8. SHORT-TERM ESTUARINE SHORELINE EROSION IN NORTH CAROLINA

8.1. REGIONAL ESTUARINE SHORELINE EROSION STUDIES

8.1.A. Summary of Former Studies

Stirwalt and Ingram (1974) developed a set of maximum annual erosion rates for 16 sites around the perimeter of Pamlico Sound that ranged from -2.5 to -11 ft/yr (Table 3.1 in Riggs, 2001). Their data were re-evaluated by Riggs and subdivided based upon the apparent shoreline type, orientation, and fronting water body. This re-evaluation demonstrated significantly different shoreline responses that ranged from -1 to -36 ft/yr (Table 3.2 in Riggs, 2001).

The USDA-SCS (1975) produced shoreline erosion data for 15 coastal counties. Three southern coastal counties were judged to have minimal erosion problems and the back-barrier estuarine shorelines were beyond the scope of their study. Their data were based upon defining a series of reaches within each county that severely generalized the variables and produced an average number over large distances that ranged from 0.5 to 39 miles in length. The USDA-SCS study calculated an average erosion rate of -2.1 ft/yr for 1,240 miles (87% eroding) of northeastern North Carolina between 1938 and 1971 (Table 3.3 in Riggs, 2001). The average for the individual coastal counties ranged from -0.9 to -4.5 ft/yr (Table 3.3 in Riggs, 2001).

The author and colleagues in the Geology and Biology departments at East Carolina University carried out numerous studies on estuarine shoreline erosion in the North Carolina coastal system during the 1970s. The location and results of these initial studies are outlined in Riggs (2001). The classification, abundance, and distribution of shoreline types studied by Bellis et al. (1975), O’Connor et al. (1978), and Riggs et al. (1978) within northeastern North Carolina are summarized in Tables 8-1-1 and 8-1-2. This estuarine shoreline erosion study consisted of physically mapping the geologic, biologic, and hydrologic character of the shorelines within northeastern North Carolina estuarine system on 1:1000 scale maps from shallow draft boats. Approximately 50% of the more than 3,000 miles of estuarine shoreline were included in the study area, which did not include the back-barrier estuarine shoreline, large portions of Pamlico Sound, and many of the small tributary estuaries. The numbers in Tables 8-1-1 and 8-1-2 represent only those miles and percentages of shorelines actually mapped by the Riggs et al. (1978) study.

Riggs et al. (1978) integrated their mapping results with the U.S. Department of Agriculture, Soil Conservation Service (USDA-SCS, 1975) study of estuarine shoreline erosion rates in the coastal counties of northeastern North Carolina. Table 8-1-3 summarizes the average annual rate of recession for each shoreline type (Riggs, 2001).

Hardaway (1980) established 10 shoreline study sites along the Pamlico River estuary (Fig. 8-1-1). These sites were selected to represent combinations of 3 types of sediment bank, marsh, and human-modified shorelines, as well as different physical variables controlling shoreline erosion. Hardaway mapped each site 3 times over a 16-month period between August 1977 and November 1978. In March 1987, a graduate student (P. Parham in Riggs, 2001) remapped 7 of the original Hardaway sites to develop a 10-year erosion record. During the
interim, the adjacent land areas at many of the 10 sites were developed and associated shorelines highly modified.

TABLE 8-1-1. Distribution and abundance of shoreline typ in the estuarine system of northeastern North Carolina. numbers represent only those miles and percentages of shorelines actually mapped by the Riggs et al. (1978) study.

STUDY REGION	ALBEMARLE SOUND	PAMLICO RIVER	NEUSE RIVER	CORE-BOGUE SOUNDS	TOTALS
MILES MAPPED	436 mi (27%)	483 mi (30%)	452 mi (29%)	222 mi (14%)	**1593 mi (100%)**

LOW-SEDIMENT BANK	159 mi (36%)	112 mi (23%)	124 mi (27%)	76 mi (34%)	**471 mi (30%)**
HIGH-SEDIMENT BANK	59 mi (14%)	19 mi (4%)	24 mi (5%)	9 mi (4%)	**111 mi (7%)**
BLUFF-SEDIMENT BANK	4 mi (1%)	5 mi (1%)	12 mi (3%)	---	**21 mi (1%)**
SWAMP FOREST	101 mi (23%)	7 mi (2%)	2 mi (<1%)	---	110 mi (7%)
MARSH	113 mi (26%)	340 mi (70%)	290 mi (64%)	137 mi (62%)	**880 mi (55%)**

TABLE 8-1-2. Natural and human features that modify various shoreline types and the erosional and accretionary status of shorelines in the northeastern North Carolina estuarine system The numbers represent only those miles and percentages of shorelines actually mapped by the Riggs et al. (1978) study.

STUDY REGION	ALBEMARLE SOUND	PAMLICO RIVER	NEUSE RIVER	CORE-BOGUE SOUNDS	TOTAL MAPPED
CYPRESS FRINGE—SEDIMENT BANK	82 mi (19%)	5 mi (1%)	29 mi (6%)	---	116 mi (7%)
MARSH FRINGE—SEDIMENT BANK	15 mi (3%)	27 mi (6%)	53 mi (12%)	47 mi (21%)	142 mi (9%)
SAND APRON—MARSH	17 mi (4%)	8 mi (2%)	32 mi (7%)	9 mi (4%)	66 mi (4%)
SIGNIFICANT SHORELINE EROSION IN 1975-1977	390 mi (90%)	457 mi (95%)	408 mi (90%)	200 mi (90%)	1455 mi (91%)
SIGNIFICANT SAND ACCRETION IN 1975-1977	4 mi (1%)	2 mi (<1%)	23 mi (5%)	3 mi (1%)	32 mi (2%)
HUMAN MODIFIED SHORELINE BY 1977	41 mi (9%)	24 mi (5%)	20 mi (4%)	19 mi (9%)	104 mi (7%)

TABLE 8-1-3. Summary of the average annual rate of estuarine shoreline erosion for shoreline types in northeastern North Carolina coastal system. The shoreline types*, their relative abundance (Table 8-1-1), and original average erosion rate da are from Riggs et al. (1978). The average erosion rate data o the
present study** are from Table 8-5-5.

SHORELINE TYPES*	**PERCENT MAPPED SHORE-LINES***	**AVERAGE EROSION RATES (FT/YR)** Riggs et al., 1978*	Riggs Present Study**
1. SEDIMENT BANK SHORELINES			
A. Low Bank (1-5 Ft)		- 2.6	**- 3.2**
B. High Bank/Bluff (> 5 Ft)		- 2.0	**- 2.4**
2. ORGANIC SHORELINES			
A. Swamp Forest		- 2.1	**- 2.2**
B. Marsh Bank		- 3.1	
Mainland			- 3.4
Back Barrier			- 1.2
WEIGHTED AVE. FOR ALL NATURAL SHORELINES	**100%**	**- 2.8**	**- 3.2**
AVE. RANGE FOR ALL SHORELINES		-0.0 to -15.0	**+6.1 to -26.3**

*** Dependent upon Shoreline Erosion Variables (see Chapter 5)

Everts et al. (1983) measured shoreline change for the period between 1852 and 1980 utilizing 42 historical maps and photos for the back-barrier estuarine system between Cape Henry and Buxton Woods. For the period prior to the 1930s, they utilized topographic surveys produced by plane-table mapping. Since the 1930s, they utilized aerial photography and photogrammetric methods. Everts et al. concluded that the average shoreline erosion rate for the north-south estuarine portion of the barriers was -0.33 ft/yr, whereas the east-west estuarine shoreline associated with Buxton Woods was eroding at an average rate of -4 ft/yr. Due to the limitations of the techniques associated with historic surveys, there is a fairly large error bar on absolute amounts and rates of shoreline change.

Murphy (2002) remapped 9 of the original Hardaway (1980) sites and mapped an additional 5 sites along the Albemarle-Pamlico mainland shoreline and 6 sites along the back-barrier shorelines. She carried out a georeferenced aerial photograph analysis of digitized shorelines on aerial photo time slices to develop a short-term erosion record. However, due to the inability to duplicate the erosion rates developed by Murphy, a complete re-evaluation of the Murphy sites was carried out for the present study. It was subsequently determined that serious problems existed with resolution in scanning the aerial photographs and procedures utilized for both georeferencing the photos and digitizing the shorelines. This resulted in significant errors in data analysis, map presentation, and calculations of erosion rates and associated error bars.

Thus, the Murphy study (2002) has serious flaws that make the erosion rate data wrong. Consequently, the present study carried out a total reanalysis of the Murphy study sites, as well as some additional sites. Based upon this re-evaluation, the present estuarine shoreline erosion data for northeastern North Carolina now supercedes the erosional data previously presented for all former studies and publications, including the Murphy study (2002).

These former studies clearly demonstrated the high variability in actual rates of estuarine shoreline recession, as well as the numerous difficulties in developing a good and reliable data analysis. This variability is a direct function of the series of physical, biological, human, and analytical variables. The first three of these varibles are considered in Chapter 5 and summarized in Table 5-1-1.

8.1.B. Overview Of Present Study

Riggs (2001) summarized the data from known estuarine shoreline erosion studies in coastal North Carolina. Because these pre-existing studies were essentially based upon old aerial photography and done without the benefit of modern computer technology and software, Riggs initiated the present estuarine shoreline erosion study that would revisit the Hardaway (1980) and Murphy (2002) study sites. The goal was to develop an improved shoreline erosion data base utilizing detailed field descriptions, an array of aerial photography through time, and new computer technology. The present study significantly expanded the shoreline area of most previous sites, added a few additional sites, and where significant, subdivided the shoreline into type and physical variable categories.

The 21 sites included in the present study are located on Figure 8-1-1. Table 8-1-3 compares the summary erosion data from the present study by shoreline type with the 1978 data of Riggs et al. The remainder of chapter 8 describes the sites and presents the newly acquired erosion data in three distinct categories delineated in Figure 8-1-1: the back-barrier sites (1 through 7),

Figure 8-1-1. Location map for the estuarine shoreline erosion sites for the present study.

the mainland Albemarle-Pamlico sites (8 through 14), and the Pamlico River sites (15 through 21).

Base-line aerial photography control for this study at each site utilized the the 1998 Digital Orthophoto Quarter Quadrangles (DOQQ). The DOQQs are in MrSid format and supplied by the the U.S. Geological Survey. All other sets of aerial photography utilized for this study and included in the various plates of Chapter 8 are in the public domain and were obtained from and utilized with permission of the following organizations: U.S. National Park Service (Cape Hatteras National Seashore, Manteo and Cape Lookout National Seashore, Harkers Island); U.S. Army Corps of Engineers (Field Research Facility, Duck); U.S. Department of Agriculture (various offices of the Soil and Water Conservation Service including Beaufort, Dare, Hyde, Pamlico, and Tyrrell counties); N.C. Department of Transportion, Raleigh; N.C. Division of Coastal Management, Raleigh; and Dare County GIS office, Manteo. All aerial photographs were scanned into the computer, georeferenced, manipulated, and shorelines digitized utilizing standard procedures and the following software programs: Adobe Photoshop, MapInfo, Ras Tools, and CorelDraw. Most study site photographs in the associated plates are by S. Riggs unless identified otherwise.

8.2. BACK-BARRIER ESTUARINE SHORELINE EROSION SITES

8.2.A. Summary: Back-Barrier Shorelines

The estuarine shorelines occurring along the back side of barrier islands are extremely diverse and variable with respect to types and erosion rates. Shorelines along the estuarine side of complex barrier islands are similar to mainland shorelines. However, generally there is more sand in the coastal system due to the presence of various barrier island sources such as back-barrier dune fields. Complex barriers are sediment-rich, resulting in high and wide islands that commonly contain extensive maritime forests. Consequently, there is little to no direct interaction between estuarine shorelines and oceanic dynamics. On the other hand, shorelines along the estuarine side of simple, overwash-dominated islands are extremely different from mainland shorelines. These low and narrow islands are periodically dominated by oceanic processes resulting in major sediment input in response to overwash events, inlet dynamics, and migrating dune sands. Consequently, many low sediment banks and marsh platforms contain extensive shallow waters with ephemeral strandplain beaches and abundant fringing marsh and offshore aquatic vegetation. These latter processes and responses not only diminish wave energy, but actually build back-barrier platforms critical for barrier island migration processes in response to rising sea level.

Another important variable is the physical character of the back-barrier estuarine water body. For example, shorelines occurring along the narrow and shallow waters of Currituck, Roanoke, and Core sounds are generally characterized by shallow water and lower wave energy conditions. This results in generally lower erosion rates. On the other hand, shorelines occurring along the very large Albemarle and Pamlico sounds or adjacent to inlets are generally characterized by large water bodies with tremendous fetches and much higher energy and storm-tide conditions. This results in higher erosion rates.

The saving grace for the estuarine shorelines between Oregon Inlet and Ocracoke Inlet is the presence of a very broad and shallow platform called Hatteras Flats (Riggs et al., 1995). Hatteras Flats is a Pleistocene structural platform that extends up to 1 to 2 miles into Pamlico Sound, is generally less than 2 feet deep, and contains vast areas of submerged aquatic vegetation. Consequently, Hatteras Flats tend to significantly decrease wave energy approaching the shoreline and resulting rates of shoreline erosion. This structural feature is the top of an interstream divide separating the paleo-Pamlico Creek drainage basin from the next drainage basin to the east that existed on the inner continental shelf during sea-level lowstand conditions of the last glacial maximum (see Chapter 6). The modern barrier island system between Oregon and Ocracoke Inlets is perched on top of this interstream divide that constitutes Hatteras Flats (Fig. 6-2-2).

Consequently, the rates of shoreline recession along the back barrier are extremely variable and critically dependent upon geographic location and the interaction with oceanic processes. If oceanic processes are cut off by increased island elevation or vegetative growth—-whether a product of natural changes or human modification such as construction of barrier dune ridges, road dams, and urban development—-rates of estuarine shoreline erosion will significantly increase. Table 8-2-1 is a summary of the average annual rates of estuarine shoreline erosion for seven sites occurring along the northern Outer Banks barrier islands. Brief descriptions of each site and a general synthesis of the erosion data occur in the following sections. The sites are located on Figure 8-1-1.

TABLE 8-2-1. Summation of the short-term estuarine shoreline erosion rates for the back-barrier sites of the northern Outer Banks based upon the present study. See Figure 8-1-1 for locations of study sites.

STUDY SITE / SHORELINE TYPE	TIME PERIOD (years)	DISTANCE ANALYZED (feet)	AVE. LONG-TERM EROSION RATE RIGGS DATA—PRESENT NET (ft/yr)	RANGE (ft/yr)
1. HATTERAS SITE-MIDDLE PAMLICO SOUND:				
Marsh Platform—NET	**1962-1998**	**1,000**	**-0.5**	**0.0 to –0.8**
Strandplain Beach—NET	**1962-1998**	**1,575**	**+0.8**	**+3.0 to –0.5**
2. BUXTON SITE-MIDDLE PAMLICO SOUND:				
Marsh Platform	1962-1974	1,800	-8.7*	-3.3 to –18.6
Marsh Platform	1974-1998	1,800	+0.2*	+4.6 to – 3.0
Marsh Platform--NET	**1962-1998**	**1,800**	**-2.6***	**+4.6 to –18.6**
*A major storm in February 1973 filled the tidal crks with +250 to +320 feet of overwash sediment. Subsequent storms and resulting overwash formed extensive strandplain beaches in front of major portions of the marsh platform.				
3. SALVO SITE-NORTHERN PAMLICO SOUND:				
Marsh Platform—NET	**1962-1998**	**1,500**	**-0.9**	**-0.2 to –2.4**
4. SEVEN SISTERS DUNE FIELD—EASTERN ALBEMARLE SOUND:				
Low Sediment Bank—NET	**1932-~1973**	**9,234**	**-5.2**	**0.0 to –8.2**
Shoreline was only locally modified prior to 1973, but has been almost totally modified through major development since 1973.				

