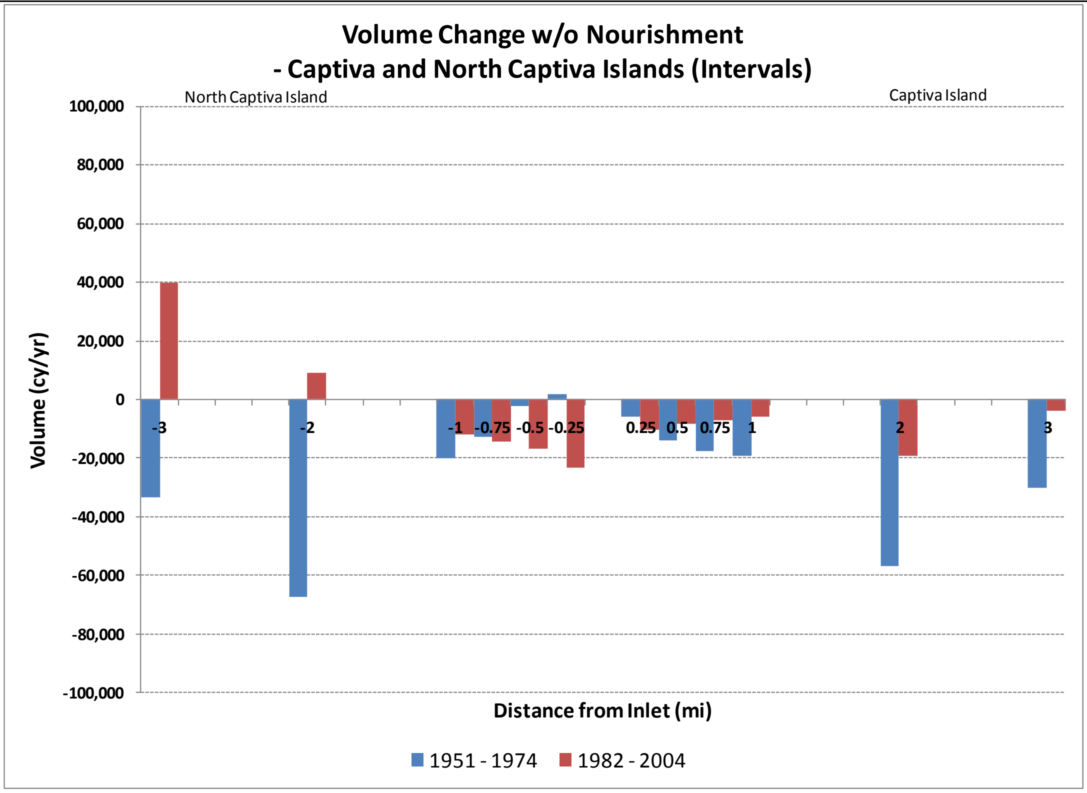


Figure II-66. Volume Changes w/o Nourishment – Captiva and North Captiva Islands (Intervals)

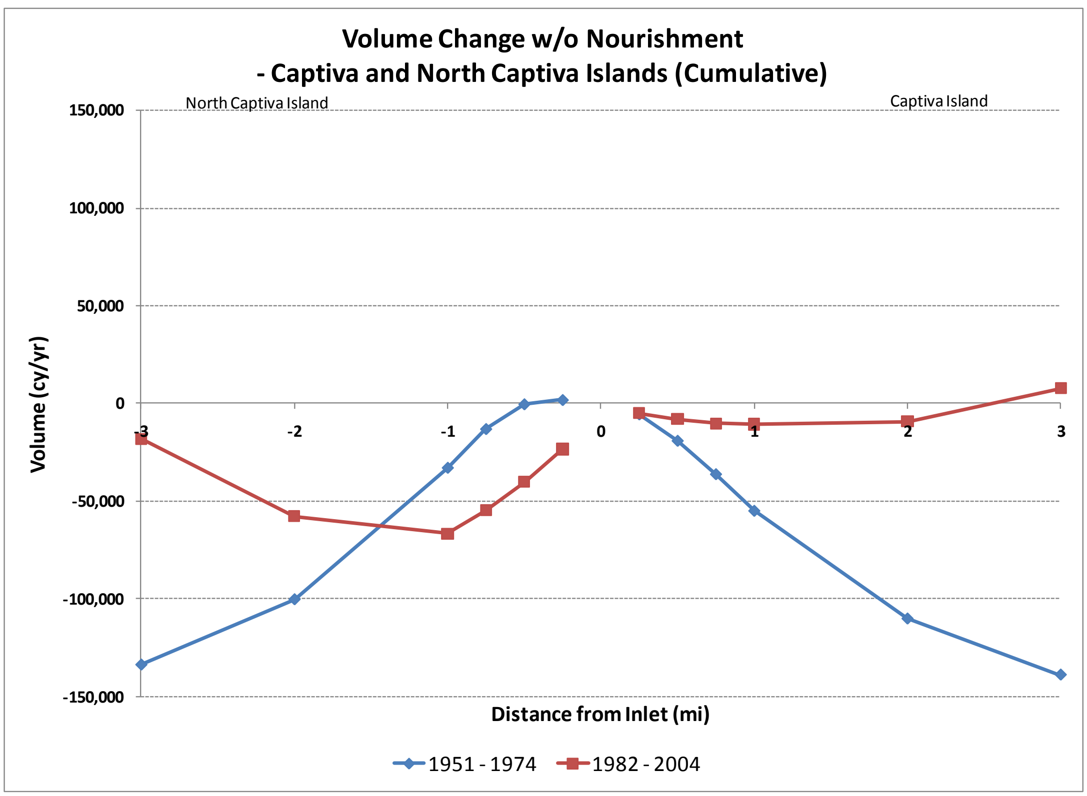


Figure II-67. Volume Changes w/o Nourishment– Captiva and North Captiva Islands (Cumulative)

d) Volumetric Changes - Dredging

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 would have an impact on the adjacent shorelines.

3. Summary

The shoreline at the Captiva Island Terminal Groin typically has extended to near the end of the groin, especially prior to lengthening by 100 feet in 2006. The beach inside the inlet has experienced cyclic changes in width over time; most likely due to the impact of storm events.

Prior to terminal groin construction, the Captiva Island shoreline was eroding fairly rapidly over the entire first three miles. After the construction of the terminal groin, the erosion has been reduced in the first mile with accretion in the next two miles. North Captiva was erosional over the first three miles prior to terminal groin construction except for the first quarter mile, but was only erosional over the first mile and accretionary over the next two miles after terminal groin construction. It must be noted, though, that these shorelines include the effects of beach nourishment, dredging activities, and natural barrier island processes.

Beach nourishment and dredging activities have occurred at Captiva Island. Since the terminal groin was constructed, over 1.3 million cubic yards of material have been placed on the first three miles of beach during the analysis time period; but the amount of dredging is unknown.

Once the beach nourishment activities are subtracted out, the volumetric analysis shows for Captiva Island that after construction of the terminal groin, the average erosion was significantly reduced over the first three miles except for a slight increase in the first quarter mile.

North Captiva Island has the same volumetric trends as the shoreline change since no nourishment has occurred on this side of the inlet.

H. Assessment of John's Pass Terminal Groin

1. Qualitative Assessment

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 Madeira 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 and a spring tidal prism of 6.0×10^6 m^3 (2.1×10^8 ft^3) (Mehta et al., 1975, 1976). The inlet is ebb-dominant having maximum ebb-tidal currents (143 cm/s or 4.7 fps) that exceed flood-tidal velocities (115 cm/s or 3.8 fps). Davis and Gibeaut (1990) found a net southerly longshore transport rate of 38,200 m^3/yr (49964 cy/yr) at John's Pass and Tidwell (2005) found a rate of 35,000 m^3/yr (45,778 cy/yr) in the vicinity of Blind Pass. Information and data regarding the tidal, wave and storm environment at John's Pass is presented in Appendix D.

b) Terminal Groin

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 inlet has terminal groins on both the north and south sides (Figure II-68). The 460 foot long north terminal groin was constructed in 1961 and rehabilitated in 1988. The south terminal groin is 400 feet long and was constructed in 2000. Between 1957 and 1974, Madeira Beach prograded significantly (Figure II-69).

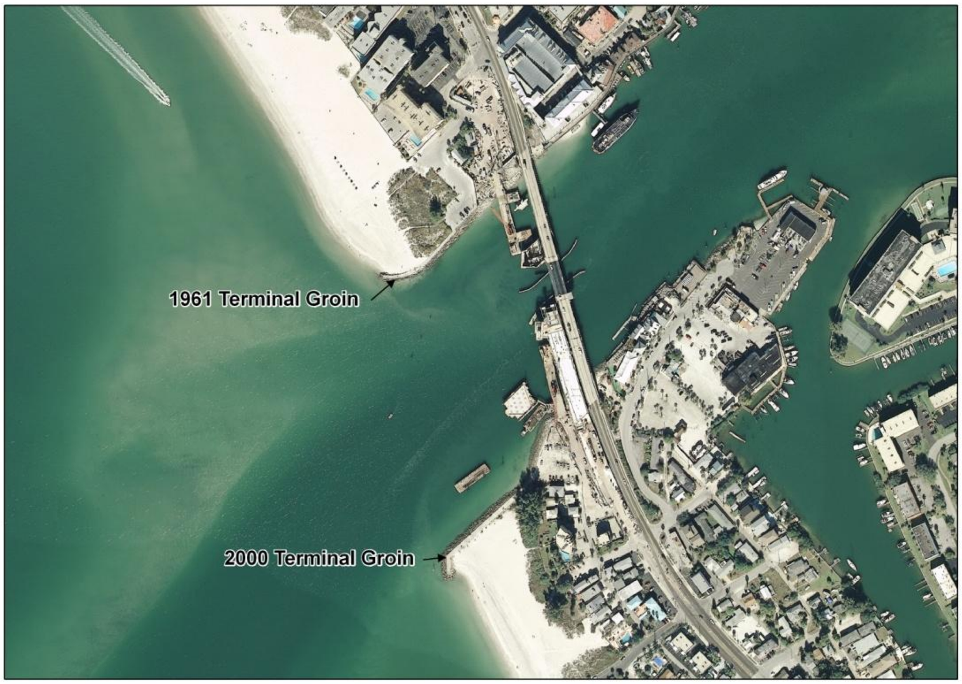


Figure II-68. John's Pass Terminal Groins

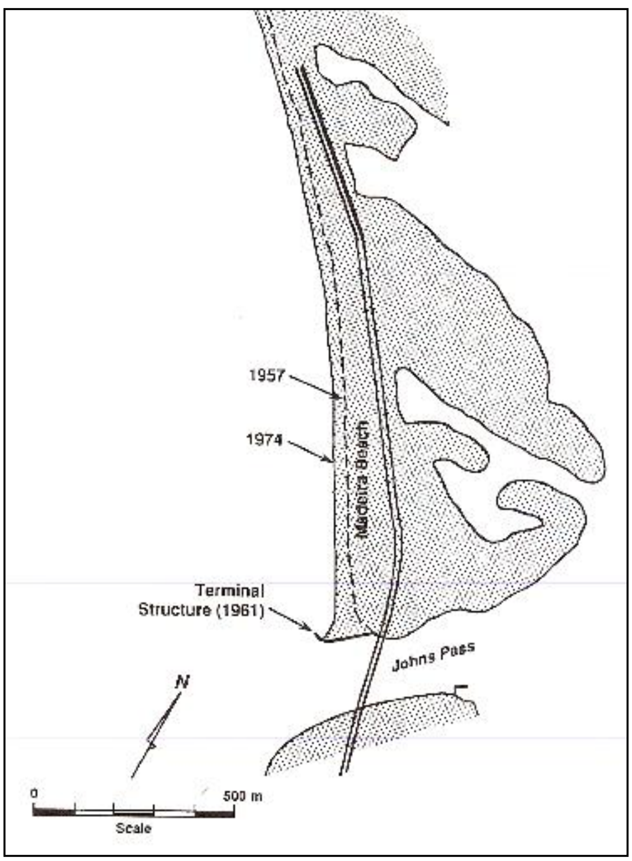


Figure II-69. Shoreline Changes Along Madeira Beach between 1957 and 1974
Note that the terminal groin at the north side of John's Pass was built in 1961

c) Dredging and Ebb-tidal Delta Changes

John's Pass is a federally maintained waterway and is dredged to a minimum depth of 3 m (10 ft) and width of 46 m (150 ft) (USACE, 2004). Dredging of the inlet channel began in the early 1960's with the sand placed 2000 feet offshore along the northern 2000 feet 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 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 II-70 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 Madeira Beach to northern Treasure Island and certainly exacerbated the periodic erosional conditions along the downdrift inlet shoreline.

A vertical aerial photograph in Figure II-71 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 II-71). 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 II-71). 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.

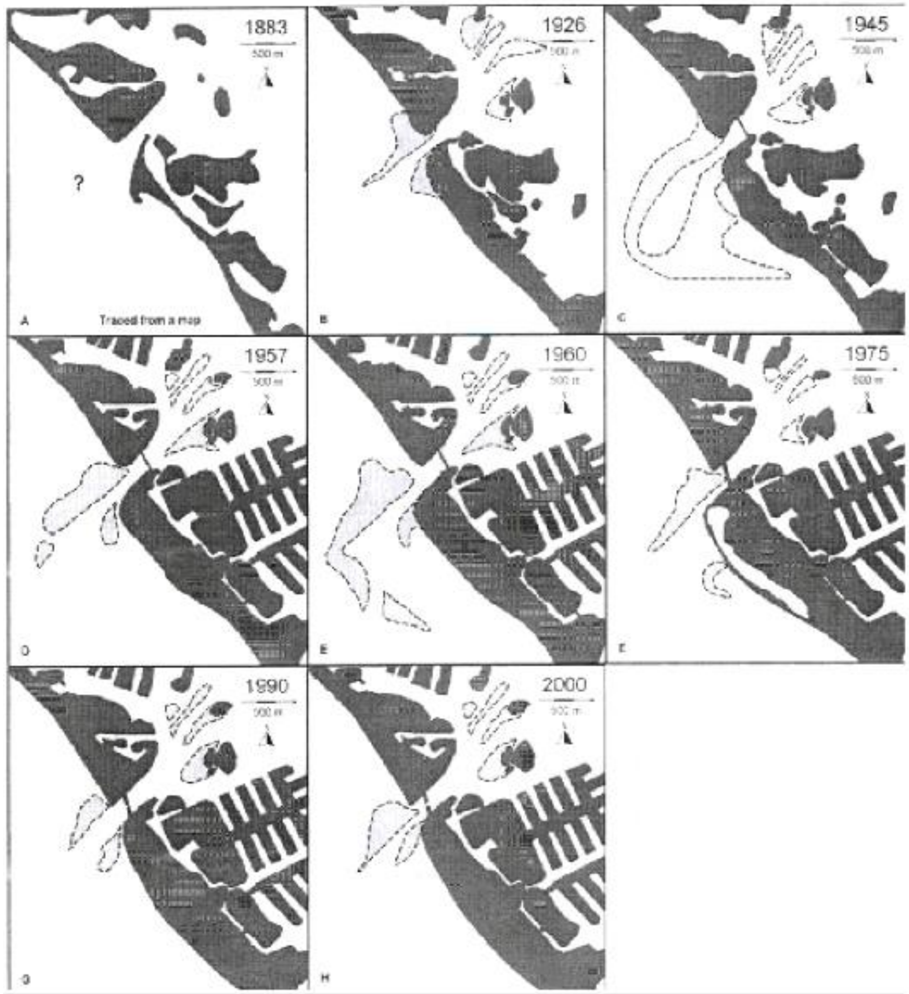


Figure II-70. Historical Morphological Changes of John's Pass from 1883 to 2000 (Davis & Vinther, 2002)
Note gradual decrease in size to the ebb-tidal delta.

Figure II-71. 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 II-72). 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 II-72).

Figure II-72. 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 II-73, depicting morphological changes at John's Pass from 1995 to 2008. Several points are apparent:

- The fillets at both terminal groins are filled with sand.
- The northern side of the ebb delta is shallower and better developed than the southern side of the delta.
- The northern part of the delta exhibits a well-developed channel-margin linear bar that defines the main ebb channel.
- The ebb delta elongates with time, as especially seen by the northern channel margin linear bar.
- The terminal groin constructed at the south side of the inlet has resulted in straighter more uniform shoreline.
- The northern Treasure Island shore undergoes periods of widening and narrowing. These changes are consistent along the entire shore, but are not reflected along Madeira Beach.

Figure II-73. Sequential Vertical Aerial Photographs of John's Inlet between 1995 and 2008 (from Google Earth)

2. Quantitative Assessment

a) 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 (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-74 illustrates the shoreline data used in the analysis.

Figure II-75 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-75 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. While this is not ideal given the long time period between this historic shoreline set and the construction of the terminal groin, it provides the best pre-construction estimate readily available for this study. 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.

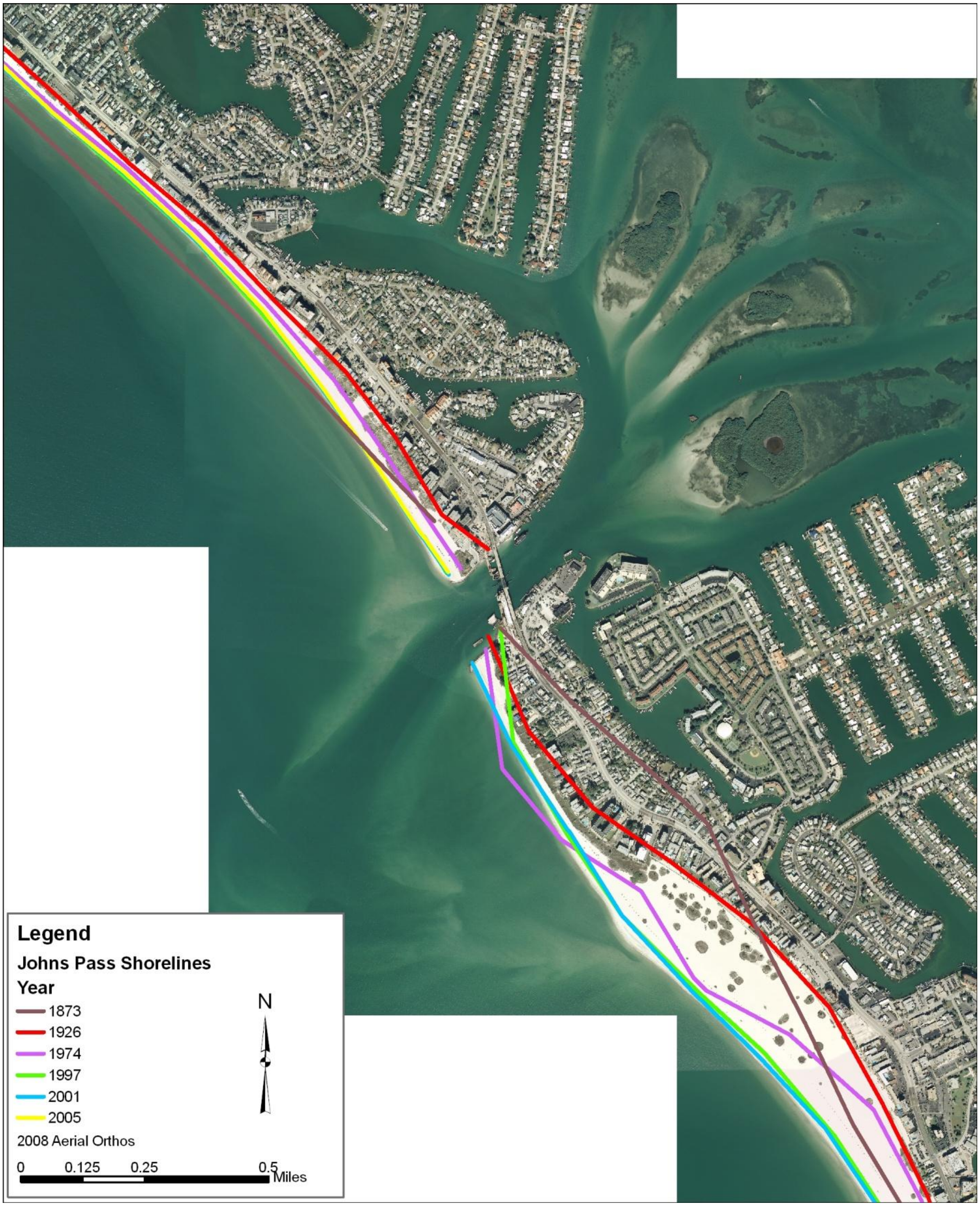


Figure II-74. Historic Shorelines – John's Pass

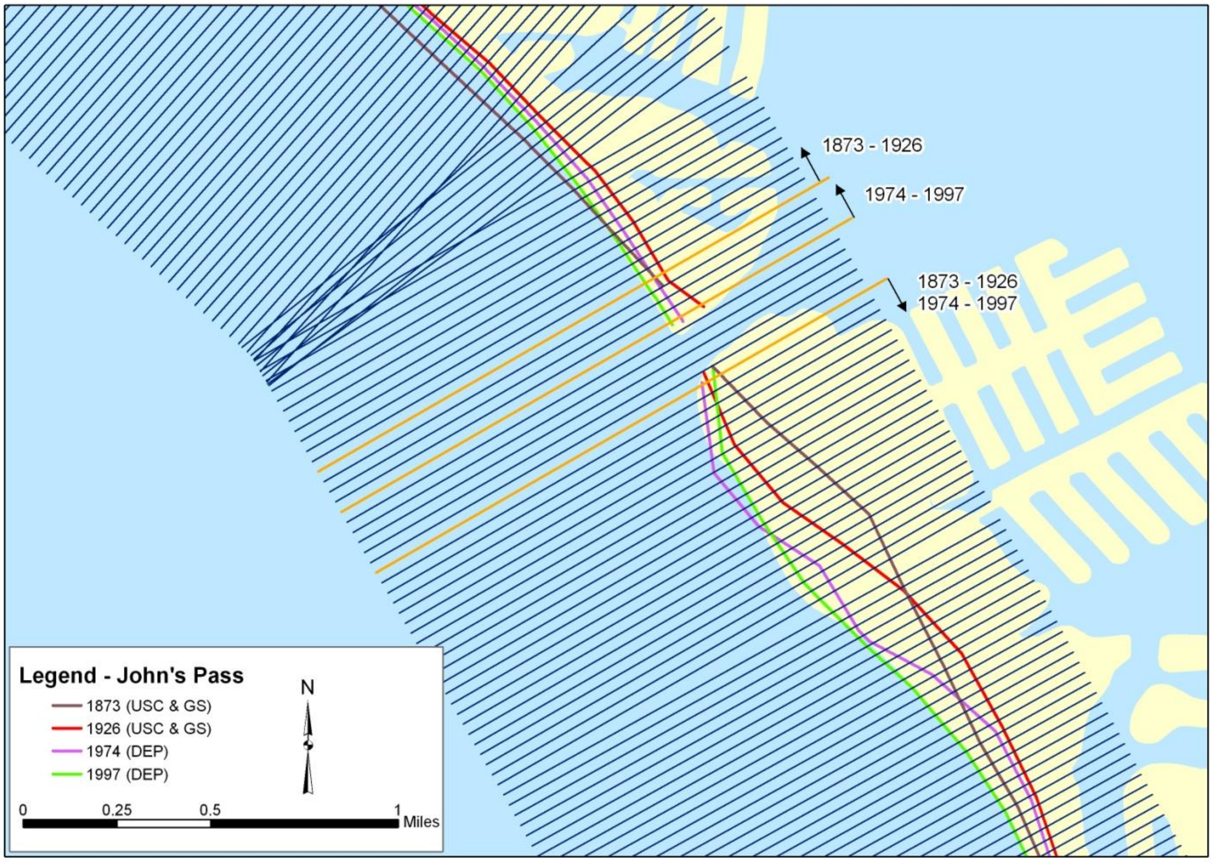


Figure II-75. John's Pass Shoreline Change Calculation Transects

The results of the shoreline change calculations for the pre- and post-structure time periods are given in Table II-66 and Table II-67 for Madeira Beach and Table II-68 and Table II-69 for Treasure Island. Values in red represent shoreline recession (erosion) and values in black represent shoreline advancement (accretion). The first table for each island presents the average shoreline change for each interval as indicated while the second table presents average shoreline change from the inlet shoulder to a total distance up to three miles. Figure II-76 and Figure II-77 display the same data graphically.

Table II-66. Shoreline Change – Madeira Beach (Intervals)

	Shoreline Change - Madeira Beach (Intervals) (ft/yr)					
Distance from Inlet (mi)	0 - 0.25	0.25 - 0.5	0.5 - 0.75	0.75 - 1	1 - 2	2 - 3
Pre: 1873 - 1926	4.0	7.0	7.7	8.3	6.8	3.5
Post: 1974 - 1997	6.4	6.6	4.5	3.1	1.4	0.9

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

Table II-67. Shoreline Change – Madeira Beach (Total Average)

	Shoreline Change - Madeira Beach (Total Average) (ft/yr)					
Distance from Inlet (mi)	0 - 0.25	0 - 0.5	0 - 0.75	0 - 1	0 - 2	0 - 3
Pre: 1873 - 1926	4.0	5.9	6.5	7.0	6.9	5.7
Post: 1974 - 1997	6.4	6.5	5.8	5.1	3.3	2.5

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

Table II-68. Shoreline Change – Treasure Island (Intervals)

	Shoreline Change - Treasure Island (Intervals) (ft/yr)					
Distance from Inlet (mi)	0 - 0.25	0.25 - 0.5	0.5 - 0.75	0.75 - 1	1 - 2	2 - 3
Pre: 1873 - 1926	8.3	12.9	5.4	3.9	3.9	0.2
Post: 1974 - 1997	8.4	2.8	9.3	9.7	12.4	3.0

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

Table II-69. Shoreline Change – Treasure Island (Total Average)

	Shoreline Change - Treasure Island (Total Average) (ft/yr)					
Distance from Inlet (mi)	0 - 0.25	0 - 0.5	0 - 0.75	0 - 1	0 - 2	0 - 3
Pre: 1873 - 1926	8.3	10.5	8.9	5.8	1.0	0.7
Post: 1974 - 1997	8.4	5.7	0.9	1.6	6.9	5.7

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

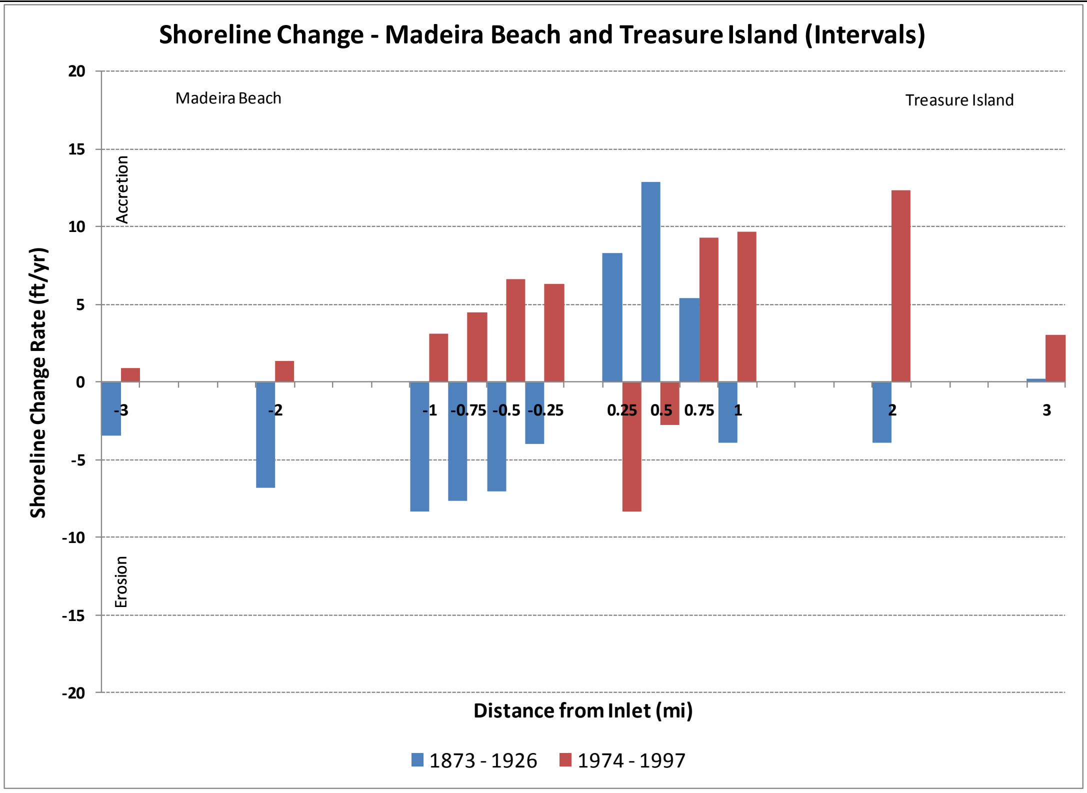


Figure II-76. Shoreline Change – Madeira Beach and Treasure Island (Intervals)

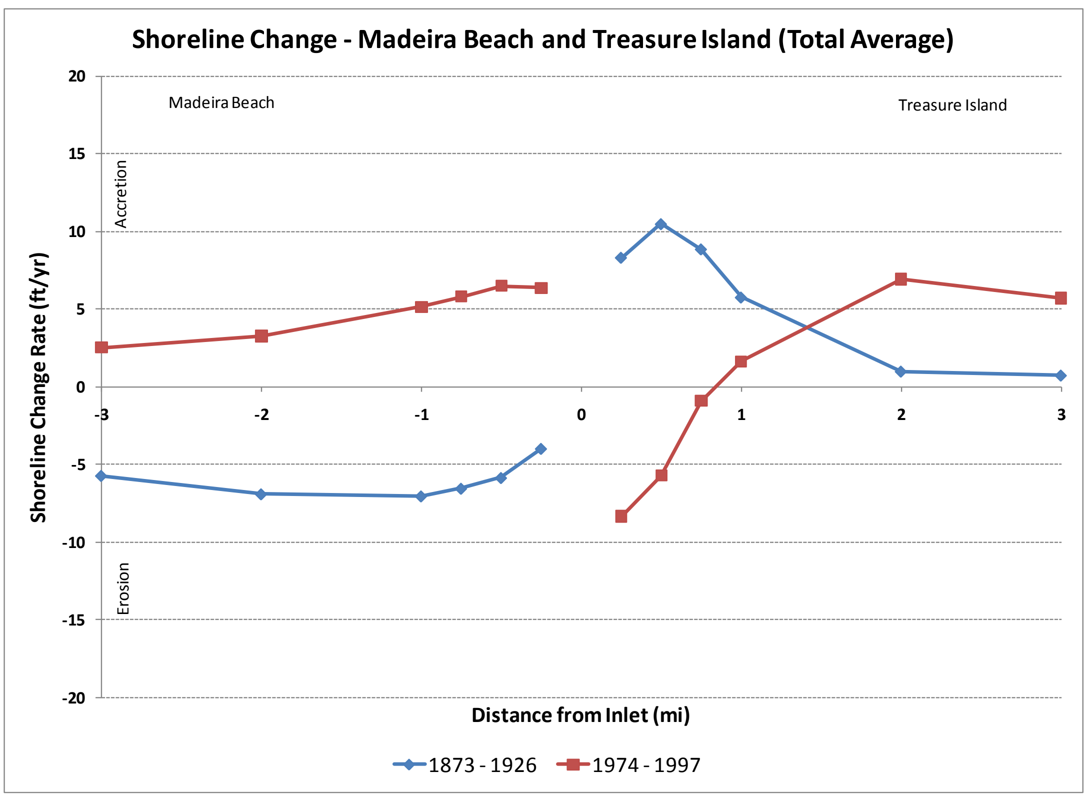


Figure II-77. Shoreline Change – Madeira Beach and Treasure Island (Total Average)

b) Volumetric Changes

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 initially evaluated based on the shoreline change. 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-70 and Table II-71 provide the volumetric beach change for the intervals and cumulative distances, respectively, along Madeira Beach based on the shoreline change rates presented previously, while Table II-72 and Table II-73 present the volumetric beach change for the intervals and cumulative distances, respectively, along Treasure Island. 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 and dredging, since these are implicitly included in the shoreline measurements. Figure II-78 and Figure II-79 present the same information graphically.

Table II-70. Beach Volume Changes – Madeira Beach (Intervals)

	Volume Change - Madeira Beach (Intervals) (cy/yr)					
Distance from Inlet (mi)	0 - 0.25	0.25 - 0.5	0.5 - 0.75	0.75 - 1	1 - 2	2 - 3
Pre: 1873 - 1926	4,782	8,444	9,211	10,011	32,591	16,644
Post: 1974 - 1997	7,639	7,971	5,355	3,772	6,581	4,420

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

Table II-71. Beach Volume Changes – Madeira Beach (Cumulative)

	Volume Change - Madeira Beach (Cumulative) (cy/yr)					
Distance from Inlet (mi)	0 - 0.25	0 - 0.5	0 - 0.75	0 - 1	0 - 2	0 - 3
Pre: 1873 - 1926	4,782	14,071	23,593	33,826	66,356	82,467
Post: 1974 - 1997	7,639	15,610	20,965	24,737	31,319	36,217

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

Table II-72. Beach Volume Changes – Treasure Island (Intervals)

	Volume Change - Treasure Island (Intervals) (cy/yr)					
Distance from Inlet (mi)	0 - 0.25	0.25 - 0.5	0.5 - 0.75	0.75 - 1	1 - 2	2 - 3
Pre: 1873 - 1926	9,992	15,515	6,495	4,713	18,851	881
Post: 1974 - 1997	10,039	3,309	11,152	11,594	59,470	14,636

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

Table II-73. Beach Volume Changes – Treasure Island (Cumulative)

	Volume Change - Treasure Island (Cumulative) (cy/yr)					
Distance from Inlet (mi)	0 - 0.25	0 - 0.5	0 - 0.75	0 - 1	0 - 2	0 - 3
Pre: 1873 - 1926	9,992	25,182	31,920	27,673	9,537	10,623
Post: 1974 - 1997	10,039	13,744	3,313	7,897	66,574	82,191

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

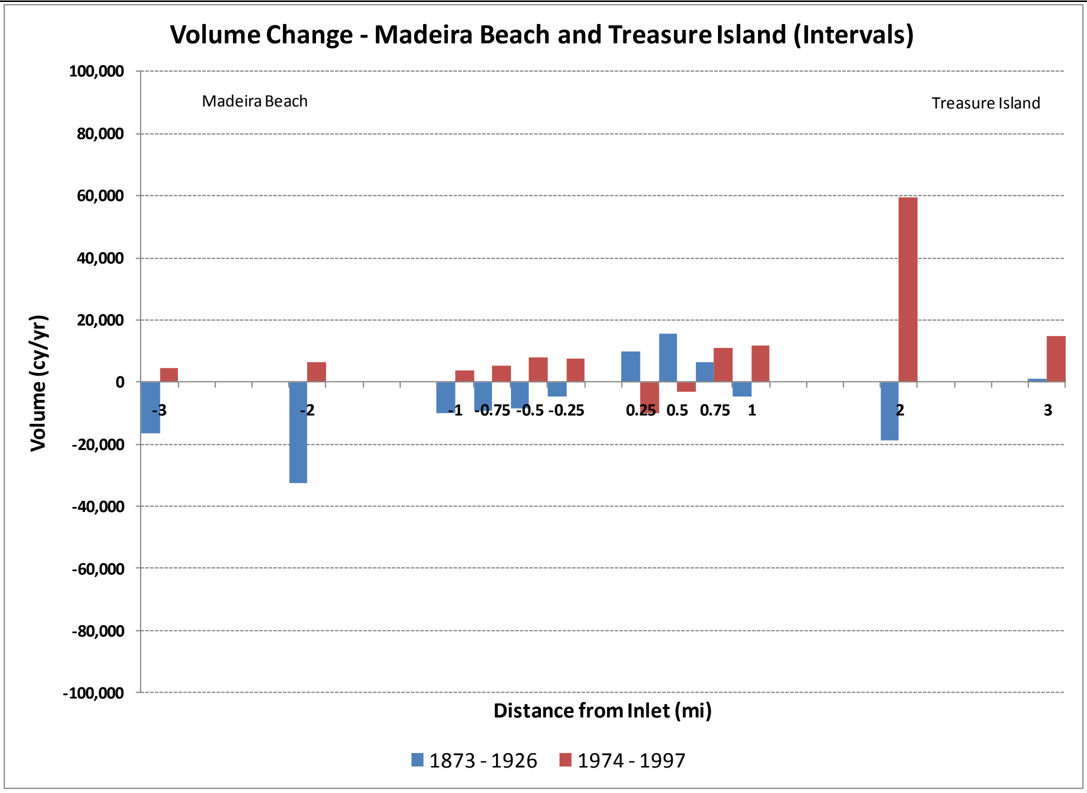


Figure II-78. Beach Volume Changes – Madeira Beach and Treasure Island (Intervals)

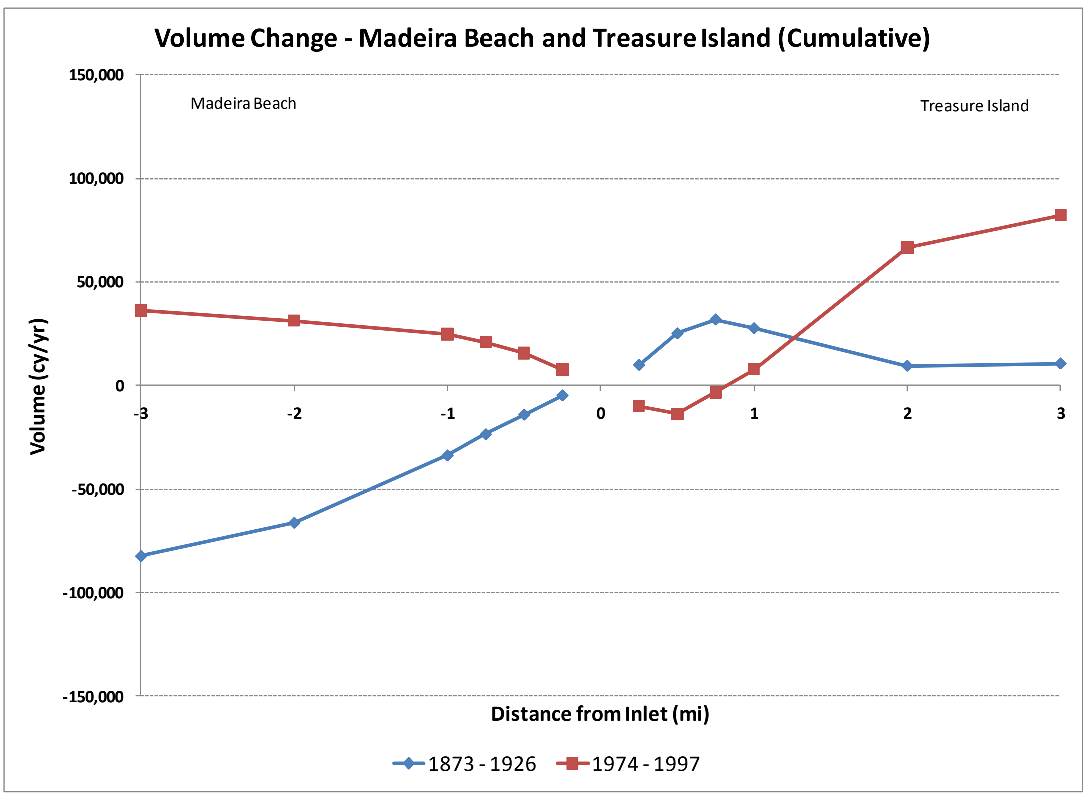


Figure II-79. Beach Volume Change – Madeira Beach and Treasure Island (Cumulative)

c) Volumetric Changes – Beach Nourishment

Since construction of the terminal groins, beach nourishment has occurred along the shoreline on Treasure Island. Table II-74 details the amounts, timing, and locations, when known, of beach nourishment activities along Treasure Island during the analysis time periods. (The engineering activities log in Appendix C provides details for all activities). Table II-75 presents a summary of this data with respect to the amounts assumed placed on each analysis interval of shoreline for each of the analysis time periods. For material placed directly on the beach, the total volumes were pro-rated over the placement stations when known. In cases where the exact placement location was not known, the material was assumed to be placed evenly along the three mile analysis area.

Table II-74. Beach Nourishment – Treasure Island

Year	Placement Location	Extent (ft)	Beach Nourishment Volume by Interval (cy)							Total Volume (cy)
			0 - 0.25	0.25 - 0.50	0.50 - 0.75	0.75 - 1.0	1.0 - 2.0	2.0 - 3.0	3.0 +	
1976	Treasure Island	-	33,737	33,737	33,737	33,737	134,950	134,950	0	404,849
1976	South of Treasure Island	7,920	0	0	0	0	0	0	380,000	380,000
1978	South of Treasure Island	-	0	0	0	0	0	0	32,000	32,000
1983	Treasure Island	-	18,333	18,333	18,333	18,333	73,333	73,333	0	220,000
1986	Treasure Island	-	0	0	0	0	137,250	137,250	274,500	549,000
1996	Sunset Beach	-	0	0	0	0	0	0	252,950	252,950

Table II-75. Beach Nourishment – Treasure Island

Period	Beach Nourishment Volume by Interval (cy/yr)							Total Volume (cy/yr)
	0 - 0.25	0.25 - 0.50	0.50 - 0.75	0.75 - 1.0	1.0 - 2.0	2.0 - 3.0	3.0 +	
Pre: 1873 - 1926	0	0	0	0	0	0	0	0
Post: 1974 - 1997	2,264	2,264	2,264	2,264	15,023	15,023	40,846	79,948

In Table II-76 and Table II-77 for Madeira Beach, and Table II-78 and Table II-79 for Treasure Island, the total beach nourishment material placed on the beach is subtracted from the volumes calculated based on shoreline change to arrive at volume changes without nourishment (as if the nourishment did not take place). Figure II-80 and Figure II-81 present the same information graphically.

Table II-76. Volume Changes Without Nourishment – Madeira Beach (Intervals)

	Volume Change w/o Nourishment - Madeira Beach (Intervals) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1873 - 1926	4,782	8,444	9,211	10,011	32,591	16,644
Post: 1974 - 1997	7,639	7,971	5,355	3,772	6,581	4,420

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

Table II-77. Volume Changes Without Nourishment – Madeira Beach (Cumulative)

	Volume Change w/o Nourishment - Madeira Beach (Cumulative) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1873 - 1926	4,782	14,071	23,593	33,826	66,356	82,467
Post: 1974 - 1997	7,639	15,610	20,965	24,737	31,319	36,217

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

Table II-78. Volume Changes Without Nourishment – Treasure Island (Intervals)

	Volume Change w/o Nourishment - Treasure Island (Intervals) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0.25 - 0.5**	**0.5 - 0.75**	**0.75 - 1**	**1 - 2**	**2 - 3**
Pre: 1873 - 1926	9,992	15,515	6,495	4,713	18,851	881
Post: 1974 - 1997	12,303	5,573	8,888	9,330	44,447	387

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

Table II-79. Volume Changes Without Nourishment – Treasure Island (Cumulative)

	Volume Change w/o Nourishment - Treasure Island (Cumulative) (cy/yr)					
Distance from Inlet (mi)	**0 - 0.25**	**0 - 0.5**	**0 - 0.75**	**0 - 1**	**0 - 2**	**0 - 3**
Pre: 1873 - 1926	9,992	25,182	31,920	27,673	9,537	10,623
Post: 1974 - 1997	12,303	18,272	10,105	1,159	42,495	43,089

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

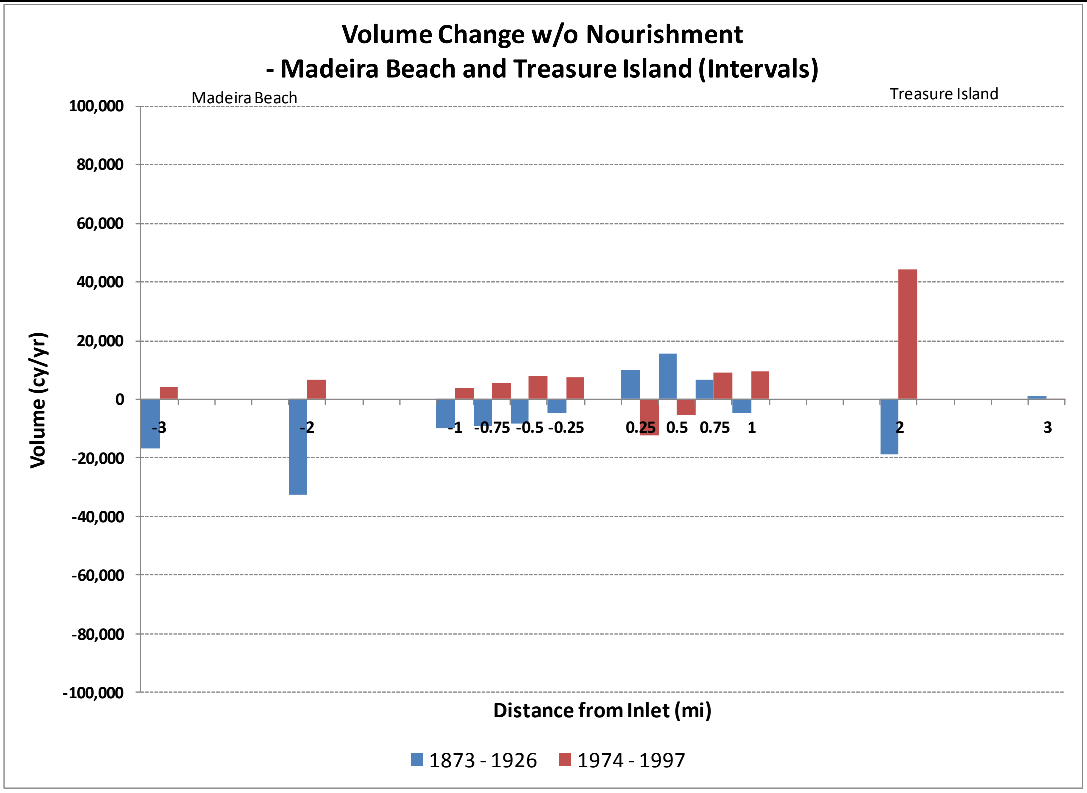


Figure II-80. Volume Changes Without Nourishment – Madeira Beach (Intervals)

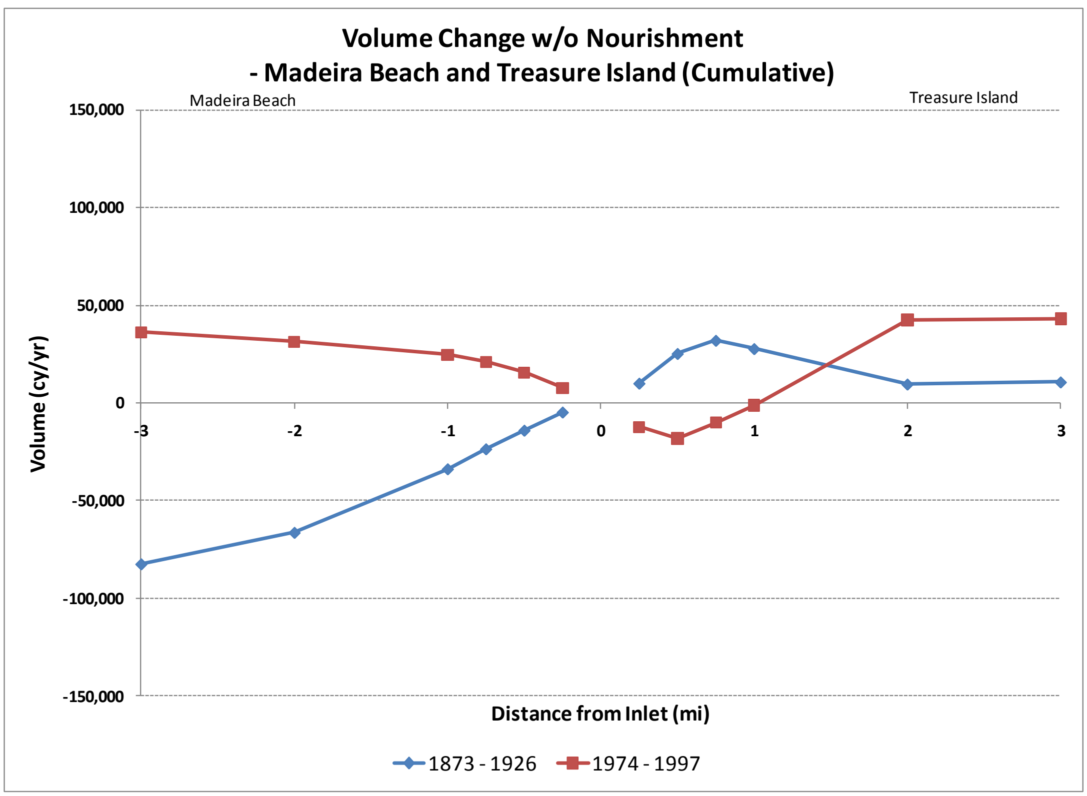


Figure II-81. Volume Changes Without Nourishment – Treasure Island (Cumulative)

d) Volumetric Changes - Dredging

Much like nourishment, the influence of dredging material must be accounted for when trying to assess the impact of the terminal groin. The channel is not dredged frequently but on occasion, sand was taken from the delta complex as a sand source for other nourishment projects.

Table II-80 details the amounts, timing and locations, when known, of dredging activities that removed material from within the inlet system during the analysis time periods. (The engineering activities log in Appendix D provides details for all activities). Table II-81 presents a summary of this data with respect to the amounts dredged during each analysis time period.

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-82 and Table II-83 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 without nourishment). The additional scenarios assume 25% or 50% of the material dredged from the inlet system would have reached the beach naturally.

Table II-80. Dredging Volumes – John's Pass

Year	Dredging Location	Total Volume (cy)
1979	Channel Maintenance	80,000
1981	Channel Maintenance	70,000
1983	Channel Maintenance	80,000
1991	Channel Maintenance	56,000

Table II-81. Dredging Volumes – John's Pass

Period	Total Volume (cy/yr)
Pre: 1873 - 1926	0
Pre: 1974 - 1997	12,435

Table II-82. Volume Change Scenarios Without Nourishment and Dredging – Madeira Beach

	Dredging Effects - Madeira Beach (cy/yr)		
Dredging Percentage Added	**0%**	**25%**	**50%**
Pre: 1873- 1926	82,467	82,467	82,467
Post: 1974- 1997	36,217	39,325	42,434

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

Table II-83. Volume Change Scenarios Without Nourishment and Dredging – Treasure Island

	Dredging Effects - Treasure Island (cy/yr)		
Dredging Percentage Added	**0%**	**25%**	**50%**
Pre: 1873- 1926	10,623	10,623	10,623
Post: 1974- 1997	43,089	46,198	49,307

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

3. Summary

Prior to terminal groin construction, the Madeira Beach shoreline was erosional and the Treasure Island shoreline was accretionary over the first three-quarter mile, erosional over the next one and quarter miles and relatively stable for the third mile. After the construction of the terminal groin, the Madeira Beach the shoreline is accretionary while the Treasure Island shoreline varies being erosional over the first half mile, but accretionary over the next 2.5 miles. It must be noted, though, that these shorelines include the effects of beach nourishment and dredging activities.

Since during the analysis periods studied no nourishment occurred on northern side of the inlet Madeira Beach has the same volumetric trends as its shoreline change.

Beach nourishment has occurred on Treasure Island since the terminal groin was constructed on the opposite side of the inlet with about 0.9 million cubic yards of material being placed on the first three miles of beach during the analysis time period; while almost 300,000 cubic yards of material has been dredged from the inlet system that might otherwise have naturally ended up on the beach. Insufficient shoreline data was available to assess Treasure Island beaches post-construction of the terminal groin on its side of the inlet in 2000.

Once all the beach nourishment activities are subtracted out and after construction of the northern terminal groin, the volumetric analysis shows that Madeira Beach accreted over the 3-mile distance from the inlet while Treasure Island had an average erosion increase over the first half mile, but was accretionary over the next 1.5 miles and then was slightly erosional over the final mile. The average change over the first three miles, though, was an increase in accretion.

Given the volume material dredged from the inlet system, it can be seen that this may have some impact on the volumetric trends, but not of a similar magnitude as the North Carolina study sites.

I. Overall Findings, Comparisons, and Summary

Terminal groins were 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. The terminal groins at the five selected study sites were constructed between 1961 and 2005 and vary in length from the longest being over 3,000 feet (including backside revetment) at Oregon Inlet to the shortest of 350 feet at Captiva Island. Table II-84 and Table II-85 summarize the environmental climate and physical characteristics of the five study sites, respectively.

Table II-84. Environmental Climate 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

Table II-85. Terminal Groin Physical Characteristics

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.

Qualitative Findings

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.

Terminal groins are typically constructed at the downdrift end of littoral transport cells; however they are also commonly built on both sides of inlets or in some instances on the opposite side of a tidal inlet because in addition to the regional dominant longshore transport system delivering sand preferentially to one side of an inlet, 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.

Tidal processes impart a strong signature on the adjacent shoreline, which is usually commensurate with the size of the inlet. 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.

Dredging can significantly impacted an inlet system, 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.

The major impact of terminal groins at the study sites is that they stabilized the location of the inlet shoulder 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 can act like bedrock outcrops, anchoring the end of the barrier and stabilizing the nearby beach.

When a tidal inlet migrates, the updrift spit fills the channel that is migrating downdrift. Commonly the depth of the inlet channel is much deeper than the sand thickness of the barrier. So as the inlet migrates and the spit progrades into the inlet channel, there is a net loss of sand. Likewise, as the inlet migrates, sand is left behind in the backbarrier (bay and lagoon) in the form of flood-tidal deltas and other sand bodies. Thus, inlet migration usually results in a net loss of sand to the downdrift barrier.

Quantitative Findings

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-86 summarizes this data for the three mile stretch of shoreline on each side of the inlet except for Pea Island, where a six mile stretch of shoreline was analyzed. Also, 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 (i.e. mixed erosion and accretion). 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-86. Comparison of the Shoreline Change Rates

Study Site	Average Shoreline Change Rates Along 3 miles (6 miles for Pea Island) (ft/yr)			
	Terminal Groin Side of Inlet		Opposite Side of Inlet	
	Pre – Construction	Post – Construction	Pre – Construction	Post – Construction
Oregon Inlet	12.7 / 36.3**	1.7 / 2.8***	3.0 / 115.4**	27.0 / 36.1***
Fort Macon	15.5	3.0	0.5	2.3
Amelia Island	3.9	2.5	10.2	n/a
Captiva Island	11.4	1.5	11.9	0.7
John's Pass – North Structure	5.7	2.5	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: 1997 – 2007 / 1998 – 2004

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. A standard rule of thumb is that 1 foot of shoreline change corresponds to 1 cubic yard of volumetric change (Herbich, 2000 and Kraus, 1998). Site specific ratios were calculated for this study and are given in Table II-87. Overton and Fisher (2005) used a 1.37 cy beach volume per foot of shoreline change relationship for shoreline near Oregon Inlet.

Table II-87. 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 then evaluated based on the shoreline change, nourishment and beach volumes placed, and quantities of material dredged from the inlet.

Table II-88 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-89 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 without nourishment.

Table II-88. Total Annual Beach Nourishment

Study Site	Beach Nourishment Volume within 3 Miles from Inlet (6 miles for Pea Island) (cy/yr)	
	Terminal Groin side of Inlet	
	Pre – Construction	Post – Construction
Oregon Inlet	0 / 0*	469,689 / 607,576**
Fort Macon	0	144,604
Amelia Island	0	200,000
Captiva Island	4,870	62,295
John's Pass– North Structure	0	0

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

Table II-89. Volume Changes Without Nourishment

Study Site	Volume Change within 3 Miles from Inlet (6 miles for Pea Island) (cy/yr)			
	Terminal Groin side of Inlet		Opposite Side of Inlet	
	Pre – Construction	Post – Construction	Pre – Construction	Post – Construction
Oregon Inlet	568,085 / 1,621,093**	395,528 / 484,038***	66,594 / 2,576,870**	602,806 / 805,272***
Fort Macon	248,603	96,826	7,447	37,309
Amelia Island	77,702	249,449	202,501	n/a
Captiva Island	144,083	54,613	134,073	18,109
John's Pass– North Structure	82,467	36,217	10,623	43,089

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

Figure II-82 through Figure II-86 show the volume rate changes with nourishment volumes removed (without nourishment) between the pre- and post-construction periods. In other words, the volume changes (both intervals and cumulative) that occurred pre-construction were subtracted from the volume changes that occurred post-construction to determine the differences between these two periods. It should be noted that positive values indicate an improvement (reduced erosion, a change from erosion to accretion, or increased accretion) while negative values indicate the converse (increased erosion, a change from accretion to erosion, or reduced accretion.

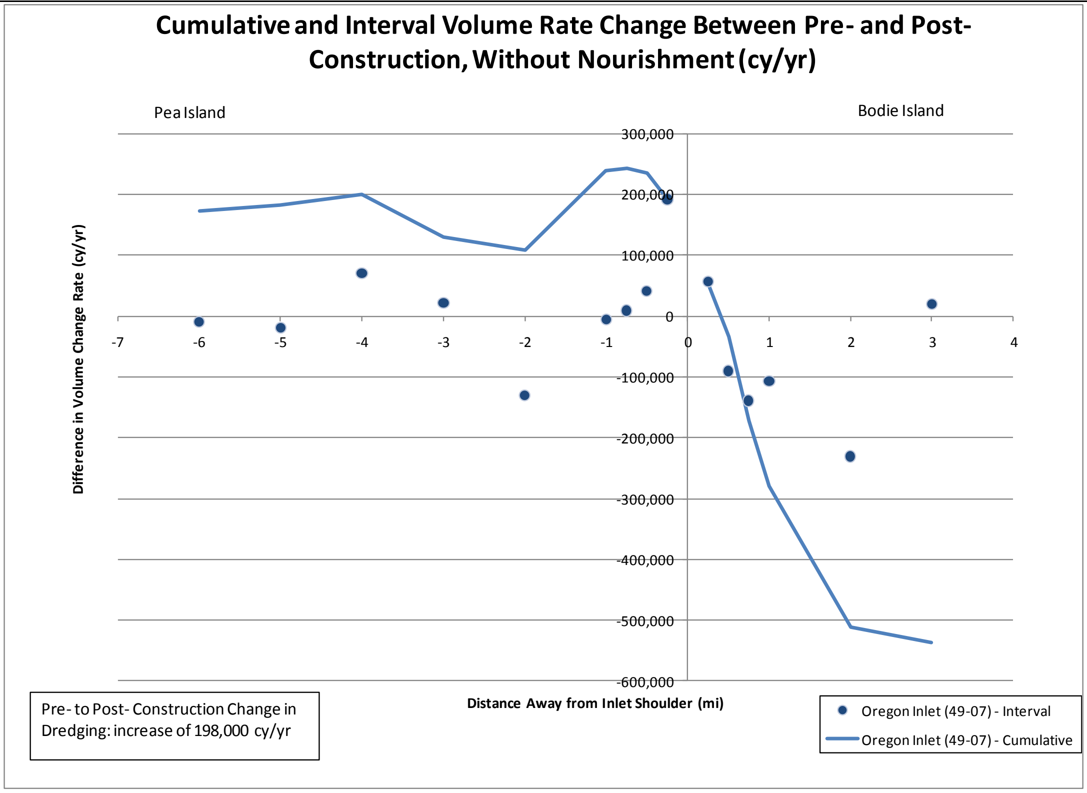


Figure II-82. Volume Rate Changes Without Nourishment – Oregon Inlet

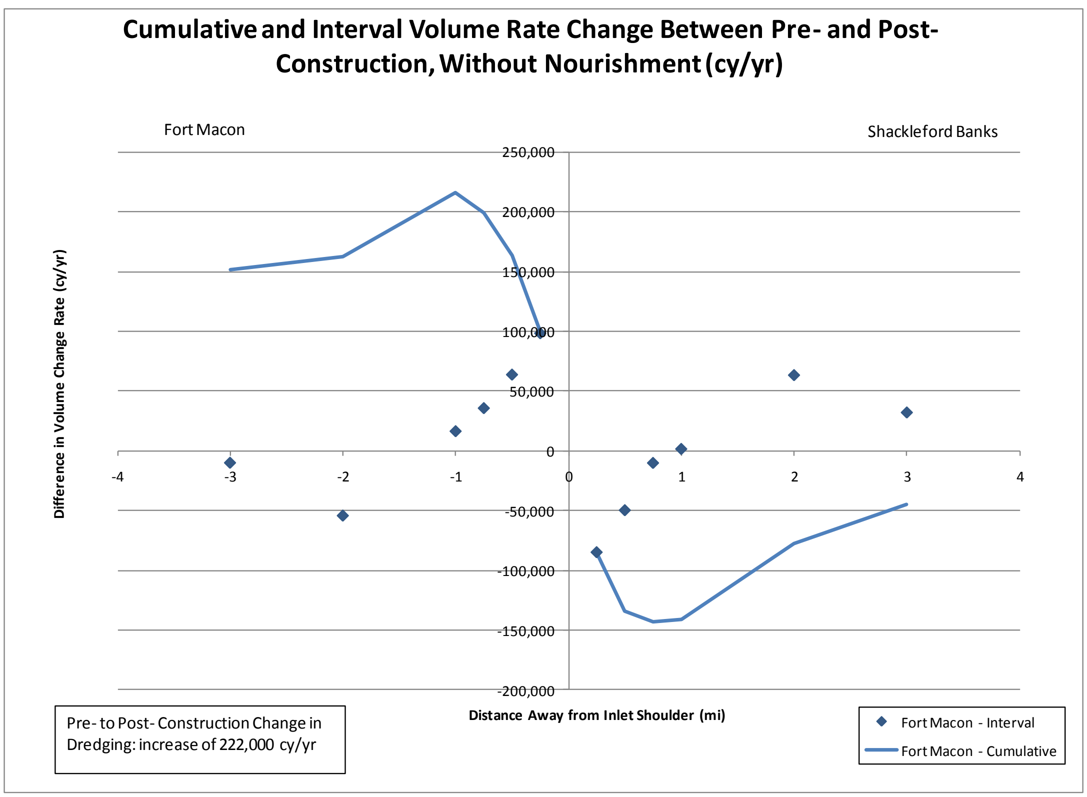


Figure II-83. Volume Rate Changes Without Nourishment – Fort Macon

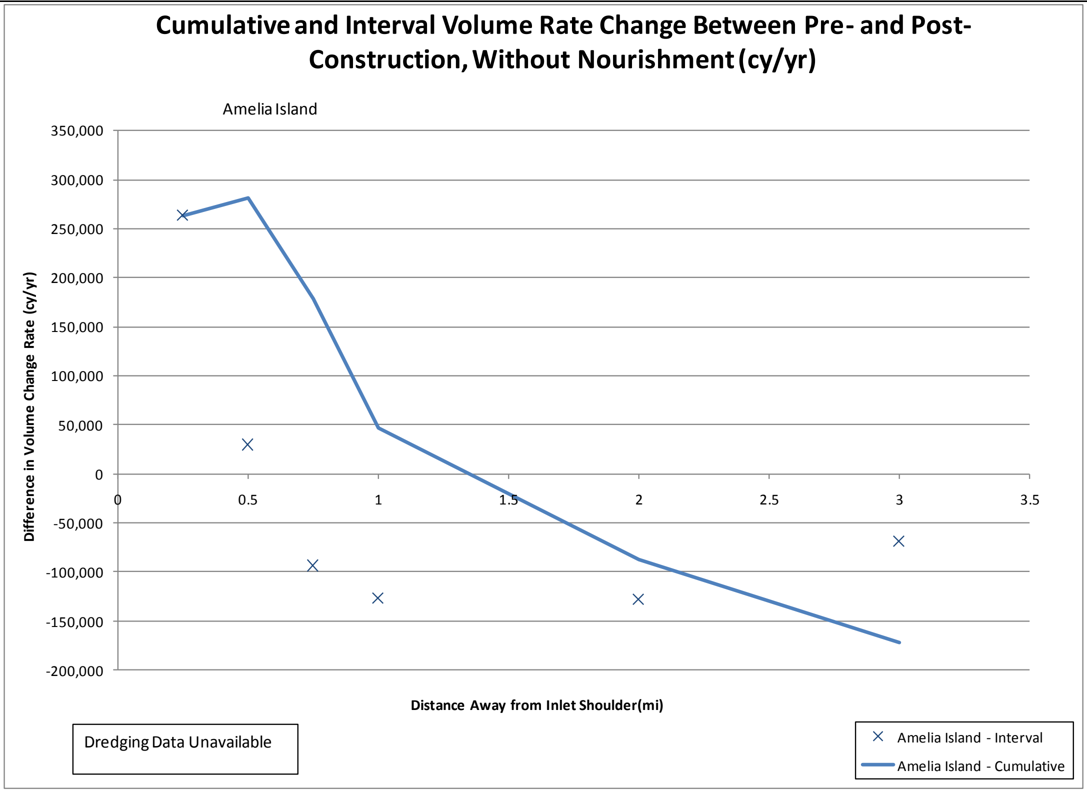


Figure II-84. Volume Rate Changes Without Nourishment – Amelia Island

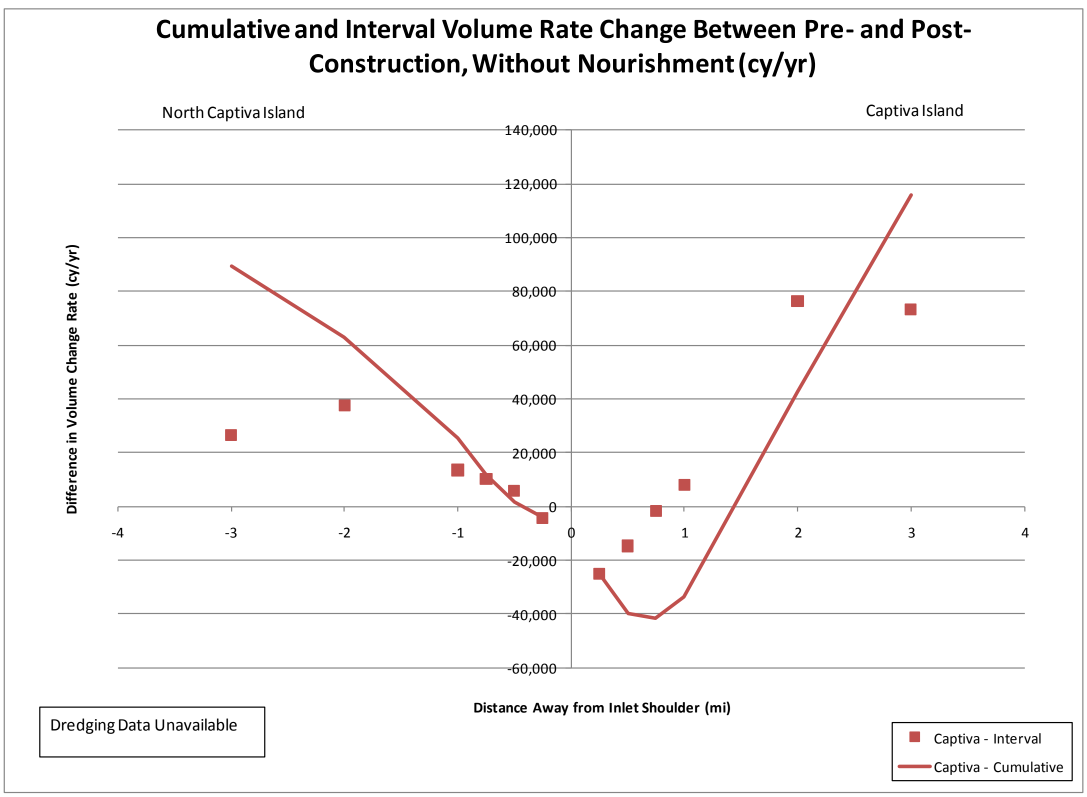


Figure II-85. Volume Rate Changes Without Nourishment – Captiva Island

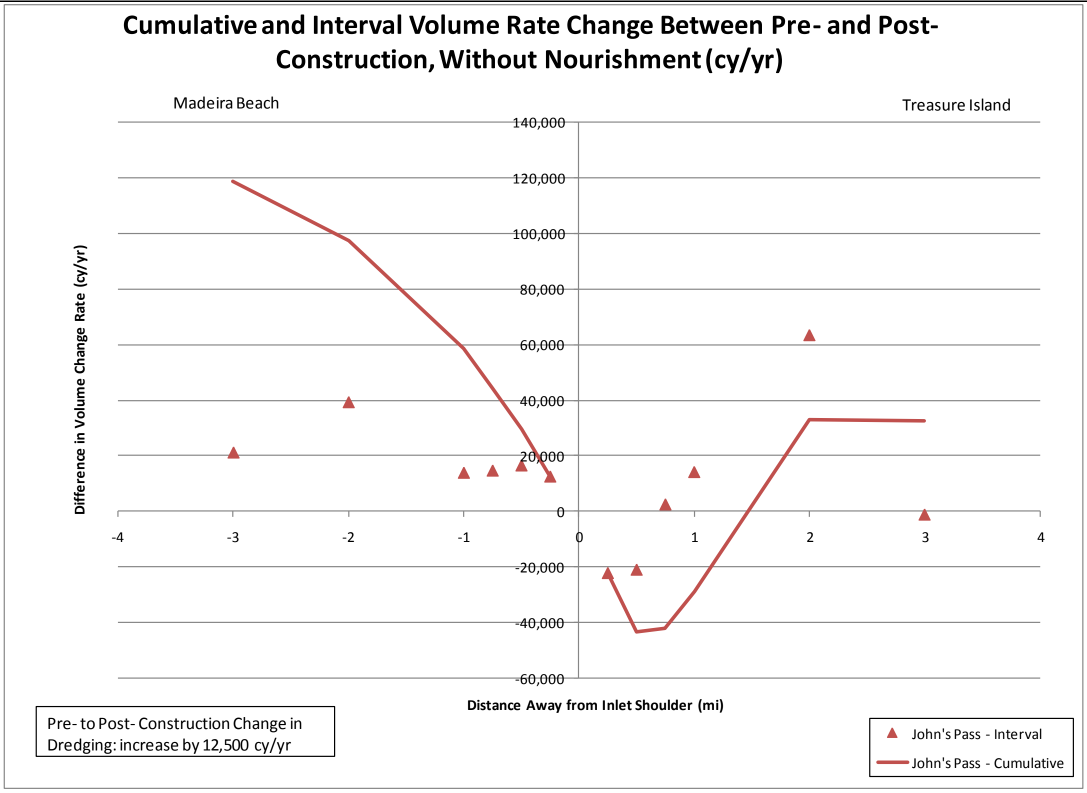


Figure II-86. Volume Changes Without Nourishment – John's Pass

These results (which do not account for changes in dredging pre- and post-construction, likely resulting in overstating any apparent negative results) show that on the terminal groin side of the inlets, there is, as would be expected, a positive result over the first mile of shoreline (except for Amelia Island where this positive result only occurs over the first half mile). Interestingly, for Oregon Inlet, Fort Macon, and Amelia Island there is a negative result over the second mile and then much less of a change (either positive or negative) over the third mile. For Oregon Inlet, further down the shoreline, a positive result is present over the fourth mile and then minimal changes over the fifth and sixth miles. Furthermore, on a cumulative basis, for Fort Macon and Oregon Inlet the positive results are significantly more (about 150,000 cy / year) than any negative results over the shoreline reaches analyzed. Amelia Island does not show a net positive result, but as discussed previously, the adjustment in the post-nourishment shoreline that occurred during the very short post-construction analysis interval analyzed is likely the cause.

