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.

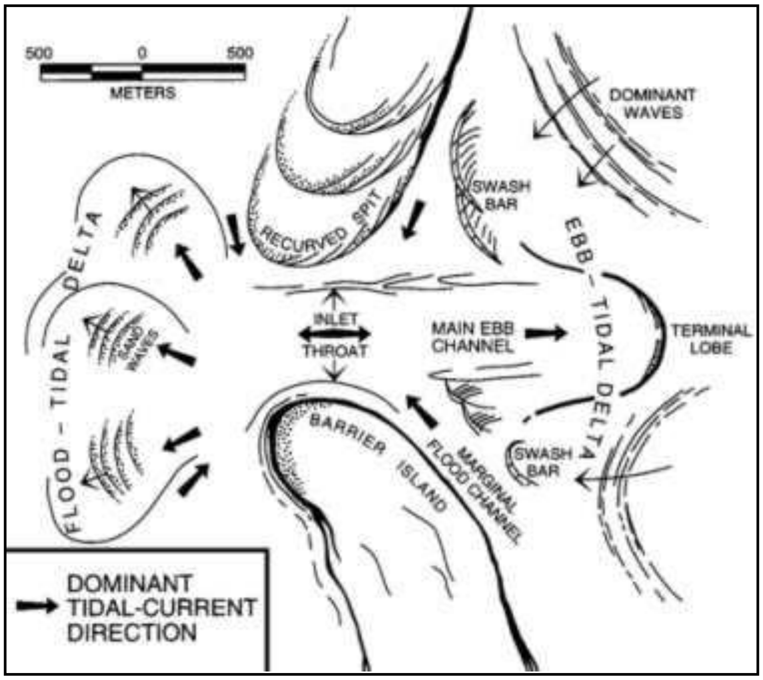


Image from Schrader, R.J., et. al. 2000.

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.

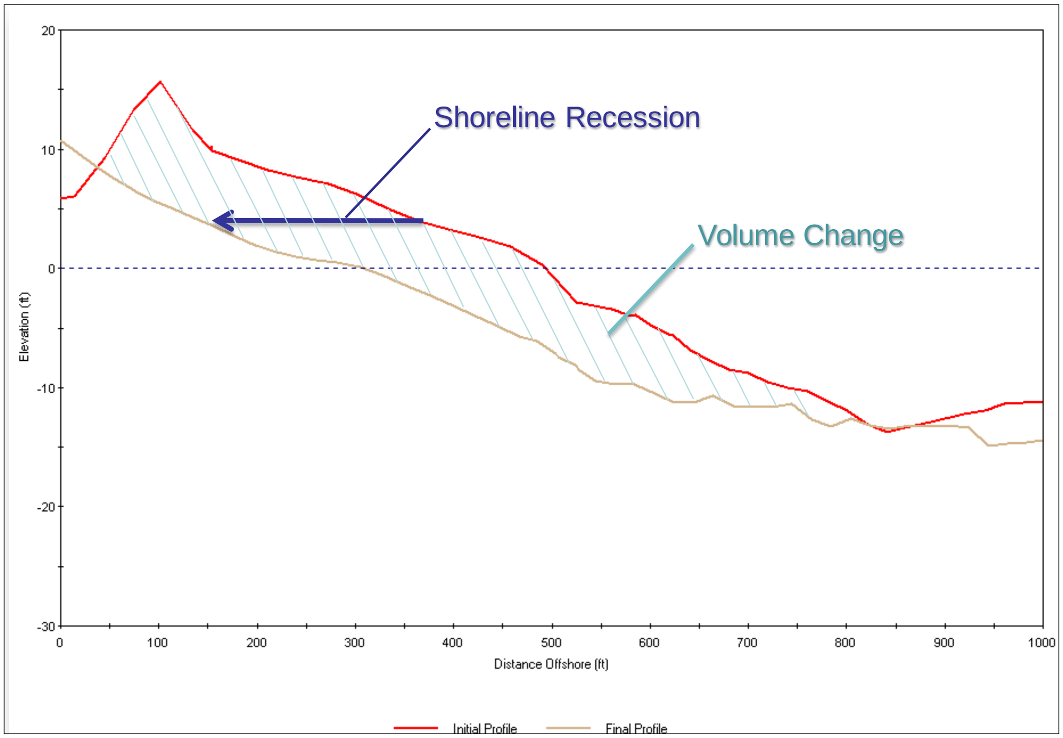


Figure II-3. Shoreline to Beach Volume Change Relationship

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

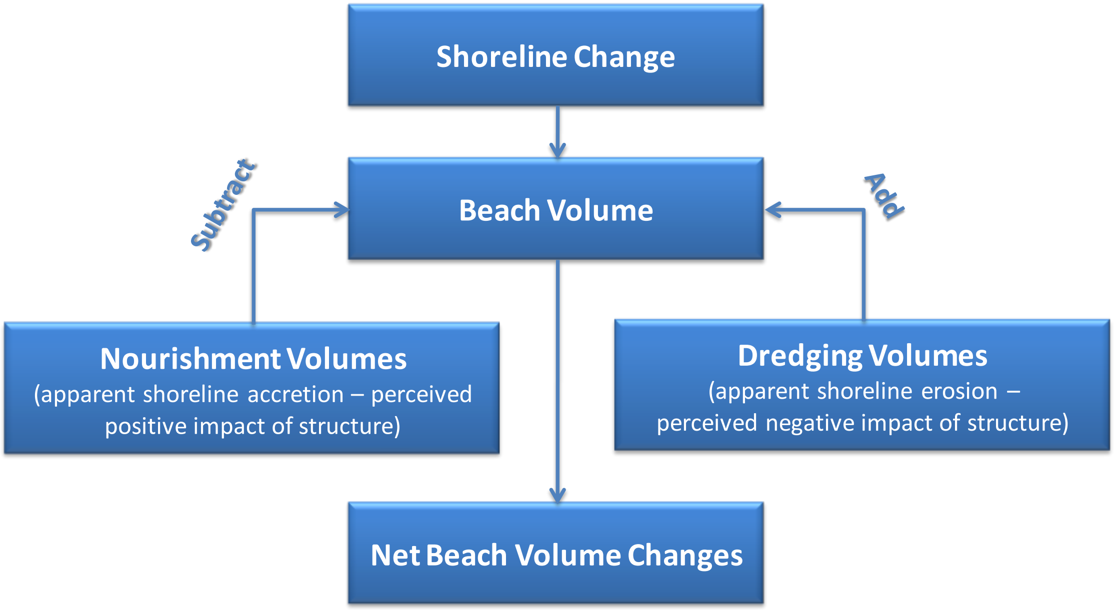


Figure II-4. Analysis Procedure

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.

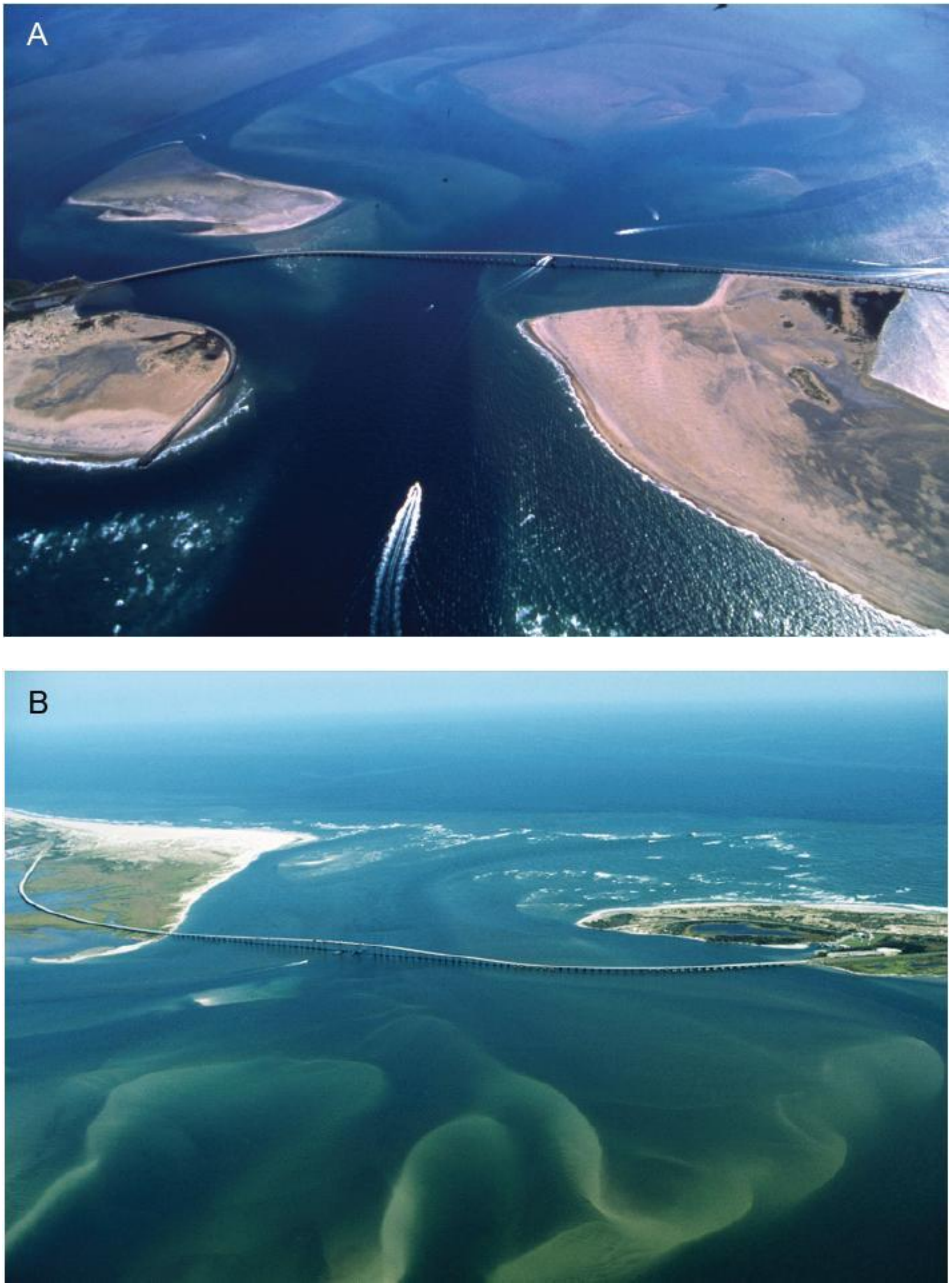


Figure II-5. Aerial Photographs of Oregon Inlet A. Looking Landward (Photograph from Ramanda, Nags Head) and B. Seaward (Photograph by D.A. Harvey)

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

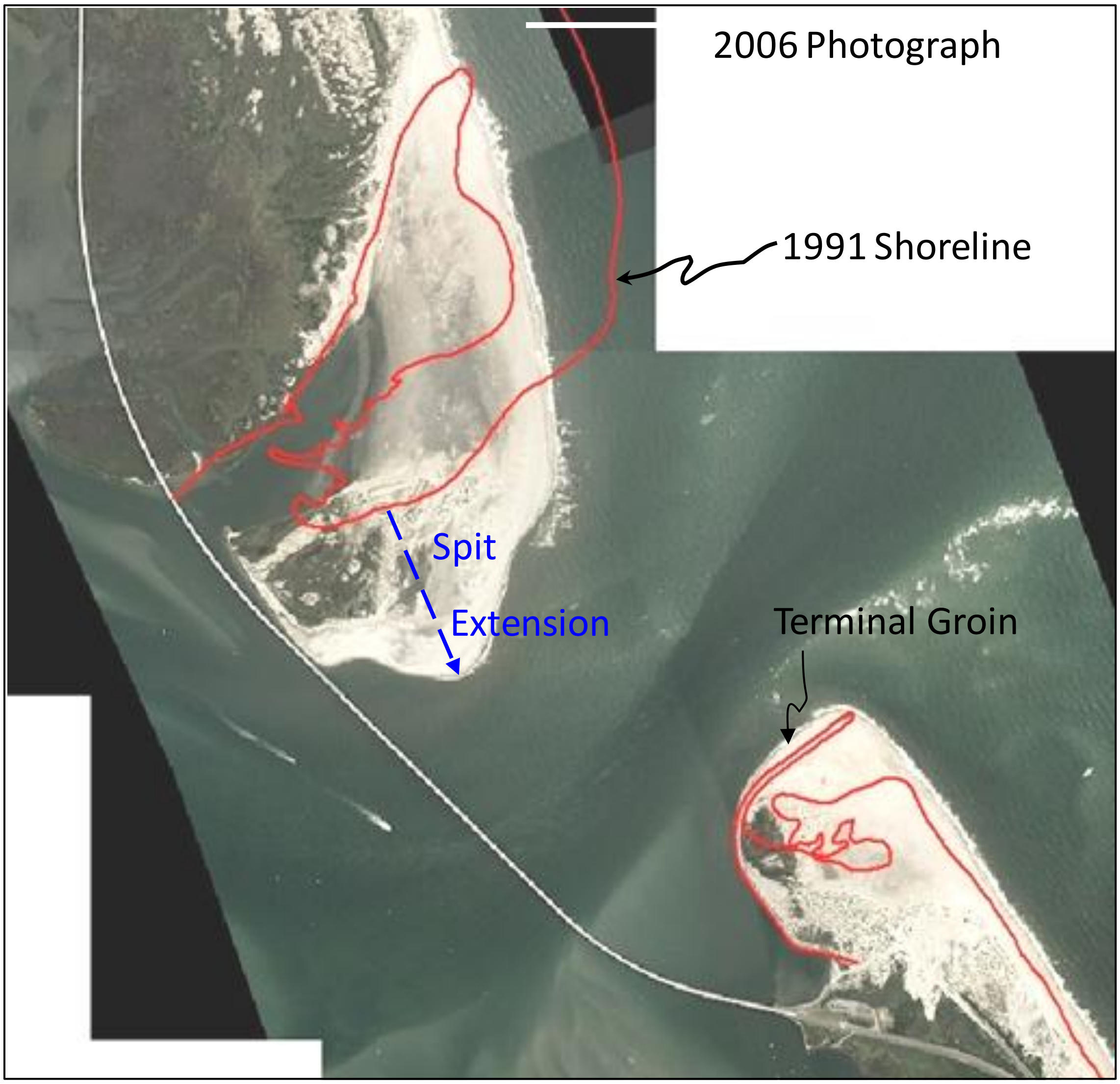


Figure II-7. Comparison of 1991 and 2006 Shorelines Along Bodie and Pea Islands

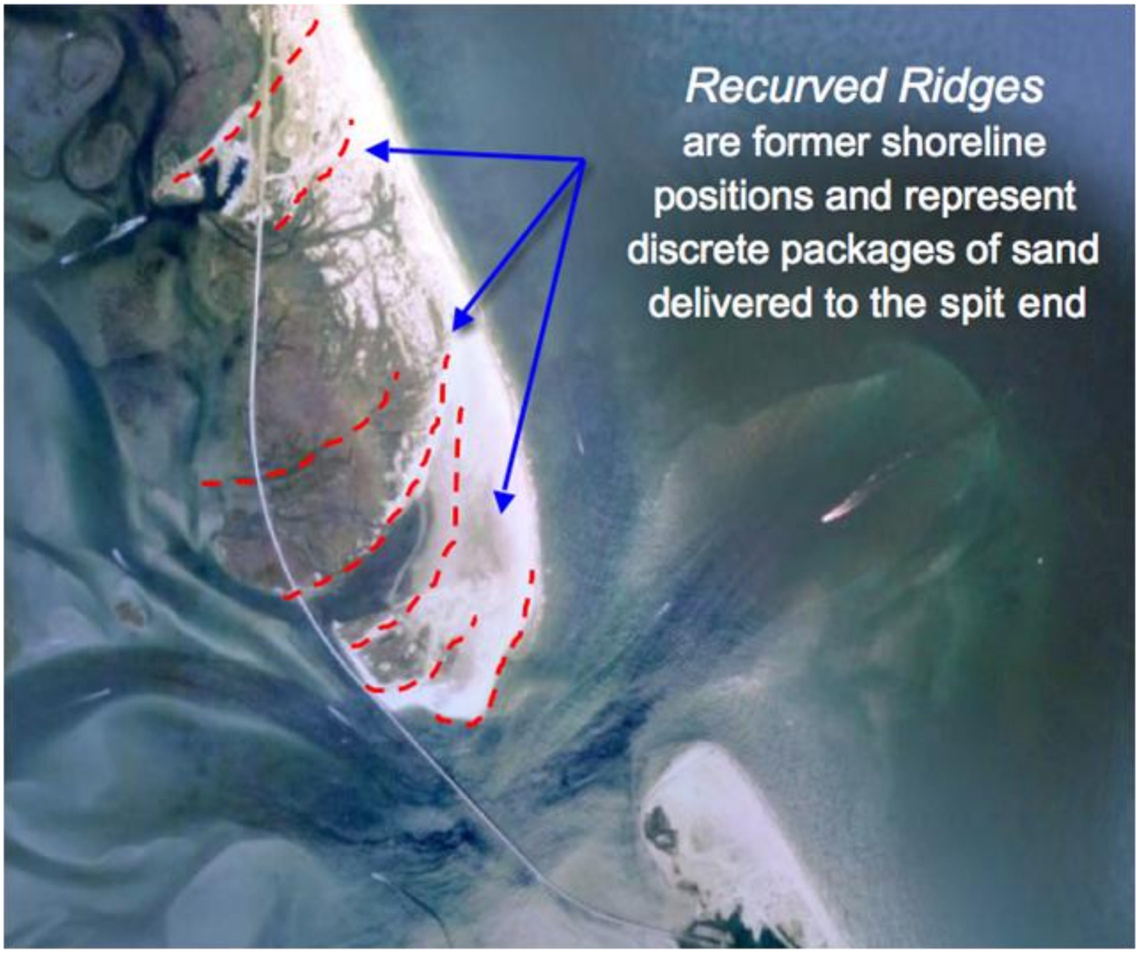


Figure II-8. Bodie Island Illustrating Recurved Ridges Comprising Spit End

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.

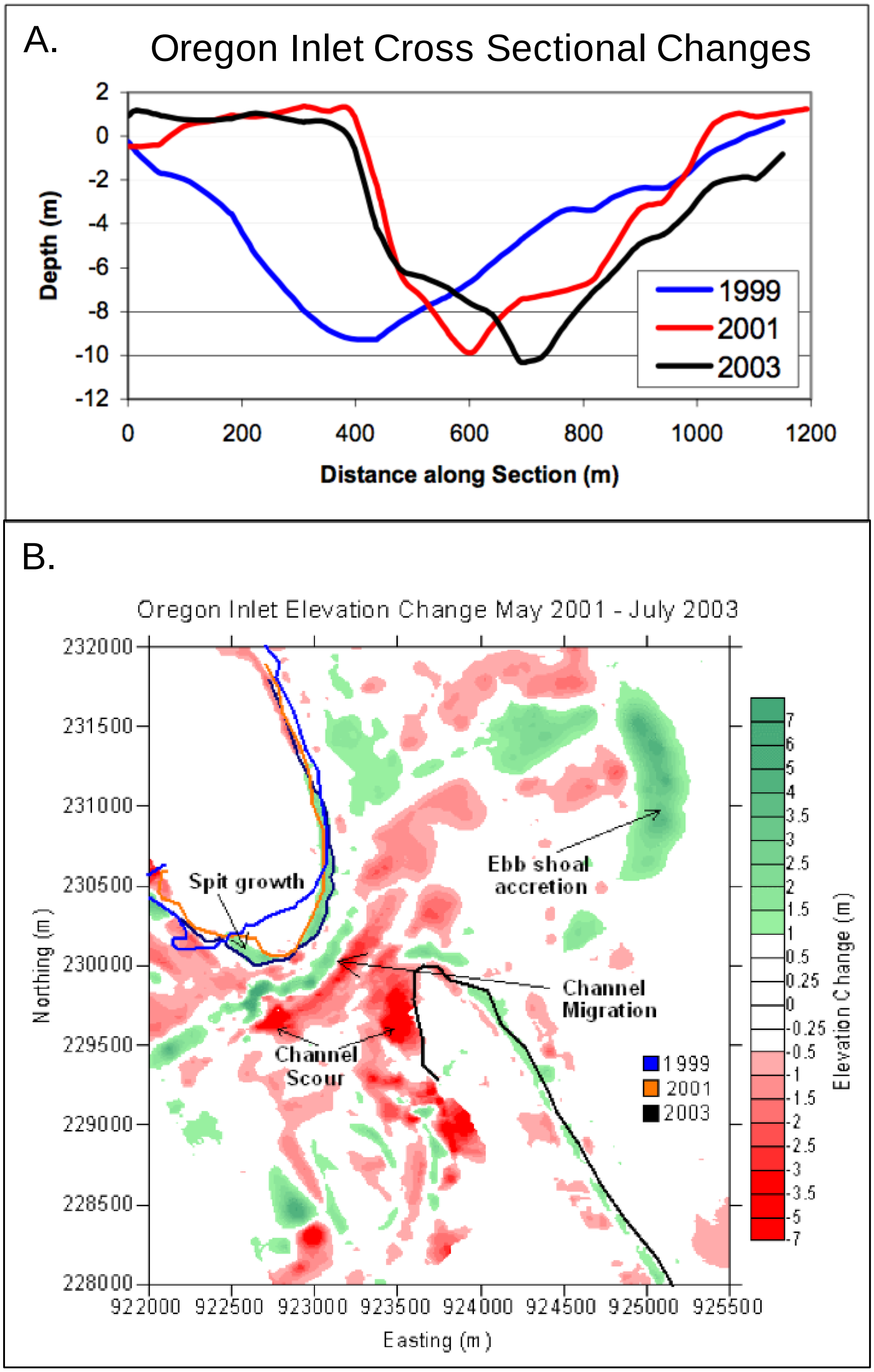


Figure II-9. Bathymetric Changes at Oregon Inlet Showing A. Cross-sectional Changes from 1999 to 2001 and B. Erosional-depositional Changes Over the 2001 – 2003 Period (Vandever and Miller, 2003)

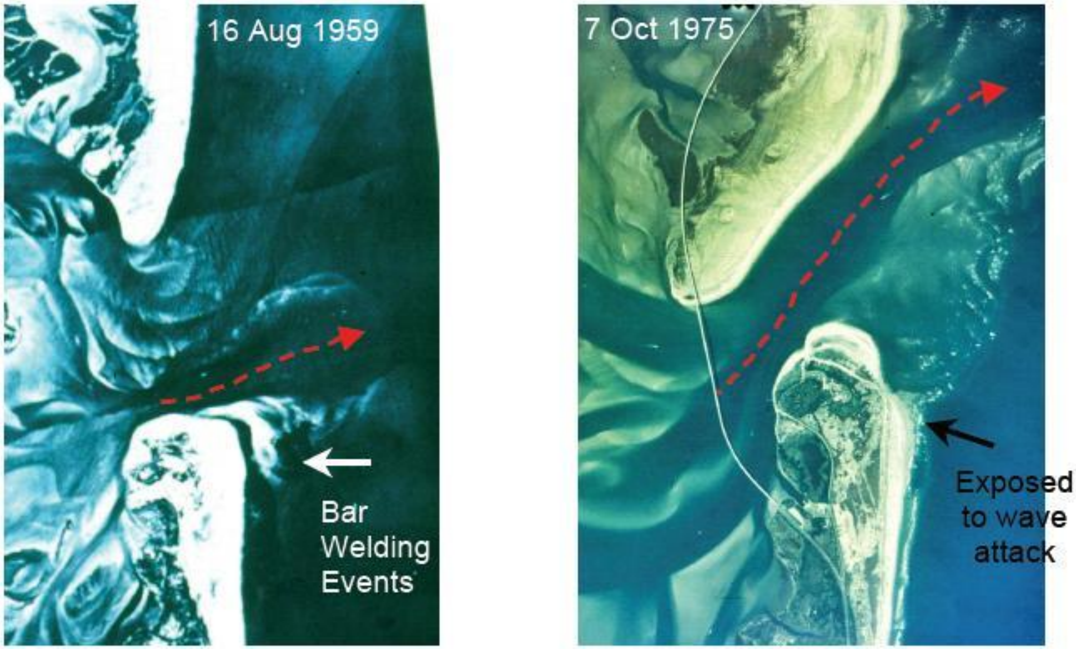


Figure II-10. Historical Aerial Photographs of Oregon Inlet Illustrating Different Ebb-tidal Delta Morphologies.
The overlap of the ebb delta dictates accretionary patterns along the adjacent beaches

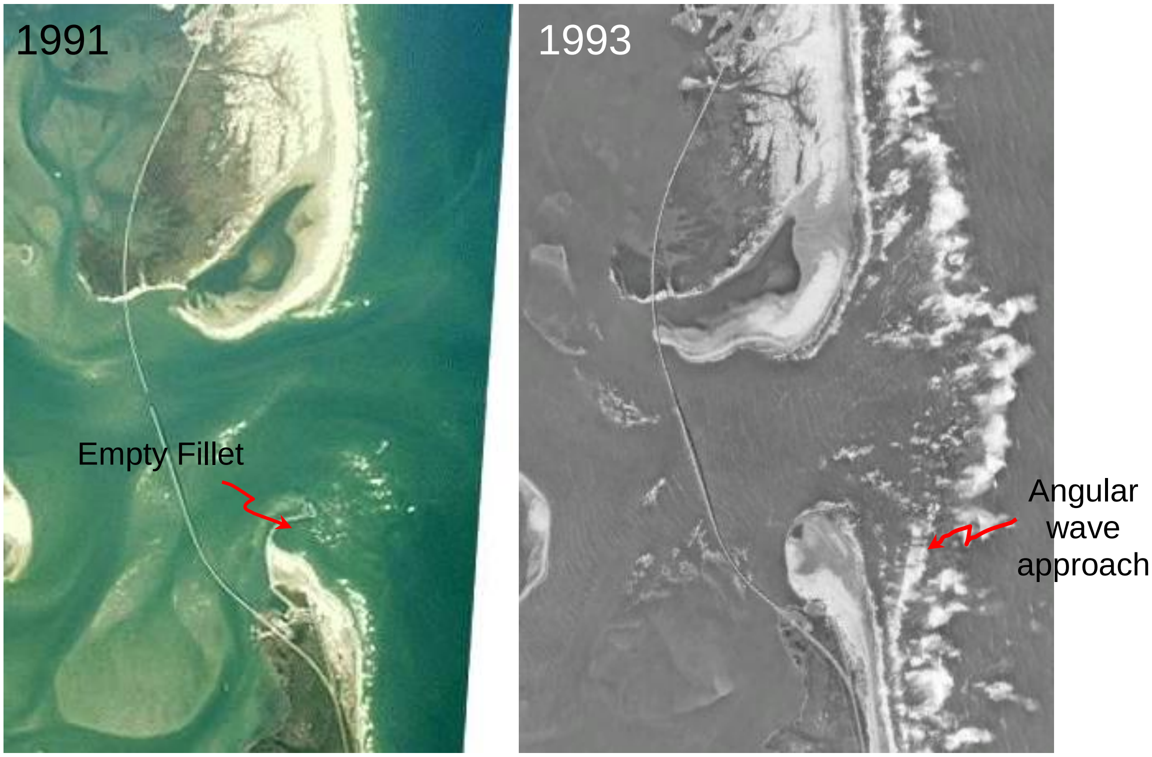


Figure II-11. Photographs of Northern Pea Island and Terminal Groin Area.
Note immediately following construction of the groin in 1991 the lack of sand in the fillet region. Two years later, it had mostly filled due to a nourishment project and from the natural northerly longshore transport of sand caused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