5. JOCKEY’S RIDGE DUNE FIELD-EASTERN ALBEMARLE SOUND:				
Low Sediment Bank—NET Northern Section	**1964-1998**	**3,290**	**-3.5**	**-0.6 to –8.3**
Strandplain Beach—NET Southern Section	**1964-1998**	**1,400**	**+1.7**	**+6.1 to –1.7**
6. NAGS HEAD WOODS SITE-EASTERN ALBEMARLE SOUND:				
Open Marsh Platform—NET	**1964-1998**	**8,590**	**-1.7**	**0.0 to -4.0**
Embayed Marsh Platform—NET	**1964-1998**	**1,000**	**+0.6**	**+1.4 to –1.2**
7. DUCK SITE-SOUTHERN CURRITUCK SOUND:				
Low Sediment Bank—NET	**1986-1998**	**1,940**	**-0.7**	**+8.4 to –4.5**
Marsh/Strandplain Beach	1986-1992	1,940	-6.3	+6.0 to –23.5
Marsh/Strandplain Beach	1992-1998	1,940	+5.7	+15.5 to -3.0
Marsh/Strandplain Bch—NET	**1986-1998**	**1,940**	**-0.3**	**+15.5 to –23.5**

Low sediment bank shoreline is fronted by a strandplain beach with a dense fringing marsh that comes and goes through time in response to storms and plantings.

8.2.B. Hatteras Overwash Site **(Figures 8-2-1, 8-2-2, and 8-2-3)**

The Hatteras overwash site is located within the Cape Hatteras National Seashore (CHNS) and about 0.5 miles northeast of the northeastern-most road in Hatteras Village. The site occurs immediately adjacent to the CHNS parking lot on the northwest side of N.C. Highway 12 and consists of one small marsh platform flanked by two sand strandplain beaches occurring within adjacent coves.

The entire back-barrier island segment between Hatteras and Frisco villages is characterized by a series of marsh platforms that increase in size from the study site northeast towards Frisco and are separated by small embayments or coves. The marsh platforms are terminated on the barrier island side by fairly abrupt 1 to 2 foot topographic rises dominated by transition zone vegetation. These are the terminal ends of more recent overwash fans whose surfaces are dominated by an extremely dense shrub/scrub zone that is narrow at the study site, but widens towards Frisco. In addition, examination of the aerial photographs suggests a major increase in vegetation density within the scrub-shrub zone over the past four decades. This increase corresponds with the minimization of overwash processes by construction and maintenance of N.C. Highway 12 and associated barrier-dune ridges.

The coves between platform marshes are former overwash tidal creeks that now contain major sand strandplain beaches that are restricted to the coves. Abundant submerged aquatic vegetation (SAV) grows on the shallow sediments within Sandy Bay and form extensive wrack lines along various storm water levels on the beach, and frequently it will bury the entire strandplain beach. Wrack is composed primarily of dead SAV grasses that have either been ripped up by storm waves or supplied by seasonal die off. Accumulated wrack is often thick enough within the coves and along scarped marsh edges to both significantly baffle wave energy reaching the shoreline and aid in trapping sand. Thus, the coves and adjacent tidal creek portions of the marsh platforms are often protected from severe erosion and may actually accrete sediment during storms. All back-barrier estuarine shorelines associated with Hatteras Flats, extending from Oregon Inlet to Ocracoke Inlet, contain major wrack deposits that vary from season to season as a function of the storm patterns.

The central portion of the Hatteras site is a soundward protruding marsh platform with an erosional scarp cut into firm peat along the outermost edge. Along the platform flanks, the peat scarp generally contains 1 to 10 foot wide sand ramps that bury the scarp and are dominated by *Spartina alternafora*. Landward of the scarp is the outer fringing marsh that has locally been stripped of *Juncus* marsh grass by storms and is dominated with patches of either *Spartina patens* or *Spartina alternaflora*, or both. The outer fringing zone of *Spartina* is separated from the interior marsh by one or more 1 to 2 foot high perimeter wrack berms with abundant sand and variable amounts of transition zone vegetation. The interior marsh consists of major stands of pure *Juncus roemerianus*. However, numerous large and irregular patches of *Distichlis, Borrichia,* and *Salicornia,* with some *Spartina alternaflora* and *Iva* dominate the former areas of wrack deposition within the *Juncus*.

It appears that the entire marsh platform formerly consisted of *Juncus*, which is becoming a smaller component as erosion diminishes the platform size and wrack covers relatively larger platform areas. Because *Juncus* does not survive wrack burial, the more restricted marsh grasses rapidly take over and dominate these irregular patches as the wrack decomposes. Peat within these irregular

Figure 8-2-1. Photographs of site

Figure 8-2-2. 1998 DOQQ with receding shorelines

Figure 8-2-3. Aerial photo time slices (1945, 1962, and 1989) patches of wrack deposition tends to be very soft, 2 to 3 feet deep, and consist of decomposed wrack. Generally, a large and irregular wrack line occurs along the landward side of the marsh platform marking the topographic limit of the former overwash fans.

The marsh platform generally consists of 1 to 3 feet of firm sandy peat with a modern root zone that is thinner than the peat platforms at Nags Head Woods or the mainland marshes. This results in similar erosional processes of the peat scarp, but at much smaller scales. Waves within the much shallower water slowly erode the soft under portions to produce root-bound overhangs that are generally 1 foot thick by 2 to 4 foot wide. These overhangs ramp down to the estuarine floor, ultimately breaking off the overhangs in response to the wave-driven flopping motion, and depositing small peat blocks in the nearshore zone adjacent to the shoreline.

The 1998 Digital Orthophoto Quarter Quardrangle for the Hatteras overwash site shows the digitized shorelines for 1962 and 1998. The marsh platform had an average shoreline erosion rate of –0.5 ft/yr for the period from 1962 to 1998 (Table 8-2-1), while the strandplain beaches within the adjacent coves actually accreted sediment at the average rate of +0.8 ft/yr. The rates ranged from an accretion rate of +3.0 ft/yr to a recession rate of –0.5 ft/yr. The low net erosion rates, as compared to other sites, are related to the extremely shallow water of Sandy Bay with abundant surficial sand from former inlets and overwash processes. In addition, the abundance of dead SAVs tend to diminish estuarine wave energy acting upon the shoreline and aid in trapping and holding sand. The Hatteras marsh platforms are similar to, but larger than the Buxton marsh platforms, possibly due to generally lower erosion rates.

8.2.C. Buxton Inlet Site
(Figures 8-2-4, 8-2-5, 8-2-6, and 8-2-7)

The Buxton site is located within the Cape Hatteras National Seashore (CHNS) and approximately 0.7 miles south of the Haulover Day Use Area, commonly known as Canadian Hole. This site is what remains of a much more extensive marsh platform on the Pamlico Sound side of a narrow overwash dominated barrier island segment. The 1962 aerial photo shows a much broader marsh platform that has been severely diminished in size as indicated on the 1999 aerial photo.

The 1940 shoreline plot on the 1962 aerial photo demonstrates that minimal estuarine shoreline erosion occurred up to 1962. In spite of a barrier dune ridge and a raised N.C. Highway 12, the 1962 Ash Wednesday nor'easter resulted in an extensive series of small-scale overwash fans and opened Buxton Inlet. The highway and protecting dune ridges were subsequently rebuilt and the inlet was closed by the U.S. Army Corps of Engineers in 1964 with automobiles and sand dredged from the shallow waters immediately behind the barrier. Additional sediment was dredged for several beach nourishment projects during the 1960s and early 1970s leaving numerous deep holes across the shallow flats that still persist today and are most obvious in the 2000 aerial photo. The fact that these submarine holes have not collapsed and are today as sharply defined as when they were dredged, suggests that the sediment is not just a thick pile of pure clean sand. Such sediment is not stable enough to hold vertical walls on land, more less beneath shallow waters in a high energy system.

The Buxton site is a narrow, north-south oriented marsh platform consisting of an outer fringing marsh and interior marsh separated by a well developed perimeter berm composed of sand and SAV grass wrack. Small overwash fan

Figure 8-2-4. Photographs of site

Figure 8-2-5. A. 1992 oblique aerial potograph showing multiple going-to-sea N.C. Highway 12. B. 1999 aerial photograph with last going-to-sea N.C. Highway 12 after Hurricane Dennis.

Figure 8-2-6. 1998 DOQQ with receding shorelines

Figure 8-2-7. Aerial photo time slices (1962, 1964, 1983, and 2000)

sediments during the 1973 storm filled some former tidal channels between marsh platform segments. Most of these sediment-filled areas have since converted to marsh and been incorporated into the adjacent platforms. More recently, a small sand headland composed of ocean beach sediment formed from a storm overwash that flowed down an ORV roadbed and was deposited into Pamlico Sound as a small overwash fan deposit on the northern end of the study site. Associated north winds transported these overwash sediments southward along
the marsh shoreline which ends abruptly with a steep foreslope at the south end of the fan delta. The overwash sands were subsequently reworked by wave processes producing a major strandplain beach in front of and on top of the outermost portion of the peat platform and has temporarily stablized the northern marsh platform segment. South of the fan delta deposit, the scarped peat shoreline persists, and continues to erode.

The marsh platforms at the Buxton site tend to be very narrow and generally consist of 1 to 2 feet of sandy peat on top of overwash fan sediments. The platform consists of an outer fringing marsh zone composed of *Spartina patens* with local patches of *Spartina alternaflora* that occurs in front of and is displacing the dominant marsh grass *Juncus roemerianus*. Locally, *Juncus roemerianus* occurs right up to the eroding scarp, suggesting more rapid rates of shoreline recession than segments dominated by *Spartina*. Landward of the *Juncus* is a discontinuous, but dense zone of *Borrichia* (sea-oxeye) and *Iva* (marsh elder) that grew within thick accumulations of wrack associated with the perimeter berm. As the wrack decomposes, the resulting soft organic mud sediment is both compacted and/or readily scoured during high storm tides, exposing the extensive root networks.

The outer fringing marsh zone is separated from the narrow interior marsh by a major perimeter berm system composed of SAV wrack and sand. Behind the perimeter berm, the interior marsh is dominated by mixed patches of *Juncus roemarianus, Spartina cynusoroides,* and wrack and associated plants that extends landward to a rise in slope marking the soundside edge of the 1962 storm overwash fans. The slope of these overwash fans are dominated by transition zone and shrub/scrub vegetation. The erosional processes along the scarped peat platform perimeter are similar to the Hatteras site with soft under portions eroding and producing root-bound overhangs. The overhanging blocks ultimately weaken and break off in response to wave action and are deposited in the zone adjacent to the shoreline, which is littered with small eroded peat blocks.

It appears that the anthropogenic projects may have altered the pre-1962 stability of this entire back-barrier segment, changing the rates of estuarine shoreline erosion. The post-1962 storm efforts to maintain N.C. Highway 12 with increased attention to construction and maintenance of the barrier dune ridge, as well as the raised road bed itself, minimized overwash sediments from renewing the back-barrier sand supply. In addition, extensive dredging of up to 20 foot deep holes in firm, nearshore sediments produced traps for shallow surface sands that would normally be used to build strandplain beaches against the marsh platform. This results in slightly deeper water allowing increased wave energy to reach the marsh shoreline and causing increased rates of shoreline erosion. The 1992 oblique aerial photograph shows three subsequent relocations of the “going-to-sea” highway 12. After the fourth N.C. Highway 12 relocation (1999 aerial photograph) resulting from Hurricane Dennis, there is no island left for future highway relocations. The combination of natural and anthropogenic processes on a sediment-starved barrier segment located within the highest wave energy regime along the northwestern Atlantic margin, will ultimately result in the collapse of this barrier segment as indicated in Figure 6-3-4A.

The 1998 Digital Orthophoto Quarter Quardrangle shows the location of digitized shorelines for years 1962, 1974, and 1998. From 1940 to 1962 there does not appear to be any significant erosion along this shoreline. However, from 1962 to 1974, the shoreline receded at an average rate of –8.7 ft/yr with an average low rate of –3.3 and an average high rate of –18.6 ft/yr (Table 8-2-1). The major tidal channels present in the 1962 aerial photograph were completely filled with washover sand after the February 13, 1973 storm to produce the fairly straight shoreline that appears in the 1974 aerial photograph. During the period from 1974 to 1998 only minimal shoreline change occurred with a net average accretion rate of +0.2 ft/yr. However, accretion was not uniform: the southern 1,450 feet accreted at an average rate of +0.8 ft/yr while the northern-most 350 feet eroded at an average rate of –2.0 ft/yr. Consequently, the net change for this site from 1962 to 1998 was an average of –2.6 ft/yr.

8.2.D. Salvo Day-Use Site (Figures 8-2-8, 8-2-9, and 8-2-10)

The Salvo site is located within the Cape Hatteras National Seashore (CHNS) day-use area, immediately south of the town of Salvo. The site is located west of the northern loop road and between two major tidal creeks that flow into Clark’s Bay. The study area is the estuarine side of a major back-barrier berm that contains scattered maritime forest with abundant live oaks and an old cemetery. This back-barrier berm is terminated at both the north and south ends by major tidal creeks that have thick *Juncus roemerianus* marsh shorelines that are not eroding and have been in a constructional phase since the mid-1960s with elimation of overwash processes. The study area does not include these marsh shorelines associated with the flanking tidal creeks.

The study site shoreline is the last remnants of an eroding marsh platform with local sand-rich segments with a strandplain beach eroded into the back-barrier berm. Sand for the strandplain beach was derived from both the erosion of the back-barrier berm during high storm tides, as well as former overwash sand deposits supplied to Clark’s Bay through the tidal creeks. Clark’s Bay is semiprotected with very broad marsh platforms extending soundward onto Hatteras Flats on both the north and south sides. Consequently, the shallow, sand-rich character of this shoreline, in concert with the semi-protected setting and location of the broad and shallow Hatteras Flats, results in this shoreline having relatively low erosion rates.

This marsh shoreline appears to be in the final stages of disappearing, assuming that it originally was more similar to the adjacent marsh platforms. Most of this shoreline consists of an eroding sandy peat that commonly displays small (< 1 foot high) erosional scarps. The small interior marshes are dominated by *Juncus roemerianus* with an narrow outer fringing marsh dominated by *Spartina patens* and *Spartina alternaflora*. Also, the *Spartina* tends to be the dominant marsh grass on the strandplain beaches. The outer fringing marsh is separated from the interior marsh by one to several perimeter berms composed of sand and SAV wrack.

The 1962 aerial photograph demonstrates the important interaction between oceanic processes and the estuarine shoreline along this narrow barrier island segment. The study site is the estuarine side of a major overwash plain with two active tidal creeks that transport sediment into Clark’s Bay and drain the overwash events during storms. The overwash sands are subsequently reworked by storm tides associated with soundside processes into strandplain beaches in front of the scarped marsh peat. This is a constructive and accretionary process that generally protects the back side of overwash barrier islands.