For the terminal groin side of Captiva Island and John's Pass, the positive result is apparent over basically the entire three mile analysis length of shoreline with cumulative positive results amounting to 90,000 – 120,000 cy / year.

For the opposite site of the inlet (note that no data was available for the Amelia Island study site), the results typically show a negative result over the first half to three-quarters of a mile. Whether this is the effect of terminal island construction or other impacts such as increased dredging or migrating inlets, though, is not possible to definitively conclude. For Captiva Island, John's Pass and Fort Macon the results turn positive after this initial distance with net cumulative positive results over the shoreline analyzed for Captiva Island and John's Pass and a negative result for Fort Macon. At Oregon Inlet, the negative result continues for the second mile with minimal change over the third mile.

However, much like nourishment, the influence of dredging material from the inlet system must be accounted for when attempting to assess the impact of the terminal groins. Table II-90 summarizes the dredging records obtained at each site for the same pre- and post-terminal groin construction periods.

Table II-90. Dredging Summary

Study Site	Pre – Construction Dredged Volume (cy/yr)	Post – Construction Dredged Volume (cy/yr)
Oregon Inlet	75,178 / 841,972*	273,106 / 366,477**
Fort Macon	563,429	785,429
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: 1997 – 2007 / 1998 – 2004

Detailed analysis of sediment budgets and sediment transport distributions was beyond the scope of this study. However, Table II-91 and Table II-92 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%.

Table II-91. Volume Change Scenario Net Nourishment and Dredging – 25% Scenario

Study Site	Volume Change within 3 Miles from Inlet (6 miles for Pea Island) (cy/yr)			
	Terminal Groin side of Inlet		Opposite Side of Inlet	
	Pre – Construction	Post – Construction	Pre – Construction	Post – Construction
Oregon Inlet	549,290 / 1,410,600**	327,251 / 392,419***	47,800 / 2,787,363**	534,530 / 713,653***
Fort Macon	107,746	99,531	148,304	159,048
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	82,467	39,325	10,623	46,198

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

Table II-92. 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	534,495 / 1,200,107**	258,975 / 300,800***	29,005 / 2,997,856**	466,253 / 622,034***
Fort Macon	33,111	295,889	289,162	355,405
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	82,467	42,434	10,623	49,307

*****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

These results show that one must assume almost 25% of the material dredged from the inlet would have naturally reached Shackleford Banks for the negative pre- to post-construction change over the three-mile shoreline analysis interval to turn positive. However, the negative changes on Bodie Island cannot be accounted for by only assuming some of the dredged material would have bypassed the inlet and reached its shoreline.

Despite limitations of the data, this section provides both a qualitative and quantitative assessment of the physical effects of the terminal groins at the five study sites which aid in understanding their impacts.

III. Environmental Assessment

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 although the Physical Assessment Section does conclude that terminal groins do not have a big impact on regional sand transport when looked at in conjunction with the other major natural and anthropogenic effects on the inlet, but can anchor an inlet shoreline at least temporarily. These factors in turn affect coastal and marine biological communities (CERC 1984).

As noted in the Physical Assessment Section, the primary geomorphological consequence of the presence of a terminal groin structure and its physical consequences on habitat is the stabilization of the inlet channel and shoreline inhibiting natural physical processes of sand flat formation, overwash to some degree, and creation of new unvegetated nesting and resting habitat for many species. The prevention of inlet migration and reduction in overwash events affects those resources dependent on dynamic inlet shorelines. The Physical Assessment data indicate the selected inlet's tidal dynamics, storm impacts, dredging, beach nourishment, and day-to-day wave processes are the chief factors affecting the sedimentation patterns and sand distribution at the selected study sites.

Coastal protection projects, whether they include hard or soft structures, have proved to be of particular environmental concern due to their magnitude, timing, and the sensitivity of high value resources within the vicinity of an inlet. A scientific literature review and discussion of the environmental considerations and the significant resources dependent upon natural dynamic barrier islands is provided in the General Environmental Effects Section. A review of primary and secondary natural resource data with respect to the selected five terminal groin locations is provided in the Environmental Assessment of the Five Study Sites Section.

1. Technical Approach of Analysis

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 via regulatory documentation and scientific literature to provide additional natural resource data in order to comprehensively analyze the effects of terminal groins. In order to conduct an interdisciplinary analysis, summary of findings from the Physical Assessment Section was integrated into the Environmental Section in order to analyze coastal habitats and organism responses based upon the dynamics of sediment transport changes and geomorphological changes potentially occurring within the selected study sites.

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 natural resources evaluated include benthic resources, shorebirds and waterbirds, fisheries, coastal habitats and associated biota, and federally protected species, such as sea turtles and piping plovers. Readily available data from each selected site was identified from web-based literature searches and over 140 contacts and interviews were made with applicable state/local and federal agencies, coastal engineering firms, non-profit organizations, and libraries (Appendix E). Table III-1 provides a breakdown of representatives contacted for environmental data. Information identified was reviewed for its usefulness in assessing natural resource effects from construction and maintenance of the selected terminal groin locations.

Table III-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 population and natural ecosystem data. Local population data from each selected study site were utilized in order to most efficiently detect a trend or change over a spatial and temporal basis. Natural resource survey data in general are not typically obtained by any rigorous scientific methodologies, and the results from year to year certainly vary due to the level of coverage as well as the weather conditions, which can vary considerably from year to year. Ecological and environmental variability as well as major data gaps in the natural ecosystems evaluated in this study provided for a complex analysis. It was understood that control sites and variability (spatial, temporal, and natural) are some of the most important concepts in impact assessments and were integrated as fully as possible into this study. In an attempt to fully evaluate potential effects of terminal groins, available natural resource data from inlet locations with no structures present were used as controls as well as to evaluate population data on a regional level. Spatial and temporal extent of each dataset varies based on local monitoring regimes and were beyond the control of this study. Considering the time scale of this study, readily available data could not be statistically evaluated based on quality and completeness therefore a Before-After and Control-Impact (BACI) analysis was precluded.

Other potential methodologies for determining the effect of a terminal groin on the environment were reviewed, including quantifying temporal changes in habitat areal coverage with the use of Geographic Information Systems and high resolution geo-referenced digital multispectral aerial photographs. However, based on experience, this methodology consumes more time than what was available for this study and can be difficult to accurately interpret in the vicinity of oceanic inlets due to their dynamic and ephemeral nature. Although biotic community changes over time weren't quantified within the vicinity of the selected terminal groin locations, habitats were evaluated on a visual basis.

Technical qualifiers that are in need of mention include the following:

- No new natural resource data were collected during this study;
- Existing secondary sources and raw data collected by other entities were evaluated for potential environmental effects;
- Readily available data were not directly related to the construction of a selected terminal groin;
- Beach nourishment, dredging, and terminal groin effects could not be evaluated separately;
- Historical nature of the selected terminal groin sites precluded the availability of pre-construction natural resource data and statistical evaluation; and
- Prior to construction and after construction data were only available for two sites and limited resources.

2. General Environmental Effects

a) Coastal and Marine Resources Effects

Tidal inlets provide tidal conveyance from open bodies of water to more sheltered lagoons, estuaries, or bays. 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 selected terminal groin site includes a coastal classification map, a habitat map depicting the major sensitive habitats, and a species occurrence map which represents species' habitat range.

Dredging and placement of beach quality sand and the construction of terminal groins are typically designed and constructed in conjunction and therefore have the potential to affect biological resources in a variety of ways. This section discusses the effects of terminal groins as well as the placement of material as it relates to each natural resource.

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 may promote restoration of important sea turtle nesting habitat that has been lost or degraded as a result of significant oceanfront erosion. Adverse affects may come in the form of the prevention of accretion of new habitat on the opposite side of the inlet, which may be more valuable to early successional species such as the piping plover, especially over the long term.

The placement of rock to construct a terminal groin would result in a temporary and footprint specific loss of the existing benthic community. 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. However, according to NCDMF, rocky habitat adjacent to an inlet, created through the installation of a terminal groin, is not natural to NC and therefore is not needed by the native fish or bird community. The addition of rocky habitat within a sandy intertidal area is not necessarily a positive benefit, rather a habitat trade-off. Chapman and Bulleri (2003) have concluded that creating rocky habitat has led to the introduction of non-native invasives within the vicinity of a hard structure.

Potential effects of shoreline protection projects, including beach nourishment and hardened structures, 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 activities. To offset some of these effects there is evidence, as described in the Physical Assessment Section, that sand bypasses terminal groins which allows for the development of beaches inside an inlet, there is existence of subtidal bars trending into the inlet channel, development of marginal flood channels, historical shoaling and closure of tidal inlets, and landward migrating swash bars welding to the downdrift inlet shorelines.

The sections below describe specific biological resources and the considerations of the effects of the construction and maintenance of a terminal groin structure and associated fillet.

b) Benthic Resources

A seafloor with physical properties ranging from dense mud 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). As supported by NOAA NMFS, a rock rubble structure extending below the intertidal zone in a sandy bottom location would likely induce and support the development of a diverse benthic community supporting higher trophic levels of both fish and birds within the vicinity and footprint of a terminal groin. 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; and 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 up to 1 kilometer from the area of sediment deposition (Bishop et al. 2006). The long-term and cumulative effects of beach nourishment on benthic infauna and surface sediments of Panama City beaches were investigated by Culter and Mahadevan (1982), resulting in seasonal variability of species composition and faunal densities. Species diversity was lowest in the swash zone and sandbar and highest offshore. No long-term adverse effects from beach nourishment were detected in the Florida or North Carolina studies (Culter and Mahadevan 1982; Carter 2008). However, a study on Pea Island found peak recruitment of coquina clams was in March and concluded that nourishment in March or April would depress the population in the region of nourishment for at least a full year (Donoghue 1999). Even if invertebrate populations fully recover within one year of a nourishment/maintenance event, this is a significant amount of time with depressed food resources available to foraging shorebirds over a large area. According to North Carolina Wildlife Resources Commission (NCWRC), the cumulative impacts of multiple nourishment events are unknown for invertebrate populations.

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. As stated previously, any reduction in the numbers and/or biomass of intertidal macrofauna may have 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). As noted by NOAA NMFS, 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.

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; and Able et al. 2009). Many of these species, such as pompano and kingfish, which use the surf zone as a nursery area also, have high site fidelity, making them vulnerable to localized impacts in benthic community changes (Ross and Lancaster 2002). 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 (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). As noted in the Physical Assessment Section, once a beach protrudes to near the end of the structure, either by natural longshore transport or through beach nourishment, wave processes transport sand around and over the groins into the tidal inlet. The same sand by-passing action would also affect the by-pass of estuarine dependant larval forms.

d) Shorebirds and Waterbirds

The dynamic coastal processes that characterize inlet and barrier beach systems create habitats maintained by coastal storm events and resulting overwash, which support various early successional nesting bird species such as the federally listed piping plover (*Charadrius melodus*). According to NCWRC (2009), the barrier islands and associated inlets on which many waterbirds depend are being severely altered by attempts to stabilize beaches and dunes. 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. The effect of beach management activities also significantly inhibits the creation and maintenance of soundside salt marsh habitat. These areas will be impacted by beach nourishment and the construction and maintenance of a storm berm. The presence of a storm berm prevents overwash fans from forming in the marsh. Overwash fans create early successional nesting habitat for plovers, terns, and skimmers, and provide for landward migration of barrier islands resulting in the extension of salt marsh into the estuary behind the island as it migrates.

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; and 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 in the Fort Macon State Park area while purple sandpipers are also occasionally abundant in flocks of 40 to 50 on the jetties at Masonboro Inlet (Personal communication, R. Newman, Fort Macon State Park, October 2009; Personal communication, J. Fussell, Birder and Author, February 2010). Both species use rocks and groins as their primary feeding habitats. Other shorebirds use them only on occasion, feeding on surrounding habitats as well (Peterson and Peterson 1979; Thayer et al. 1984).

As natural sand bypass continues around and through a terminal groin, it becomes largely covered with sand and therefore is no longer available to species such as the ruddy turnstone and purple sandpiper. This has been the case with the terminal groin at Fort Macon. According to local bird experts, the Fort Macon terminal groin attracted purple sandpipers and the occasional vagrant eider or harlequin duck in the 1960's and 1970's; in more recent years, it has been much less attractive to these birds.

Beach and early successional 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.

3. 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 III-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 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). Based on the extensive literature search conducted during this study, effects of terminal groin structures are unlikely to affect the West Indian manatee.

Table III-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."

(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).

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). 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

<u>Piping Plover</u>

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). Only the Atlantic Coast population breeds along the east coast of North America, from the Canadian Maritime Provinces to North Carolina whereas 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 2006a). Piping plovers are known to utilize all inlet areas on the North Carolina coast for breeding and/or wintering. Coastal North Carolina is at the southern end of the breeding range and the northern end of the wintering range of piping plovers.

Piping plovers depend on the natural barrier island and inlet processes that create and maintain broad flats and intertidal areas, overwash zones, and maintain early successional habitat. USFWS (1996a) identifies inlet shorelines and associated sandflats as a primary habitat for wintering and breeding piping plovers. Factors that affect distribution, abundance, and survival of the federally-threatened piping plover on wintering grounds are poorly understood (Cohen et al. 2008). Wintering plovers on the Atlantic Coast prefer wide beaches in the vicinity of accreting coastal inlets (Nicholls and Baldassarre 1990; Wilkinson and Spinks 1994; USFWS 1996). At inlets, foraging plovers are associated with moist substrate features such as intertidal sandy mudflats, 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). Wintering habitat, like Atlantic Coast breeding habitat, is dependent on natural forces of creation and renewal. Man-made structures along the shoreline or manipulation of natural inlets can upset this dynamic process and result in habitat loss or degradation (USFWS 1996).

As described by 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). The maintenance of an inlet channel location acts to stabilize the inlet. Stabilization of inlets is considered a serious threat to piping plovers because it can lead to a net loss of suitable habitat (USFWS 1996).

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. This species is not discussed further in the document as no population data was available for evaluation.

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.

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 may be altered resulting in loss of nest 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 a 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

Atlantic Sturgeon

The Atlantic sturgeon (*Acipenser oxyrhynchus*), nominated for listing as endangered, is a demersal, anadromous species. This species migrate from the marine environment to freshwater to spawn during late winter-early summer. Juveniles remain in the freshwater-estuary system for three to five years before migrating to the near-shore marine environment as adults. Tagging studies indicate that Atlantic sturgeon migrate extensively in the marine environment.

Management of this species is conducted under the Atlantic States Marine Fisheries Commission. An Interstate Fishery Management Plan was implemented in 1990 which implemented strict state regulations on sturgeon fisheries. Should the status of the Atlantic sturgeon change, it would be potentially impacted, since the species occurs in nearshore ocean waters.

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.

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 are 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.

The smalltooth sawfish is a tropical marine and estuarine elasmobranch with a circumtropical distribution. 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).

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). Seabeach amaranth appears to function in a relatively natural and dynamic manner, allowing it to occupy suitable habitat as it becomes available (USFWS 1993).

4. 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).

5. 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.

6. Summary of General Environmental Effects

In summary and based on an extensive review of scientific literature and regulatory documentation, potential effects of terminal groins in conjunction with shoreline management (i.e. beach nourishment) on natural resources vary according to the type of construction equipment used, the nature and location of sediment discharged, the time period of construction and maintenance in relation to life cycles of organisms that could potentially be affected, and the nature of the interaction of a particular species. In terms of benthic infauna, 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. In the event of a beach nourishment maintenance program downdrift of a terminal groin, beach invertebrates would more often be depressed in abundance due to temporary burial and the shorebirds and fishes that feed upon them would be deprived of food for longer periods of time. However, this would be short-term effect and recovery should occur rapidly. 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. In terms of larval transport, a terminal groin may reduce unrestricted access into inlet systems.

The construction of a terminal groin, beach nourishment, and dune construction prevents overwash and contributes to a loss of habitat for breeding and non-breeding waterbirds, including piping plovers. According to the Atlantic Coast Piping Plover Recovery Plan (USFWS 1996), nourishment of eroding beaches impedes overwash that would otherwise create and maintain ephemeral pools and bayside mudflats; preferred piping plover habitat. Tidal flats and ponds are important feeding areas to piping plovers at the start of the nesting season and at other times of the year (Fraser 2005). These areas are created during storm-caused overwash and other erosional processes (Leatherman 1982), and beach stabilization efforts reduce the number and extent of these overwash events (Dean 1999). Beach stabilization, dune construction and disruption of natural processes (erosion, accretion, overwash, longshore transport, etc.) are listed as major contributing factors to the loss of suitable breeding and non-breeding habitat for colonial waterbirds (Hunter et al. 2006).

Overwash is also important in maintaining barrier islands. Where large man-made dunes and/or hardened structures prevent overwash, beach sediment in front of the dunes can be transported offshore during storms causing the island to narrow, while if overwash is allowed to occur, the net volume of sand is often maintained and the island migrates landward (Donnelly et al. 2006). Furthermore, the prevention of island overwash can lead to sediment starvation on the sound side. Cohen (2008) described inlet stabilization with rock jetties and channel dredging for navigation as alterations in the dynamics of sediment transport and affects the location and movement rate of barrier islands (Camfield and Holmes 1995), which might in turn affect the availability of shorebird habitat.

As it relates to sea turtles, terminal groins are typically used in combination with a long-term shoreline protection program in which beach fill is used in "critical erosion" or hot spot areas. Therefore, pre-project nesting conditions are generally degraded with limited sea turtle activity necessitating the need for modification of the shoreline. 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 terminal groin both in the water and/or on the beach. Furthermore, predator concentration, including bird and fish species, may occur within the vicinity of high relief hard structures.

The primary habitat for 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). Seabeach amaranth appears to function in a relatively natural and dynamic manner, allowing it to occupy suitable habitat as it becomes available (USFWS 1993). From a water quality perspective, a frequently cited environmental concern 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. From a social perspective, 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. Yet, 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 (USACE 2008a, b).

B. Environmental Assessment of the Five Study Sites

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 III-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.

Because of the constantly shifting features of Oregon Inlet (Figure III-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.

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 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.

Figure III-1. Oregon Inlet Terminal Groin and Revetment

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).

Figure III-2. 2001 Oregon Inlet Aerial Photograph

(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 III-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 many recreational activities. NCDOT (2008) discussed two publicly owned recreation areas within the project area: the Cape Hatteras National Seashore (CAHA) and the PINWR. Hatteras Island as a whole is 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 CAHA [National Park Service (NPS) 1984] and the Draft Revised Statement for Management (NPS 1991) serve as the NPS plans for the CAHA. These management documents provide for the preservation of 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, 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. 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) as depicted by the extensive marine and estuarine habitats within the vicinity of the Pea Island terminal groin (Figure III-3).

The Cape Hatteras National Seashore, administered by the National Park Service (NPS), which includes and is adjacent to Oregon Inlet contain nationally significant natural and cultural resources and values. These resources play a vital role in the state's ecosystem and local economies. CAHA, along with the PINWR, is home to many of the federally protected species that depend upon inlet shoreline habitat. The inlet shorelines along CAHA are among the few remaining areas where natural barrier island processes occur relatively unimpeded within the Seashore. As a result, the inlets within the Seashore have become even more important as protected wildlife habitat.

Allowing natural barrier island change, which has been prevented on PINWR 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).

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

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). As discussed in the Physical Assessment Section, sand is sequestered at the northern end of Pea Island from storm overwash into the fillet region and beach sand blown into the back dune area adding to the area's sand reservoir. These accumulating sand events result in habitat changes that support certain bird species yet deter others that require overwash inlet areas.

(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 spit prior to 2004, despite surveys since 1985 (NCDOT 2008). According to NCDOT (2008), the NPS located a single seabeach amaranth on the Bodie Island flats in 2004 and two plants in 2005. No plants have been found since 2006 and the plant is currently thought to possibly be extirpated from CAHA (NPS 2009a).

As discussed by NPS (2009a), the life history of seabeach amaranth as a pioneer species accounts for the variability in plant numbers and locations of populations through time. Distribution by wind and water of seed sources into appropriate habitats is somewhat random by nature. The plants intolerance for competition by other plants limits it to areas marginally conducive to plant growth. Additionally, overwash is known to affect the plants' ability to grow. The dynamic nature of coastal islands creates and eliminates potential habitat quickly.

(2) Sea Turtles

As shown in Figure III-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 III-5).

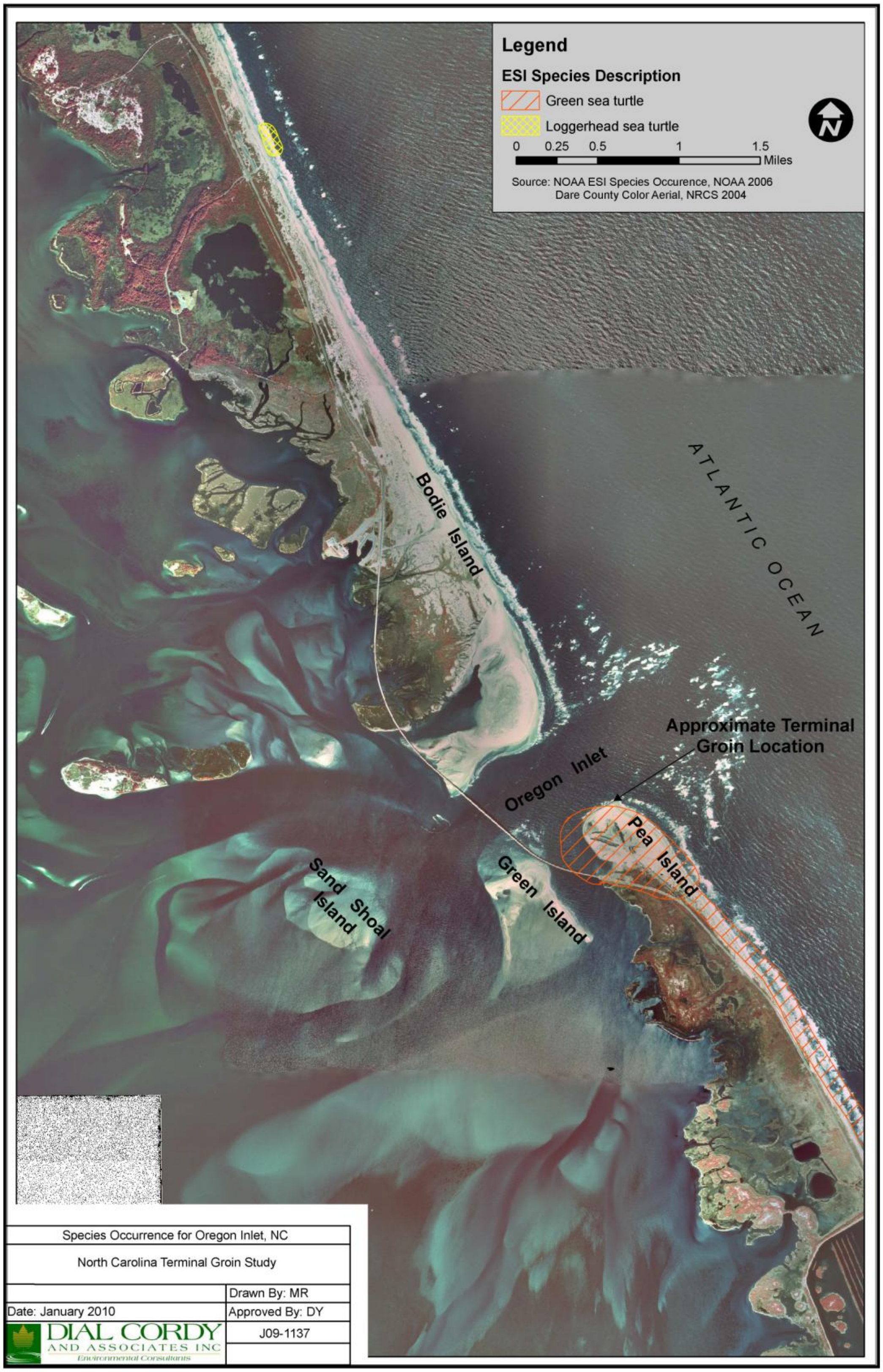


Figure III-4. Species Occurrence for Oregon Inlet, NC

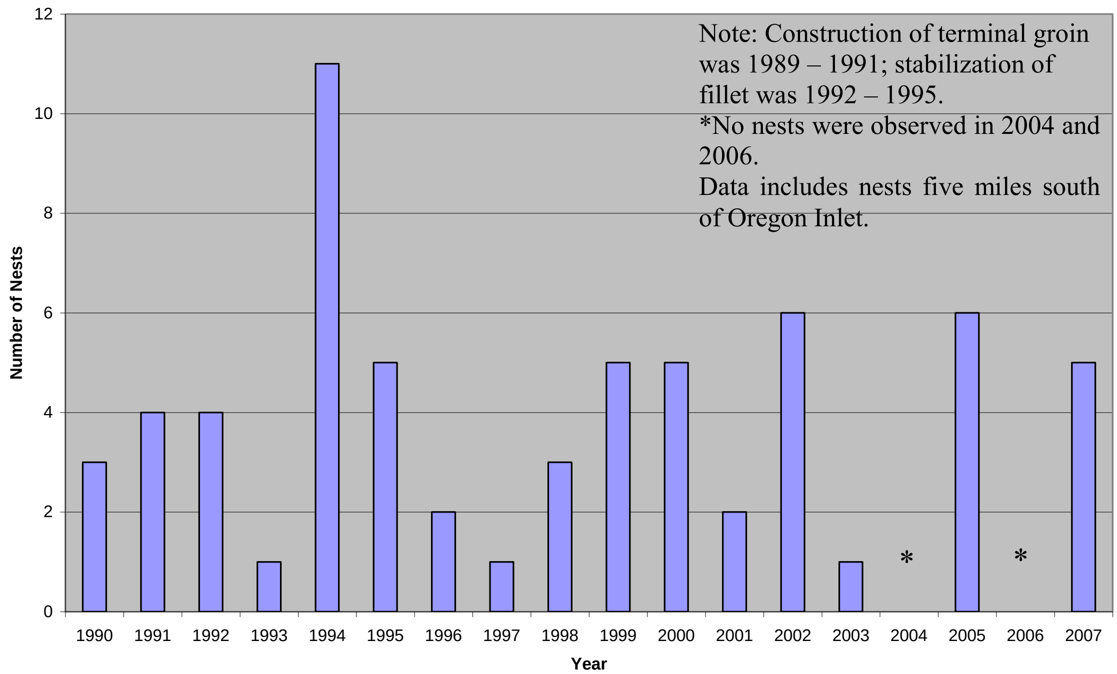


Figure III-5. Loggerhead Sea Turtle Nesting Data from PINWR

The PINWR has an average of 10 to 12 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 habitat on PINWR is subject to the effects of frequent tropical storms and regular beach renourishment projects. Since 1991, PINWR has experienced tropical storms and/or hurricanes each year with the exception of 1994, 2001, 2003, and 2005. Since 1990, beach renourishment projects have placed sand on PINWR beaches each year with the exception of 1994, 2006, and 2007. Due to the consistently low annual nesting densities and the high frequencies of both storm and renourishment events, no relationships between nesting densities and storm or renourishment events are readily apparent.

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 III-3 and Table

III-4). Oregon Inlet lies 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 III-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 III-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. Based on a study conducted by Riggs and Ames (2009), an eroding and receding beach backed by a constructed barrier dune-ridge that is fixed in space and time results in a steep beach that gets steeper with time until the dune-ridge is scarped and then breached by storms. Steep beaches are too high energy for turtle and shore bird nesting sites. Beach nourishment projects temporarily stop the recession, but do not stop the erosion and quickly return to the same unstable, steep beach profile removing that habitat as favorable nesting sites (Riggs and Ames 2009). 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 III-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 III-6 for Seagrass Habitat locations.

Figure III-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, non-breeding shorebird observational data, provided by USFWS in the form of annual narrative reports, recorded during 1950, 1960, and 1970 were compared with data collected during 2006 and 2007 (Table III-8) (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 III-7 estimates for 1950 include 500 black skimmers, 400 common terns, 1,000 least terns, and 150 red knots.

Figure III-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 (pre-1990) historical shorebird non-breeding 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 III-8 and Figure III-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. According to Riggs and Ames (2009), the Pea Island fillet is rapidly evolving which jeopardizes the overall nesting habitats for many of the species.

NCWRC has monitored shorebird nesting activity at Oregon Inlet since 1988. Nesting activity on the former Sand Shoal Island was monitored annually from 1988 through 1993 (Figure III-10). The total number of nests for all species ranged from 315 nests in 1989 to 2,242 nests in 1993. Based on the 6 years of survey data, an average of 1,193 nests were recorded annually on Sand Shoal Island. Sand Shoal Island was permanently inundated from 1994 onward; and consequently, no data for this site was collected after 1993. Shorebird nesting activity on Oregon Inlet Beach, South (Pea Island) has been monitored intermittently since 1992 (Figure III-11). Survey years include 1992, 1993, 1995, 1997, 1999, 2001, 2002, 2003, 2004, and 2007. The total number of nests for all species ranged from 9 nests in 1992 to 409 nests in 1999. Based on the 10 years of survey data, an average of 187 nests were recorded annually on the northern end of Pea Island (Oregon Inlet, South). Surveys of Oregon Inlet Shoal were conducted during 2001, 2004, and 2007 (Figure III-12). The total number of nests for all species ranged from 103 nests in 2007 to 292 nests in 2004. Based on the 3 years of survey data, an average of 195 nests were recorded annually on Oregon Inlet Shoal. Surveys of the northern end of Bodie Island (Beach Northside Oregon Inlet) were conducted during 2004 and 2007. Nesting records for this area are limited to 10 least tern nests in 2004 and 1 common tern nest in 2007.

Terns, oystercatchers, black skimmers, and piping plovers depend on natural overwash-dominated habitats that provide essential feeding habitats; however, these habitats are being converted to vegetated dune communities and marsh habitat as a result of the terminal groin preventing overwash events and the maintenance of constructed barrier dune-ridges (Personal communication, D. Stewart, USFWS, February 2010; Riggs and Ames 2009). Together the dune fields and marshes currently constitute a major portion of the fillet. This leaves a small portion of the original fillet area along the ocean shoreline that represents nesting habitat for many threatened species. However, because the ocean front is low, nesting is often terminated by flooding events (Riggs and Ames 2009).

Figure III-8. 1991 Oregon Inlet Aerial Photograph

Figure III-9. 2009 Oregon Inlet Aerial Photograph

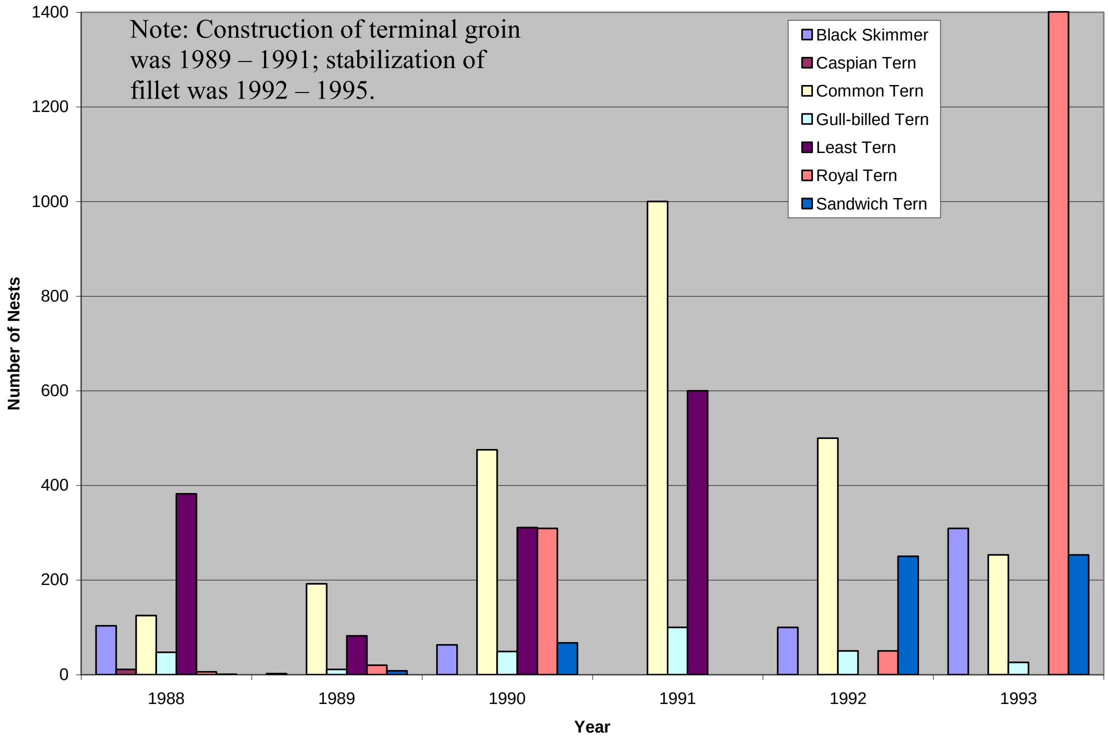


Figure III-10. Shorebird and Colonial Waterbird Nesting Activity on Sand Shoal Island, Formerly Located within the Vicinity of Oregon Inlet

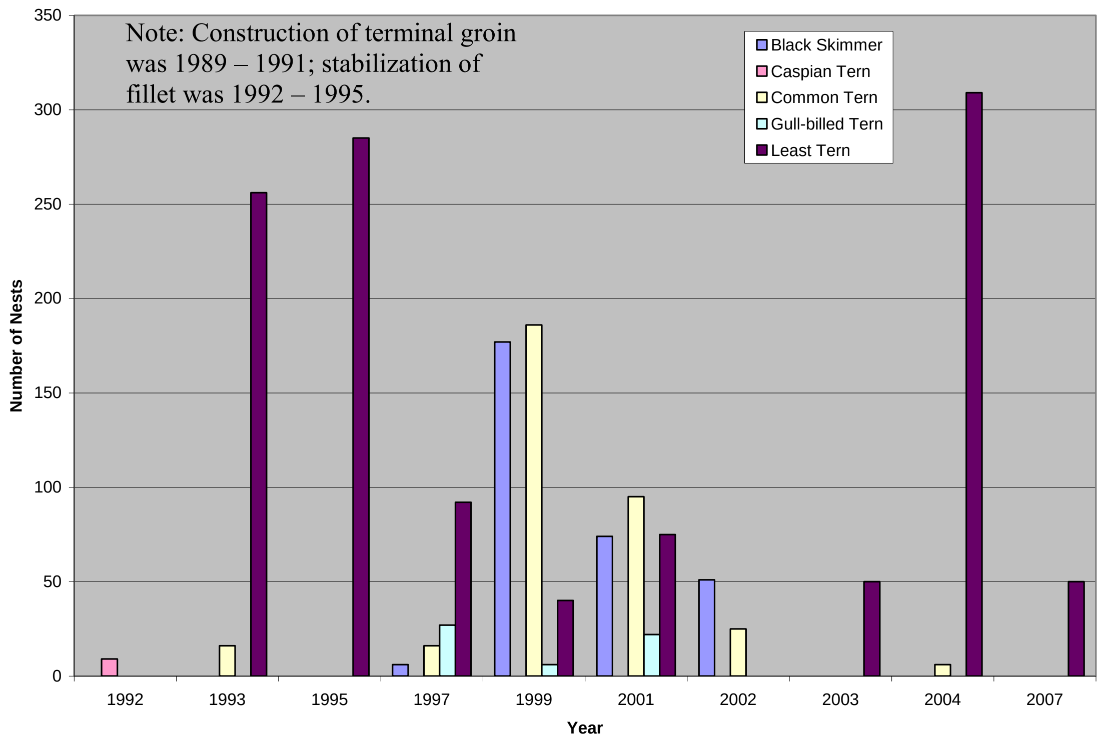


Figure III-11. Shorebird and Colonial Waterbird Nesting Activity on the Northern End of PINWR

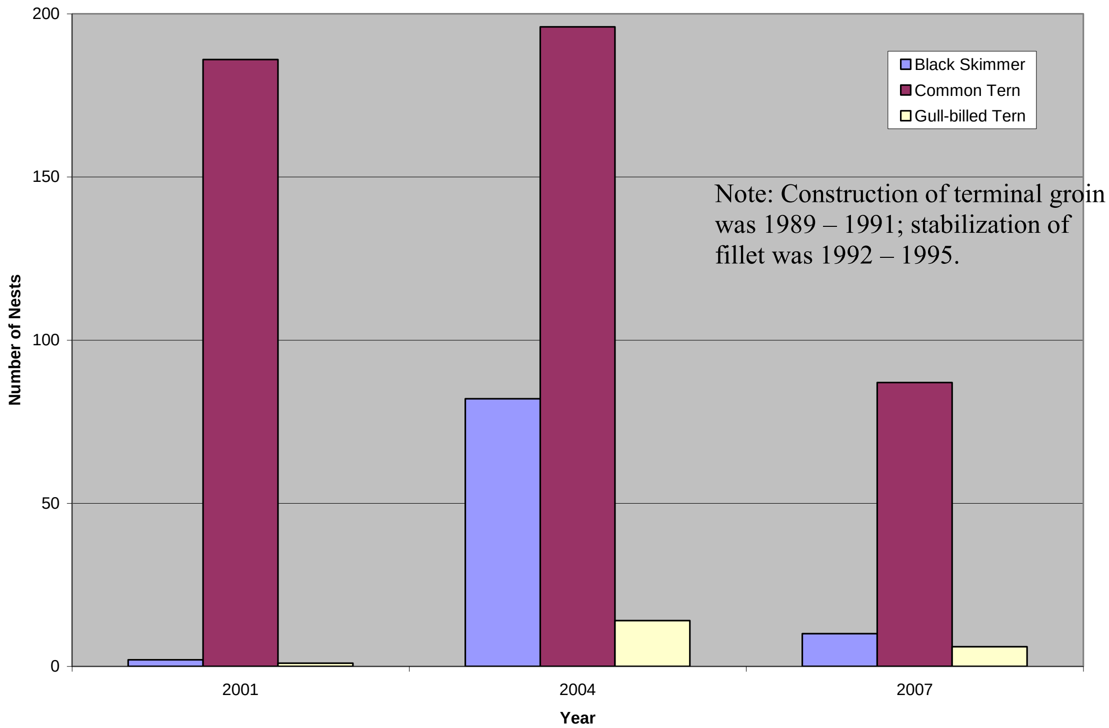


Figure III-12. Shorebird and Colonial Waterbird Nesting Activity for Oregon Inlet Shoal

Shorebird habitats on PINWR are subject to the effects of frequent tropical storms and regular beach renourishment projects. Since 1991, PINWR has experienced tropical storms and/or hurricanes each year with the exception of 1994, 2001, 2003, and 2005. Since 1990, beach renourishment projects have placed sand on PINWR beaches each year with the exception of 1994, 2006, and 2007. Due to the limited shorebird data set and the high frequencies of both storm and renourishment events, no relationships between nesting densities and storm or renourishment events are readily apparent.

Federally Threatened Species

Piping Plover

Oregon Inlet serves primarily as a wintering area for the migrating/wintering (non-breeding) 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. According to USFWS (2006b), between one and three nesting attempts have occurred annually since 1996. Over those nine years, breeding piping plovers have attempted to nest 12 times and have fledged 5 chicks (USFWS 2006b). Recent nesting attempts on Bodie Island spit have resulted in a nest in 2002, 2004, 2007, and 2008 (NPS 2009b). Annual piping plover observational data were obtained from NCWRC and USFWS for Bodie Island spit, Pea Island – northern beach, and Oregon Inlet Shoals (Figure Figure III-13 and Figure III-14).

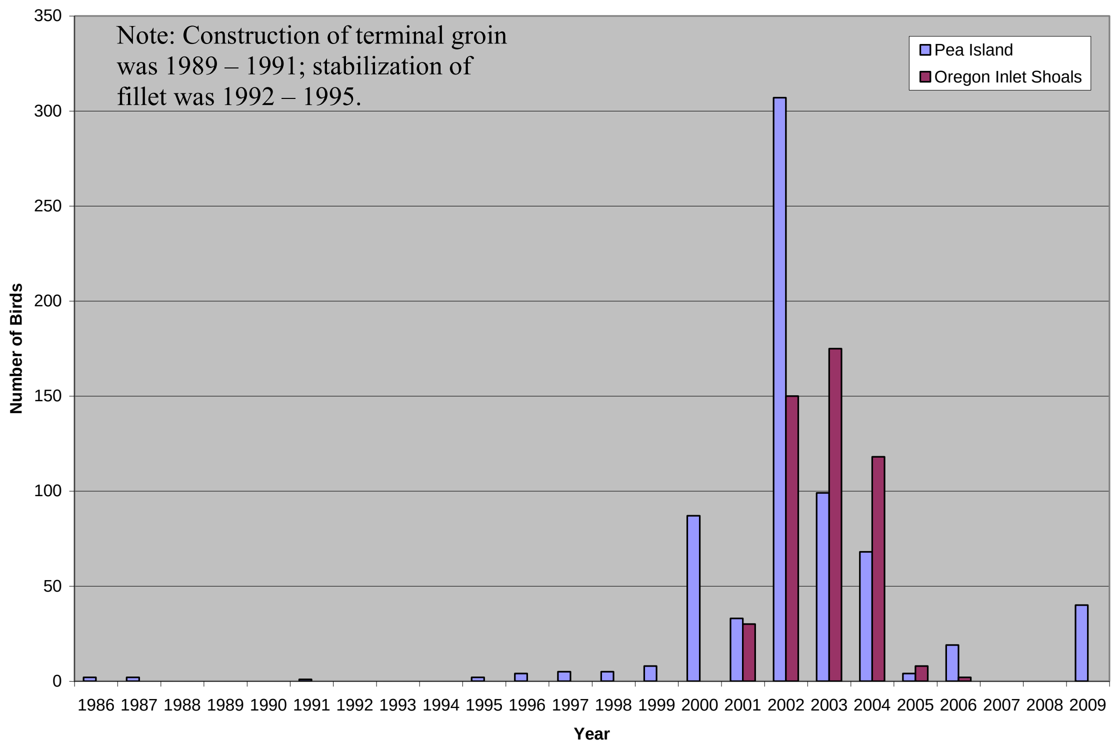


Figure III-13. Annual Piping Plover Observations in the Vicinity of Pea Island

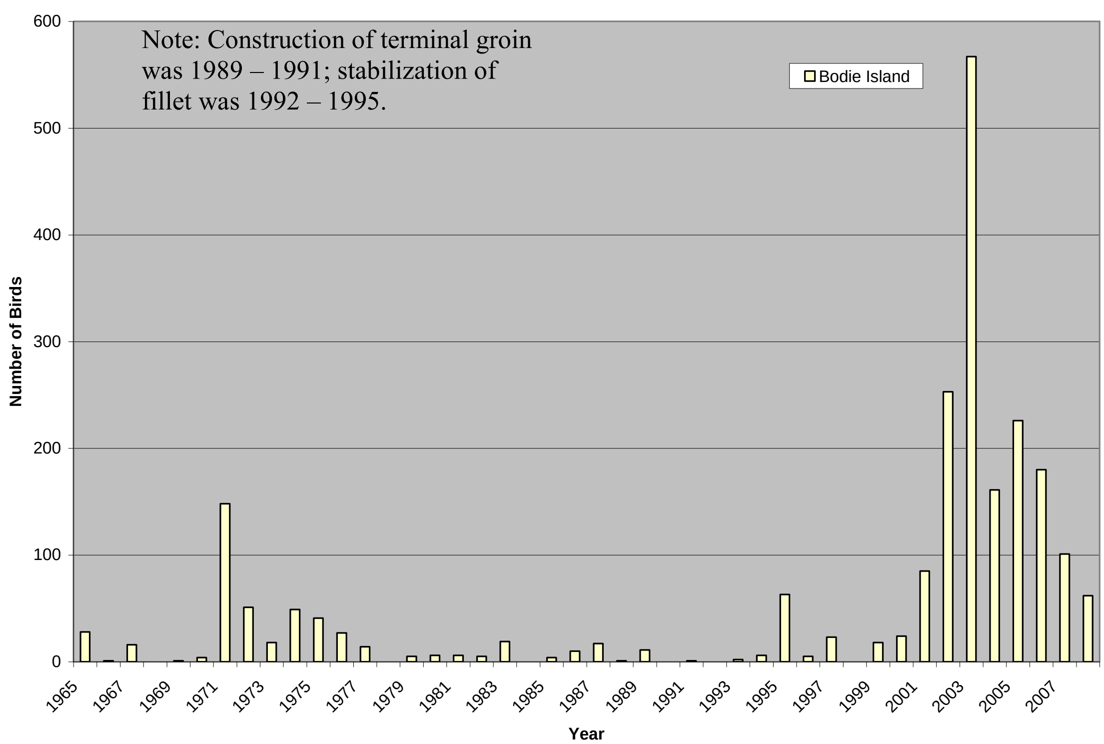


Figure III-14. Annual Piping Plover Observations in the Vicinity of Bodie Island Spit

Prior to 2001, annual piping plover observations on Bodie Island spit (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 spit. 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 spit steadily declined, reaching a low of 62 individuals in 2008.

Pea Island piping plover records from NCWRC date to 1986. Prior to 2000, annual piping plover observations on the northern end of 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. 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).

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. 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 III-8 and Figure III-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). 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 III-13). However, in more recent years the presence of the terminal groin, as well as other actions such as dredging and nourishment, has adversely modified habitat important to piping plovers by eliminating intertidal flats and allowing encroachment of vegetation in stabilized areas, and generally impeding inlet dynamics that create and maintain habitats piping plovers require.

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 III-8 and Figure III-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 in the mid-1990's due to the dynamic nature of Oregon Inlet and USACE dredging practices (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 less than 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 III-8) and after (2009, Figure III-9), the loss of vegetation habitat is evident; however, the additional dune and sand created flats may provide plover and other shorebirds supplemental habitat. Piping plover habitat on PINWR is subject to the effects of frequent tropical storms and regular beach renourishment projects. Since 1991, PINWR has experienced tropical storms and/or hurricanes each year with the exception of 1994, 2001, 2003, and 2005. Since 1990, beach renourishment projects have placed sand on PINWR beaches each year with the exception of 1994, 2006, and 2007. Due to the high frequencies of storm and renourishment events and the lack of information regarding specific effects of individual storms/renourishment events on piping plover habitat, no relationships between piping plover observations and storm or renourishment events are readily apparent.

(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.

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). 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). The Physical Assessment for Oregon Inlet discusses sediment placed from 1990 and 2002 as finer-grained and containing greater quantities of heavy minerals than the native sand. This variation in sand gradation can affect benthic resources and thereby affect upper trophic levels.

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).

According to the USACE (2001) 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.

c) Summary of Findings

The following summary is a result of extensive scientific literature review and preliminary evaluation of pre-existing biological data. CAHA along with the PINWR is home to many of the federally protected species that depend upon inlet shoreline habitat. As described by USFWS (2008); Oregon Inlet dredging, the Bonner Bridge, NC Highway 12 maintenance and protection, and the presence of the terminal groin have influenced the loss of oceanfront and inlet habitat by subduing and altering natural processes such as overwash.

The pre-construction (pre-1990) historical bird data suggests the immediate groin location was not highly used. Following construction of the terminal groin, a large sandflat developed behind the groin where shorebirds and colonial waterbirds nested (and still nest to some extent). 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 retaining heavy vegetation. According to Riggs and Ames (2009), the Pea Island fillet is rapidly evolving which jeopardizes the overall nesting habitats for many bird species.

Oregon Inlet serves primarily as a wintering area for the migrating/wintering (non-breeding) 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. Fluctuations in annual observations at 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. The presence of the terminal groin, as well as other actions such as dredging and nourishment, has adversely modified habitat important to piping plovers by eliminating intertidal flats and allowing encroachment of vegetation in stabilized areas, and generally impeding inlet dynamics that create and maintain habitats piping plovers require.

In terms of sea turtles, the PINWR has an average of 10 to 12 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. Based on a preliminary evaluation of nesting intervals per section on PINWR compared to Bodie Island, it is apparent that sea turtle nesting habitat is more readily available on PINWR versus Bodie Island. Due to the consistently low annual nesting densities and the high frequencies of both storm and renourishment events, no relationships between nesting densities and storm or renourishment events are readily apparent.

Monitoring results showed mole crab and coquina numbers were significantly reduced following shoreline placement of Oregon Inlet maintenance dredged material and that the underlying effects on the infaunal communities within a terminal groin fillet is directly related to the fill material size, the volume of material placed, and the seasonal material placement. There is also very limited information on the invertebrate communities at inlets and how inlet stabilization impacts these communities. Although there are conflicting opinions on the magnitude of impact, there is valid concern that construction of groin structures would prevent some portion of ocean-spawned larvae from reaching estuarine nursery areas (USACE 1999a).

2. Fort Macon, Beaufort Inlet, North Carolina

a) General Site Description

Beaufort Inlet is one of the most managed inlets in North Carolina (Figure III-15). When discussing environmental resources and potential effects, the number of ongoing projects in this area should to be considered. As shown in Figure III-16, 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 III-15. Beaufort Inlet

Figure III-16. Hard Structure Located on Western End of Shackelford Banks
Source: Cape Lookout National Seashore, Michael Rikard

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).

(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. Shackleford Banks forms the southernmost portion of Cape Lookout National Seashore (CALO), administered by the National Park Service (NPS), and has been designated a Wilderness Area. CALO contains nationally significant natural and cultural resources and values that play a vital role in the state's ecosystem and local economies. Many of the federally protected species that depend upon inlet shoreline habitat utilize habitat within the CALO (NPS 2009).

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). 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 CALO. Figure III-17 depicts the numerous coastal resources present within the vicinity of Beaufort Inlet and the Fort Macon terminal groin.

Figure III-17. Coastal Classification of Habitat for Beaufort Inlet, NC

(1) Seabeach Amaranth

Seabeach amaranth on Fort Macon/Atlantic Beach has been monitored since 1991 (Figure III-18). 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.

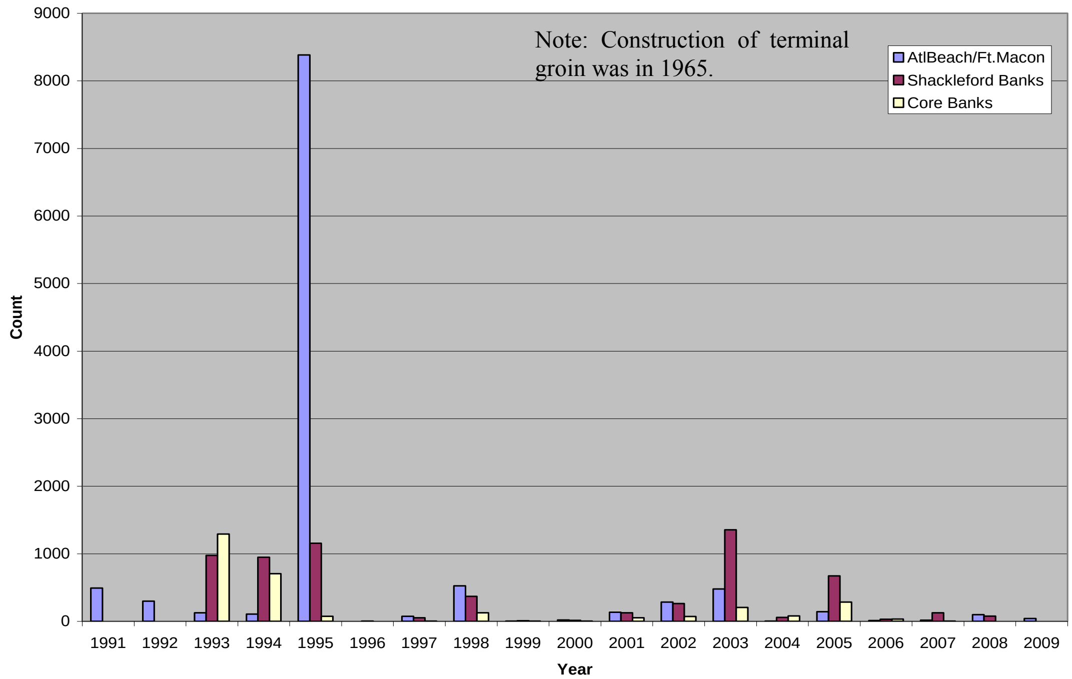


Figure III-18. Seabeach Amaranth Plants for the Beaufort Inlet Area

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 has 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 III-18, 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 while there was then a sharp decline in 1999, 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.

As seen by the data shown in Figure III-18, 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). Seabeach amaranth habitat on Fort Macon and CALO is subject to the effects of frequent tropical storms. Since 1991, Fort Macon and CALO have experienced tropical storms and/or hurricanes each year with the exception of 1994, 2001, 2003, and 2005. Due to the high frequency of storm events and the lack of information regarding specific effects of individual storms on seabeach amaranth habitat, no relationship between seabeach amaranth numbers and storm events is readily apparent. Seabeach amaranth habitat on Fort Macon is also subject to the effects of periodic beach renourishment projects. Since 1991, Fort Macon beaches have been nourished four times. Seabeach amaranth numbers increased following renourishment projects in 2002 and 2007, whereas numbers decreased following renourishment projects in 1993 and 2004. Based on these data, no consistent relationship between seabeach amaranth numbers and renourishment projects is readily apparent.

(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 III-19, 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 III-19. 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 III-20). 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.

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 III-21). 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 III-21). 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.

Figure III-20. Species Occurrence for Beaufort Inlet, NC

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 III-21, 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.

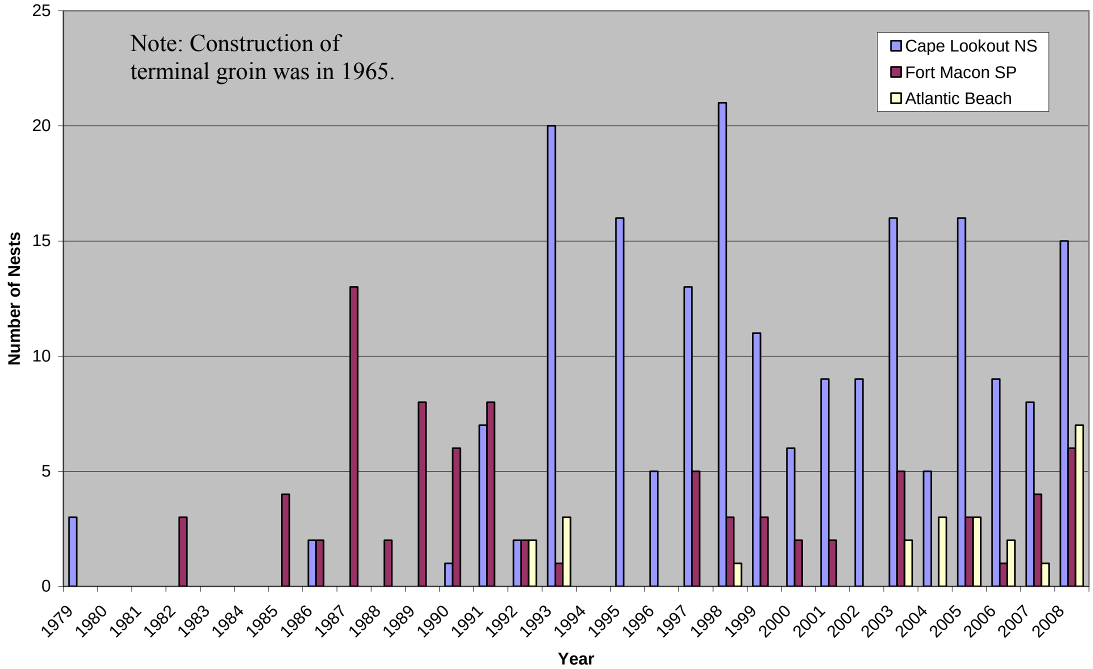


Figure III-21. Sea Turtle Nesting Activity for the Beaufort Inlet Area

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 presence 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).

Sea turtle nesting habitat on Fort Macon and CALO is subject to the effects of frequent tropical storms. Since 1991, Fort Macon and CALO have experienced tropical storms and/or hurricanes each year with the exception of 1994, 2001, 2003, and 2005. Due to the high frequency of storm events and the lack of information regarding specific effects of individual storms on sea turtle nesting habitat, no relationship between nesting densities and storm events is readily apparent. Sea turtle nesting habitat on Fort Macon is also subject to the effects of periodic beach renourishment projects. Since 1973, Fort Macon beaches have been nourished seven times. Sea turtle nesting densities increased following renourishment projects in 1986, 2002, 2004, and 2007; whereas nesting density decreased following renourishment in 1993. These data indicate that renourishment may have a positive effect on sea turtle nesting.

(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 III-22). 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 III-22); 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 (USFWS 2002). Most commonly during the summer, the Fort Macon State Park area 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). 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, western sandpiper, semipalmated sandpiper, sanderling, piping plover, black-bellied plover, and Wilson's plover.

Figure III-22. 1998 Aerial Photograph of Beaufort Inlet, NC

Wilson's plover nesting surveys were conducted by Park Service personnel on CALO from 2006 through 2009 (Figure III-23). 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. However, given the lack of long-term data and the unavailability of data specifically for western Shackelford Banks, no discernible trends can be concluded.

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 III-24). 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. Common terns, gull-billed terns, and black skimmers are formerly known to have nested at Shackelford Point; however, they have not been observed nesting there for several years (Personal communication, J. Fussell, bird expert and author, February 2010). It is believed that the decline in nesting birds at Shackelford Point is likely associated with the degradation of habitat related to the fact that the inlet shorelines have been relatively stable for decades.

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 causes vegetation 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 III-25). 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. It is significant to note that some years, Wilson's plovers were absent along the ocean and inlet beach of Fort Macon State Park (Personal communication, J. Fussell, bird expert and author, February 2010).

Shorebird habitats on Fort Macon and CALO are subject to the effects of frequent tropical storms. Since 1991, Fort Macon and CALO have experienced tropical storms and/or hurricanes each year with the exception of 1994, 2001, 2003, and 2005. Due to the high frequency of storm events and the lack of information regarding specific effects of individual storms on shorebird habitats, no relationship between shorebird numbers and storm events is readily apparent. Shorebird habitat on Fort Macon is also subject to the effects of periodic beach renourishment projects. Since 1973, Fort Macon beaches have been nourished seven times. Least tern and Wilson's plover observations at Fort Macon increased following renourishment projects in 2002, 2004, and 2007. These data indicate that renourishment may a have a positive effect on habitat utilization by these species.

