SHORELINE EROSION AND ITS RELATIONSHIP TO THE GEOLOGY OF THE PAMLICO RIVER ESTUARY

by

C. Scott Hardaway

APPROVED BY:

COMMITTEE

Stanley R. Riggs

Dr. Stanley R. Riggs, Supervising Professor

C. Q. Brown

Dr. Charles Q. Brown

Scott W. Snyder

Dr. Scott W. Snyder

Vincent J. Bellis

Dr. Vincent J. Bellis

DIRECTOR OF GRADUATE STUDIES, DEPARTMENT OF GEOLOGY

Scott W. Snyder

Dr. Scott W. Snyder

CHAIRMAN OF THE DEPARTMENT OF GEOLOGY

C. Q. Brown

Dr. Charles Q. Brown

DEAN OF THE GRADUATE SCHOOL

Joseph H. Boyette

Dr. Joseph G. Boyette

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C. Scott Hardaway

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ABSTRACT

The Pamlico River Estuary is located in the northeastern coastal plain of North Carolina and it is responding to the present, slow but steady worldwide rise in sea level (25 cm /100 yrs). This response includes flooding of the trunk estuary as well as its lateral tributaries. The shorelines which are being impounded by this transgressing estuarine system are slowly receding and this often involves active erosion. Three basic shoreline types are recognized in the Pamlico River Estuary. These are sediment banks, marsh and swamp forests. They respond differently to coastal processes and thus erode at different rates.

Sediment banks and marsh shorelines were the subject of study for the pruposes of gaining insight into the process of estuarine shoreline erosion. The sediment bank shorelines may be subdivided into three subtypes according to height above mean river level: a) low bank (0.5 to 2.0 m), b) high bank (2.0 to 6.0 m), and c) bluff (greater than 6.0 m). High bank and bluff shorelines are found in the inner and middle estuary regions and are low to moderately susceptible to erosion. Low bank shorelines occur throughout the estuary and are low to highly susceptible to erosion. Marsh shorelines occur as narrow fringes bordering sediment banks in the inner and middle estuary. In the lowlying outer estuary, marsh shorelines are the river's edge of extensive marsh plains. Exposure to the relatively "open" waters of the Pamlico Sound results in high rates of erosion for the marsh plains shorelines.

A C K N O W L E D G E M E N T S

I would like to thank the members of my thesis committee and especially Dr. Stanley R. Riggs whose patience and encouragement resulted in the completion of this paper. I would also like to thank my collegues in the Departments of Biology and Geology for their help during the field phase of this project with special thanks to Don Lewis and Mr. "E" Holzworth. I would like to extend my appreciation to Christie Hodgin for the fine landscape drawings and to Carolyn Sharpe for typing and helping to finalize this thesis. And finally, to my friends and acquaintances in and around the town of Greenville, N.C. who helped make my time there a somewhat character building experience.

TABLE OF CONTENTS

Page

LIST OF ILLUSTRATIONS

Figure		Page

LIST OF TABLES

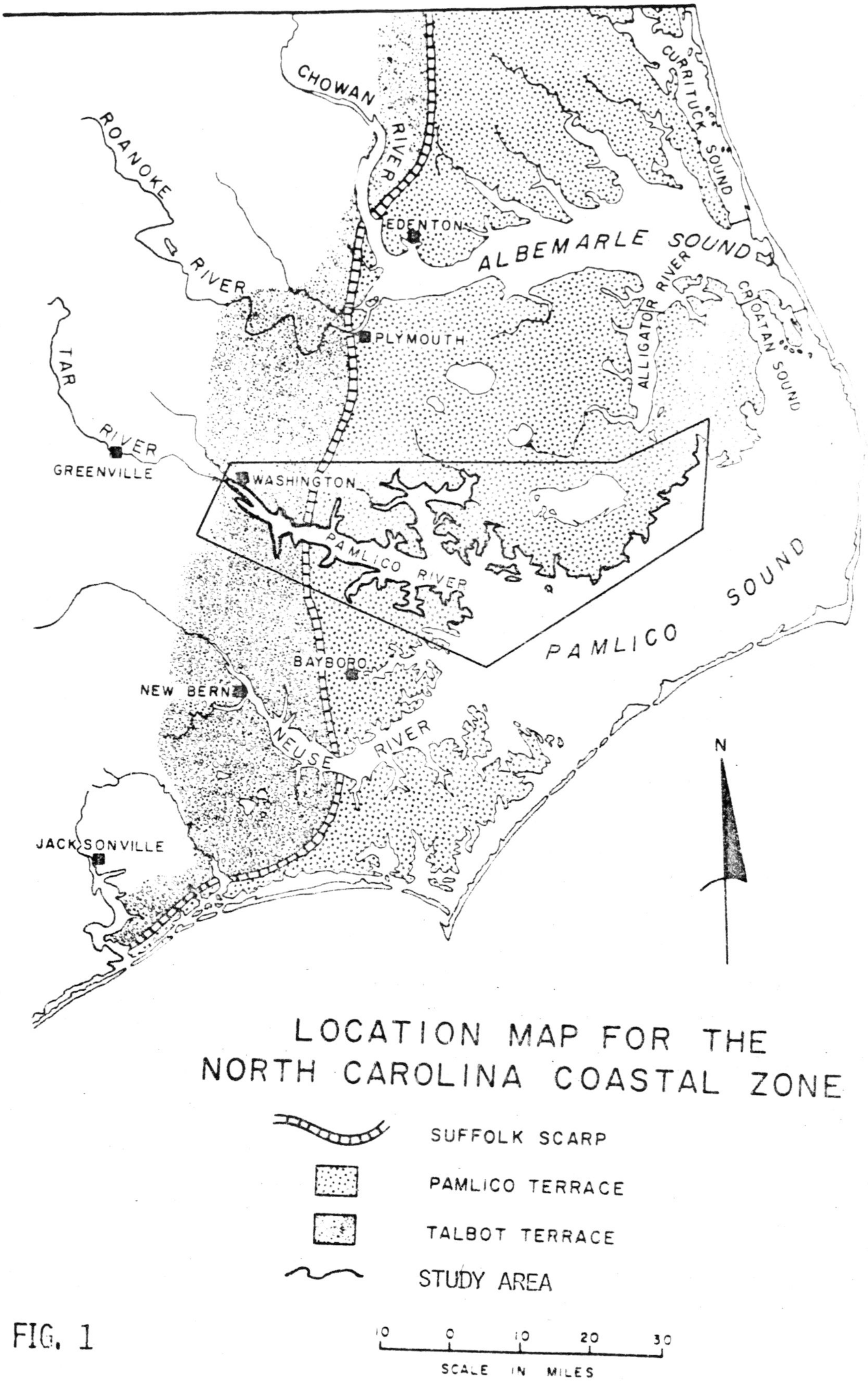
INTRODUCTION

The Pamlico River Estuary is located in the northeastern coastal plain of North Carolina. It is the downstream extension of the Tar River. The combined drainages of the Tar-Pamlico system cover more than 8,000 square kilometers. The lateral tributaries of the Pamlico River Estuary are confined to the North Carolina Coastal Plain (Fig. 1).

There are over 8,000 kilometers of estuarine shoreline in North Carolina, the shoreline being the zone of interaction between estuarine waters and the surrounding land. Three basic shoreline types are recognized in the Pamlico River Estuary: 1) sediment bank, 2) marsh, and 3) swamp forest. They respond differently to coastal erosion processes and thus erode at different rates. Ten monitor stations were established along the Pamlico River Estuary for the purpose of studying the processes and rates of shoreline erosion. The stations were chosen to represent the major variables affecting shoreline erosion of the sediment bank and marsh.

Prior to 1700, before permanent white settlers arrived, Indians of the Algonquin stock occupied the region around the Pamlico River and Albemarle and Pamlico sounds. The Indian populations were widespread and small, producing only minimal, if any, pressures upon the estuarine system.

Early explorations by men like John White and Francis Yeardly from Virginia opened the way for permanent European settlement in the early 1700's. Ever since early colonial days the white man has lived and worked on the estuaries and sounds of eastern North Carolina. Land was then cleared for agriculture and timber. The rivers and sounds provided a means of transportation for commerce and trade. Waterfront trade centers grew into towns like Belhaven, Bath and Washington.



LOCATION MAP FOR THE NORTH CAROLINA COASTAL ZONE

FIG. 1

After the Civil War logging became a major industry. Up to the early 1900's cypress tress were cut along the swampy stretches of the upper estuarine shorelines because of easy access. This logging practice appears to have been one of the events which unknowingly diminished a natural defense and opened up large portions of the shoreline to increased erosion. At that time land-use pressures were low and land was abundant and cheap; thus waterfront landowners could easily "fall back" from the regressing shoreline.

Over the past twenty years waterfront property has become a premium commodity for commercial, recreational and second home development reasons. Increased land values and land uses have resulted in a new awareness in which the problem of shoreline erosion has taken on new and major proportions. Consequently, many landowners with minimal acreage now think that bulkheads or groins must be built to prevent the loss of their land. On the other hand, large coastal landowners such as farmers, cannot afford to bulkhead long stretches of eroding shoreline. So they might subdivide their shoreline into lots for recreational or retirement homes. The problem of shoreline erosion is then passed on to the individual lot owner who must bear the consequences and costs. An unaware individual purchases the waterfront property only, in many cases, to find it "melting away". This raises the costly issue of shoreline protection.

The shoreline processes and erosional responses of the shorelines in the Pamlico River Estuary (Fig. 1) are the subject of this thesis. Utilizing a series of profiles and maps, I will try to show the control that topography has on the different types of shorelines bounding the Pamlico River Estuary and the effect weather patterns and hydraulic processes have upon the erosion of the different types of shorelines. Specific factors which affect erosion are: 1) the extent and direction of fetch,

2) storm frequency and duration, 3) shoreline geometry, 4) composition of the shore bank, 5) abundance and type of vegetation, and 6) the presence and type of man-made structures and shoreline modifications including bulkheads, rip-rap, groins, boat channels and the associated boat wakes.

Shoreline erosion on a daily basis is minimal. Noticeable erosion occurs during periods of high energy storms (i.e. hurricanes or northeasters) when one to two meters or more of land may be washed away. Undercut banks and fallen trees along the shoreline are evidence of the erosion process.

Shorelines with a long fetch (greater than 5 km) are most prone to erosion, whereas the lateral tributary creeks and areas of small fetch (less than 1 km) are less subject to shoreline erosion. The main trunk of the Pamlico River from Chocowinity Bay to the Pamlico Sound is the area of primary concern in this study.

PREVIOUS WORK

Only in the past five to ten years has there been a general public awareness of the process of shoreline erosion in the estuaries. This has been due to the increase in development along the estuarine coastal areas and the subsequent inflation of land values.

The few shoreline erosion studies to date have been based upon aerial photographs which are available for the North Carolina Coastal Plain since 1938. Stirewalt and Ingram (1974) used aerial photographs to determine shoreline changes at 16 selected areas around the Pamlico Sound. They found that shorelines are constantly changing in response to their exposure to long wind fetches. Erosion and shoreline regression is the norm, although there are some areas of temporary deposition and beach build-up.

The Soil Conservation Service (S.C.S.) (1975) studied 18 coastal counties in North Carolina to determine the magnitude of the estuarine shoreline erosion problem and to list the physical factors controlling shoreline erosion. The shorelines directly exposed to the ocean or sound side of the Outer Banks were considered beyond the scope of their inventory, although serious shoreline erosion in known to be occuring there.

The S.C.S. used the photos from 1938 to 1953 and measured the differences as compared to the set from 1968 to 1971. Thus, the longest time element between photos is 32 years. The results showed very little shoreline accretion and extensive areas of erosion. Erosion rates ranged from 1.4 m/yr. for Washington County on the Albemarle Sound to 0.28 m/yr. in Bertie County which has little "open " water. From their study the S.C.S. documented the regional extent and seriousness of shoreline erosion in the North Carolina estuaries.

The North Carolina Sea Grant college program sponsored a study of estuarine shoreline erosion by Dr. S.R. Riggs, Dr. M.P. O'Connor, and Dr. V. Bellis of East Carolina University from 1975 to 1978, entitled "Shoreline Erosion and Accretion -- A Process-Response Classification of the Estuarine Shore Zone Environments of North Carolina".

In 1975 and 1976 the co-investigators classified the different shoreline types, mapping their distribution over 2500 mi (4000 km) of North Carolina's estuarine shorelines. They also defined the numerous factors causing, as well as describing, the processes of shoreline erosion (Table 1).

In 1977, the Riggs, O'Connor, and Bellis program established ten field monitor stations along the Pamlico River Esturay which represent the basis for the subject of this thesis. These ten stations represented a combination of the different shoreline types and the more important variables controlling shoreline erosion. Detailed mapping of each of the stations was done three times over a sixteen month period. The initial mapping took place in the summer of 1977 when permanent control stakes were set. The second mapping occured during March 1978, establishing erosion rates for the high energy fall and winter seasons. The third and final mapping was done during November, 1978. During the initial mapping period 1m cores were taken every 10 to 20m along one or two transects extending from the shore for 100m offshore at each station to determine the nature of nearshore sedimentation. The results of this work appear in the following sections.

From what they learned in 1975 to 1977, Riggs, O'Connor, and Bellis developed the "Relative Estuarine Shoreline Erosion Scale" (Table 2). This is a method for planners, landowners, or prospective buyers of estuarine shoreline property to obtain an indication of the relative intensity of erosion along any specific shoreline segment. This scale was used on each

SHORELINE TYPES and DISTRIBUTION

COUNTIES (AND %) IN PAMLICO SYSTEM	BEAUFORT(100)		HYDE (100)		PAMLICO(15.3)		TOTALS	
TOTAL SHORELINE MAPPED (KM)	309.7		399.5		64.0		772.8	
— SHORELINE TYPES —								
LOW BANK	111.5	(36%)	44.0	(11.0%)	3.5	(5.5%)	159.0	(20.5%)
HIGH BANK	29.6	(9.6%)	.8	(0.2%)	0.0		30.4	(3.9%)
BLUFF	27.8	(8.9%)	0.0		0.0		27.8	(3.5%)
SWAMP FOREST	10.8	(3.5%)	0.0		0.0		10.8	(1.4%)
MARSH	130.1	(42.0%)	354.7	(88.8%)	60.5	(94.5%)	545.3	(70.5%)
— SPECIAL NATURAL SHORELINE FEATURES —								
CYPRESS FRINGE (BANK & BLUFF)	6.8	(2.3%)	0.0		0.0		6.8	(0.9%)
MARSH FRINGE (BANK & BLUFF)	17.9	(6.0%)	24.5	(6.1%)	0.0		42.4	(5.6%)
SAND APRON (MARSH)	.16	(0.05%)	12.3	(3.1%)	.3	(0.5%)	12.8	(1.7%)
— SHORELINE STATUS —								
OBVIOUS BANK & BLUFF EROSION	59.9	(17.7%)	19.4	(4.8%)	2.7	(4.3%)	82.0	(9.8%)
OBVIOUS ACCRETION	.96	(0.3%)	2.4	(0.6%)	0.0		3.4	(0.4%)
MODIFICATION	36.6	(12.2%)	1.4	(0.4%)	.8	(1.3%)	38.8	(5.1%)

TABLE 1 - SEE FIG. 6 FOR COUNTY LOCATION (Riggs et. al. 1978)

monitor station to determine the importance of each shoreline variable on that particular shoreline. The Erosion Potential Scale is not meant to give exact erosion rates of a given shoreline but to show the shoreline's susceptibility to erosion. The scale has also never been put to a test and modifications and changes will evolve with this study.

TABLE 2

RELATIVE ESTUARINE SHORELINE EROSION POTENTIAL IN NORTH CAROLINA

I. SHORELINE VARIABLES	II. DESCRIPTIVE CATEGORIES — EROSION POTENTIAL VALUE (EPV) LOCATED IN UPPER LEFT HAND CORNER OF EACH CATEGORY BOX							III. ASSIGNED EPV FOR EACH SHORELINE VARIABLE
1. FETCH - AVERAGE DISTANCE (IN KM) OF OPEN WATER MEASURED 45° EITHER SIDE OF THE PERPENDICULAR TO THE SHORELINE	0: LESS THAN .2	2: .2 TO .5	4: .5 TO 2	7: 2 TO 5	10: 5 TO 15	13: 15 TO 30	16: GREATER THAN 30	
2. DEPTH AT 20 METERS - DEPTH OF WATER (IN METERS) 20 FROM THE SHORELINE (MEASURED AT MEAN HIGH WATER)	1: LESS THAN .5	2: .5 TO 1.0	3: 1.0 TO 2.0	4: 2.0 TO 3.0	5: GREATER THAN 3.0			
3. DEPTH AT 100 METERS - DEPTH OF WATER (IN METERS) 100 FROM THE SHORELINE (MEASURED AT MEAN HIGH WATER)	1: LESS THAN .5	2: .5 TO 1.0	3: 1.0 TO 2.0	4: 2.0 TO 3.0	5: GREATER THAN 3.0			
4. BANK HEIGHT - HEIGHT OF THE BANK (IN METERS) AT THE SHORELINE OR IMMEDIATELY BEHIND THE SEDIMENT BEACH	1: GREATER THAN 6.0	2: 6.0 TO 3.0	3: 3.0 TO 2.0	4: 2.0 TO .5	5: LESS THAN .5			
5. BANK COMPOSITION - COMPOSITION AND DEGREE OF CEMENTATION OF THE SEDIMENTS	0: ROCK, MARL, TIGHT CLAY, WELL CEMENTED SAND (BREAK WITH A HAMMER OR DIG WITH A PICK), OR SWAMP FOREST	7: SOFT CLAY, CLAYEY SAND, MODERATELY CEMENTED SAND (EASILY DUG WITH A KNIFE)	15: UNCEMENTED SANDS, PEAT (EASILY DUG WITH YOUR HAND)					
6. WIDTH OF SAND BEACH - WIDTH OF SAND BEACH (IN METERS) BETWEEN BANK AND SHORELINE (MEASURED AT MEAN HIGH WATER)	0: SWAMP FOREST (NO BEACH) OR LESS THAN .5 KM FETCH	1: GREATER THAN 6.0	2: 6.0 TO 3.0	3: 3.0 TO 2.0	4: 2.0 TO 1.0	5: LESS THAN 1, OR BROAD MARSH		
7. OFFSHORE VEGETATION - TYPE AND ABUNDANCE OF THE VEGETATION OCCURRING IN THE WATER OFF THE SHORELINE	1: DENSE OR ABUNDANT CYPRESS AND/OR AQUATIC GRASSES (SUBMERGED WEED BED)	4: SPORADIC OR INTERMITTENT CYPRESS AND/OR AQUATIC GRASSES (SUBMERGED WEED BED)	7: LACK OF CYPRESS AND/OR AQUATIC GRASSES (SUBMERGED WEED BED)					
8. SHORE VEGETATION - TYPE AND ABUNDANCE OF THE VEGETATION OCCURRING ON A SAND BEACH BETWEEN THE BANK AND THE SHORELINE	0: NO SEDIMENT BEACH	1: DENSE, CONTINUOUS VEGETATION; MARSH FRINGE, CYPRESS FRINGE, AND/OR UPLAND TREES AND SHRUBS	4: SCATTERED OR PATCHY VEGETATION; MARSH GRASS, CYPRESS, AND/OR UPLAND TREES AND SHRUBS	7: LACK OF LIVING VEGETATION; FREQUENTLY ABUNDANT STUMPS AND LOGS IN THE WATER; OR A MARSH WITH NO SAND BEACH				
9. BANK VEGETATION - TYPE AND ABUNDANCE OF THE VEGETATION OCCURRING ON THE BANK AND IMMEDIATELY ON TOP OF THE BANK LIP	1: DENSE VEGETATION; UPLAND TREES AND SHRUBS, GRASS	4: CLUMPS OF VEGETATION ALTERNATING WITH AREAS LACKING VEGETATION	7: LACK OF VEGETATION (CLEARED), ANNUAL PLANTS (CROPS OR AGRICULTURAL LAND), OR EXTENSIVE MARSH					
10. SHORELINE GEOMETRY - GENERAL SHAPE OF THE SHORELINE AT THE POINT OF INTEREST PLUS 200 YARDS ON EITHER SIDE	1: COVES	4: IRREGULAR SHORELINE	8: HEADLAND OR STRAIGHT SHORELINE					
11. SHORELINE ORIENTATION - THE GENERAL GEOGRAPHIC DIRECTION THE SHORELINE FACES	0: LESS THAN .5 KM FETCH	1: SOUTH TO EAST	4: SOUTH TO WEST	8: WEST TO NORTH TO EAST				
12. BOAT WAKES - PROXIMITY TO AND USE OF BOAT CHANNELS	1: NO CHANNELS WITHIN 100 METERS, BROAD OPEN WATER BODY, OR CONSTRICTED SHALLOW WATER BODY	6: MINOR CHANNEL WITHIN 100 METERS, CARRYING LIMITED TRAFFIC, OR MAJOR CHANNEL 100' OFFSHORE	12: MAJOR CHANNEL WITHIN 100 METERS; PARTICULARLY THE INTRACOASTAL WATER WAY					
IV. CUMULATIVE EROSION POTENTIAL VALUE (CEPV) →								

V. SHORELINE EROSION POTENTIAL SCALE:

	AVERAGE EROSION METERS/YEAR
IF CEPV IS BETWEEN 0 AND 50, THEN THE EROSION POTENTIAL IS LOW	LESS THAN .6
IF CEPV IS BETWEEN 50 AND 70, THEN THE EROSION POTENTIAL IS INTERMEDIATE	.6 TO 1.2
IF CEPV IS BETWEEN 70 AND 100, THEN THE EROSION POTENTIAL IS HIGH	GREATER THAN 1.2

(after O'Connor *et al.*, 1978)

THE PAMLICO RIVER SYSTEM

Regional Setting

The Pamlico River Estuary is located in the northern coastal plain of North Carolina (Fig. 1). It is the downstream extension of the Tar River which originates in the Piedmont of North Carolina near Roxboro. The combined drainage of the Tar-Pamlico system covers more than 8,000 square kilometers (Hartness, 1977). The Pamlico River is located mostly in Beaufort County, extending southeastward from Washington, North Carolina 55 km to the Pamlico Sound. The eastern portion extends into and includes all the Hyde County shoreline on the north side and into Pamlico County to Jones Bay on the south side. The Pamlico River Estuary is less than 1 km wide at Washington and increases to 7 km at the Pamlico Sound. The Pamlico River is a major trunk estuary similar to the Neuse and Albemarle estuarine systems. The mid-river water depth varies from 2 to 3 meters in the upper estuary to 5 to 6 meters nearer the Pamlico Sound.

The lateral drainages or tributaries are confined to the North Carolina Coastal Plain region. Their areas are small and flow is low compared to the main trunk estuary. Much of the tributary drainage into the Pamlico River system drains swamps, marsh, and woodland, although there are numerous agricultural and residential areas. Lateral tributaries of the Pamlico River include the following; the Chocowinity, Rose, Swanquarter and Blounts Bays; and Broad, Blounts, Lee, Upper Goose, Bath, Durham, South, East Fork, Bond and Goose Creeks.

Hydraulic Setting

Tidal ranges for this region are dampened by the Outer Banks barrier island chain. Thus, astronomical tidal ranges recorded in this study were in the order of 0.15 m. Winds produce the major tidal flucuations which may raise or lower river level along a given reach of shoreline 0.5 to 1.5 m in a single storm. Wind patterns are seasonal. In the Pamlico region the strongest winds of longest duration occur in the late fall and winter months (U.S. Navy Weather Command, 1970) when the most frequent wind directions range from NE to N to NW to W. By April the dominant wind direction shifts to the SW and remains so until mid to late fall.

The Pamlico River is an oligohaline estuarine system. Salinity decreases upstream and into the laterals where the limit of saline encroachment marks the boundary of the estuarine system. Salinity throughout the estuary may range from 0.5 ppt in the upper reaches to 15 or 20 ppt in the outer portions of the Pamlico River system (Hobbie, 1970). Salinities are generally lower during the spring and summer months and slightly higher during the fall and winter months. Salinities as high as 15 ppt may occur near Washington during periods of low precipitation and runoff or as low as 1 ppt during periods of heavy rains and westerly winds (Hobbie, *et al.*, 1972). During periods of calm weather or when there is a large freshwater influx into the estuary, vertical salinity stratification may occur. This stratification occurs usually in late summer and often results in the mass kills of many of the benthic fauna such as the clams *Macoma* and *Mulinea*. Lateral salinity zonation is common year round. Water on the northern side of the estuary is generally 2 to 4 ppt more saline than on the southern side. This is attributed to the Coriollis Force which effects all East Coast estuaries of the United States in a similar manner (Hobbie, 1970). Winds may markedly effect horizontal salinity patterns. However, the inflow of fresh water is by far the dominant factor (Hobbie, 1970).

The water temperature closely follows the air temperature and is rather uniform throughout the estuary at any given time (Hobbie, 1970). It ranges from an average January low of 1.9 degrees celsius to an average

August high of 34.0 degrees celsius.

Suspended sediments in the Pamlico River Estuary come mainly from the Tar River with shoreline erosion adding a less significant amount (Benton, Riggs, and O'Connor, 1973). They found that the yearly mean suspended sediment concentration is 56.4 mg/l for the Tar River and 21 mg/l for the Pamlico River and outlined the following trends:

1) The Pamlico River has a slight general downstream decrease in suspended sediment concentration.
2) The suspended sediment concentration generally follows the seasonal river level curve of the Tar River, being highest during the winter and spring and lowest during the summer and fall.
3) There is a slightly higher suspended sediment concentration along the edges than in the center of the river. This may be attributable to shoreline erosion.
4) The suspended sediment concentration near the bottom of the water column is generally higher than the surface.
5) There is no apparent relationship between salinity and suspended sediment concentrations.

Bottom sediments are characterized by their relatively high organic content. Texturally there is an irregular sand apron bordering the shoreline. This passes riverward under a "gorp" or organic rich mud which fills in the center and deeper regions of the estuary (Hartness, 1977).

Geologic Setting

The eastern North Carolina Coastal Plain and continental shelf are underlain by an eastward dipping monoclinal wedge of sediments over a basement of crystalline rock. These sediments are about 10,000 ft. (3048 m) thick at Cape Hatteras and feather out to 0.0 ft (0.0 m) at the fall line. They range from Mid-Mesozoic to Recent in age.

