Coastal Erosion Study

Division of Coastal Management

North Carolina Department of Environmental Quality

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Executive Summary

In September 2015, the North Carolina General Assembly directed the N.C. Department of Environmental Quality (DEQ), Division of Coastal Management (DCM) to "study and develop a proposed strategy for preventing, mitigating, and remediating the effects of beach erosion" (S.L. 2015-241, Section 14.101.(a)). The law requires DCM to report the results to the Environmental Review Commission, the chairs of the Senate Appropriations Committee on Natural and Economic Resources and the House Appropriations Committee on Agriculture, Natural, and Economic Resources, and the Fiscal Research Division, by Feb. 15, 2016.

Between October 2015 and January 2016, DCM developed this report by reviewing relevant literature and previous studies in North Carolina, by visiting an experimental structural approach to mitigating beach erosion in South Carolina, and by drawing upon 40 years of experience in shoreline change analysis and permitting beachfront development and engineering projects.

Beach Processes

Beaches gain sand (accrete), and lose sand (erode) through a variety of natural forces and human actions. It is important to differentiate between beach erosion and shoreline migration, because while they may appear the same, they are in fact the results of different geological, biological, and physical processes. Beach erosion can be defined as a net loss of sand from a beach, while shoreline migration is simply a horizontal shift in the position of the shoreline. Shoreline migration can occur with or without an actual loss of sand from the beach; for example, sea-level rise can cause shoreline migration without reducing the volume of sand from the beach. Beach erosion can result from wave and current action (especially during storm events), wind, or an interruption of sand transport pathways as a result of an engineered structure. Interrupting the natural process of barrier island overwash can also adversely impact a barrier island's ability to maintain its width and elevation, by taking the overwashed sand that would otherwise have stayed on high ground, and placing it back onto the active shoreface where it is subject to continued erosional forces.

Beaches in North Carolina, and elsewhere along the U.S. coast, are in a state of constant fluctuation due to normal erosional actions of wind, water, and sediment supply. The region's geologic makeup is a significant factor regarding sediment supply: North Carolina's northern coast is flatter and more sediment rich than the steeper, sediment-poor southern coast. North Carolina's combination of simple and complex barrier islands, shoreface orientation, and inlet systems also influence the sediment budgets among the state's beaches (Riggs & Ames, 2003). Some inlets, for example, tend to migrate in the same general direction over time, while others oscillate back and forth. This difference influences whether the beaches adjacent to the inlets experience chronic or short-term erosion or accretion, and presents enormous management challenges and costs for property owners, local governments, and the state.

Erosion Influences

Human activities also contribute to beach erosion and accretion, inlet dynamics, and property impacts. Inlet dredging and relocation, placing structures on the beach that interfere with sediment transport, and beach nourishment are some of the activities that impact sediment budgets. The trend in North Carolina in recent years has been towards more active beach management. Of the approximately 160 miles of developed oceanfront shoreline in the state, about 120 miles have received beach nourishment, and local communities are increasingly planning for regular beach nourishment projects. There are currently 11 permanent erosion control structures along the oceanfront, mostly constructed for inlet stabilization, bridge approaches, and historic structures. The N.C. General Assembly passed legislation in 2011 and 2015 to allow up to six additional terminal groins to be built for inlet stabilization and erosion control. There are also approximately 290 sandbag revetments along the oceanfront, protecting imminently-threatened structures from further erosion and collapse. Additionally, legislation was passed in 2015 to expand the ability to use sandbags for erosion control along the oceanfront, and for potentially longer periods of time than have been previously allowed (see S.L. 2015-241, Section 14.6(p)).

Research and Studies

Efforts to understand and mitigate coastal erosion are not new to North Carolina. Since the 1800s, there have been many attempts by federal, state, and local governments, and academia, to study and address coastal erosion. The Coastal Resources Commission (CRC), created in 1974 when the General Assembly adopted North Carolina's Coastal Area Management Act (CAMA), has been actively addressing beach erosion since its inception. DCM, along with other government agencies and academia, has been calculating annual average erosion rates for decades, which the CRC uses as the basis for oceanfront construction setbacks. The erosion rate calculations and construction setbacks seek to balance private property rights with life and property protection, and with public trust rights of access to the beach.

In 1984, in recognition of the need to learn more about beach erosion and mitigation strategies, the CRC created the Outer Banks Erosion Task Force and charged them with examining how coastal processes influence shoreline movement over time, reviewing strategies for addressing beach erosion, and offering recommendations for beach management. Although the Task Force focused on the Outer Banks, some of their recommendations are applicable along other sections of the coast. One of the Task Force's key conclusions was that permanent erosion control structures can have a negative influence on adjacent shorelines and beaches, and could limit or eliminate public access and use of the beach. Therefore, the Task Force recommended that beach nourishment should be the state's preferred method for addressing beach erosion.

The North Carolina Department of Environmental Quality (DEQ) has also taken a long-term approach to the conservation and management of the state's beaches and inlets through the N.C. Beach and Inlet Management Plan (BIMP). The Division of Water Resources (DWR) coordinated with DCM and a private engineering firm to produce the original BIMP, which compiled much of the information needed to address the natural resources, funding mechanisms, and strategies for the comprehensive management of the state's ocean and inlet shorelines. Although there have been many studies addressing erosion-related issues specific to geographic regions within North Carolina, the BIMP was the first statewide compilation of data associated with the management of the state's beaches and inlets. S.L. 2015-241 also mandated an update of the 2011 BIMP, and appropriated up to $250,000 to complete the task. The BIMP update is scheduled to be completed by Dec. 1, 2016, and DCM anticipates that the new BIMP report will complement and expand upon this shorter-term study.

Mitigation Strategies

The Legislature's charge to "develop a proposed strategy for preventing, mitigating, and remediating the effects of beach erosion" is a challenging one. Preventing beach erosion essentially requires locking sand in place, contrary to its natural tendency to be transported by water and wind. Locking sand in place in one location interferes with its ability to move and replenish sand lost along adjacent beaches, which transfers an erosion problem to a different location.

Mitigating and remediating beach erosion include a suite of activities that are already in use in North Carolina, as well as others that are being actively developed. Current activities in use in North Carolina and elsewhere include beach nourishment, sandbag placement, hard structures (*e.g.*, terminal groins, seawalls, and jetties), inlet realignment, and relocation. Some localities outside North Carolina use offshore breakwaters, wave energy dissipaters, and experimental technologies.

Based on a review of historical N.C. studies, lessons learned from other coastal states, DCM experience and public comments, the following strategies should be considered:

1. Identify data and knowledge gaps in erosion hazard assessments and modeling, and the potential effects of these gaps on policy and decision making; and support additional data collection to establish subregional sediment budgets.

2. Formalize beach management at the local and subregional levels; for example, encourage beach communities to develop local beach management plans and necessary inter-local agreements; invest in local beach management staff, partnerships, and monitoring efforts; create or maintain dedicated sources of beach management funding; and explore opportunities for regional collaboration with neighboring communities.

3. Employ sensible construction setbacks to account for beach erosion and shoreline migration, taking into account the life expectancy of the structure, the range of mitigation options available, and the feasibility of their implementation.

4. Regularly evaluate the combined budgetary needs for erosion response projects, taking into consideration the prevailing and expected cost-share percentages among funding entities; and establish stable and predictable funding sources sufficient to meet statewide needs.

5. Maximize the amount of beach-compatible dredged material that is beneficially used in mitigating beach erosion.

6. Continue to streamline permitting for beach projects at the federal and state levels as a way to decrease permit processing times, permitting costs, and emergency situations.

7. Provide dedicated state agency staff support and technical assistance for local and regional beach management efforts.

As evidenced from past efforts, a state-level beach management strategy is needed to better understand local and regional sediment budgets, maintain a healthy ecosystem, protect the public's right to access and use the beach, protect property rights, and afford property owners (both public and private) with storm protection. Any new strategy should focus on continued investments in beach nourishment as the preferred alternative for mitigating beach erosion. The two largest obstacles associated with this approach are having dedicated, predictable funding sources and the identification of long-term supplies of beach-compatible sand resources.

Concurrently with the drafting of this report, DCM invited public input on the subject of beach erosion, and the charge from the Legislature. The invitation resulted in a substantial response from local governments and other interested parties, underscoring the importance of this issue to North Carolina's coastal communities, and the desire to develop a comprehensive strategy.

Introduction

The coast of North Carolina continually changes in response to wind, waves, and fluctuating sea levels, as well as human influences. These coastal processes redistribute sand within the dune, beach, and nearshore systems. Geographic, geological and oceanographic differences collectively influence sediment availability, distribution, and transport, which when better understood can help to explain why trends of erosion and accretion differ along all portions of N.C.'s barrier island shorelines. Both short- and long-term changes can be dramatically different depending on where changes are measured and how much time passes between storm events. Factors predicting short-term changes are less understood than those affecting long-term changes for a variety of reasons. Short-term changes are easily influenced by storm events and require routine monitoring, analyses, and modeling using high-resolution data in order to anticipate changes and predict where erosion will be the most extreme. Although factors affecting long-term changes are complex, the positions of the shoreline over a longer period of time can reveal a trend in movement unless beaches are renourished on a periodic cycle. Human activities (development and engineering practices) are becoming a dominant force in influencing coastal processes and modifying the geological evolution of the coast.

North Carolina began addressing coastal erosion long before the Coastal Area Management Act (CAMA) was passed in 1974. For example, dune restoration and construction of an engineered erosion control system began at Fort Macon, at Beaufort Inlet in Carteret County, in the 1820s, and a stone jetty system was installed there in the 1840s under the direction of Capt. Robert E. Lee (Wrenn, March 1970).

The same erosional forces that required engineered solutions at Fort Macon in the 1800s led the state to adopt the legal and regulatory frameworks that are in use today. The N.C. Constitution makes it the policy of the state to preserve beaches as common heritage, for the benefit of all citizens (Article 14, Section 5, North Carolina Constitution). CAMA and the Coastal Resources Commission's (CRC) rules reflect this policy by limiting the permanent usurpation of public trust rights for private purposes. CAMA describes ocean beaches as, "especially vulnerable to erosion, flooding, or other adverse effects of sand, wind and water," (§ 113A-113(b)(6)), and gives the CRC the authority to designate them as Areas of Environmental Concern (AECs). The CRC designated ocean beaches, dunes and inlets as AECs in 1977 (15A NCAC 07H .0300), and established extensive regulatory standards for oceanfront erosion control in 1979 (15A NCAC 7H .0308). The CRC also adopted shoreline erosion policies in 1979 (15A NCAC 07M .0200), that emphasize the protection of public trust rights, and state that erosion control activities on private property should be consistent with the preservation of the public trust. Public entities were allowed to retain the ability to use permanent erosion control structures to protect historic sites, when other responses such as nourishment or relocation are not sufficient, and where an overriding public benefit exists (15A NCAC 07H .0308(a)(1)(I)).

The CRC, by rule, sets standards for development within AECs to balance private and public rights of use and access, while at the same time avoiding "loss of life, property and amenities." (15A NCAC 07M .0201). To achieve the goal of balancing private property and public trust rights, CAMA and the CRC grant oceanfront property owners the right to use temporary sandbag revetments for erosion control.

Construction of permanent erosion control structures on the oceanfront has, with few exceptions, been banned under CAMA and the CRC's rules for many years. The CRC banned the construction of permanent erosion control structures on the oceanfront in 1985 (15A NCAC 07M .0202), except for structures specifically authorized under CAMA. The same rule allows the use of temporary sandbags and beach pushing, provided they are compatible with public trust rights, and proposes beach nourishment as an alternative to large-scale retreat or relocation. The CRC supports, under 15A NCAC 07M .0202, the state sharing the costs for beach nourishment projects with federal and local governments, contingent upon permanent public ownership of, and improved access to, the restored beaches. The CRC's policy also includes the provision that erosion control projects should be designed to minimize direct and indirect costs to the public.

The CRC has a stated policy to consider innovative approaches and research geared towards controlling beach erosion (15A NCAC 07H .0308(a)(1)(L)), and has been actively working with DCM staff, local governments, and the private sector in recent years to improve the ways that the state mitigates and defends against coastal erosion.

In September 2015, the North Carolina General Assembly directed the Division of Coastal Management (DCM) to "study and develop a proposed strategy for preventing, mitigating, and remediating the effects of beach erosion" (2015 Appropriations Act, S.L. 2015-241, Section 14.101.(a)). The law required DCM to report the results to the Environmental Review Commission, the chairs of the Senate Appropriations Committee on Natural and Economic Resources and the House Appropriations Committee on Agriculture, Natural, and Economic Resources, and the Fiscal Research Division, by Feb. 15, 2016 (House Bill 97, 2015).

Between October 2015 and January 2016, DCM staff developed the following report based on: 1) a review of relevant literature, prior reports and recommendations based on stakeholder engagement; 2) a field trip to Charleston, SC, to study an innovative structural approach to mitigating beach erosion, and 3) staff experience in measuring shoreline changes and trends, permitting beachfront development and engineering projects, and policy analysis in support of rulemaking by the N.C. Coastal Resources Commission. DCM also issued a public notice inviting interested parties to submit input on the study. Unfortunately, due to time constraints DCM was not able to make a draft of this study available for public review, nor to incorporate comments into the document. Nevertheless, DCM received valuable written comments and supporting documents from stakeholders, totaling over 300 pages, and the complete package of comments is appended.

1.0 Beach Erosion

Beach erosion is the loss or displacement of sediment (sand) along the state's coastline due to the actions of waves, currents, tides, winds, or human-caused actions. While many segments of North Carolina's oceanfront shoreline are affected by some degree of erosion, some segments are actually widening, or accreting. Coast-wide, long-term trends reveal that many of the state's barrier islands would naturally migrate inland, or towards the mainland, while short-term changes often reveal effects caused by storms and may not always be consistent with these long-term, gradual trends.

Although many factors influence rates of short- and long-term shoreline change, storm intensity and frequency have the most noticeable impacts on the state's oceanfront shorelines. During storms, large waves remove sand from the active beach and frontal dunes, transferring it to nearshore areas to form sandbars. Sandbars are enlarged by this process and serve to dissipate wave energy, which in turn helps to reduce beach erosion and eventually supports the natural rebuilding of the frontal dune over time. When weather conditions are calmer, usually in the summer months, small waves move sand back up onto the beach. This is primarily a seasonal process, with harsher winter storms removing beach sand and steepening the beach "profile," while calmer summer waters push sand back onto the beach and lower the beach profile.

In addition to sediment supply and underlying geology, a barrier island's orientation also explains regional differences in shoreline change rates. Northeast-facing shorelines, such as those along N.C.'s Outer Banks, are more susceptible to significant erosion on a frequent basis due to storm frequency, duration, and intensity of northeaster storms, whereas shorelines that do not face northeast may be subject to damage only from a specific subset of tropical storms or hurricanes.

Proximity to ocean inlets and capes is also a key factor in predicting short- and long-term rates of beach erosion or accretion. Some ocean inlets migrate in one direction over time, while most oscillate back and forth within a small region. These highly dynamic areas are subject to rapid changes in erosion or accretion, and are also subject to human influences from dredging operations, inlet relocation projects, and/or inlet stabilization structures. Based on DCM's past analyses, shoreline change rates within the vicinity of inlets and capes are typically higher, and show a general decrease moving farther away from these features. Erosion rates within two miles of inlets are typically higher and show a general increase toward the inlet than erosion rates farther away from inlets. Variation in rates through time is also generally higher near inlets.