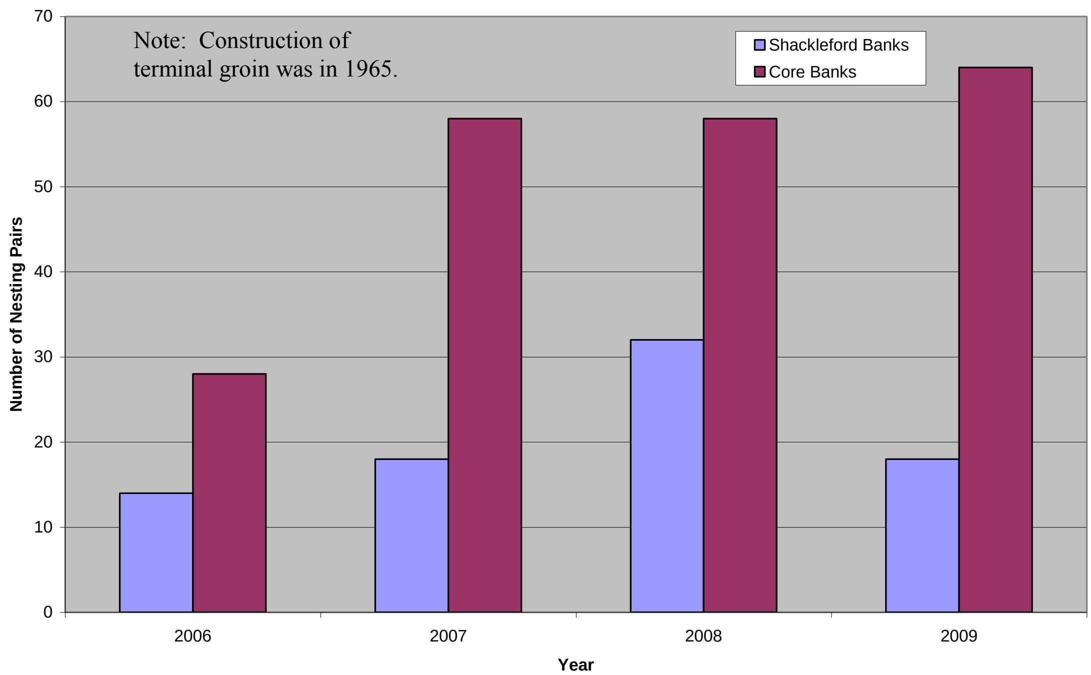


Figure III-23. Wilson's Plover Nesting Survey Data (CALO)

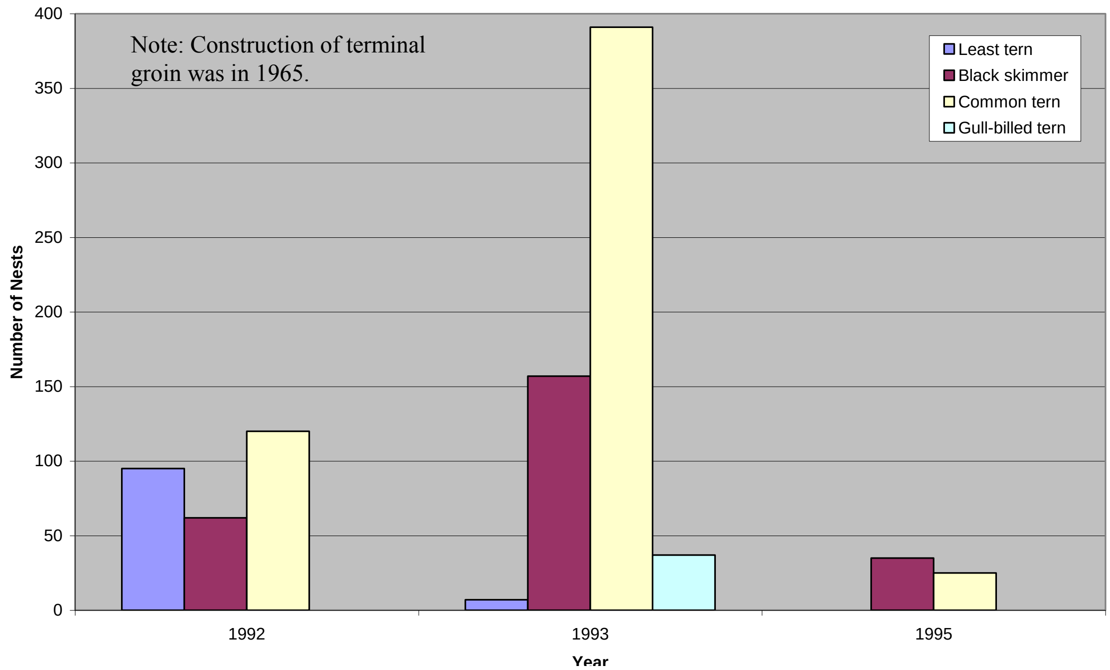


Figure III-24. Nesting Surveys for the Least Tern, Black Skimmer, Common Tern, and Gull-Billed Tern (Shackleford Point)

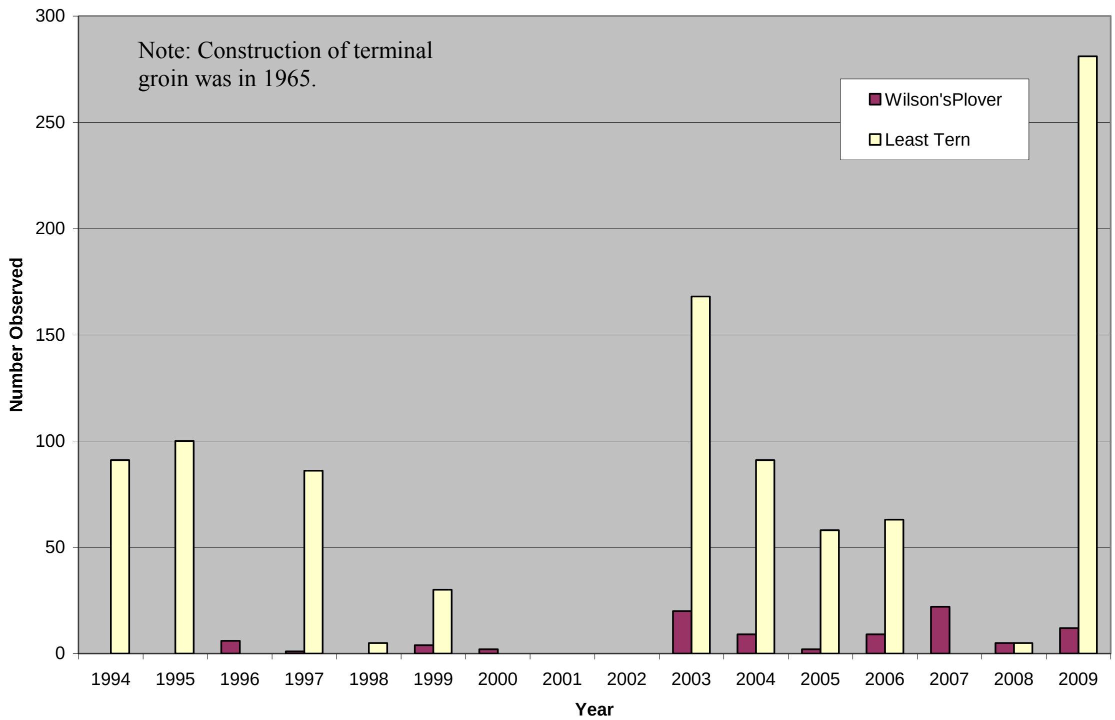


Figure III-25. Annual Least Tern and Wilson's Plover Observations (Fort Macon State Park)

Federally Threatened Species

Piping Plover

Annual piping plover data were obtained from NCWRC for Shackleford Banks West, Fort Macon, and North/South Core Banks (Figure III-26 and Figure III-27). 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. It is significant to note that the individuals in 1970 and 1980 represent breeding records. 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.

In order to compare to a regionally local control site, piping plover records for North and South Core Banks were evaluated from 1983 (Figure III-27). 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.

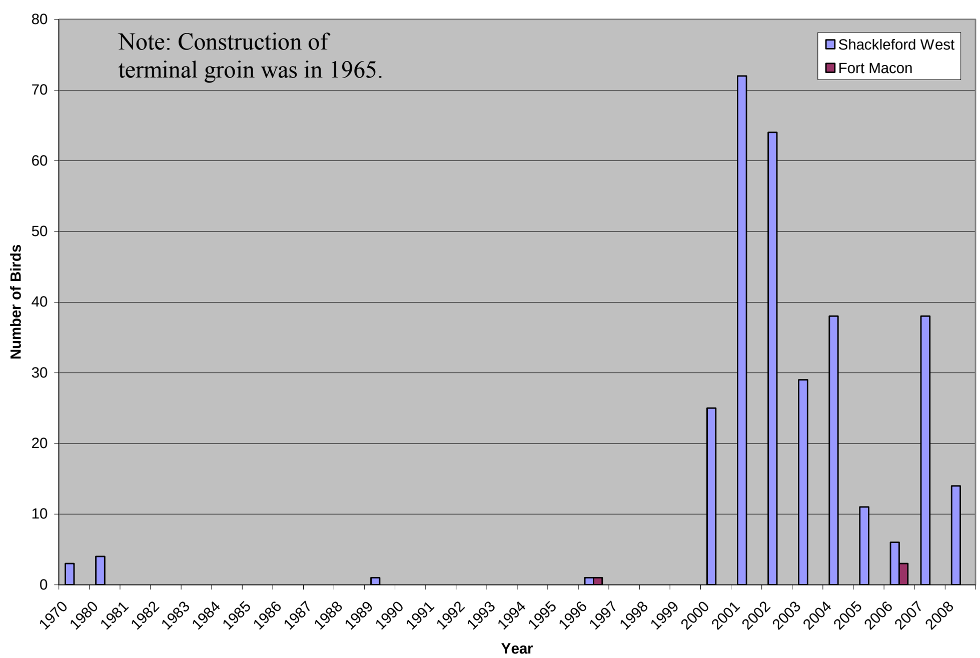


Figure III-26. Annual Piping Plover Observations for Fort Macon and Shackleford Banks, NC

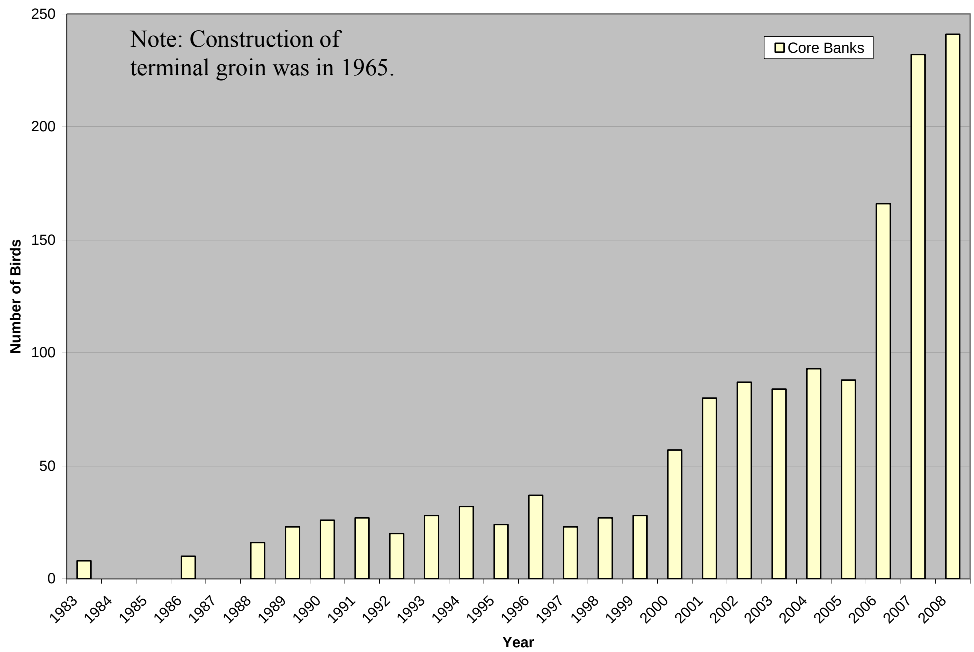


Figure III-27. Annual Piping Plover Observations for Core Banks, NC

The apparent increase in Figure III-26 is in sharp contrast to Christmas Bird Count data which show a significant decline in the numbers of piping plovers using the Beaufort Inlet system from the 1970's until the present (Personal communication, J. Fussell, bird expert and author, February 2010). The Morehead City Christmas Bird Count circle includes all of the Rachel Carson Reserve, the westernmost two miles of Shackleford Banks, and the easternmost seven miles of Bogue Banks. Thus, it includes all of the major piping plover habitat associated with Beaufort Inlet (i.e. the flats at the western end of Shackleford Banks and the flats within the Rachel Carson Reserve), as well as the shorelines of Fort Macon State Park, which are occasionally visited by the piping plovers from Rachel Carson Preserve/Shackleford Banks. Christmas Bird Count data are not typically obtained by any rigorous scientific methodologies, and the results from year to year certainly vary due to the level of coverage as well as the weather conditions, which can vary considerably from year to year at this season.

Table III-5. Piping plover counts--results of Morehead City Audubon Christmas Bird Count, for 1971 through 2008

1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
70	22	20	**81**	**54**	25	**57**	20	32	**64**	**54**	7	**40**

1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
35	24	1	25	17	9	7	8	6	7	13	12	9

1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
18	16	11	1	1	18	5	25	8	11	NC	19

Source: John Fussell, compiler for Morehead City Christmas Count from 1971 to present.
NC = Because of severe weather, no count was held in 2007.
All counts of 35 birds or greater are boldfaced and underlined.

The below discussion has been provided by John Fussell, the Morehead City Christmas Bird Count coordinator and compiler since 1971, regarding the results of Table III-5:

- In most cases, the lowest annual counts are due largely to severe weather or other factors that inhibited the level of coverage. In general, it might be best to make conclusions about trends after dropping the two lowest counts for each five-year period;
- The Fort Macon area was covered on all counts;
- The Rachel Carson Reserve was covered every year except 1986 when boat transportation to the Reserve became unavailable. On most years, the coverage of this area was good to very good (this area always gets priority coverage on counts, because it harbors large numbers of shorebirds);
- For most of the years prior to 1984, Shackleford Banks was not covered on the count. For the majority of years from 1984 on, Shackleford Banks has been covered on the count. Coverage of Shackleford Banks has generally been better during the more recent years; and
- Thus, for the count overall it can be inferred that coverage has generally been better during recent years and was less thorough during the earlier years, especially prior to 1984.

The general results of piping plover observations can be summarized as:

- Throughout the count's history, the Rachel Carson area has been a very important piping plover wintering area. Every year that Rachel Carson was covered on the count, piping plovers were found there, and more have always been found there than at other locations within the count circle except for two years;

- Although the western end of Shackleford Banks is also a major wintering site for piping plovers, they are not found there as reliably as at Rachel Carson. However, since 1984 piping plovers have been identified there on more than half of the counts; and
- During the 37 years that the count has been conducted, piping plovers have been found on the beaches of Fort Macon State Park on five occasions. The largest counts were in 1974 and 1975, when 11 and 29 plovers were observed. The last piping plover observed at Fort Macon on the Christmas Bird Count was one in 1989.

Population trends of piping plovers in the Beaufort Inlet area based on these Christmas count data include the following:

- The series of single-digit counts from 1989 through 1993 represents a true population low. Survey coverage was good on all these counts. This period may correspond, at least to some extent, to an overall population low of the species (i.e. prior to recent intensive measures to restore the population beginning to take effect). However, it is probably likely that this series of low counts is at least equally related to the severe snowstorm/wind of 23-24 December 1989 (and subsequent severe cold). This weather event was observed to cause marked mortality of water birds along the North Carolina coast, especially of shorebirds. Because shorebirds often return to the same wintering site each year, a loss of piping plovers at a site one year could result in a lower wintering population for a number of subsequent years;
- The overall pattern from 1971 until present is of a population high in the 1970's followed by a decline until about the early 1990's, followed by some degree of population recovery from about the mid-1990's until the present. The period of recovery of the Beaufort Inlet winter population is certainly related to some degree to the increase of the overall population increase of the species in recent years, an increase related to intensive recovery efforts, particularly of breeding areas on public lands; and
- However, it would seem to be the case that the overall population of the species in the Beaufort Inlet area should now be similar to what it was in the 1970's. Thus, it is probably the case that the decline (from the 1970's to the present) in the population of wintering piping plovers at Beaufort Inlet is due in part to factors within the immediate Beaufort Inlet area.

Some possible reasons for the long-term decline in the number of wintering piping plovers in the Beaufort Inlet system are:

- Based on aerial photography, it appears that there has been a loss in the extent of suitable habitat within the Beaufort Inlet system (comparing aerial photography from the l960's through 1980 as compared to aerial photography from the period after 1980). This loss of habitat is certainly related to the fact that the shorelines of the inlet are now largely "anchored" in place, largely the result of the fact that the channel location is stabilized to a major degree.

- The shorelines of the inlet at Fort Macon State Park, which have moved little from year to year, have never been very good habitat for piping plovers.
- Based on aerial photography, there appears to have been a loss of intertidal feeding habitat for piping plovers at both Shackleford Banks and Rachel Carson from the 1970's until the present. At Shackleford Banks, much of this loss has been due to plant succession. At Rachel Carson, much intertidal habitat has been lost as the outer beach of Bird Shoal has migrated inland (northward). This has resulted in formerly suitable habitat being replaced with subtidal habitat, and other areas of formerly suitable habitat building in elevation such that they are no longer intertidal, or are flooded only during the highest tides.
- Based on aerial photography, there has been loss and degradation of prime roosting/loafing habitat for piping plovers in the Beaufort Inlet system. On Shackleford Banks, plant succession and dune development have caused declines in roosting habitat, i.e. expansive above-tidal flats (and with shorelines being relatively stable since 1980, there has been little to no re-creation of such habitat). At Rachel Carson, there have also been declines in such habitat. The long barrier spit (that forms the outer beach of Bird Shoal) has migrated inland, such that it is not insulated during high tides to the degree it once was. Further, much of this strip has built up into vegetated dunes. At both Shackleford Banks and Rachel Carson, there is still some good roosting habitat, but less of it than formerly, and the fact that there is less makes it harder for birds to find alternative roosting sites when subjected to human disturbance at particular sites.
- There is more human disturbance at both Rachel Carson and Shackleford Banks nowadays as compared to the 1970's. Further, the decreased extent of suitable roosting sites makes human disturbance more of a problem than it would be otherwise; and
- It is likely that human disturbance has its greatest impact on the wintering population from about late July to Labor Day, when most wintering birds are arriving. It is likely that at this time of the year disturbance and lack of roosting sites causes some birds that might otherwise overwinter here to abandon the area and continue migrating further southward.

As indicated above, piping plover habitats on Fort Macon and CALO are subject to the effects of frequent tropical storms and periodic beach renourishment projects. Since 1991, Fort Macon and CALO have experienced tropical storms and/or hurricanes each year with the exception of 1994, 2001, 2003, and 2005. Due to the high frequency of storm events and the lack of information regarding specific effects of individual storms on piping plover habitats, no relationship between piping plover observations and storm events is readily apparent. Piping plover habitat on Fort Macon is also subject to the effects of periodic beach renourishment projects. Since 1973, Fort Macon beaches have been nourished seven times. Due to the low number of piping plover observations on Fort Macon, and considering the higher number of piping plovers observed on Shackelford Banks West, it can be concluded that appropriate habitat for piping plovers does not exist on Fort Macon due to multiple factors including beach nourishment and maintenance, the stabilization of the inlet shoreline by the terminal groin, and ongoing maintenance dredging in Beaufort Inlet which disrupts the formation of intertidal shoals, preferred foraging habitat for piping plovers.

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. 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 III-6 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 III-6. 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) however, based on Physical Assessment Section, terminal groins continue to allow sand to bypass into the adjacent tidal inlet and therefore bypasses larvae into the estuary. 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 and potentially obstructing 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 polychaetous 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). 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 III-28). 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.

Preliminary results indicate no hardbottom resources are present within the investigation areas shown in Figure III-28 (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.

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.

c) Summary of Findings

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. Beaufort Inlet's tidal dynamics and dredging maintenance processes are the chief factors affecting the sedimentation patterns and sand distribution in and out of Beaufort Inlet.

Seabeach amaranth has experienced 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. Since 1991, Fort Macon beaches have been nourished four times. Seabeach amaranth numbers increased following renourishment projects in 2002 and 2007, whereas numbers decreased following renourishment projects in 1993 and 2004. Based on these data, no consistent relationship between seabeach amaranth numbers and renourishment projects is readily apparent.

Since 1973, Fort Macon beaches have been nourished seven times. Sea turtle nesting densities increased following renourishment projects in 1986, 2002, 2004, and 2007; whereas nesting density decreased following renourishment in 1993. These data indicate that renourishment may have a positive effect on sea turtle nesting. 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.

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). 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 vegetation growth that results in unsuitable habitat and not having historical pre-construction bird surveys makes it difficult to conclusively say whether suitable habitat existed prior to terminal groin construction or if the terminal groin may have caused the loss of suitable habitat. Shorebird habitat on Fort Macon is also subject to the effects of periodic beach renourishment projects. Since 1973, Fort Macon beaches have been nourished seven times. Least tern and Wilson's plover observations at Fort Macon increased following renourishment projects in 2002, 2004, and 2007. These data indicate that renourishment may a have a positive effect on habitat utilization by these species.

Figure III-28. Location of Hardbottom and Cultural Resource Surveys Offshore of Beaufort Inlet, Source USACE 2007

Piping plover habitat on Fort Macon is also subject to the effects of periodic beach renourishment projects. Due to the low number of piping plover observations on Fort Macon, no conclusions can be drawn regarding the effects of renourishment on piping plovers. However, considering the higher number of piping plovers observed on Shackelford Banks West, it can be concluded that appropriate habitat for piping plovers does not exist on Fort Macon.

The native 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 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. The cumulative modifications in Beaufort Inlet results in a temporary reduction and slow recovery of the abundance and diversity of benthic invertebrates (SAFMC 1998).

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. 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) however; terminal groins continue to allow sand to bypass into the adjacent tidal inlet and therefore are likely bypassing larvae into the estuary.

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. Preliminary results indicate no hardbottom resources are present within the investigation areas and the sources and exact locations of potential cultural findings 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 III-29).

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.

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).

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.

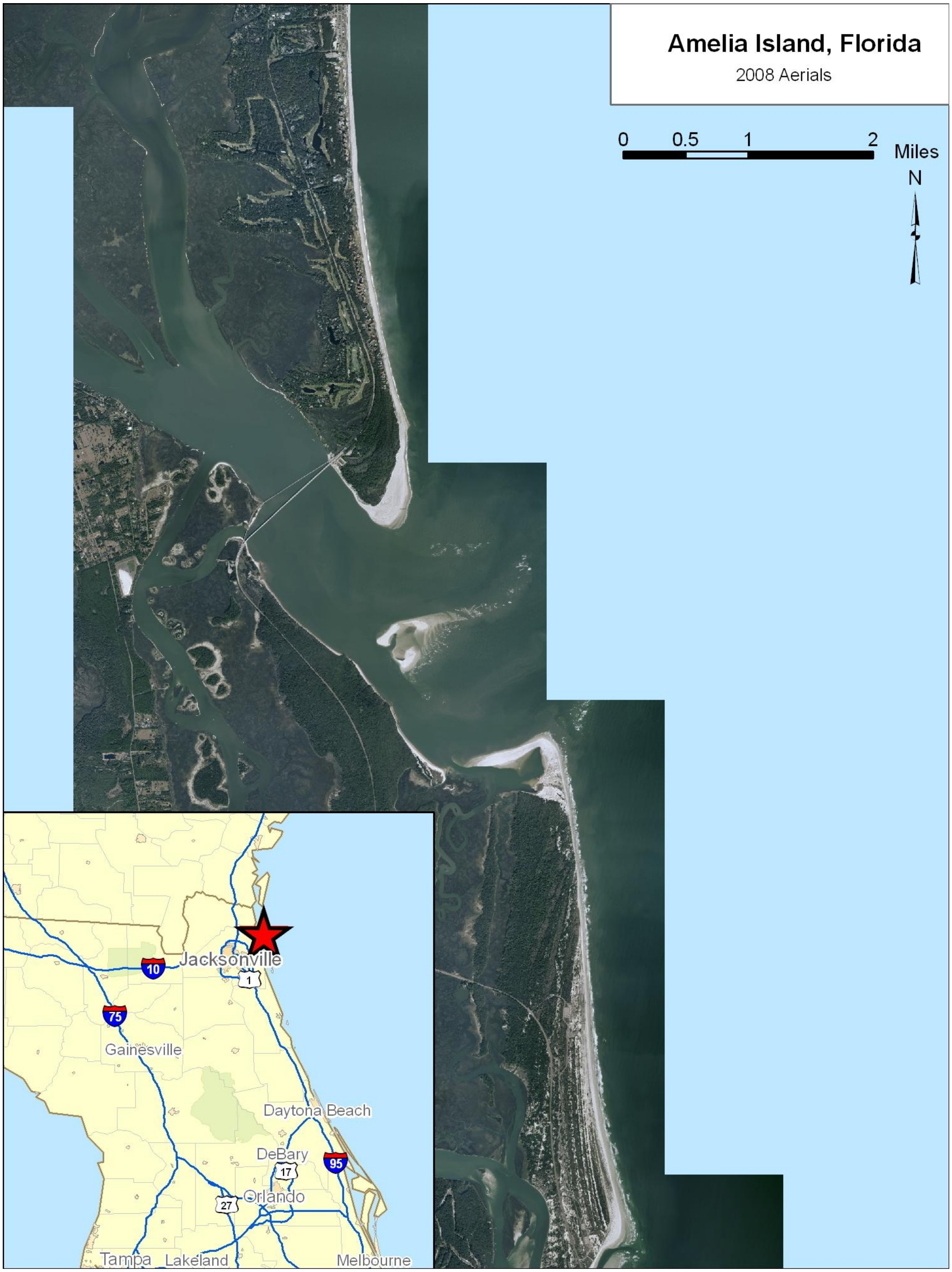


Figure III-29. Amelia Island, Florida

(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.

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 III-30). The Physical Assessment Section describes the partially permeable and low groin structures that 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.

(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 III-30). An additional community, the nearshore open sand/benthic habitat, is described under 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 accretionary, 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).

(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.

The loggerhead sea turtle is the most common sea turtle nesting on Amelia Island (Figure III-31). 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).

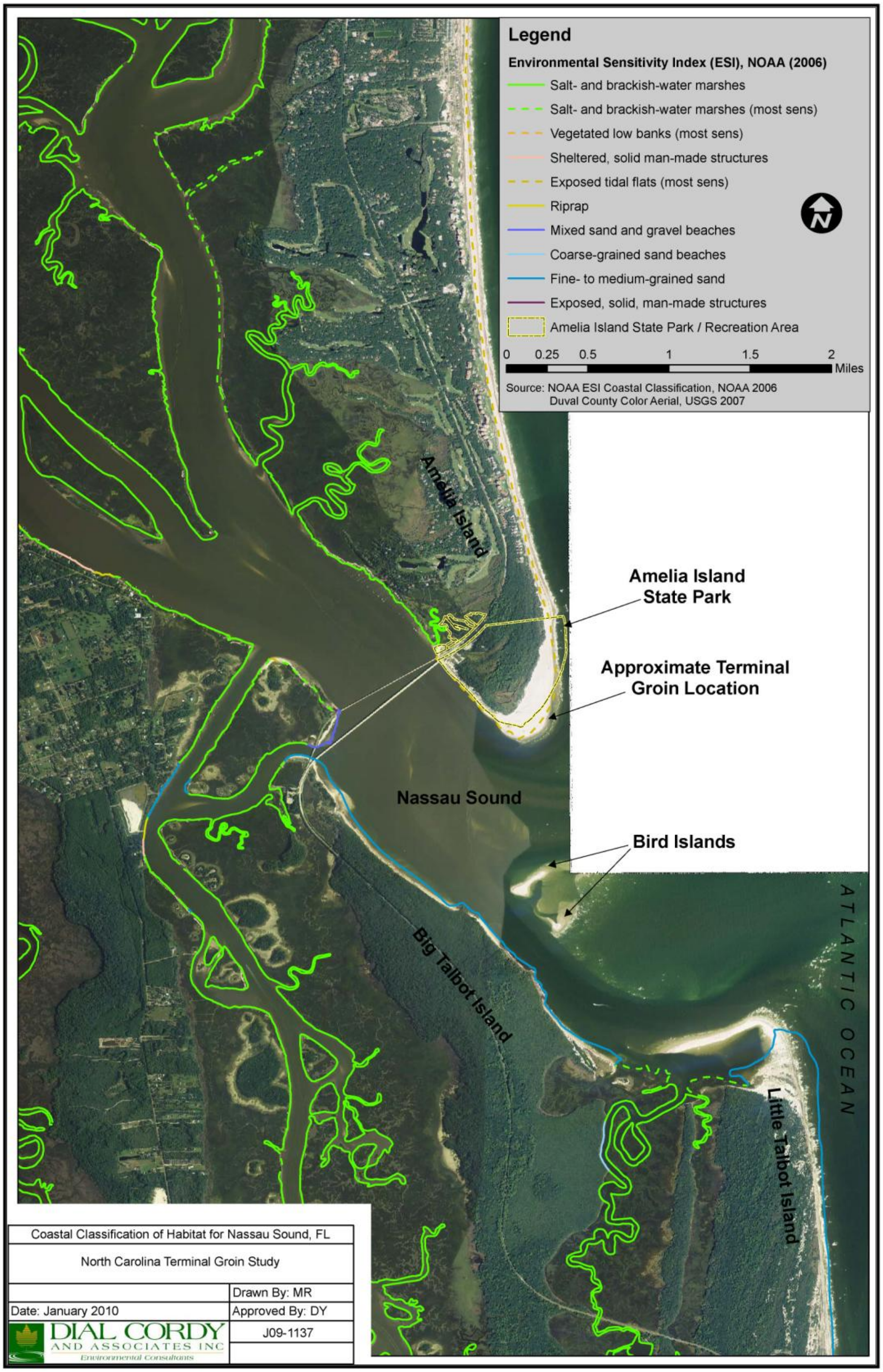


Figure III-30. Coastal Classification of Habitat for Nassau Sound, FL

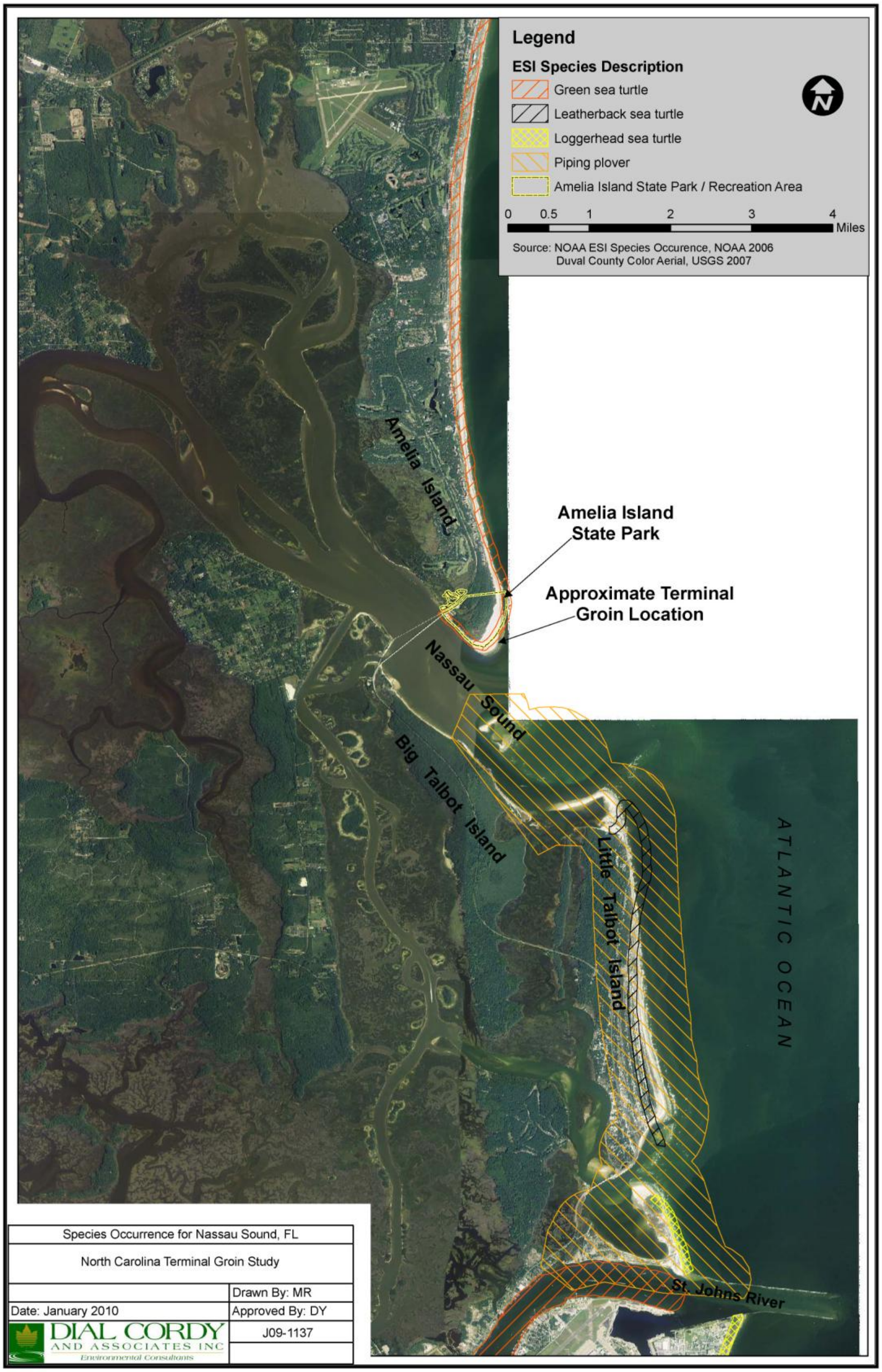


Figure III-31. Species Occurrence for Nassau Sound, FL

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 III-32). 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 III-32). 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 III-32). 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).

Sea turtle nesting habitat on Amelia Island is subject to the effects of tropical storms. Sea turtle nesting densities on Amelia Island declined following storm events in 1988, 1996, and 2000; whereas nesting densities increased following storm events in 2002 and 2004. Based on these data, there does not appear to be a consistent relationship between Amelia Island nesting densities and storm events. Due to the limited data set for Little Talbot State Park and AISP (2004 – 2008), conclusions regarding the effects of tropical storms on nesting at these sites are not possible. Sea turtle habitats on Amelia Island are also subject to the effects of periodic beach renourishment projects. Amelia Island beaches were nourished nine times between 1986 and 2005. Sea turtle nesting densities declined following renourishment in 1988, 1991, 1994, and 2001; whereas nesting densities increased following renourishment in 1987, 1989, 1993, 1997, and 2002. Based on these data, there does not appear to be a consistent relationship between Amelia Island nesting densities and renourishment events.

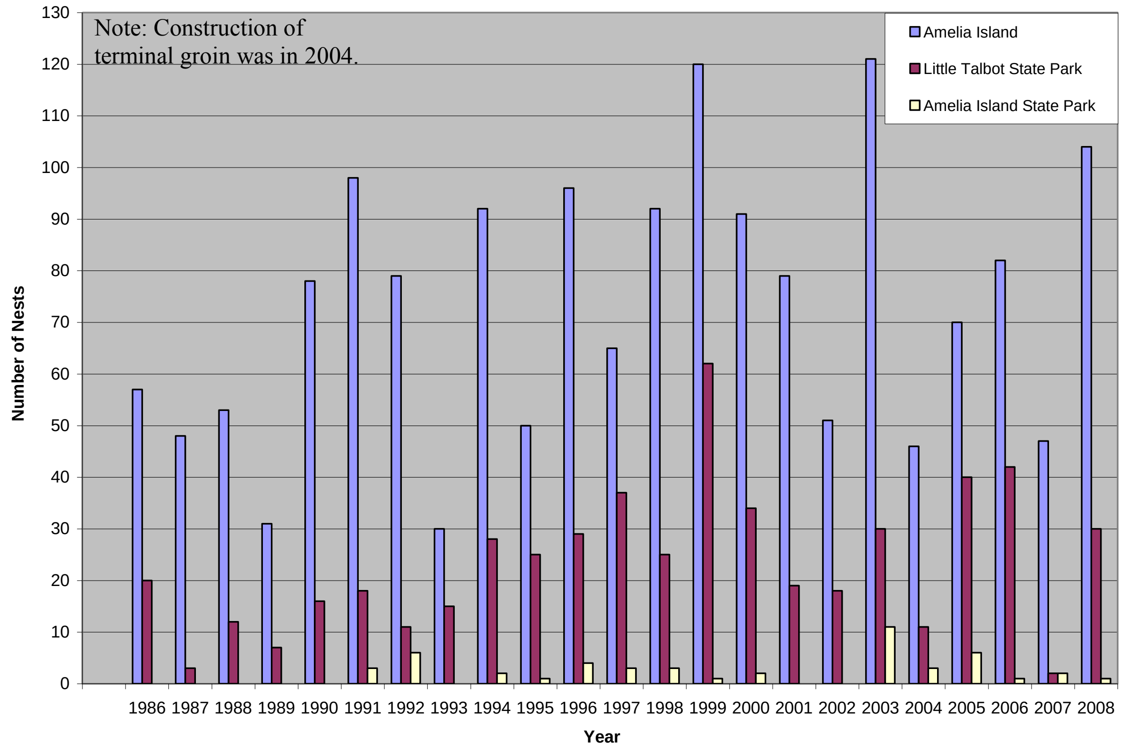


Figure III-32. Sea Turtle Nesting Data from Amelia Island and Little Talbot State Park

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 (1999) and EAI (1999) 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 III-7). 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.

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.

Table III-7. 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

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 III-33). 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 III-34). 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.

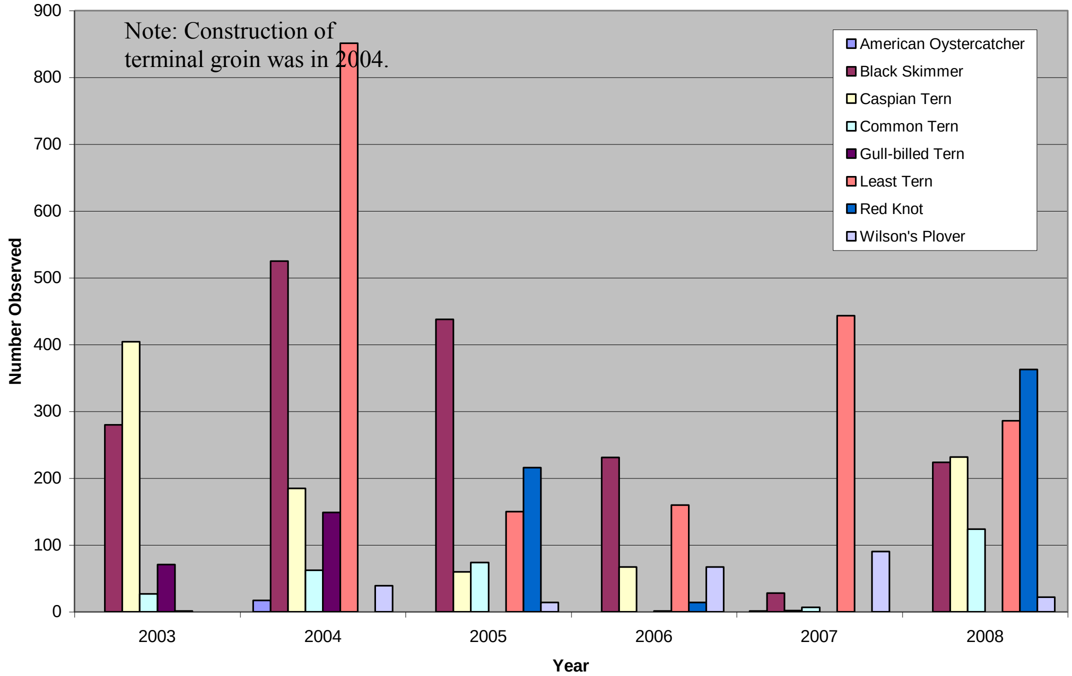


Figure III-33. Amelia Island State Park Non-Nesting Shorebird Observations

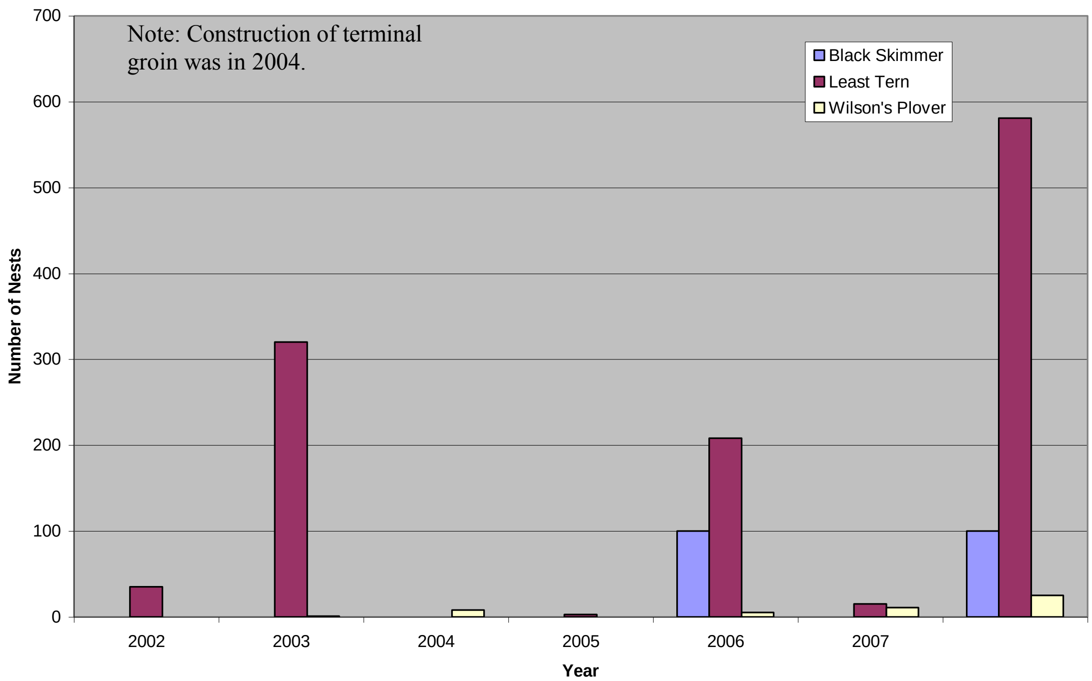


Figure III-34. Amelia Island Nesting Shorebird Observations

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 III-35). 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 III-36).

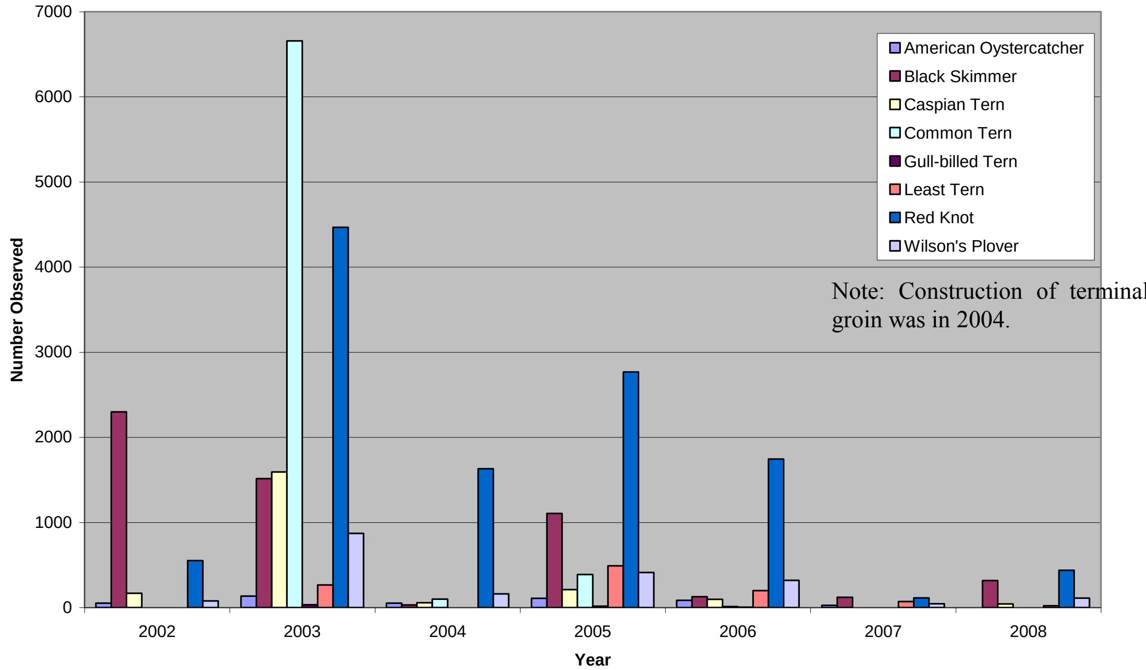


Figure III-35. Bird Islands Non-Nesting Shorebird Observations

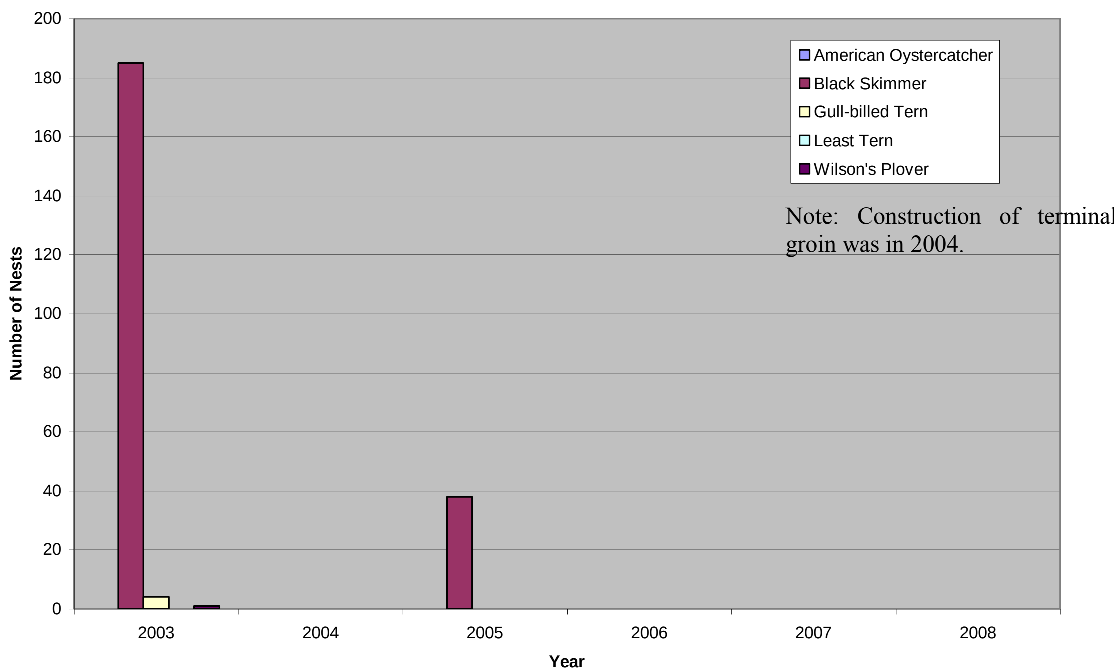


Figure III-36. Bird Islands Nesting Shorebird Observations

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 III-37). 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 III-38). 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.

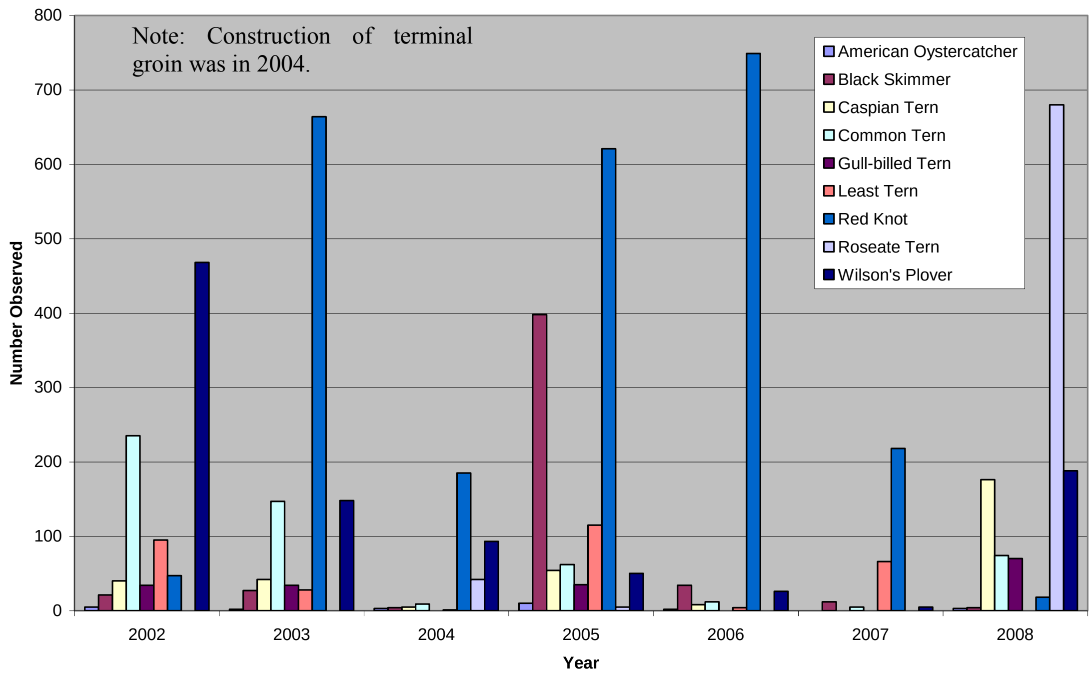


Figure III-37. Little Talbot Island State Park Non-Nesting Shorebird Observations

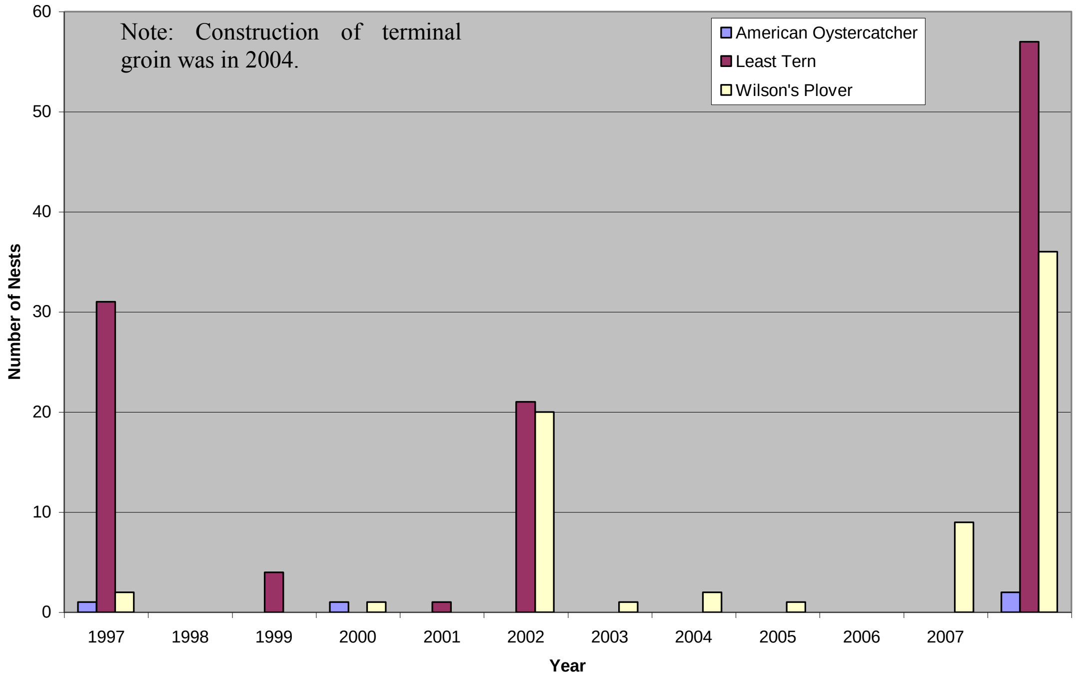


Figure III-38. Little Talbot Island State Park Nesting Shorebird Observations

Shorebird habitats on Amelia Island, Little Talbot Island State Park, and the Bird Islands are subject to the effects of tropical storms. On Amelia Island, the total number of individuals representing all of the selected species declined following tropical storm events in 2004 and 2005. On Little Talbot Island State Park and the Bird Islands, the total number of individuals representing all of the selected species increased following the tropical storm event in 2004 and decreased following the tropical storm event in 2005. Based on the limited shorebird data set (2003 – 2008 for Amelia Island and 2002 – 2008 for AISP and Little Talbot Island State Park), it is not possible to draw conclusions regarding the effects of tropical storms on shorebird populations at these sites. Shorebird habitats on Amelia Island are also subject to the effects of periodic beach renourishment projects. The total number of shorebirds on Amelia Island increased slightly following beach renourishment in 2006. Based on the limited shorebird data set for Amelia Island (2003 – 2008), it is not possible to draw conclusions regarding the effects of renourishment projects on shorebird populations.

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 III-31). 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). 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 III-39). 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.

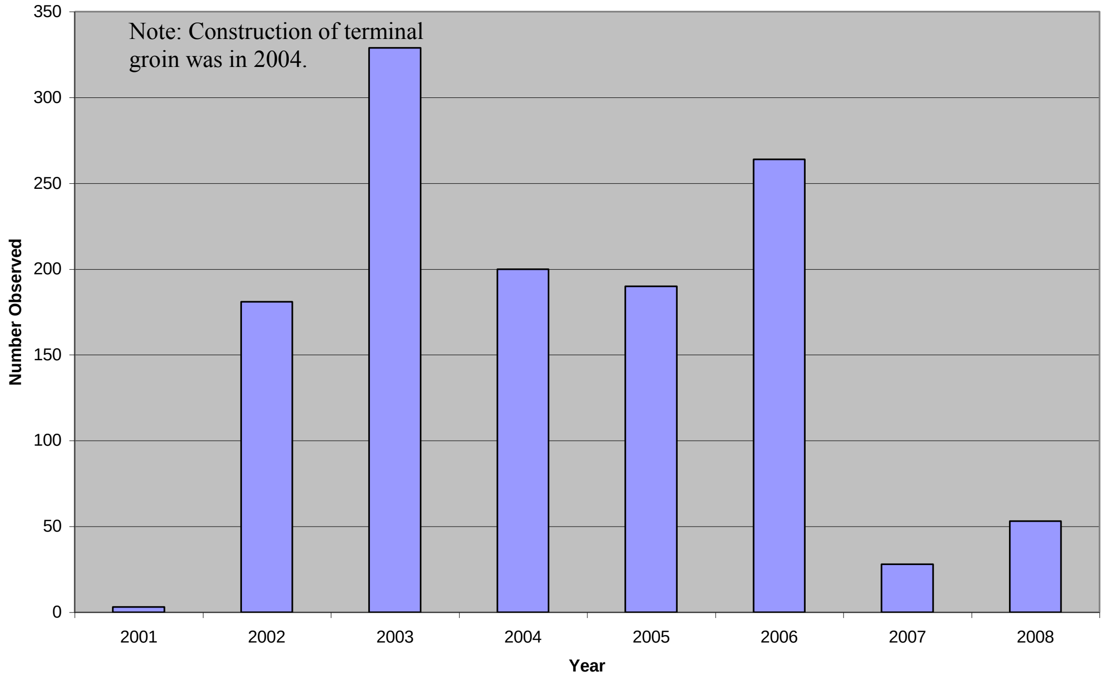


Figure III-39. Piping Plover Observations for Little Talbot Island and Bird Islands, Nassau Sound

Piping plover habitat on Little Talbot Island and the Bird Islands is subject to the effects of tropical storms. Piping plover observations on Little Talbot Island and the Bird Islands increased following a tropical storm event in 2002, decreased following a tropical storm event in 2004, and increased following a tropical storm event in 2005. Based on the limited piping plover data set (2001 – 2008), it is not possible to draw conclusions regarding the effects of tropical storms on piping plover populations at these sites.

Nesting on the Nassau Sound Islands

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 (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 physically 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 III-8 represents species that were identified within the project area or could potentially be observed in and around the project area.

Table III-8. 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.

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 mobile 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.

d) Summary of Findings

Increased erosion pressure on the southern end of Amelia Island has prompted coastal engineering actions intended to protect valuable resources along the AISP and adjacent to privately held lands northward.

Sea turtle nesting data for Amelia Island dates back to 1986 and on average, 74 nests were recorded annually from 1986 through 2005. 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 and 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 and beach nourishment on sea turtle nesting.

Because of concerns raised during the evaluation of the permit application, an extensive shoal acreage 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. Shorebird habitats on Amelia Island are subject to the effects of periodic beach renourishment projects. The total number of shorebirds on Amelia Island increased slightly following beach renourishment in 2006. Based on the limited shorebird data set for Amelia Island (2003 – 2008), it is not possible to draw conclusions regarding the effects of renourishment projects on shorebird populations.

The AISP is designated by the state as Critical Wildlife Habitat for least terns. 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. FDEP data do not include any records of piping plovers on Amelia Island. 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 or piping plover use.

The lack of raw data resulted in non-discernable trends in potential effects on benthic and fisheries resources from the terminal groin and associated fillet.

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 III-40).

Figure III-40. 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.

(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.

(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.

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 III-41).

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 III-42 (1991 snapshot) and Figure III-43 (2006 snapshot), the estuarine habitats in the vicinity of Redfish Pass has remained relatively stable.

Figure III-41. Coastal Classification of Habitat for Redfish Pass, FL

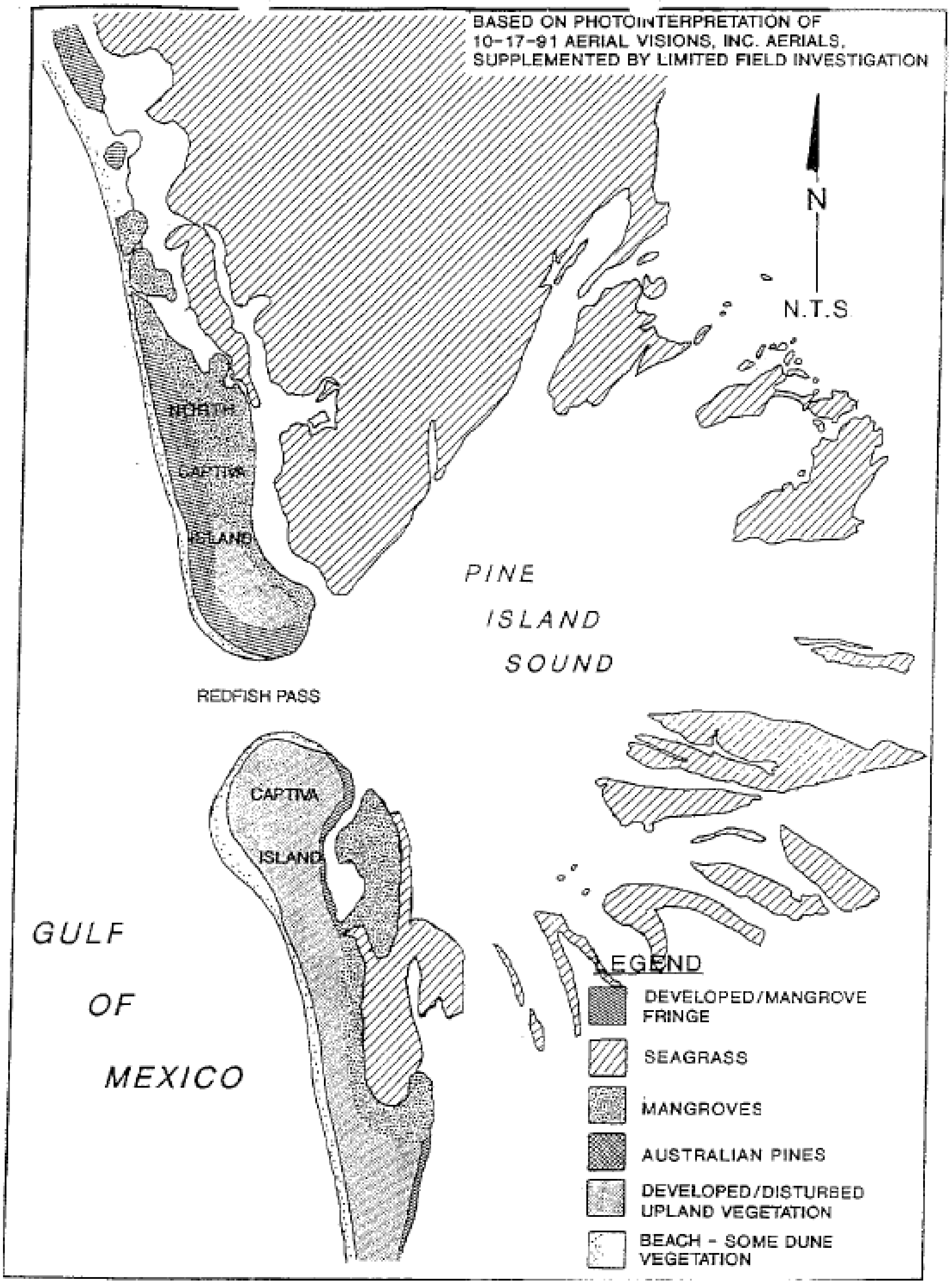


Figure III-42. Coastal Habitats of Redfish Pass (1991)

Figure III-43. 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) Sea Turtles

The beaches in proximity to Redfish Pass provide nesting habitat for the Atlantic loggerhead sea turtle (Figure III-44). 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 57 nests or a 199 percent increase over pre-restoration averages.

Sea turtle nesting data for Captiva Island, an approximate 5 mile shoreline from Redfish Pass to Blind Pass, dates back to 1986 (Figure III-45). 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. However, the 2008 nesting period resulted in a sharp increase to 137 nests and then decrease to 80 nests in 2009.

Figure III-44. Species Occurrence for Redfish Pass, FL

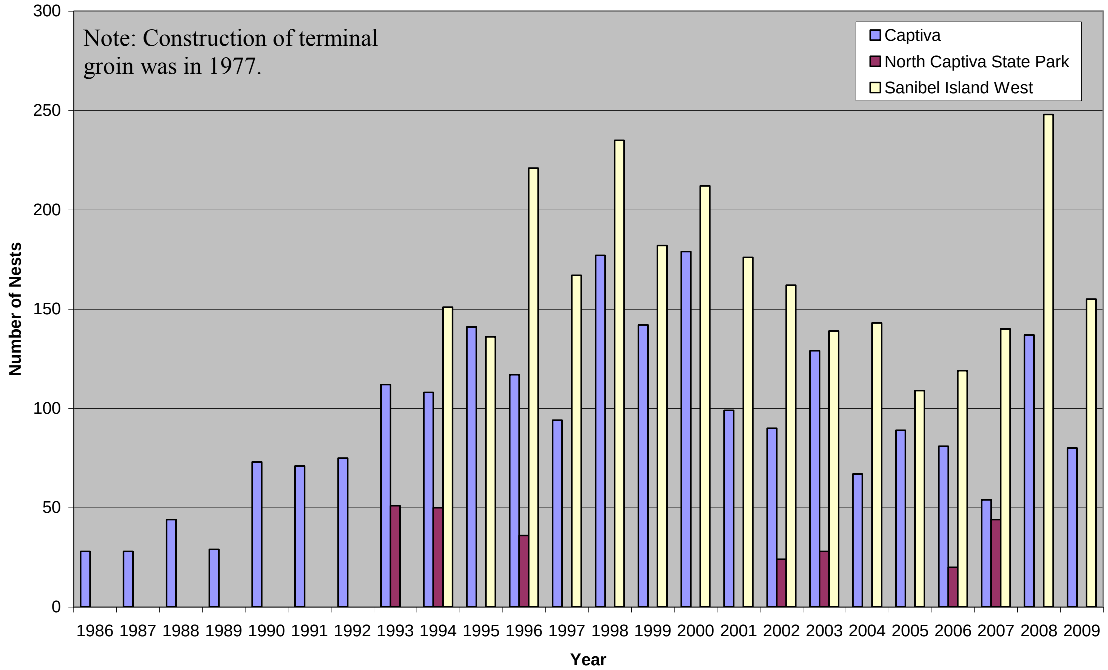


Figure III-45. Sea Turtle Nesting Data from Captiva Island, North Captiva State Park, and Sanibel Island West

Sea turtle nesting data for Sanibel Island West, an approximate 6.5 mile shoreline from Blind Pass to Tarpon Bay Road, dates back to 1994 (Figure III-45). 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, an approximate 3 mile shoreline, is intermittent. The available data set includes 1993, 1994, 1996, 2002, 2003, 2006, and 2007 (Figure III-45). The number of nests recorded ranged from 20 to 51. The average number of nests recorded was 36.