Major tectocic structures in the basement rock affect the overlying Coastal Plain sediments (Fig. 2). In North Carolina the Hatteras Embayment is an active structural low. The Cape Fear Arch is an active high. Active subsidence in the area of the Hatteras Embayment is evidenced by the large embayed estuaries and the rapid rates of shoreline erosion (Riggs, O'Connor,

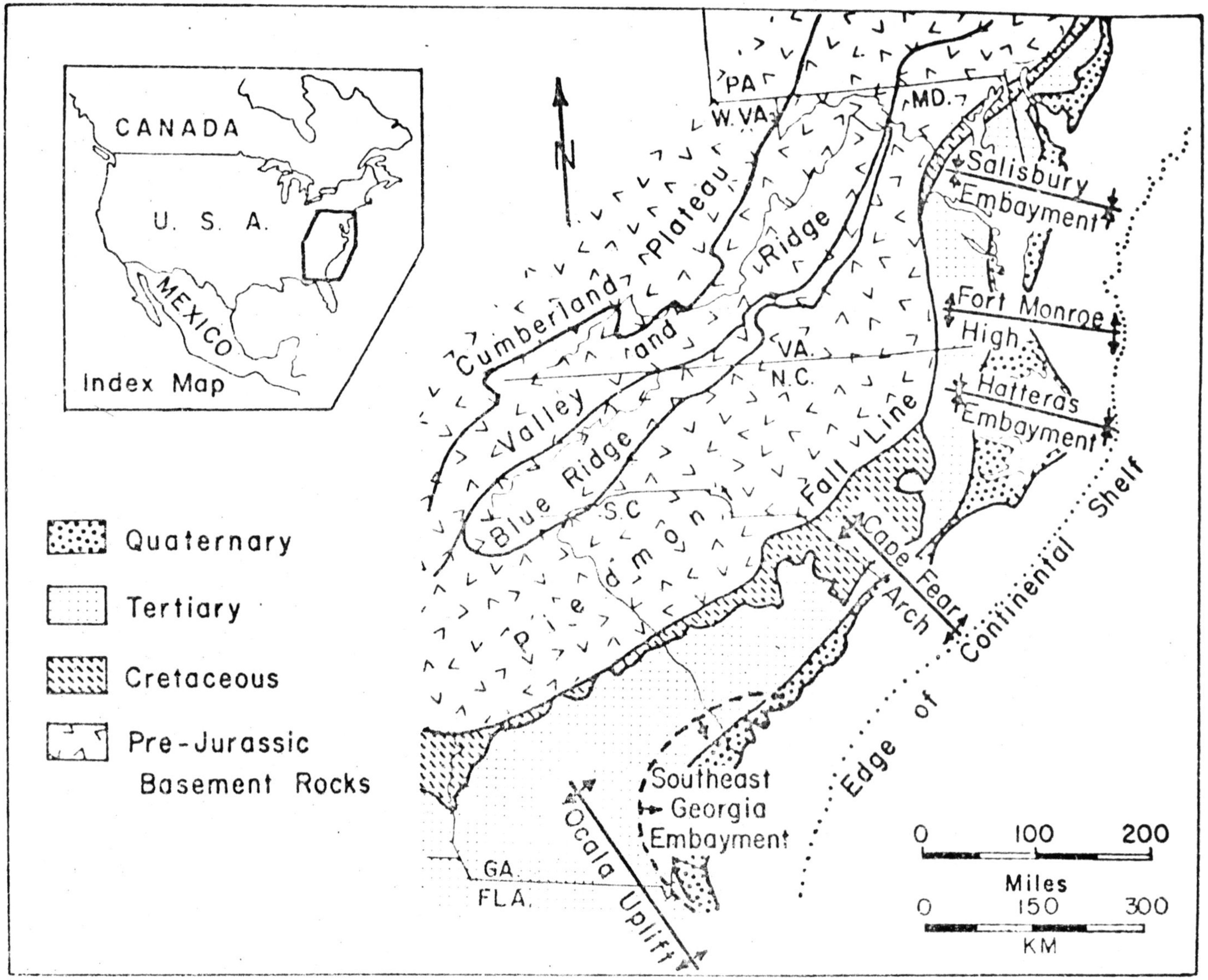


FIG. 2 MAJOR STRUCTURAL FEATURES OF THE ATLANTIC COASTAL PLAIN (AFTER LEGRAND, 1961).

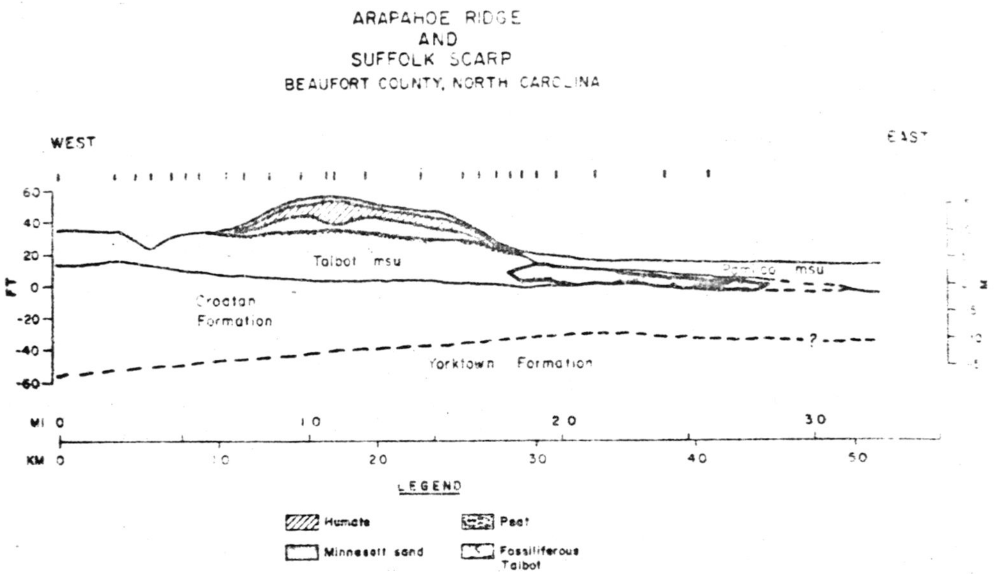


FIG. 3 Cross section of Arapahoe ridge shows the relations of sediments of the Talbot and Pamlico morphostratigraphic units. See A-A' in Figure 1. The Suffolk scarp is the east slope of the ridge. The tick marks above the drawing are the locations of power auger holes.

(Daniels et. el. 1977)

and Bellis, 1975).

Several prominent geomorphic features cross the Pamlico River drainage and affect the shoreline types and processes. These are the Talbot and Pamlico morphostratigraphic units or msu's (Daniels et al., 1977). These two msu's are separated by the Arapahoe Ridge and Suffolk Scarp (Fig. 3). The Talbot msu is the name applied to the surficial sediments west of the Arapahoe Ridge while the Pamlico msu represents surficial sediments east of the Arapahoe Ridge (Daniels et al., 1977). Many workers have studied these units in the past, which has resulted in numerous stratigraphic names (Table 3).

Sediments of the Talbot msu, which include the Flanner Beach Formation and part of the James City Formation, were deposited in mid to late Pleistocene (Dubar et al., 1974). The facies, which are subtle and complex, are generally very fine to fine grained micaceous sands with minor amounts of medium to very coarse sands and gravel, and between a 10% to 40% clay fraction. The predominant clay mineral is montmorillinite with minor amounts of illite, kaolinite, and chlorite (Dubar et al., 1974). Limonitic staining of quartz grains is characteristic of the weathered soil zone. The faunal assemblages west of the Arapahoe Ridge are indicative of a restricted, back-barrier, brackish water, low energy environment (Dubar et al., 1974).

The Arapahoe Ridge is a well-defined linear sand ridge which extends between the Pamlico and Neuse Rivers. The east sloping face of the Arapahoe ridge is called the Suffolk Scarp which is traceable south to the Cape Fear area and north into southeastern Virginia. The sands of the Arapahoe Ridge have an abrupt contact with the underlying sediments of the Talbot msu. Peat 0.3 to 1.0 m thick overlies the Talbot in many areas. The peat is part of the post Talbot emergence that preceeded the deposition of the sands of the Arapahoe Ridge. The ridge stands 3.0 to 7.0 m above

TABLE 3 **Review of terminology of Plio-Pleistocene units of the lower Coastal Plain in the Neuse-Tar area.**

	Shattuck 1901	Stephenson 1912	Richards 1950	DuBar and Solliday 1963	Fallaw and Wheeler 1969	Daniels and Others 1972	DuBar, Solliday and Howard 1974	Mixon and Pilkey 1976	Daniels and Others 1974+
Outcropping Upper Pleistocene Units	Talbot Formation	Pamlico Formation	Pamlico unit	Late Pleistocene	Surficial sands ? Neuse Formation	Pamlico msu (including Minnesott Ridge Sand)	"Cherry Point" Sand Flanner Beach Formation	Core Creek Sand (including Minnesott Sand)	Pamlico msu (including Core Creek Sand and Minnesott Sand)
			?					Flanner Beach Formation: Arapahoe Member; Beard Creek Member	Talbot msu (including Flanner Beach Formation in this area)
(lower Pleistocene does not outcrop on lower Coastal Plain)		Chowan Formation	Talbot unit in some localities	Flanner Beach Formation		Talbot msu			
			Horry Clay	Horry clay			Horry clay	Horry clay	
Pliocene (perhaps lowermost Pleistocene)		Waccamaw Formation	Croatan Formation	James City Formation	Horry clay Croatan Formation	Horry clay Small sequence or James City Formation	James City Formation	Yorktown Formation (including James City Formation)	Horry clay Croatan Formation

(Daniels et. el. 1974)

the Talbot Plain to the west and 7.0 to 12.0 m above the Pamlico Plain to the east. The ridge is 0.9 to 1.5 km wide and is continuous for 45 km.

The Arapahoe Ridge sands merge eastward with sediments of the Pamlico msu and are interpreted as contemporaneous with the Pamlico sediments (Cherry Point Unit). The Arapahoe sands are tan to yellowish brown and unfossilferous and grade into the Pamlico sediments which are slightly clayey, fine quartz sand with kaolinite dominant and illite and vermiculite minor. Stratigraphic position indicates an age of late Pleistocene, possibly the Sangamon Interglacial, for the Pamlico msu sediments (Daniels _et al_., 1976).

The geomorphic features described above directly affect the topographic expression of the Pamlico River drainage and shoreline types. The area on the south side of the river and west of the Suffolk Scarp is characterized by high relief shorelines. The shorelines on the north side of the river have much lower relief west of the scarp. The Tar-Pamlico system, as well as other fluvio-estuarine systems on the East Coast are thought to be migrating slowly southward (Stuckey 1965). This results in the development of an extensive floodplain sequence along the north side of the river and incision of the south bank. This is evidenced especially west of the Suffolk Scarp with high eroding bluffs on the south bank and low swampy land on the north bank. Consequently, the scarp is not reflected in the topography for about 1.0 km north of the river. Shorelines east of the Suffolk Scarp have lower relief and less well drained land than shorelines west of the scarp.

Geologic History

The Yorktown Formation of early to middle Pliocene age underlies much of the Coastal Plain of southeastern Virginia and North Carolina (Fig. 4). It is composed of clayey sands and silts with a rich assemblage of shallow

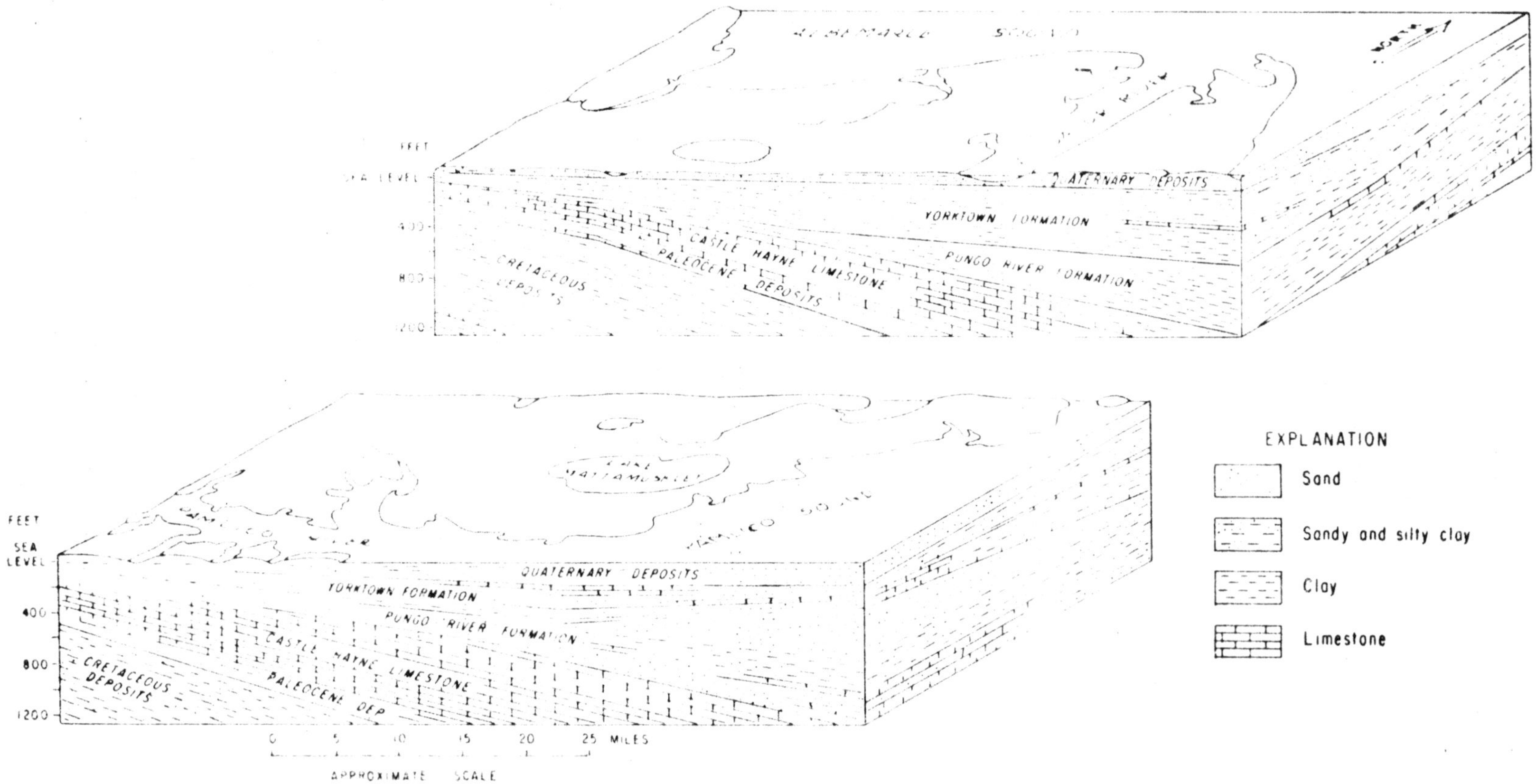


FIG. 4 --Block diagrams showing the relative position and generalized composition of the uppermost geologic units underlying the Albemarle-Pamlico region. (after Heath, 1975)

marine and warm water fossils (Oaks et al., 1974). During the protracted emergence that followed Yorktown time, fluvial channels were cut into the Yorktown Formation. According to Oaks et al., this incised drainage controlled to a remarkable degree the location of drainage lines during each subsequent Post-Yorktown emergent episode.

Emergence and submergence of the Coastal Plain during Post-Yorktown time resulted from advances and retreats of the Pleistocene polar ice sheets (Fig. 5). The major geomorphic elements within the Pamlico River Estuary drainage area were formed during two separate interglacial periods. The Talbot msu was apparently formed during the later Yarmouth Interglacial. The Pamlico msu and associated Arapahoe Ridge were formed during the Sangamon Interglacial (Daniels et al., 1977).

The present major trunk estuaries of northern North Carolina (the Albemarle, Pamlico, and Neuse) were formed sometime following the low still-stand of the late Wisconsin glacial stage which occured between 15,000 and 18,000 years B.P. (Riggs and O'Connor, 1975). The subsequent and present transgression is a response to the general Post-Pleistocene sea level rise in combination with a slight tectonic subsidence (Balaz, 1974). This transgression is migrating across a continental shelf-coastal plain surface characterized by 1) a very low regional slope with low relief, and 2) a well developed superimposed drainage system with low gradients and broad floodplains. The transgressing sea is flooding the rivers, producing the present day estuarine systems.

Present Day Geomorphology

Riggs and O'Connor (1975) described the basic geomorphic elements of the North Carolina drowned coastal plain-bar built estuarine system and defined the following types of estuaries:

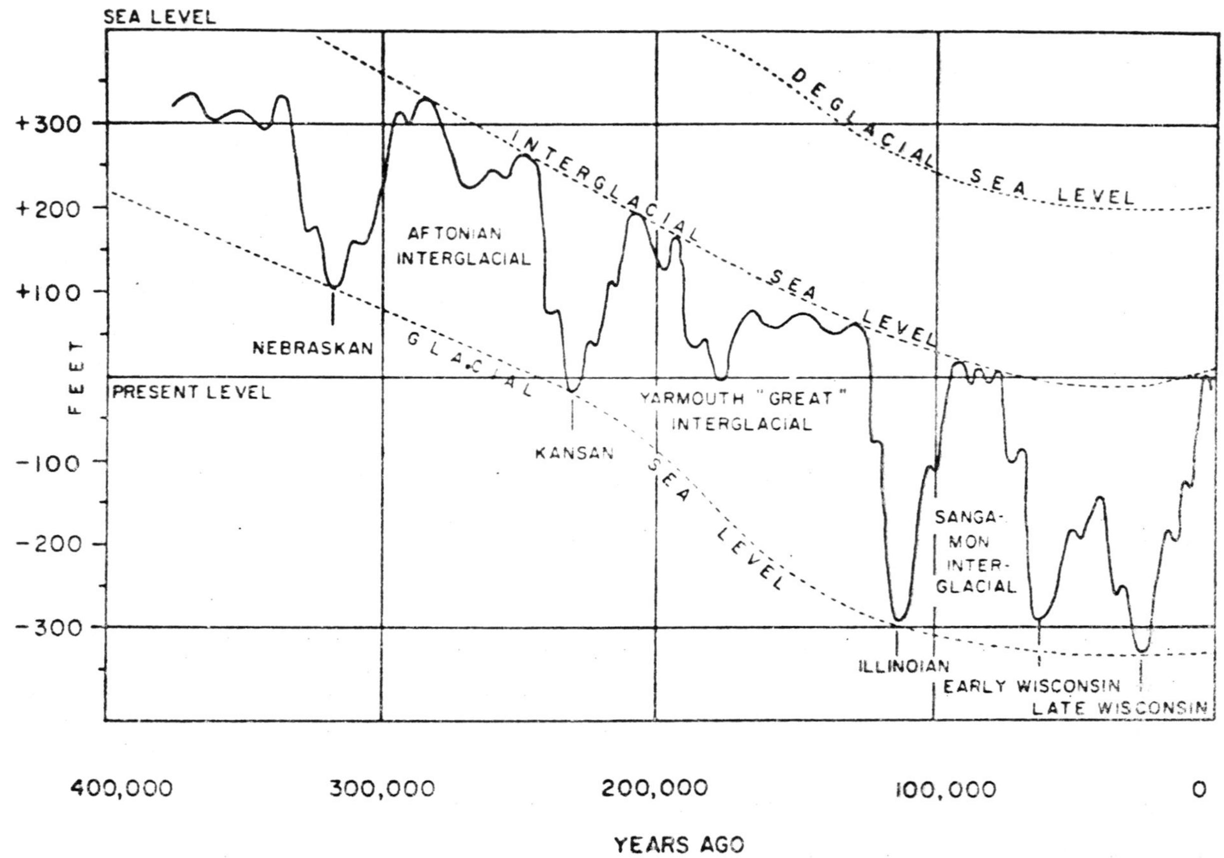


FIG. 5 The figure reproduced here (after Fairbridge 1960) indicates that the sea has advanced and retreated on at least four separate occasions during the last 400,000 years. (Recent data suggests that these events actually occurred over a period of 1.5 to 2.0 million years ago.) Sea level is currently rising at a rate of 0.5 to 1.5 feet per century, thus continuing a trend established about 18,000 years ago.

1. Trunk Streams and Trunk Estuaries

The major trunk streams (i.e. the Tar-Pamlico system) drain the Piedmont and the eastern Appalachian mountains. They have an extensive cypress-gum swamp floodplain and terrace system and deliver relatively large volumes of water to the coastal system. With transgression, the trunk stream and its broad cypress-gum floodplain are inundated producing a trunk estuary which is essentially perpendicular to the ocean shoreline.

2. Lateral Streams and Lateral Estuaries

The lateral streams have relatively samll drainage basins in the low, flat and swampy Coastal Plain. Their relatively small and acidic blackwater discharges contribute mostly organic sediments directly to the trunk estuaries. The lateral streams and their embayed estuarine system are generally perpendicular to the trunk estuaries.

3. Open Estuaries

The open estuaries form when embayed laterals flood across the very low interstream divides between adjacent trunk estuaries in the outermost reaches of the coastal system. Due to the higher salinities and lower interstream slopes, the shorelines contain little or no cypress, but rather are dominated by extensive salt marshes. All of these estuaries occur simultaneously within the coastal system and represent active and integral stages in the evolutionary pattern of the total transgressing estuarine system (Riggs, O'Connor, and Bellis, 1977).

According to Riggs et al., the resulting coastal zone of northeastern North Carolina is a complex of broad and shallow estuarine environments which extend up to 100 mi. (160 km) into the Coastal Plain. The very low regional slope and the relatively slow rate of flooding produces a very rapid rate of lateral response characterized by shoreline recession or erosion. They believe that the coastal system, including the estuaries, maintains its integrity through time as it migrates upward and landward by a systematic evolutionary succession -- the incised drainages are drowned as the estuaries and barrier bar systems displace the fluvial system landward.

In this study, I have divided the Pamlico River Estuary into three parts, the inner, middle, and outer estuary. The inner estuary extends from the confluence of the Tar River at Washington eastward to the Suffolk

Scarp. It is characterized by high bluffs and numerous intermittent streams on the south bank, low swampy banks on the north bank, and only three large but comparatively narrow lateral tributaries (Chocowinity Bay, Blounts Creek, and Broad Creek) which drain nearby pocosins. The middle estuary extends from the Suffolk Scarp to the Beaufort County Hyde-Pamlico County line and the Intracoastal Waterway which bisects the Pungo River and Goose Creek. The middle estuary is characterized by a lower relief than the inner estuary with mainly low sediment bank shorelines, 0.5 to 2.0 m high, and six large, lateral estuaries including the Pungo River. These laterals are wider and more inundated than laterals west of the scarp. The lateral tributaries often drain pocosins or swampy flat low lying areas several kilometers inland. The outer estuary extends from the Intracoastal Waterway east and around the Pamlico Sound. The very low relief is less than 1.0 m. The lateral estuaries are still more flooded, forming broad, open bays. These three divisions are based on local relief and drainage patterns.

P A M L I C O   R I V E R   S H O R E L I N E S

Classification

Three basic shoreline types have been recognized in the Pamlico River Estuary by Riggs, O'Connor, and Bellis (1975). These are sediment banks, swamp forest and marsh. They respond differently to the coastal processes and thus erode at different rates (Table 4).

Sediment bank shorelines are composed of varying mixtures of sand and clay and are subdivided into three subtypes according to height above mean river level. Low sediment banks range in height from less than 0.5 m to 2.0 m. High sediment banks range from 2.0 to 6.0 m above mean river level and bluffs are greater than 6.0 m in height.

Swamp forest shorelines are composed of cypress and gum trees which can survive periodic flooding due to storms. These shorelines consist of an extensive forest which extends from 100 to 1000 m inland, or there may be a cypress fringe from a few up to 20 m wide which grades into an upland forest of pine and oak at higher elevations.

The marsh shorelines are composed of living grasses, peat, and organic clays. They are rarely more than 1.0 m above mean river level. Marsh shorelines may be part of an extensive marsh up to 500 m wide or just a fringe along a sediment bank ranging from a few up to 30 m in width.

Another shoreline type, not listed in Table 4 is the man-modified shoreline. Man-modified shorelines are any previously mentioned shoreline type which has been altered in some fashion by human intervention which changes the natural processes acting upon that reach of shoreline. Bulldozed banks, bulkheads, rip-rap, and groins are examples of man-modifications on estuarine shorelines.

TABLE 4. Shoreline Erosion in the N.C. Estuarine System. Table from Riggs et. al. 1978.

SHORELINE TYPES	Average Rates (meters per year)
I. Sediment Banks	.60 to .80
A. Low Bank	.80
B. High Bank	.60
C. Bluff	.64
II. Swamp Forest	.64
III. Marsh	.95
Range of all shoreline	0.0 to 4.5

This data based upon the Soil Conservation Service shoreline recession study (1975).

Shoreline Erosion Variables

The absolute intensity and amount of erosion along any specific shoreline segment is directly dependent upon the following set of shoreline characteristics (Riggs, O'Connor, and Bellis, 1978):

1. Fetch - Average distance of open water in front of the shoreline.
2. Water Depth and Bottom Slope - Bottom characteristics of the near-shore area.
3. Bank Height - Height of the bank at the shoreline or immediately behind the sand beach.
4. Bank Composition - Composition and degree of cementation of the sediments.
5. Width of Sand Beach - Presence and width of the sand beach between the bank and the shoreline.
6. Vegetation - Type and abundance of vegetation occuring on the bank, the shoreline, and in the offshore area.
7. Shoreline Geometry - General shape of the shoreline.
8. Shoreline Orientation - Geographic direction that the shoreline faces.
9. Boat Wakes - Proximity to and use of boat channels.

Riggs _et al._, (1978) go on to state that much of the shoreline erosion is a direct product of high energy storms. Consequently the amount of recession at any location is quite variable from year to year and depends upon the following conditions:

1. Storm frequency
2. Storm type and direction
3. Storm intensity and duration
4. Resulting wind tides, currents, and waves

Shoreline Type Distribution

The distribution of the different shoreline types in the Pamlico River Estuary is in part a result of the topographic expression of the regional geomorphic elements combined with the affect of a transgressing estuarine system. Table 1 shows shoreline types and their distribution by county in the Pamlico River Estuary system. Figure 6 illustrates the distribution of these shoreline types. The inner estuary is dominantly low bank (44%)

and bluff (36%). The middle estuary is bounded mostly by low sediment banks (58%) and the outer estuary is mainly extensive marsh shoreline (83%).

Description of Shoreline Types

I Sediment Banks

Low Bank. Low bank shorelines are defined as those sediment banks between 0.5 and 2.0 m above mean river level (Table 4). They are the most abundant type of sediment bank shoreline. They are commonly associated with erosion of broad interstream divides, especially in the inner and middle estuary. Low banks are moderately to highly susceptible to erosion and have the highest average erosion rates of the sediment banks according to Riggs, O'Connor, and Bellis (1978).

East of the Suffolk Scarp low bank shorelines are commonly composed of a cohesive mixture of slightly micaceous, clayey sands to sandy clays with rippled clay laminae. These sediments are usually capped by a sandy humate zone about 0.3 to 0.5 m thick which is iron-stained and mottled and represents the soil horizon of the Pamlico msu. West of the Suffolk Scarp most of the low bank shorelines occur on the north side of the river.

Low bank shorelines commonly form a vertical scarp exposure which is slightly undercut. A 1 to 5 m sand beach usually occurs from the base to mean river level (Fig. 7). The dominant bank top vegetation is a pine woods. The eroding bank is characterized by exposed tree root systems in which the root entwined, sandy, humate zone hangs or flops down. As the bank erodes past the trees, the trees are blown over by wind leaving the dead stumps standing in the water. Abundant submerged logs and stumps in the nearshore area attest to positions of shorelines in the past. Logs lying perpendicular to the shore will trap sands eroded from the bank and act as natural groins.

