II. Data Acquisition

The identification and collection of pertinent data is critical to the understanding of any natural system. The nature of the beaches and inlets along the coast are influenced by a wide array of factors that include geology, sediment characteristics, waves, currents, water levels, and storms. Datasets related to socioeconomic factors are also integral to comprehensive management of the beaches and inlets.

The amount of data available for North Carolina's coast is considerable and the collection and analysis of it all is beyond the scope of this initial BIMP effort. Therefore, the objective of these data collection efforts was to develop the best understanding of the state's beaches and inlets based on the most readily available and relevant statewide data sets. Collectively this information can serve as a common reference point for the discussion of possible management strategies.

A. Review of Coastal Statewide Planning/Management Case Studies

The BIMP is intended to be a holistic examination of the oceanfront coastline focusing on a regional management approach rather than just individual beach and inlet projects. States are approaching beach and inlet management planning in a variety of ways, under a variety of titles (*e.g.*, shoreline management, regional sediment management, ocean shore management), and on a variety of scales. A literature review was conducted by the Division of Coastal Management (DCM) to identify states and other entities that have addressed statewide or local beach and inlet management plans, a well as to review the approaches studied and adopted (Appendix A). Some states have developed plans for managing beaches and inlets focusing on individual inlet management plans (AL, DE), while others have concentrated their efforts on regional sediment management (CA, SC). There have also been cases where particular aspects of the beach, such as erosion or dunes (MD, VA) have been the focus.

Only a few states currently have, or are working towards, statewide beach management plans (FL, OR). However, many states have local and regional management plans with beach, dune, and inlet management being pursued on a local scale. Several states (HI, ME, NC) are turning to strategic, statewide beach and inlet management as a way to incorporate shoreline and riverine sediment transport processes rather than the traditional beach-by-beach, project-by-project focus of past efforts. The intent of a comprehensive approach is to improve the effectiveness of beach protection projects while ensuring that sand dredged in a region stays in that region's sediment transport system.

There are several common themes that run throughout the state beach and inlet management initiatives: 1) development of more holistic, systems-wide management plans; 2) attempts to balance societal and ecological needs more effectively; 3) implementation of regional management of sand resources; 4) beach nourishment and dune ecosystem rehabilitation; and 5) assessment of the total costs of various beach management strategies.

Of the 96 documents reviewed, 26 pertained to statewide or local management plans related to beach management; 16 were proposed beach management strategies; 23 were articles that analyzed beach management strategies; six were legal policies or legislation related to beach management; and one was a commentary on sustainability of urbanized coastal environments. Seventeen documents were also found related to beach and inlet management in countries other than the U.S. including Australia, New Zealand, Mexico, and the European Union countries.

Only two states have formally titled statewide beach management plans (FL and OR); however, several states (CA, SC, GA, MS, LA, TX, and WA) have management programs, plans and/or legislation that, while not formally titled as such, are in some respect, statewide beach management plans. At least three states are currently pursuing statewide beach and inlet management plans (HI, NC, ME); and many states have beach and inlet management plans for localized areas or regions (AL, CA, DE, GA, HI, MD, ME, MA, OR, TX, VA).

While many states are addressing beach management, Florida is the most frequently referenced state when it comes to strategic beach management. Florida's plan has been in place the longest (since 1986) and has been funded continuously. The state has dedicated approximately $30 million annually for beach nourishment and administers a program for the distribution of these funds. In addition, Florida has management plans for its developed inlets.

While the incorporation of process-based, systems-wide strategies is becoming more widely embraced, the approach is still relatively new and the limited literature on its impact makes it difficult to isolate a single strategy that appears to be the most effective. One particular program being touted as a way both to manage beach and inlet systems more holistically, and also promoted as a more effective balance between social, economic and ecological needs, is the U.S. Army Corps of Engineers (USACE) Regional Sediment Management (RSM) program.

The USACE's RSM program is a relatively new strategy (developed in the late 1990s) that states such as California, Maine, Florida, and North Carolina are incorporating into beach management programs. The RSM program is based upon the principle that sediment should be managed and conserved within discrete sediment transport regions or littoral cells (USACE 2005, Martin 2002). The assertion is that the traditional method of minimizing the cost of individual projects does not always benefit nearshore systems, nor does it minimize long-term costs for the USACE. Managing sediment within littoral cell regions, however, can lead to a more effective distribution of sediment and result in long-term savings. More information on RSM is available at http://www.wes.army.mil/rsm/.

B. Data Collection Process

While the BIMP does not include all datasets, an effort was made to contact government agencies, municipalities, and university personnel with experience and knowledge of beach and inlet issues to collect readily available and published datasets. The list of agencies contacted includes:

Federal
U.S. Army Corps of Engineers
U.S. Geological Survey
U.S. Fish and Wildlife

State
DENR – Division of Water Resources
DENR – Division of Coastal Management
DENR – Division of Marine Fisheries
DENR – Division of Water Quality
DENR – Division of Land Resources, N.C. Geological Survey
DENR – Division of Parks and Recreation
DENR – Wildlife Resources Commission

Local Municipalities and Contractors
Carteret County
Dare County
New Hanover County
Town of Emerald Isle
Town of Topsail Beach
Town of North Topsail Beach
Figure Eight Island
Village of Bald Head Island
Coastal Planning & Engineering, Inc.
Olsen Associates, Inc.

Universities
North Carolina State University
University of North Carolina at Chapel Hill
Western Carolina University
East Carolina University
University of North Carolina at Wilmington
Duke University

C. Identification and Overall Summary of Key Datasets

The development of a BIMP for North Carolina requires an understanding of the processes and issues that influence and interact with the inlets and beaches. Physical processes such as sediment transport along the beaches driven by waves, currents, and changing water levels interact with and are influenced by inlets, human activities and the underlying geology. Not only are physical processes important but the ecological and socio-economic aspects of beaches and inlets also play an essential role in the decision making process. The following sections provide an overall summary of some of these data. More detailed summaries can be found in the individual region sections. A data bibliography is also provided in Appendix B to summarize where pertinent beach and inlet management data are housed and maintained.

1. Overview of North Carolina Coastal Geography

North Carolina has 326 miles of ocean shoreline across eight counties that border the Atlantic Ocean (Currituck, Dare, Hyde, Carteret Onslow, Pender, New Hanover and Brusnwick). The oceanfront shoreline includes 19 active tidal inlet complexes, a long chain of barrier islands, and three capes (Cape Hatteras, Cape Lookout and Cape Fear).

Figure II-1 illustrates key features and location of inlets along the North Carolina coast.

Table II-1 provides the estimated mileage and percentage of county shoreline for the developed and undeveloped portions of the coast. Developed shoreline is defined herein as any segment of shoreline which borders developed properties (*e.g.,* residential, commercial). Undeveloped reaches are areas within national, state, or local parks, Coastal Reserves, or reaches where development has not occurred due to the dynamic nature of the system (adjacent to inlets). The distance along the shoreline was based on the 2004 shoreline, as delineated by DCM.

Table II-1. Miles and Percentage of County Shoreline for Developed and Undeveloped Portions of the Oceanfront

County	Distance of Shoreline		Portion of County Shoreline		TOTAL (mi)
	Undeveloped (mi)	Developed (mi)	Undeveloped (%)	Developed (%)	
Brunswick	10	30	24	76	40
New Hanover	15	16	48	52	31
Pender	5	9	33	67	14
Onslow	13	14	48	52	27
Carteret	60	25	71	29	85
Hyde	14	3	82	18	17
Dare	45	44	51	49	89
Currituck	5	18	20	80	23
Total	**166**	**160**	**51**	**49**	**326**

While the length of beaches and number of inlets presents a challenge to the development of statewide management strategies, it also illustrates the importance of regional and holistic approaches to managing the system.

Figure II-1. Coastal Carolina Geography

2. Waves and Climate

The physical composition of the shoreline and the physical processes that occur both in short-term time scales and longer geological time scales influence the behavior of the beaches and inlets. Waves, hurricanes and geologic shoreface materials influence the availability and movement of beach sands which is fundamental to the understanding of the suitability and impacts of beach and inlet management practices. Waves play a major role in the shaping and evolution of beaches and inlets. Moving water suspends and transports sediment, with the severity, frequency, and direction of incoming waves influencing the beach and inlet morphology.

Wave data along the North Carolina coast is available from USACE long-term wave hindcast modeling and from measurements at various wave buoys. Wave hindcast model locations as well as physical climate data-recording stations and buoys are presented in Figure II-2.

The USACE Wave Information Study (WIS) is an extensive hindcast model that provides wave information (height, period, and direction) for the 20-year period of 1980-99 at more than 300 stations off the North Carolina coast, with water depths varying from 50 to 650 feet. Wave hindcasts are numerical models which use historical wind and meteorological data to calculate, or hindcast, what the waves would have been. These data are available and on the USACE website at http://www.frf.usace.army.mil/cgi-bin/wis/atl/atl_main.html.

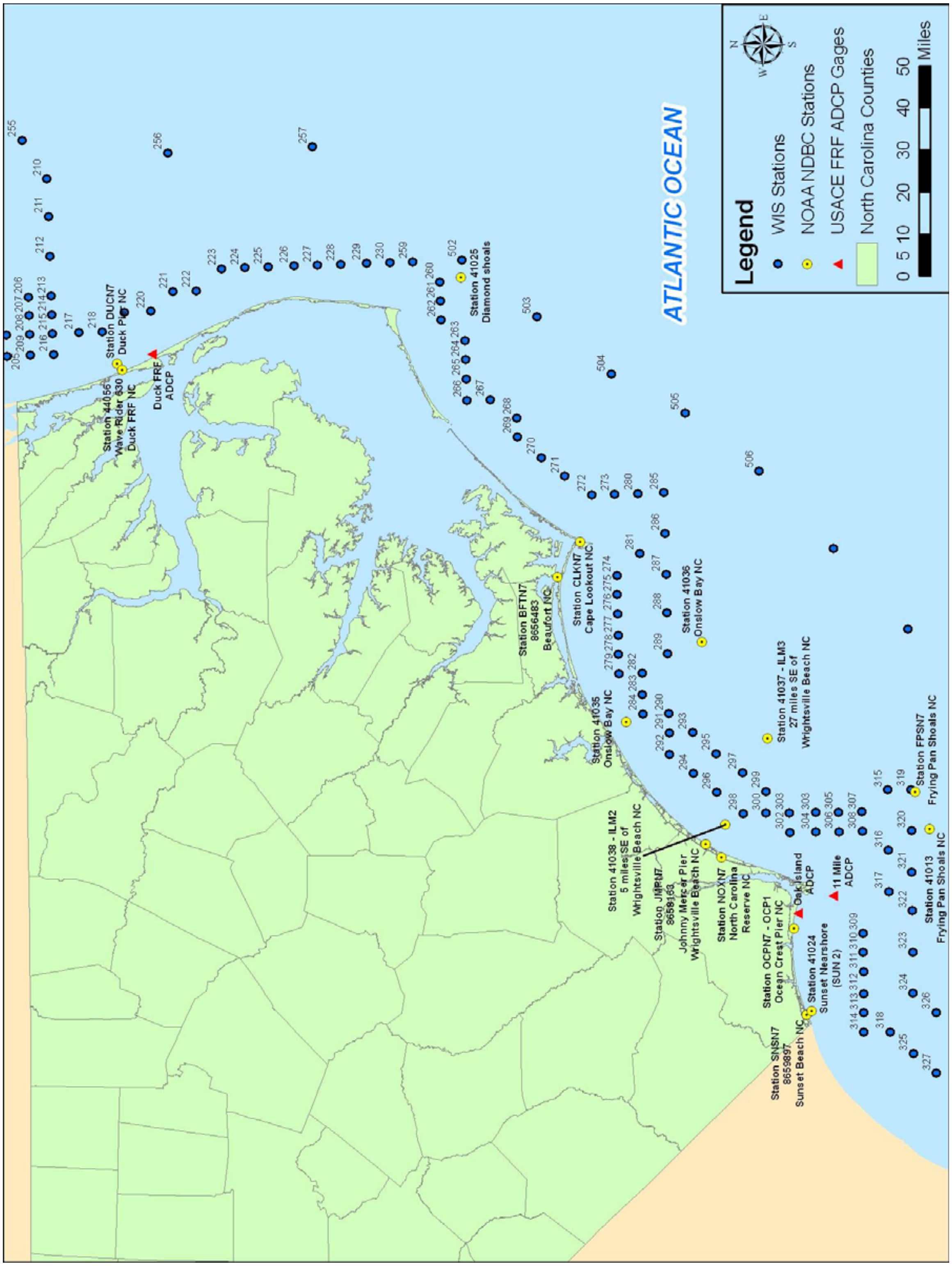


Figure II-2. Wave and Climate Recording Data Stations

3. Water Levels

Beaches and inlets are impacted by both temporal and spatial variations in water level. Water level variations can have regular periodicity, such as the tides, or be aperiodic or random, such as storm surge or wind driven tides. Water level changes can also occur over long periods of time due to relative sea level rise (the combination of global sea level rise and local/regional land subsidence).

a) Tides and Tidal Stations

Tides are long-period waves that move through the oceans in response to the forces exerted by the moon and sun. As tides progress toward the coast they appear as the regular rise and fall of the sea surface. The highest part or crest of the wave is known as high tide and the lowest part or wave trough as low tide. The difference in height between the high tide and the low tide is called the tidal range. Along the North Carolina coast tides are typically semidiurnal, having two high tides and two low tides each day of similar heights.

Figure II-3 is a conceptual example of a semidiurnal tide. It should be noted that wind tides are also present within the sounds and can overwhelm normal tidal fluctuations.

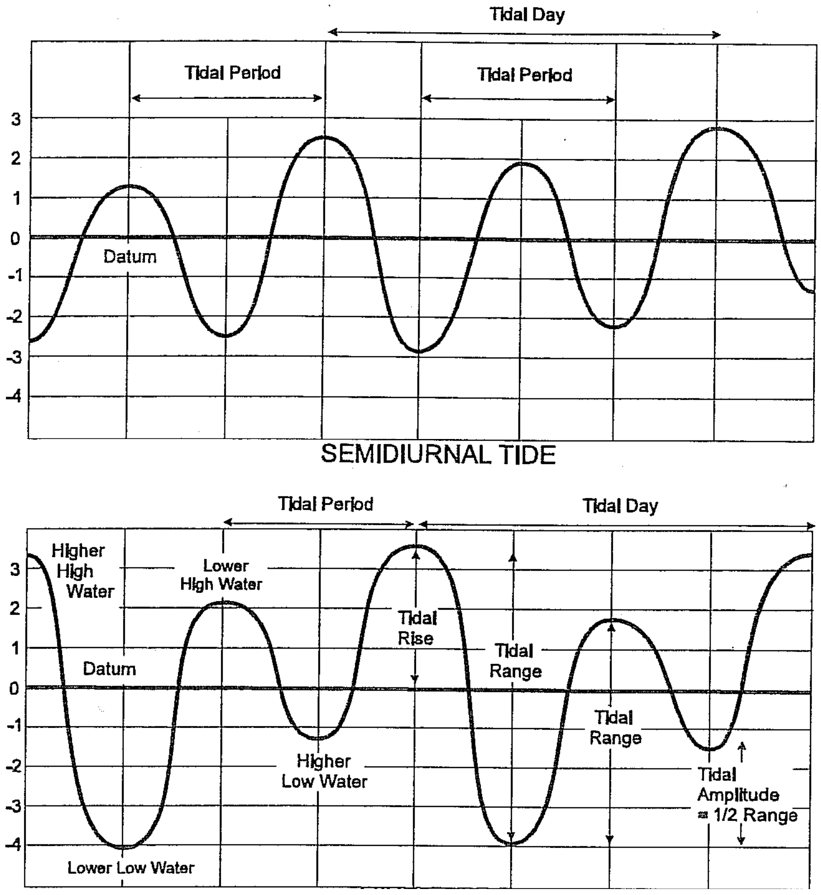


Figure II-3. Tide Variations (After NOAA Tide Tables)

Tides are currently actively measured at six locations along the North Carolina coast by the National Oceanic and Atmospheric Administration (NOAA) and the USACE. The locations of these water level measurement sites are shown in Figure II-4 and the tidal datums presented in Table II-2. The southern portion of the coast has a slightly larger tidal range than the northern portion of the coast.

Table II-2. Tidal Datums With Respect to MLLW

Datum	**Duck, NC** **Sta 8651370** **(1977-present)**	**Oregon Inlet Marina, NC** **Sta 8652587** **(1974-present)**	**Beaufort, NC** **Sta 8656483** **(1964-present)**	**Wrightsville Beach, NC** **Sta 8658163** **(2004-present)**	**Southport, NC** **Sta 8659084** **(1974-2008)**	**Sunset Beach, NC** **Sta 8659897** **(1974-2008)**
Mean Higher High Water (MHHW)	3.69	1.17	3.54	4.29	4.73	5.51
Mean High Water (MHW)	3.37	1.02	3.26	3.95	4.40	5.12
Mean Tide Level (MTL)	1.76	0.58	1.70	2.05	2.28	2.65
Mean Sea Level (MSL)	1.77	0.58	1.71	2.03	2.32	2.66
Mean Low Water (MLW)	0.14	0.13	0.15	0.15	0.16	0.18
Mean Lower Low Water (MLLW)	0.00	0.00	0.00	0.00	0.00	0.00
North American Vertical Datum (NAVD)	2.19	0.67	No Data	2.44	2.78	No Data
National Geodetic Vetical Datum (NGVD)	1.23	-0.34	No Data	No Data	1.68	No Data
Maximum	6.92	5.66	6.29	6.92	6.88	7.56
Max Date	8/30/1999	9/16/1999	9/16/1999	10/9/2006	12/2/1986	10/9/2006

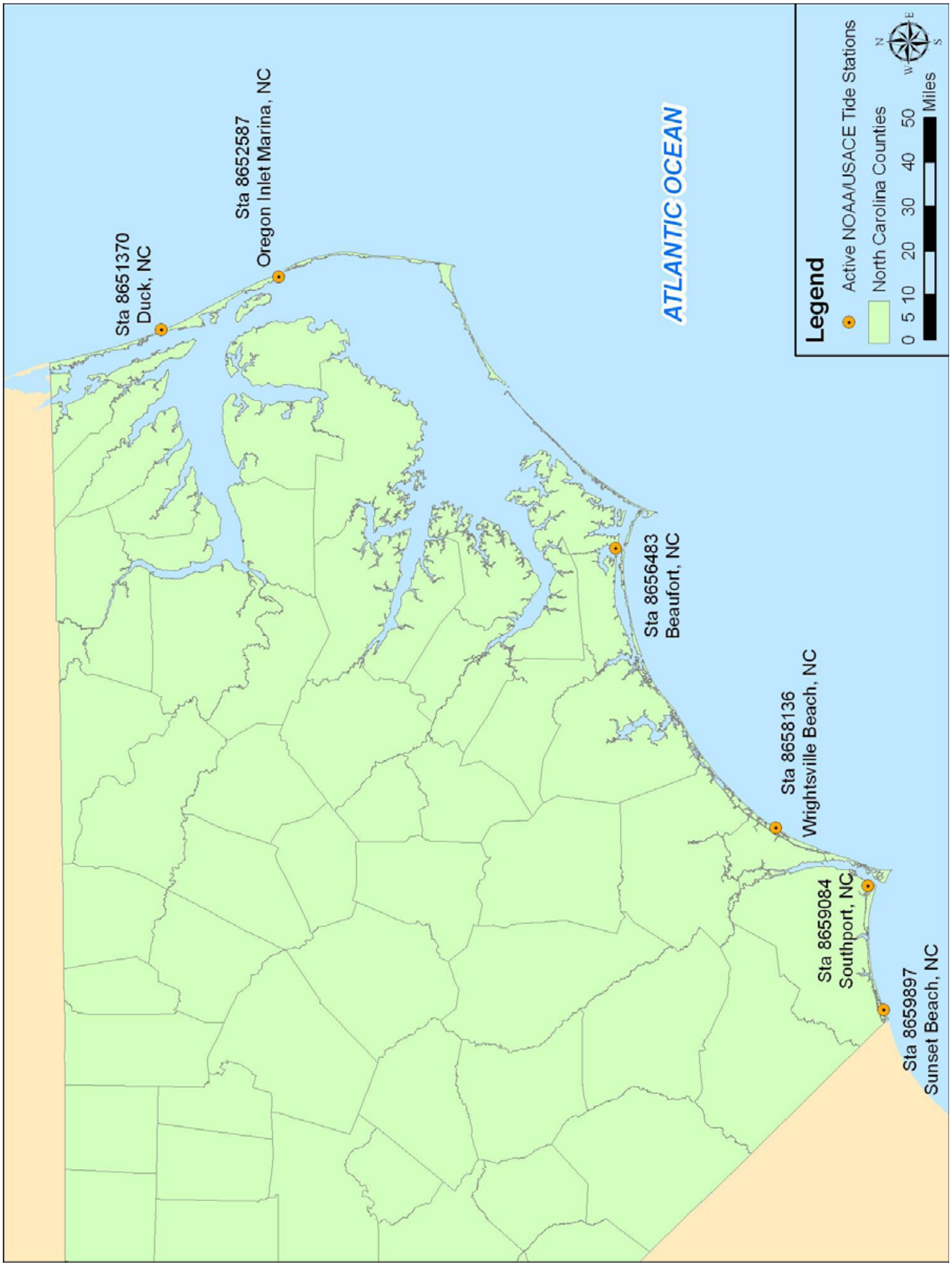


Figure II-4. NOAA/USACE Tide Station Locations

b) Tidal Currents

Tides generate tidal currents resulting from the horizontal movement of water that accompanies the rising and falling of the tide. As the water level rises, flows enter the inlets (flood currents) and as the water level drops, flows exit the inlets (ebb currents).