Sea turtle nesting habitats on Captiva Island, North Captiva Island State Park, and Sanibel Island West are subject to the effects of tropical storms. Sea turtle nesting densities on Captiva Island increased following storm events in 1992, 1994, 1999, and 2004; whereas nesting densities decreased following storm events in 1988, 1990, 1998, 2001, 2005, 2006, and 2008. Sea turtle nesting densities on Sanibel West increased following storm events in 1999, 2005, and 2006; whereas nesting densities decreased following storm events in 1994, 1998, 2001, 2004, and 2008. Due to the limited data set for North Captiva Island State Park, trends following storm events are not apparent. Based on these data, there does not appear to be a consistent relationship between nesting density and storm events. Sea turtle nesting habitat on Captiva Island is also subject to the effects of periodic beach renourishment projects. Captiva Island beaches were nourished 5 times between 1988 and 2009. Sea turtle nesting densities on Captiva Island increased following renourishment in 1991; whereas nesting densities decreased following renourishment in 1988, 1996, 2005, and 2008. These data indicate that renourishment may have had an adverse effect on sea turtle nesting.

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. No adverse effects, except for one female sea turtle becoming entrapped in the Redfish Pass terminal 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]. 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.

(2) 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 III-9 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 III-10 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 III-9. 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 III-10. 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 III-44). 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).

(3) 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.

(4) 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 III-11 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 mobile and capable of escaping temporary effects. 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. By the end of 2007, the beach had mostly disappeared which may have been the result of less sand bypassing the longer terminal groin or the passage of Tropical Storm Barry that made landfall north of this region in June 2007. The inlet beach losses may also reflect in a potential loss of larval transport around the extended groin.

(5) 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. Because there were no hardbottom formations in this location, there were no post-construction monitoring required for biological resources (Personal communication, V. George, FDEP, January 2010).

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 III-11. 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.

c) Summary of Findings

A degraded habitat was improved by the use of the terminal groin and associated fill and the project area is not considered an immediate concern of local resource agencies.

Sea turtle nesting data for Captiva Island, an approximate 5 mile shoreline from Redfish Pass to Blind Pass, dates back to 1986. On average, 94 nests were recorded annually from 1986 through 2009. However, the 2008 nesting period resulted in a sharp increase to 137 nests and then decrease to 80 nests in 2009.

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 the adjacent Sanibel Island.

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).

Because there were no live bottoms within the groin construction footprint, FDEP required no post-construction biological resource monitoring. The lack of raw data resulted in non-discernable trends in potential effects on benthic and fisheries resources from the terminal groin and associated fillet.

5. John's Pass, Florida

a) General Site Description

John's Pass, (see Figure III-46 and Figure III-47), 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. The 1958 postcard, Figure III-46, looks north at John's Pass prior to construction of the curved terminal groin. Note the inlet's developed 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 the 1965 photo. 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.

Figure III-46. John's Pass, Florida

Figure III-47. 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. 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.

(3) Public Access

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 III-48 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 III-49 and Figure III-50). Stranding records within the Pinellas County area also confirmed that loggerhead sea turtles are the most numerous species.

As shown in Figure III-50, regular monitoring of sea turtle nesting activity has been conducted on north Pinellas County beaches since 1988. The sea turtle survey boundaries of North Pinellas County beaches include Dunedin Pass to the southern boundary of Indian Shores, an approximate 15 mile stretch of oceanfront shoreline. 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 (mid) region of Pinellas County beaches since 1988 (Personal communication, B. Brost, FFWCC, February 2010). The sea turtle survey boundaries of the Mid Pinellas County beaches include Redington Shores to Blind Pass, an approximate 7 mile stretch of oceanfront shoreline. 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.

Sea turtle nesting habitat on Pinellas County beaches is subject to the effects of tropical storms and periodic beach renourishment projects. Sea turtle nesting densities on Mid-Pinellas beaches increased following storm events in 1988, 2001, and 2004; whereas nesting densities decreased following storm events in 1990 and 1995. Nesting densities on North Pinellas beaches increased following storm events in 1988, 1990, 1995, and 2001; and decreased following a storm event in 2004. Pinellas County beaches were nourished four times between 1988 and 2004. Sea turtle nesting densities on Mid-Pinellas beaches increased following renourishment in 1988, 1996, and 2004; whereas nesting density decreased following renourishment in 2000. Sea turtle nesting densities on North Pinellas beaches increased following renourishment in 1988 and decreased following renourishment in 1996, 2000, and 2004. Based on these data, there does not appear to be a consistent relationship between nesting density and storm or renourishment events.

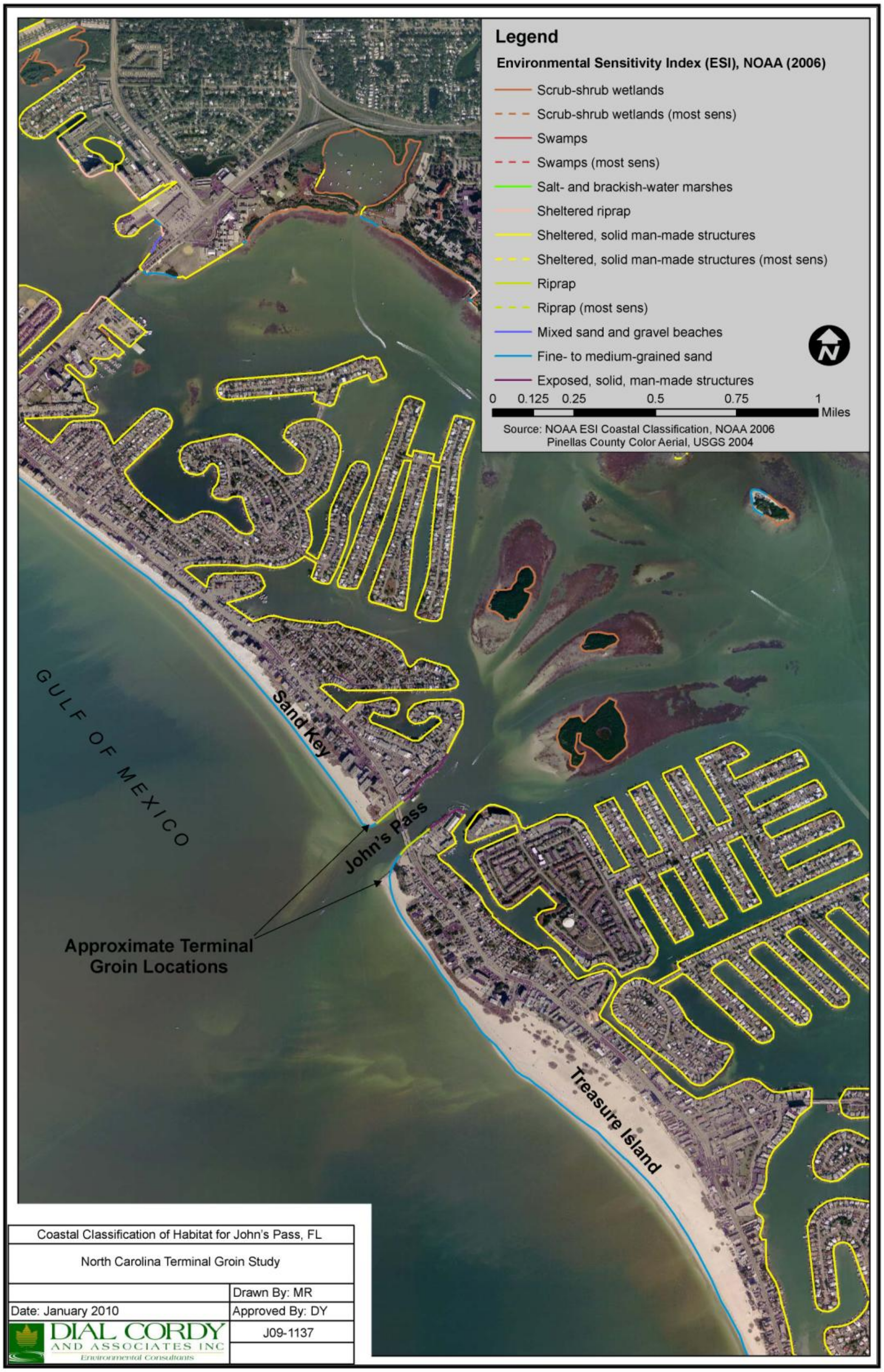


Figure III-48. Coastal Classification of Habitat for John's Pass, FL

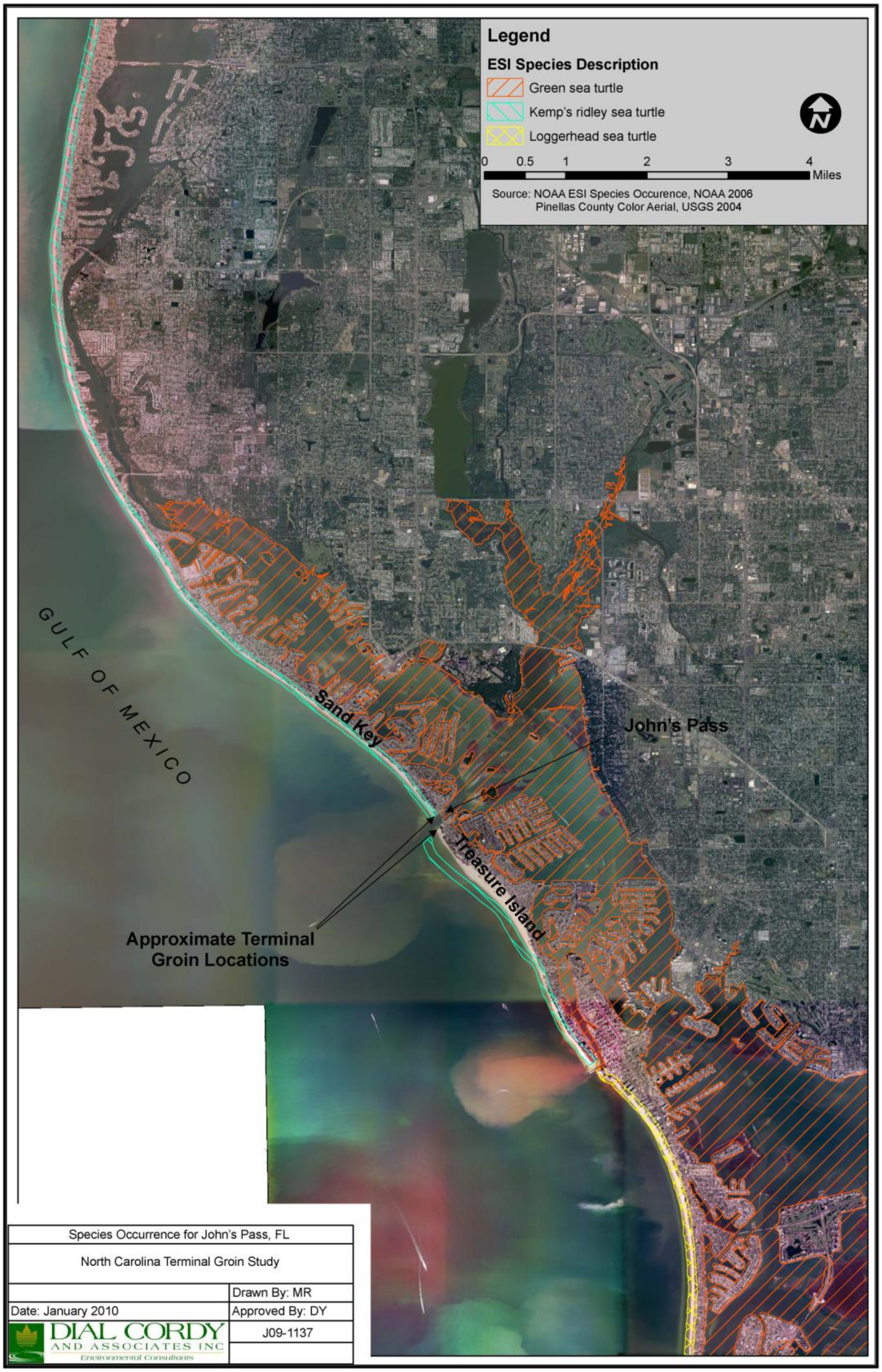


Figure III-49. Species Occurrence for John's Pass, FL

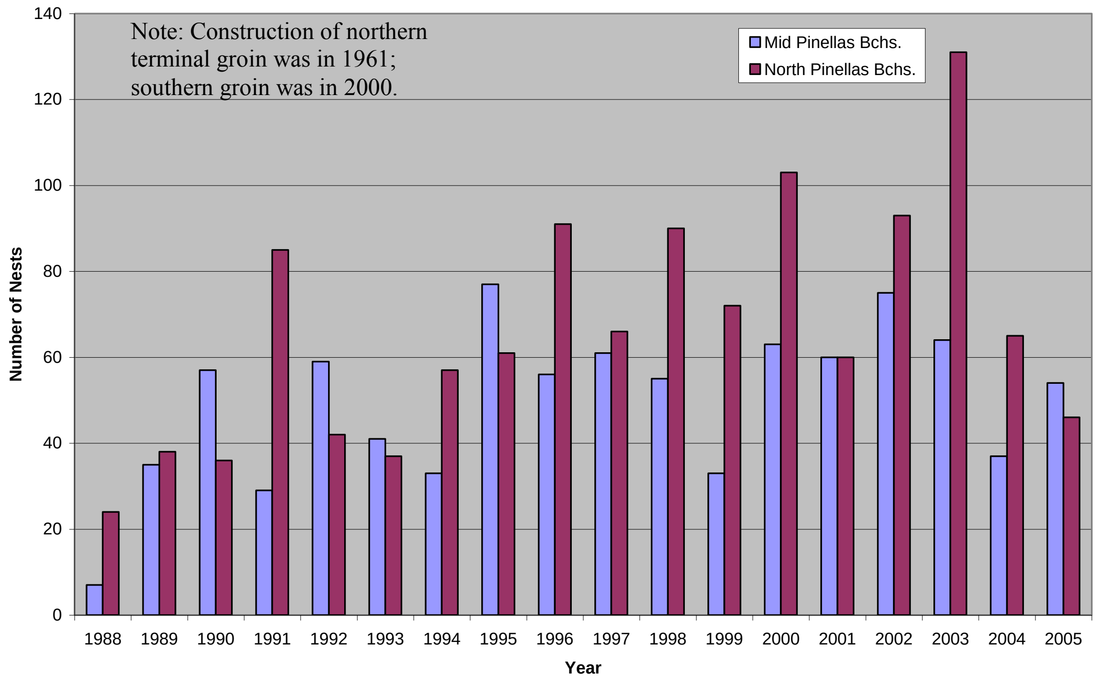


Figure III-50. Sea Turtle Nesting Data for Mid and North Pinellas Beaches

In 2007 and 2008, Audubon of 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 habitat availability, shorebird data was not accessible for review.

(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/).

(3) Seagrasses

SAV within Boca Ciega Bay and John's Pass are associated with tidal flats and shoal areas surrounding mangrove islands or along the shoreline. Figure III-51 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).

Figure III-51. Seagrass and Tidal Flats for John's Pass, FL

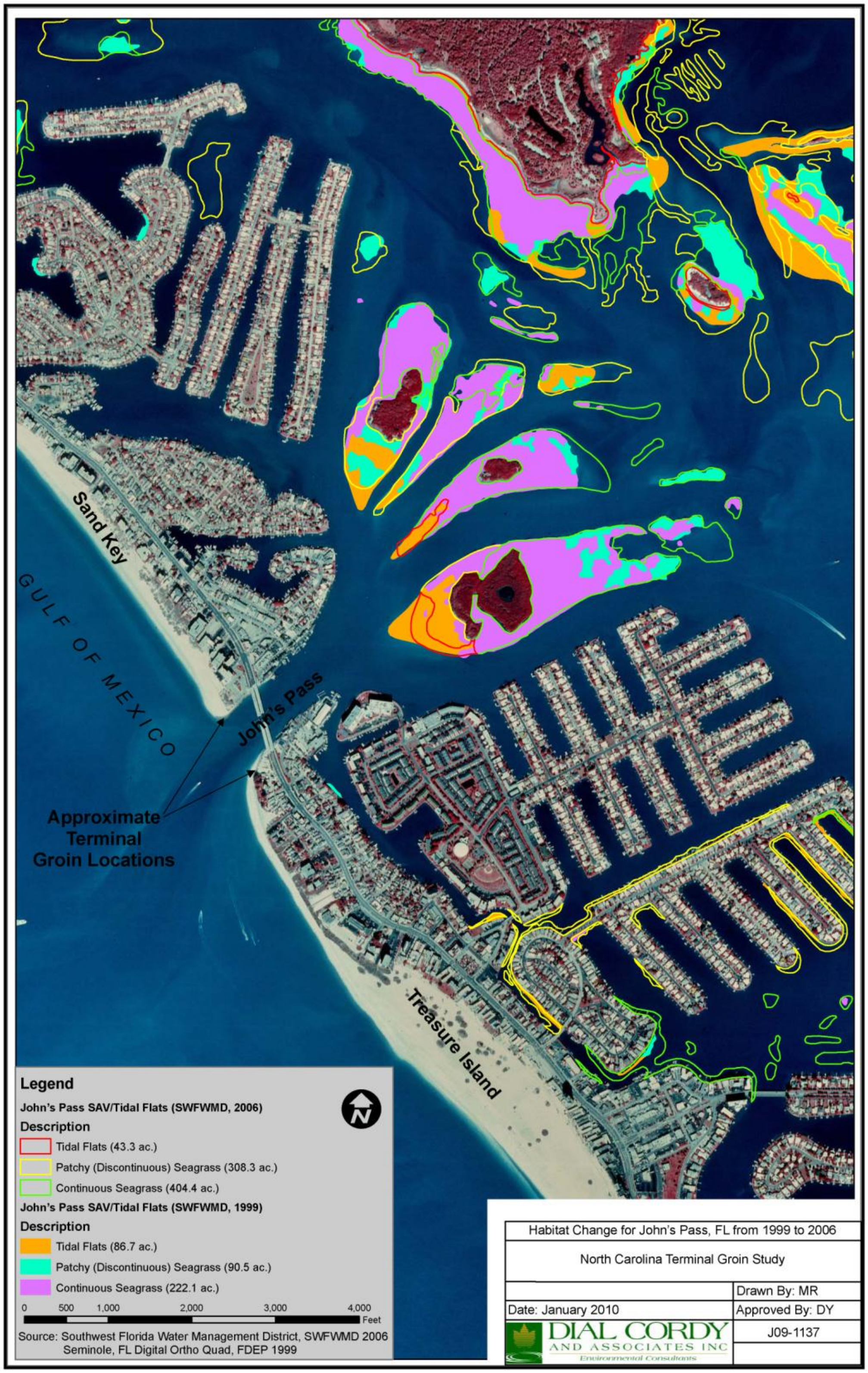


Figure III-52. Habitat Change for John's Pass, FL from 1999 to 2006

There appears to be a significant reduction in unvegetated tidal flats along with a significant increase in SAV (Figure III-52) 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 III-12).

Table III-12. 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) Summary of Findings

John's Pass is located within the Pinellas County Aquatic Preserve. 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.

The sea turtle survey boundaries of the Mid Pinellas County beaches include Redington Shores to Blind Pass, an approximate 7 mile stretch of oceanfront shoreline. 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.

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/). 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. The lack of raw data resulted in non-discernable trends in potential effects on birds, benthic resources, and fisheries from the terminal groins and associated fillets.

C. Overall Findings and Summary of NC and FL Study Sites

Based upon the historical nature of the terminal groins at Fort Macon, John's Pass (northern groin), and Redfish Pass; discernible trends 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 difficult if not impossible. While the use of control and/or regional sites strengthens the ability of a study to infer an impact from a detected change, we cannot infer an impact if there is no statistical evidence for a change (Mapstone 1995); and due to the lack of complete datasets and high levels of confidence in the quality of the data, statistical analysis was precluded. The current development and use of some of the selected 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, albeit sometimes on a limited basis.

The terminal groins at Oregon Inlet and Amelia Island are more recent construction projects, and pre- and post-construction natural resource data readily available were evaluated (sea turtle and shorebird nesting data). 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.

Because of the diversity and commercial importance of 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.

In general, the following conclusions result from an extensive evaluation of available scientific literature, regulatory documentation, and available data from each of the selected study sites:

- The effects of a terminal groin structure alone could not be assessed for most sites without considering the associated beach nourishment activity;
- Minimizing natural overwash at the end of an island limits natural barrier island processes which affects inlet habitats, thus affecting species use;
- Anchoring the end of an island may curtail an inlet's natural migration patterns thereby minimizing the formation of sand flats;

- Fillet material should be compatible to minimize effects on benthic infauna recovery and upper trophic levels;

- Resources continue to use locations where terminal groins exist, however, if habitat succession occurs, species suitability may be affected; and

- Available data and a limited time frame resulted in non-discernable site specific trends.

IV. Engineering Construction Techniques

A. Overview of Approach

Several factors contribute 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. Summary results from each site were plotted using the calculations from Section II. These plots were then reviewed against the various groin heights, lengths, and porosities. 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 highly permeable groin. Oregon Inlet has the longest selected groin at over 3,000 feet long (including the wrap around portion).

1. Oregon Inlet

The erosion control measures at Oregon Inlet include a 3,125-foot long groin and a 625-foot long revetment. Nonetheless, it should be noted that a significant portion of the structure length is taken up by the wrap around feature of the structure and that the shore perpendicular portion of the structure is approximately 1500 feet. 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 IV-1 shows the 2007 aerials, and Table IV-1 summarizes the structural information for the Oregon Inlet terminal groin.

Figure IV-1. Oregon Inlet Terminal Groin and Revetment

Table IV-1. Oregon Inlet Terminal Groin and Revetment 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 Under layer Foundation	 Type 'A-II' Stone 2.5 – 4.5 Ton 50% > 3.5 Ton Type 'U-II' Stone 500 – 1000 lbs 75% > 750 lbs Type 'F-I' Stone 0.5 – 110 lbs
-Stone Size (Station:17+50 – 29+25) Armor Under layer Foundation	 Type 'A-III' Stone 7 – 10 Ton 50% > 9.0 Ton Type 'U-III' Stone 1500 – 2000 lbs 75% > 2000 lbs 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 40-ft 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 IV-2 shows a typical cross-section for the terminal groin (taken from Oregon Inlet Plan Drawings).

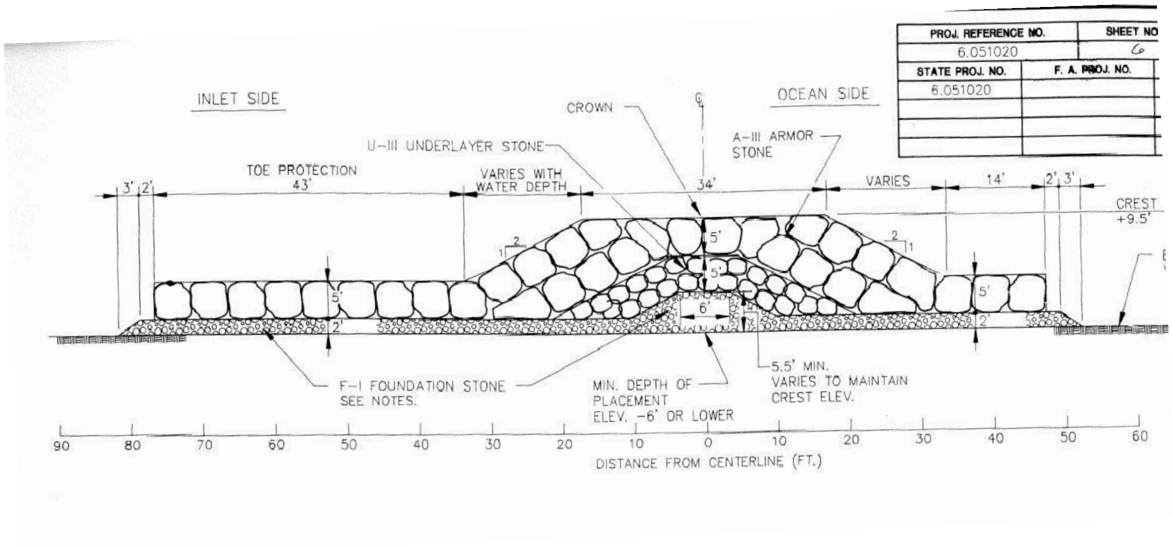


Figure IV-2. Oregon Inlet Terminal Groin Typical Cross-Section

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 IV-2 summarizes the structural information for the Fort Macon terminal groin. Figure IV-3 illustrates the typical cross-section from the 1986 groin extension permit plans.

Table IV-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%.

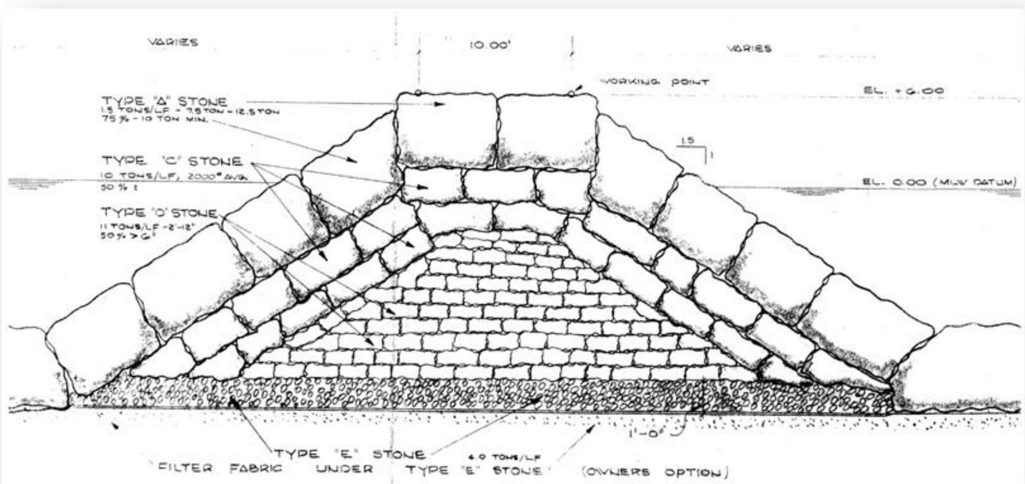


Figure IV-3. Fort Macon Terminal Groin Typical Cross-Section

Figure IV-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.

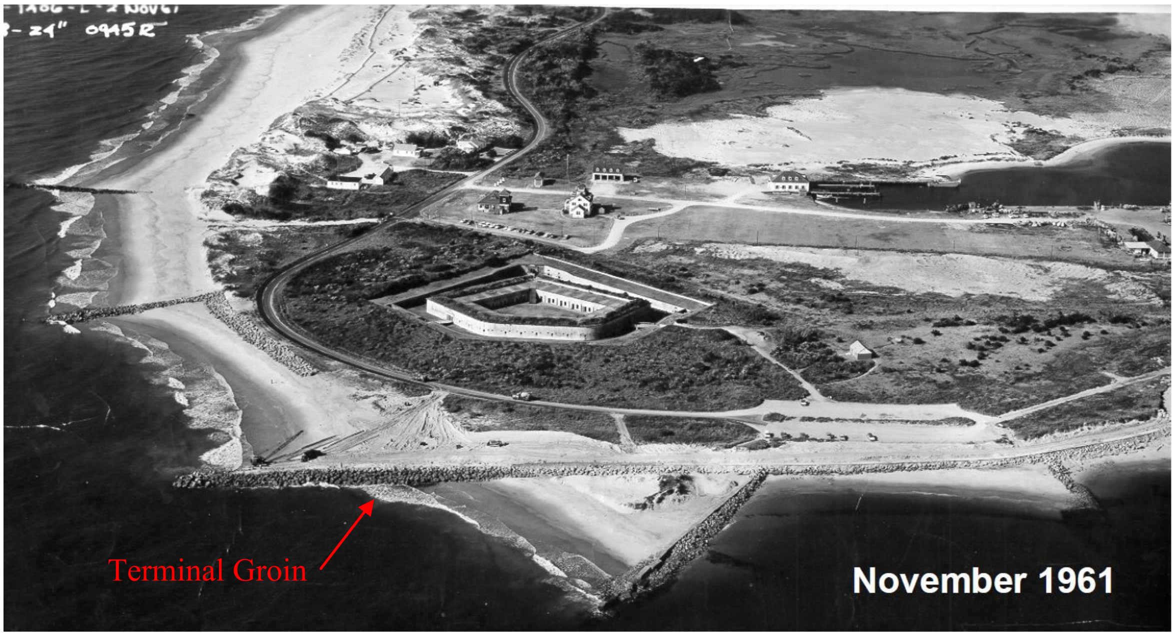


Figure IV-4. Fort Macon Terminal Groin Initial Construction (1961)

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 IV-3 summarizes the structural information for the terminal groin. Figure IV-5 illustrates the typical cross-sections for Amelia Island terminal groin (taken from Olsen Permit Drawings).

Table IV-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') Armor (Sections D-D' & E-E')	 Stone 2 – 3 Ft (0.4 – 1.5 Ton) 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 305-ft 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 2,600-ft 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). Recent aerial photography indicates that the terminal groin is completely inundated with sand and is essentially non-activated or allows sand to freely bypass the structure (Olsen, 2008). Figure IV-6 shows the Amelia Island terminal groin as of 2008.

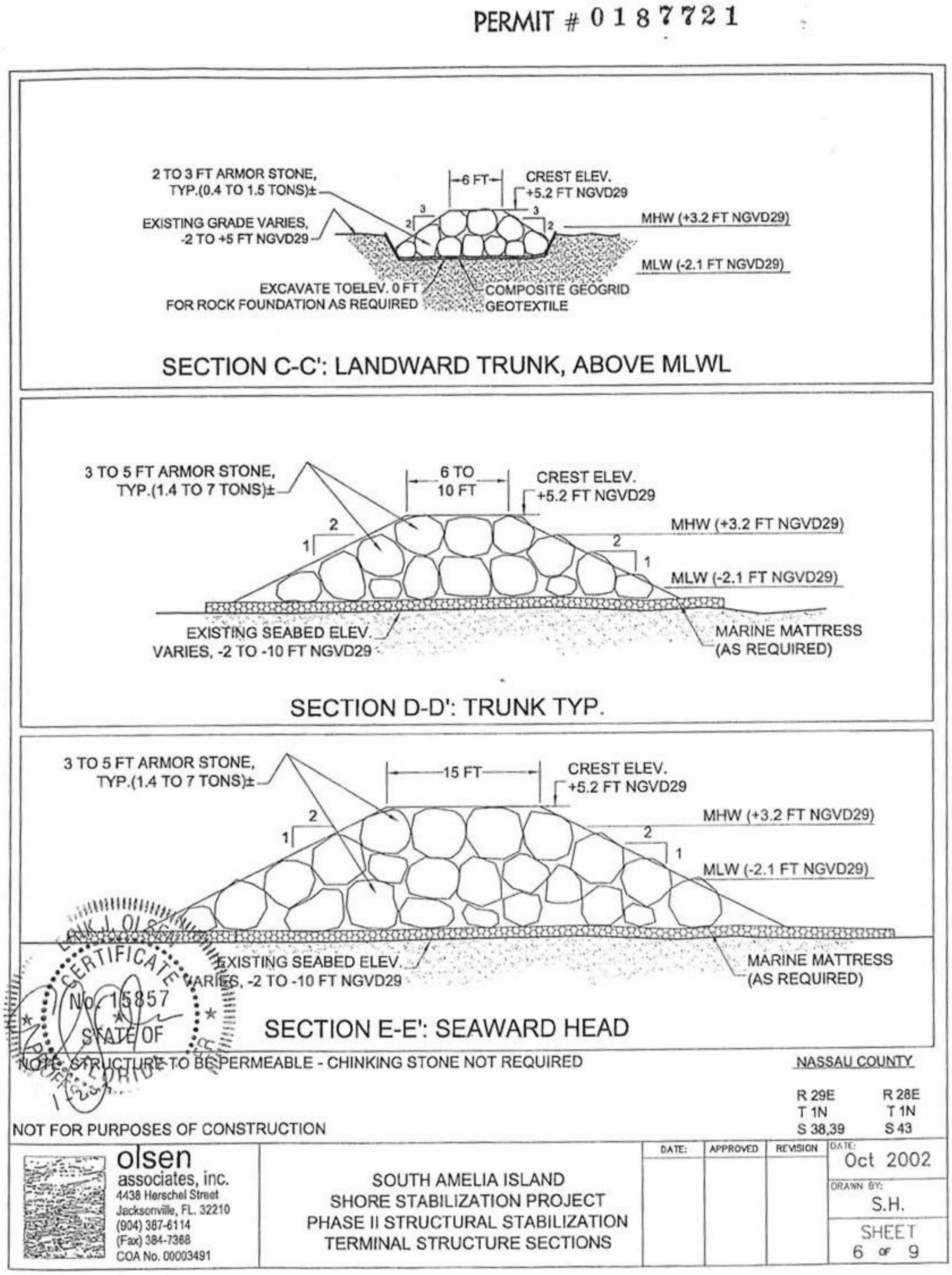


Figure IV-5. Amelia Island Terminal Groin Cross-Sections

Figure IV-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 IV-7 shows the 2006 reconstructed groin. Figure IV-8 shows the Captiva Island terminal groin in 2008.

Figure IV-7. 2006 Terminal Groin at Captiva Island

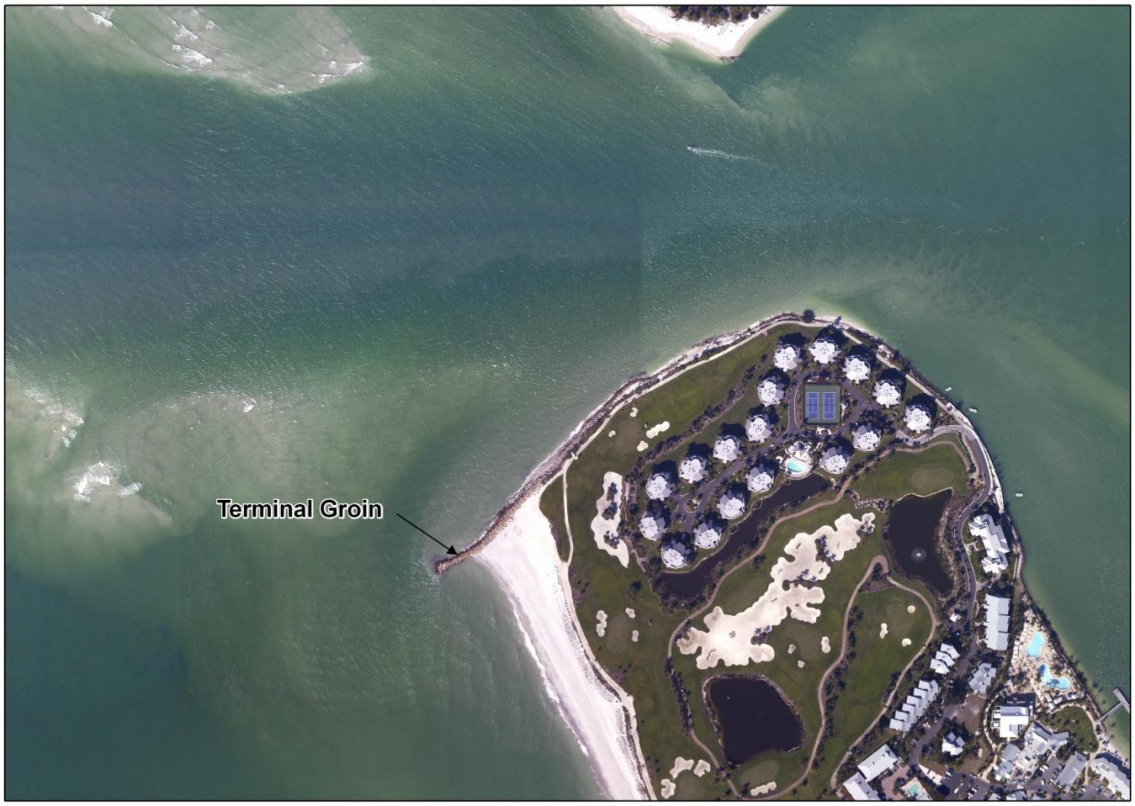


Figure IV-8. Captiva Island Terminal Groin

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 IV-4 summarizes the structural information for the terminal groin. Figure IV-9 illustrates a typical cross-section for the terminal groin (taken from the 1986 groin extension permit).

Table IV-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 IV-10 shows both terminal groins at John's Pass.

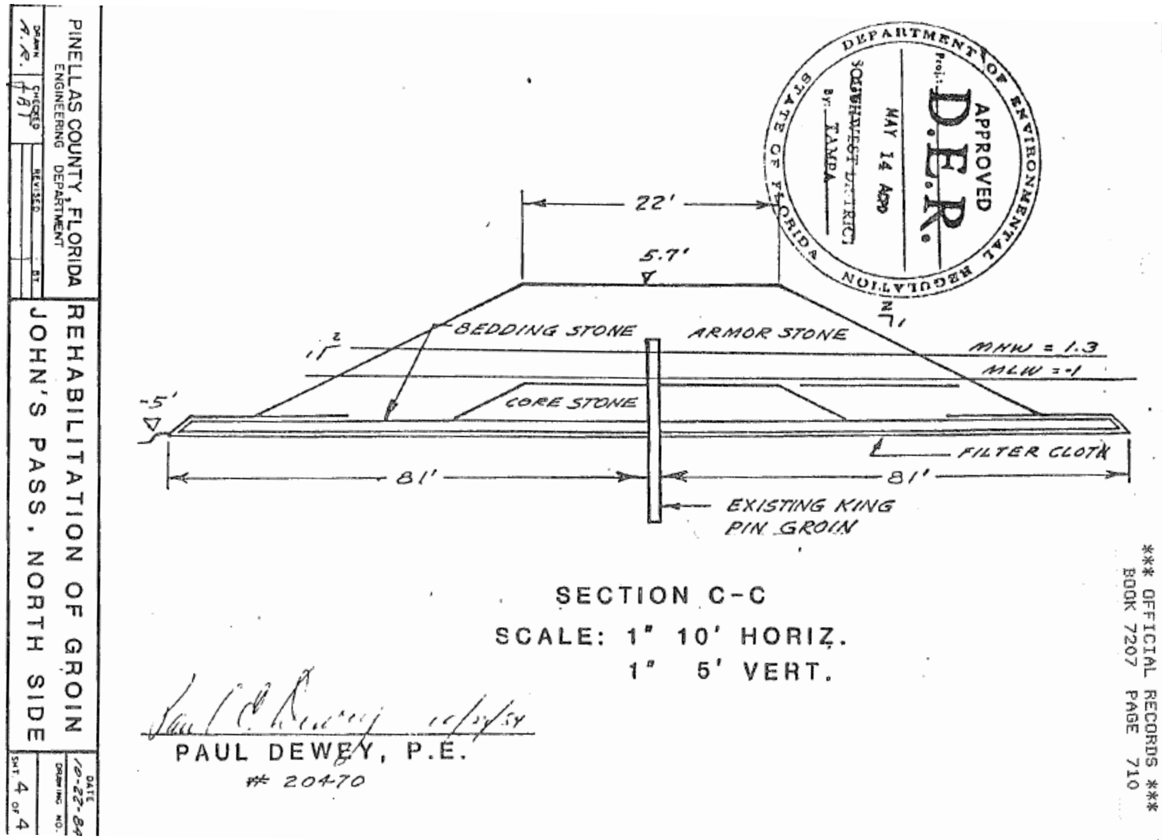


Figure IV-9. John's Pass Terminal Groin Typical Cross-Section

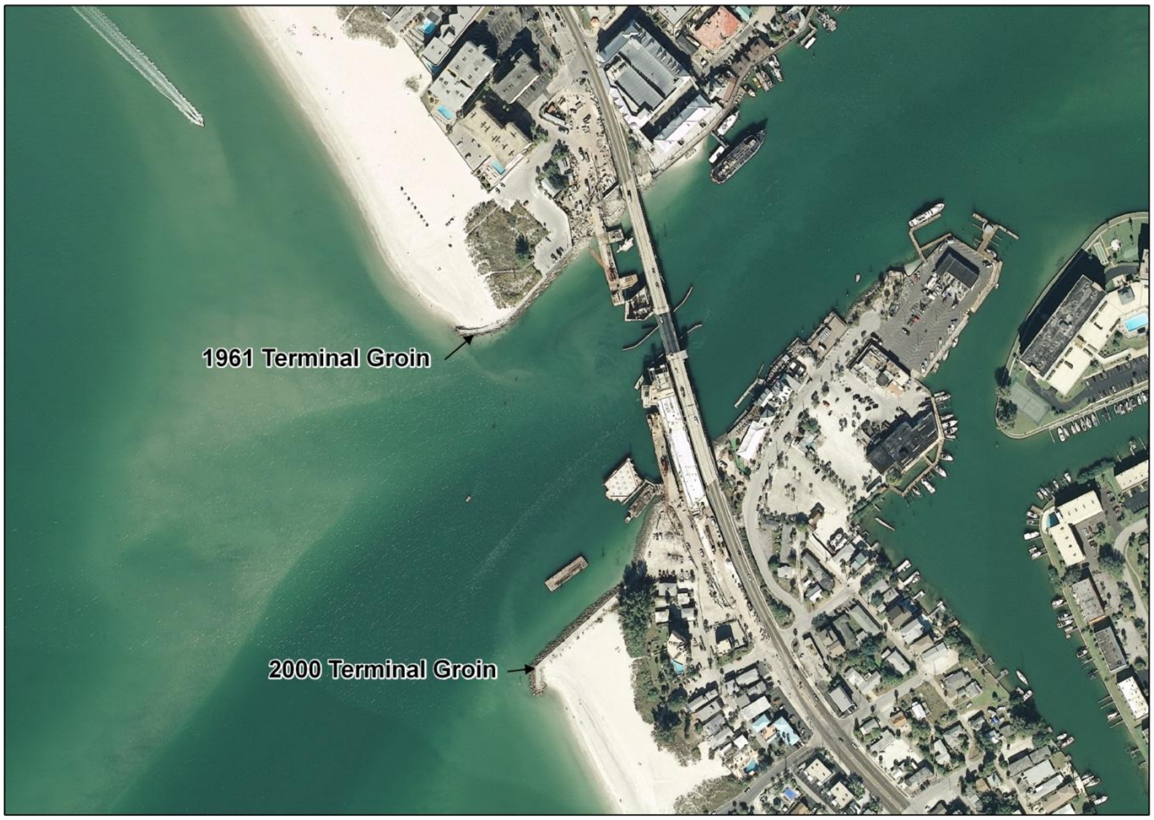


Figure IV-10. John's Pass Terminal Groins

6. Analysis of Existing Sites

In order to investigate the effects of groin length, elevation, and permeability on the adjacent shorelines, the results from the shoreline and volumetric analyses completed as part of the coastal engineering assessment were plotted for the five sites. Given the variability of the behaviors noted during the coastal engineering assessment, it was decided that the results would be plotted for both the cumulative and interval results over the 3 mile length for which calculations were completed.

a) Groin Length

The first factor investigated as part of the 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 removed. These factors were then plotted both as a cumulative total and individual intervals for both sides of the inlet. 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. Table IV-5 shows the individual groin lengths calculated. Figure IV-11 through Figure IV-13 show the results for the cumulative totals. Figure IV-14 through Figure IV-16 shows the results on an individual interval basis. Note that the results for the longer groins (~1500 ft) are shown in blue while the results for the shorter groins (~350-460 ft) are shown in red.

Table IV-5 Groin Lengths for Five Study Sites

Groin	Length (ft)
Oregon Inlet	1,500
Fort Macon	1,530
Captiva Island	350
John's Pass	460
Amelia Island	1,500

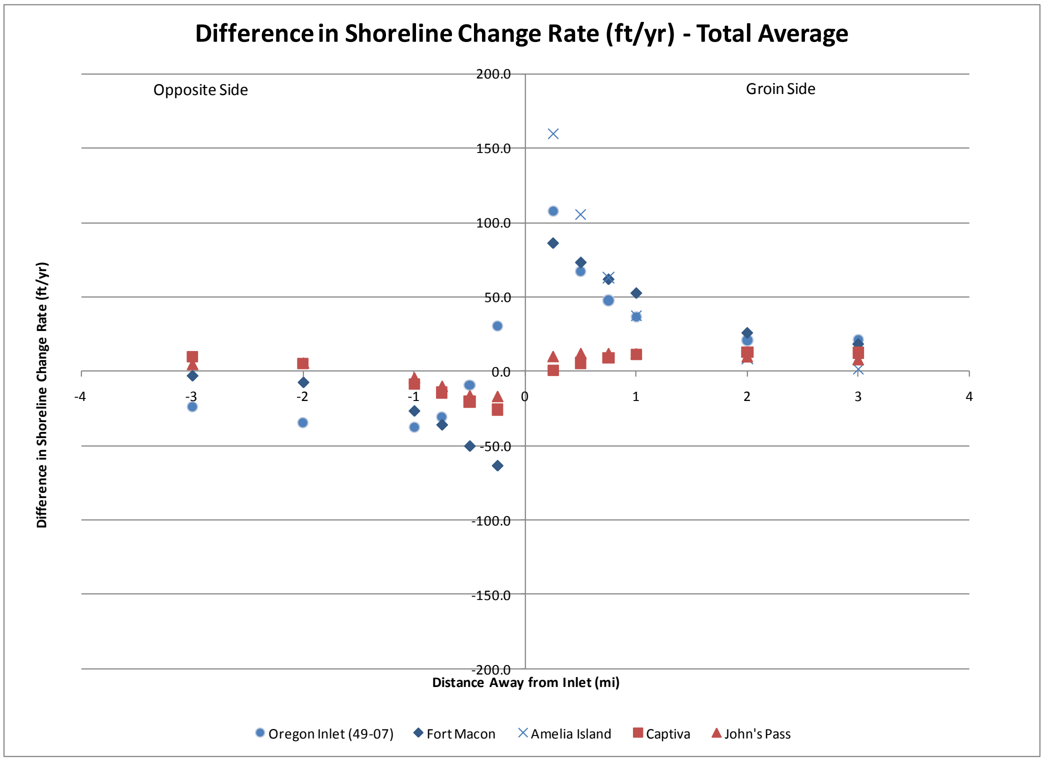


Figure IV-11. Difference in Total Average Shoreline Change Rate (ft/yr)

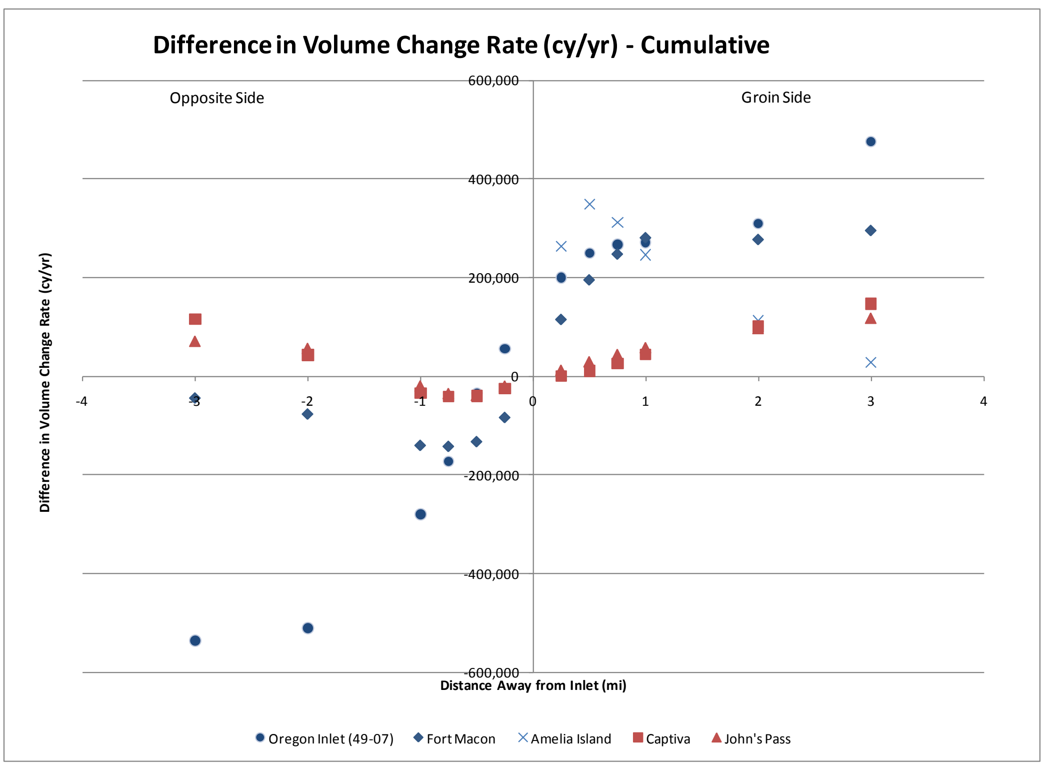


Figure IV-12. Cumulative Difference in Volume Change Rate (cy/yr) - With Nourishment

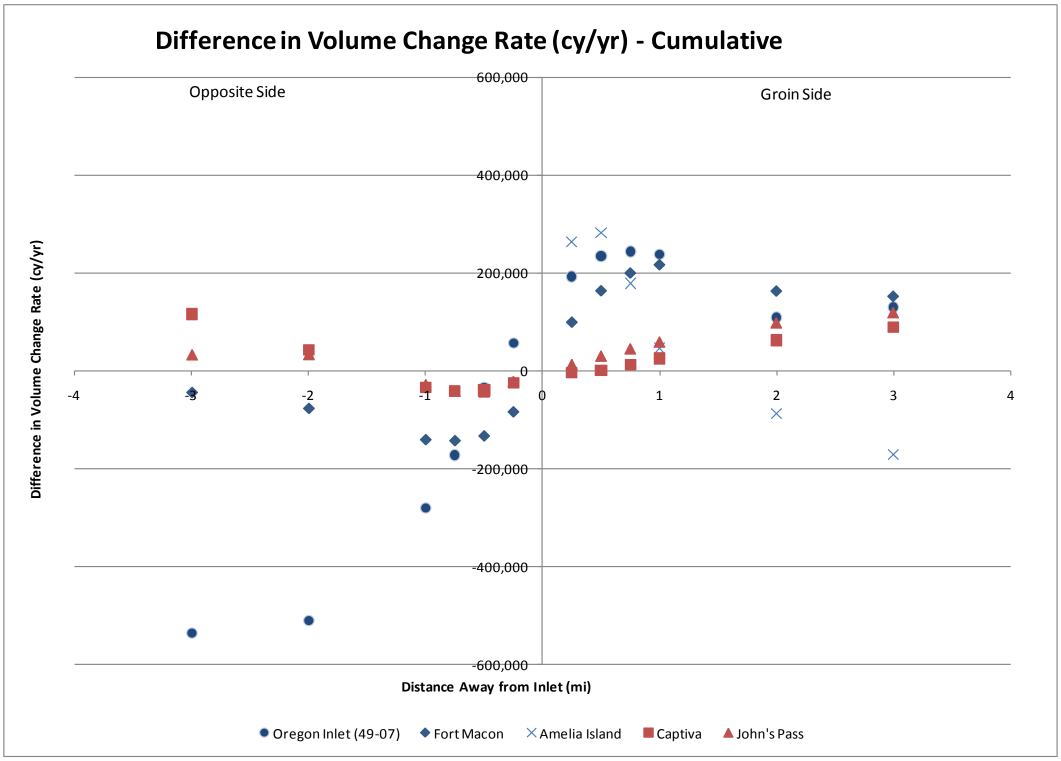


Figure IV-13. Cumulative Difference in Volume Change Rate (cy/yr) - Without Nourishment

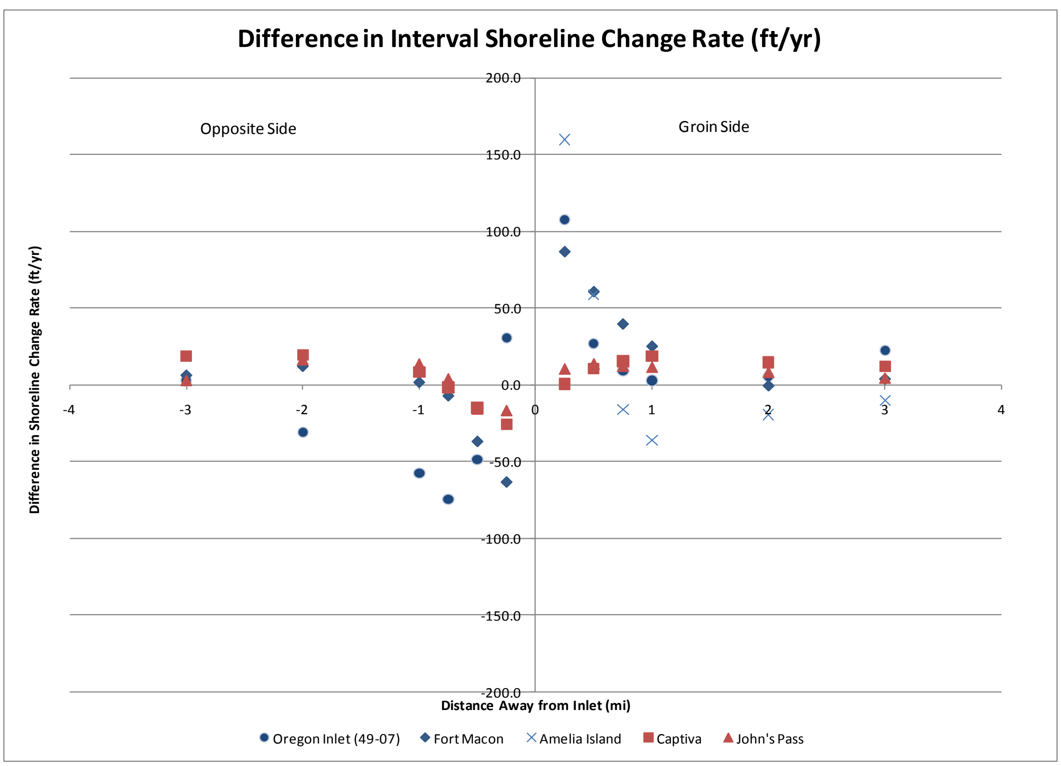


Figure IV-14. Interval Difference in Shoreline Change Rate (ft/yr)

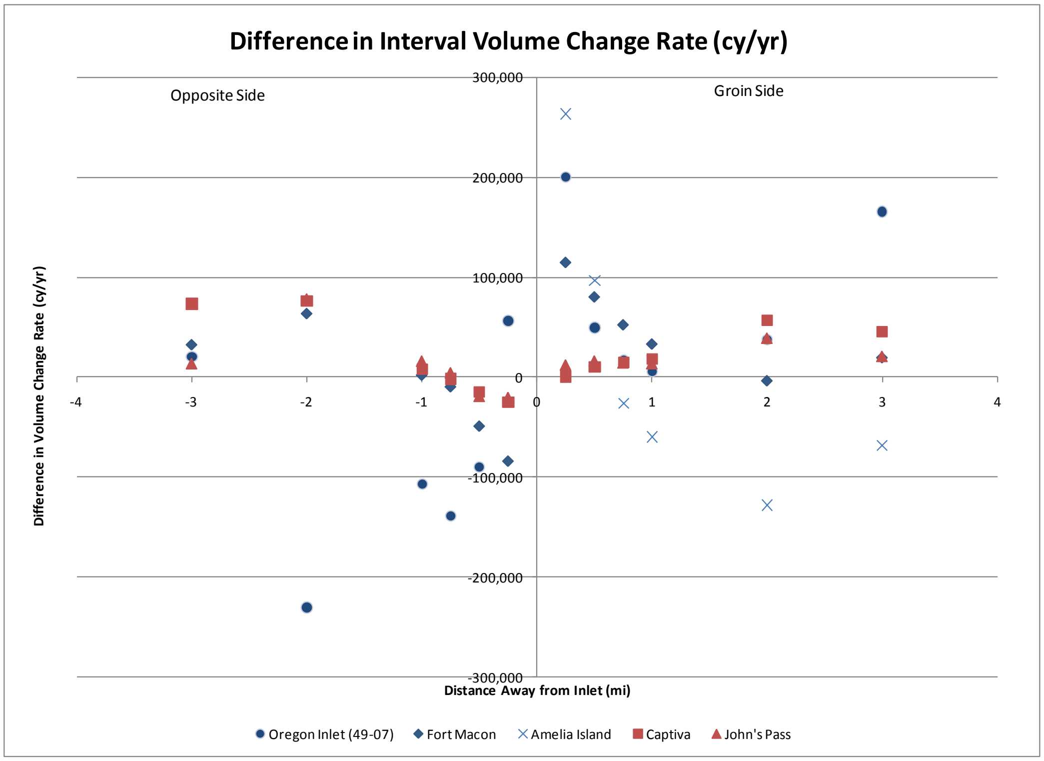


Figure IV-15. Interval Difference in Volume Change Rate (cy/yr) - With Nourishment

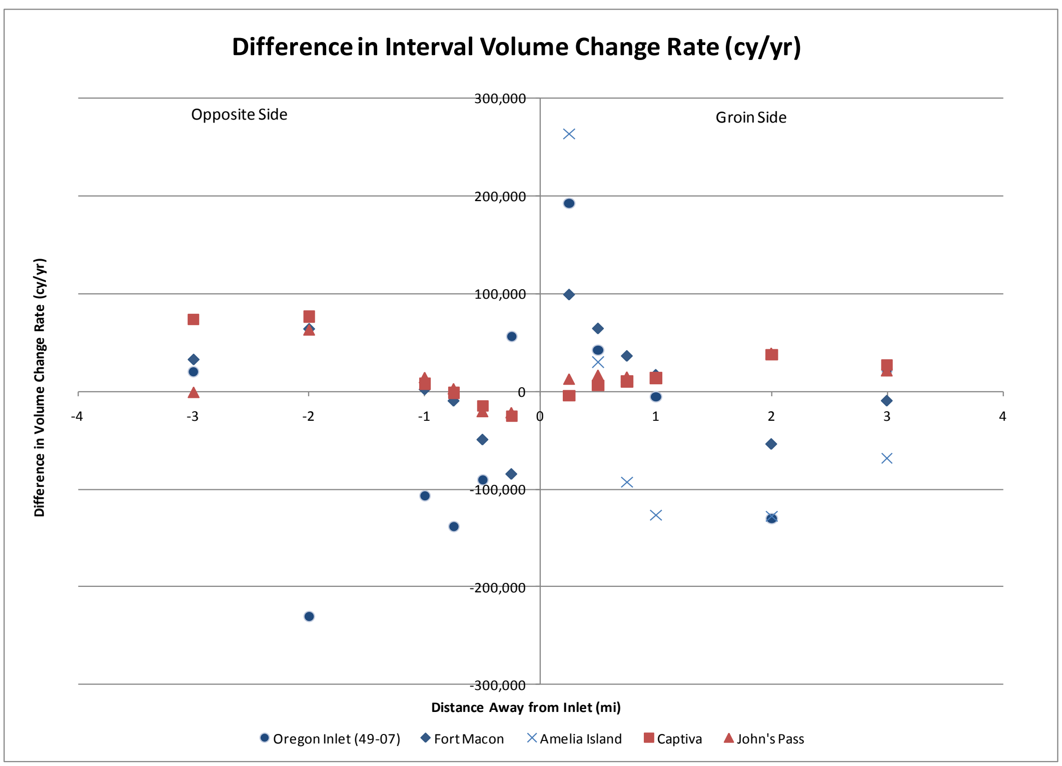


Figure IV-16. Interval Difference in Volume Change Rate (cy/yr) - Without Nourishment

As can be seen in the above graphs, on the structure side of the inlet, the shoreline change rate is lessened more over the entire 3 mile length with a longer groin than with a shorter one. It is also apparent that the greater reductions with longer groins are seen immediately adjacent to the structure and that the reductions appear to converge the further away from the structure. When looking at the volume changes, the same behavior can be seen. It is very interesting to note that there appears to be a point of diminishing returns with length especially once the nourishment effects are removed. It is also interesting to note how the "leaky" structure at Amelia Island appears to be allowing a significant portion of sediment to pass through the structure with the majority of the groin's impacts being felt within the first 0.5 mile from the structure. Also, while the cumulative behavior of the shorelines and volumes follows a distinct pattern, the interval plots do not show as clear of a trend. While still showing mostly positive impacts, there is one data point for Fort Macon and a few for Amelia Island that show a negative impact. However, it is believed that the impacts at Amelia are clouded by the equilibration of the recent large nourishment project that was completed recently. Lastly, it should be noted that the volume change rates listed above do not have the potential effects of dredging included.

Based on the above graphs, the longer structures appear to have a more pronounced effect on the opposite side of the inlet. However, it is important to note that these values were not adjusted for the dredging impacts which could be substantial and explain these apparent effects. The geologic considerations at these inlets could also explain these trends (especially Oregon Inlet). While only a few data points, they reveal the importance of the scale of these structures in relation to the other sediment transport drivers.

b) Groin Elevation

The next factor investigated was groin elevation. For each of the five sites, the shoreline change, overall volume change, and the volume change without nourishment from the above graphs could also be considered against groin elevation relative to local mean tide level. Table IV-6 shows the height relative to mean tide level for each site. Note that the results for the higher groins are shown in blue while the results for the lower groins are shown in red.

Table IV-6 Groin Height Relative to MTL for Five Study Sites

Groin	Height MTL (ft)
Oregon Inlet	8
Fort Macon	4.45
Captiva (estimated)	3.7
John's Pass	2.67
Amelia Island	4.67

As can be seen in the previous figures (Figure IV-11 through Figure IV-16), the trends are very similar on the structure side of the inlet with the shoreline change rate being 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 effects are removed.

When investigating the opposite side of the inlet, it appears that trends are again similar with higher groins having the potential for more effects than a lower one. However, it is again 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).

c) Groin Permeability

The last factor investigated as part of the study was groin permeability. Since all of the terminal groins (except Amelia) were built with a 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 effect on shorelines more than 1 mile updrift of the structure. In fact, the volume changes were negative (but likely due to the recent nourishment equilibration) past the 1 mile distance. Only by looking at the detailed results was it determined that the "leaky" structure showed shoreline and volume change benefits within the first 0.5 mile 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 IV-17 (USACE, 2002).

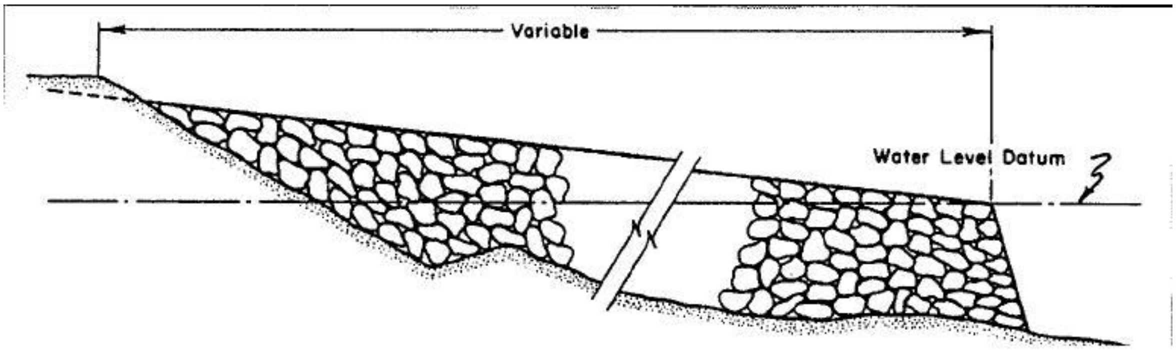


Figure IV-17. Typical Terminal Groin Profile

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).

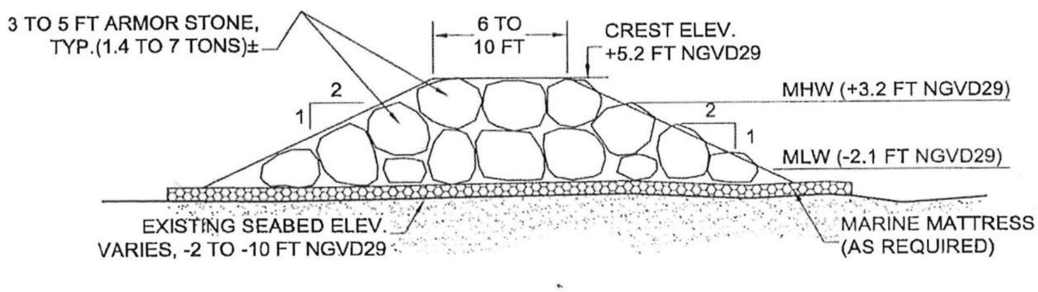
3. Permeability

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 IV-18 illustrates the difference between Amelia Island (permeable groin) and a typical rubble mound groin.