During periods of storms, high wind tides cause the river to rise,

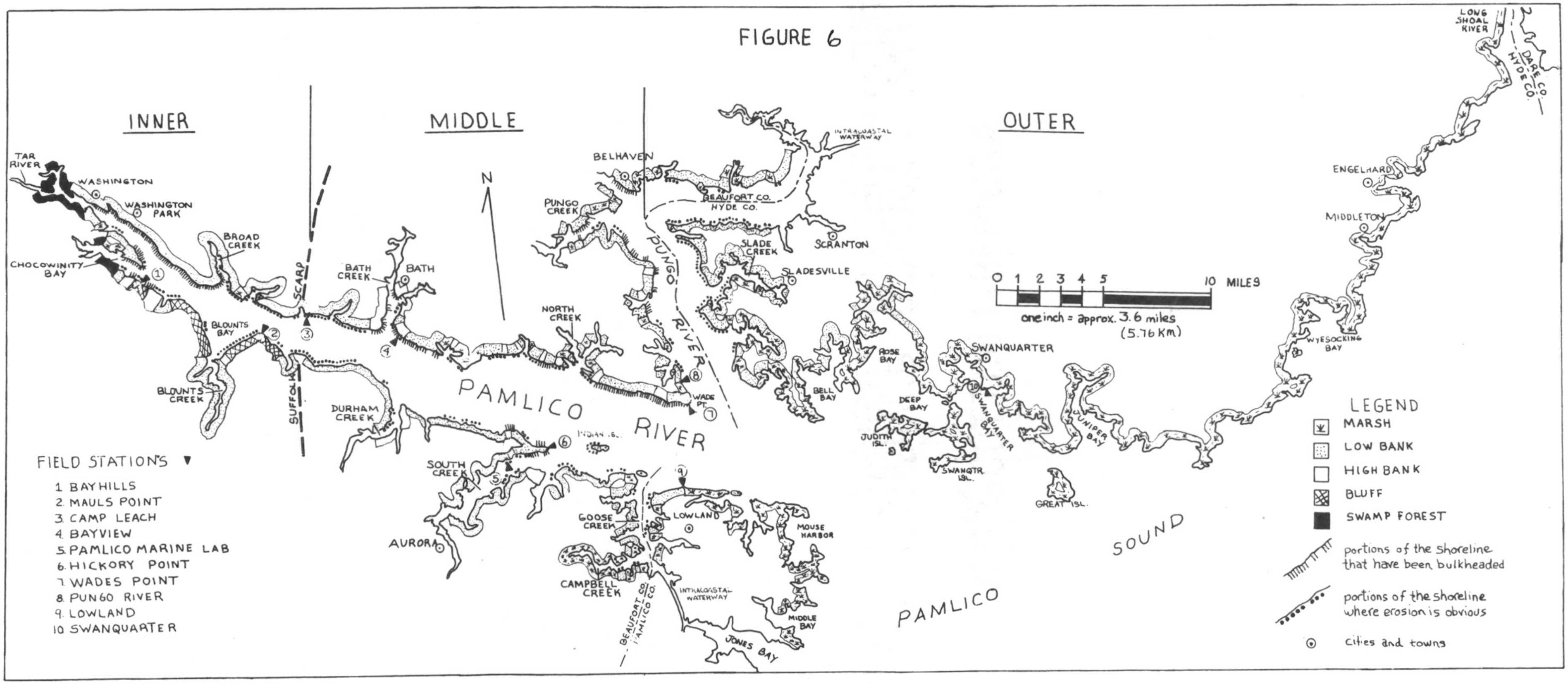


FIG. 6-Pamlico River Estuarine System, including field station locations, bank type distribution, and Inner, Middle, and Outer estuary divisions. (after Riggs et. al., 1978).

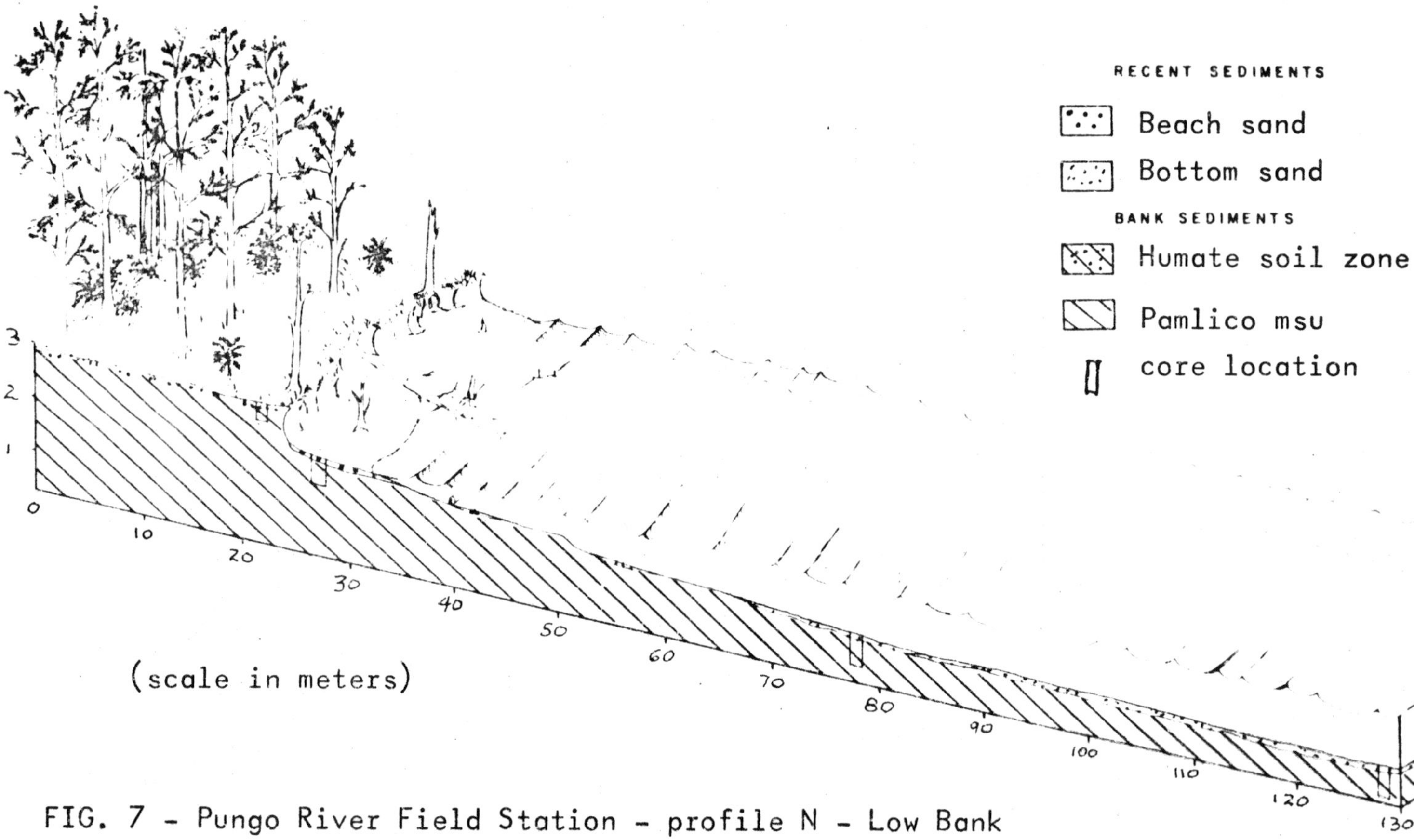


FIG. 7 - Pungo River Field Station - profile N - Low Bank

overstep the narrow sand beach, and directly attack the bank (Fig. 8). Medium to coarse sands from the eroded bank are reworked onto the beach forming the recent beach sands. The fine sands and silts are differentially deposited offshore as recent bottom sediments forming the nearshore sand apron. The clays settle out in the deeper waters and are deposited with very fine organic material producing the ubiquitous "gorp" sediments which fill the deeper central portions of most of the estuaries (Hartness, 1977).

Sands of the nearshore sand apron are deposited with fine particulate organic material derived from the eroded bank, adjacent lateral creeks, marshes and swamp forests. Nearshore (inside 100 m) this fine organic-rich sand apron shifts with prevailing wind and wave conditions across the <u>erosion surface</u> of the receding banks. Thus, the sand apron is usually thin (10 to 20 cm) or non-existent nearshore along high energy low bank shorelines which are exposed to long fetches. However, up the lateral tributaries and along areas where the fetch is minor with a consequent lower wave energy, the sand apron will accumulate in thicknesses up to 1.5 m (Fig. 9).

The surface of erosion is present in front of all eroding shoreline types. This is the lower limit or "base level" of erosion and is the surface upon which recently eroded bank sediments are deposited. It is a disconformity on which reworked sands are deposited on <u>in situ</u> sediments of the Talbot msu or Pamlico msu. This study is concerned with the erosion surface-recent sands relationship from the bank to 100 m offshore that I define as the nearshore area. The erosion surface off low bank shorelines occurs as a clayey pavement across which the sand apron shifts alternately exposing and burying the clayey pavement.

Some low bank shorelines experience little or no erosion. During these periods marsh grasses may become established along the upper beach area and form a narrow patchy marsh frings (Fig. 10). This often occurs up lateral

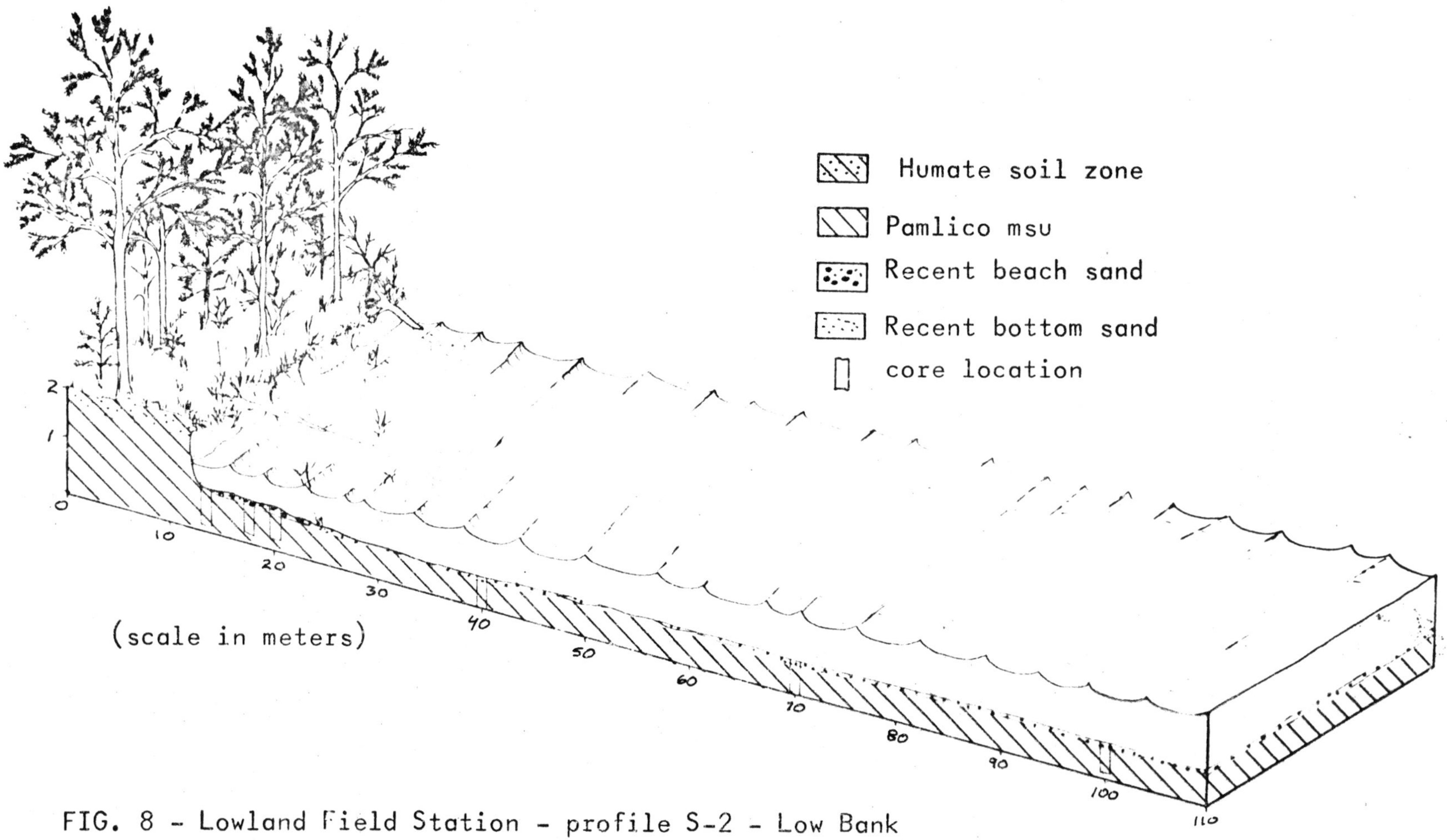


FIG. 8 - Lowland Field Station - profile S-2 - Low Bank

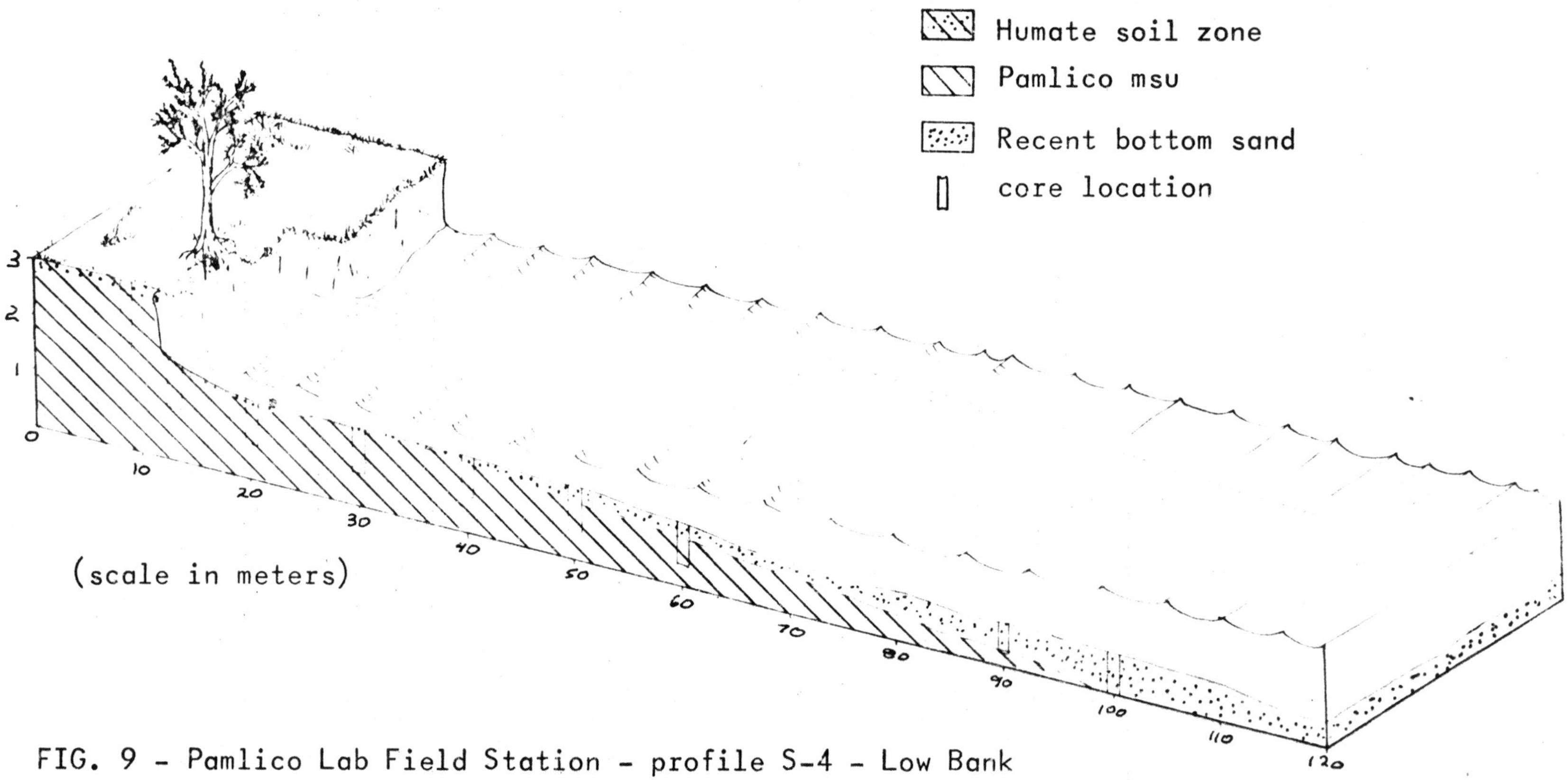


FIG. 9 - Pamlico Lab Field Station - profile S-4 - Low Bank

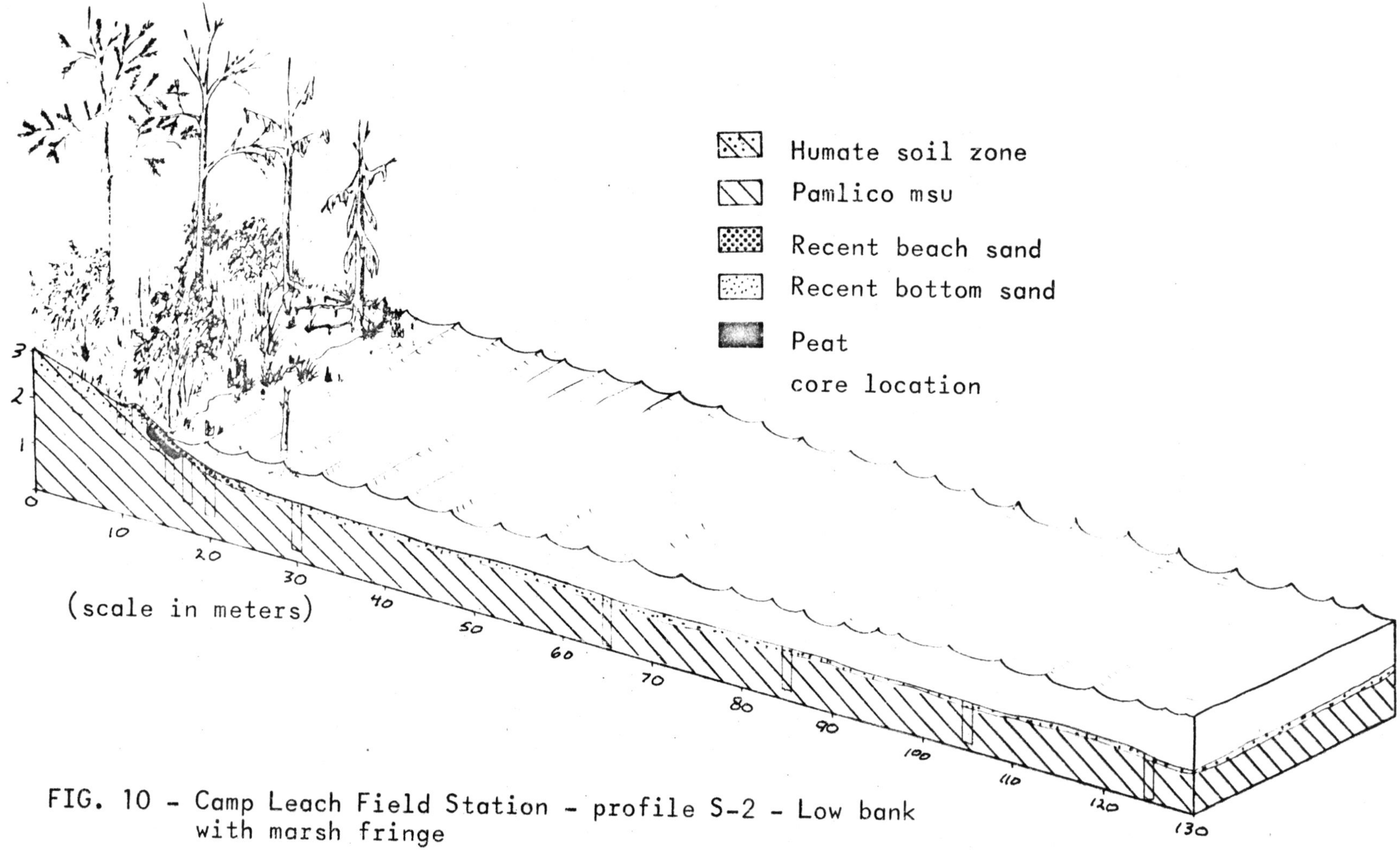


FIG. 10 - Camp Leach Field Station - profile S-2 - Low bank with marsh fringe

creeks and along reaches of the inner estuary where fringing cypress still persist to aid in trapping sand for marsh grass germination.

High Bank. High bank shorelines are defined as those sediment banks between 2.0 and 6.0 m above mean river level. They occur as areas of high relief on interstream divides, especially around Bath and Durham creeks. They also occur as topographic low areas along bluff shorelines and as transition zones between areas of bluff and low bank (i.e. at the Suffolk Scarp). The high bank shorelines are moderately susceptible to erosion along the trunk of the Pamlico River.

The high banks east of the Suffolk Scarp are generally composed of a basal tan to buff clayey sand, usually with irregular rippled and discontinuous horizontal clay laminae. The upper 2.0 m is heavily iron stained and mottled by soil development which is capped by 0.5 m of sandy humate soil. The humate soil zone is held together by root mass and often overhangs the edge of the bank. High banks along the eroding Talbot Terrace often contain a basal stiff clay 2 to 3 m thick which is more erosion resistant. High banks commonly have vertical exposed scarps which are undercut toward the base and have a sand beach at their base (Fig. 11). Undercutting may occur at the base and almost always just below the overhanging humate soil zone.

The bank top vegetation is an upland forest dominated by pine, oak, hickory and sweet gum. Undercutting of the bank by wind and wave action causes trees to topple down the bank, tearing out roots and attached bank material and leaving large cusps along the upper part of the bank. Large and small trees and clayey sand clasts up to 0.6 m in length litter the sand beach; this is evidence of active erosion. Riggs, O'Connor, and Bellis (1978) found that high banks are generally eroded during severe storms when onshore waves overstep the sand beach and break directly on the base of the bank. The undercut bank then overhangs the beach where it eventually

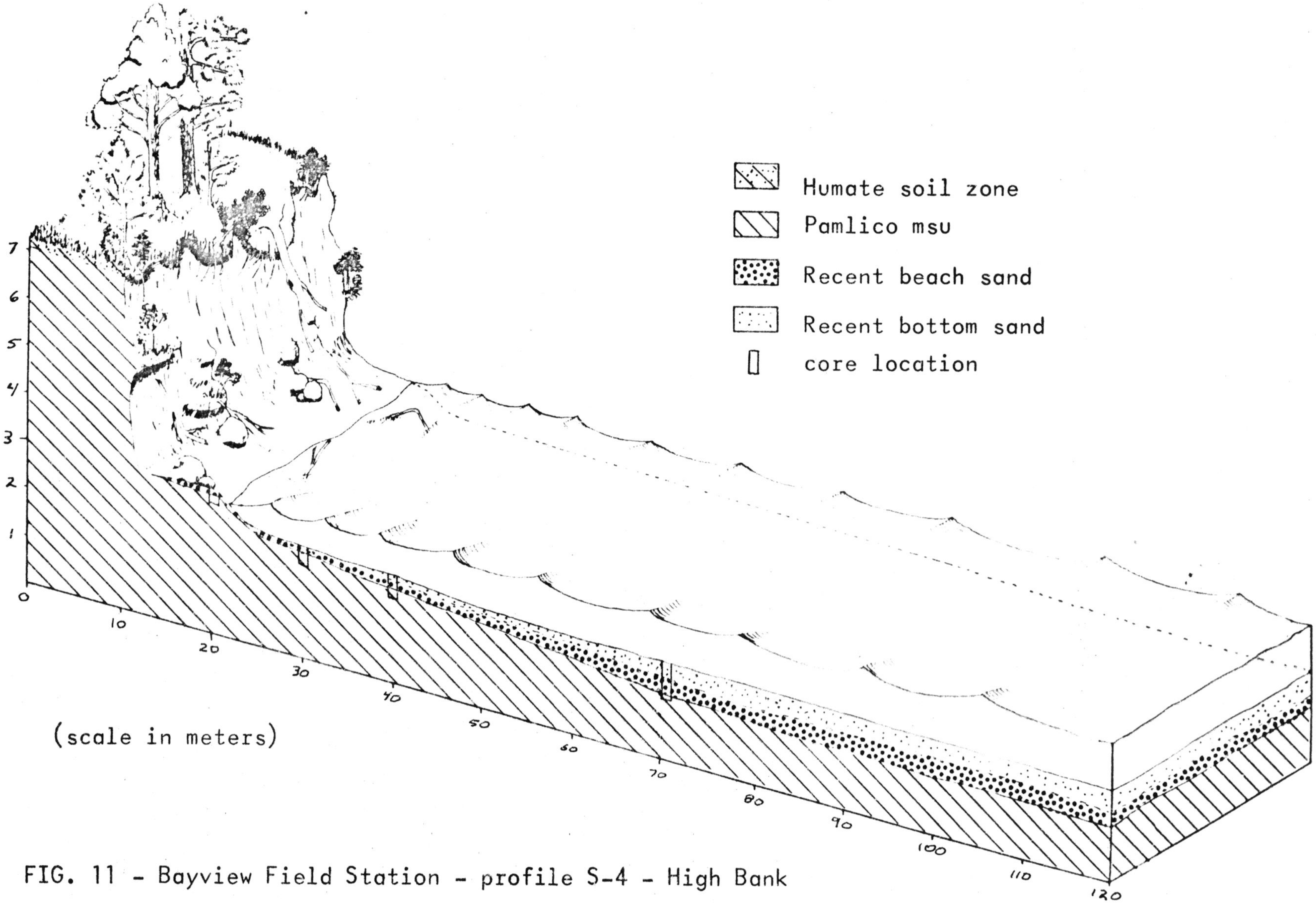


FIG. 11 - Bayview Field Station - profile S-4 - High Bank

collapses. These fresh sediments are reworked by the waves and temporarily broaden the beach. Fallen trees and brush act as natural groins and help to stabilize the beach. If vegetation of any form can become established either on the beach or on the bank, it will absorb much of the wave energy and decrease the rate and extent of shoreline recession.

Slumping of sections along the high banks is common. A large portion of the bank may collapse at one time often carrying living trees along down to the base of the bank. Sometimes these slump blocks will persist for extended periods of time, particularly if the transported trees become rerooted with the subsequent growth of stabilizing grasses. These stabilized slump blocks temporarily protect the *in situ* bank from erosion.