Knowing how much erosion is occurring over time is an important first step in developing a mitigation strategy. The federal government and academia have studied erosion in North Carolina on a site-specific scale dating back as early as the mid-1800s. The state has been calculating oceanfront shoreline change rates since the early 1970s, and in 1979, the Coastal Resources Commission adopted the state's first long-term average annual shoreline change rates for use in calculating oceanfront construction setbacks. The CRC has continued to update oceanfront shoreline change rates approximately every five years, with the most recent rates becoming effective in 2013. Calculating the shoreline's position changes over time, and applying that knowledge to policy in the form of local construction setbacks, has been a coastal erosion mitigation strategy implemented by the CRC since 1980. Some local governments have also established long-term monitoring programs that measure changes in beach profiles and shoreline positions.

As pointed out in a 1971 study of shoreline changes within the National Park Service in North Carolina, "*shoreline and dune erosion is the rule, not the exception, along the coast of North Carolina*" (Dolan R. , 1971). The extent or magnitude of ocean shoreline erosion is most noticeable where it occurs relative to manmade structures and infrastructure. Regardless of the causes, the consequences of long-term erosion and island migration are indisputable realities that coastal managers and policy makers will have to consider well into the future. Historical response has been the placement of sandbags for short-term protection, and beach nourishment for longer-term protection; however, these techniques do not eliminate the cause or long-term threat. The 1984 Coastal Resources Commission's Outer Banks Erosion Task Force identified three areas on the Outer Banks where erosion was significantly threatening structures: a three-mile stretch along South Nags Head; a one-mile stretch along Kill Devil Hills, and to a lesser degree, portions of Currituck Banks. Today, these same areas, along with many others, are continuing to struggle with beach erosion.

The Cape Hatteras Lighthouse, which was constructed in 1853, is North Carolina's most well-known response to beach erosion (Figure 1). The lighthouse once stood 1,500 feet from the ocean's edge, but by 1987 it stood only 160 feet from the Atlantic Ocean, documenting an average annual long-term erosion rate of approximately 10 feet per year. In 1999, the lighthouse was moved 2,900 feet inland (Figure 2).

Figure 1. Cape Hatteras Lighthouse (1893). Photo: National Park Service

Figure 2. Cape Hatteras Lighthouse after being moved (1999). Photo: National Park Service

The Morris Island Lighthouse located in South Carolina was constructed in 1876, and at that time stood approximately 1,200 feet from the water's edge (Figure 3). After constructing the Charleston Harbor jetties in 1889, sediment transport was disrupted, ultimately starving the downdrift area of sediment and causing the shoreline to erode hundreds of feet landward, leaving the lighthouse totally surrounded by water (Figure 4).

Figure 3. Morris Island Lighthouse, S.C. in 1893 just after construction was completed. Notice marsh in the foreground, and maritime forest in the background. Photo: U.S. Coast Guard

Figure 4. Morris Island Lighthouse (2007). Photo: SaveTheLight.org

Key public infrastructure is also at risk from beachfront erosion. For example, North Carolina's Highway 12 on the Outer Banks was first paved nearly 67 years ago, is approximately 110 miles long, and serves the public as the only road linking communities along the entire Outer Banks (Figure 5). The most recent storm to impact Highway 12 occurred on February 7, 2016, once again demonstrating how susceptible Highway 12 is to the forces of storms, and is in frequent need of repair (Figure 6).

Figure 5. N.C. 12 at Mirlo Beach in Dare County (2011)

Figure 6. Dune breach and overwash along N.C. 12 following a February 7, 2016 storm. Photo: Hyde County Emergency Services

Another example that illustrates significant erosion over a relatively short period of time is the Fort Fisher Confederate fortification at Fort Fisher State Park. Constructed in 1861-1862, Fort Fisher is currently only half its original size due to beach erosion. From the time of its construction to 1968, the shoreline retreated landward approximately 600 feet (Figure 7). In the 1950s, this loss forced the realignment of Highway 421, and the construction of a small revetment in the area called "Battle Acre." As a means to further protect the property and the highway from erosion, the N.C. Department of Transportation added a second stone revetment in 1969-1970. In 1995, the state and USACE added a multi-layered rubble revetment with tie-ins to natural ground.

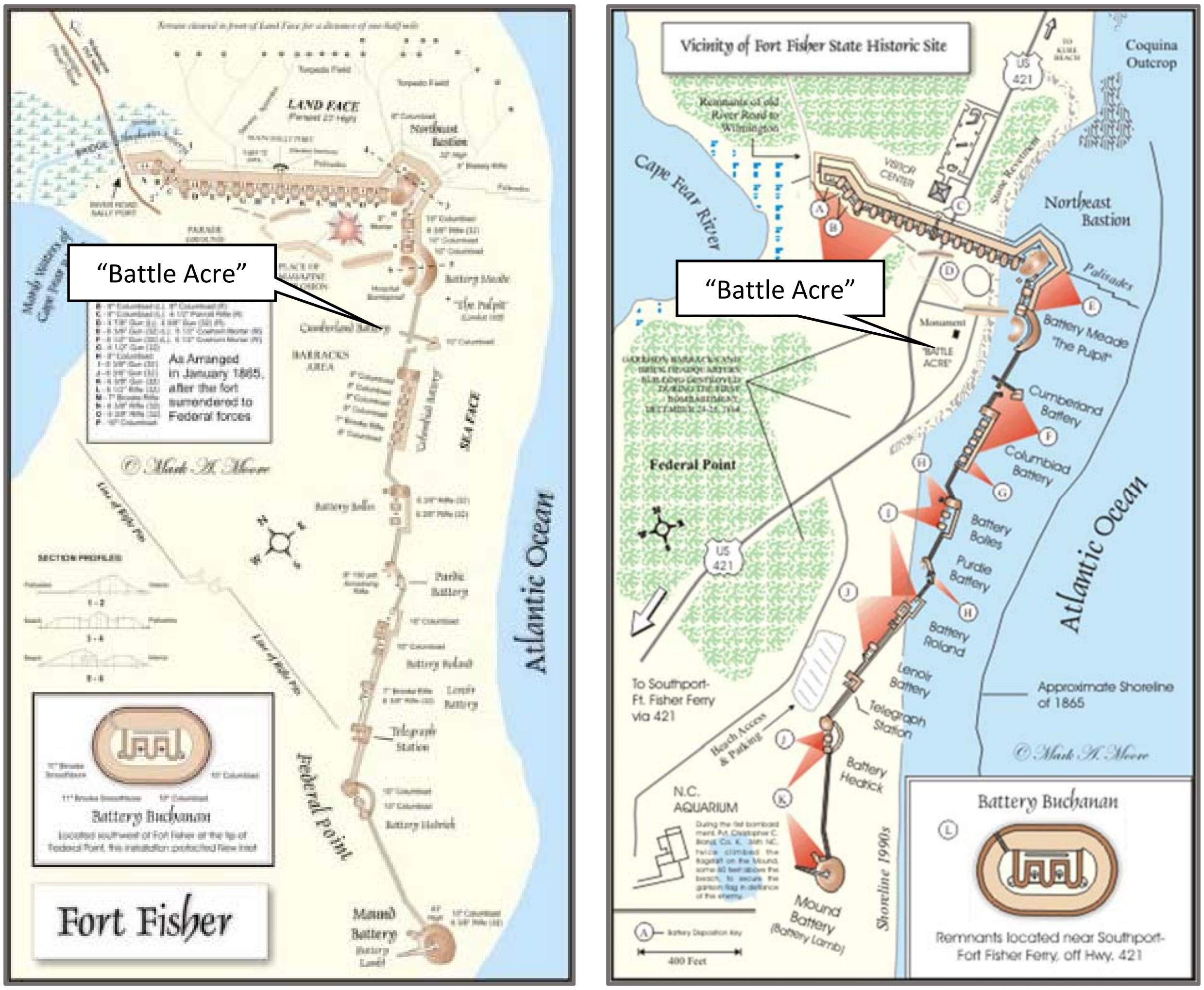

Figure 7. Fort Fisher Confederate Fortification shoreline comparison. Image on the left illustrates where the shoreline was in 1865, and the image on the right illustrates how change has occurred since. Photo: N.C. State Parks

Not all portions of North Carolina's shoreline are eroding. Long-term accretion and/or lower erosion rates are more likely to occur along the southern half of N.C.'s coast, where more barrier islands are south-facing and generally protected from the effects of northeasters. For example, at Sunset Beach, N.C. some segments of the shoreline have experienced long-term average shoreline change rates measuring accretion at plus eight (+8) feet per year since the mid-1940s (NC Division of Coastal Management, 2011). Although inlet areas and capes can experience the highest erosion rates on North Carolina's coast, they can also have the highest rates of accretion. For example, at Topsail Beach, the island's shoulder adjacent to New Topsail Inlet has benefited from accretion due to inlet migration and has accreted hundreds of feet within one year, while Lea-Hutaff Island's shoulder side of the inlet has experienced high erosion rates (Figure 8 and Figure 9). However, accretion at these locations can be short-lived due to the high energy conditions at these locations and changes in inlet dynamics.

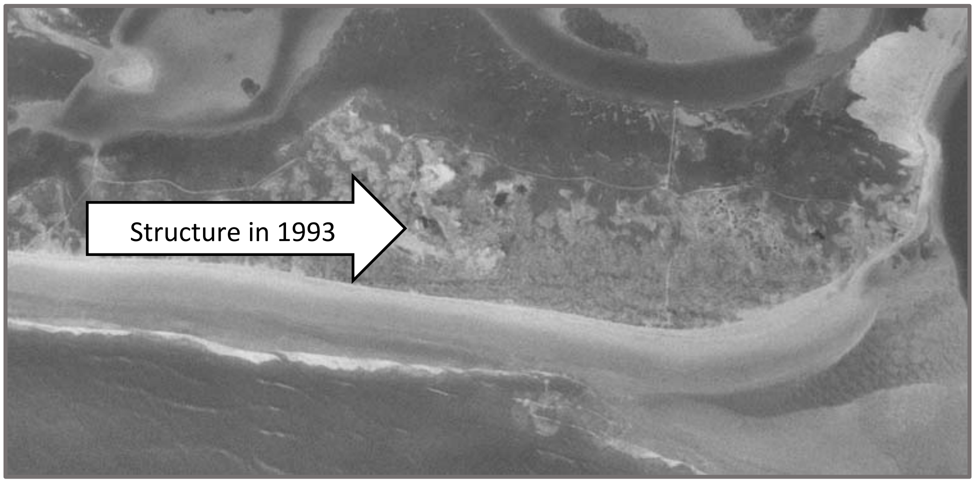

Figure 8. Constructed on Lea-Hutaff Island, N.C. in 1990, this private home sat 500 feet from the ocean. (Photo source: Google Earth 1993).

Figure 9. In 2014, the same structure identified in Figure 7 sat on the ocean's edge at low tide until finally being destroyed by a storm in 2015 (Photo source: Google Earth 2014).

While scientific understanding of coastal processes and their effects on shoreline change are better understood, it is still difficult to predict short- and long-term changes in shoreline position. This complicates management decisions, because implementation of a cost-effective solution for a temporary erosion problem can be different than the best solution to offset a long-term trend. Before mitigation strategies can be fully developed, there is an ongoing need for systematic (regular monitoring), comprehensive information (*e.g.*, sediment transport rates, sediment budgets, topographic and bathymetric data, identification of future sand sources and sand demand) to effectively deal with site-specific erosion problems.

1.1 The Natural System

The constant shifting of sand along North Carolina's oceanfront presents a fundamental challenge for predicting how the shoreline will respond. A valuable tool for managing ocean shorelines is understanding sediment budgets, or the amount of sand that moves in and out of, or is stored within a beach system (Komar, 1996). When the sediment budget becomes unbalanced, the shape or position of the shoreline is affected. Erosion occurs when sediment is removed from the beach faster than it is deposited. An important part of the sediment budget are its sources and sinks that feed sand back into the system. "Sinks" are where sediment is lost to the active beach, and "transport pathways" along which sediment is exchanged between different parts of the coastal system. In North Carolina, inlet complexes (ebb and flood tide deltas) serve as both a source and sink. Because sand is always moving, an accurate estimate of sediment gains and losses is difficult to determine, particularly along a coastline with numerous sources and sinks (Barnhardt, et al., 2009).

In the short-term, fair-weather conditions generally promote landward movement of sediment from the lower shoreface and beach system. Just offshore, this process can create areas where sediment is scarce, resulting in exposing rock (hardbottom). Once exposed, these areas are subject to forces that continue to wear them down, providing relatively small but significant quantities of new sediment that are incorporated in the active beach system (Riggs, Ambrose, Cook, & Snyder, 1998).

During high-energy conditions, waves and currents remove sand stored in the dunes and beach and transport it offshore. When waves break at an angle to the shoreline, part of the wave's energy is directed along the shore. These "longshore currents" flow parallel to the shore, moving sand along and influencing how the beach will accrete or erode. During large storm events, it is possible for sediment to be transported far enough offshore that it is no longer in the active nearshore sediment budget, thus reducing the ability of natural processes to restore the beach.

Seasonal movement of sand away from the beach can temporarily bury the hardbottom areas of the shoreface. Stripped of sand cover, rocks on the upper shoreface are eroded and contribute some new sediment to the active beach system. When fair weather returns, sediment on the lower shoreface is driven back onto the upper shoreface and beach, and if enough time passes between storm events, reestablishment of the berm and dunes can occur. The balance of this process, along with gains and losses of longshore transport, determines whether there is erosion or accretion of a particular stretch of beach. As a result of this constant shifting, the beach and its underlying rocky foundation wear away, and the beach and shoreface migrate landward as a system (Riggs, Ambrose, Cook, & Snyder, 1998).

Sediment in the active beach system is derived from multiple sources: 1) erosion of upland rivers, 2) longshore transport from adjacent coastal compartments, 3) erosion of older beach and shoreface deposits, and 4) erosion of older deposits on the inner shelf. Studies suggest that a considerable portion of sediment in the modern coastal system is derived from erosion of older materials underlying the inner shelf (offshore). One 1995 study by Wehmiller, York, and Bart provided evidence of this process by showing that up to 75% of clam shells found on beaches in the Atlantic coast region are actually fossils. Another study calculated that bio-erosion of hardbottom in Onslow Bay yields as much as 5.5 kilograms per square-meter (kg/m^2) of new sediment each year (Riggs, Ambrose, Cook, & Snyder, 1998). Large waves associated with storm events can then transport these sediments to the near shore system.

As stated earlier, North Carolina's inlets are dynamic coastal features that function as reservoirs, temporarily storing and releasing sediment within the regional system. Net changes in the volumes of sediment contained in the inlet system strongly affect the stability of adjacent beaches over the short-term. The degree of erosion and accretion that occurs in areas adjacent to inlets is highly variable, and can be easily influenced by subtle changes in orientation of the inlet's main and marginal channels, or position of sandbars and shoals within the flood and ebb-tide deltas. Further research into sediment budgets on a sub-regional scale is needed to increase understanding of why accretion and erosion might occur in a specific area.

