1984

Vegetative Erosion Control Project : Final Report

C. Scott Hardaway Jr.
Virginia Institute of Marine Science

George Thomas
Virginia Institute of Marine Science

Andrew W. Zacherle
Virginia Institute of Marine Science

B. Keith Fowler
Virginia Institute of Marine Science

VEGETATIVE EROSION CONTROL PROJECT:

FINAL REPORT 1984

Prepared for:

Virginia Soil and Water Conservation Commission
203 Governor Street Suite 206 Richmond, Virginia 23219

by

Virginia Institute of Marine Science
School of Marine Science
College of William and Mary
Gloucester Point, Virginia 23062

Prepared by:

C. Scott Hardaway
George R. Thomas
Andrew W. Zacherle
B. Keith Fowler

Contract Manager:

Robert J. Byrne

MAY 1984

VEGETATIVE EROSION CONTROL PROJECT

FINAL REPORT

1984

Prepared For:

Virginia Soil and Water Conservation Commission
203 Governor Street, Suite 206
Richmond, Virginia 23219

by

Virginia Institute of Marine Science
School of Marine Science
College of William and Mary
Gloucester Point, Virginia 23062

Prepared By:

C. Scott Hardaway
George R. Thomas
B. Keith Fowler
Andrew W. Zacherle

Contract Manager:

Dr. Robert J. Byrne

May 1984

ACKNOWLEDGEMENTS

We would like to extend our appreciation to Dr. Robert Byrne, Dr. Don Wright, and Mr. Lee Hill for their editorial comments. We would also like to thank Cynthia Gaskins for her help in compiling and processing this report. A special thanks to Beth Marshall who typed, edited and compiled the report.

TABLE OF CONTENTS

TABLE OF CONTENTS
(cont'd.)

LIST OF FIGURES

LIST OF FIGURES
(cont'd.)

LIST OF FIGURES
(cont'd.)

LIST OF FIGURES
(cont'd.)

LIST OF FIGURES
(cont'd.)

LIST OF TABLES

INTRODUCTION

The Vegetative Erosion Control (VEC) project is a four-year study with coordinated efforts by the Virginia Soil and Water Conservation Commmission (VS&WCC) through their Shoreline Erosion Advisory Service (SEAS), the Soil Conservation Service (SCS) and the Virginia Institute of Marine Science (VIMS). Initial funding was appropriated in 1980 following the recommendation of the Coastal Erosion Abatement Commission and contracted out to the SCS and VIMS by the VS&WCC, the lead agency.

In 1980 Knutson et al. performed a national survey of planted salt marshes in the contiguous United States. Twelve coastal states were involved with a total of 86 sites evaluated. Knutson among others recognized wave stress as the principal factor in marsh establishment. Indicators of wave stress were determined to be average fetch (the distance over water which the wind can blow and generate waves), longest fetch, shore geometry, and sediment grain size.

The purpose of the VEC project is to supplement previous research with detailed site analysis of the early stages of marsh development and to more precisely define the physical limits of marsh implantation for shoreline erosion control. The project also provides demonstration sites which will help the average land owner, the advisory and regulatory agencies in determining whether or not a property is conducive to this low cost erosion control method.

Sites were chosen by VIMS and SEAS through their advisory contacts. Site selection was based on trying to include as many physical variables as possible which affect the success or failure of a marsh grass planting. The main variables which determine success or failure, we feel, are: 1) fetch (wave climate), 2) shore geometry and 3) shore orientation because they are the most limiting physical factors in marsh establishment. Many secondary variables may combine to alter or moderate the above variables.

June 30, 1984 marked the termination of the VEC Project. The oldest of the planted marshes are only three years old. Results thus far have shown that marsh fringe can be established rather easily in low wave energy environments such as creeks (fetch less than 1 nautical mile). High wave energy (greater than 5.0 nautical miles) shores along the Bay are not conducive to marsh fringe establishment as its sole protection. With continual maintenance planting, marsh fringe can be established along the medium wave energy shores found in the major tributaries of the Virginia Chesapeake Bay. The effect of the medium energy fringe on long term shore erosion abatement is still unknown.

The ultimate goal of fringe marsh implantation is to arrest erosion of the fastland bank. This is achieved by isolating the toe of the bank from direct attack by waves. Application of a successful fringe marsh achieves this isolation by two means. The marsh grass traps sand thereby increasing the elevation of the backshore adjacent to the toe of the bank. The increased elevation results in wave energy dissipation on the beach rather than on the bank. As well, the marsh grass itself dissipates wave energy. Although the time required for establishment of a firm fringe marsh is variable, two to three years are generally required for substantial development of the erosion resistent peat substrate (15). Since most of the sites are less than three years old, their long term effectiveness cannot be reliably estimated. However, the relative success of the early stages of marsh fringe development can be evaluated and thus trends can be seen.

For the present purposes we shall consider the criteria for "successful trending implantation" to be a continuous marsh fringe which exhibits sand trapping in the backshore. The beginning of peat formation should be observed by the second year. An unsuccessful planting would be one which exhibits a discontinuous or complete loss of the fringe. A partially successful case would be that wherein significant sections of the planting survived and functioned.

SHORELINE EROSION IN TIDEWATER VIRGINIA (6)

Several different shore types occur within the Tidewater region including high and low sediment banks, low lying barrier-dune-beach shores, marsh, and swamp forests. In order to put shore erosion in proper perspective as a natural phenomenon, one must examine the recent geologic history of the region.

The Cause

The Chesapeake Bay and its tributaries are drowned river valleys of the ancestral Susquehanna River System (Figure 1). The Chesapeake Bay System is a geologically young portion of the Virginia coastal region. About 15,000 years ago, the ocean shoreline was some 60 miles east of the Virginia Capes and sea level was about 300 feet lower than it is today. Much of the ocean's water was locked up in the great ice sheets which covered the northern half of North America during the Late Pleistocene glacial epoch. As the glaciers began to melt and recede in response to a gradually warming climate, the melted waters began to raise the level of the oceans. The rising sea level caused the shoreline and coastal system to slowly migrate upward and westward across the continental shelf. Today's estuaries are formed as the rising sea level floods the topographically low river and stream valleys.

The process of shoreline migration is commonly referred to as shoreline erosion. In the estuaries of Virginia, shoreline erosion is a continuing process which has been operating for several thousand years.

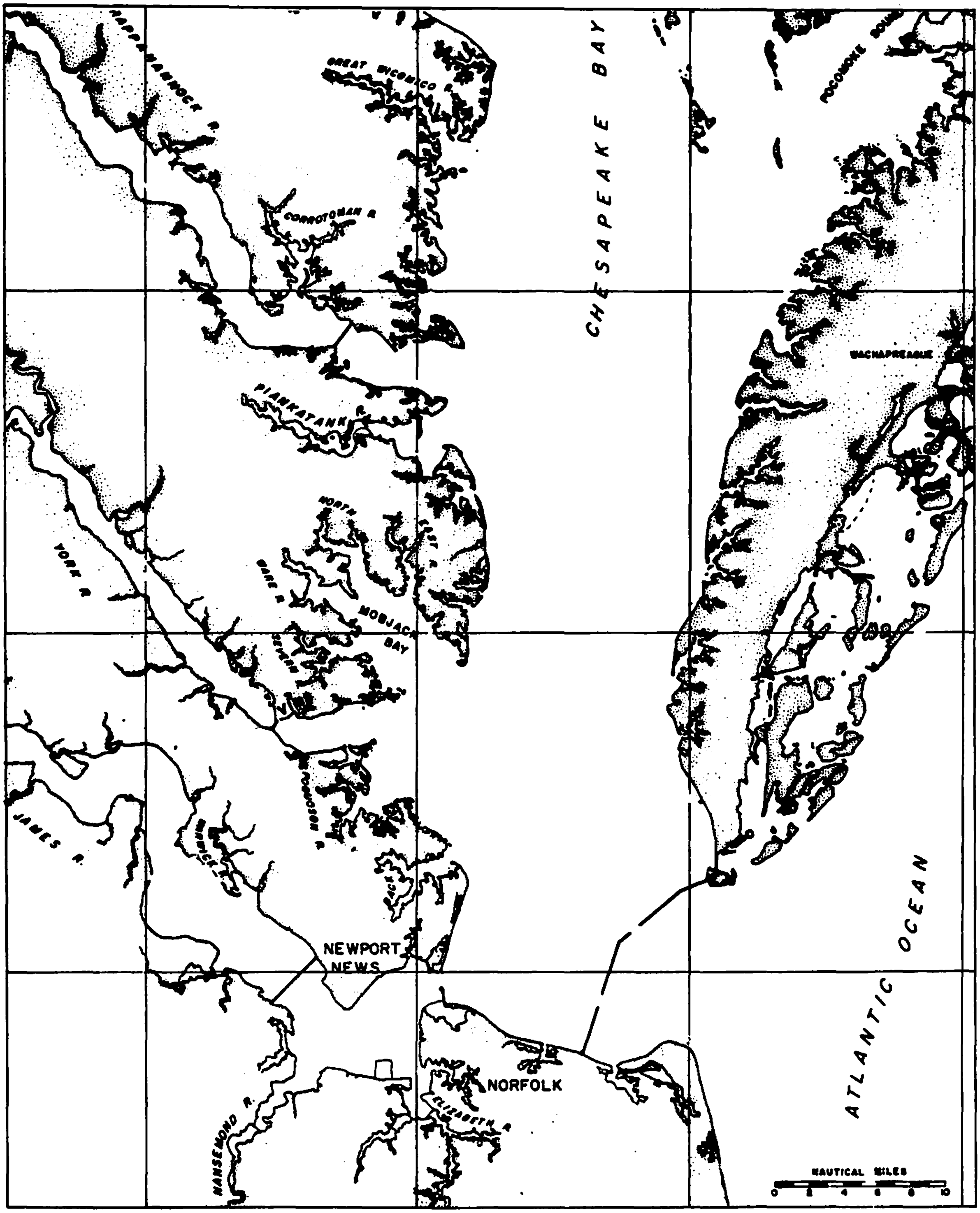


Figure 1. Virginia Chesapeake Bay and Its Tributaries.

Rates of erosion are dependent upon specific shoreline variables as well as varying wave conditions. Shoreline erosion on a daily basis may be imperceptable. Severe erosion occurs during periods of high energy storms such as northeasters and hurricanes.

The Effect

There are over 2,000 miles of shoreline along the Virginia portion of the Chesapeake Bay and its tributaries. The major tributaries are the James, York, Rappahannock, and Potomac Rivers. The shorelines of these tributary estuaries are highly dissected by numerous lateral tidal creeks.

From about 1850 to 1950, the Virginia Chesapeake Bay and its tributaries lost over 21,000 acres of land to shoreline erosion. Average shoreline erosion rates for this period are shown in Table 1. The east and west sides of the Bay, and south sides of the tributary estuaries have the highest relative erosion rates. This can be attributed to shoreline exposure to the northwest, north, and northeast directions from whence the most severe seasonal winds blow. Individual segments of shoreline have experienced erosion rates of more than seven feet per year; however, one or two feet per year is more common. For the 2,365 miles of estuarine shoreline measured, the average rate of erosion is about 0.7 foot per year (4). The Virginia Institute of Marine Science defines severe erosion as any shoreline segment with an erosion rate of two or more feet per year. Shoreline erosion becomes critical when coastal property with improvements (house, cottage, etc.) are threatened by a rapidly receding shore bank.

TABLE 1

AVERAGE SHORELINE EROSION RATES - TIDEWATER VIRGINIA

	Erosion Rates	Average
York River		
North Side -		
Gloucester County	- 0.5 ft/yr	- 0.4 ft/yr
King and Queen County	- 0.3 ft/yr	
South Side -		
York County	- 0.9 ft/yr	
James City County	- 1.8 ft/yr	- 1.2 ft/yr
New Kent County	- 0.9 ft/yr	
James River		
North Side -		
Newport News	- 0.8 ft/yr	- 0.45 ft/yr
James City County	- 0.1 ft/yr	
South Side -		
Isle of Wight County	- 1.8 ft/yr	
City of Suffolk	- 1.2 ft/yr	- 1.4 ft/yr
Surry County	- 1.2 ft/yr	
Rappahannock River		
North Side -		
Lancaster County	- 0.6 ft/yr	- 0.6 ft/yr
Richmond County	- 0.6 ft/yr	
South Side -		
Middlesex County	- 1.0 ft/yr	- 1.1 ft/yr
Essex County	- 1.2 ft/yr	
Chesapeake Bay		
Western Shore -		
Gloucester County	- 0.6 ft/yr	
Hampton	- 1.0 ft/yr	
Lancaster County	- 1.4 ft/yr	
Mathews County	- 0.8 ft/yr	- 0.9 ft/yr
Northumberland County	- 1.0 ft/yr	
York County	- 1.5 ft/yr	
Eastern Shore -		
Accomack County	- 1.5 ft/yr	
Northampton County	- 0.7 ft/yr	- 1.0 ft/yr
Fishermans Island	+11.0 ft/yr*	
Southern Shore -		
Virginia Beach	- 1.7 ft/yr	- 1.45 ft/yr
Norfolk	- 1.2 ft/yr	

* Not included in average erosion rate calculations.

Vegetation as a Low Cost Method of Shore Erosion Control

The use of vegetation to abate shoreline erosion can be very attractive in terms of cost. Costs for wooden sheet-pile bulkheads or riprap revetments range from $40.00 to $200.00 per linear foot, whereas the initial costs of creating a substantial marsh grass fringe range from $5.00 to $20.00 per linear foot, depending upon the desired width. Yearly maintenance of a marsh grass fringe generally involves fertilization and debris removal as well as additional planting. Maintenance requirements for a well constructed bulkhead or revetment should be minimal. However, high initial costs, potential deleterious effects to adjacent shores, and loss of wildlife habitat may make these structural methods unattractive in many cases. It should be noted that not all estuarine shorelines in the Commonwealth are suitable for treatment with marsh grass plantings. Shorelines exposed to greater than ten miles average fetch would be excluded from the vegetative alternative due to more frequent damaging wave action (8). It may be possible to establish a marsh fringe under these conditions in conjunction with some type of offshore breakwaters or other wave damping device.

There are several types of banks along the estuaries of Virginia (Table 2). Sediment (fastland) banks are generally the most highly developed due to their elevation above flooding waters and the aesthetic view.

TABLE 2

Estuarine Bank Types in Virginia

1. Swamp Forest
2. Sediment Banks
3. Marsh
4. Barrier Beaches and Spits
5. Man-Modified (bulkheads, groins, etc..)

Unstable and actively eroding fastland banks are evidenced by nearly vertically exposed and/or slumping slopes with little or no stabilizing vegetation (Figure 2). The critical point on an eroding slope is the toe or base where wave action is apt to be concentrated. High water and wave action against the base of a bank, especially during storms, is a major cause of continued or renewed slope instability. Groundwater seeping from the bank face may also act to decrease slope stability. Erosion of fastland banks supplies most of the sand material to estuarine beaches. The composition of the fastland bank and erosion rate will determine the type and amount of material supplied.

The base of an eroding fastland bank may be temporarily protected by a beach and/or slumped bank material. However, during periods of high water and associated wave activity, the mobile sediments will be removed. This may allow undercutting of the _in situ_ bank, thus leading to renewed slope instability.

The protection of the bank toe is commonly accomplished by emplacement of a bulkhead or revetment. The upper slope is usually graded and planted with appropriate vegetation such as fescue or rye

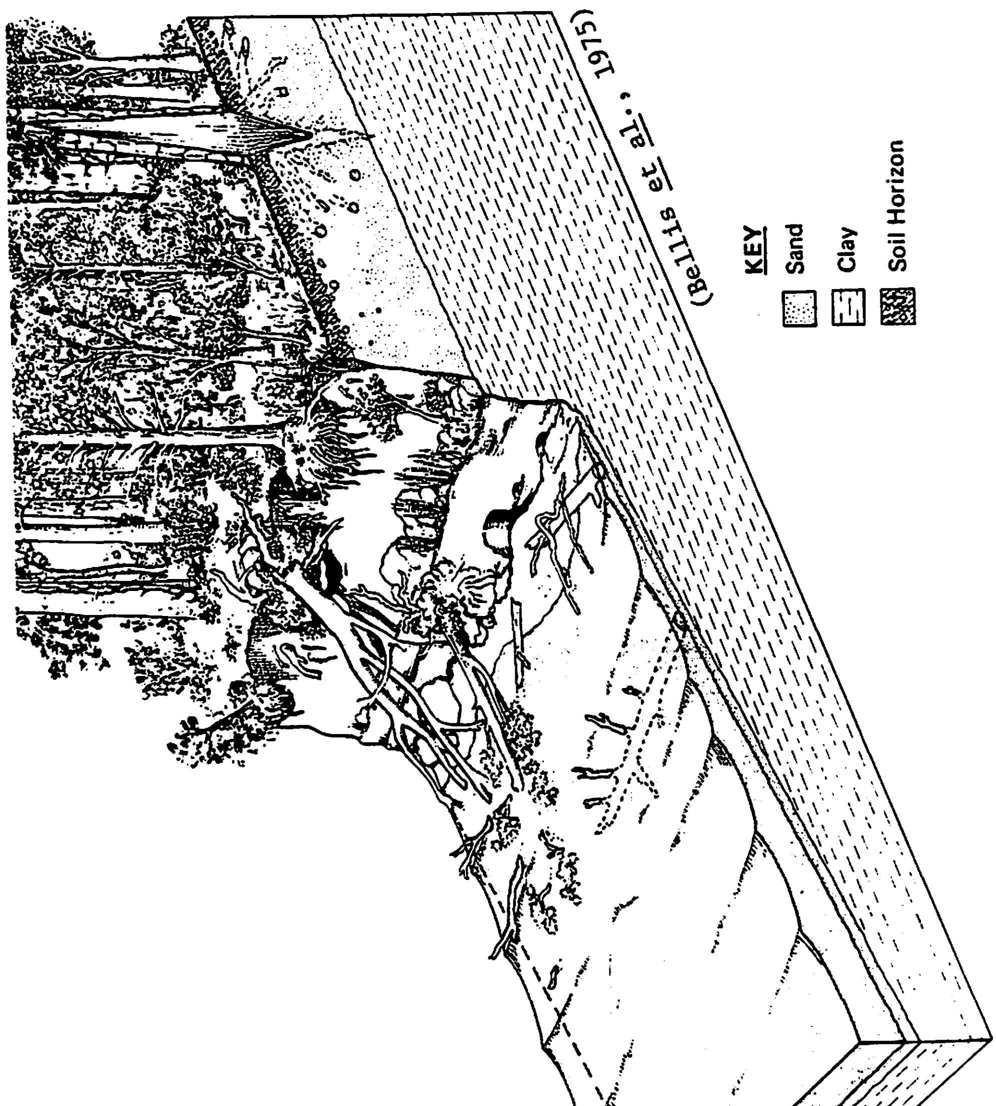


Figure 2. Generalized Fastland Bank Erosion.

grass on lesser slopes, and honeysuckle or English Ivy on steeper slopes. Groins are commonly used to trap sand and build a beach to buffer the fastland against wave action. However, often times this means a net reduction in sand to the downdrift shore which decreases beach width and is likely to increase erosion there.

A well-established marsh grass fringe can accomplish the same bank stability as a trapped sand beach or a toe structure. A natural marsh fringe along an upland shore generally reflects a stable bank face with indigenous vegetation. Planted marsh fringes have accomplished much the same slope stability over time by stabilizing the mobile beach face and by trapping sand to elevate the beach profile. The increase in beach elevation reduces the percentage of time that wave action impinges on the toe of the bank slope. The marsh grass fringe can greatly reduce the height of waves passing through it. Where a natural marsh fringe occurs adjacent to a low fastland bank exposed to the same fetch conditions, the erosion of the marsh fringe occurs at about half the rate of the fastland bank (5).

Two major species of marsh grass found along the Virginia estuaries are the smooth cordgrass (*Spartina alterniflora*) and saltmeadow hay (*Spartina patens*). These grasses have been used successfully in research and commercial plantings throughout the United States to stabilize spoil areas and reduce shoreline erosion.

TYPE I - SMOOTH CORDGRASS COMMUNITY (14)

Dominant Vegetation:	Smooth cordgrass (*Spartina alterniflora* Loisel) (Figure 3).
Associated Vegetation:	Saltmeadow hay, salt grass, black needlerush, saltwort, sea lavender, marsh elder, groundsel tree, sea oxeye.
Growth Habit:	Stout, erect grass; long, smooth leaves, often with attached periwinkle snails; located at the water's edge. Tall form 4 to 6 feet along the water; short form 1 to 2 feet at or slightly higher than MHW.
Physiographic Position:	Ranges from mean sea level to approximately mean high water.
Average Density:	Usually 20 plants per square foot. Can range from 10 to 50 plants.
Annual Production and Detritus Availability:	Average yield is about 4 tons per acre per annum; optimum growth up to 10 tons per acre. Daily tides flux through nearly all of this community. Available detritus to the marine environment is optimum. This type of marsh is recognized as an important spawning and nursery ground for fish.
Waterfowl and Wildlife Utility:	Roots and rhizomes eaten by waterfowl. Stems used in muskrat lodge construction. Nesting material for Forster's tern, clapper rail, and willet.
Potential Erosion Buffer:	Most saltmarshes and brackish water marshes are bordered by smooth cordgrass along the water's edge. A marsh/water interface of this type is highly desirable as a deterrent to shoreline erosion. The plant stems and leaves tend to dissipate wave action. Underlying peat with a vast network of rhizomes and roots is very resistant to wave energy.

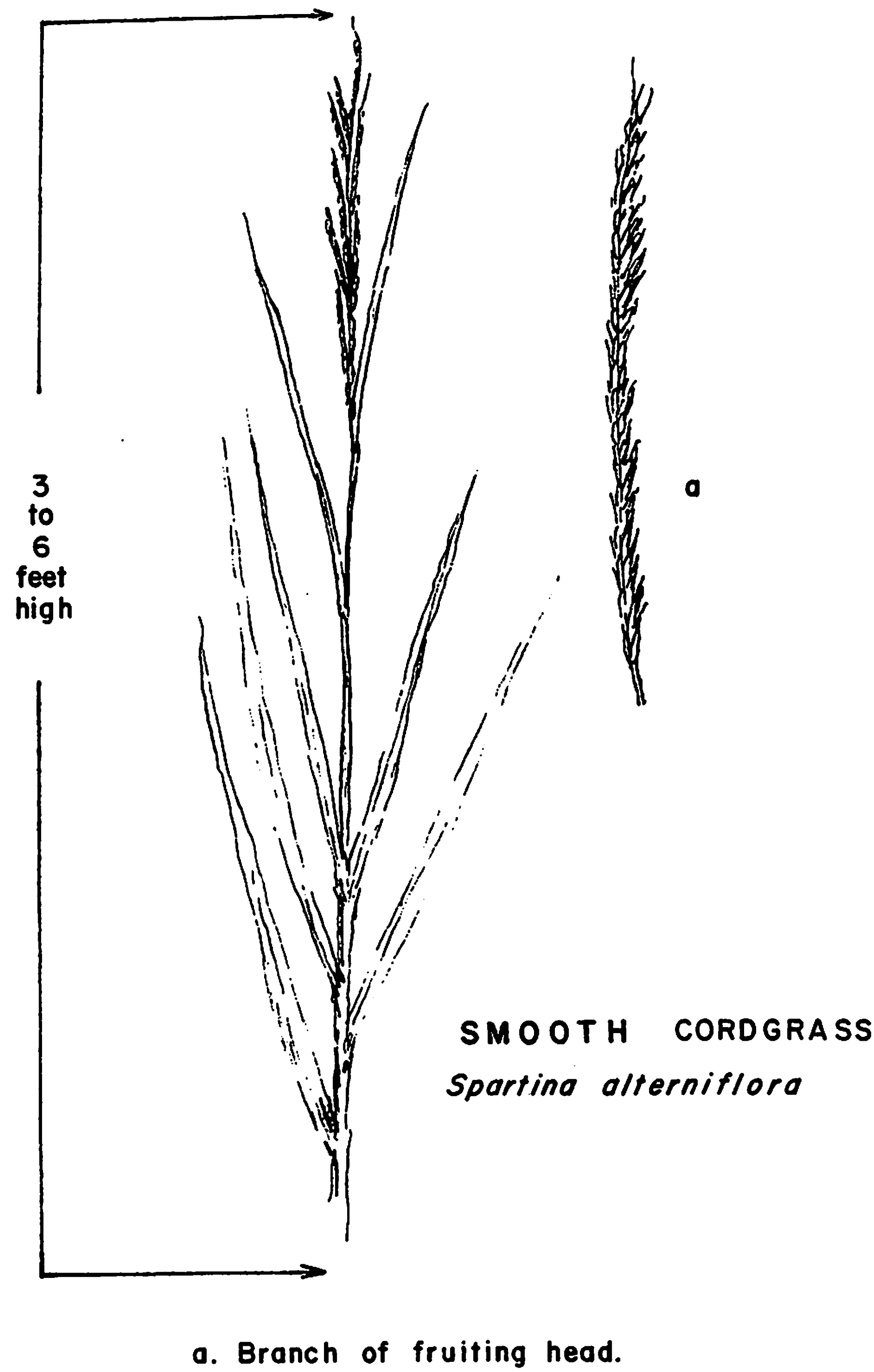


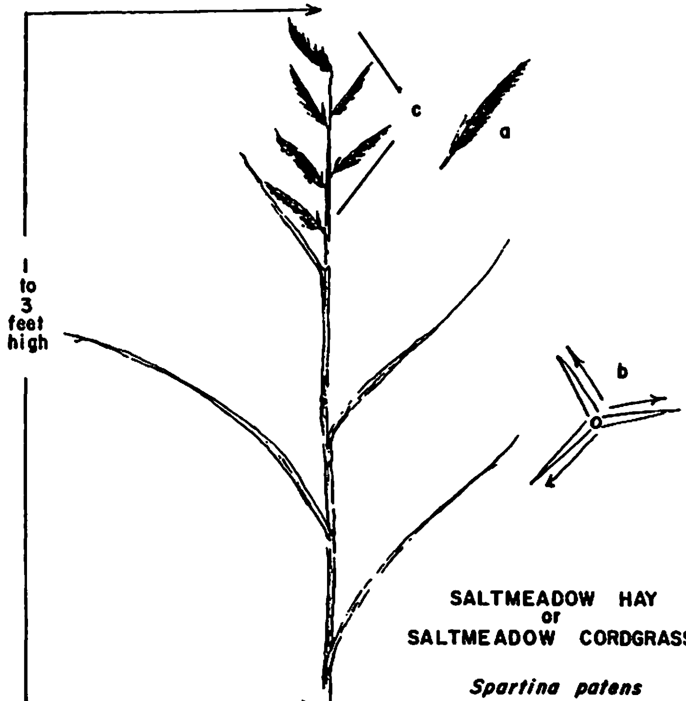
Figure 3. Smooth Cordgrass.

Water Quality Control:	Marshes of this type can also serve as traps for sediment that originate from upland runoff. This also includes large debris that may accumulate on the marsh surface.
Summary:	Considering the many attributes of this type of marsh community, its conservation should be of highest priority.

TYPE II - SALTMEADOW COMMUNITY (14)

Dominant Vegetation:	Saltmeadow hay (<u>Spartina</u> <u>patens</u> (L.) Greene) (Figure 4). Salt grass (<u>Distichlis spicata</u> (L.) Greene).
Associated Vegetation:	Smooth cordgrass, black needlerush, marsh elder, groundsel tree, saltwort, sea oxeye.
Growth Habit:	Matted meadow-like stands with swirls or "cowlicks", individual plants wiry in appearance, salt grass 1 to 2 feet high.
Physiographic Position:	About mean high tide to the limit of spring tides; salt grass at lower elevations, saltmeadow hay predominates at the higher end of the range.
Average Density:	Mixed populations; 50 to 150 stems per square foot.
Annual Production and Detritus Availability:	Ranges from 1 to 3 tons per acre per annum. Only small amounts of dead plant material are flushed out during storms and spring tides.
Waterfowl and Wildlife Utility:	Seeds eaten by birds; provides nesting area. Habitat for a snail (Melampus) important as food for birds.
Potential Erosion Buffer:	Effective erosion deterrent at higher elevations.

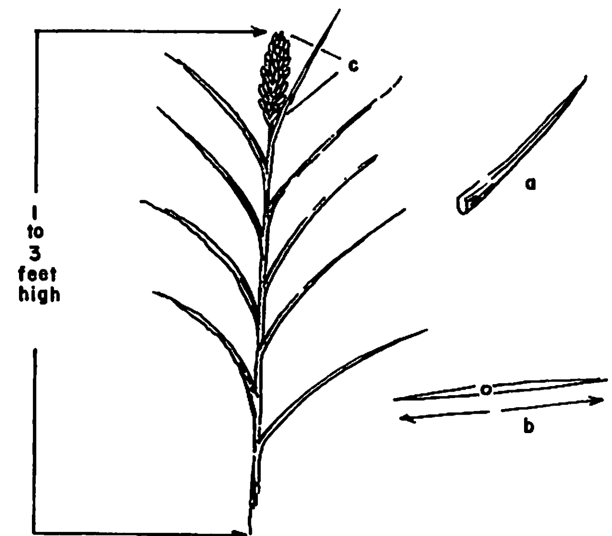
Figure 4. Saltmeadow Hay and Salt Grass.



SALTMEADOW HAY
or
SALTMEADOW CORDGRASS

Spartina patens

a. Branch with flowers.
b. Leaves arranged in 3 or more planes.
c. Flowering or fruiting head.



SALT GRASS

Distichlis spicata

a. Trough-shaped leaves (rolled inward).
b. Leaves arranged in one plane.
c. Flowering or fruiting head.

Water Quality Control: In many cases, this community represents the oldest part of a marsh system. Denseness of vegetation and deep peat filter sediments.

Summary: This system is an excellent buffer, filtering out sediments and absorbing runoff water originating in the uplands. It may be a better absorbent than Type I since it is not flooded daily by tides and its substrate is seldom saturated with water. Production and detritus are less important to the marine environment than in Type I communities. Its contributions tend to favor the upland environment. Its values rank somewhat below Type I, but nevertheless, a Type II marsh should not be unnecessarily disturbed.

VEGETATIVE EROSION CONTROL PROJECT

It is apparent from previous research (Appendix A) that a well-established marsh grass fringe can be an effective method of abating estuarine shoreline erosion. The primary purpose of the VEC project is to more precisely define the potential of marsh planting in the medium energy environments (average fetch 1 to 5 nautical miles). Secondly, the ongoing project should enhance the existing marsh grass data base as well as create demonstration sites for public review of the vegetative alternative in the Commonwealth.

Wave climate along a given shore is probably the single most limiting physical factor influencing the degree of success or failure of a marsh planting. In general, fetch is the most important factor governing wave climate at a given site. Average fetch exposure can be measured on a chart by determining the shore orientation or strike and constructing a perpendicular line on the strike at the site location across the bay, river or creek to the oposite shore. Next, one constructs two more lines originating from the site. Each are 45° from the perpendicular line. These two lines are carried across the body of water. Measuring the distance of the three lines and averaging the sums will yield the average fetch. The longer line will be the longest fetch.

Wave generation on a given shore may be duration-limited or fetch limited. According to Komar, in fetch-limited waves, the fetch area is too restricted for waves to reach their maximum energy for the given wind speed and duration. The 'fully developed sea' will require a storm duration and fetch both long enough so that energy is being dissipated internally and radiated at the same rate as it is being transferred from the wind to the water in the form of waves; thus a steady state of maximum wave development is achieved. (12)

The work of Dr. Edgar Garbisch and others (Appendix A) demonstrates that marsh establishment in areas exposed to an average fetch of 5 miles or more is difficult, if not impossible. Conversely, along shores of less than 1 mile average fetch (fetch-limited), marsh establishment is almost guaranteed provided there is sufficient sunlight. Finding the limits of marsh planting within the 1 to 5 mile average fetch range is one goal of this project. Figure 5 shows the location of the 24 sites selected over three years and Table 3 lists the sites by Soil and Water Conservation Districts.

Of these 24 sites:

7 are high energy (> 5 nautical miles average fetch);

10 are medium energy (1 to 5 nautical miles average fetch);

7 are low energy (< 1 nautical mile average fetch);

Seasonal wind patterns, along with fetch, determine the wave climate at a given site. Figure 6 shows long term wind roses from Langley Air Force Base, Patuxent Naval Air Station, Norfolk Naval Air Station, and Richmond International Airport (13). Northerly winds and northeast storms dominate the winter season while southerly winds blow most frequently in the summer months. Detailed seasonal wind roses are given in Appendix E. A southward facing shore does not receive the

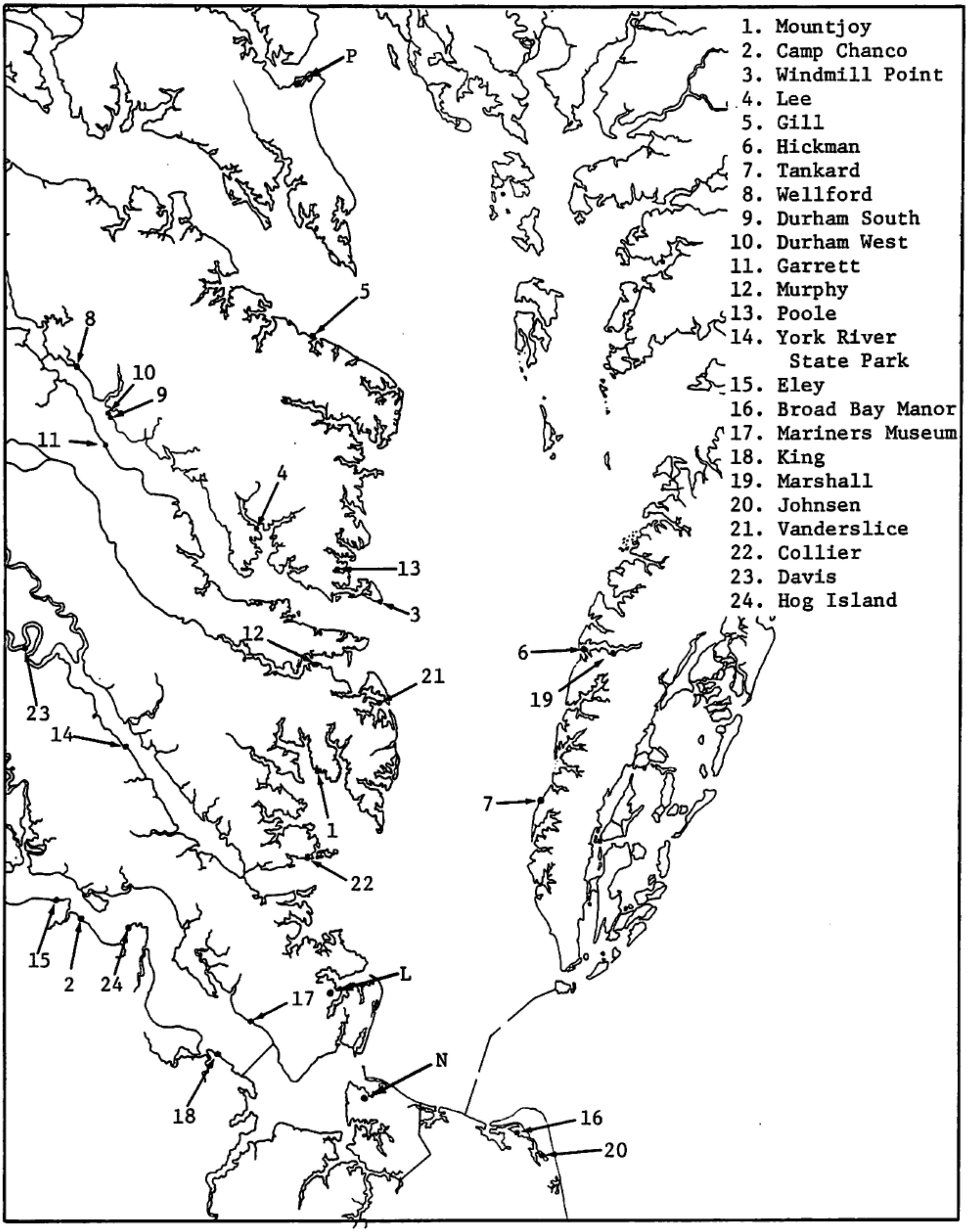


Figure 5. Planting site locations with Patuxent(P), Langley(L), and Norfolk(N) wind recording stations. Richmond is not shown.