Sediments eroded from the high bank are carried offshore by the same basic wave processes acting on low banks and all other shorelines as well. Since a greater volume of material is being derived from the erosion of high banks than from low banks, the surface of erosion (clayey pavement) is usually completely sediment covered. At the Bayview monitor station, No. 4, the medium to very coarse beach sands are buried by the fine sands of the fine sand apron. Thus, the nearshore sand apron has a basal clean, coarse sand overlying the erosion surface and an upper layer of fine organic-rich sand.

Bluff. Bluff shorelines are those sediment banks greater than 6.0 m above mean river level. Bluff shorelines occur only west of the Suffolk Scarp on the south side of the Pamlico River Estuary. Over half the bluff shoreline is temporairly stabilized by vegetated slump material. Their susceptibility to erosion is low mainly due to the smaller fetches in the inner estuary. The bluff shorelines are usually broken by low and high bank shorelines where small drainages breach the bluff and cypress headlands extend into the estuary.

Bluffs generally consist of a basal unit of tight, bluegrey clay and moderately to tightly consolidated tan to buff sand. The basal clay when present tends to resist undercutting by wave action and forms a very distinctive surface of erosion on the estuary floor. An unconsolidated water bearing unit of buff sands and clayey sands forms the upper unit. The upper several meters of this upper unit is an iron stained and mottled soil horizon covered by 0.5 m of sandy humate soil. The actively eroding bluff is a vertical scarp with fallen trees and clay boulders lying on the beach (Fig. 12). The bluff top vegetation is an upland forest of oak, hickory, pine, and sweet gum.

Slumping often occurs where ground water seeps out of the upper sand unit when it occurs on top of the impermeable basal clay. Due to the major lithologic change and the discharge from the surface aquifer, large blocks of the upper sand unit with the bank top vegetation commonly slide down to the beach below. As with the high bank example, sometimes the trees survive the fall, reroot themselves, and along with subsequent new grass growth, help stabilize the slump block (Fig. 13). This stabilized slump block is rather effective at abating further shoreline erosion until a large storm or multiple storms wash it away and the erosion cycle is renewed. While the base of the bluff is protected by slump blocks, the upper part will still be undercut and eroded by wind, rain, and frost action adding sediment to the top of the slump block.

Bluff erosion is an important source of fresh sediments for the sand beaches along the base of most bluff shorelines. Locally patches of marsh grass will become established along the waterline and aid in trapping sand. Riggs, O'Connor, and Bellis (1975) found that considerable volumes of vertical bank sediments may be lost each year in the Pamlico Estuary, however, the actual shoreline recession in meters is low, less than 0.5 m/yr.

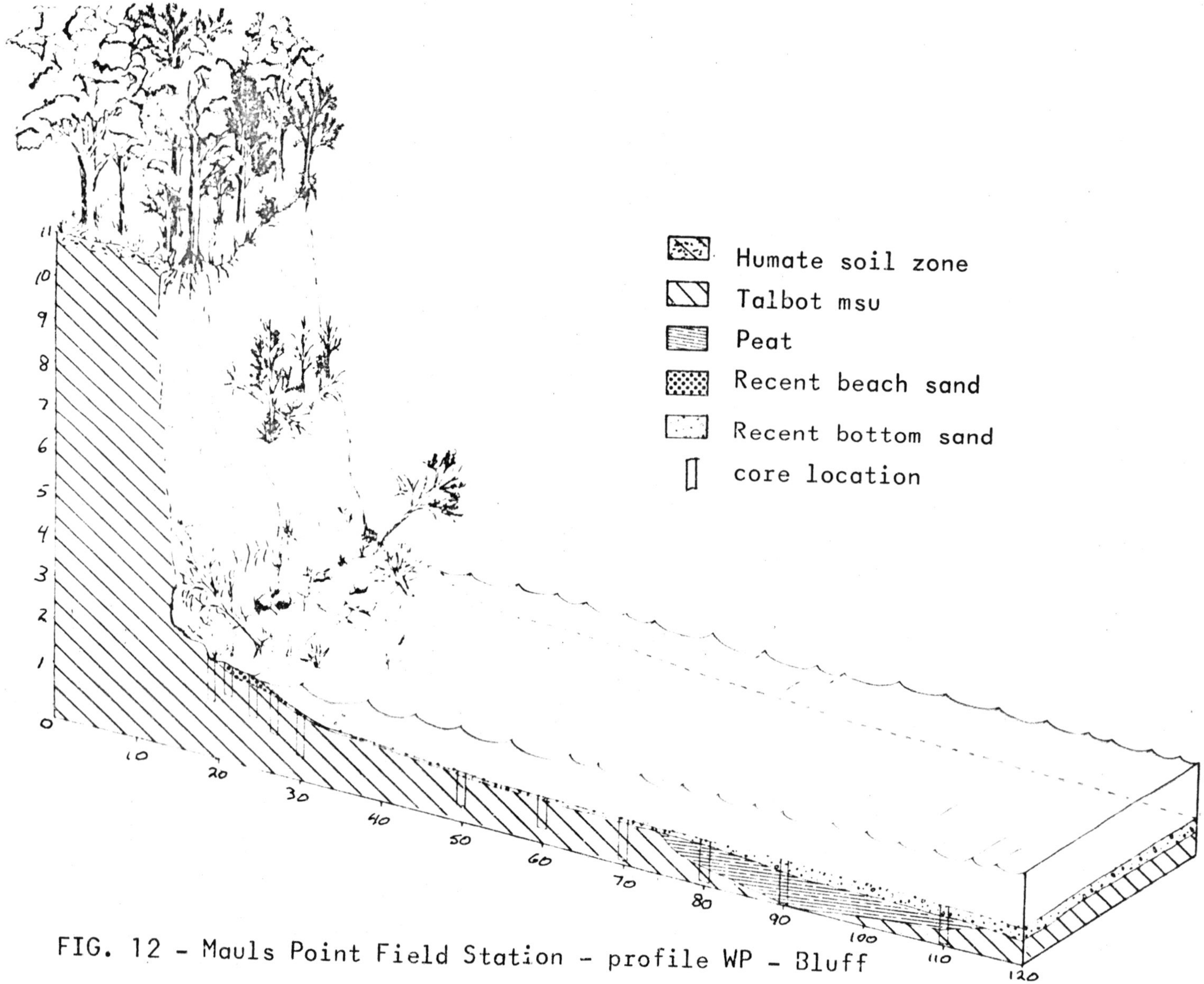


FIG. 12 - Mauls Point Field Station - profile WP - Bluff

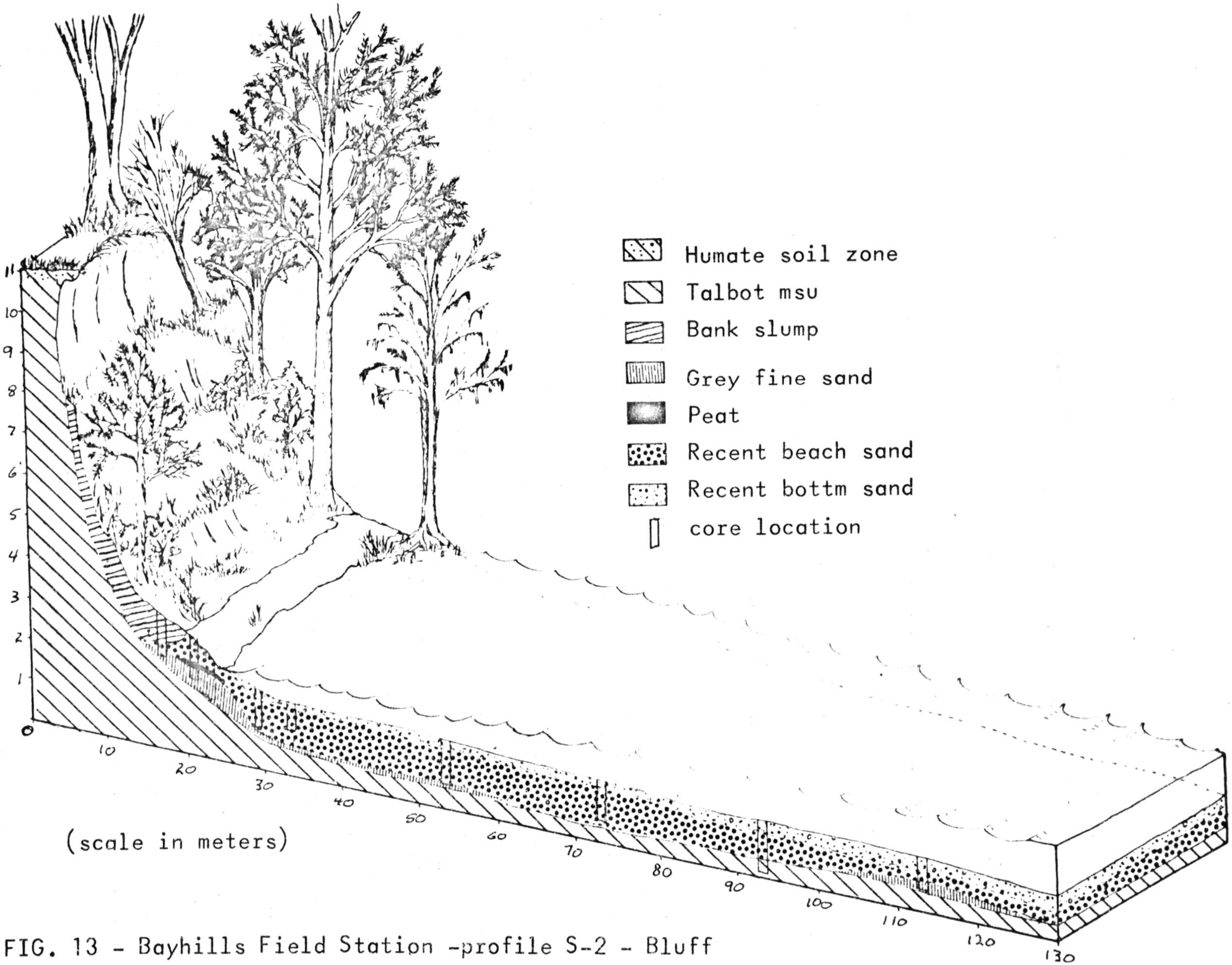


FIG. 13 - Bayhills Field Station -profile S-2 - Bluff

Eroded sediments are differientiated by wave action with the coarse sands concentrated on the beach and the finer sands deposited offshore as part of the sand apron. The clays are transported in suspension and are deposited in the central deeper portions of the river during subsequent low energy conditions. Gravels occur on the beaches adjacent to where relict indurated iron cemented channel sands are being eroded from the bluff. These relict channels are composed of very coarse sands and gravels characterized by trough cross bedding.

The erosion surface in front of bluff shorelines in covered by 0.2 to 1.0 m of sediment forming the sand apron. The basal apron sands overlying this clay are often iron stained, coarse beach sands. The upper unit is characterized by fine-grained organic-rich sands. This sand apron sediment sequence is similar to that occuring in front of the high bank.

II Marsh Shorelines

Marsh constitutes the most extensive type of shoreline in the Pamlico River Estuary (Table 1). Most of the marsh shoreline occurs in the outer estuary. An extensive marsh peat plain as much as 500 m wide in some areas forms the edge of the estuary. Less extensive marsh shorelines occur along low lying embayed drainages and lateral creeks in the inner and middle estuaries. Marsh shorelines also occur as narrow fringing marsh in front of sediment banks within the lateral estuaries and creeks. Marshlands function as effective natural barriers between waves and the easily eroded sandy soils of the sediment banks. When flooded by storms the marshes dissipate wave energy before it reaches the sandy bank. Marshes are characterized by oxygen deficient, water saturated organic sediment (peat) which is subject to periodic flooding by fresh to brackish water.

Marsh peats build vertically and laterally in response to a rising sea level. The extensive salt marsh plains of the outer estuary initially began as narrow fringing marshes of lateral estuaries when sea level was slightly lower (Foley, Hardaway, Hartness, and O'Connor, 1977). Riggs, O'Connor, and Bellis (1975) described the succession as follows. With a rising sea level and flooding, the fringing marsh expands laterally landward up and over the low interstream divides. Wherever the slope is gradual and the elevation low, the rising water table drowns the shallow root systems of the upland forest causing increasing stress. The trees eventually die and fall into the invading marsh. Vines such as poison ivy and catbrier, and evergreen shrubs like wax and salt myrtle exploit the transition zone between marsh and forest. Increased flooding of the system opens the riverside of the marsh to increased fetch increasing the erosive forces of wind and waves on exposed marsh peat shorelines. The marsh shoreline is commonly characterized by a 1 to 2 m scarp at the waters edge. Marsh peats are usually thickest on the eroding edge and thinnest where they lap onto more upland forests. As the marsh shoreline recedes, the stumps and logs of the initial drowned forest are re-exposed on the floor of the estuary. Figure 14 shows an eroding marsh shoreline in Swanquarter Bay.

The marsh shorelines are very irregular as compared to the relatively straight sediment banks. They are characterized by coves and headlands which range in width from 1 to 2 m to 100 to 1000 m.

A typical vertical section through the marsh and the underlying peat reveals the following stratigraphy. The surface layer is between 0.2 and 0.5 m thick and consists of densely intertwined networks of stems and roots. This matted layer represents the zone of living marsh grasses. The intermediate zone is 1.0 to 2.0 m of soft, decayed, fibrous, clayey peat with abundant logs and wood material in the basal portion. This is underlain by a sand which contains the soil of the old forested upland.

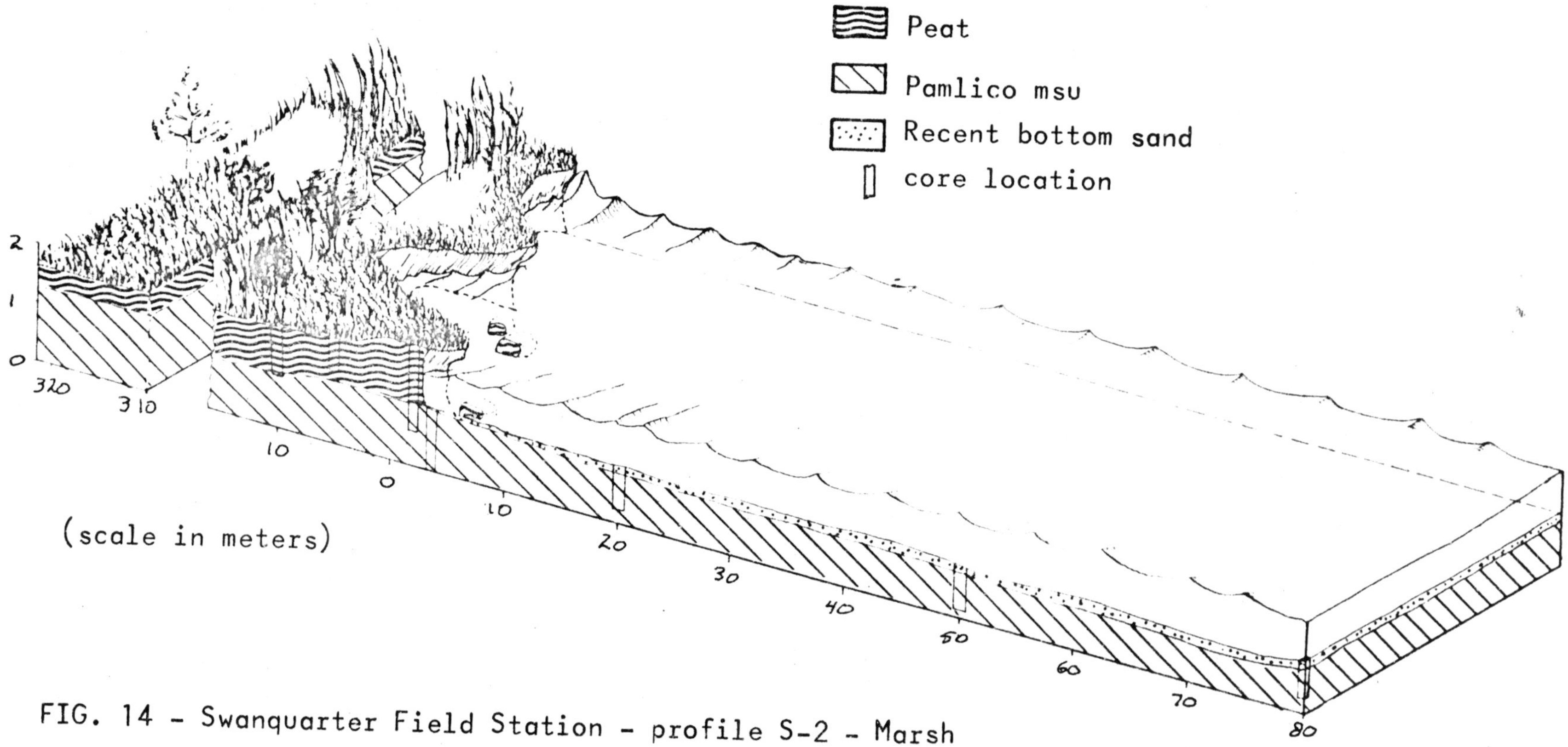


FIG. 14 - Swanquarter Field Station - profile S-2 - Marsh

The soft intermediate layer of the peat is readily undercut by wave erosion during low wind tides. This causes the tough upper mat to flop down and absorb wave energy until it breaks off allowing the erosion of the intermediate peat to continue. Algae on the peat sediment surface also aids in binding the marsh shoreline.

The extensive marshes in the Pamlico River system are composed primarily of black-needle rush (Juncus roemerianus)with some saltmarsh cordgrass (Spartina alterniflora) occurring along the outer fringes of the marsh. Fringing marshes in the upper estuary are often composed of saltmarsh cordgrass and corn spartina (Spartina cynosuroides).

Eroded organic material from the peats is carried offshore and deposited with fine sand forming a thin sand apron similar to low banks. The organic content of the fine sand appears higher than the sand apron off sediment banks. The surface of erosion is covered by a thin fine sand veneer similar to the situation off low bank shorelines. Figure 14 depicts the relationship between the surface of erosion, the sand apron, and the peat.

III Swamp Forest

The bald cypress (Taxodium distichum) is a major wetlands species of the freshwater river floodplains of north-eastern North Carolina. Its characteristic broad fluted base and shallow anastomizing root system with the familiar knee structures are well adapted to extensive periodic flooding of the fluvial swamp forest (Riggs, O'Connor, and Bellis, 1977). This species can readily tolerate salinities up to 5 ppt. and permanent water depths up to 1.5 m but the seeds must have periodic dry conditions for germination.

Riggs, O'Connor, and Bellis (1977) found that the distribution and occurrence of cypress within the estuarine system is a direct function of the evolutionary history of the estuarine transgression. The most extensive swamp forest shorelines occur along the leading edge of the trunk estuary and up the fresher headwaters of the lateral tributaries where the fluvial floodplain is being embayed by the transgression. This occurs in the Pamlico River around Washington and in Chocowinity Bay.

Riggs, O'Connor, and Bellis (1977) describe the evolutionary sequence of swamp forests as follows. With continued flooding in response to the transgression, the cypress shoreline slowly recedes by drowning back to the first fluvial terrace. At this stage there is a sediment bank shoreline with a primary cypress fringe preserved in the shallow waters in front of the bank (Fig. 15). The resulting primary cypress fringe helps to maintain the sediment bank shoreline by acting as a natural bulkhead. The cypress fringe filters the wave energy, slowing the rate of shoreline recession and actively trapping sediment, thus producing a broad sand berm in front of the sediment bank. The resulting high and somewhat protected sand berm can then become the site of development of heavy vegetative growth and cypress regeneration. A secondary cypress fringe develops which will take over with time as the shoreline slowly recedes and the primary fringe drowns out.

Secondary cypress fringes occur along many of the low bank shorelines and some high bank and bluff shorelines in the inner estuary west of the Suffolk Scarp. East of the scarp, cypress is generally not an important shoreline element, except in the fresher headwaters of the laterals, as it gives way to coastal marsh grass systems. According to Riggs, O'Connor, and Bellis (1977) this decline of cypress is in response to the increasing salinity, the very low slope, and the increasing wave energy levels which prevent germinated seedlings from surviving from year to year.

Riggs, O'Connor, and Bellis (1977) found that any permanent stream

FIG. 15 - Cypress Fringe, Mauls Point,N.C.

which has enough water flow to have a distinctive channel-floodplain system will embay and respond to the transgression in the same way as the trunk of the Pamlico River Estuary with cypress playing the same role. However, they found that any intermittent stream that does not have a well developed channel and flows into either the trunk or lateral estuaries will develop cypress headlands. The rate of shoreline recession of the adjacent higher interstream divides and their sediment bank shorelines is greater than the cypress dominated floodplain. Consequently, the cypress is left extending up to 100 m out into the estuary forming a major headland. Riggs, O'Connor, and Bellis believe that the resulting cypress headland acts as a natural groin field which modifies the wave energy and traps the sediment derived from the erosion of the adjacent sediment banks. This results in the development of fairly stable accretionary strandplains along both sides of the headland. Also, they believe this unique geomorphic inversion subdivides the estuarine shoreline into a series of depositionally and erosionally discrete compartments or reaches. Consequently, the headlands represent a small but important natural element in controlling the sediment processes of the estuarine shorelines.

IV Man-Modified Shorelines

Man-modified shorelines are any shorelines in the Pamlico River Estuary which have been altered in such a way as to disrupt the natural shoreline processes. This modification is done to slow or stop the effects of shoreline erosion or to "improve" the aesthetic nature of the shoreline. Bulkheads, rip-rap and groins are the most common modifications. Riggs, O'Connor, and Bellis (1978) found that over 5% of the shorelines in the Pamlico River system have been modified (Table 1).

Since low bank shorelines are most abundant, they are most heavily developed. They also are very susceptible to flooding and high erosion rates (Table 4). Thus, they are most often bulkheaded (Fig. 16). Bulkheading usually results in the loss of any sandy beach that may have existed and an increase in water depth directly in front of the structure. The vertical wall effectively resists wave action and erosion. However, erosion on the flanks continues and may even be accelerated, thus the subsequent need for more bulkheading on the flanks.

Marsh and swamp forest shorelines have experienced little development in the Pamlico River. However, marshes have been filled with dredged material and top soil in the past to create solid ground on which to build. This has generally been controlled and largely terminated by recent legislation.

The fewer bluff and high bank shorelines have been developed to some extent for second homes, especially the bluffs at Bayview. At Bayview a bulkhead was built at the shoreline, then the high bank sediment was bulldozed down behind it. This has been done along a continuous reach of shoreline and for the present appears to have stopped erosion. At Bayhills, portions of the bluff were bulldozed down onto the beach (Fig. 17) and grass planted along the graded slope. This has created an enlarged beach front for the property owners. Most of the bluff shorelines along the Pamlico River remain in their natural state; however development pressure continues.

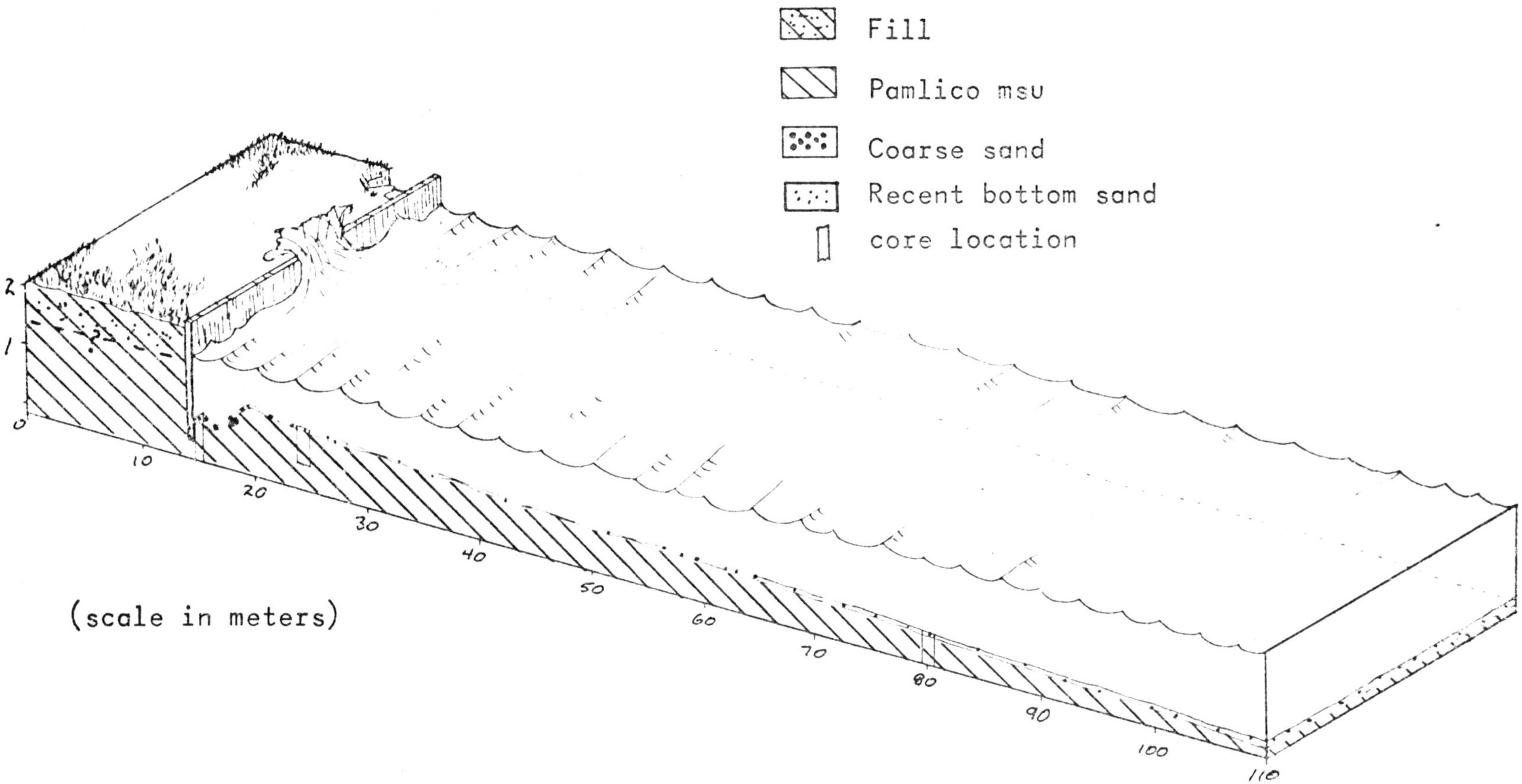


FIG. 16 - Wades Point Field Station - profile S-4 - Man-modified

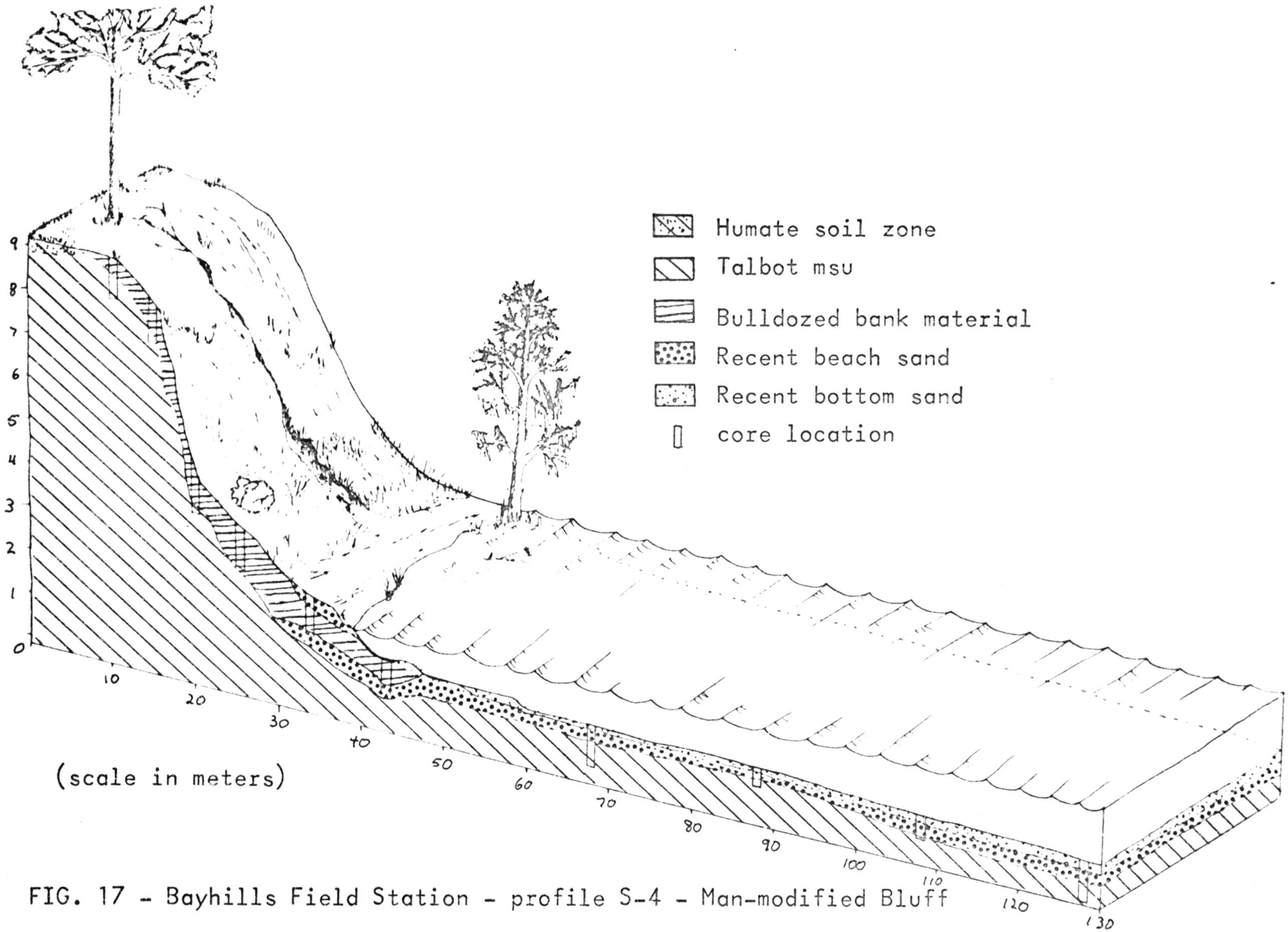


FIG. 17 - Bayhills Field Station - profile S-4 - Man-modified Bluff

MONITOR FIELD STATIONS

Field Methods

Ten monitor stations were established along the Pamlico River Estuary during the summer of 1977 for the purpose of studying the processes and rates of shoreline erosion (Fig. 6). Five of the stations are on the north shore and five are on the south. They extend from Chocowinity Bay on the west, east to Swanquarter Bay. The stations were chosen to represent the major variables affecting shoreline erosion as well as each shoreline type except swamp forest. Each monitor station was studied in terms of its geology and biology so that inherent characteristics of the shoreline type could be evaluated.

