North Carolina's Terminal Groins at Oregon Inlet and Fort Macon

Descriptions and Discussions

Oregon Inlet Terminal Groin

Introduction/Background

Oregon Inlet was created by a hurricane on September 8, 1846. The inlet separates Bodie Island to the north and Pea Island/Hatteras Island to the south (Figure 1). For the purpose of this report, Pea Island/Hatteras Island will be referred to as the Pea Island National Wildlife Refuge (PINWR).

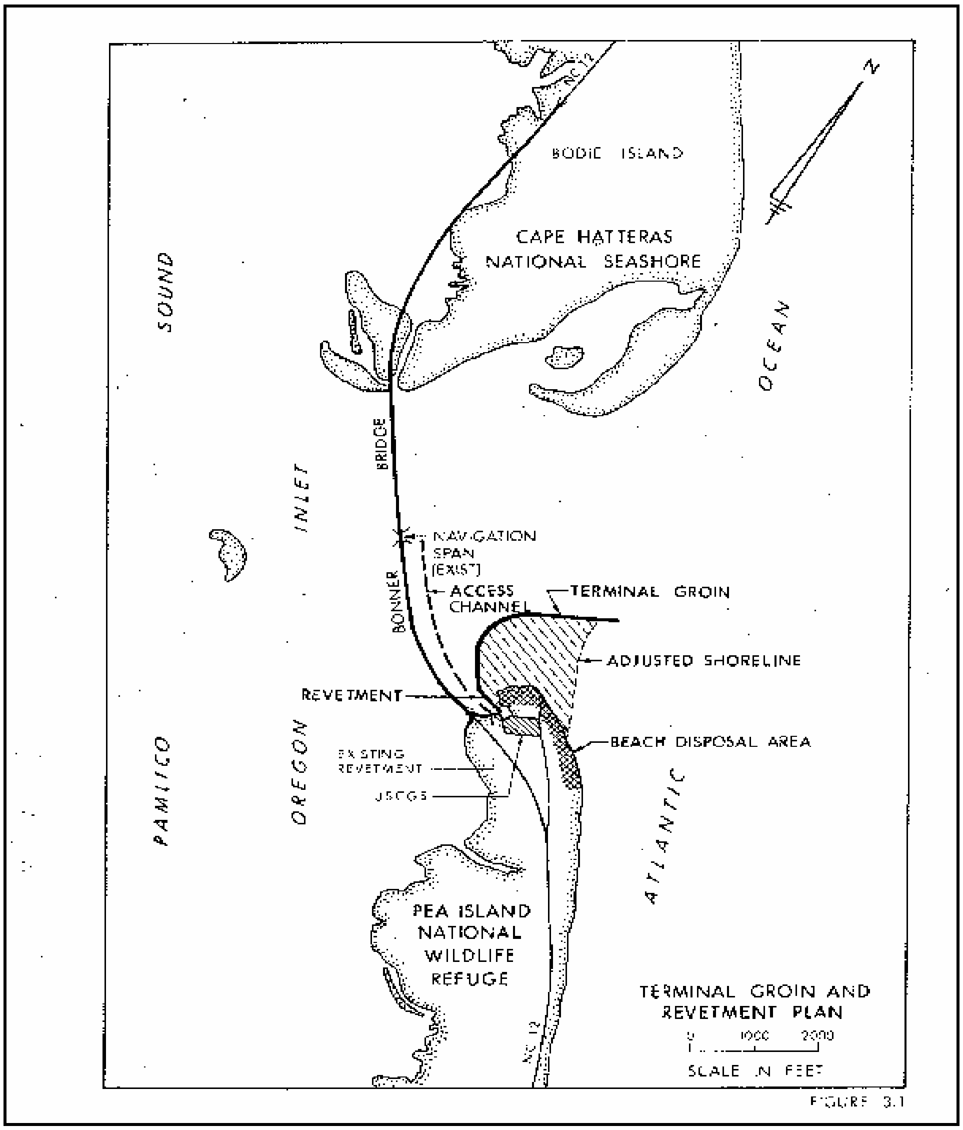

Figure 1. Location of Oregon Inlet and Terminal groin.

As with most natural tidal inlets, Oregon Inlet has had a history of dynamic change and migration since it's opening, having migrated more than 2 miles south of its original location. Because of the constantly shifting features of Oregon Inlet (Figure 2), the existing Herbert C. Bonner Bridge has been a maintenance issue for the North Carolina Department Of Transportation (NCDOT) since it was constructed in 1962. This highly turbulent area requires the US Army Corps of Engineers (USACE) to spend approximately five million dollars per year for dredging the Oregon Inlet channel. The USACE is only able to maintain the authorized 14-foot depth of the channel, on average about 25% of the time (Bill Dennis Pers Comm 2008). Shoreline change rates along both sides of the inlet are highly erosive with long-term rates of –5 ft to –17 ft/yr (Dennis and Miller 1993). The persistent southward Oregon Inlet migration has resulted in shorter-term erosion rates documented from 1981-1988, of approximately 180 ft/yr (Dennis and Miller 1993). Moreover, between April 1988 and March 1989, the erosion at the northern end of PINWR occurred at a rate of 1,150 ft/year. During one severe "nor'easter" in March 1989, the northern end of PINWR eroded 350 to 400 feet southward. This series of storms created the potential of destroying the southern abutment of the Bonner Bridge and severing the land transportation link between Bodie Island and PINWR. NCDOT data from 2002 show an average daily traffic of 5,400 vehicles per day with the highest daily traffic volume being 14,270 vehicles on Saturday, July 6. To ensure the Highway 12 transportation corridor was not lost, the USACE utilized engineering and design analysis of navigation jetties for Oregon Inlet in conjunction with the Manteo Shallowbag Bay project (NCDOT 1989) to design a terminal groin for the northern end of PINWR. The terminal groin was designed to be a portion of and incorporated into the jetties if and when they were constructed. The terminal groin construction was financed by the Federal Highway Administration with any maintenance and monitoring to be completed by the NCDOT.