TABLE 3

VEGETATIVE RESEARCH PROJECT PLANTINGS

(Organized by Soil and Water Conservation Districts)

Colonial	County or City
S. Whitfield Davis	New Kent
York River State Park	James City
Mariners Museum	Newport News
Eastern Shore	
Milton T. Hickman, Jr.	Northampton
William Marshall, Jr.	Northampton
John E. Tankard	Northampton
Northern Neck	
Fred D. Durham (2)	Richmond
Hurley H. Gill	Northumberland
F.N. Lee	Lancaster
Robert Poole	Lancaster
Carter R. Wellford	Richmond
Windmill Point Marine Resorts, Inc.	Lancaster
Peanut	
Camp Chanco	Surry
Claud E. Eley	Surry
Lloyd N. King, Sr.	Isle of Wight
Hog Island State Waterfowl Refuge	Surry
Three Rivers	
W.C. Garrett	Essex
Tidewater	
Frank L. Collier	Gloucester
Thelma W. Mountjoy and Reginald H. Williams	Mathews
Dr. W.F. Murphy	Mathews
Frances Knight Vanderslice	Mathews
Virginia Dare	
Stephen A. Johnsen	Virginia Beach
Broad Bay Manor	Virginia Beach

effects of the winter's strong northerly winds as do the north facing shores. This in fact has resulted in historical erosion rates along the north shores (south facing) of the rivers being about half the erosion rate of the south shores (north facing) (Table 1). Hence, in addition to fetch, sites were selected to encompass as many shore orientations as possible. Most of the medium energy shores will face either northeast or southwest since the major rivers trend along the northwest-southeast direction. Figure 7 displays the marsh sites as a function of their average fetch exposure, shore orientation and shore geometry.

Shoreline geometry can be important for success or failure of a marsh. The site located on a headland or a straight shore receives wave attack from several wind directions. In contrast, a site located in a cove, embayment, or protected by headlands, shoals, spits or islands may only receive wave attack from one or two directions. The degree of protection will vary with the amplitude of the embayment or the extent of the spit, shoal or island. For example, the effect of a protruding headland two miles up river from a site will be much less protective than a headland 200 yards up river.

Beyond wave climate, shore orientation, and shore geometry other variables of more local significance were measured. These include:

1. Bank type and elevation
2. Nearshore bathymetry
3. Sediment source, type and littoral drift direction
4. Beach and intertidal slope
5. Tidal range

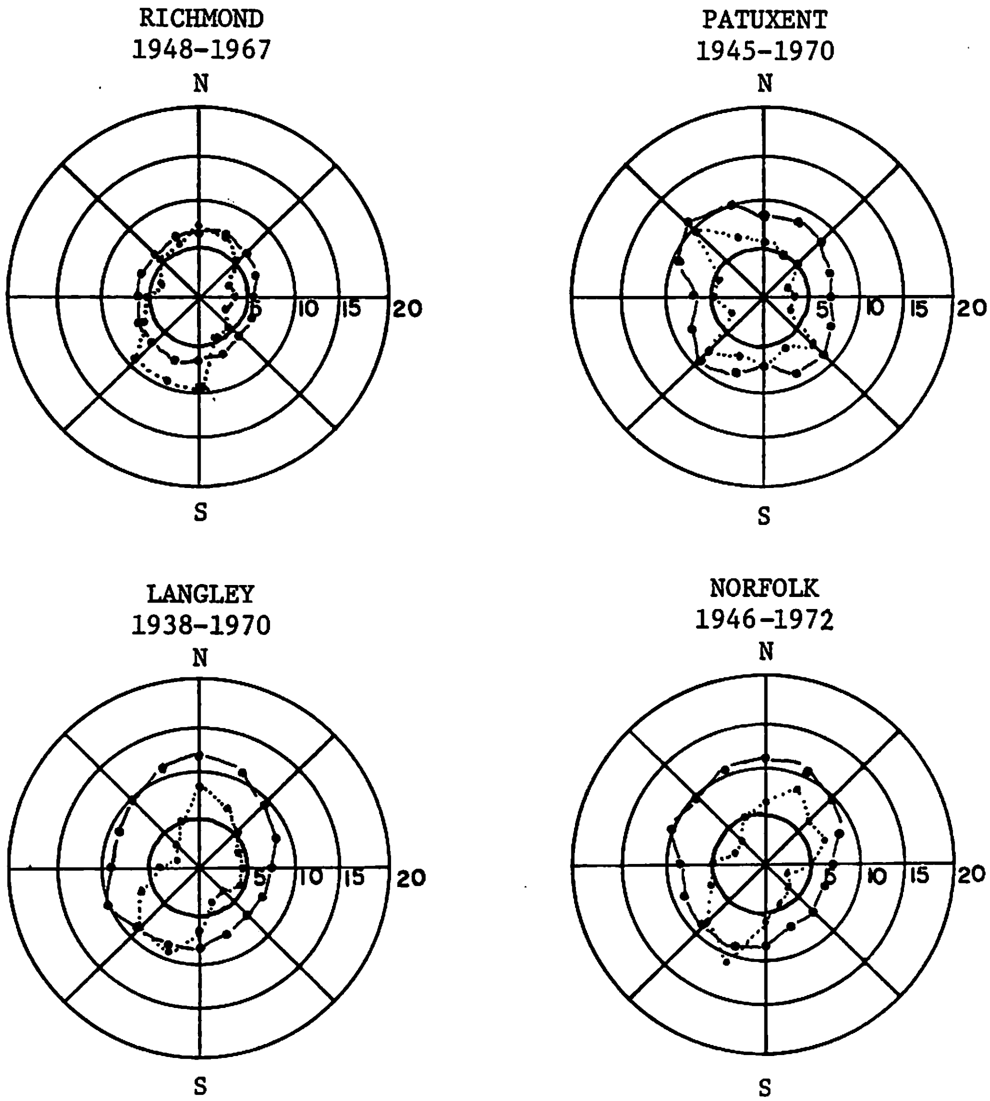


Figure 6. Long term wind roses for Richmond, Patuxent, Langley, and Norfolk.
•⋯⋯• Frequency of occurrence(%)
•——• Average velocity(kts)

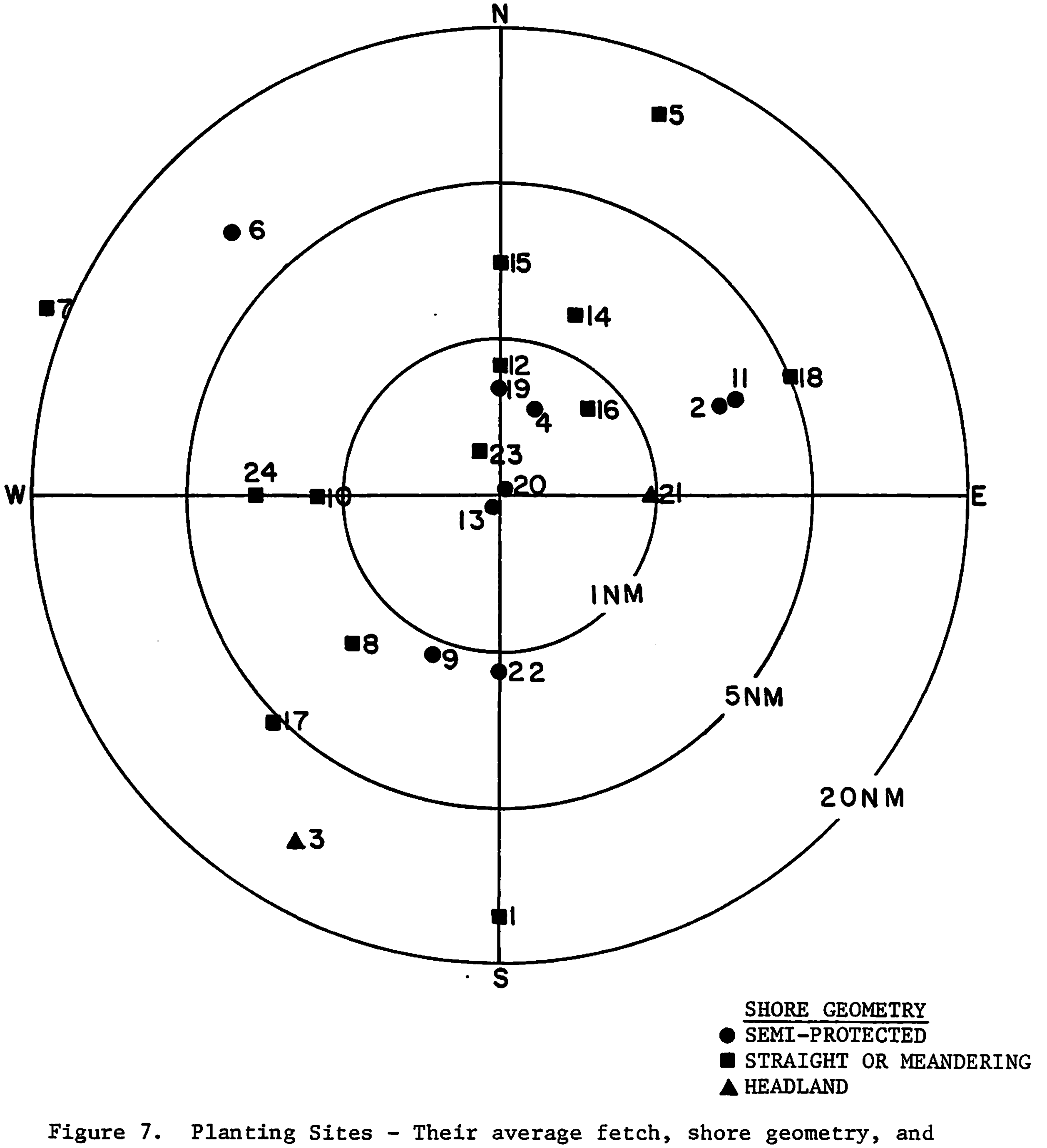


Figure 7. Planting Sites - Their average fetch, shore geometry, and orientation (the direction that the shore faces).

Methodology

Once the sites were selected, the following procedures were followed:

1. Base map - a base map of the planting site was made using a plane table and alidade. On this the relative positions of the bank top, bank toe, beach, and profiles were plotted.

2. Profiles - profiles across the planting site were established using a Nikon auto-level AE. The profiles extended from onshore pipes riverward into the nearshore region. Profiling several times a year will show how a particular planting has elevated or otherwise affected the beach and nearshore. The degree of error is ± 3%.

3. Sediments - sediment samples were taken of the beach and nearshore for the first 12 sites. They were analyzed for percent sand, silt, clay and mean sand grain size.

4. Marsh sampling (for detail refer to Appendix C) - random samples for biomass were taken at the end of each growing season and the amount of above and below ground growth and biomass measured.

5. Planting methods - planting teams of from 4 to 11 individuals consisting of persons from the Virginia Institute of Marine Science, Shoreline Erosion Advisory Service, Soil and Water Conservation Commission, and Soil Conservation Service were sent to each site. The number of individuals at each site was dependent on the size of the area to be planted. To lessen the possibility of plant washout and damage due to severe weather, the marshes were not planted until the late spring.

Prior to planting, grids were drawn on the beach marking the location of each plant. The *Spartina alterniflora* sprigs were planted every 1.5 feet from above MHW down to either MTL or MLW depending on the slope of the beach. *Spartina patens* sprigs were also planted every 1.5 feet and extended from above MHW upward to the edge of the fastland or toe of the bank.

Transplanting was performed while the beach surface was exposed to make planting easier and to prevent "float out". Planting holes were opened to a depth of 4 to 6 inches using a dibble bar. One ounce of Osmocote slow-release fertilizer was poured into the bottom of each hole before the plants were inserted. Plants contained within peat pots were crushed before the soil was firmed around the plants to decrease the possibility of any scour around the pot to inhibit the possibility of washout. In fact, washout of the peat pots was a problem on the early plantings in 1981, prior to using the crushing method.

Plants for the VEC project were supplied by the SCS National Plant Materials Center in Beltsville, Maryland and the SCS Plant Materials Center in Cape May, New Jersey.

Environmental Stress

A rust fungus infected 13 of the VEC sites during the summer of 1982. The rust first appeared on both species of grasses as a bright orange, powder-like infection on the leaves and stems but not the root matter. The rust was also found in natural stands adjacent to and distant from the VEC sites. The infection on the natural stands was generally not as severe as that on the VEC plants. Samples of the infected plants were collected from natural marshes and the VEC sites. After acquiring the proper mailing forms and permits, these samples were sent to Dr. C.G. VanDyke, a pathologist at North Carolina State University, for evaluation.

Dr. VanDyke identified the rust as Pucinia sparganiodes. It has been found on Spartina sp. (alterniflora, patens and cynosuroides). According to Dr. VanDyke P. sparganiodes alternates its life cycle by producing other spore types on either Fraxinus (ash) or Forestiera (a swamp shrub privet). The urediniospores have been found on young Spartina plants in North Carolina marshes in January. These spores may be dispersed for hundreds of miles via winds. In other words the alternate host may not control the location of the disease.

There did not seem to be any relation to the rust infection among the VEC sites and salinity, shore exposure, shore orientation or other variables. There did however seem to be a direct relation between the degree of rust infection and what we termed "relative lushness". The marshes with higher stem densities were most infected. Perhaps a humid environment was created by the dense planting, which Dr. VanDyke said may be conducive to rust growth. Whatever the reason, the above ground material decayed rather rapidly after the infection. Infected plants at sites which received severe wave attack during the fall and winter were left as exposed stubble. In 1983 10 sites were reinfested with the rust. Hog Island (no. 24), the only new site, was also infected. Table 4 shows the sites and their relative degree of infestation. During the winter, ice, frost and wave attack combine to reduce the above ground

TABLE 4

EVALUATION OF RUST INFECTION

	1982 Plants Infected	1982 Degree Infected	1982 Relative Lushness	1983 Plants Infected	1983 Degree Infected	1983 Relative Lushness
1. Mountjoy						
2. Camp Chanco	Sa	Heavy	Good	Sa	Light	Poor
3. Windmill Point						
4. Lee	Sa, Sp	Heavy	Good	None	N/A	Good
5. Gill						
6. Hickman	None	N/A	Poor	None	N/A	Poor
7. Tankard						
8. Wellford	Sa	Heavy	Good	Sa	Light	Good
9. Durham South	Sa	Heavy	Good	None	N/A	Good
10. Durham West	Sa	Heavy	Good	None	N/A	Good
11. Garrett	None	N/A	Poor	None	N/A	Good
12. Murphy	Sa	Heavy	Good	Sa, Sp	Heavy	Poor
13. Poole	Sa	Moderate	Good	None	N/A	Good

TABLE 4
Cont'd.

		1982			1983	
	Plants Infected	Degree Infected	Relative Lushness	Plants Infected	Degree Infected	Relative Lushness
14. York River State Park	None	N/A	Poor	None	N/A	Poor
15. Eley	Sa	Heavy	Good	Sa	Heavy	Good
16. Broad Bay Manor	Sa, Sp	Light to Heavy	Good	Sa	Moderate	Good
17. Mariners Museum	None	N/A	Poor	None	N/A	Poor
18. King	Sa	Light	Good	Sa, Sp	Moderate	Poor
19. Marshall	Sa	Moderate	Good	Sa	Heavy	Good
20. Johnsen	Sa	Light to Heavy	Poor	None	N/A	Good
21. Vanderslice	None	N/A	Poor	None	N/A	Poor
22. Collier	None	N/A	Poor	None	N/A	Good
23. Davis	Sa	Moderate	Good	Sa	Light	Good
24. Hog Island	N/A	N/A	N/A	Sa	Light	Good

Sa = *Spartina alterniflora*

Sp = *Spartina patens*

growth at medium and high energy sites, particularly those previously infected by rust.

It should be noted that several moderate northeast storms impacted the coastal waters of Virginia during the fall and winter of 1982-1983. These occurred on October 25, 1982, January 27, 1983, February 12, 1983, and March 1, 1983. The storms most affected northerly facing shores of the estuaries. Plantings most affected include the Garrett site (No. 11), the York River State Park site (No. 14), the Eley site (No. 15), Camp Chanco (No. 2), and the King site (No. 18). The October 25, 1982 storm did perhaps the most damage to these planted marsh fringes and adjacent banks. All these were maintenance planted in 1983 except Camp Chanco. There was very little storm activity in winter of 1983-1984 as compared to 1982-1983. Consequently, there were fewer significant erosion events.

Strong and frequent northwest winter winds appear to be the principal cause of erosion of the leading edge of the planted marsh fringes in the more exposed medium energy shores. Recovery of an eroding leading edge is essential to the long term integrity of the fringe. Renewed summer growth and rhizome spread is usually enough in low energy shores. However, on medium energy sites annual maintenance planting is required.

SITES

Included in the discussion of each site where a marsh fringe remains (i.e. all sites but Mountjoy (No. 1), Windmill Point (No. 3), Gill (No. 5) and Tankards (No. 7)) is a time series graph. This graph shows changes in marsh area, length and width as well as the erosion rate of the top of the bank (TOB) and base of the bank (BOB) on each monitoring date. The base of the bank may actually be slump material, especially on the high banks. The erosion rates are expressed as an equivalent yearly rate. For example, if on two profiling dates, two months apart, there is 2 feet of erosion across the site then the rate is 12 feet per year. Any positive numbers in the erosion rate column generally represent slumping of the bank.

Also included in the time series graph are beach volume changes between monitoring dates. The values shown represent the volume per linear foot for each site between mean tide level (MTL) and spring high water (SHW). This is generally the area where the marshes are most effective in trapping sand in the intertidal zone. Thus, the term intertidal marsh or fringe will be frequently used. This is also the zone that is typically occupied by the *Spartina alterniflora*. The column designated "without marsh" represents the site before planting or that part of the site that was washed out between the site boundary profiles.

A base map showing marsh area changes and profile location is included for each site as well as fetch vectors depicting each site's exposure to different wind directions. These do not necessarily depict the average fetch. Photos are also included for ease of discussion. A representative profile for each site is shown as an illustration of the site response. Mean sea level (MSL) and mean tide level (MTL) are used interchangeably in this report.

Additional readings on marsh grass establishment are found in Appendix A. An outlined summary of physical parameters and marsh history for the sites can be found in Appendix B. Data from biomass analysis for three years is included in Appendix C. Site profiles for the entire project are assembled in Appendix D and wind rose diagrams are in Appendix E.

Planting dates for each site are listed in Table 5. Plants received in the initial 1981 planting were not hardened to the proper salinity. Consequently there were early losses due to plant death on all the sites. This usually occurred below mean tide level if plants were emplaced there. Plants received in 1982 and 1983 were generally of very good quality.

TABLE 5

PLANTING SCHEDULE OF VEC SITES

		Spring 1981		Spring 1982		Spring 1983	
		Date	Species	Date	Species	Date	Species
1.	Mountjoy	27 May	Sa	19 May	Sa	-	-
2.	Camp Chanco	26 May	Sa, Sp	-	-	-	-
3.	Windmill Point	27 May	Sa, Sp	18 May	Sa, Sp	-	-
4.	Lee	6 May	Sa, Sp	-	-	3 Jun	Sa
5.	Gill	6 May	Sa, Sp	-	-	-	-
6.	Hickman	29 May	Sa, Sp	-	-	-	-
7.	Tankard	29 May	Sa, Sp	-	-	-	-
8.	Wellford	5 May	Sa	-	-	2 Jun	Sa
9.	Durham South	5 May	Sa, Sp	21 May	Sa, Sp	-	-
10.	Durham West	5 May	Sa, Sp	21 May	Sa	-	-
11.	Garrett	6 May	Sa, Sp	18 May	Sa, Sp	2 Jun	Sa, Sp
12.	Murphy	27 May	Sa, Sp	19 May	Sa	2 Jun	Sa, Sp
13.	Poole	-	-	18 May	Sa	3 Jun	Sa
14.	York River State Park	-	-	2 Jun	Sa	7 Jun	Sa

TABLE 5
Cont'd.

	Spring 1981		Spring 1982		Spring 1983	
	Date	Species	Date	Species	Date	Species
15. Eley	-	-	3 Jun	*Sa*	15 Jun	*Sa*
16. Broad Bay Manor	-	-	15 Jun	*Sa*, *Sp*	8 Jun	*Sa*
17. Mariners Museum	-	-	3 Jun	*Sa*, *Sp*	8 Jun	*Sa*
18. King	-	-	3 Jun	*Sa*, *Sp*	7 Jun 8 Jul	*Sa*, *Sp*
19. Marshall	-	-	15 Jun	*Sa*, *Sp*	-	-
20. Johnsen	-	-	15 Jun	*Sa*	8 Jun	*Sa*
21. Vanderslice	-	-	19 May	*Sa*	22 Jun	*Sa*
22. Collier	-	-	3 Jun	*Sa*	7 Jun	*Sa*
23. Davis	-	-	2 Jun	*Sa*	-	-
24. Hog Island	-	-	-	-	15 Jun	*Sa*

Sa = *Spartina alterniflora*

Sp = *Spartina patens*

1. MOUNTJOY - MOBJACK BAY, MATHEWS COUNTY

Planted 1981

Replanted 1982

(Refer to Appendix B)

The Mountjoy site (Figure 8) represents a south facing, low fastland bank and high energy shore. Even with its average fetch of 15.6 nautical miles, we felt that this site had a fair chance for success due to its southern exposure. Unfortunately, the plants delivered to this site in 1981 were apparently not hardened to the appropriate salinity. Thus, within three weeks, the plants had turned brown and died. This site was replanted in spring of 1982 and was washed out by mid-summer.

Bank erosion rates for the project are 3.9 feet per year for the top and base of the bank (Figure 9). Numerous trees and stumps on the beach and nearshore are evidence of rapid retreat of the shore bank (Figure 10).

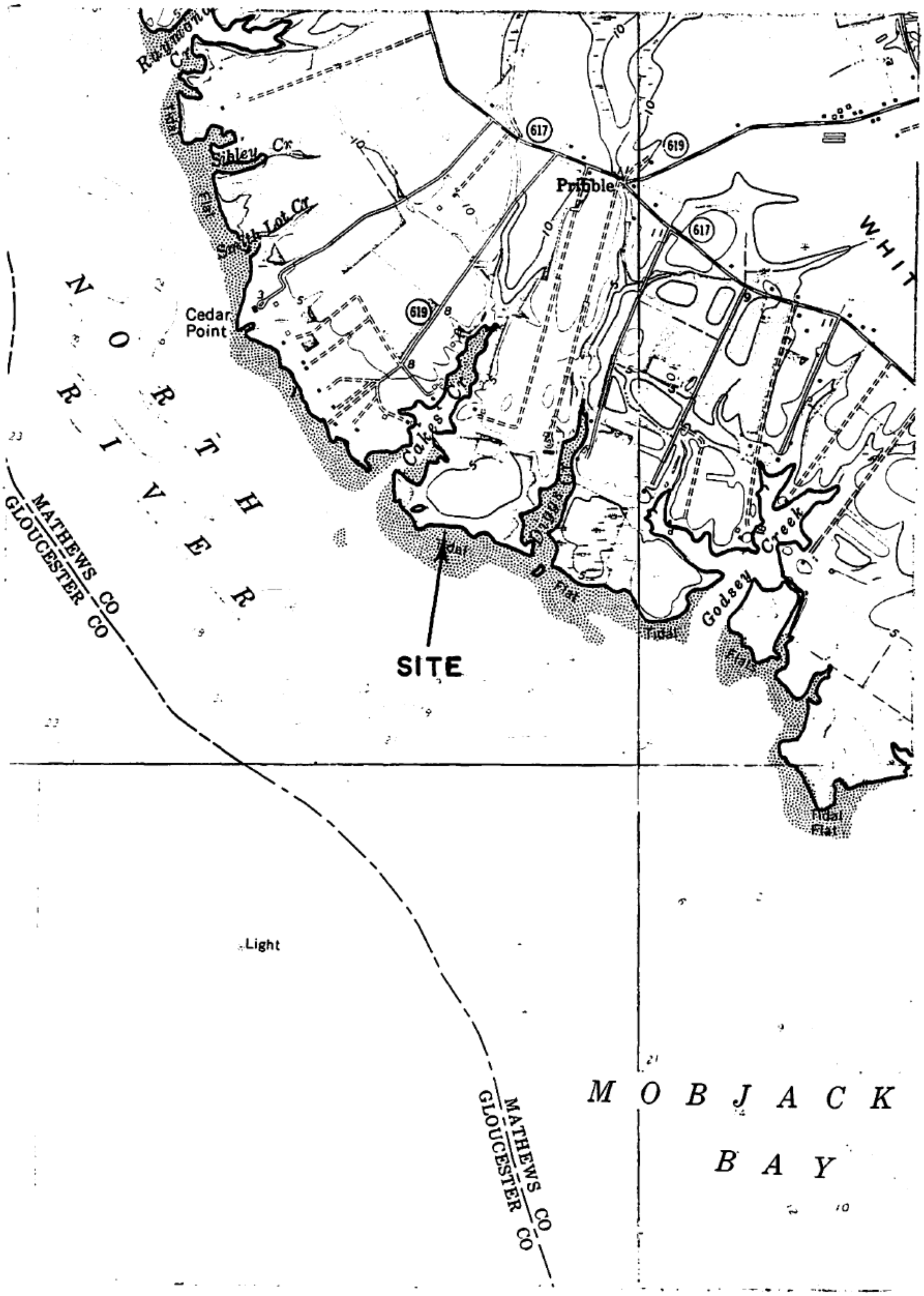


Figure 8. Mountjoy Site - from Ware Neck, Mathews, New Point Comfort 7.5 minute quadrangles.
Scale: 1 inch = 2,000 feet.

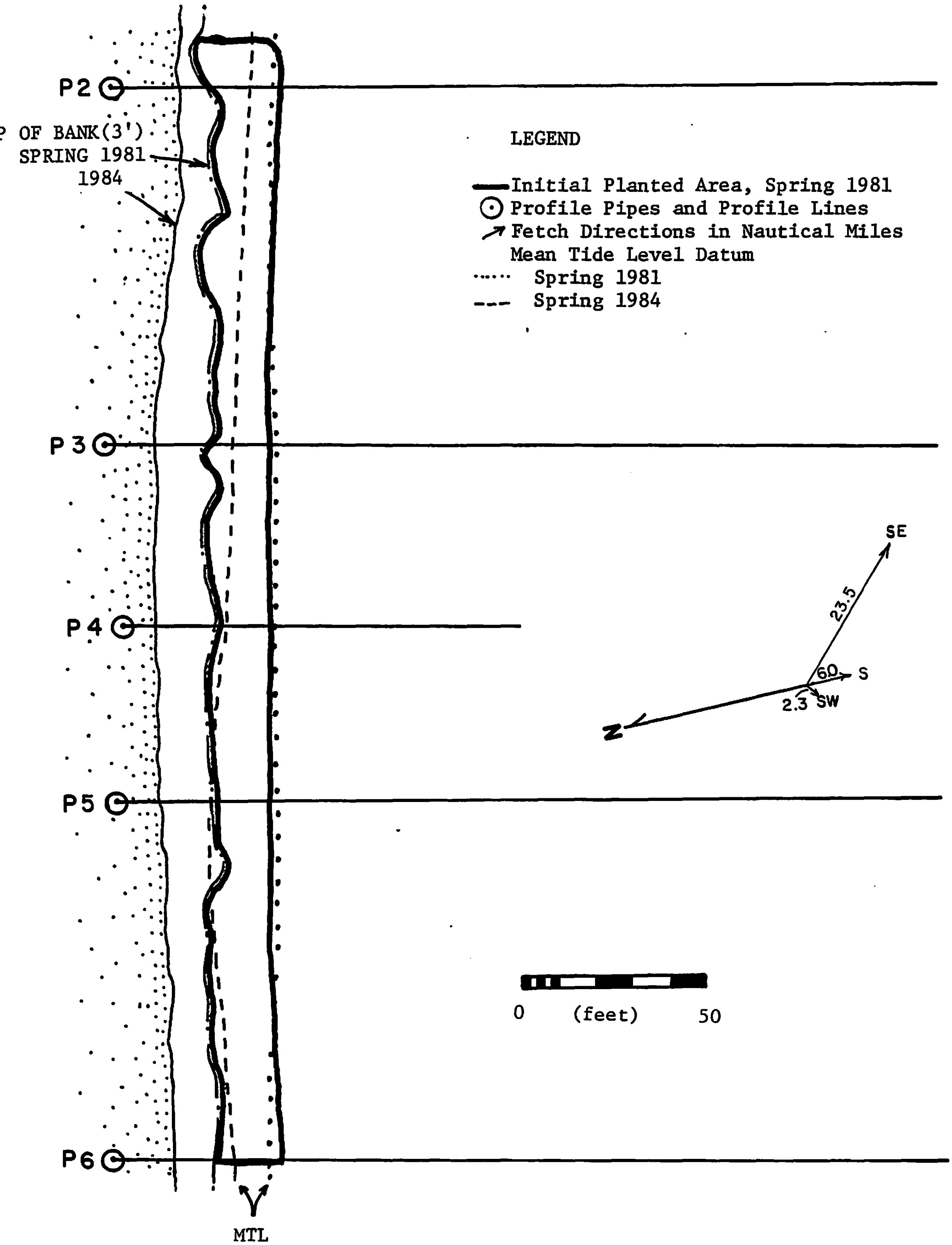
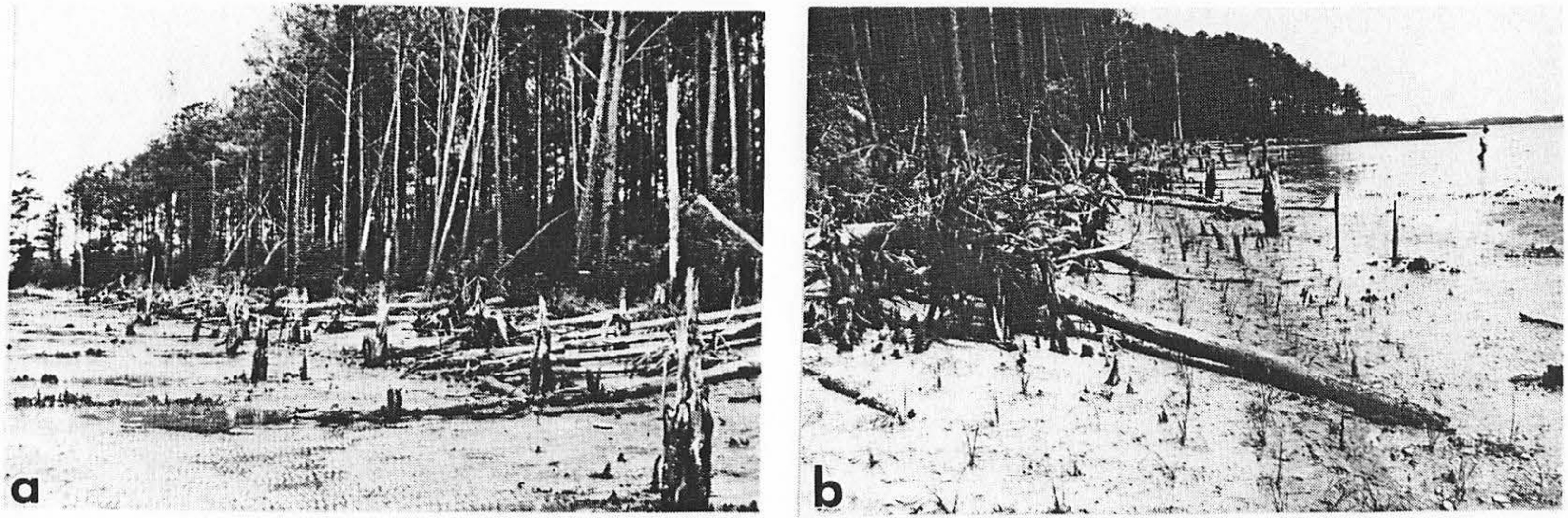


Figure 9. Mountjoy Site - Base Map.



a. May 27, 1981
Looking west.

b. May 19, 1982
Looking east.

FIGURE 10

MOUNTJOY

2. CAMP CHANCO - JAMES RIVER, SURRY COUNTY

Planted 1981

(Refer to Appendix B)

Camp Chanco is a medium energy shore (average fetch, 3.1 nautical miles) facing northeast with a high eroding bank. The site is located just down river from the Jamestown Ferry, Scotland Wharf (Figure 11). Shoreline erosion here has historically proceeded at about one foot per year (3). The 45-foot bank face is vertical along the upper half with slump material along the lower half. The lower part is partially covered with kudzu.

The beach, composed of coarse sand, gravel and fossil shell material, extends from the base of the bank riverward some 30 feet. Sediment source for the beach is principally from erosion of the adjacent fastland bank. The site is protected from northwest winds by a nearby headland.

Camp Chanco was initially planted in May 1981 (Figure 12). Both smooth cordgrass and saltmeadow hay were planted. By November 1981 much of the planting had been reduced in width (Figure 13b). There was considerable erosion along the base of the bank. This loss probably supplied material to the planting and thus explains a slight increase in volume in the intertidal fringe (Figure 14).

In the spring of 1982 there was an overall gain of sediment along the base of the bank from slumping but a slight volume loss within the marsh. Sediment continued to leave the marsh fringe in the fall of 1982

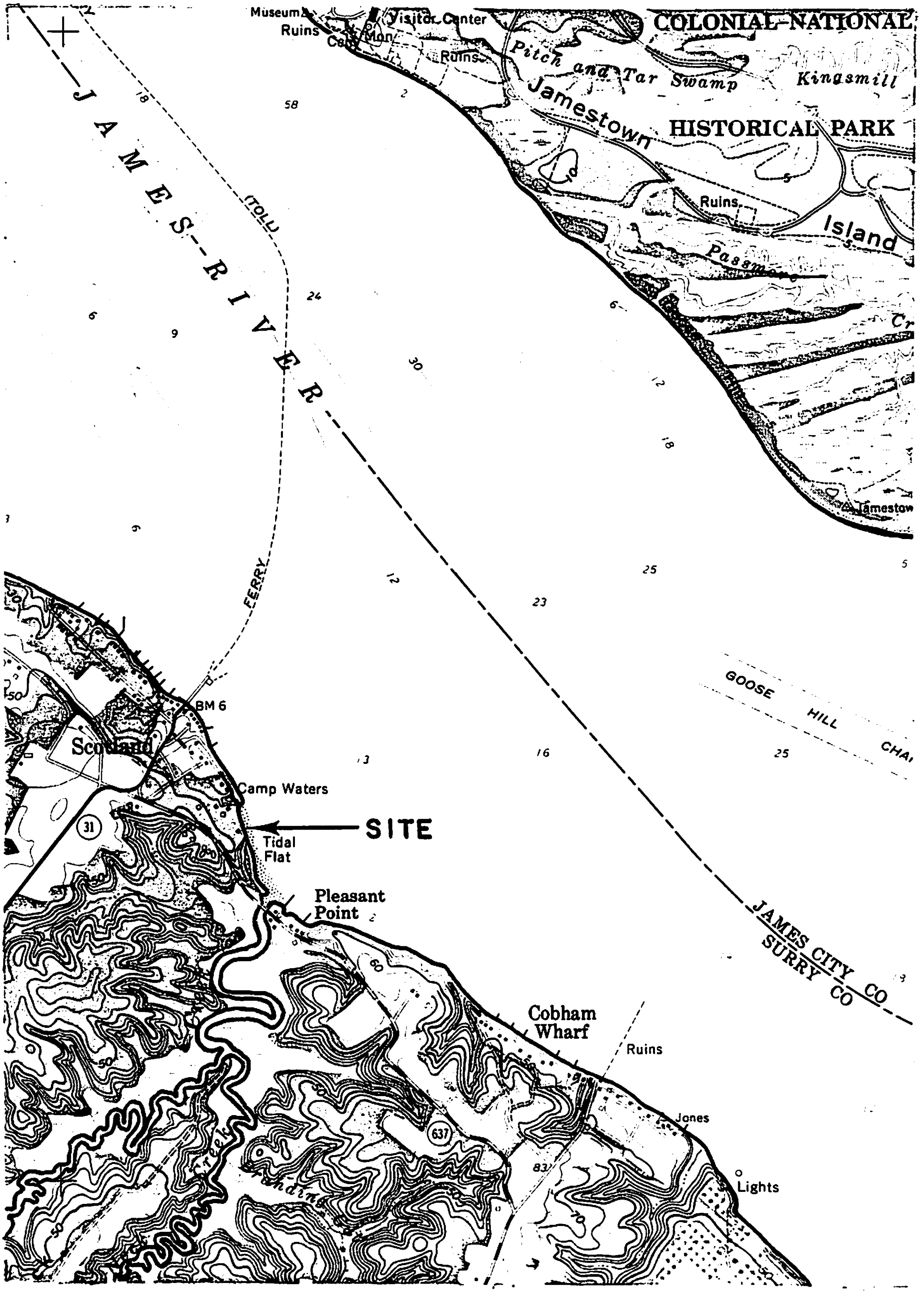


Figure 11. Camp Chanco Site - from Surry 7.5 minute quadrangle.
Scale: 1 inch = 2,000 feet.