Depending on the geometry and volume of the inlet or estuary, these tidal currents can be quite large and move substantial volumes of sediment and water. A tidal shoal system is typically formed in an inlet, as illustrated in Figure II-5. North Carolina currently has 19 active tidal inlet complexes (Drum Inlet, while comprised of three distinct inlets at present, is considered one inlet complex for the purpose of this study).

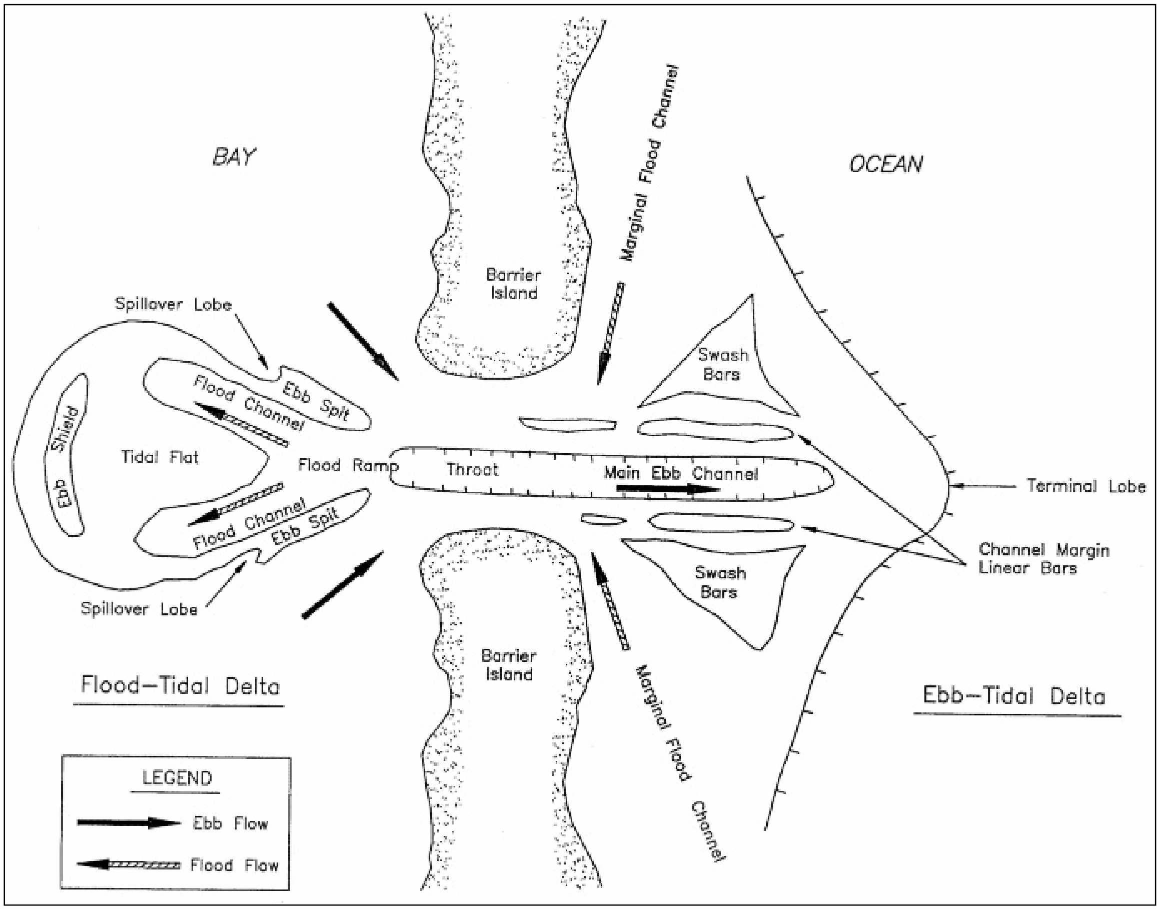


Figure II-5. Tidal Shoal System (USACE Coastal Engineering Manual, 2008)

c) Storm Surge and Coastal Flood Water Levels

Shorter-term water level fluctuations due to passing storms, both extratropical (northeasters) and tropical (tropical storms and hurricanes), can elevate water levels along the coast that results in flooding and the reach of waves farther up the beach face. See Figure II-6 which illustrates the influence of water level across a typical beach profile.

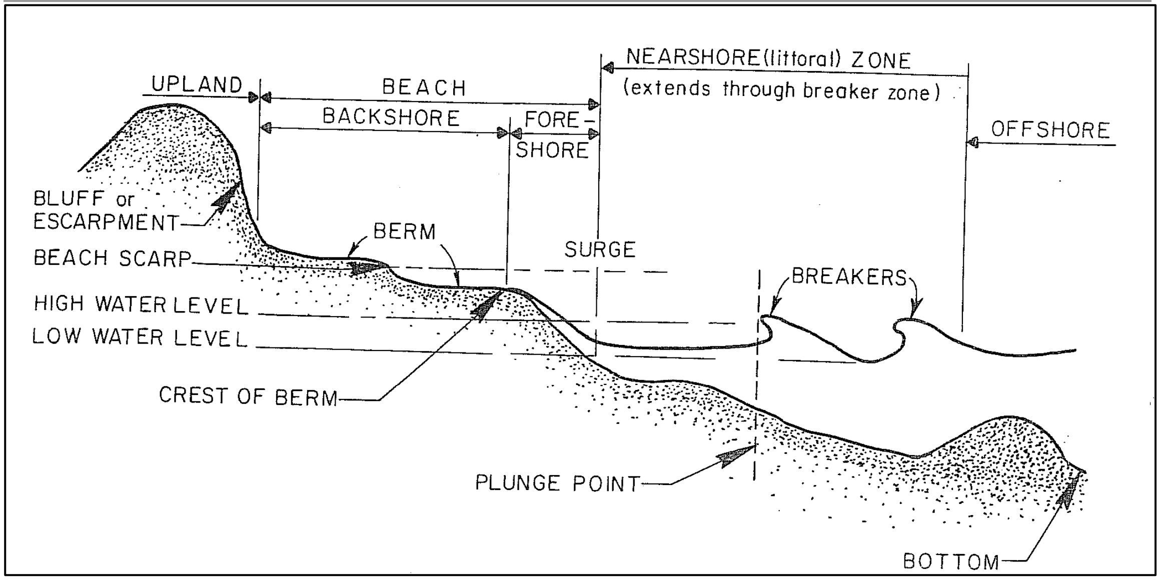


Figure II-6. Typical Beach Profile – Illustrates Influence of Water Level

Storm-driven water levels along the coast are available for events with a one percent annual chance of occurrence (100-year return period) from the Flood Insurance Rate Maps (FIRM) and Flood Insurance Studies (FIS) developed by the Federal Emergency Management Agency (FEMA). North Carolina is currently in the process of updating these maps along coastal regions through the North Carolina Floodplain Mapping Program (NCFMP) under the North Carolina Office of Geospatial and Technology Management (NCGTM) (www.ncfloodmaps.com).

The NCGTM is implementing the next phase of FEMA’s Map Modernization through a recently authorized $5 million study. The NCGTM’s vision of enhanced and integrated hazard risk management (IHRM) couples hazard mapping and risk assessment with communication and mitigation efforts. The IHRM supports and supplements FEMA’s Risk MAP (Mapping, Assessment, and Planning) vision and will serve as a test case for the rest of the nation. Because North Carolina has released digital flood maps for all 100 counties, the state is uniquely suited to partner with FEMA to lay the foundation for a second phase of Map Modernization. The demonstration will be conducted in four representative counties (to be determined) and will emphasize five key activities: 1) maintenance of data developed in Phase 1; 2) data development and collection of additional hazard data, applications and protocols needed to enable N.C. communities to take proactive measures to quantify and mitigate hazard risk; 3) transition to a completely digital program; 4) obtaining full delegation from FEMA; and 5) integrating multiple hazards into the digital map. The demonstration will serve as a test for the latest concepts on how to move beyond the single emphasis of identifying flood hazards, to an emphasis on a variety of hazards and associated risk management strategies. Initial efforts focus on the development of a robust multi-hazard geodatabase, digital map implementation, modeling and mapping of multiple flood recurrence intervals, identification of residual flood risk associated with levees and dams, high wind risk, coastal erosion zones, earthquakes and landslides. Innovative communication strategies such as identifying the critical return period of structures, assessing expected annual damages, and mapping flood depths will be explored and demonstrated through web-based tools and mitigation strategy toolbox.

d) Sea Level Rise

Relative sea level is rising along the North Carolina coast is a combination of global sea level rise and regional land subsidence. Long-term tidal water level recording stations estimate the rate of this rise as approximately 1 to 1.5 feet/century along the North Carolina coast.

Figure II-7 shows the sea level rise in feet at the Beaufort (Carteret County-NOAA gauge) tidal measurement station. The mean sea level rise trend is 1.22 ft./century with a standard error of 0.21 feet/century based on monthly mean sea level data from 1973 to 1999. The upper and lower hindcast lines indicate the upper and lower 95 percent confidence interval, respectively. Short-term sea-level rise from 1980 to 2000 at Duck, N.C. (Dare County), based on tide level readings, is estimated to be 1.5 ft./century (Riggs, 2008). Other studies show estimates of sea-level rise for the Outer Banks of 10.5 in./century (Pietrafesa *et al.*, 2005). All of these estimates are based on extrapolation of measurements less than 100 years.

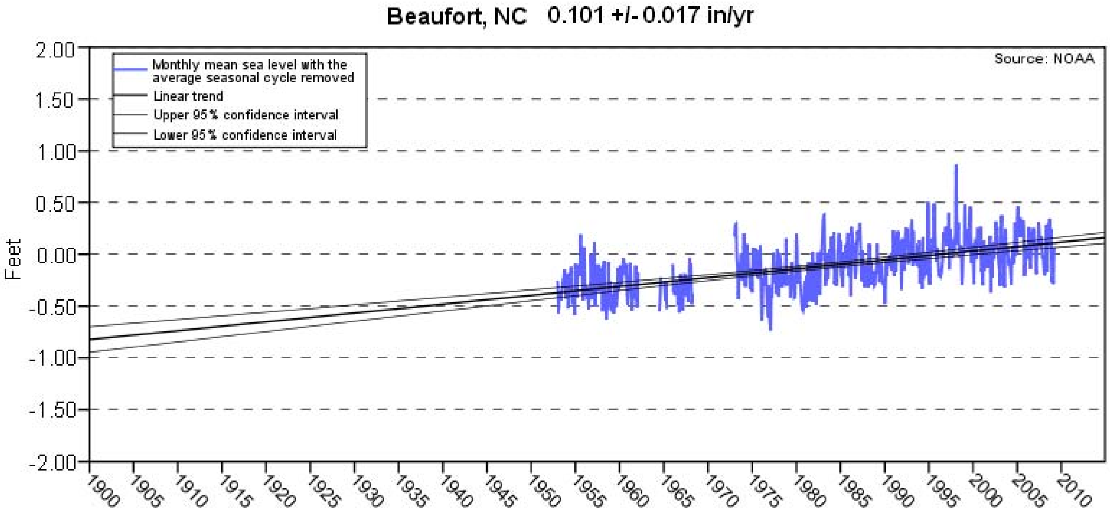


Figure II-7. Sea-Level Rise at Beaufort, N.C.

The CRC Science Panel on Coastal Hazards released a report based on a review of the published literature, of the known state of sea-level rise for North Carolina. The intent of this report is to provide North Carolina's planners and policy makers with a scientific assessment of the amount of SLR likely to occur in this century. The report does not attempt to predict a specific future rate or amount of rise because that level of accuracy is not considered to be attainable at this time. Rather, the report constrains the likely range of sea-level rise and recommends an amount of sea-level rise that should be adopted for policy development and planning purposes. The Science Panel found the most likely scenario for 2100 is a rise of 0.4 meter to 1.4 meters (15 inches to 55 inches) above present, and recommended that a rise of one meter by 2100 be adopted for planning purposes.

Increasing sea level over time will flood some low lying coastal areas and also, during elevated storm water levels, allow waves and currents to travel farther up the beach and into the inlets. This may result in greater wave-induced erosion of the beaches and shifting of the inlets and associated sediments.

A recently authorized study will provide even more insight into sea-level rise and its potential impacts. FEMA's FY 2009 Budget Appropriation (PL 110-329) included $5 million for the state of North Carolina to conduct a North Carolina Sea Level Rise Risk Management Study, with final scenarios expected in mid-2011. The following is excerpted from the "Explanatory Statement" accompanying P.L. 110-329: The Bill provides $5 million for the State of North Carolina to perform a risk assessment and mitigation strategy demonstration of the potential impacts of sea level rise in that state associated with long-term climate change, as discussed in the House report (http://www.ncsealevelrise.com/). FEMA is directed to use the study results to assess the long-term fiscal implications of climate change as it affects the frequency and impacts of natural disasters, and to disseminate information from the study to other states to inform their climate change mitigation efforts. This study is being performed by the North Carolina Office of Geospatial and Technology Management's (NCGTM) Division of Emergency Management, who will be responsible for the risk assessment of sea-level rise and increased flooding associated with long-term climate change in North Carolina as required by PL 110-329. Aspects of flooding to be evaluated are: 1) sea-level rise, 2) increasing frequency and/or intensity of coastal flooding (surge, wave heights), and 3) erosion. The study will develop reasonable scenarios of potential sea-level rise and demographic conditions in North Carolina for four "time slices" through 2100: near-term (2025), medium-term (2050), long-term (2075), and end of the century (2100). For more details on this study and other ongoing and proposed studies, see the policy considerations portion of Section VI.B.

4. Tropical Storms

North Carolina has been affected by many tropical cyclones (storms and hurricanes) throughout its history. A tropical cyclone is a low pressure system that forms over warm oceans which may eventually reach tropical depression, tropical storm, or hurricane status if conditions are favorable. The state's protruding coastline makes it susceptible to hurricane and tropical storm landfall. The coast of North Carolina can expect to receive direct landfall of a tropical cyclone once every four years, while a tropical cyclone which may have made landfall in another state and later passed through North Carolina affects the state every 1.3 years. Only the states of Florida, Louisiana, and Texas experience more hurricane landfalls and passing tropical cyclones within 50 miles. North Carolina tropical cyclone statistics from the N.C. State Climate Office (http://www.nc-climate.ncsu.edu/climate/hurricanes/statistics.php) are presented in Table II-3.A list of hurricanes which have made landfall in North Carolina is presented in Table II-4.

Additional storms which have affected North Carolina either by moving through the state after making landfall elsewhere or skirting the coastline are presented in Table II-5.

Table II-3. N.C. Tropical Cyclone Statistics (1851-2009)

Statistic	Direct Landfalling Hurricanes in NC	Hurricanes and Tropical Storms Affecting NC	Total Storms Affecting NC
Number of Storms	48	172	252
Percentage of Storms	3.42	12.26	17.96
Average Number of Years Between Storms	3.29	0.92	0.63
Average Number of Storms Per Year	0.3	1.09	1.59

Table II-4. Direct Landfalling Hurricanes in North Carolina (State Climate Office)

Storm Name	Max Classification	Year
Ophelia	Category 1	2005
Charley	Category 4	2004
Alex	Category 3	2004
Isabel	Category 5	2003
Floyd	Category 4	1999
Bonnie	Category 3	1998
Fran	Category 3	1996
Bertha	Category 3	1996
Emily	Category 3	1993
Charley	Category 1	1986
Gloria	Category 4	1985
Diana	Category 4	1984
Ginger	Category 2	1971
Donna	Category 5	1960
Ione	Category 3	1955
Diane	Category 3	1955
Connie	Category 4	1955
Hazel	Category 4	1954
Carol	Category 2	1954
Barbara	Category 2	1953
Unnamed	Category 2	1949
Unnamed	Category 4	1944
Unnamed	Category 1	1944
Unnamed	Category 3	1936
Unnamed	Category 3	1933
Unnamed	Category 3	1933
Unnamed	Category 1	1920
Unnamed	Category 1	1913
Unnamed	Category 1	1908
Unnamed	Category 1	1906
Unnamed	Category 1	1901
Unnamed	Category 2	1899
Unnamed	Category 4	1899
Unnamed	Category 3	1896
Unnamed	Category 3	1893
Unnamed	Category 3	1893
Unnamed	Category 3	1887
Unnamed	Category 3	1885
Unnamed	Category 3	1883
Unnamed	Category 2	1881
Unnamed	Category 1	1880
Unnamed	Category 3	1879
Unnamed	Category 2	1878
Unnamed	Category 3	1876
Unnamed	Category 1	1874
Unnamed	Category 1	1861
Unnamed	Category 1	1861
Unnamed	Category 2	1857

Table II-5. Storms That Have Affected North Carolina (State Climate Office)

Storm Name	Max Classification	Year
Unnamed	Tropical Depression	2009
Hanna	Category 1	2008
Fay	Tropical Storm	2008
Cristobal	Tropical Storm	2008
Gabrielle	Tropical Storm	2007
Barry	Tropical Storm	2007
Ernesto	Category 1	2006
Alberto	Tropical Storm	2006
Cindy	Category 1	2005
Jeanne	Category 3	2004
Ivan	Category 5	2004
Gaston	Category 1	2004
Frances	Category 4	2004
Bonnie	Tropical Storm	2004
Bill	Tropical Storm	2003
Allison	Tropical Storm	2001
Helene	Tropical Storm	2000
Gordon	Category 1	2000
Dennis	Category 2	1999
Earl	Category 2	1998
Danny	Category 1	1997
Josephine	Tropical Storm	1996
Jerry	Tropical Storm	1995
Allison	Category 1	1995
Gordon	Category 1	1994
Beryl	Tropical Storm	1994
Alberto	Tropical Storm	1994
Andrew	Category 5	1992
Marco	Tropical Storm	1990
Hugo	Category 5	1989
Chris	Tropical Storm	1988
Kate	Category 3	1985
Danny	Category 1	1985
Bob	Category 1	1985
Frederic	Category 4	1979
David	Category 5	1979
Babe	Category 1	1977
Unnamed	Tropical Storm	1976
Dottie	Tropical Storm	1976
Eloise	Category 3	1975
Agnes	Category 1	1972
Edith	Category 5	1971
Alma	Category 1	1970
Abby	Category 1	1968
Unnamed	Tropical Storm	1965
Dora	Category 4	1964
Cleo	Category 4	1964
Gracie	Category 4	1959
Cindy	Category 1	1959
Arlene	Tropical Storm	1959
Flossy	Category 1	1956
Able	Category 2	1952
Unnamed	Category 4	1949
Unnamed	Tropical Storm	1947
Unnamed	Tropical Storm	1947
Unnamed	Category 4	1946
Unnamed	Category 4	1945
Unnamed	Category 3	1944
Unnamed	Category 1	1940
Unnamed	Category 1	1939
Unnamed	Category 5	1935
Unnamed	Tropical Storm	1934
Unnamed	Category 4	1933
Unnamed	Tropical Storm	1932
Unnamed	Category 4	1929
Unnamed	Category 5	1928
Unnamed	Category 1	1928
Unnamed	Category 2	1928
Unnamed	Tropical Storm	1927
Unnamed	Category 2	1916
Unnamed	Category 4	1915
Unnamed	Category 2	1915
Unnamed	Tropical Storm	1915
Unnamed	Category 1	1913
Unnamed	Tropical Storm	1912
Unnamed	Category 2	1911
Unnamed	Tropical Storm	1908
Unnamed	Tropical Storm	1907
Unnamed	Tropical Storm	1905
Unnamed	Category 1	1904
Unnamed	Category 1	1903
Unnamed	Category 2	1902
Unnamed	Tropical Storm	1902
Unnamed	Tropical Storm	1901
Unnamed	Tropical Storm	1900
Unnamed	Category 2	1896
Unnamed	Category 3	1894
Unnamed	Category 4	1893
Unnamed	Category 2	1889
Unnamed	Tropical Storm	1888
Unnamed	Category 1	1887
Unnamed	Category 2	1887
Unnamed	Category 2	1886
Unnamed	Category 2	1886
Unnamed	Tropical Storm	1885
Unnamed	Category 3	1882
Unnamed	Category 2	1878
Unnamed	Category 3	1877
Unnamed	Category 1	1867
Unnamed	Category 1	1859
Unnamed	Category 3	1856
Unnamed	Category 3	1854
Unnamed	Category 2	1852
Unnamed	Category 3	1852
Unnamed	Category 3	1851

NOAA maintains a GIS database that includes tracks for Atlantic and Pacific hurricanes, cyclones, and extratropical systems. Approximate storm location, date, wind speed, pressure, and category have been recorded for storms beginning in 1851. GIS shapefiles can be downloaded at NOAA's website. A map displaying the recorded Atlantic hurricane tracks from 1851 to 2007 is presented in Figure II-8. Detailed maps of the extratropical storms affecting the coast can be found in the individual Region sections (VIII.A, IX.A, X.A, XI.A). While the entire coast is vulnerable to hurricanes, the coastline south of Cape Hatteras experiences a higher density of hurricane tracks passing nearby.