Amelia Island Typical Cross-Section

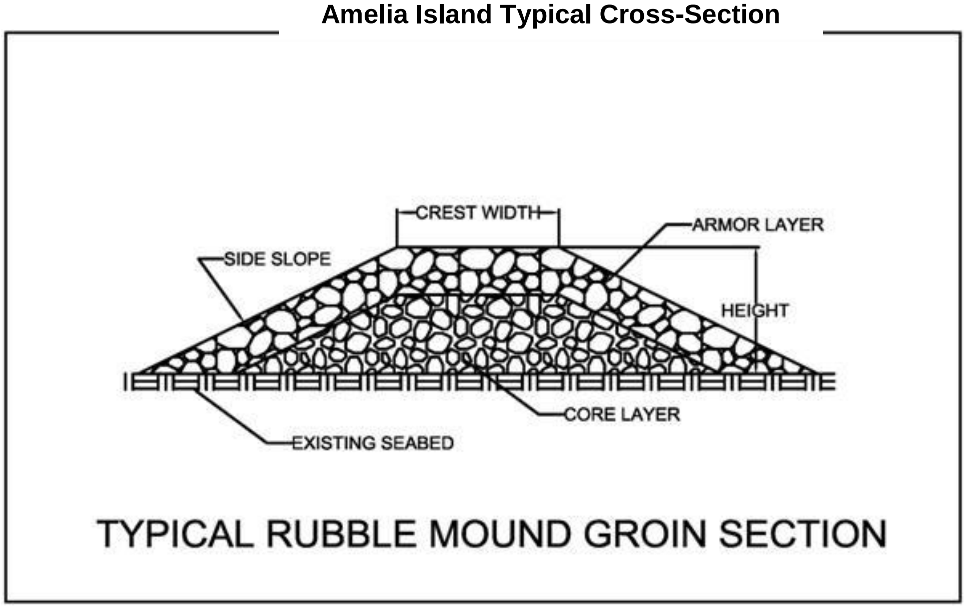


Figure IV-18. Permeable Groin vs. Typical Groin

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 IV-19. 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.

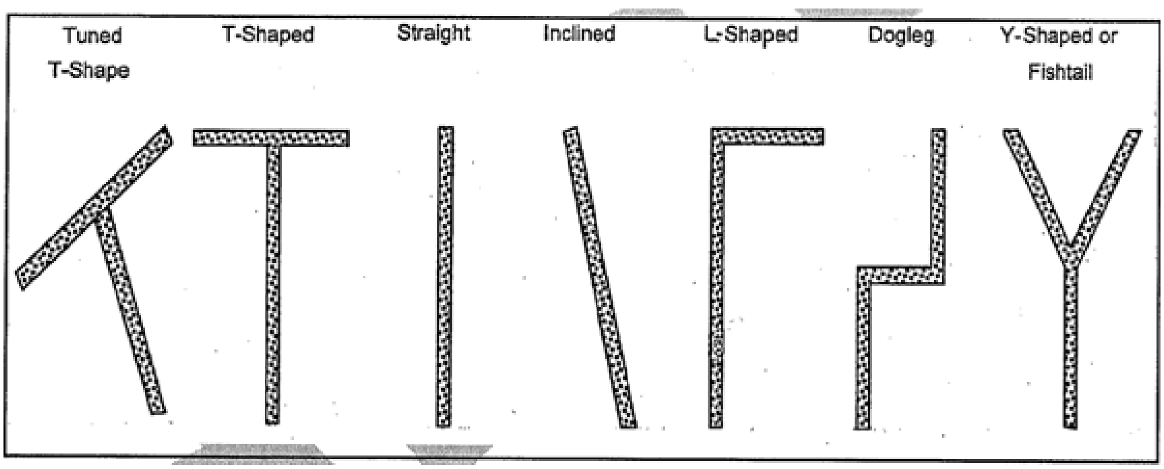


Figure IV-19. Possible Groin Configurations (taken from USACE Coastal Engineering Manual, 2002)

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 IV-20 illustrates an example of concrete sheet piles. Given the application environment and the need for a cantilever installation, it is expected that a terminal groin made of concrete panels would be limited to water depths of 10 ft or less.

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 IV-21 shows some examples of different concrete armor units.

Figure IV-20. Example of Concrete Sheet Piles

Figure IV-21. 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 IV-22 illustrates an example of a steel sheet pile terminal groin. Given the application environment and the need for a cantilever installation, it is expected that a terminal groin made of steel sheet piling would be limited to water depths of 15 ft or less.

Figure IV-22. 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).

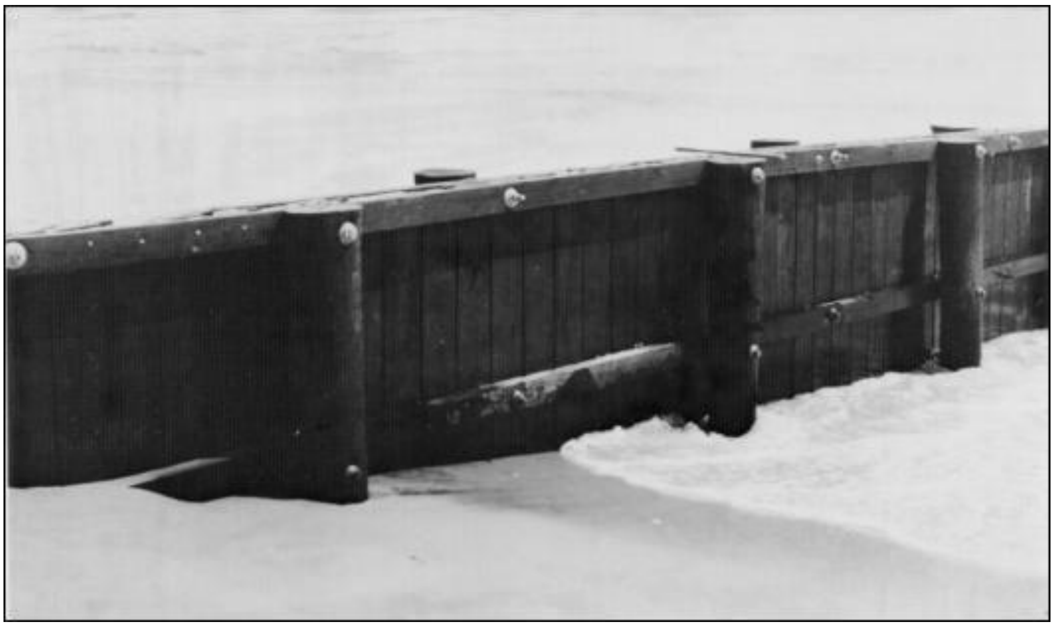


Figure IV-23. Example of a Timber Groin

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). Given the application environment and the need for a cantilever installation, it is expected that a terminal groin made of timber would be limited to water depths of 6-8 ft or less.

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 IV-24 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. Given the application environment, it is expected that a terminal groin made of geotextile tubing would be limited to water depths of 6 ft or less.

Figure IV-24. Example of a Geotextile Tube

6. Alternative Construction 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).

Figure IV-25 Example of Notched Groins (New Jersey DEP Website)

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 (Figure IV-25). 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).

In addition to groin notching, the selection of material type has a great deal to do with how adaptable the structure can be. For example, steel or concrete sheet piling would allow the opportunity to lower various sections by notching even after initial construction. These types of sheet pile structures would also allow for complete removal of the structure if unacceptable impacts were to occur. While rock structures can be removed, the marine environment and the weight of the armor units would likely cause 100% removal of the structure to be unattainable; especially in deeper water where the armor units may settle into the substrate.

Lastly, as stated previously, terminal groins made of rock are also now being constructed with only armor units to increase their permability. The lack of an impermeable core allows more wave energy and hence sediment to pass through the structure. Nonetheless, the elevation of the impermeable core within the structure could also be adjusted to change the overall permeability of the structure.

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.

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 shorter, mid to shallow-water groins; however, these materials tend to be cost-prohibitive. Timber and geotextile groins are less expensive alternatives and can be adapted to a variety of beach conditions. Concrete, steel, and timber structures have the advantage of being adjustable with the beach profile without having to rebuild or remodel the groin. However, timber and geotextile structures cannot withstand the loads experienced with deep-water groins and should not be used in these applications.

Groin notching is an emerging technique that allows for adaptive management. 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 smaller compared to the overall magnitude of sediment transport and the muted impacts seen both updrift and downdrift of the inlet. There also seems to be a threshold that appears with both length and height to be crossed where adjacent impacts become more pronounced. While it is possible that dredging impacts may be responsible for this threshold crossing, it underlies the importance to considering the overall length of the structure in relation to the exterior man-made and natural processes that also drive sediment transport so that the structure's relative effects are minimized or eliminated.

Finally, the permeability of the structure has a significant impact on adjacent shorelines. Based on the results from Section II, one can see that the Amelia Island structure has allowed material to bypass the structure. 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 after the first 0.5 mile. The other structures have impermeable cores and appear to hold more sand for a greater distance updrift of the structure.

V. Economic Assessment

A. Overview of Economic Considerations

The potential economic impact to State and local governments, and the 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 coastal risks are often calculated over this time period, a 30-year risk time period was used in the economic assessment. Additionally, as a means to assess the immediate and current property imminently at risk the value of properties and infrastructure with sandbags in place for temporary protection was evaluated.

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) and the imminent risk properties (IRPs) 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
* Lockwood 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.

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 V-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. The 30-yr risk line shown on Bald Head Island at the Cape Fear River Inlet still requires adjustment, however, most of the suspect region encompassed is part of a golf course and should not adversely impact the economic assessment performed in this study. The risk lines are a result of examining the historic shorelines around the inlets to determine a designation of risk that is approximately equal to the level of risk indicated by the setbacks in adjacent oceanfront areas. These lines were agreed upon by the Science Panel for use in this assessment since they represent the best currently available data.

3. Imminent Risk Properties (IRPs)

In order to provide some assessment of the current or imminently at risk property and infrastructure due to potential erosion from shifting inlets, the DCM sandbag database (2008) was used to identify properties and infrastructure that have temporary sandbag protection. The database is not all inclusive and may have some sandbags in its records that are presently buried or removed, but it provides a means to select properties at more imminent or current risk rather than over a 30-year period. Properties and infrastructure located immediately adjacent to erosion control sandbags locations or between two nearby sandbag locations were considered to be IRPs. Sandbag locations on ocean-facing or inlet-facing beaches within the 30YRAs were considered to be inlet IRPs. The economic value associated with these properties and infrastructure is tabulated for each side of the inlets in Section V-B.

4. 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
* Property tax base and revenues
* 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 V-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, the most recent assessed value was simply used as the 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 and IRPs 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, the existing values of the structures in their current locations are simply presented. 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 and IRPs 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 and IRPs 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 and IRPs. These plans typically contain maps of water and sewer infrastructure locations. In general, water lines run along all streets in the 30YRAs and IRPs. As a result, the length (feet) of road infrastructure within each 30YRA or IRP 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 and IRPs. In general, sewer lines run along all streets in the 30YRAs and IRPs. As a result, the length (feet) of road infrastructure within each 30YRA or IRP 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.

e) Tax Values

The property tax base and property tax revenues originating from within each 30YRA and IRPs were determined based on the residential and commercial property values located within each 30YRA or for each IRP and the property tax rates applicable within in the respective county or municipality. 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 (NCDR 2009a). 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 were divided by $100 and then multiplied by the applicable tax rate to estimate property tax revenues originating from within each 30YRA or for the IRPs. To help put these values into perspective, the total assessed tax value (tax base) of all properties within each county and municipality containing 30YRAs and IRPs is presented for the fiscal 2007-2008 tax year. These values are presented in the tables in Section V-B.

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). Also the economic value of property and infrastructure imminently at risk is presented in a separate table.

Table V-1 through Table V-24 present components of economic value within the 30YRAs and for the IRPs for each side of each inlet (excluding Oregon Inlet). Figure V-1 through Figure V-12 shows the 30 year risk line used for the economic evaluation at each inlet (excluding Oregon Inlet) and the location of sandbags given in the DCM database.

Following the figures and tables is a special discussion of economic value at risk to shifting of Oregon Inlet.

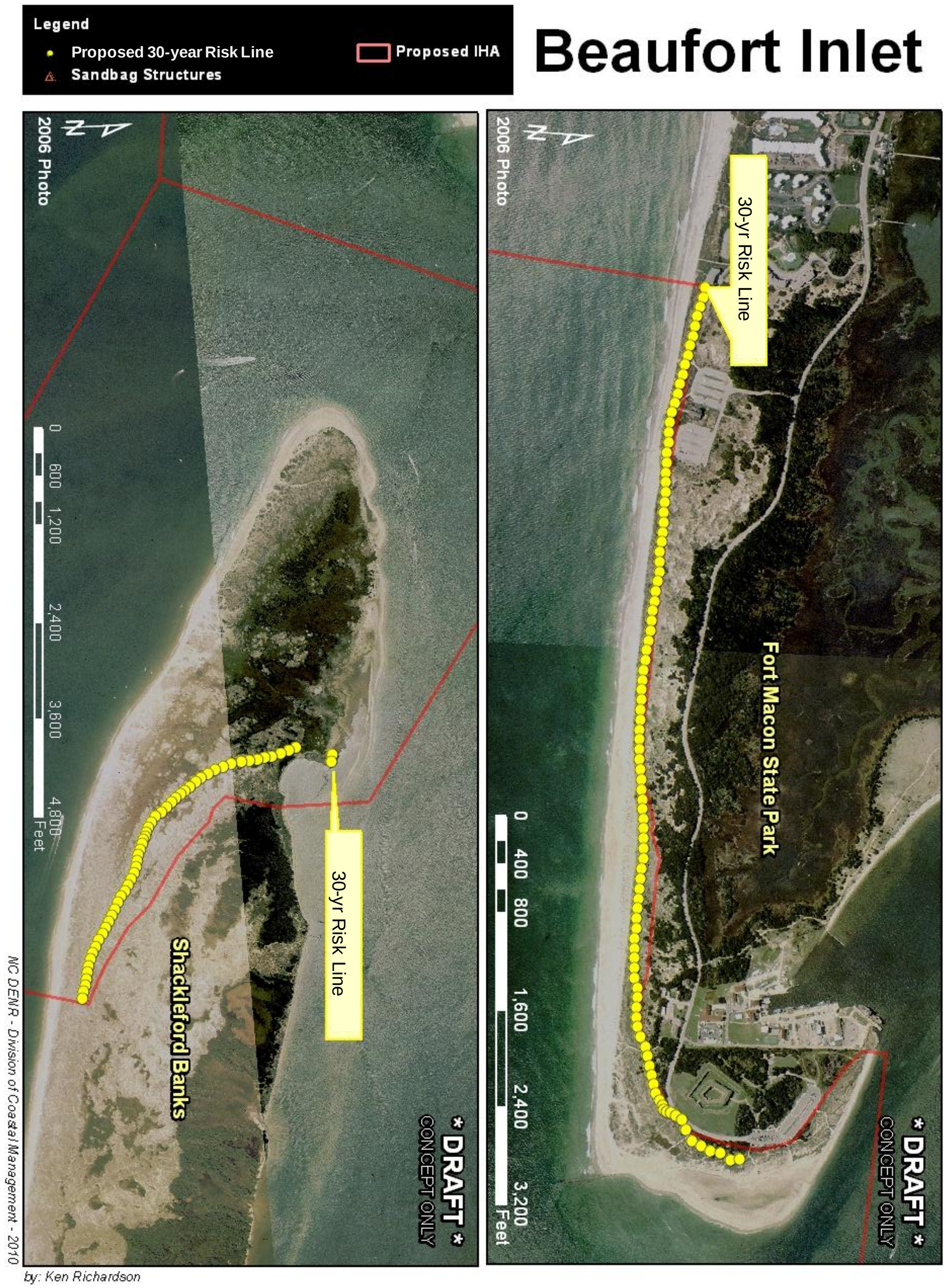


Figure V-1. 30-yr Risk Line and Sandbags at Beaufort Inlet

Table V-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)**

Property Tax Base within 30-yr Risk Lines	Zero (exempt, state property)	Zero (exempt, fed. property)
Property Tax Revenue within 30-yr Risk Lines	Zero (exempt, state property)	Zero (exempt, fed. property)
Municipal Property Tax Base	Tax Exempt (Fort Macon State Park)	Tax Exempt (National Seashore)
County Property Tax Base	$17.5 billion (entire Carteret County)	

Table V-2. Economic Value at Imminent Risk (Sandbags) – 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.	None (undeveloped island)
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Commercial Property Value		
Number of Parcels	None.	None (undeveloped island)
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None.	None (undeveloped island)
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	None.	None (undeveloped island)
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Waterline Infrastructure Value		
Type	None.	None (undeveloped island)
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Sewer Infrastructure Value		
Type	None.	None (undeveloped island)
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
GRAND TOTAL VALUE	**None.**	**None (undeveloped island)**

Property Tax Base of IRPs	Zero (exempt, state property)	Zero (exempt, fed. property)
Property Tax Revenue of IRPs	Zero (exempt, state property)	Zero (exempt, fed. property)
Municipal Property Tax Base	Tax Exempt (Fort Macon State Park)	Tax Exempt (National Seashore)
County Property Tax Base	$17.5 billion (entire Carteret County)	

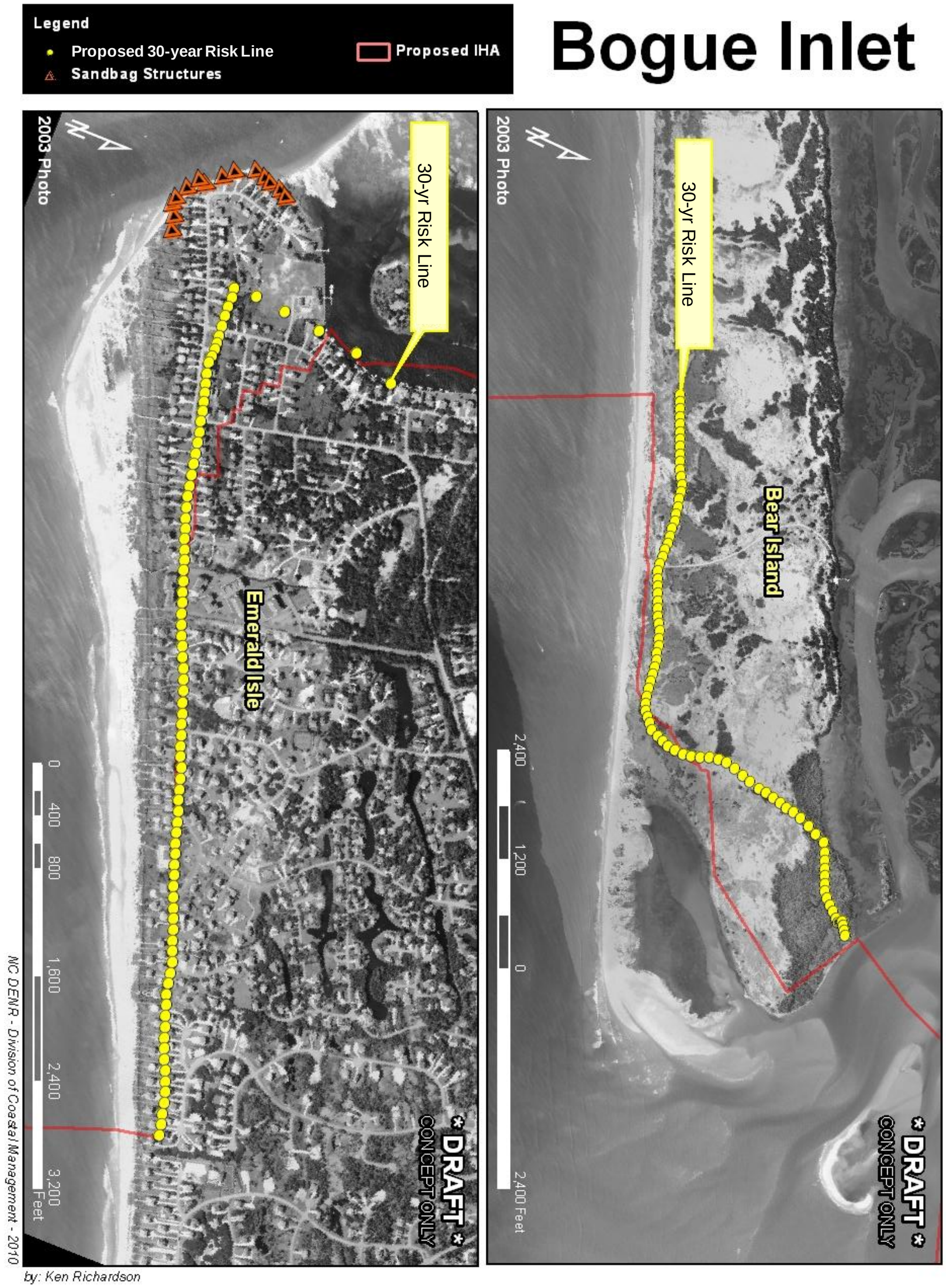


Figure V-2. 30-yr Risk Line and Sandbags at Bogue Inlet

Table V-3. 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**

Property Tax Base within 30-yr Risk Lines	Zero (exempt, state property)	$89,450,000
Property Tax Revenue within 30-yr Risk Lines	Zero (exempt, state property)	$265,667 annually
Municipal Property Tax Base	Tax Exempt (Hammocks Beach State Park)	$4.23 billion (Emerald Isle)
County Property Tax Base	$9.7 billion (entire Onslow County)	$17.5 billion (entire Carteret County)

Table V-4. Economic Value at Imminent Risk (Sandbags) – 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)	13 SFR
Land Value	-----	$10,676,000
Structure Value	-----	$3,523,000
Other Value	-----	$176,000
Total Value	-----	$14,375,000
Commercial Property Value		
Number of Parcels	None (undeveloped island)	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None (undeveloped island)	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	None (undeveloped island)	None.
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Waterline Infrastructure Value		
Type	None (undeveloped island)	None.
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Sewer Infrastructure Value		
Type	None (undeveloped island)	None.
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
GRAND TOTAL VALUE	**None (undeveloped island)**	**$14,375,000**

Property Tax Base of IRPs	Zero (exempt, state property)	$14,375,000
Property Tax Revenue of IRPs	Zero (exempt, state property)	$42,694 annually
Municipal Property Tax Base	Tax Exempt (Hammocks Beach State Park)	$4.23 billion (Emerald Isle)
County Property Tax Base	$9.7 billion (entire Onslow County)	$17.5 billion (entire Carteret County)

SFR = Single family residences.

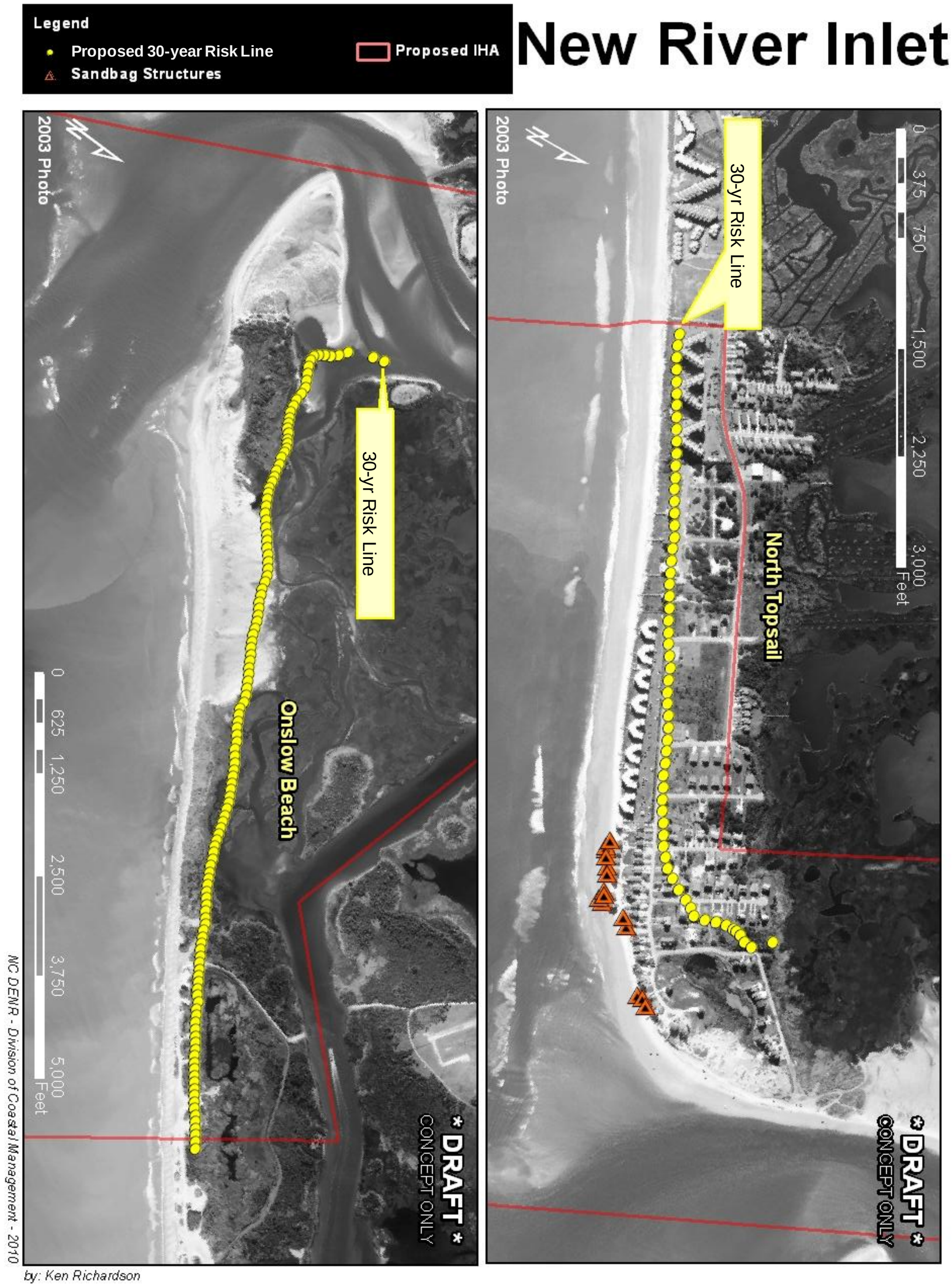


Figure V-3. 30-yr Risk Line and Sandbags at New River Inlet

Table V-5. 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**

Property Tax Base within 30-yr Risk Lines	None (undev. military land)	$66,817,693
Property Tax Revenue within 30-yr Risk Lines	None (undev. military land)	$443,001 annually
Municipal Property Tax Base	Tax Exempt (military)	$1.50 billion (North Topsail Beach)
County Property Tax Base	$9.7 billion (entire Onslow County)	

Table V-6. Economic Value at Imminent Risk (Sandbags) – 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)	37 parcels (of which 15 have structures)
Land Value	-----	$1,328,850
Structure Value	-----	$1,556,901
Other Value	-----	$28,460
Total Value	-----	$2,914,211
Commercial Property Value		
Number of Parcels	None (undev. military land)	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None (undev. military land)	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	None (undev. military land)	None.
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Waterline Infrastructure Value		
Type	None (undev. military land)	None.
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Sewer Infrastructure Value		
Type	None (undev. military land)	None.
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
GRAND TOTAL VALUE	**None (undev. military land)**	**$2,914,211**

Property Tax Base of IRPs	Exempt	$2,914,211
Property Tax Revenue of IRPs	Exempt	$19,322 annually
Municipal Property Tax Base	Tax Exempt (military)	$1.50 billion (North Topsail Beach)
County Property Tax Base	$9.7 billion (entire Onslow County)	

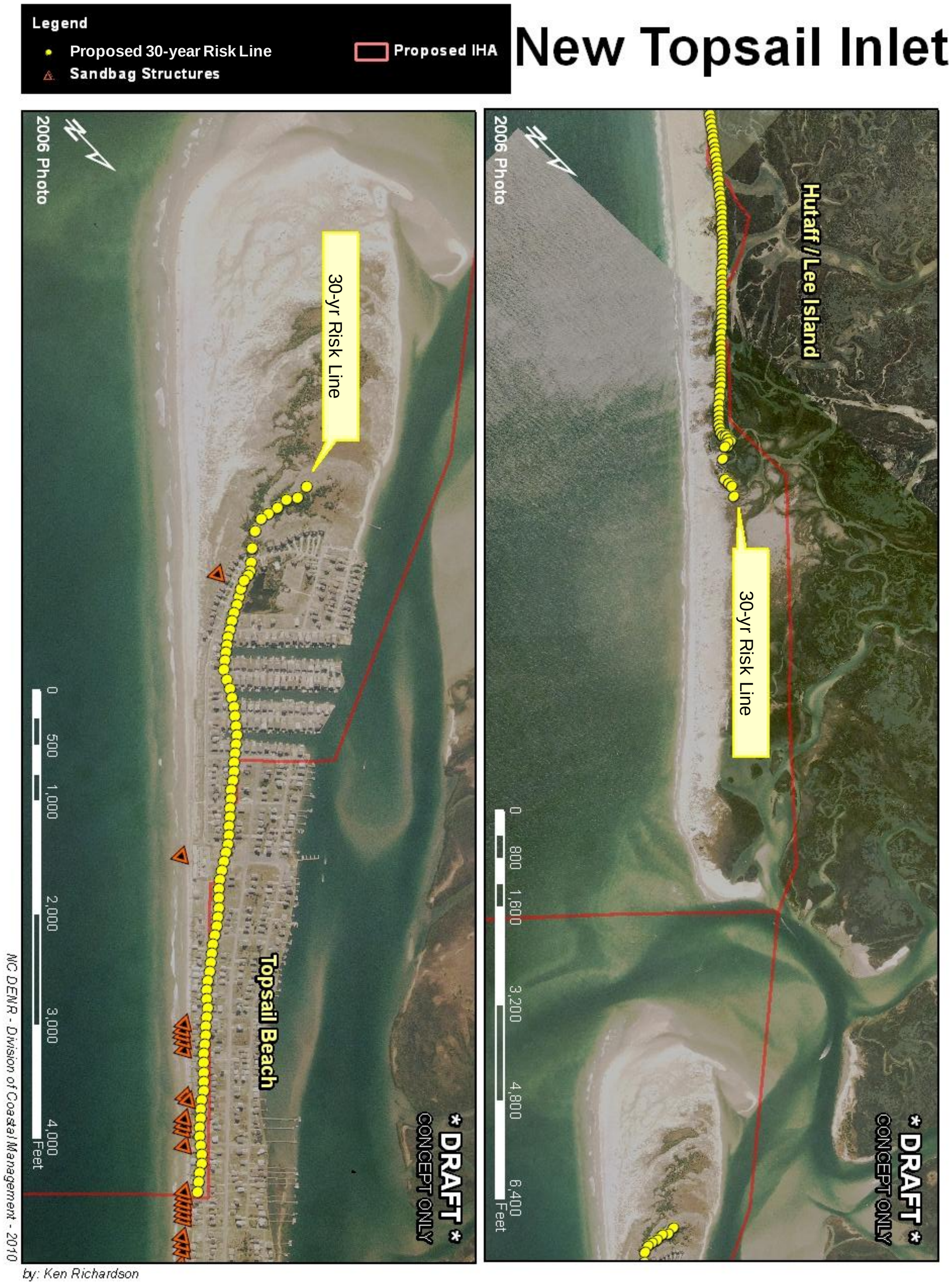


Figure V-4. 30-yr Risk Line and Sandbags at New Topsail Inlet

Table V-7. 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)**

Property Tax Base within 30-yr Risk Lines	$33,279,000	None (undeveloped island)
Property Tax Revenue within 30-yr Risk Lines	$342,774 annually	None (undeveloped island)
Municipal Property Tax Base	$0.42 billion (Topsail Beach)	$608,000 (Lea-Hutaff Island)
County Property Tax Base	$3.8 billion (entire Pender County)	

Table V-8. Economic Value at Imminent Risk (Sandbags) – 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	21 SFR & duplexes plus 36 condo units	None (undeveloped island)
Land Value	$5,735,000	-----
Structure Value	$3,213,000	-----
Other Value	$0	-----
Total Value	$8,949,000	-----
Commercial Property Value		
Number of Parcels	None.	None (undeveloped island)
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None.	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)	755	-----
Replacement Cost / ft	$568	-----
Total Value	$429,000	-----
Waterline Infrastructure Value		
Type	Typical.	None (undeveloped island)
Length (ft)	755	-----
Replacement Cost / ft	$55	-----
Total Value	$42,000	-----
Sewer Infrastructure Value		
Type	Typical.	None (undeveloped island)
Length (ft)	755	-----
Replacement Cost / ft	$150	-----
Total Value	$113,000	-----
GRAND TOTAL VALUE	**$9,533,000**	**None (undeveloped island)**

Property Tax Base of IRPs	$8,949,000	None (undeveloped island)
Property Tax Revenue of IRPs	$92,175 annually	None (undeveloped island
Municipal Property Tax Base	$0.42 billion (Topsail Beach)	$608,000 (Lea-Hutaff Island)
County Property Tax Base	$3.8 billion (entire Pender County)	

SFR = Single Family Residences.

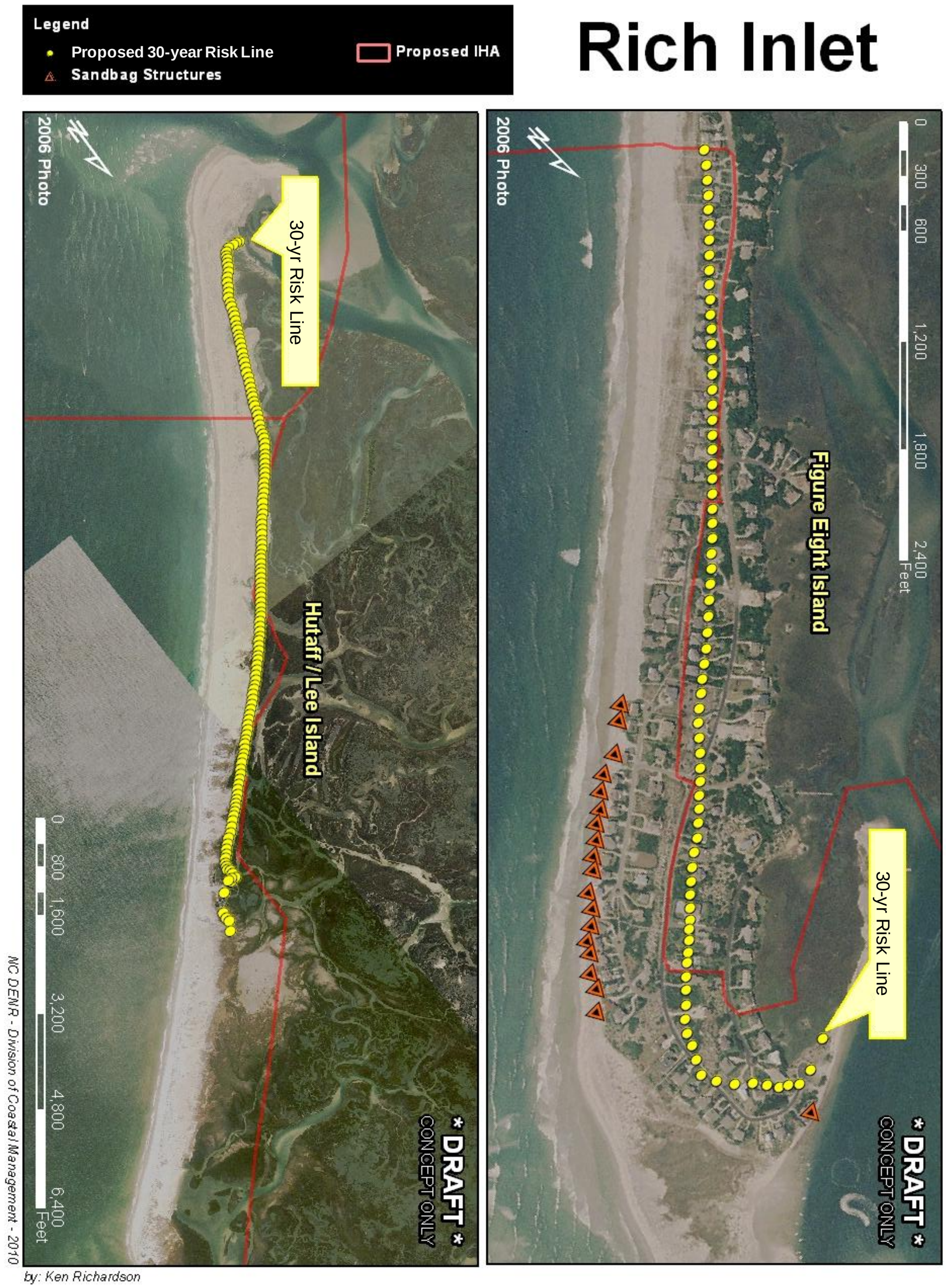


Figure V-5. 30-yr Risk Line and Sandbags at Rich Inlet

Table V-9. 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**

Property Tax Base within 30-yr Risk Lines	None (undeveloped island)	$163,186,000
Property Tax Revenue within 30-yr Risk Lines	None (undeveloped island)	$685,381 annually
Municipal Property Tax Base	$608,000 (Lea-Hutaff Island)	$1.20 billion (Figure Eight Island)
County Property Tax Base	$3.8 billion (entire Pender County)	$29.1 billion (entire New Hanover County)

Table V-10. Economic Value at Imminent Risk (Sandbags) – 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)	21 SFR
Land Value	-----	$14,854,000
Structure Value	-----	$11,114,000
Other Value	-----	$0
Total Value	-----	$25,968,000
Commercial Property Value		
Number of Parcels	None (undeveloped island)	None in EHA.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None (undeveloped island)	None in EHA.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	None (undeveloped island)	None in EHA.
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Waterline Infrastructure Value		
Type	None (undeveloped island)	None in EHA.
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Sewer Infrastructure Value		
Type	None (undeveloped island)	None in EHA.
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
GRAND TOTAL VALUE	**None (undeveloped island)**	**$25,968,000**

Property Tax Base of IRPs	None (undeveloped island)	$25,968,000
Property Tax Revenue of IRPs	None (undeveloped island)	$109,066 annually
Municipal Property Tax Base	$608,000 (Lea-Hutaff Island)	$1.20 billion (Figure Eight Island)
County Property Tax Base	$3.8 billion (entire Pender County)	$29.1 billion (entire New Hanover County)

SFR = Single Family Residences.

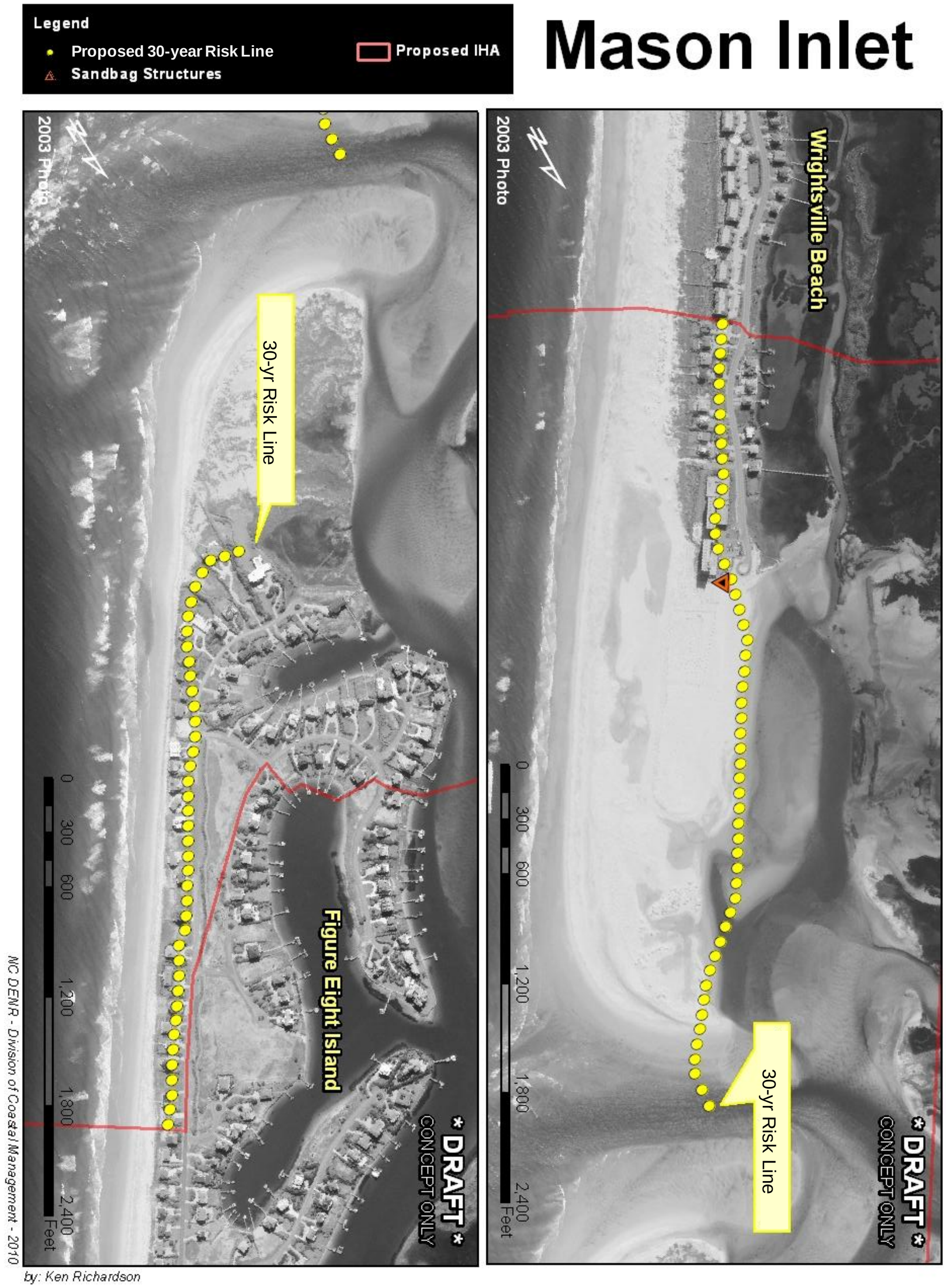


Figure V-6. 30-yr Risk Line and Sandbags at Mason Inlet

Table V-11. 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**

Property Tax Base within 30-yr Risk Lines	$46,408,941	$84,710,027
Property Tax Revenue within 30-yr Risk Lines	$194,918 annually	$409,488 annually
Municipal Property Tax Base	$1.20 billion (Figure Eight Island)	$3.22 billion (Wrightsville Beach)
County Property Tax Base	$29.1 billion (entire New Hanover County)	

Table V-12. Economic Value at Imminent Risk (Sandbags) – 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	None.	None. (Sandbag shown is remnant from before inlet relocation)
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Commercial Property Value		
Number of Parcels	None.	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None.	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	None.	None.
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Waterline Infrastructure Value		
Type	None.	None.
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Sewer Infrastructure Value		
Type	None.	None.
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
GRAND TOTAL VALUE	**None.**	**None.**

Property Tax Base of IRPs	None.	None.
Property Tax Revenue of IRPs	None.	None.
Municipal Property Tax Base	$1.20 billion (Figure Eight Island)	$3.22 billion (Wrightsville Beach)
County Property Tax Base	$29.1 billion (entire New Hanover County)	

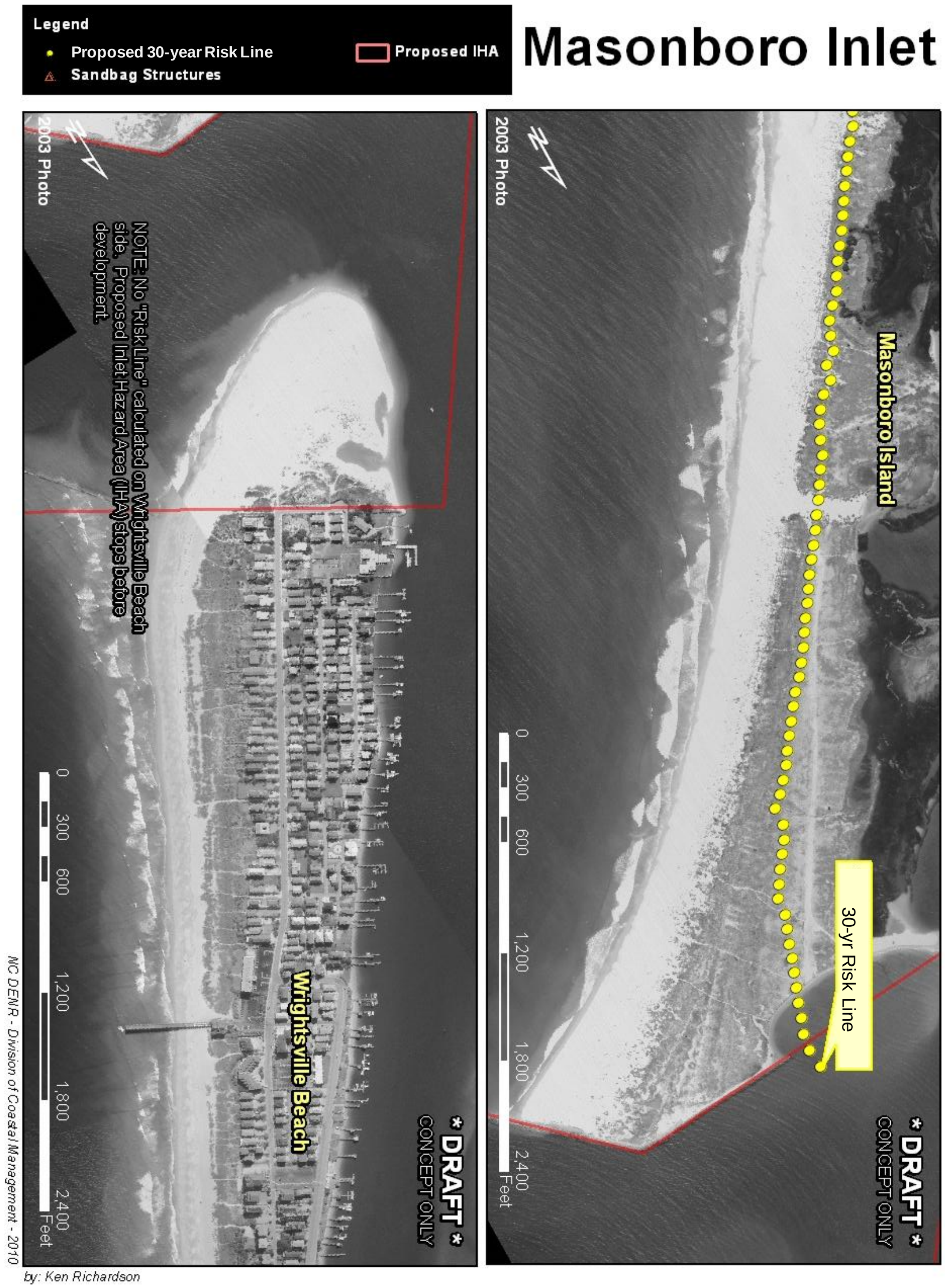


Figure V-7. 30-yr Risk Line and Sandbags at Masonboro Inlet

Table V-13. 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)**

Property Tax Base within 30-yr Risk Lines	None w/n 30-yr Risk Lines.	None (undeveloped island)
Property Tax Revenue within 30-yr Risk Lines	None w/n 30-yr Risk Lines.	None (undeveloped island)
Municipal Property Tax Base	$3.22 billion (Wrightsville Beach)	Tax Exempt (Nature Preserve)
County Property Tax Base	$29.1 billion (entire New Hanover County)	

Table V-14. Economic Value at Imminent Risk (Sandbags) – 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.	None (undeveloped island)
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Commercial Property Value		
Number of Parcels	None.	None (undeveloped island)
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None.	None (undeveloped island)
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	None.	None (undeveloped island)
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Waterline Infrastructure Value		
Type	None.	None (undeveloped island)
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Sewer Infrastructure Value		
Type	None.	None (undeveloped island)
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
GRAND TOTAL VALUE	**None.**	**None (undeveloped island)**

Property Tax Base of IRPs	None.	None (undeveloped island)
Property Tax Revenue of IRPs	None.	None (undeveloped island)
Municipal Property Tax Base	$3.22 billion (Wrightsville Beach)	Tax Exempt (Nature Preserve)
County Property Tax Base	$29.1 billion (entire New Hanover County)	

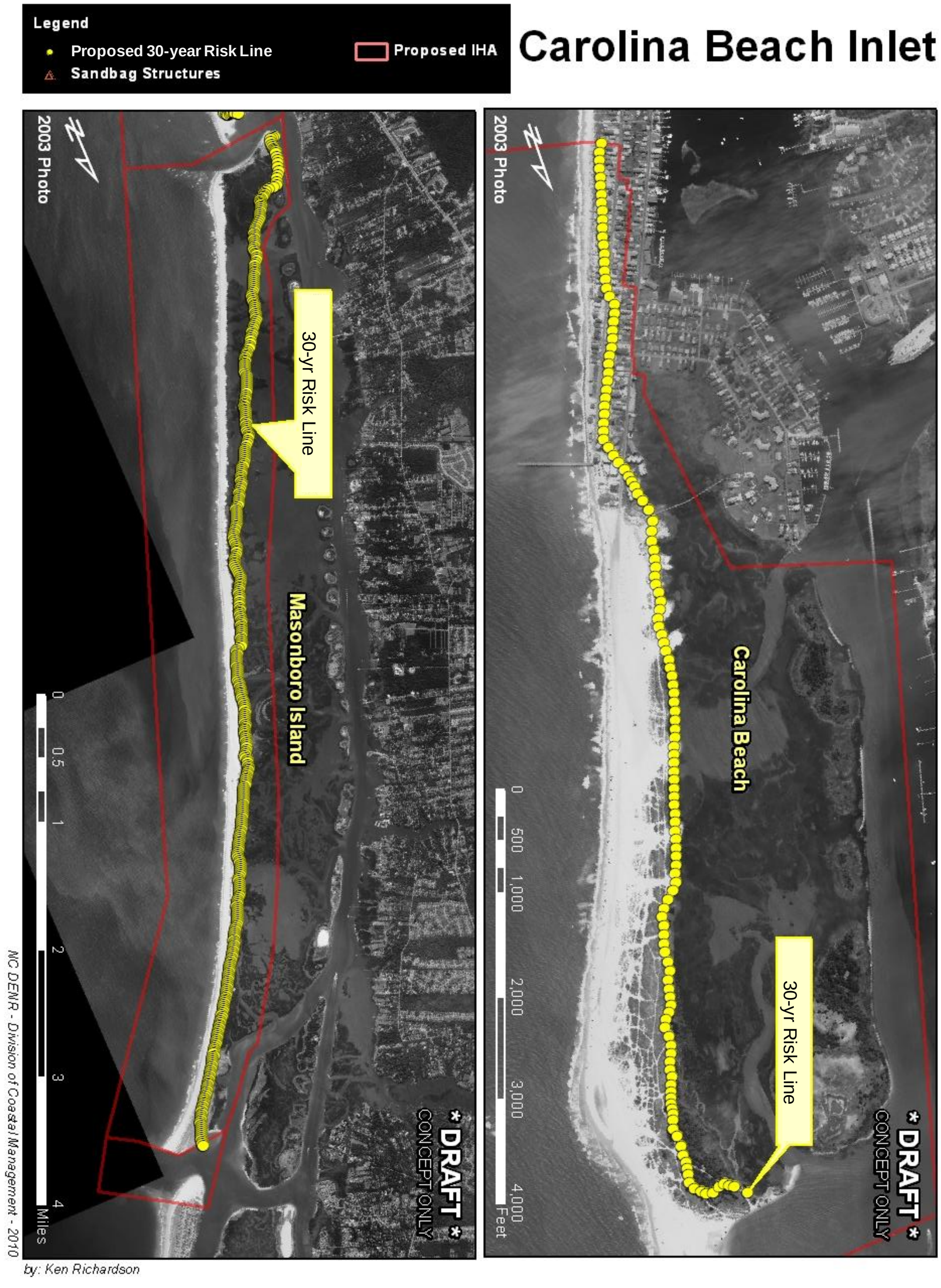


Figure V-8. 30-yr Risk Line and Sandbags at Carolina Beach Inlet

Table V-15. 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**

Property Tax Base within 30-yr Risk Lines	None (undeveloped island)	$34,729,000
Property Tax Revenue within 30-yr Risk Lines	None (undeveloped island)	$206,638 annually
Municipal Property Tax Base	Tax Exempt (Nature Preserve)	$2.38 billion (Carolina Beach)
County Property Tax Base	$29.1 billion (entire New Hanover County)	

Table V-16. Economic Value at Imminent Risk (Sandbags) – 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)	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Commercial Property Value		
Number of Parcels	None (undeveloped island)	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None (undeveloped island)	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	None (undeveloped island)	None.
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Waterline Infrastructure Value		
Type	None (undeveloped island)	None.
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
Sewer Infrastructure Value		
Type	None (undeveloped island)	None.
Length (ft)	-----	-----
Replacement Cost / ft	-----	-----
Total Value	-----	-----
GRAND TOTAL VALUE	**None (undeveloped island)**	**None.**

Property Tax Base of IRPs	None (undeveloped island)	None.
Property Tax Revenue of IRPs	None (undeveloped island)	None.
Municipal Property Tax Base	Tax Exempt (Nature Preserve)	$2.38 billion (Carolina Beach)
County Property Tax Base	$29.1 billion (entire New Hanover County)	

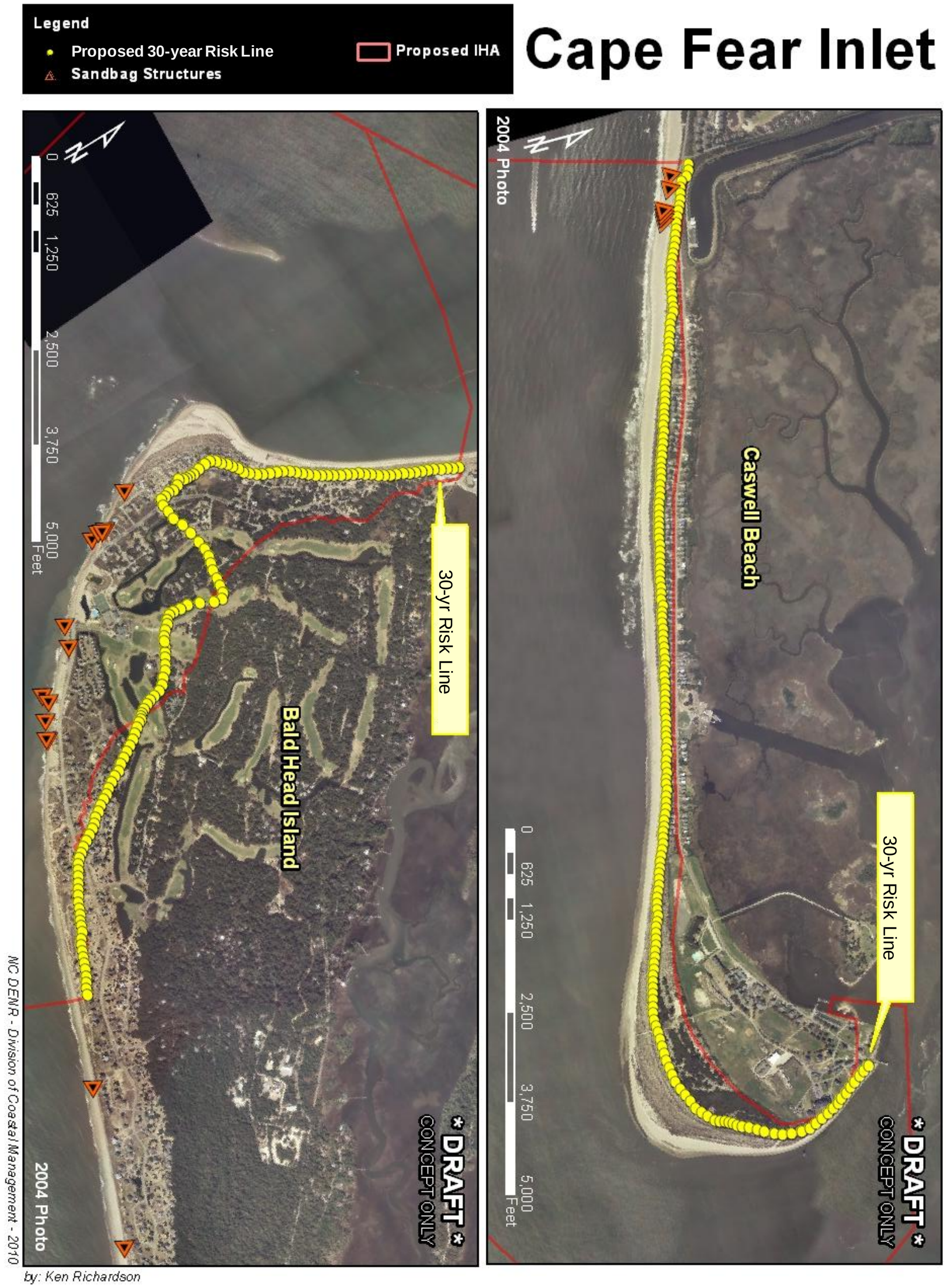


Figure V-9. 30-yr Risk Line and Sandbags at Cape Fear Inlet
(Note: Draft 30-year risk line subject to revision)

Table V-17. 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 (Bald Head 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**

Property Tax Base within 30-yr Risk Lines	$108,873,000	$312,220,000
Property Tax Revenue within 30-yr Risk Lines	$495,372 annually	$1,826,487 annually
Municipal Property Tax Base	$0.41 billion (Caswell Beach)	$1.96 billion (Bald Head Island)
County Property Tax Base	$28.6 billion (entire Brunswick County)	

Table V-18. Economic Value at Imminent Risk (Sandbags) – Cape Fear River Inlet

Value Type	West Side of Inlet (Caswell Beach side)	East Side of Inlet (Bald Head Island side)
Residential Property Value		
Number of Parcels	None.	22 SFR
Land Value	-----	$7,228,000
Structure Value	-----	$3,713,000
Other Value	-----	$27,000
Total Value	-----	$10,968,000
Commercial Property Value		
Number of Parcels	None.	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None.	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	None.	2-lane road w. 2' paved shoulders (no curb, gutter, parking or sidewalk)
Length (ft)	-----	1845
Replacement Cost / ft	-----	$568
Total Value	-----	$1,048,000
Waterline Infrastructure Value		
Type	None.	Typical
Length (ft)	-----	1845
Replacement Cost / ft	-----	$55
Total Value	-----	$101,000
Sewer Infrastructure Value		
Type	None.	Typical
Length (ft)	-----	1845
Replacement Cost / ft	-----	$150
Total Value	-----	$277,000
GRAND TOTAL VALUE	**None.**	**$12,394,000**

Property Tax Base of IRPs	None.	$10,968,000
Property Tax Revenue of IRPs	None.	$64,163 annually
Municipal Property Tax Base	$0.41 billion (Caswell Beach)	$1.96 billion (Bald Head Island)
County Property Tax Base	$28.6 billion (entire Brunswick County)	

SFR = Single family residences.

Figure V-10. 30-yr Risk Line and Sandbags at Lockwood Folly Inlet

Table V-19. Economic Value at Risk Within 30-yr Risk Lines at Lockwood 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**

Property Tax Base within 30-yr Risk Lines	$27,240,000	$109,900,000
Property Tax Revenue within 30-yr Risk Lines	$101,878 annually	$515,981 annually
Municipal Property Tax Base	$2.21 billion (Holden Beach)	$4.14 billion (Oak Island)
County Property Tax Base	$28.6 billion (entire Brunswick County)	

Table V-20. Economic Value at Imminent Risk (Sandbags) – Lockwood Folly Inlet

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

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

SFR = Single family residences.

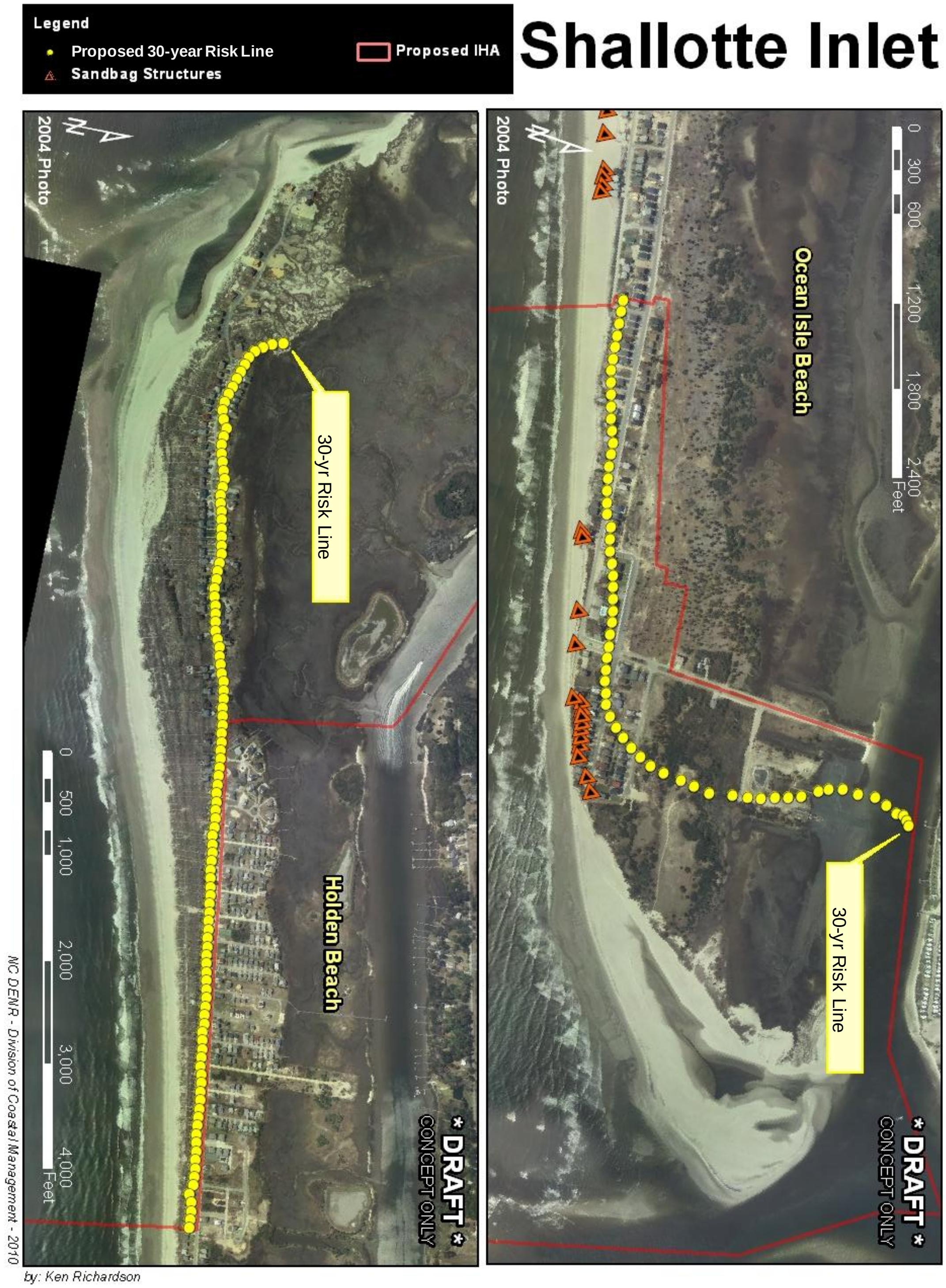


Figure V-11. 30-yr Risk Line and Sandbags at Shallotte Inlet

Table V-21. 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**

Property Tax Base within 30-yr Risk lines	$25,069,000	$273,855,000
Property Tax Revenue within 30-yr Risk lines	$96,516 annually	$1,024,218 annually
Municipal Property Tax Base	$2.61 billion (Ocean Isle Beach)	$2.21 billion (Holden Beach)
County Property Tax Base	$28.6 billion (entire Brunswick County)	

Table V-22. Economic Value at Imminent Risk (Sandbags) – Shallotte Inlet

Value Type	West Side of Inlet (Ocean Isle side)	East Side of Inlet (Holden Beach side)
Residential Property Value		
Number of Parcels	24 SFR	None.
Land Value	$1,546,000	-----
Structure Value	$1,002,000	-----
Other Value	$20,000	-----
Total Value	$2,569,000	-----
Commercial Property Value		
Number of Parcels	None.	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None.	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	2-lane road w. 2' paved shoulders (no curb, gutter, parking or sidewalk)	None.
Length (ft)	2055	-----
Replacement Cost / ft	$568	-----
Total Value	$1,167,000	-----
Waterline Infrastructure Value		
Type	Typical	None.
Length (ft)	2055	-----
Replacement Cost / ft	$55	-----
Total Value	$113,000	-----
Sewer Infrastructure Value		
Type	Typical	None.
Length (ft)	2055	-----
Replacement Cost / ft	$150	-----
Total Value	$308,000	-----
GRAND TOTAL VALUE	**$4,157,000**	**None.**

Property Tax Base of IRPs	$2,569,000	None.
Property Tax Revenue of IRPs	$9,891 annually	None.
Municipal Property Tax Base	$2.61 billion (Ocean Isle Beach)	$2.21 billion (Holden Beach)
County Property Tax Base	$28.6 billion (entire Brunswick County)	

SFR = Single family residences.