1.2 Human Influences

Human influences such as dredging, beach nourishment, inlet relocation and shoreline hardening collectively affect how natural processes respond and shape the state's coastal shorelines. Hardened structures (*e.g.*, groins, bulkheads, jetties, seawalls, and revetments) reflect wave energy and often result in accelerated erosion along their seaward side and on adjacent properties. Jetties, groins, and breakwaters also act as sediment traps as sand moves along the shoreline; thus causing sand starvation in the sediment budget on the downdrift side of the structure.

Generally, there are two categories of erosion control structures that serve two separate purposes: *shore protection* and *erosion control*. Shore protection structures armor the shoreline to prevent it from retreating as a result of chronic erosion, but may not stop erosion because wave reflection will likely transfer wave energy around the structure's flanks. Erosion control structures are intended to change the conditions that are causing erosion with the intent of slowing or stopping it (The American Shore & Beach Preservation Society, 2013).

Permanent erosion control structures can be engineered to offer a degree of erosion protection for a period of time. However, there is a tradeoff as engineered structures placed in the coastal system will interfere with sediment transport, and they will likely cause erosion in adjacent areas. The presence of the structure can have a series of effects:

- Trapping of sand on the updrift side of the structure interfering with sediment transport along adjacent shorelines.
- Loss of sand to deep water because the water-land interface is blocked (*e.g.*, bulkhead).
- Trapping of sand in entrance channels and outer harbors.

Both accretion and erosion patterns adjacent to engineered structures also depend on these factors:

- The type of coastline (*i.e.*, ocean, estuarine), wave climate and orientation of the shoreline.
- The extent of the structure relative to the width of the surf zone.
- The detailed shape of the coastal structure.

Seawalls, bulkheads, and revetments are structures that generally run parallel to the land-water interface, and are designed to prevent erosion by fixing the position of the shoreline. When waves hit a solid surface, such as a seawall, the wave energy is reflected back towards the ocean, which causes scouring and further removal of sediment from the waterward side of the structure and nearshore system. These structures can also cause increased erosion ("flanking erosion") on adjacent property by reflecting energy near its ends causing sediment loss to accelerate. While common on soundside shorelines, these structures are currently prohibited along the state's ocean shoreline (N.C.G.S. §113A-115.1). One exception is the revetment constructed to protect historically significant property at Fort Fisher State Park.

Groins are constructed perpendicular to the shoreline, and designed to prevent erosion by trapping sand. These structures disrupt littoral transport causing a deficit in the littoral drift budget, which results in sand build up, or accretion, on the updrift side of the structure. This disruption in sediment transport comes at an expense to the downdrift side where erosion is likely to increase. For this reason, groins are often built in series along the shoreline known as a "groin field," like those initially installed along the Cape Fear Inlet at the Village of Bald Head Island (Figure 10). The groin field at Bald Head Island was first installed via a variance from the CRC's rules in 1996 in conjunction with a beach fill project, and later replaced with newer sand-filled tubes in 2005. Post-installation (April to November 2006) monitoring indicated that modest losses of sediment occurred (-7,700 cubic yards) (Land Management Group & Olsen Associates, 2008), and that the structure had performed as expected. The efficiency of a groin field is generally dependent on the length of the groins relative to the width of the littoral zone, and the number and spacing of the groins.

Figure 10. Groin field installed in 2005 at Village of Bald Head Island. Photo: NCDCM, 2007

Terminal groins are hardened structures constructed at a barrier island's terminus (at an inlet), and are designed to prevent erosion by fixing the position of the end of the island. Effectiveness of these structures depends on height and length, and the coastal dynamics affecting the shoreline where the groin is installed. Although modeling during the pre-construction phase can help understand how natural processes will be influenced, it is not until post-construction that impacts can be both seen and measured. Currently, North Carolina has three terminal groins: one newly constructed at Bald Head Island at the entrance to the Cape Fear Inlet/River, one at Fort Macon State Park at the entrance to Beaufort Inlet, and one at Oregon Inlet protecting the Bonner Bridge at Pea Island.

Jetties, like those at Masonboro Inlet, are similar to groins in that they are typically perpendicular to the shoreline and are constructed of rock material. These structures are generally longer than groins and designed to protect navigational channels (at inlets) rather than to prevent shoreline change or protect structures. Jetties also obstruct littoral transport, meaning that the updrift side of the structure will experience sand accumulation, while the downdrift side will experience erosion due to sediment starvation. Because jetties affect the sediment budget within the natural system, jetties are often constructed in association with a "sand bypass" plan to dredge the inlet channel and nourish the shoreline on the downdrift side.

Breakwaters are large piles of rock or other material constructed parallel to the land-water interface and designed to block, or reduce, wave energy from reaching the shore. These structures are generally designed to provide calm waters for harbors and marinas. Several North Carolina Ferry Terminals have breakwaters installed to protect soundside docking facilities from high-energy conditions, and reduce frequency of dredging channels leading into the terminal. Detached breakwaters are used as shore protection and installed parallel to the shoreline inside or close to the surf zone. A detached breakwater provides shelter from the waves, whereby the littoral transport behind the breakwater is decreased and the transport pattern adjacent to the breakwater is modified. Because wave energy is interrupted, sand often fills the area between the breakwater and shoreline, and the result can be downdrift erosion due to interruption of longshore transport of sand.

Along the state's 326 miles of oceanfront and inlet shorelines, there are eleven hardened structures, most of which pre-date the Coastal Resources Commission's 1985 prohibition on permanent erosion control structures (later codified in the Coastal Area Management Act). Most recently, a terminal groin was constructed at the Village of Bald Head Island and permitted pursuant to recent legislation (Session Law 2011-387) (Figure 11).

Figure 11. Terminal groin being installed at the Village of Bald Head Island in 2015. Photo: Village of Bald Head Island, 2015

2.0 Historical Shoreline Change

When the last period of glaciation ended between 14,000 and 18,000 years ago, sea level was approximately 300 feet lower that it is today, and North Carolina's shoreline was 50 to 75 miles seaward of its present position (Emory, 1968). With the change from glacial to interglacial conditions marking the transition from Pleistocene to Holocene, sea level began rising. With the rising seas, the shoreline responded by moving across the Continental Shelf and pushing large masses of sand in the form of beach deposits with it. When the rate of sea-level change slowed approximately 4,000 years ago, waves, currents, and winds reworked the sand to form the beaches and barrier islands we see today (Dolan & Lins, 2000).

The rate at which sea level is rising has been the focus of much debate in recent years. Regardless of the rate, sea level is rising and North Carolina's barrier islands are still responding just as they have for thousands of years (N.C. Coastal Resources Commission Science Panel, 2015). In response to rising water levels and storm events, the Atlantic coast of the U.S. experiences on average annual erosion rates between two and three feet per year (H. John Heinz III Center for Science, 2000). This average is consistent with shoreline change rates calculated for the state by the N.C. Division of Coastal Management (NC Division of Coastal Management, 2011). The next DCM erosion rate update is scheduled to begin in 2016.

2.1 North Carolina's Erosion Studies

North Carolina has been measuring rates of shoreline change for the purpose establishing oceanfront construction setback factors used in the siting of oceanfront development for nearly 40 years. Although site-specific studies occurred prior to 1979 (Wahles, 1973), it wasn't until that year that the Division of Coastal Management completed its first erosion rate study (Tafun, Rogers, and Langfelder, 1979), and subsequently provided update studies approximately every five years.

DCM calculates shoreline change rates by measuring the distance between an early and most recent shoreline, then divides distance by time to calculate average rates of change. Most shorelines used in current studies are based on aerial images that were digitally orthorectified to ensure a high degree of mapping accuracy. DCM uses the most advanced mapping and computation software available; however, the fundamental techniques for measuring beach erosion using data derived from aerial photographs were first developed and applied to the North Carolina coast in 1968 (Stafford, 1968), with techniques from that study still in use today. It should be noted that the calculations used by DCM to document long-term shoreline change are influenced by repeated beach nourishment projects, since a recently renourished shoreline position may be similar to the historic shoreline position. This can result in an artificially low rate of shoreline change, and mask the underlying rate of erosion and changes in beach profiles. For example, calculations for barrier islands such as Atlantic Beach, Pine Knoll Shores, Indian Beach/Salter Path, Emerald Isle, Wrightsville Beach, Kure and Carolina Beaches, Caswell Beach, and Ocean Isle all demonstrate less than average long-term average annual rates.

The following summarizes past DCM studies, which included opportunities for public review and comment and were approved by the N.C. CRC:

- **1979 NCDCM Study:** Measured long-term average annual shoreline change rates between 1930s and 1977. This study did not include Currituck, Dare and Hyde Counties. Rates were adopted by the CRC on July 15, 1979.

- **1980 NCDCM Study:** Measured long-term average annual shoreline change rates between 1930s in Currituck, Dare, and Hyde Counties using Dolan's 1980 data, and were amended to the 1979 results generated by Tayfun and Rogers. Rates were adopted by the CRC on June 1, 1980.
- **1983 NCDCM Study:** Measured long-term average annual shoreline change rates updated to 1980. This was also the first statewide update using a data set spanning the entire oceanfront shoreline. Rates were translated into oceanfront construction setback factors and became effective on March 18, 1983. On Nov. 18, 1983, the CRC also modified its rules to specifically reference this study, thus requiring rule updates with each consecutive study, and also added large structure setback requirements to their rules. Earlier, the rule had just referenced "the most recently approved rates by the CRC." Sixty-one percent (61%) of the shoreline analyzed in this study measured shoreline change rates at -2 feet per year or less, and 21% measured erosion rates between -2.5 and -5 feet per year.
- **1986 NCDCM Study:** Measured long-term average annual shoreline change rates to 1986. Rates were translated into oceanfront construction setback factors and became effective on Nov. 1, 1988. This study used the same method used in the 1980 study with the exception of the smoothing interval. In 1980, data were smoothed over 31 transects 100 meters apart, while this study smoothed over 17 transects, 50-meters apart. Like the previous study, 61% of the shoreline analyzed in this study measured shoreline change rates at -2 feet per year or less, while 18% measured erosion rates between -2.5 and -5 feet per year.
- **1992 NCDCM Study:** Measured long-term average annual shoreline change rates to 1992. Rates were translated into oceanfront construction setback factors and became effective on April 01, 1997. Fifty-nine percent (59%) of the shoreline analyzed in this study measured shoreline change rates at -2 feet per year or less, and 19% measured erosion rates between -2.5 and -5 feet per year (Overton and Fisher, 1997).
- **1998 NCDCM Study:** Measured long-term average annual shoreline change rates to 1998. Rates were translated into oceanfront construction setback factors and became effective on Jan. 1, 2004. DCM funded work to acquire 1998 oceanfront imagery, while the early shoreline was derived from National Oceanographic Survey Topographic maps (NOS T-sheets) and were rectified by N.C. State University. Sixty-two percent (62%) of the shoreline analyzed in this study measured shoreline change rates at -2 feet per year or less, and 20%) measured erosion rates between -2.5 and -5 feet per year (Overton and Fisher, 1998).
- **2011 NCDCM Study:** Measured long-term average annual shoreline change rates to 2009. Rates were translated into oceanfront construction setback factors and became effective on Jan. 31, 2013. This study used the same early shoreline from the previous study, and 2009 USDA National Agriculture Imagery Program (NAIP) photos to digitize the 2009 shoreline. Like the previous study, 62% of the shoreline analyzed in this study measured shoreline change rates at -2 feet per year or less, and 20% measured erosion rates between -2.5 and -5 feet per year.

2.2 Long-Term vs. Short-Term Studies

In North Carolina, short- and long-term rates do not necessarily correspond for a variety of reasons. In 2000, the U.S. Geological Survey (USGS), East Carolina University (ECU), and N.C. Geological Survey (NCGS) established the Coastal Geology Research Cooperative to examine the coastal geology of North Carolina between Cape Lookout and Currituck County, and also compare short- and long-term shoreline change rates.

Baseline data used in the study were initially collected by U.S. Army Corps of Engineers (USACE) (1960 to 1962), Godfrey and Godfrey (G&G, 1962 to 1971), and then supplemented by ECU in 2001. Data from each were compared in order to examine temporal differences (short-term vs. long-term).

ECU's data (1960 to 2001) compared short-term and long-term rates to both studies by the USACE and G&G, and to NC DCM's long-term data (1940's to 1998). Integration of USACE's, G&G's, ECU's, and N.C. DCM's shoreline change rate data for Core Banks shows several important points about shoreline recession:

1. ECU's and DCM's data demonstrated that there is an ongoing net, long-term, but small-scale shoreline recession associated with the Core Banks;
2. The USACE short-term data demonstrates that processes associated with individual storm events, or sets of events, produce extremely large-scale changes that include both erosion and accretion;
3. The short-term, non-stormy period data set of G&G demonstrated that if given enough time between storms, barrier islands can rebuild, to some degree, to their pre-storm period conditions; and
4. The post-storm response generally tends to approach the pre-storm location, but rarely reaches it before the next storm or stormy period sets in.

As the 2000 Coastal Geology Research Cooperative study demonstrated, short- and long-term rates can and do differ. Depending on design, engineering practices (dredging and erosion control structures) can have a significant influence on short-term erosion; however, in North Carolina, it is storm intensity and frequency that have the greatest influence over short-term changes. Like short-term erosion, storms do influence long-term erosion as well – differences can be attributed to beach nourishment and natural post-storm accretion occurring during periods of reduced storm activity.

2.3 Regional Variation

North Carolina's oceanfront is made up of two distinct zones that vary in geology and coastal processes. The Southern Coastal Zone (south of Cape Lookout) is characterized by a relatively steep land slope compared to the gentler slope of the Northern Zone (north of Cape Lookout) (Riggs, et al., 2008). The steeper slope of the Southern Zone produces short, stubby barrier islands separated by a series of inlets that hug the mainland shoreline and is considered to be sediment-poor, while the gentler slope of the Northern Zone produces long barrier islands, and broad expanses of drowned-river estuaries (Albemarle and Pamlico estuary systems).

Additional zones can also be delineated within the two primary zones at the state's capes, or cuspate embayment (Cape Fear, Cape Lookout, and Cape Hatteras) (North Carolina Beach and Inlet Management Plan (NC BIMP), 2011) (Figure 12). The shape and orientation of each compartment determine how wave and current dynamics, tidal, and storm-tide characteristics influence shoreline changes.

Barrier islands in all regions form and evolve based on four physical criteria: 1) the presence of a gently sloping coastal plain-continental shelf; 2) availability of adequate sediment; 3) sea level; and 4) the occurrence of high-energy storms that build islands and maintain them through time. Because of these various complex factors, erosion and accretion rates will not only vary regionally, but can vary significantly within a two-mile stretch on the same barrier island (NC BIMP, 2011).