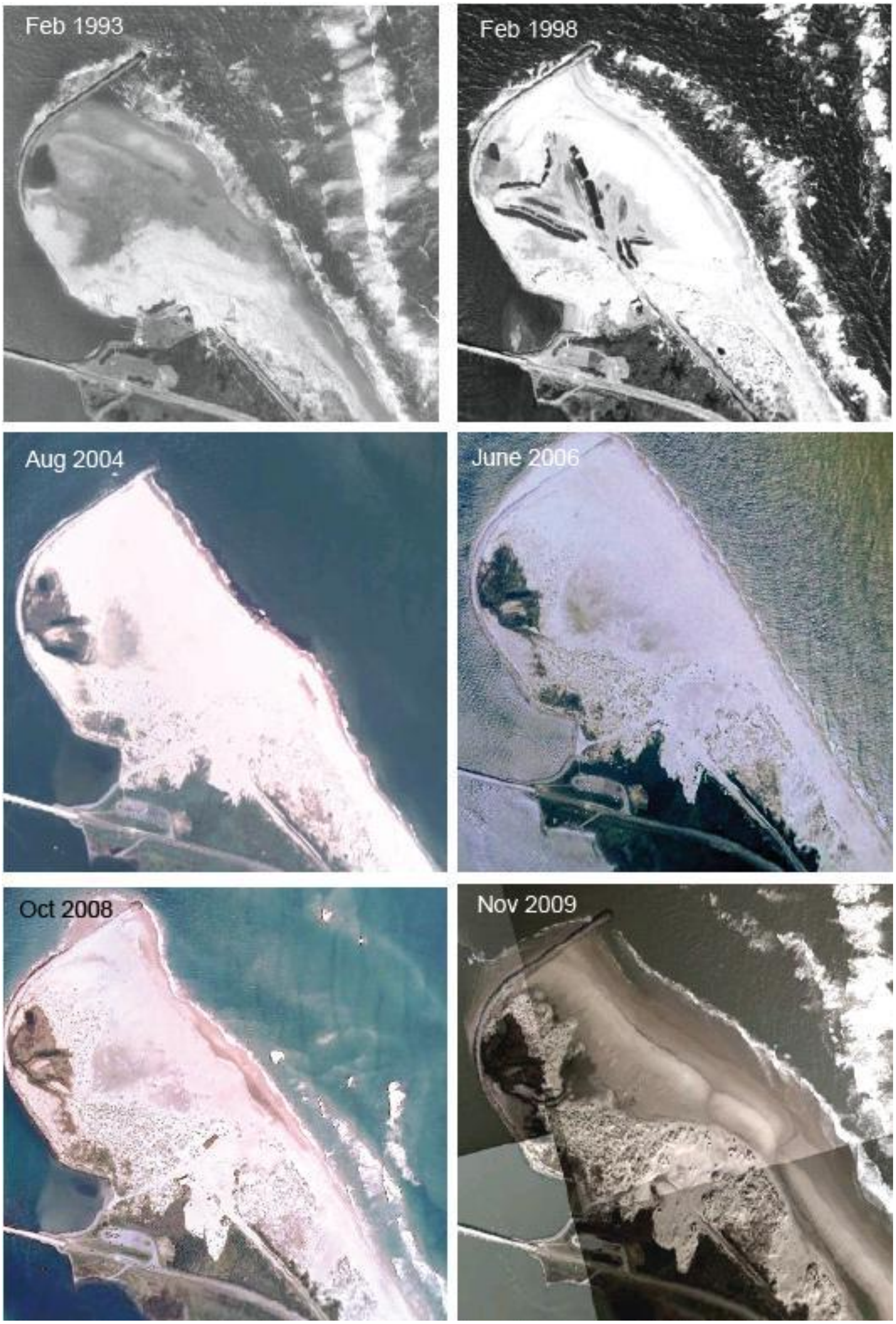


Figure II-14. Historical Changes of the Northern Pea Island Shoreline (downloaded from Google Earth)

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.

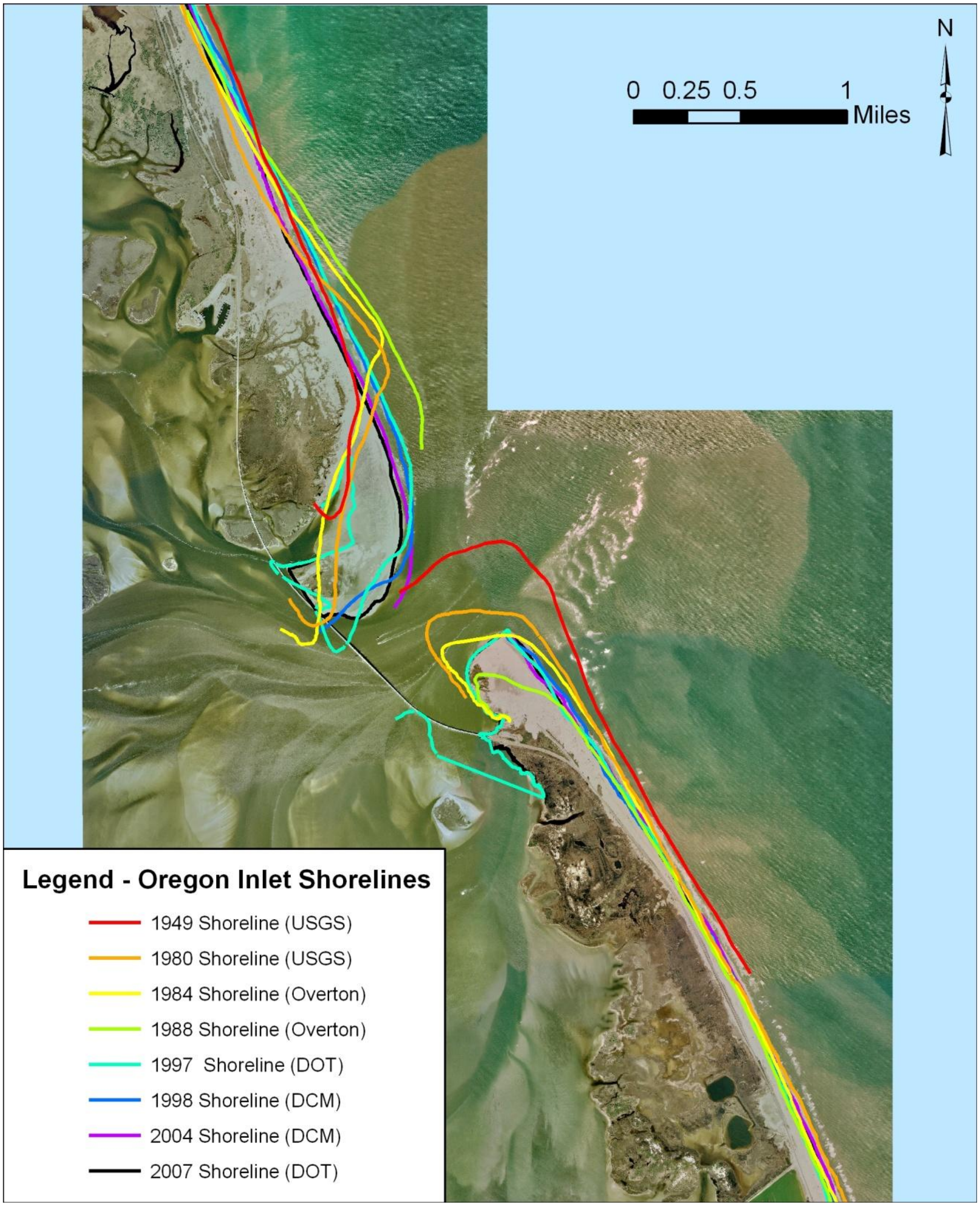


Figure II-15. Historic Shorelines – Oregon Inlet

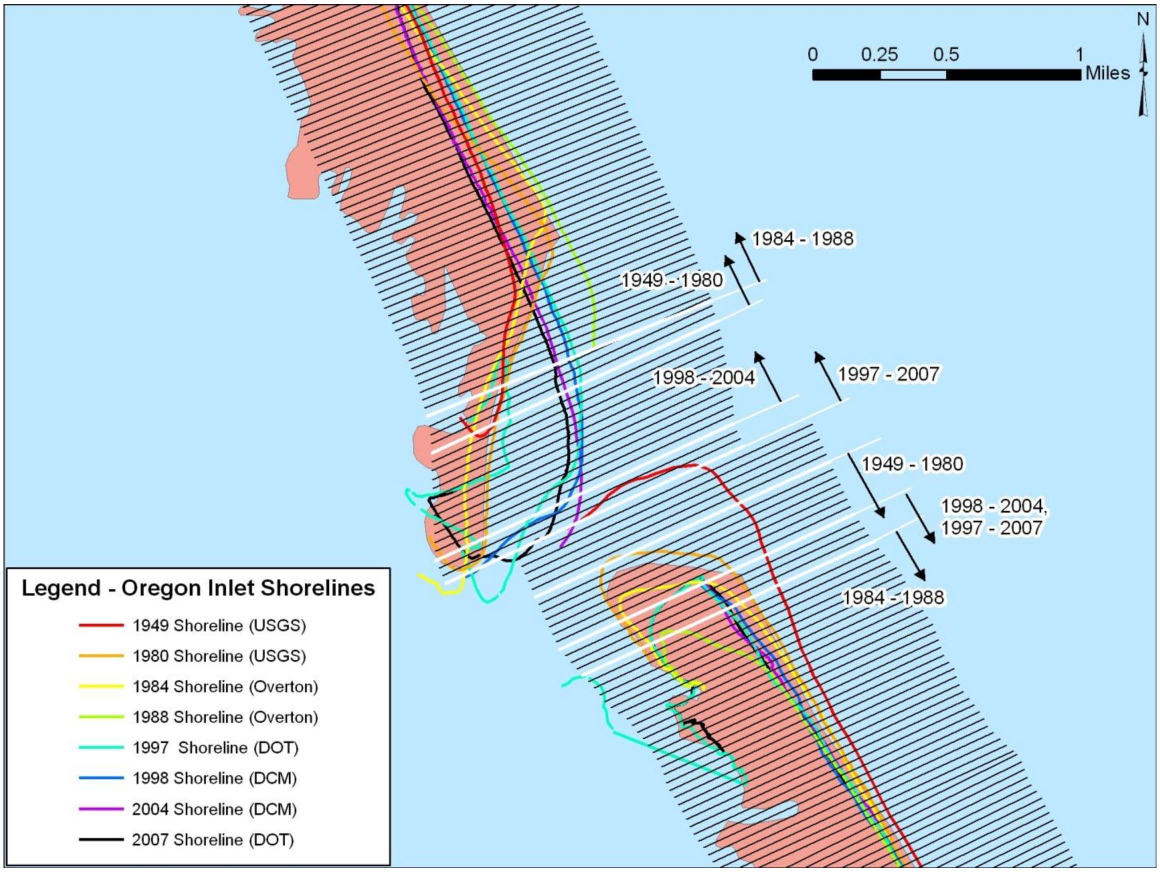


Figure II-16. Oregon Inlet Shoreline Change Calculation Transects

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)

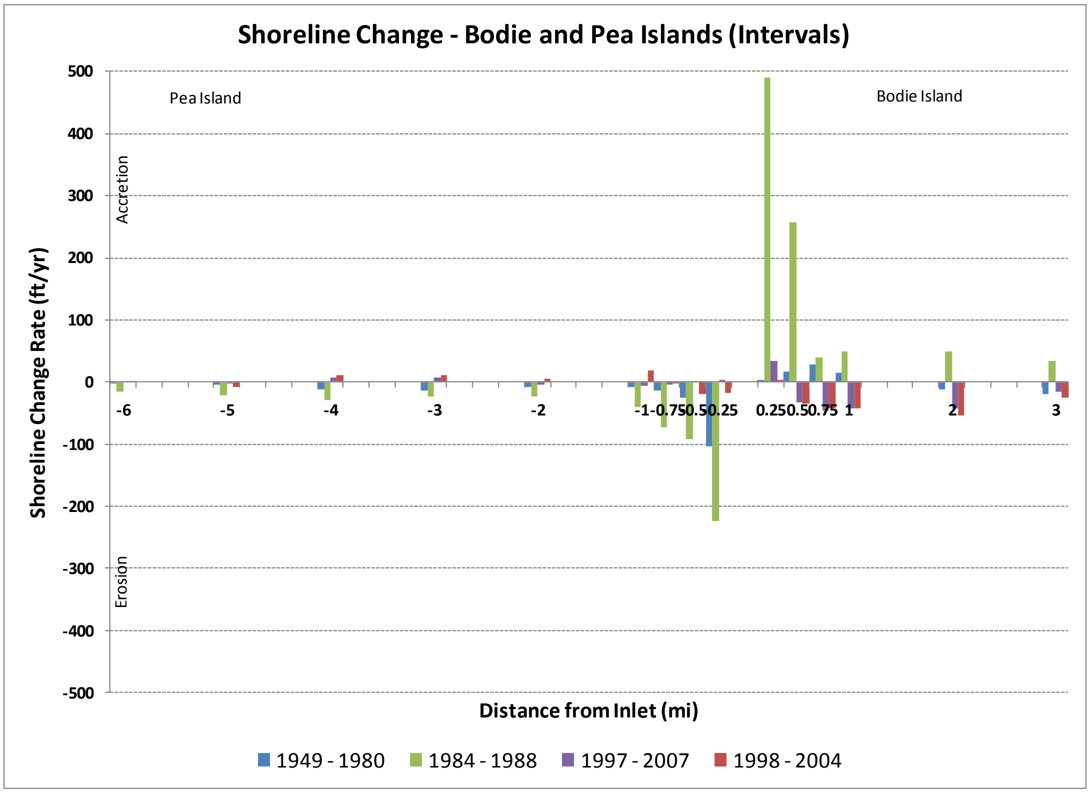


Figure II-17. Shoreline Change – Bodie and Pea Islands (Intervals)

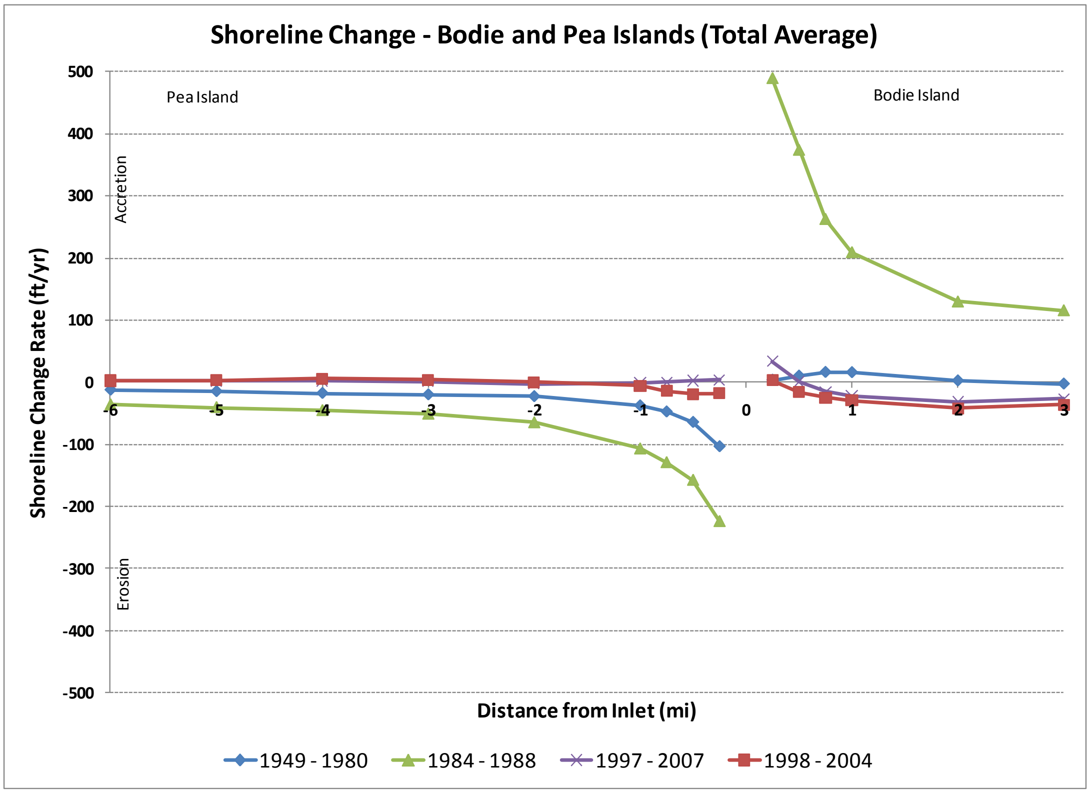


Figure II-18. Shoreline Change – Bodie and Pea Islands (Total Average)

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.

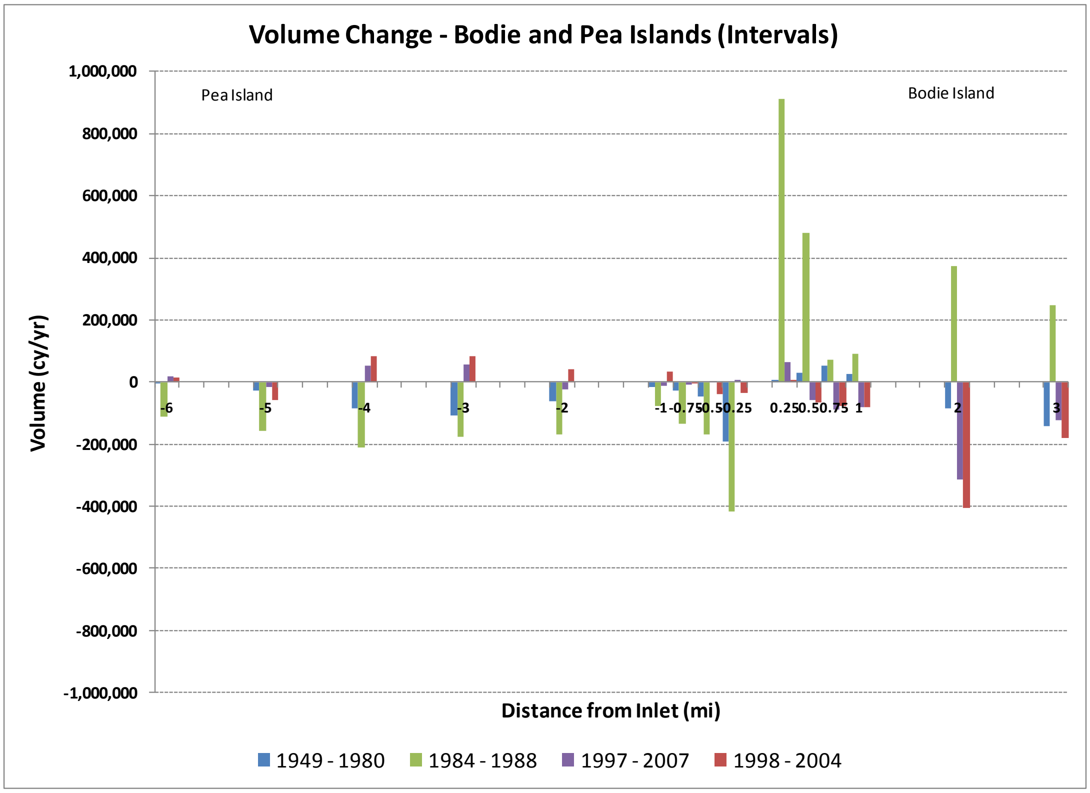


Figure II-19. Beach Volume Changes – Bodie and Pea Islands (Intervals)

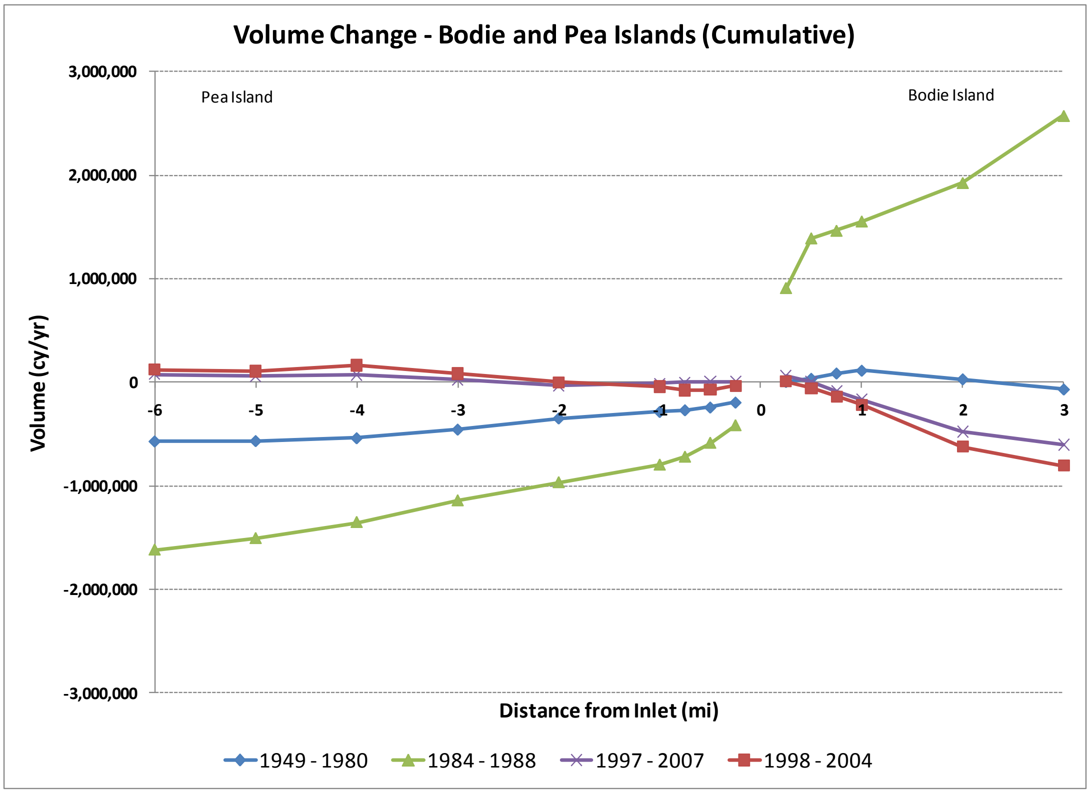


Figure II-20. Beach Volume Changes – Bodie and Pea Islands (Cumulative)

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.

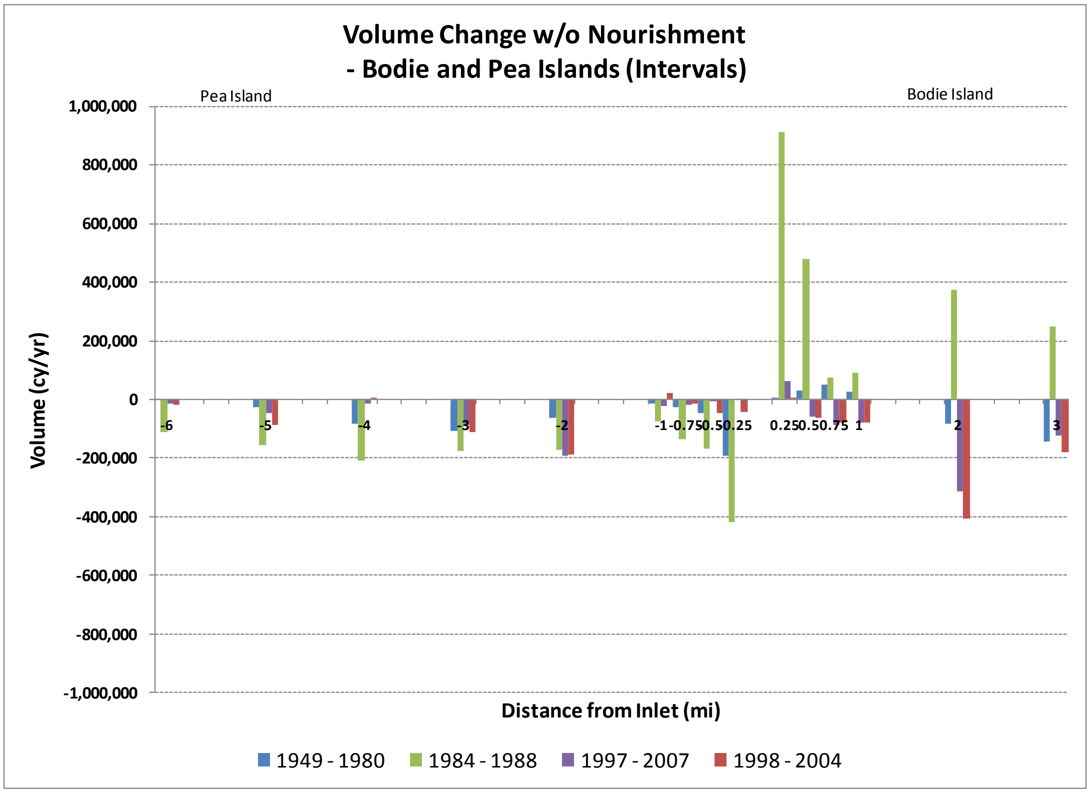


Figure II-21. Volume Changes Without Nourishment – Bodie and Pea Islands (Intervals)

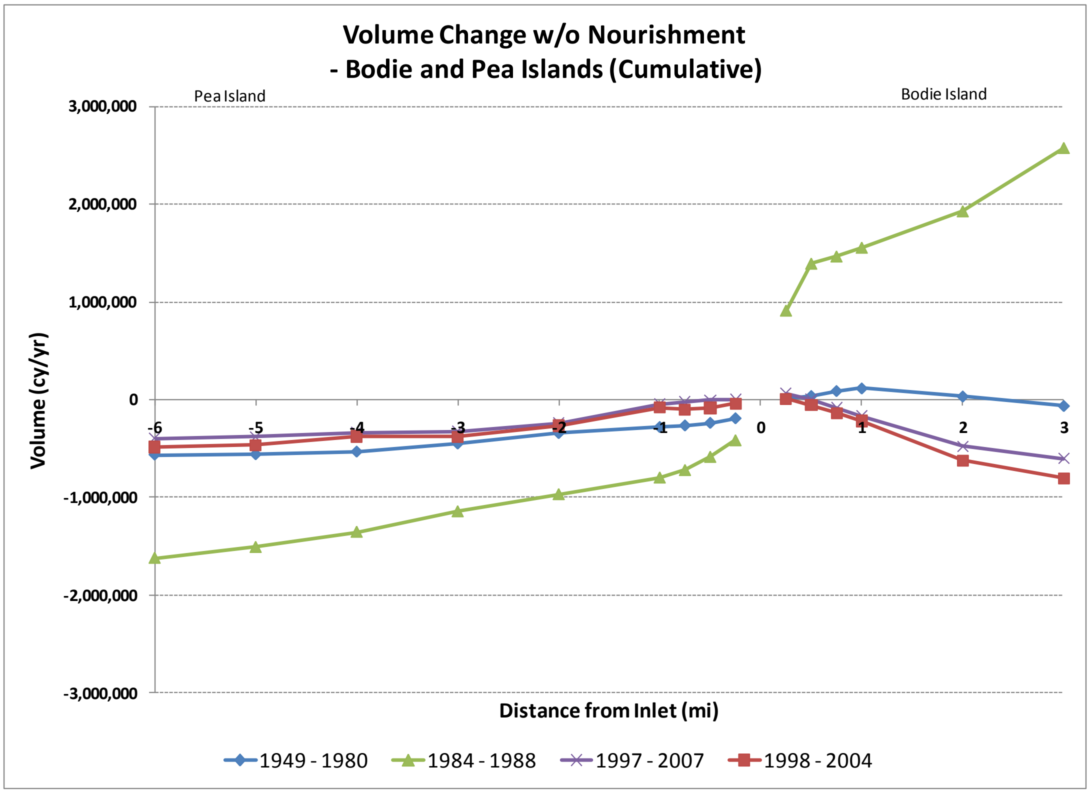


Figure II-22. Volume Changes Without Nourishment – Bodie and Pea Islands (Cumulative)

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.