Figure V-12. 30-yr Risk Line and Sandbags at Tubbs Inlet

Table V-23. 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**

Property Tax Base within 30-yr Risk Lines	None w/n 30-yr Risk Lines.	$35,966,000
Property Tax Revenue within 30-yr Risk Lines	None w/n 30-yr Risk Lines.	$138,469 annually
Municipal Property Tax Base	$2.05 billion (Sunset Beach)	$2.61 billion (Ocean Isle Beach)
County Property Tax Base	$28.6 billion (entire Brunswick County)	

Table V-24. Economic Value at Imminent Risk (Sandbags) – 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.	3 SFR
Land Value	-----	$4,464,000
Structure Value	-----	$1,752,000
Other Value	-----	$184,000
Total Value	-----	$6,400,000
Commercial Property Value		
Number of Parcels	None.	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Government Property Value		
Number of Parcels	None.	None.
Land Value	-----	-----
Structure Value	-----	-----
Other Value	-----	-----
Total Value	-----	-----
Road Infrastructure Value		
Type	None.	2-lane road w. 2' paved shoulders (no curb, gutter, parking or sidewalk)
Length (ft)	-----	192
Replacement Cost / ft	-----	$568
Total Value	-----	$109,000
Waterline Infrastructure Value	-----	
Type	None.	Typical
Length (ft)	-----	192
Replacement Cost / ft	-----	$55
Total Value	-----	$11,000
Sewer Infrastructure Value		
Type	None.	Typical
Length (ft)	-----	192
Replacement Cost / ft	-----	$150
Total Value	-----	$29,000
GRAND TOTAL VALUE	**None.**	**$6,549,000**

Property Tax Base of IRPs	None.	$6,400,000.
Property Tax Revenue of IRPs	None.	$24,640 annually
Municipal Property Tax Base	$2.05 billion (Sunset Beach)	$2.61 billion (Ocean Isle Beach)
County Property Tax Base	$28.6 billion (entire Brunswick County)	

SFR = Single family residences.

Oregon Inlet

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.

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) Bodie Island – Cape Hatteras National Seashore

The National Park Service administers the Cape Hatteras National Seashore (CAHA), our nation's first National Seashore, which includes and is adjacent to Oregon Inlet (National Park Service 2010a, 2010b). Hiking, bird watching, swimming and camping are allowed on Bodie Island. Fishing is also allowed, subject to fishing regulations including seasons, size limits and licensing requirements set by the North Carolina Division of Marine Fisheries. Off-road vehicles may be driven on designated portions of the beach. This site contains nationally significant natural and cultural resources and values that play a vital role in the state's ecosystem and local economies, and they are also home to many of the federally protected species that depend upon inlet shoreline habitat. For example, at CAHA, the inlet shorelines are among the few remaining areas where natural barrier island processes occur relatively unimpeded within the Seashore. As a result, the inlets within the Seashore have become even more important as protected wildlife habitat. See the environmental resources sections of this report for additional detail on ecological resources found within CAHA. See Whitehead (1993), for example, for estimates of economic value arising from non-game wildlife in beach and coastal wetland areas of North Carolina. National Park Service data show that in 2008 CAHA experienced 2.24 million visitors, supporting 2,243 local jobs and $211 million in regional economic output (National Park Service 2010b). If portions of CAHA were lost due to shifting inlets, some of this value might be lost. However, the inlet hazard areas are small relative to the total size of CAHA. On the other hand, if inlet habitat-dependent species were adversely affected by shifting inlets, CAHA might experience somewhat fewer visitors and provide less economic value supported by inlet-dependent non-game wildlife.

i) Pea Island National Wildlife Refuge – Cape Hatteras National Seashore

Pea Island National Wildlife Refuge (PINWR) is located in Dare County on the north end of Hatteras Island, adjacent to Oregon Inlet (http://www.fws.gov/peaisland/). PINWR is part of CAHA, but is administered by the U.S. Fish and Wildlife Service. PINWR supports a portion of the visitation and economic value reported in the Bodie Island -- Cape Hatteras National Seashore section of this report. Portions of PINWR 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). The 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. The 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. If Oregon Inlet were to erode southward, some beach area of PINWR could be lost, reducing the recreation value supported by PINWR; however, the lost area would likely be a small proportion of the entire PINWR.

j) Shackleford Banks - Cape Lookout National Seashore

Cape Lookout National Seashore (CALO) consists of 56 miles of undeveloped beach located on 4 barrier islands in North Carolina from Ocracoke Inlet on the northeast to Beaufort Inlet on the southeast (National Park Service 2010c). Shackleford Banks, one of the 4 CALO islands, is located on the north side of Beaufort Inlet. The undeveloped island is reachable only by boat. Passenger ferries depart from Morehead City, Beaufort, and Harkers Island. In 2008, CALO had 491,000 total visitors (National Park Service 2010c), of which some undetermined number visited Shackleford Banks. Wild horses live on Shackleford Banks, and viewing them is a common reason for visiting the island (National Park Service 2010d). Available by advance reservation, half-day and day-long horse watching trips are popular among wild-horse enthusiasts. Groups (usually organizations or classes) travel by charter ferry to Shackleford Banks where they are met by park rangers. Hiking, bird watching, swimming and camping are allowed on Shackleford Banks. Fishing is also allowed, subject to fishing regulations including seasons, size limits and licensing requirements set by the North Carolina Division of Marine Fisheries. Driving is not allowed on Shackleford Banks. No food, beverages, changing rooms, showers, trash cans or trash pickup service are available on Shackleford Banks. Composting-style toilets are located near the dock on the west end of the island. If Beaufort Inlet were to erode eastward, some beach area of Shackleford Banks could be lost; however, the lost area would likely be a small proportion of the entire island.

k) 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) (NCDPR 2009). 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.

A recent economic impact study of the NC State Park system (Greenwood and Vick 2008) found that in 2004, Fort Macon State Park had about 1.3 million visitors, of which over 300,000 (24 percent) resided outside the county and had visiting the park as the primary purpose of their trip to the area. These "primary purpose" visitors spent an estimated $12 million while visiting the region. If Beaufort Inlet were to erode westward toward the Fort, potentially large portions of the Park's beach recreation area could be lost, creating significant losses in recreation value.

l) 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) (NCDPR 2009). 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.

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.

A recent economic impact study of the NC State Park system (Greenwood and Vick 2008) found that in 2004, Hammocks Beach State Park had over 133,000 visitors, of which over 69,000 (52 percent) resided outside the county and had visiting the park as the primary purpose of their trip to the area. These "primary purpose" visitors spent an estimated $1.6 million while visiting the region. If Bogue Inlet were to erode south/westward, some portion of the beach area could be lost, reducing the recreation and wildlife habitat values supported by the island.

m) 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.

The Deputy Director of the North Carolina Audubon Society reports that recreational visitation information is unavailable for Lea-Hutaff Islands (Golder 2010). If New Topsail Inlet were to erode southward, or if Rich Inlet were to erode northward, then portions of the recreation and wildlife habitat values supported by the island could be lost.

n) 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. Reserve managers estimate that approximately 9,300 recreationists visited the island in 2009, with an additional 12 visits by a local ecotour business (Sutton 2010). If Masonboro Inlet were to erode southward, or if Carolina Beach inlet were to erode northward, then portions of the recreation and wildlife habitat values supported by the island could be lost.

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 values in excess of $100 Million within the 30YRAs (30 years) and in excess of $10 Million in IRPs (current), 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.

Beach and wetland areas adjacent to inlets can support significant recreation and environmental values. Recreation values include walking, shell collecting, sunbathing, swimming, surfing, birdwatching, hiking, camping, education, fishing, kayaking, and canoeing. Environmental values include juvenile fish and shellfish habitat (supporting recreational and commercial fishing industries), protected species habitat, rest and feeding areas for migrating birds, and water quality improvement and wave energy dissipation (wetland areas). In general, areas that are more unique in terms of recreational opportunities or environmental conditions or wildlife, relative to other barrier island locations in the region or nation, would be expected to have higher recreation and environmental values per unit of land area. Although studies have documented some recreation values for some North Carolina inlet areas (primarily beach recreation and shore fishing), other inlets are missing recreation value information, and some environmental values have not been assessed for N.C. inlet areas. As many environmental values are very site-specific, site-specific studies would be required to assess these values on a "for each side of each inlet" basis. Where available, results from studies of other barrier island areas in the southeastern United States have been provided to give a rough indication of the potential order of magnitude of some of these environmental values. If shifting inlets were to erode beach and wetland areas, some recreation and environmental value would be lost.

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VI. Initial Construction and Maintenance Costs

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 in the Southeast (VA, NC, and GA) with similar water depths and constructability issues in shallower water, 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 potential terminal groins in North Carolina with varying lengths and slopes.

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 VI-1 and Figure VI-2 show the range of structure depths which may be experienced along North Carolina shorelines and lead to the various unit costs per linear foot that were developed.

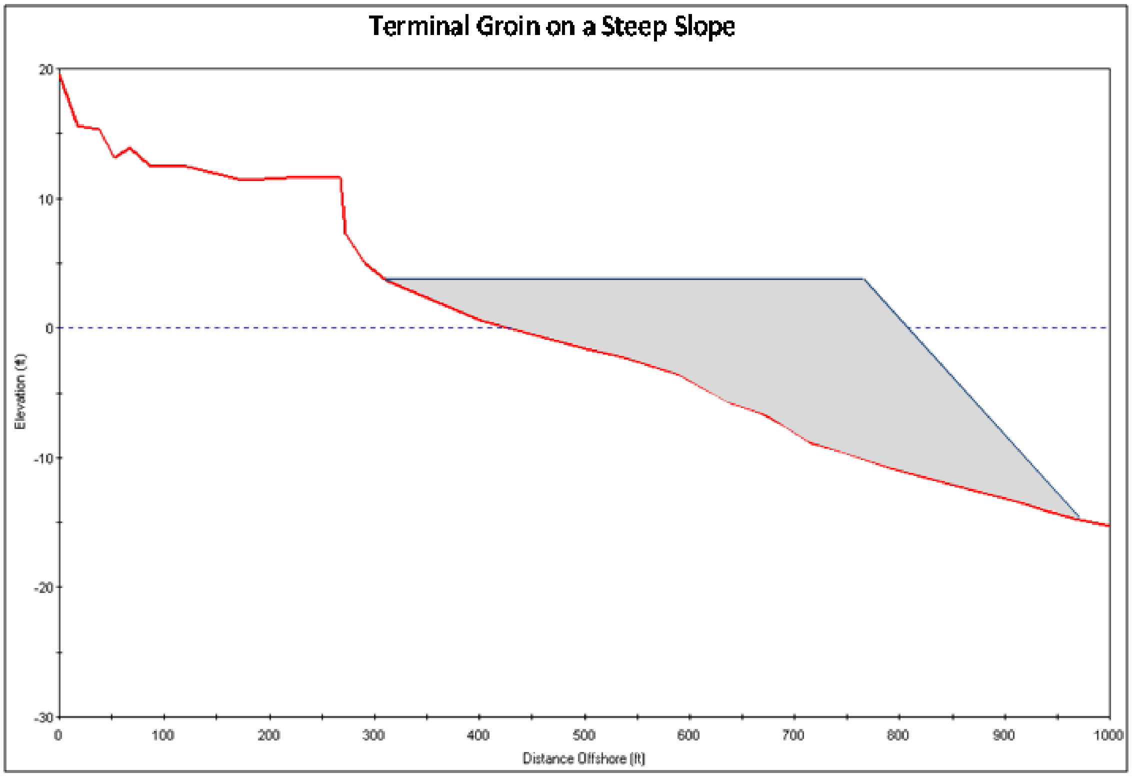

Figure VI-1. Terminal Groin Length along a Steep Slope

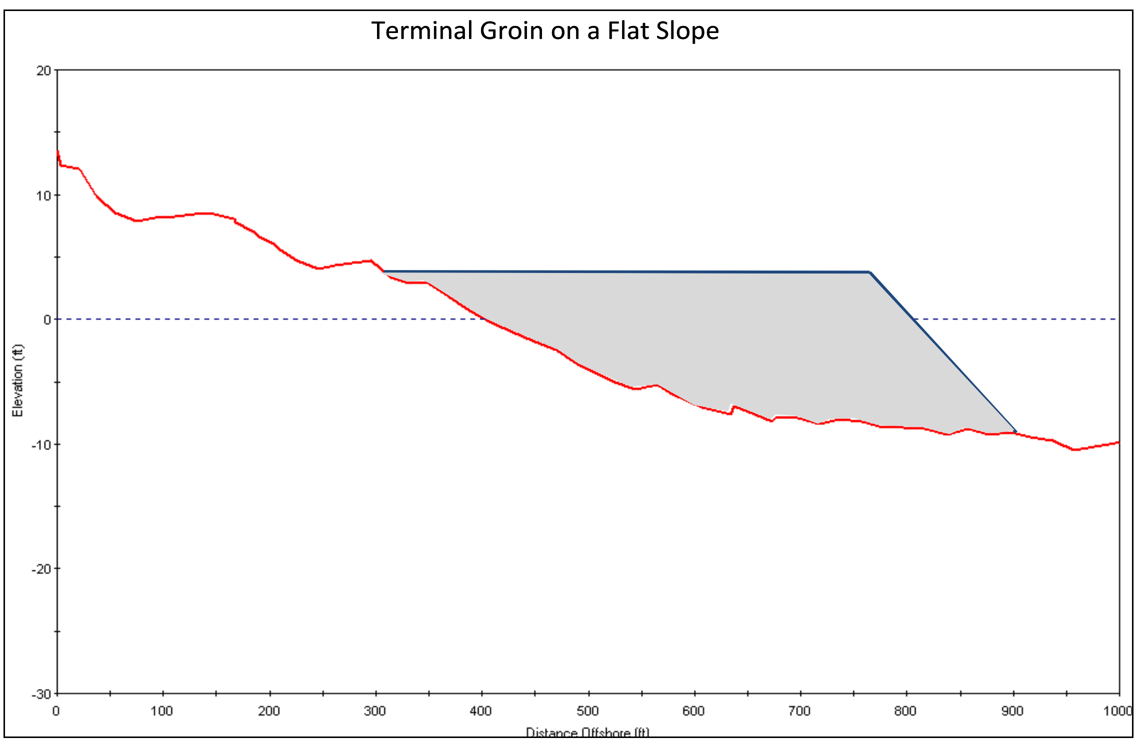

Figure VI-2. Terminal Groin Length along a Flat Slope

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 VI-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.

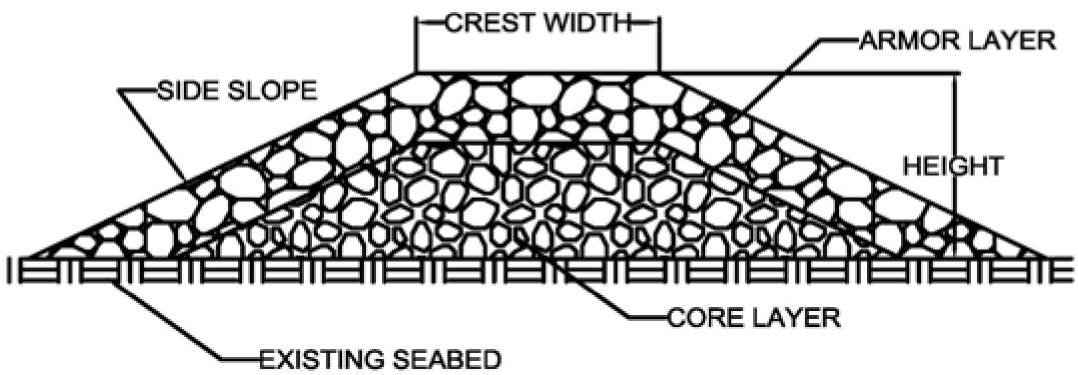

Figure VI-3. Rubble Mound Construction

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 concrete sheet pile groin, the unit cost is approximately $4,000 - $5,000 per linear foot up to a height of 16 feet (maximum water depth ~10 ft.). Typically, concrete groins would not be used for greater heights. Figure VI-4 illustrates an example of concrete sheet piles.

Figure VI-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 and/or built with a concrete cap or fascia. A steel groin with concrete fascia and cap is approximately $4,000 - $5,000 per linear foot for groins up to 15 - 20 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 VI-5 illustrates an example of a steel sheet pile groin.

Figure VI-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; 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 6-8 feet. A timber pile groin's cost could range from approximately $3,000 to $4,000 per linear foot. Figure VI-6 illustrates an example of a timber groin with planks and pilings (taken from the Federal Highway Administration website).

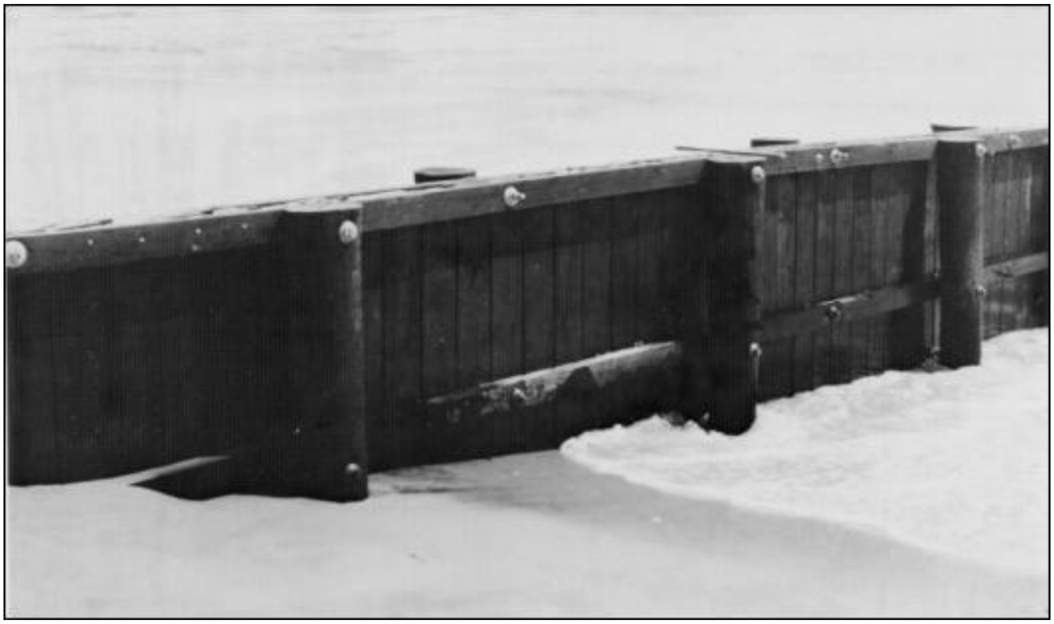

Figure VI-6. Example of a Timber Groin

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. The geotextile tubes should not be utilized for longer groins in deeper water due to wave loading and scour concerns. 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 VI-7 shows the typical cross section for the Fort Macon terminal groin. Table VI-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.

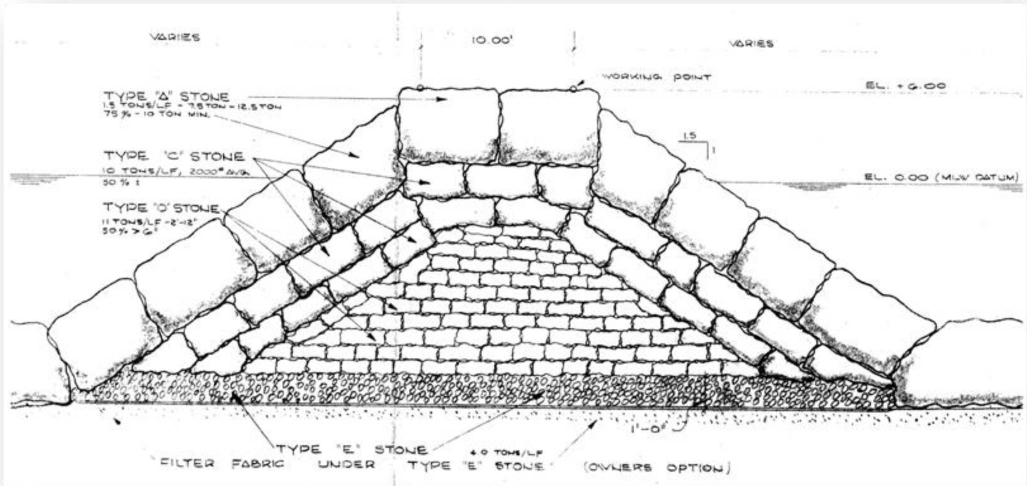

Figure VI-7. Typical Cross Section for Fort Macon Terminal Groin

Table VI-1. Fort Macon Terminal Groin Estimated Costs

Length	1,530 ft
Height	Up to 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 underlayer stone ranges from 500 to 2000 lbs. The armor layer stone ranges from 2.5 to 10 tons. Figure VI-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 VI-2 shows theses estimated costs for the Oregon Inlet terminal groin.

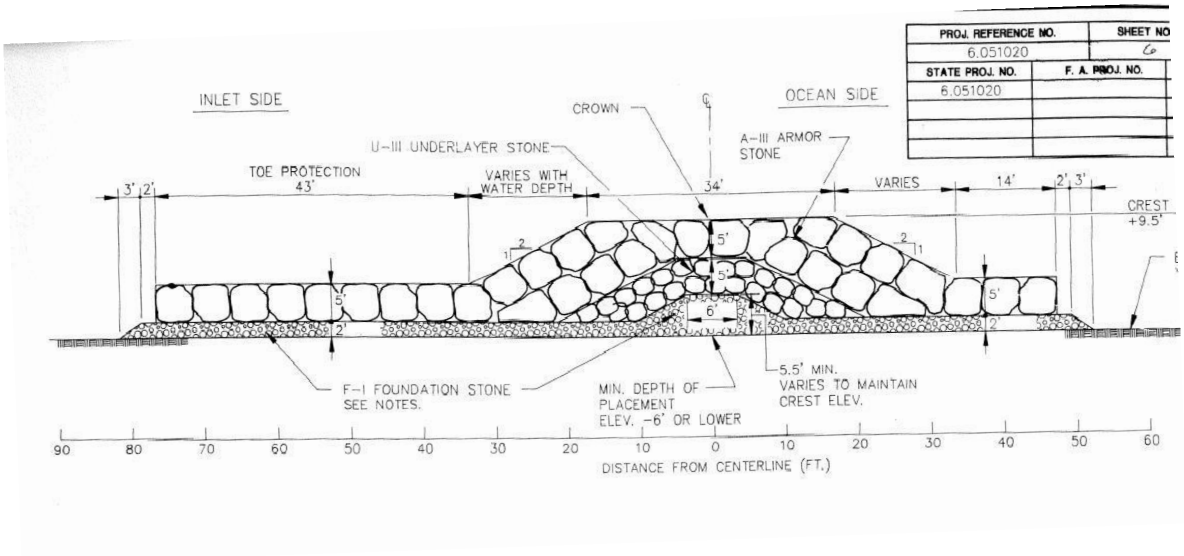

Figure VI-8. Oregon Inlet Typical Cross-Section

Table VI-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 VI-9 shows the cross-sections for the Amelia Island terminal groin. Table VI-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 VI-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%

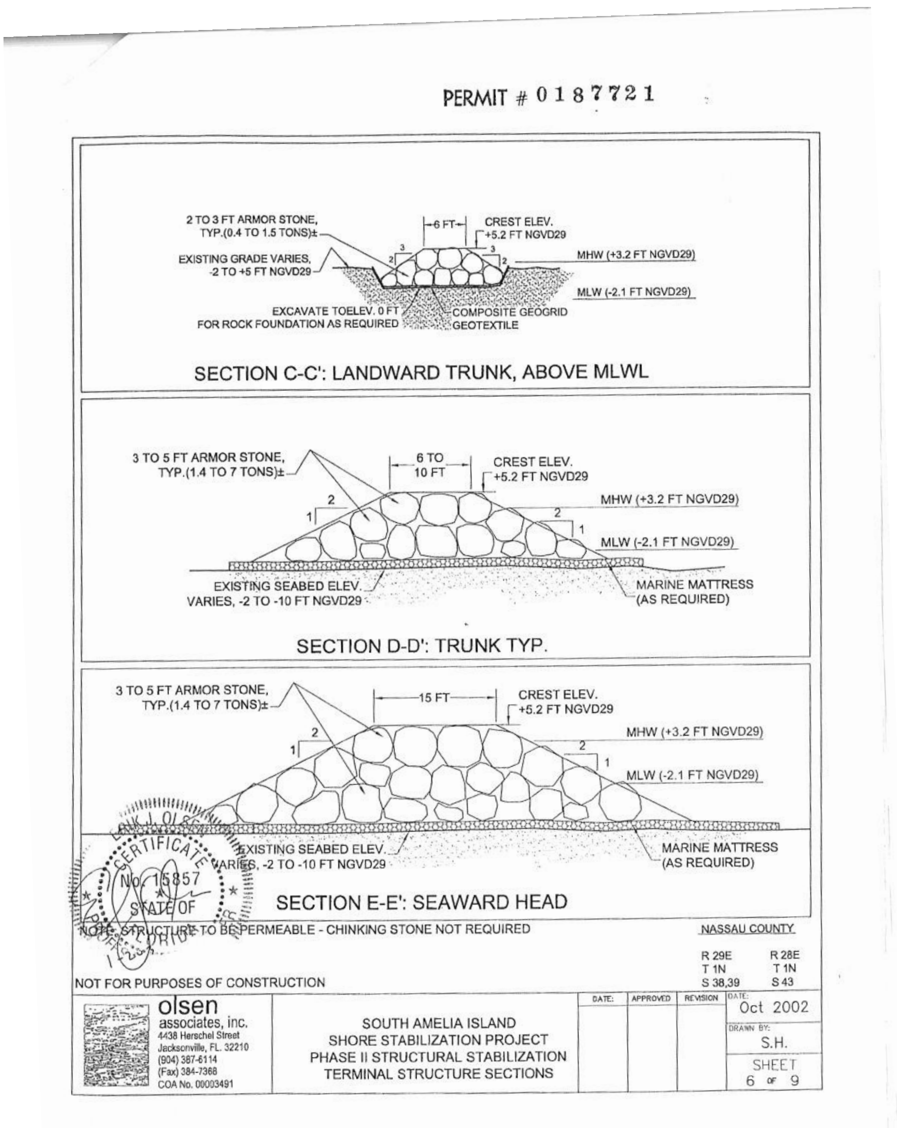

Figure VI-9. Amelia Island Terminal Groin Typical Cross-Section

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, and 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 VI-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.

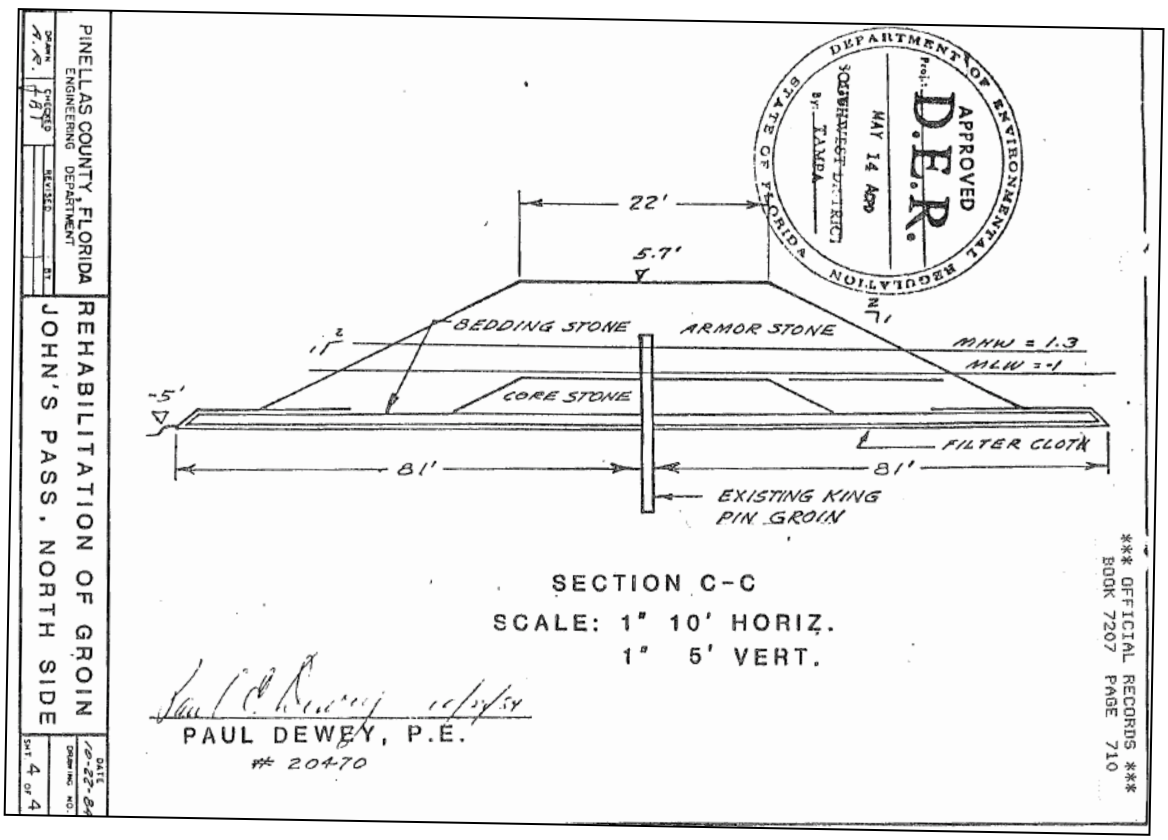

Figure VI-10. Typical Cross-Section for John's Pass Terminal Groin

Table VI-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 VI-5 summarizes the cost information for Captiva Island terminal groin.

Table VI-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 VI-11 illustrates the typical cross section for this scenario.

Figure VI-12 and Figure VI-13 show some typical beach slopes for this scenario. **Error! Reference source not found.** shows the ranges of anticipated unit and total costs for the above scenarios. 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 – 2.2 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.

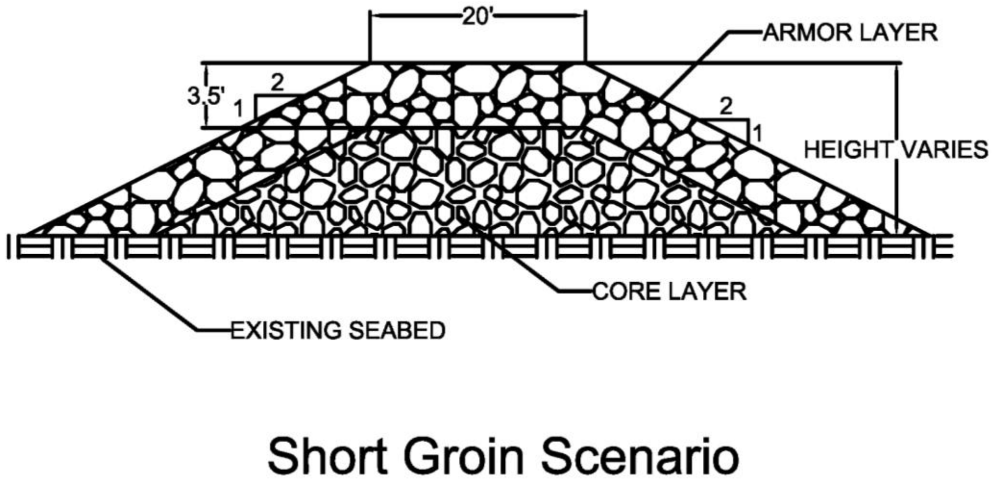

Figure VI-11. Typical Cross Section for Short Groin Scenario

Table VI-6. Short Groin Scenario Unit Costs

	Flat-Sloped Beach	Steep-Sloped Beach
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		
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

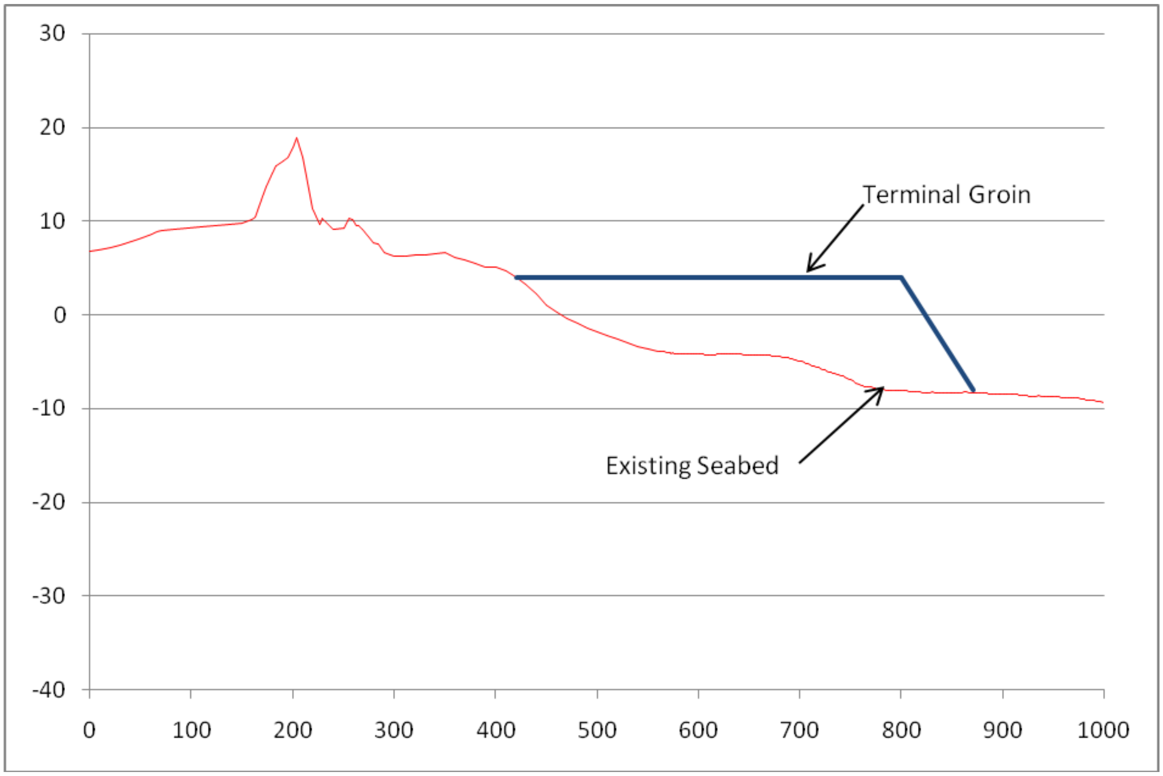

Figure VI-12. Short Groin along a Flat-Sloped Beach

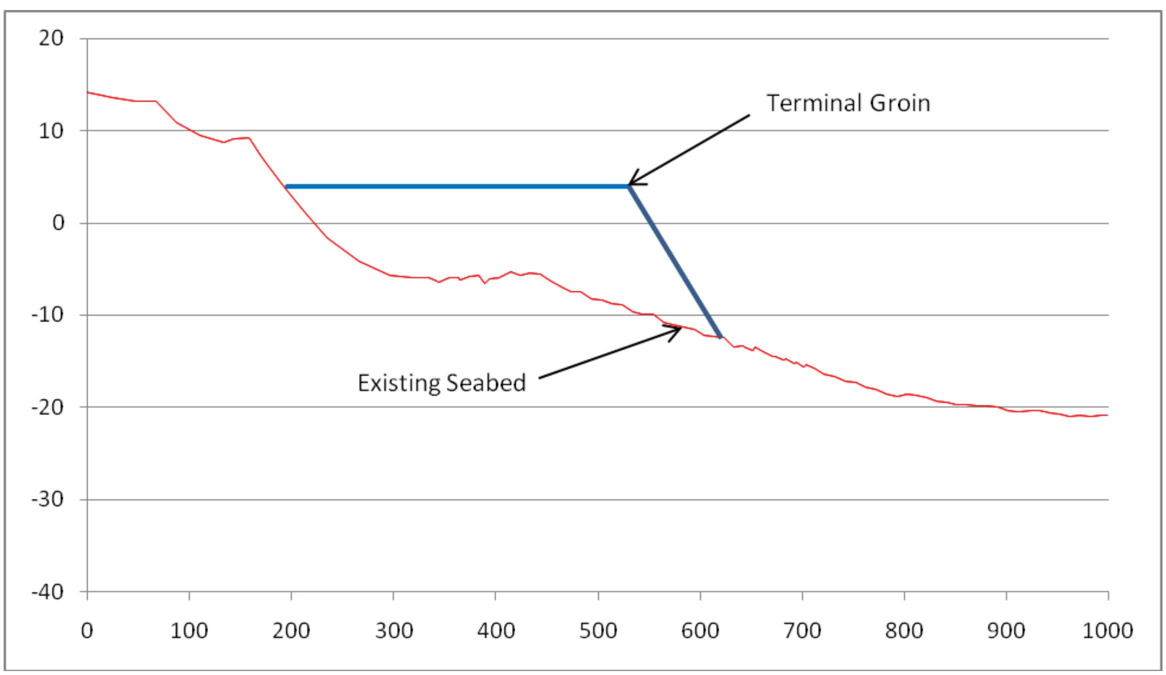

Figure VI-13. Short Groin along a Steep-Sloped Beach

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. Figure VI-14 illustrates the typical cross-section for the long groin scenario. Figure VI-15 and Figure VI-16 show examples of this groin along various North Carolina beaches.

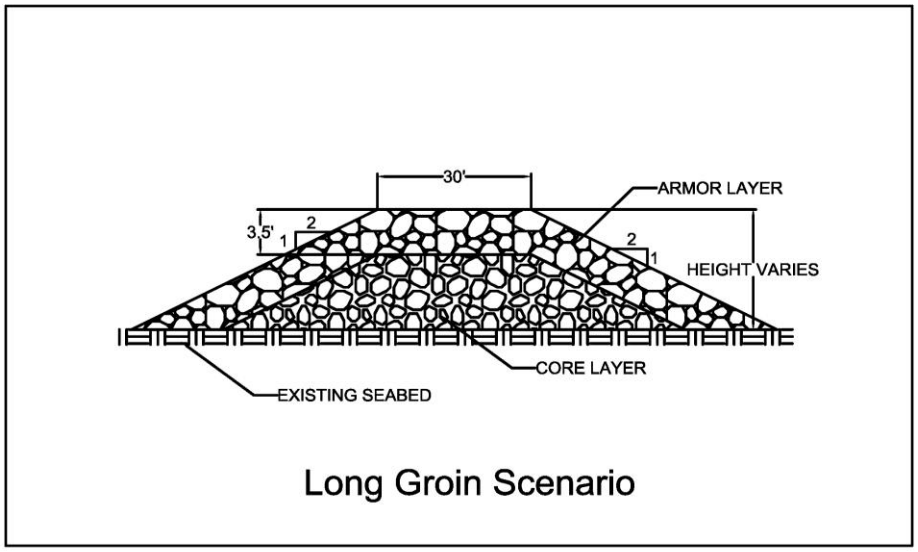

Figure VI-14. Typical Long Groin Scenario Cross Section

Table VI-7 shows the ranges of anticipated unit and total costs for the above scenarios. Based on the scenario, a typical long terminal groin initial construction cost may range from $4 - $8 million**.**

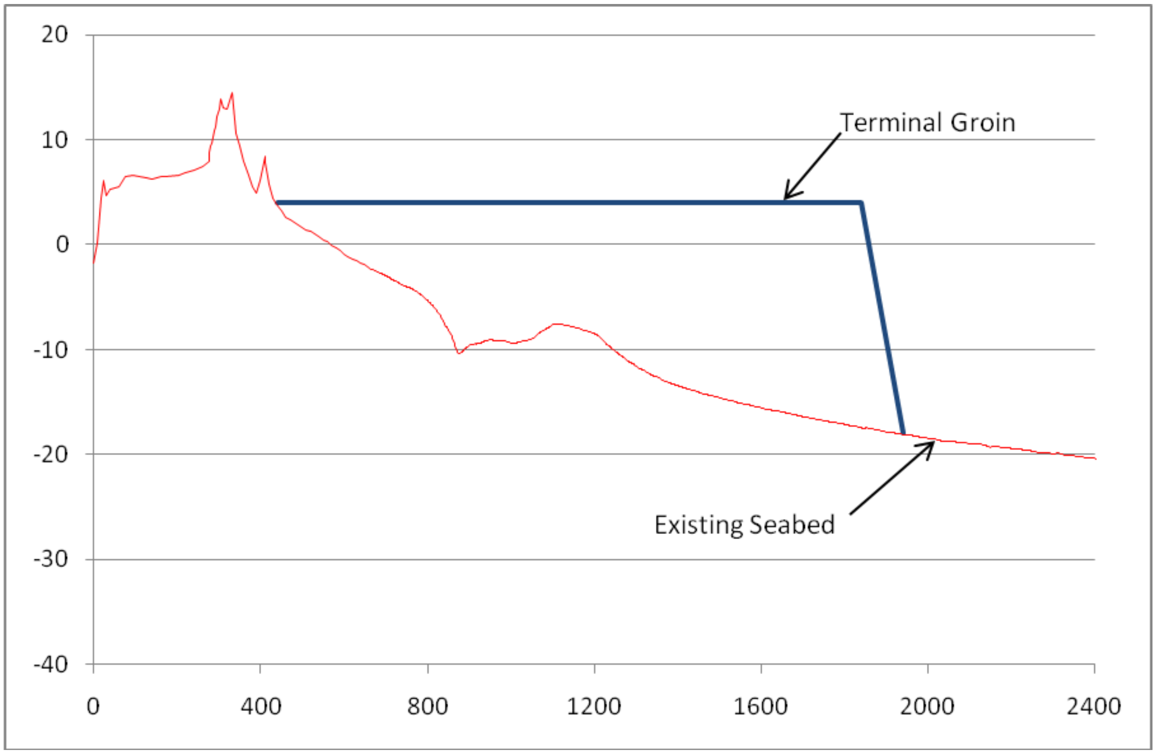

Figure VI-15. Long Groin Cross Section on a Flat-Sloped Beach

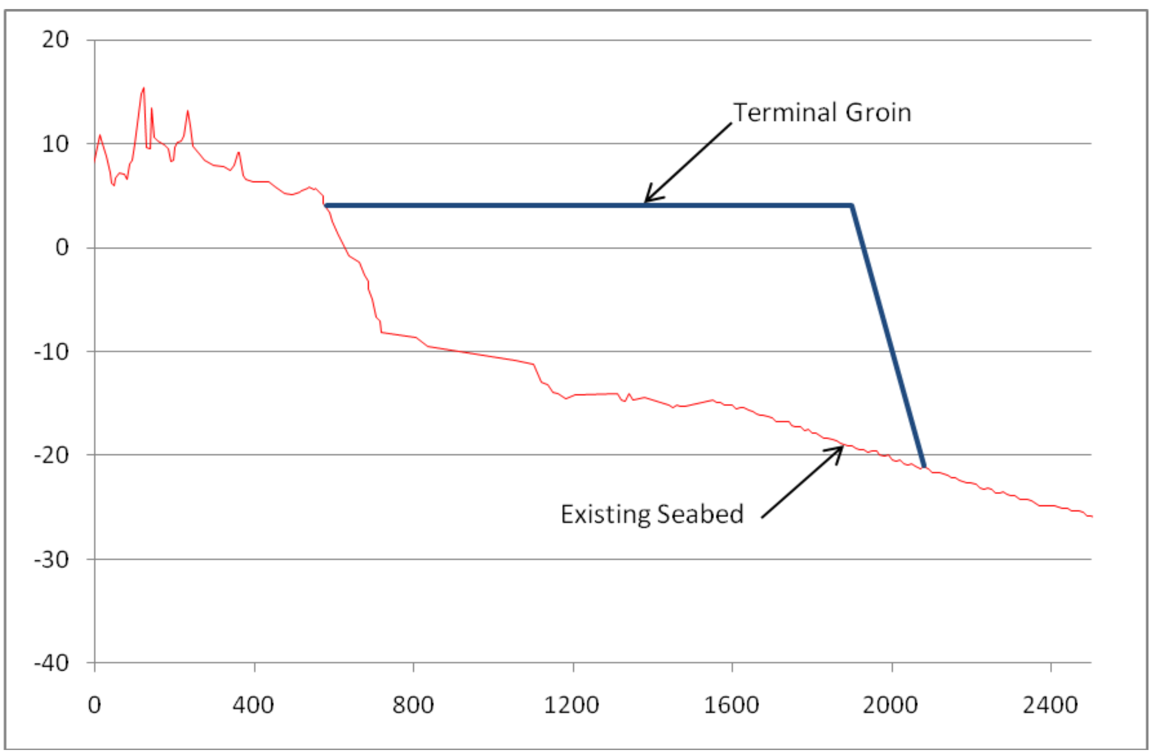

Figure VI-16. Long Groin Cross Section on a Steep-Sloped Beach

Table VI-7. Long Groin Scenario Unit Costs

	Flat-Sloped Beach	Steep-Sloped Beach
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**		
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 and Fort Macon have been negligible so this is likely a conservative estimate). With increased storminess and the possibility of accelerated sea level rise, 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/cy, the initial beach nourishment costs would range between $1.2 and $3.6 million. A review of the results tables in Section II shows that for the five sites that an average cumulative volume loss along the groin side over the first 2 miles would be around 25,000 cy/yr for the shorter groins (~450') while the longer groins (~1,500') would average around 100,000 cy/yr. It should be noted that these volume losses are less than the pre-structure values (short groin average loss = ~100,000 cy/yr, long groin average loss = ~225,000 cy/yr), but the presence of a structure will not eliminate the need for beach nourishment but rather will lessen it. Nonetheless, ongoing nourishment costs should be included in the annual maintenance costs (since the terminal groin is specifically used to retain sand as part of a sand management plan) and may range from $300,000 /yr for the smaller groin to $1.2 million /yr for the larger groin. Detailed studies should be completed during the planning process to be sure that an adequate sand source exists to meet this ongoing need.

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 for a larger groin project. Given the level of scrutiny that the first terminal groin project would receive, it is likely the that the permitting and engineering design costs would be similar for a small groin as well. Therefore, it is expected that permitting and design costs would likely be between $1 – 1.5 million. Monitoring costs would likely range from $100,000 (2 surveys/year) to $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 if this were to change the monitoring requirements during the first few years before and after terminal groin construction 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 $250 (timber); $500 (steel); $750 (concrete sheets) per linear foot. For rock or concrete armor groins, the cost of removal is approximately $500 - $1500 per linear foot (depending on section). The rock structures would also provide the complicating factor that 100% removal of the structure would be difficult given the marine environment and substrate conditions.

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 VI-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 VI-9 summarizes the range of anticipated costs for the developed scenarios.

Table VI-9. Estimated Costs for Potential North Carolina Groins

	Flat-Sloped Beach	Steep-Sloped Beach	Flat-Sloped Beach	Steep-Sloped Beach
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 the total costs for the structures including maintenance are shown in Table V-10. Note that the results in the table are averages and that the actual initial and maintenance costs can vary substantially based on site conditions and the return period storm used in the design (higher return period = higher initial costs/lesser maintenance/repair costs).

Site specific analyses would be required for a potential site to determine if the initial and maintenance costs are outweighed by the infrastructure and property protection as well as reduced nourishment volumes benefits. Sand source investigations should also be completed to verify that a sustainable, adequate source is available (offshore, inlet crossings, etc.)

Table VI-10. Total Project 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	LS	$1,250,000	$1,250,000
Total Initial Costs	**Total**	**$3,450,000**	**$10,850,000**

Removal ($/LF)	$1,000	$450,000	$1,500,000

Annual Costs			
Annual Structure Maintenance ($/yr)	12.5%	$125,000	$750,000
Annual Beach Nourishment ($/yr)	LS	$300,000	$1,200,000
Annual Monitoring ($/yr)	LS	$300,000	$300,000
Total Annual Maintenance Costs	**Total**	**$725,000**	**$2,250,000**

VII. Potential Locations

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 VII-1). After an exhaustive review of the literature and multiple contacts with leading coastal experts, the following list of terminal structures was developed (Table VII-1).

Figure VII-1. Potential Study Sites

Table VII-1. Potential Terminal Groin Study Site Locations

Potential Study Site	Adjacent to Dredged Inlet	Comments
Rockaway, NY	✓	
Coney Island, NY	✓	Structure offset 3000' from edge of island
Ocean City Inlet, MD	✓	Jetties
Willoughby Spit, VA	✓	
Chesapeake Beach, VA		Mid-beach structure
Oregon Inlet,NC	✓	Includes revetment
Buxton, NC (Cape Hatteras Lighthouse)		Several historic groins to protect lighthouse
Fort Macon, NC	✓	
Shell Island, NC (removed)		Sandbags
Folly Beach, SC	✓	
Hunting Island, SC		Proposed (not built)
Hilton Head, SC	✓	
Tybee Island (north), GA	✓	
Tybee Island (south), GA	✓	
Amelia Island, FL	✓	
St. Lucie Inlet, FL	✓	
Jupiter Inlet, FL	✓	Structures on both sides of inlet
Baker's Haulover Inlet, FL	✓	Structures on both sides of inlet
Bonita Beach, FL		
Captiva Island, FL	✓	
Boca Grande Lighthouse, FL	✓	
Blind Pass, FL	✓	Structures on both sides of inlet
John's Pass, FL	✓	Structures on both sides of inlet
Clearwater Pass, FL	✓	Structures on both sides of inlet
Honeymoon Island, FL	✓	

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. 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, some 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 VII-2

Table VII-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 VII-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 VII-3. Dredging Summary

Study Site	Pre – Construction Dredged Volume (cy/yr)	Post – Construction Dredged Volume (cy/yr)
Oregon Inlet	**75,178 / 841,972***	**273,106 / 366,477****
Fort Macon	**563,429**	**785,429**
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: 1997 – 2007 / 1998 – 2004

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 potential negative effects 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 impacts to adjacent areas are minimized or eliminated.

It is also important to note that all five of the study sites do currently require regular beach nourishments as part of the shoreline management within the area. It does appear that the terminal groins have reduced volume losses at the sites and hence lessened potential nourishment quantities.

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. Great care should be exercised when siting a terminal groin in this setting as the channel may shift and potential undermining of the groin may become a concern.

Based on the existing study sites and the literature review completed, the impacts of terminal groins on adjacent shorelines is difficult to identify if they exist at all if located adjacent to a highly managed, deeper-draft navigable inlet. The relative impact of these structures on adjacent areas is likely increased when sited next to natural or minimally managed shallow-draft inlets. For these locations, additional care and study (geologic setting, sediment budgets, etc.) is warranted to be sure that the terminal groin's impacts are acceptable or can be mitigated through minimal human activities (dredging and nourishment).

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VIII. Summary of Findings

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. The section presents a summary list of the findings of this technical study.

Selection of Study Sites

- For this study, a *terminal groin* was defined as a structure built with the primary purpose to retain sand and not for navigation. It is a narrow, roughly shore-normal structure that generally only extends a short distance offshore.
- In consultation with the Science Panel, 25 sites with terminal structures along the Atlantic and Gulf coasts were initially considered. Five sites were then selected to be included in the study: Oregon Inlet, NC; Fort Macon, NC; Amelia Island, FL; Captiva Island, FL; and John's Pass, FL
- Only existing data was collected; no new data was acquired for this study
- Uncertainties are associated with the data and should be recognized with any analyses.
- All five of the existing study sites have sand management activities (dredging, nourishment) as part of the overall project.

Physical Assessment

General

- Although terminal groins trap sand, they are dissimilar to a jetty, because once the terminal groin fills with sediment, additional sand bypasses the structure and enters the nearshore and / or the tidal inlet.
- Terminal groins are commonly built on either (or both) sides of inlets because in addition to the regional dominant longshore sediment transport system delivering sand preferentially to one side of an inlet, wave refraction around the ebb delta results in sand transport back toward the inlet along the downdrift shoreline.
- A 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.

- Dredging can have significant impacts on the inlet morphology and sedimentation processes of the ebb-tidal delta.
- Interpreting the potential impact of a terminal groin requires understanding the influence of placing sand on the beach (nourishment) and removing sand from the inlet system (dredging) on the observed shoreline change.

Oregon Inlet

A 3125-foot long rubble mound revetment and terminal groin, completed in 1991, is located on the south side of the inlet on Pea Island. Bodie Island is located on the north side of the inlet. (See Figure II-15).

- Pea Island is impacted by numerous processes including sequestration of sand at Bodie Island and Oregon Inlet, human impacts, and major storms.
- During periods of spit building at Bodie Island, the natural process of sand bypassing Oregon Inlet is drastically reduced.
- Continuous dredging at the inlet creates a sediment sink, which further diminishes the volume of sand moving around the inlet.
- Construction of the terminal groin stabilized the northern end of Pea Island and prevented Oregon Inlet from migrating southward.
- Prior to terminal groin construction, the Pea Island shoreline was eroding fairly rapidly.
- After construction, the Pea Island shoreline was still eroding but at a much lower rate, and even accreting at some locations. However, it must be noted that these shorelines included the effects of millions of cubic yards of beach nourishment and dredging activities.
- Prior to terminal groin construction, Bodie Island was accretionary in the first mile but erosional over the next two miles. After construction, the shoreline was generally erosional at higher rates, except at the south end of the spit.
- Once all beach nourishment and nearshore placement activities are subtracted out, the volumetric analysis for Pea Island shows that after construction of the terminal groin, the average erosion was significantly reduced over the first mile; moderately increased over the second mile; remained about the same over the third mile; moderately decreased again over the fourth mile and was relatively stable with a slight increase in the fifth and sixth miles. The average erosion, though, over these six miles, did decrease significantly.
- There are significant questions as to whether the nearshore placement material is ever actually moved onto the beach or whether it is placed too far offshore, in too deep of water, to achieve any positive benefits.
- Assuming a small percentage of the dredged material would have naturally been transported to the Pea Island beach could significantly reduce or eliminate any apparent negative impacts in some of the pertinent intervals within the six mile analysis area.

Fort Macon

The rubble mound terminal groin was lengthened to its present size (1,530 feet) in 1970 and is located on the west side (Fort Macon) of Beaufort Inlet. Shackleford Banks is located on the east side of the inlet. (See Figure II-32).

- The terminal groin was built to protect and preserve Fort Macon from erosion. The fort has a long history of being at risk from the Atlantic and the shifting of Beaufort Inlet.
- Beaufort Inlet is heavily dredged to maintain a deep-draft navigational channel for the North Carolina State Ports' Morehead City Terminal.
- The dredging has significantly changed the morphology and sedimentation processes of the ebb-tidal delta. Impacts include:
    - Decreasing flow resistance which increased tidal exchange and ultimately the tidal prism;
    - Creating a sediment sink resulting in a siphoning of sediment from the inlet;
    - Creating a complete disruption of the natural processes of inlet sediment bypassing; and
    - Steepening the gradient of the delta, resulting in less attenuation of wave energy and more susceptibility of erosion.
- The Fort Macon beach has maintained a position near the end of the terminal groin since 1993 and sand has been moving eastward around and over the groin, building a beach along the inlet shoreline.
- Prior to terminal groin construction, the Fort Macon shoreline was eroding fairly rapidly over the first mile and was relatively stable over the next two miles. After construction of the terminal groin, the shoreline is relatively stable or accretionary with significant accretion immediately adjacent to the terminal groin. However, it must be noted that these shorelines included the effects of millions of cubic yards of beach nourishment and dredging activities.
- Shackleford Banks was highly accretionary in the first half-mile and mostly erosional over the next 2.5 miles during the pre-construction time period. After construction of the terminal groin, the shoreline was erosional over the first mile and then relatively stable over the next two miles.
- Once all the beach nourishment activities are subtracted out, the volumetric analysis shows for Fort Macon that after construction of the terminal groin, the average erosion was significantly reduced over the first mile; moderately increased over the second mile; and was relatively stable in the third mile. The average erosion, though, over these three miles did decrease significantly.
- Given the very large volumes of material dredged from the inlet system, it can be seen that even assuming a small percentage of the dredged material would have naturally been transported to either Fort Macon or Shackleford Banks could significantly reduce or eliminate any apparent negative impacts in some of the pertinent intervals within the three mile analysis area.

Amelia Island

A 1,500–foot-long “leaky” rubble mound terminal groin was constructed in 2004 on the south end of Amelia Island. Lttle Talbot Island is located on the southside of Nassau Sound. (See Figure II-45).

- The construction of the terminal groin has occurred relatively recently, thus making definitive conclusions about its performance difficult at best, as the shoreline has not had time to equilibrate to the new structures and a recent large beach nourishment.
- It is apparent that the “leaky” rock terminal groin does allow material to pass over / through it as evidenced by the spit-like feature building to its south.
- Prior to terminal groin construction, the Amelia Island shoreline was eroding over most of the first three miles, except for the first quarter mile. After construction, the shoreline has accreted substantially over the first half mile, but erosion is evident over the next 2.5 miles. This trend is even more evident once the beach nourishment is subtracted out.
- A significant beach nourishment placement occurred during the short two-year post-construction time period used for analysis and any changes may simply be indicative of the shoreline adjusting to an equilibrium state.
- Little Talbot Island experienced erosion over its first three-quarter mile interval with accretion beyond prior to construction. No post- construction data was available.
- No dredging data was available, although it is understood that some dredging of Nassau Sound has occurred.

Captiva Island

A 350-foot-long rubble mound terminal groin was constructed on the north end of Captiva Island adjacent to Redfish Pass in 1977 and rehabilitated in 2006. North Captiva Island is located on the north side of Redfish Pass. (See Figure II-60).

- The Captiva Island shoreline has typically extended to near the end of the terminal groin, especially prior to lengthening by 100 feet in 2006.
- The beach inside the inlet has experienced cyclic changes in width over time; most likely due to the impact of storm events.
- Prior to terminal groin construction, the Captiva Island shoreline was eroding fairly rapidly over the entire first three miles. After the construction of the terminal groin, the erosion has been reduced in the first mile with accretion in the next two miles. It must be noted, though, that these shorelines include the effects of beach nourishment and dredging activities.

- North Captiva was erosional over the first three miles prior to terminal groin construction except for the first quarter mile, but was only erosional over the first mile and accretionary over the next two miles after terminal groin construction. It must be noted, though, that these shorelines include the effects of dredging activities.
- Beach nourishment and dredging activities have occurred at Captiva Island. Since the terminal groin was constructed, over 1.3 million cubic yards of material have been placed on the first three miles of beach during the analysis time period; but the amount of dredging is unknown.
- Once the beach nourishment activities are subtracted out, the volumetric analysis for Captiva Island shows that after construction of the terminal groin, the average erosion was significantly reduced over the first three miles except for a slight increase in the first quarter mile.

John's Pass

A 460-foot-long rubble mound terminal groin was constructed in 1961 and rehabilitated in 1988 on the north side of John's Pass on Madeira Beach. Treasure Island is located on the south side of the pass where a terminal groin was constructed in 2000. (See Figure II-74).

- The Madeira Beach shoreline was erosional prior to terminal groin construction but accretionary afterwards over the entire three miles.
- Prior to terminal groin construction on Madeira Beach, the Treasure Island shoreline was accretionary over the first 0.75 miles, erosional over the next 1.25 miles and relatively stable for the next mile. After the construction of the terminal groin, the shoreline was erosional over the first half mile, but accretionary over the next 2.5 miles. It must be noted, though, that these shorelines include the effects of beach nourishment and dredging activities.
- Once all of the beach nourishment activities are subtracted out, the volumetric analysis for Treasure Island shows that after construction of the Madeira Beach terminal groin, the average erosion increased over the first half mile, but was actually accretionary over the next 1.5 miles and then was slightly erosional over the final mile. The average change over the first three miles, though, was a significant increase in accretion.
- Since no beach nourishment occurred on Madeira Beach, the results still show that is was accretionary over the entire three miles after terminal groin construction.

Summary

- In all cases, the shorelines on the structure side of the inlet were eroding prior to construction of the terminal groin; and after construction, the shorelines on the structure side of the inlet were generally accreting.
- The data on the opposite side of the inlet does not display a clear trend (i.e. mixed accretion and erosion).
- 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.
- After subtracting out all beach nourishment activities (but not accounting for dredging), the changes between pre- and post-construction periods on the terminal groin side show (note – "positive result" indicates an improvement; either reduced erosion, a change from erosion to accretion, or increased accretion; while "negative" indicates the converse):
    - There is a significant positive result over the first mile of shoreline (except for Amelia Island where this positive result only occurs over the first half mile);
    - For Oregon Inlet, Fort Macon, and Amelia Island there is a moderate negative result over the second mile and then much less of a change (either positive or negative) over the third mile;
    - For Oregon Inlet, further down the Pea Island shoreline, a positive result is present over the fourth mile and then minimal changes over the fifth and sixth miles;
    - On a cumulative basis, for Fort Macon and Oregon Inlet the positive results are significantly greater (about 150,000 cy / year) than any negative results over the shoreline reaches analyzed;
    - Amelia Island does not show a net positive result, but the adjustment in the post-nourishment shoreline that occurred during the very short post-construction analysis interval analyzed is likely the cause; and
    - For Captiva Island and John's Pass, the positive result is apparent over basically the entire three mile analysis length of shoreline with cumulative positive results amounting to 90,000 – 120,000 cy / year.

- After subtracting out all beach nourishment activities (but not accounting for dredging), the changes between pre- and post-construction periods show on the side opposite the terminal groin (note that no data was available for the Amelia Island study site):
    - Typically a minor to moderate negative result occurs over the first half to three-quarters of a mile. Whether this is the effect of terminal groin construction or other impacts such as increased dredging or migrating inlets, though, is not possible to definitively conclude.
    - For Captiva Island, John's Pass and Shackelford Banks the results turn positive after this initial distance with net cumulative positive results over the shoreline analyzed for Captiva Island and John's Pass and a negative result for Shackleford Banks.
    - At Oregon Inlet, the negative result continues for the second mile with minimal change over the third mile.
- Much like nourishment, the influence of dredging material from the inlet system must be accounted for when attempting to assess the impact of the terminal groins. These results show:
    - One must assume about 25% of the material dredged from the inlet would have naturally reached Shackleford Banks for the negative pre- to post-construction change over the three-mile shoreline analysis interval to turn positive.

Environmental Assessment

General

- The environmental effects of a terminal groin structure alone could not be assessed for the sites without considering the associated beach nourishment activity.
- Potential effects of terminal groins in conjunction with shoreline management (i.e. beach nourishment) on natural resources vary according to the type of construction equipment used, the nature and location of sediment discharges, the time period of construction and maintenance in relation to life cycles of organisms that could be potentially affected, and the nature of the interaction of a particular species.
- The construction of a terminal groin, beach nourishment and dune construction prevents overwash and inlet migration thereby contributing to a loss of habitat for breeding and non-breeding shorebirds and waterbirds, including the piping plover.
- Terminal groins are typically used in combination with a long-term shoreline protection program (beach fill), in areas where pre-project shoreline conditions are generally degraded with limited potential sea turtle nesting activity.

Oregon Inlet

- Oregon Inlet dredging, the Bonner Bridge, NC Highway 12 maintenance and protection, and the presence of the terminal groin have influenced the loss of oceanfront and inlet habitat by subduing and altering natural processes such as overwash and inlet migration.
- The pre-construction historical non-breeding shorebird data suggests the immediate groin location was not highly used due to lack of appropriate habitat.
- Following construction of the terminal groin, a large sandflat developed behind the groin where shorebirds and colonial waterbirds nested (and still nest to some extent). Some of this area is still kept in good bare sand condition by overwash during large storms; but much of the area is retaining heavy vegetation.
- Oregon Inlet serves primarily as a wintering area for the migrating/wintering (non-breeding) 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.
- Fluctuations in annual observations of piping plovers at 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.
- The terminal groin, as well as dredging and nourishment, has adversely modified habitat important to early successional species, such as piping plovers, by

eliminating intertidal flats and allowing encroachment of vegetation in stabilized areas, and generally impeding inlet dynamics that create and maintain habitats piping plovers require.

- In terms of sea turtles, the PINWR has an average of 10 to 12 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. Based on a preliminary evaluation of nesting intervals per section on PINWR compared to Bodie Island, it is apparent that sea turtle nesting habitat is more readily available on PINWR versus Bodie Island. Due to the consistently low annual nesting densities and the high frequencies of both storm and renourishment events, no relationships between nesting densities and storm or renourishment events are readily apparent.
- Invertebrate monitoring results showed mole crab and coquina clam numbers were significantly reduced following placement of Oregon Inlet maintenance dredged material. The underlying effects on the infaunal communities within a terminal groin fillet is directly related to the fill material size, the volume of material placed, and the seasonal material placement.

Fort Macon

- Seabeach amaranth has experienced 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. Since 1991, Fort Macon beaches have been nourished four times. Seabeach amaranth numbers increased following renourishment projects in 2002 and 2007, whereas numbers decreased following renourishment projects in 1993 and 2004. Based on these data, no consistent relationship between seabeach amaranth numbers and renourishment projects is readily apparent
- Since 1973, Fort Macon beaches have been nourished seven times. Sea turtle nesting densities increased following renourishment projects in 1986, 2002, 2004, and 2007; whereas nesting density decreased following renourishment in 1993. These data indicate that renourishment may have a positive effect on sea turtle nesting. 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.
- 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). Lack of historic natural resource data hinders drawing conclusions on the effects of the construction and operation of the terminal groin on natural resources.
- Colonial waterbirds and shorebirds depend on ephemeral habitats while stabilization of inlet shoreline usually causes vegetation growth that results in unsuitable habitat and not having historical pre-construction bird surveys makes it

difficult to conclusively say whether suitable habitat existed prior to terminal groin construction or if the terminal groin may have caused the loss of suitable habitat.