The following procedures were carried out at each station. First, a base map of the shoreline was prepared on herculene drafting plastic to prevent warping using a plane table and alidade. One permanent copper coated iron stake and numerous wooden stakes were set as reference points for the next two mapping periods. Second, one or two 100 m offshore profiles were made, usually from a control stake on or just behind the shoreline and run perpendicular to the shore. An offshore bathymetric profile was constructed using the plane table and alidade. Third, beach (if any) and river bottom surface sediment samples were taken along the profile(s) every meter for the first ten meters and then every ten meters out to the end of the profile. Fourth, one meter cores were taken onshore and offshore every 10 to 20 m using a four inch PVC pipe as the core barrel and a sledge hammer. Fifth, the surface samples and the cores were described and logged in the field using a binocular microscope. Sixth, distribution and abundance of vegetation were mapped both along the shore zone and in the offshore area along the profile.

A second mapping was done of each station about eight months later, during March of 1978, to establish specific shoreline changes over the fall and winter seasons. Changes in the bank were measured. Mapping was done on the original base map using a different colored pencil. The third and final mapping of the stations took place during November of 1978. The base maps appear in this section along with the descriptions of each of the monitor stations.

During the initial mapping period in the summer of 1977, the river level varied no more than $\pm$ 20 cm (except during storms). Bank heights were determined from the level of the river at this time. The river level was considered to be "normal" for this season and is herein defined to be "mean river level" for the remainder of this study.

Station No. 1 - Bayhills

The Bayhills station is located on the south side of the Pamlico River Estuary near the mouth of Chocowinity Bay (Fig. 6). The sediment bluff shoreline is oriented NW-SE with a perpendicular fetch toward the NE of about 2.5 km. The 230 m of mapped shoreline extended from a pier on the western boundary to a cypress headland on the east. The eastern 95 m (part A) is a natural bluff (Fig. 18) while the western 135 m (part B) has been modified and developed (Fig. 18). An intermittent drainage with a small cypress headland is the boundary between the two (Fig. 19).

The natural bluff, part A rises between 6.0 and 7.0 m above mean river level. The bank sediments consist of a basal very stiff blue-grey, slightly micaceous clay extending up to about 3.0 m above river level. The clay unit grades upward into a tan to orange, very fine to fine quartz sand with faint cross-bedding. The upper 2.0 m of the bluff becomes mottled and iron stained by soil development and culminates in a 0.4 to 0.5 m sandy humate soil at the surface. The mottled and sandy humate soil zones contain abundant tree roots from the forest on top of the bluff. The forest vegetation consists of dominantly oak, sweet gum, pine, and hickory.

The natural bluff has experienced considerable slumping in the past. The slump material occurs along the complete length of the natural bluff and covers the base of the bank as high as 4.0 to 6.0 m above mean river level(Fig. 13). Many small trees, shrubs, and grasses are growing on this slumped material including six to eight pines and gum (5 to 15 m in height). The upper few meters of bluff is a vertical scarp which becomes undercut below the sandy humate soil zone exposing many tree roots. Erosion of this upper bank procedes by rainwash, runoff, and frost action.

A sandy beach occupies the area from river level to the lower limit of slump. Grasses have stabilized the back beach area directly in front

part A - Looking east from A/B line.

part B - Looking west from A/B line.

FIG. 18 - Bayhills Field Station, July 1977

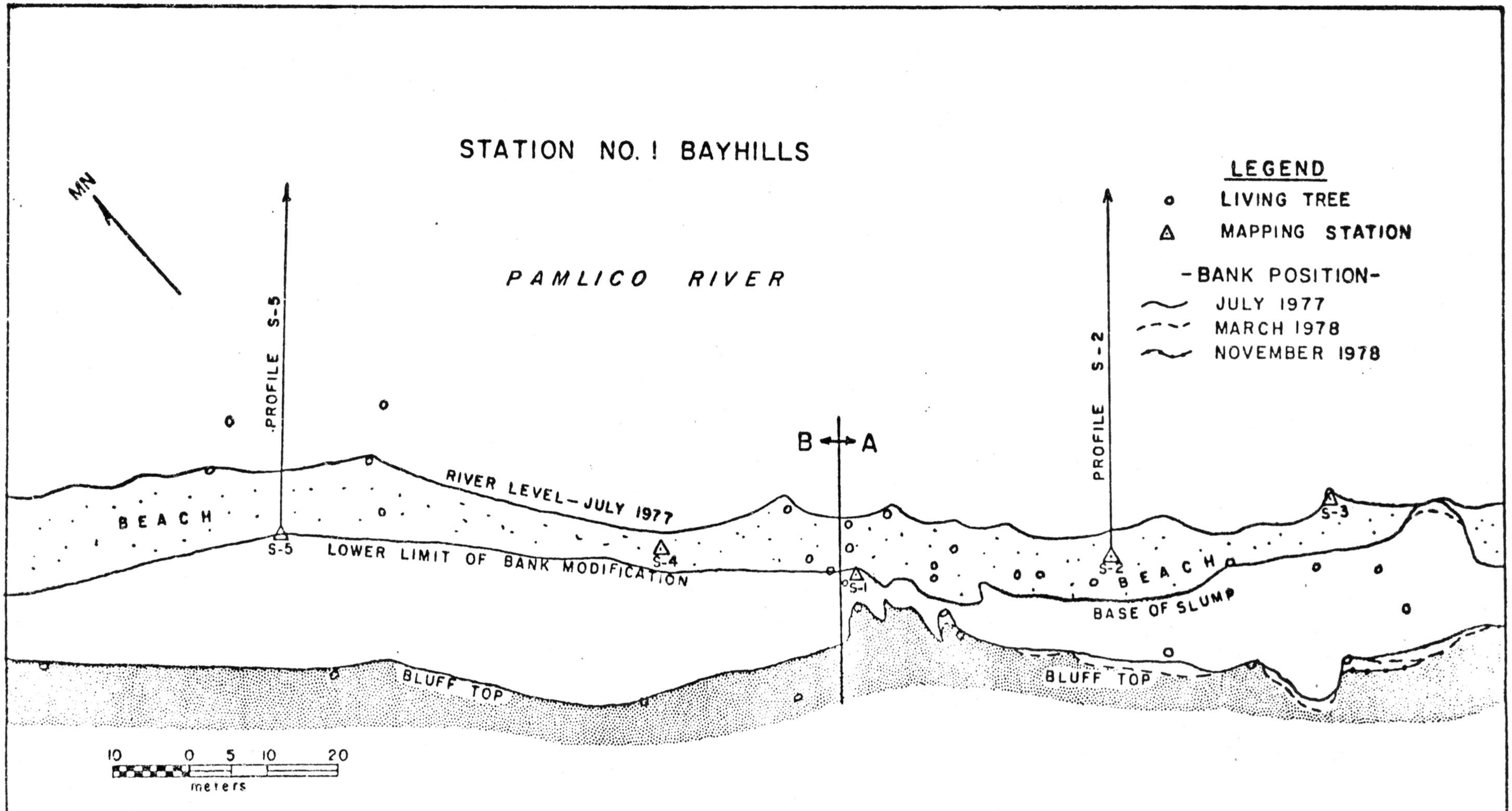


FIG. 19-BAYHILLS MONITOR STATION

of the slump zone. Erosion of the slump material supplies a continuous source of sand to the beach. Four small patches or tussocks of black needlerush (Juncus roemarianus) have established themselves along the shoreline proper and have formed small headlands by trapping sand.

Eel grass occurs in beds or patches in the nearshore area during the summer and fall but were difficult to map. These beds of eel grass mostly occur along shorelines of the inner and middle estuary and may aid in slowing down wave action directed against the shoreline. In the winter they die and are probably not a factor. Many old logs occur along the shoreline and nearshore area and act as small groins, trapping sand on each side. The eel grass and logs in the nearshore area also occur riverward of the modified reach (part B) of bluff.

The modified bluff (part B) was bulldozed down to the beach in 1975 (Fig. 17). The bluff top has been rounded and the bank graded to about a 1:1 slope. The graded bluff was planted in grasses also to aid in stabilizing the bank. In 1977, numerous gullies or rills were present along the slope as a result of runoff during heavy rains. By November, 1978 the slope was well stabilized by the grass. The bank top had been cleared except for a few large shade trees and domesticated grasses had been planted.

The modified bluff has the same lithology as the natural bluff and responds to the same sedimentary shoreline and nearshore processes. When the modified bluff was bulldozed, bank sediments and any slumped material that may have been present were both pushed down to the beach zone. A sand beach occurs between the base of the graded slope and the river. The beach is continuous from the natural bluff but is 3 to 6 m wider. The storm beach terrace occupies the upper half of the beach zone and contains abundant grasses and cypress seedlings. These seedlings were one to two years old in 1977 and were still alive in mid 1979. This new secondary cypress zone will help stabilize and protect the modified bluff.

The nearshore sand apron in front of the natural bluff varies from 0.5 m thick at the shoreline, to about 1.3 m forty meters offshore. A basal very coarse sand layer of varying thickness overlies the surface of erosion in the basal blue-grey clay unit of the bluff stratigraphy. The coarse sand zone is overlain by a thin layer (0.2 do 0.5 m) of fine-grained organic-rich sand which thickens riverward.

The nearshore sand apron in front of the modified bluff does not occur everywhere, and where it does occur it is only half as thick as that in front of the natural bluff shoreline. An indurated, iron-cemented, cross-bedded very coarse sandstone (hardpan) is locally exposed in the nearshore area. This hardpan is part of the basal bluff stratigraphy and forms a pavement on the river bottom. This unit supplies the very coarse sands and gravels which occur in the nearshore and beach zones.

Bayhills is exposed to relatively short fetches in the inner estuary region and has a relatively small erosion rate for the sixteen month study period (Table 5). Measurable erosion only took place along the upper parts of the vertical scarp of the natural bluff shoreline (Fig. 19). Most erosion occurred during the winter season with high energy storms and frost heaving acting as the major erosional agents. The stabilized slump block has protected the base of the natural bluff. The low erosion rate is in part the result of exposure to short fetches and thus low wave energies which has allowed for the stabilization of the slump material. The modified bluff is somewhat protected by its wider beach zone which is stabilized with grasses.

Bayhills monitor station scored a 38 on the Erosion Potential Scale (Table 2). This places Bayhills in the low erosion potential category or less than 0.6 m/yr. The natural bluff top experiences an erosion rate of

0.5 m/yr and if the modified bluff had remained in its natural state, similar erosion would have probable occurred. The modified bluff suffered virtually zero erosion during the sixteen month study period, thus lowering the overall erosion rate for the station.

The Erosion Potential Scale asseses only the potential for erosion of a given natural or unmodified shoreline and the modified bluff may have experienced no erosion over the short study period but the erosion potential does exist. The test for bluff stability will come with the next severe tropical strom or "northeaster".

Station No. 2 - Mauls Point

Mauls Point is the easternmost point of Blounts Bay on the south shore of the Pamlico River Estuary. The monitor station itself is located on the NW side of Mauls Point (Fig. 6). It represents a sediment bluff shoreline type (Fig. 20). The base map extends 155 m between two large cypress headlands. The shoreline is oriented NE to SW with an oblique fetch of about 10 km NW up the estuary towards Washington. The bluff is essentially in its natural state but there has been some bank modification in the middle and northeast part of the area. I have divided the station into two parts: part A is the natural bluff on the west and part B is the modified bluff on the east (Fig. 21).

The natural bluff (part A) rises about 9.0 m above mean river level at control station S-2. The bluff top slopes gradually westward down to less than 1 m above mean river level where it slopes into a low intermittent drainage with a cypress headland composed of five large dead trees. The bluff sediments are a complex sequence of trough and tabular cross-bedded and rippled, clayey quartz sands and are characterized by laterally continuous thin clay layers (1 to 5 cm thick). The upper 2.0 m is an iron-stained and mottled soil zone which is capped by about 0.5 m of sandy humate soil. The bluff top vegetation is an upland forest of oak, sweet gum, pine, and hickory.

Erosion is quite obvious along the natural bluff. The bank is a vertically exposed scarp from the top down to the beach with no large slump blocks. Some undercutting occurs (0.5 to 1.5 m deep) beneath the upper sandy humate zone which often flops down over the bank. Some clayey sand slump material from the bank accumulates along lower parts of the bluff along with fallen trees and shrubs with bank material attached to the roots.

part B - Looking south from pier.

part A - Looking west from pier.

FIG. 20 - Mauls Point Monitor Station, July 1977

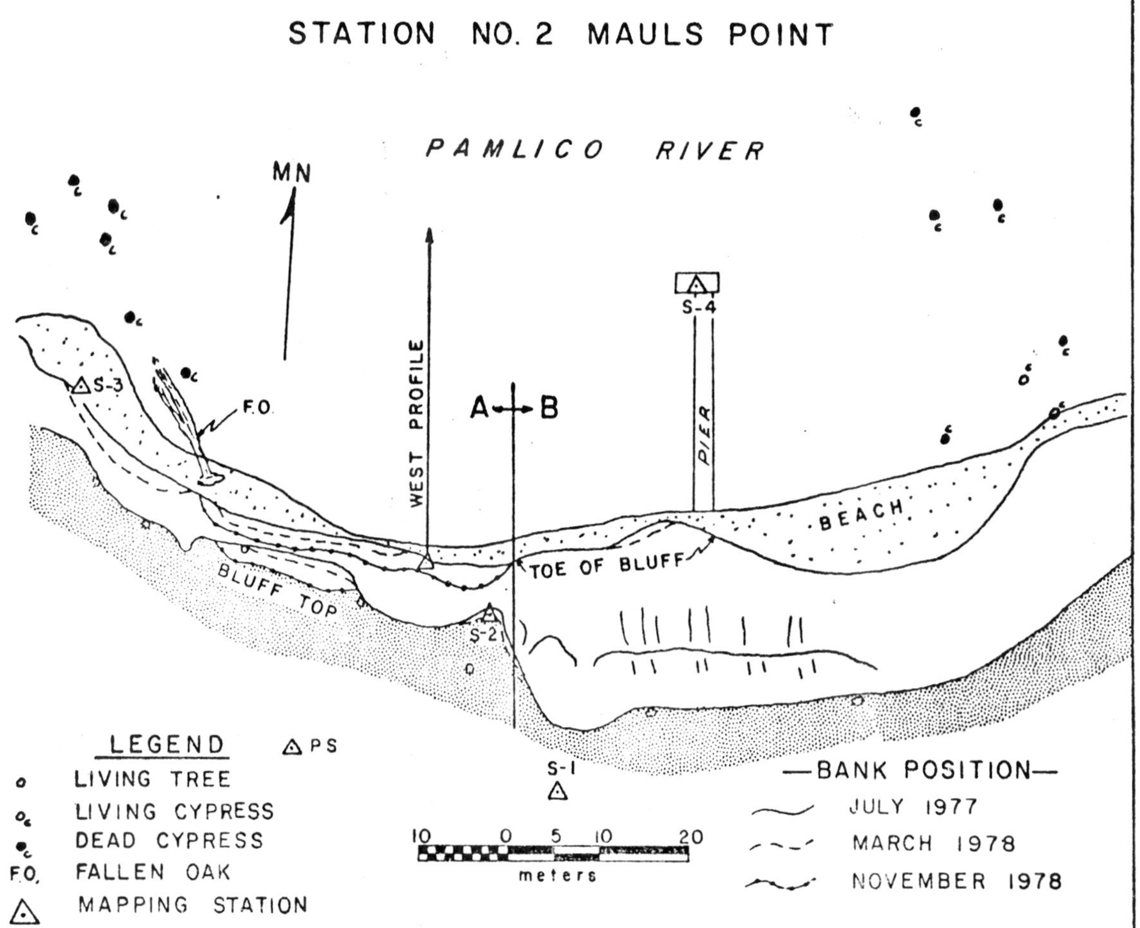


FIG.21-MAULS POINT MONITOR STATION

A large fallen oak tree occurs near the cypress headland on the southwest that left a 15 m diameter cusp in the bank top. A 1 to 5 m wide sand beach occurs between the bluff and the river. Numerous logs and dead shrubs lie along the beach but there is no living stabilizing vegetation.

The natural bluff was modified for about 50 m northeast of control station S-2. The modification appears to have involved clearing the trees and vegetation off the bluff top, the side of the bank, and the beach zone. The vertical bluff was graded down to the beach, but unlike Bayhills, no grasses were planted. Erosional gullies created by rainwash and runoff have since eroded the bank back to a vertical scarp in many places.

Pine trees have been planted on the upper portion of the sloping bluff top to aid in stabilizing it. Beach grasses and some cypress seedlings have become established along the beach zone and in front of the graded bank. They now aid in stabilizing the back beach area. Behind the bluff top, the forest has been cleared and domestic lawn grasses planted. The natural or unmodified bank occurs again near the east edge of the base map where it is situated behing a large cypress fringe which continues eastward around Mauls Point.

The nearshore area of the Mauls Point monitor station has summer patches or beds of eel grass and many old logs. The sand apron over the surface of erosion is about 20 cm at 100 m offshore (Fig. 12). No measurable shoreline erosion of the modified bluff was recorded at the Mauls Point monitor station. However, the natural bank lost 0.5 m/yr over the sixteen month study period with most of the erosion occurring between the spring 1978 and fall 1978 mapping periods.

Mauls Point scored a 51 on the Erosion Potential Scale (Table 5), on the border line between low and intermediate erosion potential categories (0.6 m/yr). This is a close correlation with the actual rate of natural bluff erosion. To date, the modified bluffs at Mauls Point and Bayhills have experienced little or no erosion over this study period. This could support bank modification as a means of erosion control. However, the potential for 0.6 m/yr of shoreline erosion may occur and actually increase with time as the erosional processes slowly encroach upon the modified bluffs.

Some basic differences exist between Bayhills and Mauls Point. The basal blue-grey clay at Bayhills is absent at Mauls Point which may account for the lack of a stabilized slump block at Mauls Point. At Bayhills the stiff clay zone apparently slumps in large sections or blocks whereas the sandier banks at Mauls Point erode in smaller slumps which come down with fallen trees and are washed out by wave action. The nearshore sand apron is much thinner at Mauls Point than at Bayhills. I believe that exposure to a longer fetch at Mauls Point from the northwest, which is the dominant winter wind direction in this region (U.S. Naval Weather Service Command), accounts for this. Instead, the eroded bank sediments are carried along shore, during high energy storms, eastward around Mauls Point to accumulate as an accretionary spit on the east side of the point.

The bluff shoreline along the southern shore of the inner estuary from Bayhills to Blounts Creek are mostly stabilized banks and are also exposed to relatively short fetches. Whereas, the bluff shorelines from Blounts Creek to Mauls Point are almost all vertical scarps with very little slump block stabilization. The corresponding perpendicular fetch is three times longer than any bluff shoreline to the west and it directly faces the northwest, a dominant winter wind direction.

Station No. 3 - Camp Leach

Camp Leach is about 1 km east of Ragged Point on the north side of the Pamlico River Estuary (Fig. 6). The mapped shoreline is located at the east end of the Camp Leach property. The base map consists 115 m of fringing marsh shoreline (Fig. 22) which is oriented east-west with a perpendicular fetch of 4.0 km south across the Pamlico River. More than a 25.0 km long oblique fetch occurs to the southeast and about 5.0 km southwest a fetch occurs across the river into Blounts Bay (Fig 6).

The fringing marsh shoreline is very narrow, from less than 1.0 m to a maximum of 3.8 m wide. The marsh quickly grades into a low sandy upland with pine tree vegetation. The fringing marsh vegetation along the mean river level is mostly black needlerush (Juncus roemerianus). The needlerush grows on a peat substrate about 0.5 to 0.8 m thick on the river side to to 0.0 m about 4.0 m landward where it grades into the sandy soil of the forested upland. The shoreline is irregular with small marsh grass islands or tussocks at mean river level. In 1977 six headlands along the shoreline were composed of needlerush covered peat and the adjacent cusps were filled with sand. The headlands were severely eroded during the winter of 1978.

From the needlerush along the shoreline, the vegetation grades landward to a transition zone between marsh and forest. This transition zone includes salt reed grass (Spartina cynosuroides), high water shrub (Iva frutescens), groundsel tree (Baccharis halimifolina), and the common wax myrtle shrubs (Myrica cerifera). The width of the transition zone varies, occurring at slightly higher elevations than the needlerush and often resulting from the build up of washover sand behind the shoreline. In the sand filled cusp in front of control station S-4, where the peat is absent (Fig. 23), the sand extends from the river onto the sandy upland.

FIG. 22 - Camp Leach Field Station, July 1977.

Looking east from 30m offshore and 50m west of field station western boundary.

STATION NO. 3 CAMP LEACH

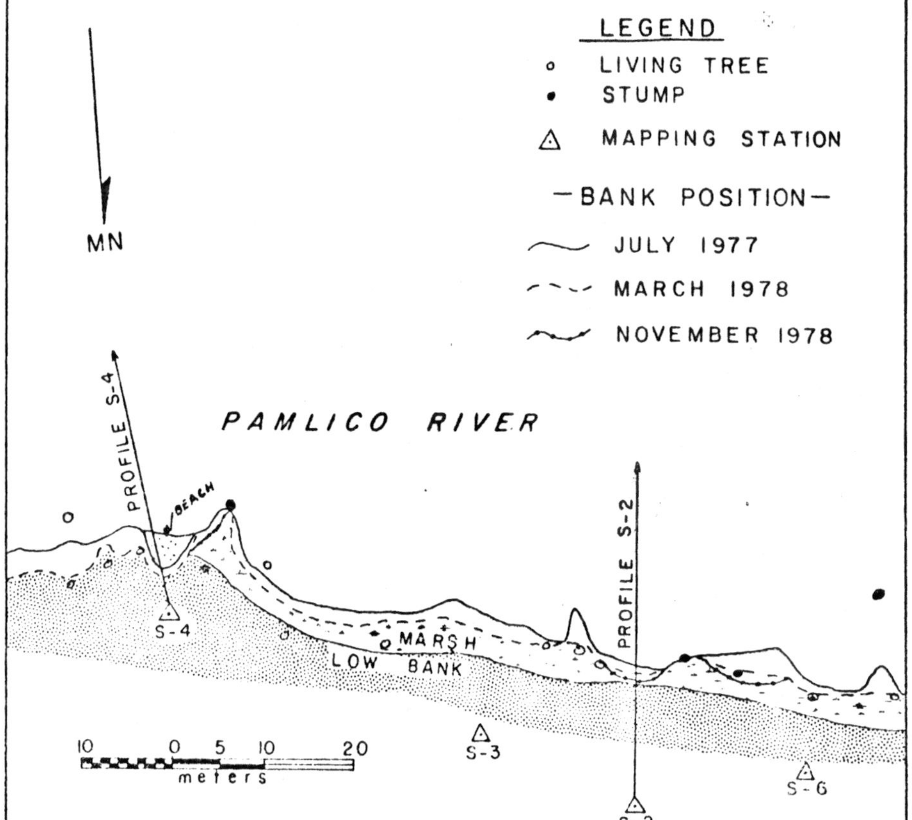


FIG.23-CAMP LEACH MONITOR STATION

The sandy upland, behind the transition zone, rises to about 1.2 m above mean river level (defined as the lower limit of active needlerush growth on the peat). Core data shows that the upland consists of 0.5 m of very sandy humate soil overlying a mottled, iron-stained, slightly clayey sand. The trees are pine and sweet gum, many of which are greater than 20 m high.