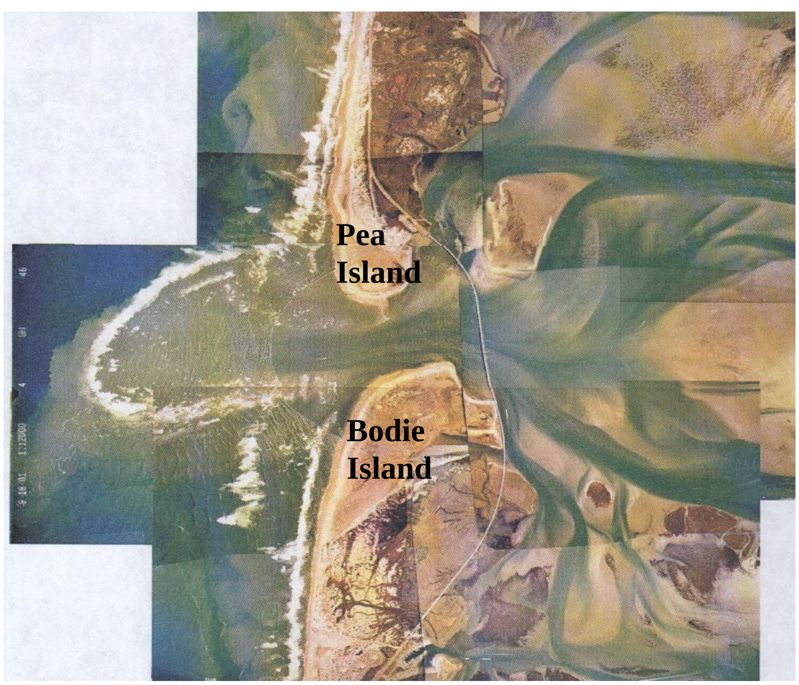

Figure 2. Dramatic aerial view of Oregon Inlet. Note the extensive sand bodies on the ocean (left) and sound side (right).

Terminal Groin Structure and Construction Description

The terminal groin at Oregon Inlet is located on the southern side of the inlet along the north end of the PINWR (Figure 1). The project consists of a terminal groin and revetment (3,125 and 625 feet long, respectively) starting at the US Coast Guard Station bulkhead. The groin extends from the bulkhead in a northwest direction, curving 90 degrees towards the northeast, and then straightening out again to be perpendicular with the natural inlet shoreline of PINWR. This alignment places the groin near the position that the north point of PINWR occupied in April 1985. An accretionary fillet was designed to impound sediment transported alongshore towards the inlet in order to provide enough wave sheltering for protection of the southern Bonner Bridge abutment. Once filled, the areal extent of this fillet was planned to be 60 acres. The groin was designed to withstand a still water level of eight feet above mean sea level (msl) and waves between 9 and 15 feet. The groin ranges in width between 110 to 170 feet at the base and 25 feet at the landward end to 39 feet at the seaward end. The design elevation ranged between 8 and 9.5 feet above msl (NCDOT 1989). Toe protection on the inlet side of the groin is provided by a 43 feet wide single layer of armor stone on top of a layer of core material (NCDOT 1989). Construction began in 1989 and was completed in October 1991 at a cost of 13.4 million dollars (1991 dollars).

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

Although the net sediment transport direction at Oregon Inlet is from the north to the south, a substantial south-to-north component also exists in this area. 1992 estimates used for design and construction purposes by the USACE assumed an average northward transport (toward the inlet from PINWR) of 611,000 cubic yards with the southward transport (from Bodie Island) to be 1,473,000 cubic yards.

Terminal Groin Monitoring and Local Impacts

A monitoring program, developed by the USACE, NC DOT and the US Fish and Wildlife Service (USFWS), was required as part of the USACE permit by the Department of the Interior. Specifically the permit required that the six miles of shoreline south of the groin be monitored (Overton and Fisher 2007), and that the structure be designed to ensure that any accretion within the terminal groin fillet was not at the expense of the erosion along downdrift beach shorelines. Any adverse impacts above the historical erosion rates for this area would be mitigated by beach nourishment provided by NCDOT (Overton 2007). The monitoring program, which has been in place since construction, includes aerial photography, flown every other month and immediately after severe storms, as well as bi-annual seasonal (spring and autumn) field surveys during high tide, the NC DOT completes the flights and surveys, and the shoreline analysis is contracted to North Carolina State University (NCSU).

Whenever possible, dredged material from Oregon Inlet is to be placed on PINWR to mitigate the naturally occurring high erosion rates. Based on the most recent erosion data calculated by the North Carolina Division of Coastal Management (NCDCM), the long-term averages (50-60 years) for the 6 miles of shoreline south of the terminal groin range from 16 to 6.5 feet per year.

The quantity and disposal location(s) of sediment derived from dredging of the channel beneath the navigation span of Bonner Bridge and/or the ocean sand bar between August 31, 1989 and November 3, 2005 is shown in Table 1.

Table 1: Dredging activities for Oregon Inlet from August 31, 1989 through November 3, 2005.

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

Inlet Migration and Sediment Bypassing

The inlet has persistently migrated southward since it opened in 1846, albeit with considerable variability. Alternate widening and narrowing of the inlet, due to hurricanes and northeasters, have accompanied this southward movement. Moreover, the channel throat has also undergone significant changes in both position and alignment. The channel has tended to follow two basic alignments, one approximately perpendicular to the adjacent shorelines (indicative of post-storm periods), and the other a more northerly alignment almost parallel to the shore (storm-free periods) (Figure 3.) (Sheldon et al. 1992). The latter description occurs when the north shoulder of the inlet (i.e., the southern end of Bodie Island) is in the form of an elongated spit, and the channel tends to rotate towards a more northerly alignment. As the inlet alignment changes, the inlet cross-section changes as well. A narrow and deep cross-section with steep banks occurs in relatively storm-free periods, while a shallow channel with wide overbanks occurs after stormy periods.