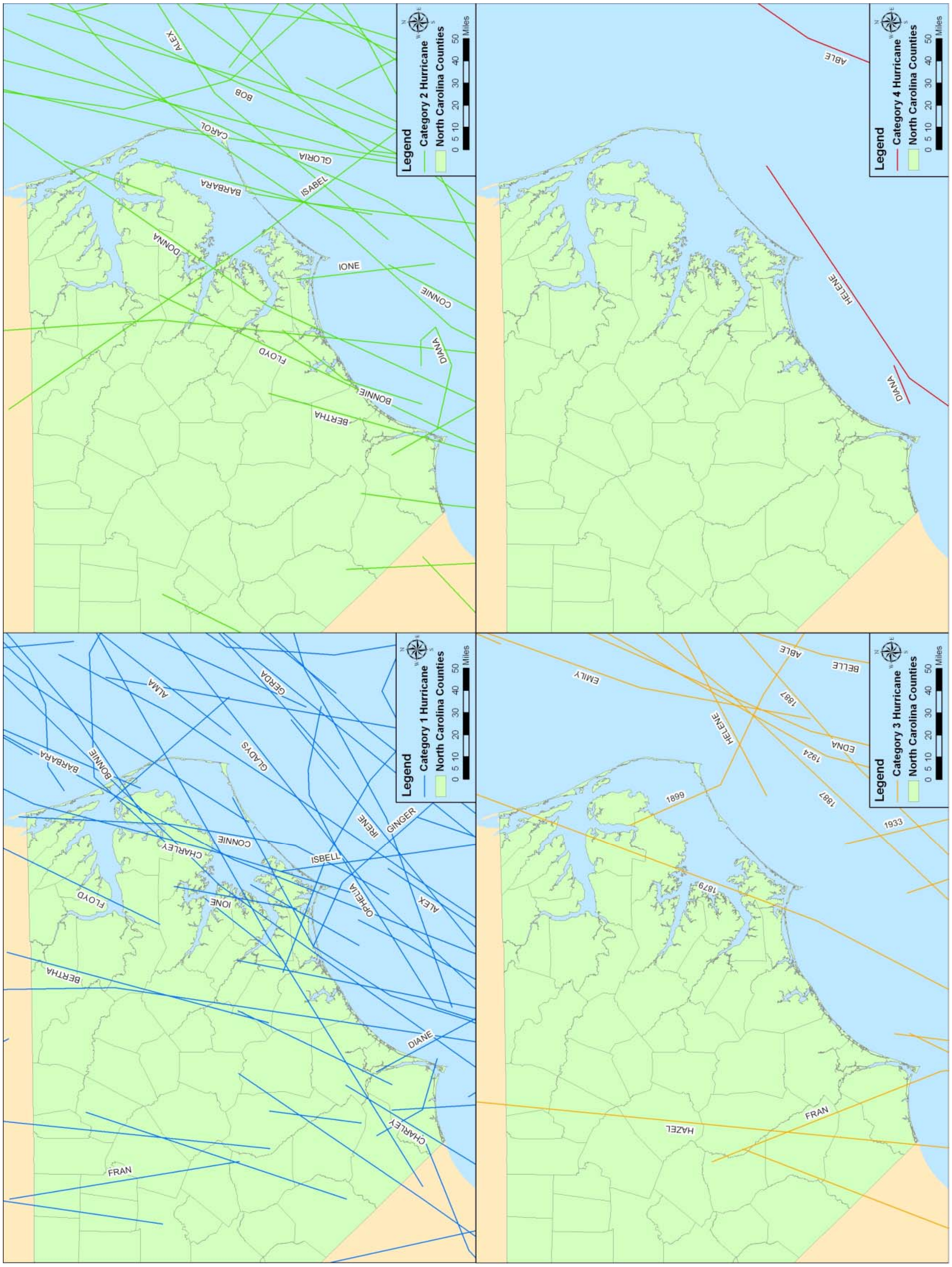


Figure II-8. Atlantic Hurricane Tracks (1851-2007)

5. Digital Ortho Photographs

DCM has compiled and maintains an archive of historical shoreline near-vertical aerial color and black and white photography. Photography is also available from other sources including USGS, National Agriculture Imagery Program (NAIP), and individual county governments. Contiguous aerials of the entire oceanfront shoreline were taken by DCM in 1998 and 2004 (0.5′ resolution or 1:100 scale). In 2003, post-Isabel aerials were taken of the ocean shoreline by USGS with the exception of Dare and Hyde counties (2′ resolution or 1:400 scale). In 2006, the NAIP created mosaics from orthotiles for the entire coastline (1′ resolution or 1:200 scale). Various counties also have oceanfront aerial photography from a variety of dates, varying in resolution and scale. See the regional sections for tables detailing the available digital orthophotos.

6. Historical Shorelines and Erosion Rates

a) Historical Shorelines

In support of coastal planning efforts, the DCM began developing a historical shoreline database dating back to 1933. Table II-6 provides a summary of the shorelines compiled by DCM. The primary source of historical data is the geo-referenced T-Sheets, provided by the NOAA Coastal Services Center (CSC). DCM has collaborated with the USGS and USACE to document the most recent shorelines both based on delineation of wet dry line as interpreted from ortho photography as well as deriving the Mean High Water Line (MHWL) based on Light Detection and Ranging (LiDAR) survey data.

Table II-6. NCDCM and USGS Delineated Oceanfront Shorelines

Date	Coverage	Type	Source
1933-1952	NC Shoreline (Bird Island to Kill Devil Hills)	NOS T-Sheet (MHW)	DCM
1940-1962	NC Shoreline (Kill Devil Hills to VA)	Photo-Wet/Dry	DCM
1998	Entire NC Shoreline	Photo-Wet/Dry	DCM
2003	NC Shoreline (Bird Island to Bear Island)	NOAA Photo-Wet/Dry	DCM
2004	Entire NC Shoreline	NCDCM Photo-Wet/Dry	DCM
1849-1873	Entire NC Shoreline	NOS T-Sheet (MHW), CERC map	USGS, Coastal Carolina
1925-1946	Entire NC Shoreline	CERC map, USACE Photos, NOS T-Sheet (MHW)	USGS, NOAA, DCM
1970-1988	Entire NC Shoreline	CERC map, NOS T-Sheet (MHW)	USGS, NOAA, Coastal Carolina
1997	Entire NC Shoreline	LIDAR MHW Shoreline	USGS

GIS shape files of historical shorelines may be accessed via DCM’s website at http://dcm2.enr.state.nc.us/Maps/chdownload.htm.

Referenced LiDAR data used to derive the 2004 shoreline is posted on NOAA’s website at http://www.csc.noaa.gov/crs/tcm/about_ldart.html.

In addition to the statewide oceanfront shoreline datasets, DCM has compiled a historical shoreline database in the vicinity of inlets. Reference to these data can be found in the regional sections of this report.

The inlet historical shoreline data set has served as the basis for the analysis of the Inlet Hazard Area (IHA) Areas of Environmental Concern (AECs) for the state’s 12 developed inlets (Warren & Richardson, 2009). As an example, Figure II-9 illustrates the extent of the inlet historical shoreline data at Tubbs Inlet.

The USGS source historical shoreline datasets identified in Table II-6 (above) were compiled and analyzed as part of a national assessment for shoreline change documented by Morton and Miller (2005). To delineate historical shorelines, USGS staff interpreted the wet-dry line from near-vertical aerial photography. For the most recent shoreline (1997), the MHWL was generated based on analysis of LiDAR data using shore-normal transects at 50-meter (164 feet) intervals alongshore. An algorithm was used to determine the shoreline position for each profile based on a linear regression fit through the foreshore of the profile to identify the horizontal position of the shoreline.

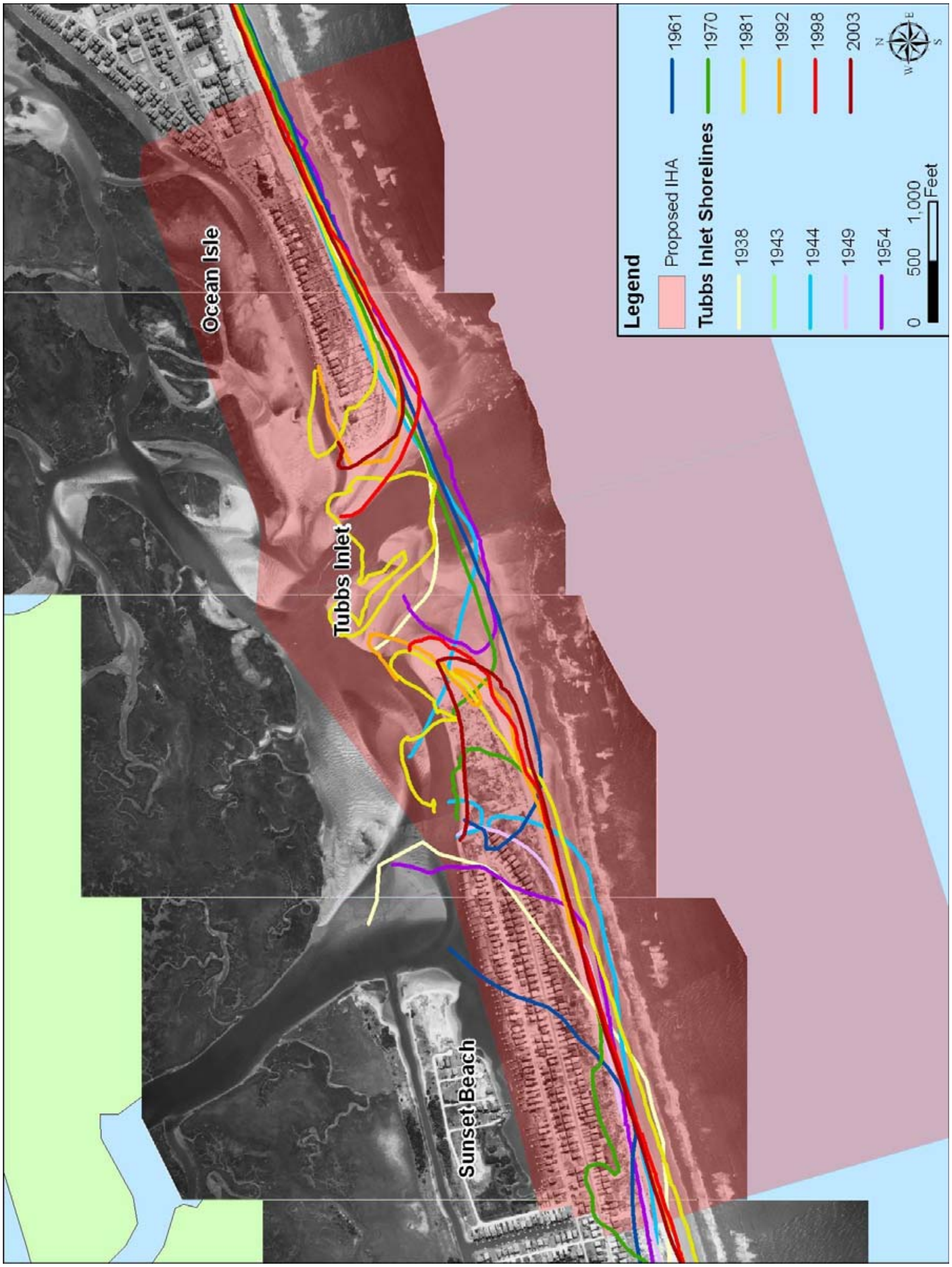


Figure II-9. Tubbs Inlet Historical Shorelines

b) Erosion Rates

Since June 1979, the Coastal Resources Commission (CRC) has established oceanfront development setbacks based on long-term shoreline change rates. Shoreline change is estimated by DCM using the endpoint rate method, based on the distance from the earliest shoreline archived by the state (varies for segments of shoreline but typically from the 1940s) to the most recent (1998). Raw rates are then "smoothed" and then blocked (rounded to a specific range of values) to account for local variance and influences of inlets. DCM then determines construction setback factors based on "smoothed/blocked rates." Current blocked setback factors are available online at www.nccoastalmanagement.net. Erosion rates are calculated at 50 m shore-perpendicular transects alongshore. Details regarding the methods used to conduct the most recent setback rates (based on the 1998 shoreline location) are documented by Overton and Fisher (March 2004) and Benton *et al.* (2004).

Table II-7 provides a statewide summary of shoreline change for the period from the 1940s to 1998, based on the DCM smoothed erosion rates. Following DCM convention for reporting shoreline change, the table designates erosion rates as positive (>0) and accretion negative (<0). Erosion rate points, calculated at 50 m (164 ft) transects, cover 300 miles of the total 326 miles of shoreline due to differing extents of the 1940s shorelines as compared to the 1998 shoreline. Erosion rates could only be calculated where the shorelines overlapped.

Table II-7. Summary of DCM Smoothed Erosion Rates – 1940 to 1998

Shoreline Change (ft/yr)	Length Along Shoreline (mi)	Portion of Shoreline (%)
<0	93.5	31.2
0-2	65.7	21.9
2-4	61.9	20.6
4-6	29.6	9.9
>6	49.4	16.5
Total	300.1	100.0

*Distance is measured based on 1998 erosion rate point coverage (300 of 326 mi due to shoreline extents)

During the period between 1940 and 1998, approximately 31 percent, or 94 miles, of the state's shoreline experienced net shoreline accretion; 22 percent of the shoreline has experienced erosion at a rate of zero to two feet/year. Approximately 17 percent of the shoreline experienced erosion at a net rate greater than or equal to six feet/year. Tables II-8 and II-9 illustrate the erosion experienced by each county from 1940-1998 by mile of shoreline and by percent of the total county's shoreline.

Table II-8. Summary of DCM Smoothed Erosion Rates (mi) - 1940 to 1998 by County

Shoreline Change (ft)	Distance Along Shoreline by County (miles)							
	Brunswick	New Hanover	Pender	Onslow	Carteret	Hyde	Dare	Currituck
<0	17.5	14.3	9.8	5.5	11.6	5.4	24.0	5.3
0-2	8.0	2.2	0.7	11.0	8.7	3.0	21.7	10.3
2-4	5.0	2.0	0.4	3.6	29.4	1.3	17.9	2.4
4-6	3.4	3.1	0.7	1.5	12.2	1.5	6.1	1.0
>6	4.9	5.3	1.6	2.7	11.8	4.8	15.0	3.1
Total	38.9	26.9	13.3	24.3	73.7	16.1	84.7	22.2

Table II-9. Summary of DCM Smoothed Erosion Rates (%) - 1940 to 1998 by County

Shoreline Change (ft)	Portion of Shoreline by County (%)							
	Brunswick	New Hanover	Pender	Onslow	Carteret	Hyde	Dare	Currituck
<0	45.0	53.2	74.2	22.5	15.7	33.7	28.3	23.9
0-2	20.7	8.3	5.2	45.2	11.8	18.9	25.6	46.6
2-4	12.8	7.3	3.3	14.7	39.9	8.1	21.1	10.8
4-6	8.9	11.5	4.9	6.3	16.6	9.2	7.2	4.6
>6	12.7	19.6	12.4	11.3	16.0	30.1	17.7	14.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table II-10 identifies the location and extent of shoreline erosion rates greater than or equal to six feet per year based on the DCM blocked long-term 1940 to 1998 rates.

The highest rates of long term erosion are predominantly located along undeveloped stretches of the coast, within the National Seashores and the North Carolina National Estuarine Research Reserves. Many of the sites are either located adjacent to inlets (*e.g.,* Pea Island National Wildlife Refuge at Oregon Inlet, Dare County); at the Capes (*e.g.,* Cape Hatteras at Buxton) or where there is a significant change in shoreline orientation (*e.g.,* Rodanthe, Dare County); at locations with varying geologic framework (*e.g.,* Fort Fisher State Park, New Hanover County) or a combination of the above.

Table II-10. Erosion Rate Summary (≥6ft/yr) by Location

County	*Shoreline Length (mi)* [2]	*Geographic Location /Jurisdictional Area*	*Influential Inlet(s) (where applicable)* [3]
Brunswick	1.6	East Holden Beach	Lockwoods Folly [1]
	0.6	West Beach, Bald Head Island	Cape Fear Inlet
	1.3	Cape Fear, Bald Head Island	N/A
	1.7	Cape Fear; Bald Head Island State Natural Area	N/A
New Hanover	1.5	Zeke's Island; Fort Fisher State Park	N/A
	3.9	North Carolina Beach; South Masonboro Island Coastal Reserve	Carolina Beach Inlet [1]
Pender	1.2	Hutaff Island (bound by Rich and New Topsail Inlets)	Rich and New Topsail Inlet[1]
Onslow	2.1	Onslow Beach; Camp Lejeune Military Base	New River Inlet[1]
	0.3	Brown's Island; Camp Lejeune Military Base	Bear Inlet [1]
Carteret	1.7	Shackelford Banks; Cape Lookout National Seashore (CLNS)	N/A
	2.1	Cape Lookout, CLNS	N/A
	5.5	North Core Banks, CLNS	Drum Inlet
	2.9	North Portsmouth Island, CLNS	Ocracoke Inlet
Hyde	4.9	North Ocracoke Island, Cape Hatteras National Seashore (CHNS)	Hatteras Inlet
Dare	2.3	West Hatteras Island, CHNS	Hatteras Inlet
	4.0	Cape Hatteras at Buxton, CHNS	N/A
	2.6	Hatteras Island at Rodanthe, CHNS	N/A
	4.3	Pea Island National Wildlife Refuge	Oregon Inlet
	2.6	CHNS	Oregon Inlet
	0.8	Nags Head	Oregon Inlet
Currituck	3.3	North Corolla, Currituck National Wildlife Refuge	N/A
TOTAL	51		

[1] reach is located within a proposed inlet hazard area
[2] distance measured along DCM setback segments
[3] inlets are noted where high erosion rates occur at the mouth, influencing adjacent areas

In addition to the erosion rates documented by DCM, the USGS has compiled short-term and long-term erosion rates for North Carolina (Morton and Miller, 2005) at 50-meter (164 feet) transects. These are not the same transects used by DCM, although they use the same spacing. Shorelines identified in Table II-6 served as the basis for the computations. Long-term rates are calculated using linear regression based on four shorelines (from the earliest documented to the most recent [1997], derived from LiDAR); where there are less than four shorelines available, no data is reported. The short-term rates are calculated for the most recent period (1970s to 1997) using the end point method. Table II-11 provides a summary of the shoreline change rates estimated by the USGS.