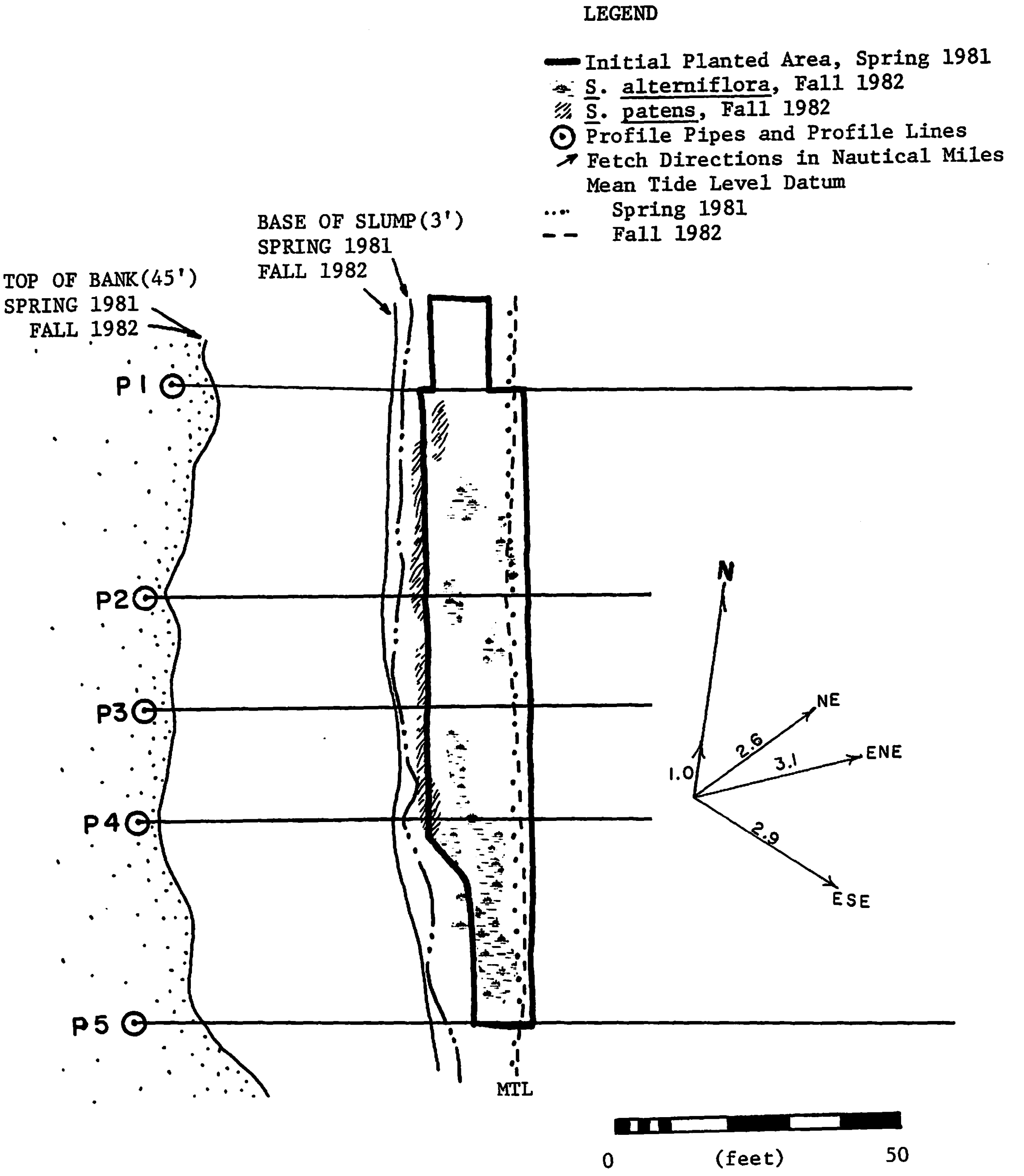


Figure 12. Camp Chanco Site - Base Map.

FIGURE 13

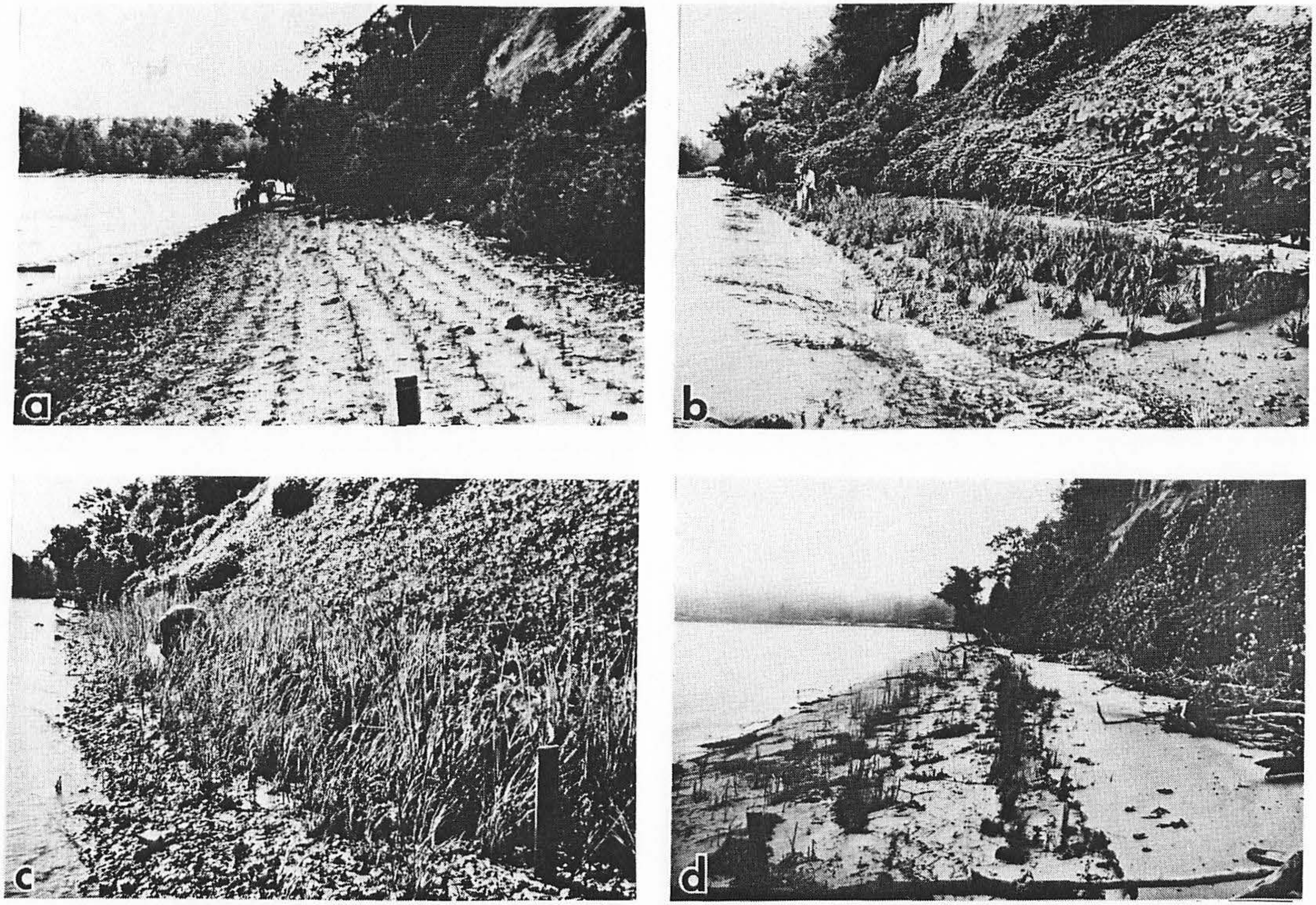
CAMP CHANCO

a. May 27, 1981
Looking southeast.

b. September 18, 1981
Looking southeast.

c. September 23, 1982
Looking southeast.

d. November 3, 1982
Looking southeast.
Post October 25, 1982
storm.


a
b
c
d

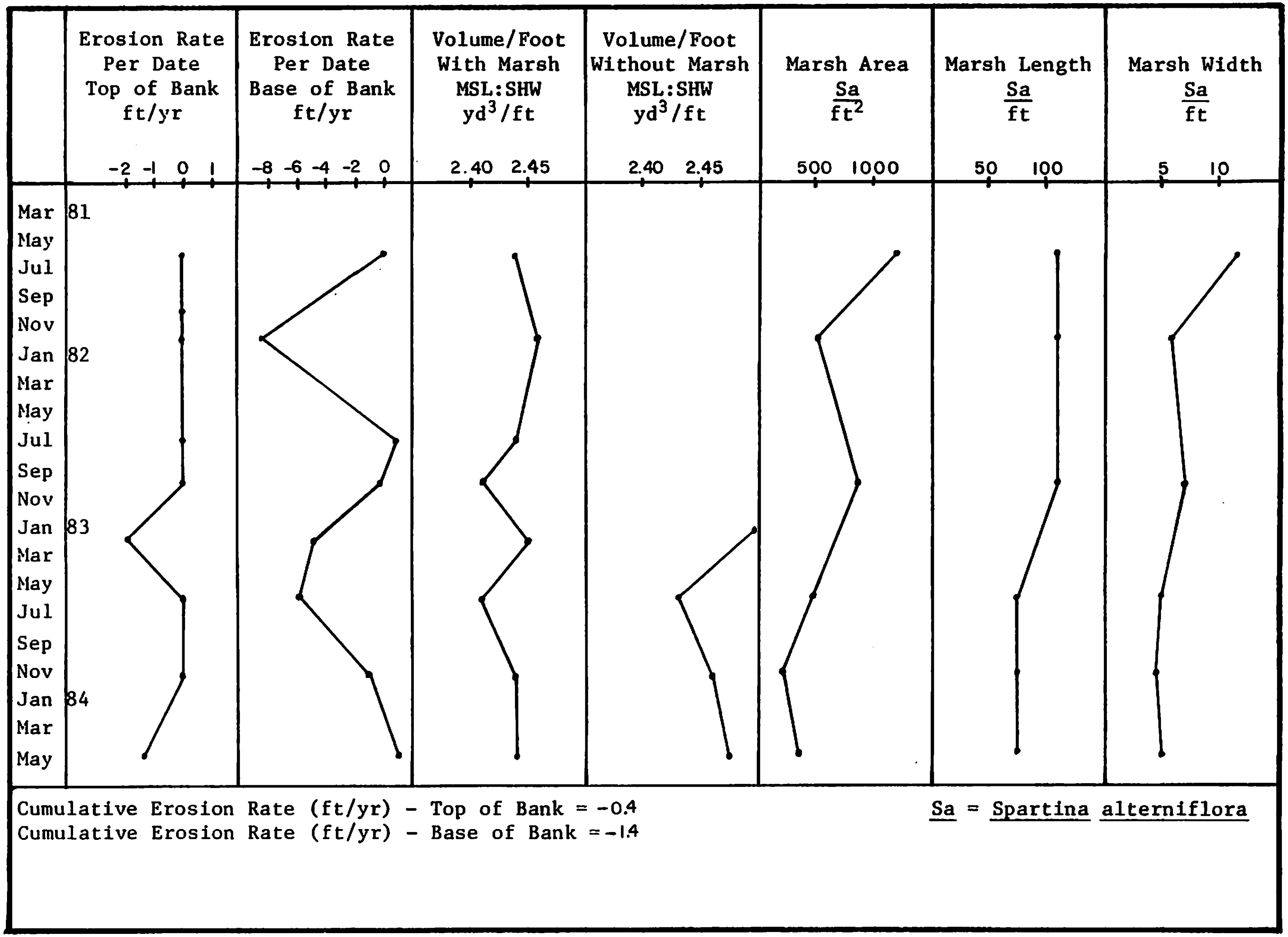


Figure 14. Camp Chanco Time Series.

although there was an increase in marsh area and width. Moreover, peat formation was becoming obvious and the marsh fringe provided a region for kudzu to expand riverward (Figure 13c).

The northeast storm of October 25, 1982 caused erosion of the top and base of the bank. This reduced the marsh area but temporarily provided sediment to the remaining fringe by mid-January 1983 (Figure 14). A wave cut scarp through the saltmeadow hay was formed after deposition of this material (Figure 13d).

Over the winter of 1982-1983 bank erosion continued. By the spring there were noted sediment losses to the intertidal fringe and adjacent area with little or no vegetation (Figure 14). These losses are attributed to winter northeast storms. There was a slight decrease in smooth cordgrass (Figure 15) and an increase in backshore elevation due to remaining saltmeadow hay (Figure 16). By the fall of 1983 an increase in sediment volume in both vegetated and nonvegetated areas was noted (Figure 14). The rate of base of bank erosion had slowed over the summer of 1983.

There was little storm activity over the winter of 1983-1984. However, erosion across the top of the high bank had supplied material to the base, thus an increase along the base is seen in the spring of 1984. The sediment volumes within the intertidal marsh remained essentially the same since fall 1983 with a slight increase in marsh area (Figure 15). The saltmeadow hay has been important in maintaining the backshore elevation through time (Figure 16). Also there has been good but patchy peat formation within the smooth cordgrass (Figure 16d).

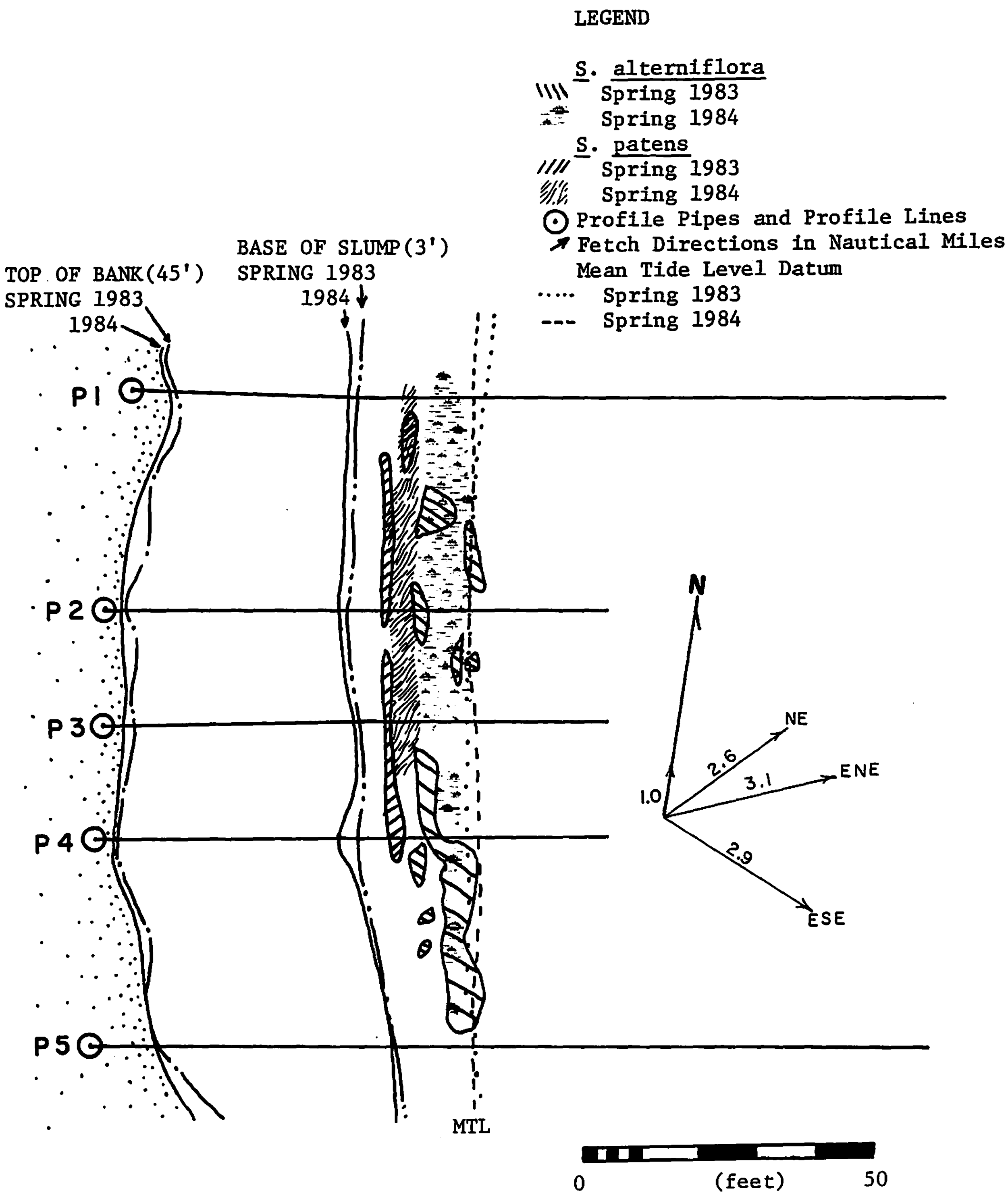


Figure 15. Camp Chanco Site - Base Map.

FIGURE 16

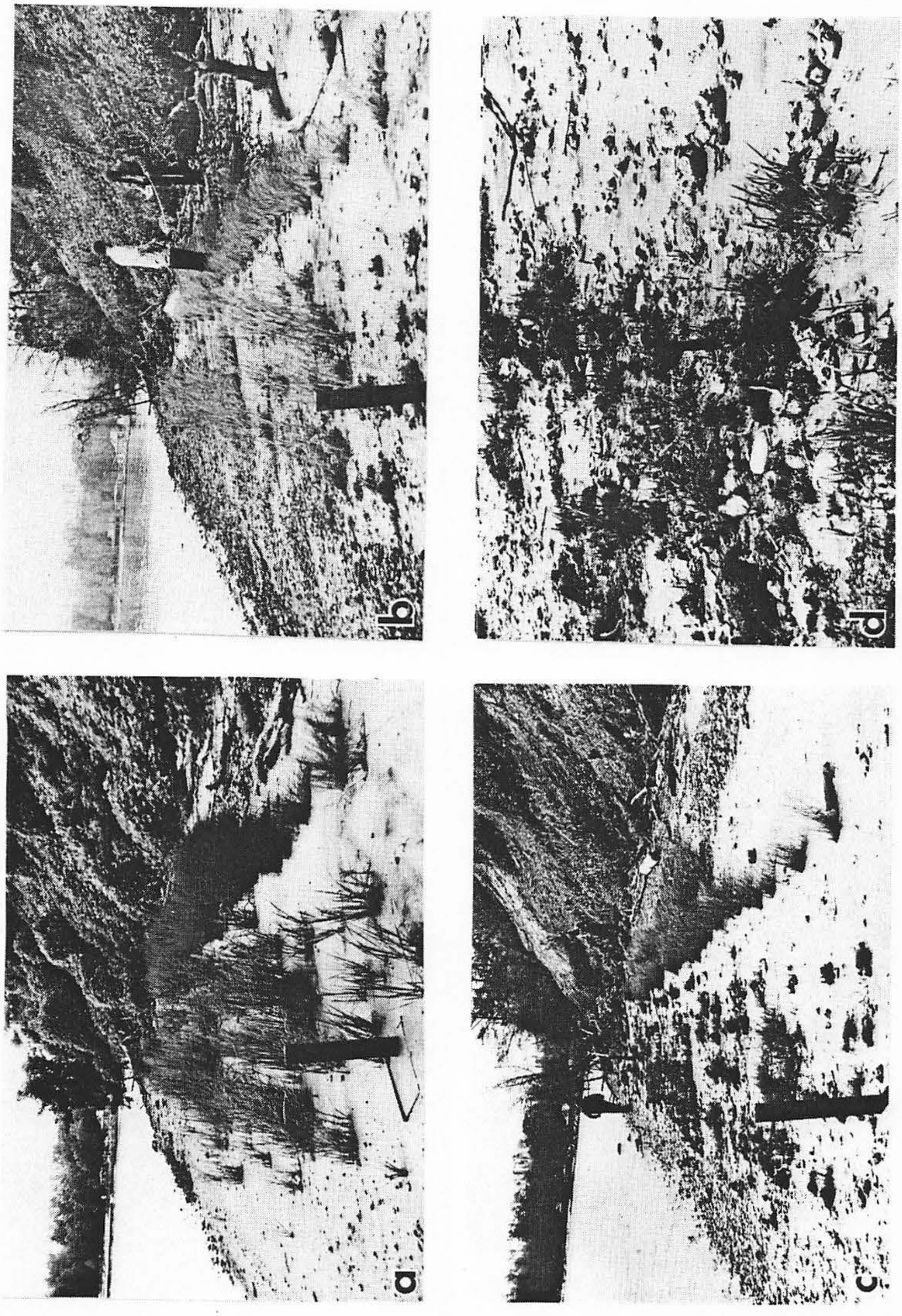
CAMP CHANCO

a. July 19, 1983
Looking southeast.

b. November 28, 1983
Looking southeast.

c. April 20, 1984
Looking southeast.

d. April 20, 1984
Smooth cordgrass peat
formation, 3 years old.


a
b
c
d

Overall there has been no net gain or loss of sediment within the intertidal marsh fringe since 1981. The top of the bank has eroded at a rate of 0.4 feet per year and the base of the bank at 1.4 feet per year. Increased elevation of the backshore since 1981 has usually corresponded with an erosional event along the base of the bank supplying material to the fringe. Backshore elevation has actually remained fairly stable through time (Figure 17).

The marsh fringe at Camp Chanco has gone through periods of growth and losses in its aerial extent. It has brought some stability to the upper tide zone by peat formation through time. The fringe may have reduced bank erosion during low stands in water and high wave conditions. However, more severe storm events and high water levels have continued to erode the adjacent fastland bank.

The fringe itself may be considered partially successful. The erosion rate may be reduced with annual maintenance planting.

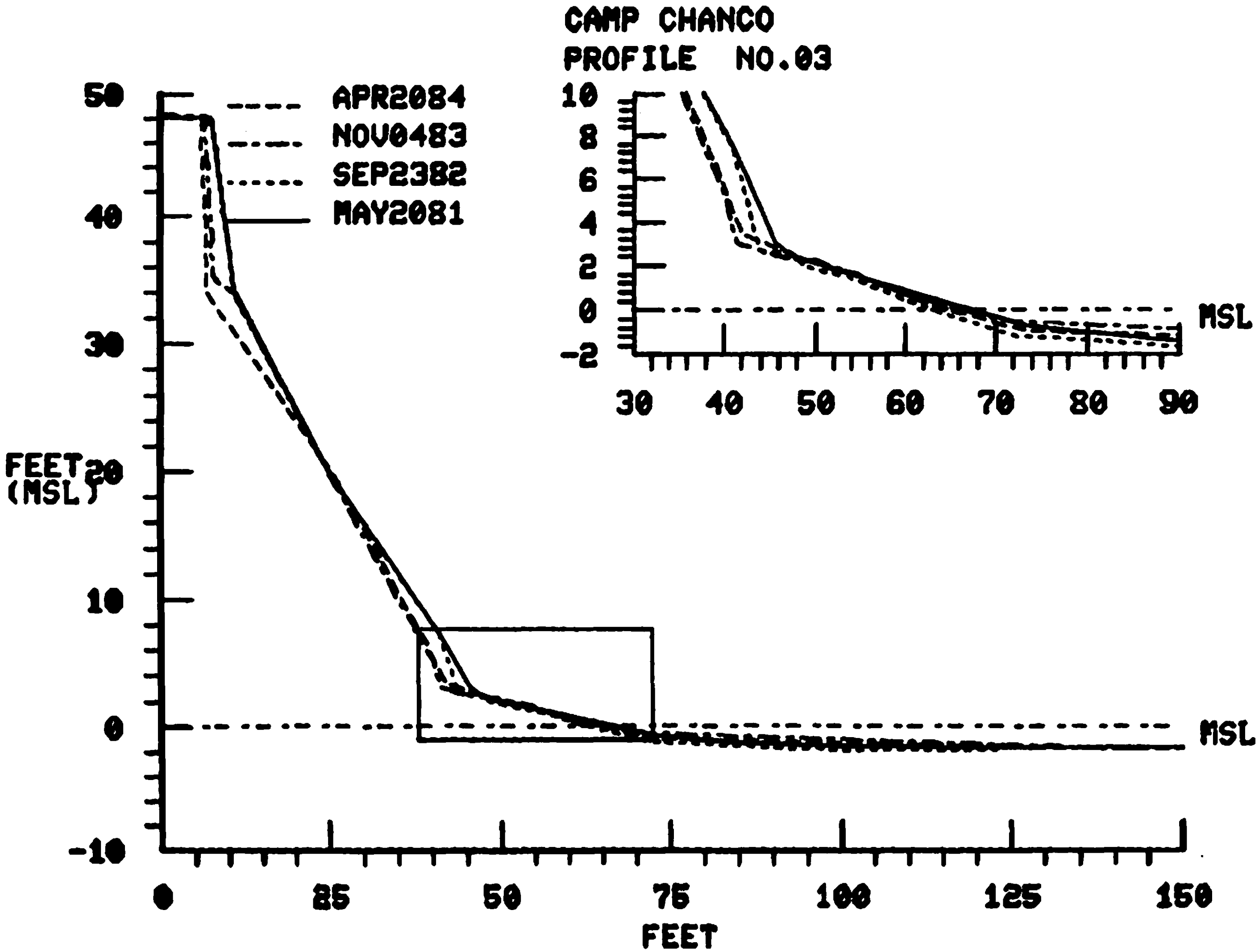


Figure 17. Camp Chanco Site - Representative Profile.

3. WINDMILL POINT - RAPPAHANNOCK RIVER, LANCASTER COUNTY

Planted 1981

Replanted 1982

(Refer to Appendix B)

The Windmill Point site (Figure 18) suffered essentially the same fate as the Mountjoy site. In 1981 the plants died due to insufficient hardening. The site was replanted in 1982 but the plants were washed out by mid-summer (Figure 19). The 13.4 nautical mile fetch exposure was just too much for the young plants. It was not planted again but remains part of the overall data base. The cumulative erosion rate over three years is 4.5 feet per year (Figure 20).

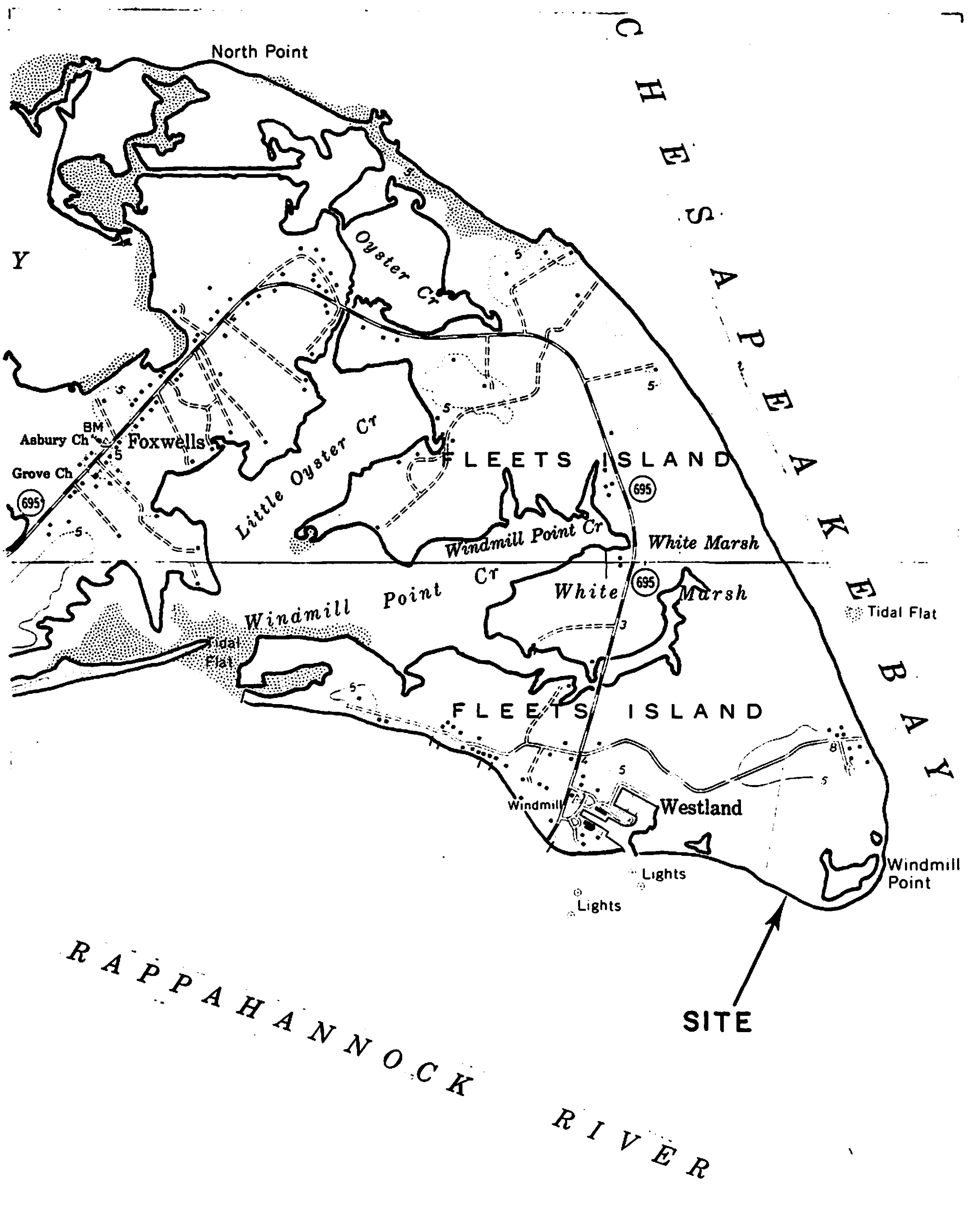
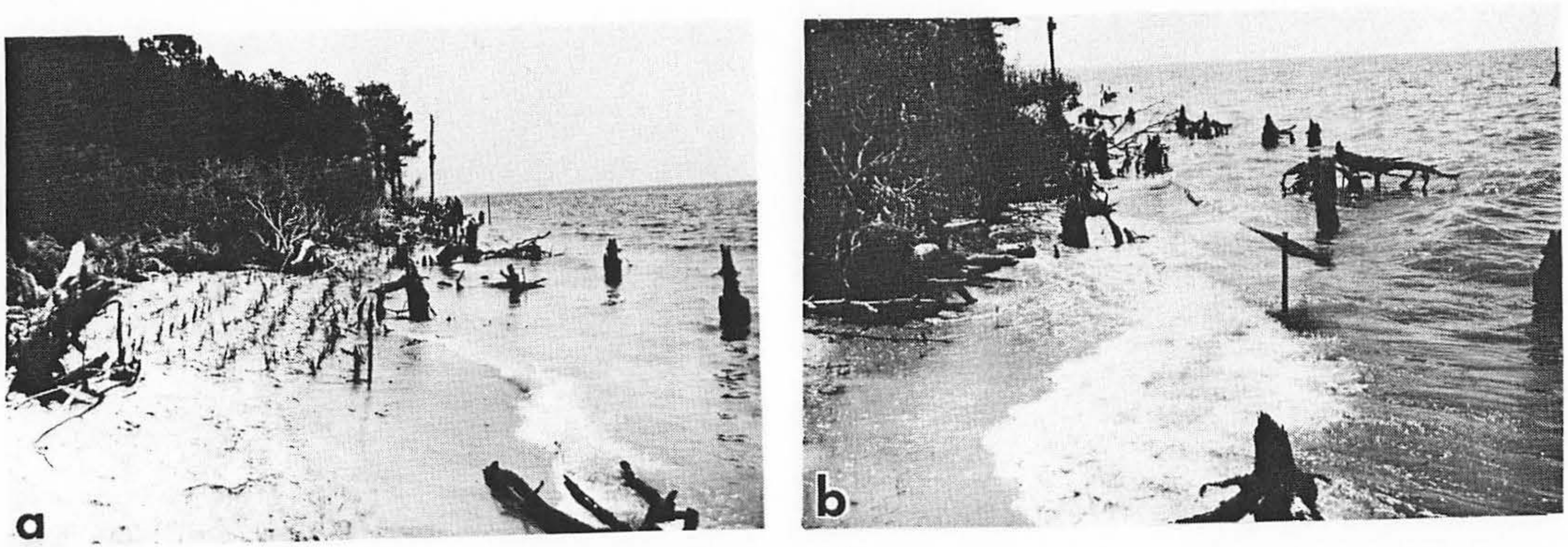


Figure 18. Windmill Point Site - from Deltaville and Fleets Bay 7.5 minute quadrangles.
Scale: 1 inch = 2,000 feet.



a. May 18, 1982

b. June 4, 1983

FIGURE 19

WINDMILL POINT

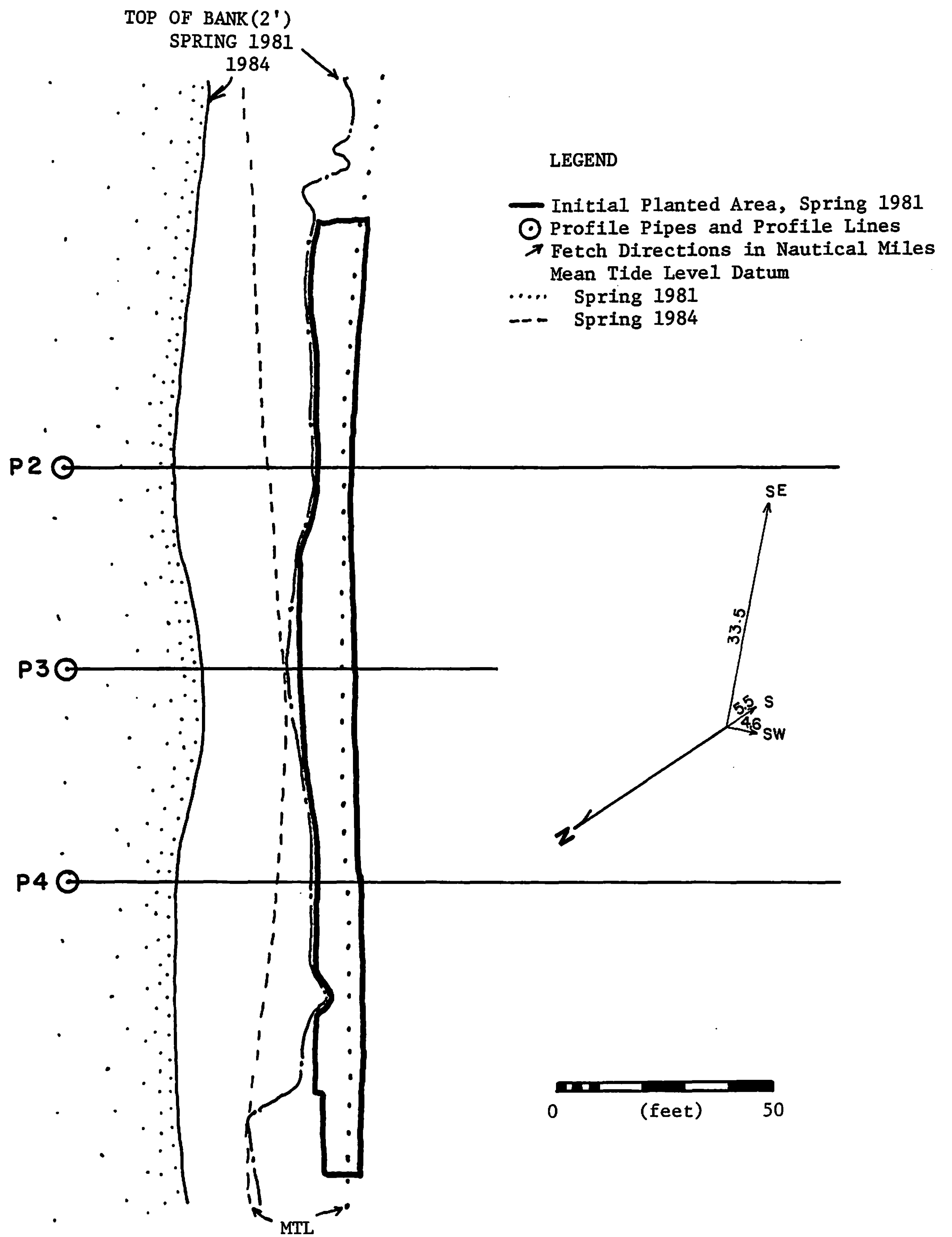


Figure 20. Windmill Point Site - Base Map.