Many stumps and submerged logs occur in the nearshore area, out about 20 m from the needlerush line. The stumps are cypress and may reflect a time in the past when a cypress fringe occupied its shoreline position. The sand apron is less than 30 cm thick within the 100 m nearshore zone. The sand apron apparently supplies sand for the shore zone and washover zone.

Almost the entire length of the monitor station experienced some shoreline recession during the high energy winter period between the first and second mapping periods (Table 5). The actual yearly erosion rate for the sixteen month study period was 0.7 m/yr. The Camp Leach monitor station recieved a 51 on the Erosion Potential Scale (Table 2). The erosion potential for Camp Leach just falls into the intermediate erosion potential category which encompasses average erosion rates between 0.6 and 1.2 m/yr. Thus, there is a fair comparison of the actual erosion rate and the erosion potential of the Camp Leach shoreline for the study period.

Station No. 4 - Bayview

The monitor station at Bayview is about 0.5 km east of Plum Point at the entrance to Bath Creek (Fig. 6). The base map includes 194 m of shoreline (Fig. 25) consisting of both high and low sediment banks (Fig 24). On the north is 94 m of high bank (part A) whereas the 100 m to the south (part B) is low bank. The shoreline is oriented roughly NW-SE with a perpendicular fetch across the Pamlico River of about 5.5 km. There is an oblique fetch west across the mouth of Bath Creek of 1.2 km.

The low bank shoreline (part B) has a bank top which is less than 1.0 m above mean river level. The bank top vegetation is a very dense growth of shrubs and pine trees. The sediment bank consists of a mottled tan to orange clayey sand between 0.4 and 0.8 m thick. This clayey sand is capped by 0.5 m of a sandy humate zone which is severely undercut by daily wave action. As the clayey sand bank recedes, it leaves the entwined root mat which may extend outward more than a meter over the waters edge. The shrubs in and along the bank are mainly the marsh elder (*Iva frutescens*), the groundsel tree(*Baccharis halimifolia*), and wax myrtle (*Myrica cerifera*).

No sand beach occurs at the base of the scarp. The nearshore area of the low bank shoreline contains many logs and stumps. Between 10 and 15 m offshore there occurs an almost straight line of dead cypress tree trunks and stumps (Fig. 25). These are probable remnants of floodplain vegetation and also indicate a shoreline position and/or a cypress fringe in the past.

About 4.0 m landward of the middle of the low bank shoreline, the low bank abruplty rises to about 4.0 m above mean river level. This rise has a 5:1 slope with abundant upland forest vegetation along the slope and bank top. Proceeding north from point "X" on the base map (Fig. 25), the low bank gets narrower in width. At the division line separating part A from part B, the landward scarp intersects the river forming the high bank shore-

part B - Looking south from A/B line.

part A - Looking east from A/B line.

FIG. 24 - Bayview Field Station, Sept. 1979.

STATION NO. 4 BAYVIEW

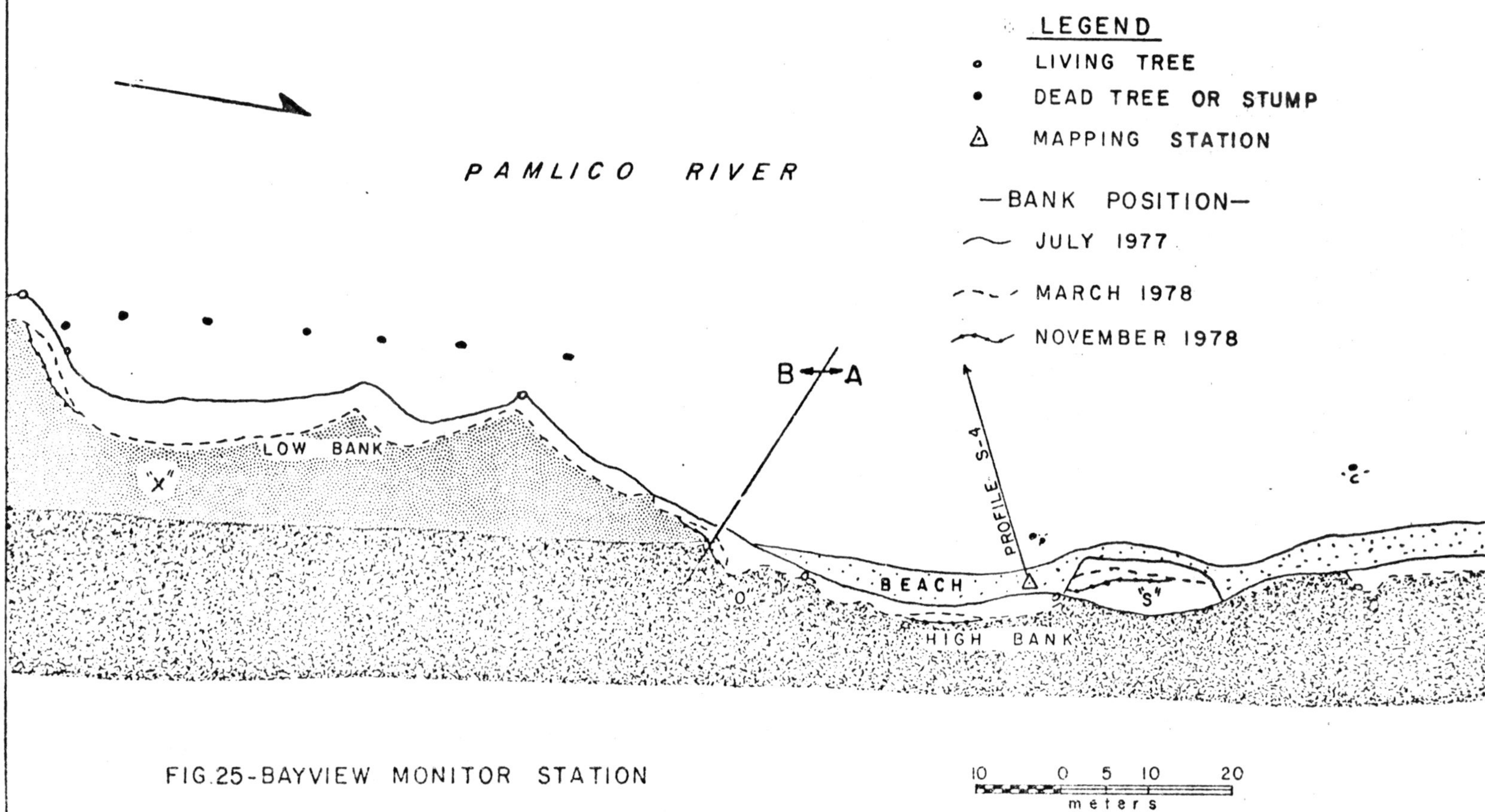


FIG. 25-BAYVIEW MONITOR STATION

line of part A. In front of the high bank is a sand beach which continues northward.

The high sediment bank (part A) rises 3.0 and 4.2 m above mean river level. The high bank is a vertically exposed scarp with a 2 to 4 m wide sand beach at its base. Many fallen trees from the bank top and clayey sand clasts from within the bank occur on the beach at the base of the bank. One large vegetated slump block occurs at point "S" on the base map. The bank top vegetation is that of an upland forest dominated by oak, pine, sweet gum, and hickory.

The high bank sediments consist of a basal 2.0 m of tan to buff interbedded sands and clays. The clay occurs as continuous planar rippled laminae 1 to 3 cm thick. The sands range from very fine to coarse with up to 5% pea gravel. The intermediate unit is a 1.5 m iron-stained and mottled sandy clay. Much of the clay bedding has been destroyed by soil development. The upper unit is 0.3 to 0.5 m of sandy humate soil which is severely undercut exposing many tree roots. This undercut surface usually flops down over the bank.

Fallen trees and logs litter the beach and nearshore area. Two in-place stumps occur in the nearshore area off the high bank shoreline, one 4.0 m and the other 8.0 m offshore. The stump marked "P" on the base map appeared to be a pine stump. It either is an erosional remnant from a vegetated slump block or grew in place along a low bank shoreline in front of the high bank. The stump marked "C" on the base map is cypress and must have grown in place along a low swampy shoreline or occurred offshore as a part of a cypress fringe. Thus, it appears that the low bank shoreline previously existed in front of much of the high bank shoreline of part A. An extensive nearshore sand apron occurs in front of the high bank shoreline which completely covers the surface of erosion (Fig. 11) and thickens riverward. At 50 m offshore, the apron consists of a basal unit of clean medium to coarse sand which is thick (30 cm) and grades upward into 30 cm of fine-grained organic-rich sand. The surface of erosion is cut into a laminated tan to buff clayey sand.

The erosion rate for the entire monitor station was 1.4 m/yr for the sixteen month study period. The rate of recession for the low bank (part B) is 1.7 m/yr (Table 5). During the fall and winter of 1977 and 1978 this stretch of shoreline experienced severe erosion. Little shoreline was lost during the following summer season. The low bank accumulated a 67 on the Erosion Potential Scale, placing it in the upper portion of the intermediate erosion category which ranges between 0.6 and 1.2 m/yr; however the actual recession rate for the study period was in the high erosion rate category. The Erosion Potential Scale is a relative evaluation of the potential for each type of shoreline to erode over an extended period. However, any given shoreline may have special hydraulic effects or a series of storms over a short term period for which the scale does not account.

The high bank shoreline has an erosion rate of 1.0 m/yr (Table 5). As with the low bank section, erosion proceeded most rapidly during the fall and winter of 1977 and 1978. The shoreward edge of the vegetated slump block "S" receded over 3.0 m during the sixteen month study period. No new slumps developed, but two large oak trees fell from the bank top producing large cusps at points "O" on the base map. These trees fell during the fall and winter seasons of 1977 and 1978. The high bank shoreline rated a 60 on the Erosion Potential Scale. This is the middle of the intermediate erosion potential category and correlates rather well with the actual rate of 1.0 m/yr.

TABLE 5.A - Pamlico River Monitor Station Erosion Data

Monitor Station		1.Bayhills		2.Mauls Point		3.Camp Leach	4.Bayview		5.Pamlico Lab
Erosion Variables		Bluff	Mod. Bluff	Bluff	Mod. Bluff	Low Bank w/ Marsh Fringe	High Bank	Low Bank	Low Bank
Erosion Rate 16 months(m/yr)		0.5	-	0.5	-	0.7	1.0	1.7	0.5
Length of Shoreline (m)		95	132	65	95	115	94	100	260
Erosion Rate for station		0.2		0.2		0.7	1.4		0.5
Erosion Potential Score (see Table 2)		38	-	51	-	51	60	67	50
Length Eroded	Jul'77-Mar'78	60	0	25	0	25	55	99	165
	Mar'78-Nov'78	12	0	13	0	13	10	17	35
	Total	72	0	38	0	38	65	116	200
Area Eroded(m^2)	Jul'77-Mar'78	45	0	10	0	100	110	220	172
	Mar'78-Nov'78	12	0	27	0	11	10	11	16
	Total	57	0	37	0	111	120	231	188

TABLE 5.B - Pamlico River Monitor Stations Erosion Data

Monitor Station		6.Hickory Point		7.Wade Point		8.Pungo River		9.Lowland		10.Swanquarter
Erosion Variables		Low Bank	Mod. Low Bank	Marsh	Low Bank	Marsh	Low Bank	Marsh	Low Bank	Marsh
Erosion Rate 16 month (m/yr)		1.3	0.5	0.8	1.5	0.7	1.6	0.7	1.5	0.2
Length of Shoreline (m)		60	180	115	65	216	82	240	102	240
Erosion Rate for station		0.4		0.9		1.0		1.0		0.2
Erosion Potential Score (see Table 2)		69	-	75	67	82	70	81	71	62
Length Eroded	Jul'77-Mar'78	60	41	72	50	152	82	162	102	130
	Mar'78-Nov'78	66	20	42	48	119	80	130	60	10
	Total	126	61	114	98	271	162	292	162	140
Area Eroded (m^2)	Jul'77Mar'78	38	25	65	70	96	105	134	139	55
	Mar'78-Nov'78	66	31	60	60	113	75	102	69	4
	Total	104	56	125	130	209	180	236	208	59

Station No. 5 - Pamlico Lab

The Pamlico Estuarine Lab, managed by East Carolina University, is located on the north shore of South Creek, about 1.5 km west of Hickory Point (Fig. 6). The base map includes 260 m of shoreline, which extends along most of the shoreline in front of the E.C.U. facilities. The shoreline is a low sediment bank (Fig. 26), which is a soil horizon of the Pamlico msu. The shoreline is oriented east-west with a perpendicular fetch across South Creek of 1.3 km. The general east-west orientation and relatively narrow width of South Creek makes it very susceptible to strong winds and wind tides. During the winter, sustained strong westerly winds can lower the water level more than a meter in twelve hours.

The low sediment bank rises between 0.9 and 1.5 m above mean river level. The bank is a vertically exposed scarp which is undercut less than 50 cm. A narrow discontinuous sand beach 1.0 to 2.0 m wide occurs along the base of the bank.

The bank sediments are a tan to light orange, very clayey, fine to medium-grained sand which is iron-stained and mottled by the soil development. Faint ripple cross-beds and horizontal clay laminae occur in the clayey sand unit. This is overlain by about 30 cm of sandy humate soil which often flops over the lower undercut bank.

The vegetation along the base of the bank includes scattered patches of Spartina cynosuroides, Spartina patens, and Juncus roemerianus. There is no peat accumulation along the shoreline. The vegetation on the top bank includes sweet gum, pine, wax myrtle and annual plants. Between the pier and headland "J" (Fig. 27), the bank top is covered with domestic lawn grass and a few pines less than 2 m high. Elsewhere the lawn begins meters behind the low bank shoreline fringe of wild vegetation.

Headland "J" is composed of an old stump, Juncus romerianus, and

Looking west from pier.

Looking east from pier.

FIG. 26 - Pamlico Lab Field Station, Sept. 1979.

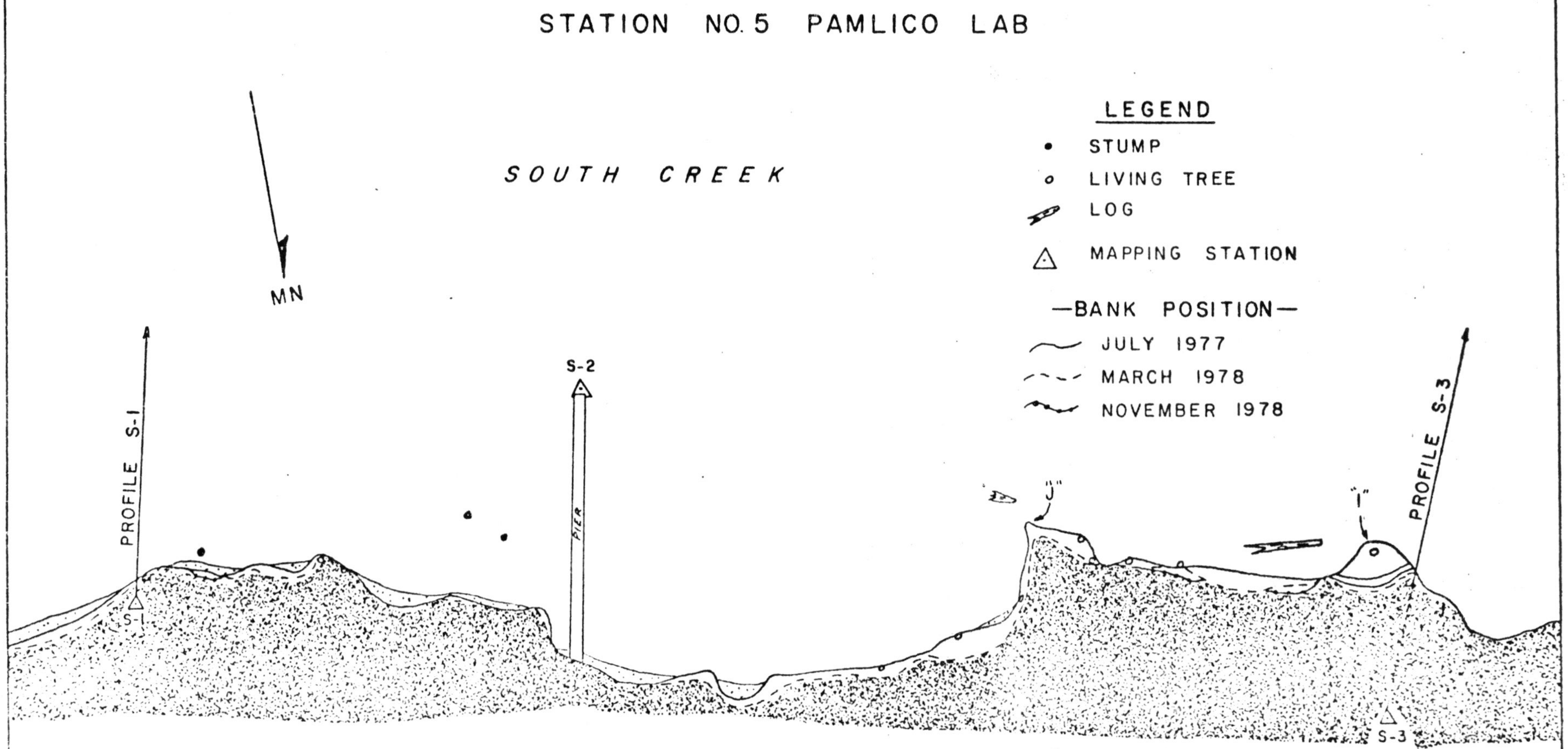


FIG.27-PAMLICO LAB MONITOR STATION

Spartina patens. The bank top between headlands "J" and "I" contains five or six large pines and sweet gums. Headland "I" has a 20 m high pine tree in the middle of it. The headland actually forms an island since it has been cut off from the main shoreline. During the winter of 1978, the pine was blown over to the landward, pulling the entire island over with it exposing the massive sediment encrusted root system to the waves of South Creek.

Many submerged stumps and logs occur in the nearshore area of the monitor site. The ones within 20 m of the shore aid on trapping sand on the sand apron. Two large fallen trees on either side of headland "I" also appear to be effective in trapping sand. The sand apron is mostly medium to fine-grained organic-rich sand which becomes finer offshore. The sand apron is thin and discontinuous from the bank to about 20 to 30 m offshore often exposing the underlying clayey erosional surface. From there, the sand apron occurs everywhere and thickens riverward becoming more than a meter thick 80 m offshore (Fig. 9). The organic content appears to increase riverward.

The erosion rate for the Pamlico Lab shoreline is 0.5 m/yr (Table 5). The most severe erosion occured during fall and winter of 1977 and 1978. The headland "I" was lost and a gum and two pines were severely undercut and and left behind in the water as the bank receded. If the trees (just east of headland "J") are not blown over by the wind they will die and eventually become offshore stumps reflecting the shoreline position at some previous time.

The Pamlico Lab low bank shoreline recieved a 50 on the Erosion Potential Saale. This is the cutoff between the low and intermediate categories of average erosion rates which is defined as 0.6 m/yr. The actual rate of 0.5 m/yr fits into the low category of theoretical average yearly erosion rates. Over a longer time period the potential for erosion may be a little higher than indicated over the sixteen month study period.

Station No. 6 - Hickory Point

Hickory Point is the eastward apex of the narrow peninsula formed by the confluence of the Pamlico River and South Creek (Fig. 6). The area has a low sediment bank shoreline, most of which is or has been modified by various man-made erosion protection devices such as concrete block and rock rip-rap, bulkheads, and rock rip-rap groins (Fig. 28). The shoreline at this station has been divided into two parts. Part A extends from the point for 190 m to the WNW along the Pamlico River which part B extends from the point for 90 m to the WSW along South Creek. Indian Island is 3.0 km east but offers little protection to the greater than 40 km fetch across Pamlico Sound. The fetch due north across the Pamlico River is 6.0 km and due south is 1.5 km across South Creek.

Most all the land comprising Hickory Point has been cleared for home and cottage development. However, many large pines have been left for shade and lawn grasses have been planted out to the edge of the low bank. Some small patches of marsh grasses occur along the north shore and on the point proper.

Part A of the Hickory Point area is exposed to the large fetch of the Pamlico River and consequently over 50% of it has been modified or protected in some fashion (Fig. 29). The low sediment bank between points "X" and "Y" is unmodified and exposed along 75 m of shoreline. This bank rises less than 1.0 m above mean river level and has a vertically exposed scarp. The bank sediments are an iron-stained and mottled buff to tan to orange clayey sand overlain by 20 to 30 cm of sandy humate soil. The lithology is similar to the bank at Pamlico Lab and is also part of the Pamlico msu. A 1.0 to 5.0 m wide sand beach occurs along this unmodified stretch of shoreline. From 10 to 15 m riverward of the sand beach there is little or no sand apron. Beyond the beach zone, the clay erosion surface is exposed. This is near-

Looking west mapping station S-1.

Looking east from mapping station S-1.

FIG. 28 - Hickory Point Field Station, Sept. 1979.

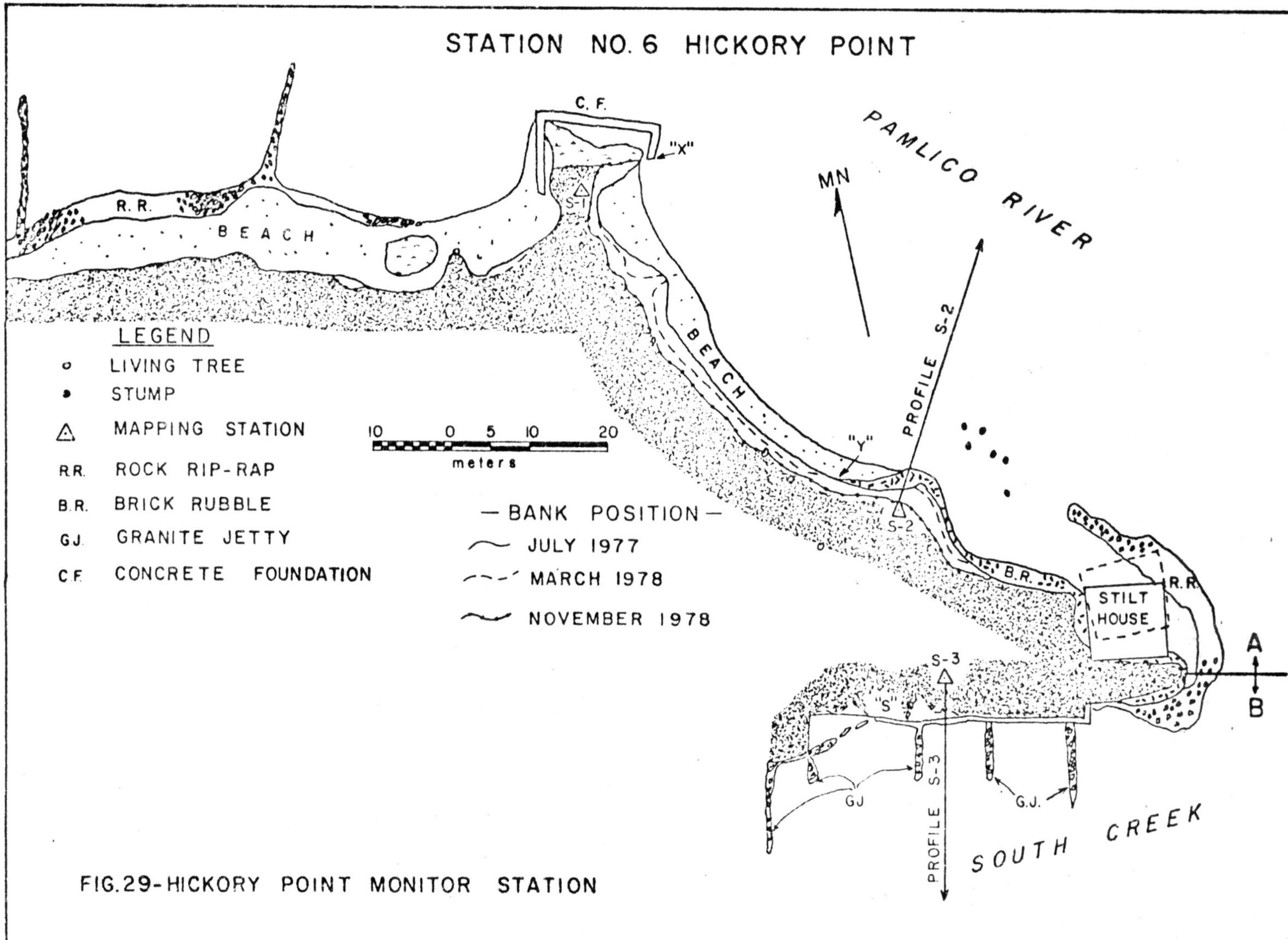


FIG.29-HICKORY POINT MONITOR STATION

shore and is littered with bricks, concrete blocks, old rip-rap groins and bulkheads, a septic tank and numerous stumps and logs, none of which have trapped any sand. The sand apron begins to be developed 10 to 15 m offshore. Ninety percent of the erosion along the Hichory Point monitor station occurred along this unmodified shoreline segment between points "X" and "Y".

West of point "X" a sand beach, 2.0 to 4.0 m wide laps up onto the modified low sediment bank. Rock rip-rap protects and appears to maintain this beach. Very little bank erosion has occurred here. An old concrete foundation protects a headland of marsh grasses adjacent to point "X".

Southeast of point "Y" brick rip-rap has been placed along the bank out to and around the point. Some erosion of the bank has occurred here and a house on stilts was blown over by a storm during the winter of 1978. The base map shows its original and fallen positions (Fig. 29).

Part B of the Hickory Point shoreline has been well protected by concrete block bulkheads and granite rock jetties. Some slumping has occurred behind the bulkhead at point "S". No sand beach exists in front of most of this shoreline since mean river level laps the base of the bulkheads.

The erosion rate for the entire Hickory Point monitor station is 0.4 m/yr (Table 5). However, most of the erosion has occurred along the virtually unprotected shoreline segment between points "X" and "Y" in part A. The erosion rate for this shoreline is 1.3 m/yr (Table 5). Similar amounts of erosion occurred during both winter and summer seasons during the sixteen month study period. It is not known whether the adjacent protected shorelines influenced the effects of winds and waves concentrating their erosive forces upon the unprotected shoreline or whether the modifications helped to protect the unmodified portions of the shore.

Considering all the man-made modifications, both on shore and off, the Erosion Potential Scale does not readily apply here. However, if no structures were present the erosion potential rating would be 69 on the north shore and 53 on the south shore making the theoretical erosion rate between 0.6 and 1.2 m/yr for parts A and B respectively. The unprotected low bank falls just above this range.

