VIII. Summary of Findings

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

Selection of Study Sites

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

Physical Assessment

General

- Although terminal groins trap sand, they are dissimilar to a jetty, because once the terminal groin fills with sediment, additional sand bypasses the structure and enters the nearshore and / or the tidal inlet.
- Terminal groins are commonly built on either (or both) sides of inlets because in addition to the regional dominant longshore sediment transport system delivering sand preferentially to one side of an inlet, wave refraction around the ebb delta results in sand transport back toward the inlet along the downdrift shoreline.
- A consequence when the structure is built on the downdrift side of the inlet is the stabilization of the inlet by preventing migration of the inlet channel. The groin inhibits erosion of the side of the channel by tidal currents and thus the inlet is not allowed to migrate.

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

Oregon Inlet

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

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

Fort Macon

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

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

Amelia Island

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

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

Captiva Island

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

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

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

John's Pass

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

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

Summary

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

- After subtracting out all beach nourishment activities (but not accounting for dredging), the changes between pre- and post-construction periods show on the side opposite the terminal groin (note that no data was available for the Amelia Island study site):
    - Typically a minor to moderate negative result occurs over the first half to three-quarters of a mile. Whether this is the effect of terminal groin construction or other impacts such as increased dredging or migrating inlets, though, is not possible to definitively conclude.
    - For Captiva Island, John's Pass and Shackelford Banks the results turn positive after this initial distance with net cumulative positive results over the shoreline analyzed for Captiva Island and John's Pass and a negative result for Shackleford Banks.
    - At Oregon Inlet, the negative result continues for the second mile with minimal change over the third mile.
- Much like nourishment, the influence of dredging material from the inlet system must be accounted for when attempting to assess the impact of the terminal groins. These results show:
    - One must assume about 25% of the material dredged from the inlet would have naturally reached Shackleford Banks for the negative pre- to post-construction change over the three-mile shoreline analysis interval to turn positive.

Environmental Assessment

General

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

Oregon Inlet

- Oregon Inlet dredging, the Bonner Bridge, NC Highway 12 maintenance and protection, and the presence of the terminal groin have influenced the loss of oceanfront and inlet habitat by subduing and altering natural processes such as overwash and inlet migration.
- The pre-construction historical non-breeding shorebird data suggests the immediate groin location was not highly used due to lack of appropriate habitat.
- Following construction of the terminal groin, a large sandflat developed behind the groin where shorebirds and colonial waterbirds nested (and still nest to some extent). Some of this area is still kept in good bare sand condition by overwash during large storms; but much of the area is retaining heavy vegetation.
- Oregon Inlet serves primarily as a wintering area for the migrating/wintering (non-breeding) piping plover. Areas on either side of Oregon Inlet have been designated as critical habitat for wintering piping plovers. Successful nesting has been documented on Pea Island in the area just south of the terminal groin.
- Fluctuations in annual observations of piping plovers at Pea Island, Oregon Inlet Shoals, and Bodie Island followed a similar pattern from 2000 through 2008. This common pattern is characterized by sharp increases in the number of annual observations from 2000 through 2003, followed by sharp declines from 2004 through 2008.
- The terminal groin, as well as dredging and nourishment, has adversely modified habitat important to early successional species, such as piping plovers, by

eliminating intertidal flats and allowing encroachment of vegetation in stabilized areas, and generally impeding inlet dynamics that create and maintain habitats piping plovers require.

- In terms of sea turtles, the PINWR has an average of 10 to 12 nests per year although on average, 3.4 loggerhead nests have been recorded within five miles south of Oregon Inlet annually over the course of the last 19 years. Based on a preliminary evaluation of nesting intervals per section on PINWR compared to Bodie Island, it is apparent that sea turtle nesting habitat is more readily available on PINWR versus Bodie Island. Due to the consistently low annual nesting densities and the high frequencies of both storm and renourishment events, no relationships between nesting densities and storm or renourishment events are readily apparent.
- Invertebrate monitoring results showed mole crab and coquina clam numbers were significantly reduced following placement of Oregon Inlet maintenance dredged material. The underlying effects on the infaunal communities within a terminal groin fillet is directly related to the fill material size, the volume of material placed, and the seasonal material placement.