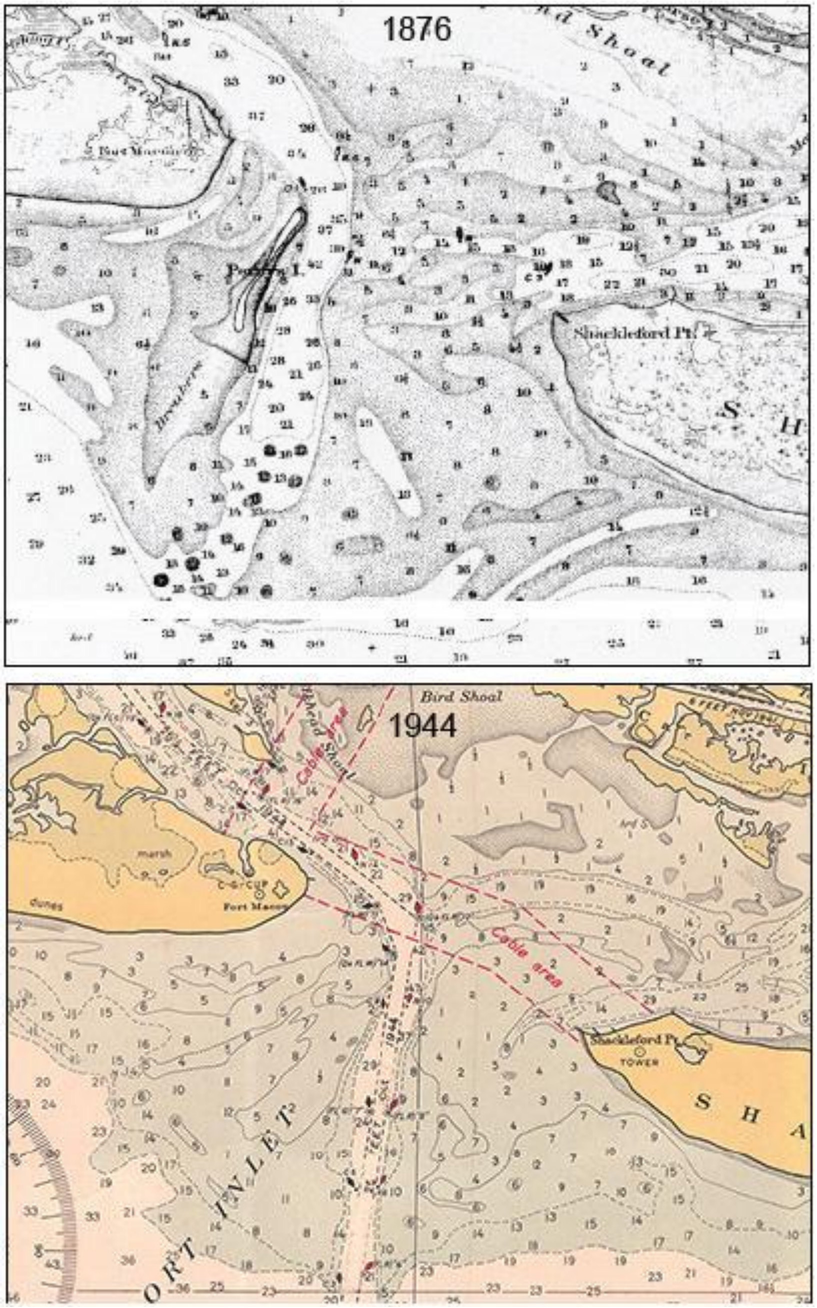


Figure II-25. Historical Coastal Charts of Beaufort Inlet in 1876 and 1994

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).

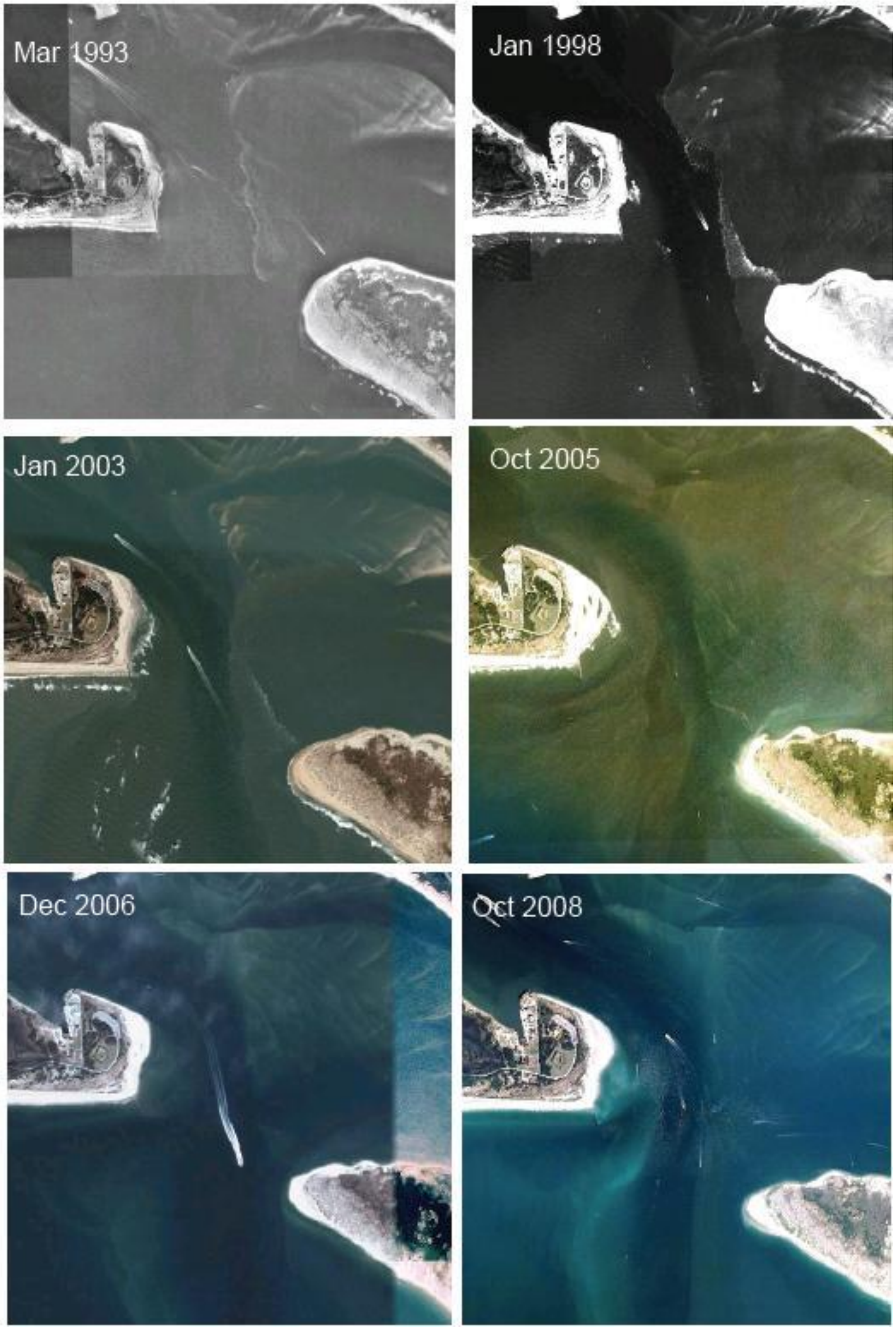


Figure II-26. Aerial Photographs Showing Shoreline Changes in the Vicinity of Fort Macon Terminal Groin.
Note the shoreline progradation inside the inlet (2005) and west of the terminal groin (taken from Google Earth)

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

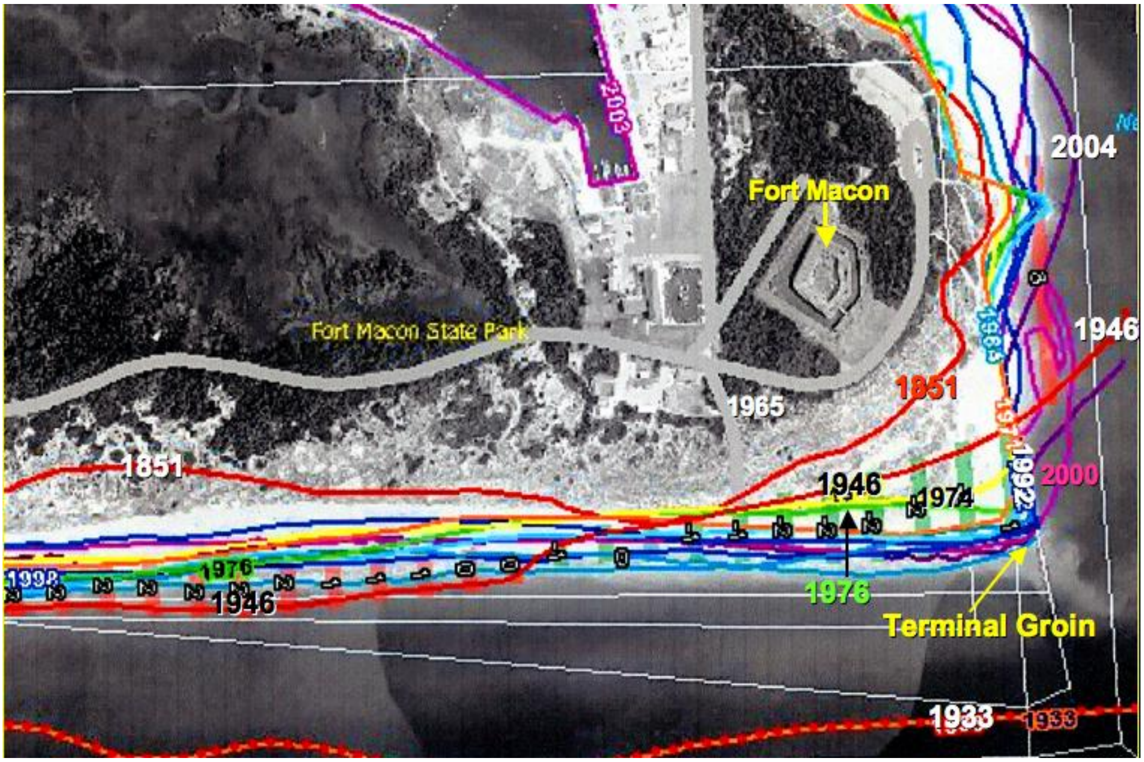


Figure II-28. Compilation of Historic Shorelines in the Vicinity of Fort Macon Terminal Groin (Cleary, 2009).

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).

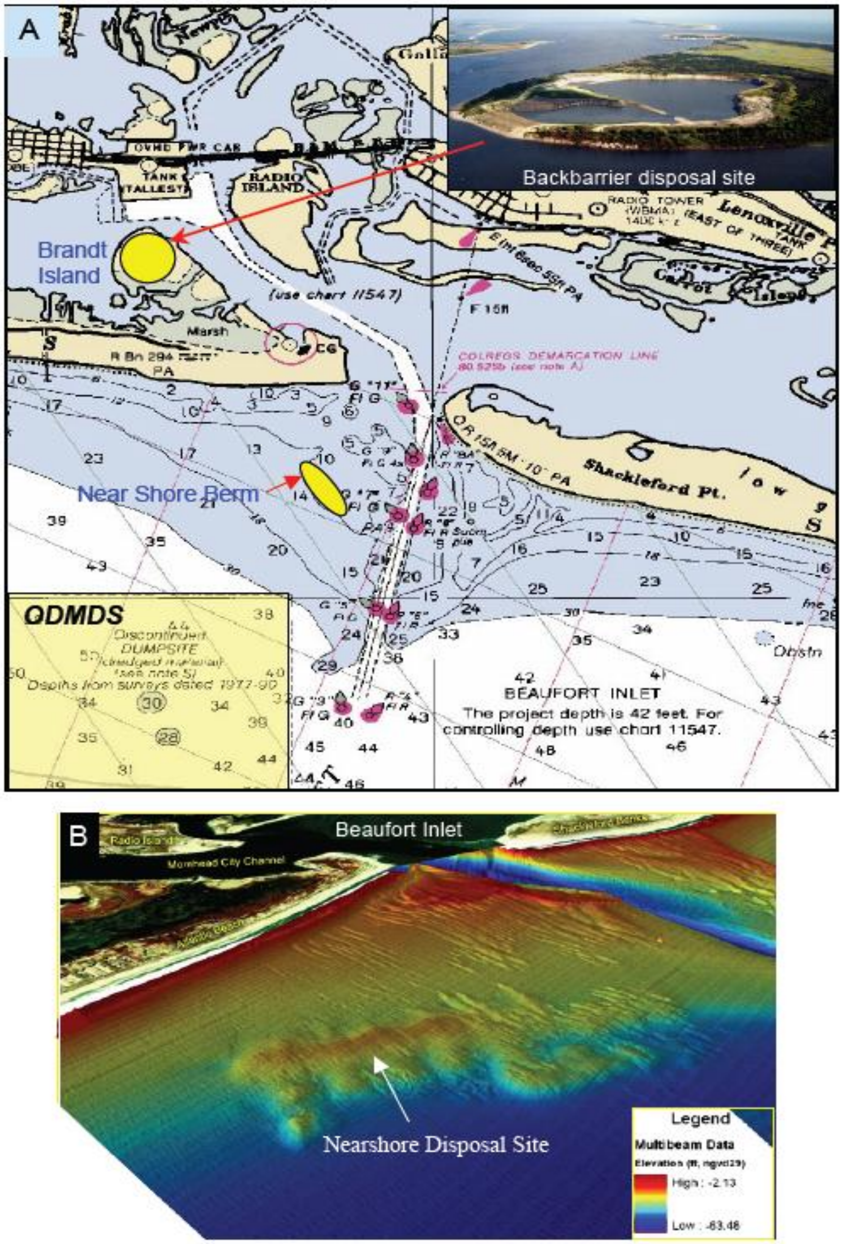


Figure II-29. A. Dredge Disposal Sites Used in Maintaining Navigation Channels for Morehead City and Beaufort Inlet. B. DEM Showing Build-up of Sand at Nearshore Site

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.

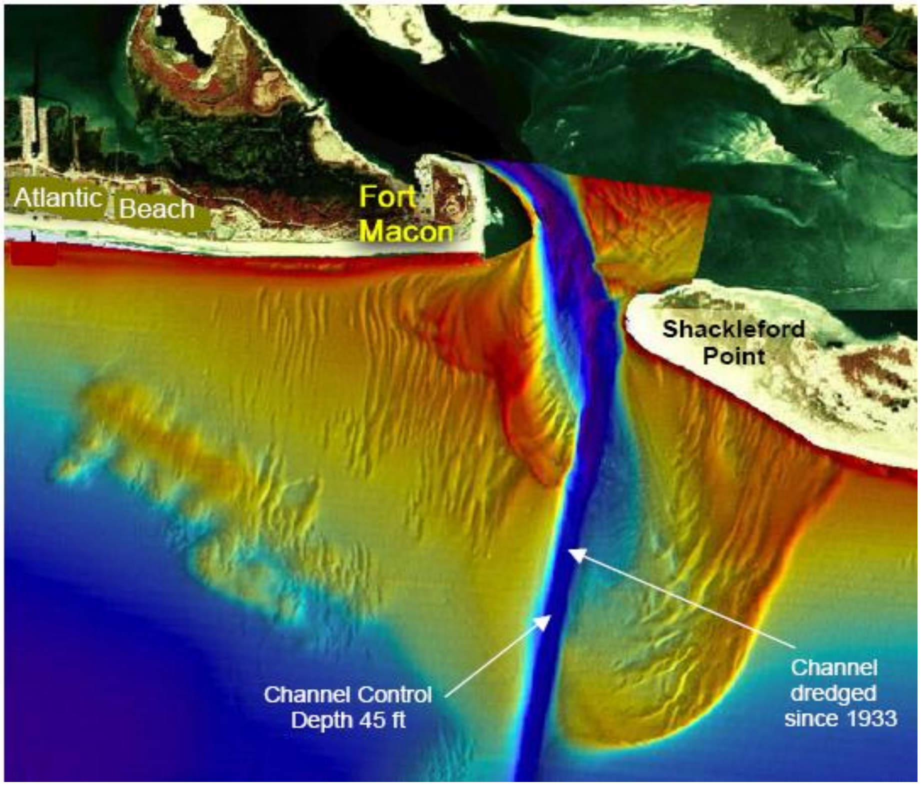


Figure II-30. Digital Elevation Model Illustrating the Relief of the Ebb-tidal Delta. Note that the main channel has been dredged since 1933 and is presently maintained to a depth of 45 feet.

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).

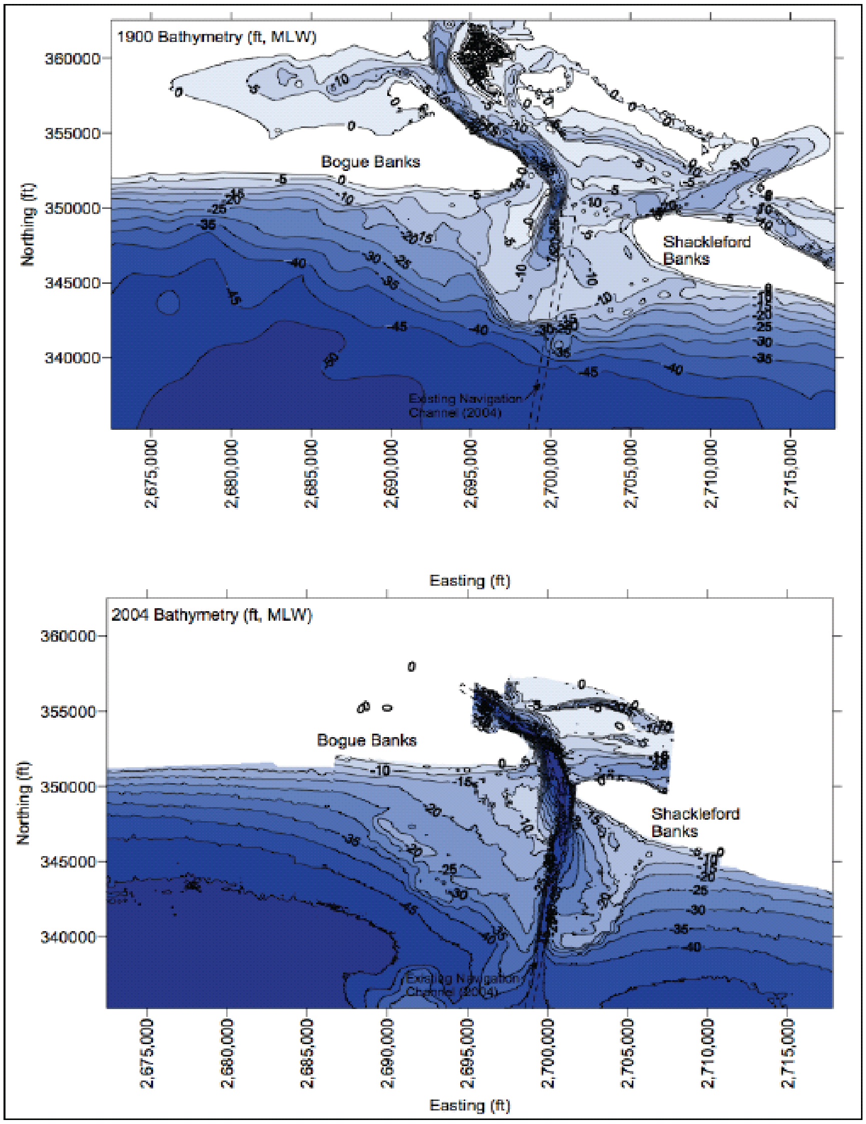


Figure II-31. Comparison of Bathymetry between ca. 1900 and 2004 (Olsen, 2004)

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.

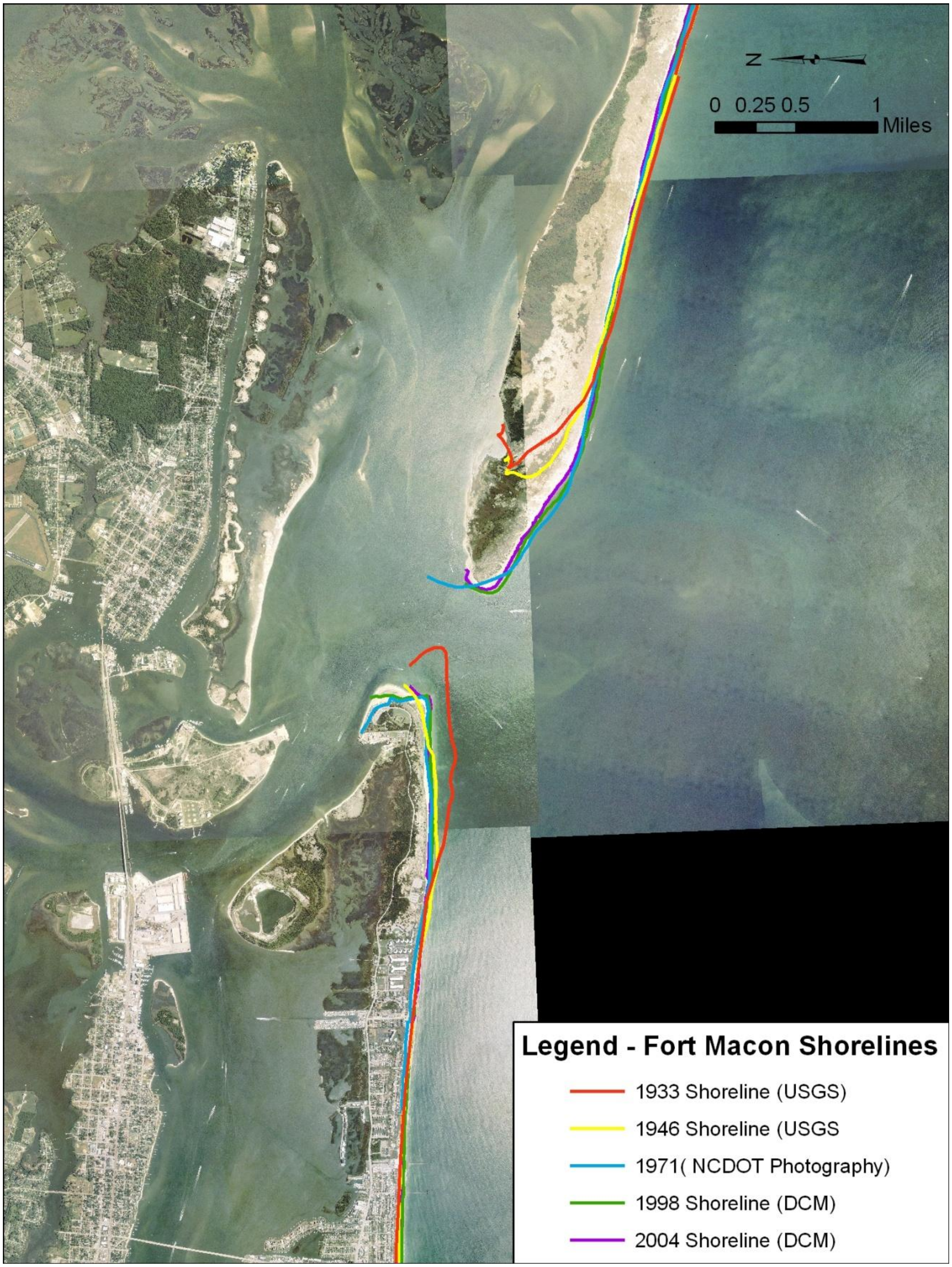


Figure II-32. Historic Shorelines – Fort Macon (Beaufort Inlet)

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.