Table II-11. Summary of USGS Shoreline Change Rates

Shoreline Change (ft/year)	USGS Long Term Rates[1]		USGS Short Term Rates[2]	
	Length Along Shoreline (mi)	Portion of Shoreline (%)	Length Along Shoreline (mi)	Portion of Shoreline (%)
<-1	136	52	136	47
-1 to 0	45	17	31	11
0-2	48	18	40	14
2-4	13	5	25	9
4-6	8	3	15	5
6+	12	5	42	15
Total	262	100	289	100

[1] earliest available to 1997
[2] 1970s to 1997
Positive values mean erosion

7. Beach Profiles

Beach profile data has been collected for various beaches along the North Carolina coast. This data is available in various formats (XYZ text files, GIS shapefiles, offset/elevation excel files, CADD/Microstation files, etc.) depending on the location. Coverage varies temporally and spatially throughout the state with some areas undergoing regular beach monitoring (*e.g.,* Carteret County), whereas other long stretches of coast have no data at all. Beach profiles have been collected by local communities, the USACE, and other federal and state agencies. Details of available data, including dates and profile coverage, can be found in region sections of this report. Figure II-10 illustrates the locations of past beach profile surveys that were readily available.

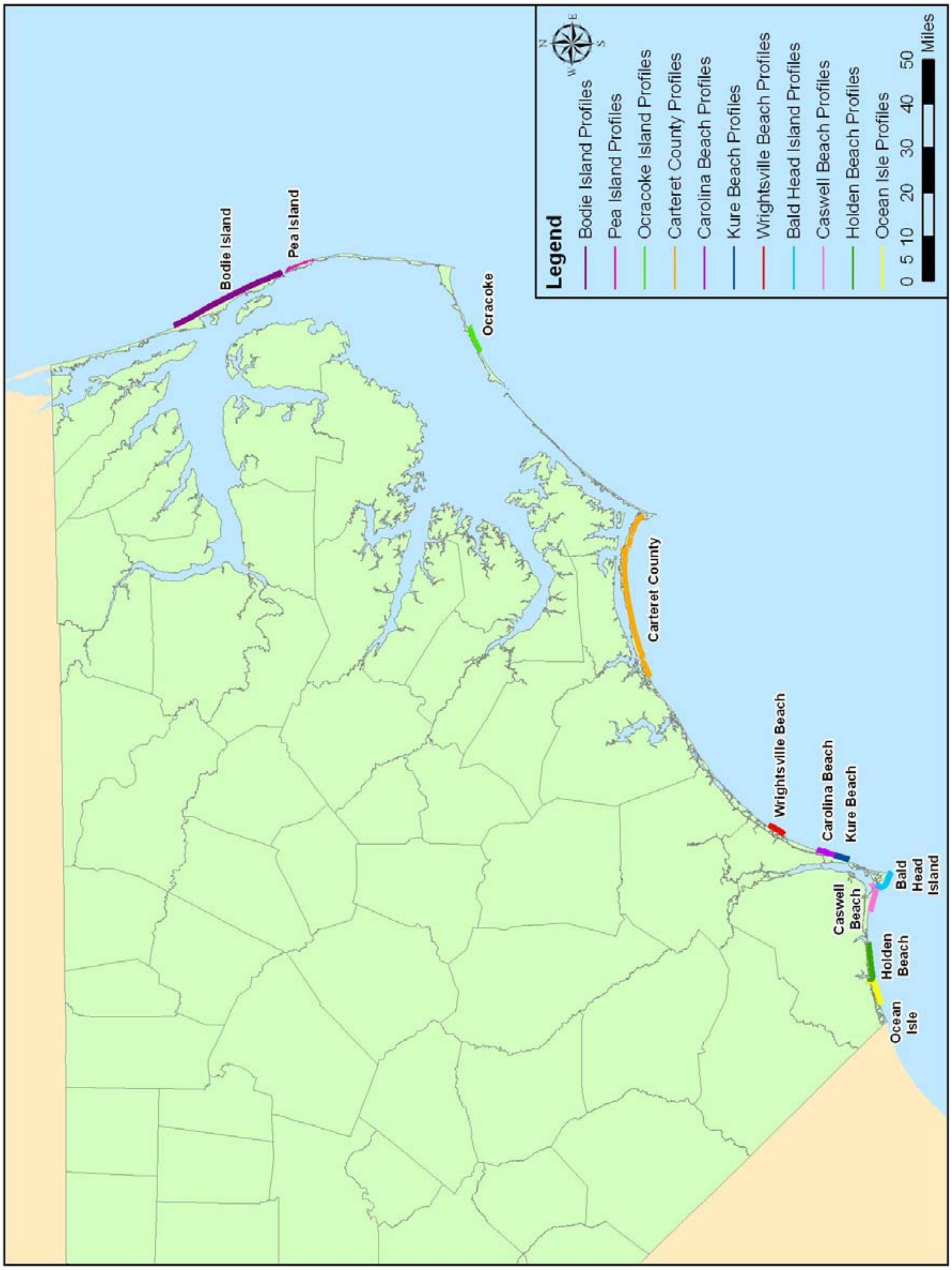


Figure II-10. Beach Profile Locations

8. Geological Framework, Inlets, and Sand Resources

a) Geological Framework

Coastal geology involves the origin, structure, and characteristics of coastal sediments with the geological formation of the coastline over thousands of years of physical and chemical processes dictating the properties of the sediments. Coastal processes, of varying temporal and spatial scales, driven by water level changes, tides, waves, currents and winds interact with the local coastal geology and sediment supply to form and modify the configuration of the coastal region forming features such as beaches, dunes, and inlets.

(1) Northern Province

Cape Lookout separates the 326 mi long coastline into two distinct provinces: north and south (Figure II-11). Each province has a unique geologic framework that results in distinctive coastal features. In general, the Northern Province extends from Cape Lookout northward and is characterized by lower, flatter beach slopes, and large shallow sounds having few inlets. The low lying coastal area that evolved along this gentle depositional surface consists of wide shallow bays fronted by long narrow barriers. Specifically, the Northern Province is underlain primarily by unconsolidated sediments of Quaternary age that thicken northward to fill the Albemarle Embayment with up to 230 ft of material. The low-lying coastal area that has evolved along this gentle depositional surface consists of wide shallow bays fronted by long narrow barriers. A few hardbottom areas of Pleistocene age are found scattered across the shoreface (Riggs *et al.*, 1992, 1995; Boss and Hoffman, 1999).

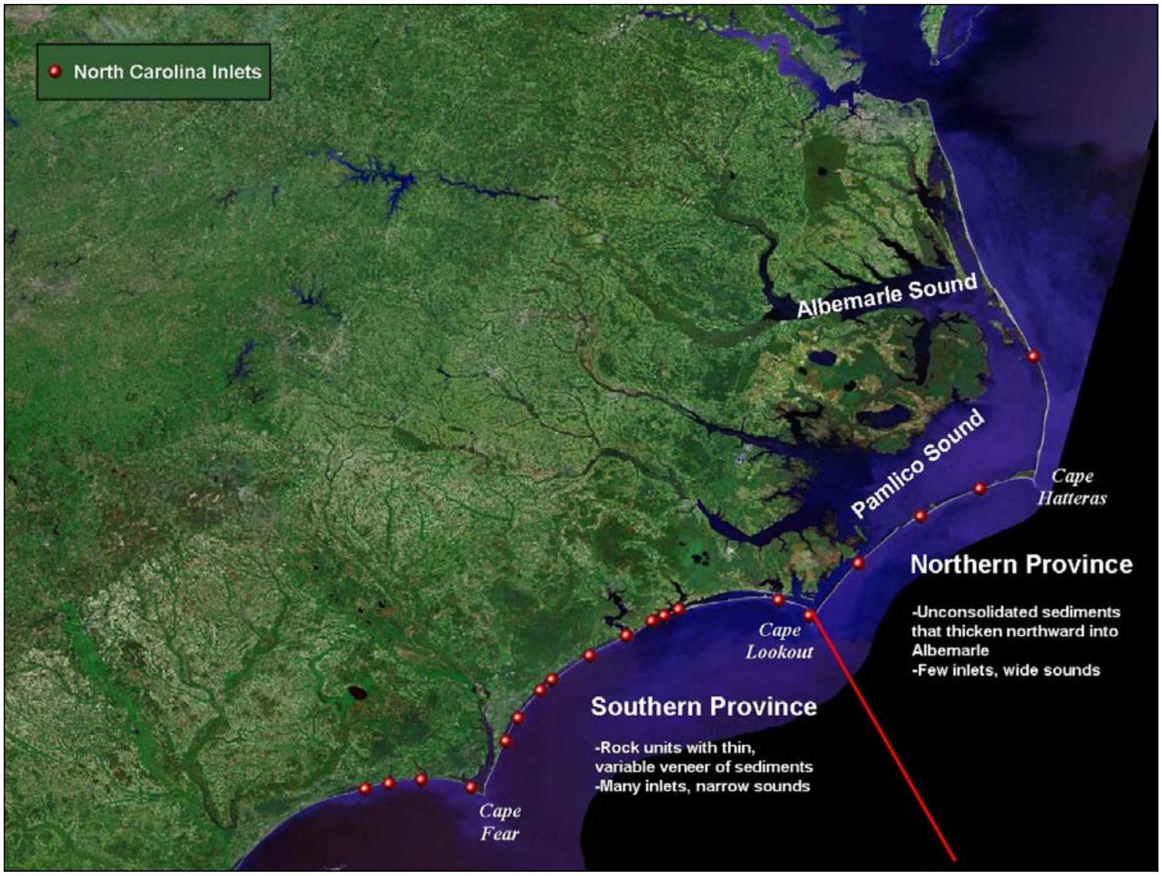
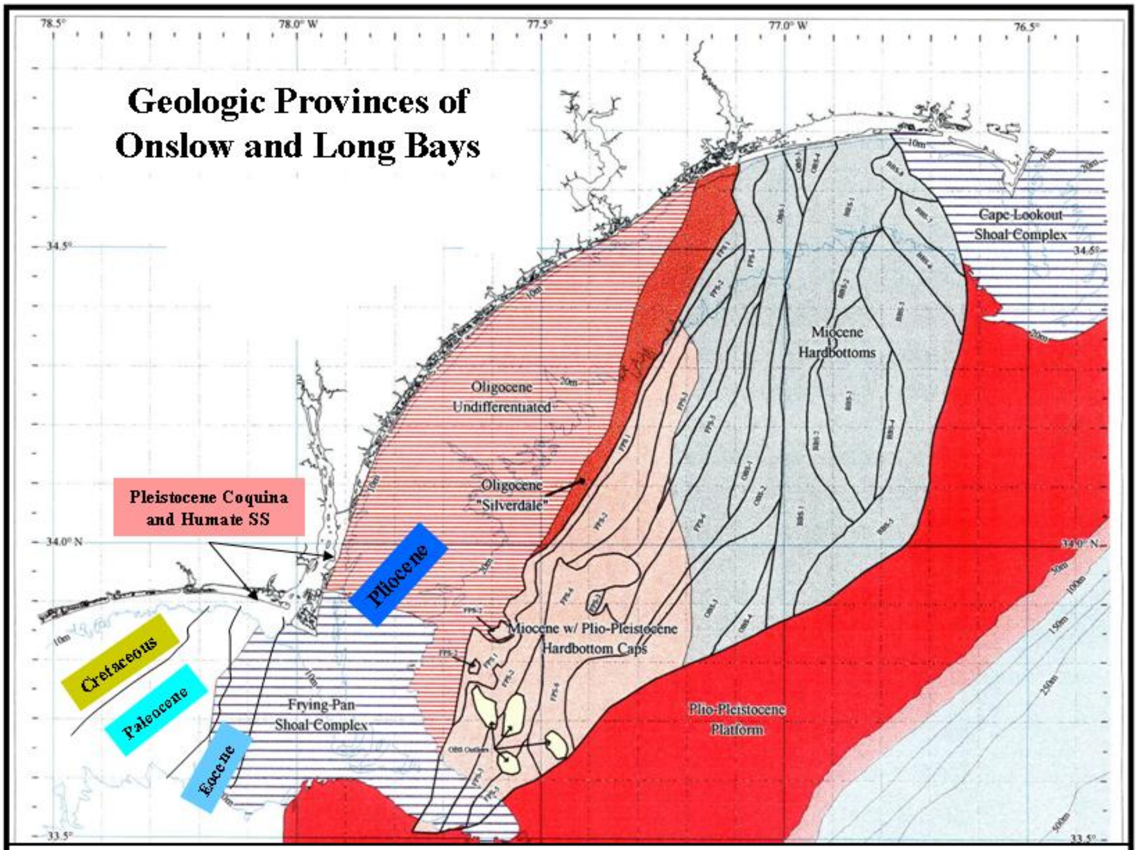


Figure II-11. Geologic Provinces of North Carolina

(2) Southern Province

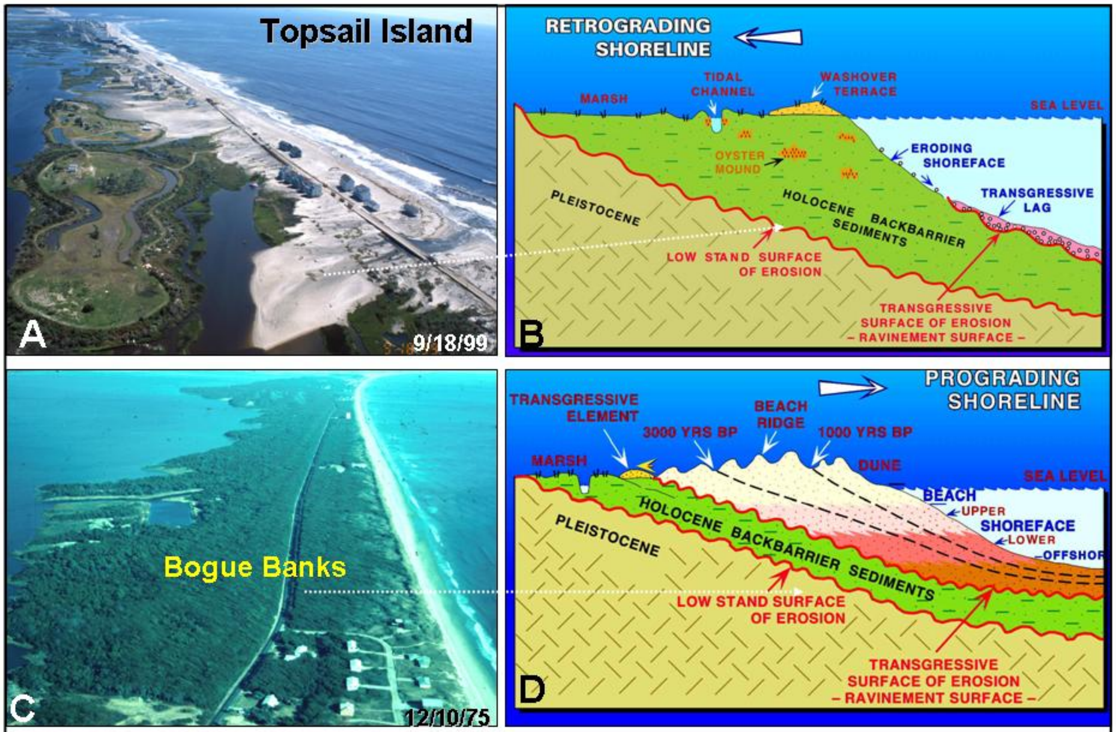
The Southern Province, by contrast, has many inlets and smaller, narrower sounds with higher, steeper beach slopes. The coastal system in the southern province, from Cape Lookout (Figures II-11 and II-12) south to the South Carolina border, is underlain by rock units that ranges in age from the Upper Cretaceous through the Pleistocene (Meisburger, 1977 and 1979; Snyder *et al.*, 1982; Snyder *et al.*, 1994 and Cleary *et al.*, 1996). In this region, only a thin and highly variable veneer of sediments of Quaternary age is preserved. The underlying units are associated with the Carolina Platform that forms the base of the region between Myrtle Beach, S.C. and Cape Fear, N.C. This structural platform has risen slightly, causing the units to dip to the north and east. This dip causes the units to be truncated by the shoreline and the shoreface. Consequently, a steep erosional topography exists along the southern coastal system with common exposures of these Cretaceous to Quaternary age units across the shoreface (Riggs *et al.*, 1995). A more detailed description of the coastal geology of the Southern Province is contained in Appendix C. A generalized description follows.



Geologic Provinces of Onslow and Long Bays, NC after Snyder, 1982, Riggs et al., 1985, Snyder et al., 1994 and Riggs and Cleary, 1998. Miocene units dominate the shoreface off Bogue Banks while Oligocene limestone and siltstone underlie the majority of the shoreface between Onslow Beach and Kure Beach. Pliocene limestone is exposed locally on the Fort Fisher - Kure Beach shoreface segment. Cretaceous, Paleocene and Eocene units underlie the Long Bay shoreface. Pleistocene units (coquina and partially lithified humate sandstones occur along the subaerial headlands at Fort Fisher-Kure Beach and Oak Island.

Figure II-12. Geologic Provinces of Onslow and Long Bays

Coastlines with limited sand supplies, such as most of the Southern Province, have thin barriers resting atop older geologic units that constitute the shoreface (Davis and Kuhn, 1985; Cleary and Hosier 1987; Riggs *et al*., 1995). Other than the sand rich barriers (former progradational or accretional barriers) near Bogue Banks (Figure II-13), perched barriers are common along the coastline of southeastern North Carolina and consist of a thin layer of sand that occurs directly on top of a shoreface extension composed of older, eroding, geologic units (Riggs *et al*., 1995; Thieler *et al*., 1995 and 2001). Depending upon the composition and geometry, this underlying platform can act as a headland, strongly influencing the beach dynamics and sediment composition, as well as the shape of the shoreface. In addition, along many parts of the coast, erosion resistant rocks that occur in the shoreface form shoal features that affect the local shoreline change patterns and sediment transport. The complex variability in this underlying geologic framework, coupled with the physical dynamics of a specific setting, ultimately determines the: 1) three-dimensional shoreface geometry, 2) availability and composition of sediments, and 3) shoreline erosion rates.



Photographs and cartoons depicting basic types of barrier islands in Onslow and Long Bays, NC. **A.** and **B.** depict sand poor barriers such as Topsail Beach (North Topsail Beach shown). **C.** and **D.** depict sand rich barriers such as the Bogue Banks – Browns Island shoreline segment. Cartoons courtesy of Miles Hayes (RPI Columbia, SC). Most barriers in the study area have a history of retrogradation (transgressive features).

Figure II-13. Sand Rich and Sand Poor Barriers

Dissecting the underlying geologic units is a paleo-drainage system consisting of a series of major and minor stream valleys and adjacent inter-stream divides (Riggs *et al.*, 1995). This drainage system controls the large-scale topography and forms a series of non-headland and headland influenced segments of the coast. The coastal features are perched on top of this framework which controls the overall geometry as well as the availability of sand resources.