The construction of the terminal groin at the north end of PINWR does alter the natural processes described above at Oregon Inlet. With the PINWR groin in place, the migration of the north end of PINWR has ceased because the terminal groin immobilizes the south shoulder of the inlet. Therefore, future changes in inlet widths, channel depths, and channel orientations may not be in strict accordance with established historical norms. The inlet's stability, updrift and downdrift erosion rates are highly dependent on the natural bypassing of material across the inlet. Unfortunately, with or without the terminal groin, natural bypassing is not efficient at Oregon Inlet (Miller et al. 1996). The causes for this decrease in downdrift bypassing efficiency (producing downdrift shoreline erosion) include: periodic increases of sediment immediately updrift of Oregon Inlet causing accretion along southern Bodie Island, the renewed use of hopper dredges to maintain the navigation channel across the ocean bar removing sediment out of the nearshore system; and high retention rates of sand in the sound caused by frequent water circulation changes from storms. All of these factors influence Oregon Inlet's ability to bypass sediment downdrift.

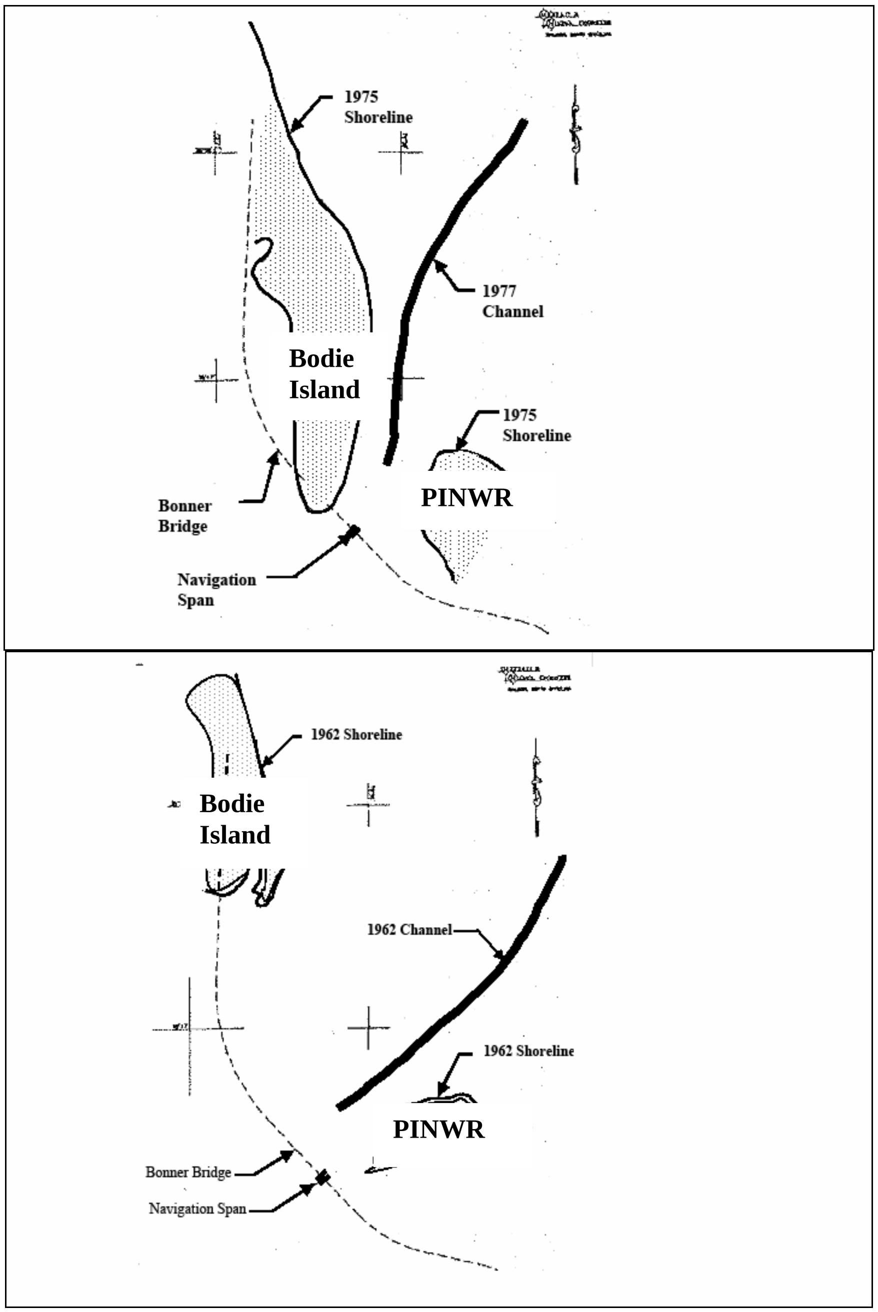

Figure 3. Top picture (1975) is indicative of pre-storm configurations of the Barrier Islands and channel orientation. Bottom picture (1962) is a typical post-storm configuration. (Sheldon et al 2000)

Shoreline Changes and Downdrift Impacts (1990-2006)

The USACE conducted a study in 1993 (Dennis and Miller 1993) of the pre- and post-construction shoreline changes in order to assess the overall impact of the terminal groin on the northern end of PINWR. The study assessed the shoreline up to four miles south of the terminal groin and reviewed five years of pre-construction and 2.5 years of post-construction data. The 50-acre fillet became impounded to capacity two years after the terminal groin entered the water (Jan 1990 to Jan 1992). This fairly short-term effect was attributed to a number of factors: (1) the fairly large south to north (toward the terminal groin) sediment transport rate of 611,000 cy/yr; (2) in the fall of 1991, the rate of northward sediment transport was greatly accelerated to 202,900 cy/month, due to two very large storms (1991 Halloween storm, and January 1992 storm); and (3) the placement of approximately 470,000 cy of fill material on to the PINWR beach from April to November of 1991. All of these factors contributed to positive impacts (i.e. oceanfront accretion) along an area that was approximately two miles south of the terminal groin. For the remaining two miles of shoreline to the south of this area, there has been no generalized trend in the shoreline response. In other words, the measured shoreline changes appear to be within the range of natural variability for this area. Similar findings over an area of six miles south of the terminal groin were reported by monitoring conducted by NCDOT (Overton, et al. 1996)