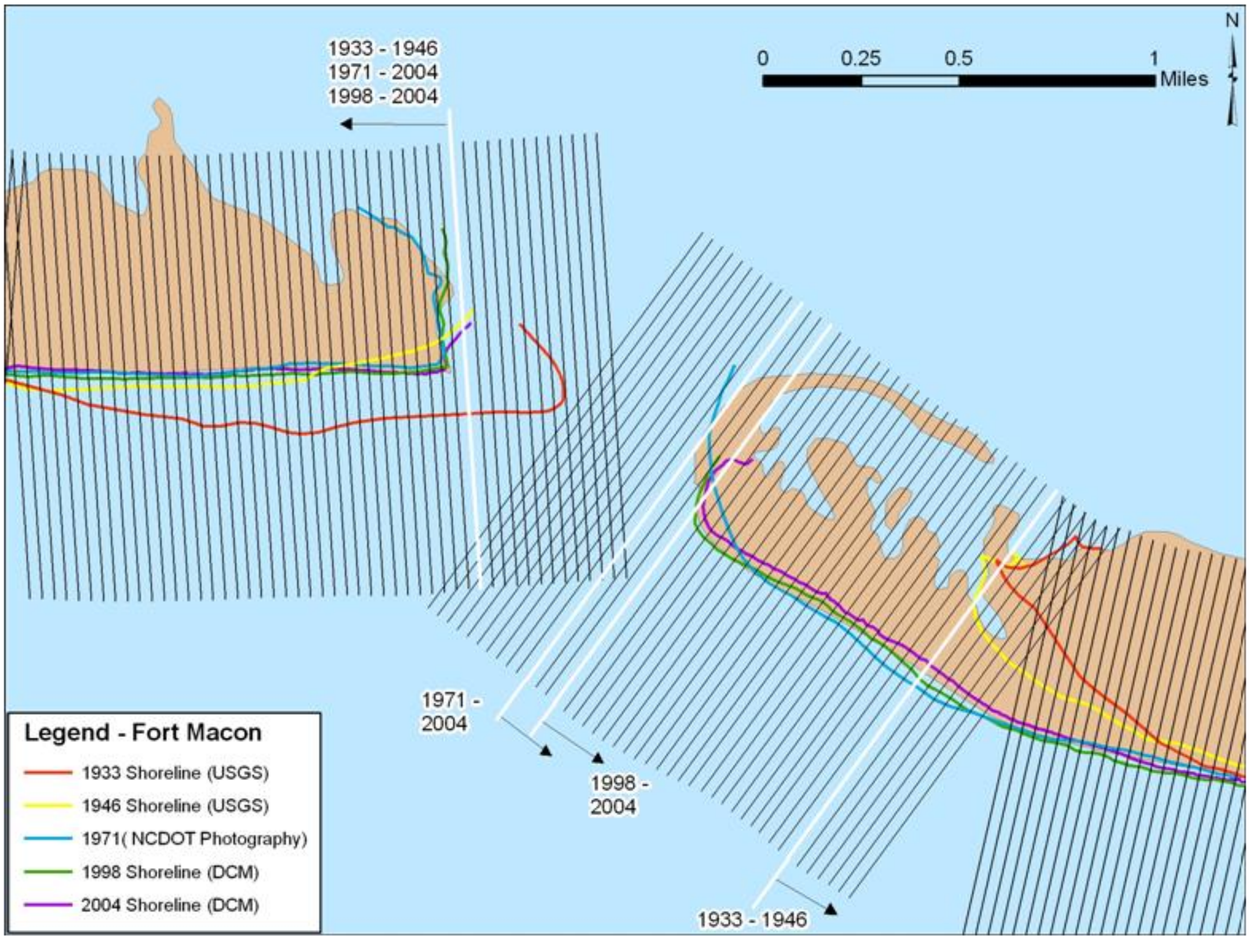


Figure II-33. Fort Macon (Beaufort Inlet) Shoreline Change Calculation Transects

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)

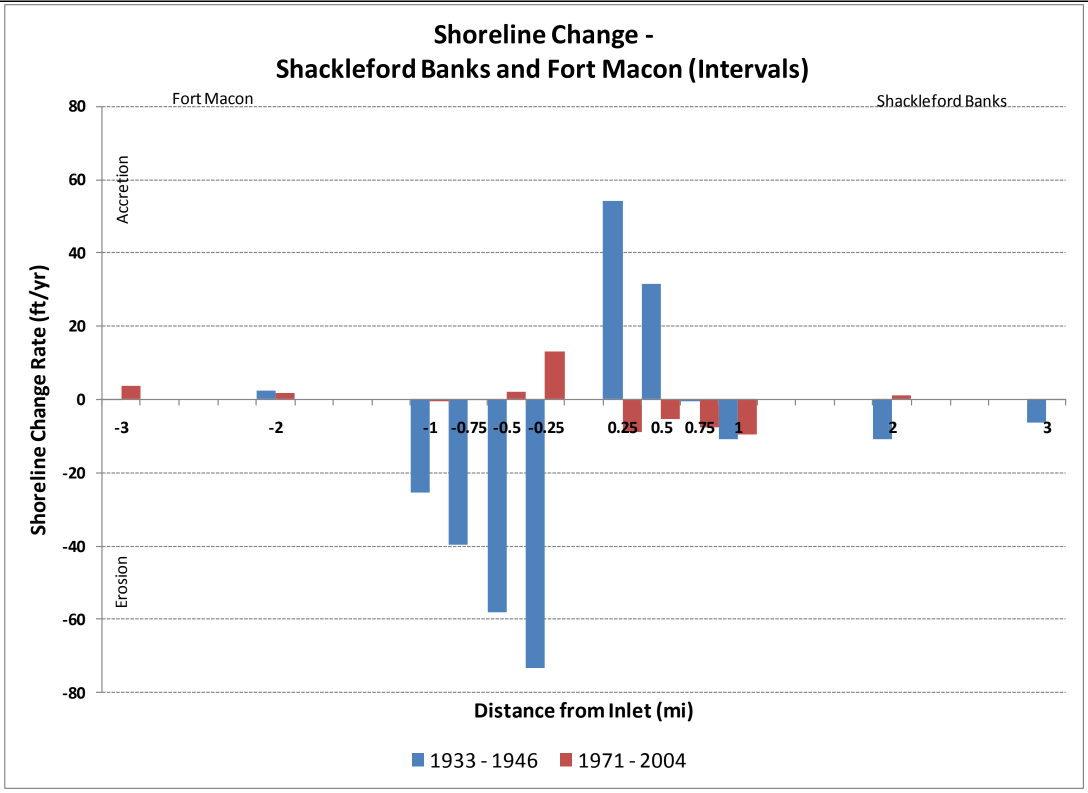


Figure II-34. Shoreline Change – Shackleford Banks and Fort Macon (Intervals)

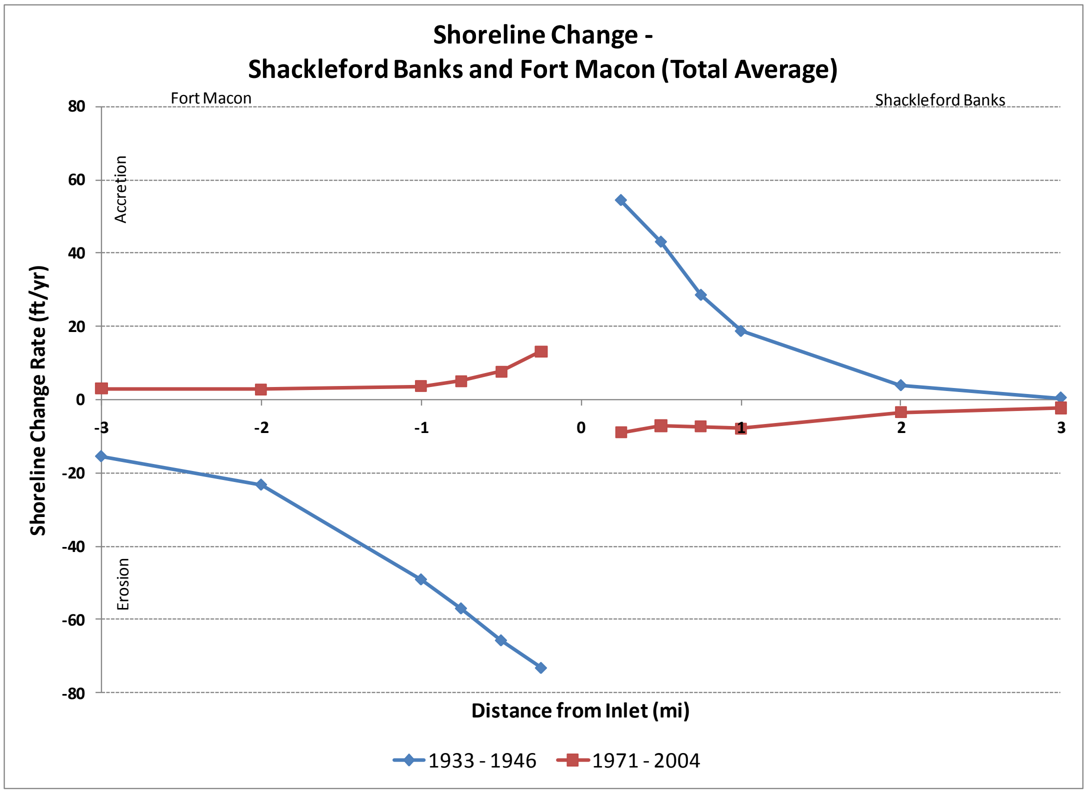


Figure II-35. Shoreline Change – Shackleford Banks and Fort Macon (Total Average)

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.

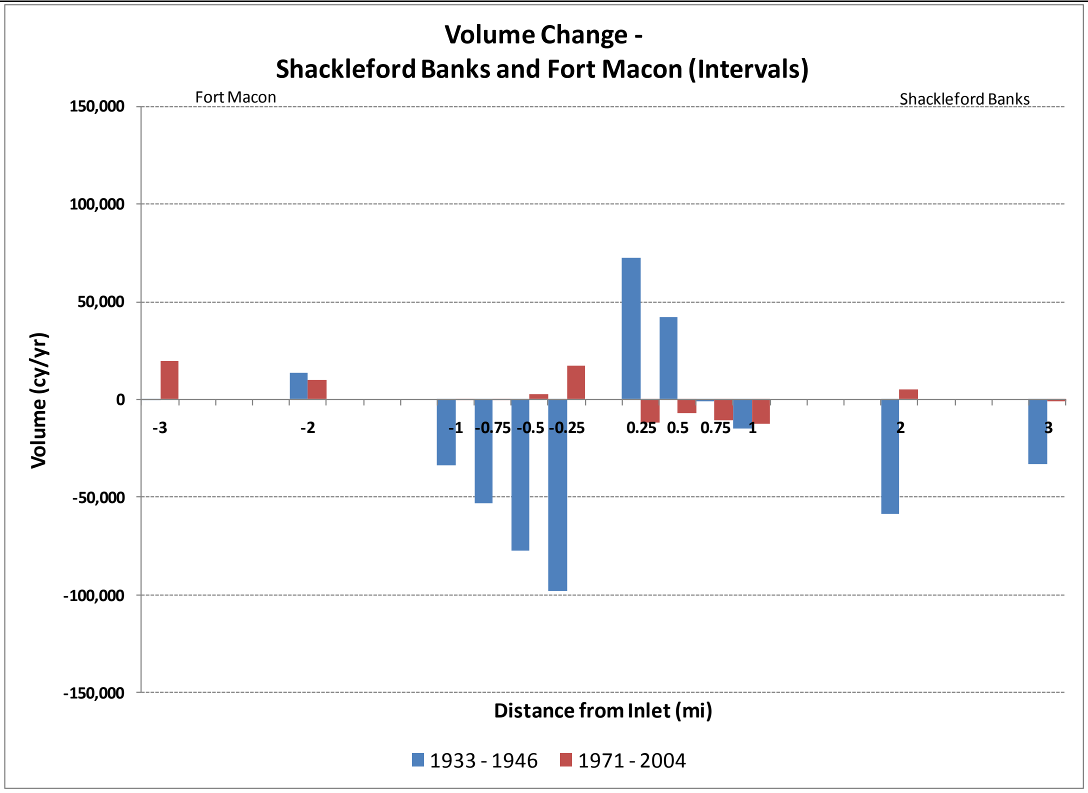


Figure II-36. Beach Volume Changes – Fort Macon (Intervals)

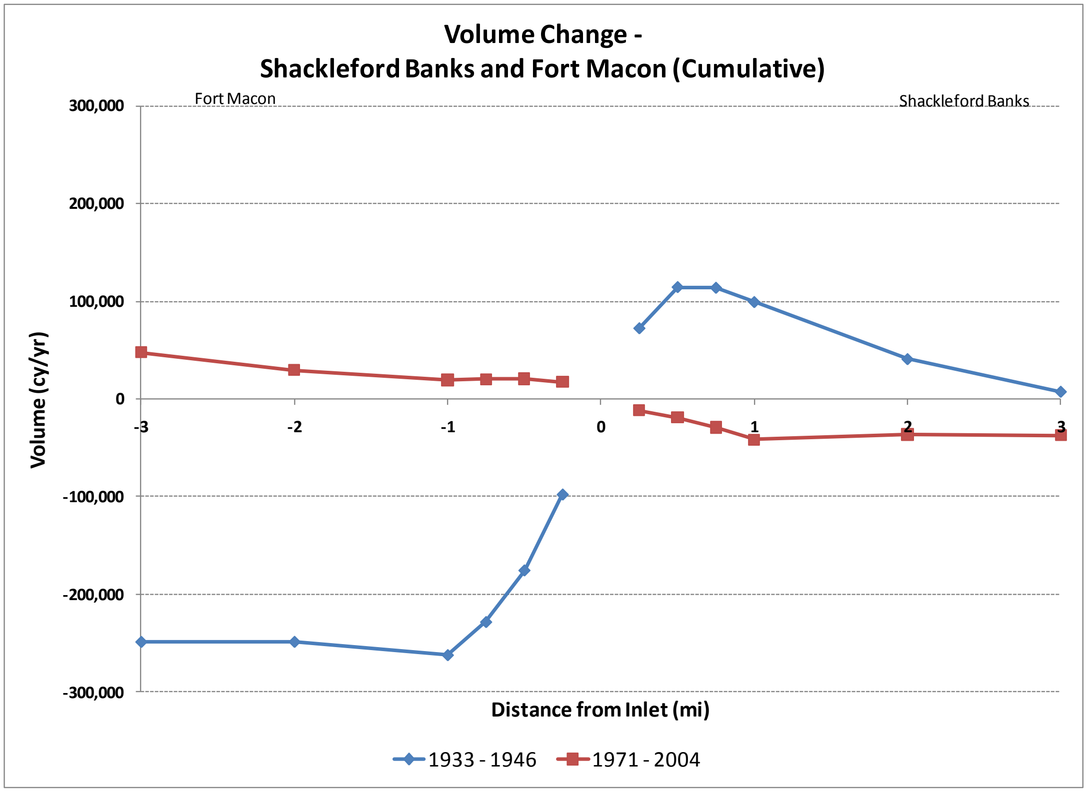


Figure II-37. Beach Volume Changes – Fort Macon (Cumulative)

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.

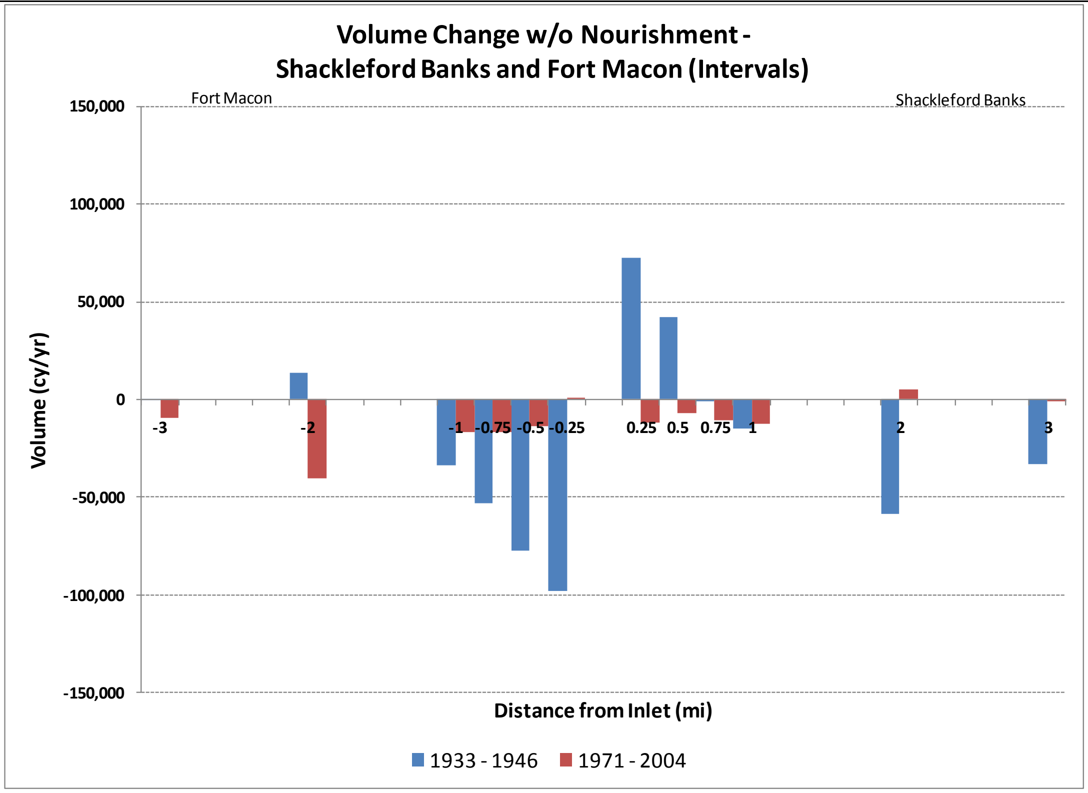


Figure II-38. Volume Changes w/o Nourishment – Shackleford Banks and Fort Macon (Intervals)

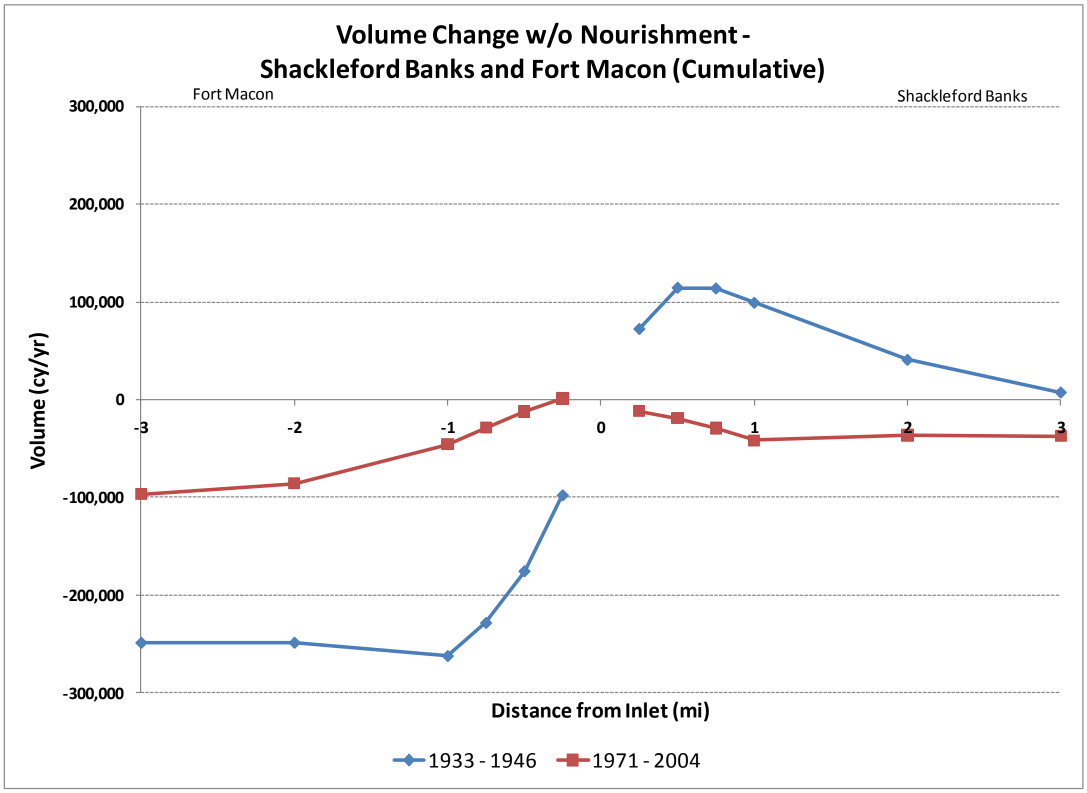


Figure II-39. Volume Changes w/o Nourishment – Shackleford Banks and Fort Macon (Cumulative)

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.

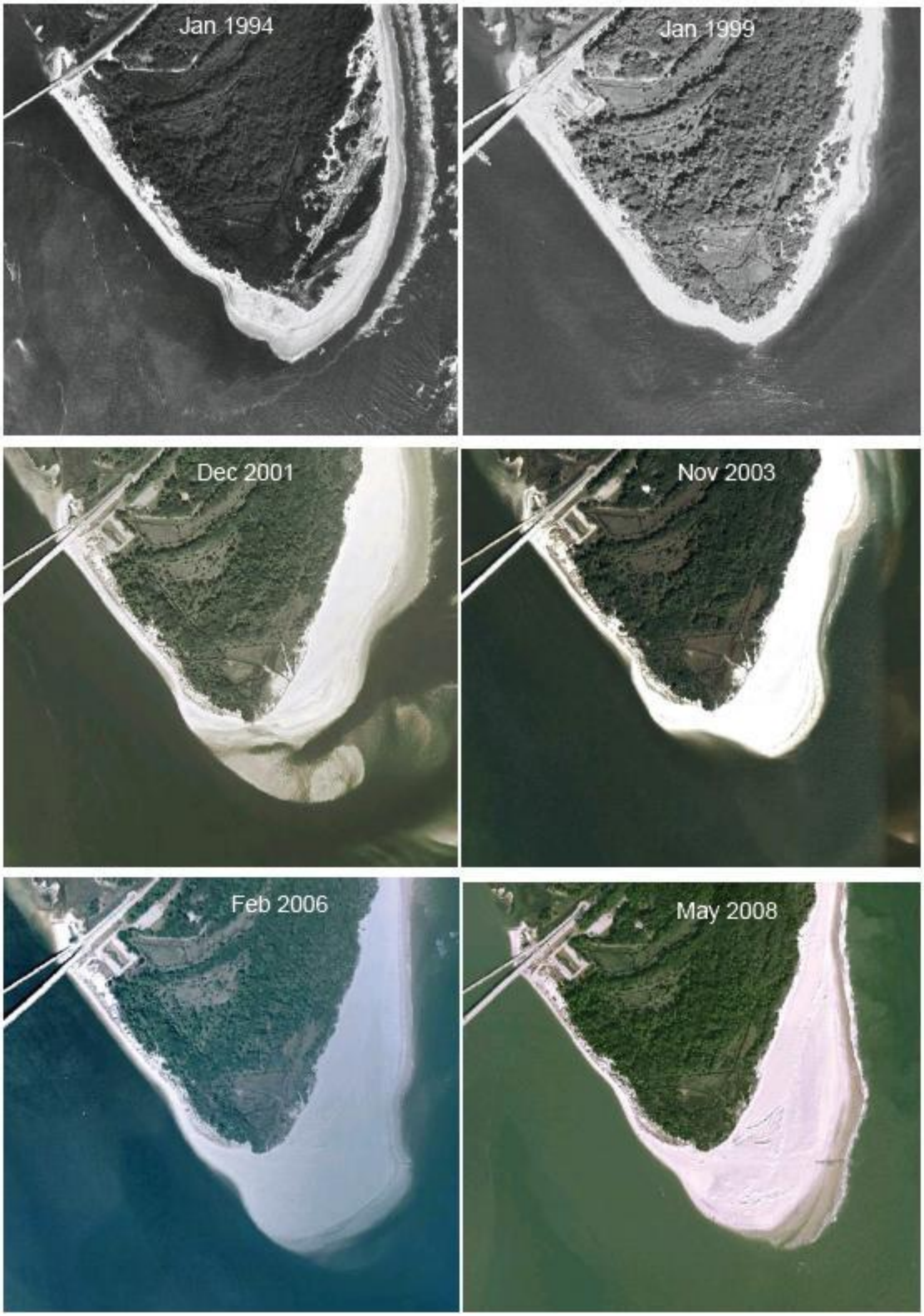


Figure II-42. Sequential Vertical Aerial Photographs of Amelia Island between 1994 and 2008 (from Google Earth)

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.

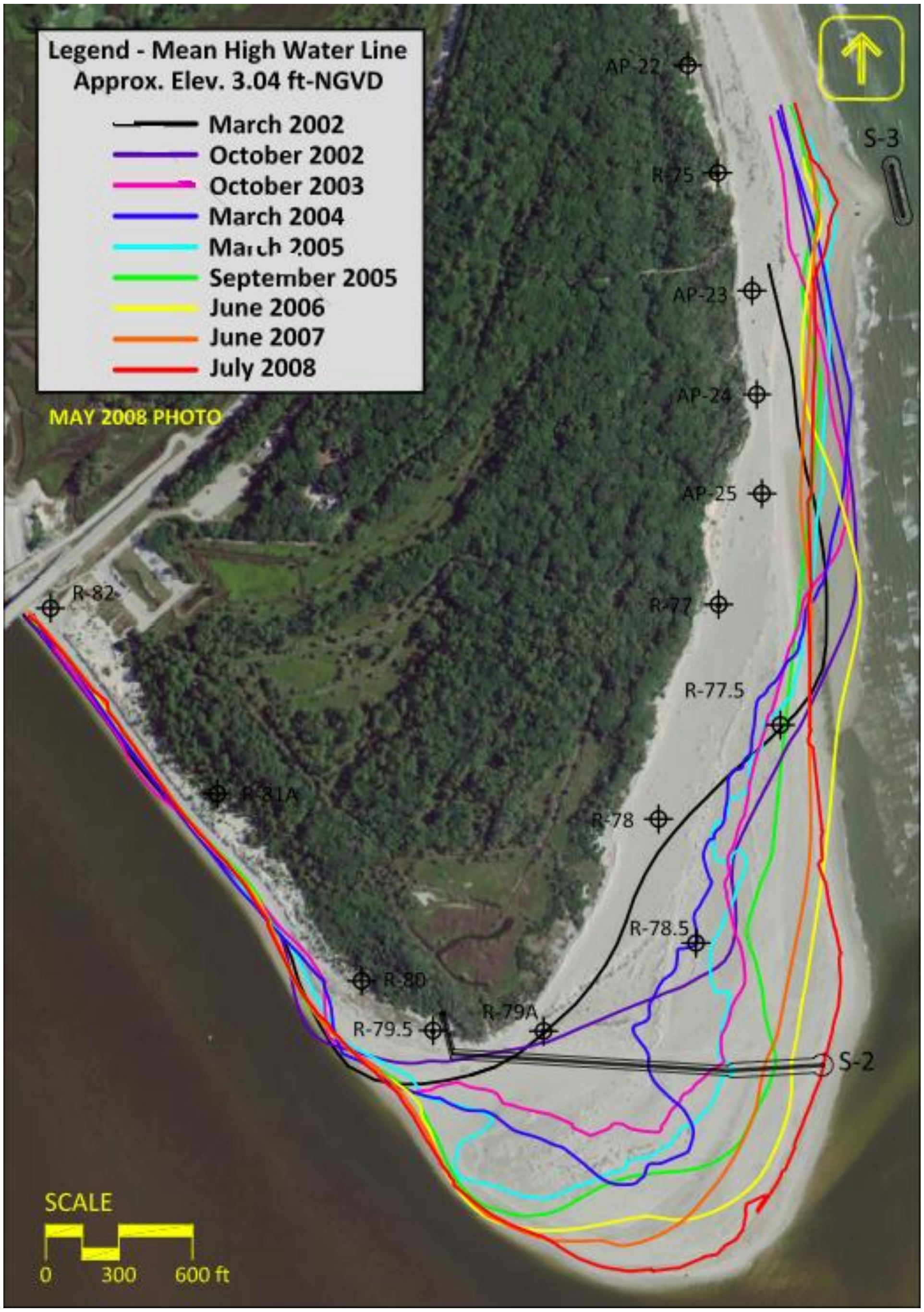


Figure II-43. Shoreline Changes on Southern Amelia Island between 2002 and 2008
Note that the southern tip of the barrier prograded to the south. This extension of the spit was facilitated, in part, from sand eroded from the beach directly north and transported south. (Olsen, 2008)

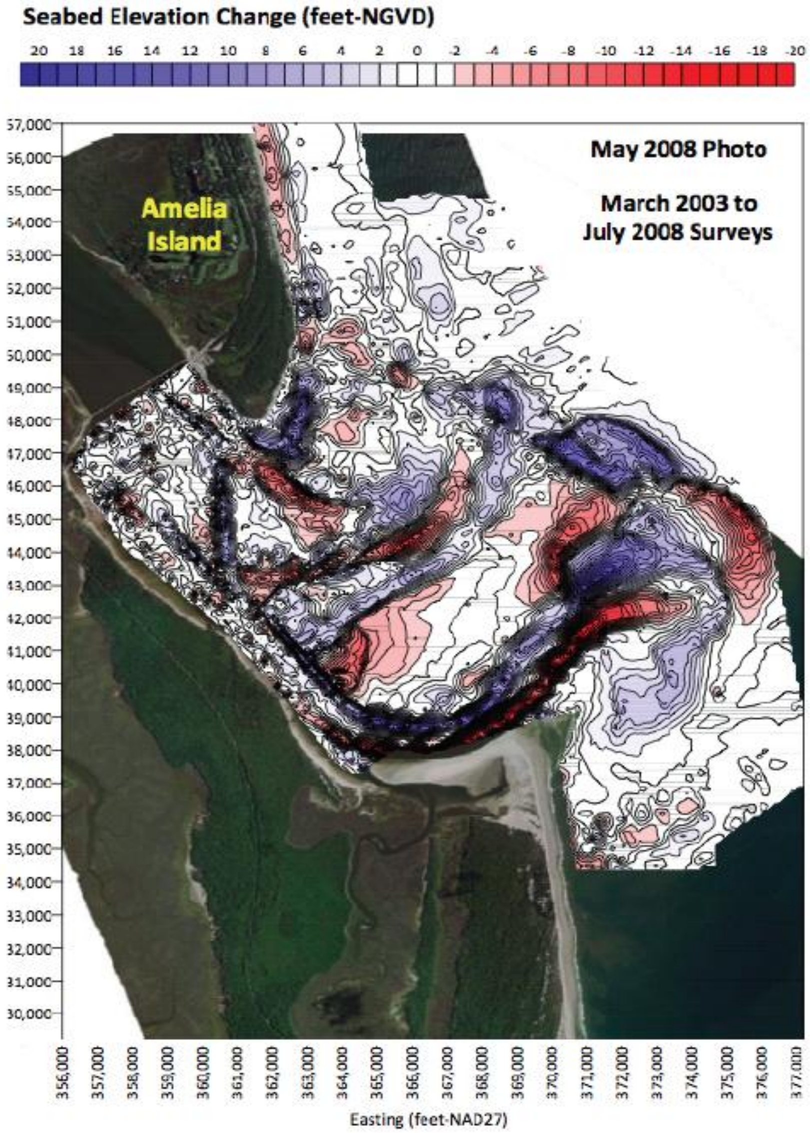


Figure II-44. Bathymetric Changes of Nassau Sound Determined from Repetitive Bathymetric Surveys from 2003 - 2008 (Olsen, 2008)

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.