Fort Macon

- Seabeach amaranth has experienced a great deal of natural population variability from one year to the next. These natural fluctuations can be attributed to a number of factors; such as erosion, storms, and seed dispersal. Since 1991, Fort Macon beaches have been nourished four times. Seabeach amaranth numbers increased following renourishment projects in 2002 and 2007, whereas numbers decreased following renourishment projects in 1993 and 2004. Based on these data, no consistent relationship between seabeach amaranth numbers and renourishment projects is readily apparent
- Since 1973, Fort Macon beaches have been nourished seven times. Sea turtle nesting densities increased following renourishment projects in 1986, 2002, 2004, and 2007; whereas nesting density decreased following renourishment in 1993. These data indicate that renourishment may have a positive effect on sea turtle nesting. Although historical data for sea turtle nesting was obtained, it is difficult to analyze as Fort Macon State Park relocates most of the nests due to the high number of tourists.
- Overall, Beaufort Inlet provided the sixth largest inlet complex in North Carolina in terms of habitat available to migratory shorebirds and waterbirds in 1998 (USFWS 2002). Lack of historic natural resource data hinders drawing conclusions on the effects of the construction and operation of the terminal groin on natural resources.
- Colonial waterbirds and shorebirds depend on ephemeral habitats while stabilization of inlet shoreline usually causes vegetation growth that results in unsuitable habitat and not having historical pre-construction bird surveys makes it

difficult to conclusively say whether suitable habitat existed prior to terminal groin construction or if the terminal groin may have caused the loss of suitable habitat.

- Shorebird habitat on Fort Macon is also subject to the effects of periodic beach renourishment projects. Least tern and Wilson's plover observations at Fort Macon increased following renourishment projects in 2002, 2004, and 2007. These data indicate that renourishment may have a positive effect on habitat utilization by these species.
- Piping plover habitat on Fort Macon is also subject to the effects of periodic beach renourishment projects. Due to the low number of piping plover observations on Fort Macon, no conclusions can be drawn regarding the effects of renourishment on piping plovers. However, considering the higher number of piping plovers observed on Shackelford Banks West, it can be concluded that appropriate habitat for piping plovers does not exist on Fort Macon.
- The native beaches of Bogue Banks often have depressed infaunal populations due to beach scraping and beach fill activities relative to pre-project levels (Peterson et al. 2000a; Peterson and Manning 2001; Reilly and Bellis 1978). The cumulative modifications in Beaufort Inlet results in a temporary reduction and slow recovery of the abundance and diversity of benthic invertebrates (SAFMC 1998).
- Hardened structures can potentially interfere with the passage of larvae and early juveniles from offshore spawning grounds into estuarine nursery areas (Street et al. 2005; Kapolnai et al. 1996; Churchill et al. 1997; Blanton et al. 1999) however; terminal groins continue to allow sand to bypass into the adjacent tidal inlet and therefore are likely bypassing larvae into the estuary.

Amelia Island

- Sea turtle nesting data for Amelia Island dates back to 1986 and on average, 74 nests were recorded annually from 1986 through 2005. The number of nests declined sharply to 46 in 2004, followed by an increase to 70 in 2005. Other than the steady decline between 1999 and 2003, no obvious trends in nesting activity are evident over the course of the monitoring period. Additional data specific to AISP spans the period of 2004 through 2008 and on average 26 nests have been recorded annually over the course of the five-year monitoring period. The number of nests recorded ranged from 2 to 43. Due to inconsistent monitoring protocols and the lack of historical monitoring data for AISP, it is difficult to draw conclusions regarding the effects of the terminal groin and beach nourishment on sea turtle nesting.
- Based on pre- and post-construction data within Nassau Sound, the Bird Islands have not experienced a change in total acreage. Shorebird habitats on Amelia Island are subject to the effects of periodic beach renourishment projects. The total number of shorebirds on Amelia Island increased slightly following beach renourishment in 2006. Based on the limited shorebird data set for Amelia Island (2003 – 2008), it is not possible to draw conclusions regarding the effects of renourishment projects on shorebird populations.
- FDEP data do not include any records of piping plovers on Amelia Island. Due to inconsistent monitoring protocols and the lack of historical monitoring data for AISP, it is difficult to draw conclusions regarding the effects of the terminal groin on shorebird or piping plover use.
- The lack of scientific monitoring data resulted in non-discernable trends in potential effects on benthic and fisheries resources from the terminal groin and associated fillet.