Inlet Navigation Morphological Changes

Joyner et al in 1998, conducted a study of the post-stabilization morphology of Oregon Inlet. The investigation examined data from the USACE and NCDOT programs from October 1989 through April 1997, to determine the relationship between the growth of the Bodie Island spit to the north and the resulting bathymetric changes in the inlet. This study provided insight as to the expected changes in configuration of the main inlet channel as the southern migration of Bodie Island spit approached the terminal groin along northern PINWR. Changes in the inlet's bathymetric configuration were observed in both the inlet width and orientation. Accretion of the spit on Bodie Island and the location of the terminal groin were responsible for a change in location and orientation of the main channel section. The shifting of the channel became noticeable in April 1995, which coincided with the beginning of a significant widening of the Bodie Island spit at the bridge. The shift of the channel bayward (landward) required a rotation of the inlet channel section, since the terminal groin remained fixed at the southern extent of the inlet. The inlet channel continued to move bayward and orient it self in a more northerly direction. Channel deepening also occurred along with its lateral migration. In order to maintain a constant cross-sectional area, a narrowing inlet must become deeper to accommodate the same discharge volume (also known as tidal prism). The data shows that this has happened since the terminal groin was constructed. According to Joyner et al. (1998), Oregon Inlet exhibited changes as expected with the stabilization of a single side of a tidal inlet.

Structure Maintenance

There has not been any maintenance needed to date on the Oregon Inlet terminal groin. Any maintenance that becomes necessary is to be conducted by the North Carolina Department of Transportation with potential federal funding from the Federal Highway Administration.

Summary and Conclusions

The terminal groin has stopped the southerly migration of Oregon Inlet and protected the base of the southern end of the Herbert C. Bonner Bridge. The terminal groin has impounded sediment resulting in a fillet with an approximate area of 50 acres.

The six miles of PINWR shoreline south of the terminal groin fillet that was monitored, continues to erode at rates that range from slightly more to slightly less than the pre-terminal groin shoreline erosion rates, in spite of frequent dredging and beach nourishment efforts.

Approximately 7.7 million cubic yards of sediment have been dredged from Oregon Inlet and mined from the terminal groin fillet to be either deposited on the PINWR beaches or in the nearshore ocean environment from one to six miles south of the terminal groin.

The main navigation channel has shifted laterally and has deepened to adjust to the reduced inlet width between the northern side of Bodie Island and the stabilized downdrift side of PINWR.

The consequences of this continued channel migration south are problematic for the maintenance of a navigation channel within the current fixed navigation span of the bridge, and require increased frequencies of channel dredging.

Locking an inlet in place with a terminal groin takes away the natural self-adjusting mechanisms that inlets possess (e.g., sediment bypass across the inlet, migration and depth change of the channel(s) within the inlet, shoreline migration along the inlet, changes in ebb tidal delta morphology). One of the most observable effects is the impact to sediment bypassing between the adjacent shorelines, and the exchange of sediment to the shoals that lie on the ocean side (ebb-tidal delta) and the estuarine side (flood-tidal delta). Overall, the sum of all coastal processes active within an inlet, and how these processes affect the transport and storage of sediment, are extremely important in not only how inlets function but also to the long-term survival and evolution of the barrier islands.

Over time, potentially within the next 10-20 years, and with continued southward migration of the Bodie Island spit, the main channel in Oregon Inlet may migrate against the terminal groin structure itself. If this were to occur, the result would be severe scour and an increase in the maintenance necessary to preserve the threatened integrity of the structure itself.

Beaufort Inlet/Fort Macon Terminal Groin

Introduction/Background

Beaufort Inlet has been continuously open since 1585, although the exact year of its creation is unknown (Payne 1985). Beaufort Inlet's adjacent beaches, Bogue Banks (west) and Shackleford Banks (east), are south facing beaches. The Bogue Banks area is sheltered somewhat from the damaging effects of winter extratropical nor'easters because of the very large shoal complex of Cape Lookout that lies approximately 12 miles to the east (Figure 4). Beaufort Inlet is utilized as part of the commercial navigation project connecting the Atlantic Ocean to the waterways of the NC State Ports' Morehead City (MHC) harbor and the Town of Beaufort (Figure 5). Improvements for navigation at Beaufort Inlet began in 1911 when a 300-ft wide channel was dredged through the ebb tidal shoal to a depth of –20 ft. In 1936, the outer bar channel was deepened to –30 ft and widened to 400 feet, and the channel location became fixed at this time. In 1997, the channel was dredged to -47 feet and 450 feet wide along the outer channel for approximately 2.5 miles. Interior channels and the Port of MHC are maintained at –45 ft depth. Since 1911, the navigation project channel depth and width has steadily increased, hastening the erosion along Beaufort Point (western side of inlet). Property in this area includes the historical Fort Macon, which was incorporated into the State Park system in 1924. In 2007, 1.2 million guests made the park the most visited State Park in the State. Erosion control structures have been a common occurrence adjacent to Beaufort Inlet since the construction of Fort Macon from 1829 to 1834. Around Fort Macon, there have been approximately 25 "hardened" erosion control structures including groins, breakwaters, timber cribbing, revetments, sand-fencing, and seawalls as well as numerous beach nourishment projects ("soft" erosion control). When emplaced, a hardened shoreline was deemed necessary to save Fort Macon from being lost to the sea (Figure 6).