Station No. 7 - Wade Point

Wade Point is the southeastward projecting point formed by the confluence of the Pungo and Pamlico Rivers (Fig. 6). The monitor station includes Wade Point proper and the shoreline which extends 25 m to the north along the Pungo River and the shoreline extending 185 m to the west along the Pamlico River. Alternating shoreline types occur in this area and include 65 m of low sediment bank, 145 m of marsh peat, 30 m of man-modified shore which has been filled in and bulkheaded. The perpendicular fetch south across the Pamlico River is approximately 6.2 km. However, long (greater than 30 km) oblique fetches occur both west up the Pamlico River and southeasterly across the Pamlico Sound. Consequently, Wade Point is subject to rather intense wind and wave activity (Fig. 30).

Part A (Fig. 31) of the monitor station, extends eastward from the A-B division line and includes the eastern portion of the Pamlico shoreline, Wade Point, and the Pungo River shoreline. It consists of 40 m of low sediment bank, 55 m of "unvegetated" marsh peat which continues around the point and grades into 20 meters of low sediment bank.

The marsh peat shoreline has no living grasses on it, however it does contain modern roots. The shoreline is characterized by three terraces, each about 2 to 3 m wide. The lower terrace is below normal river level and rises as a 45 degree slope to about 70 cm above the sandy river bottom. The second terrace is defined by a 20 cm scarp and occurs along the swash zone of mean river level. The third terrace is also defined by a 20 cm scarp. An overwash sand berm occurs on top of the third terrace which grades into the pine woods behind the low bank to the west. The peat appears to be a remnant of a fringing marsh.

The low bank north of the marsh peat is less than a meter above mean river level and gently slopes down to a 2.0 m wide sand beach. The bank

Looking west from pier.

Looking east from pier.

FIG. 30 - Wade Point Field Station, Sept. 1979.

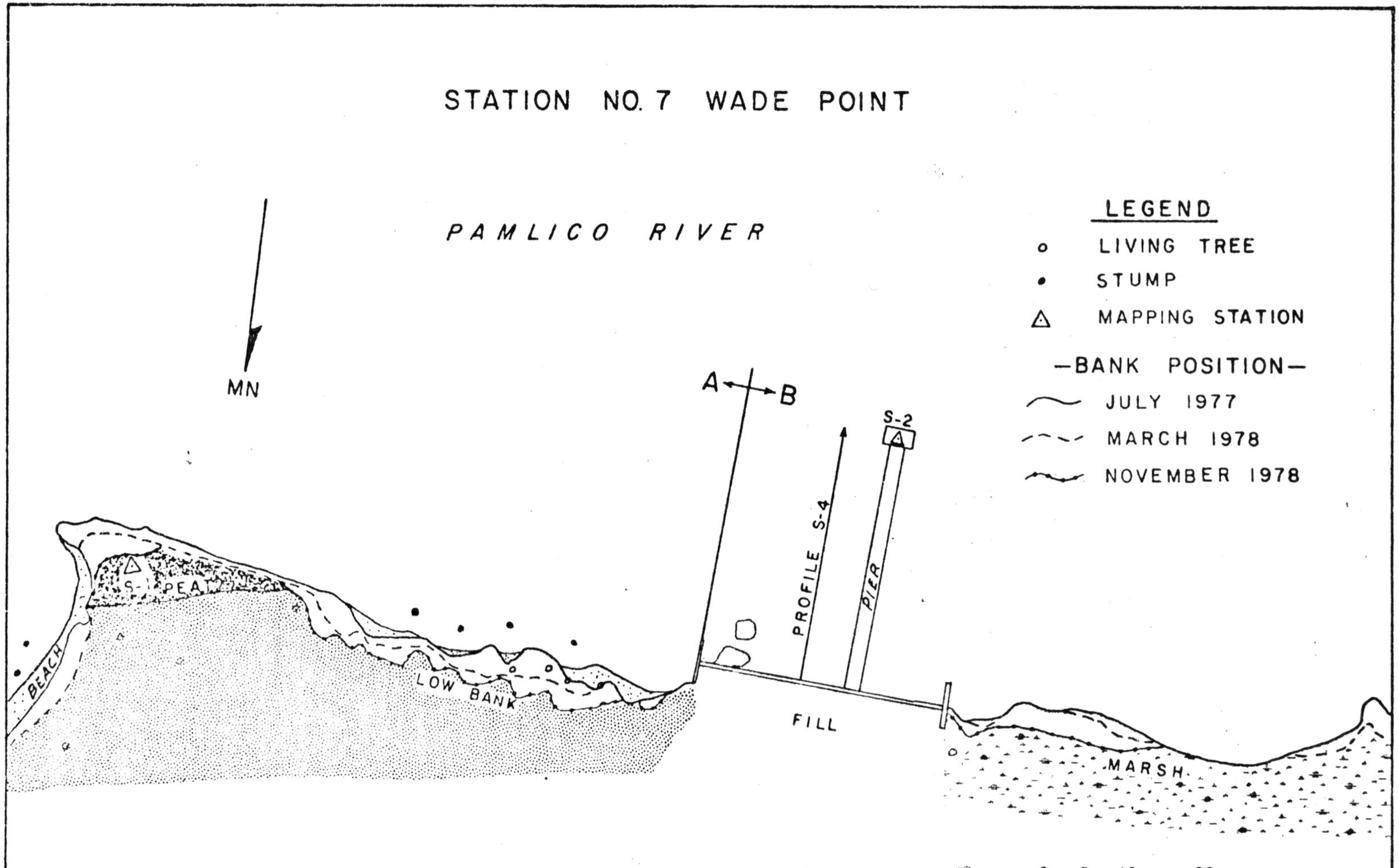


FIG.31- WADE POINT MONITOR STATION

top has been cleared of trees and underbrush exposing the sandy humate soil.

The low sediment bank west of the marsh peat shoreline in part A, is a vertical scarp 1.0 to 1.2 m high with a narrow (less than 2.0 m), discontinuous sand beach at its base. Bank sediments are an iron-stained, mottled, grey to light orange very clayey fine sand. The bank is undercut about 50 cm causing the upper 30 cm of sandy humate soil to flop down. The bank top vegetation is the pine woods with no trees larger than 10 or 15 m high. Numerous trees are undercut or have fallen back into the woods, tearing out bank material and leaving cusps in the bank.

The nearshore area is discontinuously covered by the fine-grained organic-rich sand apron which overlies the surface of erosion. No evidence of peat exists offshore but nearshore stumps stop less than 10 m offshore. This may be the point at which the fringing marsh peat was eroded out and erosion of the low bank began. Marsh peats lap onto the sediment bank to the east and under the bulkhead fill to the west of the A-B division line.

Part B of the Wade Point shoreline starts on the east side of the bulkhead (Fig. 31). The bulkhead extends 30 m to the west and is constructed of pressure treated wood. It has a short wooden groin at each end and the area behind it has been filled and planted with lawn grass. Two marsh peat tussocks with living Juncus romerianus occur just offshore of the east end. There is no sand beach in front of the bulkhead. Rather, there is a deep trough in front of the bulkhead as it drops off 1.6 m from the top of the bulkhead (Fig. 16). The trough is floored with medium to coarse sands which rise up and onto the clay pavement of the erosion surface and quickly grade riverward into the fine-grained organic-rich sands of the sand apron. The sand apron in thin and discontinuous out to about 50 m offshore where it begins to completely cover the clay pavement. At 100 m offshore the sand apron is about 25 cm thick.

The shoreline west of the bulkhead consists of 60 m of marsh peat which is terraced similar to the peat previously described at Wade Point. However, this area has living marsh vegetation on the washover sand berm on top of the upper terrace that includes Spartina cynosuroides, Iva, and Baccharis. About 20 m behind the shoreline is the landward limit of the fringing marsh as the vegetation grades into a pine woods.

During the sixteen month study period at Wade Point, the erosion rate for the marsh peat shorelines was 0.8 m/yr (Table 5). The low sediment bank receded at a rate of 1.5 m/yr. Almost as much erosion occurred during the summer period of 1978 as during the winter period (Table 5). The bulkheaded shoreline had remained intact but the adjacent unprotected shorelines continued to recede. In fact, an additional flanking bulkhead was built to the east of the initial bulkhead sometime between the original mapping in the summer of 1977 and March of 1978. Slumping continued even after the construction of the flanking bulkhead.

The Wade Point area is apparently very susceptible to wind and wave action and consequently has severe erosion. From 1955 to 1970, Wade Point lost almost 50 m of shoreline at a very high rate of 3.3 m/yr (Fig. 32). The rate was determined by comparing aerial photographs for 1955, 1963, and 1970. The highest rate and greatest amount of erosion occurred between 1955 and 1963. Several major hurricanes also occurred during that time.

Each shoreline type was calculated separately and received its own rating on the Erosion Potential Scale because of the difference in bank composition, variable no. 9 on Table 2. The low bank received a 67, in the intermediate category. However the actual rate of 1.5 m/yr falls into the high erosion potential category (Table 2). The marsh peat received a 75 on the Erosion Potential Scale placing it just in the high erosion category.

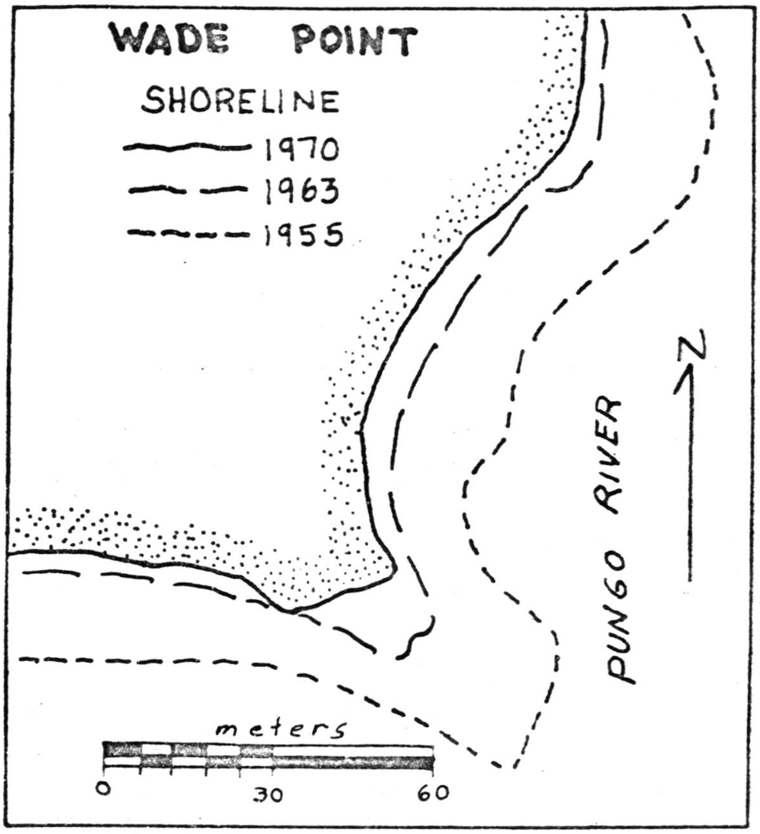


FIG. 32 - Wade Point - 15 year shoreline recession (Riggs et. al. 1978).

The actual rate of 0.8 m/yr would place the marsh peat into the intermediate category producing an apparent discrepancy. I believe that the shoreline variable of bank composition may need to be re-evaluated as to the relative erosional resistance of the peat shorelines. This data suggests that the marsh peats may not erode as fast as previously thought. This point will be considered further in the discussion.

Station No. 8 - Pungo River

The Pungo River monitor station is located about 300 m north of Wade Point on the Pungo River (Fig. 6). The shoreline is oriented almost north-south. The perpendicular fetch is about 7 km east across the Pungo River. However, the oblique fetch southeast across the Pamlico Sound exceeds 40 km, and northward up the Pungo River it is greater than 10 km. About 298 m of shoreline were mapped, including the northern 82 m which is low sediment bank (part A) and the southern 216 m which is marsh grass shoreline (part B) (Fig. 33). The transition is marked by the A-B division line on the base map (Fig. 34).

The shoreline goemetry differs between the two shoreline types. The low bank has small cusps in the bank formed when trees fall, tearing out a segment of bank material. The overall geometry, however, is relatively straight (Fig. 34). On the other hand, the marsh grass shoreline is quite irregular and cuspate where grasses are growing on the peat surface. Where the peat surface lacks living grasses the shoreline becomes straighter such as shoreline segment "Z" in Fig. 34.

The low sediment bank (part A) rises between 0.7 and 0.9 m above mean river level. The bank consists of an iron-stained, mottled, tan, buff, and orange very clayey sand which is capped by 0.2 to 0.3 m of sandy humate soil. The bank is a vertical scarp which is slightly undercut causing the sandy humate zone to flop over the bank. This flopping occurs along almost the entire length of the low bank shoreline. A 3.0 to 6.0 m wide sand beach occurs in front of the bank (Fig. 7).

The bank vegetation is primarily a pine woods in which the ground cover was recently thinned by fire. Many old pine stumps and logs occur in the nearshore and beach zones. This is evidence that former shorelines occurred some distance riverward and that the processes of erosion are active. The

part A - Looking north from A/B line.

part B - Looking south from A/B line.

FIG. 33 - Pungo River Field Station, Sept. 1979.

STATION NO. 8 PUNGO RIVER

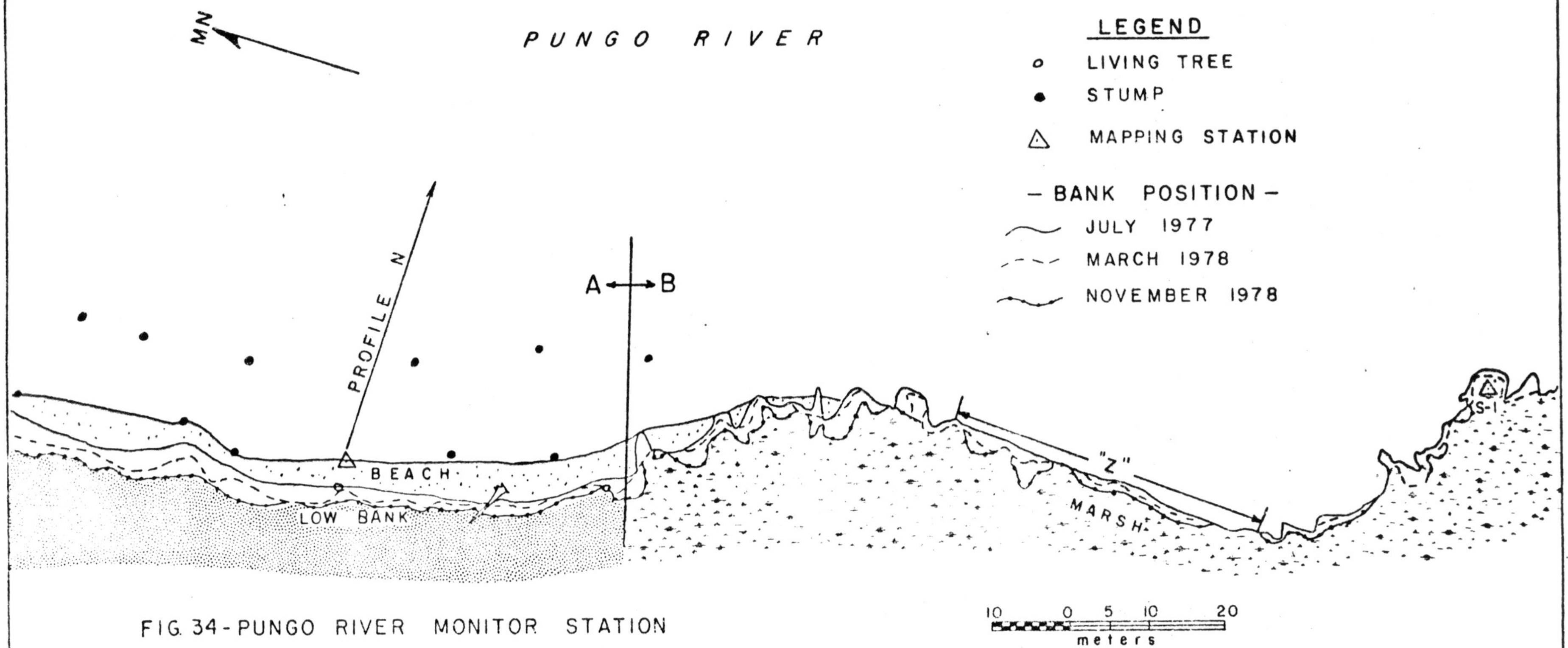


FIG. 34 - PUNGO RIVER MONITOR STATION

nearshore sand apron is very thin and discontinuous often exposing the clayey pavement of the surface of erosion.

The marsh peat shoreline (part B) is interpreted to be the remnant of a low embayed drainage. At the transition of parts A and B, the peat laps on top of the low bank just above mean river level. The peat bank rises 0.9 to 1.2 m from the river bottom. Unlike the Wade Point marsh peat shoreline, the Pungo River marsh peat contains live marsh grass vegetation. The upper 0.1 to 0.3 m of peat bank consists of the tightly woven roots of the modern surface vegetation. Underlying this root zone is a soft clayey peat that erodes easily. Normal river level occurs from 0.65 to 0.85 m above the river bottom. The peat bank is an almost vertical scarp which is often undercut as much as 1.0 m causing the upper root entwined zone to flop down into the water. Undercutting of the peat bank is most severe at the headlands, due to more open exposure to wave action.

The cusp areas along the marsh grass shoreline often act as sand traps accumulating sands brought up by wave activity from the nearshore sand apron. During high energy conditions the coarser sand is transported into the cusps and accumulates as a washover sand berm behind the peat bank shoreline. This sand berm is 1.0 to 2.0 m wide and up to 30 cm thick.

Three main vegetation zones are associated with the embayed marsh. First, the sand berm supports the high water shrub (*Iva frutescens*), the groundsel tree (*Baccharis halimifolia*), and the common wax myrtle (*Myrica cerifera*). Clusters of salt reed grass (*Spartina cynosuroides*) are also found in this zone. Second, salt meadow hay (*Spartina patens*) occurs as the vegetation on the riverward side of the washover sand berm. Third, on the marsh side of the sand berm, black needlerush (*Juncus romerianus*) is the dominant plant. Scattered patches of *Spartina cynosuroides* occur on topographic highs in the back marsh zone. Between 50 and 80 m behind the shore zone, the marsh vegetation grades up into a pine forest.

The nearshore sand apron is thin and discontinuous off the marsh grass shoreline. A few stumps can be seen exposed on peat bank headlands, remnants of an upland forest buried by the marsh transgression. There is no peat exposed or remaining offshore; erosion of the thin peat bank in complete.

Not only is the Pungo River shoreline affected by long oblique fetches but also by wakes from large boats traveling the Intracoastal Waterway. The waterway bisects the Pungo River and is about 2.0 km offshore. The boat wakes at the shore can be up to 0.7 m in height.

The erosion rate for the low sediment bank during the sixteen month study period was 1.6 m/yr. The rate of shoreline recession for the marsh grass shoreline was 0.7 m/yr (Table 5). The rate for the low bank is more than twice as fast as that for the marsh grass shoreline.

The geometry of the marsh grass shoreline changes with time. Headlands are eroded and cusps often increase in length and width. The shoreline appears to remain irregularly cuspate as long as marsh grasses grow on the peat surface. Some parts of the marsh grass shoreline experienced no erosion over the sixteen month study period. On the other hand, the low bank appears to recede as a single unit along its entire length. It maintains a general straightness through time. This straightness of the low bank shoreline may add to its rapid recession because strom induced waves are able to attack the whole length of the shoreline which has no stabilized slump blocks for protection as do the higher sediment banks. Storm waves which attack the marsh grass shoreline are somewhat broken up and rendered less effective by the shoreline's irregularity. This subject shall be considered further in the Discussion.

There are two ratings on the Erosion Potential Scale for the Pungo River shoreline. The low bank received a 70 on the scale, placing it on the boundary between the intermediate and high categories; the theoretical erosion rate is 1.2 m/yr. This is lower than the actual rate of 1.6 m/yr. The adjacent marsh grass shoreline received a rating of 82 on the Erosion Potential Scale, placing it into the high category with a theoretical erosion rate of 1.2 m/yr or greater. This does not correspond too well with the actual rate of 0.7 m/yr.

Station No. 9 - Lowland

The Lowland monitor station is about 3.0 km east of Goose Creek on the south side of the Pamlico River Estuary (Fig. 6). Two shoreline types occur at this station, 102 m of low sediment bank in the western part of the area (part A) and 240 m of marsh grass shoreline on the eastern side (part B) (Fig. 35). The shoreline is oriented generally eastwest. The oblique fetch northeast across the mouth of the Pungo River reaches 6.0 km. Northwest up the Pamlico River the fetch exceeds 10 km.

The shoreline situation at Lowland is very similar to that of the Pungo River monitor station. Lowland's two types of shorelines have essentially the same bank composition, bank vegetation, and erosion features as the Pungo River shoreline, including close proximity to the Intracoastal Waterway. The only major difference at Lowland is that there is little or no sand beach along the low bank shoreline; mean river level intersects the base of the clayey sand bank with sand accumulations only occurring along the base of the bank in some of the larger cusps.

The erosion rate for the whole area is 1.0 m/yr, the same as the rate at the Pungo River station. After sixteen months of estuarine erosion the Lowland low sediment bank eroded at a rate of 1.5 m/yr and the marsh grass shoreline at 0.7 m/yr (Table 5). Most of the shoreline erosion took place during the fall of 1977 and winter of 1978 (Fig. 36). It should be noted that the erosion rate for the low bank is again twice as much as for the marsh grass shoreline. This is a similar situation to the rates for the Wade Point and Pungo River stations, and probably results from the same reasons.

Referring to the Erosion Potential Scale (Table 2), the low bank received a 71 rating and the marsh grass shoreline an 81. The low bank poten-

part A- Looking west from A/B line.

FIG. 35 - Lowland Field Station, Sept 1979.

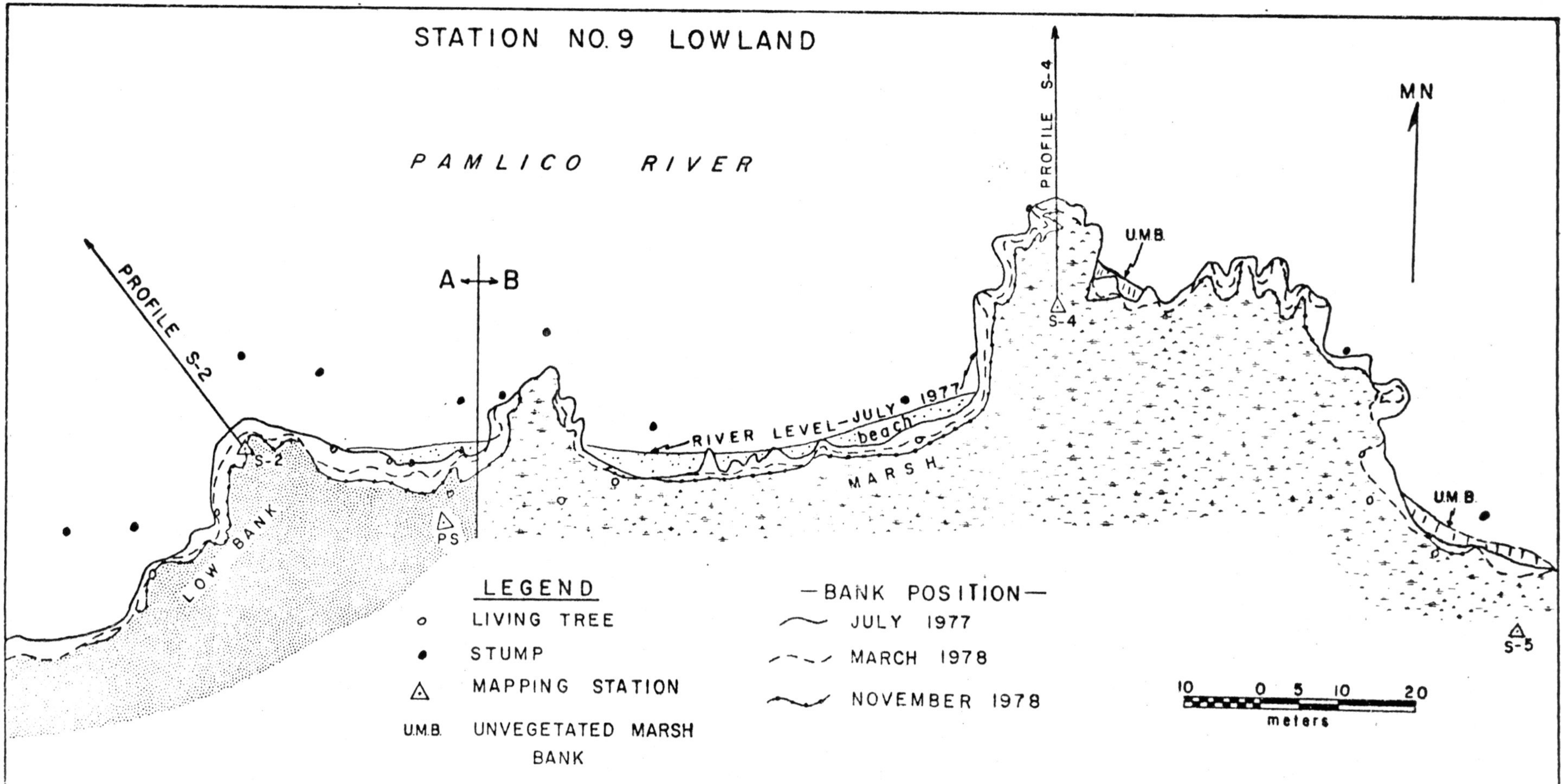


FIG. 36-LOWLAND MONITOR STATION

tial is very close to the actual rate, whereas the marsh grass potential is much higher than the actual measured erosion rate during the sixteen month study period.

Station No. 10 - Swanquarter

The Swanquarter monitor station is located in Swanquarter Bay (Fig. 6) and represents an extensive marsh grass shoreline. About 240 m of marsh grass shoreline were studied. A long perpendicular fetch (greater than 30 km) exists to the south out Swanquarter Bay and across the Pamlico Sound. However, this stretch of shoreline is somewhat protected by marsh islands 200 m to the west. The shoreline geometry is irregularly cuspate (Fig. 37).