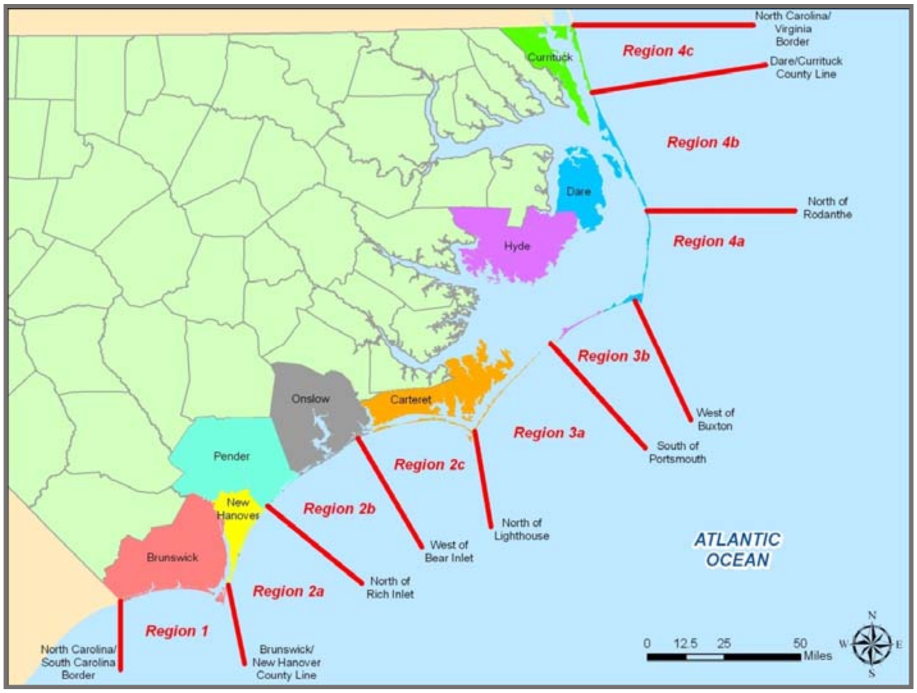

Figure 12. Beach and Inlet Management Plan (BIMP) regions.

2.4 Forecasting Shoreline Change

The Division of Coastal Management's erosion rate studies do not forecast future beach erosion, since many factors cause shoreline position to change in time and space. This includes geological settings of the coast, which affects the quantity and quality of available sediment; coastal processes such as waves and currents that move the sediment; human modifications to the coast such as jetties, groins, and beach nourishment; and changes in sea level; collectively determining the location of the shoreline's position. Although DCM does not attempt to predict future changes, understanding historic long-term trends of shoreline movement are important scientific and management objectives because of the importance of coastal beaches for recreation, tourism, storm protection, and ecosystem services (Massachusetts Coastal Erosion Commission, 2015).

While forecasting shoreline change has been an important area of research that has been advanced by improved technology and data accuracy, coastal scientists continue to research how understanding historical records could be applied to predicting the future. There are two approaches to consider when forecasting: 1) statistics-based, and 2) process-based.

Statistics-based shoreline change forecasting relies exclusively on historical observations of shoreline position and movement over time, and forecasting changes based on different statistical techniques. Process-based shoreline change forecasting uses not only historical observations of shoreline position, but also observations and defining parameters of processes that are principal drivers of shoreline change. Most commonly, this process is referred to as modeling, which is an attempt to describe a time-varying forcing-response relationships.

Each of these approaches makes a number of assumptions that constrain their utility in North Carolina at this time, including: 1) things that limit the ability of the shoreline to move (*e.g.,* underlying geology or construction of groins and jetties); 2) sediment availability is often modeled as unlimited; 3) there is a constant background trend; and 4) the processes being modeled does not sufficiently capture potential future changes resulting from storms or engineering practices (Massachusetts Coastal Erosion Commission, 2015).

3.0 Mitigation & Prevention - Responses to Erosion

Most of the beachfront development as we know it today did not begin until the early to mid-1900s. Typically starting on the most stable portions of barrier islands, early beach cottages were constructed on pilings and periodically relocated landward when threatened by erosion. Today, much of North Carolina's oceanfront is already developed and/or expensive property, which makes building relocation a less desirable or available option in many cases.

Government involvement in beach erosion projects began in the late 1930s with the building of barrier island dunes from Virginia to Ocracoke. While these dunes, or berms, have not been effective at preventing long-term erosion, they were able to reduce the frequency of overwash events long enough to allow vegetation to grow and stabilize much of the interior portions of the islands. In the 1960s, Congress authorized the U.S. Army Corps of Engineers to conduct a national study on erosion and flood problems, and as a result another berm project for the developed portions of the northern Outer Banks was proposed. This project was never built due to issues with funding. However, two federal beach nourishment projects associated with that effort were constructed: one at Carolina Beach and the other at Wrightsville Beach.

When considering mitigation alternatives, experiences from past storms should be considered to guide decision making. Beginning with Hurricane Opal in October 1995 and ending with Hurricane Fran in September 1996, North Carolina experienced five presidentially declared disasters within a 12-month period. As a result, Governor Hunt formed a Disaster Recovery Task Force in October 1996 to develop a comprehensive set of recommendations to facilitate the state's recovery. The N.C. Division of Emergency Management (NCDEM) published a Mitigation Strategy Report that included a recommendation that "*…recovery after Hurricanes Bertha and Fran should be viewed as an important window of opportunity for advocating and achieving the use of sound mitigation techniques to better prepare for the next storm.*" NCDEM's recommendations were based on community site visits, discussions with county emergency management personnel, interviews with local public officials, information obtained during statewide Hazard Mitigation Grant Program Workshops, and information generated by other federal and state agencies (NC Division Emergency Managment, 1997). It was determined that storm surge caused most of the destruction, particularly in areas where construction standards were pre-Flood Insurance Rate Maps (FIRM), and those with enclosures below the Base Flood Elevation (BFE). The debris from destroyed homes further battered nearby structures, significantly magnifying the damages. Structures were also particularly vulnerable to storm surge due to the destruction of the protective frontal dune system from Hurricane Bertha. The recommendations also included a review of the CRC's hazard mitigation rules and Ocean Hazard Areas. Specifically, the CRC was requested to evaluate the methodologies used to delineate hazard areas, including an assessment of erosion rate calculations, setback requirements and accuracy of ocean, flood and inlet hazard area delineations.

Historically, beach nourishment, structure relocation, and sandbags have typically been used to protect infrastructure and homes. In 1985, the CRC studied the effects of hard erosion control structures and concluded that the potential negative effects associated with hard structures on the oceanfront could cause irreversible damage to N.C.'s beaches, and recommended that they be prohibited. In 2003, the N.C. General Assembly voted unanimously to formally adopt the hard structures ban as a law and incorporated the prohibition on permanent erosion control structures into the Coastal Area Management Act.

In 2008, the N.C. Senate passed a bill to allow terminal groins, but the bill did not gain support in the N.C. House. However, the N.C. Legislature did direct the CRC to conduct a study on the feasibility and advisability of the use of terminal groins as an erosion control device (Session Law 2009-479). Through that study, it was determined that terminal groins, in combination with beach nourishment, can be effective at controlling erosion at the end of barrier islands. They can likely protect some property at risk but not all properties. However, the individuality of inlets would require site-specific analysis. The construction and maintenance of terminal groins is very expensive and removing them, if necessary, would be both expensive and disruptive to natural resources. Inlets also provide sediment to build up the backside of barrier islands, a vital function in the natural maintenance of these islands.

The study findings were mixed regarding the effects of terminal groins on wildlife habitat and marine resources, so the CRC made recommendations for specific conditions to be placed on the use of terminal groins for erosion control. The conditions included avoiding interruption of natural sand movement, providing notice to adjacent property owners likely to be affected, requiring local financial assurances to cover the cost of structure removal and restoration activities, establishing monitoring requirements, and requiring a long-term shoreline management program including beach nourishment.

In 2011, Session Law 2011-387 (SB110) amended CAMA to allow up to four terminal groin pilot projects to be built in North Carolina. Projects have subsequently been proposed at Figure Eight Island, Ocean Isle Beach, and Holden Beach. One project has already been permitted and constructed at Bald Head Island, as described earlier in this report. In 2015, Session Law 2015-241 contained provisions allowing two more terminal groins, bringing the total to six.

3.1 Shoreline Hardening & Structural Approaches

Since 1985, the CRC has prohibited oceanfront shoreline armoring with exceptions granted for the purpose of safeguarding key public infrastructure, historically significant landmarks, or a regionally significant commercial navigation channel (15A NCAC 7H.0308(a)(1)(H).

As described earlier, permanent stabilization techniques along high energy ocean shorelines may accelerate erosion in some locations along the shore resulting in alteration of longshore sediment transport (NCCHPP 2010; Defeo et al. 2009). The resulting hydromodifications may modify sediment grain size, increasing turbidity in the surf zone, as well as narrowing of beaches. This reduced intertidal habitat may affect the diversity and abundance of macroinvertebrates (NCCHPP 2010; Walton and Sensabaugh 1979; NRC 1995; Dolan et al. 2004: 2006; Pilkey et al. 1998; Peterson et al. 2000a; Miles et al. 2001; Dugan et al. 2008; Walker et al. 2008; Riggs and Ames 2009). The use of terminal groins to anchor inlets may also prevent shoal formation and reduce the size of ebb tidal deltas, which are important foraging grounds for many fish species. Due to the potential damage that hardened structures can have on recreational beaches and the intertidal zone, at least four states along the U.S. Atlantic shoreline have prohibited oceanfront shoreline armoring, including Maine, Rhode Island, South Carolina, and North Carolina.

3.1a Bulkheads and Seawalls

Bulkheads, seawalls (larger, more permanent bulkheads), and revetments (seawalls made of stone or rubble) are designed to prevent a change in the shoreline location, and specifically designed to protect public infrastructure, culturally significant areas, and homes and property. They do not protect the beach, and can instead increase beach erosion in front of the structures and transfer or accelerate erosion problems on the structure's flanks. They also interfere with the movement of sand between the dune and offshore bar, an important natural beach energy dissipation process during storms and winter seasons.

At the expense of maintaining the dry sand beach, bulkheads are engineered to provide protection to the infrastructure or structures on the landward side for several generations. The Galveston, Texas seawall (Figure 13), N.C. Fort Fisher State Park rock revetment (Figure 14) and several structures in New Jersey are examples of permanent shoreline hardening. However, if the beach is to be preserved, shoreline hardening must be accompanied by long-term beach nourishment. If a seawall is designed to last 50 years, preserving the beach will require regular nourishment with the amount of maintenance nourishment depending on the specific beach and other factors at each site.

Figure 13. Seawall in Galveston, Texas. Photo: USACE, 2005

Figure 14. Fort Fisher State Park, N.C. rock revetment. Photo: NCDCM

In the Isle of Palms, South Carolina, an experimental, or “innovative” approach to manage erosion is currently being tested. The structure is called a “wave dissipation system” that is theoretically designed to dissipate wave energy while allowing water and sediment to flow back and forth between horizontal, flexible pipes, and is intended to simulate the flow of an unobstructed beach. Because the structure “allows water and sediment to pass through it,” it is also theoretically designed not to exacerbate erosion on its flanks (Figure 15, Figure 16, and Figure 17).

One observed benefit is that the “wave dissipation system” can be easily installed/uninstalled as long as a construction crew and their equipment can access the installation site. However, on a November 2015 site visit by NC DCM, the structure visually appeared to be functioning as one might expect most shore-parallel erosion control structures to perform: sand appeared to be retained on the landward side, with accelerated loss of the sand beach on the oceanward side of the structure (Figure 17). Again, the structure is still in testing, so it may be too early to draw any conclusions. The South Carolina Office of Ocean and Coastal Resource Management is monitoring and assessing the structure for efficacy and impacts through January 2016.

Figure 15. Experimental erosion control structure installed at land-ocean interface at Isle of Palms, S.C. with partially damaged sandbags behind the structure. Photo: NCDCM, 2015

Figure 16. Experimental structure at Isle of Palms, S.C. Photo: NCDCM, 2015

Figure 17. Experimental structure at Isle of Palms, S.C., where sediment appears to have been retained on the landward side of the structure, while the dry sand beach on the ocean side appears to have been lost to erosion. Photo: NCDCM, 2015

3.1b Breakwaters

Breakwaters are offshore structures built parallel to the coast. They are designed to break the energy of waves, interrupting longshore sand transport (Figure 18). They have been used successfully in slowing erosion in several areas along the Atlantic, Pacific, and Great Lakes shorelines; however, they too interfere with sediment transport (*e.g.*, Port Fourchon, LA; Breakwater Harbor, DE; Elmer, UK).

Figure 18. Breakwaters installed at Elmer, UK. Although erosion appears to be reduced, these structures do interfere with sediment transport causing a "scalloping effect" on the beach as sediment fills in behind each breakwater.

In an attempt to reduce costs, the use of surplus barges or ships have been suggested as potential, relatively inexpensive alternatives to traditional boulder or concrete breakwaters. However, structures made of steel tend to rust and deteriorate rapidly in the oxygen-rich surf zone. As with vessels utilized for artificial reefs, there are also significant costs associated with preparation and cleaning (petroleum products and hazardous material removal) prior to sinking. Structure stability, anchoring, and settling into the bottom may also be problematic.

Port Fourchon, Louisiana is a large port serving the offshore oil industry that is one of the southernmost points in a state that is losing about 35 square miles of land each year to coastal erosion. Stone barriers along the beach and rock breakwaters offshore have failed to stop the beach's retreat around Port Fourchon. After Hurricane Andrew in 1992, a segmented breakwater was constructed by lining up and sinking 14 salvage barges at 300-foot intervals along the beachfront and filling the barges with stone. Hurricane George hit the area in 1998, damaging the barges, scattering some of the stone, and claiming still more of the beach. With Federal Emergency Management Agency funding to restore the beach, the Greater Lafourche Port Commission decided to further fortify the breakwater. Seven of the barges, about 1,400 feet altogether, were topped with double rows of interlocking concreate units, call A-Jacks, produced by Armortec of Bowling Green, KY. Once installed, they did seem to dissipate smaller waves (3 to 4 feet).

In most cases, breakwaters have been utilized to create a sheltered harbor for boats and ships rather than to protect the shoreline from wave erosion. A breakwater may be located offshore, such as the inner and outer breakwaters in Breakwater Harbor east of Lewes, Delaware (Figure 19), or it may be connected to the shoreline and extend out into the water, such as the one at the Cedar Island, N.C. Ferry Terminal (Figure 20). Although the reduction of wave energy due to the sheltering effect of the breakwater is beneficial to the safe anchorage of vessels, a negative side effect is that the lowered energy conditions contribute to accelerated shoaling and sedimentation in harbors. Shore-connected breakwaters may interrupt longshore transport, resulting in downdrift sand starvation similar to the effects of the jetties.

Figure 19. Delaware's Breakwater Harbor. Photo: U.S. National Park Service

Figure 20. Breakwater connected to the beach at Cedar Island, N.C. ferry terminal. Photo: NCDCM, 2012

3.1c Groins and Jetties

Some of the most studied, and controversial, structures on the oceanfront are those built perpendicular to the shoreline, which includes groins, jetties, and breakwaters that are also connected to the shore. Groins are constructed perpendicular to the shoreline and designed to trap sand moving in the longshore transport. Sand accumulates on the updrift side of the structure resulting in increased erosion on the downdrift side.