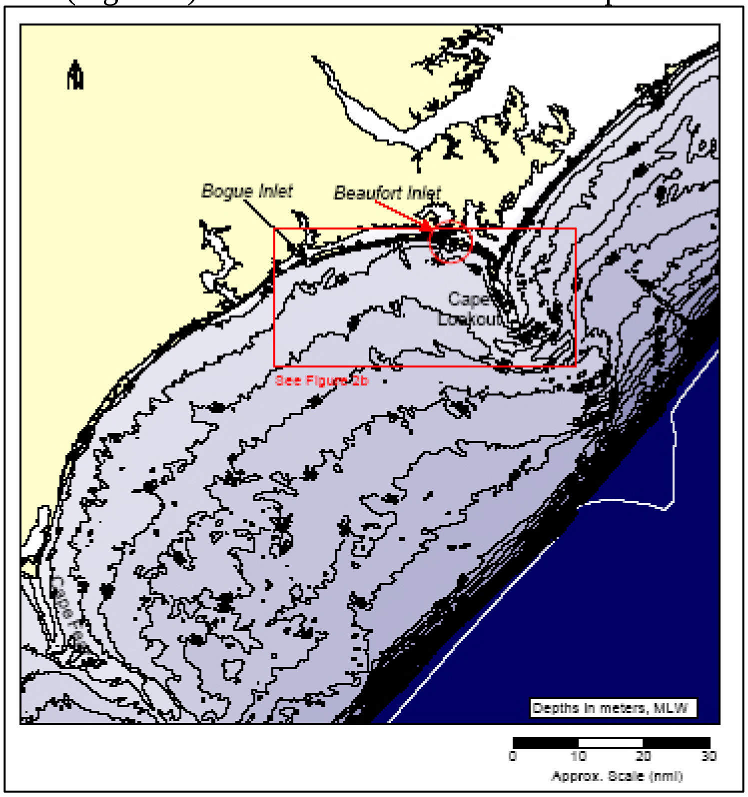

Figure 4. Location of Beaufort Inlet in proximity to Cape Lookout shoals (Olsen and Associates, 2004)

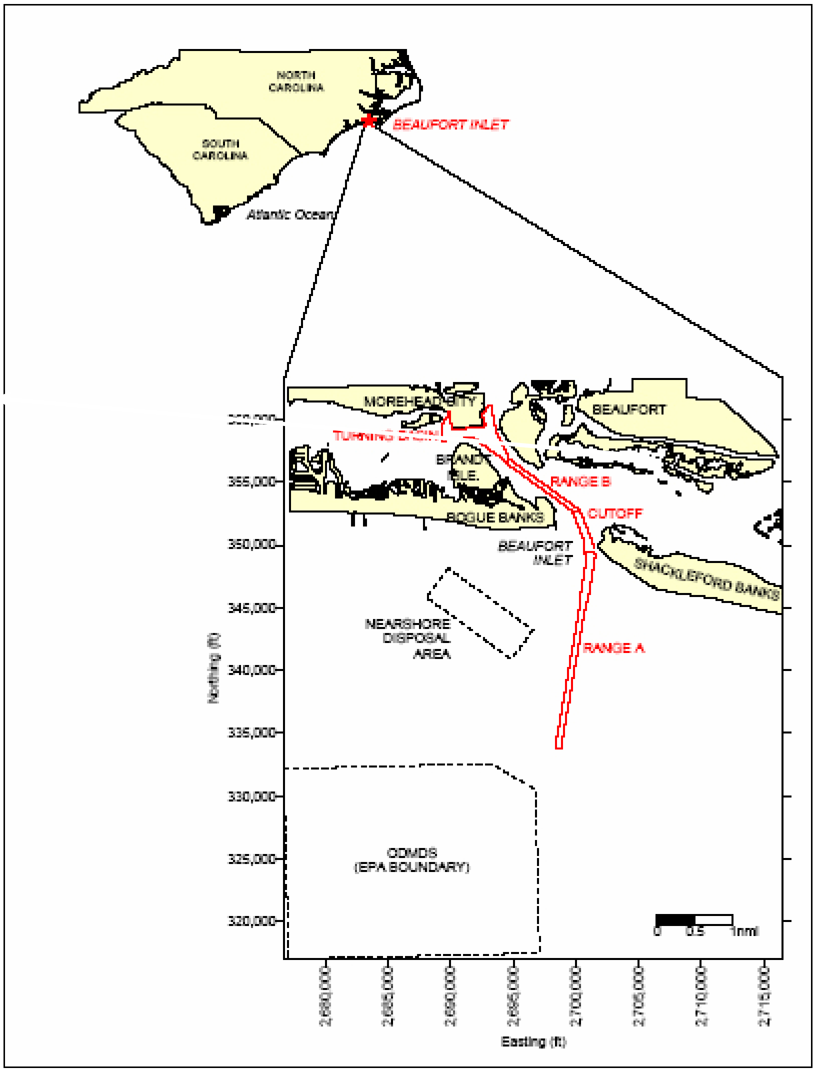

Figure 5. Location of federal navigation channel (red dotted line) in Morehead City and adjacent to Beaufort (Olsen and Associates, 2004)

Figure 6. Picture of Fort Macon terminal groin under construction from Nov 1961, and showing all the hard structures placed around the perimeter to try and offset the shoreline erosion.

In 2004, a study was prepared by Jacksonville, Florida-based Olsen Associates for Carteret County entitled "Regional Sand Transport Study: Morehead City Harbor Federal Navigation Project." A plethora of information regarding the impacts of construction and maintenance of the navigation channel on the inlet and the adjacent barrier island complex of Bogue and Shackleford banks was detailed and quantified. The pre- (prior to 1936) and post-navigation project changes in the inlet morphology and adjacent shorelines helped establish a better understanding of the active coastal processes in the area and what effect, if any, the terminal groin at Fort Macon could have in stopping this erosion. The results discussed herein are taken mostly from their report.

Structure Description and Local Impacts

The construction of the Fort Macon terminal groin, revetment, and seawall was completed in three phases. The first phase began in 1961 and featured the construction of a seawall, revetment, and a portion of the terminal groin that, due to financial constraints, was only built to a length of 720 feet at an elevation of six feet instead of nine and excluded the structure's top armor layer. The revetment (250 feet) and seawall (530 feet) were constructed along the dune bank starting just north of the present-day Fort Macon parking lot in a southeastern direction.

Phase two began in 1965 and extended the groin by an additional 410 feet oceanward. An additional groin was constructed west of the revetment due to extensive erosion on the back, or sound side, of the island and its impact to the US Coast Guard Station. Beach fill (93,000 cubic yards) was also placed on the beach between the present day bathhouse and boardwalk region and the terminal groin.