Figure 8-2-8. Photographs of site

Figure 8-2-9. 1998 DOQQ with receding shorelines

Figure 8-2-10. Aerial photo time slices (1962, 1978, and 1983)

However, since construction of N.C. Highway 12 and increased maintenance of associated barrier dune ridges on the ocean side, as demonstrated on the 1978, 1983, and 1998 aerial photographs, the overwash process has essentially been eliminated at this site since the Ash Wednesday 1962 nor'easter. Thus, without the periodic input of "new sand" into this estuarine shoreline segment, this site will probably begin to see increased rates of shoreline erosion and recession through time.

The 1998 Digital Orthophoto Quarter Quardrangle for the study site shows the location of digitized shorelines for 1962 and 1998. The long-term pattern of shoreline change for this site is a fairly slow and consistent –0.9 ft/yr average erosion rate with a range from an average low of –0.3 ft/yr to an average high of –2.4 ft/yr (Table 8-3-1). This site is moderately well protected inside Clark's Bay with very shallow water and a sand-rich bay bottom. All environmental indicators at this site support slow recession rates. However, major shoreline erosion is noticeable on the large marsh platform that forms the south shore of Clark's Bay where the ditched and diked area dug within the marsh prior to 1940, has been severely breached on the western side by 1998.

8.2.E. Jockey's Ridge and Seven Sisters Dune Fields (Figures 8-2-11, 8-2-12, 8-2-13, 8-2-14, and 8-2-15)

The Jockey's Ridge site is located on the Roanoke Sound side of Jockey's Ridge State Park (JRSP). The site extends from Sound Side Road, northwest to the boundary between the park and a private sound-side development. The shoreline is oriented NW-SE and occurs at the confluence of the west-east oriented Albemarle Sound and the north-south oriented Roanoke Sound (Fig. 8-1-1). JRSP is an active portion of the back-barrier dune field that constitutes the area from Nags Head Woods to the Seven Sisters dune field. Figure 8-2-10 dramatically demonstrates the severe modification this vast dune field has undergone between the 1932 and 1999 aerial photographs. Extensive urban development in concert with heavy vegetative growth have essentially fixed the highly mobile back-barrier dune field everywhere except within the park. However, to some extent, even within the park, there has been significant vegetative growth around the flanks of the main dune field through time, including portions of the study site.

The shoreline is a low sediment bank eroded into small dunes associated with Jockey's Ridge and an associated strandplain beach. Erosion of the dunes results in a very sand-rich, extremely broad and shallow strandplain beach that occurs throughout the study site, but is the dominant shoreline type along the southern 1,400 feet, forming an excellent swimming beach. Much of the dune field along the shoreline has been stabilized by pine and shrub/scrub vegetation, resulting in the evolution from a slightly curved shoreline in 1964 to a shoreline characterized by a series of headlands and coves today. The headlands are semistabilized by a dense outer fringing marsh composed primarily of *Spartina alternaflora* and *Juncus roemerianus*. Above the sand berm, the inner marsh zone is composed primarily of *Phragmites australis* and *Baccharis* with minor *Spartina cynosuroides*. These headland marshes have been growing long enough to form thin and poorly developed peaty sand substrates that now partially bind the sediments. This is an excellent example of a fringing marsh as compared to the marsh platform at the Nags Head Woods site with its thick substrate of pure peat and an eroding scarped shoreline.

The 1998 Digital Orthophoto Quarter Quardrangle shows digitized estuarine shorelines for 1964 and 1998. The Jockey’s Ridge shoreline was divided into

Figure 8-2-11. Photographs of site

Figure 8-2-12. 1998 DOQQ with receding shorelines for Jockey’s Ridge and Nags Head Woods sites.

Figure 8-2-13. Aerial photo time slices

Figure 8-2-14. 1932 and 1999 aerial photo sequence for the Jockey’s Ridge and Seven Sisters Dune Field sites.

Figure 8-2-15. 1932 aerial photo for the Seven Sisters Dune Field site with the 1998 shorelines.

two segments. The southern segment is about 1,400 feet of well-developed strandplain beach in front of the adjacent dune field. This shoreline displays a net accretion of +1.7 ft/yr during the study period with a range from +6.1 ft/yr to local erosion of –1.7 ft/yr (Table 8-2-1). The northern segment, about 3,290 feet, is dominated by a low sediment bank shoreline that is actively eroding into the adjacent dune field. Due to the sand abundance, there is a small strandplain beach in front of the eroding shoreline. The
northern shoreline is receding at –1.7 ft/yr with a range from a low of –0.6 ft/yr to a high of –8.3 ft/yr (Table 8-2-1).

The Seven Sisters dune field occurs due south of Sound Side Road and extends more than 9,000 feet along the Roanoke Sound shoreline. The 1932 georeferenced aerial photograph for the Seven Sisters area shows the location of the 1998 Digital Orthophoto Quarter Quardrangle shorelines and roads. This figure suggests that the ocean shoreline has receded along a fairly uniform line approximately 400 feet during this 66 year time period. During the same time interval, the estuarine shoreline receded along a much more irregular pattern with some areas receding up to 360 feet and other spots experiencing little to no change. This shoreline was only locally modified prior to 1973, but has been almost totally hardened through major development within the Seven Sisters dune field since that time.

8.2.F. Nags Head Woods Site (Figures 8-2-16 and 8-2-17)

The Nags Head Woods site is located on The Nature Conservancy (TNC) property at the west end of TNCs Roanoke Hiking Trail. The overall shoreline is oriented northwest-southeast and is semiprotected within Buzzards Bay at the eastern-most end of the west-east oriented Albemarle Sound (Fig. 8-1-1). The site is a vast marsh platform that drops off into 2-4 feet of water, but has an overall unique location with respect to both estuarine and oceanic dynamics. The eastern portion of Albemarle Sound that occurs immediately west of Nags Head Woods is characterized by a vast shallow-water (1 to 6 feet deep) sand deposit known as Colington Shoals that extends almost 5 miles to the west. On the eastern side of Colington Shoals, and directly opposite the Nags Head Woods site, is a slightly submergent (< 1 foot deep) smaller sand shoal that extends south off of Colington Island and produces the semiprotected Buzzards Bay. These sand bodies absorb much of the wave energy from the long fetch of Albemarle Sound. In addition, the site occurs along the back side of the very high and extensive back-barrier dune field containing Nags Head Woods maritime forest. Thus, oceanic influences do not directly affect this site and the erosion processes are significantly diminished along the back side of Nags Head Woods.

The Roanoke Trail runs west along a finger of uplands that extends soundward to the shoreline. Where the upland intersects the sound it forms a short (~100 ft) zone of low sediment bank shoreline fronted with a strandplain beach and old trees dying from root systems exposed by erosion. However, the greatest portion of this site, both north and south of the cove with the low sediment bank, consists of an extensive marsh platform that projects soundward. The marsh platform consists of organic peat sediment that is up to about 5 feet thick on the headlands and thins to zero feet onto the low sediment bank shoreline dominated by upland forests within the center of the site. The marsh shoreline generally consists of a 1 to 4 foot erosional scarp. Because the peat is generally thicker than the erosion depth, the nearshore estuarine floor consists of soft, in situ peat that extends hundreds of feet offshore. This demonstrates that the marsh itself extended at least this far offshore in the recent past and has been lost to shoreline erosion.

Figure 8-2-16. Photographs of site

Figure 8-2-17. Aerial photo time slices

The marsh is dominated by a dense growth of *Spartina cynosuroides* along the outer zone with *Juncus roemerianus* forming vast areas of the back marsh. Waves erode this classic marsh platform composed of a thick sequence of almost pure organic matter to produce a scarped shoreline. As the soft peat that underlies the <1-foot thick modern root zone is eroded, large blocks of the tightly matted uppermost peat form extensive overhanging blocks, up to 5 to 10 feet across, that slosh with every wave. Ultimately the blocks weaken, finally break, and fall to the floor of the adjacent estuarine waters to be slowly broken down with time. Many of these blocks can be seen in the shallow near-shore waters. Along most of the marsh shoreline *Spartina cynosuroides* or *Juncus roemerianus* occurs right up to the eroding edge. However, in some areas erosion strips the main marsh plants off narrow patches on the peat surface, as well as upper plates of the peat itself producing a stair-step erosional geometry. These barren peat surfaces develop a narrow outer fringe of fast growing *Spartina patens* during periods of low erosion.

The 1998 Digital Orthophoto Quarter Quardrangle shows the location of digitized estuarine shorelines for 1964 and 1998. The data summarized in Table 8-2-1 support the following interpretation. The open marsh shoreline at this site is eroding at an average rate of –1.7 ft/yr with rates ranging from 0.0 ft/yr to highs of –4.0 ft/yr. The northern-most 1,000 feet analyzed is a similar marsh shoreline that occurs within an embayment and is significantly protected from most wind directions. Consequently, the protected marsh shoreline displayed long-term accretion with an average rate of +0.6 ft/yr as the marsh grew out over sand deposited within the embayment.

8.2.G. Duck Field Research Facility (Figures 8-2-18, 8-2-19, and 8-2-20)

The Duck Site is located north of Duck Village in Dare County (Fig. 8-1-1). It occurs west of N.C.Highway 12 on the Currituck Sound side of the entrance gate to the U.S. Army Corps of Engineer's Field Research Facility (USACE-FRF). Currituck Sound is narrow and shallow estuarine system that contains low-brackish to fresh water. The USACE-FRF is on a very narrow barrier island segment, however, there is a significant sand volume in a major dune field situated between the highway and ocean. The ocean shoreline is anomalously stable within this coastal segment. Consequently, overwash has not been a dominant process along this portion of the barrier during recent times.

The shoreline is oriented northwest-southeast and occurs along the back side of the dune field that is stabilized by a major shrub/scrub zone west of the highway. At the western edge of the shrub/scrub zone is a low sediment bank up to 3 to 5 feet high that is occupied during high water storm tides. Erosion along this scarp produces abundant sand that generally fills much of this scarp with a major strandplain beach. Today, the strandplain beach contains a dense fringing marsh consisting primarily of *Phragmites australis* with varying amounts of *Juncus roemerianus* and *Spartina patens*. Wherever *Juncus* becomes established, a fringing peat begins to form that binds the sand and helps hold the outer marsh. In addition, abundant submerged aquatic vegetation (SAV) grows on the submerged portions of the strandplain beach where the SAVs help to buffer wave energy and the fine roots tend to help bind the sand.

The 1998 Digital Orthophoto Quarter Quardrangle shows the location of digitized estuarine shorelines for 1986, 1992, and 1998. The low sediment bank at this site had a net average shoreline recession rate of –0.7 ft/yr, while the outer marsh/strandplain beach had a net average recession rate of –0.3 (Table 8-2-1). The 1998 aerial photo displays a wide and continuous fringing marsh stabilizing the strandplain beach on the estuarine side of the

Figure. 8-2-18. photos of the site

Figure. 8-2-19. 1998 DOQQ with old shorelines

Figure. 8-2-20. Aerial photo time slices (1986, 1992, 1998)

shrub/scrub zone. However, preliminary data suggest alternating periods of erosion and accretion. For example, significant shoreline erosion occurred between 1986 and 1992 (Ave. = -6.3 ft/yr) with specific locations having average rates that range from +8.4 to –4.5 ft/yr. The 1992 aerial photo demonstrates an eroding shoreline that intersects the low sediment bank covered with dense shrub/scrub. From 1992 to 1998, major sand accretion and shoreline growth occurred (Ave. = +5.7 ft/yr) with specific locations having
average rates ranging from +15.5 to –23.5 ft/yr. A more detailed inspection of annual aerial photographs taken at this site by the USACE-FRF suggest that within the time frames presented in this study, there are smaller scale alternations in erosion and accretion.

To understand the dynamics at this site, it is imperative to understand the specific site history. A major effort was undertaken between 1973 and 1979 to abate a serious erosion problem by the USACE, the U.S. Soil Conservation Service, and researchers at N.C. State University (Birkemeier, et al., 1985). These projects involved extensive planting of many different marsh grasses during different seasons and areas with periodic monitor surveys. During the 1973-79 USACE study period the erosion rate of the 3 to 5 foot high sediment bank was about -5 ft/yr (Birkemeier, et al., 1985). The plantings were carried out on the south side of the access road with an unplanted control area to the north. According to Birkemeier (pers. com.) since 1979, numerous grass planting workshops on the estuarine shoreline, have been held at the Field Research Facility.

The Duck site is an excellent example of the role of dense fringing marsh in the short-term stabilization of a low sediment bank and associated strandplain beach. In most situations, the fringing marsh minimizes, but does not eliminate erosion of the associated low sediment bank shoreline. The fringing marsh comes and goes in a complex pattern depending upon the storm activity and human plantings. This site demonstrates the importance of understanding human events as well as the natural processes associated with any given shoreline, rather than just considering the net rate of change in the fringing marsh of –0.3 ft/yr recession between 1983 and 2001.

8.3. MAINLAND ALBEMARLE—PAMLICO SOUND SITES

8.3.A. Summary: Mainland Albemarle-Pamlico Shorelines

The sites selected to determine the shoreline erosion rates for the mainland Albemarle-Pamlic sound estuarine area represent all major shoreline types, but generally with extremely large fetches. The sites are located on Figure 8-1-1 and occur in the outermost portion of the Pamlico River estuary, Pamlico Sound, Albemarle Sound, and along the Alligator River. All of these sites are generally unmodified except for the north end of Roanoke Island. At this latter site, a small unmodified bluff segment, located between highly modified sediment bank shorelines, was selected for the study site.

All sites, except the northern end of Roanoke Island, are characterized by extremely low elevations characteristic of the mainland peninsulas. The mainland peninsulas slope gradually seaward, finally intersecting sea level at the coast and giving rise to the name “down-east lowlands”. The underlying mineral soil forms the framework of these lands and was formed primarily during previous glacial and interglacial periods of the Pleistocene. The modern swampforest and marsh systems produced peat that fills the topographic lows and caps the Pleistocene sediment surface. These peat deposits have formed in response to ongoing conditions of sea-level rise during the 10,000 years of the Holocene epoch. The anomalous bluffs and high banks on the north end of Roanoke Island also obtained their high elevation and sand-rich deposits as products of the present Holocene interglacial events, in a similar fashion to other elevated features such as sand ridges on Currituck Peninsula, Colington Island, Nags Head, Kitty Hawk, and Buxton Woods. The erosion rate data for the outer estuarine shoreline sites are summarized in Table 8-3-1. These are the sites where the lowland meets the rising sea level and angry waves of large drowned water bodies. Consequently, the erosion rates are high and land loss is great.

TABLE 8-3-1. Summation of the short-term estuarine shoreline erosion rates for the mainland Albemarle-Pamlico sound estuarine sites based upon the present study. See Figure 8-1-1 for locations of study sites.