4. F.N. LEE - WESTERN BRANCH OF THE CORROTOMAN RIVER, LANCASTER COUNTY

Planted 1981

(Refer to Appendix B)

The Lee site is a low energy, high fastland bank shore which faces north northeast. It is located on the south side of the Western Branch of the Corrotoman River just downriver from the Merry Point Ferry (Figure 21). The historical erosion rate is less than one foot per year (3). Presently, the bank appears to be rather stable with abundant vegetation on the slope (vines, small trees and grasses). In the spring of 1981, there was a wave cut scarp (1 to 2 feet high) along the base of the bank slope. This would make the whole of the bank slope eventually unstable and could cause slumping over time.

The beach is composed of medium to coarse grained sand and gravel. It extends from the base of the bank riverward for about 30 feet. Sediment source to the beach probably has come from bank erosion just upriver.

The Lee site was initially planted in May 1981 with both species of marsh grasses (Figure 22). The most severe losses were among the unhardened smooth cordgrass plants. Losses were mostly along the lower portion between MTL and MLW. This considerably reduced marsh width and area (Figure 23a). Saltmeadow hay lost about half the original plants probably due to shading between P1 and P2. The base of the bank experienced minor erosion during the summer and early fall of 1981 (Figure 24).

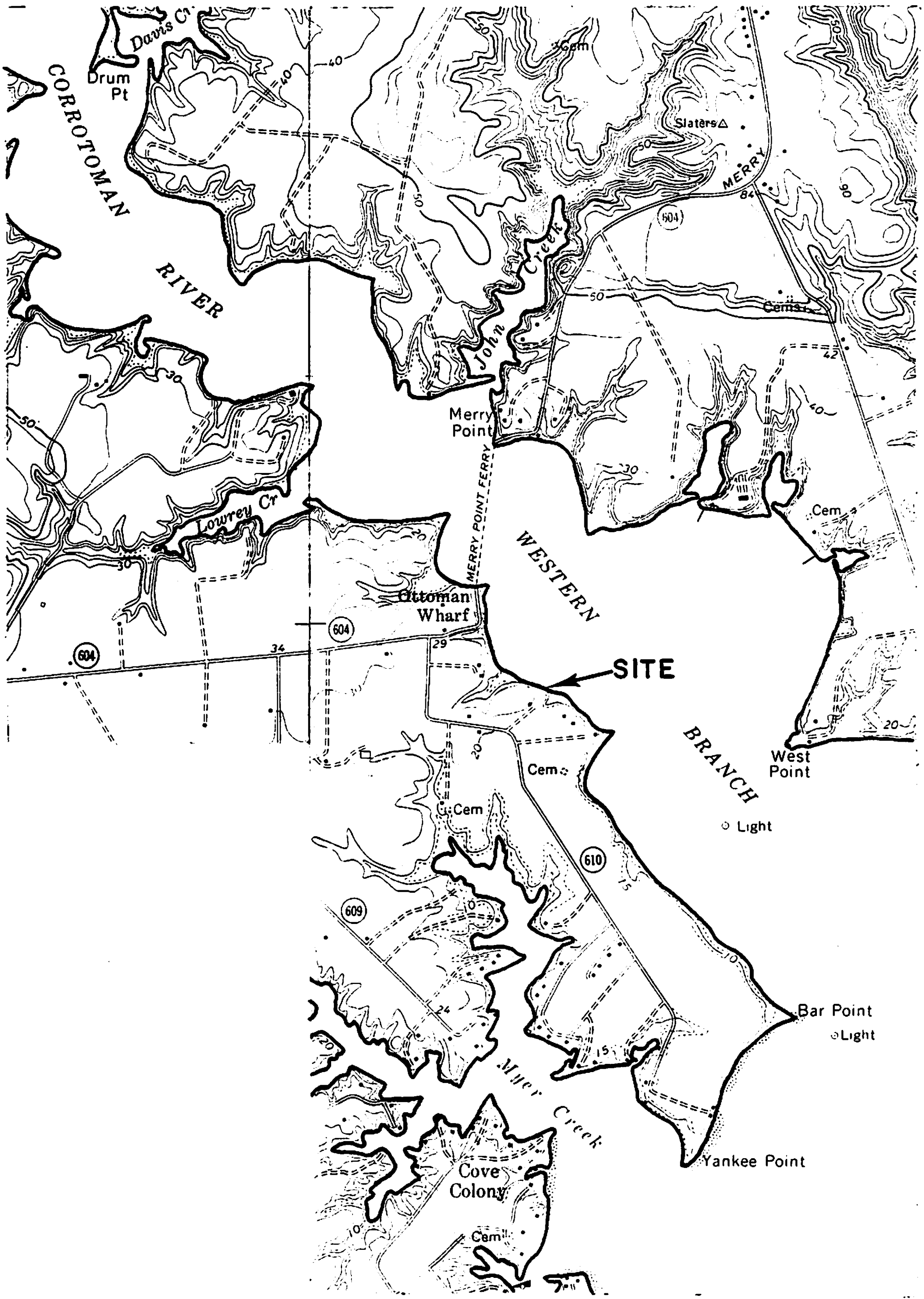


Figure 21. Lee Site - from Irvington and Urbanna 7.5 minute quadrangles.
Scale: 1 inch = 2,000 feet.

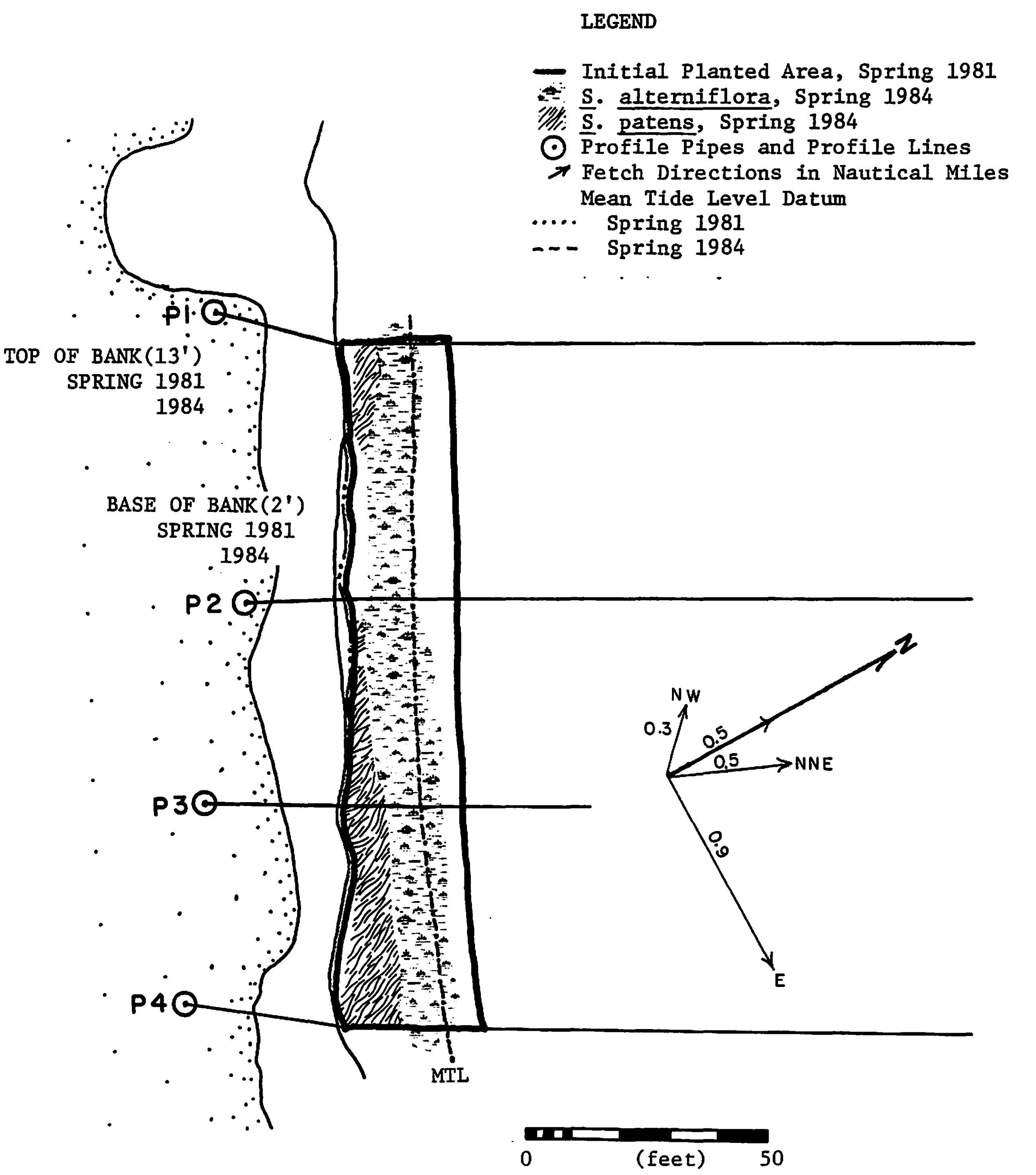


Figure 22. Lee Site - Base Map.

FIGURE 23

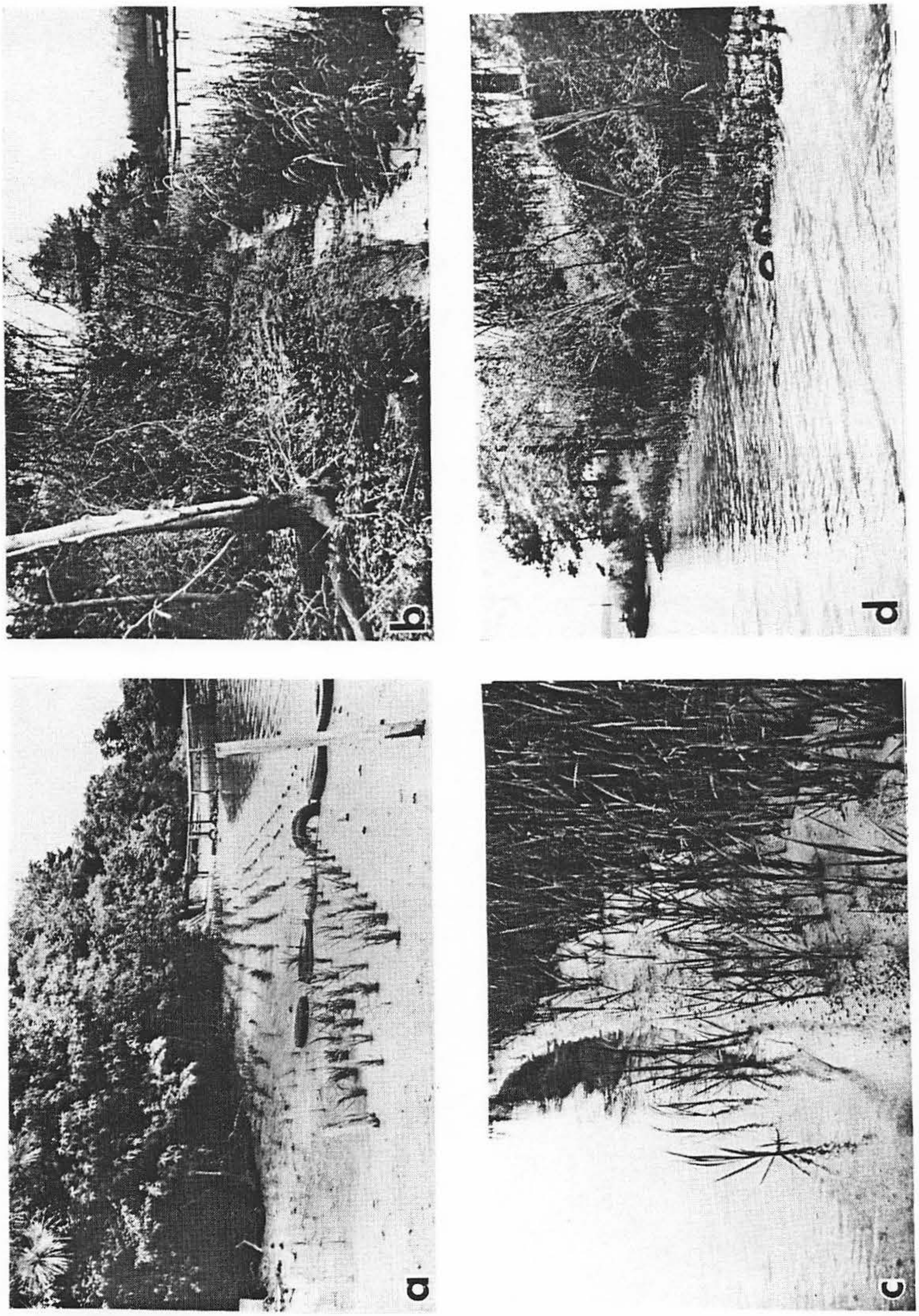
LEE

a. June 23, 1981
Looking northwest.

b. November 10, 1982
Looking northwest.

c. June 3, 1983
Note widening of smooth cordgrass marsh down-slope by rhizome spread.

d. March 8, 1984
Looking southeast.



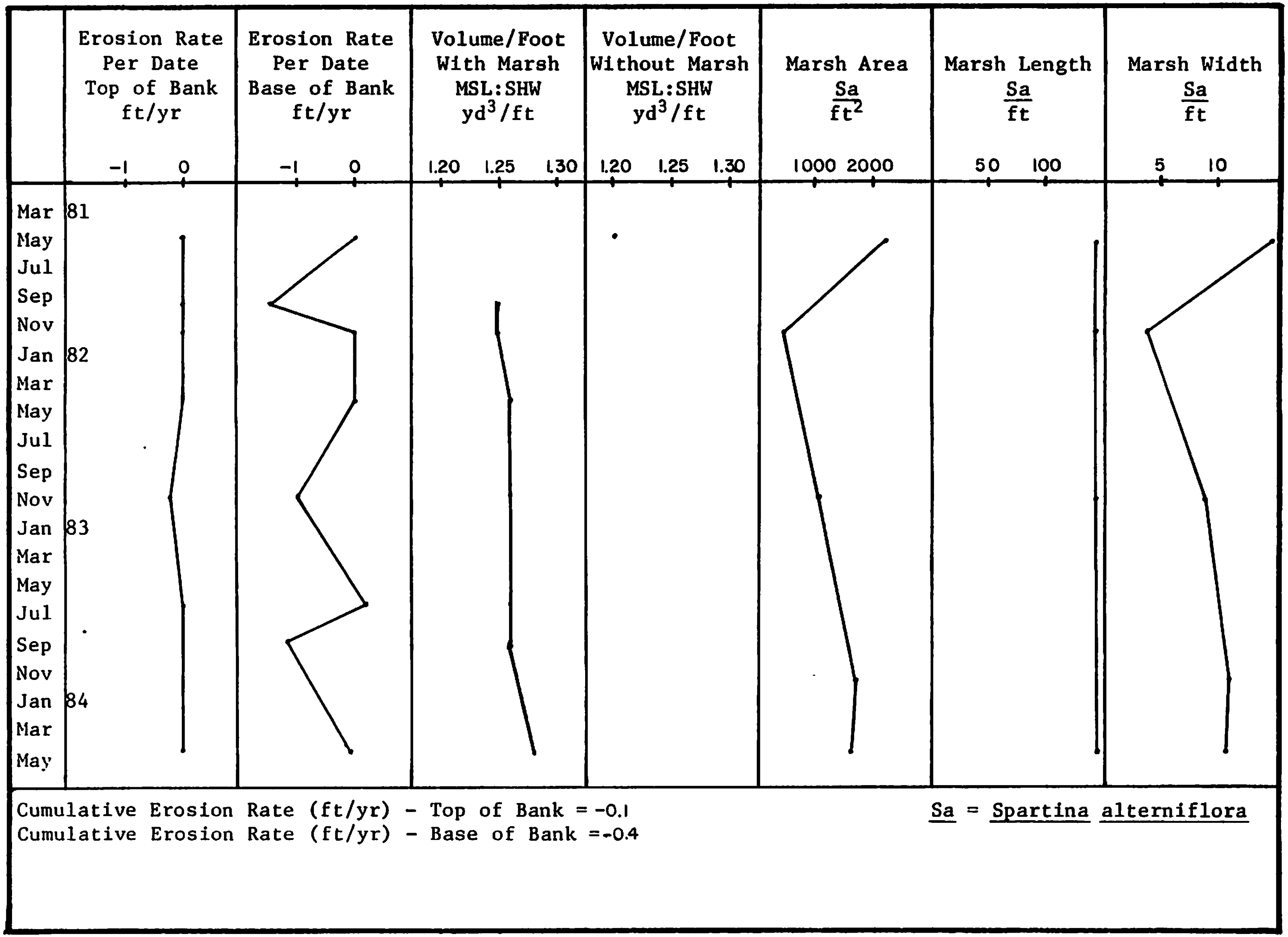


Figure 24. Lee Time Series.

The intertidal fringe gained some sediment during the winter of 1981-1982. Bank erosion was zero. A standing crop of smooth cordgrass existed during the winter months which helped deter wave attack. The marsh fringe expanded over the summer and fall of 1982. The saltmeadow hay was maintaining the backshore elevation (Figure 23b). Minor bank erosion occurred as the result of the October 25, 1982 storm. There was little change over the winter of 1982-1983. Minor maintenance planting was done in the spring of 1983 to fill a small void between P3 and P4.

The marsh fringe continued to expand through the summer of 1983 with minor base of bank erosion. By the spring of 1984 bank erosion was almost zero, the backshore was stable and the intertidal fringe had trapped additional sediment (Figure 25). Marsh area had decreased slightly but will probably expand this summer (1984).

Since 1981 there has been no major loss of bank by slumping or undercutting. The top of the bank has remained very stable. The marsh fringe has continued to expand and grow. The saltmeadow hay has helped elevate and maintain the backshore elevation. At this point the planted marsh appears to be a success and should continue to improve with periodic maintenance planting, fertilization and debris removal.

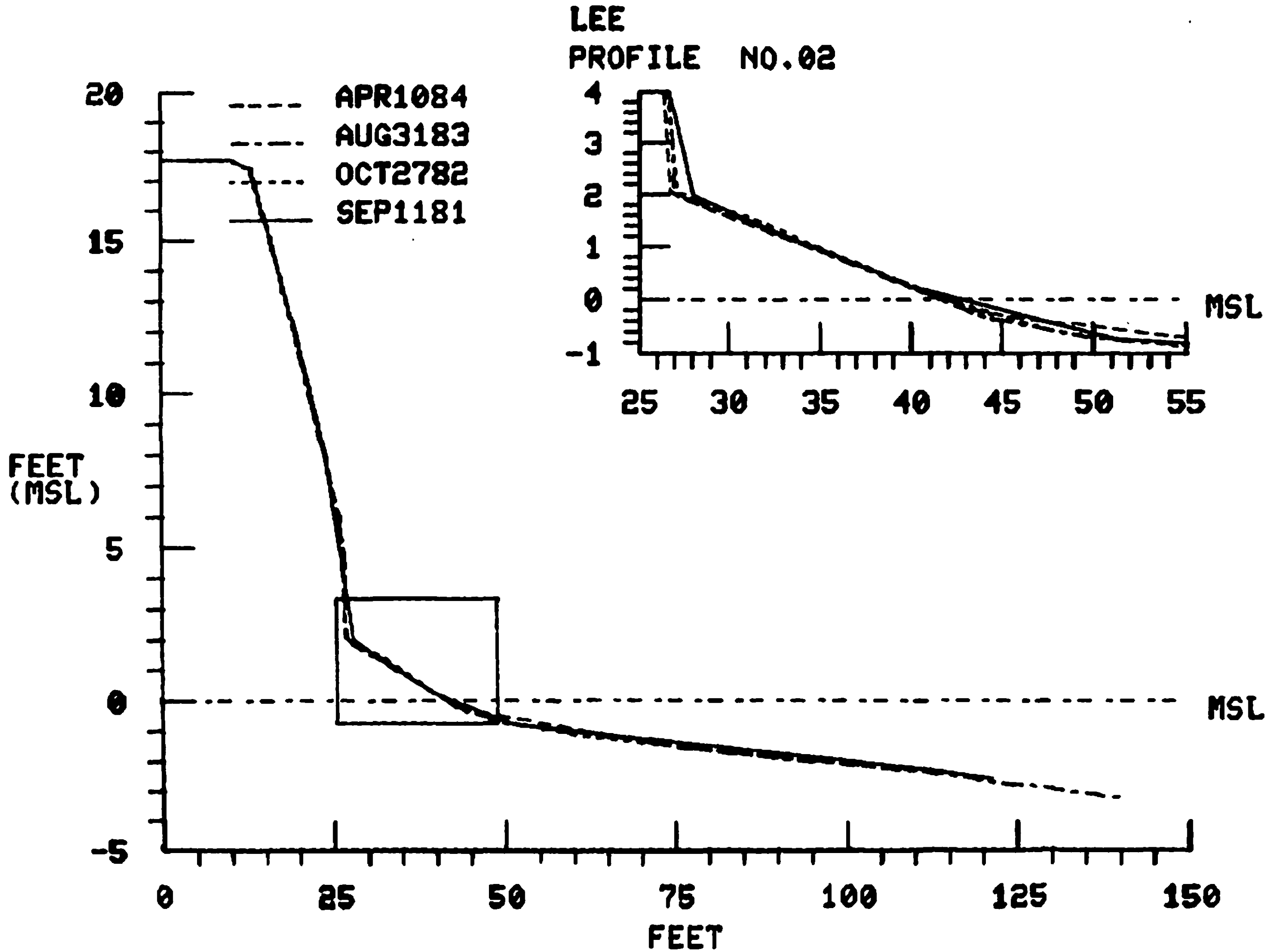


Figure 25. F.N. Lee Site - Representative Profile.

5. GILL - POTOMAC RIVER, NORTHUMBERLAND COUNTY

Planted 1981

(Refer to Appendix B)

The Gill site is a high energy shore with north northeast facing high bank. It is located just west of Hull Creek (Figure 26). The shoreline erosion rate here is almost 4 feet per year (3).

This site was completely washed out shortly after planting in 1981 by a moderate northeast wind (Figure 27). It was not replanted in 1982 but remains part of the project's data base. The erosion rate over three years has been 3.6 feet per year for the top of the bank and 4.6 feet per year for the base of the bank (Figure 28).

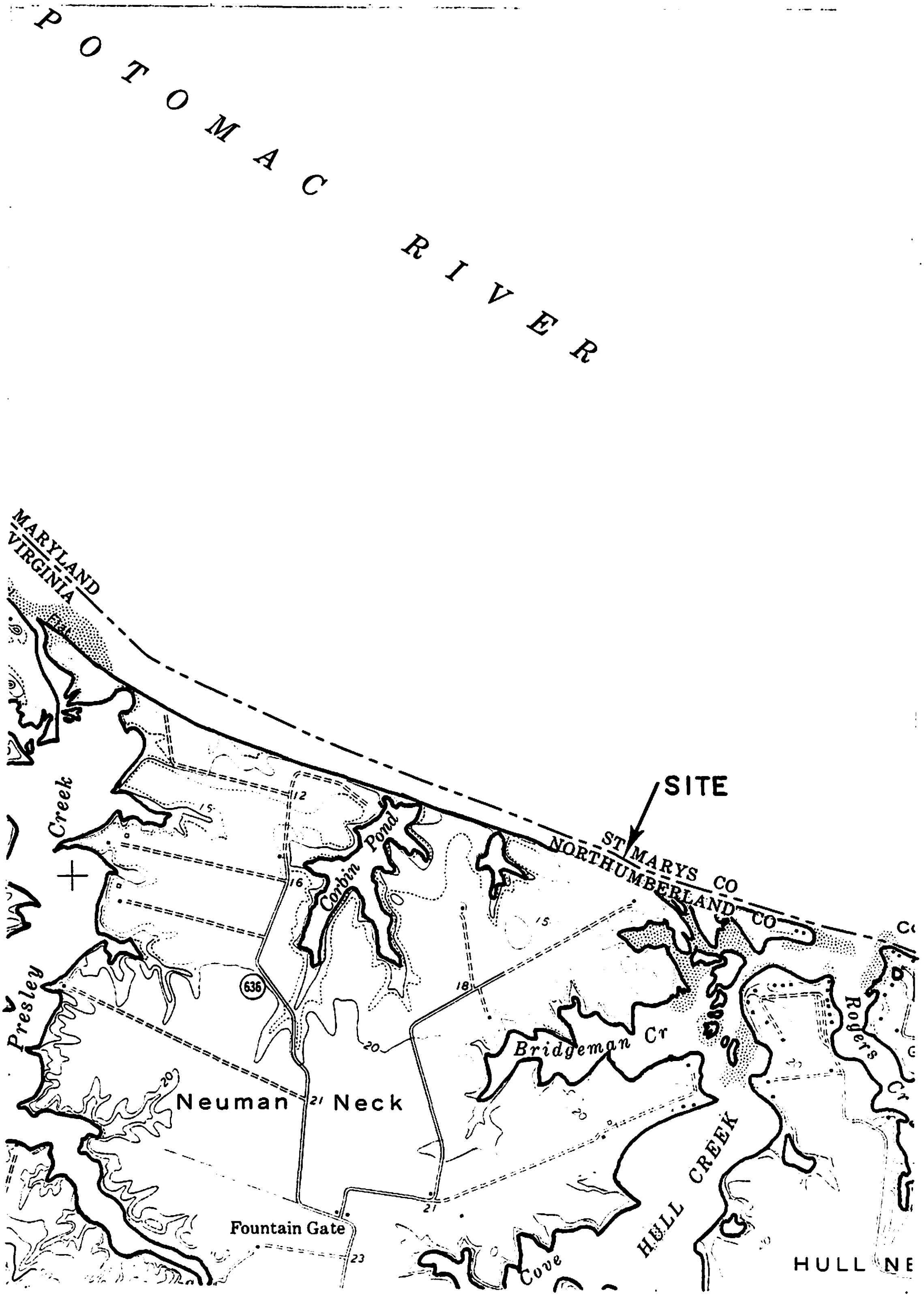
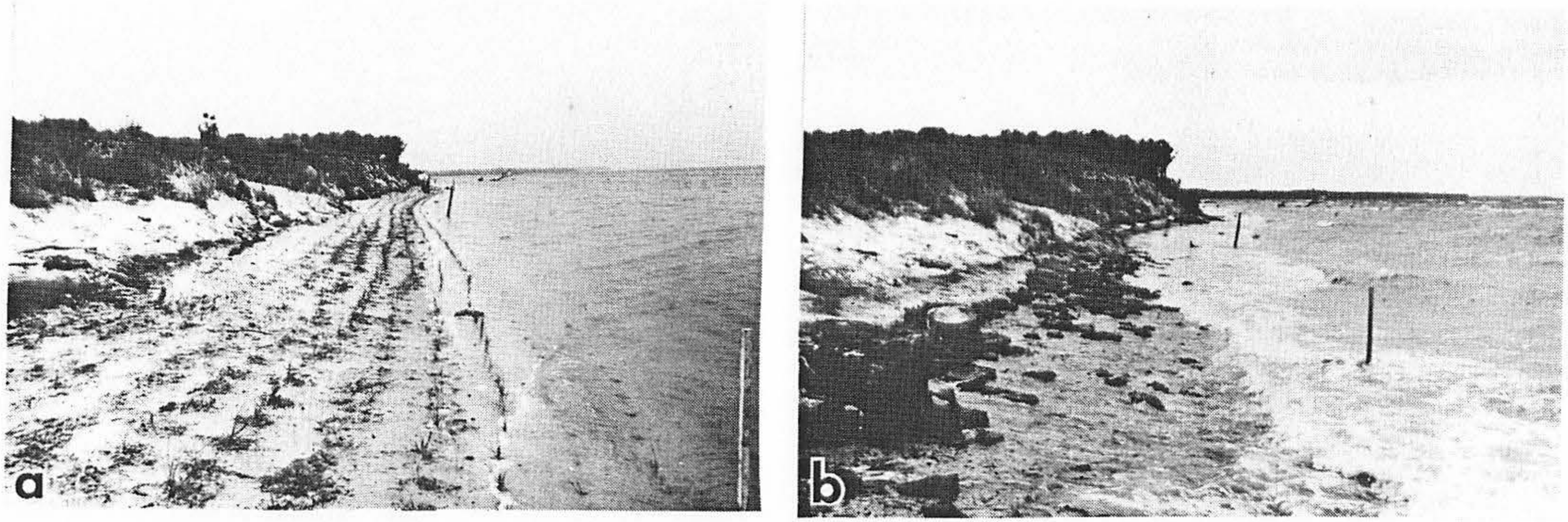


Figure 26. Gill Site - from Heathsville 7.5 minute quadrangle.
Scale: 1 inch = 2,000 feet.



a. May 6, 1981
Looking northwest.

b. May 11, 1981
Looking northwest.

FIGURE 27

GILL

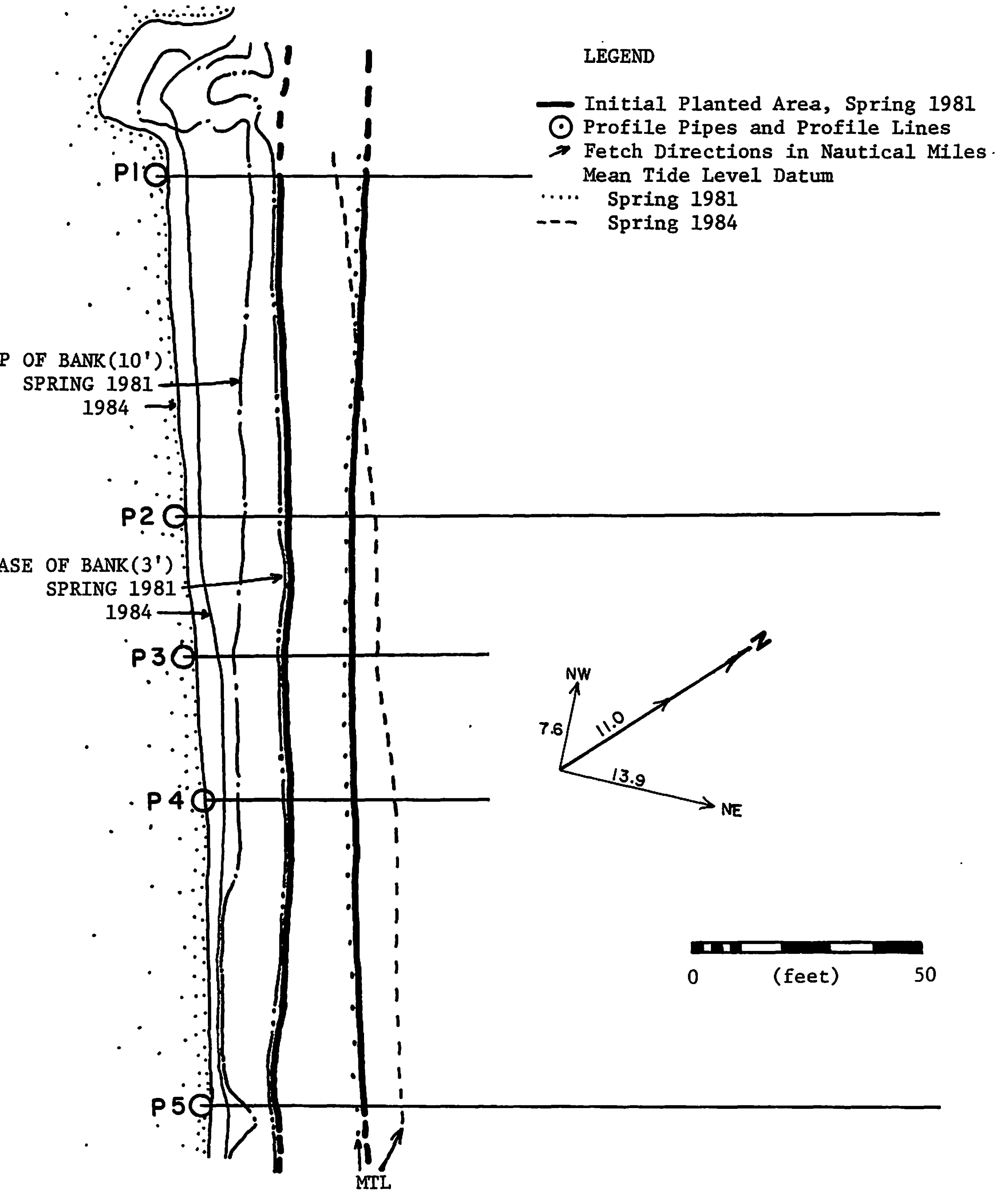


Figure 28. Gill Site - Base Map.

6. HICKMAN - OCCOHANNOCK CREEK, NORTHAMPTON COUNTY

Planted 1981

(Refer to Appendix B)

The Hickman site is located at the mouth of Occohannock Creek (Figure 29). It is a north westward facing, low bank, high energy shore. This site is well protected from northwest winds by a sand spit (Powell Bluff) across the creek in that direction. Historically, erosion has proceeded here at about 2.5 feet per year (3). Numerous old stumps, representing the retreating shoreline, occur in the nearshore region. The bank is a very low clayey sand fastland bank and humus soil. The nearshore region is rather broad with MLW occurring 80 feet offshore in some places. There is little or no beach and the intertidal substrate is a very clayey light brown medium sand.

The Hickman site was initially planted in May 1981 (Figure 30). Both species were planted but by the fall all of the saltmeadow hay was washed out and the smooth cordgrass was reduced by over 50% (Figure 31b). These plants were not properly hardened to the existing salinity. Also, remaining plants were severely stunted due to grazing by the local goat population. The fastland bank is so low that the top and base occupy the same position. By the fall of 1981 bank erosion and loss of sediment within the intertidal fringe were measured (Figure 32).

Through the winter of 1981-1982 bank erosion continued. The loss of saltmeadow hay left the backshore unprotected. There was a slight gain in sediment volume in the intertidal fringe by spring 1982 possibly

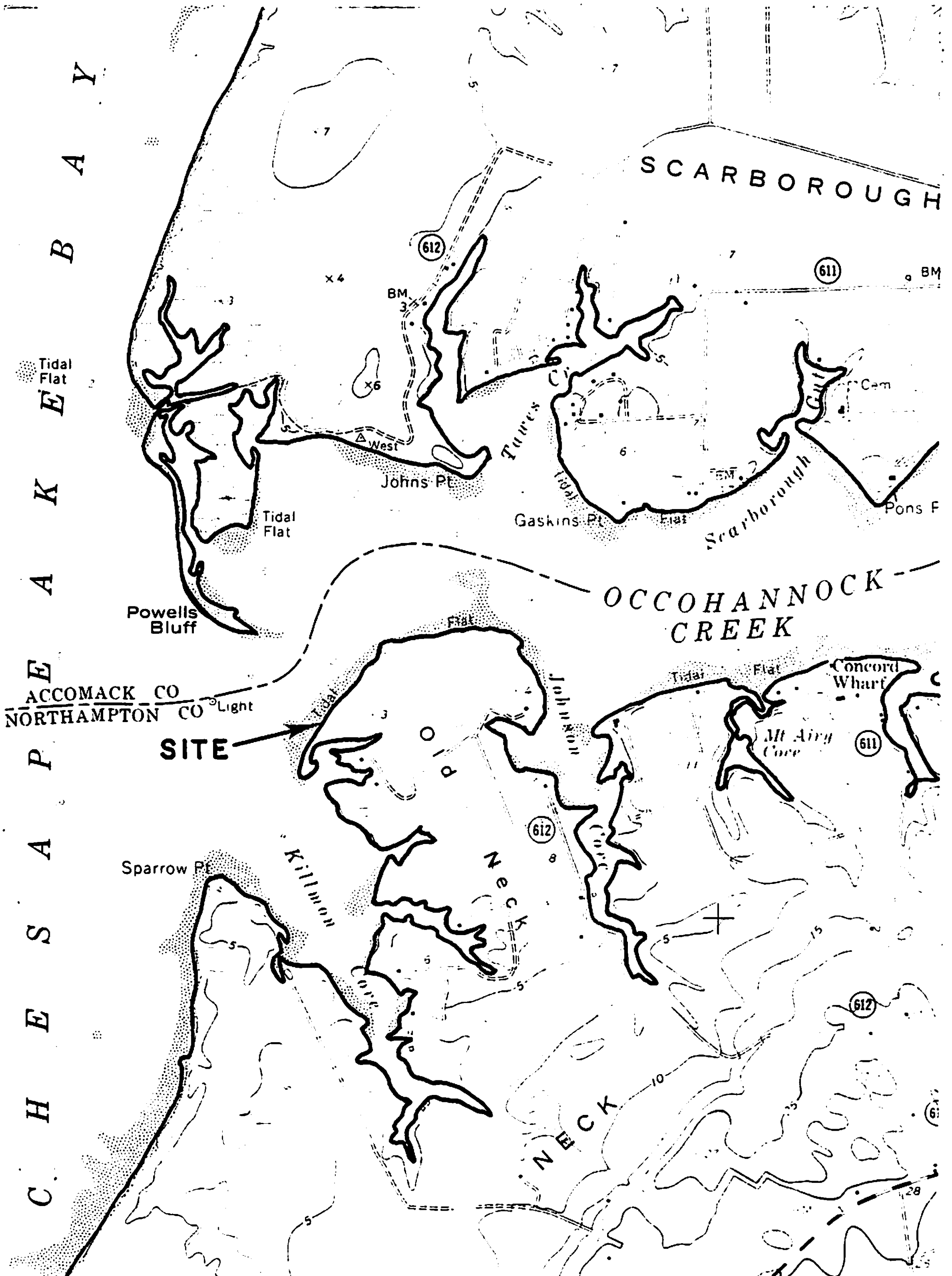


Figure 29. Hickman Site - from Jamesville 7.5 minute quadrangle. Scale: 1 inch = 2,000 feet.