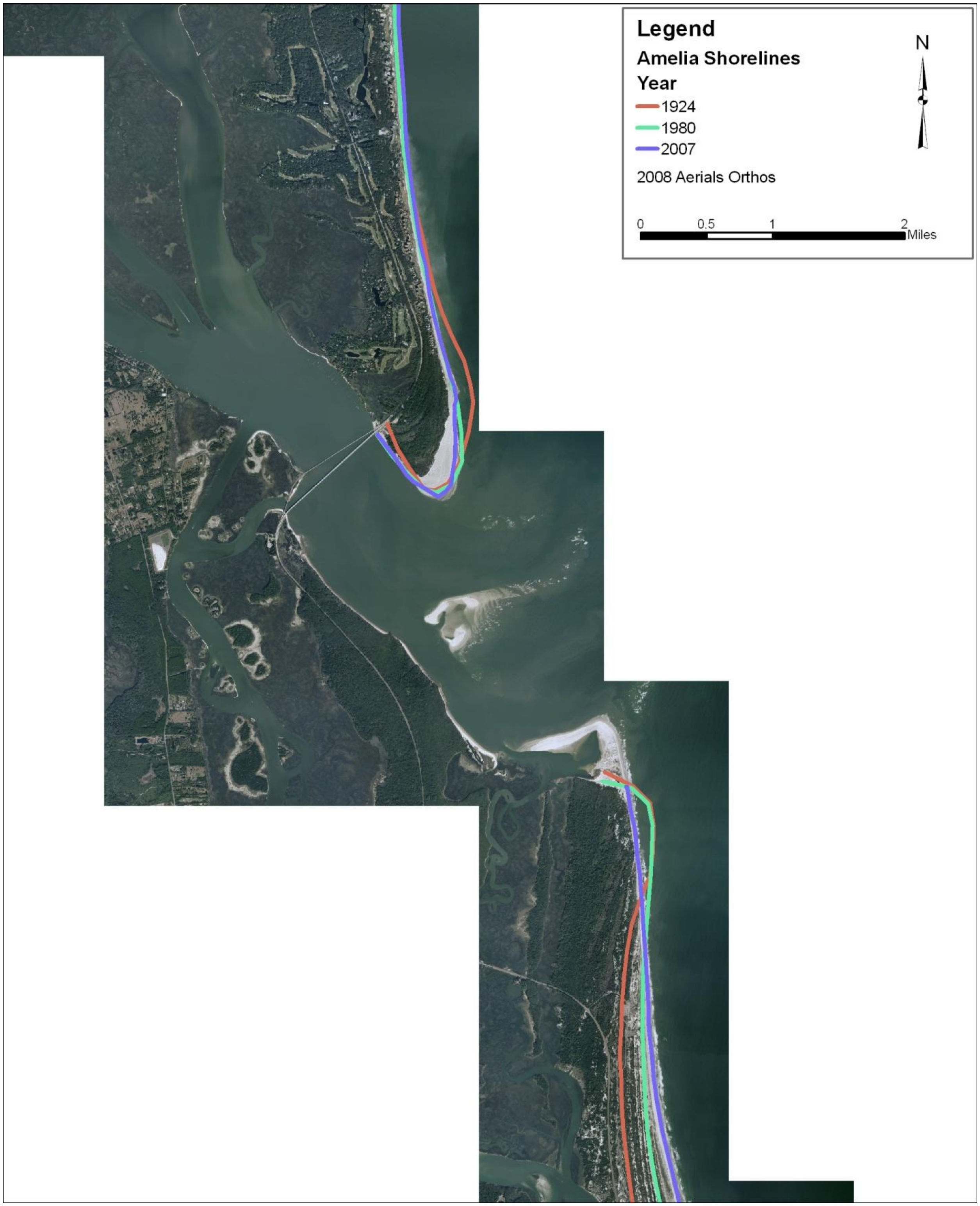


Figure II-45. Historic Shorelines – Amelia Island

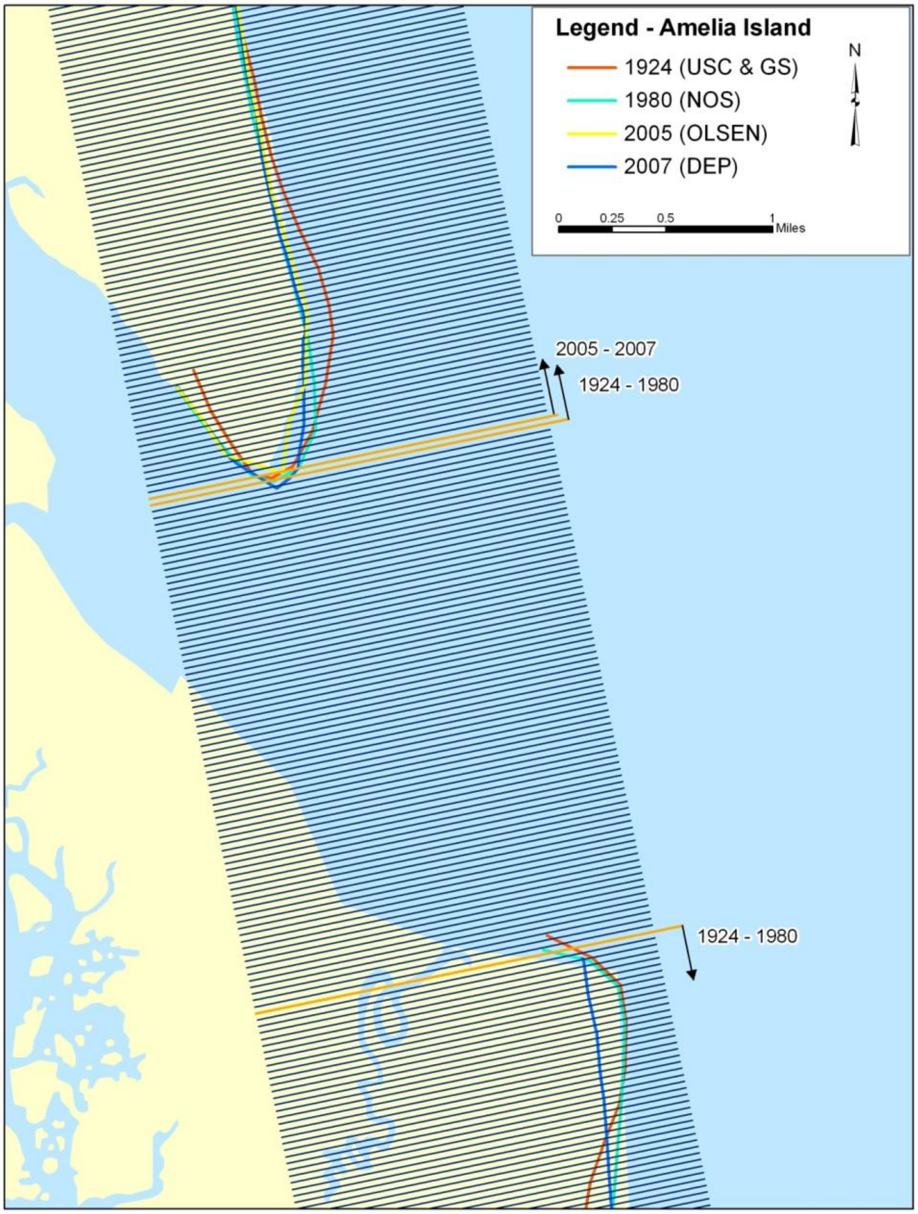


Figure II-46. Amelia Island Shoreline Change Calculation Transects

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)

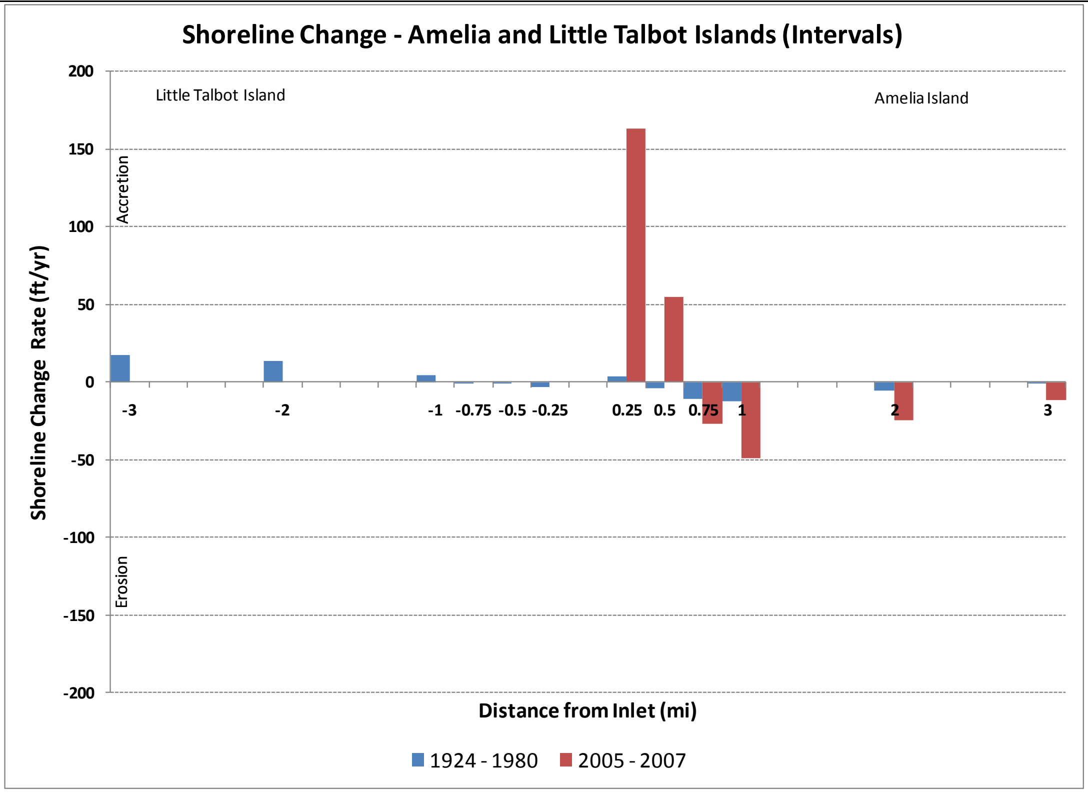


Figure II-47. Shoreline Change – Amelia and Little Talbot Islands (Intervals)

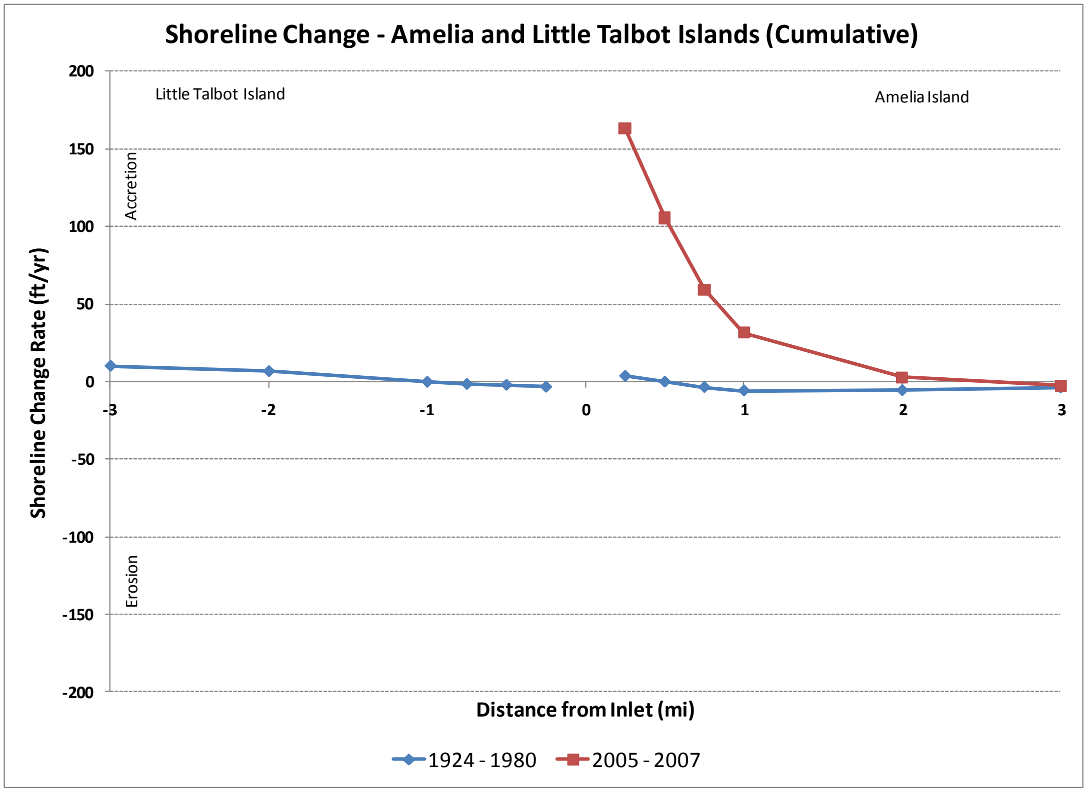


Figure II-48. Shoreline Change – Amelia and Little Talbot Islands (Total Average)

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.

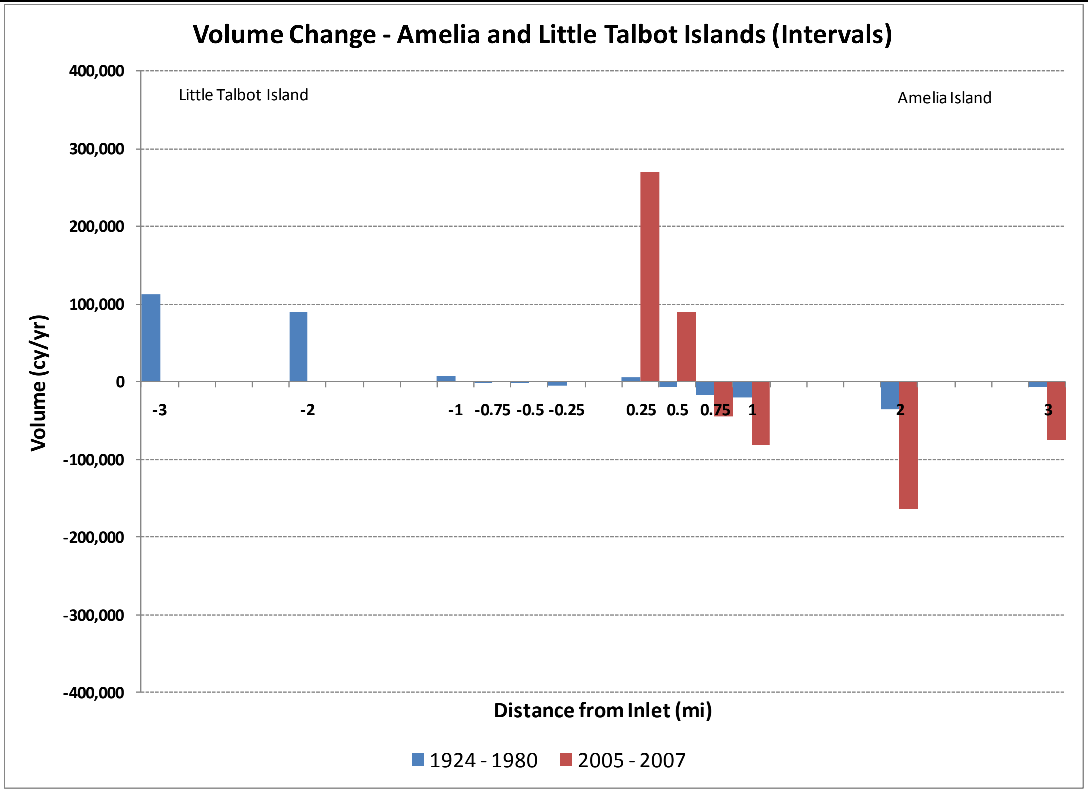


Figure II-49. Beach Volume Changes – Amelia and Little Talbot Islands (Intervals)

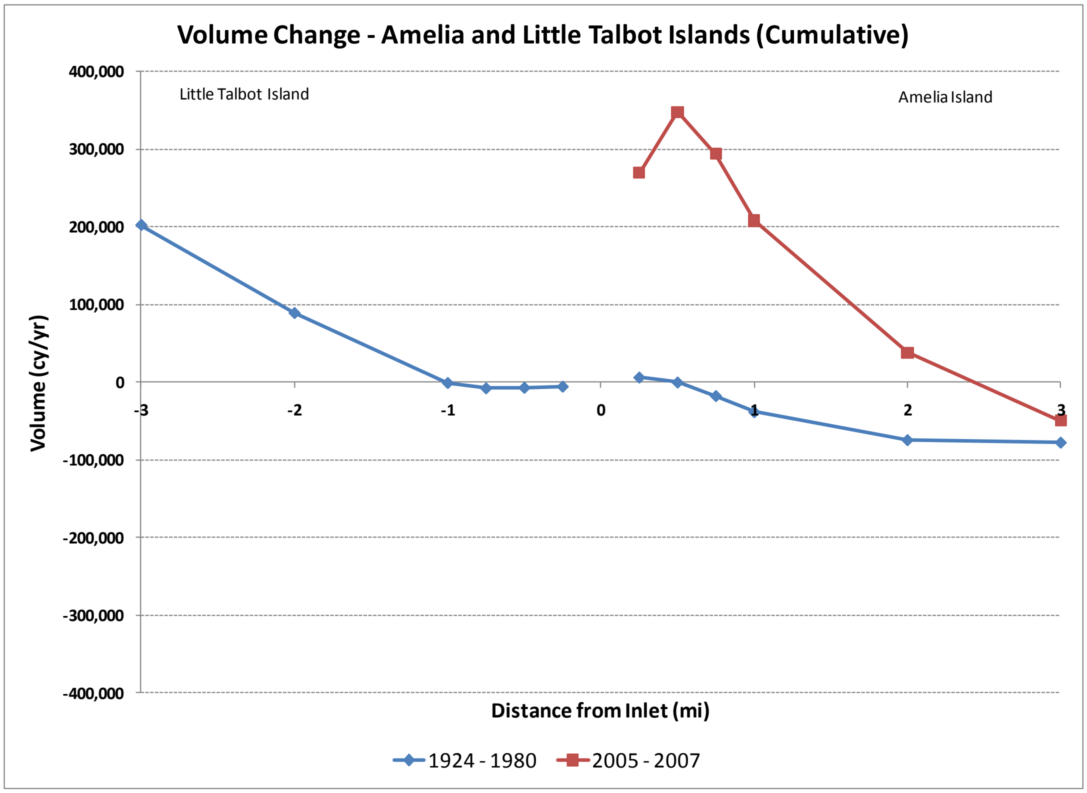


Figure II-50. Beach Volume Changes – Amelia and Little Talbot Island (Cumulative)

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.

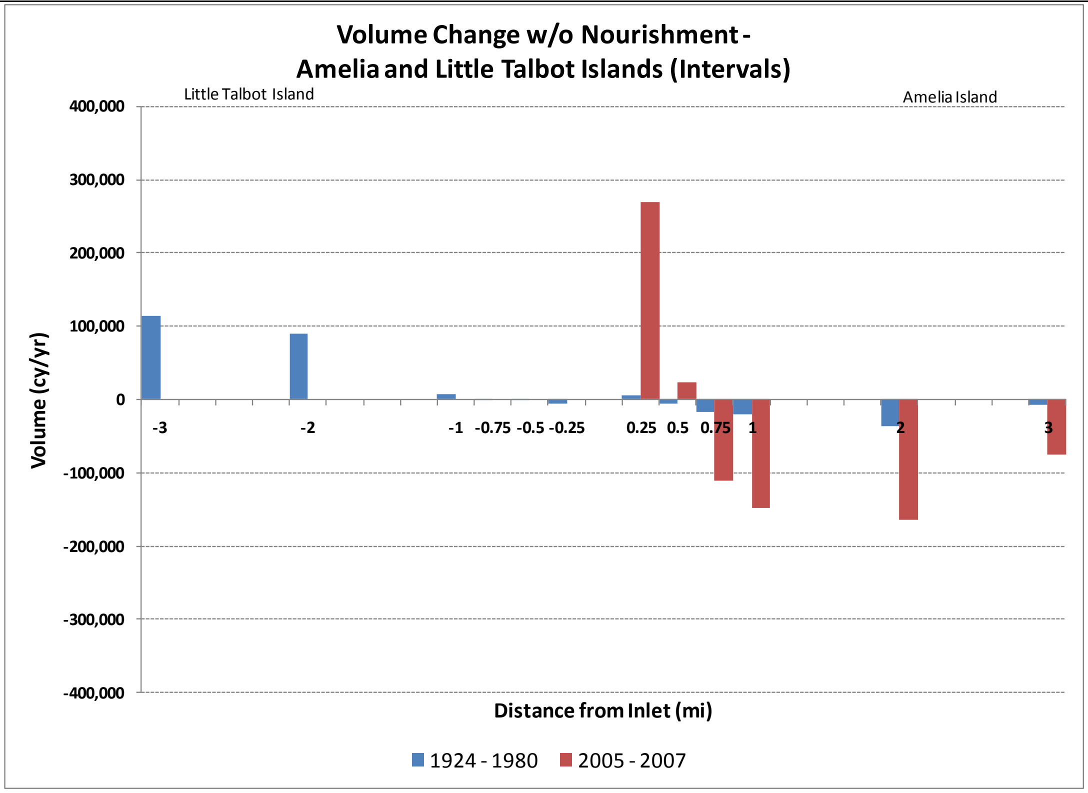


Figure II-51. Volume Changes w/o Nourishment – Amelia and Little Talbot Islands (Intervals)

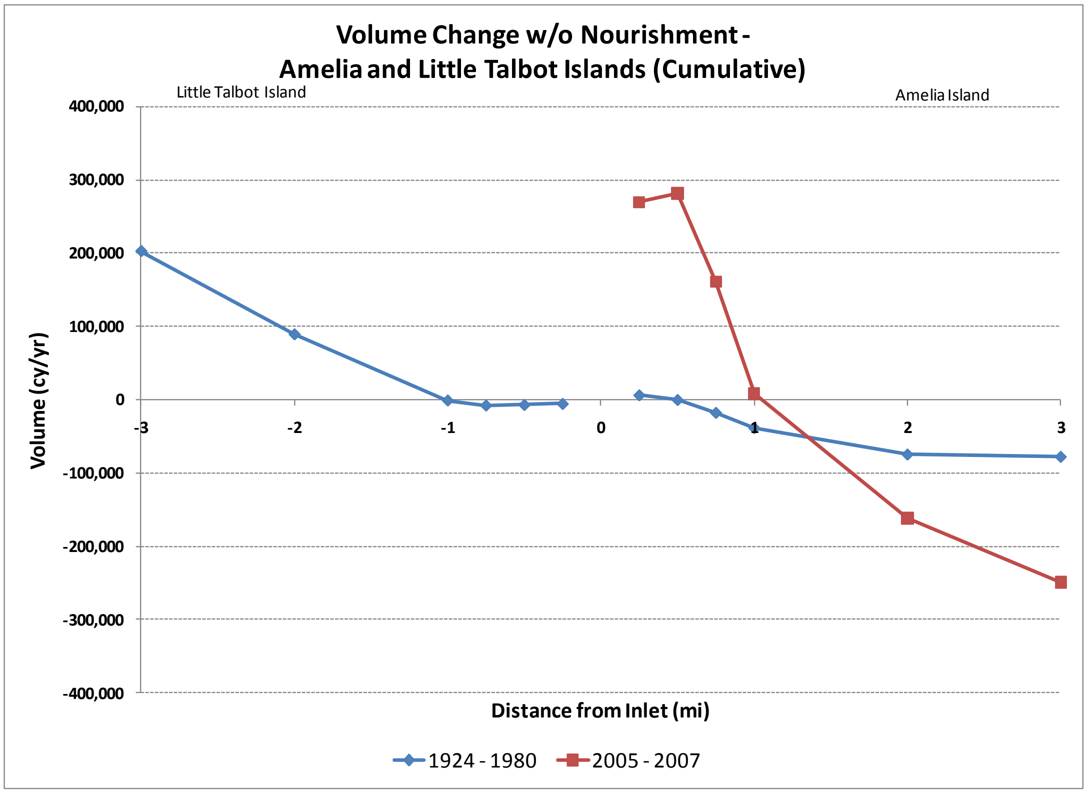


Figure II-52. Volume Changes w/o Nourishment – Amelia and Little Talbot Islands (Cumulative)

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.