The use of permanent erosion control structures, specifically terminal groins and jetties, to stabilize inlets has been shown to interrupt the inlet migration and overwash processes, causing several other effects (Riggs and Ames 2009). The use of a terminal groin anchored to the north end of Pea Island at Oregon Inlet has stopped the southward migration of the inlet. However, the continued migration of the north end of Bodie Island has led to an increased need for inlet dredging. In addition, the reduced longshore transport of sediment due to the groin and the post-storm dune construction to protect N.C. Highway 12 highway has prevented overwash processes that allow Pea Island to maintain its elevation over time. The island's vulnerability to storm damage has been increased due to this disruption of overwash processes and a steepened beach profile which has caused a flattened and narrowed island (NCCHPP 2010; Dolan et al. 2006; Riggs and Ames 2009; Riggs et al. 2009). From 1983 to 2009, approximately 12.7 million cubic yards of sand have been added to the shoreline within three miles of the terminal groin at Oregon Inlet (Riggs and Ames 2009), which has resulted in a significant reduction in grain size and reduction in mole crab abundance (Dolan 2006). Mole crabs are considered an important indicator of beach conditions due to their importance in the food web as prey for shorebirds and surf fish (NCCHPP 2010). It has also been shown that in addition to increased erosion on downdrift beaches, jetties may obstruct larval fish passage through adjacent inlets (Blanton et al. 1999).

Along the Atlantic Ocean in the Southeastern U.S., these structures are generally constructed of boulders in order to withstand the forces of the ocean environment. One example of an attempt to reduce erosion on the downdrift side of a groin is a structure developed by Holmberg Technologies called an undercurrent stabilizer. These structures are placed underwater and perpendicular to the shoreline, and are comprised of geotextile tubes that are filled in place with concrete or sand to alter the dynamics of current. These structures are intended to facilitate sand deposition to rebuild the eroding beach, much like groins. Unlike traditional groins, undercurrent stabilizers taper as they get farther from shore. The stabilizers are designed to reduce wave reflection and turbulence to create a "low-energy beach." Holmberg Technologies claim that the primary source of beach sand is the offshore shelf, and not along the beach. In 2000, Holmberg Technologies installed these structures near an oil refinery in Saudi Arabia where a 14-foot high seawall surrounded the structure. Several hundred feet of seawall was removed, while the remaining structure was left in place and the stabilizer was installed in both areas. According to Holmberg Technologies, sand was elevated six feet across the entire zone within five weeks of installation. Although the designer claims that these structures worked in the Saudi Arabia test study, it is uncertain how they would perform in North Carolina's coastal environment. Structures such as these have traditionally been prohibited in North Carolina (15A NCAC 7H.0308(1)(B)).

3.2 Beach Nourishment

Beach nourishment is the process of rebuilding an eroded beach by trucking or pumping (by pipeline) sand onto the beach from an outside source. Although it can be an effective erosion mitigation method, it is a costly option particularly where there is no nearby sand source, and frequent periodic maintenance is needed. This management strategy works with the sediment budget within a beach system, and mitigates erosion by adding sand from a source outside of the eroding system. In order to be effective in the long-term, beach nourishment projects generally require large volumes of sand to withstand erosion, both chronic and from storm events. Beach nourishment does not prevent erosion, nor does it stop the movement of sand along a beach, it simply resets the "erosional clock" by adding sediment to the system and re-establishing the buffer of sand between the ocean and oceanfront structures, providing storm protection to developed areas in addition to maintaining the recreational beach and biological habitat.

Depending on the frequency of beach nourishment, is not necessarily free of ecological impacts. In a 2001 report to the N.C. General Assembly, Kevin Moody, a Senior Biologist with the U.S. Fish and Wildlife Service, expressed the USFWS concerns with frequent nourishment projects, due to their potential impact on beach and near-shore birds and animals. The USFWS expressed particular concern with frequent nourishment (every 3-5 years) not allowing enough time for mole crabs, coquina, and other organisms to recover. Inadequate recovery times could seriously impact migrating shore birds and other animals dependent on these organisms for survival (NC Legislative Research Commission, 2001).

To be effective over the long-term, projects must be periodically maintained. The design and success of a beach nourishment project depends on many factors, including an evaluation of the causes of erosion (chronic versus storm induced) and shoreline history of the area; a determination of the level of storm protection that the designed beach is expected to provide; quantity of sand needed for the project; funding plan for the initial project and maintenance; and establishment of a long-term monitoring program to allow a quantitative assessment regarding the performance of the project.

Initiating a project requires first determining the volume of sand that is needed to meet the project goals, and identifying sources of sufficient beach-compatible material to meet the volume needs. Fill volumes are typically based on beach profile surveys, which are shore-perpendicular cross-sections of the beach that are used to determine how much sand is on the beach and calculate how much is needed to ameliorate chronic erosion as well as future storm scenarios. Beach profiles also help to determine the necessary placement areas along the beach. For multi-year projects, such as U.S. Army Corps of Engineers (USACE) 50-year Coastal Storm Damage Reduction Projects, a time interval between successive beach nourishment projects is proposed.

While smaller site-specific beach fill projects can utilize sand trucked to the beach from an upland source, typically beach-compatible sand sources are located through bathymetric surveying and geological and geophysical sampling of the seafloor or inlets. Potential sediment sources must provide sufficient volumes to meet the needs of the project, and the sediment must have similar characteristics as the native beach where it is being place (15A NCAC 7H .0312). Coastal Resources Commission rules require a comprehensive characterization of the native, recipient beach to determine beach fill compatibility. Specific sediment grain sizes are used to characterize the beach, and are categorized as "fine" (< 0.0625 mm), "sand" (≥ 0.0625 mm and < 2 mm), "granular" (≥ 2 mm and < 4.76 mm), "gravel" (≥ 4.76 mm and < 76 mm), and a final broad category of all sediment or shell material greater than 76 mm in diameter. The grain size of sand used for nourishment must be compatible with the sand at the project site.

The characterization of borrow area sediment is accomplished through three main tasks: 1) geophysical imaging of the seafloor surface; 2) geophysical imaging of the seafloor subsurface; and 3) coring with a core barrel no less than three inches in diameter. Geophysical imaging of the seafloor surface involves mapping the entire borrow site's bathymetry, or the depth of the ocean and shape of the seafloor, with a multibeam swath sonar system. Sidescan sonar can also provide information regarding the character of sediment on the seafloor surface. Subsurface geophysical imaging techniques such as seismic profiling depict the vertical thickness of potential beach fill deposits and other adjacent geologic strata. Finally, physical sampling, such as coring, must be used to ground truth the geophysical data. Grain size and carbonate analyses of core samples must be completed so that the borrow sediment can be accurately matched to the native beach sediment characteristics. For Ocean Dredged Material Disposal Sites (ODMDS), maintained navigation channels, or sediment deposition basins within the active nearshore, beach or inlet shoal system, two sets of sampling data (with at least one dredging event in between) may be used to characterize material for subsequent nourishment events from those areas if the sampling results are found to be beach-compatible.

The CRC rules provide a compatibility exemption for sediment from regularly maintained navigation channels (15A NCAC 7H .0312). Assuming this sediment is essentially beach-quality, it only has to meet one compatibility threshold: the average percentage by weight of fine sediment must be less than 10%. A second compatibility exemption exists that facilitates the timely infilling of storm-induced barrier island breaches to maintain transportation corridors. Sediment used to initially fill inlet breaches must meet permit requirements, but does not need to meet any compatibility thresholds.

In addition to the sand that is already on a barrier island, there are four major potential sand sources that play a role in the sediment budget:

1. Inlets between barrier islands contain several types of deposits within the channel system, the flood-tide delta on the estuarine side and the ebb-tide delta on the ocean side;
2. Deposits of sand and gravel sand occur in the paleo-riverine channels and paleo-deltaic sediments deposited by the larger trunk rivers on the continental shelf during previous glacial intervals characterized by sea-level lowstands (Mallinson, et al., 2005);
3. Shoals off of each cape (Diamond Shoals – Cape Hatteras, Lookout Shoals – Cape Lookout, and Frying Pan Shoals – Cape Fear) potentially hold large volumes of beach quality sand; and
4. Local, sand-rich areas exposed on the shoreface and inner continental shelf (Riggs & Cleary, 1997, 1998), (Boss & Hoffman, 2000), (Thieler, et al., 2006).

While surprising to some, the ocean floor does not contain vast deposits of suitable sand, and finding beach compatible sand sources in and of itself can be a costly and time-consuming process. Further studies are needed to evaluate potential source areas before they can be practically utilized.

3.2a History of Beach Nourishment in N.C.

Prior to the storms of the late 1990s, only about 12 miles of beaches in North Carolina were regularly nourished. Nourishment projects began early in Wrightsville Beach (1939), Carolina Beach (1955), and Kure Beach (1997), all with federal funding programs. Between 1955 and 2004, Carolina Beach has had 28 operations averaging one operation approximately every two years and placing nearly 700,000 cubic yards of sand each time. Between 1955 and 2004, Wrightsville Beach has had 19 operations, averaging one project every 2.5 years, placing approximately 600,000 cubic yards of fill during each event. North Carolina has approximately 160 miles of developed oceanfront shoreline, and of that total communities are planning for approximately 120 miles of nourishment. Since the 1970s, there has been an upward trend in the number of beach fill projects and volumes installed (Figure 21 and Figure 22).

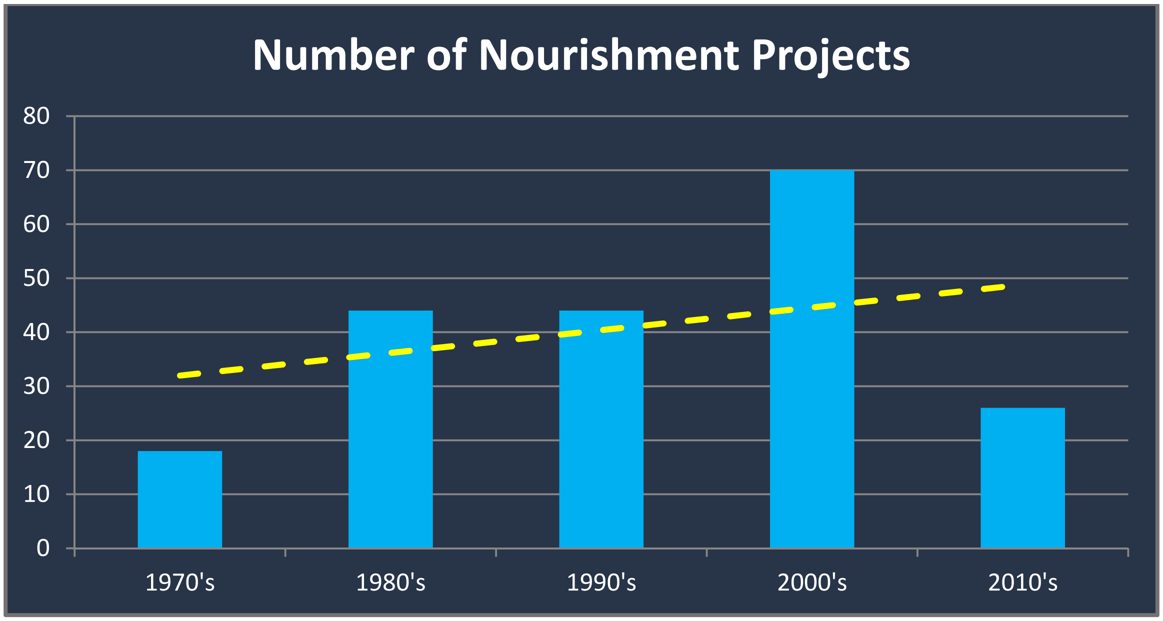

Figure 21. Since the 1970s, the average number of beach nourishment projects per year has increased (trend from 1970s to 2010s)

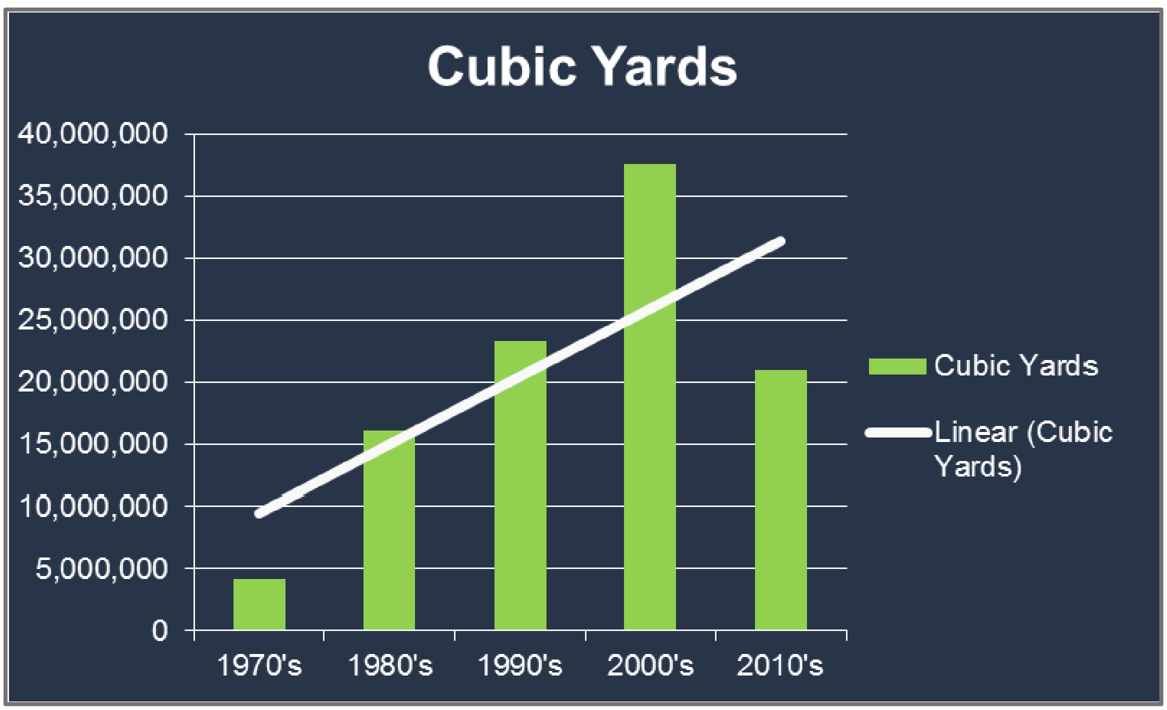

Figure 22. Since the 1970s, beach nourishment projects are larger in terms of average sand volume (1970s to 2010s)

3.2b Benefits of Beach Nourishment

Primarily, benefits associated with beach nourishment include storm damage reduction and enhanced recreational/tourism opportunities. A wide beach not only acts as a direct buffer to absorb wave energy during storm events, but it also provides a reservoir of sand that may be transported to an offshore bar.

During storm events, large waves will break on the offshore bar, reducing the amount of wave attack on the upper beach, thereby reducing the amount of erosion and damage. Coastal engineers report that reductions in wave height and wave forces due to relatively small additional beach widths are surprisingly large. In Florida and North Carolina, several studies have documented that damage to structures after hurricanes was significantly reduced in areas that had wider beaches (Rogers, 2006).