Headland dominated shorefaces are areas that occur on topographically high inter-stream features composed of semi-indurated sediments and rocks of older geologic units (Morefield, 1978; Riggs *et al.*, 1995, Marden and Cleary, 1999). These features may crop out on the subaerial beach such as the Quaternary sequences along the isolated locales on Masonboro Island, Carolina Beach/Fort Fisher and Yaupon Beach along Oak Island. More commonly, the rocks occur as submarine features where they crop out on the shoreface such as the submarine headland along portions of North Topsail Beach and nearby Onslow Beach. In this area Oligocene age limestones form high-relief hard bottoms immediately seaward of the recreational beach (Crowson, 1980; Cleary and Hosier, 1987; Riggs *et al.*, 1995; Cleary *et al.*, 1996; Johnston, 1998; Cleary and Riggs, 1998 and Cleary *et al.*, 1999). These rocks extend beneath portions of North Topsail and Onslow Beaches affecting both their planform, rates of erosion, and sediment supply.

Non-headland dominated shorefaces are the most common type along southeastern North Carolina's coastal system. These shorefaces are generally composed of one of four different kinds of sediment components: valley-fill, inlet-fill, transgressive, or regressive coastal lithosomes. The barrier segments that flank the Yaupon Beach headland segment of Oak Island and the southern portion of North Topsail Beach are examples of transgressive segments. Examples of regressive shoreline reaches that are usually sand rich include major portions of Bogue Banks and adjacent to Bear and Browns Islands.

b) Inlets

There are currently 19 inlet complexes along the North Carolina coast (Drum Inlet is comprised of three distinct inlets but is considered as one complex for the purpose of this study). Two inlets are deep draft inlets (Cape Fear Inlet and Beaufort Inlet), which serve as the entrances to North Carolina's two major ports (Wilmington and Morehead City, respectively). The remaining inlets are shallow draft with Congressionally-authorized depths ranging from 6-14 feet. Table II-12 shows their authorized channel depth, and width (where known). Inlets with no values in the table are natural inlets with no authorized project depth (Tubbs, Rich, Brown's, and Bear Inlets). Figure II-14 also displays the inlet locations along the North Carolina Coast.

Table II-12. Authorized Inlet and Waterway Dimensions

Inlet/Waterway	Authorized Depth	Authorized Width
AIWW	12	90-300
Tubbs Inlet	N/A	N/A
Shallotte Inlet	4	36
Lockwoods Folly Inlet	12	150
Cape Fear Inlet	44	650
Carolina Beach Inlet	8	150
Masonboro Inlet	14	400
Mason Inlet	10	500
Rich Inlet	N/A	N/A
New Topsail Inlet	8	150
New River Inlet	6	90
Brown's Inlet	N/A	N/A
Bear Inlet	N/A	N/A
Bogue Inlet	8	150
Beaufort Inlet	45	650
Barden Inlet	7	100
Drum Inlet	9	150
Ocracoke Inlet	18	400
Hatteras Inlet	10	100
Oregon Inlet	20	400

*N/A=No Congressional Authorized Depth or Width

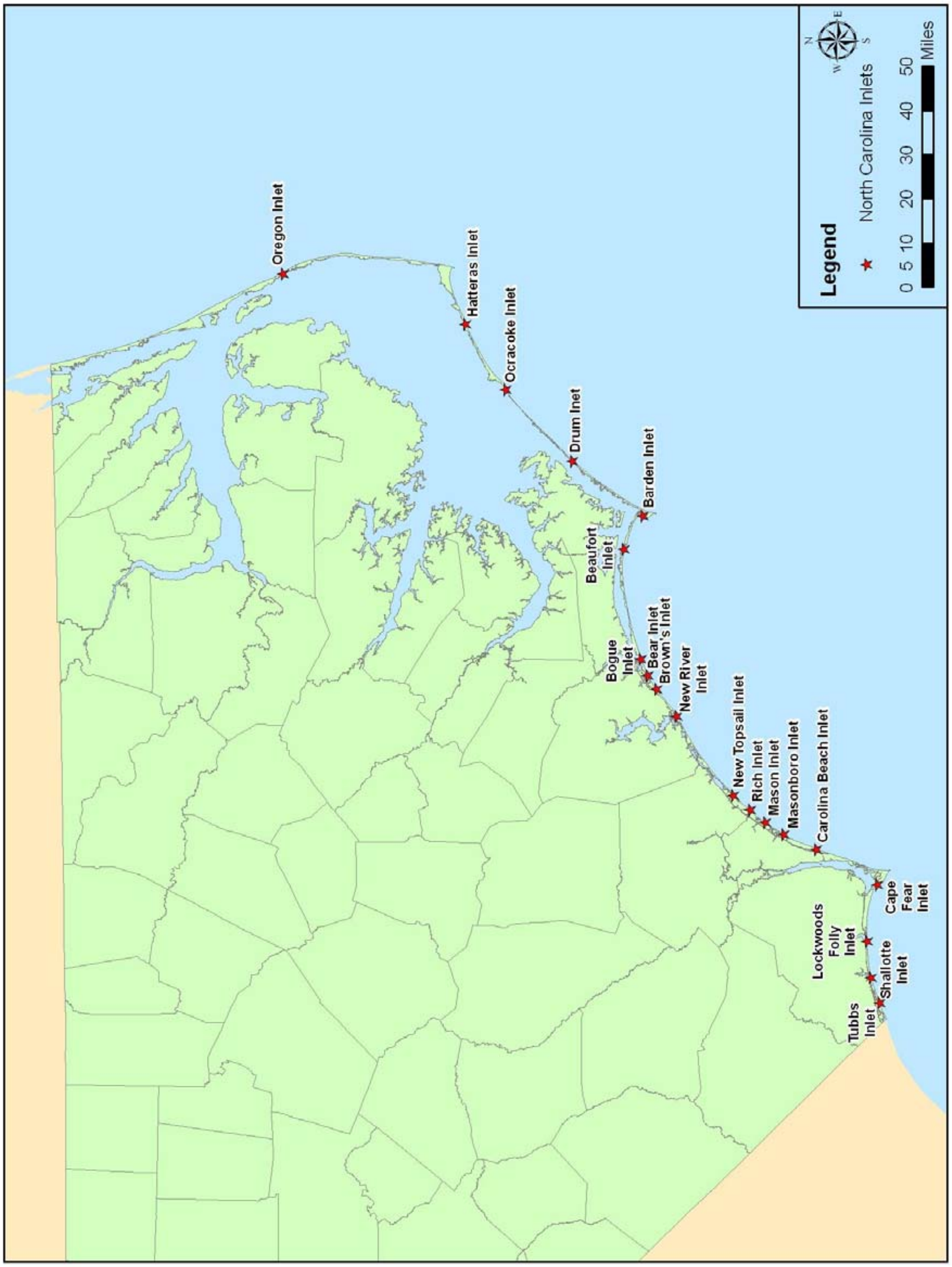


Figure II-14. North Carolina Inlet Locations

Resources describing North Carolina's inlets and their morphological changes over time include: 1) *Shifting Shorelines: A Pictorial Atlas of North Carolina Inlets*, by Dr. William Cleary and Tara Marden (1999), 2) *Geomorphic Expressions of Former Inlets*, by John Fisher (1962), 3) *A Historical Review of Some of North Carolina's Coastal Inlets*, by Langfelder *et al.* (1974), and 4) *The Citizen's Guide to North Carolina's Shifting Inlets*, by Baker (1977). Detailed information concerning specific inlets is outlined within each of the region chapters.

c) Sand Sources

The data sources investigated to develop available sand sources included the USACE, the Carteret County Shore Protection Office, USGS, NCGS, Dr. William Cleary (UNC-Wilmington), NCDOT, NOAA, Coastal Planning & Engineering Inc., and others. A compilation of these datasets is represented in Figure II-15 which outlines potential sand sources for North Carolina beaches. Detailed information concerning sand sources is outlined within each of the region chapters. Note that these identified sand sources are not meant to be an all-inclusive assessment but simply note potential sand sources where investigations have taken place.

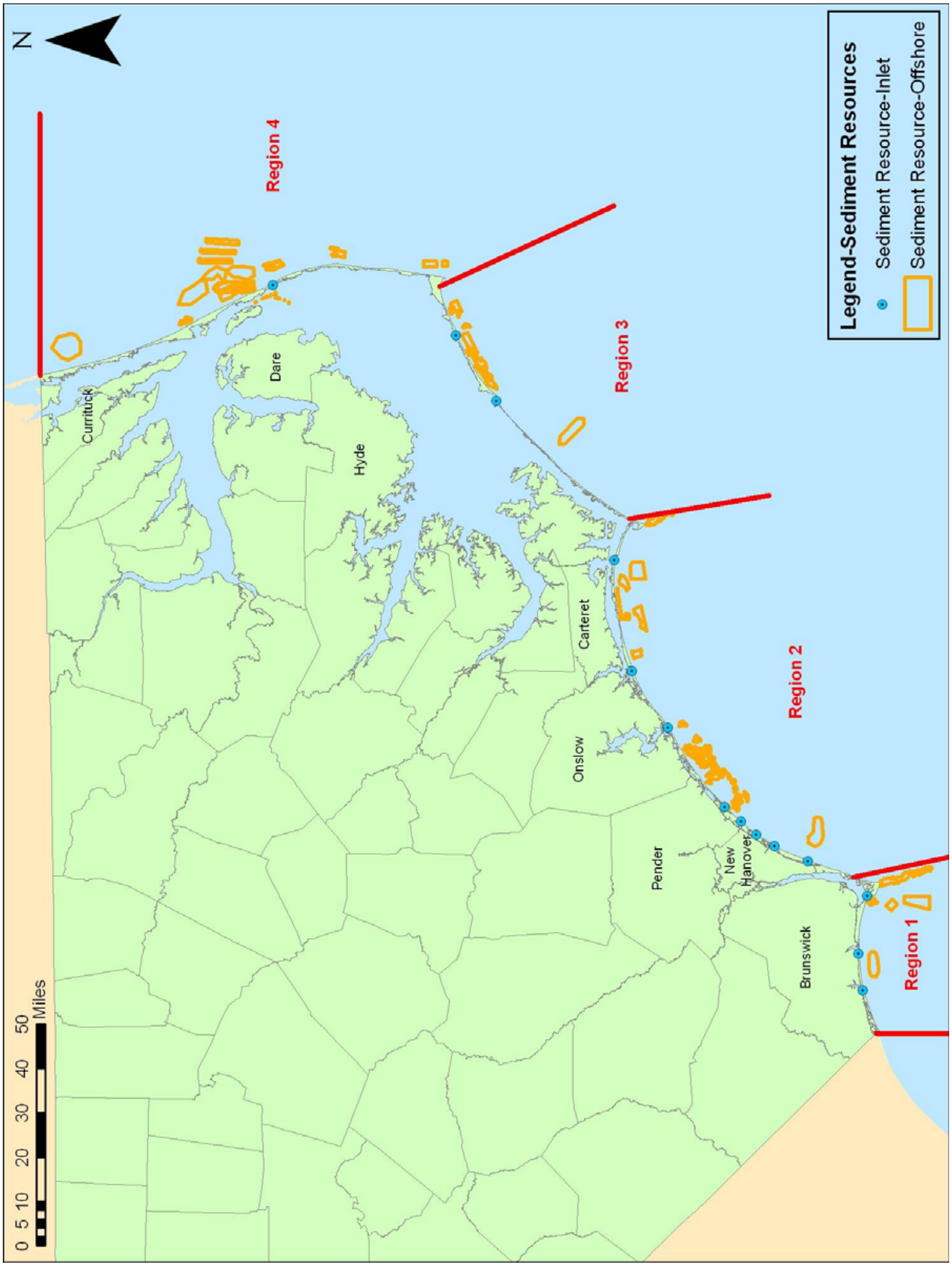


Figure II-15. Identified Potential Sand Resources

9. Beach & Inlet Management Strategies Used in North Carolina

a) Beach Nourishment

A beach nourishment database has been compiled from several sources to provide a comprehensive summary of the state's nourishment activities. Sources include the USACE, Western Carolina University's Program for the Study of Developed Shorelines, the Carteret County Shore Protection Office, N.C. Sea Grant, and Coastal Planning and Engineering, Inc. Projects were sorted by location and year to provide a complete list of projects to date. A summary of the beach nourishment data is presented in Table II-13. A map displaying the location of beach nourishment projects is presented in Figure II-16. A database of known beach nourishment projects is located in Appendix D.

Table II-13. Summary of Beach Nourishment Data

Location	Number of Times Nourished	Total Amount Nourished (cy)	First Year of Record
ATLANTIC BEACH/FORT MACON	8	13,857,543	1961
BALD HEAD ISLAND	7	6,613,818	1991
CAPE HATTERAS	3	1,812,000	1966
CAPE LOOKOUT	1	75,700	2006
CAROLINA BEACH	32	23,928,573	1955
CASWELL BEACH	1	133,200	2001
EMERALD ISLE	15	3,693,153	1984
FIGURE EIGHT ISLAND	13	2,836,821	1979
HATTERAS ISLAND	7	961,297	1974
HOLDEN BEACH	38	3,253,676	1971
INDIAN BEACH/SALTER PATH	3	1,454,881	2002
KILL DEVIL HILLS	1	38,016	2004
KITTY HAWK	1	143,000	2004
KURE BEACH	6	1,757,248	1997
MASONBORO ISLAND	6	4,652,938	1986
MONK ISLAND	3	197,955	1981
NAGS HEAD	2	200,000	2001
OAK ISLAND	6	5,363,294	1986
OCEAN ISLE BEACH	15	5,659,766	1974
OCRACOKE ISLAND	5	516,062	1986
OREGON INLET DISPOSAL ISLAND	1	167,258	1989
OREGON INLET OFFSHORE	2	522,799	1990
PEA ISLAND	21	8,138,023	1990
PINE KNOLL SHORES	4	4,236,382	2001
TOPSAIL ISLAND	7	455,296	1982
WEST ONSLOW BEACH	1	101,653	1990
WILMINGTON HARBOR ODMDS*	11	17,082,712	1997
WRIGHTSVILLE BEACH	24	12,427,158	1939

* Dredging source believed to be beach compatible location

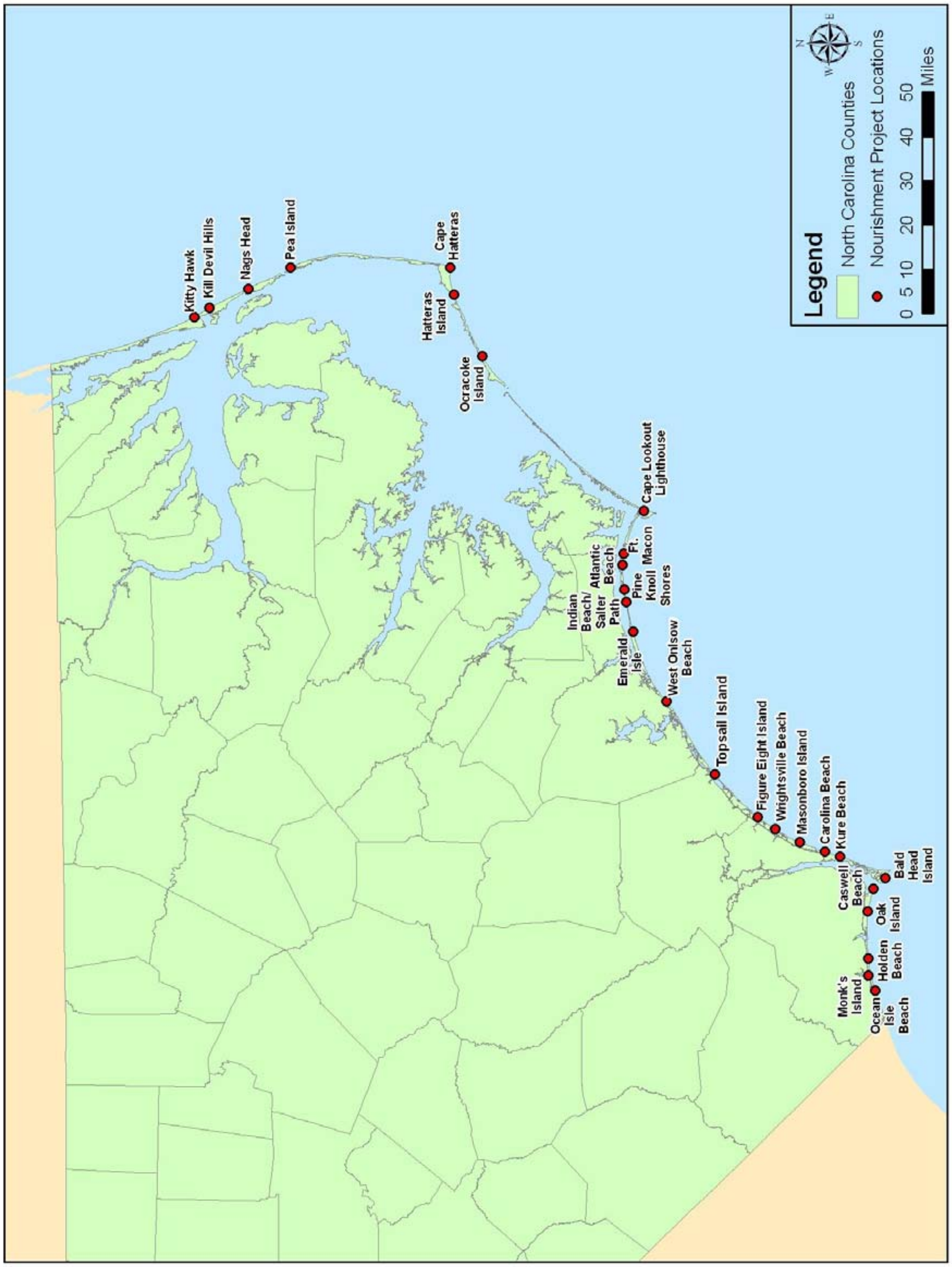


Figure II-16. Beach Nourishment Project Locations

b) Dredging/Inlet Maintenance

A dredging database has been compiled utilizing dredge projects performed or contracted by the USACE from 1975 to 2007. Dredging data performed by the USACE (1995-2007) and dredging done under contract (1990-2007) data was available from the Corps website. Projects occurring prior to these dates were obtained from the North Carolina Historic Dredging Data book from the USACE -Wilmington District. In a previous study by Moffatt & Nichol on shallow draft navigation (November 2005), a database was composed containing all shallow draft projects from 1975 through 2004. Deep draft projects and projects from 2005 to 2007 have been added to this database. A summary of the dredge data is presented in Table II-14. A map displaying the location of USACE and contract dredge project locations from 1975 to 2007 is presented in Figure II-17. A database of known dredging projects is located in Appendix E.