SITE	**SHORELINE TYPE**	**TIME PERIOD (years)**	**DISTANCE ANALYZED (feet)**	**AVE. LONG-TERM EROSION RATE NET (ft/yr)**	**RANGE (ft/yr)**
RIGGS DATA—PRESENT STUDY					
8. NORTH ROANOKE ISLAND-EASTERN ALBEMARLE SOUND:					
	Sediment Bluff-NET	**1969-1998**	**900**	**- 5.8**	**-3.9 to – 7.1**

Sediment Bluff	1969-1975	1,380	-22.4	-17.5 to –26.3
Sediment Bluff	1975-1998	900	- 1.8	- 0.8 to – 3.3
Modified Bluff	1980-2003	480	0.0	0.0 to 0.0
9. WOODARD’S MARINA-MIDDLE ALBEMARLE SOUND:				
Swamp Forest	**1963-1998**	**860**	**- 2.4**	**- 1.5 to – 3.9**
10 GRAPEVINE LANDING-SOUTHERN ALLIGATOR RIVER:				
Swamp Forest	**1981-1998**	**2,000**	**- 1.9**	**- 0.7 to – 5.8**
North of Canal	1981-1998	460	- 1.4	
South of Canal	1981-1998	1,540	- 2.2	
11 POINT PETER ROAD-NORTHERN PAMLICO SOUND:				
Marsh Platform	**1969-1998**	**1,250**	**- 7.5**	**- 7.1 to – 8.3**
12 NORTH BLUFF POINT-SOUTHERN PAMLICO SOUND:				
Marsh Platform—NET	**1983-2000**	**6,520**	**- 5.7**	**- 1.1 to –11.5**
SW of Canal	1983-2000	4,970	- 6.9	- 3.6 to –11.5
NE of Canal	1983-2000	1,550	- 2.2	- 1.1 to – 3.8
13 SWAN QUARTER MARSH PLATFORM—SOUTHERN PAMLICO SOUND:				
Open—S Swan Quarter Is.	**1956-1998**	**15,000**	**- 2.9**	**0.0 to –10.9**
Embayed—N Swan Quarter Is. & E Judith Is.	1956-1998	100,620	- 1.2	0.0 to – 6.4
14 LOWLAND-OUTER PAMLICO RIVER:				
Low Sediment Bank	**1964-1998**	**9,846**	**- 4.0**	**- 0.8 to – 8.1**
Low Sediment Bank Coves		4,923	- 4.9	
Marsh Headlands		4,923	- 1.7	

8.3.B. North Roanoke Island
(Figures 8-3-1, 8-3-2, 8-3-3, and 8-3-4)

Dolan and Bosserman (1972) and Dolan and Lins (1986) studied historic rates of shoreline recession at 17 locations along the north end of Roanoke Island (Fig. 8-3-1). They used aerial photographs (1943, 1963, and 1970) along with estimates of shoreline location obtained off maps from 1851 and 1903. Table 8-3-2 and Figure 8-3-1A show the shoreline data of Dolan and others, as well as the shoreline types of Riggs, fetch determinations for each shoreline segment, and present status of shoreline hardening.

The shoreline along segments 5 and 6 is a 20 to 30 foot high bluff composed almost totally of clean sand with mixed upland hardwood and pine forest cover on top of the bluff. Due to the sand composition, this shoreline has always been sand rich and characterized by a strandplain beach littered with trees and shrub debris from collapsing slump blocks.

TABLE 8-3-2. Generalized shoreline characteristics along the north side of Roanoke Island as of 2001. The shoreline segments, types, modifications, and fetch are from Riggs (this report) and are summarized on Figures 8-3-1A and 1B. The station numbers and average erosion rate for 1851-1970 are from Dolan and Bosserman (1972), Dolan and Lins (1986), and their unpublished reports in the Cape Hatteras National Seashore files.

RIGGS SHORELINE SEGMENT	DOLAN STATION NUMBER	SHORELINE TYPE	SHORELINE MODIFICATION AS OF 2001	FETCH IN MILES	DOLAN AVE EROSION RATE 1851-1970 FT/YR
1	1	Low Sed Bank	Extensive Strandplain Beach	3	-1
2	2	Marsh Peat	Minor Strandplain Beach	5	-2
3	3	Low Sed Bank	Rock Bulkhead/Jetties	25	-5
3	4	Low Sed Bank	Wood Bulkheads	25	-4
3	5	Low Sed Bank	Wood Bulkheads	25	-4
4	6	High Sed Bank	Strandplain Beach/Trees	35	-6
5	7	Bluff	Rock Bulkhead	30	-8
5	8	Bluff	Rock Bulkhead	30	-9
6	9	Bluff	Strandplain Beach/Trees	20	-3
6	10	Bluff	Strandplain Beach/Trees	20	-3
7	11	Bluff	Wood Groins/Strandplain Bch	5	-3

8	12	High Sed Bank	Rock Bulkhead	5	-3
9	13	High Sed Bank	Wood Groins/Breakwaters	4	-4
10	14	Low Sed Bank	Mixed Modifications	3	-4
10	15	Low Sed Bank	Mixed Modifications	3	-4
11	16	Marsh Peat	Major Sand Aprons	3	-3
11	17	Marsh Peat	Major Sand Aprons	3	-4
12		Sand Spit/Marsh	Local Peat Headlands	3	

During normal fair-weather conditions, the water level and wave action is located well down on the strandplain beach. At this time the bluff is not being eroded by wave action, but it does erode slowly in response to wind activity, ground-water seepage, and gravity. However, the major periods of erosion occur during high storm tides, when water level rises above the strandplain beach allowing wave energy to directly impact the bluff. Undercutting the lower portion of the bluff leads to instability of the steep and often overhanging upper portion that contains trees. Overhanging trees are heavy and are generally being severely blown by strong winds with rain saturating the sands. Eventually large unstable sections of bluff, slump onto the strandplain beach to be directly eroded by wave action. As slump blocks are reworked with time, new sand is added to the beach with the larger vegetation developing natural groins that aid in trapping and holding the strandplain beach.

FIGURE 8-3-1. North end of Roanoke Island--Dolan

Figure 8-3-2. Site photos

Figure 8-3-3. 1998 DOQQ with shoreline locations

Figure 8-3-4. Time slice aerial photo series: 1969, 1975, 1998, The 1969 and 1994 aerial photos demonstrate the significant shoreline recession for this area through time. Notice the generally smooth shoreline on the 1969 photo in which old U.S. Highway 64 forms a mini-headland as road debris collapses onto the beach. Data from Table 8-3-1 suggest that from 1969-1975, this shoreline was receding at an average rate of -22.4 ft/yr. Dolan et al. estimated their highest shoreline erosion rates of -8 to -9 ft/yr for the shoreline in front of old U.S. Highway 64 and Dough Cemetery (stations 7 and 8 of Dolan and segment 5 of this report) (Fig. 8-3-1A). In response, the National Park Service hardened all of segment 5. The 1994 and 1998 photos display a much broader headland forming in response to the heavy rock revetment emplaced in front of old U.S. Highway 64 and the Dough Cemetery to the east. The natural bluff shoreline of segment 6, east of the Dough Cemetery, continued to recede.

In the 1969 photo, notice the extensive sand spit in front of the main shoreline along the northeast portion of Roanoke Island. The sand to build Crab-Claw Spit came from erosion of the northern shoreline and subsequent longshore transport in response to strong northwest winter winds. Notice that by 1994 Crab-Claw Spit has largely broken down and portions have migrated further to the southeast. This dramatic breakup and spit migration is a direct response to the loss of the sediment source that came with hardening most of the northern shorelines (Fig. 8-3-1A and Table 8-3-2).

The shoreline erosion data presented in Tables 8-3-1, 8-3-2 and Figures 8-3-1, 8-3-3 demonstrate several important relationships that can be summarized as follows.

1. Prior to 1970, the overall average rate of shoreline recession for the north end of Roanoke Island ranged from about -4 to -5 ft/yr.
2. Between island segments, the average shoreline recession data ranged from -1 to -22 ft/yr; actual erosion rates along any shoreline segment were directly related to shoreline type and fetch.
   A. Low sediment bank and marsh peat = erosion rates of -1 to -4 ft/yr.
   B. Bluff and high sediment bank = erosion rates of -4 to -22 ft/yr.
   C. Low fetch (3-5 mi) = erosion rates of -1 to -4 ft/yr.
   D. High fetch (20-35 mi) = erosion rates of -3 to -22 ft/yr.
3. Shoreline segments that have abundant sand available to build offshore sand bars, spits and lagoons, or broad strandplain beaches have minimum annual erosion rates and are even accretionary on a local and temporary basis.
   A. Shorelines in coastal segments 1 and 2 on the west (Fig. 8-3-A1) are eroding slightly, in spite of local protective structures. In addition to the low fetch, the -1 to -2 ft/yr rate is partly due to availability of large sand volumes that form an extensive strandplain beach with many shallow sand bars in near shore areas.
   B. The shorelines in coastal segments 11 and 12 on the east (Fig. 8-3-A1) are only slightly eroding today due to a large sand spit, back-spit lagoon, and marsh system. Thirty years ago the spit system was in front of and protected segment 11. However, the spit system has migrated SE in front of segment 12. This has exposed back-spit marsh peat in segment 11, which is now an eroding peat shoreline.
   C. Shoreline protection measures have been implemented, since the Dolan et al. studies, along the rapidly receding shoreline in segments 3, 5, and 7 through 10. These structures terminated production of “new” sand sediment that had previously been supplying “new” sand to beaches in segments 1-2 and 11-12 in response to northeast and northwest storms, respectively. Consequently, unprotected shorelines in segments 1 and 2

have begun to erode more severely. Also, the spit that protected segment 11 has increased its rate of migration to the SE and has begun to break up resulting in eroding peat headlands along the shoreline of segment 12. Segment 11 has now begun to erode the back-spit marsh peat and will begin to erode the adjacent sediment bank in the near future, followed by the segment 12 shoreline.

4. Prior to 1970, only a few segments of the shoreline were modified by shoreline protection structures. Since 1970, human modifications have hardened many remaining shoreline segments, significantly decreasing erosion rates along most of the north Roanoke Island shorelines.
   A. Today about 75% of the north end of Roanoke Island (Fig. 8-3-A1) has been armored with a combination of rock riprap, wooden bulkheads, groins, and breakwaters.
   B. Shoreline recession appears to have been temporarily stopped along most of these coastal segments. However, many wooden bulkheads and older groins are failing.
   C. None of the areas with bulkheaded or rock ripraped shorelines have sand beaches. Whereas, those areas with only groin fields have trapped sand and have major sand strandplain beaches.
5. The 1998 Digital Orthophoto Quarter Quadrangle shows the location of digitized estuarine shorelines for 1969, 1975, and 1998 from the present study with the following conclusions.
   A. From 1969 to 1998, segment 6 had an overall average rate of shoreline recession of –5.8 ft/yr (Table 8-3-1). This is a slightly slower rate than what Dolan et al. obtained for segment 5 during the period from 1851 to 1970.
   B. However, coastal segments 5 and 6 eroded at an average rate of –22.4 ft/yr from 1969-1975 (Table 8-3-1).
   C. Due to this large erosion rate and threat to the historic Dough Cemetery, a massive rock revetment was built by the National Park Service in segment 5 in 1980. Since 1980, no further shoreline recession of segment 5 has occurred.
   D. Segment 6 continued to erode since 1980, however at a much slower average rate of –1.8 ft/yr between 1975 to 1998. Erosion rates in segment 6 are highest immediately east of the stabilization at the Dough Cemetery (-3.3 ft/yr) and slowly decreases eastward to zero in segment 7, that contains a wooden groin field. These groins have trapped significant sand and produced a wide strandplain beach off the Elizabethan Gardens.
6. Long-term shoreline changes have been significant along the north Roanoke Island shoreline.
   A. Assume an average shoreline recession rate for nonhardened portions of the north shore to be 5 ft/yr and that this rate has been constant over the past 320 or so years since the Lost Colonists landed.
   B. Then the estimated net shoreline recession would be about 1600 feet or 0.3 miles. This would have resulted in the loss of about 388 acres off a 2 mile segment along the northern end of the island.

8.3.C. Woodard’s Marina Site (Figures 8-3-5, 8-3-6, and 8-3-7)

Woodard's Marina site is located about five miles northeast of Columbia in Tyrrell County (8-1-1). The site is on the southern shore of Albemarle Sound and occurs on the soundward side of a commercial fishing marina excavated within the upland between 1995 and 1998. Along the sound is a narrow wetland consisting of swampforest vegetation that increases in width in both the east and west directions from the marina. This site is a small and accessible swampforest shoreline characteristic of many miles of larger and inaccessible shoreline occurring along vast stretches of Albemarle Sound and its tributary estuaries.

This particular swampforest is a portion of floodplain associated with the small tributaries of an old stream system that is being drowned by rising sea level. The first- and second-order streams of this older drainage system are generally shore parallel and flow into larger third-order tributary streams that are generally shore perpendicular. These drainages are obvious on the associated figures containing aerial photographs of the region. The latter streams flowed north into the Roanoke River during the last glacial maximum and are now slowly being consumed by the ongoing rise in sea level associated with the present interglacial period (Fig. 6-2-1).

As depicted on Figure 8-3-7, rising sea level drowns the land and associated drainage systems causing the shoreline type to change through time. Shoreline erosion intersects uplands on the interstream divides producing low sediment bank shorelines. With continued erosion of the low sediment bank, the shoreline ultimately intersects the floodplain swampforest of the next first- or second-order stream further up the drainage system. Wherever the larger third- and fourth-order streams enter Albemarle Sound, a major cypress headland extends out into the Sound, as seen in the aerial photographs on both the right and left sides of the study site. Notice that the headlands get larger through time and extend further out into the Sound. This results from the differential erosion between low sediment banks, which have higher rates of shoreline recession compared to the more slowly eroding swampforest shorelines.

Swampforest shorelines are difficult to define due to the diffuse nature of the erosion process. Because it is a drowning process, there generally is a series of broad zones that occur from landward to soundward as follows.

A. ZONE 1: The inner-most zone is the floodplain swampforest that is now below sea level and therefore is continuously flooded with sound water. Swamp maple and gum trees within this zone become stressed and begin to die in response to a more permanent flooding state. In addition, there is a major growth of new wetland species, including reeds and marsh grasses, as this system transitions from an irregularly and temporarily flooded swampforest to a permanently flooded condition.

B. ZONE 2: The middle zone is usually defined as the shoreline. It is a highly variable zone that contains the dying and recently dead trees and generally contains a small sand berm, if sand is available in the shallow waters of the adjacent estuary. Most swamp maples are now dead and gum trees are dying. If cypress is present in the swampforest, it generally persists through the middle zone and is still viable well into the outer zone.

C. ZONE 3: The outer zone is the ghost forest that resembles the shambled remnants of a once great army, now lying defeated on the battlefield. Solitary, bare, broken, and steely gray tree trunks occur in all stages of collapse. Fallen and crumpled logs litter the sound floor like land mines. Ghostly and gnarled tree stumps are excavated by ongoing erosion processes exposing their complex root networks like spider webs that have trapped the invading army. Locally some live, but now stressed cypress trees extend well into the outer zone where they stand guard like old battle-worn soldiers frozen in time.

Woodard’s Marina site is characterized by these three zones. A well-developed sand berm separates the inner and outer zones and semi-isolates the waters within zone 1 from zone 3. The berm is a product of storms when it is an active and dynamic beach. A dense growth of *Spartina cynosuroides,* with some *Spartina patens,* forms a fringing marsh on much of the sand berm and extends

Figure 8-3-5. Site photos

Figure 8-3-6. 1998 DOQQ with shoreline locations

Figure 8-3-7. Time slice aerial photo series: 1956, 1978, 1989, 2000

back into the inner swampforest. The peat sediment that underlies this swampforest (zone 1) was formed within a riverine floodplain and is up to 5 feet thick. Underlying the peat is a tight, Pleistocene age clay. The peat bed extends beneath the shoreline (zone 2) and onto the floor of Albemarle Sound (zone 3) where this in situ peat forms a soft and spongy estuarine bottom. However, with time, the upper-most portion of peat is systematically eroded away by wave activity in the offshore areas.