Captiva Island

- An eroded inlet shoreline was improved by the construction of the terminal groin and associated fill. Due to the absence of hardbottom habitat within the project area, the terminal groin is not considered an immediate concern of local resource agencies.
- Sea turtle nesting data for Captiva Island, an approximate 5 mile shoreline from Redfish Pass to Blind Pass, dates back to 1986. On average, 94 nests were recorded annually from 1986 through 2009. However, the 2008 nesting period resulted in a sharp increase to 137 nests and then decrease to 80 nests in 2009.
- In 2009, a USACE sponsored bird survey for Lee County was conducted (Lott et al. 2009). Results indicate that Captiva Island has an elevated area on the inlet beach that larids and shorebirds use for roosting. Species diversity was low as only nine species were observed over three visits: the great egret, snowy egret, black-bellied plover, willet, ruddy turnstone, sanderling, laughing gull, royal tern, and sandwich tern. All observations were either on intertidal or shallow-water

substrates, and no wrack line was present. The disturbances were low at this site relative to other surveyed areas. During the three surveys; no vehicles, no dogs, and no parked boats were observed. Based on irregular surveys, Captiva Island has less shorebird diversity and abundance as compared to the adjacent Sanibel Island.

- There was a proposed critical overwintering habitat for piping plovers covering Captiva Island and Sanibel Island; however, due to the lack of use by piping plover in this specific area, this unit has been deleted from the finalized Federal Register (USFWS 2001b).
- Because there were no live bottoms within the groin construction footprint, FDEP required no post-construction biological resource monitoring. The lack of raw data resulted in non-discernable trends in potential effects on benthic and fisheries resources from the terminal groin and associated fillet.

John's Pass

- The sea turtle survey boundaries of the Mid Pinellas County beaches include Redington Shores to Blind Pass, an approximate 7 mile stretch of oceanfront shoreline. On average, 50 nests have been recorded annually for this region of Pinellas County beaches. The number of nests recorded from 1988 through 1994 was relatively low, with an annual average of 37 nests. The number of nests recorded from 1995 through 2005 was significantly higher, with an average of 58 nests.
- Shorebirds that are known to nest on Pinellas County Beaches include American oystercatcher, black skimmer, laughing gull, Caspian tern, least tern, royal tern, sandwich tern, snowy plover, Wilson's plover, and willet (Hodgson et al. 2009; FFWCC Shorebird/Seabird Monitoring Website http://myfwc.com/ shorebirds/). The area evaluated in proximity to John's Pass consists of suitable habitat for wintering piping plover; however, no piping plover critical habitat is designated within the project area. In addition, this region experiences greater human activity during the winter season. Therefore, the likelihood of piping plover utilizing the beach habitat in the project area is low. The lack of raw data resulted in non-discernable trends in potential effects on birds, benthic resources, and fisheries from the terminal groins and associated fillets.

Summary

- Based upon the historical nature of the terminal groins at Fort Macon, John's Pass (northern groin), and Redfish Pass; discernible trends of the effects of these terminal groins on the natural resources is somewhat limited. Lacking pre-construction data makes an empirical determination of post-construction effects at these sites difficult if not impossible.
- While the use of control and/or regional sites strengthens the ability of a study to infer an impact from a detected change, one cannot infer an impact if there is no statistical evidence for a change (Mapstone 1995); and due to the lack of complete datasets and high levels of confidence in the quality of the data, statistical analysis was precluded.
- The current development and use of some of the selected sites precludes unrestricted utilization by the site's natural resources. Sea turtles, avian species, and marine species, however, continue to make use of these managed sites, albeit sometimes on a limited basis.
- The terminal groins at Oregon Inlet and Amelia Island are more recent construction projects, and pre- and post-construction natural resource data readily available were evaluated (sea turtle and shorebird nesting data). The more recent data collected since construction, indicates an increase in public interest/participation, and funding for monitoring of these resources.
- Although shorebirds and sea turtles utilize both locations, neither significant trends nor adverse effects were discernable from the available data. The resources present at both the Amelia Island and Fort Macon terminal groin locations were compared to undisturbed neighboring barrier islands where data indicated resources were more prevalent, as expected.
- Because of the diversity and commercial importance of hardbottom areas, appropriate effort should be employed ensuring avoidance of such habitats while assessing potential groin locations, borrow sources, and/or shoreline and adjacent shoreline sand placement templates.
- Anchoring the end of an island may curtail an inlet's natural migration patterns thereby minimizing the formation of sand flats.
- Fillet material should be compatible to minimize effects on benthic infauna recovery and upper trophic levels.
- Resources continue to use locations where terminal groins exist, however, if habitat succession occurs, species suitability may be affected.