A 1995 National Research Council (NRC) study on beach nourishment reports that while beach nourishment is suitable for some, but not all locations where erosion is occurring, it is a viable engineering alternative for shore protection and is the principal technique for beach restoration. The NRC report suggests that "…*government authorities with responsibilities for coastal protection should view beach nourishment as a valid alternative to hardened erosion control structures for providing natural shore protection and recreational opportunities, restoring dry beach area that has been lost to erosion*."

A wide recreational beach results in increased income to the coastal region, and a healthy beach is a major draw for tourists. If a wide sandy beach were not accessible, the recreational value of the beach is significantly diminished, if not lost (Figure 23). If the recreational beach experience is unpleasant, or simply not available, many visitors will eventually decide to travel to another coastal destination for their next visit (Massachusetts Coastal Erosion Commission, 2015). Maintenance of a wide upper beach and dune area also results in benefits to plants and animals that use the beach as habitat as well as foraging and nesting sites, in comparison with a hardened shoreline with no remaining intertidal, sandy beach.

Figure 23. Sandbag structures at North Carolina's North Topsail Beach have been successful in providing short-term home protection from erosion at the expense of losing a sandy beach. Photo: NCDCM, 2015

3.2c Beneficial Use of Dredged Material

Beneficial use dredging projects are channel maintenance projects where beach compatible sand is dredged from an inlet or other navigable waterway and placed on the beach (or otherwise used for a beneficial project) as opposed to offshore disposal (USACE). While the primary goal of the project is focused on providing or improving marine navigation, beach-quality sand dredged from the inlet or waterway can also be "beneficially used" to widen a beach and address erosion issues. Many beneficial use beach nourishment projects have taken place in the state. However, there can be funding challenges with using dredged material for the purpose of beach nourishment if extra costs drive up the costs of the navigation projects.

Historically, dredged material was regarded as a waste, a view that was reflected the historic term dredging "spoils." Today, dredged material is considered a resource that can be used to accomplish economic and environmental goals, while also providing storm protection. The USACE's involvement in dredging activities is rooted in more than a century of federal regulation and management of coastal waterways. The Rivers and Harbors Act of 1890 provided the Corps with the authority to maintain navigable waterways. Section 404 of the Clean Water Act of 1972 gave the Corps the power to regulate discharges of dredged materials in the waters of the United States. The third major legislative foundation for the Corps' dredging program is the Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA), which authorizes the USACE to issue permits for the transportation of dredged material to be dumped at selected offshore dredged material disposal sites (ODMDS). Each year Congress makes project specific appropriations for the maintenance of existing channels and harbors. The USACE regulations prescribe that the dredging project should assure that the disposal of dredged material from the project occurs in the "least-costly, environmentally acceptable manner, consistent with engineering requirements established for the project." The term "least costly, environmentally acceptable" alternative has become termed the "federal standard" and is the base plan from which project planning and budgeting is performed.

Dredging projects depend on a complex intergovernmental process that tries to balance economic costs and benefits while minimizing environmental harm. This process occasionally creates conflicts between agencies when the Corps selects offshore disposal of beach quality sand rather than beneficially using the material for beach projects.

In 1999, the U.S. Army Corps' National Dredging Team held a workshop for the purpose of bringing together state and federal agencies to discuss issues related to management of dredged material. This effort resulted in suggestions and recommendations falling into four general categories (National Academy of Public Administration, 1999):

1. **Use the regulatory process to facilitate beneficial use.** There was a widely held sentiment that regulatory relationship between the USACE and the state coastal management programs can be improved.
2. **Improve intergovernmental coordination and project planning.** Starting the communication and planning process early will contribute to better project implementation and funding.
3. **Increase funding for beneficial use, and promote local, state, and federal cost sharing.** In many cases, the beneficial use of dredged material costs more than disposal at the ODMDS, and its uses can potentially benefit more than just those with navigation interests.
4. **Better science and public education.** Making the public aware of the benefits of beneficial use will help garner support.

3.3 Sandbag Structures

While the Coastal Area Management Act and CRC rules prohibit most permanent erosion control structures along oceanfront beaches, sandbags used as temporary erosion control structures are allowed to provide sufficient time for the relocation of structures or to carry out an allowable erosion control measure (beach renourishment, inlet realignment, etc.)(N.C.G.S. §113A-115.1; 15A NCAC 7H .0308).

As the CRC began development of rules prohibiting the placement of permanent shoreline stabilization structures along the oceanfront, sandbags were allowed to be used as a temporary means of protecting imminently threatened structures. This policy (15A NCAC 7M .0202(e)) was in accordance with the 1984 recommendations of the CRC Outer Banks Erosion Task Force and that stated:

> *"Temporary measures to counteract erosion, such as beach nourishment, sandbag bulkheads and beach pushing, should be allowed, but only to the extent necessary to protect property for a short period of time until threatened structures may be relocated or until the effects of a short-term erosion event are reversed. In all cases, temporary stabilization measures should be compatible with public use and enjoyment of the beach."*

Since sandbags were first allowed as a temporary erosion control measure in 1985, the CRC has struggled with balancing the needs of property owners to protect oceanfront structures with protecting the public's use of the state's ocean beaches. Sandbags were intended to provide temporary protection to imminently threatened structures and were not envisioned as a permanent protective measure for chronic oceanfront erosion.

The development and evolution of the CRC's sandbag rules reveals that the CRC has maintained an understanding that coastal property owners need a way to temporarily protect their homes from beach erosion. Over the years, the commission has generally been accommodating of property owners and local government as more permanent solutions, such as beach nourishment or relocation of the structure have been pursued. This accommodation has often been perceived as a lack of enforcement of the temporary erosion control rules on the part of the division and commission. However, with the exception of inlet areas, many sandbags structures have become unnecessary as local governments have become more committed to beach nourishment and inlet relocation projects. From a policy standpoint, the commission has tried to manage sandbags from a time limit perspective, keeping in mind that both by rule and law, they are a temporary erosion control measure requiring justifiable limits. The commission has also attempted to address protection of the public's use of the state's ocean beaches by limiting the structural dimensions of temporary erosion control structures.

Since local governments have been pursuing beach nourishment as a viable solution to chronic erosion issues, the policy focus has shifted from time limits to a discussion of necessity and at what point do sandbags need to be removed. The current rules governing the use of sandbags require them to be removed in the event of a beach nourishment project, which has raised the question of allowing sandbags to be covered with sand during a project. This action can be complicated by the necessity of easements being granted by private property owners as well as the involvement of public funds. Discussions of covering sand bags has also called into question the necessity and practicality of requiring sandbags to be covered ***and*** vegetated in order to remain in place (15A NCAC 7H .0308).

Recent discussions among stakeholders have included an expanded use of sandbags to protect natural features (dunes) in addition to structures, expanding the definition of "imminently threatened," and allowing the use of geo-textile tubes as well as individual sandbags. In addition, the N.C. General Assembly in Session Law 2015-241 directs the CRC to amend its rules for the use of temporary erosion control structures (sandbags) (S.L. 2015-241). Specifically, the commission is directed to amend its rules for the use of temporary erosion control structures to provide for all of the following: (1) Allow the placement of temporary erosion control structures on a property that is experiencing coastal erosion even if there are no imminently threatened structures on the property if the property is adjacent to a property where temporary erosion control structures have been placed. (2) Allow the placement of contiguous temporary erosion control structures from one shoreline boundary of a property to the other shoreline boundary, regardless of proximity to an imminently threatened structure. (3) The termination date of all permits for contiguous temporary erosion control structures on the same property shall be the same and shall be the latest termination date for any of the permits. (4) The replacement, repair, or modification of damaged temporary erosion control structures that are either legally placed with a current permit or legally placed with an expired permit, but the status of the permit is being litigated by the property owner.

This legislation has the potential to expand the use of sandbags by allowing sandbag structures on properties without imminently threatened structures since the only stipulation is that the adjoining property also have a sandbag structure. Under the current rules, sandbags are only allowed if the erosion scarp is within 20 feet of the foundation of a structure or in cases of accelerated erosion or flat beach profile (15A NCAC 7H .0308).

3.4 Beach Bulldozing or "Pushing"

Beach bulldozing is the mechanical reshaping of the beach, and usually entails pushing sand from the lower to the upper portions of the dry sand beach for the purpose of repairing storm-damaged dunes. Dune building is the physical piling of sand into a dune or the placing of sand fencing or brush to encourage sand deposition. This is generally accompanied by planting of vegetation. Dunes offer some protection to development during storms. They do not provide protection from long-term erosion however, and unless dunes are allowed to migrate landward, dune building will generally result in a narrowing of the beach. A large storm may also relocate a dune landward and widen the beach.

Some researchers have argued that artificial barrier island dunes function similarly to bulkheads and cause accelerated erosion. Others argue that dunes cause adjustments in the energy dissipation regime and erosion is not accelerated. The CRC allows dune building due to the ease with which it can be done, the storm protection it offers, and its low cost.

3.5 Relocation

Relocation involves moving a structure from a location threatened by erosion to a safer location farther inland. Before the onset of high density development, endangered beach cottages were typically moved landward on the existing lot. Today, due to the small size of most lots, and the increased size of structures, this option is not as readily available and the costs can be significant. One problem identified by the Coastal States Organization in 2015 is that the Federal Emergency Management Agency (FEMA) does not reimburse claims for houses that have not yet collapsed or succumbed to erosion under the National Flood Insurance Program (NFIP). If those claims were allowed, or if a funding program existed such as the former Upton-Jones Act (1988), which provided support for the relocation or removal of insured structures under imminent threat of collapse due to shoreline erosion, property owners would have additional financial options to consider moving an at-risk structure. This would also reduce the risk of marine debris from a house that collapses into the ocean, and would be a net economic gain since much of an existing home could be salvaged before a total loss. Other options for local governments and homeowners also exist, such as Public Beach and Coastal Waterfront Access Grant Program. Under this program, local governments may request grants for public access projects such as land acquisition, including the acquisition of unbuildable lots (15A NCAC .0307). DCM recommends that remaining undeveloped beachfront properties be evaluated by local governments, in partnership with the division, to identify opportunities to expand public access in areas that are especially hazardous for private development.

A 2001 study by the University of Delaware examined the economics of strategic retreat in Delaware. The study explained social and economic costs associated with strategic retreat that include capital loss, transition loss, land loss, and proximity loss.

3.6 Policies & Rules - Oceanfront Construction Setbacks

North Carolina has long recognized that absolute safety from the natural hazards associated with the Atlantic shoreline is an impossibility for development located adjacent to the coast. The management objectives of the CRC have focused on reducing the loss of life and property to these forces by the proper location and design of structures and by preventing damage to natural protective features, particularly primary and frontal dunes. It has been the objective of the state and the Coastal Resources Commission to provide management policies and standards for ocean hazard areas that serve to eliminate unreasonable danger to life and property and achieve a balance between the financial, safety, and social factors that are involved in hazard area development. The CRC's policies are focused on minimizing losses to life and property resulting from storms and long-term erosion, preventing encroachment of permanent structures on public beach areas, preserving the natural ecological conditions of the barrier dune and beach systems, and reducing the public costs of inappropriately sited development. It is also the objective of the CRC to protect present common-law and statutory public rights of access to and use of the lands and waters of the coastal area (15A NCAC 7H .0303).

North Carolina uses oceanfront construction setbacks as a mitigation strategy to maintain a buffer between development and the ocean. North Carolina's setbacks are based on localized, long-term average annual shoreline change rates and are measured from first line of stable and natural vegetation (FLSNV). When erosion moves the shoreline and vegetation line landward of its position at the time the structure was built, there is a chance that the structure can no longer meet the required setback, and therefore could not be rebuilt if destroyed.

Another N.C. policy intended to prevent structures from being built in harm's way pertains to large-scale beach fill projects. When a community constructs a large-scale beach nourishment project (>300,000 cubic yards), the pre-project FLSNV is surveyed and is referenced as the Static Vegetation Line, from which all future development setbacks are measured. Since the pre-project vegetation line represents the location of the ocean hazard prior to the project, this policy ensures that if vegetation grows oceanward after a beach nourishment project structures will not be sited even closer to the ocean in an area that could once again be claimed by erosion. The CRC has established a number of exceptions to this rule, for example, when a coastal community demonstrates to the CRC a long-term commitment and plan to continue to mitigate beach erosion (15A NCAC 7J.1200).

In addition to North Carolina, other states have a history of using construction setbacks as a means to guide development adjacent to oceanfront shorelines (Owens, 1980). While no recent compilation was found during this review, examples cited in Owens' 1980 study include:

- Maryland – Atlantic Coast Beach Erosion Control District Act passed by the state legislature. All construction in the area from the ocean inland to the west crest of the existing natural dune line is prohibited. Erosion control structures are allowed in the area only by permit.

- South Carolina – No structures allowed in the area from the ocean to the frontal dune.
- Delaware – No construction is allowed seaward of the "building line." The building line is defined by law as a line generally parallel to the coast and located 100 feet landward of the seaward 11-foot contour. This 11-foot contour is generally behind the frontal dune. The building line is being surveyed now (1980). Variances will be allowed if construction standards are met.
- Texas – Open Beaches Act established a presumption of public beach use seaward of the vegetation line. No construction is allowed on this beach.
- Hawaii – Setback 20 to 40 feet landward of the "upper reach of the wash of the waves."
- Alabama – Permit required for structures on dunes or beaches. Construction not allowed seaward of a line 40 feet landward of the crest of the primary dune.
- Michigan – Construction is not allowed in the area that is within 30 times the annual erosion rate if that rate is more than one foot per year.
- Maine – All principal construction has to be setback 75 feet from the normal high water in "limited residential" districts. In "resource protection" areas (flood prone areas), no structures are allowed within 250 feet of normal high water.

North Carolina's oceanfront setback requirements are based on the size of the structure and a setback factor determined by the erosion rate. In areas where the erosion rate is less than two feet per year, or the beach is accreting, the default setback factor is two, thus making the minimum setback distance equal to sixty feet for structures 5,000 square feet or less (Table 1).

Table 1. North Carolina's oceanfront setback requirements based on structure size and setback factors determined by North Carolina's shoreline change studies.

Structure Size	Setback (ft.)	*example using setback factor = 2*
less than 5,000 sq. ft.	60 feet or 30 times the setback factor	*2 x 30 = 60 feet*
greater than or equal to 5,000 sq. ft.	120 feet or 60 times the setback factor	*2 x 60 = 120 feet*
greater than or equal to 10,000 sq. ft.	130 feet or 65 times the setback factor	*2 x 65 = 130 feet*
greater than or equal to 20,000 sq. ft.	140 feet or 70 times the setback factor	*2 x 70 = 140 feet*
greater than or equal to 40,000 sq. ft.	150 feet or 75 times the setback factor	*2 x 75 = 150 feet*
greater than or equal to 60,000 sq. ft.	160 feet or 80 times the setback factor	*2 x 80 = 160 feet*
greater than or equal to 80,000 sq. ft.	170 feet or 85 times the setback factor	*2 x 85 = 170 feet*
greater than or equal to 100,000 sq. ft.	180 feet or 90 times the setback factor	*2 x 90 = 180 feet*

3.7 Funding and Institutional Concerns

Beach nourishment and other erosion control projects can be expensive and are more effective when done as part of a comprehensive and regional approach along a shoreline reach with similar characteristics. Therefore, most major erosion control projects have involved a combination of federal, state, and local government funding.