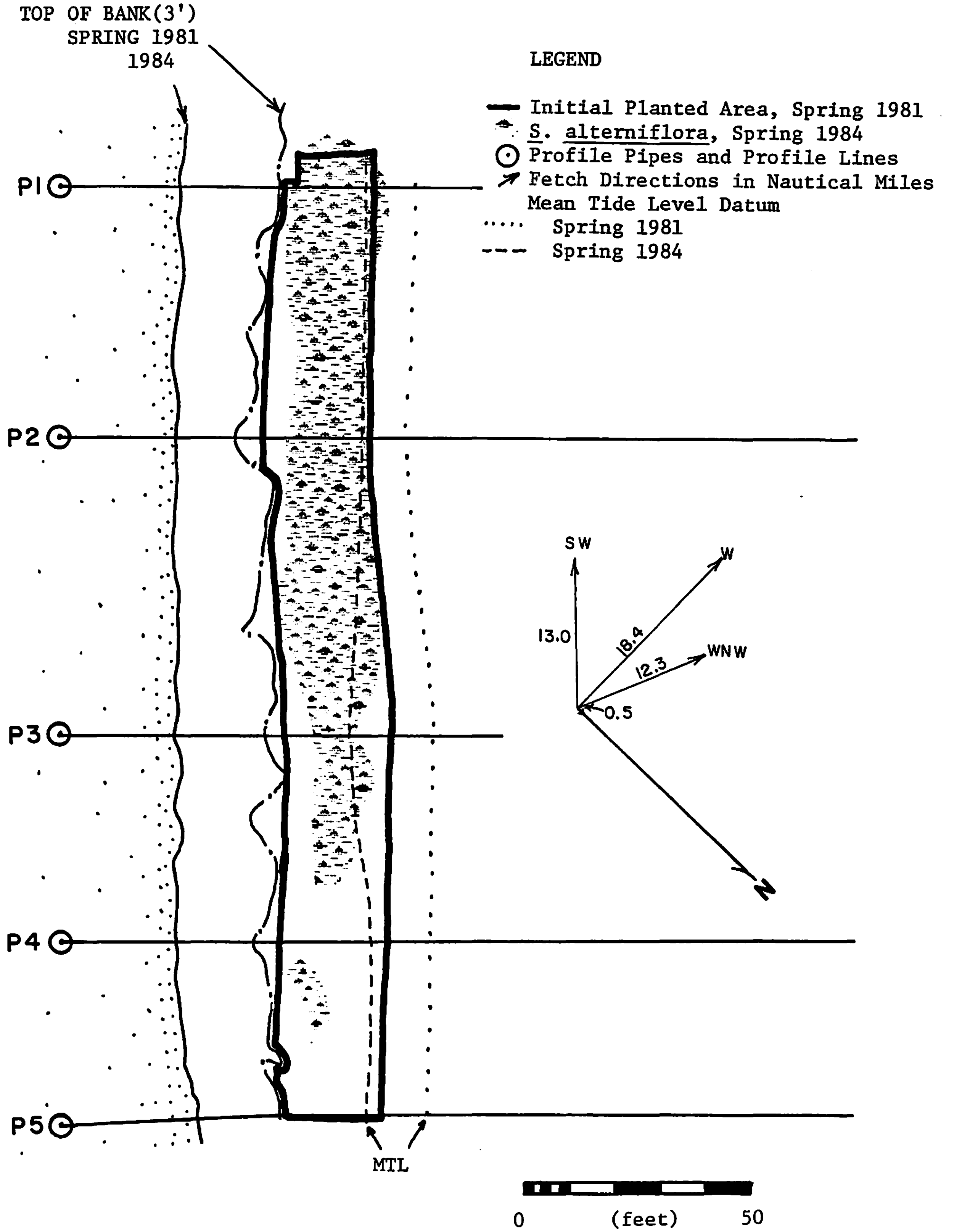


Figure 30. Hickman Site - Base Map.

FIGURE 31

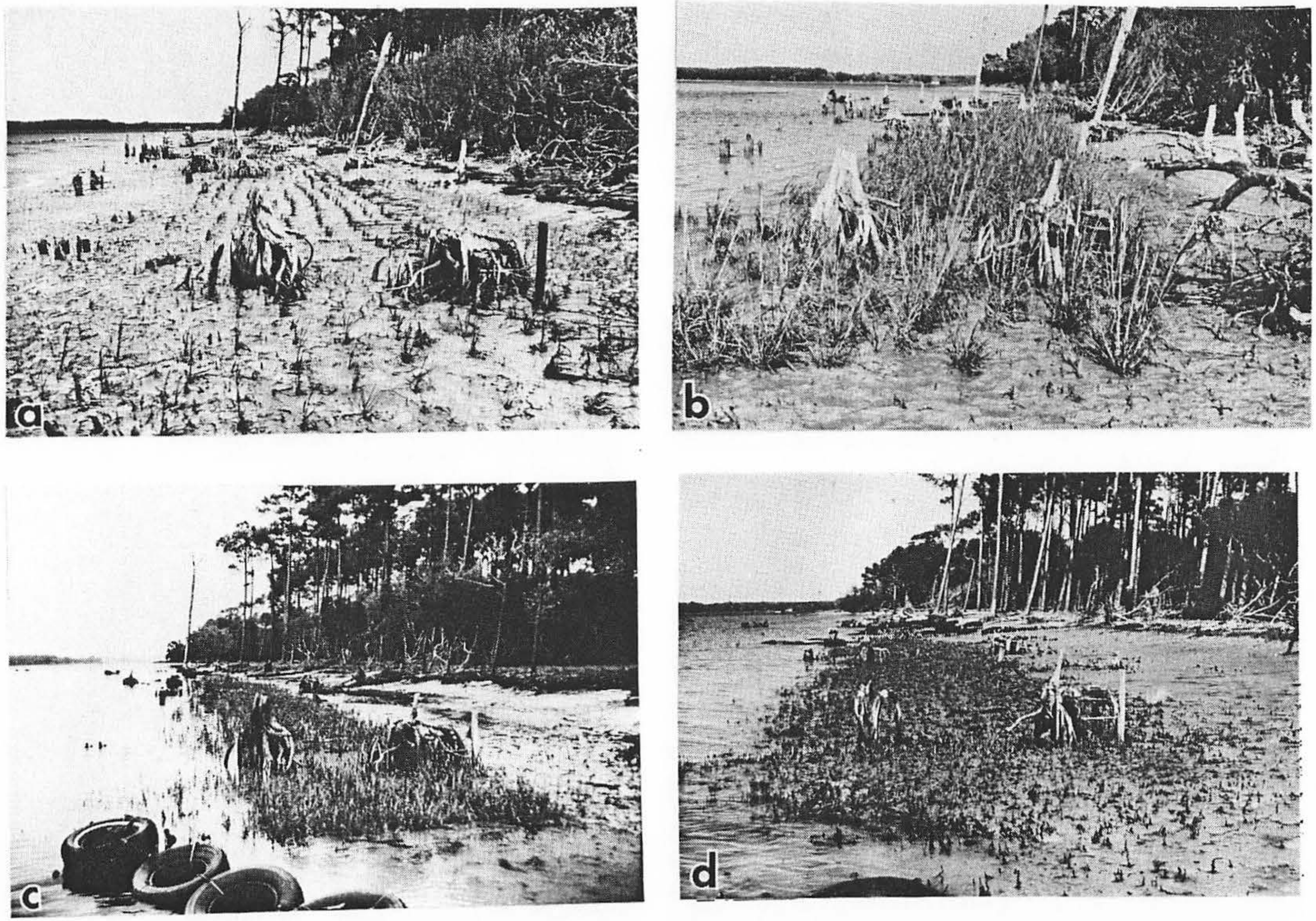
HICKMAN

a. June 26, 1981
Looking northeast.

b. October 28, 1981
Looking northeast.

c. October 12, 1982
Looking northeast.

d. April 12, 1984
Looking northeast.


a
b
c
d

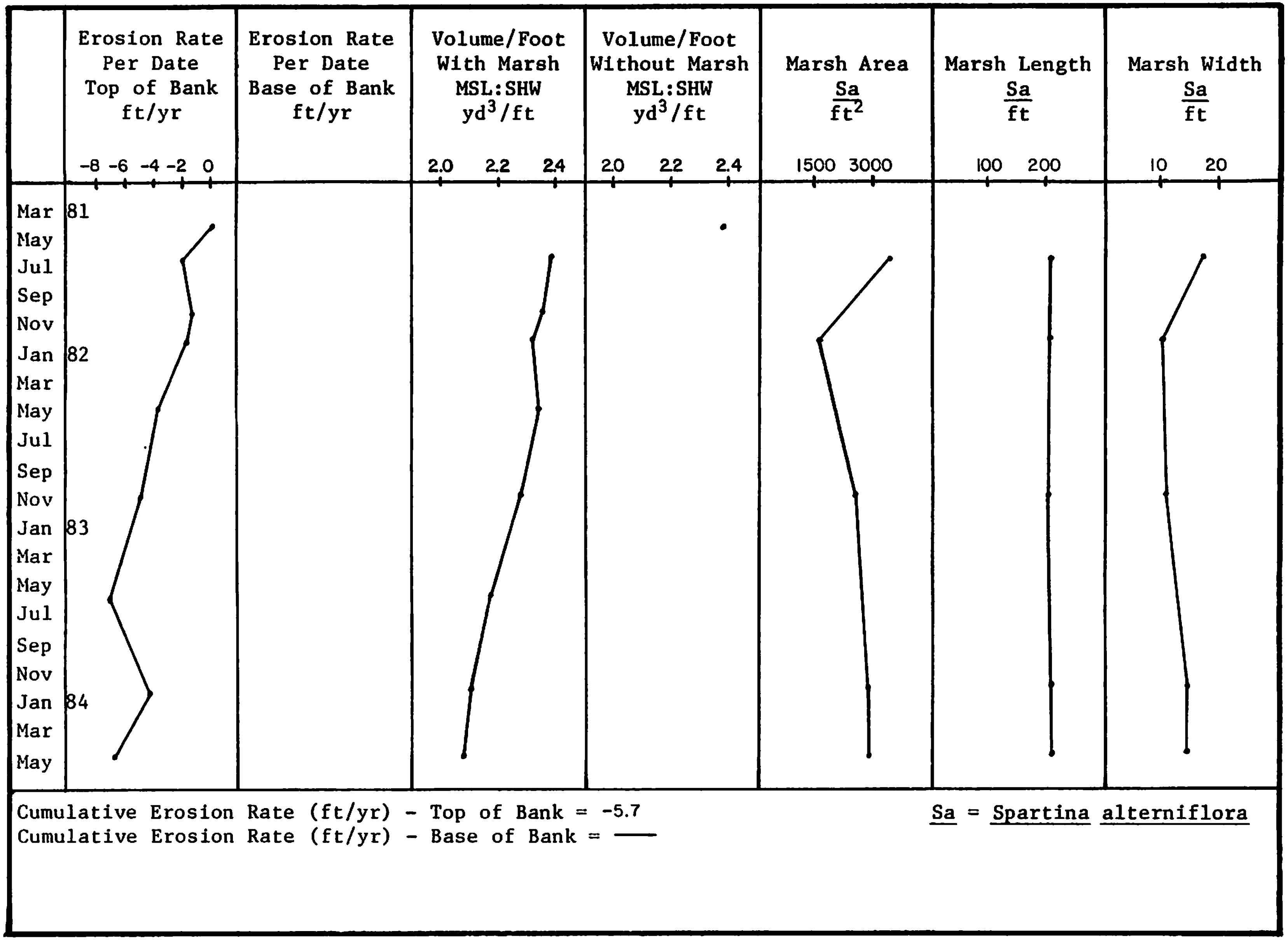


Figure 32. Hickman Time Series.

as a consequence of the eroding bank. The goats were still present and the plants were cropped as soon as they became green. The fringe did expand in area and width over the summer of 1982 and by the fall had regained much that was previously lost. During the fall the fringe continued to lose sediment and bank erosion rate was increasing.

Bank erosion and sediment loss to the intertidal fringe continued through the winter of 1982-1983. The fringe was unable to maintain backshore elevation. Peat development was noted in the spring of 1983. The marsh fringe expanded during the summer of 1983 and the rate of bank erosion decreased. Sediment volume in the intertidal fringe continued to decrease also. As the bank eroded back, the mean tide level datum shifted landward.

Figure 30 shows the position of the bank in the spring of 1984. Bank erosion through the winter of 1983-1984 was severe. A cumulative erosion rate of 5.7 feet per year was measured over three years (Figure 33). Although the marsh fringe has expanded and remained very much continuous and wide, it has been unable to maintain a stable backshore or slow the erosion rate. The goats have left but their effect was to reduce the sediment trapping capability of the fringe from 1981 to fall 1983.

Although the site is semi-protected by a headland spit and shallow nearshore bottom, it is still exposed to 18 miles of open bay to the west. The fringe will have to expand landward considerably before erosion is slowed. In spite of the exposure the marsh has expanded steadily after its early losses. If it were not for its protective situation, marsh establishment at the Hickman site would not have occurred.

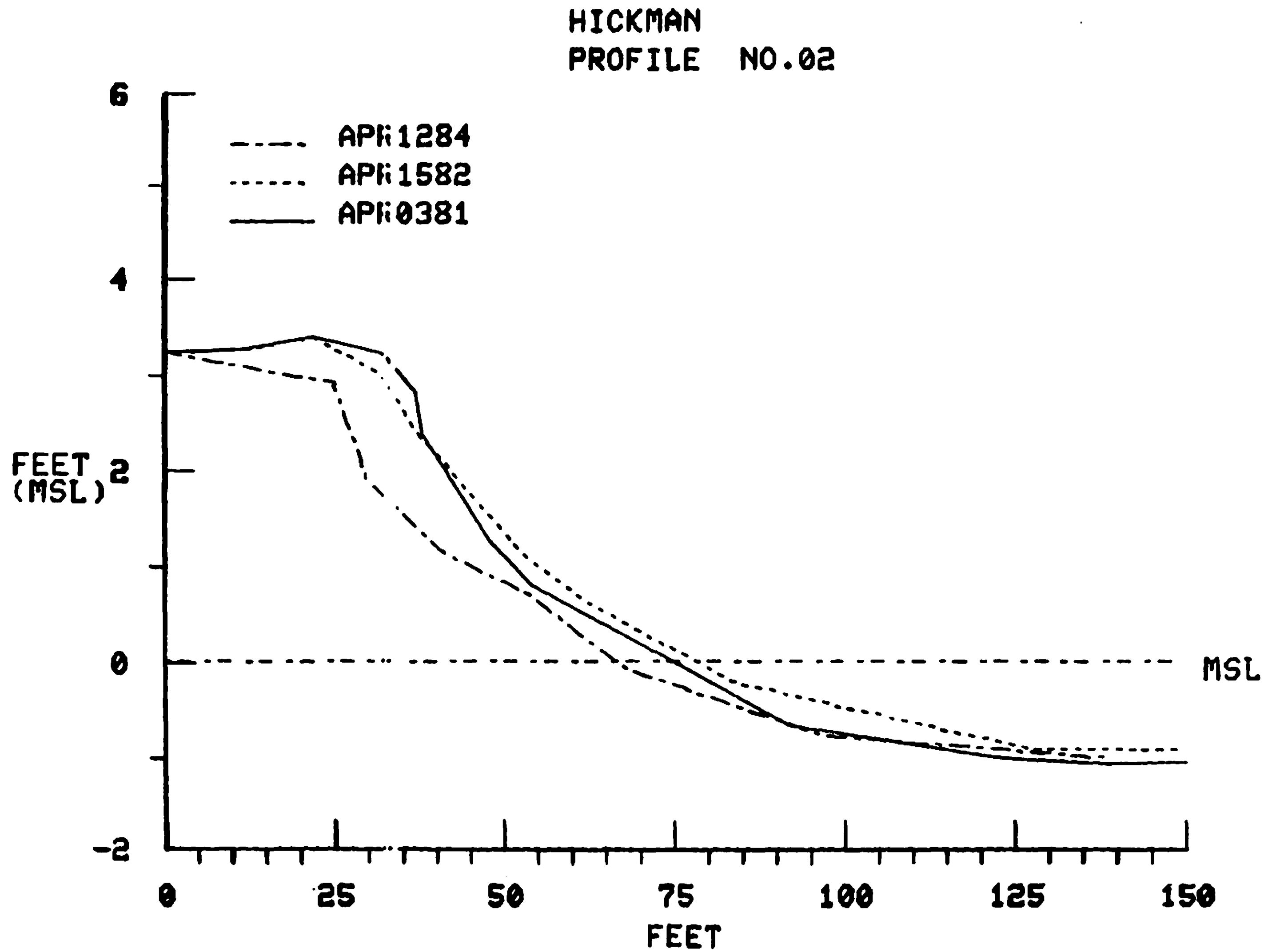


Figure 33. Hickman Site - Representative Profile.

7. TANKARD - CHESAPEAKE BAY, NORTHAMPTON COUNTY

Planted 1981

(Refer to Appendix B)

The Tankard site (Figure 34) is a high fastland bank which is exposed to an average fetch of 22.0 nautical miles westward across the Chesapeake Bay. The bank is composed of loose, easily erodable sand. The site was planted in the spring of 1981 with both species of marsh grass (Figure 35a). Most of the smooth cordgrass was washed out or died by mid-August (Figure 35b). The remaining grasses were completely washed out by Hurricane Dennis on August 20, 1981 (Figure 35c). The erosion rate has been calculated at 16.5 feet per year for the top of the bank and 17.7 feet per year for the base of the bank. Figure 36 shows bank position retreat since 1981.

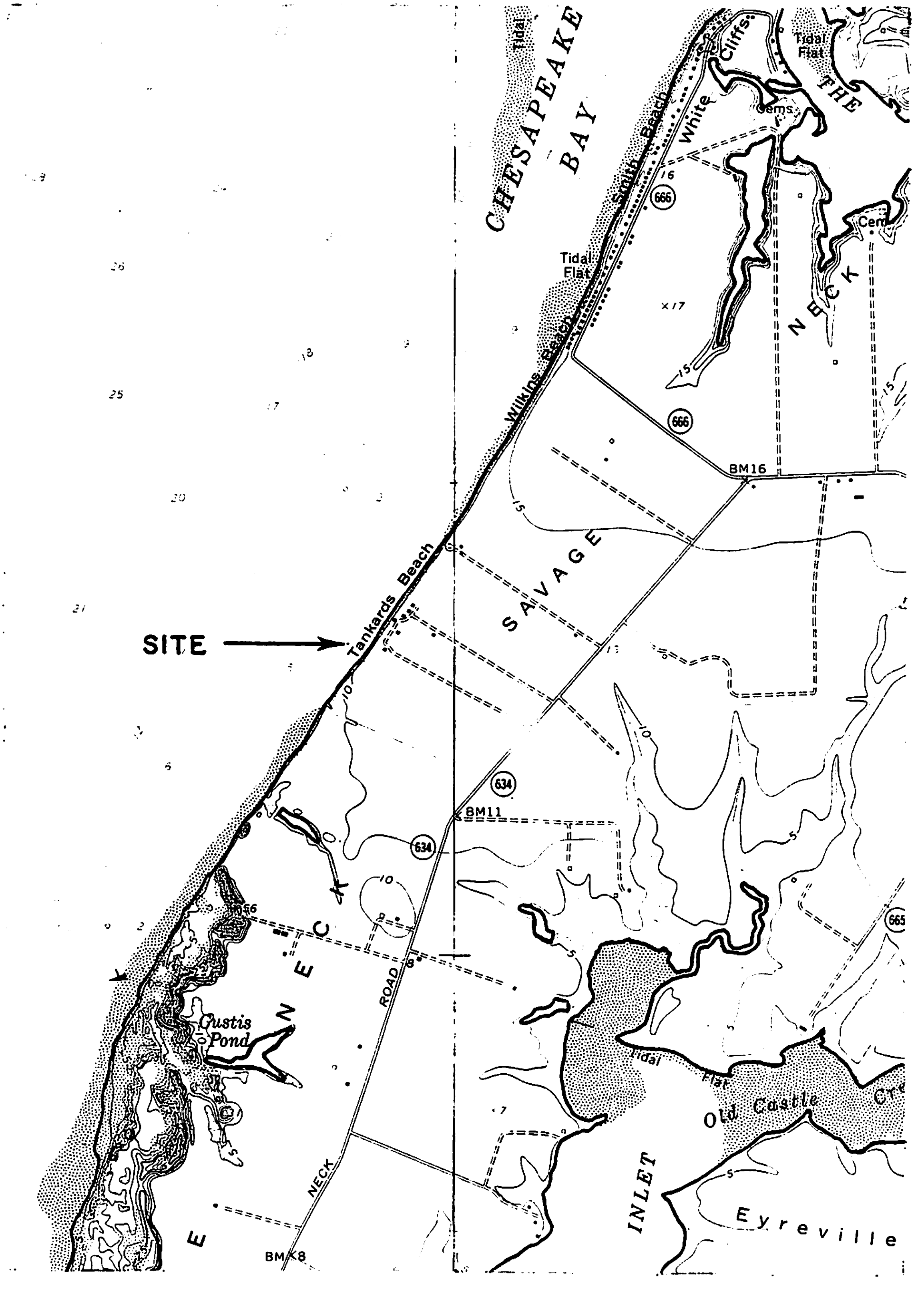


Figure 34. Tankard Site - from Cape Charles and Cheriton 7.5 minute quadrangles.
Scale: 1 inch = 2,000 feet.

FIGURE 35

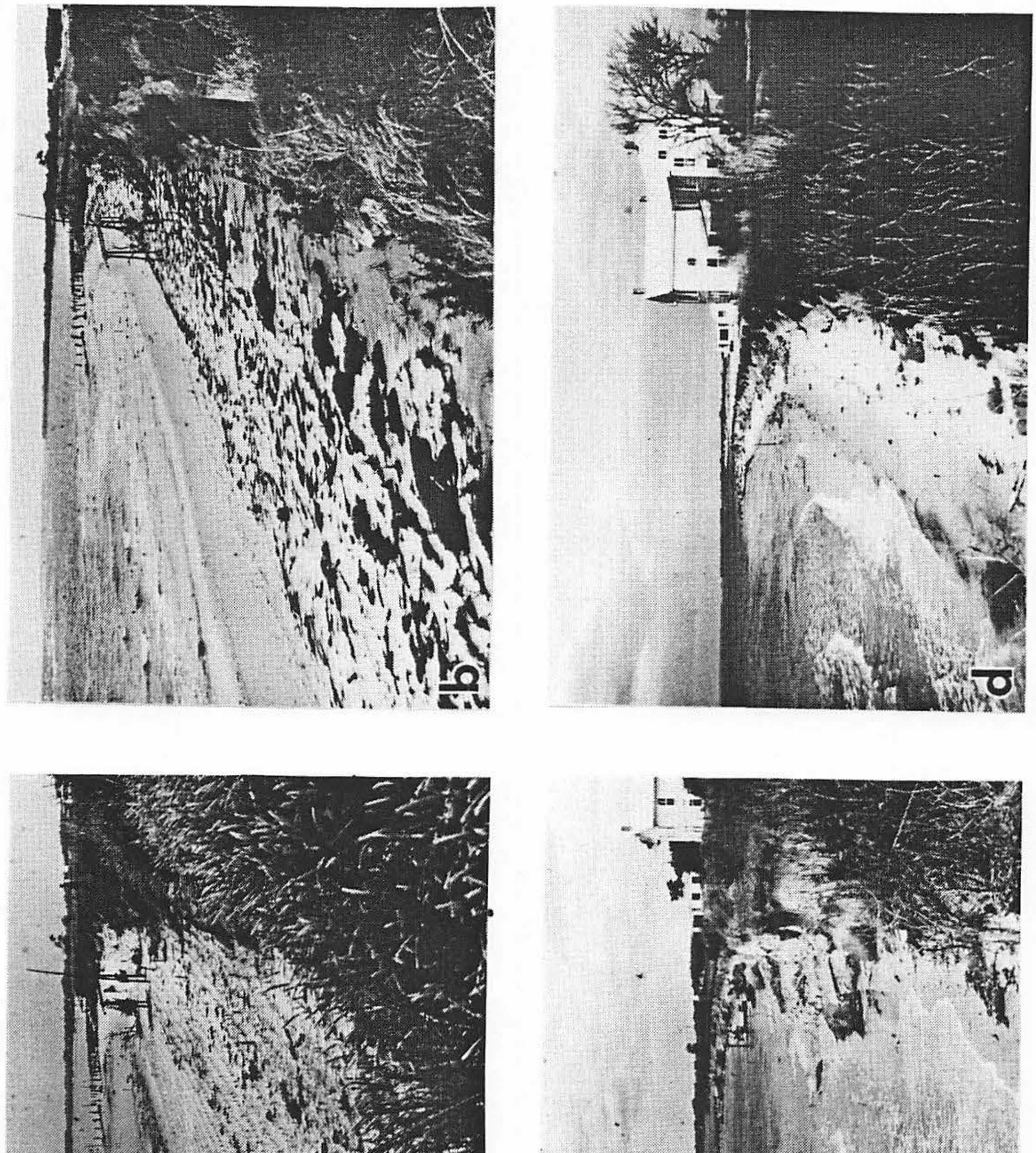
TANKARD

a. May 29, 1981
Looking northeast.

b. August 12, 1981
Looking northeast.

c. August 21, 1981
Looking northeast.
Post Hurricane Dennis.

d. February 3, 1982
Looking northeast.


b
d
a
c

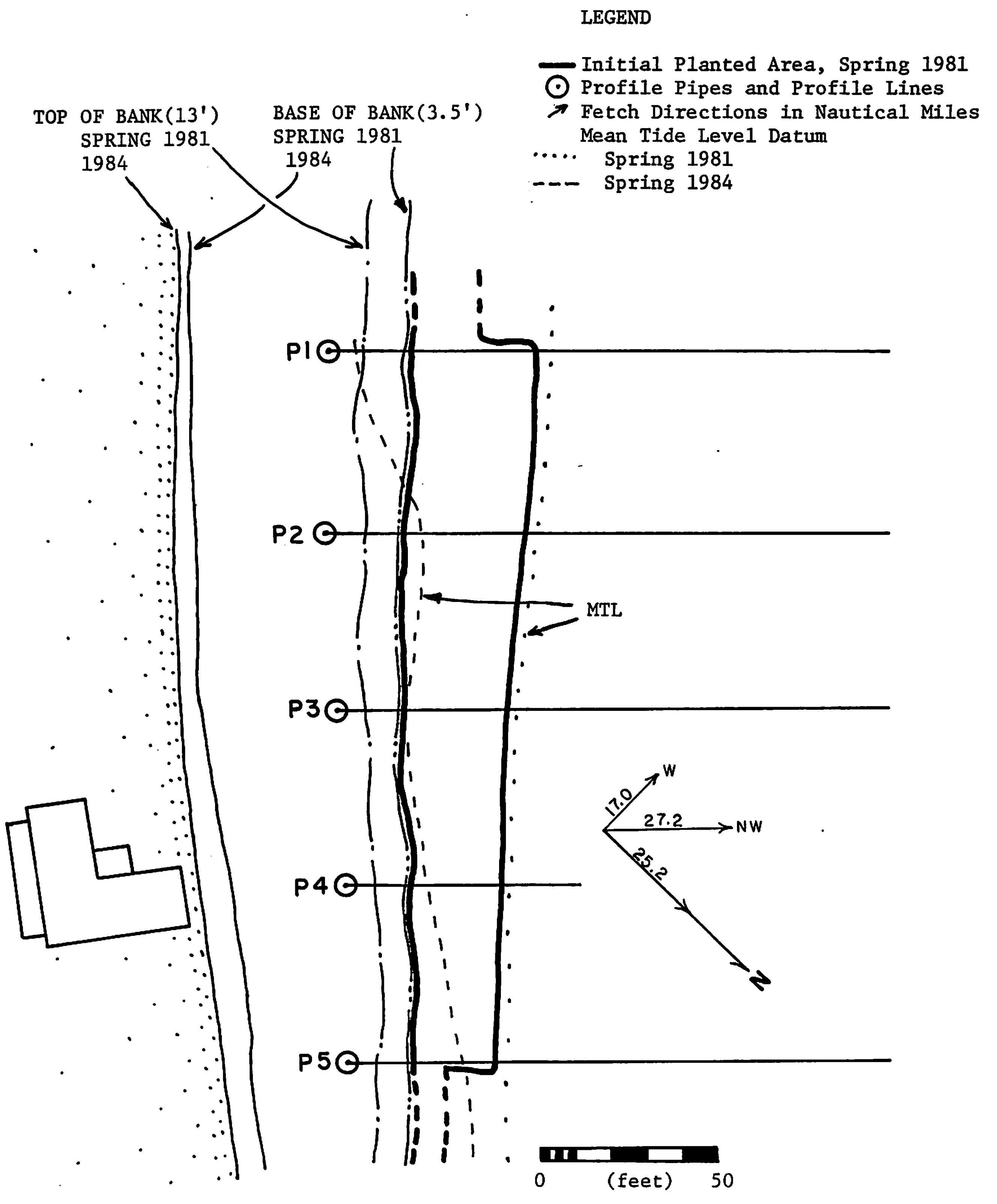


Figure 36. Tankard Site - Base Map.

8. WELLFORD - RAPPAHANNOCK RIVER, RICHMOND COUNTY

Planted 1981

(Refer to Appendix B)

The Wellford site is a high fastland bank, facing southwest with an average fetch of 2.3 nautical miles (medium energy) along a fairly straight shoreline. The site is located about a mile downriver from the Rappahannock River Bridge at Tappahannock on an estate known as Sabine Hall (Figure 37). The shoreline erosion rate here is about one foot per year (3). The bank face is moderately unstable with sparse vegetation of grasses, shrubs and small trees. Initially the base of the bank was intermittently exposed as a wave cut scarp which exposed a basal blue-gray fossiliferous sandy clay. This clay is overlain by sandy material about three to five feet from the base. The clay apparently acts as an aquaclude as evidenced by ground water seeping out of the bank slope. This may cause increased slumping of the upper bank slope. The beach is composed of medium to coarse sand and gravel and extends from the base of the bank riverward about 30 feet.

The Wellford site was first planted in May 1981 (Figure 38). Only smooth cordgrass was planted. The marsh area and width had been significantly reduced by November 1981, especially along the front edge of the fringe (Figure 39b). There was also a corresponding increase in backshore elevation which was probably the result of bank slumping causing an increase of material along the base of the bank (Figure 40).

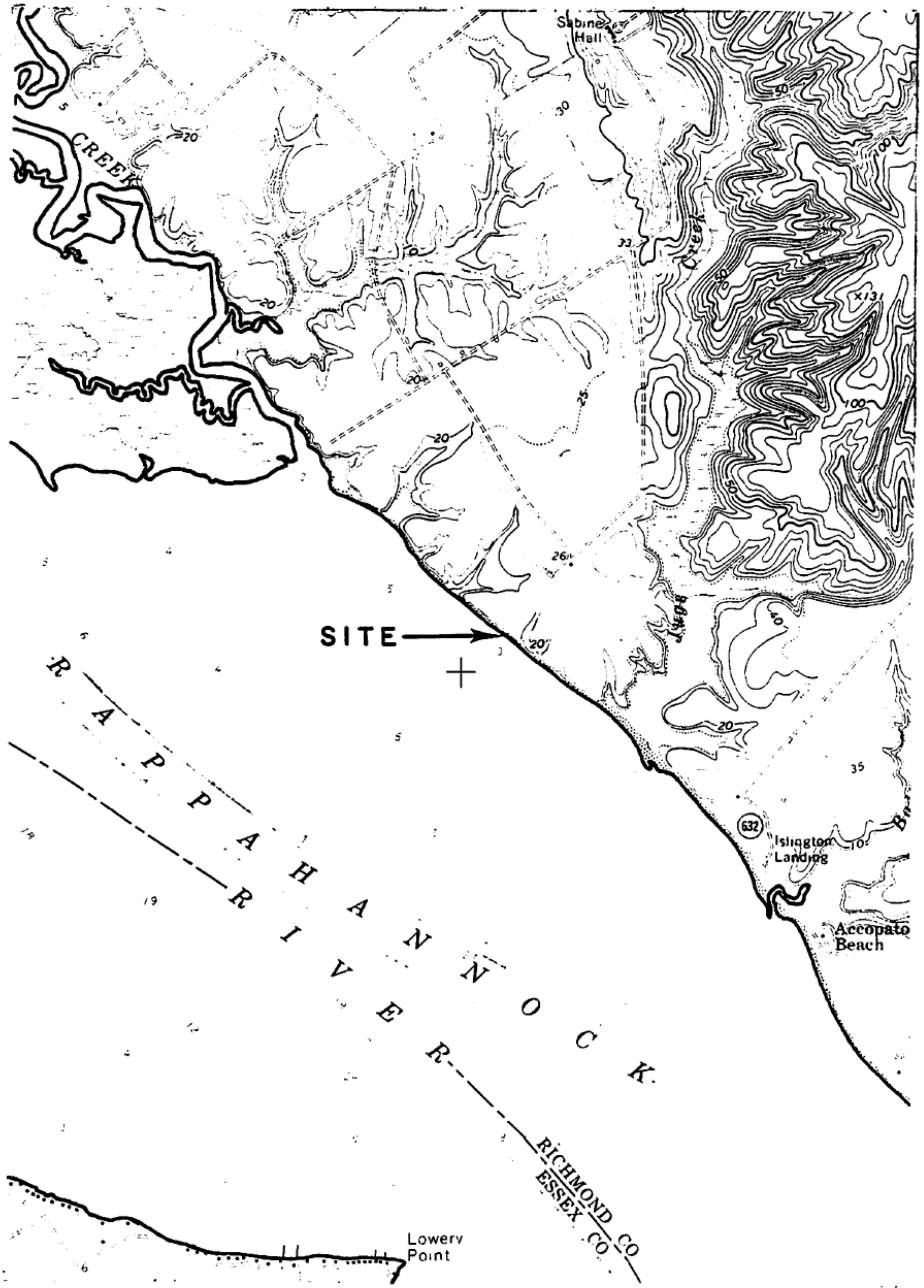


Figure 37. Wellford Site - from Tappahannock 7.5 minute quadrangle.
Scale: 1 inch = 2,000 feet.