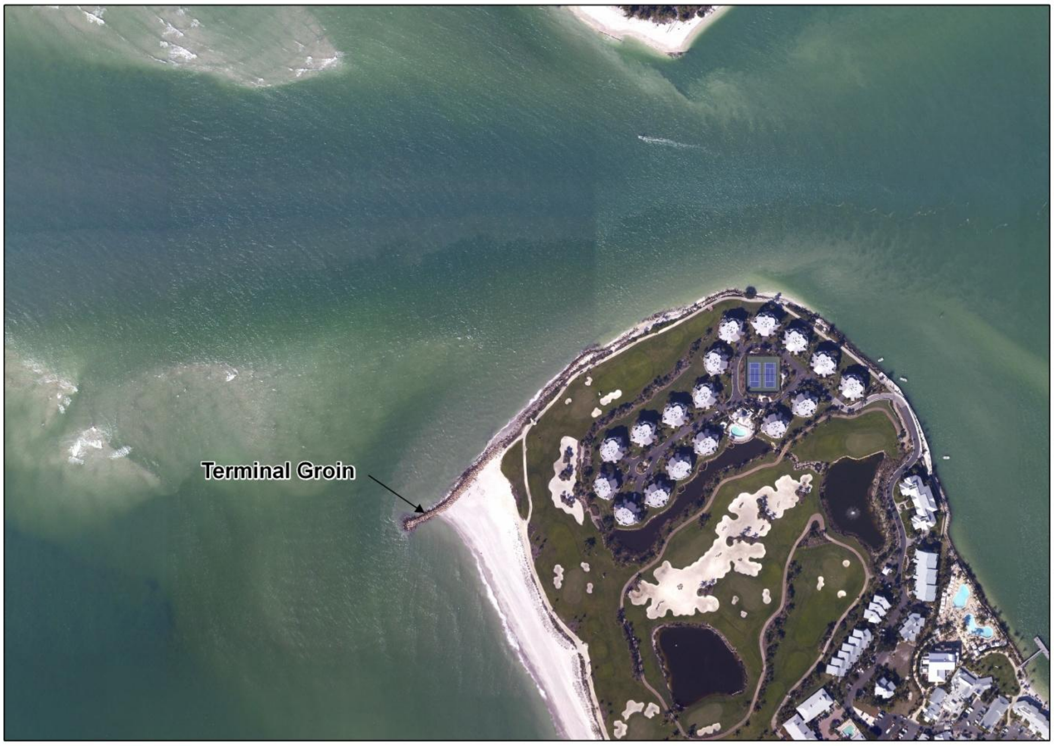


Figure II-53. Captiva Island Terminal Groin

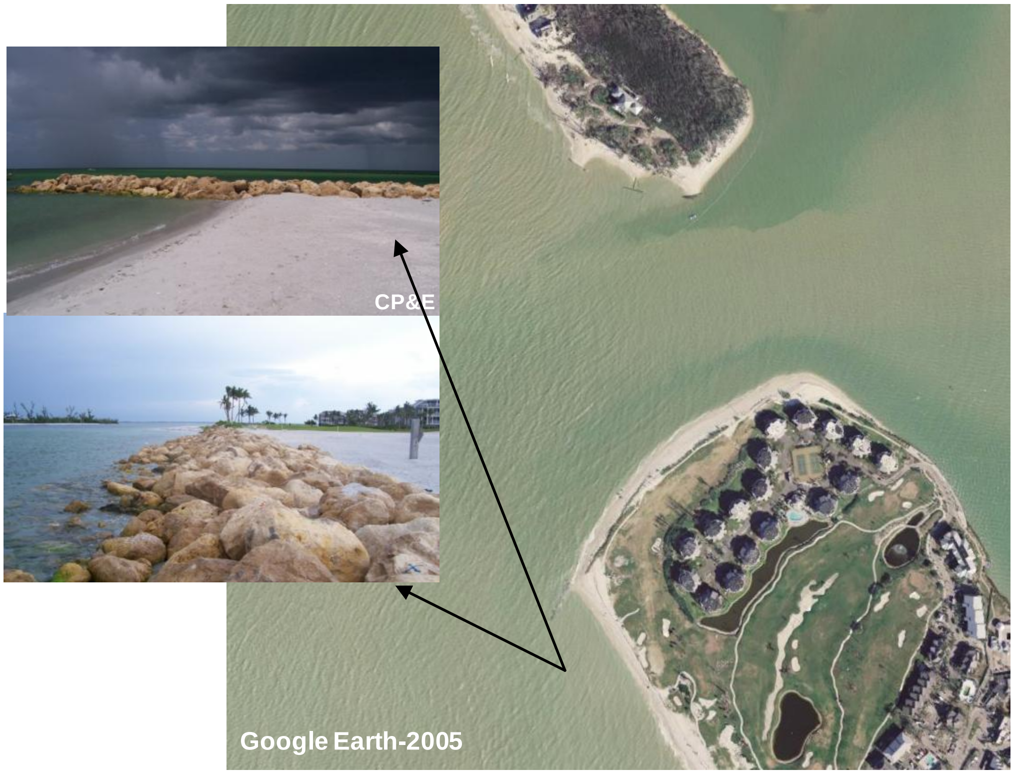


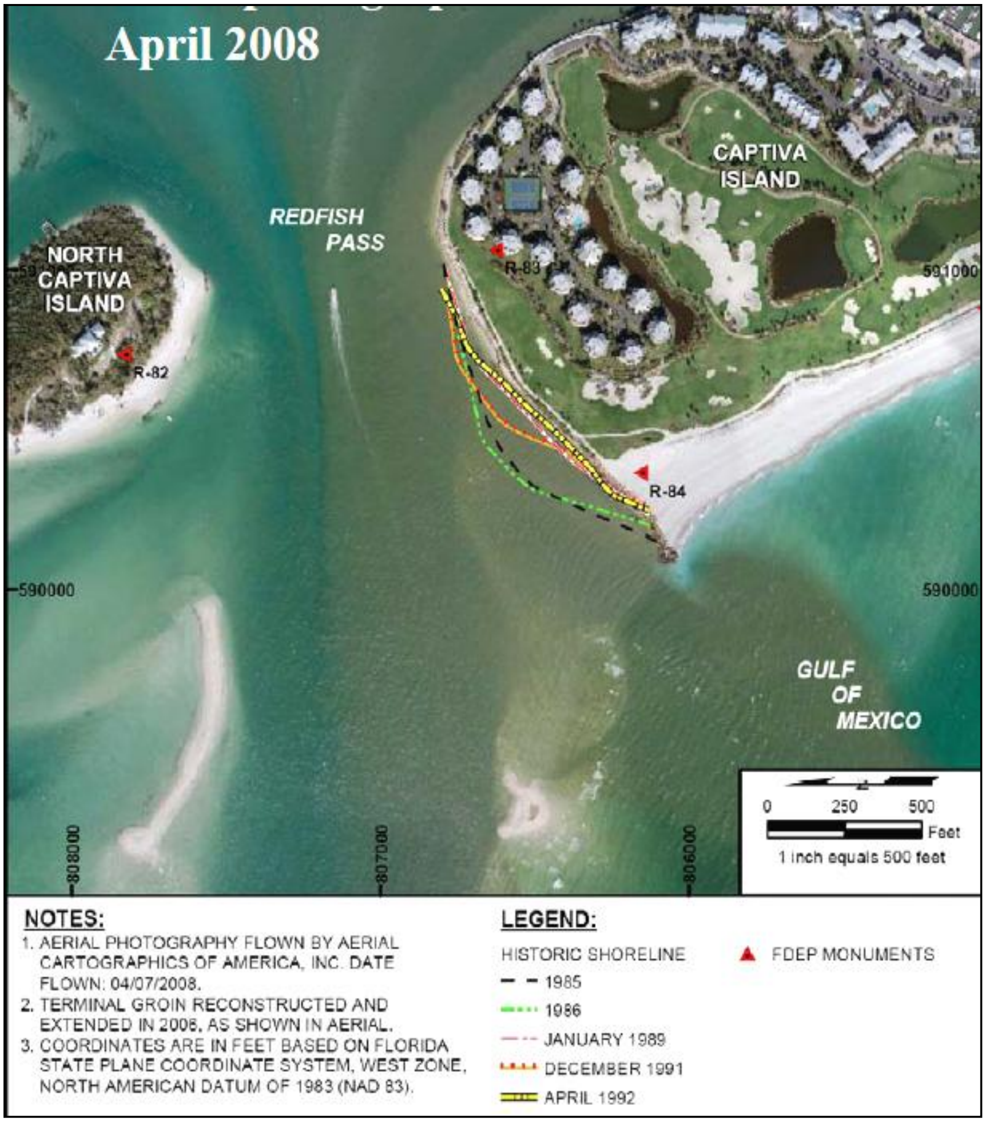
Figure II-54. Terminal Groin Rehabilitation

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).



NOTES:

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

LEGEND:

HISTORIC SHORELINE
1985
1986
JANUARY 1989
DECEMBER 1991
APRIL 1992

▲ FDEP MONUMENTS

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

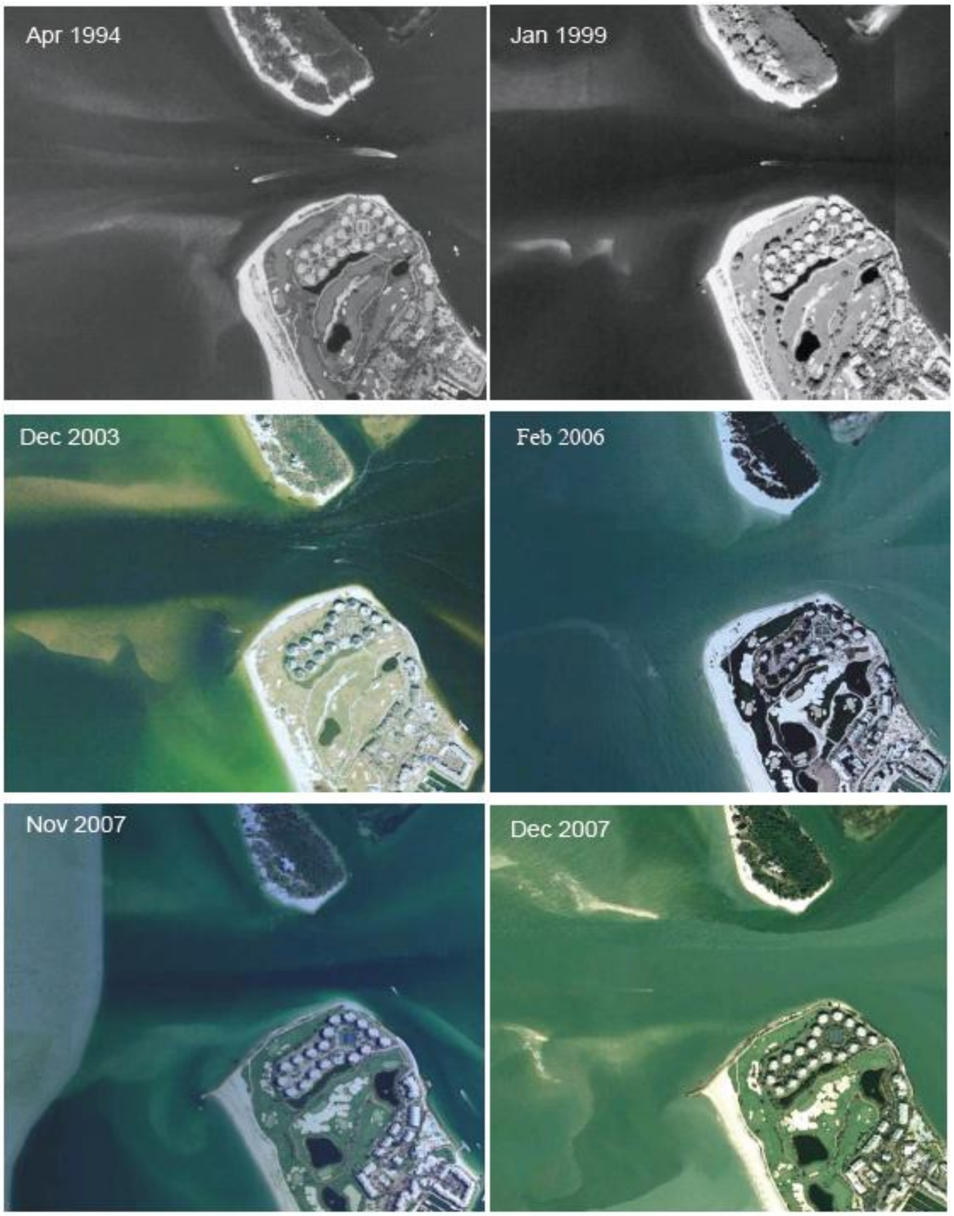


Figure II-58. Sequential Vertical Aerial Photographs of Captiva Inlet between 1994 and 2007 (from Google Earth)

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.

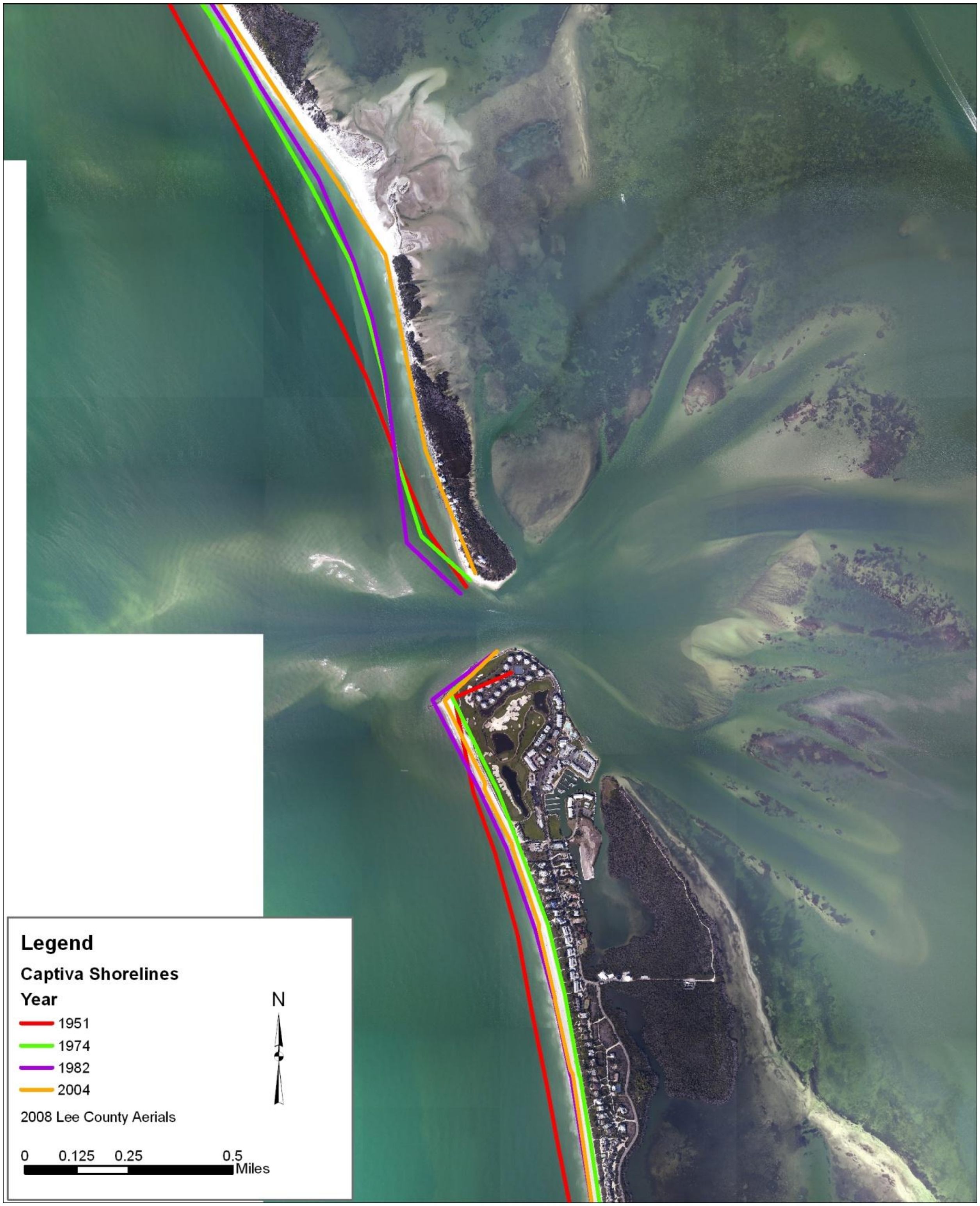


Figure II-60. Historic Shorelines – Captiva Island

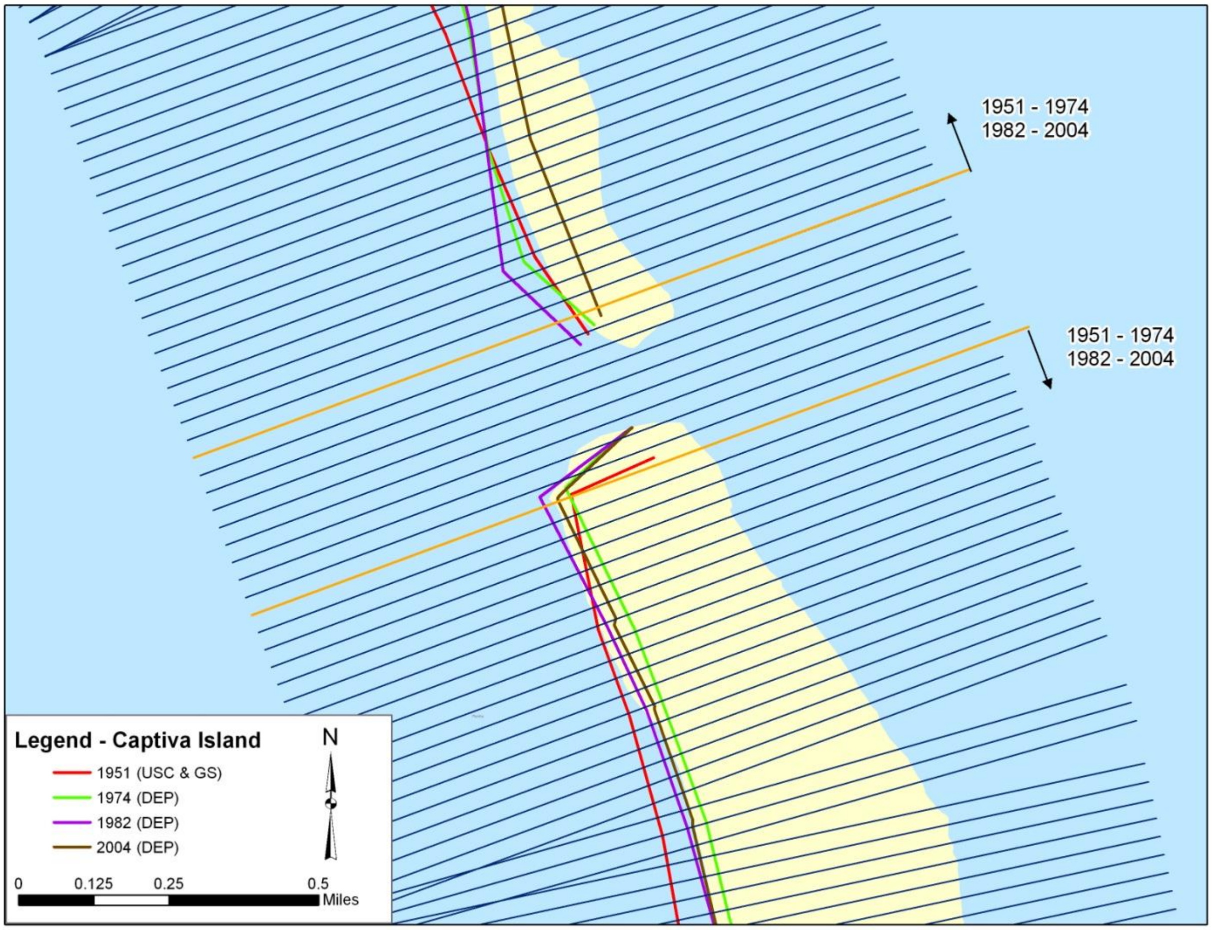


Figure II-61. Captiva Island Shoreline Change Calculation Transects

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)

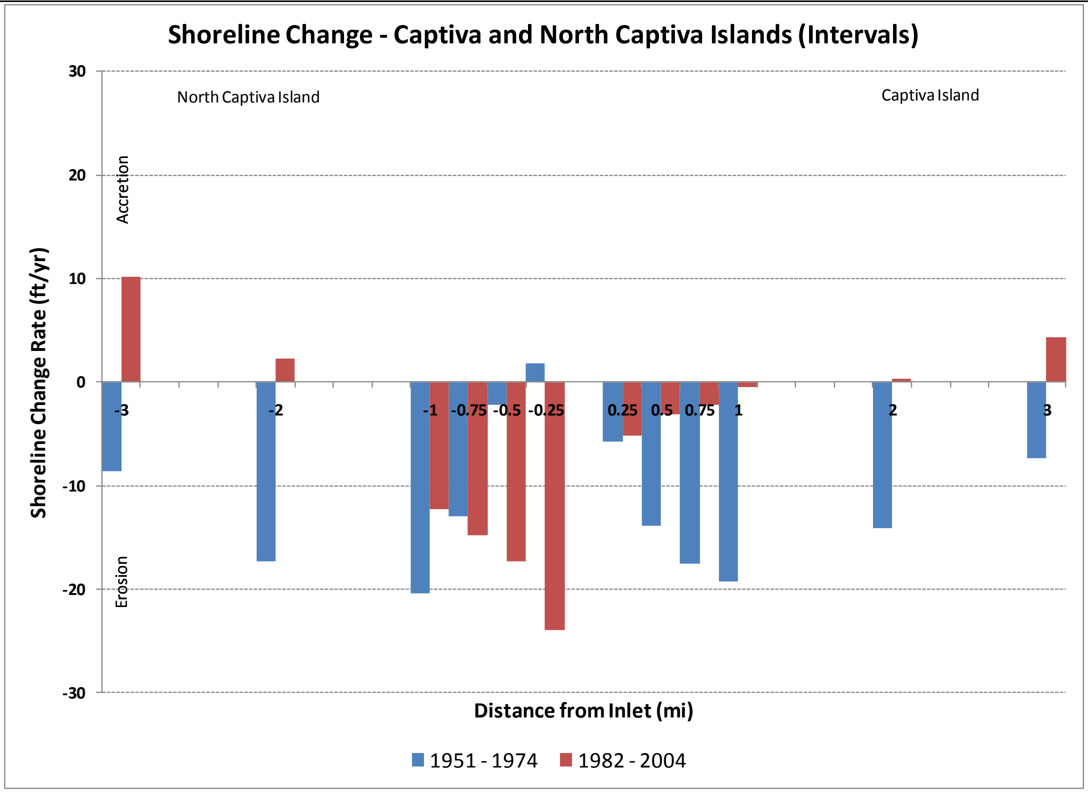


Figure II-62. Shoreline Change – Captiva and North Captiva Islands (Interval)

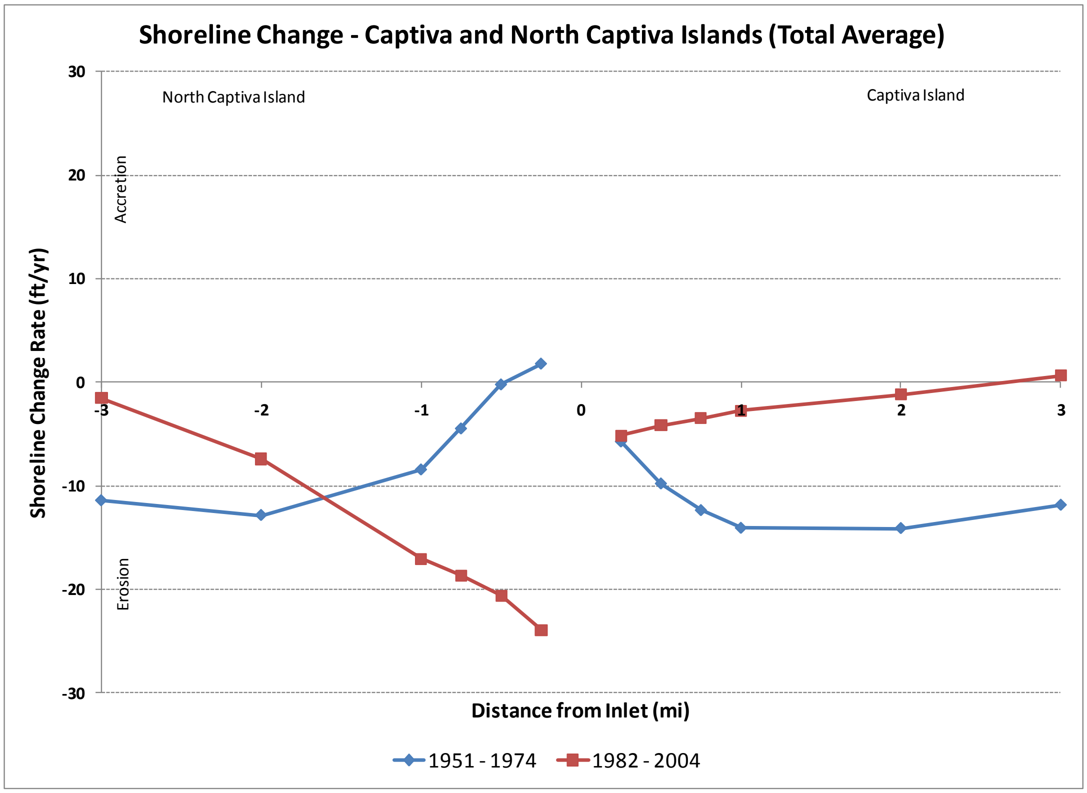


Figure II-63. Shoreline Change – Captiva and North Captiva Islands (Total Average)

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.