3.7a Federal Funding

In North Carolina, a USACE project begins with a local government contacting its congressional representative. This initiates a process which includes the following actions: 1) a congressional resolution to conduct a feasibility study; 2) Corps preparation and review of the feasibility study results; 3) congressional authorization for the project; 4) advanced engineering design; and 5) construction of the project.

In the past, the authorization of new projects in the Wilmington Corps District has typically required 15 to 18 years. More recently, the process from start to finish has required eight years as a new, more simplified feasibility study process has been developed by the USACE. Under this process, an initial evaluation of both the economics and engineering of a proposed project can be completed in one year, and a determination made of whether or not the project merits further detailed study.

3.7b State Funding

In the past, the state has participated primarily in two types of erosion projects: large USACE nourishment projects, and small sandbag groin fields. In some instances, NCDOT has undertaken emergency actions to protect critical road links and bridge foundations. The small sandbag groin field projects, built mostly in the 1960s and early 1970s, have had a mixed record of effectiveness. The state can participate in large USACE projects by funding up to 75% of the non-federal share.

3.7c Local Funding

Local governments have traditionally been required to contribute a minimum of 25% of the non-federal share of a federally funded beach nourishment project. The two primary sources of revenue for local governments are sales and property tax. The first communities to receive approval from the General Assembly for a lodging tax of 3% were Topsail Beach, Ocean Isle Beach, and Surf City. New Hanover County received approval for a 2% lodging tax. By statute (N.C.G.S.§153A-185 and 153A-18), New Hanover County is required to spend 80% of its lodging tax for beach erosion abatement.

In addition to general property taxes, the General Assembly has passed enabling legislation for two other property tax assessment measures -- service districts and special assessments. Service districts (G.S. 153A, Sections 300-307) enable local governments to define district boundaries and levy an additional tax from the district for its special needs. This allows local governments to establish an oceanfront property district and use the additional property tax revenues for beach nourishment.

Special assessments (G.S. 153A, Section 1) are like service districts in that they tax only the properties benefited. They offer somewhat greater flexibility because the assessment may be made on the basis of acreage or front footage rather than property value.

The General Assembly passed enabling legislation (G.S. 160A-460 et seq.) which allows local governments to administer joint programs. Therefore, once a course of action is chosen, local governments can develop, fund, and administer erosion abatement programs which cross political boundaries. Local governments can also combine several revenue sources such as general revenues and special assessments or service districts to fund a single project.

When tax revenues are raised and then divided amongst multiple municipalities, inter-local agreements guide the distribution of funds for beach and inlet projects. In the case of Bogue Banks, an inter-local agreement was signed by the Bogue Banks towns and Carteret County in 2010 to share Carteret County Beach Commission occupancy tax revenues and to pursue the 50-year Master Plan. In New Hanover County, an inter-local agreement was signed in 2011 by the county, Town of Wrightsville Beach, Town of Carolina Beach, and Town of Kure Beach. The agreement sets percentages of financial participation in the event shortfalls occur within federal and state budgets. Under this agreement, if no federal or state funding is provided, the three beach towns would provide 17.5% of the funds needed for periodic nourishment of their respective projects and the County would contribute 82.5%. Inter-local agreements help ensure that tax revenues are distributed consistently and provide additional stability in an era of reduced federal and state expenditures for beach and inlet projects.

With anticipated reductions in federal funds and few new authorizations, local governments are having to determine how to fund most, if not all of their beach nourishment projects locally. For example, the town of Nags Head constructed a $36 million project along 10 miles of its ocean shoreline in 2011 without any state or federal funds.

4.0 Recommend Policies, Standards, and Actions

Approaches to managing beach erosion generally fall under four categories, which are not mutually exclusive:

1. No Action
2. Shoreline Hardening
3. Beach Nourishment
4. Managed Relocation of Threatened Structures

Coastal erosion and how to mitigate or prevent it is a topic that has been discussed and researched for many decades by researchers and local, state, and federal agencies. The following provides a brief history of recommendations generated in North Carolina and other coastal states.

4.1 Prior Studies by the N.C. General Assembly

In 1997, a study of coastal beach movement issues was authorized by 2.1(3) of Chapter 483 of the 1997 Session Laws, and under authority of G.S. 120-30.17(1), the Legislative Research Commission established a study committee to review coastal beach movement issues including financial aspects of beach nourishment and storm hazard mitigation on the barrier islands. However, due to the unusual length of the 1998 Regular Session of the General Assembly, the Legislative Research Commission's Study Committee only met once, and later recommended that the study be reauthorized.

In 1999, the study of Coastal Beach Movement, Beach Nourishment and Storm Mitigation was authorized by Part II, Section 2.1(6)(e) of Chapter 395 of the 1999 Session Laws (Regular Session, 1999). The Legislative Research Commission reported its findings and recommendations to the N.C. General Assembly in 2001. In finding that beaches of the state are to be preserved as part of our common heritage (Article XIV, Section 5 of the North Carolina Constitution), the commission recommended continued support for the Coastal Resources Commission's rules protecting the recreational use of the state's shorelines, and ensuring the protection the public's right to use and enjoy the ocean beaches. The Legislative Research Commission also supported private property owner's rights to protect property in ways that are consistent with public's rights to access and use the recreational beach, and found that there is a need to provide a legislative mandate that acknowledges the value of the beaches to the people of the state and declares that it is in the public interest to preserve and restore the beaches of the state. The commission also recognized a need for reliable, regular and significant funding to address beach erosion, air pollution, and other environmental threats to the state's natural heritage and economic health (NC Legislative Research Commission, 2001).

4.2 CRC's 1984 Outer Banks Erosion Task Force Recommendations

The Outer Banks Erosion Task Force was established in 1984 by the CRC in response to growing concerns over beach erosion in Dare and Currituck Counties. The 16-member group was comprised of commissioners, the Coastal Resources Advisory Council, town and county governments, the USACE, and specialists in coastal erosion, in addition to 13 technical and policy advisors. The task force made the following recommendations to the CRC:

- Beach Use
  - The public's right to use and enjoy the ocean beaches must be protected.
  - Private property rights in oceanfront properties, including the right to protect that property in ways that are consistent with public rights, should be protected.
- Economic Impacts
  - Larger structures should be discouraged from locating in erosion-prone areas.
  - Responses to erosion should be designed to limit public costs.
- Erosion Response
  - Efforts to permanently stabilize the location of the shoreline by massive seawalls and similar protection structures which do not preserve public trust rights should be prohibited.
  - Temporary measures to counteract erosion should be allowed, but only to the extent necessary to protect property for a short period of time until the threatened structure can be relocated, or until the effects of a short-term erosion event are reversed via natural processes or beach nourishment.
  - Erosion abatement measures which will interfere with public access to and use of the ocean beaches should be prohibited.
  - Erosion abatement measures which will significantly increase erosion rates on adjacent properties should be prohibited.

- Innovative measures which may be developed in the future that minimize adverse impacts on the public trust beach and on nearby properties should be encouraged.
- Government policies should not only address existing erosion problems, but should aim to minimize future erosion problems.
- Regulations concerning the use of oceanfront erosion abatement measures should apply to all oceanfront properties without regard to size and use.
- The federal government should be encouraged to amend the National Flood Insurance Program (NFIP) to fund the relocation of structures threatened by erosion and the resultant flooding.
- Bonding, title restrictions and liability provisions should be required in order to guarantee removal of the structure if performance standards in the permit conditions are not met.
- The strategic relocation of vulnerable structures is another approach that should be considered at the regional level.
- Buildings, debris, and erosion abatement structures which impede travel along the beach and interfere with public use of the beach should be prohibited.
- The following standards should be required with state involvement (funding or sponsorship) in oceanfront abatement projects:
    - There should be no unacceptable environmental impacts.
    - The entire restored portion of the beach should be in permanent public ownership.
    - Adequate parking and public access should be provided.
    - State expenditures should be limited to maintenance of the public beach and not be used to protect endangered seawalls or other erosion control structures.

- Federal Legislative Needs
    - Congress should be encouraged to amend, if necessary, the NFIP to provide coverage for relocation of structures.
    - Congress should be encouraged to provide adequate funding under Section 1362 of the NFIP, as well as other programs, for the purchase of severely flood-damaged or immensely endangered structures, if the land is suitable to be used for open space, beach access, or other valid public purposes.
- State Legislative Needs
    - Legislative authorization of a bonding requirement should be obtained to ensure that performance standards for construction of erosion control structures are followed.
    - Legislative authorization to acquire and accept deed restrictions for ongoing conditions for construction and use of erosion control structures.
    - Legislation should be passed to create strict liability for damage resulting from construction and use of erosion control structures.
    - Legislation should be enacted designating an agency or agencies of state government to enforce public trust rights on the oceanfront. Such legislation should authorize the designated official to remove structures and obstructions after notice to the person who placed or owns the structure at the expense of that person. If the structure is causing imminent danger to, or is damaging other properties, whether public or private, the designated official should be allowed to remove the structure without notice.
- Research Needs

- Annual beach erosion surveys are an important tool for monitoring the condition of the beach and any changes that are taking place. The data are useful for evaluating the performance of beach nourishment projects, determining when a new beach nourishment project may be necessary, and calculating the volumes of sand that would need to be added to the beach to withstand different storm scenarios. For any town, county, or region that is interested in pursuing regional projects, establishing a network of beach profile survey locations and surveying the beach each year would be a cost-effective way to plan for sand needs in the future. Without annual beach profile data, beach nourishment projects are typically more reactive to an existing erosion problem instead of being proactive and anticipating a future erosion problem.

4.3 N.C. Division of Emergency Management's Recommendations

The following is a summary of recommendations made by the N.C. Division of Emergency Management in 1997, as a result of lessons learned in the aftermath of Hurricane Fran and relevant to beach erosion (NC Division Emergency Managment, 1997):

- Coastal community officials should provide information to current and potential residents and business persons regarding the policy implications of CBRA.
- Real estate agents who sell coastal property should inform potential buyers of the hazards associated with home ownership or the operation of a business on a barrier island.
- As a requirement of maintaining a real estate license, coastal real estate agents should be thoroughly familiar with Coastal Barrier Resource Act (CBRA) Zones and the implications of purchasing in these areas.
- Because of substantial dune erosion and destruction of structures on Topsail Island following Hurricanes Bertha and Fran, any future development should comply with sound land use planning techniques.
- Existing dune fields should be maintained using native vegetation and sand fencing to promote additional dune growth.
- CAMA's prohibition on the cutting of roads or pathways through the dune line should be stringently enforced.
- Reconstruction of substantially damaged seawalls, revetments, groins, or jetties should not be allowed in order to facilitate the natural movement of sand.
- If numerous contiguous properties exist along the coast that cannot be built back, and property owners are willing to release the title, the state should work with local governments to dedicate the land as open space.

4.4 N.C. Beach and Inlet Management Plan

Session Law 2015-241 requires a 2016 update to the N.C. Beach and Inlet Management Plan (BIMP), which was originally published in 2011 and identified two changes that could support more cost-effective and environmentally sound management of the state's beaches and inlets: 1) expanded use of regional planning for beach and inlet management projects; and 2) a dedicated state fund to support regional projects. Since 2011, DCM has been focusing on the regional planning recommendation. The BIMP divides the North Carolina coast into four main beach and inlet management regions and five sub-regions (Figure 11). The delineation of the regions and sub-regions included consideration of the geologic framework, the physical processes (wave exposure, sediment transport, etc.), geography, sand sources and natural resources, and common sociopolitical concerns.

Sustainable management of the state's beaches and inlets can benefit from regional approaches that consider related segments of the coast rather than merely a project-focused approach. Planning projects regionally allows for an efficiency of scale, which can reduce the costs associated with individual projects. For projects in the same region, there is the potential to save time and reduce costs associated with mobilization and demobilization of equipment, area-wide sand search investigations, and coordinated environmental studies if the projects are combined. In addition to reducing costs, a regional approach avoids individual local governments competing for the same resources and allows for better management of cumulative and secondary impacts. Regional efforts may also provide justification for state and local funding for beach and inlet management projects and streamline permitting, endangered species assessments, and monitoring requirements. A comprehensive review of existing sand sources coupled with the ability of stakeholders to plan for long-term needs of multiple communities would facilitate a streamlined and proactive approach to beach and inlet projects, including beneficial use projects. By adopting a regional approach to beach and inlet management projects, the entire coastal environment is taken into account, including natural processes as well as the effect of human activities.

4.5 Examples of Local Mitigation Strategies

Increasingly, local governments are developing strategies and becoming more proactive in managing beaches and inlets. The Carteret County Beach Commission was formed by the Carteret County Board of Commissioners in 2001 to advise on strategies for beach nourishment and the expenditure of occupancy tax proceeds dedicated to beach nourishment. Bogue Banks includes the towns of Atlantic Beach, Pine Knoll Shores, Indian Beach/Salter Path, and Emerald Isle, and residents from each of these areas serve on the commission. The commission has helped to strengthen municipal relationships by speaking with a unified voice on beach and inlet management topics. New Hanover County and Dare County use a similar framework to coordinate beach and inlet projects through the New Hanover County Port, Waterways, and Beach Commission and the Dare County Board of Commissioners, respectively. The Topsail Island Shoreline Protection Commission also coordinates projects for the beaches of Onslow and Pender Counties.

Bogue Banks Master Beach Nourishment Plan – Carteret County, N.C.

The Carteret County Beach Commission and Carteret County Shore Protection Office are leading the development of the Bogue Banks Master Beach Nourishment Plan (Master Plan) in an effort to develop a comprehensive, multi-decadal erosion response program for the entire 25-mile long island. The planning horizon for the Master Plan is 50 years, and unlike USACE 50-year Coastal Storm Damage Reduction Projects, which require a mix of federal and state or local funds, the Master Plan will be locally funded and implemented. Receiving permits from federal and state agencies for the local Master Plan would allow Carteret County and the Bogue Banks communities to implement nourishment projects proactively without relying on Congress for authorization and funding.

The Carteret County Shore Protection Manager is employed by the county and is responsible for advising and staffing the Beach Commission and overseeing beach and inlet projects. The position was created in 2001 at the same time as the commission using county occupancy tax revenues. The Shore Protection Manager also works with consultants to guide the collection of annual beach erosion surveys along Bear Island, Bogue Banks, and Shackleford Banks. Approximately 110 profile locations were established and surveyed in 1999, and serve as a baseline condition for assessing beach conditions along Bogue Banks. The monitoring network has been augmented by 10 additional profiles since 1999 for a total of 120 along Bogue Banks. In 2005, Shackleford Banks, which encompasses a portion of the Cape Lookout National Seashore, and Bear Island (Hammock's Beach State Park) were added to the annual surveying work to gain a better understanding of coastal dynamics on a regional scale.