Table II-14. Summary of Dredge Data

Location	Number of Times Dredged	Total Amount Dredged (cy)	First Year of Record
ATLANTIC INTRACOASTAL WATERWAY*	89	25,979,777	1975
ATLANTIC BEACH CHANNELS, NC	3	130,298	1976
AVON HARBOR	2	126,877	1986
BEAUFORT HARBOR	19	1,029,187	1975
BOGUE INLET AND CHANNELS	73	4,942,252	1980
CAPE FEAR RIVER	13	780,384	1975
CAPE LOOKOUT NATIONAL SEASHORE	1	73,727	2006
CAROLINA BEACH INLET & CHANNELS	126	5,993,308	1982
CHANNEL FROM BACK SOUND TO LOOKOUT BIGHT	11	601,988	1975
DRUM INLET	7	863,949	1975
EDENTON HARBOR	1	17,066	1975
FAR CREEK	4	723,605	1985
HATTERAS INLET	6	296,750	1999
LOCKWOODS FOLLY INLET	62	4,241,740	1980
LOCKWOODS FOLLY RIVER	33	2,008,234	1976
MANTEO (SHALLOWBAG BAY)/OREGON INLET	186	40,280,213	1975
MASONBORO INLET	2	2,026,491	1986
MILE HAMMOCK	1	280,000	2000
MOREHEAD CITY HARBOR	38	32,780,865	1975
NEW RIVER INLET	111	7,543,265	1980
NEW TOPSAIL INLET & CHANNELS	80	4,444,547	1980
OCRACOKE INLET	11	559,586	1975
ROLLINSON CHANNEL	6	663,981	1984
SHALLOTTE RIVER	5	217,161	1975
SILVER LAKE HARBOR	31	2,844,409	1975
STUMPY POINT BAY	2	205,580	1979
WW CONNECTING PAMLICO SOUND & BEAUFORT HARBOR	12	875,212	1975
WW CONNECTING SWANQUARTER BAY WITH DEEP BAY	7	1,937,063	1977
WILMINGTON HARBOR	65	49,770,724	1975
WRIGHTS CREEK	1	66,584	1977

*Includes AIWW channels and inlet crossings

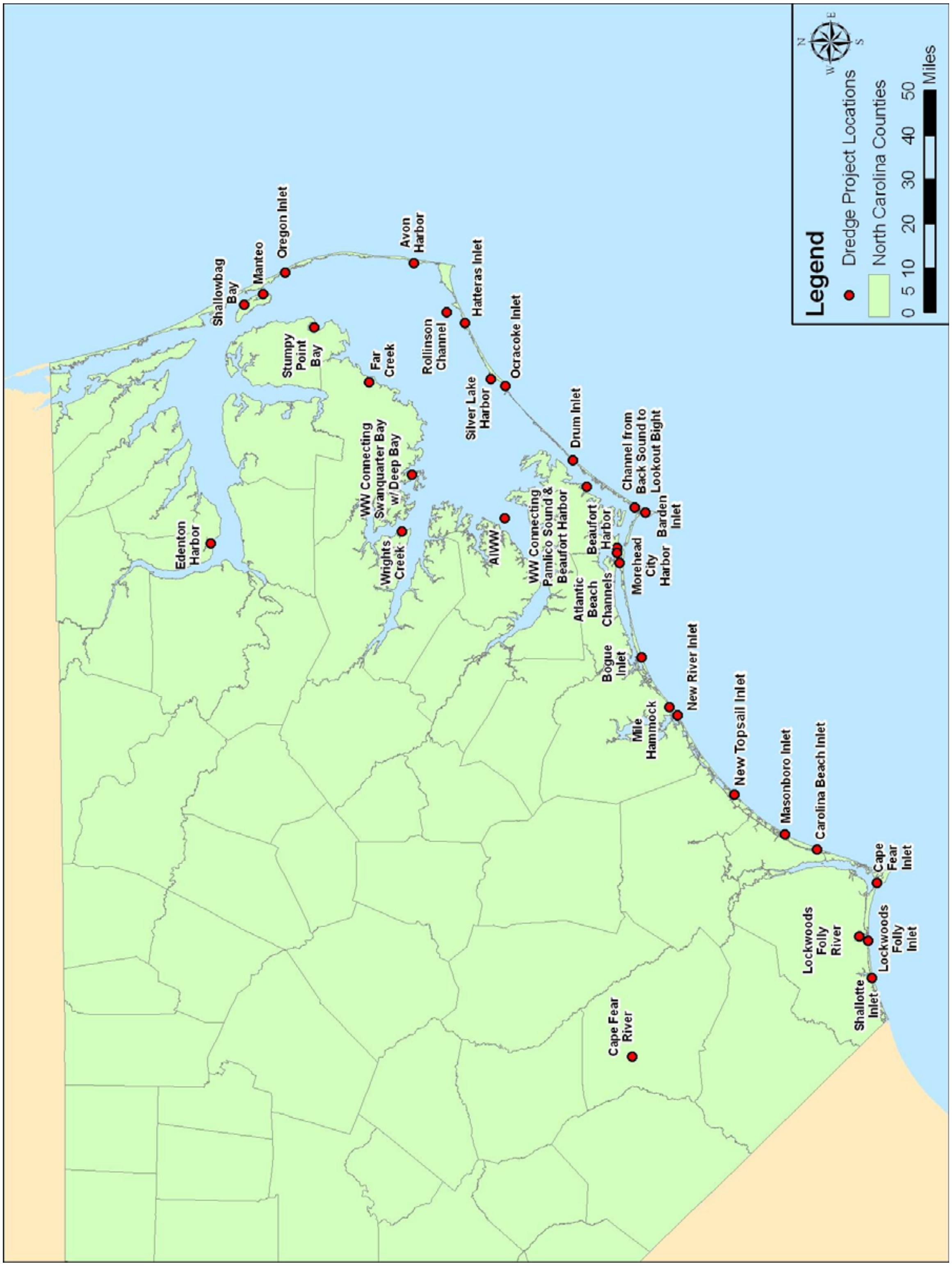


Figure II-17. USACE Dredge Project Locations (1975-2007)

c) Inlet and Channel Realignment/Relocation

Bogue Inlet (Carteret County) underwent a channel realignment to address an erosion problem that threatened the west end of the Town of Emerald Isle. In an effort to support shoreline restoration and to provide a long-term solution to inlet-related erosion, the Town contracted with Coastal Planning & Engineering (CPE-NC) to realign the ebb channel to a mid-inlet position and nourish a portion of the oceanfront with the associated dredge materials. The total cost of the project, including nourishment, was approximately $9.8 million. Details of the Bogue Inlet channel realignment can be found in the EIS prepared for the project (CPE, 2004) available on the USACE website at http://www.saw.usace.army.mil/WETLANDS/Projects/BogueInlet/index.html.

The Wilmington Harbor navigation channel has recently undergone improvements to alleviate navigation constraints that required larger vessels entering through Cape Fear Inlet to travel light-loaded or wait for high tide. It was determined that it would be necessary to widen and deepen the channel along a new alignment to alleviate the problem. It was also determined that widening and deepening the channel along the old alignment would have had severe environmental impacts while the a new alignment reduced dredging costs and environmental impacts, and made beach compatible sand available for use on nearby Brunswick County beaches. Continued maintenance of the new channel will provide additional sediment for use on Region 1 beaches from direct placement.

Mason Inlet (New Hanover County) is a natural unstabilized inlet that had migrated to the south along Figure Eight Island over the past 30 years. Between 1985 and 2000, the migration resulted in a loss of 2,200 feet of shoreline at the north end of Wrightsville Beach. A plan was developed to relocate Mason Inlet 2,500 feet north of its 2001 alignment. The project was designed to include the excavation of a new inlet channel, the realignment of Mason Creek, and the closure of the old Mason Inlet. During the winter of 2001-2002, Applied Technology & Management (ATM) began the construction phase of the Mason Inlet Relocation project. The new Mason Inlet was opened on March 7, 2002, and the old inlet was closed by March 14, 2002 (Figure II-18). The total cost of the project, including nourishment, was approximately $6.7 million.

Figure II-18. Mason Inlet Relocation

In addition to protecting properties on Wrightsville Beach from erosion, the Mason Inlet Relocation Project provided sand for beach nourishment at Figure Eight Island and Wrightsville Beach (New Hanover County). This project prevented the adverse economic impact of $237 million that would have resulted from property and land losses, as well as rental property, hotel and tax revenue losses (Applied Technology & Management). This value represents the present value of these losses over 30 years. Mason Creek was reopened for navigational use and improved flushing of the Middle Sound Estuary and local beaches were restored for public recreational use (swimming, fishing, etc.).

Tubbs Inlet (Brunswick County) was relocated in December 1969 to mitigate erosion of the eastern portion of Sunset Beach due to inlet migration of approximately 131 ft./year to the west. The inlet was relocated to a position 3,280 feet eastward that approximated the inlet's 1938 location (Masterson *et al*., 1973).

d) Permanent Engineered Structures

Due to the state's policy of limiting the use of hardened erosion control structures on oceanfront shorelines, the coast of North Carolina is relatively free of engineered structures used to influence beach or inlet behavior. North Carolina law currently prohibits permanent erosion control structures in most situations. In 1985, the CRC banned seawalls and other similar structures. In 2003, House Bill 1028 amended the N.C. Coastal Area Management Act (CAMA), placing into law the CRC's prohibition. The few exceptions are limited to structures which protect important transportation corridors, existing commercial navigation channels of regional importance and locations of historical significance. Currently, there is considerable debate in North Carolina over the use of terminal groins. During the last two legislative sessions, bills have been introduced to allow the limited installation of terminal groins but have not been passed by both houses of the General Assembly. The following is a list of some places where permanent erosion control structures do exist:

Inlet Structures

- Jetty and weir jetty at Masonboro Inlet (Figure II-19)

Shoreline Erosion/Property Protection

- Rock revetment along northern Carolina Beach built in 1970 and 1972 (Figure II-20)
- Rock revetment near Fort Fisher constructed in 1996
- Sandbags (various locations to protect homes and structures – Figure II-21)
- Groins at the Cape Hatteras Lighthouse and Coast Guard Station
- Terminal groin at north end of Pea Island at Oregon Inlet completed in fall of 1990 to protect the Bonner Bridge (Figure II-22)
- (Terminal) Groin at Fort Macon (Beaufort Inlet) constructed in two phases (1962 and 1966) to protect the historically significant location

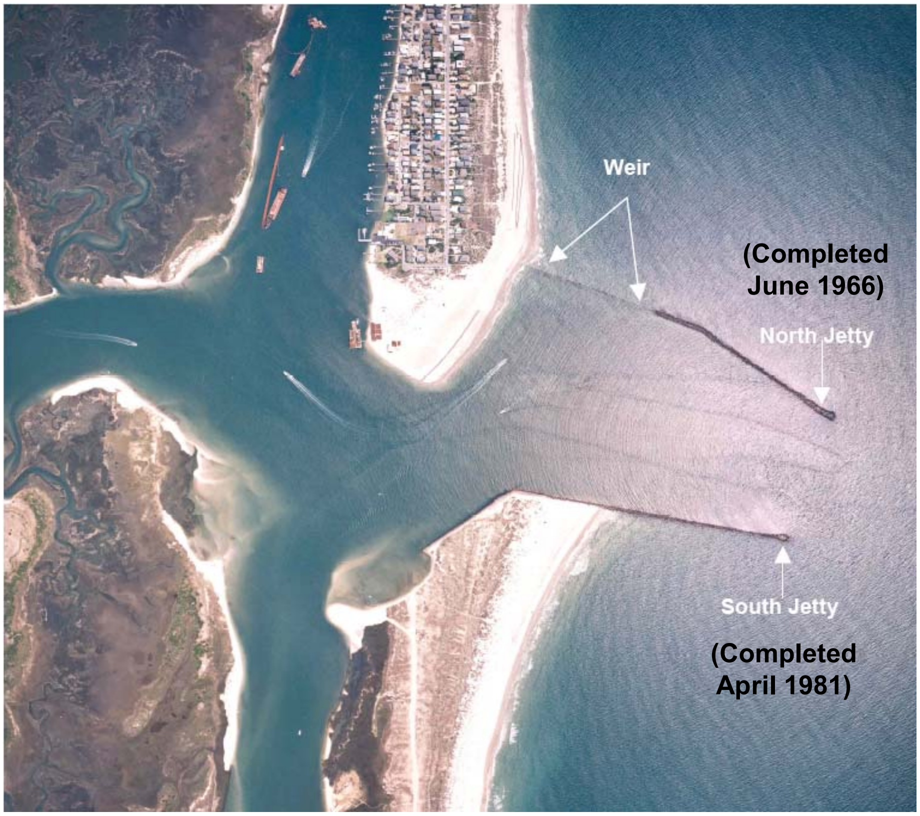


Figure II-19. Masonboro Inlet Jetties (May 2002 – USACE)

Figure II-20. Northern Carolina Beach

Figure II-21. Example of Sandbags Used as Temporary Erosion Control Structures at South Nags Head

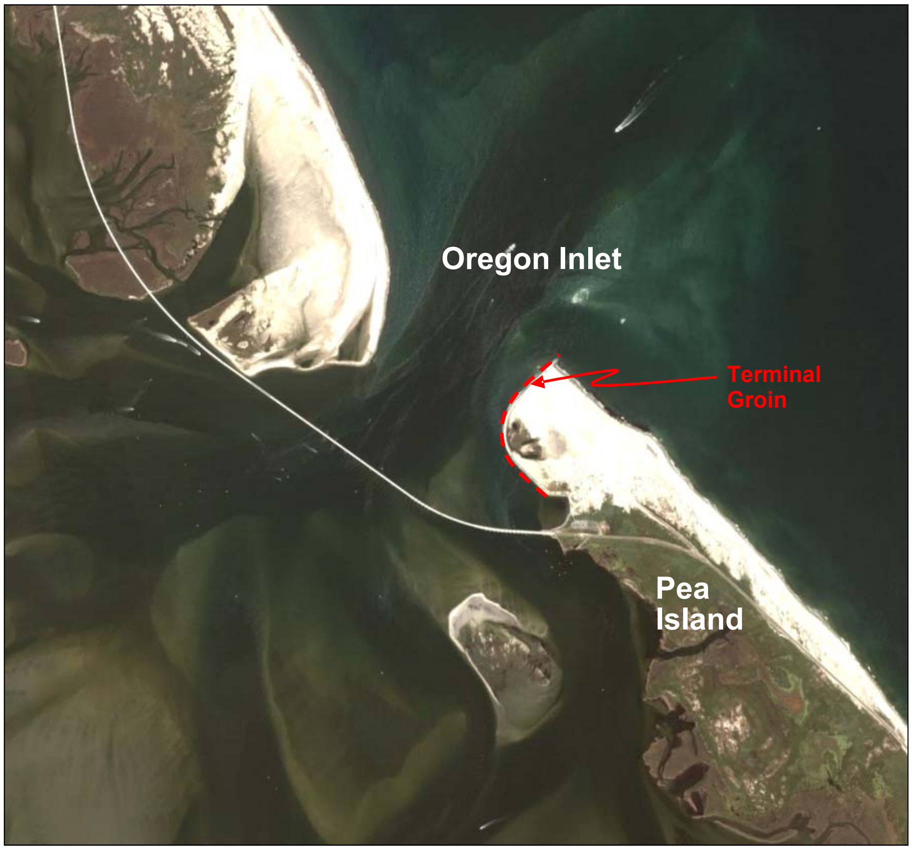


Figure II-23. Terminal Groin at North End of Pea Island

e) Temporary Erosion Control Structures

In response to the 1984 prohibition of permanent erosion control structures on ocean shorelines, the CRC adopted the Outer Banks Erosion Task Force recommendation:

> "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."

The purpose of allowing measures such as sandbags was to provide for the temporary protection of a structure until the owner could make arrangements to move the structure or until the beach and dune system could naturally repair itself. They were not meant to be a solution to long-term chronic erosion

There are currently about 350 sandbag structures along the oceanfront. The CRC's sandbag rules [see 15A NCAC 07H.0308(a)(2)] allow property owners to temporarily protect imminently threatened oceanfront structures.

Typically, sandbags are allowed for a two-year period if the structure is less than 5,000 square feet and up to five years if the structure is greater than 5,000 square feet. Provisions are also made for sandbag structures to remain in place for longer periods of time if they are located in a community pursuing a beach nourishment project (five years) or an inlet relocation project (eight years). Sandbag use has been controversial since in addition to blocking public access along the beach, they may be harmful to the nesting habitats of endangered species, such as sea turtles, and also may accelerate erosion on neighboring properties. The specifics of sandbags use are further outlined in Section VI.

f) Structure Relocation

The relocation of structures has also been employed along the North Carolina coast as strategy to address chronic erosion problems. In addition to residential and commercial structures, the most significant example was the relocation of the Cape Hatteras Lighthouse completed in 1999. After years of debate, the National Park Service moved the lighthouse 2,900 feet landward from its original location (Figure II-23).

Figure II-23. Relocation of the Cape Hatteras Lighthouse

10. Coastal Environment

Critical elements of sustainable coastal planning involve environmental considerations. As mentioned previously, the N.C. Coastal Habitat Protection Plan (CHPP) was a key document recommending the development of a Beach and Inlet Management Plan. Activities involving beaches and inlets must consider relevant environmental constraints and seize opportunities for habitat enhancement or conservation. Extensive amounts of coastal environmental habitat and key species data were compiled as part of the BIMP. Section III discusses the pertinent environmental data sets with region specific environmental considerations presented in the individual regional sections of the report. Detailed mapping of environmental considerations is provided in Appendix F.

11. Socio-Economic Value of N.C. Beaches and Inlets

North Carolina beaches and inlets have tremendous economic value. Beaches and inlets support a thriving tourism industry, provide billions of dollars in residential and commercial property value, provide access for commercial and recreational fishermen, and serve as important habitat for fish and wildlife resources. Understanding the socioeconomics of beaches and inlets is complicated as it cannot be solely measured by the more conventional economic values. Section IV discusses in detail the economic valuation of North Carolina beaches and inlets and helps put into perspective aspects such as beach recreation, fishing, and marine services.

12. Regional Numerical Models and Investigations

Some larger scale investigations and modeling efforts have been undertaken along the coast of North Carolina in an effort to gain an understanding of dynamics involved in the various systems. Notable recent studies include coastal circulation and storm surge modeling. The University of North Carolina-Chapel Hill, together with the USACE and North Carolina Floodplain Mapping Program (conducted by NCGTM), are developing an Advanced Circulation Model (ADCIRC) of the North Carolina coast to examine storm surge and remap flood elevations. Figure II-24 illustrates an example ADCIRC model grid along the North Carolina coast.

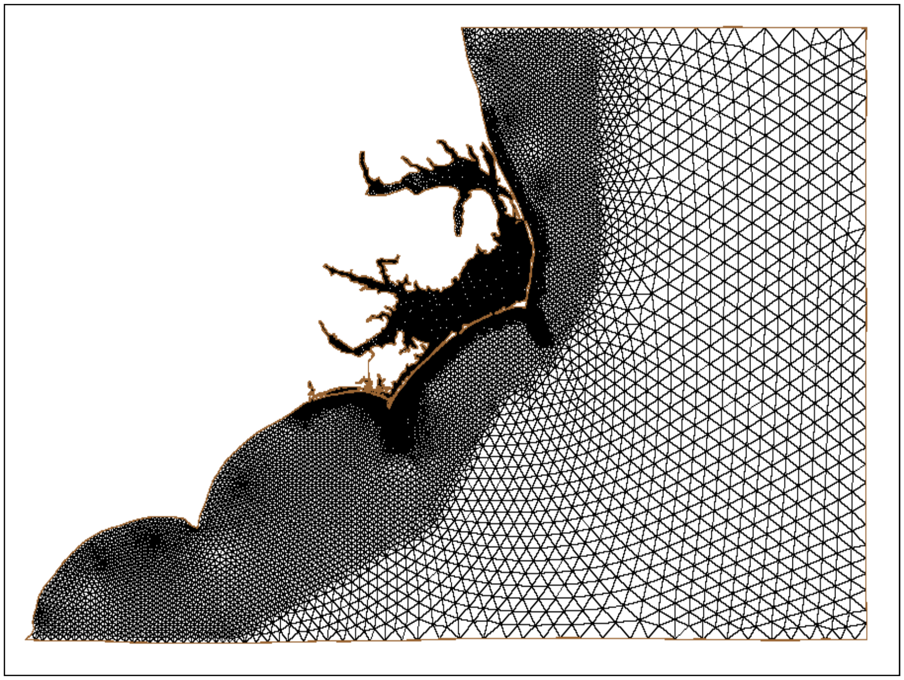


Figure II-24. ADCIRC Model Grid

13. Vulnerability Studies

A number of investigations have been completed within the past ten years to characterize the risk of inundation and physical change along the North Carolina coast. The geographic scope and methods employed vary among the studies. Vulnerability has predominantly been defined relative to potential storm damage to existing development and infrastructure (housing, roadways and bridges). Several studies have also documented the risk of barrier island breaching by new inlet formation and additional investigations have more broadly quantified direct and indirect economic impacts to recreation, tourism and ecological habitat. Risk is categorized based on a number of potential forcing mechanisms including: storm surge, wave impacts, coastal erosion and sea level rise. Analyses are conducted for either event based or long term processes.

For purposes of this evaluation, vulnerability was defined as the susceptibility or risk of upland areas (both developed and undeveloped shoreline) to long term shoreline recession. Pertinent investigations conducted by state and other governmental and non-governmental organizations, relevant to the BIMP, are discussed below.

a) Division of Coastal Management – North Carolina Ocean Hazards Assessment

The State of North Carolina regulates coastal development in accordance with the CAMA. Geographic areas of regulation, Areas of Environmental Concern (AEC), on ocean shorelines are designated based on the possibility of flooding, erosion and shoreline fluctuations.