The 1998 Digital Orthophoto Quarter Quadrangle shows the location of digitized estuarine shorelines for 1963 and 1998. The Woodard's Marina site has an average shoreline recession rate of –2.4 ft/yr (Table 8-3-1) with a range in erosion rates from –1.5 to –3.9 ft/yr.

8.3.D. Grapevine Landing Site (Figures 8-3-8 and 8-3-9)

Grapevine Landing is located within the Pocosin Lakes National Wildlife Refuge of the U.S. Fish and Wildlife Service. The site is situated on the southwestern shore of Alligator River in Tyrrell County. It is approximately 3 miles east of the Gum Neck community at the east end of Cahoon Road. The road and its adjacent canal intersect the shoreline in the apex of Grapevine Bay. Consequently, the shoreline at this site has two distinct regional orientations: a northeast-facing shoreline segment with a relatively large fetch and a southeast-facing segment with a relatively smaller fetch. The Alligator River is a fresh, black-water estuary due to the drainage from vast pocosin swampforests that fringe most of this drowned-river system.

Grapevine Landing is extremely complex and quite irregular on the local scale. It is first and foremost a swampforest-dominated shoreline. However, some sand is available on the bottom of nearshore regions within the Alligator River. Thus, strandplain beaches occur in many coves along the swampforest shoreline. Because this is generally a low energy system, the lower portions of some strandplain beaches are also covered with a dense fringing marsh of *Juncus effusus*, a freshwater species. Because of the energy levels, the *Juncus* actually forms thin sandy peats. The upper portions of strandplain beaches, formed by high water storm surges from northerly winds, are covered with a fringing marsh of *Spartina cynosuroides*, which often extend landward into the swampforest vegetation. When the storm beaches are being formed, high wave energy commonly strips off the lower zone of *Juncus* marsh, exposing the peaty sand substrate for *Spartina patens* recruitment.

Almost the entire Alligator River shoreline is composed of swampforest peat, which is all slowly eroding. This results in a very large sediment component of detrital organic matter everywhere around the shores. The organic detritus accumulates on top of the heavier quartz sand component of strandplain beaches. The upper organic layer dries out and becomes slightly indurated. The next wind tide brings in a new layer of quartz sand that buries the semi-indurated organic layer. As the high water subsides, the abundant and lighter organic detritus settles out of the water and is concentrated by the wave energy on the strandplain beach. This results in alternating deposits of sand and organic detritus that accumulate until a large storm erodes the entire strandplain beach and directly attacks the exposed swampforest shoreline. It is then that wave energy erodes the soft peat from around swampforest trees exposing the root masses. From the time the storm subsides until the next storm, depositional processes rebuild the strandplain beach that temporarily buries and protects the shoreline. However, the exposed trees are now stressed and ultimately either die or are blown over by subsequent storms leaving a trail of logs, stumps, and roots behind on the adjacent estuarine floor.

Figure 8-3-8. Oblique aerial photo and site photos

Figure 8-3-9. 1998 DOQQ with shoreline locations

The 1998 Digital Orthophoto Quarter Quadrangle shows the location of digitized estuarine shorelines for 1981 and 1998. During this period, the Grapevine Landing site had an average shoreline recession rate of –1.9 ft/yr with a range from –0.7 to –5.8 ft/yr (Table 8-3-1). This site has two distinct shoreline orientations with significantly different fetches that erode at slightly different rates. The northeast-facing shoreline, south of the canal, has a fetch of about 10 miles and erodes at an average rate of –2.2 ft/yr. Whereas, the southeast-facing shoreline, north of the canal, has a fetch of about 4 miles and erodes at an average rate of –1.4 ft/yr.

8.3.E. Point Peter Road Site (Figures 8-3-10, 8-3-11, and 8-3-12)

The Point Peter Road site is in the Alligator River Wildlife Refuge of the U.S. Fish and Wildlife Service. It is located on the western shore of northern Pamlico Sound about 4.25 miles north of Stumpy Point village in mainland Dare County. It occurs about 1.6 miles east of U.S. Highway 264 at the end of Point Peter Road, a seasonal road built on material dredged from the adjacent ditch.

The Dare-Hyde Peninsula is a vast flat, upland, pocosin swampforest with a narrow zone of marsh vegetation around the outer rim. This entire peninsula has been severely ditched and diked through centuries of drainage alteration and land modification. Since the outer-most rim of the peninsula is the lowest, modifications are generally limited to past construction of impoundments, drainage ditches, and road dams such as U.S. Highway 264 that passes near this site. The 1969 aerial photograph shows a major impoundment along the shoreline on the north side of Point Peter Road and associated ditch.

This low pocosin peninsula is being drowned by the present ongoing rise in sea level causing major shifts in vegetation zonation around the peninsula perimeter. Rising water levels drown the swampforest and systematically replace it with transition vegetation and coastal marsh grasses. The 1983 and 1998 aerial photos are both false color images taken in the winter months that differentiate photosynthesizing vegetation in the red colors (i.e., pines, bays, etc.) from inactive plants (i.e., deciduous trees and grasses) as yellow- and gray-green colors. Comparison of these two images 15 years apart, demonstrate a significant landward expansion of marsh at the expense of the pocosin swampforest, particularly up the drainage ditch beside Point Peter Road. As sea level continues to rise, the impact of modification structures will become increasingly important in determining the ultimate transition of vegetative zones.

Traveling east from U.S. Highway 264, Point Peter Road transects three prominent zones. First, is a vast fresh water pocosin swampforest that grades into a transition zone of low scrb-shrub vegetation and finally a fresh water marsh along the Pamlico Sound shore. These zones display strikingly different color patterns on the 1998 Digital Orthophoto Quarter Quadrangle. The outer zone is dominated by *Spartina patens* (salt-meadow grass) and *Baccharis* (cotton bush) with varying amounts of *Cladium* (sawgrass) and *Myrica* (wax myrtle) scattered throughout. Minor patches of *Phragmites australis* are beginning to appear. The sawgrass and wax myrtle grow primarily in fresh water marshes, but now find themselves extending all the way to the shoreline of a brackish water sound with most of the *Myrica* dead in the outermost zone. This suggests that the shoreline marsh is out of equilibrium with the adjacent estuarine system due to either rapid rates of erosion or hydrologic changes in fresh vs brackish water affecting the system. If the shoreline were in equilibrium, the

Figure 8-3-10. Site photos

Figure 8-3-11. 1998 DOQQ with shoreline locations

Figure 8-3-12. Time slice aerial photo series: 1969, 1983, 1998, 2000

outer marsh zone would evolve into a brackish-water marsh dominated by species such as *Juncus roemerianus*.

The overall shoreline is a north-south feature that contains a large-scale, smooth, cuspate geometry. However, on the smaller scale along the marsh edge, the shoreline is quite irregular and dominated by a series of narrow headlands and associated embayments with amplitudes up to 25 feet. The marsh headlands are slightly more erosion resistant due to the presence of *Myrica* stumps and root systems that temporarily stabilize the points. The marsh embayments drop off into 1 to 2 feet of water, whereas the headlands generally drop off into 2 to 3 feet of water.

Some small embayments contain strandplain beaches in front of the eroding peat bank. The beaches generally contain a thin (< 0.5 feet) basal layer of sand overlain by a thicker (0.5 to 2.0 feet) layer of lighter wood and other detrital organic matter derived from the erosion of the peat shoreline. At times this dark brown organic detritus beach becomes so thick and wide that it totally buries the eroding marsh shoreline, forming beautiful small-scale depositional and erosional structures including berms, channels, tidal deltas, collapsed scarps, etc.

Underlying the surface marsh is a pure Holocene peat substrate that ranges from 4 to 6 feet thick. The peat overlies a tight clay of late Pleistocene age. The erosional scarp along the shoreline is cut 1 to 3 feet into the peat causing the floor of the inner estuarine area to be composed of soft in situ peat. The peat floor continues soundward for several hundred yards, thinning to zero thickness in about 4 to 5 foot water depths where tight Pleistocene clay forms the estuarine floor.

The 1998 DOQQ shows the location of digitized estuarine shorelines for 1969 and 1998. During this period, the Point Peter site had an average rate of shoreline recession of –7.5 ft/yr (Table 8-3-1). Recession rates were laterally very uniform with recession rates ranging from only a low of –7.1 to a high of –8.3 ft/yr.

8.3.F. North Bluff Point Site (Figures 8-3-13, 8-3-14, and 8-3-15)

North Bluff Point occurs on the North Carolina Gull Rock Game Land property in Hyde County. It is located at the end of the Outfall Canal road and ditch draining Lake Mattamuskeet. The road turns off of U.S. Highway 264 at Holland and runs southeast about 6.7 miles to the shores of southern Pamlico Sound. The all-weather road is built on dredged material derived from the adjacent large canal and rises significantly above the surrounding land. Thus, the canal road itself is surrounded by shrub/scrub and upland forest. However, traveling southeast from U.S. Highway 264, the Outfall Canal road transects through an extensively ditched and drained agricultural area and freshwater pocosin swampforest. The outer 0.7 miles grades into a transition zone characterized by stressed and dead trees with transition zone vegetation and a broad marsh zone. Remnants of old freshwater impoundments along the west side of the road have severely modified the natural marsh zonation that can be seen along the east of the canal in the 1983, 1995, and 1998 aerial photographs.

The inner marsh zone is a low brackish-water system dominated by *Juncus roemerianus* with large patches of *Disticulus spicata* and variable amounts of *Spartina patens* and *Scirpus*. The outer marsh, along the Pamlico Sound shore, is an intermediate brackish-water system composed primarily of *Spartina alternaflora* and *Spartina patens* with minor *Juncus roemerianus*. A thick zone

Figure 8-3-13. Site photos

Figure 8-3-14. Time slice aerial photo series: 1983, 1995

Figure 8-3-15. 1998 DOQQ with shoreline locations

of *Spartina cynosuroides* occurs along the shoreline and growing on the berm created by the dredge spoils from the old impoundment ditch. Each of these zones display strikingly different color patterns on the aerial photos. Along the shoreline the Holocene peat is about 6 to 7 feet thick and occurs on top of a light gray-blue silty clay that can be seen at the road end where it is being eroded. This clay was dredged from the canal and used to build the elevated road bed in 1914 to drain Lake Mattamuskeet for agricultural development (Forrest, 1999). The shallow waters adjacent to the canal mouth are floored in soft, in situ peat that slopes gently offshore for several hundred yards to water depths of about 5 to 6 feet, where the underlying tight clay crops out and forms the estuarine floor. The peat bed thins gradually northwards towards the swampforest.

The eroding peat bank drops off into 2 to 4 feet of water littered with large eroded peat blocks. The peat banks are severely undercut below the tough zone containing a dense modern root mass. With undercutting, the enlarged overhanging peat blocks move with the waves and ultimately break off and fall to the estuarine floor. The extent of erosion between 1983 and 1995 is obvious in the aerial photographs by comparing the amount of land lost relative to the outermost ditch.

The 1998 Digital Orthophoto Quarter Quadrangle shows the location of digitized estuarine shorelines for 1983 and 2000. During this period, the average shoreline recession rate for the entire reach considered was –5.7 ft/yr with a range from a low of –1.1 to a high of –11.5 ft/yr. However, the marsh shoreline on the southwest side of the canal eroded at an average rate of –6.9 ft/yr while the northeast side eroded at an average rate of only -2.2 ft/yr (Table 8-3-1). It is not clear why these different rates occur.

8.3.G. Swan Quarter Site (Figure 8-3-16)

The Swan Quarter site occurs within the Swan Quarter National Wildlife Refuge of the U.S. Fish and Wildlife Service. The site is located in Hyde County and along the northern shore of southern Pamlico Sound at the confluence with the Pamlico River estuary. The portion of shoreline analyzed for this study includes Swan Quarter Island and East Judith Island occurring between Rose Bay on the west and Swan Quarter Bay on the east. Due to the vast size and limits concerning accessibility and control stations, this site was only analyzed via aerial photography utilizing the 1956 and 1998 end-member photographs.

The study area consists of two different platform marsh shoreline segments on Swan Quarter and East Judith Islands. The southern side of Swan Quarter Island is an open shoreline with a 20 to 25 mile fetch from the south and southeast across southern Pamlico Sound. The second segment of marsh shoreline includes the north shore of Swan Quarter Island and the outer perimeter of East Judith Island. This latter segment is a semiprotected platform marsh shoreline occurring along the shorelines of Swan Quarter and Rose bays with fetches that range from 0.5 to 5 miles. Analyzing these two segments provides important data concerning the role of fetch in shoreline erosion, as well as the many miles of semiprotected marsh that occur in coastal North Carolina.

The marsh islands within the Swan Quarter National Wildlife Refuge are world class platform marshes composed of an interior marsh dominated by *Juncus roemerianus*. A low berm occurs slightly inland of and parallels the shoreline and consists of transition zone vegetation including *Spartina cynosuroides*, *Iva* (marsh elder), and *Baccharis* (cotton bush). Soundward of the berm, the *Juncus* has largely been stripped off the peat surface and now consists

Figure 8-3-16. 1998 DOQQ with shoreline locations

primarily of a narrow zone of *Spartina patens*, which is capable of more rapid recruitment after storms than is the *Juncus*. The marsh is growing on a very thick bed of Holocene peat that forms the eroding banks around the island perimeters. This peat is up to 8 to 10 feet thick. Due to the high energy environment, water depths right up to the edge of the eroding peat banks are generally 2 to 6 feet deep and often up to 6 to 10 feet deep. Strandplain beaches occur locally within some coves, primarily on the southern shore of Swan Quarter Island where short-term erosion rates may decrease to 0 ft/yr.

The 1998 Digital Orthophoto Quarter Quadrangle shows the location of digitized estuarine shorelines for 1956 and 1998. During this time period, the open marsh shoreline receded at an average rate of –2.9 ft/yr with ranges from low rates of 0 ft/yr to high rates of –10.9 ft/yr (Table 8-3-1). In contrast, the semiprotected shorelines within Rose and Swan Quarter bays and associated embayments, receded at an average rate of –1.2 ft/yr with a range from 0 to –6.4 ft/yr.

8.3.H. Lowland Site (Figures 8-3-17, 8-3-18, and 8-3-19)

The Lowland site is located along the southern shore of the Pamlico River estuary on Goose Creek Island in Pamlico County. The site occurs at the north end of a 0.5-mile fair weather track through the swamp. The track occurs at a major west turn in the Fulford Point Road located 1.2 miles north of Lowland Road and 1.5 miles east of Goose Creek.

The geometry and erosion at this site is complex and controlled by the paleotopography of the Pleistocene clay surface. At the large-scale, the entire Oyster Creek drainage system incised into the underlying Pleistocene clay during the last sea level low stand. The subsequent rise in sea level systematically flooded up the drainage system to produce the marshes and resulting peat deposits. The initial drowning and first peat development took place in the Oyster Creek stream bottom and sequentially migrated upward and outward across the clay slopes through time. Today, all of the headwater and tributary creeks feeding the main stem of Oyster Creek, are surrounded by broad marshes that lap onto the adjoining clay uplands.