The third and final phase began in August 1970, extended the terminal groin by an additional 400 feet to a total length of 1,530 feet. A stone groin, 480 feet long, was built near the bathhouse in an effort to stabilize beach fill placed in the area. Another 100,000 cubic yards of sand was placed in the bathhouse and boardwalk area for erosion mitigation.

The total cost of the terminal groin, beach fill, seawall, and revetment was $1,348,000 (1960s dollars). The two-thirds Federal cost share was $894,000.

A study completed by the USACE Wilmington District (USACE 1970) on possible placement of jetties at Beaufort Inlet discusses the impacts of the terminal groin between 1961 and 1970. According to that report, the terminal groin was functioning somewhat as a littoral barrier, with some sand passing through voids in the structures. By 1968, the fillet was full and sand was bypassing the outer end of the structure. Erosion had continued near the boardwalk and bathhouse area (approximately 7,000 feet west of the terminal groin) and is the reason for the additional groin placement during the third phase of construction. The volume of the westward accretion of sediment that began to occur when the fillet reached capacity was not calculated by the USACE in their 1970 investigation, but was determined not to have any effect on shoaling in the Port of MHC. DCM has approximated from a series of ortho-photographs dating back from 1962 – 2004, that the shoreline has migrated seaward approximately 400 feet over the past 40 years.

Inlet Morphological Changes

Records prior to 1839 indicate that the direction of the main ebb channel within the inlet had varied from somewhat west of south to southeast (USACE 1962). The inlet channel naturally migrated between the two islands. To illustrate this point, the locations of the inlet channel from a number of time periods between 1850 and 1960 are shown in Figure 7. Sand was exchanged between the adjacent shorelines and the inlet, and bypassed across the bar. The sediment transport movement was east to west, bypassing approximately 94,000 cy/yr, and the ebb shoal gained volume at a net rate of approximately 200,000 cubic yards per year. The inlet morphology was broader in nature with a semi-symmetrical ebb tidal shoal extending out into 10 to 15 feet of water (Figure 8).

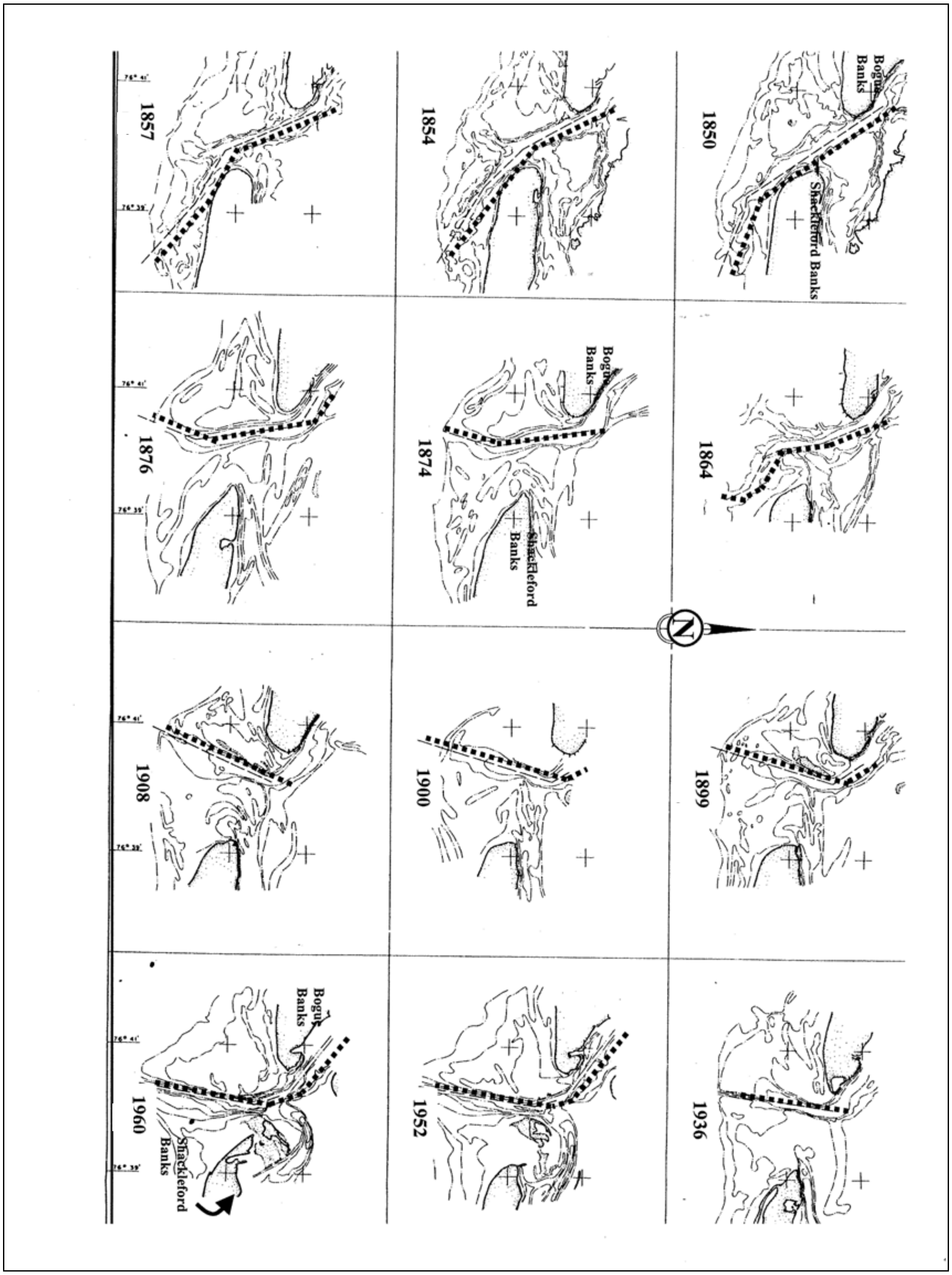

Figure 7. Various locations of the inlet channel from 1850 – 1908 (pre-project) and 1936-1960 (post project) (Modified from USACE 1962)