Each profile represents a shore perpendicular line where elevations are measured to capture the dune, beach, and offshore environments at the same location each year. The goal of the monitoring program is to track changes in the size and shape of the beach over time to help determine when additional sand should be added. The surveys also play an important role in quantifying the condition of the beach by measuring volumetric rates of erosion and accretion, confirming sediment volumes added by beach nourishment, tracking the movement of sand in the alongshore and cross-shore directions by comparative surveys, and comparing beach conditions from one reach to another (Carteret County Shore Protection Office, 2014).

Carteret County has taken steps toward a regional approach to mitigating coastal erosion. For Bogue Banks, Carteret County has created a Master Beach Nourishment Plan designed to: 1) calculate sand needs for the next 50 years, 2) locate sufficient volumes of beach-compatible sand sources to meet the needs for the next 50 years, 3) identify local funding sources and strategies to pay for the next 50 years of beach projects, and 4) obtain the necessary permits from state and federal agencies to implement the Master Plan. Multiple alternatives were considered to meet the project needs, including no action, relocation or abandonment of structures, a federal 50-year project, beach nourishment only, and beach nourishment with inlet management. The only alternative that could meet the project's stated purpose and need is beach nourishment with non-structural inlet management.

To calculate sand needs, consultants rely upon the record of annual beach profile volumetric data and "designed" storm scenarios to ensure that an equivalent level of protection is met by future beach nourishment projects. The designed storm has the parameters of a 25-year event, so the project is intended to provide protection from a 25-year storm. Based on statistical analysis of monitoring data, it has been determined that the sand volume need for Bogue Banks for 50 years would be between 45 and 50 million cubic yards. Of this total, about 23 million cubic yards are attributed to background erosion and between 22 and 27 million cubic yards are attributed to hurricane storm erosion. The sand to meet this need would come from a combination of the following sources: Morehead City Harbor Federal Navigation Project dredging, Bogue Inlet dredging, Atlantic Intracoastal Waterway dredging, upland sources, ODMDS offshore of Beaufort Inlet, or other offshore borrow sites. Dredging of Beaufort Inlet and Bogue Inlet is a renewable source of nourishment material, but some offshore areas would likely only be used once. The renewable sources represent about half of the 50 million cubic yards of sand that would be needed over 50 years, and non-renewable sources represent the other half. To determine sand compatibility for beach nourishment, geological and geophysical sampling is performed according to the standards in 15A NCAC 07H.0312.

The beaches of Bogue Banks qualify for FEMA reimbursement to place sand back on the beach after a major storm. Therefore, the Master Plan assumes that Carteret County and the municipalities on Bogue Banks will be responsible for the estimated background erosion need while hurricane storm erosion will be covered by FEMA. Expected funding breakdowns are close to 67% for the county and 33% for the towns. The annual cost to the county to implement the Master Plan for all 25 miles of Bogue Banks would be about \$3.1 million/year., and the total annual cost to the Towns would be about \$1.5 million/year. The average annual county occupancy tax for beach nourishment over the next five years is expected to generate about \$2.9 million/year. The proposed funding breakdown appears to be a good starting point, but minor adjustments will be necessary to respond to significant coastal storms and uncertainty of FEMA reimbursement funds.

Carteret County and the municipalities on Bogue Banks intend for the Master Plan to facilitate a 50-year permit authorization for future beach nourishment and inlet management activities. In conjunction with the Master Plan, a Programmatic Environmental Impact Statement (EIS) is being developed in an effort to obtain a multi-decadal authorization from DCM and the other regulatory and resource agencies. If granted, the authorization would allow nourishment projects to take place as needed, provided that they adhere to certain standards laid out in the Master Plan and Programmatic EIS. The Programmatic EIS would address short-term, long-term, and cumulative impacts of proposed projects. The anticipated outcome of this effort is a streamlined permitting mechanism to complete future projects in a shorter timeframe and at a relatively lower cost.

4.6 Other Coastal States

In 2015, the Coastal States Organization and the American Shore and Beach Preservation Association adopted a joint policy statement entitled "*A Joint Call for the Improved Management of America's Beaches*." The policy statement supports five general positions, as follows:

1) Ensure beach-compatible dredged materials are beneficially used through the establishment of a national policy;
2) Promote streamlined permitting of beach and inlet management projects (through the federal Coastal Zone Management Act);
3) Encourage predictable funding of coastal storm damage reduction projects;
4) Encourage responsible beachfront building setbacks, redevelopment standards, and construction practices, including voluntary relocation programs; and
5) Authorize and fund a national study to coordinate and implement efficiencies across federal, state, and local beach mapping programs.

Example of a State Mitigation Strategy & Recommendations: The Massachusetts Case Study

In 2013, the Massachusetts Legislature established a Coastal Erosion Commission to investigate and document the levels and impacts of coastal erosion, and develop strategies and recommendations to reduce, minimize, or eliminate the magnitude and frequency of coastal erosion and its adverse impacts on property, infrastructure, public safety, and beaches and dunes. The following summarizes their findings and recommendations, and represents the most recent documented effort by a state (Massachusetts Coastal Erosion Commission, Report of the Massachusetts Coastal Erosion Commission, Volume 1: Findings and Recommendations, 2015).

Strategy #1: Increase understanding of coastal and nearshore sediment dynamics, including the effects of man-made, engineered structures, to inform potential management actions and other responses to coastal erosion.

1. Increase observational capabilities for waves, water levels, and coastal response
2. Advance sediment transport mapping and modeling to develop regional sediment budgets.

3. Continue to asses long-term and cumulative effects of shoreline management techniques and practices, including impacts to adjacent properties and natural resources (physical and biological) and the cost and cost-effectiveness of the practices.

Strategy #2: Enhance available information based on type, extent, impacts, and costs of coastal erosion on public infrastructure, private property, and natural resources to improve the basis for decision making.

1. Improve the ability to isolate damage due to coastal erosion from other hazards (*e.g.*, flooding, wind damage).
2. Establish inter-agency agreements with federal agencies (*e.g.*, FEMA, NOAA/NWS, U.S. Army Corps of Engineers, U.S. Geological Survey) to facilitate timely collection of perishable data on post-storm damage impacts.
3. Develop a comprehensive economic valuation of Massachusetts beaches; including information at community, regional, and state level.

Strategy #3: Improve mapping and identification of coastal hazard areas to inform managers, property owners, local officials and the public.

1. Develop estimates of future shoreline change by assessing use of approaches that combine observed and model-derived shoreline positions for shoreline change.
2. Improve ability to assess vulnerability of sites by characterizing geologic and geographic variables that are not currently accounted for in inundation maps but have potential to significantly increase risk to erosion and inundation hazards. Evaluate the potential integration of these factors into an exposure index or other tool.
3. Produce comprehensive online atlas of potential flood inundation areas from a range of scenarios, including different timescales and intensities.

Strategy #4: Reduce and minimize the impacts of erosion (and flooding) on property, infrastructure, and natural resources by siting new development and substantial re-development away from high hazard areas and incorporating best practices in projects.

1. Evaluate the applicability, benefits, concerns and legal authority for coastal hazard area setbacks.
2. Develop and promulgate performance standards for land subject to coastal flooding.
3. Adopt the 2015 International Building Code for structures in floodplain, including freeboard requirements for buildings in "A zones," in addition to current requirements for "V zones."
4. Incorporate assessment of sea level rise impacts during regulatory review of coastal projects and evaluate alternatives that eliminate/reduce impacts to coastal resource areas and provide appropriate mitigation, as allowed within existing authorities.
5. Finalize and release the guidance document *Regional Planning and Permitting of Beach and Inlet Projects: Guidance for Local Governments.*

Strategy #5: Improve the use of sediment resources for beach and dune nourishment and restoration.

1. Advance the evaluation and assessment of the use of offshore sand resources for beach and dune nourishment and restoration.
2. Explore and implement regional dredging programs to allow for greater efficiencies and cost-effectiveness.

3. Support the advancement of the top policy position in the joint Coastal States Organization (CSO) and American Shore and Beach Preservation Society (ASBPS) *call for the Improved Management of America's Beaches,* calling for national policy to ensure that beach-compatible dredged materials are beneficially used.

Strategy #6: Promote the development of local and regional beach and shoreline management plans

1. Support coastal communities in their development of new or updating of existing local and regional beach and shoreline management plans.

Strategy #7: Maintain and expand technical and financial assistance and communication and outreach to communities to support local efforts and address the challenges of erosion, flooding, storms, sea level rise, and other climate change impacts.

1. Develop outreach program to expand on coastal community resilience and green infrastructure, and continued discussions on hazards and risks, assessment of vulnerabilities, and implement natural and nonstructural approaches ("green infrastructure").
2. Increase public awareness of coastal processes, storm events, and risks associated with development on/near coastal shorelines and floodplains; promote better understanding and adoption of best practices.

The following table represents the most current effort (2015) by Massachusetts Coastal Erosion Commission to list available options for mitigating coastal erosion, environmental suitability, and generalized cost for each approach (Massachusetts Coastal Erosion Commission, 2015). The table outlines the type of erosion control technique, environmental energy levels, and general costs associated with designing, constructing, and maintaining the structure if applicable.

Table 2. This table compares erosion control alternatives, energy levels in the environment, and relative costs associated with design, construction, maintenance, and mitigation, and was prepared by the State of Massachusetts in 2015 (Massachusetts Coastal Erosion Commission, 2015). Costs are based on linear feet of shoreline, where low < $200, medium = $200 to $500, high = $500 to $1,000, and very high > $1,000. Although this information can serve N.C. as a good reference, additional studies are needed for a more accurate N.C. comparison.

Shoreline Management Technique	Environment	Relative Costs			
		Design	**Construction**	**Average Annual Maintenance Costs**	**Average Annual Mitigation Costs**
Adapting Existing Infrastructure					
Relocate Buildings	low - high energy	low	very high	none	none
Relocate Roads & Infrastructure	low - high energy	low	very high	none	none
Elevate Existing Buildings	low - high energy	low	very high	low	none
Enhancements to the Natural System					
Dune Restoration	low - high energy	low	low	low	none
Beach Nourishment	low - high energy	low-medium	low-high	low-medium	none
Bioengineering	low - high energy	medium - high	low - medium	low - medium	low
Erosion Control Vegetation	low - high energy	low	low	low	none
Sand Fencing	low - high energy	low	low	low	low
Salt Marsh Creation	low energy	low - high	low - medium	low - medium	none
Sand By-Pass	low - high energy	low - medium	low - medium	low	none
Sand Back-Pass	low - high energy	medium - high	low - medium	low	none
Nearshore Coastal Engineered Structures					
Breakwater/Reef Nearshore	low - high energy	medium - high	high - very high	low	low
Shore Parallels Coastal Engineered Structures					
Dike/Levee	low - high energy	medium - high	medium - high	low	low
Rock Revetment - Toe Protection	low - high energy	medium - high	high	low	low - medium
Revetment - Full Height	low - high energy	high - very high	very high	low	medium
Geotextile Tubes	low - high energy	very high	high	medium - high	medium
Gabions	low energy	high - very high	high	medium	low
Seawall	low - high energy	high - very high	very high	low	medium - high
Bulkhead	low energy	high - very high	high	low	low

Shore Perpendicular Coastal Engineered Structures					
Groin	low - high energy	very high	very high	low	low - high
Jetty	low - high energy	very high	very high	low	low - high
Offshore Coastal Engineered Structures					
Breakwater - Offshore	low - high energy	very high	very high	low	none

5.0 Summary of Strategies and Recommendations

Based on a review of historical N.C. studies, lessons learned from other coastal states, DCM experience and public comments, the following strategies should be considered:

- Identify data and knowledge gaps in erosion hazard assessments and modeling, and the potential effects of these gaps on policy and decision making; and support additional data collection to establish subregional sediment budgets.

- Formalize beach management at the local and subregional levels; for example, encourage beach communities to develop local beach management plans and necessary inter-local agreements; invest in local beach management staff, partnerships, and monitoring efforts; create or maintain dedicated sources of beach management funding; and explore opportunities for regional collaboration with neighboring communities.

- Employ sensible construction setbacks to account for beach erosion and shoreline migration, taking into account the life expectancy of the structure, the range of mitigation options available, and the feasibility of their implementation.

- Regularly evaluate the combined budgetary needs for erosion response projects, taking into consideration the prevailing and expected cost-share percentages among funding entities; and establish stable and predictable funding sources sufficient to meet statewide needs.

- Maximize the amount of beach-compatible dredged material that is beneficially used in mitigating beach erosion.

- Continue to streamline permitting for beach projects at the federal and state levels as a way to decrease permit processing times, permitting costs, and emergency situations.

- Provide dedicated state agency staff support and technical assistance for local and regional beach management efforts.

As evidenced from past efforts, a state-level beach management strategy is needed to better understand local and regional sediment budgets, maintain a healthy ecosystem, protect the public's right to access and use the beach, protect property rights, and afford property owners (both public and private) with storm protection. Any new strategy should focus on continued investments in beach nourishment as the preferred alternative for mitigating beach erosion. The two largest obstacles associated with this approach are having dedicated, predictable funding sources and the identification of long-term supplies of beach-compatible sand resources.

6.0 Summary of Public Comments

All public comments have been included in the appendices of this report (Appendix A – G). The following summarizes the comments and recommendations received by DCM during the comment period from October 14 through December 31, 2015:

1. Monitoring and Research
    a. In order to better understand sediment budgets and sand volume changes over time, funding should be established so that routine monitoring of the shoreface, beach and dunes can be performed for the entire oceanfront.
    b. In the past, N.C. has focused its attention on oceanfront shoreline change rates. It is recommended that the state also routinely study changes occurring at developed inlets to include mapping of inlet features (channels, swash bars, ebb and flood-tide deltas, etc.).
2. Funding and Management
    a. The state should develop a dedicated funding source for locally-initiated beach nourishment and inlet management projects similar to the "Shallow Draft Navigation Channel and Lake Dredging Fund." Beach nourishment projects have occurred where only local, or local and federal funds have been used without any contribution from the State.
    b. The state should promote and support regional approaches to beach and inlet management that cross multiple jurisdictions, which are codified by state law, inter-local agreements, or some other legal mechanism.
    c. Beneficial use of dredged material should be a priority. The state should continue working with the USACE to ensure disposal of dredged beach quality material is done in a manner that replicates the sand budget to keep it in the system.
3. Regulatory
    a. Beach nourishment is the most effect solution to mitigate erosion. The state should endorse beach nourishment as the primary alternative for dealing with erosion, and abandon the concept of "retreat" since this is not a practical option for most.
    b. Responsibly expand dredging windows with safeguards and mitigation measures in an effort to reduce local and potentially state costs, while allowing more time for projects to be completed.
    c. Improve permitting timelines. Knowing that beach nourishment is the primary method communities will be using to mitigate most erosion, the permitting process should be streamlined, and Environmental Assessments/FONSIs should be required for individual nourishment and inlet relocation projects.
    d. When merited, the state should oppose future species listing (endangered or threatened) and critical habitat designations established by the U.S. Fish and Wildlife Service and National Marine Fisheries Service. These designations create another layer

of review and consultation that require additional funds when seeking a nourishment project.

e. The state should require the USACE to abide by its erosion monitoring and mitigation obligations made in the environmental review process and incorporated in the State's consistency determination.
f. The state should work with the USACE to adequately study the effects and impacts of shipping channel dredging.

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