- Shorebird habitat on Fort Macon is also subject to the effects of periodic beach renourishment projects. Least tern and Wilson's plover observations at Fort Macon increased following renourishment projects in 2002, 2004, and 2007. These data indicate that renourishment may have a positive effect on habitat utilization by these species.
- Piping plover habitat on Fort Macon is also subject to the effects of periodic beach renourishment projects. Due to the low number of piping plover observations on Fort Macon, no conclusions can be drawn regarding the effects of renourishment on piping plovers. However, considering the higher number of piping plovers observed on Shackelford Banks West, it can be concluded that appropriate habitat for piping plovers does not exist on Fort Macon.
- The native 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 cumulative modifications in Beaufort Inlet results in a temporary reduction and slow recovery of the abundance and diversity of benthic invertebrates (SAFMC 1998).
- 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) however; terminal groins continue to allow sand to bypass into the adjacent tidal inlet and therefore are likely bypassing larvae into the estuary.

Amelia Island

- Sea turtle nesting data for Amelia Island dates back to 1986 and on average, 74 nests were recorded annually from 1986 through 2005. 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 and 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 and beach nourishment on sea turtle nesting.
- Based on pre- and post-construction data within Nassau Sound, the Bird Islands have not experienced a change in total acreage. Shorebird habitats on Amelia Island are subject to the effects of periodic beach renourishment projects. The total number of shorebirds on Amelia Island increased slightly following beach renourishment in 2006. Based on the limited shorebird data set for Amelia Island (2003 – 2008), it is not possible to draw conclusions regarding the effects of renourishment projects on shorebird populations.
- FDEP data do not include any records of piping plovers on Amelia Island. 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 shorebird or piping plover use.
- The lack of scientific monitoring data resulted in non-discernable trends in potential effects on benthic and fisheries resources from the terminal groin and associated fillet.

Captiva Island

- An eroded inlet shoreline was improved by the construction of the terminal groin and associated fill. Due to the absence of hardbottom habitat within the project area, the terminal groin is not considered an immediate concern of local resource agencies.
- Sea turtle nesting data for Captiva Island, an approximate 5 mile shoreline from Redfish Pass to Blind Pass, dates back to 1986. On average, 94 nests were recorded annually from 1986 through 2009. However, the 2008 nesting period resulted in a sharp increase to 137 nests and then decrease to 80 nests in 2009.
- In 2009, a USACE sponsored bird survey for Lee County was conducted (Lott et al. 2009). Results indicate that 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 the adjacent Sanibel Island.

- 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).
- Because there were no live bottoms within the groin construction footprint, FDEP required no post-construction biological resource monitoring. The lack of raw data resulted in non-discernable trends in potential effects on benthic and fisheries resources from the terminal groin and associated fillet.

John's Pass

- The sea turtle survey boundaries of the Mid Pinellas County beaches include Redington Shores to Blind Pass, an approximate 7 mile stretch of oceanfront shoreline. 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.
- 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/). 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. The lack of raw data resulted in non-discernable trends in potential effects on birds, benthic resources, and fisheries from the terminal groins and associated fillets.

Summary

- Based upon the historical nature of the terminal groins at Fort Macon, John's Pass (northern groin), and Redfish Pass; discernible trends 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 difficult if not impossible.
- While the use of control and/or regional sites strengthens the ability of a study to infer an impact from a detected change, one cannot infer an impact if there is no statistical evidence for a change (Mapstone 1995); and due to the lack of complete datasets and high levels of confidence in the quality of the data, statistical analysis was precluded.
- The current development and use of some of the selected 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, albeit sometimes on a limited basis.
- The terminal groins at Oregon Inlet and Amelia Island are more recent construction projects, and pre- and post-construction natural resource data readily available were evaluated (sea turtle and shorebird nesting data). 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.
- Because of the diversity and commercial importance of 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.
- Anchoring the end of an island may curtail an inlet's natural migration patterns thereby minimizing the formation of sand flats.
- Fillet material should be compatible to minimize effects on benthic infauna recovery and upper trophic levels.
- Resources continue to use locations where terminal groins exist, however, if habitat succession occurs, species suitability may be affected.

Engineering Construction Techniques

- The five study sites all consist of rubble mound (rock) groins.
- 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.
- 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 shorter, mid to shallow-water groins; however, these materials tend to be cost-prohibitive. Timber and geotextile groins are less expensive alternatives and can be adapted to a variety of beach conditions, but also have limited applicability to shorter, shallow-water conditions.
- Concrete, steel, and timber structures have the advantage of being adjustable with the beach profile without having to rebuild or remodel the groin.
- Groin notching is an emerging technique that allows for adaptive management. 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.
- It appears that for shorter groins, the interruption to littoral transport is smaller compared to the overall magnitude of sediment transport and the muted impacts seen both updrift and downdrift of the inlet.
- There also seems to be a threshold that appears with both length and height to be crossed where adjacent impacts become more pronounced. While it is possible that dredging impacts may be responsible for this threshold crossing, it underlies the importance to considering the overall length of the structure in relation to the exterior man-made and natural processes that also drive sediment transport so that the structure's relative effects are minimized or eliminated.
- The permeability of the structure has a significant impact on adjacent shorelines. The Amelia Island structure has allowed material to bypass the structures to limit effects on downdrift shorelines and volumes. However, the structure has also had a limited impact on the updrift shoreline (mainly within the first 0.5 miles). The other structures have impermeable cores and appear to hold more sand for a greater distance updrift of the structure.

Economic Assessment

- The economic value at risk within the 30 year risk areas for developed shorelines varies greatly from about $27 million at Ocean Isle to over $320 million at Bald Head Island. It must be noted, though, that not all of these properties can be protected by a terminal groin.
- The economic value at current or imminent risk (as defined by the presence of sandbags for temporary protection) for developed shorelines varies from just under $3 million at North Topsail Beach to about $26 million at the north end of Figure Eight Island.
- Barrier island municipality tax bases range from $409 million for Caswell Beach to over $4.2 billion for Emerald Isle. The countywide tax bases range from $3.8 billion for Pender County to $29.1 billion for New Hanover County.
- The full value of residential property 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 soundfront location may transfer to nearby properties.
- Additional factors affecting the economic value of inlet areas were reviewed but not specifically quantified due to lack of data. Where possible, qualitative and case study information is provided for the following factors:
  - Beach Recreation Value
  - Shore / Surf / Beach Fishing
  - Primitive Area Hiking / Camping Value
  - Wetland Recreation Value
  - Value of Non-Game Wildlife in Beach and Coastal Wetland Areas
  - Value of Coastal Wetlands in Supporting Recreational Fishing
  - Value of Wetlands in Protecting Property from Hurricane Wind Damage
  - National Seashores and Refuges
  - State Parks

Initial Construction and Maintenance Costs

- Construction costs of terminal groins can vary greatly depending upon construction materials, length and beach profile.
- The construction costs (in 2009 dollars) of the five terminal groins analyzed range from less than $1 million for John's Pass and Captiva Island to about $24 million for Oregon Inlet.
- Four cost scenarios were developed:
  - Short, smaller cross-section groin (450 feet) on a flat-sloped beach
  - Short, smaller cross-section groin (450 feet) on a steep-sloped beach
  - Long, larger cross-section groin (1500 feet) on a flat-sloped beach
  - Long, larger cross-section groin (1500 feet) on a steep-sloped beach
- Rubble-mound terminal groins could range from about $1,230 per linear foot to $5,180 per linear foot.
- Geotextile Tube terminal groins could range from about $350 per linear foot to $660 per linear foot (short groin only; not recommended for longer groin)
- Steel or Concrete Sheet Pile or Timber terminal groins could range from about $4,000 per linear foot to $4,800 per linear foot. (Timber only recommended for short groin scenarios)
- Initial project costs including construction of the terminal groin, initial beach nourishment and permitting and design fees may range from about $3.5 million for a shorter groin to over $10 million for a larger one.
- Annual project costs including structure maintenance / repair, annual beach nourishment, and monitoring could be in the range of $0.7 million to over $2 million.
- Terminal groins are typically constructed as part of a broader beach management plan and may make nourishment adjacent to inlets feasible, but they do not eliminate the need for ongoing beach nourishment.
- These costs could vary substantially based on site conditions and design storm parameters.

Potential Locations

- The vast majority of the structures considered for this study were located at inlets with most of these adjacent to navigable, dredged channels.
- No terminal groins were identified as being located at the end of a non-inlet littoral cell.
- 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. These dredging activities may greatly outweigh any potential long-term shoreline changes resulting from the construction of a terminal groin.
- 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 may have the additional impact of "stabilizing" the location of a migrating inlet, such as the case at Oregon Inlet where this impact has also resulted in changes to the inlet cross-section – a general narrowing and deepening over time since terminal groin construction. Great care should be exercised when siting a terminal groin in this setting as the channel may shift and potential undermining of the groin may become a concern.
- Based on the existing sites and the literature review completed, the impacts of terminal groins on adjacent shorelines is difficult to identify if they exist at all if located adjacent to a highly managed, deeper-draft navigable inlet.
- The relative impact of these structures on adjacent areas is likely increased when sited next to natural or minimally managed shallow-draft inlets. For these locations, additional care and study (geologic setting, sediment budgets, etc.) is warranted to be sure that the terminal groin's impacts are acceptable or can be mitigated through minimal human activities (dredging and nourishment).

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IX. References

Able, K.W., D.H. Wilber, A. Muzeni-Corino, and D.G. Clarke. 2009. Spring and Summer Larval Fish Assemblages in the Surf Zone and Nearshore off Northern New Jersey, USA. Estuaries and Coasts. Springer, New York.

Adams, S. W. 1976. "The Ecology of Eelgrass Zostera Marina (L.), Fish Communities I. Structural Analysis." Journal of Experimental Marine Biology and Ecology, 22: 269-291.

Alexander, R.R., R.J. Stanton, and J.R. Dodd. 1993. Influence of Sediment Grain Size on the Burrowing Bivalves: Palaios, v. 8, pp. 289-303.

Altman, J. 2008. American oystercatcher (*Haematopus palliatus*) Monitoring at Cape Lookout National Seashore 2008 Summary Report. National Park Service, Cape Lookout National Seashore, Harkers Island, NC.

American Shore & Beach Preservation Association (ASBPA). 2008. Terminal Groins at Coastal Inlets. Prepared by the ASBPA Science & Technology Committee.

Barnes, R.D. 1974. Invertebrate Zoology. Third Edition. W.B. Saunders Company. Philadelphia.

Becker, M.L. and M. A. Ross. 1999. A model study of Boca Ciega Bay, John's Pass, and Blind Pass. Publication Report: No. CMHAS.FDOT.99.01. University of South Florida. Tampa, Florida.

Bell, F. W. 1997. The Economic Valuation of Saltwater Marsh Supporting Marine Recreational Fishing in the Southeastern United States. Ecological Economics. 21(3):243-254.

Bergstrom, J.C., J.R. Stoll, J.P. Titre and V.L. Wright. 1990. Economic Value of Wetlands-Based Recreation. Ecological Economics. 2:129-147.

Bertasi, F., M.A. Colangelo, M. Abbiati, and V.U. Ceccherelli. 2007. Effects of an artificial protection structure on the sandy shore macrofaunal community: the special case of Lido di Dante (Northern Adriatic Sea). Hydrobiologia 586, 277–290.

Bin, O., T. Crawford, J. Kruse, and C. Landry. 2006. "Viewscapes and Flood Hazard: Coastal Housing Market Response to Amenities and Risk." Working Paper. East Carolina University.

Bin, P., Dumas, C. F., Poulter, B., and Whitehead, J. 2007. *Measuring the Impacts of Climate Change on North Carolina Coastal Resources*. Washington, DC: National Commission on Energy Policy.

Bin, Okmyung, Landry, Craig E.; Ellis, Christopher L., Vogelsong, Hans. 2005. Some Consumer Surplus Estimates for North Carolina Beaches. Marine Resource Economics 20(2): 145-61.

Bin, O., and J.B. Kruse. 2006. "Real Estate Market Response to Coastal Flood Hazards." Natural Hazards Review 7(4): 137-44.

Bin, O. and S. Polasky. Effects of Flood Hazards on Property Values: Evidence Before and After Hurricane Floyd. *Land Economics* 80(2004): 490-500.

Bishop, M.J., Peterson, C.H., Summerson, H.C., Lenihan, H.S., Grabowski, J.H., 2006. Deposition and long-shore transport of dredge spoils to nourish beaches: impacts on benthic infauna of an Ebb-Tidal Delta. Journal of Coastal Research 22, 530–546.

Blanton, J. O., F.E. Werner, A. Kapolnai, B.O. Blanton, D. Knott, and E.L. Wenner. 1999. Wind-generated transport of fictitious passive larvae into shallow tidal estuaries. Fisheries Oceanography 8(2): 210-223.

Bodge, K. R. 2003. Design Aspects of Groins and Jetties. In: Advances in coastal structure design. Ed. R. Mohan, O. Magoon, and M. Pirrello. American Society of Civil Engineers (ASCE). Reston, VA. ISBN 0-7844-0689-8. Pp. 181-199.

Boss, K. Stephen, Charles W. Hoffman, and Stanley R. Riggs. 1999. Interpretation Of Side-Scan Sonar Records Of A Portion Of The Inner North Carolina Continental Shelf Between Oregon Inlet And Kitty Hawk. Final Contract Report to Minerals Management Service under Cooperative Agreement 14-12-0001-30348. January 1999.

Bowman, M.L., and R. Dolan. 1985. The Relationship of *Emerita talpoida* to Beach Characteristics. Journal of Coastal Research. 1(2):151-163.

Bowker, J.M. 2006. Wilderness and Primitive Area Recreation Participation and Consumption: An Examination of Demographic and Spatial Factors. Journal of Agricultural and Applied Economics. 38(2):317-326.

Brander, L.M., R.J.G.M. Florax and J.E. Vermaat. 2006. The Empirics of Wetland Valuation: A Comprehensive Summary and a Meta-Analysis of the Literature. Environmental and Resource Economics. 33(2):223-250.

Brown, S., C. Hickey, B. Harrington, and R. Gill, eds. 2001. The U.S. Shorebird Conservation Plan, 2nd ed. Manomet Center for Conservation Sciences, Manomet, MA.

Bullock, L.H, M.F. Godcharles, and R.E. Crabtree. 1996. Reproduction of yellowedge grouper, *Epinephelus flavolimbatus*, from the eastern Gulf of Mexico. Bull. Mar. Sci. 59(1): 216-224.

Burger, J., M. A. Howe, D. C. Hahn, and J. Chase. 1977. Effects of tide cycles on habitat partitioning by migrating shorebirds. Auk 94: 743-758.

Burlas, M, G.L. Ray, and D.G. Clarke. 2001. The New York District's biological monitoring program for the Atlantic coast of New Jersey, Asbury Park to Manasquan Section beach erosion control project. Final report. US Army Engineer District, New York, and US Army Engineer Research and Development Center, Waterways Experiment Station, Vicksburg, MS. Available at www.nan.usace.army.mil/business/prjlinks/coastal/Asbury/ index.htm.

Burton, N. H. K., P. R. Evans, and M. A. Robinson. 1996. Effects on shorebird numbers of disturbance, the loss of a roost site and its replacement by an artificial island at Hartlepool, Cleveland. Biological Conservation 77: 193-201.

Byrnes, M.R. and Hiland, M.W. 1995. Large-scale sediment transport patterns of the continental shelf and influence on shoreline response: St. Andrew Sound, Georgia to Nassau Sound, Florida, USA, Marine Geology, 126, Elseview Science, B.V., Amsterdam, The Netherlands, pp 19-43.

Camfield, F. E. and C. M. Holmes. 1995. Monitoring completed coastal projects. Journal of Performance of Constructed Facilities 9: 169-171.

Captiva Erosion Prevention District (CEPD). 1995. Environmental Assessment and Design Memorandum for the First Renourishment Project, Captiva Island Segment. Lee County, Florida. Beach Erosion Control Project.

Captiva Erosion Prevention District. 2002. Joint Coastal Permit Application for the Captiva and Sanibel Islands Renourishment Project. Submitted to the Florida Department of Environmental Protection.

Carlson, J.K., J. Osborne, and T.W. Schmidt. 2007. Monitoring the recovery of Smalltooth sawfish, *Pristis pectinata*, using standardized relative indices of abundance. Biological Conservation, 136(2), 195-202.

Carraway, R. J. and L.J. Priddy. 1983. Mapping of submerged grass beds in Core and Bogue Sounds, Carteret County, North Carolina, by conventional aerial photography. CEIP Report No. 20, 88p.

Carter, A. 2008. Town of Emerald Isle, North Carolina Bogue Inlet Channel Erosion Response Project. Final Summary of Infaunal Macroinvertebrate Sampling Events. Boca Raton, Florida: Coastal Planning & Engineering, Inc. 28p. Prepared for the Town of Emerald Isle, North Carolina.

Carteret County Shore Protection Office. 2002. Draft Sand Management Plan for the Morehead City Harbor Federal Navigation Project. Carteret County, North Carolina.

Charlier, R.H., M.C.P Chaineux, and S. Morcos. 2005. Panorama of the history of coastal protection. Journal of Coastal Research 21, 79–111.

Child, C.A. 1992. Shallow water Pychnogonida of the Gulf of Mexico. Mem. Hourglass Cruises 9(1): 86 pp.

Churchill, J. H., F.E. Werner, R. Luettich, and J.O. Blanton. 1997. Flood tide circulation near Beaufort Inlet, NC: implications for larval recruitment. Estuaries 22 (in press).

Churchill, J. H., R.B. Forward, R.A. Luettich, J.J. Hench, W.F. Hettler, L.B. Crowder, and J.O. Blanton. 1999. Circulation and larval fish transport within a tidally dominated estuary. Fisheries Oceanography. 8 (Suppl. 2): 173-189.

Clark B.M., B.A. Bennett, and S.J. Lamberth. 1996. Factors affecting spatial variability in seine net catches of fish in the surf zone of False Bay, South Africa. Marine Ecology Progress Series 131: 17–34

Clark, J. 1974. Coastal ecosystems, ecological considerations for management of the coastal zone. The Conservation Foundation, Washington D.C.

Cleary, W.J. 1996. Inlet induced shoreline changes: Cape Lookout-Cape Fear: Carolina Geological Society Fieldtrip Guidebook, p. 49-59.

Cleary, W.J, 2009, North Carolina's Tidal Inlets and Terminal Groins: Facts and Fiction, Zullo Seminar Series, Dept of Geography and Geology, University of North Carolina, Wilmington.

Coastal Engineering Research Center (CERC). 1980. Biological effects of a rubble-mound structure on the California coast. Technical Note CETN-V-6. Waterways Experiment Station, Vicksburg, Mississippi. 2pp.

CERC. 1981. Groins – their Applications and Limitations. CETN-III-10, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

CERC. 1984. Biological Effects of Jetty Construction on Coastal Marine Communities. CETN-V-18, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Coastal Planning & Engineering, Inc. (CPE). 1992. Blind Pass Inlet Management Plan, Pinellas County, Florida, 68 p.

CPE. 1993. Redfish Pass Inlet Management Plan. Submitted to Captiva Erosion Prevention District.

CPE. 1995. Environmental Assessment for the Design Memorandum for the First Renourishment Beach Erosion Control Project, Captiva Island Segment. Lee County, Florida.

CPE. 2008. Biological Assessment, Section 7 Consultation Endangered Species Act. Breakers Hotel T-Groin Reconditioning Project. Prepared for NOAA National Marine Fisheries Service, St. Petersburg, FL. and USACE, Palm Beach Gardens Regulatory Branch, West Palm Beach, FL.

CPE. 2009. Final Supplemental Environmental Impact Statement for the Topsail Beach Interim Beach Fill Project. Prepared for the US Army Corps of Engineers.

Coastal Zone Resources, Inc. (CZR). 1991. Indian Shores beach nourishment project side-scan mosaic and biological report. Prepared for Pinellas County Board of County Commissioners, Clearwater, FL.

Cohen, J.B., S.M. Karpanty, D.H. Catlin, J.D. Fraser, and R.A. Fischer. 2008. Winter Ecology of Piping Plovers at Oregon Inlet, North Carolina. Waterbirds 31(3): 472-479

Conaway, C.A. 2000. Aeolian dynamics and erosion mitigation at mechanically modified shorelines: Bogue Banks, NC. Unpublished Master's Thesis, Department of Marine Sciences, University of North Carolina at Chapel Hill. 175 p.

Continental Shelf Associates, Inc. 1987. Southwest Florida Shelf Regional Biological Communities Survey, Year 3 Final Report. Vol. I, Executive Summary. A final report for the U.S. Department of the Interior, Minerals Management Service Gulf of Mexico OCS Region, New Orleans, LA. Contract No. 14-12-0001-29036. 49 pp.

Continental Shelf Associates, Inc. 1993. A Brief Environmental Analysis of a Potential and Borrow Area offshore of Amelia Island, FL. Continental Shelf Associates, Inc., Jupiter, Florida.

Culter, J.K. and S. Mahadevan. 1982. Long-term effects of beach nourishment on the benthic fauna of Panama City Beach, Florida. Mote Marine Laboratory. Sarasota, Florida.

Davis, R.A., Jr., and J.C. Gibeaut. 1990. Historical Morphodynamics of Inlets in Florida: Models for Coastal Zone Planning, Florida Sea Grant College, Technical Paper 55, p. 20, 29-35. 81.

Davis, P., B. Howard, S. Derheimer. 2002. Effects of T-Head Groins on Reproductive Success of Sea Turtles in Ocean Ridge, Florida: Preliminary Results. Proceedings of the Twentieth Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-477. 369 pp.; 2002, p. 327-329

Dean, C. 1999. Against the tide. Columbia University Press, New York, USA.

Dean, R.G. 1993. Terminal Structures at Ends of Littoral Systems. Journal of Coastal Research. Special Issue 18. Pp. 195-210.

Defeo, O. and A. McLaclan, et al. 2009. Threats to sandy beach ecosystems: A review. Estuarine, Coastal and Shelf Science. 81(1). Pp. 12.

Dennis, W. and H. Miller. 1993. Shoreline Response: Oregon Inlet Terminal Groin Construction. Proceedings of the Hilton Head Island South Carolina USA International Coastal Symposium. June 6-9, 1993.

Dial Cordy and Associates Inc. (DC&A). 2001a. Environmental Assessment South Amelia Island Beach Stabilization Project. Phase I – Beach Nourishment. Jacksonville, Florida.

DC&A. 2001b. Marine Biological Survey Pinellas County Shore Protection Project Comprehensive Borrow Area Study. Prepared for U. S. Army Corps of Engineers, Jacksonville District, Jacksonville FL. 51 pp.

DC&A. 2002. Marine Biological Survey. Pinellas County Shore Protection Project. Comprehensive Borrow Area Study. Prepared for the US Army Corps of Engineers – Jacksonville District.

DC&A. 2003. Environmental Assessment of the South Amelia Island Beach Stabilization Project. Phase II – Structural Stabilization (USACOE 2001103870 IP-BL) (JCP – TBD) (FDEP 0187721-002-JC). Prepared for Olsen Associates, Inc.

DC&A. 2009. Draft Environmental Assessment, Beach Restoration Project for Treasure Island and Long Key, Pinellas County, Florida. Prepared for the US Army Corps of Engineers – Jacksonville District.

Dias, M. P., J. P. Granadiero, M. Lecoq, C. D. Santos, and J. M. Palmierim. 2006. Distance to high-tide roosts constrains the use of foraging areas by dunlins: implications for the management of estuarine wetlands. Biological Conservation 131: 446-452.

Diaz, H. 1980. The mole crab *Emerita talpoida* (say): A case study of changing life history pattern: Ecological Monographs 50(4):437-456.

Dinsmore, S. J., J. A. Collazo, and J. R. Walters. 1998. Seasonal numbers and distribution of shorebirds on North Carolina's Outer Banks. Wilson Bulletin 110:171–181.

North Carolina Division of Marine Fisheries (DMF). 2000. Red drum fishery management plan. DMF, Morehead City, NC, 106p.

Dolan, R., et al., 2004. Analysis of Changes in the Beach Sediment and Beach-face Organisms Associated with Sand Bypassing from the Oregon Inlet to Pea Island, North Carolina, 1990 to 2002. Unpublished Technical Report: Coastal Research Associates, 71 pp.

Dolan, R. et.al. 1994. Progress Report: Pea Island Beach Nourishment Project and Extension for Additional Sampling and Analysis. Prepared for USFWS, Pea Island National Wildlife PINWR. Manteo, North Carolina. September 1994.

Dolan, R. et.al. 1999. Review of the Beach Nourishment Plan for Dare County, North Carolina. Submitted to the USFWS. Raleigh, North Carolina. June 1999.

Dolan, R., et.al. 2001a. Draft Final Report: Summary of Results of the 2000-2001 Monitoring Program of Hopper Dredge Disposal, Oregon Inlet and Pea Island, North Carolina and Coordination and Review of the NCDOT/NC State Oregon Inlet Groin Monitoring Project. Prepared for USFWS, Pea Island National Wildlife PINWR. Manteo, North Carolina. September 2001.

Dolan, R., et.al. 2001b. The US Fish and Wildlife Service's Monitoring Program Oregon Inlet and Pea Island. Summary of Results of Dredging and Sand Bypassing. Prepared for USFWS, Pea Island National Wildlife PINWR. Manteo, North Carolina. October 2001.

Donnelly, C., N. Kraus and M. Larson. 2006. State of knowledge on measurement and modeling of coastal overwash. Journal of Coastal Research 22(4): 965-991.

Donoghue, C. R. 1999. The influence of swash processes on *Donax variabilis* and *Emerita talpoida*. PhD. Dissertation, Univ. of Virginia. Department of Environmental Sciences. 197 p.

Dorfman, J.H., Keeler, A.G., and W. Kriesel. 1996. "Valuing risk-reducing interventions with hedonic models: the case of erosion protection." Journal of Agricultural and Resource Economics. 21(1): 109-119.

Douglass, N.J., and L.M. Coburn. 2002. Survey of breeding American oystercatcher (*Haematopus palliatus*) populations in Florida. Final Performance Report. Tallahassee, FL: Florida Fish and Wildlife Conservation Commission.

Drake, K. R., J. E. Thompson, and K. L. Drake. 2001. Movement, habitat use, and survival of nonbreeding Piping Plovers. Condor 103: 259-267.

Dugan, J.E. and D.M. Hubbard. 2006. Ecological responses to coastal armoring on exposed sandy beaches. Shore and Beach 74, 10–16.

Dugan, J.E., D.M. Hubbard, I. Rodil, D.L. Revell, and S. Schroeter. 2008. Ecological effects of coastal armoring on sandy beaches. Marine Ecology 29, 160–170.

Earnhart, D. 2001. Combining Revealed and Stated Preference Methods to Value Environmental Amenities at Residential Locations. *Land Economics* 77: 12-29.

Ecological Associates Inc. 1999. Martin County beach nourishment project sea turtle monitoring and studies. 1997 annual report and final assessment. Jensen Beach, Florida.

Edgren, R.A. 1959. Coquinas (*Donax variabilis*) on a Florida beach. Ecology 40:498-502.

Elko, N.A. and Davis, R. A. Jr., 2000. Sediment budget for Treasure Island, Pinellas County, Florida. Tampa, FL: University of South Florida, Coastal Research Laboratory, 40p.

Environmental Protection Agency (EPA). 1981. Marine sampling and measurement program off northern Pinellas County, Florida. A Technical Report, S. Mahadevan, ed. Vol. 1: 306 pp.

EPA & USACE, 1996, Site Management and Monitoring Plan. Wilmington District, Wilmington, NC, 31 p.

Epperly, S. P., and S. W. Ross. 1986. Characterization of the North Carolina Pamlico-Albemarle Complex. Technical Memorandum. NMFS-SEFC-175. NOAA. Beaufort, North Carolina.

Evermann, B.W., and B.A. Bean. 1898. Indian River and its fishes. Report of United States Fisheries Commission 1896:227-248.

Farber, S.C. 1987. The Value of Coastal Wetlands for Protection of Property against Hurricane Wind Damage. Journal of Environmental Economics and Management. 14(2):143-151.

Ferguson, R. L., G. W. Thayer, and T. R. Rice. 1981. "Marine Primary Producers," Functional Adaptations of Marine Organisms. Edited by: F. J. Vernberg and W. B. Vernberg. Academic Press, New York, New York. pp. 9-63.

Ferland, C.L., and S.M. Haig. 2002. 2001 International Piping Plover Census. Corvallis, OR: U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center.

Fisher, J.S., Overton, M.F., and Jarrett, T. 2004. Pea Island Shoreline: 100-Year Assessment. FDH Engineering, Inc. for NC DOT, 18 p.

FitzGerald, D.M., 1988, Shoreline erosional-depositional processes associated with tidal inlets, in: Aubrey, D.G., and Weishar, L. (eds.), Hydrodynamics and Sediment Dynamics of Tidal Inlets, Springer-Verlag, New York, 269-283.

Florida Department of Environmental Protection – Division of Recreation and Parks (FDEP). 2005. Cayo Costa State Park. Approved Unit Management Plan.

FDEP. 2006. About the Boca Ciega Bay and Pinellas County Aquatic Preserves. http://www.dep.state.fl.us/coastal/sites/bocaciega-pinellas/info.htm. Last updated 13 April 2006.

FDEP. Bureau of Beaches and Coastal Systems. 2008. State of Florida Strategic Beach Management Plan.

FDEP. 2009. About Florida's Aquatic Preserves. http://www.dep.state.fl.us/coastal/programs/ aquatic.htm. Last updated 27 April 2009.

Florida Game and Freshwater Fish Commission. 1997. Florida's Endangered Species, Threatened Species and Species of Special Concern. Florida Game and Freshwater Fish Commission. 15 pp.

Florida Fish and Wildlife Conservation Commission. 2004. Florida's Endangered Species, Threatened Species, and Species of Special Concern. 6 pp.

Florida Marine Research Institute (FMRI). 2000. Statewide Nesting Survey Data Base.

Florida Department of Environmental Protection, 2008, Strategic Beach Management Plan for the Southwest Gulf Coast Region. Tallahassee, FL. 54 p.

Flournoy, P.H., S.G. Rogers, and P.S. Crawford. 1992. Restoration of shortnose sturgeon in theAltamaha River, Georgia. Final Report to the U.S. Fish and Wildlife Service, Atlanta, Georgia.

Fonseca, M. S., W. J. Kenworthy, J. Homziak, and G. W. Thayer. 1979. "Transplanting of Eelgrass and Shoalgrass as a Potential Means of Economically Mitigating a Recent Loss Bonner Bridge Replacement FEIS F- 8 NCDOT TIP Project Number B-2500 of Habitat," Proceedings of the 6th Annual Conference on Wetlands Restoration and Creation. Edited by D. P. Cole. Hillsborough College, Tampa, Florida. pp. 279-326.

Foote, J.J. 2003. Gasparilla Island Beach Nourishment Project: Hatchling Marine Turtle Interaction with Erosion Control Structure Study. Mote Marine Laboratory.

Fort Macon State Park. 2000. Park Profile – Park Purpose Statement. Accessed 16 December 2009 at http://www.ncparks.gov/About/plans/systemwide/docs/foma.pdf.

Fraser, J.D., S.E. Keane, and P.A. Buckley. 2005. Prenesting use of intertidal habitats by piping plovers on South Monomoy Island, Massachusetts. Journal of Wildlife Management 69(4): 1731-1736.

Fussell, J.O., III. 1985. Finding Birds in Carteret County. 96 p.

Garcia-Rodriguez, A.I., B.W. Bowen, D. Domning, A.A. Mignucci-Giannoni, M. Marmontel, R.A. Montoya-Ospina, B. Morales-Vela, M. Rudin, R.K. Bonde, and P.M. Mcguire. 1998. Phylogeography of the West Indian manatee (Trichechus manatus): how many populations and how many taxa? Molecular Ecology 7(9), 1137–1149.

Georgia Department of Natural Resources. 1999. Protected Animals of Georgia. Georgia Department of Natural Resources, Wildlife Resources Division, Nongame Wildlife Natural Heritage Section. 247 pp.

Gilmore, R.G., L.H. Bullock, and F.H. Berry. 1978. Hypothermal mortality in marine fishes of south-central Florida January 1977. Northeast Gulf Science 2(2): 77-97.

Golder, W. 2010. Personal communication. Deputy Director, Audubon North Carolina. Wilmington, NC. February 23, 2010.

Gore, J. A., J. A. Hovis, G. L. Sprandel, and N. J. Douglass. 2007. Distribution and abundance of breeding seabirds along the coast of Florida, 1998 – 2000. Final Performance Report. Tallahassee, FL: Florida Fish and Wildlife Conservation.

Goss-Custard, J. D., R. T. Clarke, S. E. A. Le V. Dit Durell, R. W. G. Caldow, and B. J. Ens. 1996. Population consequences of winter habitat loss in a migratory shorebird. II. Model predictions. Journal of Applied Ecology 32: 337-351.

Grabe, S.A. 1998. Overview of Boca Ciega Bay Benthos: 1997. Environmental Protection Commission of Hillsborough County, Tamps, FL.

Greenwood, J.B., and C.G. Vick. 2008. Economic Contributions of Visitors to Selected North Carolina State Parks. Prepared by: North Carolina State University. Prepared for: Division of Parks and Recreation, N.C. Department of Environment and Natural Resources. Raleigh, NC. May 2008.

Griggs, G.B. 2005a. California's retreating coastline: where do we go from here? In: Magoon, O.T., Converse, H., Baird, B., Miller-Henson, M. (Eds.), California and the World Ocean. 1997 Conference Proceedings, American Society of Civil Engineering, pp. 121–125.

Griggs, G.B. 2005b. The impacts of coastal armoring. Shore and Beach 73 (1), 13–22.

Grober, L.E. 1992. The Ecological Effects of Beach Replenishment. Master's thesis, Duke University, Durham, NC, 88 p.

Gulf of Mexico Fishery Management Council. 1998. Generic Amendment for Addressing Essential Fish Habitat Requirements of the Gulf of Mexico. 237 pp.

Hackney C.T., M.H. Posey, S.W. Ross, and A.R. Norris. 1996. A review and synthesis of data on surf zone fishes and invertebrates in the South Atlantic Bight and the potential effects from beach nourishment. Contract Report to the US Army Engineer Wilmington District, Wilmington, NC.

Hall, W. 2000a. Archeological Diver Identification and Evaluation of Seven Potentially Significant Submerged Targets in the John's Pass Navigation Channel, Pinellas County, Florida. A Report Prepared for US Army Corps of Engineers, Jacksonville District by Mid-Atlantic Technology and Environmental Research, Inc., Castle Hayne, North Carolina.

Hall, W. 2000b. Archaeological Diver Identification and Evaluation of Five Potentially Significant Submerged Targets in the Blind Pass Borrow Area, Pinellas County, Florida. A Report Prepared for US Army Corps of Engineers, Jacksonville District by Mid-Atlantic Technology and Environmental Research, Inc., Castle Hayne, North Carolina.

Hall, W.J., T.I.J. Smith, and S.D. Lamprecht. 1991. Movements and habitats of shortnose sturgeon *Acipenser brevirostrum* in the Savannah River. Copeia (3):695-702.

Hare, J.O., J.A. Quinlan, F.E. Werner, B.O. Blanton, J.J. Govini, R.B. Forward, L.R. Settle, and D.E. Hoss. 1999. Larval transport during winter in the SABRE study area: results of a coupled vertical larval behavior-three-dimensional circulation model. Fisheries Oceanography. 8(2): 57-76.

Harrington, B. R. 2008. Coastal inlets as strategic habitat for shorebirds in the southeastern United States. DOER Technical Notes Collection. ERDC TN-DOER-E25. Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://el.erdc.usace.army.
mil/dots/doer/.

Hay, M.E., and J.P. Sutherland. 1988. The ecology of rubble structures of the South Atlantic Bight: a community profile. U.S. Fish Wildlife Service Biological Report 85(7.20). 67 pp.

Hays, G.C., J.S. Ashworth, M.J. Barnsley, A.C. Broderick, D.R. Emery, B.J. Godley, A. Henwood, and E.L. Jones. 2001. The importance of sand albedo for the thermal conditions on sea turtle nesting beaches. Oikos 93: 87-94.

Heidt, A.R., and R.J. Gilbert. 1979. Movements of shortnose sturgeon, Acipenser brevirostrum, in the Altamaha River, Georgia. ASB Bulletin 26.

Herbich, John B. 2000. Handbook of Coastal Engineering. McGraw-Hill, New York.

Herren, R.H. 1999. The effect of beach nourishment on loggerhead (*Caretta caretta*) nesting and reproductive success at Sebastian Inlet, Florida. M.S. thesis, University of Central Florida. Orlando, Florida.

Herstine, Jim, Jeffery Hill, Bob Buerger, John Whitehead and Carla Isom, "Determination of Recreation Demand for Federal Shore Protection Study Area: Overview and Methodology," Final Report Prepared for U.S. Army Corps of Engineers, Wilmington District, 2005.

Hettler, W. F. J. and D.L. Barker. 1993. Distribution and abundance of larval fish at two North Carolina inlets. Estuarine, Coastal, and Shelf Sciences 37: 161-179.

Hodgson, A.B., A.F. Paul, and M. Rachal. 2009. Monitoring Important Bird Colonies; Pinellas County and Tampa Bay, Florida; Pinellas County Environmental Fund and National Fish and Wildlife Foundation Final Report December 1, 2006 - November 30, 2008. Audubon of Florida, Florida Coastal Islands Sanctuaries Program, Tampa, Florida. Report submitted to the National Fish and Wildlife Foundation.

Holloman, K. T. and M. H. Godfrey. 2006. 2005 Sea Turtle Monitoring Project Report. Bogue Banks, North Carolina. Submitted by the NC Wildlife Resources Commission.

Homziak, J., M. S. Fonseca, and W. J. Kenworthy. 1982. "Macrobenthic Community Structure in a Transplanted Eelgrass (Zostera marina) (L). Meadow," Marine Ecology Program Series, 9: 211-221.

Humphrey, S.R. 1992. Rare and Endangered Biota of Florida, Volume I. Mammals: 190-198.

Hunter, W.C., W. Golder, S. Melvin and J. Wheeler. 2006. Southeast United States Regional Waterbird Conservation Plan. Atlanta, GA

Jaramillo, E., H. Contreras, and A. Bollinger. 2002. Beach and faunal response to the construction of a seawall in a sandy beach of south central Chile. Journal of Coastal Research 18, 523–529.

Jarrett, T. 2007. North Carolina should study use of terminal groins. White paper. Submitted to: Save Our Sand: The Inlet Solution. http://inletsolutions.org/WhatTheExpertsSay/tabid/56/Default.aspx.

Jarrett, T. 2008. Research indicates terminal groins can be effective. White paper. Submitted to: Save Our Sand: The Inlet Solution. http://inletsolutions.org/WhatTheExpertsSay/tabid/56/Default.aspx.

Johnson, C. M. and G. A. Baldassarre. 1988. Aspects of the wintering ecology of Piping Plovers in coastal Alabama. Wilson Bulletin 100: 214-233.

Joyner, B. P., M.F. Overton, and J. S. Fisher. 1998. Post-Stabilization Morphology of Oregon Inlet, NC. International Conference of Coastal Engineering 1998 Conference Proceedings.

Jutte, P.C., R.F. Van Dolah, and M.V. Levisen. 1999. An environmental monitoring study of the Myrtle Beach Renourishment Project: intertidal benthic community assessment of Phase II, Myrtle Beach. Supplemental Report. Prepared for US Army Corps of Engineers, Charleston District. Marine Resources Division, South Carolina Department of Natural Resources, Charleston, SC.

Kapolnai, A., R.E. Werner, and J.O. Blanton. 1996. Circulation, mixing, and exchange processes in the vicinity of tidal inlets. Journal of Geophysical Research 101(14): 253-268.

Kenworthy, W. J., G. W. Thayer, and M. S. Fonseca. 1988. "The Utilization of Seagrass Meadows by Fishery Organisms," The Ecology and Management of Wetlands Vol. I.,Ecology of Wetlands. Edited by D. D. Hook, W. H. McKee, Jr., H. K. Smith, J. Gregory, V. G. Burrell, Jr., M. R. DeVoe, R. E. Sojka, S. Gilbert, R. Banks, L. H. Stukey, C., Brooks, T. D. Matthews, and T. H. Shear. Timber Press, Oregon.

Kieffer, M., and B. Kynard. 1993. Annual movements of shortnose and Atlantic sturgeons in the Merrimack River, Massachusetts. Transactions of the American Fisheries Society 122:1088-1103.

Kikukawa, A., N. Kamezaki, and H. Ota. 1999. Factors Affecting Nesting Beach Selection by Loggerhead Turtles (*Caretta caretta*): A Multiple Regression Approach. Journal of Zoology, 249 (4): 447-454.

Kraus, N.C., M. Larson, and R.A. Wise. 1998. Coastal Engineering Technical Note: Depth of Closure in Beach-fill Design. USACE.

Kriesel, W., A. Randall, and F. Lichtkoppler. 1993. Estimating the Benefits of Shore Erosion Protection in Ohio's Lake Erie Housing Market. Water Resources Journal 29(4):795-801.

Krock, J.R., 2005, Historical Morphodynamics of John's Pass, West-Central Florida, unpub. Masters Thesis, University of South Florida, 98 p.

Knott, D.M., Van Dolah, R.F., and Calder, D.R. 1984. Ecological effects of rubble weir jetty construction at Murrells Inlet, South Carolina Volume II: Changes in macrobenthic communities of sandy beach and nearshore environments. US Army Corps of Engineers Technical Report EL-84-4. 46 pp.

Kushlan, J.A., et al. 2002. Waterbird Conservation for the Americas: The North American Waterbird Conservation Plan, Version 1. Waterbird Conservation for the Americas,Washington, DC, U.S.A., 78 pp.

Lach, C. 2001. Colonial Waterbird Nesting Reports. Unpublished Data, Talbot Islands State Park, Florida.

Lamonte, K. M., N. J. Douglass, J. G. Himes, and G. E. Wallace. 2006. Status and distribution of the Snowy Plover in Florida. 2002 Study Final Report. Tallahassee, FL: Florida Fish and Wildlife Conservation Commission.

LaSalle M.W., D. G. Clarke, J. Homziak, J.D. Lunz, and T.J. Fredette. 1991. A framework for assessing the need for seasonal restrictions on dredging and disposal operations. Technical Report D-91–1. US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Lasiak, T.A. 1984. Structural aspects of the surf-zone fish assemblage at King's Beach, Algoa Bay, South Africa: long-term fluctuations. Estuarine and Coastal Shelf Science 18:459-483.

Landry, C.E., A.G. Keeler, and W. Kriesel. 2003. An Economic Evaluation of Beach Erosion Management Alternatives. *Marine Resource Economics* 18: 105-27.

Layman, C.A. 2000. Fish assemblage structure of the shallow ocean surf-zone on the eastern shore of Virginia barrier islands. Estuarine and Coastal Shelf Science 51:201-213.

Lazzari, MA, S. Sherman, C.S. Brown, J. King, B.J. Joule, S.B. Chenoweth, and R.W. Langton. 1999. Seasonal and annual variations in abundance and species composition of two nearshore fish communities in Maine. Estuaries 22:636-647

Leatherman, S.P. 1982. Barrier island handbook. University of Maryland Press, College Park, USA.

Lebuff, C. R. 1990. The Loggerhead Sea Turtle in the Eastern Gulf of Mexico. Caretta Research Inc., Sanibel, FL. Pp 185, 190.

Lee County (Natural Resources Division). 2005. Lee County Artificial Reef Plan.

Leonard, L.A., K.L. Dixon, and O.H. Pilkey. 1990. A Comparison of Beach Replenishment on the U.S. Atlantic, Pacific, and Gulf Coasts. Journal of Coastal Research. Special Issue 6. Pp 127-140.

Lindquist, N., and L. Manning, 2001. Effects of Beach Nourishment and Beach Scraping on Critical Habitat and Productivity of Surf Fishes. Final Report to the NC Fisheries Resource Grant Program. 41 p. + appendices.

Loflin, R.K. 2005. Sanibel Island Beach Nourishment Shorebird Management Plan. JCP Permit No. 0200269-001-JC (-003-EM).

Loftin, R. W. 1978. The Bird Islands of Nassau Sound. Florida Wildlife 31(5):16-20.

Lott, C.A., K.L. Volansky, and C.S. Ewell, Jr. 2009. Habitat Associations of Shoreline-Dependent Birds in Barrier Island Ecosystems during Fall Migration in Lee County, Florida. Final report prepared for U.S. Army Corps of Engineers. Washington, DC. September 2009.

Lucas, L.L., B.E. Witherington, A.E. Mosier, and C.M. Koeppel. 2004. Mapping Marine Turtle Nesting Behavior and Beach Features to Assess the Response of Turtles to Coastal Armoring. Proceedings of the Twenty-First Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-528. 368 pp.; 2004, p. 32-34.

Lyons, W.G., and Collard, S.B. 1974. Benthic invertebrate communities of the eastern Gulf of Mexico. In R.E. Smith, ed. Proceedings of marine environmental implications of offshore drilling in the eastern Gulf of Mexico. State Univ. Syst. FL. Inst. Oceanogr.,St. Petersburg, FL. 157-166 pp.

MacDonald, D., J. Murdoch, and H. White. 1987. Uncertain Hazards, Insurance and ConsumerChoice: Evidence from Housing Markets. *Land Economics* 63: 361-71.

MacDonald, D., H. White, P. Taube, and W. Huth. 1990. Flood Hazard Pricing and Insurance Premium Differentials: Evidence from the Housing Market. *Journal of Risk and Insurance* 57:654-63.

Martin, D., F. Bertasi, M.A. Colangelo, M. de Vries, M. Frost, S.J. Hawkins, E. MacPherson, P.S. Moschella, M.P. Satta, R.C. Thompson, and V.U. Ceccherelli. 2005. Ecological impact of coastal defense structures on sediment and mobile fauna: evaluating and forecasting consequences of unavoidable modifications of native habitats. Coastal Engineering 52, 1027–1051.

Mapstone, B. D. 1995. Scalable decision rules for environ-mental impact studies: effect size, type I, and type II errors. Ecological Applications 5:401-410.

McMichael, R. H., Jr., and K. M. Peters. 1989. “Early Life History of Spotted Seatrout,Cynoscion nebulosus (Pisces: Sciaenidae) in Tampa Bay, Florida.” Estuaries, 12(2): 98-110.

McRoy, C. P., and C. Helfferich. 1980. "Applicated Aspects of Seagrasses," Handbook of Seagrass Biology. Edited by R. C. Phillips and C. P. McRoy. Garland STPM Press, New York, New York.

Mead, S. and K. Black. 2005. Balancing Coastal Protection with Social and Environmental Needs on Exposed Coasts. Keynote Address for the 3rd West Australian Coastal Conference.

Mehta, A. J., Byrne, R. J. and DeAlteris, 1975. Hydraulic constants of tidal entrances III: Bed friction measurements at John's Pass and Blind Pass. University of Florida, Coastal and Oceanographic Engineering Laboratory, Technical Report no. 26, 78p.

Mehta, A. J., Jones, C. P. and Adams, W. D., 1976. John's Pass and Blind Pass: Glossary of Inlets Report Number 4, Florida Sea Grant Program, 66p.

Meylan, A., A. Redlow, A. Mosier, K. Moody, A. Foley. 1999. Occurrence and distribution of sea turtles in Tampa Bay, FL. In J.R. Pribble, A. J. Janicki, and H. Greening , eds. Baywide environmental monitoring report, 1993-1998, Tampa Bay, FL. Tampa Bay Estuary Program, Technical Publication 07-99. St. Petersburg, FL. Chapter 13, 13-1-13-15 pp.

Miller, J. M. 1992. Larval fish migration at Oregon Inlet, North Carolina. Supplemental Reports to the Department of the Interior Consultant's Report. US Dept. of the Interior. USFWS 8: 27.

Miller, J. M., and M. L. Dunn. 1980. "Feeding Strategies and Patterns of Movement in Juvenile Estuarine Fishes," Estuarine Perspectives. Edited by V. S. Kennedy. Academic Press, New York, New York.

Milon, J., J. Gressel and D. Mulkey. 1984. Hedonic Amenity Valuation and Functional Form Specification. *Land Economics* 60: 378-87.Moe, M.A., and G.T. Martin. 1965. Fishes taken in monthly trawl samples offshore of Pinellas County, Florida, with new additions to the fish fauna of the Tampa Bay area. Tulane Studies in Zoology. 12(4): 129-151.

Moser, M. L. and B. L. Taylor. 1995. Hardbottom habitat in North Carolina state waters: a survey of available data. Final Report to NC Division of Coastal Management. Unpub. doc., 20p.

Mosier, A.E. 2000. What is Coastal Armoring and How Can it Affect Nesting Sea Turtles in Florida. Proceedings of the Nineteenth Annual Symposium on Sea Turtle Biology and Conservation. U.S. Dept. Commerce. NOAA Tech. Memo. NMFS-SEFSC-443. 291 pp.; 2000, p. 231.

Moslow, T.F. and Heron, S.D. 1994. The Outer Banks of North Carolina: In Geology of Holocene Barrier Island Systems, Springer-Verlag, p. 47-74.

Mrosovsky, N., S.R. Hopkins-Murphy, and J.I. Richardson. 1984. Sex ratio of sea turtles: seasonal changes. Science 225: 739-741.

Mrosovsky, N. and J. Provancha. 1992. Sex ratio of hatchling loggerhead sea turtles: data and estimates from a 5-year study. Canadian Journal of Zoology 70: 530-538.

Mulvihill, E.L., C.A. Francisco, J.B. Glad, K.B. Kaster, and R.E. Wilson. 1980. Biological impacts of minor shoreline structures on the coastal environment: State of the art review. US Fish and Wildlife Services, Biological Services Program. FWS/OBS – 77/51. 2 vol.

Myers, R.L. and J.J. Ewel, eds. 1990. Ecosystems of Florida. University of Central Florida Press, Orlando, FL. 765 pp.

Myers, S., N. Page, and A. Squires. 2000. Ambient Surface Water Quality Monitoring Report 1991-1997, Pinellas County, Florida. Pinellas County Department of Environmental Management, Clearwater, FL.

NMFS. 2003. Humpback Whale Stock Assessment. http://www.nmfs.noaa.gov/pr/species/ mammals/cetaceans/humpbackwhale.htm. Site last visited 16 December 2009.

NMFS. 2006. Recovery Plan for Smalltooth Sawfish (*Pristis pectinata*). Prepared by the Smalltooth Sawfish Recovery Team for the National Marine Fisheries Service, Silver Spring, Maryland.

NMFS. 2009. Gulf sturgeon protected species description. http://www.nmfs.noaa.gov/ pr/species/fish/gulfsturgeon.htm. Accessed 9 December 2009.

NMFS and U.S. Fish and Wildlife Service. 2008. Recovery Plan for the Northwest Atlantic Population of the Loggerhead Sea Turtle (*Caretta caretta*), Second Revision. National Marine Fisheries Service, Silver Spring, MD.

National Oceanic and Atmospheric Administration National Ocean Service (NOAA). 2008. Environmental Sensitivity Index Mapping.

National Oceanic and Atmospheric Administration Coastal Services Center. Beach Nourishment: A Guide for Local Officials. Accessed 6 December 2009. Available on-line at: http://www.csc.noaa.gov/beachnourishment/html/geo/shorelin.htm.

National Park Service (NPS). 1984. General Management Plan and Amended Environmental Assessment for Cape Hatteras National Seashore. US Department of Interior, Manteo, North Carolina.

NPS. 1991. Draft Revised Statement for Management. US Department of the Interior, Manteo, North Carolina.

NPS. 2009a. Cape Hatteras National Seashore Seabeach Amaranth Surveys 2009 Annual Report. US Department of the Interior, Manteo, North Carolina.

NPS. 2009b. Cape Hatteras National Seashore Piping Plover Monitoring 2009 Annual Report. US Department of the Interior, Manteo, North Carolina.

NPS. 2010a. Cape Hatteras National Seashore, Park Statistics. U.S. Department of Interior, National Park Service. Available: http://www.nps.gov/caha/parkmgmt/statistics.htm

NPS. 2010b. Comments on Working Draft Report, Terminal Groin Study, dated February 1, 2010. U.S. Department of Interior, National Park Service, Southeast Regional Office, Atlanta, GA.

NPS. 2010c. Cape Lookout National Seashore, Park Statistics. U.S. Department of Interior, National Park Service. Available: http://www.nps.gov/calo/parkmgmt/statistics.htm

NPS. 2010d. Cape Lookout National Seashore, Horses of Shackleford Banks. Brochure. U.S. Department of Interior, National Park Service. Available: http://www.nps.gov/calo/index.htm

Nelson, B. D., and S.A. Bortone. 1996. Feeding guilds among artificial-reef fishes in the northern Gulf of Mexico. Gulf of Mexico Science. 1996(2): 66-80.

Nelson, D.A., and D.D. Dickerson. 1988. Effects of beach nourishment on sea turtles. Proc. Of the Beach Preservation Technology Conference '88. Florida Shore and Beach Preservation Association, Inc. Tallahassee, Florida. pp 285-293.

Nelson, W.G. 1993. Beach restoration in the southeastern US: environmental effects and biological monitoring. Ocean Coast Manage 19:157-182.

Nicholls, J. L. and G. A. Baldassarre. 1990. Habitat selection and interspecific associations of Piping Plovers along the Atlantic and Gulf Coasts of the United States. Wilson Bulletin 102: 581-590.

Noble, E. B., and R. J. Monroe. 1990. Classification of Pamlico Sound Nursery Areas: Recommendations for Critical Habitat, Albemarle-Pamlico Estuarine Study.

Nordstrom, K. F. 2000. Beaches and dunes of developed coasts. University Press, Cambridge, United Kingdom.

North Carolina Department of Revenue (NCDR). 2009a. Effective Tax Rates for North Carolina Counties and Municipalities, Fiscal Year 2007-2008. North Carolina Department of Revenue. Raleigh, NC. Available: http://www.dornc.com/publications/effective_rates.html

NCDR. 2009b. Taxable Real Property by County, Fiscal Year 2007-2008. North Carolina Department of Revenue. Raleigh, NC. Available: http://www.dornc.com/publications/taxable_real_property.html

North Carolina Department of Transportation, Division of Highways (NCDOT). 1989. Environmental Assessment and Finding of No Significant Effect – Construction of a Terminal Groin and Revetment at Pea Island for the Protection of the Herbert C. Bonner Bridge and North Carolina Highway 12. Dare County, North Carolina.

NCDOT. 2008. NC 12 Replacement of Herbert C. Bonner Bridge Final Environmental Effect Statement and Section 4(f) Evaluation. Volume 1.

NCDOT 2008b. Final Environmental Impact Statement and Section 4(f) Evaluation. NC 12 Replacement of Herbert C. Bonner Bridge. US Department of Transportation, Federal Highway Administration, North Carolina Department of Transportation. FHWA-NC-EIS-93-01-F.

NC Division of Coastal Management (NCDCM). 2006. Recommendations for Appropriate Shoreline Stabilization Methods for the Different North Carolina Estuarine Shoreline Types. Prepared by Bonnie M. Bendell. Prepared for the North Carolina Coastal Resources Commission Estuarine Shoreline Stabilization Subcommittee.

NCDCM. 2009. CRC Science Panel on Coastal Hazards. September 29, 2009 Meeting Minutes. Available online at http://dcm2.enr.state.nc.us/CRC/tgs/Sept%2029%202009%20Science%20Panel%20minutes.pdf.

North Carolina Division of Parks and Recreation (NCDPR). 2009. North Carolina Division of Parks and Recreation -- 2009 Annual Report. Division of Parks and Recreation, N.C. Department of Environment and Natural Resources. Raleigh, NC.

North Carolina State Ports Authority (NCSPA). 2001. Final Environmental Effect Statement Administrative Action for the Port of Morehead City – Radio Island Expansion. Project No. A/E 159(m). ID No. 4696100052A.

North Carolina Wildlife Resources Commission (NCWRC). 2009. Bogue Inlet Waterbird Monitoring and Management 2003-2008 Final Report.

O'Brien, M. 1976. Notes on Tidal Inlets on Sandy Shores, Department of Army Corps of Engineers, GITI Report 7, 26 p.

Oceanfront Communities: A Geological Perspective", *Eds*. J.T. Kelley, O.H. Pilkey, and J.A.G. Cooper. Geological Society of America, Special Publication 460, p. 43-72.

Olsen Associates, Inc. 1993. Nassau Sound Inlet Management Plan, DRAFT. Report submitted to Nassau County Soil and Water Conservation District. Jacksonville, Florida. 256 pp.

Olsen Associates, Inc. 2000. South Amelia Island Shoreline Stabilization Study, Amelia Island, Florida. Report prepared for Nassau County Board of Commissioners. Jacksonville, Florida. 61 pp.

Olsen Associates, Inc. 2001. South Amelia Island Shoreline Stabilization Project. Geotechnical Information, Abbreviated Version. Jacksonville, Florida. 35 pp.

Olsen Associates, Inc. 2002. Joint Coastal Permit Application for Phase II of the South Amelia Island Shore Stabilization Project. Permit No. 0187721-001-JC.

Olsen Associates, Inc. 2003. January 2, 2003 Letter to Florida Department of Environmental Protection Regarding JCP File No. 0187721-002-JC, Nassau County.

Olsen Associates, Inc. 2008. South Amelia Island Shore Stabilization Project Monitoring Report. Phase I – Beach Restoration; Phase II – Structures. Prepared for Florida Park Service & SAISSA, Inc. Submitted to Bureau of Beaches & Coastal Systems, FDEP.

Olsen Associates, Inc. 2006, Regional sand transport study: Morehead City Harbor Federal Navigation project, Jacksonville, Florida, 110 p.

Olsen, E.J. and Bodge, K.R. (2006). "Application of Porous ("Leaky") Rock Terminal Structures", Proceedings of the 30th International Conference on Coastal Engineering, COPRI, American Society of Civil Engineers.

Overton, M.F. June 2007. Shoreline Monitoring at Oregon Inlet terminal groin. Reports 28 to 31 in June 2007. Prepared for NC Dept. of Transportation, 15 p.

Overton, M.F., and Fisher, J.S. June 2005. Bonner Bridge Replacement Parallel Bridge Corridor with NC12 Maintenance: Shoreline Change and Stabilization Analysis. For URS Corporation, Tip No. B-2500, Task Orders 18 and 20, 38 p.

Overton, M.F., and Fisher, J.S. March 2005. Shoreline Monitoring at Oregon Inlet Terminal groin. Reports 1 to 27 in March 2005. Prepared for NC Dept. of Transportation, 16 p.

Palmquist, R. "Property Value Models," in K-G Maler and J. Vincent, eds., *Handbook of Environmental Economics*, volume 2, North Holland, 2004.

Peters D.J. and W.G. Nelson. 1987. The seasonality and spatial patterns of juvenile surf zone fishes of the Florida east coast. Florida Science 50:85–99.

Peters, D. S., L.R. Settle, and J.D. Fuss. 1995. Larval fish abundance in the vicinity of Beaufort Inlet prior to berm construction. NMFS, Beaufort, NC, NMFS Progress Report, 20 p.

Peters, D. S. and L.R. Settle. 1994. Larval fish abundance in vicinity of Beaufort Inlet prior to berm construction. NMFS data summary report of project funded by the US Army Corps of Engineers. NMFS, Beaufort, NC, 38 p.

Peterson, C.H., and N.M. Peterson. 1979. The ecology of intertidal flats of North Carolina: a community profile U.S. Fish and Wildlife Service. Office of Biological Services. FWS/OBS-79/39. 73 pp.

Peterson, C.H., H.C. Summerson, H.L. Lenihan, and G.W. Safrit, Jr. 1995. Beaufort Inlet Benthic Resources Survey. Interior Report to the Army Corps of Engineers.

Peterson, C.H., H.C. Summerson, H.L. Lenihan, and G.W. Safrit, Jr. 1996. Beaufort Inlet Benthic Resources Survey. Interior Report to the Army Corps of Engineers.

Peterson, C.H., D. H. M. Hickerson, and G. G. Johnson. 2000a. Short-term consequences of nourishment and bulldozing on the dominant large invertebrates of a sandy beach. Journal of Coastal Research. 16:368-378.

Peterson C.H., H.C. Summerson, E. Thomson, H.S. Lenihan, J. Grabowski, L. Manning, F. Micheli, and G. Johnson. 2000b. Synthesis of linkages between benthic and fish communities as a key to protecting essential fish habitat. Bulletin of Marine Science 66:759–774.

Peterson, C.H., and L.M. Manning. 2001. How beach nourishment affects the habitat value of intertidal beach prey for surf fish and shorebirds and why uncertainty still exists. Proceedings of the Coastal Ecosystems and Federal Activities Technical Training Symposium, August 20-22, 2001, Gulf Shores, Alabama. U.S. Fish and Wildlife Service, CD-ROM.

Peterson, C.H., M.J. Bishop, G.A. Johnson, L.M. D'Anna, L.M. Manning. 2006. Exploiting beach filling as an unaffordable experiment: benthic intertidal impacts propagating upwards to shore birds. Journal of Experimental Marine Biology and Ecology 338, 205–221.

Petrolia, D.R., and T-G. Kim. 2009. What Are Barrier Islands Worth? Estimates of Willingness to Pay for Restoration. Marine Resource Economics. 24:131-146.

Pierce, D.J., J.E. Wallin, and B. Mahmoudi. 1998. Spatial and temporal variations in the species composition of bycatch collected during a striped mullet survey. Gulf of Mexico Science 1998(1): 15-27 pp.

Pilkey O.H., H.L. Wright III. 1988. Seawalls versus beaches. Journal of Coastal Research (Special Issue) 4:41–64.

Pinellas County. 2007. Pinellas County Motel, hotel and condominium visitation trend statistics for 2007. Pinellas County Tax Authority, Pinellas County, FL.

Pinellas County. 2008. Pinellas County Tourist Development Tax for 2007 and 2008. Pinellas County Tax Authority, Pinellas County, FL.

Pinellas County Department of Public Works. (Coastal Management and St. Petersburg/Clearwater Area Convention and Visitors Bureau). 2009. Pinellas County's Public Beach Access Guide. http://www.pinellascounty.org/Environment/pagesHTML/ coastalMngmt/Coastal/Beach_Access_Guide.pdf.

Pinellas County Department of Environmental Management. 2008. http://www.pinellas county.org/Environment/pagesHTML/coastalMngmt/pdfs/JohnsPassHistory.pdf. Site last visited: 2 November 2009.

Pinellas County Department of Environmental Management. 2009. Ambient Monitoring Program Annual Report. 2004 - 2008. Pp 52.

Posey, M., W.J. Lindberg, T. Alphin, and F. Vose. 1996. Influence of storm disturbance of an offshore benthic community. Bull. Mar. Sci. 59(3): 523-529.

Potter, E. F., J. F. Parnell, and R. P. Teulings. 1980. Birds of the Carolinas. University of North Carolina Press, Chapel Hill, North Carolina, USA.

Reilly, F.J. Jr., and V.J. Bellis. 1978. A study of the ecological effect of beach nourishment with dredged materials on the intertidal zone. East Carolina University Institute for Coastal and Marine Resources, Technical Report No. 4., Greenville, North Carolina. 107 pp.

Reilly F.J., and B.J. Bellis. 1983. The ecological effect of beach nourishment with dredged materials on the intertidal zone at Bogue Banks, North Carolina. Miscellaneous Report 83-3. US Army Engineer Coastal Engineering Research Center, Fort Belvoir, VA.

Riggs, S.R., Ames, D.V., 2009, Impact of the Oregon Inlet terminal groin on downstream beaches of Pea Island, NC Outer Banks, Unpublished Technical Report, Department of Geological Sciences, East Carolina University, Greenville, NC. 19 pp.

Riggs, S.R., Ames, D.V., Culver, S.J., Mallinson, D.J., Corbett, D.R., and Walsh, J.P. 2009. In the eye of a human hurricane: Oregon Inlet, Pea Island, and the Northern Outer Banks, North Carolina; *In* Identifying America's Most Vulnerable

Riggs, S.R., Cleary, W.J., and Snyder, S.W., 1995, Influence of inherited geologic framework upon barrier beach morphology and shoreface dynamics: Marine Geology, v. 126, p. 213-234.

Roberts, C., W.J. Ballantine, C.D. Buxton, P. Dayton, L.B. Crowder, W. Milon, M.K. Orback, D. Pauly, J. Trexler, and C.J. Walters. 1995. Review of the use of marine fishery reserves in the U.S. southeastern Atlantic. NOAA Technical Memorandum NMFS-SEFSC-376. 31pp.

Rogers, D. I., P. F. Battley, T. Piersma, J. A. Van Gils, and K. G. Rogers. 2006. High-tide habitat choice: insights from modeling roost selection by shorebirds around a tropical bay. Animal Behavior 72: 563-575.

Rogers, S.G., and W. Weber. 1995. Status and restoration of Atlantic and shortnose sturgeons in Georgia. Final Report to the National Marine Fisheries Service, Southeast Regional Office, St. Petersburg, Florida.

Rosen, S. 1974. Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. *Journal of Political Economy* 82(1): 34-55.