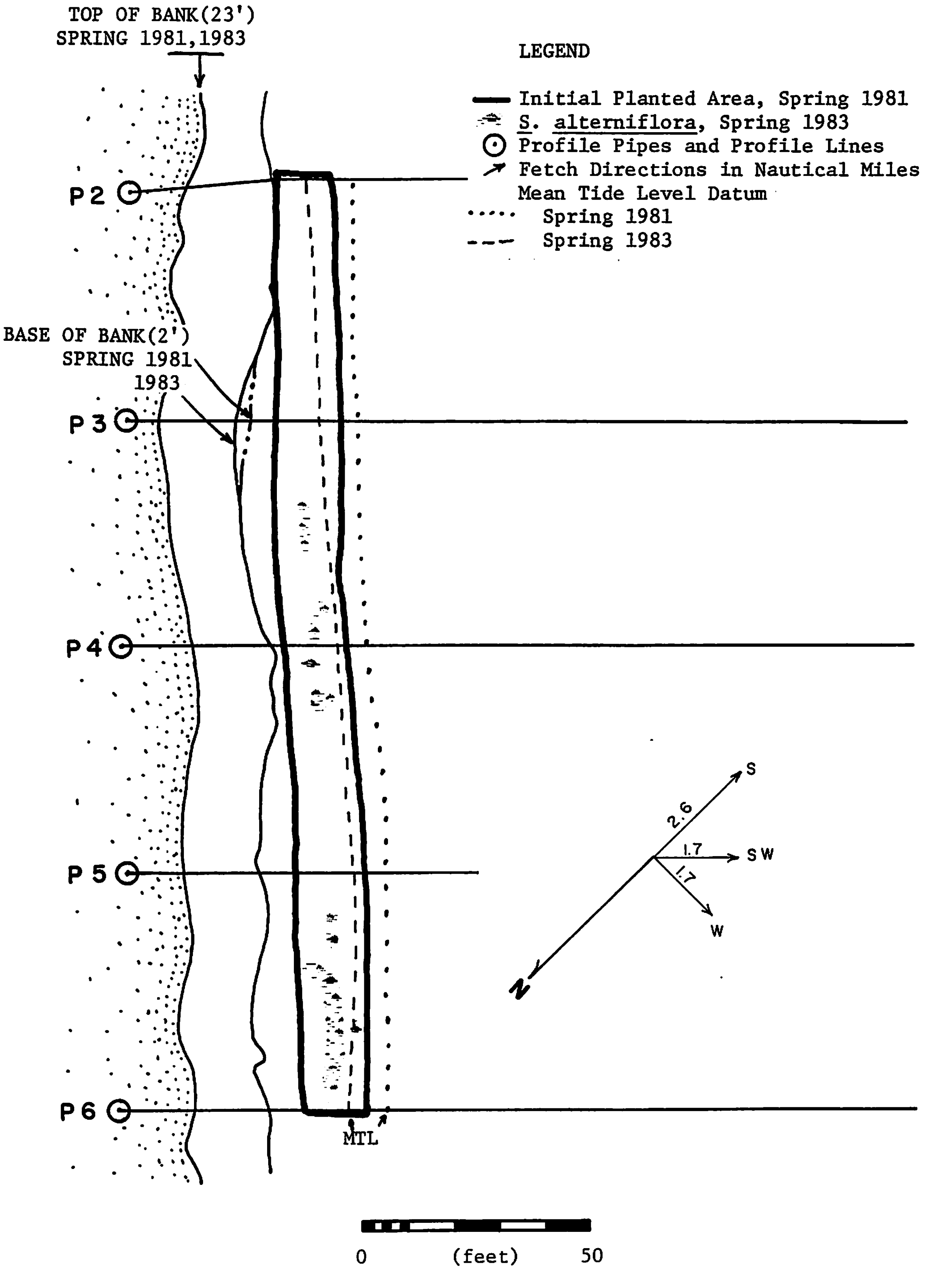


Figure 38. Wellford Site - Base Map.

FIGURE 39

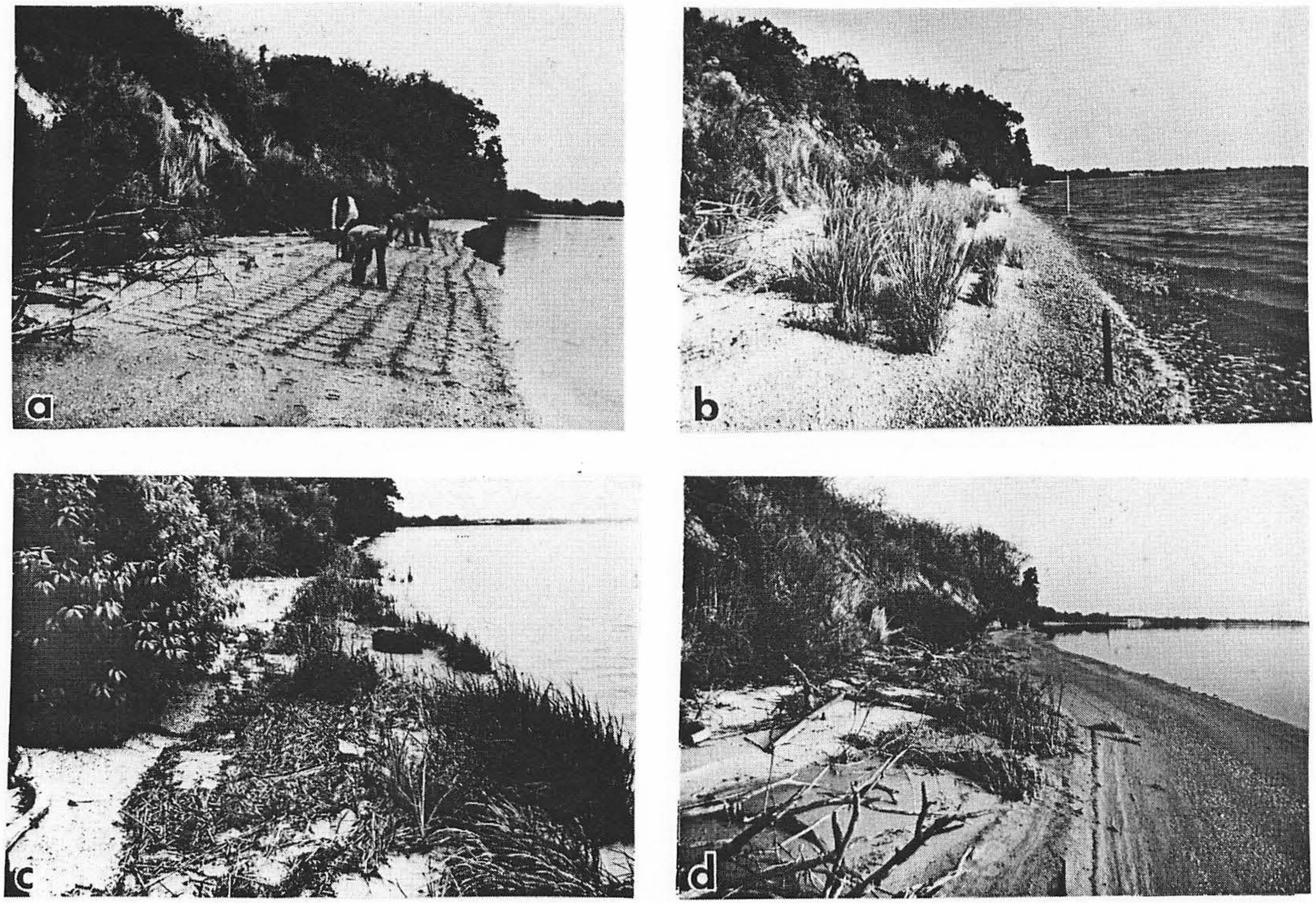
WELLFORD

a. May 5, 1981
Looking southeast.

b. September 21, 1981
Looking southeast.

c. June 8, 1982
Looking southeast.

d. January 25, 1983
Looking southeast.


a
b
c
d

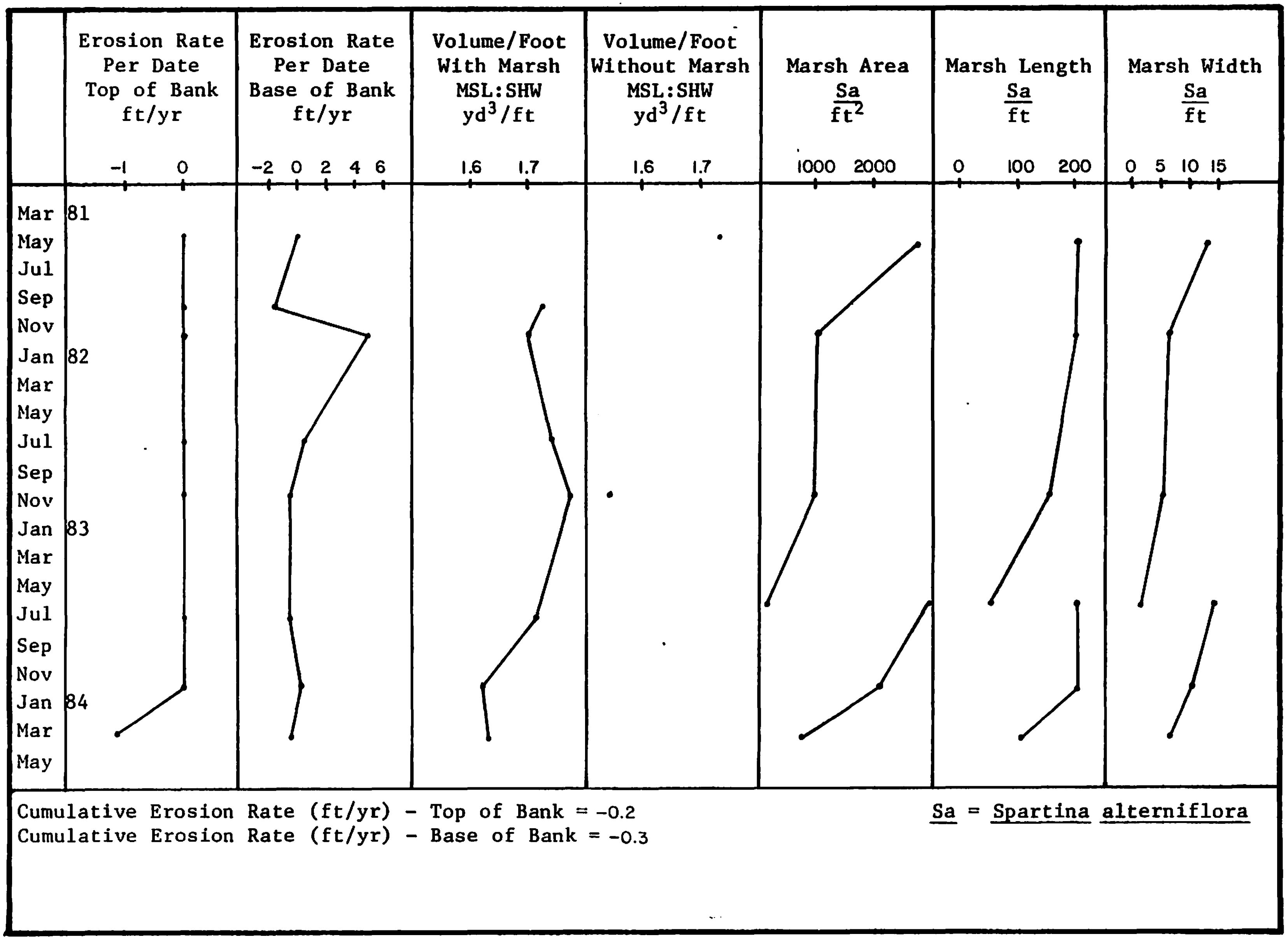


Figure 40. Wellford Time Series.

By the spring of 1982 much of the downriver end of the fringe had been washed out. However, most of the fringe was intact and maintaining the backshore and upper tidal zone elevation (Figure 39c). In November 1982 the fringe was holding more sediment within its limits. More so than the adjacent downriver part that washed out. A little base of bank erosion may have supplied material to the fringe at that point.

In the spring of 1983 the marsh fringe had been reduced in area, length and width (Figure 41). Consequently, the volume of sediment within the marsh had also decreased. In June 1983 maintenance planting was done with smooth cordgrass (Figure 42). The area around the fringe that remained from the 1981 planting was the most stable in terms of being intact over time.

The fringe was reduced in width and area by November 1983. This was expected since the maintenance planting brought the lower limit below MTL. In general, the fringes on the VEC project hold a lower position at or near MTL until they become established. At that point expansion might ensue toward MLW. The volume of sediment held by the intertidal fringe was reduced by November 1983.

Significant loss of marsh area, length and width occurred over the winter of 1983-1984. There was also some erosion of the top of the bank as measured for the first time since the spring of 1981. This and some base of bank erosion may have supplied material to the remaining fringe as noted by a slight increase in intertidal volume. The remaining fringe is part of the 1981 planting with moderate peat formation (Figure 42d).

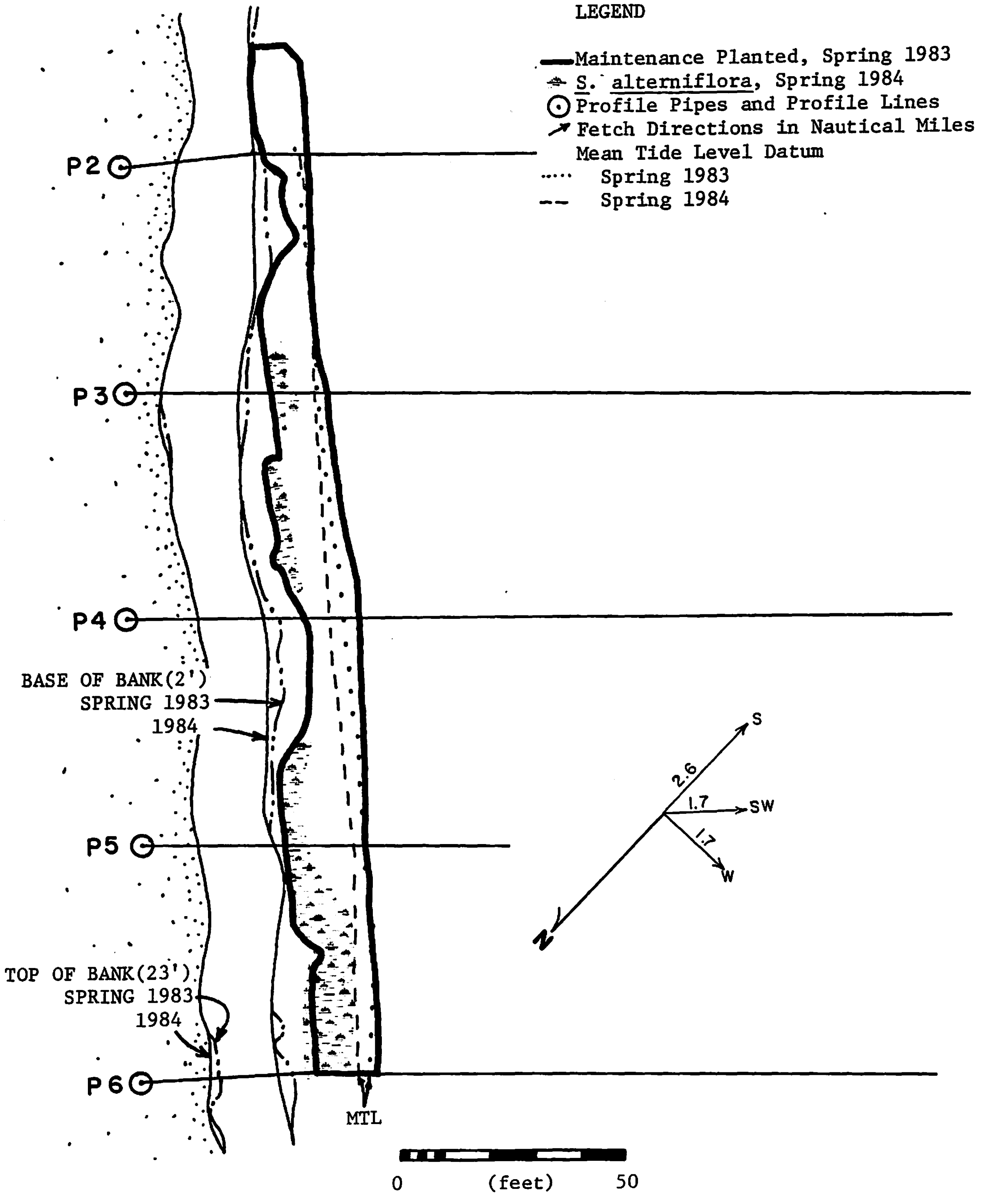


Figure 41. Wellford Site - Base Map.

FIGURE 42

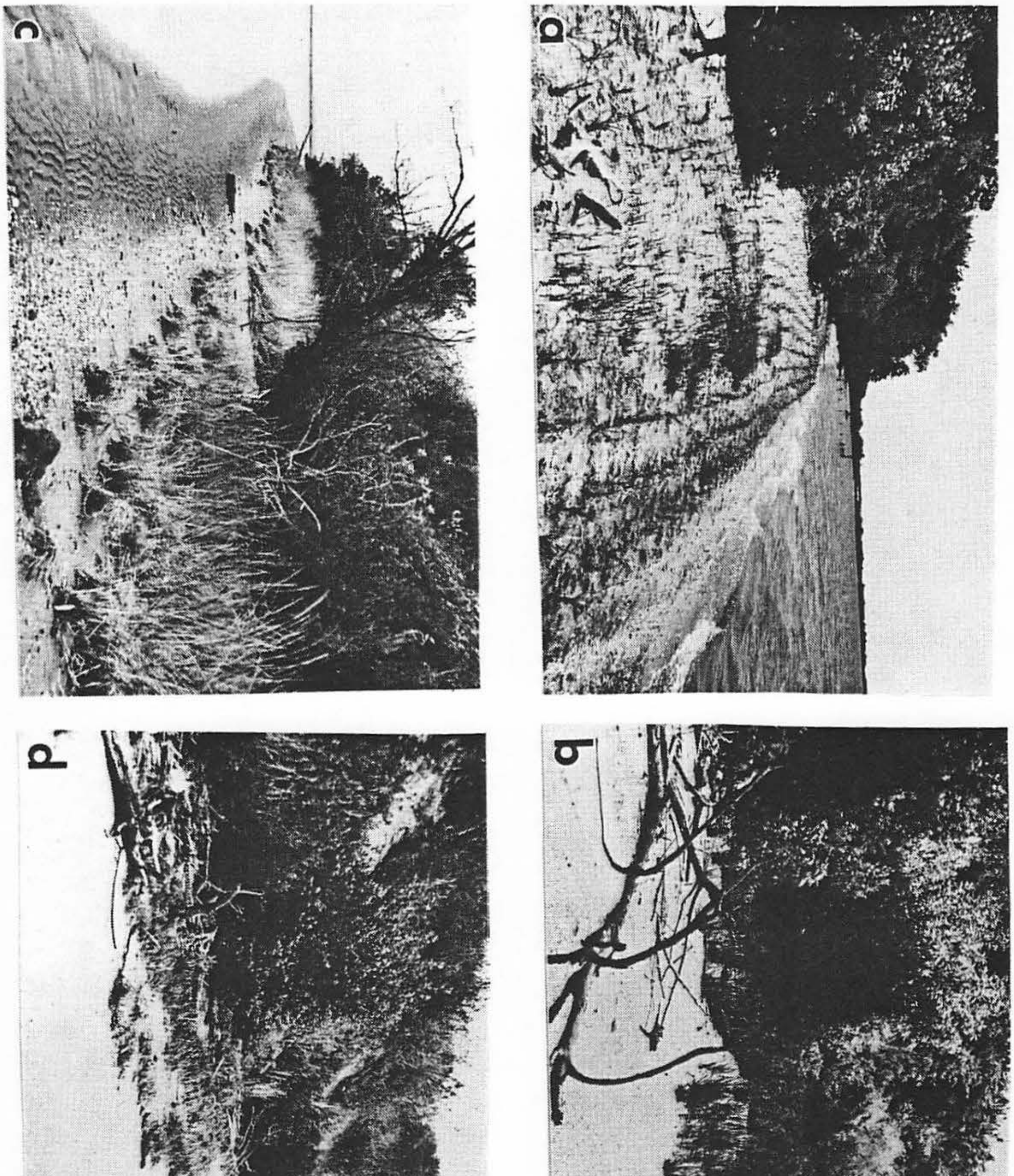
WELLFORD

a. June 2, 1983
Looking southeast.

b. July 27, 1983
Looking southeast.

c. November 23, 1983
Looking northwest.

d. May 9, 1984
Looking southeast.


a
b
c
d

Cumulative annual erosion rates are small (Figure 40). The fringe had been very successful in maintaining the backshore elevation up until spring of 1983 (Figure 43). The site was only partially successful in slowing the erosion of the base of the bank. The future trend seems to be toward failure without continued extensive maintenance planting.

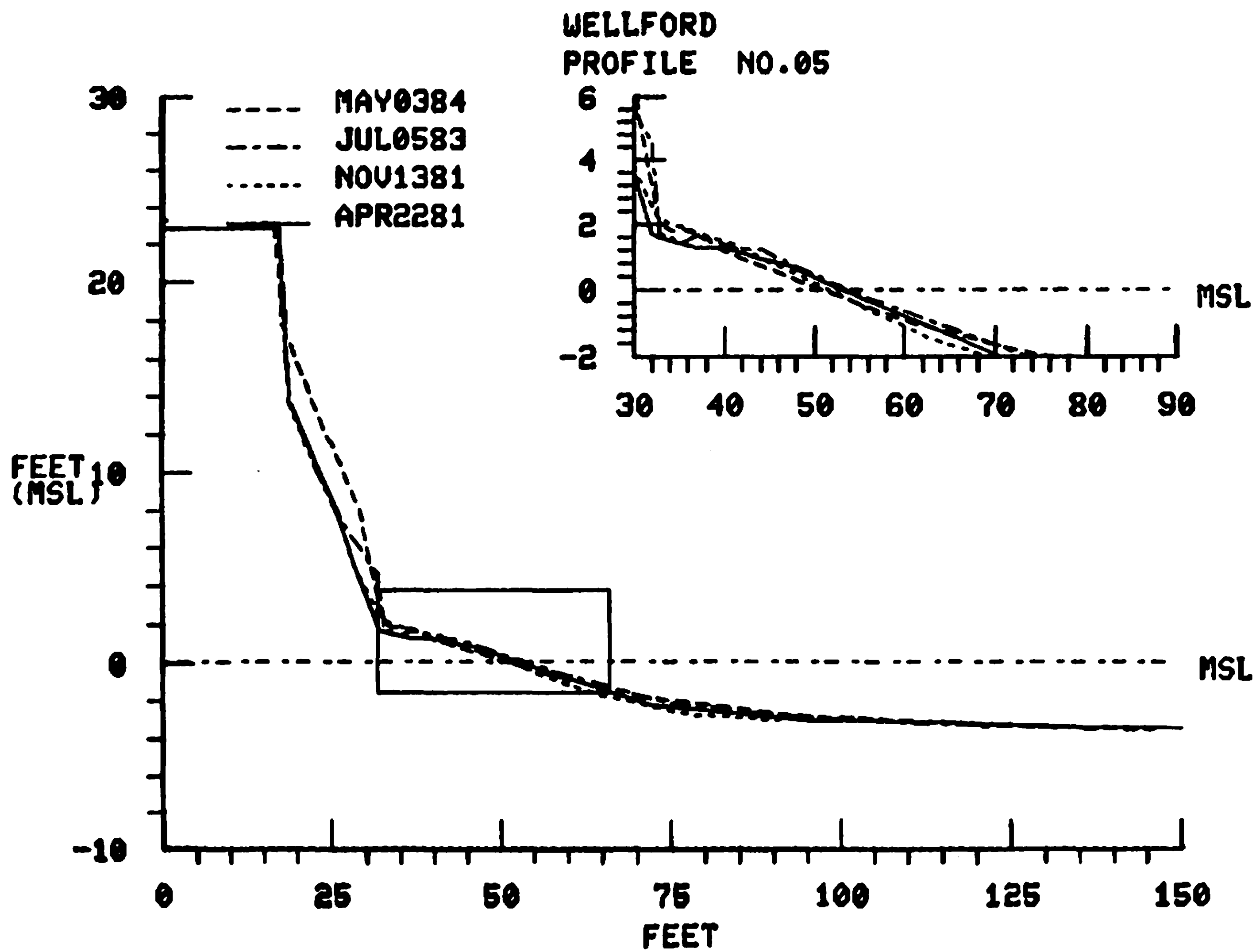


Figure 43. Wellford Site - Representative Profile.

9. DURHAM SOUTH - RAPPAHANNOCK RIVER, RICHMOND COUNTY

Planted 1981

Maintenance Planted 1982

(Refer to Appendix B)

The Fred Durham property, known as Shandy Hall, is the location of two sites (Figure 44). Durham South is located in front of the main house and faces south southwest. Previously, Mr. Durham had created a substantial vegetative fringe during the 1940s in front of an eroding high fastland bank. The bank was graded and several species of high marsh grasses were planted, mostly saltmeadow hay with american beach grass, rye and honeysuckle vine. The leading edge of this high marsh fringe had been eroding back before spring 1981. The purpose for this site was to reestablish the lower marsh and protect the existing fringe. The 1981 planting of smooth cordgrass and saltmeadow hay was severely reduced by wave action and washout and maintenance planting was required in 1982. It should be noted that the actual shore (bank) erosion rate here has been nil since the 1940s planting.

The beach extends from the limit of the old fringe riverward for 40 feet (Figure 45). It is composed of medium coarse sand and gravel. The main sediment source for the beach along this reach is believed to come from erosion of the fastland banks around Neals Point to the west. Site No. 10 (Durham West) is located in that area. Neals Point acts as a protective headland from westerly winds. The net drift of sediment

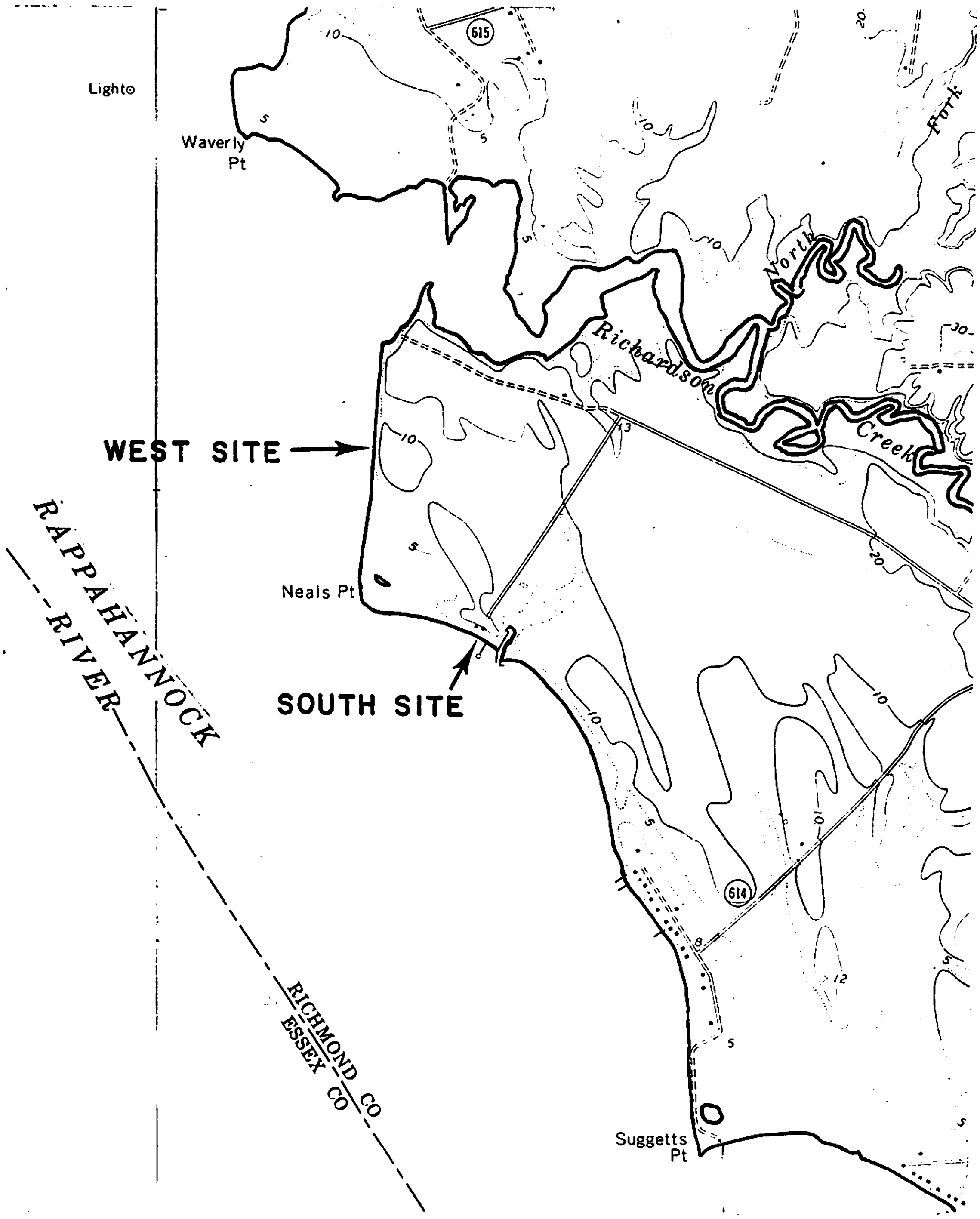


Figure 44. Durham Sites - from Morattico and Dunnsville 7.5 minute quadrangles.
Scale: 1 inch = 2,000 feet.

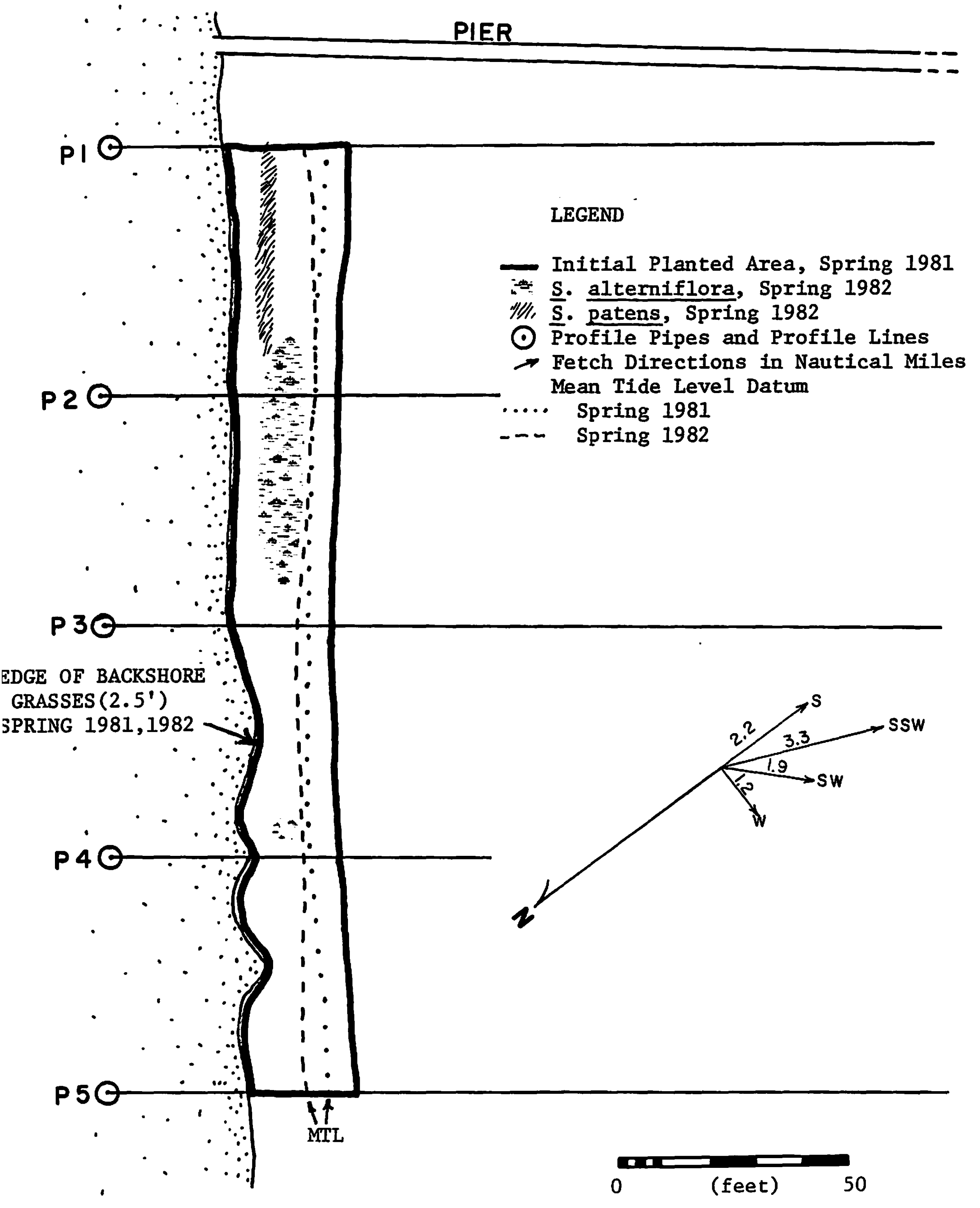


Figure 45. Durham South Site - Base Map.

along the beach is from west to east. Durham South receives an ample sand supply by littoral transport.

The high marsh fringe existed as a sandy terrace. In 1981 the leading or river's edge of this terrace was eroding, exposing a very low sandy substrate with roots and rhizomes of the high marsh grasses (Figure 46a). There were initial losses but generally good growth during the summer of 1981 (Figure 46b). However, severe erosion of the low bank and washout occurred during the winter of 1981-1982 (Figure 46c).

After maintenance planting in May 1982 (Figure 47) the fringe grew well, expanded in area, trapped sand and elevated the backshore. In the fall of 1982 the fringe had increased the volume of sediment trapped and increased the leading edge of the sandy bank (Figure 48a). However, during the following winter loss of sediment and bank erosion ensued (Figure 49).

During the summer of 1983 the intertidal marsh fringe expanded, trapped sediment and once again halted erosion of the low bank. In the winter of 1983-1984 the fringe lost some volume and the width was reduced within the smooth cordgrass. However, the saltmeadow hay maintained the backshore elevation causing further accretion of the bank by May 1984 (Figure 50).

The Durham South site was the only medium energy site with an accretion rate along the bank. That being 0.3 feet per year. After the maintenance planting in 1982 the fringe remained continuous, eventually elevated the backshore and halted the erosion of the low sandy bank. It would seem that this site has been successful to this point. It must be remembered that the site is located in a fairly protective embayment. The only direct winds come from the south and southwest.

FIGURE 46

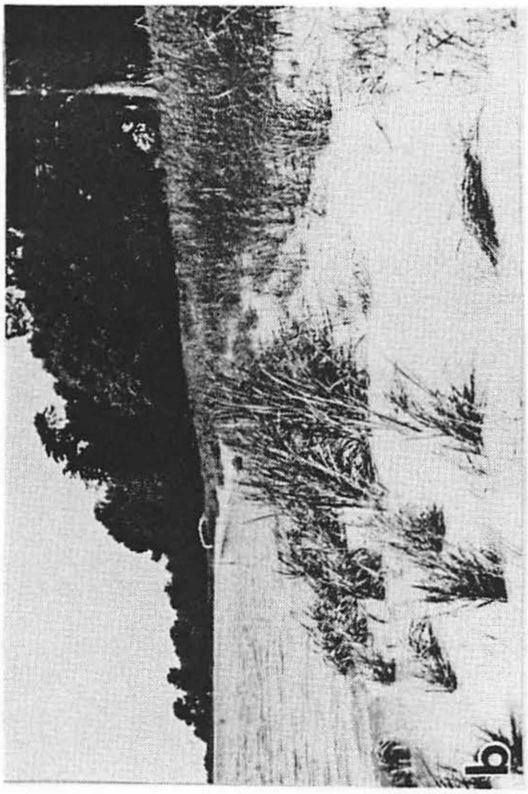
DURHAM SOUTH

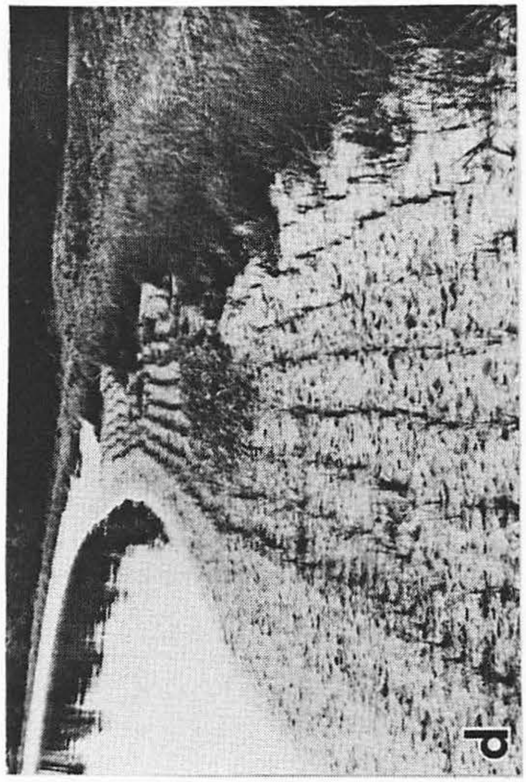
a. May 8, 1981
Looking west.

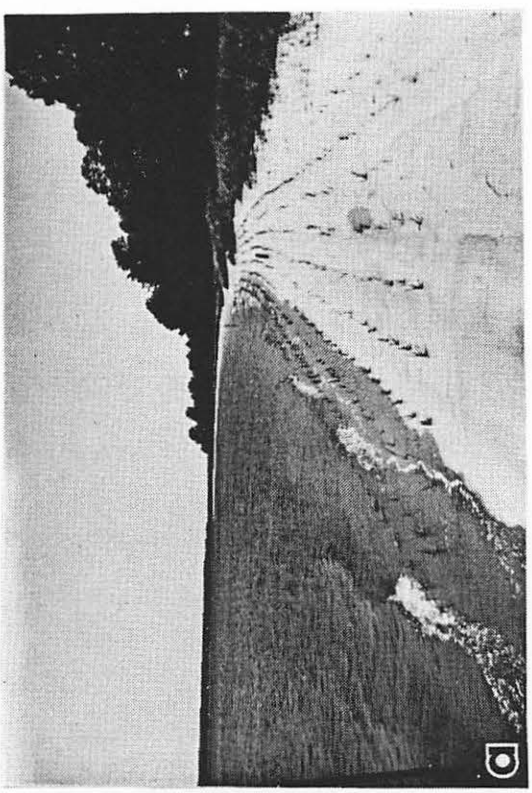
b. August 16, 1981
Looking west.