Engineering Construction Techniques

- The five study sites all consist of rubble mound (rock) groins.
- Terminal groin design is very site-specific. The length, height, and permeability of the groin will determine how effective the groin is at trapping sediment updrift of the groin and the overall impact of the groin on sediment transport.
- Long groins that are built above the seasonal high water level or are completely impermeable will most effectively block sediment. However, short groins with high permeability may not block enough sediment to be effective. Terminal groins should be just long enough to retain the required beach width, without causing an undue reduction in sediment transport downdrift.
- Ideally, the groin height should be limited to just above beach level. Adjustable heights to nourishment volumes and design berm heights are also beneficial. The design groin height should also account for wave overtopping and the desired amount of sediment transmission over the structure.
- Rock is generally the most widely used building material since it is readily available and highly durable. Concrete and steel are suitable building materials for shorter, mid to shallow-water groins; however, these materials tend to be cost-prohibitive. Timber and geotextile groins are less expensive alternatives and can be adapted to a variety of beach conditions, but also have limited applicability to shorter, shallow-water conditions.
- Concrete, steel, and timber structures have the advantage of being adjustable with the beach profile without having to rebuild or remodel the groin.
- Groin notching is an emerging technique that allows for adaptive management. Notching allows for sediment to bypass the groin where it would normally be trapped. This may prove to be a cost-effective alternative to groin removal.
- It appears that for shorter groins, the interruption to littoral transport is smaller compared to the overall magnitude of sediment transport and the muted impacts seen both updrift and downdrift of the inlet.
- There also seems to be a threshold that appears with both length and height to be crossed where adjacent impacts become more pronounced. While it is possible that dredging impacts may be responsible for this threshold crossing, it underlies the importance to considering the overall length of the structure in relation to the exterior man-made and natural processes that also drive sediment transport so that the structure's relative effects are minimized or eliminated.
- The permeability of the structure has a significant impact on adjacent shorelines. The Amelia Island structure has allowed material to bypass the structures to limit effects on downdrift shorelines and volumes. However, the structure has also had a limited impact on the updrift shoreline (mainly within the first 0.5 miles). The other structures have impermeable cores and appear to hold more sand for a greater distance updrift of the structure.

Economic Assessment

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

Initial Construction and Maintenance Costs

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

Potential Locations

- The vast majority of the structures considered for this study were located at inlets with most of these adjacent to navigable, dredged channels.
- No terminal groins were identified as being located at the end of a non-inlet littoral cell.
- The most substantial (longer, higher and / or less permeable) terminal groins were typically found where the greatest amount of dredging activity occurs. While this may be obvious, it is worth stating that the more significant the dredging activities, the potentially greater the impacts on adjacent shorelines; the greater the potential need for more nourishment and / or more substantial stabilization structures. These dredging activities may greatly outweigh any potential long-term shoreline changes resulting from the construction of a terminal groin.
- With respect to locating a terminal groin on the updrift or downdrift side of an inlet, it is interesting to note that both sides were represented among the five structures selected for this study. While an initial thought might be that a terminal groin should be located on the updrift side of an inlet in order to capture sediment, it must be noted that sediment typically moves in both directions along a shoreline depending upon the incident wave activity, and significant reversals in sediment transport direction often occur near an inlet due to the presence of the ebb shoals and other inlet features which transform the waves as they approach the shoreline.
- Locating a terminal groin on the "net" downdrift side of inlet may have the additional impact of "stabilizing" the location of a migrating inlet, such as the case at Oregon Inlet where this impact has also resulted in changes to the inlet cross-section – a general narrowing and deepening over time since terminal groin construction. Great care should be exercised when siting a terminal groin in this setting as the channel may shift and potential undermining of the groin may become a concern.
- Based on the existing sites and the literature review completed, the impacts of terminal groins on adjacent shorelines is difficult to identify if they exist at all if located adjacent to a highly managed, deeper-draft navigable inlet.
- The relative impact of these structures on adjacent areas is likely increased when sited next to natural or minimally managed shallow-draft inlets. For these locations, additional care and study (geologic setting, sediment budgets, etc.) is warranted to be sure that the terminal groin's impacts are acceptable or can be mitigated through minimal human activities (dredging and nourishment).

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