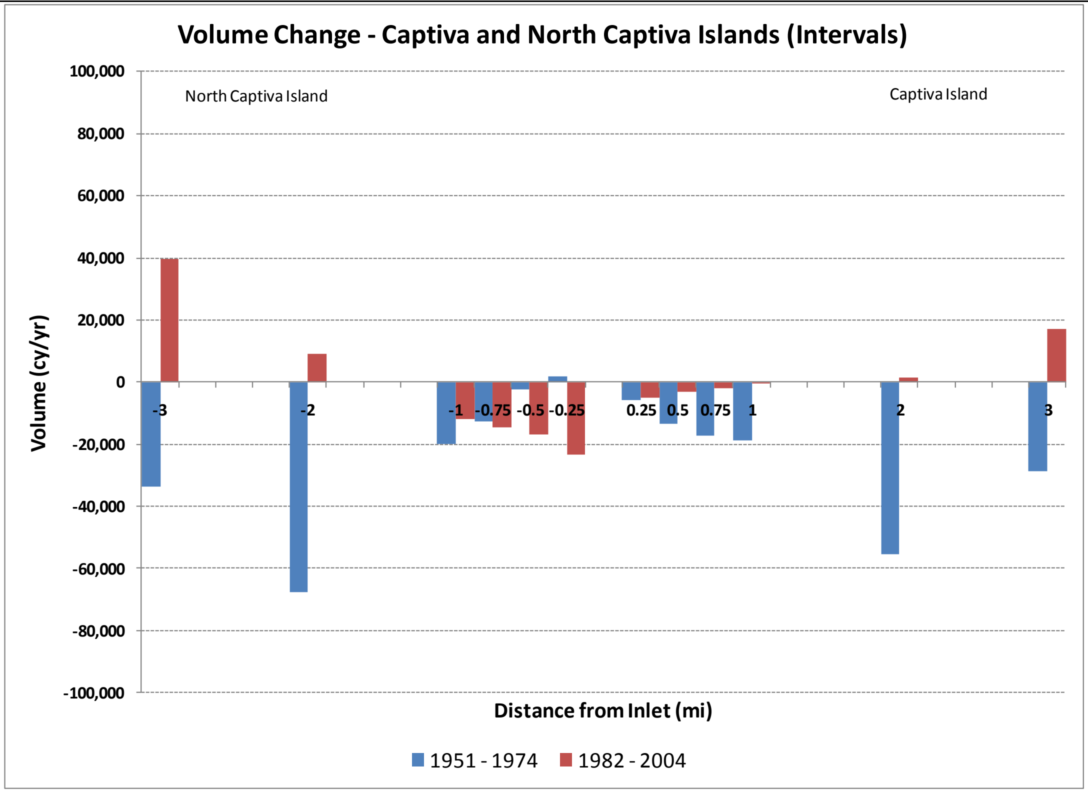


Figure II-64. Beach Volume Change – Captiva and North Captiva Islands (Intervals)

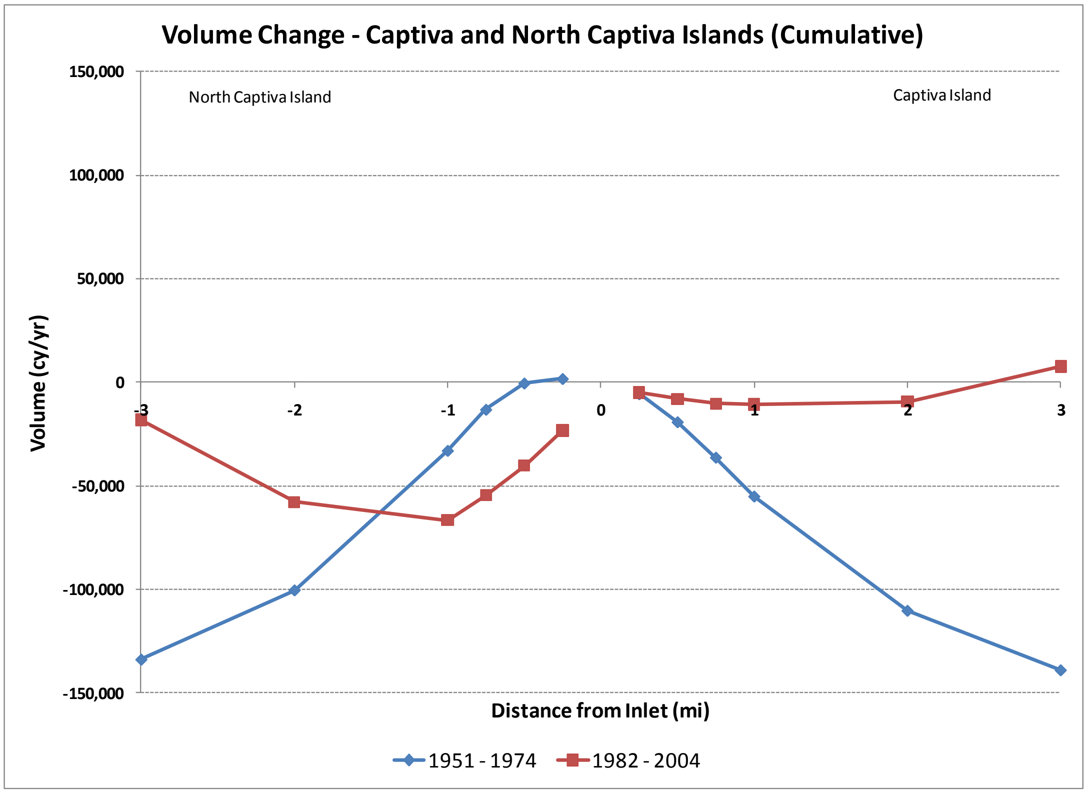


Figure II-65. Beach Volume Change – Captiva and North Captiva Islands (Cumulative)

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 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 +	
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 (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: 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.

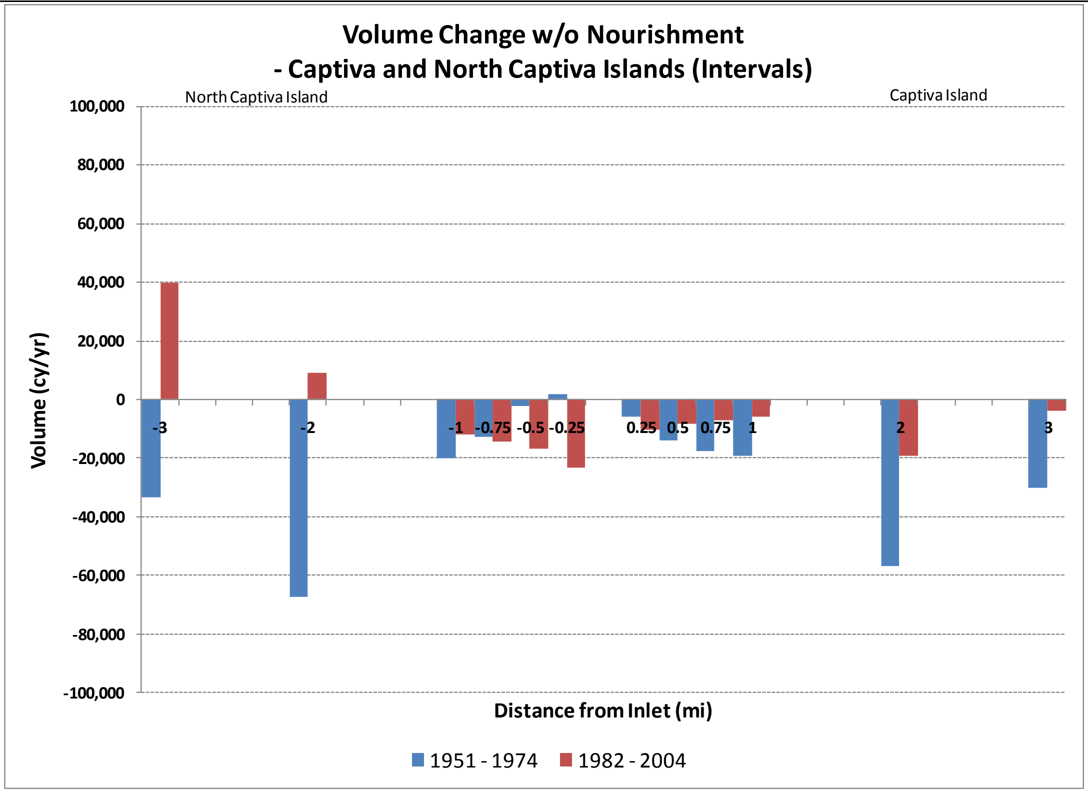


Figure II-66. Volume Changes w/o Nourishment – Captiva and North Captiva Islands (Intervals)

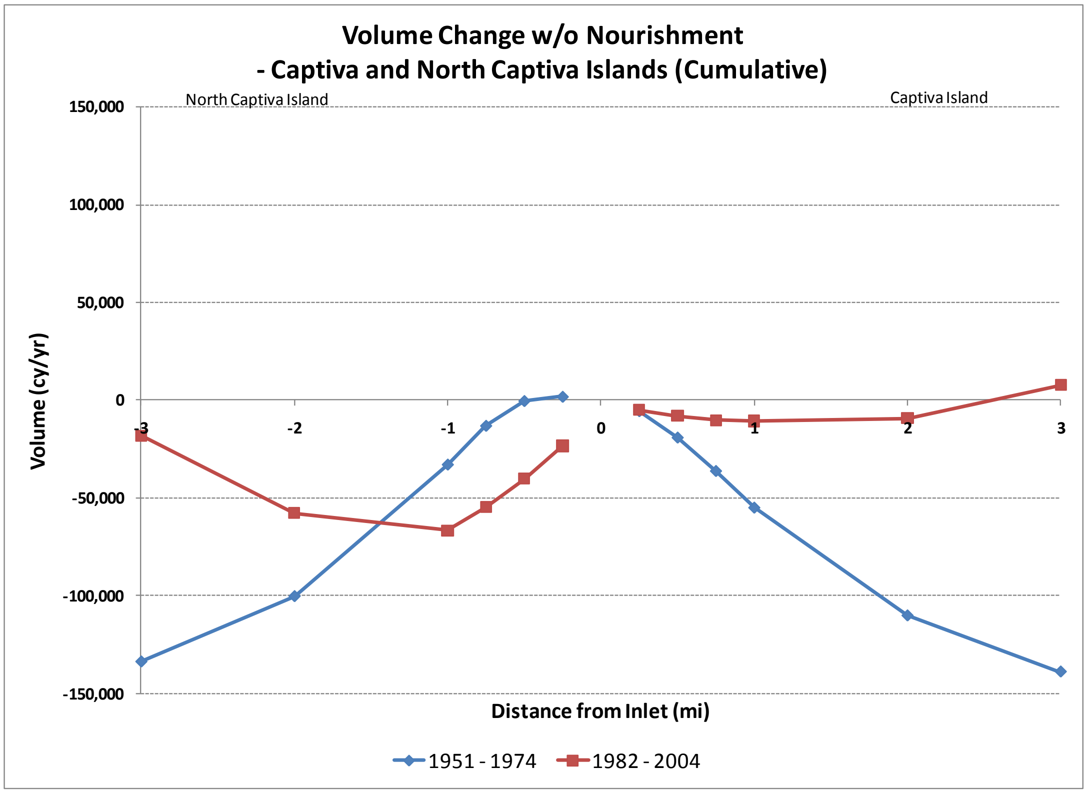


Figure II-67. Volume Changes w/o Nourishment– Captiva and North Captiva Islands (Cumulative)

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).

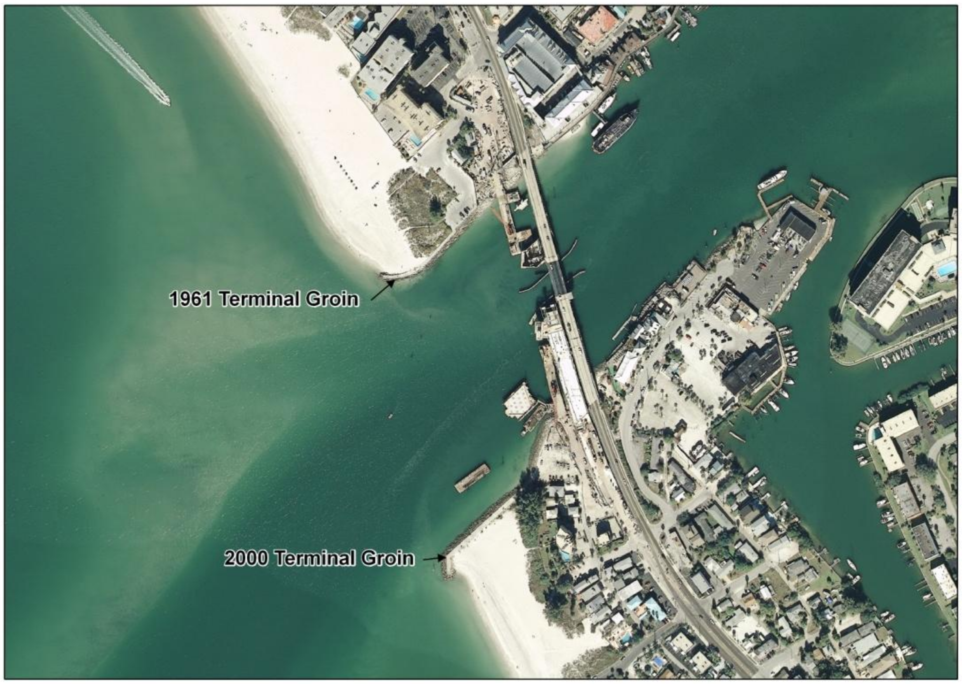


Figure II-68. John's Pass Terminal Groins

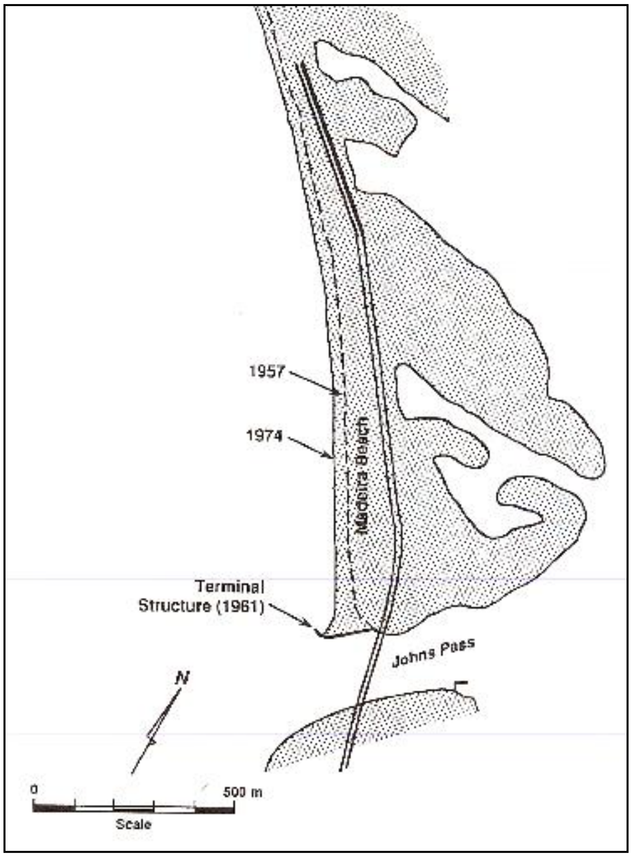


Figure II-69. Shoreline Changes Along Madeira Beach between 1957 and 1974
Note that the terminal groin at the north side of John's Pass was built in 1961

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.

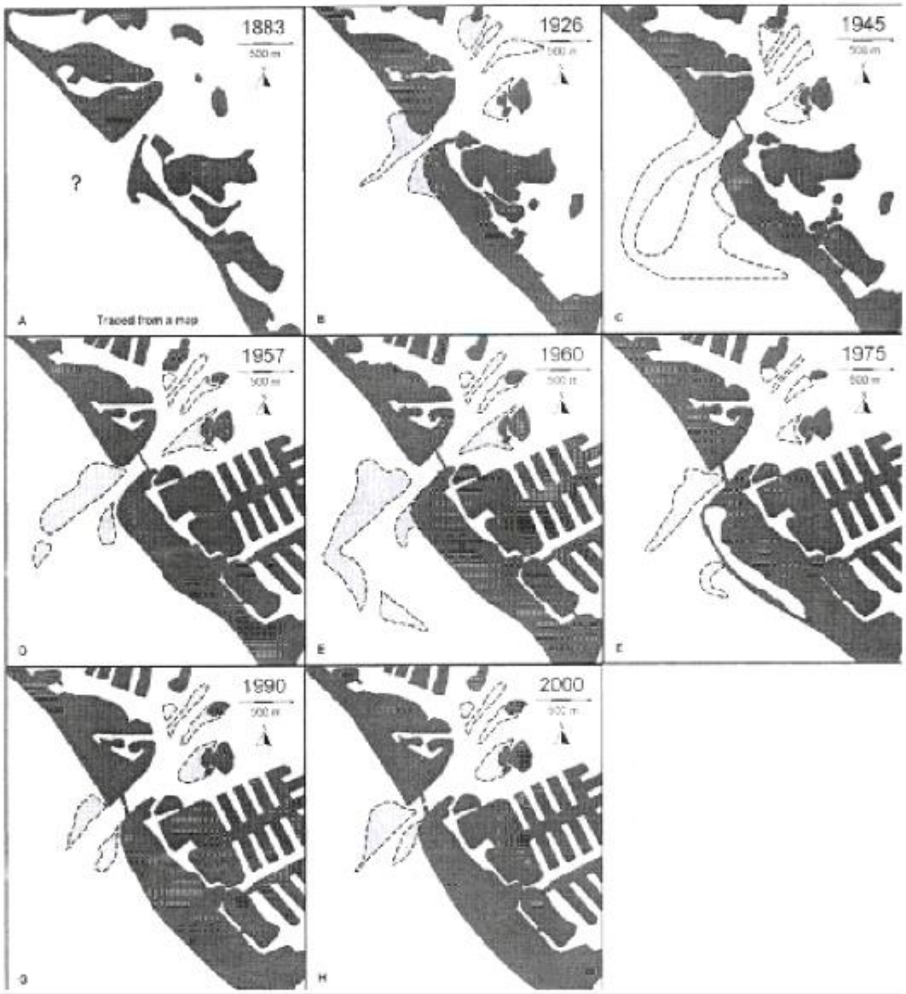


Figure II-70. Historical Morphological Changes of John's Pass from 1883 to 2000 (Davis & Vinther, 2002)
Note gradual decrease in size to the ebb-tidal delta.

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.

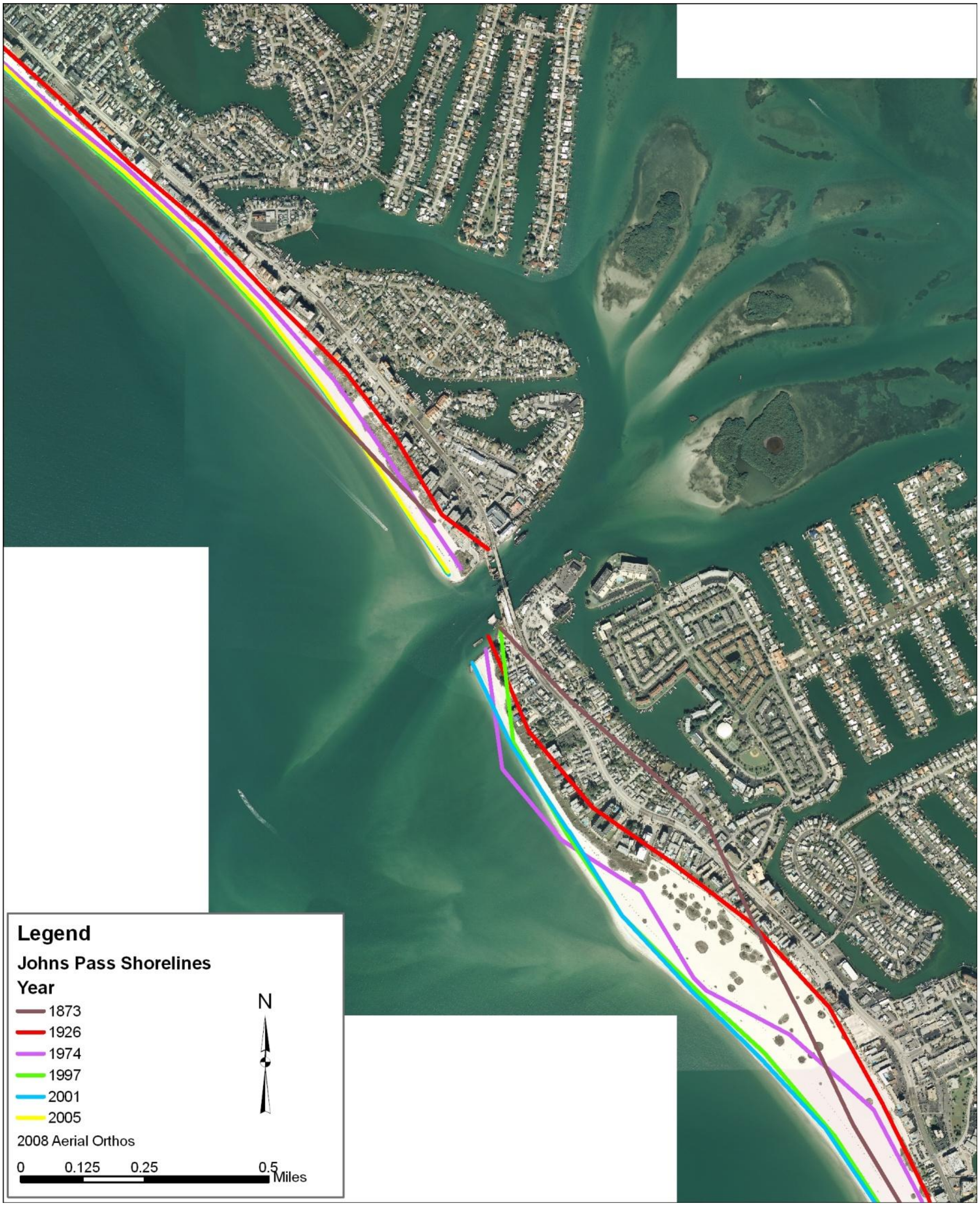


Figure II-74. Historic Shorelines – John's Pass

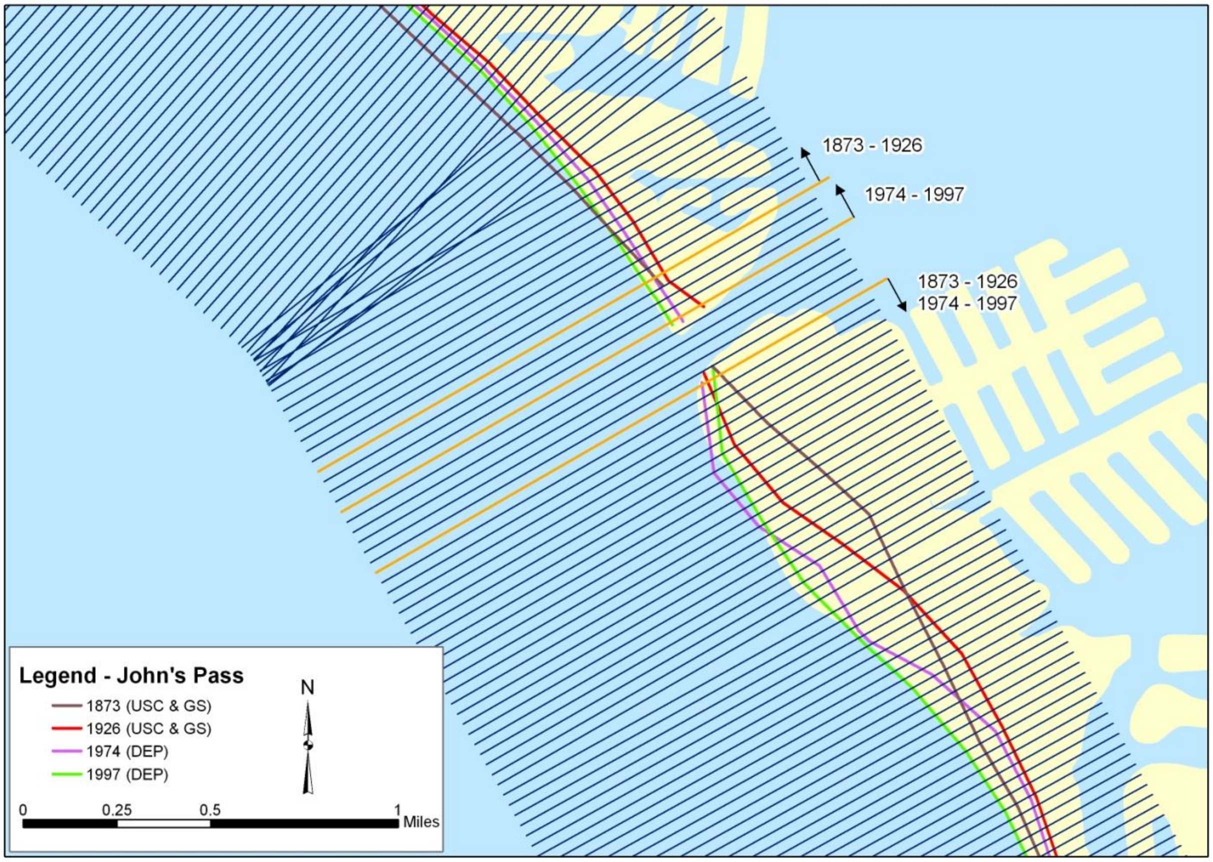


Figure II-75. John's Pass Shoreline Change Calculation Transects

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)

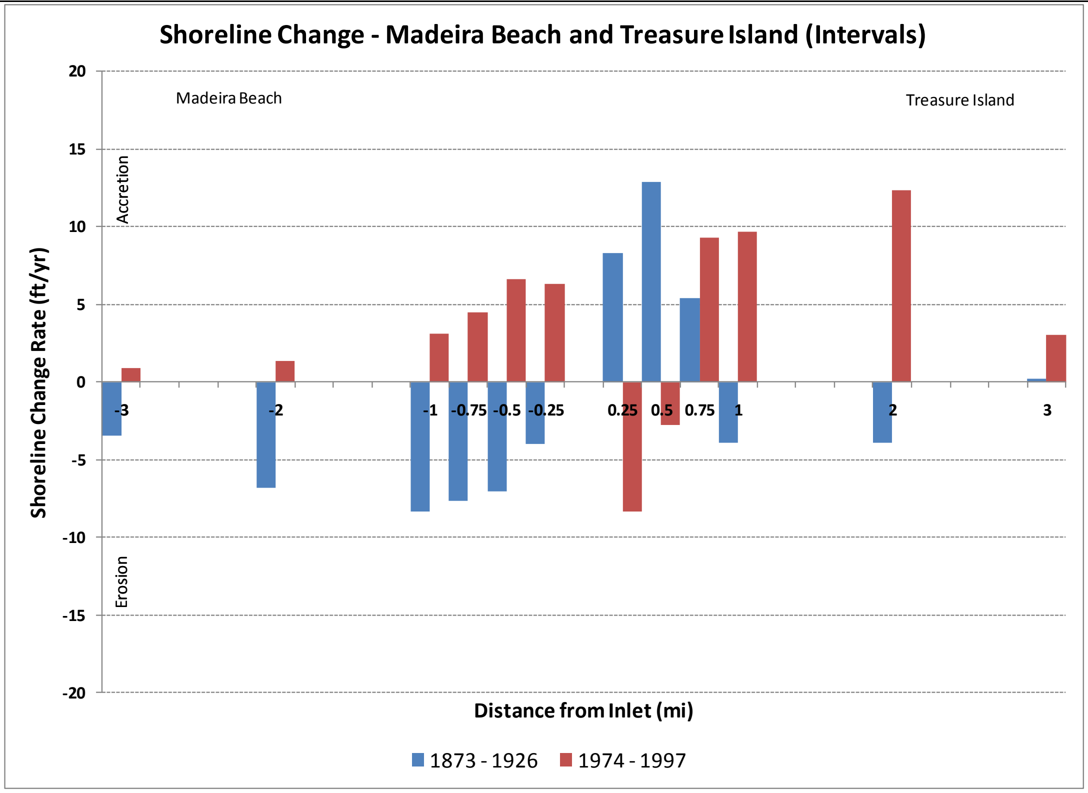


Figure II-76. Shoreline Change – Madeira Beach and Treasure Island (Intervals)

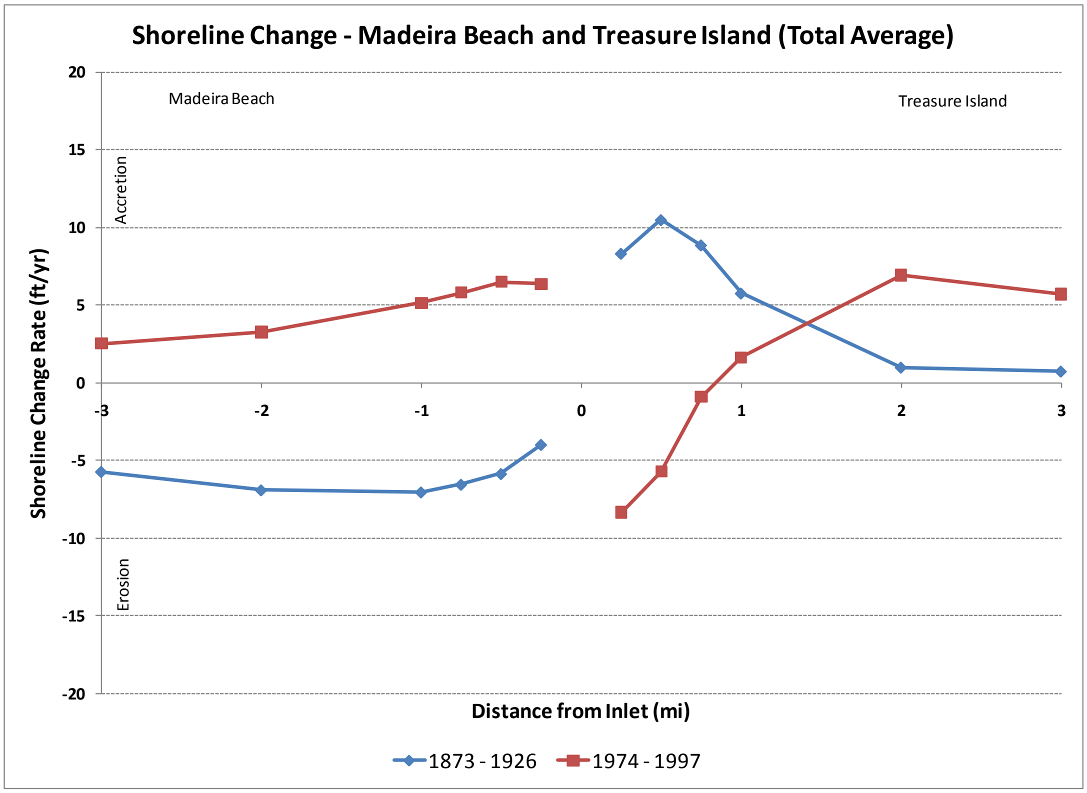


Figure II-77. Shoreline Change – Madeira Beach and Treasure Island (Total Average)

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.