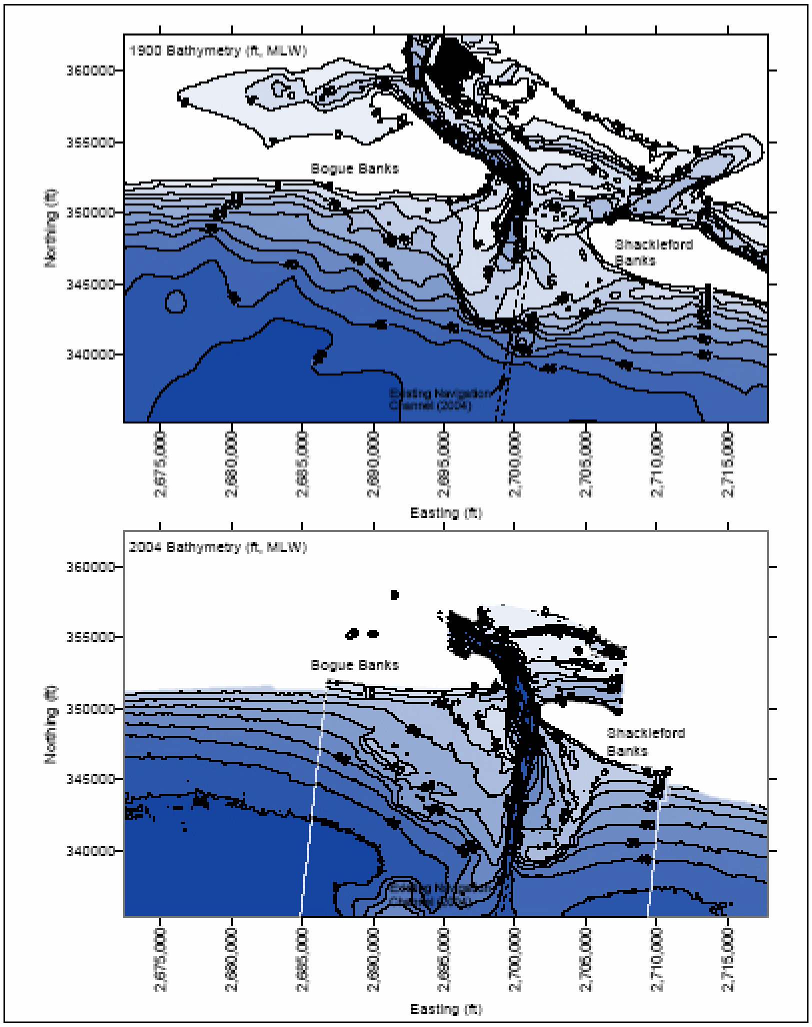

Figure 8. Differences in the shape of the inlet morphology from pre-project condition (1900) and Post project conditions (2004) (Olsen and Associates, 2004)

In contrast to the pre-project conditions (prior to 1936), the ebb tidal shoal is now much more elongated and non-symmetrical. The controlling depth through the inlet is now at 47 feet, extending seaward for approximately 2.5 miles. The seaward extent of the ebb shoal and ocean bar is influenced entirely by the seaward terminus of the navigation channel, and the channel precludes any natural sand bypassing across the inlet. The channel serves as a huge trap for any littoral material transported to the inlet from adjacent beaches. Currently, once the material is deposited into the channel it cannot be removed from the channel by natural processes, rather, it has to be removed by dredging during navigation maintenance operations. The removal of sediment from the inlet system at a volume in excess of the rate of longshore sediment transport has resulted in deflation or erosion of the ebb tide delta (USACE 2001) and deepening of the offshore beach profiles adjacent to the west side of the inlet along Bogue Banks (Figure 9; Olsen and Associates 2004).

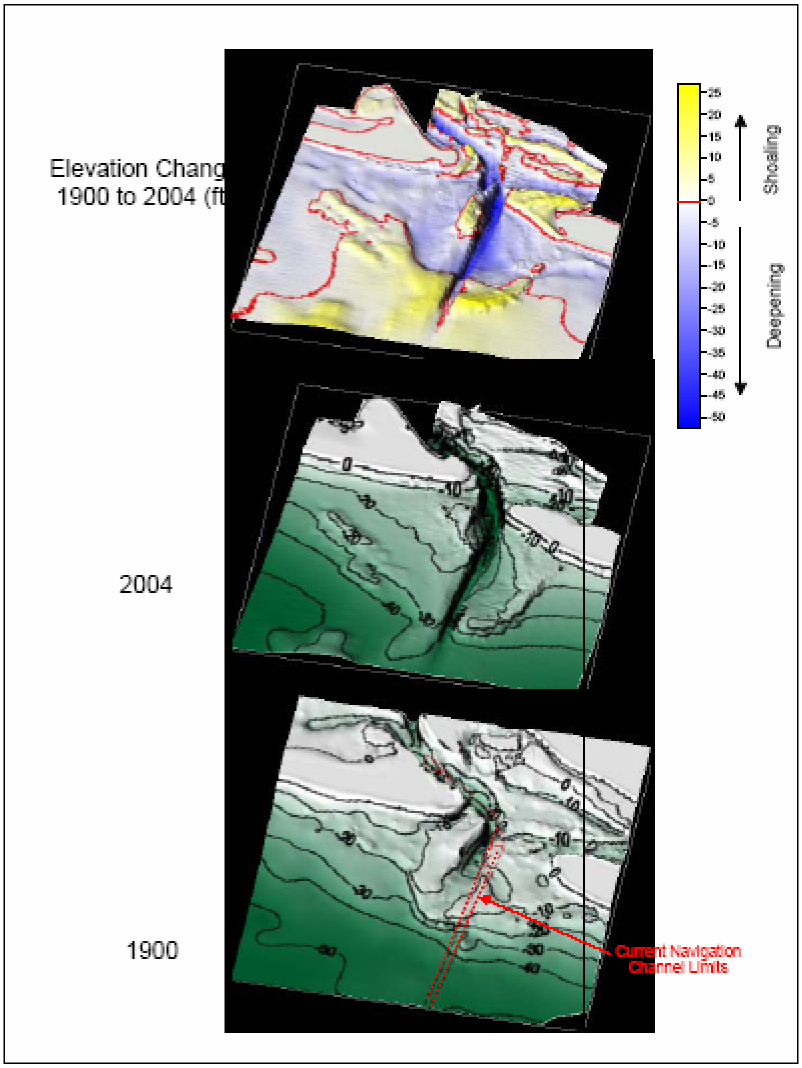

Figure 9. With the amount of material being removed from the inlet system by dredging exceeding the rate of longshore sediment transport, the result is deflation or erosion of the ebb tide delta (Olsen and Associates, 2004)