The marsh grass shoreline consists of a peat bank scarp which may be undercut as much as a meter. In some places, especially the headlands, the peat bank rises 0.9 to 1.1 m above the bottom of the estuary. The section is composed of a 0.3 to 0.5 m thick basal organic-rich blue grey clay overlying the iron-stained and mottled tan to buff clayey sand of the transgressed relict upland soil. Overlying the basal blue grey clay is 0.4 to 0.6 m of very soft brown clayey peat which is capped by 0.3 m of matted modern root zone on which the living marsh grasses grow. Mean river level intersects the bank 0.6 to 0.9 m above the base of the estuary bottom. Undercutting of the soft peat underpinning causes the tightly woven grass root zone to flop down into the water. Undercutting of the peat bank will continue until the root zone can no longer support inself out over the water and the block breaks off. Peat blocks often occur in front of eroding headlands (Fig. 14). Four of the larger cusps along the monitored shoreline have accumulated sand wedges. This sand is brought up from the nearshore area by wave action, especially during high energy periods of storm activity. An overwash sand berm up to 3.0 m wide occurs behind the shoreline in the cusps. The sand berm is about 10 to 20 cm above the marsh surface and supports the plants *Iva*, *Bacchaus*, *Myrica*, and clusters of *Spartina cynosuroides*. *Spartina alterniflora* and *Spartina patens* grow along

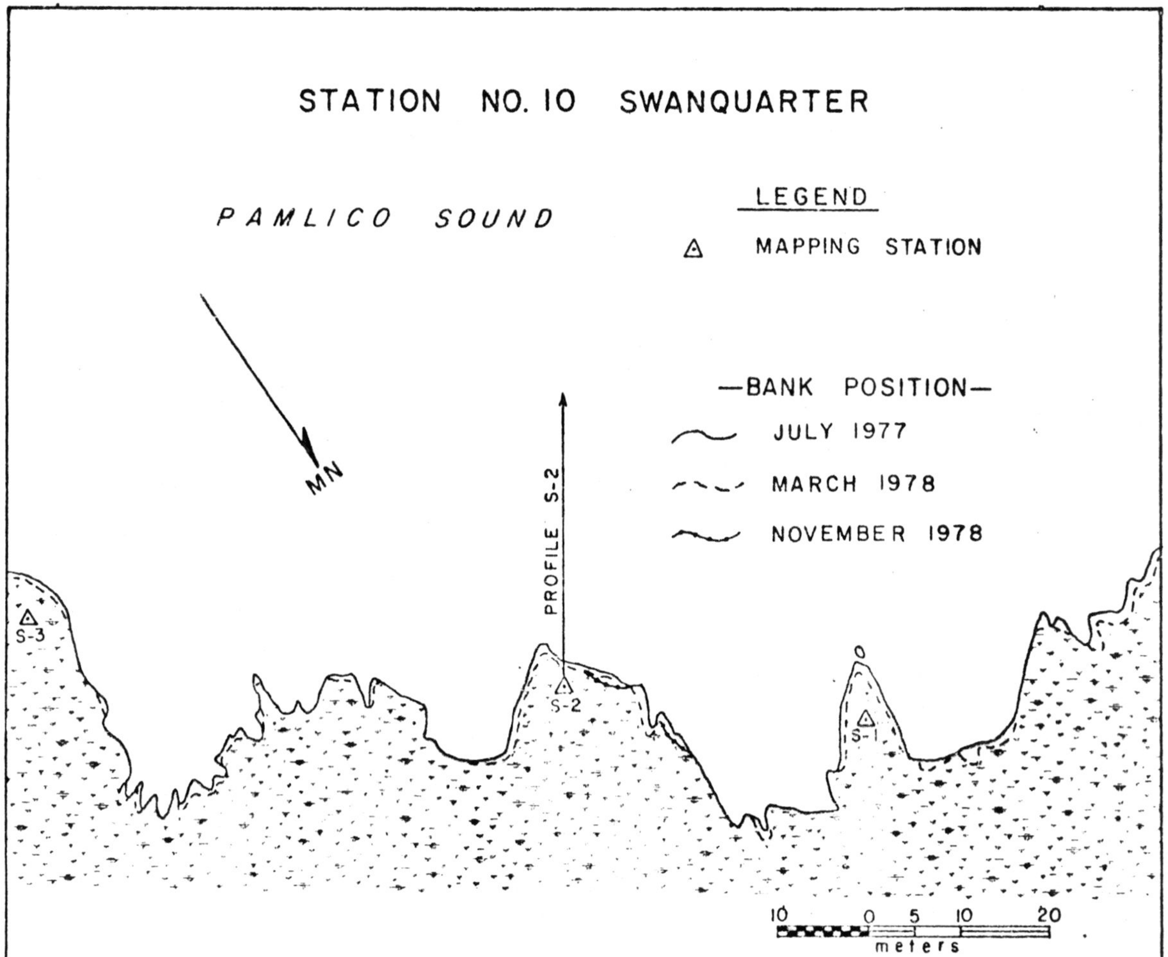


FIG. 37 - SWANQUARTER MONITOR STATION

the marsh shoreline on the soundside of the sand berm. Landward of the sand berm, Juncus roemerianus is the dominant and almost exclusive plant. The Juncus marsh extends over 350 m before grading into a transitional zone of Myrica, Iva, and Baccharis which grades landward into upland forest dominated by pine.

No stumps or logs were noted in the nearshore area. The fine-grained organic-rich sand apron is 10 to 30 cm thick and continuous, completely covering the erosion surface. Core data suggests that no peat material occurs in the nearshore area. Thus, the lower limit of erosion is below the lower limit of the marsh grass peat bank.

The erosion rate for the Swanquarter monitor station is a rather low 0.2 m/yr (Table 5). Most erosion occurred during the winter study period. The pattern of erosion appears to be as irregular as the shoreline geometry. Major headlands have experienced some erosion (Fig. 37) as have some of the cusps and the adjacent headland flanks.

The erosion potential for the Swanquarter monitor station is 62, utilizing a shorter fetch figure due to its somewhat protected nature within Swanquarter Bay. This puts the shoreline in the intermediate erosion potential category with a theoretical erosion value higher than the actual rate.

D I S C U S S I O N

The Pamlico River Estuary is responding to the present slow but steady world wide rise in sea level, about 25 cm per 100 years. The response includes flooding of the trunk estuary and its lateral tributaries. The shorelines bordering this transgressing estuarine system are slowly receding through the process of erosion of the banks. The distribution of shoreline types is a result of this transgression superimposed upon the regional geomorphology of the estuarine drainage system (Fig. 6 and Table 6).

Shoreline erosion involves many variables (Table 2). One of the most important variables is fetch. As fetch increases from the inner estuary to the outer estuary region so does the rate of shoreline erosion (Fig. 38). The fetch of the Pamlico River is determined by the mean width of the estuary (Table 6) measured roughly perpendicular to the north and south shores. In addition, there are extensive oblique fetches which may affect a given reach of shorelime. In general, as the width of the Pamlico River Estuary increases, exposure to oblique fetches also increases.

The relationship between fetch and shoreline erosion is well documented by the ten monitor field stations (Fig. 39). "X" represents a line drawn through a cluster of plotted points. It shows that generally, increased fetch results in increased erosion. Four monitor stations (Nos. 4,5,6,and 10) deviate noticeably from line "X". The deviation of each of these four stations represents the local importance of other shoreline erosion variables. Station No. 4, Bayview, has the highest relative erosion rate (Fig. 39). I feel the bank composition is one reason for this. The high and low banks at this station are composed of fine to medium sands which are easily eroded by frost, water runoff, and wave action. Also, the upland forests along

TABLE 6 - Pamlico River Estuary Data

Variables		Inner Estuary	Middle Estuary	Outer Estuary
Erosion Rate (m/yr.)	Mean	0.5	0.7	0.8
	Range	0.2 - 0.6	0.4 - 1.1	0.5 - 1.2
Bank Types	Swamp Forest	10%	-	-
	Bluff	36%	-	-
	High Bank	5%	20%	-
	Low Bank	44%	58%	17%
	Marsh	5%	22%	83%
Bank Height (m)	Mean	2.5	1.2	0.9
	Range	0.5 - 8.9	0.7 - 3.9	0.2 - 1.2
Fetch (km)	Mean	2.8	4.9	-
	Range	0.8 - 4.8	3.5 - 6.4	7.2 - >30.0

Data Source: S.C.S.(1975) and Riggs et.al.(1978).

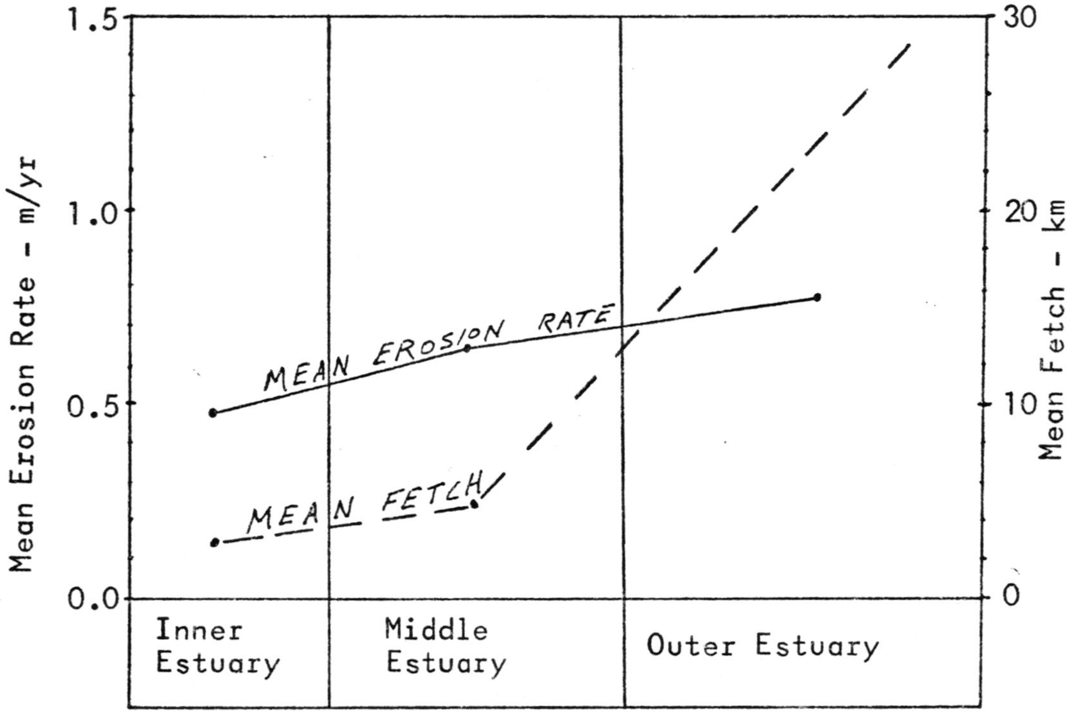


FIG. 38 - Mean Erosion Rate vs. Fetch in the Pamlico River Estuary. Fetch is determined by mean width of each portion of estuary.

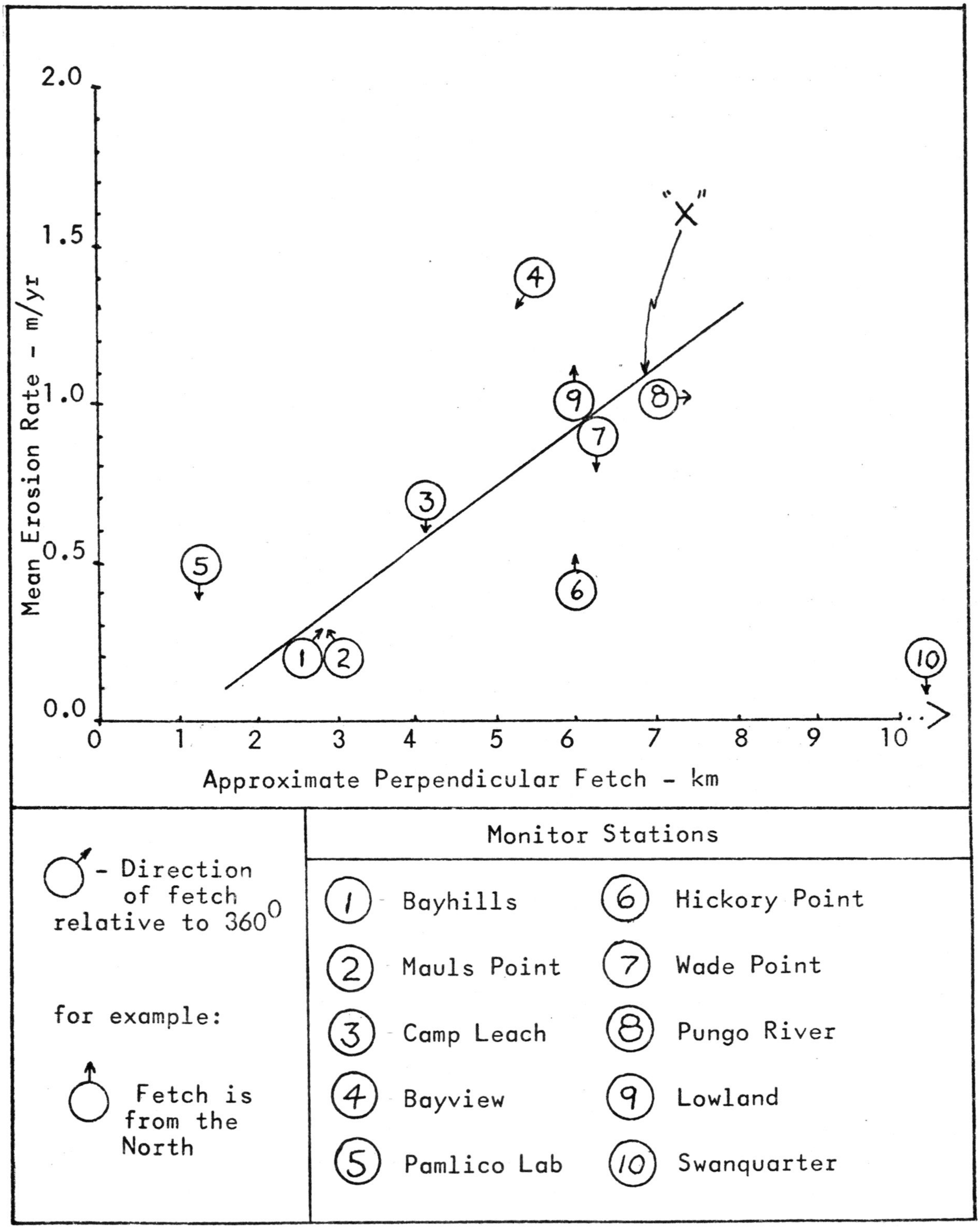


FIG. 39 - Mean Erosion Rate vs. Fetch for 10 monitor field stations in the Pamlico River Estuary.

the shorelines contain many large trees with large root systems. When they are eroded out and blown over, large volumes of bank sediment attached to the root systems are released into the estuarine system. Station No. 5, the Pamlico Lab, has a short southern perpendicular fetch, but long oblique fetches to the southwest and northeast may account for a relatively high erosion rate. Station No. 6, Hickory Point, has an overall erosion rate of 0.4 m/yr. This is a relatively low rate on such an open and exposed point. The low rate of erosion is undoubtedly due to the numerous protective shoreline structures present. Finally Station No. 10, Swanquarter, although exposed to a very long southward fetch is very well protected on the west and east by points of marsh. Thus, it has a relatively low rate of erosion.

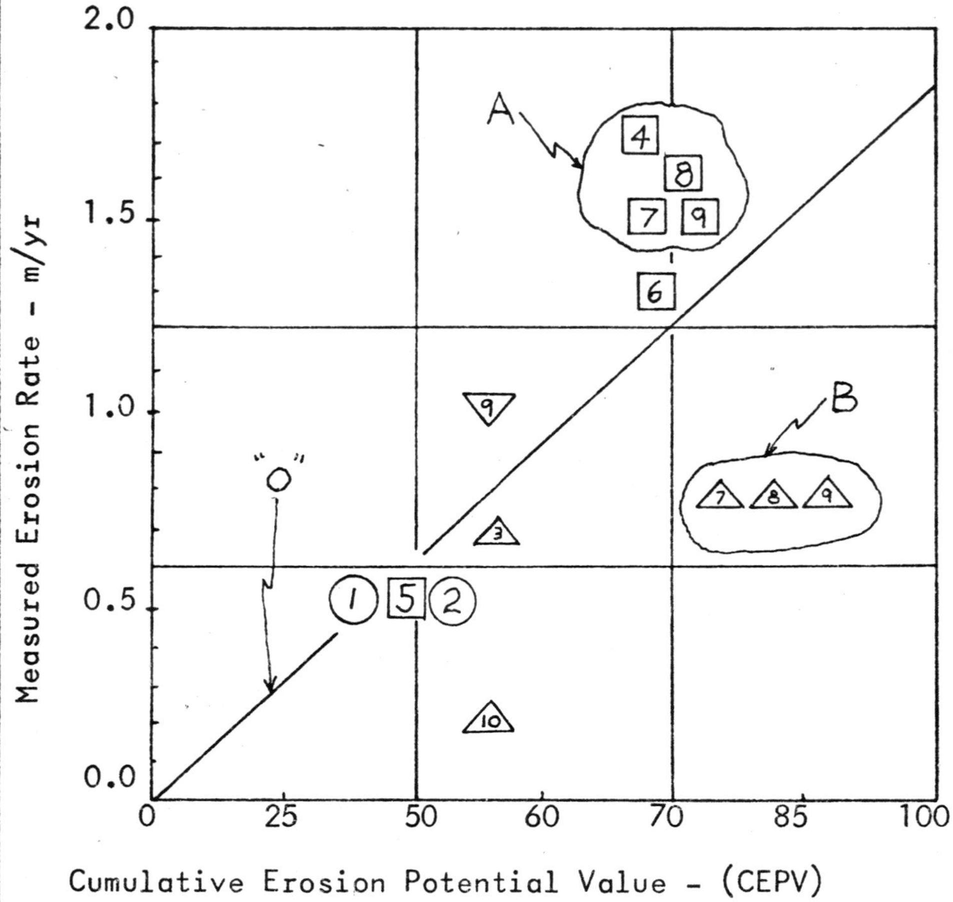
It is important to discuss the other shoreline variables of O'Connor, Riggs, and Bellis (1978) in terms of the Erosion Potential Scale (Table 2). The purpose of the Erosion Potential Scale is to assess the most important variables acting on any given shoreline and assign a relative erosion potential value to each variable. This relative number value reflects the potential for erosion along that particular shoreline segment. The "cumulation of the erosion potential values" (CEPV) for a given segment allows that shoreline to be placed in one of the three erosion potential categories. Thus, a "cumulative erosion potential value" (CEPV) between 0 and 50 places the shoreline into the low erosion potential category. Theoretically, this means that one can expect anywhere from 0.0 to 0.6 m of erosion per year as an average. A value between 51 and 70 means an average erosion potential of between 0.6 and 1.2 m/yr, while a value between 71 and 100 indicates average erosion rates greater than 1.2 m/yr. These ranges are theoretical values which were assigned after 3 years of mapping and observations by O'Connor, Riggs, and Bellis (1978).

This study represents the field test for the Erosion Potential Scale. Fig. 40 plots the actual erosion rates versus the "cumulative erosion potential values" (CEPV) for the different shoreline types of the ten monitor stations (except man-modified reaches). The different symbols represent shoreline types and the numbers enclosed in the symbols correspond to the numbers assigned to each monitor station.

The "O" line in Fig. 40 represents the theoretical 1 to 1 relationship between the range of erosion rates and the corresponding CEPV scores. Exact correspondence should not be expected due to the relative nature of the Erosion Potential Scale.

First consideration shall be given to two clusters of values which are noticeably off the "O" line in Fig. 40. All low sediment bank shorelines which have higher erosion rates than predicted by their erosion potential score (CEPV) fall into cluster A. Stations in cluster B are all marsh shorelines which have lower erosion rates than predicted by their CEPV score. What is noteworthy is that monitor stations 7, 8, and 9 are common to both clusters; low bank and marsh shorelines occur adjacent to each other at each of these three stations.

The data from these three monitor stations suggests that under the same conditions of fetch and shoreline orientation, low bank shorelines erode more than twice as fast as the adjacent marsh shoreline. It has been recognized by O'Connor, Riggs, and Bellis (1978) that most shorelines erode significantly during high energy storm periods when the high winds produce abnormally high wind tides and waves. Thus, the river rises and oversteps the sand beach along the low bank allowing the waves to directly attack the bank. At the same time, the high wind tides overstep the peat bank and the wave energy is baffled and absorbed by the marsh grasses with little peat loss.



Bank Types	Monitor Stations			
○ Bluff	1	Bayhills	6	Hickory Point
▽ High Bank	2	Mauls Point	7	Wade Point
□ Low Bank	3	Camp Leach	8	Pungo River
△ Marsh	4	Bayview	9	Lowland
	5	Pamlico Lab	10	Swanquarter

FIG. 40 - Measured Erosion Rates vs. Erosion Potential for 10 monitor field stations in the Pamlico River Estuary.

It should be noted that according to Table 4, marsh shorelines have the highest rate of erosion of all shoreline types. This Table and the Erosion Potential Scale were developed on the basis of Soil Conservation Service (U.S.D.A., 1975) data. Almost 90% of all the marsh shorelines in the Pamlico River Estuary occur in the outer estuary region and are exposed to long fetch conditions (Fig. 38). Consequently, fetch appears to be the single most important variable in terms of shoreline erosion. Also, marsh shorelines in the outer estuary region often have water depths ranging from 1 to 4 m either at the shoreline or less than 100 m offshore. Whereas the shorelines in the inner and middle estuary regions rarely have water depths greater than 2 m at distances 100 m offshore. These relatively greater water depths in the nearshore area in the outer estuary mean that there is a greater amount of wave energy expended directly upon the marsh shoreline. Nearshore water depth is accounted for on the Erosion Potential Scale by shoreline variables Nos. 2 and 3, depth at 20 m and depth at 100 m offshore. And so, deep nearshore waters and long fetches combine to erode the outer estuary marsh faster than any other shoreline in the Pamlico River Estuary.

Some of the shoreline erosion variables on the Erosion Potential Scale (Fig. 2) concerning peat or marsh shorelines need to be re-evaluated. These variables are No. 5 - bank composition, No. 6 - width of sand beach, No. 8 - shore vegetation, and No. 9 - bank vegetation; all of these variables assign the highest Erosion Potential Value (EVP) to marsh shorelines. In variables No. 8 and No. 9, the marsh should be moved from the EPV category of 7 to the 4 category. Variable No. 6 places broad marsh in category 5. I recommend this be changed to category 0. Variable No. 5, bank composition, is the most important variable related to marsh. Peat should be moved from the EPV category of 15 to category 7. Whereas the clayey sands, the major composition of low sediment banks, should possibly be changed from category

7 to either a new category 12 or to 15. All these changes would tend to move cluster B in Fig. 40 much closer to the "O" line along the x-axis which is the Erosion Potential Score. Also, changing the values of bank composition will move cluster A toward the "O" line. These changes will put the majority of points on Fig 40 closer to a one to one correspondence of actual erosion rates and cumulative erosion potential values (CEPV). Since the monitor stations were selected to be representive of the variables occurring in the Pamlico River system, these recommended changes should also be applicable to the entire North Carolina estuarine system.

Variable No. 4 on the Erosion Potential Scale (Table 2), bank height, is an important factor related to the erosion of sediment bank shorelines. Most sediment banks occur in the inner and middle estuary regions with the inner region having the highest mean bank height (Table 6). Low bank shorelines erode much faster than high banks of bluffs (Fig 40). Station No. 4, Bayview, contains both low bank and high bank shorelines which are exposed to the same fetch conditions. The low bank erodes at 1.7 m/yr, the high bank erodes at 1.0 m/yr. However, the higher erosion rates for low banks is partially due to the exposure of the majority of low banks to greater fetches in the outer estuarine region. An additional factor affecting the lower erosion rates of the high bank and bluff shorelines is the large volume of sediment exposed to the forces of erosion. The high banks and bluffs erode by runoff and groundwater, frost action, and wave action causing large slump blocks. The slump blocks will essentially protect the high bank and bluff proper from wave action until the slump material is eventually broken down supplying large volumes of sediment to produce wide beaches. Then undercutting and saturation of the bank during heavy rain may cause more slumping. If slump blocks become stabilized by vegetation they should remain even longer before wave activity washes them away. Consequently, high bank and bluff shorelines often have a more extensive beach than the low bank. This means a broader buffer to wave action. Low bank shorelines may produce small slump blocks, but the low volume of material is rapidly washed away by wave action with only minor and narrow development of sand beaches.

The other shoreline variables on the Erosion Potential Scale include variables No. 7 - offshore vegetation, No. 10 - shoreline geometry, No. 11 - shoreline orientation and No. 12 - boat wakes. The relative values for these shoreline variables appear to be appropriate.

Finally, several conclusions can be made about man-modified shorelines on the basis of this study. When vertical wooden bulkheads are erected, water depths at the base of the bulkhead increase and become much deeper than adjacent unprotected or natural banks. Bulkheads seem to be effective in stopping erosion on a short term (5 to 15 yrs) basis, but this also effectively cuts off a source of sand to the nearshore sand apron and the sand beach is generally lost. With increased development pressures for waterfront property, there will probably be an increase in bulkheading. This will tend to deepen the nearshore area and reduce the extent and thickness of the minor sand beach that usually exists in front of the sediment bank shorelines.

Rock rip-rap and concrete rubble have essentially the same effect as bulkheads but to a lesser degree. However, maintence on the rip-rap type structure is usually less than the vertical wooden bulkhead.

The grading of high sediment banks and bluffs is a common practice along the Pamlico River Estuary. At Bayhills this method has created an extended beach zone with easy access. As increased vegetation stabilizes the backshore, the more protected the bank becomes. In the inner estuary, the short fetch conditions allows for this situation. However, on shorelines exposed to a greater fetch, increased erosion would cause rapid loss of the beach zone and recession of the shoreline during major storm conditions.

CONCLUSIONS

1. The transgressing sea across the geomorphology of the Pamlico River drainage system dictates the present day shoreline types and their distribution. The shoreline types, their distribution and rates of recession will continue to change through time in direct response to the future patterns of sea level change.

2. Rates of erosion in the Pamlico River Estuary generally increase from the inner to the outer estuarine region. This increase is primarily a function of the increased fetch.

3. In general, the highest rates of shoreline recession occur along the marsh shorelines because a) they are the dominant shoreline in the outer estuary, and b) the outer estuary has the longest fetches in the North Carolina estuarine system.

4. However, under the same conditions of fetch and shoreline orientation, low sediment banks erode at nearly twice the rate of marsh shorelines.

5. Each shoreline type is characterized by specific erosion cycles which are modified products of the interaction of the many shoreline variables with the erosional forces of waves, tides, frost action, groundwater, and surface runoff.

6. The Erosion Potential Scale itemizes the 12 major variables affecting estuarine shoreline erosion in North Carolina. Modifications made to the scale based upon the data from the ten monitor stations have brought the estimated relative erosion potential values for each variable into a closer correspondence with actual measured erosion rates within the system.

SUGGESTIONS FOR FURTHER RESEARCH

A number of suggestions for further research have resulted from this investigation:

1. Continued mapping of the monitor stations at regular time intervals would yeild longer term baseline data on shoreline erosion.

2. Coring and sampling in the nearshore area should be implemented on a yearly or seasonal basis to determine the movement and accumulation of sediments in the sand apron. The nature of the gorp-sand apron boundary should also be documented.

3. Size analysis and petrographic study of the bank sediments and nearshore sands would help to more precisely determine provenance of the eroded sediments.

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