On a smaller scale, the upland Pleistocene clay surface is slightly undulating. The east-west oriented shoreline generally consists of low sediment banks with a platform marsh fringe that has been largely eroded away. The marsh is completely gone in the coves, which today are dominated by low sediment bank shorelines, with marsh persisting along the headlands. Within the coves, the 1 to 2.5 foot high low sediment bank scarp and associated land are composed of tight gray clay substrate that holds surface water. This results in poorly drained land that generally contains a mixed growth of shrub/scrub, pond pine, and hardwoods with abundant bay trees. As the clay surface declines in elevation, a marsh occurs with a thin layer of organic peat lapping onto the clay surface. The peat thickens to 3 to 4 feet into the drainages or soundward into the headlands as the clay surface topography declines.

Along the headlands, the outer portion of the marshes are dominated by *Juncus roemerianus,* with a narrow zone of *Spartina patens* around the outermost estuarine perimeter where *Juncus* has been stripped off by storms. Extensive growths of *Spartina cynosuroides* and *Phragmites australis,* along with variable amounts of the shrubs *Iva* and *Baccharis,* occur primarily on the wrack storm berm and landward into the inner portion of the marsh. The marsh grades landward into a freshwater swamp dominated by saw grass, pond pine, and

Figure 8-3-17. Site photos

Figure 8-3-18. 1998 DOQQ with shoreline locations

Figure 8-3-19. Time slice aerial photo series: 1964, 1970, 1983, 1995

abundant wax myrtle and bay shrubs. This habitat produces a fine-grained organic peat that is about 0.5-foot thick on top of the clay throughout the upland area.

Within the coves, erosion of the low sediment banks leave a trail of pine stumps standing in the shallow water on lone tap roots with a whorled mass of shallow surface roots radiating outward like a lace collar. Low sediment bank shorelines often have thin and local strandplain beaches that form on the clay surfaces. The clay surfaces slope down to about 2 to 3 feet below mean sea level and continue offshore for at least several hundred yards. Scattered across this flat clay surface in the offshore area is a thin and variable layer of sand with local sand bars. Frequently, a small storm berm composed of sand, occurs on top of the clay scarp and in front of the freshwater swamp on the landward side as previously described.

On the 1964 aerial photograph of the Lowland site the shoreline consisted entirely of marsh and was more regular and significantly further soundward than today. By 1970, the irregular erosion of marsh began to develop coves that intersected upland vegetation and formed the initial low sediment bank shorelines. The abundance and distribution of low sediment banks continued to expand since 1970. Today, the shoreline consists of a mixed low sediment bank with remnants of the former marsh platform.

The 1998 Digital Orthophoto Quarter Quadrangle shows the location of digitized estuarine shorelines for 1964 and 1998. During this period, the combined low sediment bank and marsh platform at the Lowland site eroded at an average rate of –4.0 ft/yr with a range from –0.8 to –8.1 ft/yr (Table 8-3-1). It appears that the marsh platform on the headlands is eroding at the average rate of –1.7 ft/yr while the low sediment banks within the coves are eroding at an average rate of –4.9 ft/yr. The rate of recession for a marsh platform with a significant fetch is quite low. However, this shoreline consisted of 100% marsh platform during the early portion of the study interval, while the latter portion was characterized by decreased amounts of marsh and increased low sediment banks. Consequently, the overall low recession number probably reflects a complexly mixed shoreline that is changing relative abundance of shoreline types through time.

8.4. PAMLICO RIVER SHORELINE EROSION SITES

8.4.A. Summary: Pamlico River Shorelines

At the time Hardaway (1980) determined the shoreline erosion rates for sites along the Pamlico River estuary, the efforts to stabilize the shoreline with hard structures were minimal. Only portions of Hickory Point and segments of the Pamlico shore at Wades Point were hardened. However, since the Hardaway study, six Pamlico River sites were largely developed and included major shoreline erosion protection procedures. These six sites include Bay Hills, Mauls Point, Camp Leach, Pamlico Marine Lab, Hickory Point, and the Pamlico side of Wades Point. Thus, the potential for obtaining high quality shoreline erosion data requires knowing when each structure was built or rebuilt, as well as knowing the specific history of which shoreline segments were eroded and structures rebuilt following specific high storm tides such as the 1996-1999 hurricanes. To carry out a study evaluating the response of stabilized shorelines during major storm events, requires good historical documentation and permit records, along with high quality post-storm aerial photographs. This type of information does not presently exist and such an effort was beyond the scope of the present study. Consequently, the six modified sites

are revisited in a general mode in the present study, while the unmodified sites are analyzed in more detail. Table 8-4-1 summarizes the long-term shoreline erosion data developed by the present study.

TABLE 8-4-1. Summation of the short-term estuarine shoreline erosion rates for the Pamlico River sites based upon the present study. See Figure 8-1-1 for site locations.

SITE **SHORELINE TYPE**	**PERIOD** **(years)**	**ANALYZED** **(feet)**	**RIGGS DATA--PRESENT STUDY** **NET (ft/yr)**	 **RANGE (ft/yr)**
15. WADES POINT-CONFLUENCE OF PUNGO AND PAMLICO RIVERS:				
Marsh– Platform NET	**1970-1998**	**5,105**	**-3.2**	**-0.8 to –7.0**
Marsh–Platform	1970-1984	5,275	-3.4	-0.9 to –7.0
Marsh–Platform	1984-1998	4,936	-2.9	-0.8 to –6.1

Low Sediment Bank—NET	**1970-1998**	**3,308**	**-4.1**	**-0.6 to –8.9**
Low Sediment Bank	1970-1984	3,407	-3.3	-1.2 to –6.1
Low Sediment Bank	1984-1998	3,208	-5.2	-0.6 to –8.9
Modified Low Bank—NET	**1970-1998**	**3,252**	**-0.6**	**+1.9 to –2.6**
Modified Low Bank	1970-1984	2,308	-0.3	+1.9 to –1.9
Modified Low Bank	1984-1998	4,196	-0.9	-0.6 to –2.6
16. HICKORY POINT-PAMLICO RIVER AND SOUTH CK:				
Marsh--Platform	**1970-1998**	**1,928**	**-3.6**	**-1.8 to –4.9**
Low Sediment Bank	**1970-1998**	**2,992**	**-4.3**	**-2.2 to –6.6**
Modified Low Bank-NET	**1970-1998**	**4,866**	**-1.4**	**0.0 to –6.6**
Modified Low Bank	1970-1984	4,866	-2.4	0.0 to –5.1
Modified Low Bank	1984-1998	4,866	-0.4	0.0 to –6.6
17. PAMLICO MARINE LAB-SOUTH CREEK:				
Low Sediment Bank-All	**1970-1989**	**1,430**	**-4.9**	**-3.3 to –6.3**
Low Sediment Bk-E Side	**1989-1998**	**570**	**-2.5**	**-0.6 to –3.4**
Modified Low Bk-W Side	1989-1998	860	Negligible	
Modified Low Bank-All	1998-2003	1,430	Negligible	
18. BAYVIEW-BATH CREEK AND INNER PAMLICO RIVER:				
High Sediment Bank	**1970-1998**	**930**	**-0.2**	**+0.8 to –1.0**
Low Sediment Bank	**1970-1998**	**1,050**	**-1.4**	**-0.7 to –2.4**
19. CAMP LEACH-INNER PAMLICO RIVER:				
Marsh—Platform	**1970-1998**	**315**	**-1.3**	**-0.9 to –2.0**
Marsh--Swampforest	**1970-~1986**	**2,255**	**-0.3**	**+2.1 to –0.8**
Modified Marsh	~1986-1998	2,255	Negligible	
Low Sediment Bank	**1970-~1986**	**1,940**	**-0.6**	**0.0 to –1.1**
Modified Low Bank	~1986-1998	1,940	Negligible	
20. MAULS POINT-BLOUNTS BAY AND INNER PAMLICO RIVER:				

Bluff	**1970-1984**	**803**	**-2.9**	**-0.6 to –3.1**
Modified Bluff	1984-1998	803	-0.2	+2.6 to –2.6
Modified Low Bank	1970-1998	344	+0.8	+1.2 to –0.4
Modified Bank-All	1998-2003	1,147	Negligible	
21. BAY HILLS-CHOCOWINITY BAY AND INNER PAMLICO RIVER:				
Bluff	**1970-1998**	**750**	**< -1.0**	
Modified Bluff	1970-1998	2,990	< -0.5	

8.4.B. Wades Point Site (Figures 8-4-1, 8-4-2, and 8-4-3)

Wades Point is the northwest point at the confluence of the Pungo and Pamlico river estuaries. It is located 1.4 miles east of Pamlico Beach in Beaufort County and at the southeast end of Pamlico Beach Road, a classic "going-to-sea" road. The site consists of two very different shorelines. The east-west trending shoreline is a low sediment bank along the north shore of the Pamlico River, that has been largely modified through the years. The northwest-southeast trending Pungo River shoreline remains totally undeveloped and dominantly a marsh with a small segment of low sediment bank.

The interior of the marsh is irregularly flooded and dominated by *Juncus roemerianus.* Locally, a thin sand and wrack berm parallels the shoreline with a narrow 10 to 20 foot wide fringe along the shoreline dominated by *Spartina patens*. The berm contains mixed patches of *Phragmites australis* and *Spartina cynosuroides* with scattered *Iva,* and *Baccharis* shrubs. The shoreline zone consists of *Juncus* peat in which the *Juncus* has been stripped off by wave activity and is rapidly recolonized by the *Spartina patens*. In addition, wave action tends to strip off upper plates of the peat producing a stair-step erosion pattern, as well as undercutting the modern root mass zone. The peat is underlain by a tight clay. The peat pinches out where the clay surface rises above mean sea level producing pine dominated islands in the marsh. Away from the pine islands, the clay surface drops below sea level and the peat thickens to 2 to 3 feet or more into these topographic lows.

Erosion of the marsh produces small-scale, irregular shorelines characterized by alternating headlands and embayments with 5 to 20 foot amplitudes. The marsh is generally characterized by a 1 to 3 foot high eroding scarp in approximately 2 feet of water and a tight clayey sand bottom in the nearshore area. The low sediment bank shorelines tend to be fairly straight, are composed of tight clayey sand, and rise up to two feet above mean sea level. Sand derived from the eroded sediment bank forms a 10 to 20 foot wide strandplain beach containing many pine stumps in front of the eroding sediment bank.

The 1998 Digital Orthophoto Quarter Quadrangle shows the location of digitized estuarine shorelines for 1970, 1984, and 1998. The aerial photographs demonstrate both the human and natural ecologic evolution of the Wades Point site through time. The Pamlico River shoreline is primarily a low sediment bank and is where all development and shoreline modifications have taken place. The 1970 aerial photograph displays a fairly straight, low sediment bank that was eroding uniformly at the average rate of –3.3 ft/yr except for a couple of small hardened segments that displayed almost negligible recession rates of –0.3 ft/yr (Table 8-4-1). Three additional segments of this shoreline were hardened sometime between 1970 and 1984, which essentially slowed the average erosion rate down to –0.9 ft/yr for the period between 1984 and 1998. However, the three small unprotected low sediment bank segments experienced increased rates of erosion from 1984 to 1998, receding at an average rate of –5.2 ft/yr. Today, these three eroding sites almost intersect the road.

The Pungo River shoreline from 1970 to 1984 was entirely marsh and eroded at an average rate of –3.4 ft/yr. By 1984, the receding shoreline intersected a pine upland resulting in a low sediment bank shoreline segment. From 1984 to 1998, the marsh eroded at an average rate of –2.9 ft/yr (Table 8-4-1) while the low sediment bank portion of shoreline receded at an average rate of –5.2 ft/yr. Notice that the higher portions of land along the shoreline, labeled low sediment bank in the 1998 photo, developed a fairly heavy growth of pine

Figure 8-4-1. Site Photographs

Figure 8-4-2. 1998 DOQQ with old shorelines

Figure 8-4-3. Aerial photo time slices: 1970, 1984, 1989, 2000 trees between 1970 and 1998. This is seen as dark gray on the 1970 aerial photo, dark green on the 1984, 1989, and 2000 aerials, and red color on the 1998 infrared aerial photograph. Notice that in 1970 the entire Pungo River shoreline consisted of marsh. However, during the Hardaway study (1980), the shoreline had receded enough to intersect the low sediment bank island, which still persists today. This demonstrates both shoreline recession and changing patterns of shoreline types through time.

8.4.C. Hickory Point and Pamlico Marine Lab Sites (Figures 8-4-4, 8-4-5, 8-4-6, and 8-4-7)

Hickory Point and the Pamlico Marine lab are on the narrow peninsula that extends east between the Pamlico River south shore and South Creek north shore in Beaufort County. Hickory Point is about 3 miles east of the N.C. Department of Transportation ferry terminal at Aurora. The Hickory Point site is at the end of N.C. Highway 306, whereas the Pamlico Marine Lab site is about 2.4 miles east of the ferry terminal down an access road south of N.C. Highway 306.

The Hickory Point peninsula used to be connected to Indian Island. They are part of the interstream divide between Pamlico River and South Creek. However, rising sea level and long-term shoreline erosion processes have systematically eroded the upland rsulting in a shallow, underwater ridge that extends from Hickory Point east to Indian Island. Today, both Indian Island and Hickory Point continue to slowly disappear due to the systematic erosion of their shorelines.

The Hickory Point site is divided into three shoreline segments. Both sides of the outer portion of the point, segment 2, consist of severely modified low sediment banks. To the west along the Pamlico River is segment 1, a natural low sediment bank, and to the west along South Creek is segment 3, an extensive platform marsh. The natural low sediment bank along segment 1 is characterized by a 2 to 3 foot high erosional scarp, abundant eroded stumps and roots occurring along the shoreline, and downed shrubs and logs on the shoreface. The bank is composed of a tight clayey sand substrate that continues onto the estuarine floor. A thin and narrow (5 to 20 feet wide) strandplain beach occurs along most of the shoreline. The low sediment banks within segment 2 are mostly modified with little to no strandplain beach. The segment 3 marsh consists dominantly of *Juncus roemerianus* with a fringe of *Spartina cynosuroides* and *Phragmites australis* forming an inner zone in front of the transition zone vegetation.

Development at Hickory Point began many decades ago and consisted initially of small, low-cost beach cottages. Shoreline protection measures consisted of cement debris, broken bricks, cinder blocks, and miscellaneous junk. Through time, storms repeatedly tore up these makeshift shoreline protection structures, as well as many of the small cottages. The size and value of replacement dwellings have increased through time, as well as an increased effort to protect the shoreline with wooden bulkheads, rock riprap revetments, and groins.

The 1998 Digital Orthophoto Quarter Quadrangle shows the location of digitized estuarine shorelines for 1970, 1984, and 1998. Between 1970 and 1998 the natural low sediment bank eroded at an average rate of -4.3 ft/yr with a range from –2.2 to –6.6 ft/yr (Table 8-4-1). The eastern and highly modified portion along both the Pamlico River and South Creek shorelines eroded during the same time period at an average rate of –1.4 ft/yr. However, between 1970 and 1984, the early efforts consisting of dumped rubble along the shoreline only

Figure 8-4-4. Site photos of Hickory Point

Figure 8-4-5. 1998 DOQQ with Hickory Point and Pamlico Marine Lab and their eroding shorelines

Figure 8-4-6. Time slice aerial photos for Hickory Point and Pamlico Marine Lab: 1970, 1984, 2000

Figure 8-4-7. Site photos of Pamlico Marine Lab slightly moderated the average erosion rates to –2.4 ft/yr. However, since 1984 many modification structures either have been rebuilt or upgraded along this shoreline with a significant decrease in the average erosion rate to –0.4 ft/yr. No significant difference occurred in the erosion rates between the north- and south-facing, modified low sediment bank shorelines. Segment 3, consisting of a marsh platform along western portion of South Creek, eroded at an average rate of –3.7 ft/yr between 1970 and 1998.