Ross S.T., R.H. McMichael Jr, and D.L. Ruple. 1987. Seasonal and diel variation in the standing crop of fishes and macroinvertebrates from a Gulf of Mexico surf zone. Estuarine and Coastal Shelf Science 25:391-412.

Ross, S.W. and J.E. Lancaster. 2002. Movements and site fidelity of two juvenile fish species using surf zone, nursery habitats along the southeastern North Carolina coast. Environ. Biol. Fish. 63:161-172.

Saloman, C.H., and S.P. Naughton. 1979. Fishes of the littoral zone, Pinellas County, Florida. Florida Sci. 42(2):85-93.

Schaefer, R.H. 1967. Species composition, size and seasonal abundance of fish in the surf waters of Long Island. NY Fish Game J 1:1-46

Schirripa, M. J., and K. M. Burns. 1997. Growth estimates for three species of reef fish in the eastern Gulf of Mexico. Bull. Mar. Sci. 61(3): 581-591.

Schmidly, DJ. 1981. Marine mammals of the southeastern United States coast and the Gulf of Mexico. USFWS-Office of Biological Services Report No. 80/41, 165 pp.

Schrader, Robert J. et al. Tidal Inlets – A Major Hurdle to Effectively Protecting Sensitive Coastal Resources. Site Remediation News. Vol 12, No 1. Article 03. July 2000.

Schroeder, B.A. and A.E. Mosier. 2000. Between a Rock and a Hard Place: Coastal Armoring and Marine Turtle Nesting Habitat in Florida. Proceedings of the Eighteenth International Sea Turtle Symposium. U.S. Dept. of Commerce. NOAA Technical Memorandum NMFS-SEFSC-436, 293 pp.; p. 290-292.

Seim, H., 2002, Reynolds stress measurements in a short tidal inlet, 2nd Meeting on the Physical Oceanography of Sea Straits. Villefranche, France, April 2002.

Shabman, L. and M. Bertelson. 1979. The Use of Development Value Estimates for Coastal Wetland Permit Decisions. *Land Economics* 55: 213-22.

Simmons, K.M., J.B. Kruse, and D.A. Smith. 2002. Valuing Mitigation: Real Estate Market Response to Hurricane Loss Reduction Measures. *Southern Economic Journal* 68(3): 660-71.Simpfendorfer, C.A. 2002. Smalltooth sawfish: the USA's first endangered elasmobranch? Endangered Species Update, 19, 45-49.

Slay, C. 1993. Right Whale Research Project, New England Aquarium. Personal communication regarding seasonal occurrence of right whales of the Cape Fear region; p.5, In: Biological Assessment: Channel Realignment Masonboro Inlet, New Hanover County, NC. August 1995. USACE.

Smith A. C. and E.Nol. 2000. Winter foraging behavior and prey selection of the semipalmated plover in coastal Venezuala. Wilson Bulletin 112: 467-472.

Sobocinski, K.L., 2003. The impact of shoreline armoring on supratidal beach fauna of Central Puget Sound. MSc Thesis, University of Washington, Seattle.

Sorenson, R. M. 1997. Basic Coastal Engineering. Chapman & Hall. New York.

South Atlantic Fisheries Management Council (SAFMC). 1998. Final habitat plan for the South Atlantic region: Essential Fish Habitat requirements for fishery management plans of the South Atlantic Fishery Management Council. SAFMC, Charleston, SC.

SAFMC. 1999. Recovery plan for the Roseate tern *Sterna dougallii dougallii*. Site last visited 17 December 2009. http://www.safmc.net/Portals/0/Protres/New_PR/mangt_cons%20effort_section/roseate%20tern%20recovery.pdf.

Southeast Area Monitoring and Assessment Program (SEAMAP-SA). 2001. South Atlantic Bight Hardbottom Mapping. SEAMAP South Atlantic Bottom Mapping Workgroup, Charleston, South Carolina, 166p.

Southeastern Archaelogical Research Inc. (SEARCH). 2009. Submerged Cultural Resource Assessment Survey of John's Pass and Blind Pass, Pinellas County, Florida. 96 pp.

Sprandel, G. L., J. A. Gore, and D. T. Cobb. 1997. Winter shorebird survey. Final Performance Report. Tallahassee, FL: Florida Fish and Wildlife Conservation Commission.

Stoner, A. W. 1980. "The Feeding Ecology of Lagodon Rhomoides (Pisces: Sparidae), Variation and Functional Responses." US National Marine Fisheries Service. Fish Bulletin 78:337-352.

Street, M.W., A.S. Deaton, W.S. Chappell, and P.D. Mooreside. 2005. North Carolina Coastal Habitat Protection Plan. North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries, Morehead City, NC. 656 pp.

Sutton, H. 2010. Personal communication. Southern Sites Manager, NC Coastal Reserve & National Estuarine Research Reserve. Wilmington, NC.

Thayer, G. W., S. M. Adams, and M. W. LaCroix. 1975. Structural and Functional Aspects of a Recently Established Zostera Marina Community. Estuarine Research Volume I. Edited by L. E. Cronon. Academic Press, New York, New York. pp. 518-540

Thayer, G. W., W. J. Kenworthy, and M. S. Fonseca. 1981. The Ecology of Eelgrass Meadows of the Atlantic Coast: A Community Profile. FWS/OBS 84-02. US Fish and Wildlife Service, Washington, DC.

Thayer, G. W., H. H. Stuart, W. J. Kenworthy, J. F. Ustach, and A. B. Hall. 1979. Habitat Values of Salt Marshes, Mangroves, and Seagrass for Aquatic Organisms. Wetland Functions and Values. Edited by P. E. Greeson, J. R. Clark, and J. E. Clark. American Water Resources Association, Minneapolis, Minnesota. pp. 235-247.

Thayer, G.W., W.J. Kenworthy, and M.S. Fonseca. 1984. The ecology of eelgrass meadows of the Atlantic coast: a community profile. U.S. Fish. Wildl. Serv. FWS/OBS-84/02. 147 pp.

Thayer, G. W., and R. C. Phillips. 1977. Importance of Eelgrass Beds in Puget Sound. US National Marine Fisheries Service. Marine Fisheries Review. 39(11): 18-22.

Tidwell, D. K., 2005. Sedimentation patterns and hydrodynamics of a wave dominated tidal inlet: Blind Pass, Florida. Tampa, FL: University of South Florida, unpublished Master's Thesis, 104p.

US Army Corps of Engineers (USACE). 1976a. Shoreline Erosion Mitigation, Presque Isle Harbor, Marquette, Michigan. EIA. USACE, St. Paul, MN. 23pp + appendices.

USACE. 1976b. General design memorandum: Morehead City Harbor, North Carolina. Wilmington District, USACE, 41 pp. + app.

USACE (USACE Coastal Engineering Research Center). 1981. Coastal Engineering Research Center. Groins – Their Applications and Limitations. Coastal Engineering Technical Note CETN-III-10 3/31.

USACE (USACE Jacksonville District). 1984. Feasibility Report with EIS for Beach Erosion Control – Nassau County, Florida (Amelia Island). Jacksonville, Florida.

USACE. 1999a. Environmental Effect Statement: Manteo (Shallowbag) Bay North Carolina, Draft Supplement #3. U.S. Army Corps of Engineers, Wilmington District, 232p.

USACE (USACE Jacksonville District). 1999b. Final Environmental Assessment for the Nassau County, Florida Shore Protection Project. Includes Updated Finding of No Significant Effect.

USACE (USACE New York District). 2001a. The New York District's Biological Monitoring Program for the Atlantic Coast of New Jersey, Asbury Park to Manasquan Section Beach Erosion Control Project. Final Report. U.S. Army Engineer District, New York and U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

USACE. 2001b. Manteo (Shallowbag) Bay North Carolina. Supplemental No. 2 General Design Memorandum, Final Supplemental No. III Environmental Impact Statement. Wilmington, North Carolina. August 2001.

USACE. 2002. Coastal Engineering Manual. U.S. Army Corps of Engineers, Engineer Manual 1110-2-1100, Washington, DC (in 6 volumes).

USACE (USACE Wilmington District). 2003. Evaluation Report and Finding of No Significant Effect. Morehead City Harbor Section 933. Carteret County, North Carolina.

USACE (USACE Wilmington District). 2006. Draft General Reevaluation Report and Draft Environmental Impact Statement, West Onslow Beach and New River Inlet (Topsail Beach), NC. Prepared by the US Army Corps of Engineers, Wilmington District.

USACE (USACE New York District). 2008a. Environmental Assessment for the Raritan Bay and Sandy Hook Bay Hurricane and Storm Damage Reduction Study. Port Monmouth, New Jersey.

USACE (USACE Wilmington District). 2008b. Regional Biological Assessment for Dredging Activities in the Coastal Waters, Navigation Channels (including designated Ocean Dredged Material Disposal Sites), and Sand Mining Areas in the South Atlantic Ocean. USACE, Wilmington District. Submitted to NMFS on 12 September 2008.

USACE (USACE Environmental Laboratory). 2009. Habitat associations of shoreline-dependent birds in barrier island ecosystems during fall migration in Lee County, Florida. ERDC/EL TR-09-14

USACE, 1970, Morehead Cit Harbor, N.C. Jetties at Beaufort Inlet, Wilmington District, Wilmington, NC, 58 p.

USACE, 2004. Channel Condition Report, John's Pass Inlet. Corps of Engineers, Jacksonville District, Navigation Branch, 1p. (Florida EPA, 2008)

U.S. Fish and Wildlife Service (USFWS). 1951. Pea Island Nation Wildlife Refuge, Annual Narrative Report, Calendar Year 1950. Manteo, North Carolina.

USFWS. 1961. Pea Island Nation Wildlife Refuge, Annual Narrative Report, Calendar Year 1960. Manteo, North Carolina.

USFWS. 1971. Pea Island Nation Wildlife Refuge, Annual Narrative Report, Calendar Year 1970. Manteo, North Carolina.

USFWS. 1989. Environmental Assessment and Finding of No Significant Effect for Issuance of a Right-of-Way Permit to North Carolina Department of Transportation to Provide Access to Pea Island National Wildlife Refuge to Provide Protection of Bonner Bridge and North Carolina Highway 12, Dare County, North Carolina.

USFWS. 1993. *Amaranthus pumilus* (seabeach amaranth) determined to be threatened: Final rule. Federal Register. 58, 65: 18035-18042.

USFWS. 1995. U.S. Fish and Wildlife Service and Gulf states Gulf Sturgeon Recovery Plan. Atlanta, GA. 170pp.

USFWS. 1996a. Piping Plover (*Charadrius melodus*), Atlantic Coast Population, Revised Recovery Plan. Hadley, Massachusetts. 258 pp.

USFWS. 1996b. Recovery Plan for Seabeach amaranth *(Amaranthus pumilus)* Rafinesque. Atlanta, Georgia.

USFWS. 2001a. Amended Biological Opinion for ACOE Permit Application No. 200103870 (FWS Log No. 01-985), Florida Park Service/South Amelia Island Shore Stabilization Association, Inc. Nassau County, Florida.

USFWS. 2001b. Endangered and Threatened Wildlife and Plants; Wintering Piping Plovers. *Federal Register* 50 CFR Part 17.

USFWS. 2002. Draft Fish and Wildlife Coordination Act Report for the Bogue Banks Shore Protection Project in Carteret and Onslow Counties, North Carolina.

USFWS. 2004. Biological Opinion for the Proposed Construction of Phase II – South Amelia Island Shore Stabilization Project. Nassau County, Florida.

USFWS. 2006a. Piping Plovers in North Carolina. http://www.fws.gov/northeast/pipingplover/status/index.html. Updated January 27, 2005.

USFWS. 2006b. Pea Island National Wildlife Refuge Comprehensive Conservation Plan. US Department of the Interior, Fish and Wildlife Service, Southeast Region.

USFWS. 2007. Seabeach amaranth (*Amaranthus pumilus*)**,** http://www.fws.gov/nc-es/plant/seabamaranth.html.

USFWS. 2007a. West Indian manatee, (*Trichechus manatus*). http://www.fws.gov/species/species_accounts/bio_mana.html. Last updated March 1995.

USFWS. 2007b. West Indian manatees in North Carolina. http://www.fws.gov/nc-es/mammal/manatee.html.

USFWS. 2007c. Guidelines for Avoiding Effects to the West Indian Manatee, Precautionary Measures For Construction Activities In North Carolina Waters. http://www.fws.gov/nc-es/mammal/manatee_guidelines.pdf.

USFWS. 2007d. Pea Island Nation Wildlife Refuge, Annual Narrative Report, Calendar Year 2006. Manteo, North Carolina.

USFWS. 2008. Pea Island Nation Wildlife Refuge, Annual Narrative Report, Calendar Year 2007. Manteo, North Carolina.

Van Dolah, R.F., D.M. Knott, and D.R. Calder. 1984. Ecological effects of rubble weir jetty construction at Murrells Inlet, South Carolina; Volume 1: Colonization and community development on new jetties. US Army Corps of Engineers Technical Report. EL-84-4, Coastal Engineering Research Center. Vicksburg, Mississippi. 143 pp.

Van Dolah, R.F., R.M. Martore, A.E. Lynch, P.H. Wendt, M.V. Levisen, D.J. Whitaker, and W.D. Anderson. 1994. Environmental evaluation of the Folly Beach nourishment project. Final report. Prepared for US Army Corps of Engineers - Charleston District, South Carolina. Marine Resources Division, South Carolina Department of Natural Resources, Charleston, NC.

Van Gils, J. A., B. Spaans, A. Dekinga, and T. Piersma. 2006. Foraging in a tidally structured environment by red knots (*Calidris canutus*): ideal, but not free. Ecology 87: 1189-1202.

Vincent, M. 1992. John's Pass Scour Assessment Model, The Center for Modeling Hydrologic and Aquatic Systems, University of South Florida, 57 p.

Vladykov, V.D., and J.R. Greeley. 1963. Order Acipenseroidei. Pages 24-60 in Fishes of the western North Atlantic. Part III. Memoirs of the Sears Foundation for Marine Research 1.

Vandever, J.P. and Miller, H.C., 2003, How efficient is Mother Nature at Oregon Inlet, NC? Proceeding of the International Conference on Coastal Sediments 2003.

Watts, J. G. 1987. Physical and biological effects of bulkheads on North Carolina's estuarine shoreline. Duke University, Durham, NC, Report to North Carolina Division of Coastal Management, 39 p.

Weakley, A.S. and M.A. Bucher. 1992. Status survey of seabeach amaranth (*Amaranthus pumilus* Rafinesque) in North and South Carolina. Report submitted to the North Carolina Plant Conservation Program, and Endangered Species Field Office.

Weber, W. 1996. Population size and habitat use of shortnose sturgeon, *Acipenser brevirostrum*, in the Ogeechee River sytem, Georiga. Masters Thesis, University of Georgia, Athens, Georgia.

Weinstein, M. P. 1985. Distributional Ecology of Fishes Inhabiting Warm-Temperate and Tropical Estuaries: Community Relationships and Implications. Fish Community Ecology in Estuaries and Coastal Lagoons: Towards an Ecosystem Integration. Edited by A. Yanex-Arancibia. DR (R) UNAM Press. Mexico.

Weinstein, M. P., and K. L. Heck, Jr. 1979. Ichthyofauna of Seagrass Meadows Along the Caribbean Coast of Panama and in the Gulf of Mexico: Composition, Structure, and Community Ecology. Marine Biology, 50: 97-107.

Wells, J.T., and McNinch, J.E., 2001, Reconstructing shoal and channel configuration in Beaufort Inlet: 300 years of change at the site of Queen Anne's revenge. Southeastern Geology, v. 40, p. 11-18.

Whitehead, John C., Christopher F. Dumas , Jim Herstine , Jeffery Hill , Bob Buerger. 2008. Valuing Beach Access and Width with Revealed and Stated Preference Data. Marine Resource Economics. 23:119-135.

Whitehead, John C., Ben Poulter, Christopher Dumas and Okmyung Bin. 2009. Measuring the Economic Effects of Sea Level Rise on Shore Fishing. Mitigation and Adaptation Strategies for Global Change. 14:777-792.

Whitehead, John C. Total Economic Values for Coastal and Marine Wildlife: Specification, Validity, and Valuation Issues. 1993. Marine Resource Economics. 8:119-132.

Wibbels, T. 2003. Critical approaches to sex determination in sea turtles. In: Biology of Sea Turtles, vol. II (Eds. Lutz, P.L., Musick, J.A. and Wyneken, J.) pp. 103-134. Boca Raton: CRC Press.

Wilber, D. H., D. G. Clarke, G.L. Ray, and M. Burlas. 2003. Response of surf zone fish to beach nourishment operations on the northern coast of New Jersey, USA. Marine Ecology Progress Series. Vol. 250: 231-246.

Wiley, D.N., R.A. Asmutis, T.D. Pitchford, and D.P. Gannon. 1995 Stranding and mortality of humpback whales, Megaptera novaengliae, in the mid_Atlantic and southeast United States, 1985-1992. Fish. Bull., U.S. 93: 196-205.

Wilkinson, P. M. and M. Spinks. 1994. Winter distribution and habitat utilization of Piping Plovers in South Carolina. Chat 58: 33-37.

Woodward, R.T., and Y-S. Wui. 2001. The Economic Value of Wetland Services: A Meta-Analysis. Ecological Economics. 37:257-270.

Zieman, J. C. 1975. Tropical Seagrass Ecosystems and Pollution. Tropical Marine Pollution. Edited by E. J. F. Wood and R. E. Johannes. Elsevier, New York, New York. pp. 63-74.

Zimmerman, R. J., and T. J. Minello. 1984. Fishery Habitat Requirements: Utilization of Nursery Habitats by Juvenile Penaeid Shrimp in a Gulf of Mexico Salt Marsh. . Proceedings of Research for Managing the Nation's Estuaries edited by B. J. Copeland, K. Kart, N. David, and S. Friday. UNC Sea Grant Publication 84-08.

Zivojnovich, M. J. and G. Baldassarre. 1987. Habitat selection, movements, and numbers of Piping Plovers wintering in coastal Alabama. Project number W-44-12, study number II-A & B. Alabama Department of Conservation and Natural Resources, Montgomery, AL.

Appendix A

Committee Lists

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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

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Appendix B

Session Law 2009-479

House Bill 709

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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 C

Engineering Activity Logs

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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		504,266	5043	100	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	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	107	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

Physical Data

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Appendix D – Physical Data

1. Oregon Inlet

a) 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 D-1 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 D-1 presents the tidal datums for both gages.

Table D-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

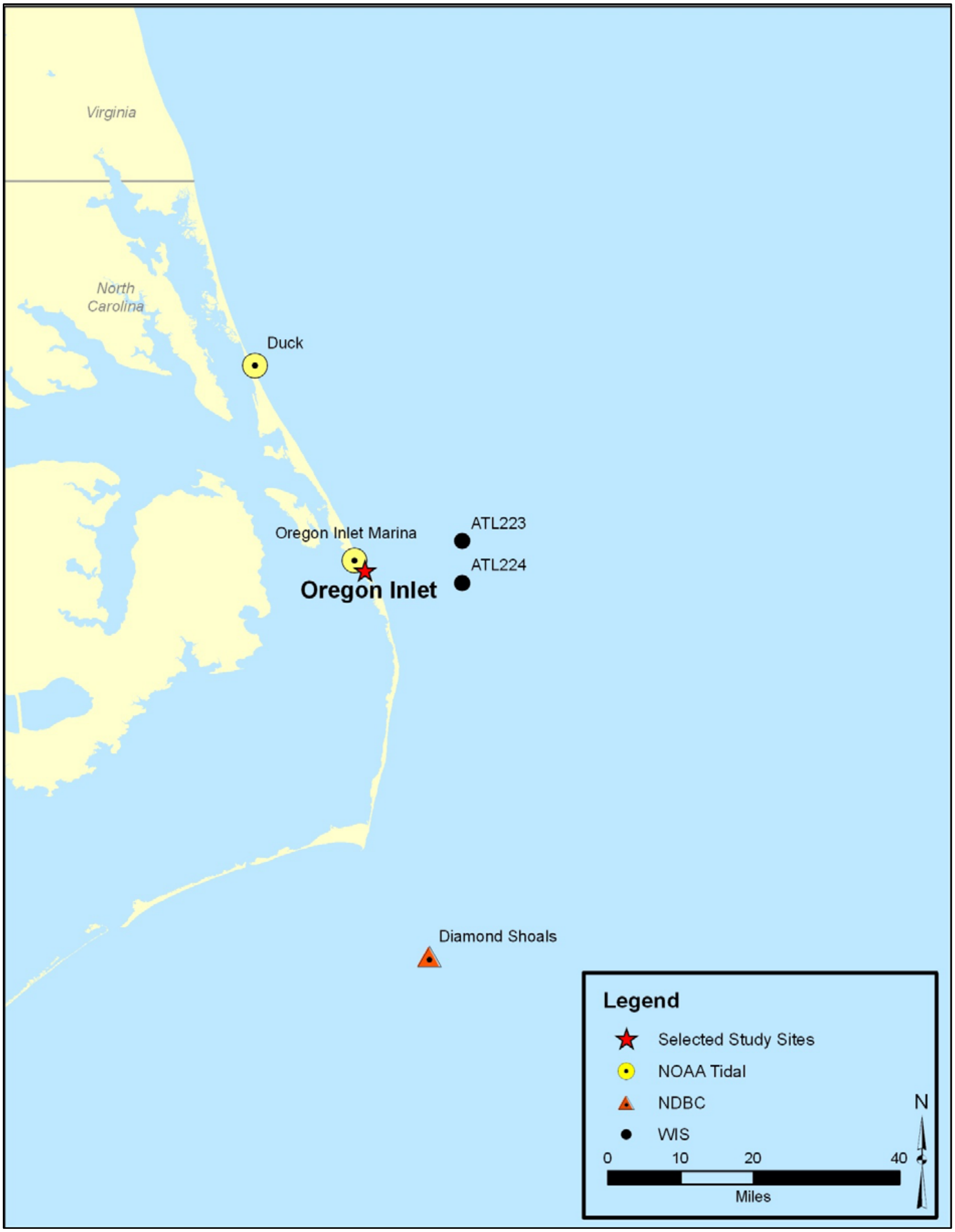

Figure D-1. Wave and Tidal Stations near Oregon Inlet

Table D-2 and Table D-3 summarize the percent occurrences by wave height and direction for WIS stations ATL 223 and 224. Figure D-2 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 D-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
1.50 – 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 D-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

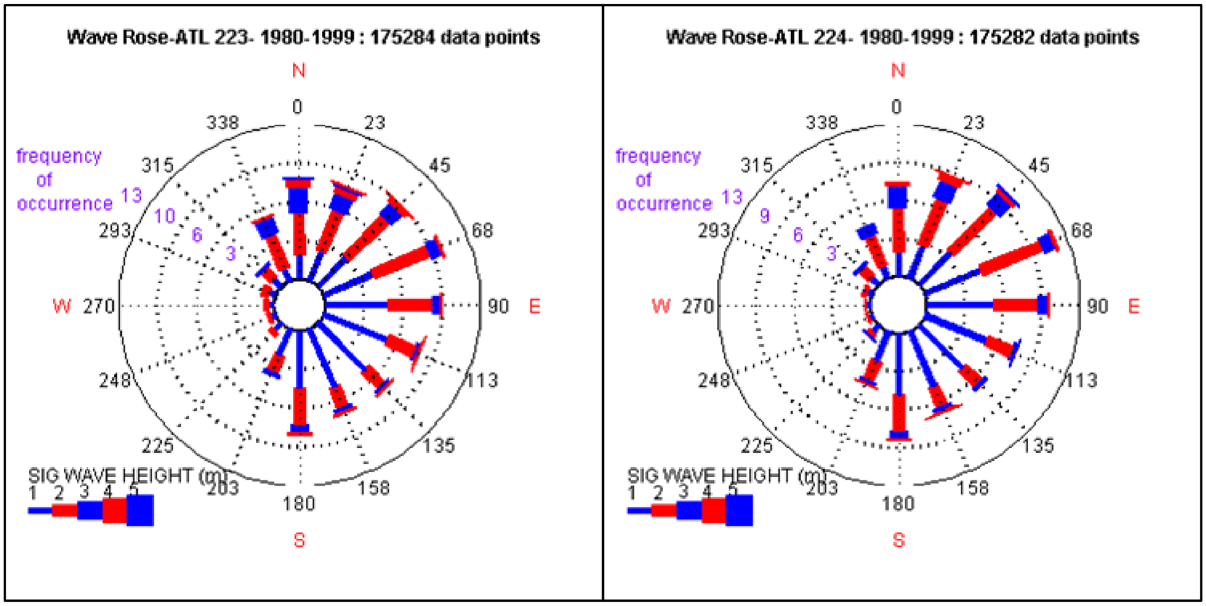

Figure D-2. Wave Roses (USACE WIS Hindcast)

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.

b) Storms

The NOAA database of historical storms records approximate storm track, wind speed, pressure, and category for storms since 1851. Figure D-3 illustrates the hurricane tracks in the vicinity of Oregon Inlet and Table D-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.

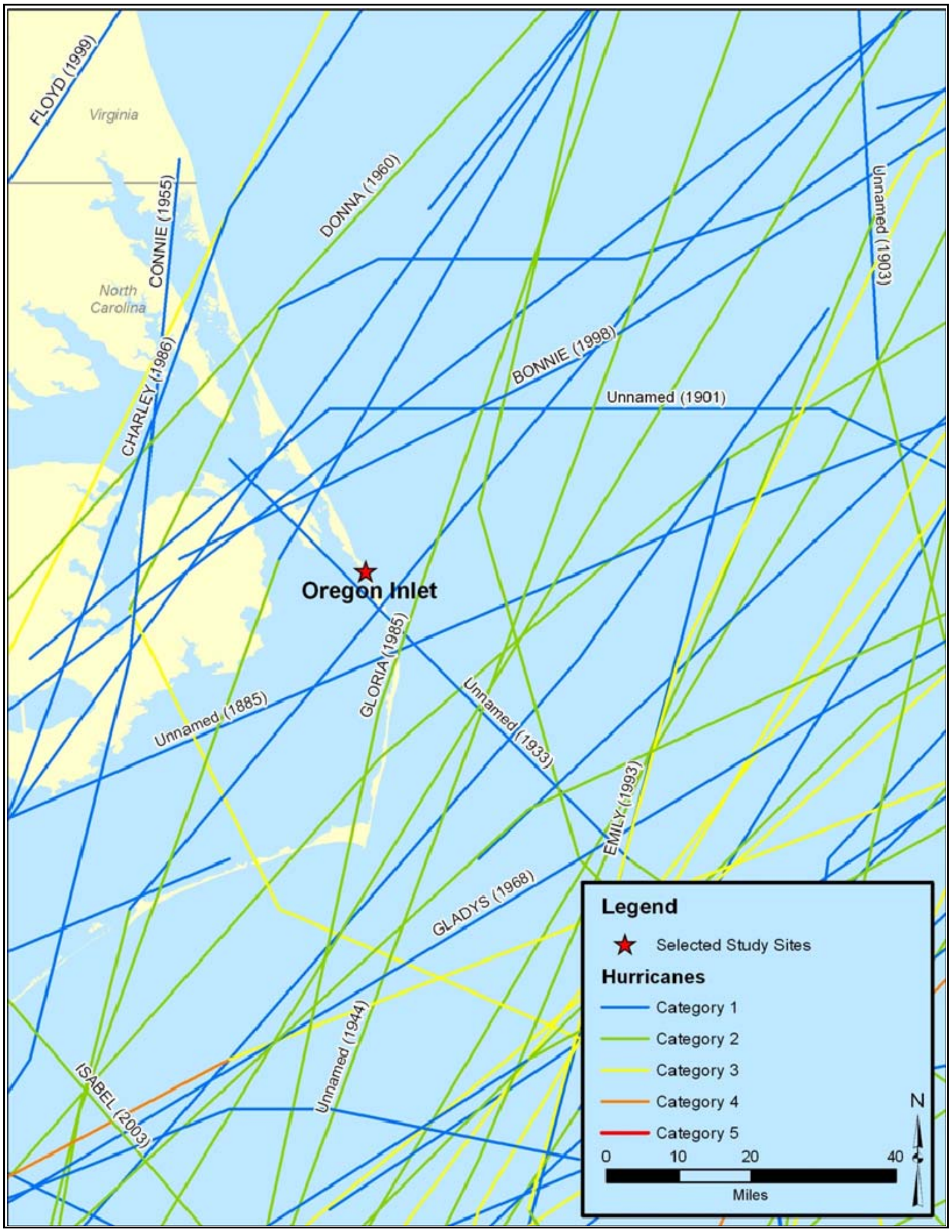

Figure D-3. Hurricanes in the Vicinity of Oregon Inlet

Table D-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

2. Fort Macon

a) 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 D-4 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 D-5 presents the tidal datums for both gages.

Table D-5. 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

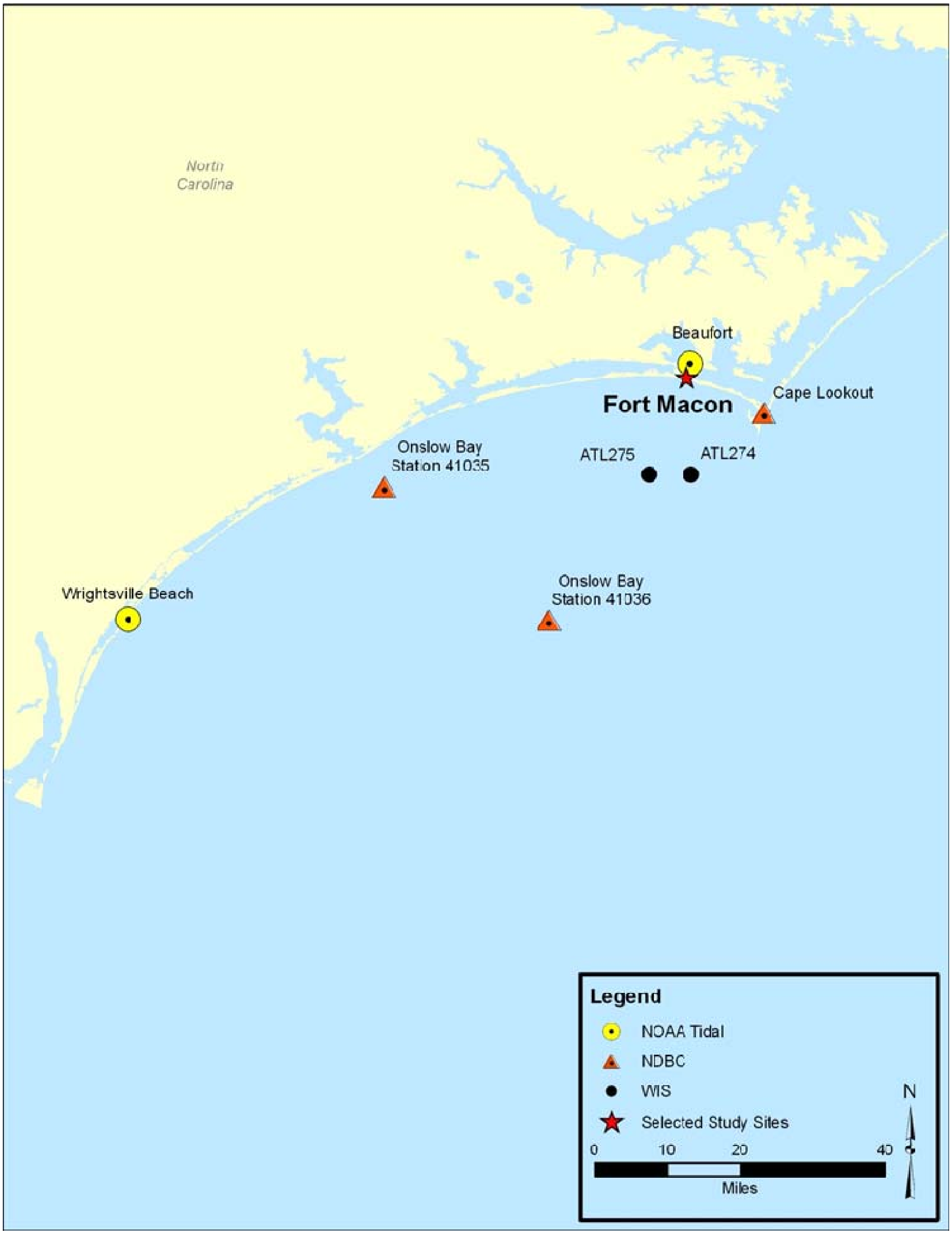

Figure D-4. Wave and Tidal Stations near Fort Macon (Beaufort Inlet)

Table D-6 and Table D-7 summarize the percent occurrences by wave height and direction for WIS stations ATL 274 and 275. Figure D-5 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 D-6. 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 D-7. 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

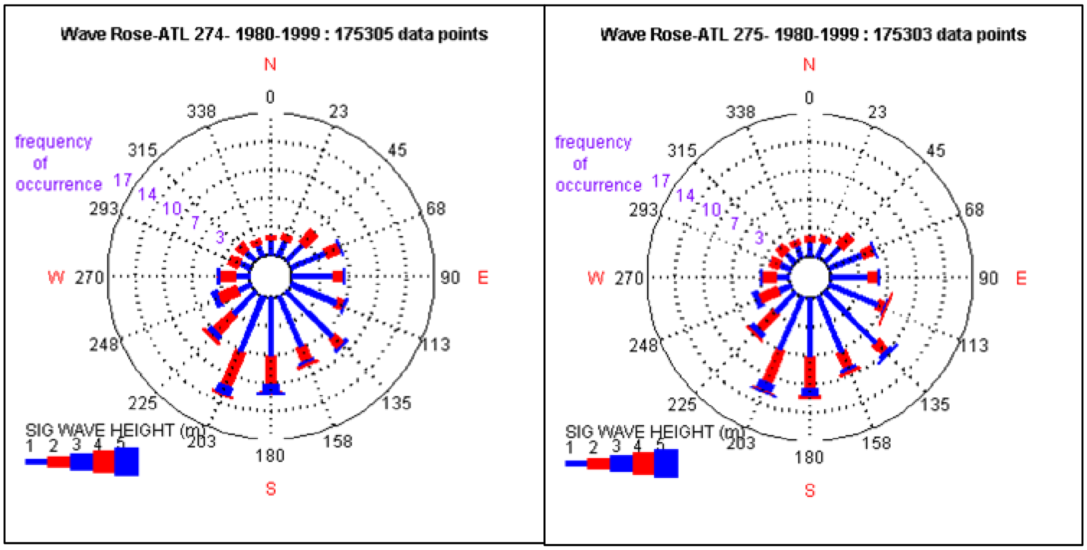

Figure D-5. Wave Roses (USACE WIS Hindcast)

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).

b) Storms

The NOAA database of historical storms records approximate storm track, wind speed, pressure, and category for storms since 1851. Figure D-6 illustrates the hurricane tracks in the vicinity of Fort Macon and Table D-8 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.

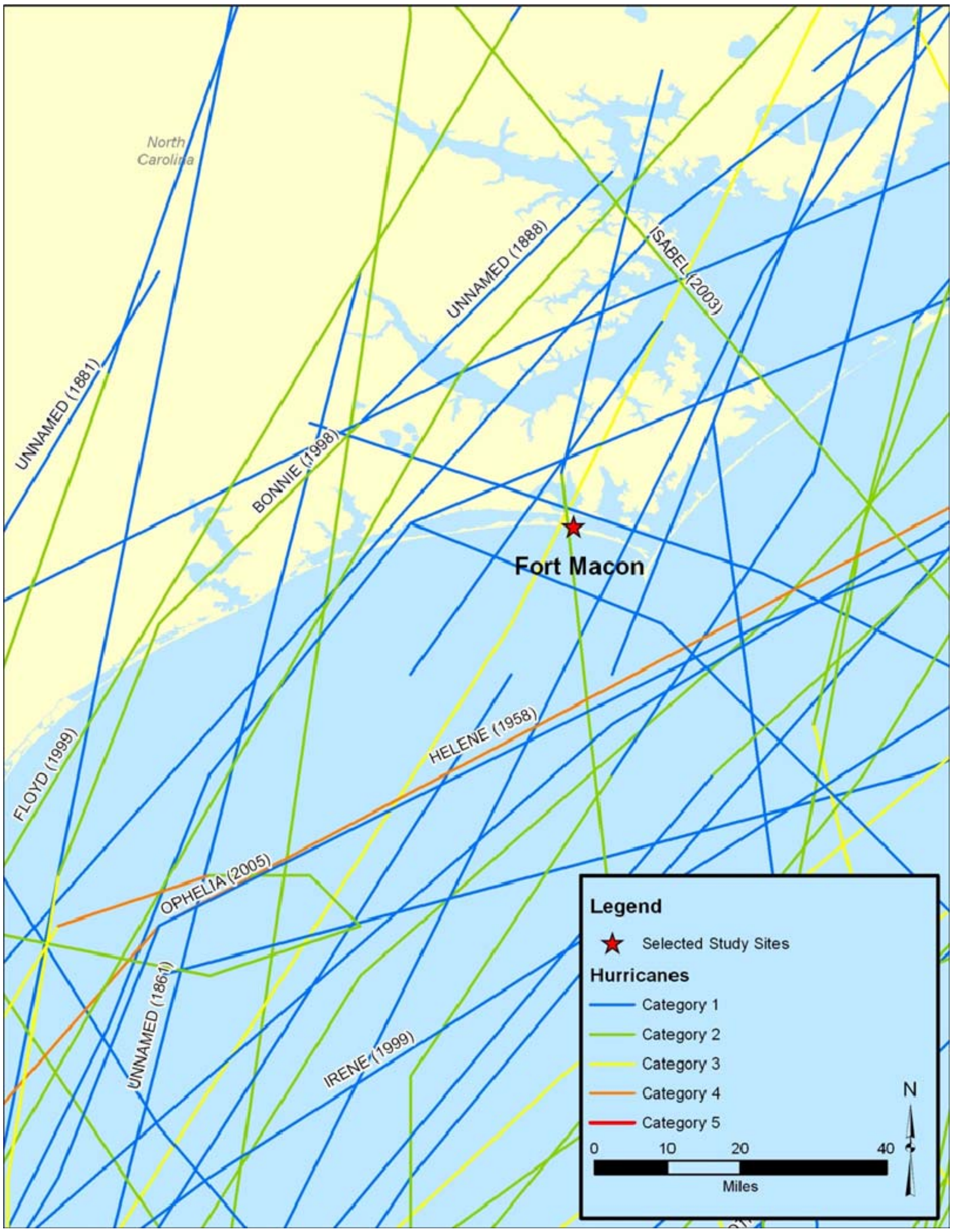

Figure D-6. Hurricanes in the Vicinity of Fort Macon

Table D-8. 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

3. Amelia Island

a) 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 D-7 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 D-9 lists the tidal datums for both gages.

Table D-9. 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	-

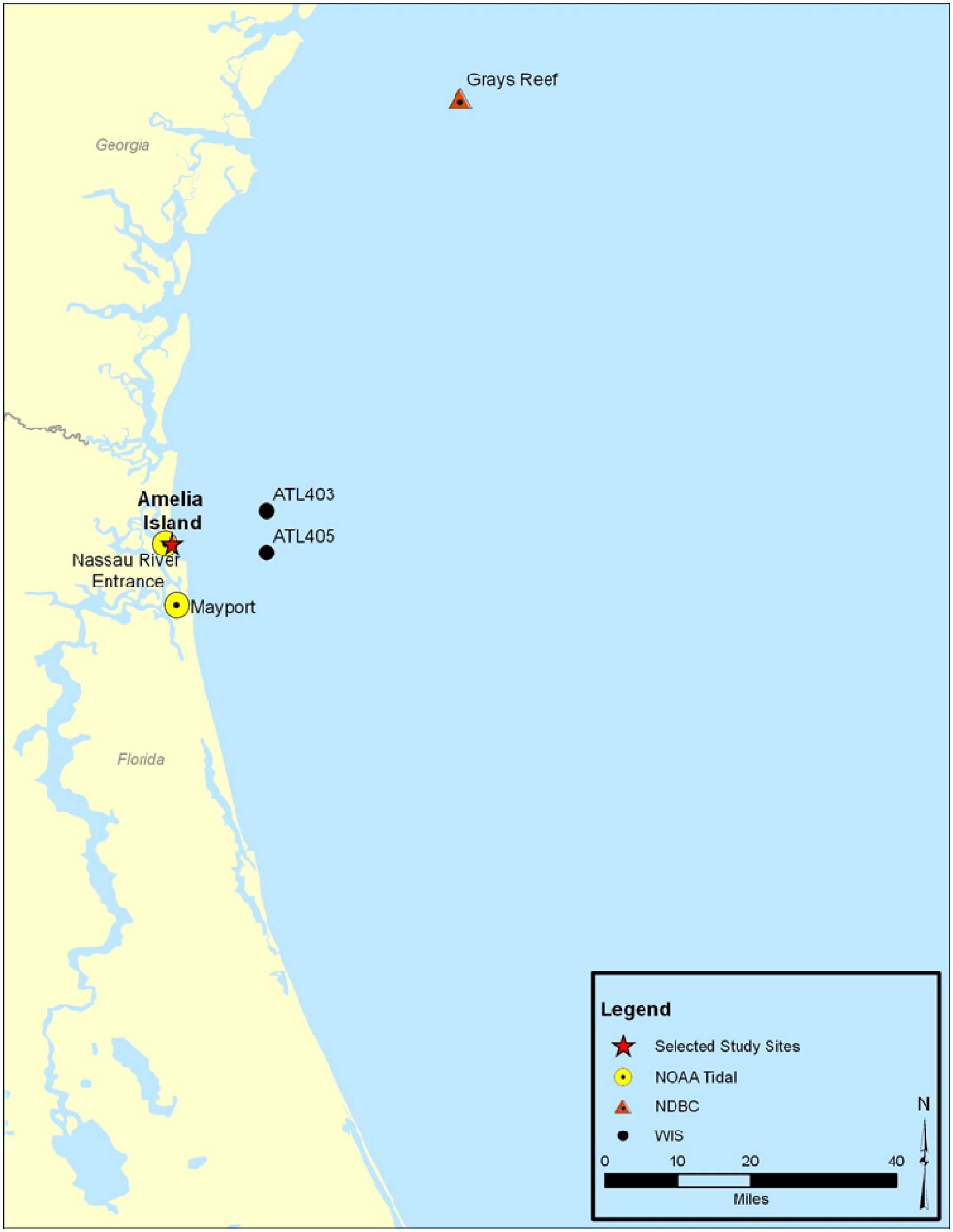

Figure D-7. Wave and Tidal Stations near Amelia Island

Table D-10 and Table D-11 summarize the percent occurrences by wave height and direction for WIS stations ATL 403 and 405. Figure D-8 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 D-10. 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 D-11. 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

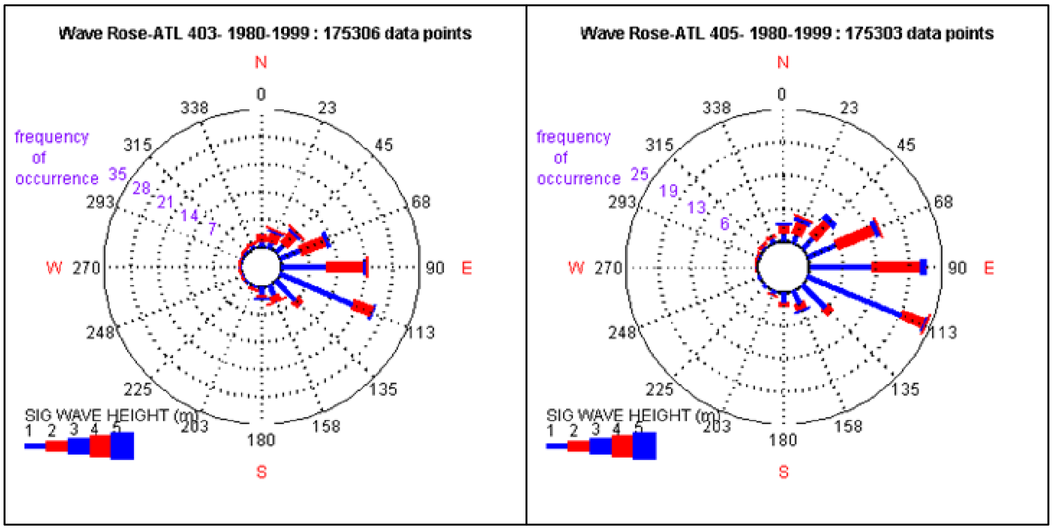

Figure D-8. Wave Roses (USACE WIS Hindcast)

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.

b) Storms

The NOAA database of historical storms records approximate storm track, wind speed, pressure, and category for storms since 1851. Figure D-9 illustrates the hurricane tracks in the vicinity of Amelia Island and Table D-12 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.

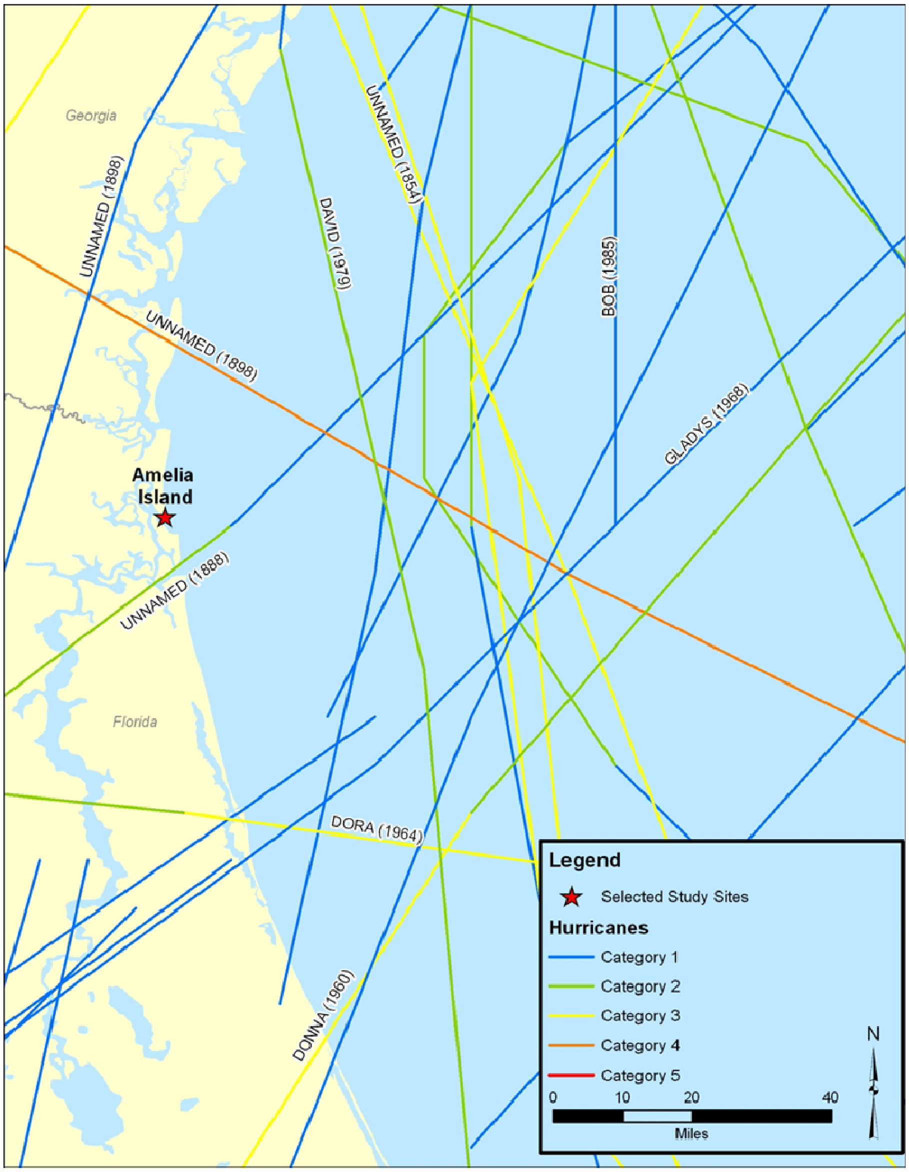

Figure D-9. Hurricanes in the Vicinity of Amelia Island

Table D-12. 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

YEAR	STORM NAME	MAXIMUM CATEGORY
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

4. Captiva Island

a) 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 D-10 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 D-13 lists the tidal datums for both gages.

Table D-13. 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

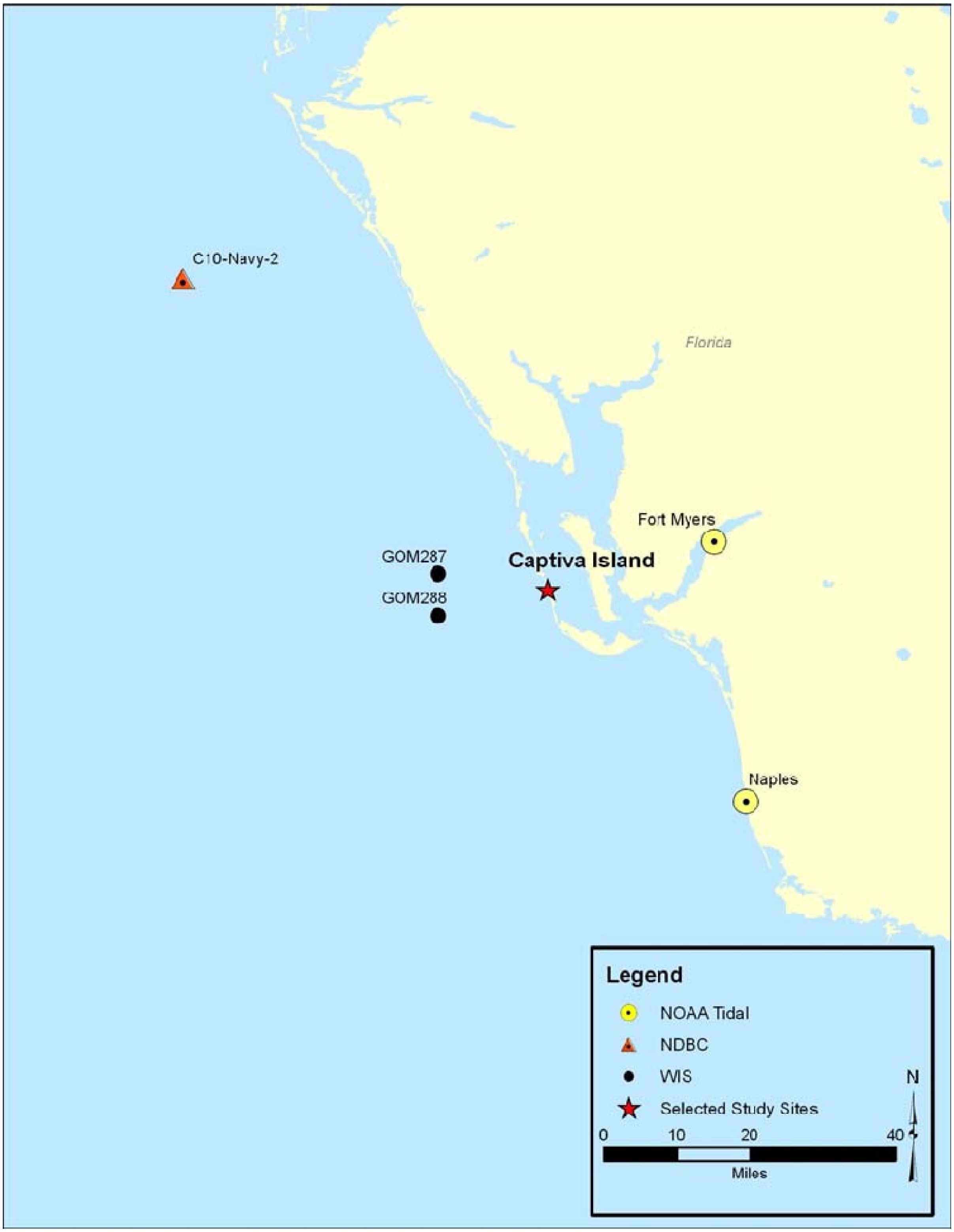

Figure D-10. Wave and Tidal Stations near Captiva Island

Table D-14 and Table D-15 summarize the percent occurrences by wave height and direction for WIS stations GOM 287 and 288. Figure D-11 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 D-14. 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 D-15. 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

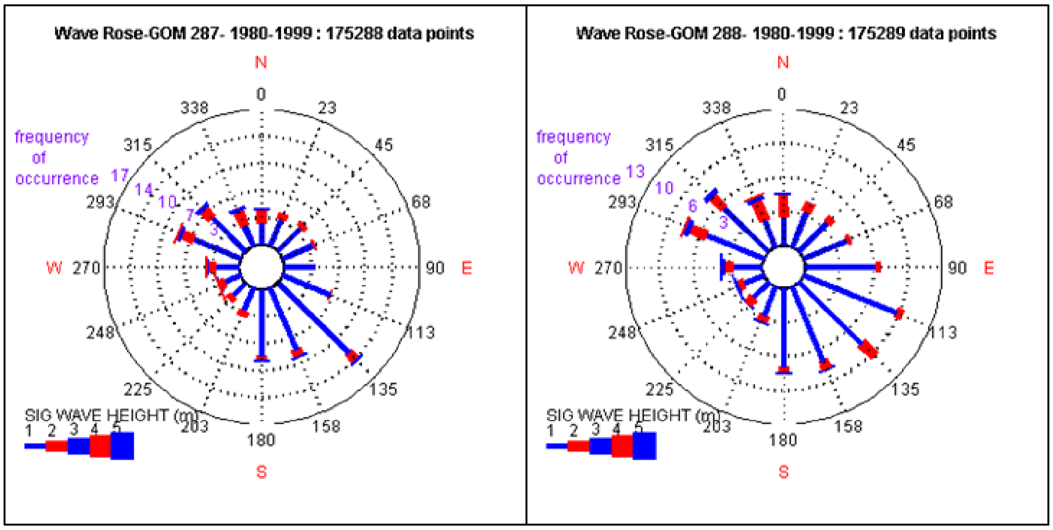

Figure D-11. Wave Roses (USACE WIS Hindcast)

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

b) Storms

The NOAA database of historical storms records approximate storm track, wind speed, pressure, and category for storms since 1851. Figure D-12 illustrates the hurricane tracks in the vicinity of Captiva Island and Table D-16 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.

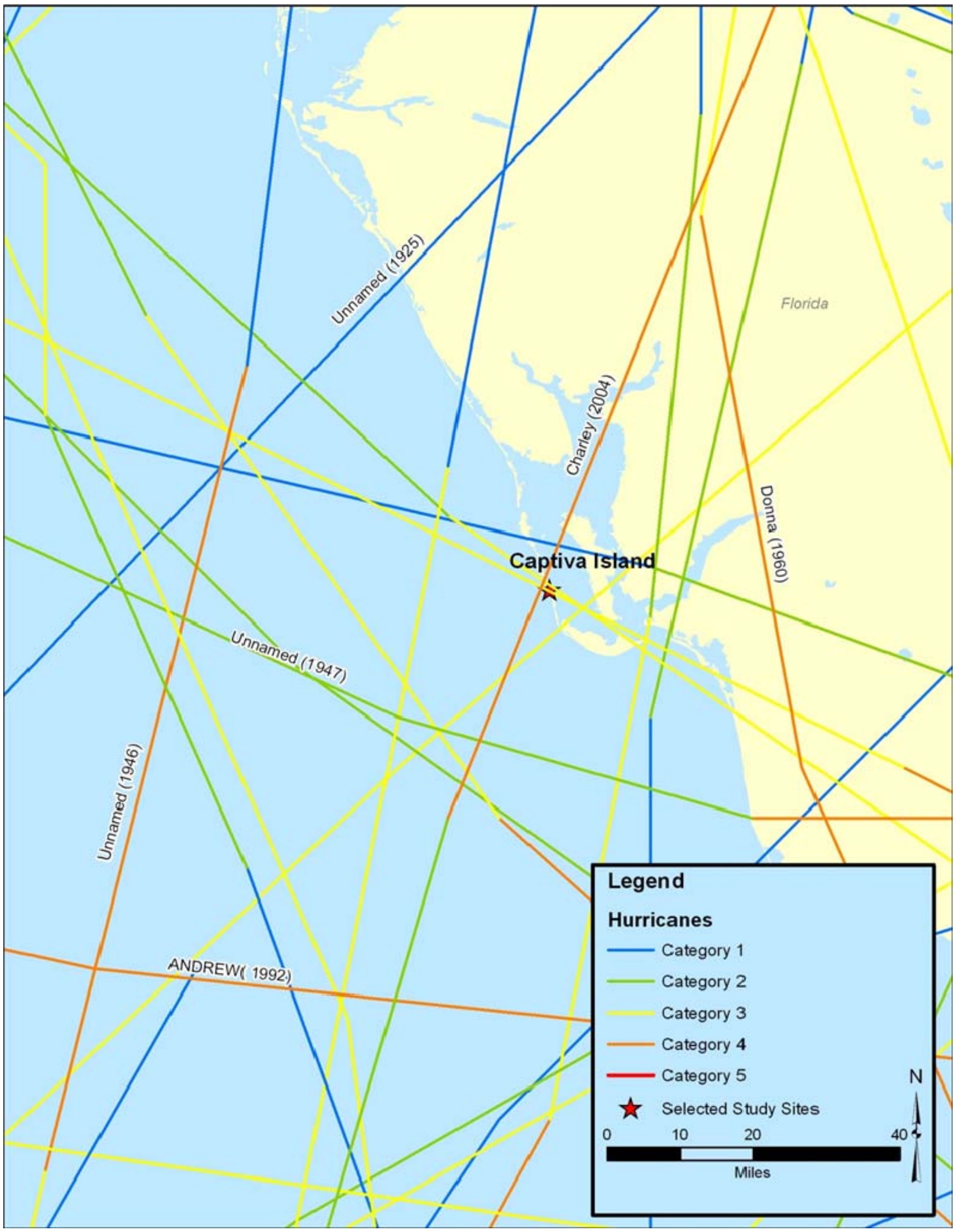

Figure D-12. Hurricanes in the Vicinity of Captiva Island

Table D-16. 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

5. John's Pass

a) 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 D-13 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 D-17 lists the tidal datums for all three gages.

Table D-17. 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

Figure D-13. Wave and Tidal Stations near John's Pass

Table D-18 and Table D-19 summarize the percent occurrences by wave height and direction for WIS stations GOM 268 and 269. Figure D-14 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 D-18. 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 D-19. 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

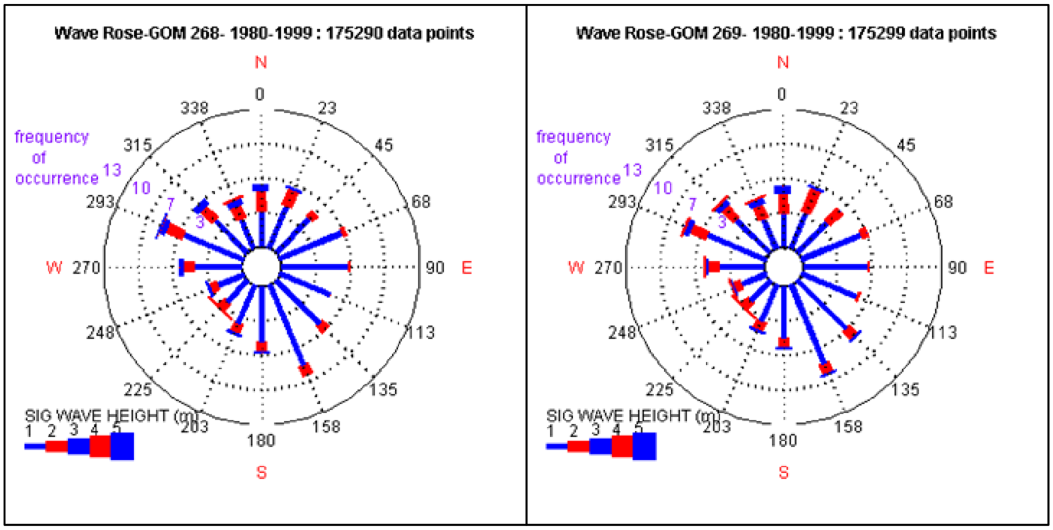

Figure D-14. Wave Roses (USACE WIS Hindcast)

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.

b) Storms

The NOAA database of historical storm records approximate storm track, wind speed, pressure, and category for storms since 1851. Figure D-15 illustrates the hurricane tracks in the vicinity of John's Pass and Table D-20 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.

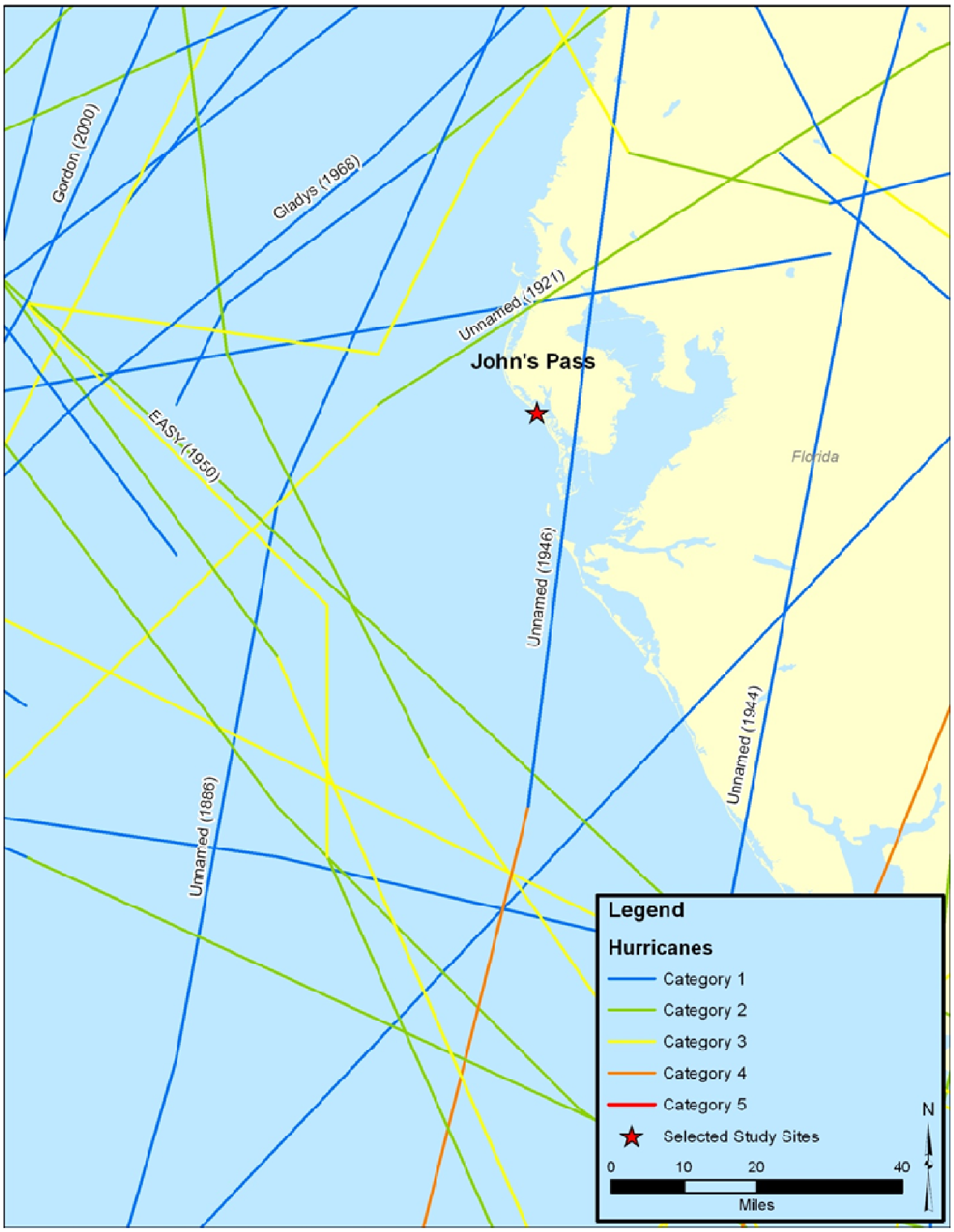

Figure D-15. Hurricanes in the Vicinity of John's Pass

Table D-20. 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

YEAR	STORM NAME	MAXIMUM CATEGORY
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

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Appendix E

Environmental Contacts

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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
Ann Marie Lauritsen	Biologist	USFWS Jacksonville	904-525-0661	annmarie_lauritsen@fws.gov	10/28/09	biological information on Johns Pass and Amelia Island

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
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.mil	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.mil	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
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

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
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.mil	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.mil	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
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

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
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.mil	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
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

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
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.army.mil	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
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	

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
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.mil	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	
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

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
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
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

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
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
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

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
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
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 - inlet 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	

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
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
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.mil	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

Contact	Title	Agency/Company	Phone Number	Email	Date Contacted	Information
USACE Florida Shore Protection and Sea Turtle Management System	NA	NA	NA	http://el.erdc.usace.army.mil/flshore/refs.cfm	NA	literature on FL sea turtle nesting
USACE Turtle Warehouse Data	NA	NA	NA	http://el.erdc.usace.army.mil/seaturtles/refs-bo.cfm	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)
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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