The deepening of the ebb tidal delta and offshore beach profiles has increased the wave energy along the western side of the channel along the Bogue Banks/Fort Macon area (Figure 10). This increase along Bogue Banks was three times greater than along Shackleford Banks. Future increases in wave energy are predicted, based upon the continued deflation of the ebb tidal shoal. This increase in wave energy will undoubtedly have an adverse impact on navigation and increase the wave energy within the inner harbors and sound including portions of the Rachel Carson National Estuarine Research Reserve (Olsen and Associates 2004).

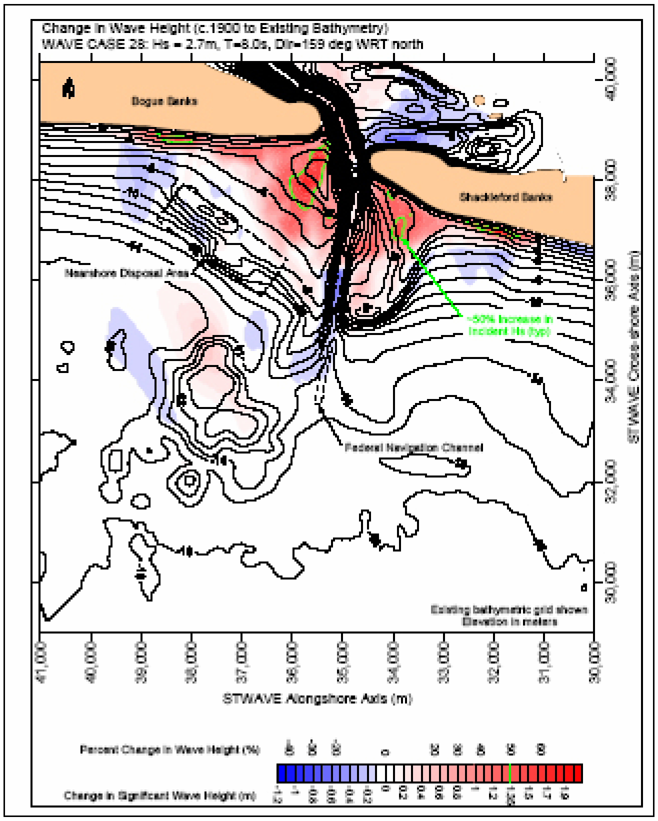

Figure 10. The deepening of the ebb tidal delta and offshore beach profiles has increased the wave energy along both sides of the channel

Sediment Transport and Shoreline Changes

The net littoral drift transport found along both Shackleford and Bogue Banks is east to west. However, at the east end of Bogue Banks, within 2.4 miles of Beaufort Inlet, there is a nodal point (a net easterly reversal) in sediment transport directed towards the inlet. The general location of this point is near the Triple S and Oceanna Piers in Atlantic Beach, although seasonal variation of its exact location occurs. The sediment that moves back towards Beaufort Inlet (east of this nodal point) is captured by the navigation channel and, thus, becomes unavailable for westward transport as it would in a natural system. This sediment deficit results in erosion on the inlet's western shoreline.

Prior to navigation improvements spanning 1876 to 1933, Beaufort Inlet was migrating in an eastward direction. During the first 40 years after navigation improvements from (i.e., 1933 to 1974), the migratory trend reversed, and Bogue Banks retreated rapidly back toward its 1876 location. Efforts were made to stabilize the inlet's eastern shoreline and protect Fort Macon with hardened structures. Between 1974 and 1994, beach disposal of inner harbor dredged material has resulted in a fairly stable Bogue Banks shoreline. Since 2004, the sand spit at Fort Macon has advanced along and into the western bank of the navigation channel inside the inlet throat, suggesting the terminal groin is now very inefficient at trapping sediment (Figures 11 and 12).

Figure 11. As nourished sand is put on the beach, the sand moves toward the inlet and through the terminal groin to just inside the western edge of Beaufort Inlet.

Figure 12. Sand spit growth showing the inability of the terminal groin to trap sediment.

Summary and Conclusions

Existing structures along Fort Macon include a terminal groin east of the fort and a relic groin field along the oceanfront and inlet throat shorelines. The low elevation and porous nature of these structures allow significant quantities of sand to be transported into the inlet resulting in persistent deposition of sand along the west bank of the inlet.

Ten years of shoreline change data (1997 to 2007) provided by Carteret County show no shoreline change along the five miles of oceanfront west of the groin. Since 2002, approximately 600,000 cubic yards were placed along this stretch of beach. This beach fill, at least in part, accounts for the "no net change" in shoreline position.

The ebb shoal deflation over time has exasperated the erosion along the Fort Macon side of the inlet. This loss of sediment volume steepened the nearshore beach profiles that, in turn, increased the wave energy reaching the coast and inner harbor area. Erosion of the shorelines adjacent to the inlet occurs as the inlet attempts to move sediment into the inlet to establish equilibrium and maintain its own sediment balance. Overall, Beaufort Inlet's historical sediment bypassing capability, and its ability to maintain some form of stability/equilibrium with its adjacent shorelines, has been impeded, if not totally lost, by the additional trapping effect of the USACE-maintained navigation channel through the inlet.

The placement of sediment along the shoreline to the west of the inlet is still required for the Fort Macon State Park area, without which the vulnerability of Fort Macon to the forces of nature would be increased. The terminal groin and other hard structures, by themselves, would not be able to provide adequate protection to coastal hazards such as storms, tides and sea level rise. Without constant beach nourishment, the terminal groin would no longer perform as observed historically and, potentially fail altogether.

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