Pamlico Marine Lab is located on South Creek, about 1.2 miles west of the point at Hickory Point. The entire shoreline is a low sediment bank that ranges from 3 to 4 feet high with abundant tree stumps and root masses. The vertical bank is composed of a lower, very clayey sand overlain by an upper one foot of sandy soil. The erosion of this upper unit supplied sand for a strandplain beach that existed prior to shoreline modification. Due to high erosion rates, the shoreline was hardened with rock riprap starting in about 1989.

The 1998 Digital Orthophoto Quarter Quadrangle shows the location of digitized estuarine shorelines for 1970, 1984, and 1998. Prior to modification (from 1970 to 1989), the entire natural low sediment bank shoreline in front of Pamlico Marine Lab receded at an average rate of –4.9 ft/yr. During the period from 1989 to 1998, the stabilized western 860 feet showed negligible shoreline erosion. However, the nonhardened eastern 570 feet continued to recede at an average rate of –2.5 ft/yr. As a result of this erosion at the east end, a new section of rock riprap was added along that shoreline in 1999. There has been no further shoreline erosion along the modified shoreline, but the strandplain beach has disappeared.

8.4.D. Bayview Site (Figures 8-4-8 and 8-4-9)

The Bayview site is in Beaufort County along the eastern shore of outer Bath Creek near the confluence with the Pamlico River estuary. The site is east of Bath and south off of N.C. Highway 92 about 1.6 miles at the southwest end of Breezy Shore Road and northwest end of Bayview Road, respectively. At the end of the paved road, walk northwest through the woods to the shore and continue north past a marsh and low sediment bank to the high sediment bank shoreline.

According to Hardaway (1980) this shoreline is a mixed low and high sediment bank with the low bank in front of the high bank everywhere except in the northern segment. Here the low bank disappears and the high bank intersects the shoreline. The high bank rises about 10 to 15 feet above mean sea level with a hardwood forest on top. The high bank consists of a lower 7-foot thick unit of interbedded clean sands and thin tight clay laminae, overlain by a 5-foot thick unit of iron-stained sandy clay, and a 1 to 2 foot thick upper unit of sandy soil (Hardaway, 1980). The abundance of sand in the high banks results in a major strandplain beach littered with fallen trees and logs. The low bank rises 2 to 4 feet above mean sea level with a dense growth of shrubs and pine trees on top. It consists of 1 to 2 feet of dense clayey sand overlain by 1 to 2 feet of a sandy soil horizon. The shore is littered with shrubby debris, logs, and stumps.

The 1998 Digital Orthophoto Quarter Quadrangle shows the location of digitized 1970 and 1998 estuarine shorelines. The long-term average erosion rate developed by the present study for the low sediment bank is –1.4 ft/yr, and for the high sediment bank is –0.2 ft/yr. The low erosion rates are attributed to the semi-protected character of the site within the mouth of Bath Creek, resulting in a small southwest fetch. In addition, abundant tree and stump

Figure 8-4-8. Site photos of Bayview

Figure 8-4-9. 1998 DOQQ with Bayview and the 1970 and 1998 shorelines litter occurs on the strandplain beach and the nearshore area that tends to break down incoming wave energy.

8.4.E. Camp Leach Site (Figures 8-4-10 and 8-4-11)

Camp Leach is located in Beaufort County, along the northern shore of the inner Pamlico River and immediately east and across an unnamed creek from Goose Creek State Park. It is about 3.8 miles south along the Camp Leach Road from Midway Crossroads on U.S. Highway 264.

Throughout the time this site was occupied by Camp Leach, the shoreline consisted of a narrow marsh with abundant cypress trees in front of a natural low sediment bank. The remnant marsh occurring along much of the shoreline was quite irregular, about 3 to 15 feet wide, and composed of *Juncus roemerianus* growing on a peat substrate up to 2 feet thick. The presence of a marsh, associated peat, and cypress suggest that the stream valley occurring along the western boundary formerly flowed southeast and east in front of Camp Leach. A major section of marsh shoreline still exists across most of the stream mouth on the western side of the site.

The marsh pinched out landward onto the upland sandy surface of the forested low sediment bank. Within high-use areas of the camp, the marsh was largely gone and the low sediment bank and associated trees were exposed to the water with local strandplain beaches. The low sediment bank consists of 1 to 2 feet of sandy soil overlying a clayey sand substrate. The present housing development took place sometime between 1984 and 1995 after much of the marsh had been eroded away. With this development came extensive bulkheading. Whatever vegetation remained was cleared from the shoreline during shoreline modification. Strandplain beaches no longer exist in front of the bulkheads.

The 1998 Digital Orthophoto Quarter Quadrangle shows the location of digitized estuarine shorelines for 1970 and 1998. Notice that the 1970 purple shoreline is almost coincident with the red 1998 shoreline. Since development and bulkheading did not take place until sometime between 1984 and 1995, whatever shoreline was eroded during the time prior to bulkheading was gained back through the bulkheading process. The average erosion rate figures in Table 8-4-1 represent only the net change between 1970 and 1998. Consequently, the western marsh across the stream mouth has eroded at about –1.3 ft/yr between 1970 and 1998, while the middle segment shows no net change. The eastern low sediment bank/modified low sediment bank displays a –0.6 ft/yr net loss over the same time period. Prior to modification, the Camp Leach shoreline was characterized by minor rates of local shoreline erosion that were storm dependent. In response to a major storm in 1978, Hardaway (1980) obtained a
-2.3 ft/yr average erosion rate for this low sediment bank shoreline.

8.4.F. Mauls Point Site (Figures 8-4-12, 8-4-13, and 8-4-14)

Mauls Point is located in Beaufort County, along the south shore of the inner Pamlico River estuary. It is a southwest-northeast oriented bluff shoreline situated at the northeastern end of Blounts Bay and about 5.4 miles north of N.C. Highway 33 at Coxs Crossroads. This entire northwest-facing Blounts Bay shoreline consists of bluff sediment banks that are occasionally broken by small stream valleys. Within these valleys are narrow segments of low sediment banks and floodplain swampforests forming small cypress headlands. Two such cypress headlands occur at either end of the study site where the small

Figure 8-4-10. Site photos of Camp Leach

Figure 8-4-11. 1998 DOQQ with Camp Leach and the eroding shorelines floodplain lobes form low sediment bank shorelines. This low sediment bank on the southwestern side of the site has been bulkheaded with an older beach cottage located on the delta lobe. The northeastern stream valley generally runs parallel to the northeast-facing shore resulting in an extensive cypress fringe and headland located in front of the highly vegetated bluff to the southwest. In 1977, the cypress headlands consisted of very dense swampforest vegetation. However, by 1998 much of this swampforest had been either cleared or severely thinned.

The photographs show the bluff before development, as well as the severely modified shoreline during and after development. The 30 foot high bluff is a thick Pleistocene sequence of interbedded tight gray clay and crossbedded quartz sand with several zones of iron oxide pavements and accretions. The bluff base is undercut during high storm tides causing the unstable upper blocks to slump onto the beach. With time, the slump blocks are reworked by wave energy into strandplain beaches up to 25 feet wide. Abundant trees and shrubbery debris from the slump blocks end up on the beach and act as natural breakwaters and groins that trap and hold sand. Longshore currents transport some of the abundant sand supplies to the northeast producing a major sand berm that buries the outer cypress and pine and develops a major spit at the Point. Prior to development, the bluff top was characterized by mixed hardwood and pine forests.

A portion of the bluff between the two cypress headlands was initially bulldozed prior to the Hardaway study (1980) with no vegetation planted on the raw bank. Consequently, the bank severely eroded and gullied. Subsequently, the entire bluff within the site was bulldozed to produce a grassed ramp with double rock, wood, and steel bulkheads. The bulldozing processes put a lot of sediment into the near shore area with redevelopment of a major strandplain beach. However, this strandplain beach is slowly being lost due to stabilization of the bluff. Wherever the bulkheads temporarily fail, bank erosion results in deposition of small sediment lobes in front of the bulkhead.

The 1998 Digital Orthophoto Quarter Quadrangle shows the location of digitized estuarine shorelines for the period between 1970 and 1998. This site was a natural bluff shoreline for the period from 1970 to 1984 with an average rate of shoreline recession of –2.9 ft/yr (Table 8-4-1) and a range in erosion rates from –0.6 to –3.1 ft/yr. The period from 1984 to 1998 represented mixed conditions when the natural bluff was severely modified by bulldozing and bulkheading. This resulted in a slight net shoreline loss for this period of -0.2 ft/yr with an average range from –2.6 to +2.6 ft/yr (Table 8-4-1). Due to the amount of sediment bulldozed onto the bluff shoreline, the adjacent modified low sediment bank to the southwest displayed average accretion rates of +0.8 ft/yr.

8.4.G. Bay Hills Site (Figures 8-4-15, 8-4-16, and 8-4-17)

The Bay Hills site is located on the south shore of Chocowinity Bay at the western end of the inner Pamlico River estuary in Beaufort County. The site occurs one mile north of Old Blounts Creek Road at the end of Bay Hills Drive and River Hills Road. The area extends for about 2,440 feet to the west and 1300 feet to the east of Bay Hills Drive. About 2,990 feet of this shoreline is generally a bluff that has been extensively developed and modified by bulldozing and bulkheading. Whereas, 750 feet of bluff shoreline, located east of the developed bluff, remains in its natural condition. The 1970 aerial photograph shows a small stream dissecting the bluff and flowing into

Figure 8-4-12. Site photos of Mauls Point

Figure 8-4-13. 1998 DOQQ with Mauls Point and the eroding shorelines

Figure 8-4-14. Time slice aerial photos for Mauls Point: 1970, 1984, 2000

Chocowinity Bay west of Bay Hills Drive. Where this stream floodplain enters the bay, is a nice example of a cypress headland.

The natural bluff rises 25 to 30 feet above mean sea level with a very tight blue Pleistocene clay cropping out in the lower 15 feet of the bluff. The basal clay grades upward into a 5 to 10 foot thick unit of muddy fine sand and an upper 7 foot thick unit of iron-stained clayey sand and soil. The vegetative cover above the bluff is hardwood forest. The upper sandy portion of the natural bluff slumps onto the beach and is reworked by waves to produce a 20 to 30 foot wide strandplain beach littered with logs and stumps. The shoreline itself is eroded into the lower clay unit forming an erosional clay platform that continues riverward under the strandplain beach and onto the estuarine floor.

The entire shoreline within this portion of Chocowinity Bay was undeveloped in 1970. The developed portion of Bay Hills was initially bulldozed in 1975 to a 1:1 sloped ramp with a low sediment bank shoreline located in front of the bluff slope (Hardaway, 1980). The graded slope was vegetated, but seriously eroded until it was stabilized in 1978. The resulting low sediment bank was pushed riverward about 10 to 20 feet further than along the natural bluff shoreline. Today, most of this shoreline has been either bulkheaded or armored with rock riprap.

The 1998 Digital Orthophoto Quarter Quadrangle shows the location of digitized shorelines for 1970 and 1998. Comparison of these shorelines suggest that the amount of change is < 1.0 ft/yr. This low erosion rate occurs within the error associated with the analytical procedures. The larger error bar at this site results from analyzing photographs taken at different times of day and along different flight paths relative to the shadow created by the north-facing bluff, as well as the poor quality of the older aerial photographs. Consequently, the errors associated with georeferencing, digitizing, and measuring the individual photographs is greater than the erosion rate at this site. Long-term shoreline erosion is taking place along the natural bluff in direct response to major storm events, such as the series of hurricanes during the late 1990s. However, most structures along the modified shorelines were quickly rebuilt to their prestorm locations.

The overall low erosion rates at Bay Hills result from several major factors. First, the semiprotected character of the south shore of Chocowinity Bay results in fetches less than 4 miles in all directions. Second, the presence of a thick, tight clay bed along the bluff base protects the bluff from direct wave erosion by small storms. Third, through time the shoreline has eroded a shallow water, nearshore platform into the clay bed which breaks incoming wave energy, except during the high storm tides associated with major hurricanes. Fourth, the bluff consists a dense clay bed overlain by a sand bed. This geometry results in preliminary retreat of the upper sandy bluff creating a sloped surface that develops a significant vegetative cover. The lower bluff, composed of dense clay, tends to resist erosion and generally holds the overall bank in place.

Figure 8-4-15. Site photos of Bay Hills.

Figure 8-4-16. 1998 DOQQ of Bay Hills with the 1970 and 1998 shorelines

Figure 8-4-17. Time slice aerial photos for Bay Hills: 1938, 1970, 1984

9. CONCLUSIONS

9.1. SYNTHESIS OF ESTUARINE SHORELINE EROSION DATA

Tables 9-1-1, 9-1-2, and 9-1-3 summarize the range and mean shoreline erosion rates for each study site within the back-barrier island, mainland Albemarle—Pamlico sounds, and Pamlico River areas, respectively. It is clear that the processes of estuarine shoreline erosion are extremely variable from site to site with large ranges within most sites. The actual rates are dependent upon the numerous variables previously summarized in Chapters five and six. The site with the highest average rate of recession is the marsh platform at Point Peter Road with an average recession rate of –7.5 ft/yr in contrast to the lowest average recession rate of < -1.0 ft/yr along the bluff shoreline at Bay Hills. Locally, erosion rates varied from 0 ft/yr during periods of low storm activity to a high of -26.3 ft/yr along the sand bluffs at the north end of Roanoke Island and during periods of high storm activity.

TABLE 9-1-1. SUMMARY OF ESTUARINE SHORELINE EROSION DATA FROM THE BACK-BARRIER ISLAND STUDY SITES

STUDY SITES	EROSION RATES RANGE FT/YR	EROSION RATES MEAN FT/YR
1. BUXTON—MARSH 1962-74	- 3 to -19	- 8.7
MARSH 1962-98	+ 5 to -19	- 2.6
2. SEVEN SISTERS—LOW BANK	0 to - 8	- 5.2
3. JOCKEY'S RDG—LOW BANK	- 1 to - 8	- 3.5
SP BCH	+ 6 to - 2	+1.7
3. NAGS HEAD WDS—MARSH	0 to - 4	-1.7
EMBAYED MARSH	+ 1 to - 1	+0.6
4. HATTERAS—MARSH/SP BCH	0 to - 2	-0.5/+0.8
5. SALVO—MARSH	0 to - 2	- 0.9
6. DUCK FRF—LOW BK/MARSH	+15 to -23	-0.7/- 0.3

Several important patterns concerning average annual shoreline erosion rates for major shoreline types and estuarine regions are obvious from these data and are summarized in Tables 9-1-4 and 9-

1-5, respectively. Table 9-1-4 demonstrates the relationship between erosion rates and shoreline type. Mainland marsh (-3.4 ft/yr) and low sediment bank (-3.2 ft/yr) have the overall highest average rates of estuarine shoreline erosion. They are also the most abundant shoreline types, constituting 85% of the coastal system in northeastern North Carolina. Bluffs and high sediment banks are less abundant (8%) and generally erode more slowly (-2.4 ft/yr) compared to low sediment banks (-3.2 ft/yr). This is largely due to the higher volume of sand available from eroding bluffs and high banks to build large strandplain beaches, as well the availability of abundant wood debris and growth of fringing vegetation. Swamp forest shorelines are the least abundant (7%) and erode the slowest (-2.2 ft/yr) due to their lack of elevation and low bottom gradients in concert with the role of trees in abating wave energy.