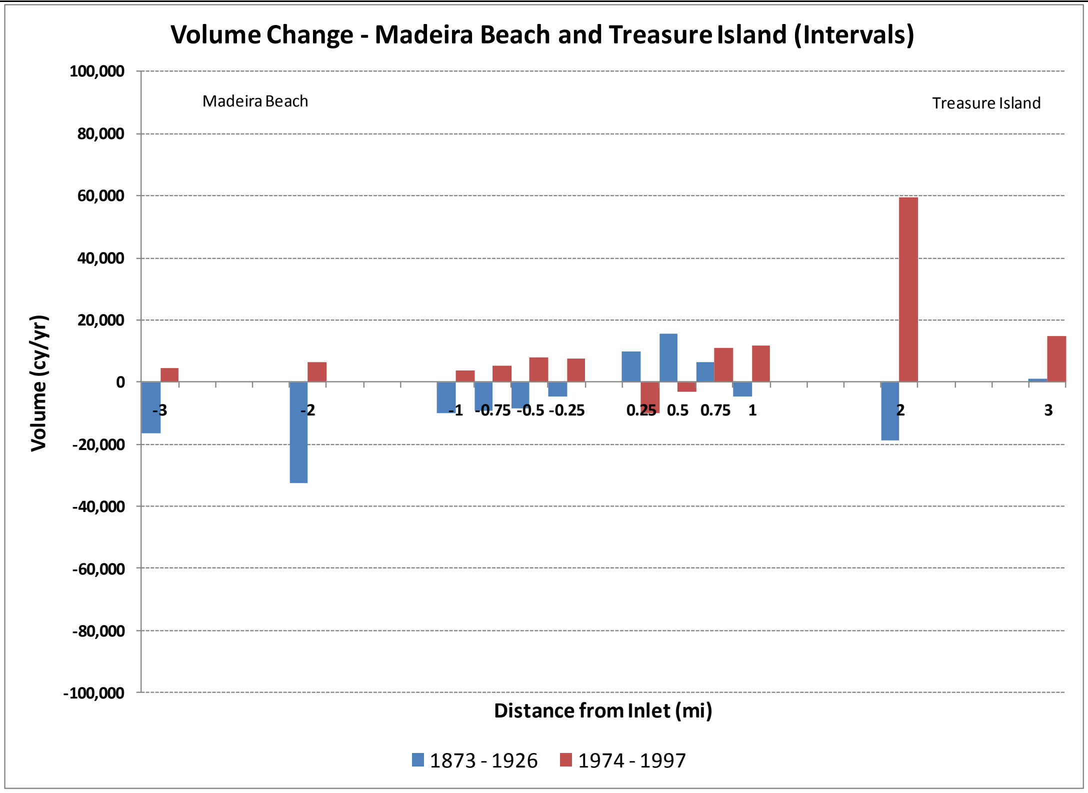


Figure II-78. Beach Volume Changes – Madeira Beach and Treasure Island (Intervals)

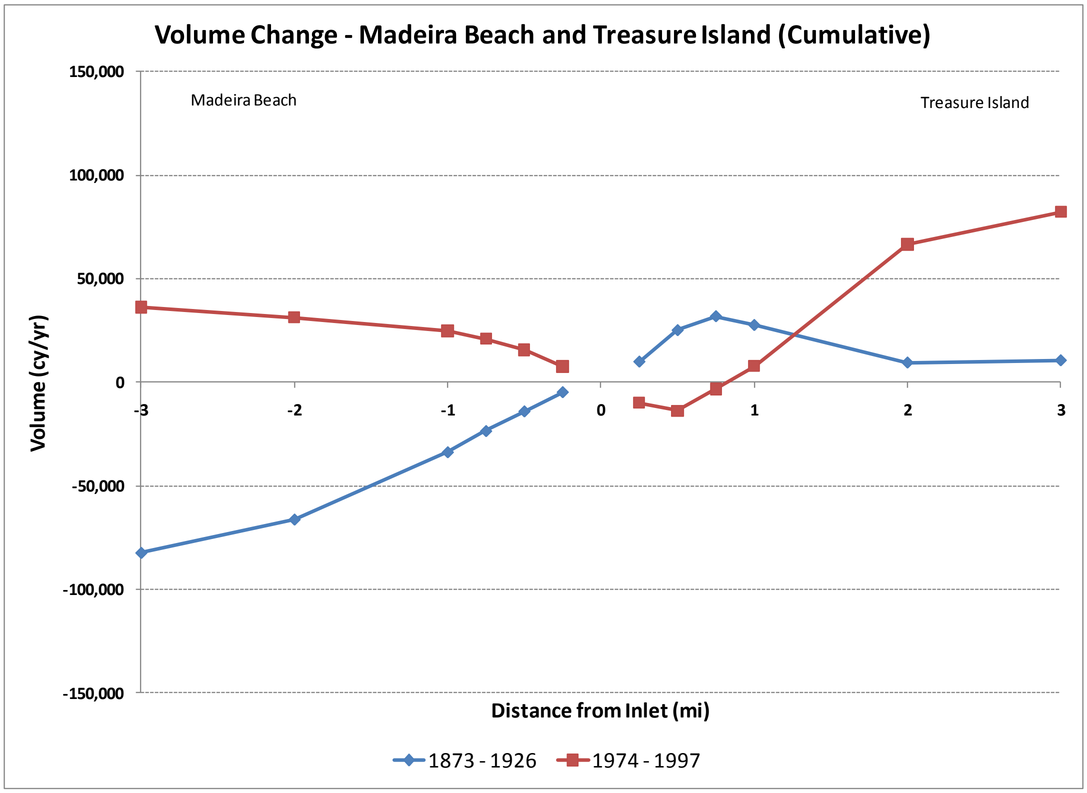


Figure II-79. Beach Volume Change – Madeira Beach and Treasure Island (Cumulative)

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.

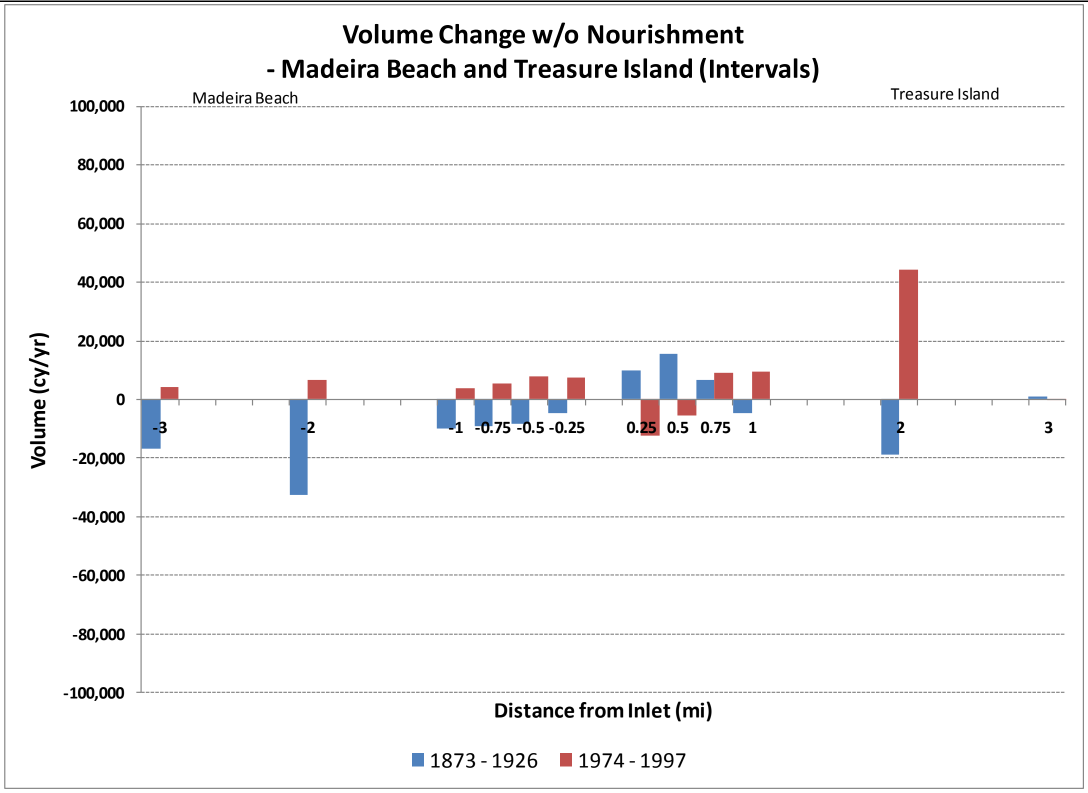


Figure II-80. Volume Changes Without Nourishment – Madeira Beach (Intervals)

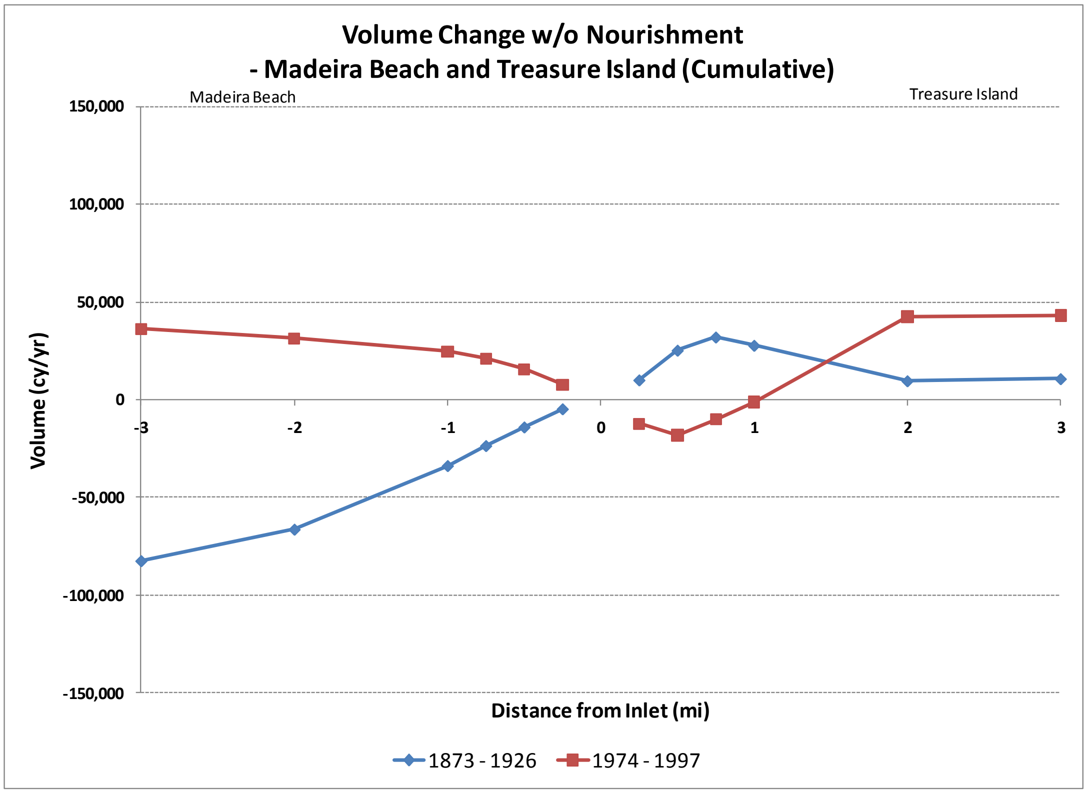


Figure II-81. Volume Changes Without Nourishment – Treasure Island (Cumulative)

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).

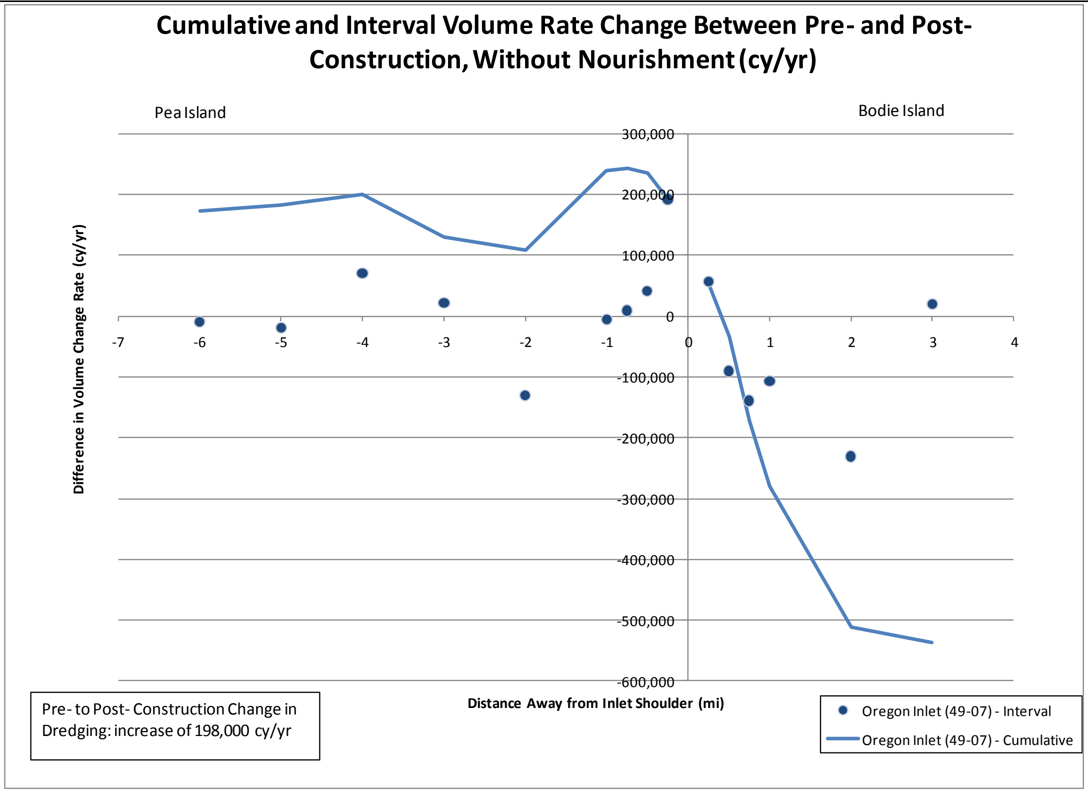


Figure II-82. Volume Rate Changes Without Nourishment – Oregon Inlet

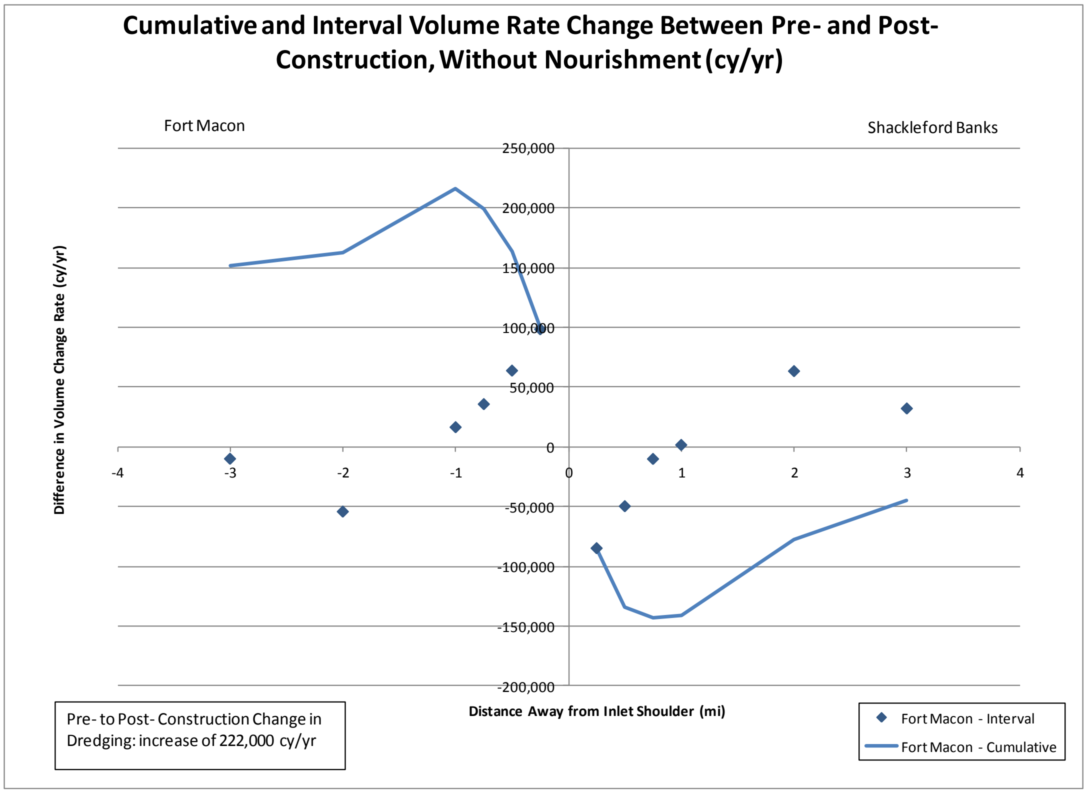


Figure II-83. Volume Rate Changes Without Nourishment – Fort Macon

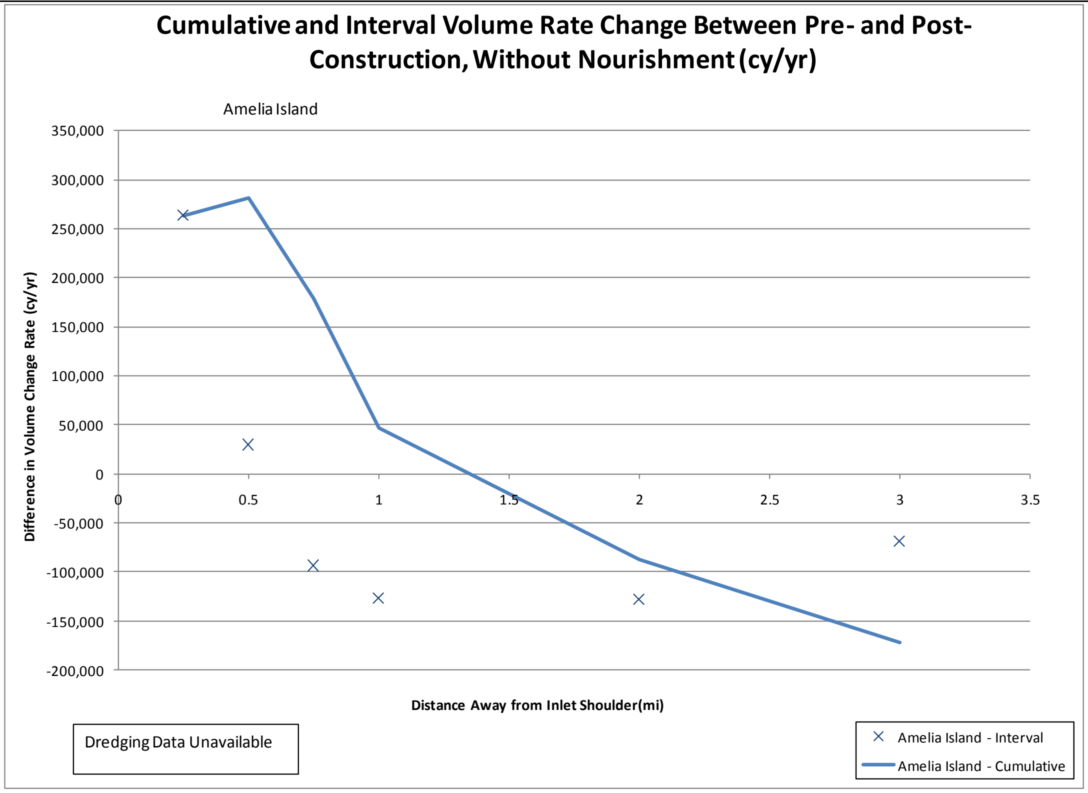


Figure II-84. Volume Rate Changes Without Nourishment – Amelia Island

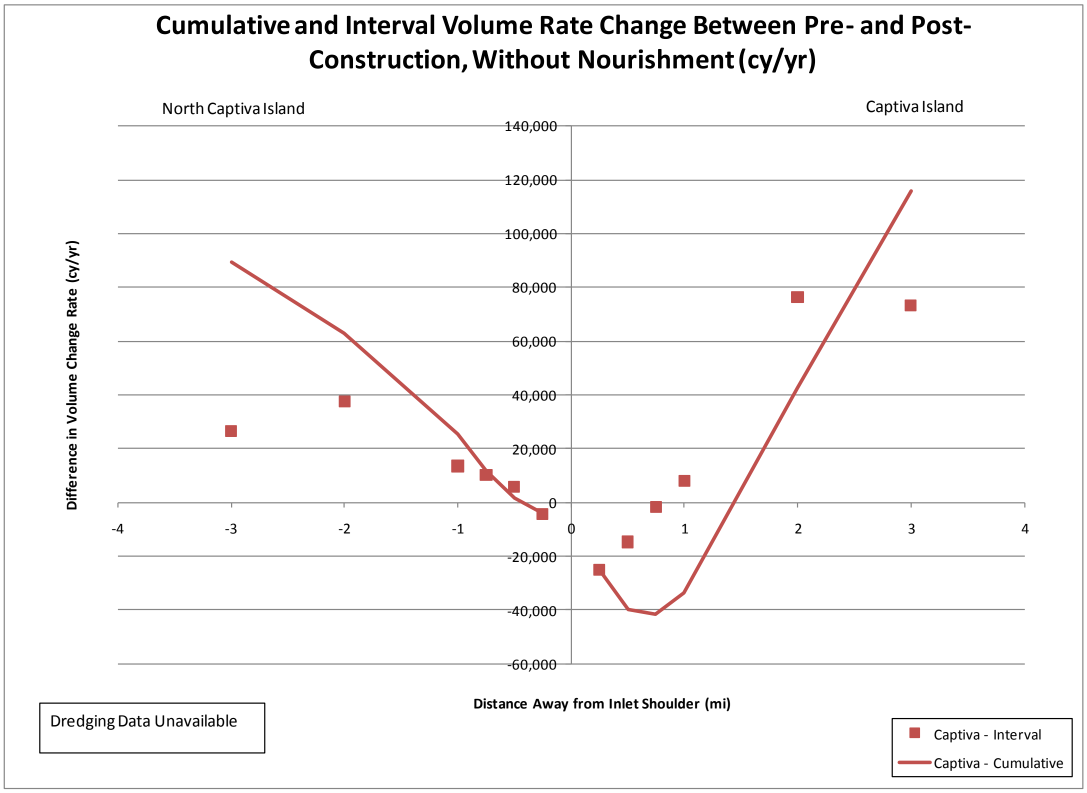


Figure II-85. Volume Rate Changes Without Nourishment – Captiva Island

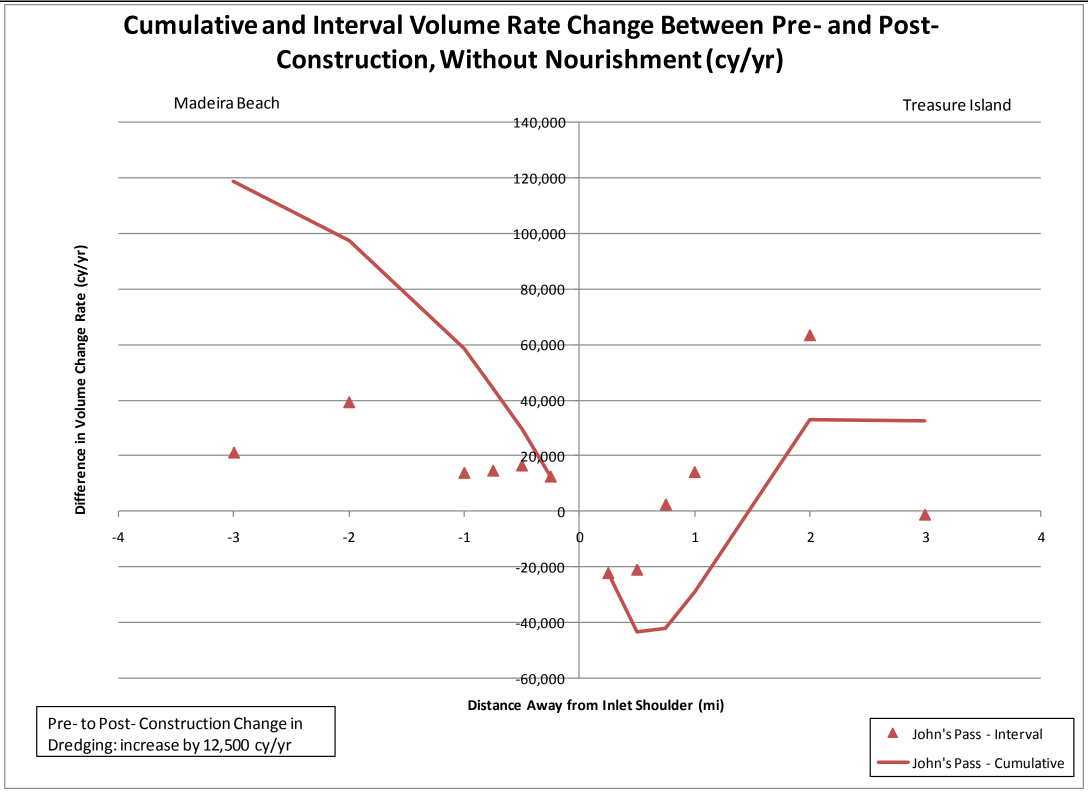


Figure II-86. Volume Changes Without Nourishment – John's Pass

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.