As prescribed in North Carolina Administrative Code (NCAC) Subchapter 7H, Section 0304, four Areas of Environmental Concern comprise Ocean Hazard Areas (OHAs):

- Ocean Erodible Area (OEA) – Region where there is a substantial possibility of excessive erosion and shoreline fluctuation. The seaward boundary of this area is the Mean Low Water (MLW) line. The landward boundary of this area is equal to 90 times the long-term average annual erosion rates (relative to a stable vegetation line) plus the distance of erosion expected during a storm with a 100-year recurrence interval.

- High Hazard Flood Area (HHFA) – The area subject to high velocity waters (including hurricane wave wash). This area is designated as a “V zone” on flood insurance rate maps prepared by FEMA. These lands are subject to flooding, high waves and wave currents during 100 year recurrence interval storm.

- Inlet Hazard Area (IHA) – These areas are especially vulnerable to erosion, flooding and other adverse effects of sand, wind and water because of their proximity to dynamic ocean inlets.

- Unvegetated Beach Area (UBA) – Areas where there is no stable natural vegetation is present and may be designated an UBA by the CRC on either a temporary or permanent basis.

An example of the delineation of Coastal Hazard Areas at Ocean Isle in the vicinity of Shallotte Inlet is provided (Figure II-25).

Figure II-25. Ocean Hazard Areas in the Vicinity of Shallotte Inlet

(1) DCM Ocean Erodible Area (OEA)

The siting of oceanfront development is determined by setback factors established by the Coastal Resources Commission. Those setback factors and the 100-year storm recession rate are used to delineate the OEA; therefore the extent of the OEA is partially based on the long term erosion rate calculations performed at an alongshore spacing of 50 m. Additionally, the Storm Induced Beach Change model (SBEACH) was used to develop the initial estimates of distance of erosion expected during a storm with a 100-year recurrence interval at each transect (referred to as the 100-year storm recession rate). The OEA is defined as a distance landward from the first line of stable natural vegetation to the recession line that would be established by multiplying the long-term annual erosion rate the distance of 90 feet times the erosion rate, plus the 100-year recession rate as measured landward from the first stable line of vegetation.

(2) High Hazard Flood Area (HHFA)

FEMA is responsible for conducting floodplain mapping of the coast. As part of this effort, a characterization of erosion potential and storm protection during the 100-year recurrence interval storm is completed in accordance with FEMA "Guidelines and Specifications for Flood Hazard Mapping Partners: Appendix D – Guidance for Coastal Flooding Analyses and Mapping" (April 2003). The methods presented rely on empirical results from 38 notable dune erosion cases documented primarily along the Gulf and Atlantic coasts.

Nearly all communities in North Carolina participate in the National Flood Insurance Program (NFIP). The NFIP was created to make flood insurance available to property owners in communities that enact and administer floodplain management regulations that meet program requirements. In coastal areas, buildings must be adequately elevated and protected from the effects of high velocity flood flow. In V zones for example, buildings must be elevated on piling foundations and the lowest horizontal structural member must be at or above the base flood elevation (BFE); in addition if the foundation is enclosed, the walls must be non-supporting breakaway walls. In coastal A zones (not expected to be affected by velocity and wave action) the lowest floor of the building must be at or above the BFE. The CRC considers the V zone to be the extent of the HHFA.

(3) DCM Inlet Hazard Area (IHA)

DCM has defined the inlet hazard areas based on statistical analyses of inlet migration, geomorphology and anthropogenic effects (*e.g.,* beach nourishment, structures). IHAs were first defined by the state in a report to the CRC in 1978, and later amended in 1981, by Loie J. Priddy and Rick Carraway.

In 2007, DCM staff collaborated with the CRC Science Panel on Coastal Hazards to re-delineate the IHAs at 12 inlets that have associated development (Table II-15). The proposed revisions to the IHA delineation are documented in a report by Warren and Richardson (2009).

Table II-15. Summary of Proposed IHA Delineations

Inlet
Tubbs
Shallotte
Lockwood Folly
Cape Fear
Carolina Beach
Masonboro
Mason
Rich
New Topsail
New River
Bogue
Beaufort

(4) Unvegetated Beach Area (UBA)

Dynamic areas which are subject to rapid and unpredictable landform change from wind and wave action may be designated as permanent UBAs by the CRC. In addition, areas that become unvegetated as a result of a storm overwash may be designated as UBA for specified periods of time until stable, natural vegetation has reestablished or the area is permanently designated as a UBA.

b) North Carolina Geologic Survey (NCGS)

The NCGS assessed risk of coastal erosion due to storm damage for populated areas of the North Carolina coast (Hoffmann, 2006). The study covered approximately 234 miles of developed coastline, including seventeen barrier islands.

NCGS evaluated risk of overwash and erosion of coastal areas due to storms, assuming that risk is dependant *solely* on physical characteristics of the fore-island dune. Parameters that were used to establish the integrity of the fore-dune include: volume, average, minimum elevation, and continuity of the dune. The shoreline was divided into segments that are 1,000 meters in length; parameters were manually estimated for each discrete segment of shoreline. LiDAR data collected in 2001 by the North Carolina Flood Insurance Management Program (NCFIMP) was used to estimate the dune volume. NCGS used 1998, 2003 and 2004 aerial photography in the evaluation process.

A composite vulnerability was assigned for each shoreline segment using a weighting factor (a) 75 percent composite of average elevation & fore-island dune volume and (b) 25 percent based on fore-island dune continuity and minimum elevation. Each shoreline segment was assigned one of five risk classes (low, medium, high, very high, highest) based on the composite weighting (Figure II-26). The sample set was evenly divided such that each class represented 20 percent of the total shoreline (*e.g.,* dune volume was assigned to bins approximately as follows: 0 – 100 cubic yards per linear foot; 100 – 150 cubic yards per linear foot; 150 – 225 cubic yards per linear foot; 225-350 cubic yards per linear foot; 350+ cubic yards per linear foot).

In the study, NCGS did not attempt to evaluate vulnerability based on a simulated storm event. Although the long term erosion rates were presented, they are not accounted for in the characterization of vulnerability. Existing infrastructure is identified within critical segments; however no attempt is made to characterize risk of the infrastructure to storm damage either based on setback or event based simulation modeling.

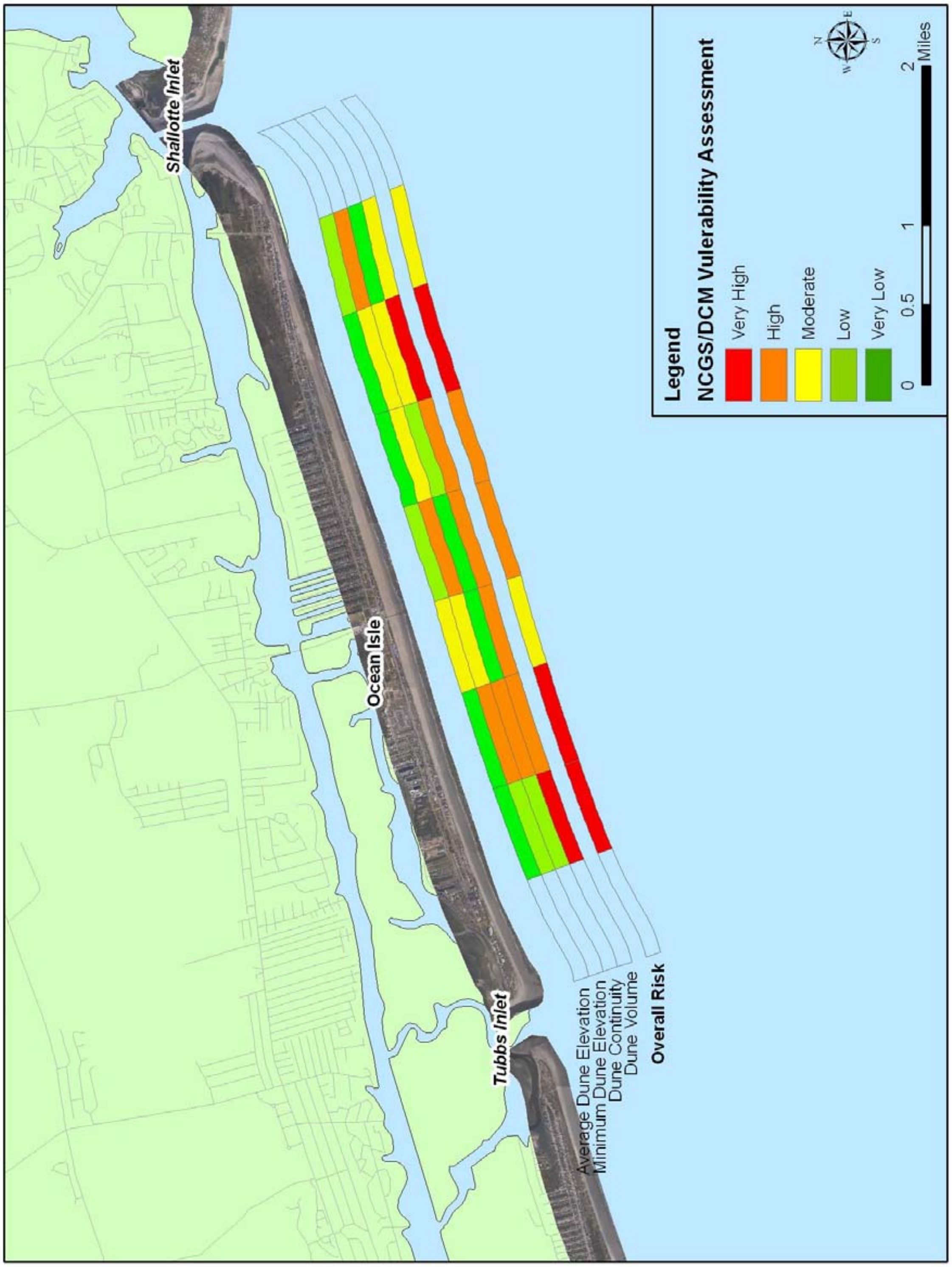


Figure II-26. Example of NCGS Overwash Risk Due to Storms at Ocean Isle

c) United States Geologic Survey (USGS)

A number of investigations have recently been completed by the USGS to characterize vulnerability.

(1) National Assessment of Coastal Vulnerability (Theiler and Hammer-Klose, 2001)

Theiler and Hammar-Klose (2001) conducted a classification of vulnerability and risk of the coastline of the United States to long term erosion and sea level rise. A coastal vulnerability index (CVI) was developed based on the following parameters: 1) tidal range – contributing to inundation hazard, 2) offshore wave height (WIS Phase III 75 – 95), 3) nearshore slope, 4) background erosion rates, 5) geomorphology, and 6) historic relative sea level rise/subsidence. A rating (very low, low, moderate, high risk) was assigned at a resolution of approximately 1:18,000 feet. Based on Theiler and Hammer-Klose (2001), the relative level of sea level rise ranged from moderate to very high along the North Carolina coast.

The study characterized sea level rise as moderate (2.5-2.9 mm/yr or 0.82-0.85 ft/century) in Brunswick County and New Hanover County, high (2.95-3.16 mm/yr or 0.97-1.04 ft/century) in Carteret County, and very high (>3.16 mm/yr 1.04 ft/century) in the Outer Banks. Pendleton et. al. (2004) subsequently applied this method for the Cape Hatteras National Seashore with more recent shoreline data. Figure II-27 illustrates an example of the resolution and mapping of the CVI index for a shoreline segment at Ocean Isle. The results of this study can be found at http://woodshole.er.usgs.gov/project-pages/cvi and http://pubs.usgs.gov/of/1999/of99-593/.

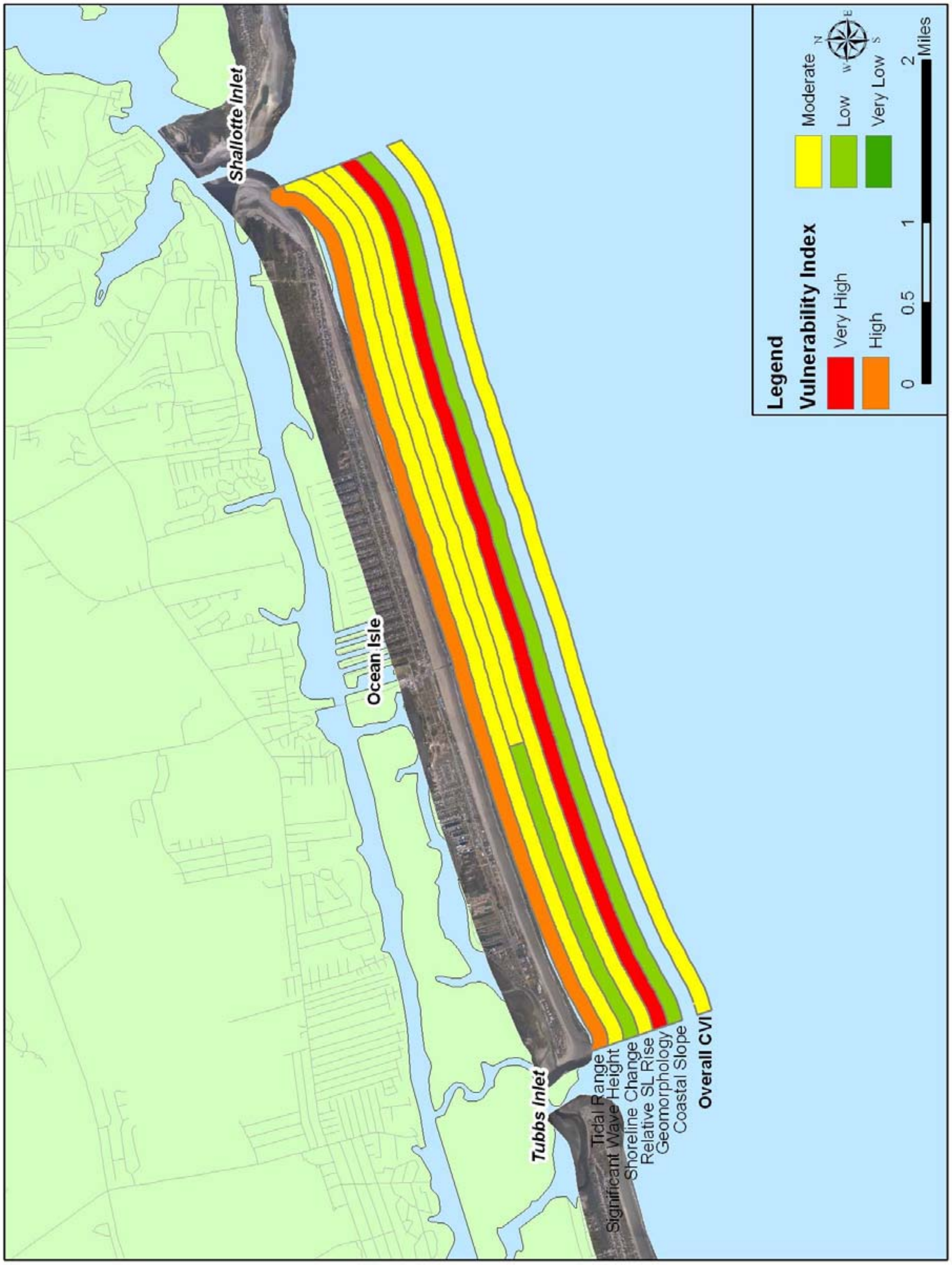


Figure II-27. Example of Coastal Vulnerability Index (2001) to Sea Level Rise at Ocean Isle

(2) Coastal Vulnerability Index for Cape Hatteras National Seashore (Pendleton et. al., 2004)

A CVI was used to map the relative vulnerability of the coast to future sea level rise following the general methods developed by Theiler and Hammer-Klose (2001). Relative sea level rise was estimated by Hammar-Klose (2004), based on gage data at Beaufort (27 years of data), to be greater than 3.5 mm/yr (1.15 ft/century) for the Cape Hatteras study area. The coast was divided into a resolution with shoreline segments established at 1 minute grid cells, a spacing of approximately 6,000 feet. Figure II-28 illustrates the mapping of the CVI index performed for the Cape Hatteras National Seashore. The results of this study can be found at http://pubs.usgs.gov/of/2004/1064/.

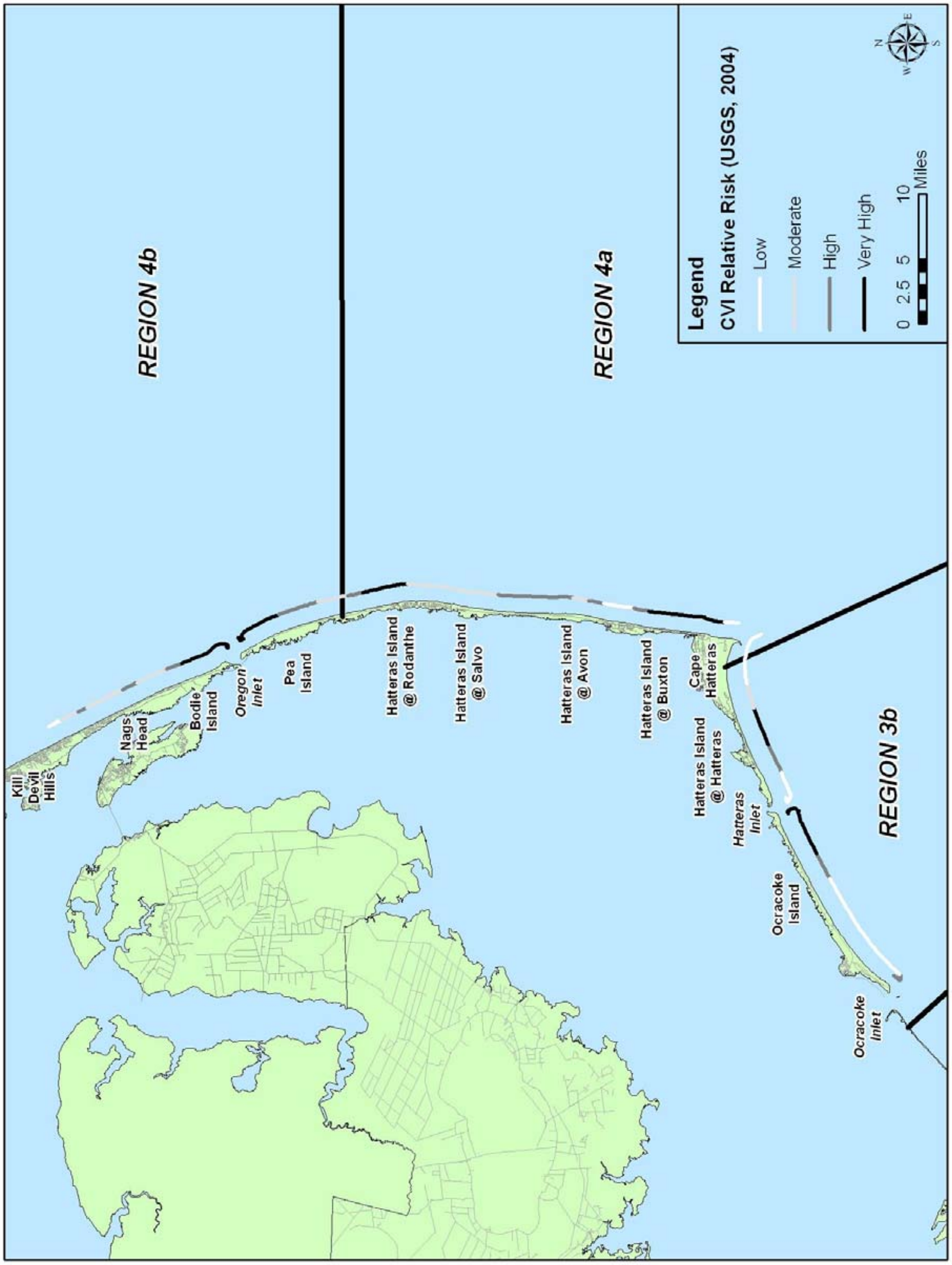


Figure II-28. Coastal Vulnerability Index (2004) for Cape Hatteras National Seashore

(3) Potential Inundation for Cape Lookout National Seashore (USGS, 2007)

USGS investigations (Stockdon and Thompson, 2007) applied a GIS based analysis to map vulnerability for the Cape Lookout National Seashore. The study can be found at http://pubs.usgs.gov/of/2007/1376/. Elevations of storm-induced mean-water levels (storm surge) were compared to the elevations of the crest of the sand dune that defines the beach system. Predicted elevations of storm surge for Saffir-Simpson Category 1-5 hurricanes were extracted from the NOAA SLOSH (Sea, Lake and Overland Surges from Hurricanes) model, a real-time forecast model for hurricane induced water levels for the Gulf and Atlantics coasts. The crest elevation of the foredune was mapped using 2005 LiDAR coverage, extracting data alongshore every 20 meters. Maps detailing the inundation potential for Category 1-5 hurricanes were used to determine the relative vulnerability and identify which areas of the park are susceptible to inundation. Additionally, long-term and short-term erosion rates are quantified and presented. No attempt was made to combine vulnerability with susceptibility to long-term erosion.

d) North Carolina Department of Transportation (NCDOT)

A number of transportation planning studies have been completed to characterize the risk and vulnerability of N.C. Highway 12 in the Outer Banks during the past ten years.