TABLE 9-1-2. SUMMARY OF ESTUARINE SHORELINE EROSION DATA FROM THE MAINLAND ALBEMARLE—PAMLICO SOUND STUDY SITES

STUDY SITES	EROSION RATES RANGE FT/YR	MEAN FT/YR
1. POINT PETER RD—MARSH	-7 to - 8	-7.5
2. N ROANOKE ISLAND—BLUFF	-1 to -26	-5.8
3. N BLUFF POINT—MARSH	-1 to -12	-5.7
4. LOWLAND—LOW BK/MARSH	-1 to - 8	-4.9/-1.7
5. SWAN QUARTER—MARSH	-0 to -11	-2.9/-1.2
6. WOODARDS MAR—SWP FOR	-2 to - 4	-2.4

TABLE 9-1-3. SUMMARY OF ESTUARINE SHORELINE EROSION DATA FROM THE PAMLICO RIVER STUDY SITES

STUDY SITES	EROSION RATES RANGE FT/YR	EROSION RATES MEAN FT/YR
1. WADES POINT—MARSH/LOW BK	-1 to -9	-3.2/-4.1
2. HICKORY PT—MARSH/LOW BK	-2 to -7	-3.6/-4.3
3. PAMLICO MARINE —LOW BK	-1 to -6	-4.9/-2.5
4. BAYVIEW—HIGH BK/LOW BK	-1 to -2	-0.2/-1.4
5. CAMP LEACH—MARSH/LOW BK	-1 to -2	-1.3/-0.6
6. MAULS POINT—BLUFF	-1 to -3	-2.9
7. BAY HILLS—BLUFF	-1 to -2	< -1.0

Strandplain beaches, associated with all shoreline types, effectively absorb wave energy under normal storm conditions and generally tend to slow relative rates of shoreline recession. Also, shorelines with major strandplain beaches are the only shorelines that are either holding their own or locally accreting (Table 9-1-4). Strandplain beaches can form adjacent to any shoreline type if a source of “new sand” exists and if the adjacent water is not too deep. If strandplain beaches form and maintain themselves, they form critical substrates available for vegetative growth including formation of fringing marsh and cypress. Since development of strandplain beaches in front of scarped sediment- and organic-bank shorelines break wave energy and trap sand, strandplain beaches are important natural shoreline protection agents in most physical settings.

TABLE 9-1-4. EROSION RATES FOR DIFFERENT ESTUARINE SHORELINE TYPES, NE NORTH CAROLINA

SHORELINE TYPE (% OF SHORELINES*)	MAXIMUM RATE FT/YR	AVERAGE RATE FT/YR

SEDIMENT BANK	**(38%)**		
LOW BANK	**(30%)**	**- 8.9**	**- 3.2**
BLUFF/HIGH BANK	**(8%)**	**- 26.3**	**- 2.4**
STRANDPLAIN BEACH			
BACK BARRIER		**- 2.0**	**+ 1.2**
ORGANIC SHORELINE	**(62%)**		
MARSH			
MAINLAND	**(55%)**	**- 18.3**	**- 3.4**
BACK BARRIER		**- 19.0**	**- 1.2**
SWAMP FOREST	**(7%)**	**- 5.8**	**- 2.2**
OVERALL WEIGHTED AVERAGE			**- 3.2**
HUMAN MODIFIED	**(?)**	**- 6.6**	**- 0.3**

*** MAINLAND ESTUARINE SHORELINES ONLY**

Most shoreline modification is designed to stop shoreline recession and consists of some form of hardening or hardening in concert with vegetative plantings (Rogers and Skrabel, 2001). However, most shoreline modifications are short-term controls that only temporarily slow or stop shoreline erosion. Since terminating sediment bank erosion results in the loss of "new sediment" necessary for either building or maintaining a strandplain beach, the ultimate consequence is generally the total loss of strandplain beaches and their function. Also, most structures deteriorate with time and large storms take their toll resulting in a net long-term recession of most hardened shorelines (Table 9-1-4).

Table 9-1-5 summarizes the shoreline erosion rate data by region. These data demonstrate a clear and strong relationship between actual rates of recession and the physical setting, including the size of adjacent estuarine water body or fetch. The lowest average erosion rate occurs in the inner Pamlico River with an average of < –1 ft/yr. Within the Pamlico River there is a general increase in erosion rates from the innermost site (Bay Hills) to the outermost sites (Wades and Hickory Points) as indicated by the arrow on Table 9-1-3. These data are equally applicable to the small, inner portions of major drowned rivers, as well as small lateral tributaries. This includes the inner Neuse River and lateral tributaries such as the Broad and Clubfoot Creeks, Bath and Durham creeks adjacent to the Pamlico River, and Yeopim and Scuppernong rivers that flow into Albemarle Sound.

Erosion rates increase dramatically to an average of –3.8 ft/yr within the outer Pamlico River estuary and the mainland Pamlico—Albemarle Sound region (Table 9-1-5). Most of these sites have low elevations with extremely large fetches across vast expanses of estuarine water. If shorelines within this outer region are regular and openly exposed to the large estuarine bodies (i.e., the bluff at north Roanoke Island, swampforest at Woodard's Marina, or marsh platform at Point Peter Road), erosion rates tend to be very regular (Table 9-1-2). However, if extensive embayments and irregularities occur along the shoreline (i.e., the Swan Quarter marsh platform), erosion rates within the semiprotected areas are significantly less than those that are openly exposed (Table 9-1-2).

The back-barrier estuarine shorelines are generally adjacent to major water bodies with extremely large fetches. However, the average erosion rate of –1.3 ft/yr is significantly less than either the outer Pamlico River or the mainland Albemarle—Pamlico sound region, both with average erosion rates of –3.8 ft/yr (Table 9-1-5). The generally lower rates are attributable to the very shallow water character of the nearshore systems. The three southern sites are situated on the broad and shallow water feature known as the Hatteras Flats. The sites at Duck, Jockey's Ridge, and Seven Sisters dune fields are located within the very shallow waters of Currituck and Roanoke sounds, respectively. The Nags Head Woods site occurs behind the shallow waters of Colington and Buzzards Bay shoals that occur on the eastern end of Albemarle Sound. Thus, all of these sites tend to be semiprotected by the presence of broad, shallow-water systems occurring in front of them.

Overwash processes on low and narrow barrier-island segments and erosional processes of back-barrier dune fields on high and wide complex barrier segments normally feed critical sand to the back barrier coastal system. These sources of "new" sand are necessary to build and maintain overwash fans, marsh platforms, and associated strandplain beaches in front of eroding back-barrier shorelines. The resulting strandplain shorelines are shallow beaches that ramp up onto and protect the eroding scarp on the adjacent land and marsh. Also, strandplains commonly grow broad fringing marshes during low storm activity periods. These factors tend to minimize rates of shoreline recession as indicated by the low average back-barrier erosion rate (ave. = -1.3 ft/yr), while some sand-rich back-barrier shorelines actually have accretion rates that average +1.2 ft/yr (Table 9-1-4).

However, human activity on the barriers has critically impacted sand supplies to the back-barrier coastal system during the past decades. Dune-ridge building, urban growth, highway construction and maintenance have all lead to increased barrier island elevation and the expansive growth of upland vegetative. Vegetative stabilization and development of back-barrier dune fields on the complex barriers (i.e., Jockey's Ridge and Seven Sisters dune fields) have had a tremendous negative effect upon the adjacent estuarine shoreline systems. Additionally, increased rates of hardening back-barrier shorelines, along with dredging projects for sand and navigation in the immediate back-barrier system, have major impacts upon shoreline erosion processes and resulting recession rates. Thus, increased human activities through time have dramatically diminished major sand sources, resulting in either the total loss of or development of more ephemeral strandplain beaches. As the occurrence and size of strandplain beaches are diminished through time, erosion rates increase.

TABLE 9-1-5. SUMMARY OF ESTUARINE SHORELINE EROSION DATA IN NORTHEASTERN NORTH CAROLINA

ESTUARINE REGIONS	AVERAGE EROSION RATES FT/YR
1. INNER PAMLICO RIVER	- 1.0
2. OUTER PAMLICO RIVER	- 3.8
3. ALBEMARLE—PAMLICO SOUNDS	- 3.8
4. BACK-BARRIER—N OBX	- 1.3
5. NE NC ESTUARINE SYSTEM— WEIGHTED AVERAGE*	- 3.2

*INCLUDES ALL TYPES EXCEPT MODIFIED AND BACK-BARRIER SHORELINES

All the estuarine shorelines in northeastern North Carolina are eroding in response to the ongoing long-term rise in sea level. As indicated in Table 9-1-5, the weighted average for the recession of all shoreline types throughout the highly variable regional setting of coastal systems is –3.2 ft/yr. Erosion, largely driven by storm processes, results in the systematic loss of both uplands and wetlands through time. The approximate rate of land loss to estuarine shoreline erosion can be estimated from the data developed in this study (Tables 9-1-1 through 9-1-4).

Table 9-1-6 approximates the total amount of land lost to erosion at the sites studied in this report and during the time intervals analyzed for each site (Tables 8-2-1, 8-3-1, and 8-4-1). At the 21 sites studied, approximately 139 acres of upland and 226 acres of wetlands were lost during the time intervals analyzed. If the assumption is made that the average annual recession rates for each shoreline type are applicable to the entire 1,593 miles of estuarine shoreline mapped by Riggs et al. (1978), then approximately 629 acres of land are lost each year within the 1,593 miles.

TABLE 9-1-6. MEASURED AND ESTIMATED LAND LOSS DUE TO ESTUARINE SHORELINE EROSION IN NORTHEASTERN NORTH CAROLINA

1. TOTAL LAND LOST FOR 21 FIELD SITES MEASURED FOR THE TIME BETWEEN OLDEST AND NEWEST AERIAL PHOTOS USED AT EACH STUDY SITE = 365 ACRES (0.57 mi^2) INCLUDING 258 ACRES OF MARSH.

2. LAND LOST FOR 1,593 MILES OF MAPPED ESTUARINE SHORELINE (RIGGS ET AL., 1978) = 629 ACRES/YEAR OR ~1 mi^2/yr.

3. IF RIGGS ET AL. (1978) MAPPED ~50% OF MAINLAND ESTUARINE SHORELINES IN NE NC, THE TOTAL MAINLAND SHORELINE = ~3,186 MILES.

4. ASSUMING THE SAME PROPORTIONS OF SHORELINE TYPES AND SAME EROSION RATES OF THIS STUDY, THE ANNUAL LAND LOSS = ~1,258 acres/yr OR ~2 mi^2/yr.

5. IF WETLANDS = 62% OF THE ESTUARINE SHORELINES, THE ANNUAL WETLAND LOSS = ~780 acres/yr OR ~1.2 mi^2/yr.

6. TOTAL LAND LOSS FOR THE 25-YEAR PERIOD BETWEEN 1975-2000 = ~49 mi^2.

7. TOTAL WETLAND LOSS FOR THE 25-YEAR PERIOD BETWEEN 1975-2000 = ~30 mi^2.

However, Riggs et al. only mapped about 50% of the estuarine shoreline in northeastern North Carolina. If it is assumed that the remaining 50% of unmapped shoreline has the same relative distribution of shoreline types defined by Riggs et al., the total annual shoreline loss for northeastern North Carolina can be estimated (Table 8-5-6). This results in a loss of about 478 acres of uplands per year and about 780 acres of wetlands per year. Spread over a year within the tremendous size of the North Carolina coastal system, these amounts would probably not be noticeable. However, the cumulative effects of this loss rate through time represents an inevitable and significant change to both North Carolina’s coastal system and individual property owners.

We do not advocate trying to stop the ongoing and natural process of drowning the North Carolina coastal system—-after all, change is the only constant within our coastal system. However, we do advocate learning to live with the evolutionary processes by changing the way shorelines are utilized. And most importantly, the natural and ongoing upward and landward migration of wetlands in response to slowly rising sea level, must not be hindered. The continued modification of wetlands with drainage networks, highway road dams, and bulkheads, will lead to a one-way net loss of wetlands. However, if the natural migration processes are recognized and honored with continued rise in sea level, the net expansion of new wetlands along the inner zone should equal the loss of wetlands on the outer shoreline zone. Wetland habitats of the North Carolina coastal system must be allowed to expand into the future or there will be ever decreasing amounts of this critical coastal habitat.

9.2. LIVING WITH ESTUARINE SHORELINE EROSION

North Carolina's estuaries represent a geologically young and dynamic portion of the coastal system. As the last great Pleistocene ice sheet began to melt in response to global climate warming, the present coastal system began to develop. As the glaciers melted and receded, the melt waters raised the ocean level. This rising sea level caused the coastal system to migrate across the continental shelf, flooding over the land and up the topographically low river valleys to form our present estuarine system. After 10,000 years, 425 feet of sea-level rise, and a lateral migration of 15 to 60 miles westward, the North Carolina coast began to develop a familiar look.

The glaciers are still melting today, sea level continues to rise, and the ocean slowly, but relentlessly continues to flood the coastal lands of North Carolina. This results in the continuing upward and landward migration of the shoreline. The process of shoreline migration is better known as **SHORELINE EROSION**. The fact that sea level is rising worldwide means that erosion is ubiquitous to all of North Carolina's thousands of miles of shoreline. The only differences between shorelines are the rates of erosion which are dependent upon specific shoreline variables and varying storm conditions. Locally, a shoreline may appear stable or actually accrete sediments. However, such a situation is anomalous and is usually ephemeral in nature.

Because change is a constant within dynamic coastal zones, natural and human-induced hazards to normal styles of development abound in the coastal region. For those who live and work in the coastal zone there is an extremely high level of property loss that results from flooding, shoreline erosion, and other storm induced factors. The burgeoning population and exploding development demands stability that results in negative impacts upon the coast and a cumulative toll on the health of the entire natural system. The dynamic character of the coastal resources make this an earth habitat that truly does have "limits to growth".

Another serious effect of rapid population growth and development rates is habitat modification within our coastal system. Some of the greatest population growth rates in North Carolina occur within the coastal counties leading to unprecedented urban explosion within the coastal zone. New four-lane roads and bridges are being constructed at unparalleled rates, new water supplies are being developed, and pressures are increasing upon severely overloaded sewage disposal systems. This growth is intimately intertwined with a booming tourist industry causing major cumulative wetland losses and habitat modifications.

Maritime forests are cleared, shorelines are bulkheaded, shallow-waters are dredged, wetlands are channelized, dune fields are bulldozed, and the surface is paved for parking lots. All of these activities modify the land surface, alter the drainage, and result in increased contaminants moving into the adjacent coastal waters.

The coastal system is not fragile! It is a high-energy dependent system that is characterized by environmental extremes and reliant upon storm events to maintain the overall health of the natural system. Rather, it is the fixed human superstructure superimposed upon this dynamic system that is fragile. The fact is that there is no guaranteed permanency to any characteristic or feature within the North Carolina coastal system. Early settlers of the coastal system understood this! However, modern society has forgotten these environmental constraints in the headlong rush to transpose “Raleigh-style” developments and living to this dynamic and changeable coastal system!