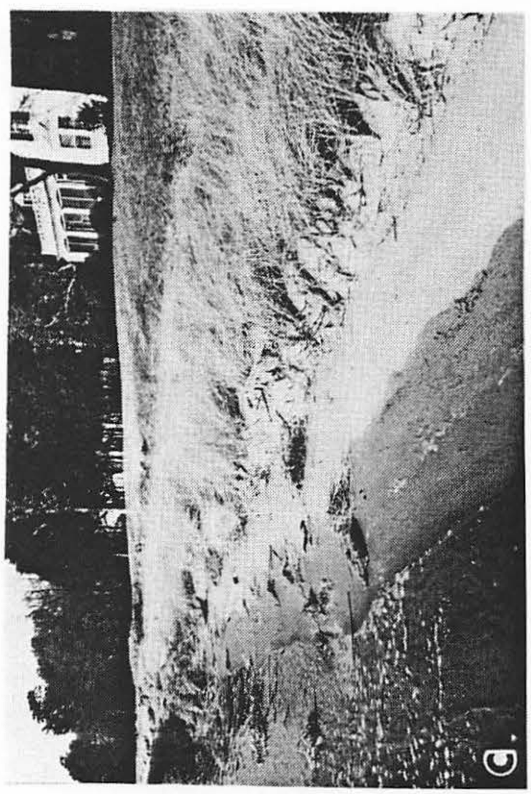
c. February 8, 1982
Looking west.

d. May 21, 1982
Looking west.









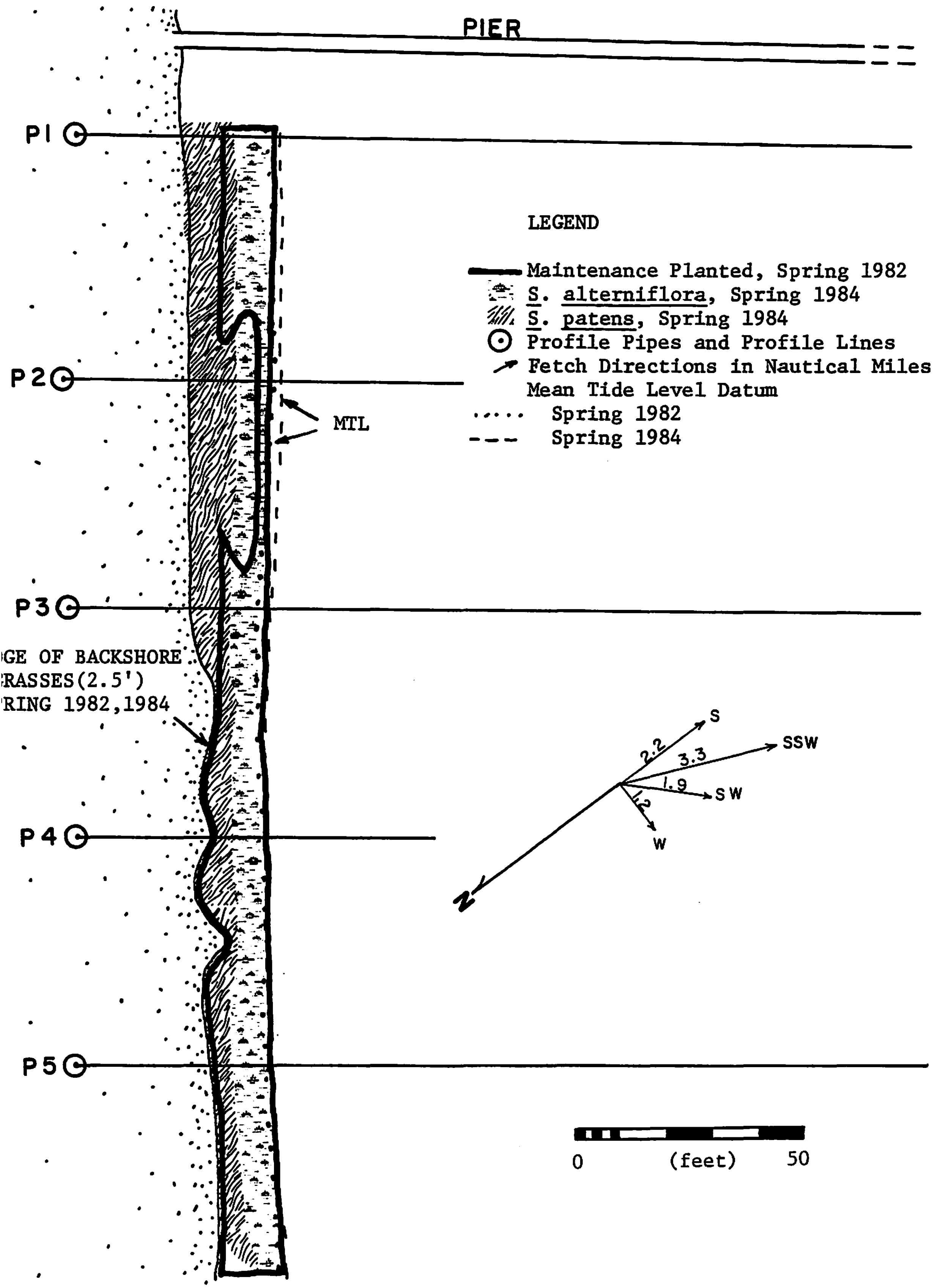


Figure 47. Durham South Site - Base Map.

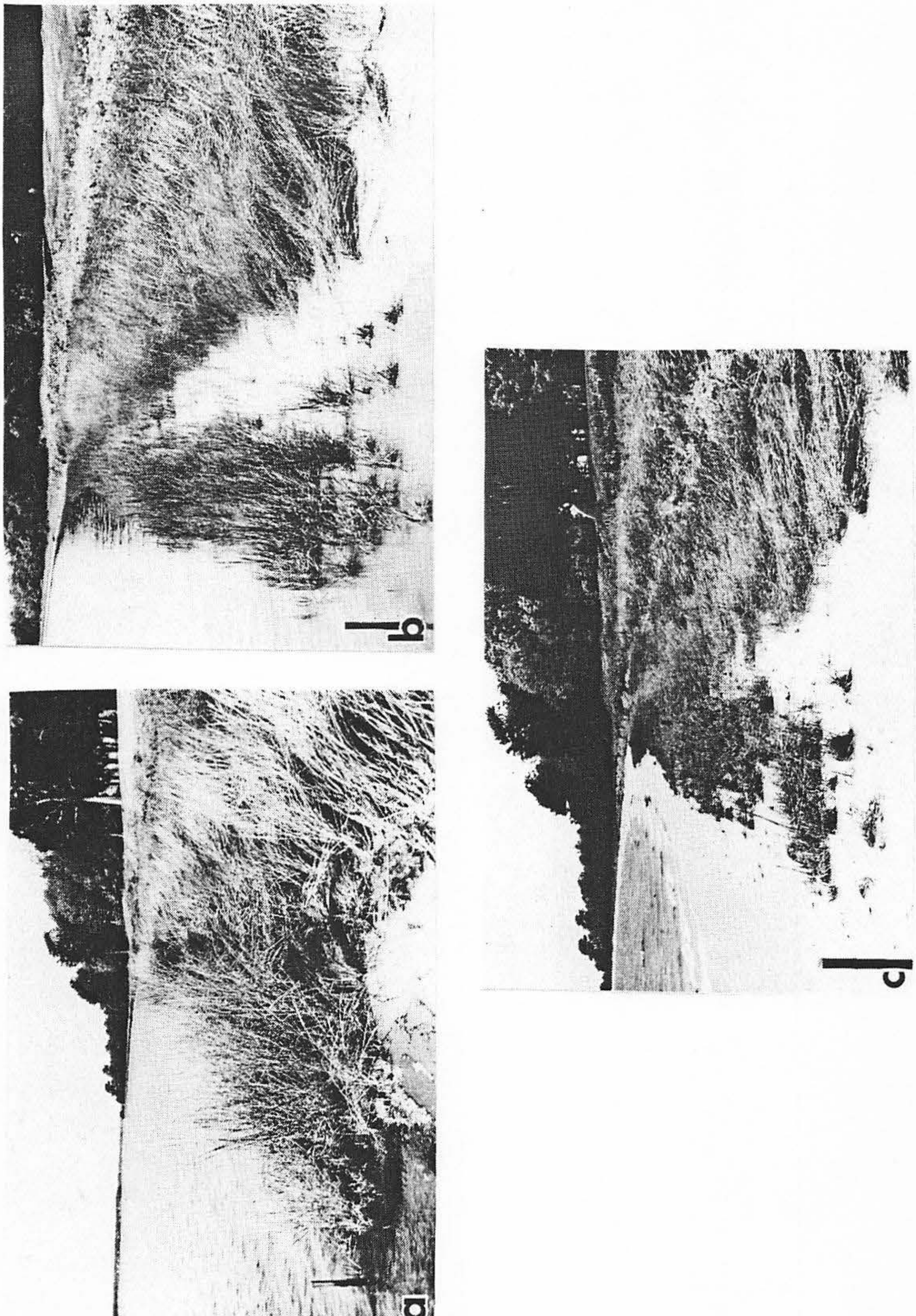
FIGURE 48

DURHAM SOUTH

a. November 30, 1982
Looking west.

b. July 27, 1983
Looking west.

c. May 9, 1984
Looking west.


a
b
c

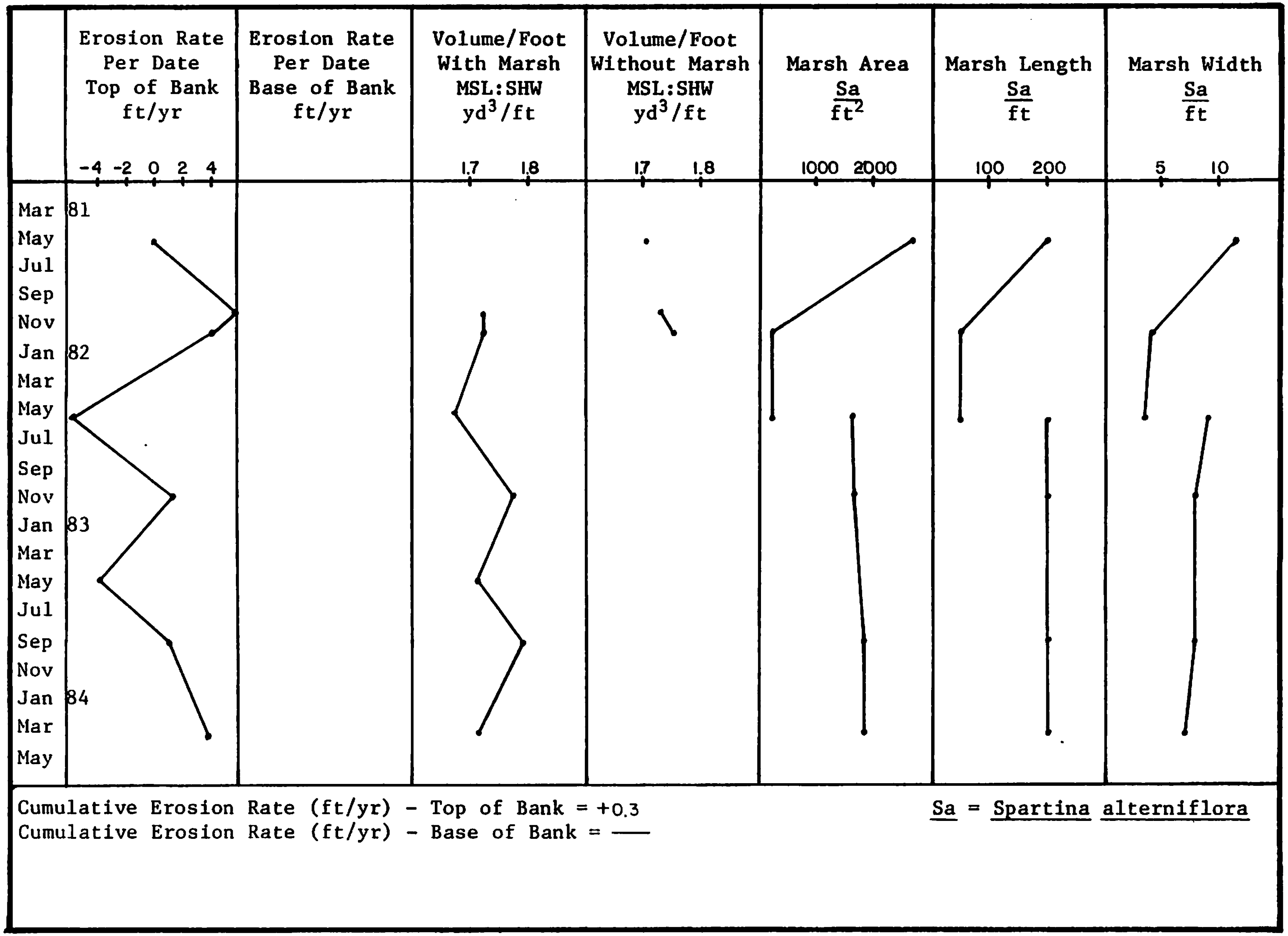


Figure 49. Durham South Time Series.

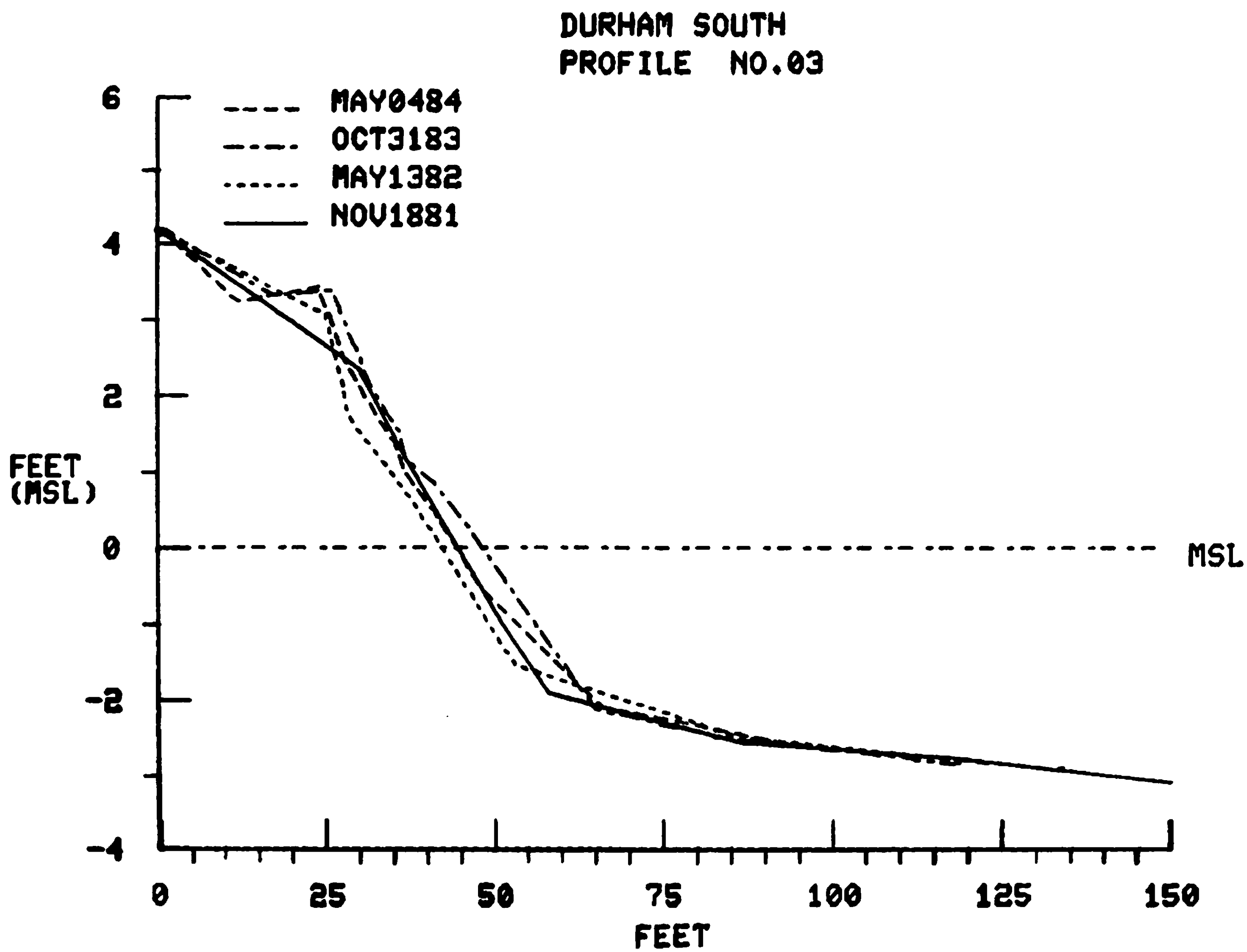


Figure 50. Durham South Site - Representative Profile.

10. DURHAM WEST - RAPPAHANNOCK RIVER, RICHMOND COUNTY

Planted 1981

Maintenance Planted 1982

(Refer to Appendix B)

Durham West is a medium energy, high bank shore facing almost due west (Figure 44). Historical erosion here is almost two feet per year (3). The bank is about nine feet above MTL and is composed of fine to coarse, slightly clayey sand. The nine foot bank face is mostly vertically exposed with little or no stabilizing vegetation. Erosion of this bank supplies much of the sediment to the adjacent beach and nearshore regions. The beach extends from the base of the bank riverward to about 20 feet below MLW. The beach is composed of medium coarse sand and gravel.

Durham West was first planted in May 1981 with smooth cordgrass and saltmeadow hay (Figure 51). Plants not hardened to the proper salinity and washout combined to reduce the planting significantly by the fall of 1981 (Figure 52b). The winter of 1981-1982 had reduced the marsh fringe to a patch about 20 feet long (Figure 52d). Ice rafting on the marsh was noted on two separate visits.

Maintenance planting in the spring of 1982 reestablished the smooth cordgrass fringe (Figure 53). Saltmeadow hay was not replanted. Slight slumping and subsequent gain across the base of the bank was noted from winter winds and waves. During the summer of 1982 there was reduction in marsh area and width, mostly along the leading edge of the fringe.

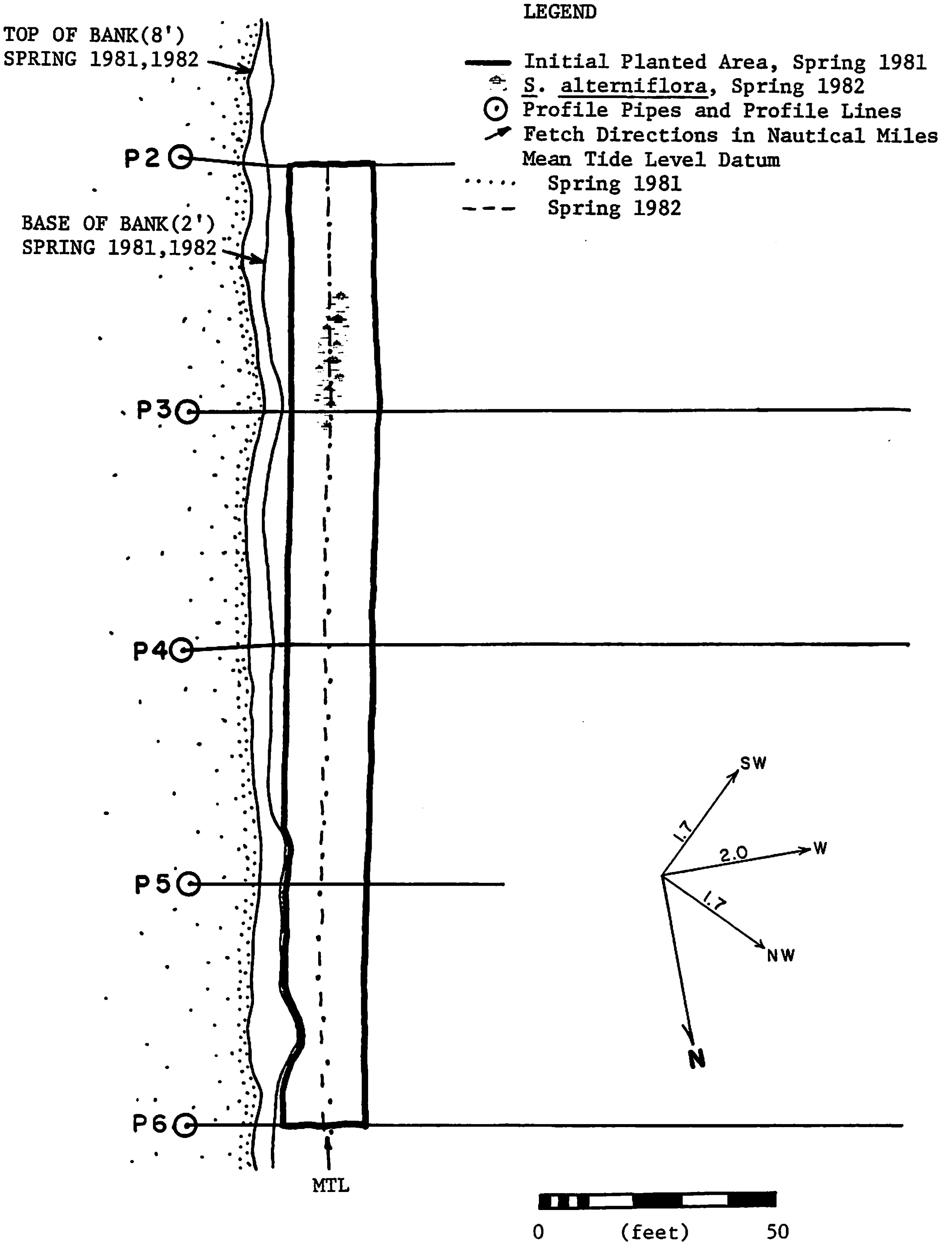


Figure 51. Durham West Site - Base Map.

FIGURE 52

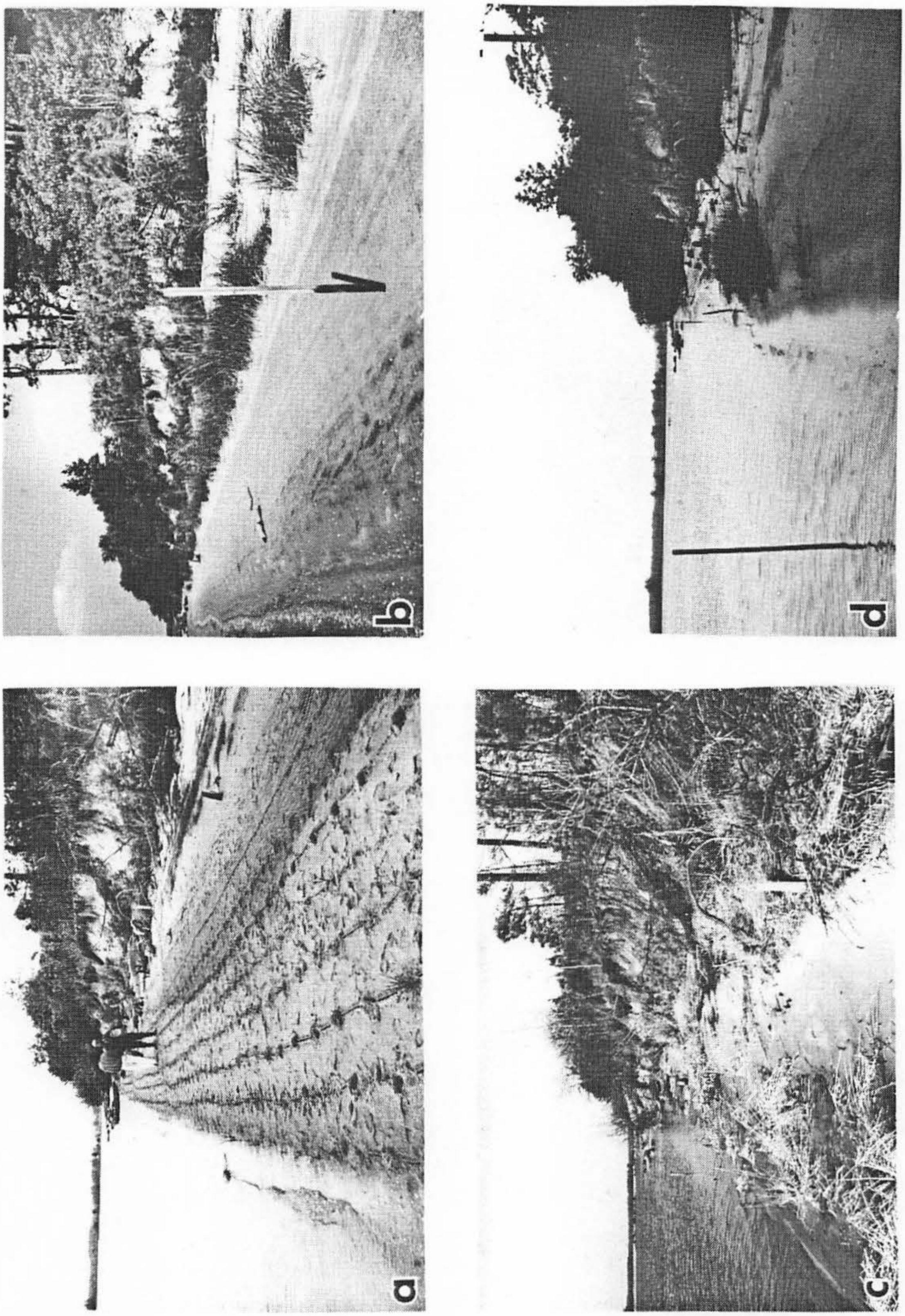
DURHAM WEST

a. May 5, 1981
Looking north.

b. September 21, 1981
Looking north.

c. February 8, 1982
Looking north.

d. May 21, 1982
Looking north.



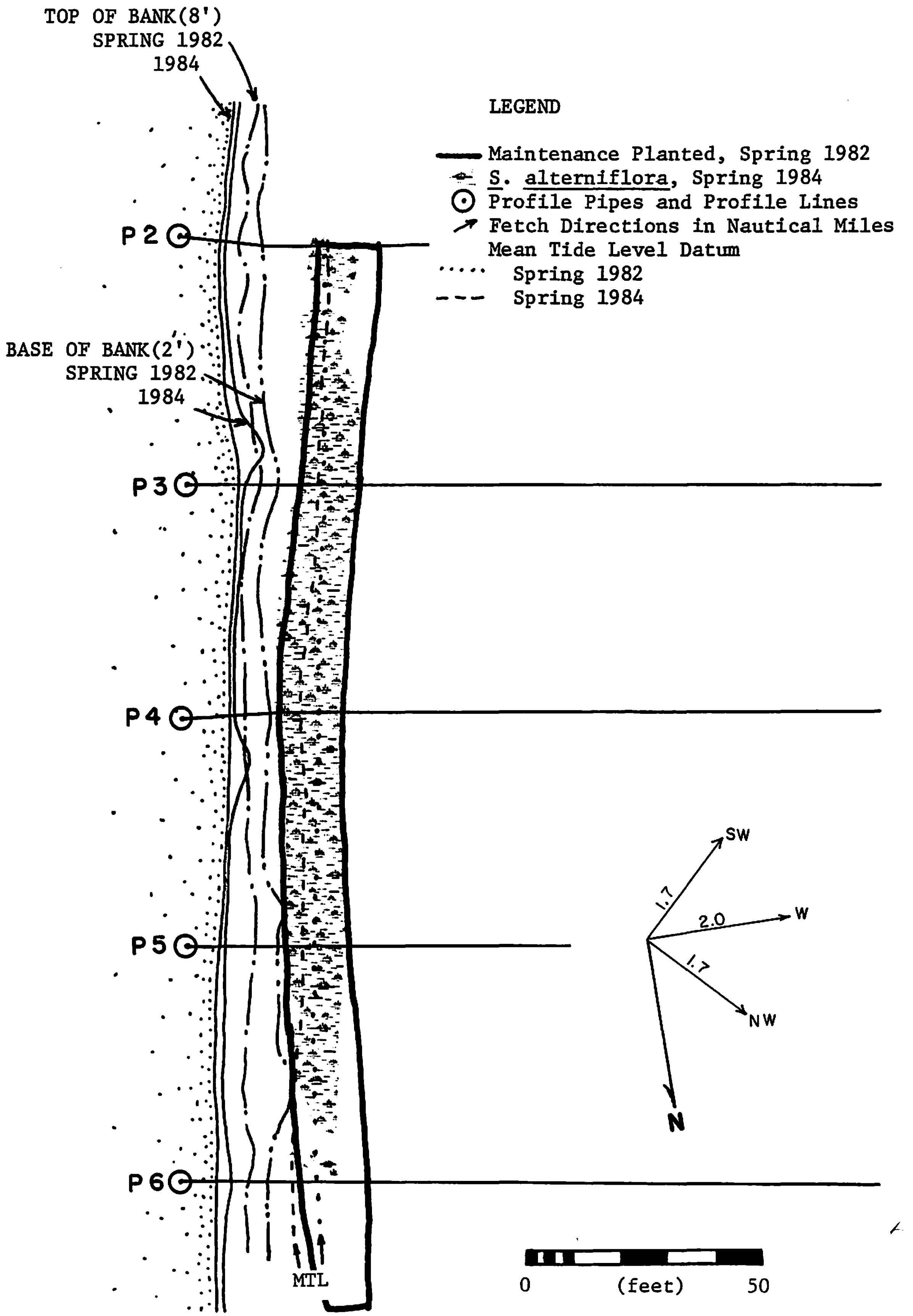


Figure 53. Durham West Site - Base Map.

By October 1982 there was considerable loss of bank, both top and bottom behind the marsh (Figure 54b).

The fringe remained fairly well intact during the winter of 1982-1983 even with frequent strong, northwesterly winds that followed the numerous northeast storms. However, erosion of the entire bank continued unchecked due to these wind and wave conditions. The marsh fringe, with virtually no standing crop, was unable to capture much of the eroding bank material. However, during the spring and summer of 1983 the fringe began trapping sediment under low wave energy conditions and vibrant above ground growth. Bank erosion ceased for a time (Figure 54c) and slumping increased the position of the base of the bank (Figure 55).

In the winter of 1983-1984 there was renewed bank erosion and the inability of the fringe to hold sediment (Figure 55). The fringe itself was pretty well intact by the spring of 1984 with good peat substrate formation (Figure 54d).

The marsh fringe that was replanted in 1982 has remained fairly continuous up until the spring of 1984. However, it has been unable to maintain backshore elevation and bank erosion has continued (Figure 56). Erosion of the bank took place mostly during the winter months. Thus, it seems the site is deemed a partial success until such time that it can establish and maintain the backshore. Maintenance planting may have to be done. Another application across the backshore would be worth a try. Saltmeadow hay, once established, can do well to stabilize the backshore region.

FIGURE 54

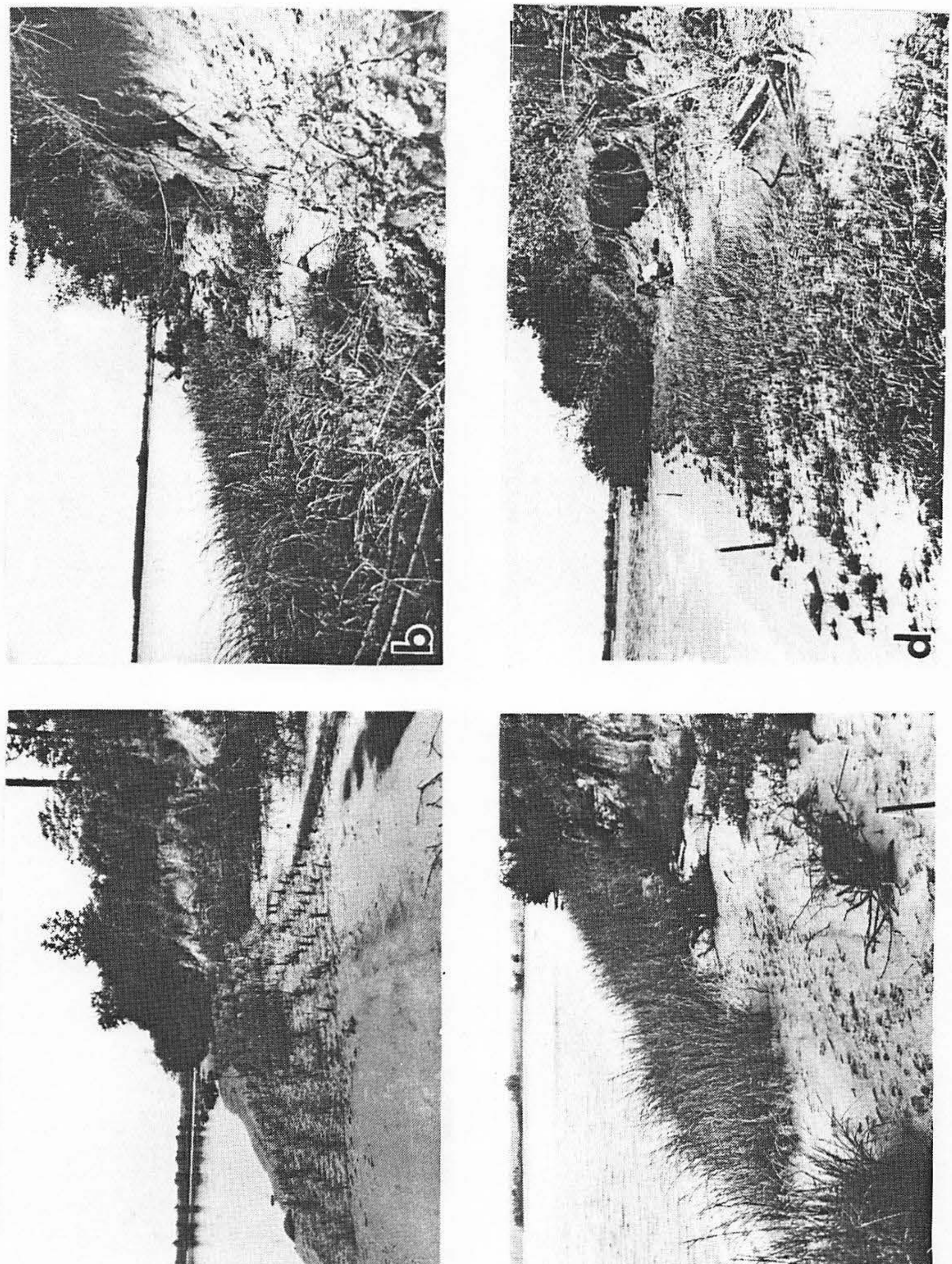
DURHAM WEST

a. May 21, 1982
Looking north.

b. October 20, 1982
Looking north.

c. September 28, 1983
Looking north.

d. May 9, 1984
Looking north.


a
b
c
d

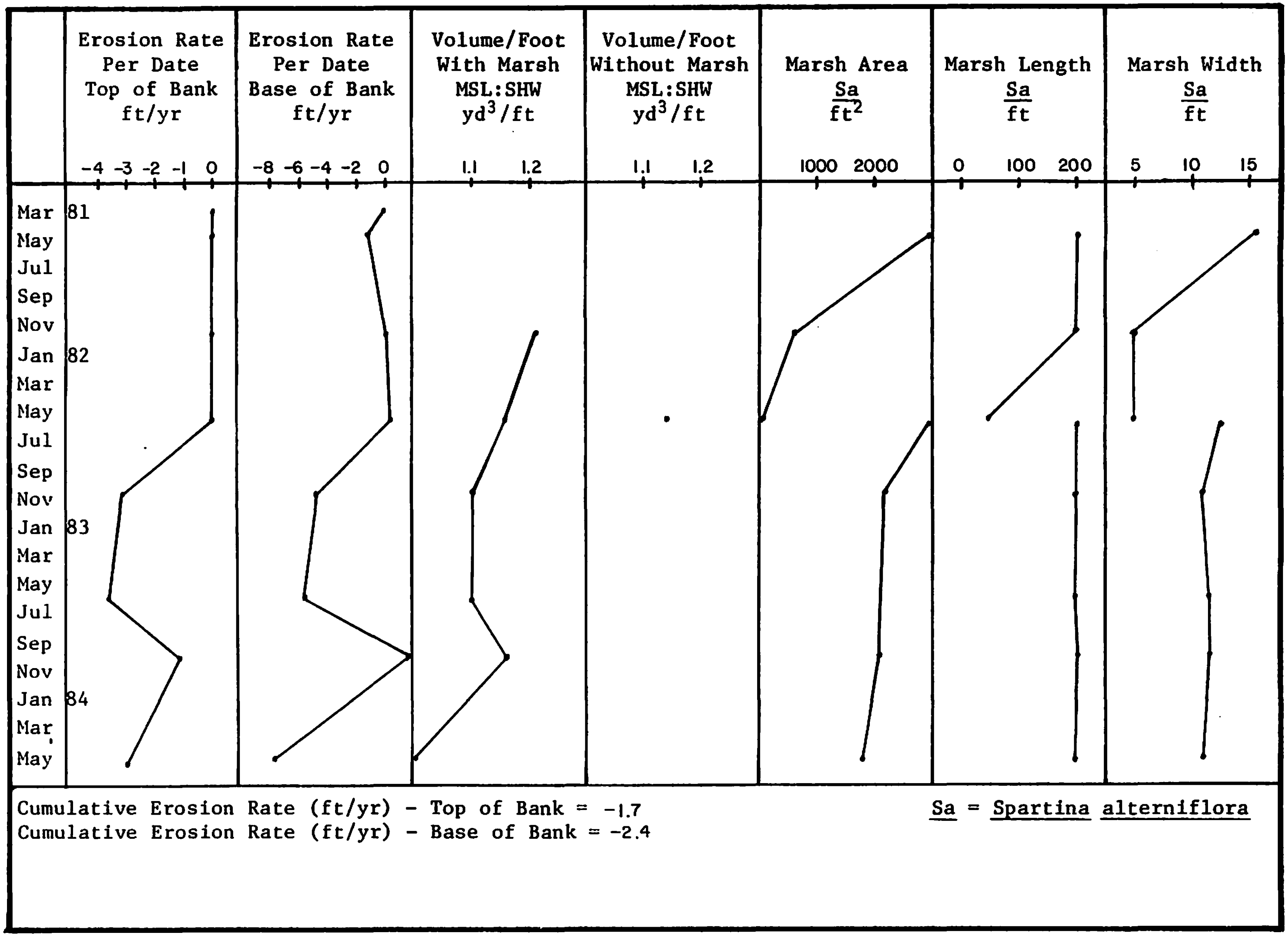


Figure 55. Durham West Time Series.