Studies led by Overton and Fisher (2003, 2004, 2005) evaluated the risk of damage during specific storms events as well as long term erosion along NC 12. The most recent analysis by Overton and Fisher (2005) was performed in support of evaluation of replacement of the Bonner Bridge and focused on the reach from Oregon Inlet south to Rodanthe. In each of the studies, cross-shore sediment transport models were applied to estimate landward limits of erosion for various recurrence interval storms; additional setbacks were established based on long-term erosion rates. Moffatt & Nichol (2003, 2004) employed a similar methodology to characterize vulnerability of additional reaches of NC 12 along Ocracoke Island.

Based on the above investigations, a critical setback distance of 230 feet from the highway to the active shoreline was established as an indicator of when the highway would become vulnerable to repetitive overwash and road maintenance becomes excessive. Recommendations were made to maintain a dune with a design template such that there is a 50 percent risk that 50 percent of the dune would be lost in a single storm with a 12-year recurrence interval (Overton & Fisher, 2005); following this standard the design template ranged from 44 cubic yards per linear foot to 200 cubic yards per linear foot. Moffatt & Nichol characterized the cumulative probability and risk associated with multiple storm events for Ocracoke Island.

Based on the above research and investigations, the NCDOT Outer Banks Task Force (www.obtf.org) developed a map of erosion “hotspots” for planning and management of NC 12. Hotspots were defined as those areas where NC 12 was deemed to have the highest susceptibility to future erosion and damage. Figure II-29 illustrates the location of the “hotspots” characterized by NCDOT.

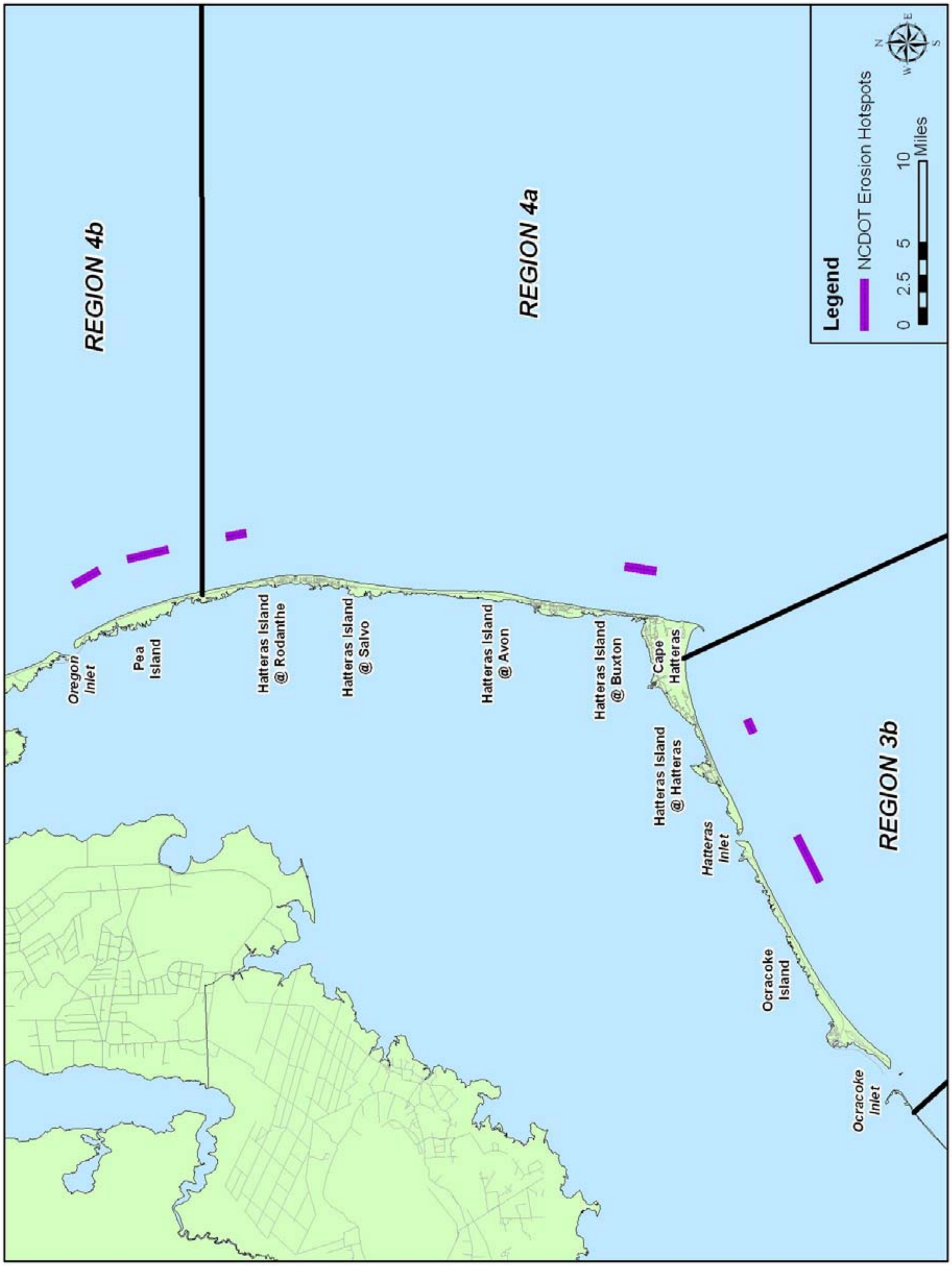


Figure II-29. Erosion "Hotspots" Identified by NCDOT Outer Banks Task Force

e) Other Research

(1) Coastal Hazard Mapping

Pilkey *et al*. (1998) developed coastal hazard maps considering the risk of hurricane and winter storm damage based on geologic and natural resources characteristics (elevation, forest cover, width, frontal and island interior, sand dune height, width, historic storm response, engineering structures). Maps were developed for the entire state and are made available on the coastal hazards website at Western Carolina University (http://coastalhazards.wcu.edu/CoastalHazardMaps/North%20Carolina/NorthCarolina.htm). Categorization of the risk of property damage which may be realized due to wind, flooding and wave damage during a Category 3 (winds between 111 and 130 mph) storm is documented.

(2) Inlet Opening Potential

Inlet formation under episodic events has been a dominant process in the Outer Banks environment. Oregon and Hatteras Inlet were opened in 1846 by hurricanes near sites of prior inlets. New-Old Drum Inlet (opened in 1999 by Dennis) and Ophelia Inlet (opened in 2005 by Ophelia just southwest of Drum Inlet) are both sited within undeveloped Core Banks, within the Cape Lookout National Seashore and, for the purpose of this study, considered two of the three inlets of the Drum Inlet complex (with Drum Inlet, artificially opened in 1971, being the third).

Two events occurring in the past 50 years, Hurricane Isabel (2003) and an Ash Wednesday nor'easter (1962) resulted in breaches of NC 12. Both breaches were subsequently filled by the USACE. The Isabel breach formed at a location which was previously breached and filled in 1933. Following Isabel, in conjunction with evaluating design alternatives for the Bonner Bridge at Oregon Inlet, vulnerability of NC 12 to future inlet breaches has been further evaluated by the Outer Banks Task Force.

The potential formation of new inlets or reformation of past inlets should be a primary consideration in coastal planning and inlet management on the Outer Banks. As cited by Mallison *et al.* (2009), under joint state and federal funding, work has been conducted to identify location and probability of occurrence of inlet formation. One of the studies presented and published on the North Carolina Coastal Hazards website (http://coastal.geology.ecu.edu/NCCOHAZ/maps/inlet_potential.html), characterizes the potential of inlet opening based on cross-section island volume. A categorization was made into four general levels of risk of potential inlet opening: low, medium, high, very high. Eight locations were characterized as being very highly vulnerable to inlet formation along Hatteras Island between Oregon Inlet and Hatteras Inlet; three of those reaches correspond to locations where inlets have formed within the past century. Stretches predicted to be vulnerable to inlet formation are characterized by narrow and low lying barrier islands where underlying geology is not resistant to erosion.

Figure II-30Figure II-30 illustrates the areas which are delineated as very high potential risk of inlet opening (Mallinson *et al.,* 2008); also depicted are those areas defined by Pilkey *et al.* (1998) to be potential inlet sites. As illustrated, there is generally a good correlation of the two assessments (Figure II-30). Other assessments have been completed by Overton and Fisher (2000) and DCM (1987).

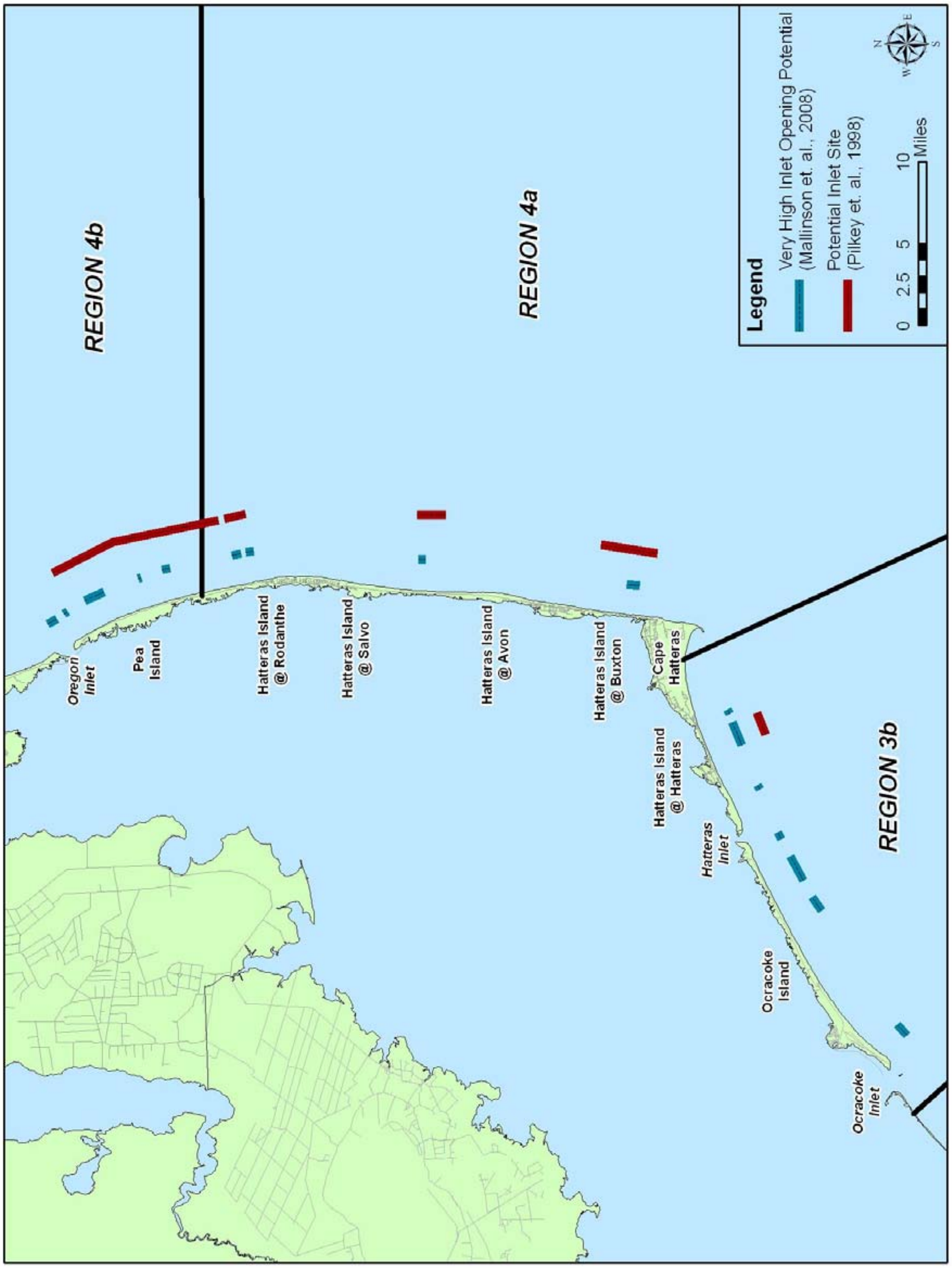


Figure II-30. Inlet Opening Potential Taken from Mallinson *et al.* (2008) and Pilkey *et al.* (1998)

14. Sediment Budgets and Sediment Transport Potential

A coastal sediment budget refers to the identification of sediment sources (credits, input to the region) and sinks (debits, leaves region), and the quantification of the amounts and rates of sediment transport, erosion, and deposition within a defined region. They are useful tools to examine shoreline changes and help predict or assess future behavior. Figure II-31 illustrates an example of the possible components of a sediment budget. Sediment budgets and assessments of sediment transport are two useful tools for gaining insight into sediment propagation and pathways. Understanding the movement of sand along the coast is a key part of developing a beach and inlet management plan.

Waves and currents move sediment on a daily basis along the coast. Sediment enters a region by transport along the coast and from rivers, and leaves a region by transport along the coast and across the coast (offshore or through inlets into sounds). The magnitude and directions of these motions determine whether the beach erodes or accretes and whether an inlet closes or migrates. Knowing the magnitude and direction of sediment transport is a key component in choosing how to manage a beach/inlet system and assessing what impacts various actions will have on the region. Sediment budgets are a method of ‘sand accounting’ for a segment of coast or inlet.

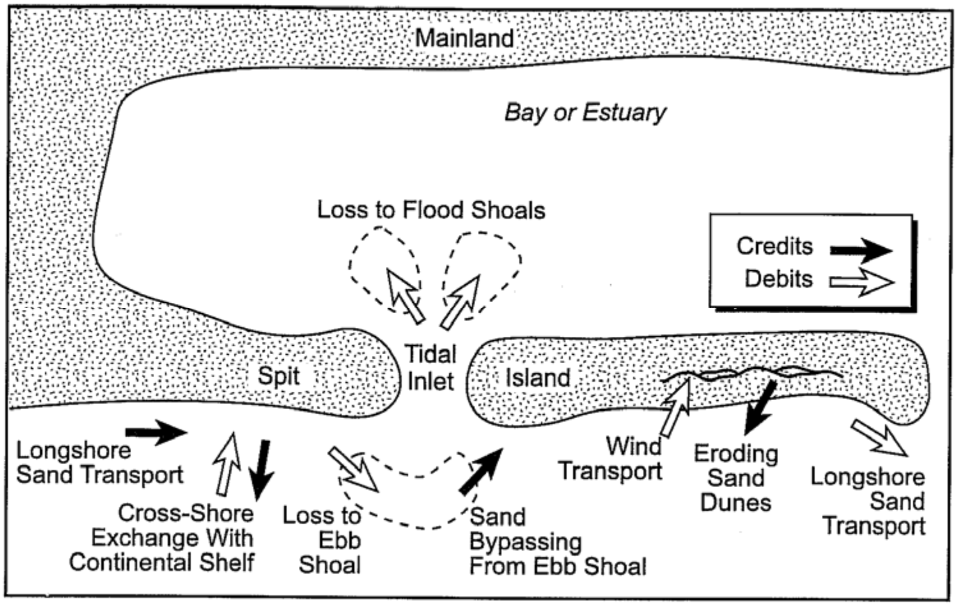


Figure II-31. Sediment Budget at an Inlet

Development of a detailed sediment budget requires an understanding of numerous variables along the coast, as well as the complex and dynamic processes that define the environment in this region. Comprehensive physical surveying programs to monitor the beaches are essential in developing a sediment budget.

It was not the goal of this initial BIMP to develop detailed sediment budgets for the entire coast, but rather to compile the sediment budget analyses already performed. Significant gaps exist in sediment transport and sediment budget information and much of the available information is outdated. The regional sections of this report (Section VIII to Section XI) provide information on the sediment budgets that have been identified to date.

D. Data Gaps

While large amounts of data covering a wide range of topics related to beach and inlet management were compiled or identified in this report, it should be noted that additional data do exist. Many academics, state and federal agencies, local communities, non-government organizations (NGOs), and consultants are continuing to study and collect data related to the North Carolina coast.

During the data collection efforts, several data gaps were identified that if filled, would greatly aid future updates to the BIMP and beach and inlet projects. The following lists some of these key data gaps by general topic:

1. Geology

- Inlet bathymetry
- Sand source investigations
- Underlying geology

Two areas that require additional information are the inlets and sand sources investigations. While much mapping of shorelines and aerial photography of the inlets has been performed over time, few inlets have detailed bathymetric surveys to help identify channel and shoal locations which would be useful in the formulation of inlet management strategies.

2. Physical Processes

- Sediment budget
- Longshore sediment transport rates
- Updated shoreline change rates

Directly related to the geologic data gaps of inlet morphology and sand source investigations, are sediment budget and longshore sediment transport analyses. With the exception of a few areas (Brunswick County and Beaufort Inlet) detailed sediment budget data are lacking, out of date, or contradictory. Longshore sediment transport rates, while available in some locations (and in the sediment budgets), have not been developed in any detail for the state. General global studies detailing the cape formations and long-term transport directions and probable transport rates have been discussed in the literature but little detailed modeling performed. Another shortcoming of the current data set highlighted by numerous stakeholders was the need to update the current DCM shoreline change rates established from 1998 black and white orthophotography.

3. Economics

- Extend property at risk study to include all eight oceanfront coastal counties
- Extend and refine beach recreation value surveys/study to include all eight oceanfront coastal counties

Economic valuation provides an important means of informing policy makers, politicians, and the public of the value of various aspects of beaches and inlets, and also providing a framework for management and funding decisions. Two areas of considerable interest where recent studies have been completed on only select coastal counties (Dare, Carteret, and New Hanover) are in the areas of properties at risk (sea level rise, storms, etc.) and beach recreation values. Extending these studies to the entire coast would help reduce the assumptions made in arriving at estimates of economic values at the local beach and inlet level.

4. Monitoring

- Coast wide beach profile monitoring

While certain areas of the coast have regular beach monitoring surveys (*e.g.,* Carteret County) many areas are surveyed only periodically if at all. The knowledge gained about beach profile change from dune to depth of closure (*i.e.,* sand volume change along the oceanfront shoreline) would aid in the understanding and decision making for beach and inlet strategies. Regular monitoring would also provide baseline surveys needed in part, to qualify for FEMA reimbursement funding after declared events (see Section XIII.B.).

5. Sea Level Rise (SLR)

Although DCM/CRC incorporates aspects of SLR into coastal management (*e.g.,* increasing setbacks and using long-term erosion rates, which are driven in part by eustatic SLR), there are gaps to its full incorporation. There are some current and future efforts being funded by the Department of Homeland Security Appropriation Act (P.L. 110-329), through the Geospatial and Technology Management Office (GTM), to perform a risk assessment and mitigation strategy demonstration of the potential impacts of sea level rise in that state associated with long-term climate change. DCM is working on more explicitly incorporating sea level rise and its impacts into coastal policy and planning. See the policy considerations in Section VI.B for more details on these projects.