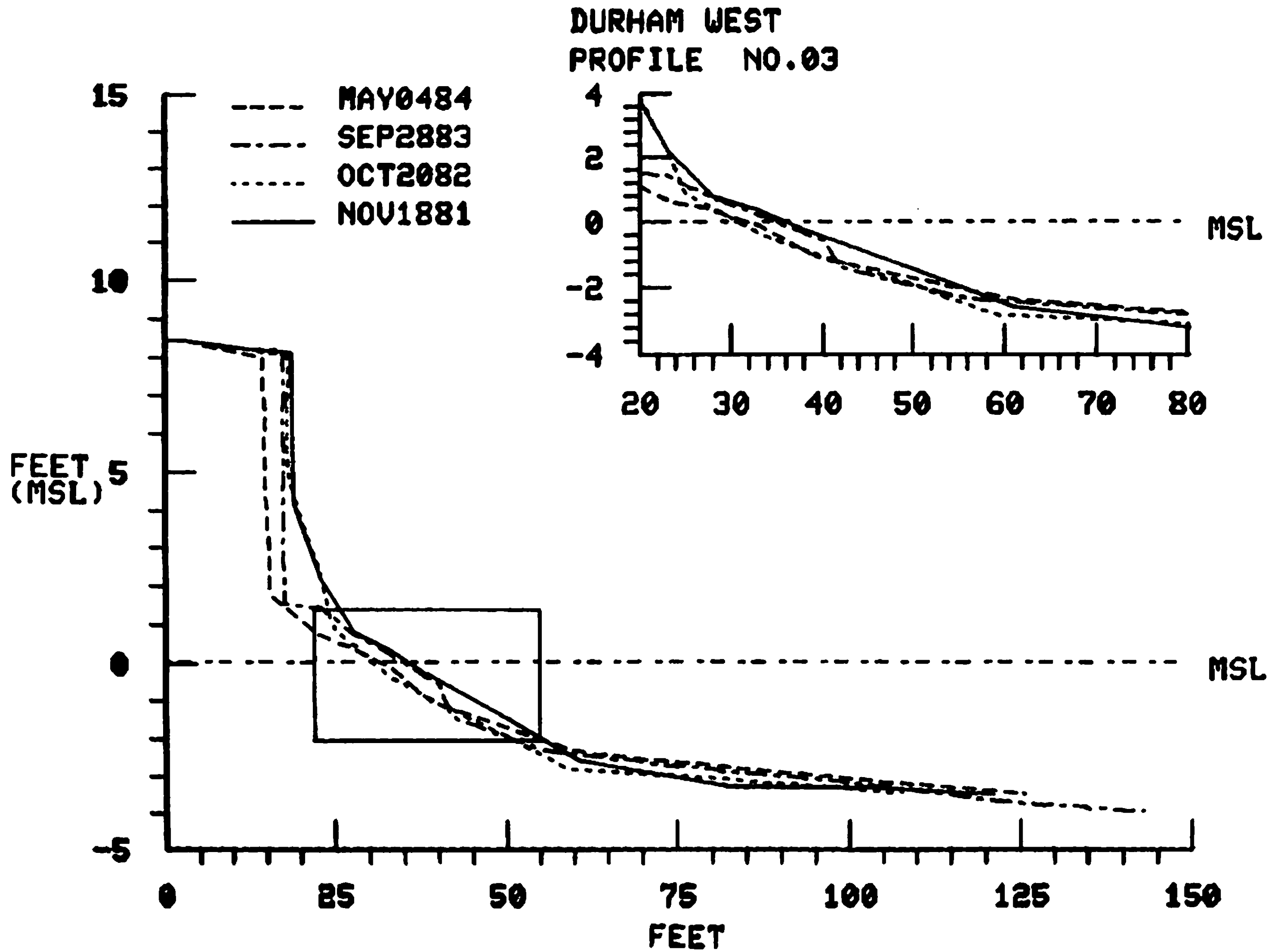


Figure 56. Durham West Site - Representative Profile.

11. GARRETT - RAPPAHANNOCK RIVER, ESSEX COUNTY

Planted 1981

Replanted 1982

(Refer to Appendix B)

The Garrett site is a medium energy shore with an average fetch exposure of 3.5 nautical miles (Figure 57). It has a high bank shore which faces northeast. Historically, the erosion rate along the shore has been less than two feet per year (3). The bank face is intermittently covered with vegetation which adds to slope stability.The beach extends from the base of the bank riverward 40 feet.

The Garrett site is a pocket beach located in a somewhat protective cove with a marsh headland upriver and a man-made rock headland (revetment) downriver. There are also several fallen trees bordering the west side of the site. These appear to interrupt wave trains approaching from the northwest. The fine to coarse beach sands will shift from one end of the pocket beach to the other depending on prevailing wind conditions. As seen through time this can cause burial or washout of young plants.

Garrett's was first planted in May 1981 (Figure 58). Both smooth cordgrass and saltmeadow hay were planted. The site was completely washed out by the fall of 1981 (Figure 59b). Strong northeast winds and accompanying waves only a few days after planting were responsible for most of the losses.

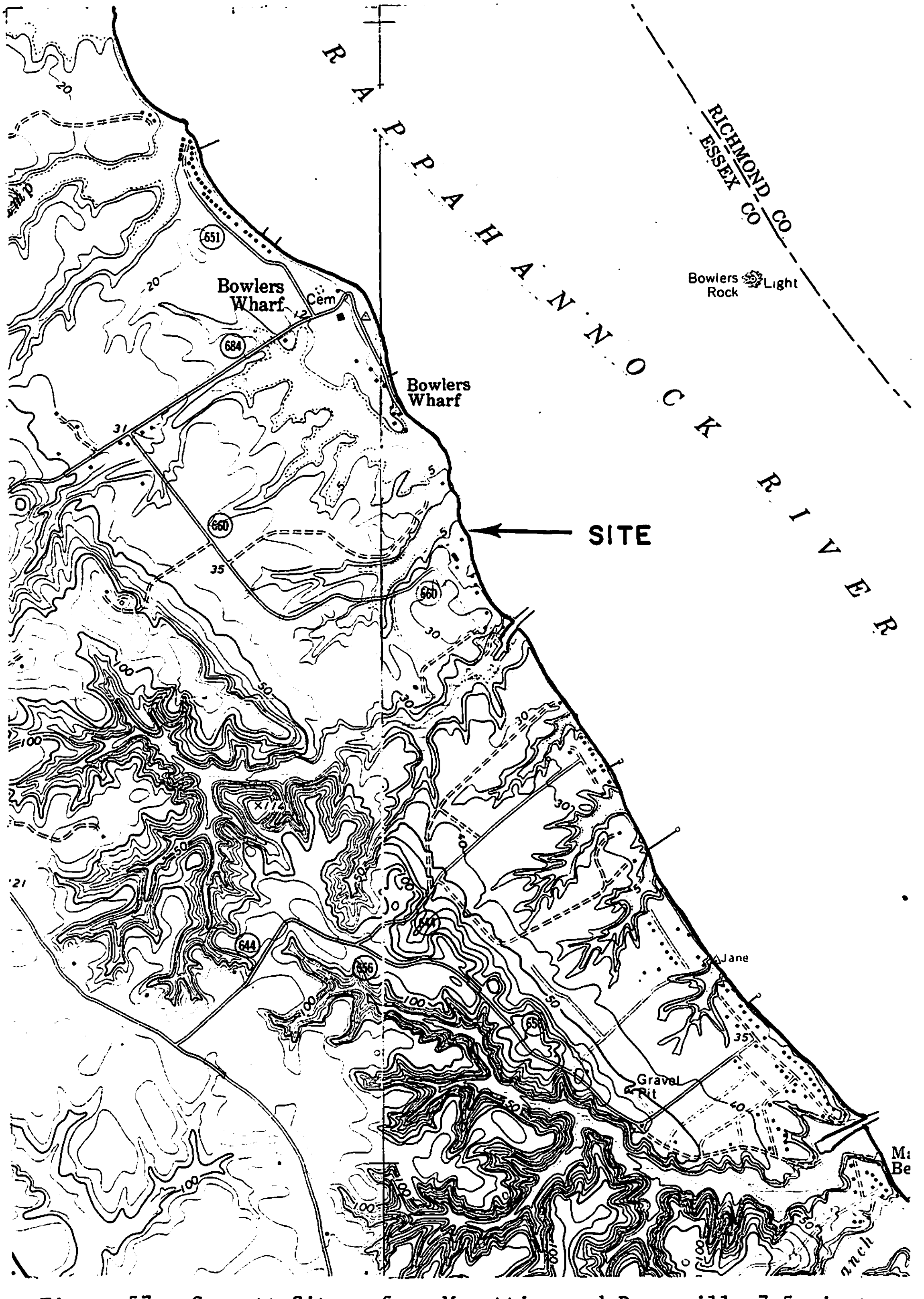


Figure 57. Garrett Site - from Morattico and Dunnsville 7.5 minute quadrangles.
Scale: 1 inch = 2,000 feet.

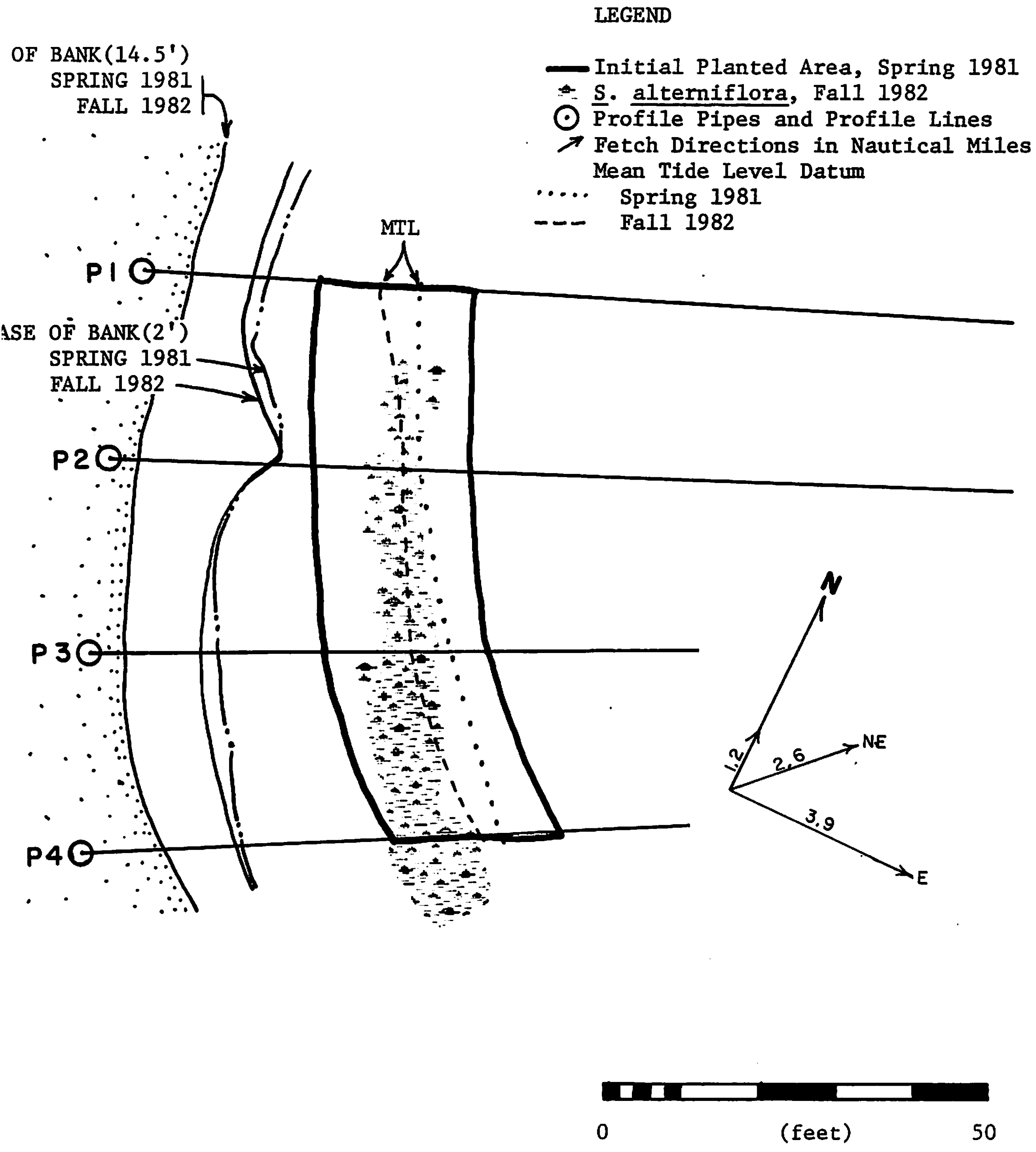


Figure 58. Garrett Site - Base Map.

FIGURE 59

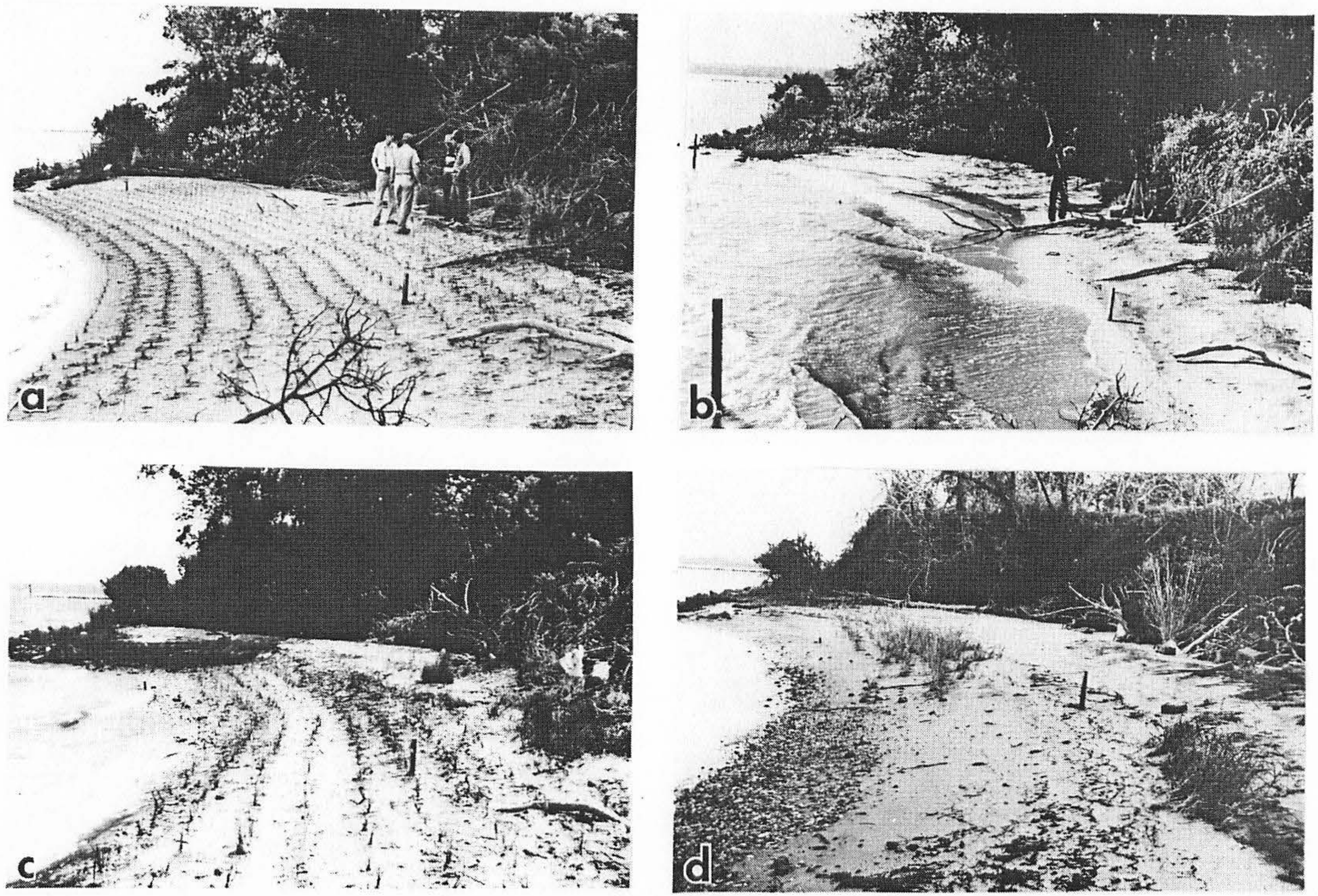
GARRETT

a. May 6, 1981
Looking southeast.

b. September 23, 1981
Looking southeast.

c. May 18, 1982
Looking southeast.

d. November 10, 1982
Looking southeast.


a
b
c
d

The site was maintenance planted in May 1982 (Figure 59c). Once again with both species of grasses. By November 1982 the planting had been reduced in area and erosion of the base of the bank was significant (Figure 59d). Most of these effects can be attributed to the northeast storm of October 25, 1982.

The following spring, sediments within much of the intertidal fringe had been removed, even with a slight increase in marsh area (Figure 60). Another maintenance planting was done in June 1983 (Figure 61). A noticeable increase in backshore elevation was seen in the fall of 1983 and continuing to April 1984 (Figure 62c). Bank erosion increased during this same period probably supplying material to the backshore (Figure 63).

After three years of planting the marsh fringe has finally been able to remain fairly continuous and stabilize the backshore region. The fringe may be considered at least partially successful. Maintenance planting will probably have to be done within the next year. Although the site is somewhat protected by adjacent headlands, it does face the northeast and the potential for severe wave attack from northeast storms. The current fringe is part one year and part two years old. It is mostly smooth cordgrass with very little saltmeadow hay left. The relative youth of the site has not really checked the erosion of the base of the bank to date. However, an erosion rate of 0.8 feet per year for the base of the bank is relatively low considering the northeast exposure.

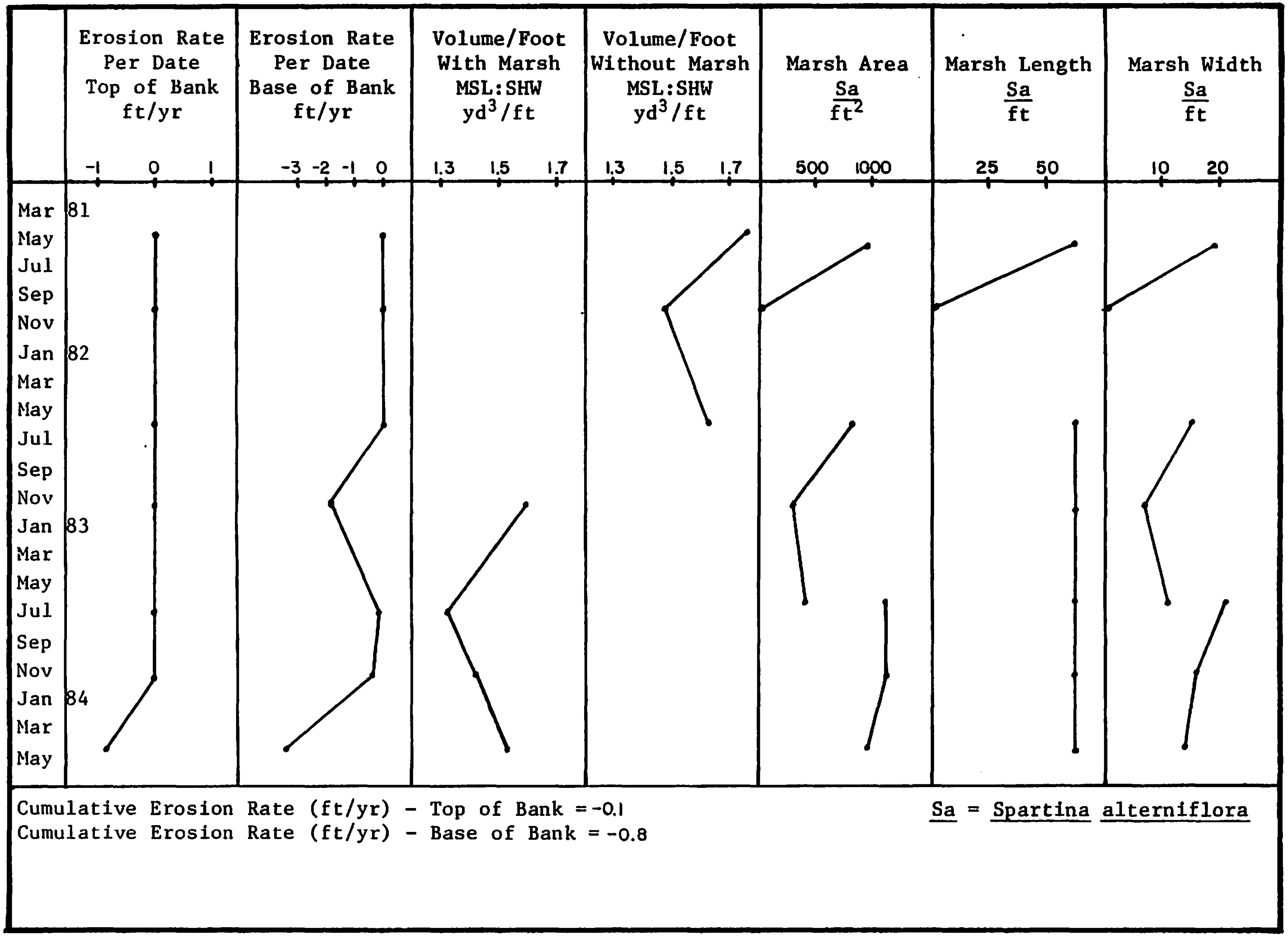


Figure 60. Garrett Time Series.

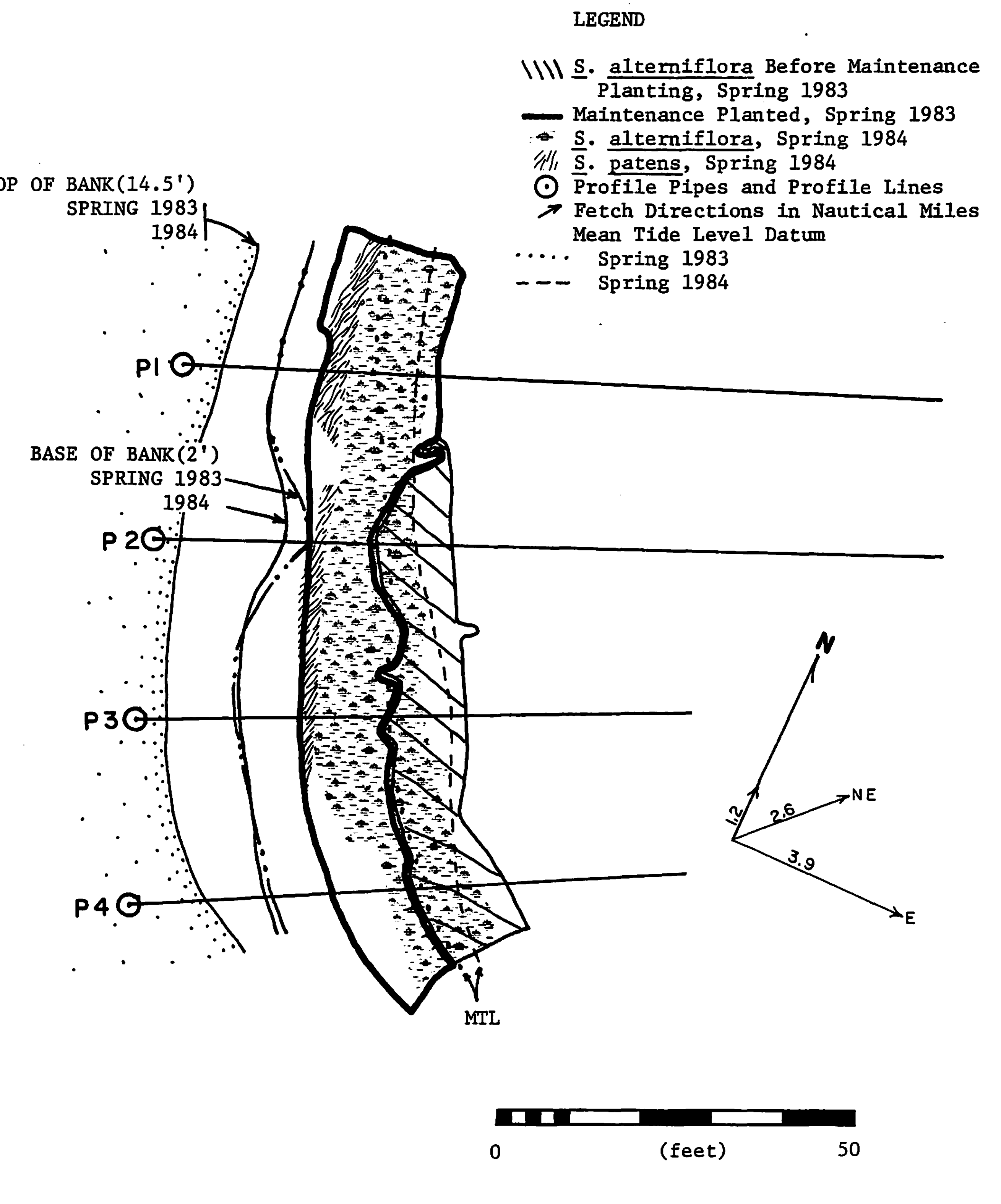


Figure 61. Garrett Site - Base Map.

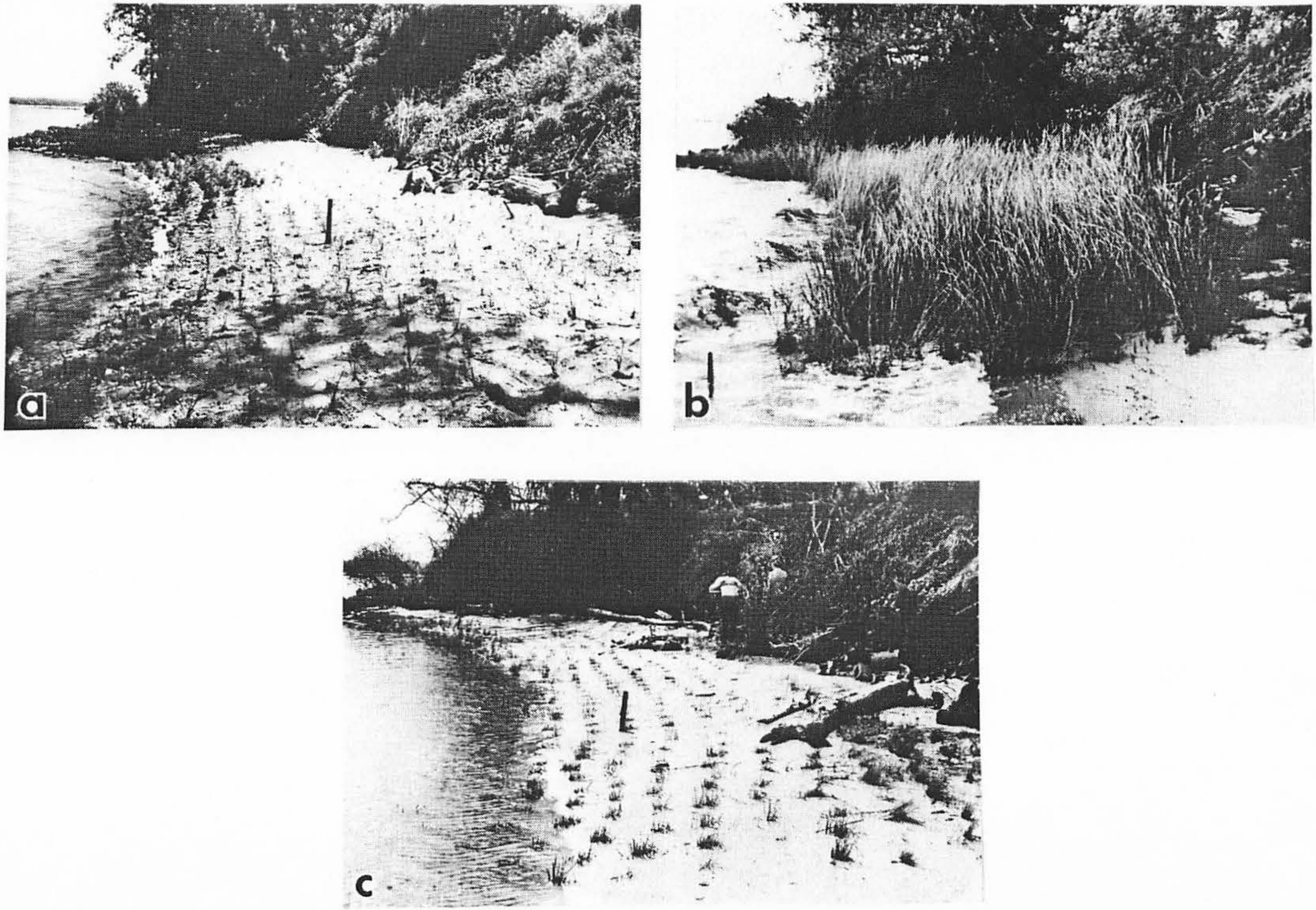
FIGURE 62

GARRETT

a. June 2, 1983
Looking southeast.

b. October 10, 1983
Looking southeast.

c. April 5, 1984
Looking southeast.


a
b
c

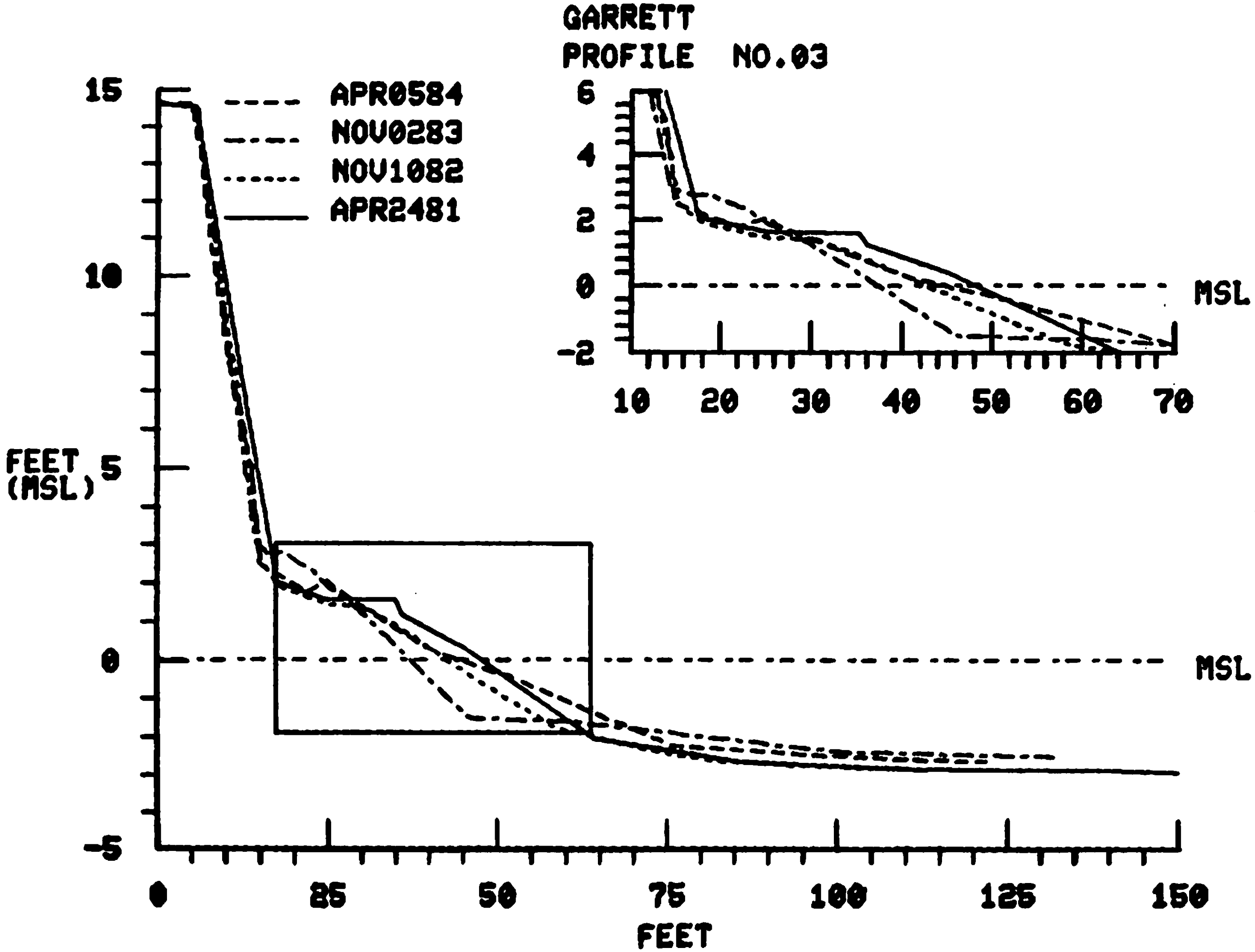


Figure 63. Garrett Site - Representative Profile.

12. MURPHY - PIANKATANK RIVER, MATHEWS COUNTY

Planted 1981

Replanted 1982

(Refer to Appendix B)

The Murphy site represents a low energy, high fastland bank shore (Figure 64). The historical erosion rate is less than one foot per year (3). The fastland bank face was initially covered with logs and stumps placed there by the landowner. Site conditions are similar to the Lee site, a rather straight, low energy shoreline facing north. The beach is composed of coarse sand and gravel with abundant fossil shell fragments eroded from the adjacent bank. The first planting was done in 1981 (Figure 65). The plants were not quite hardened to the proper salinity and most of the plants turned brown and died three weeks after planting. By the fall of 1981 only a small amount of saltmeadow hay remained. There was some bank erosion and subsequent slumping during that fall.

The site was replanted in spring 1982 (Figure 66b). Unfortunately, sometime in early fall a bulldozer was brought in to clear the logs and stumps from the bank face (Figure 66d). This also effectively destroyed much of the west end of the newly planted fringe around P1. The erosion rate in Figure 67 for November 1982 can be mostly attributed to this.

By spring 1983 the marsh fringe had been reduced even more along with sediment within the intertidal fringe. Another maintenance planting of both species was done at that time (Figure 68).

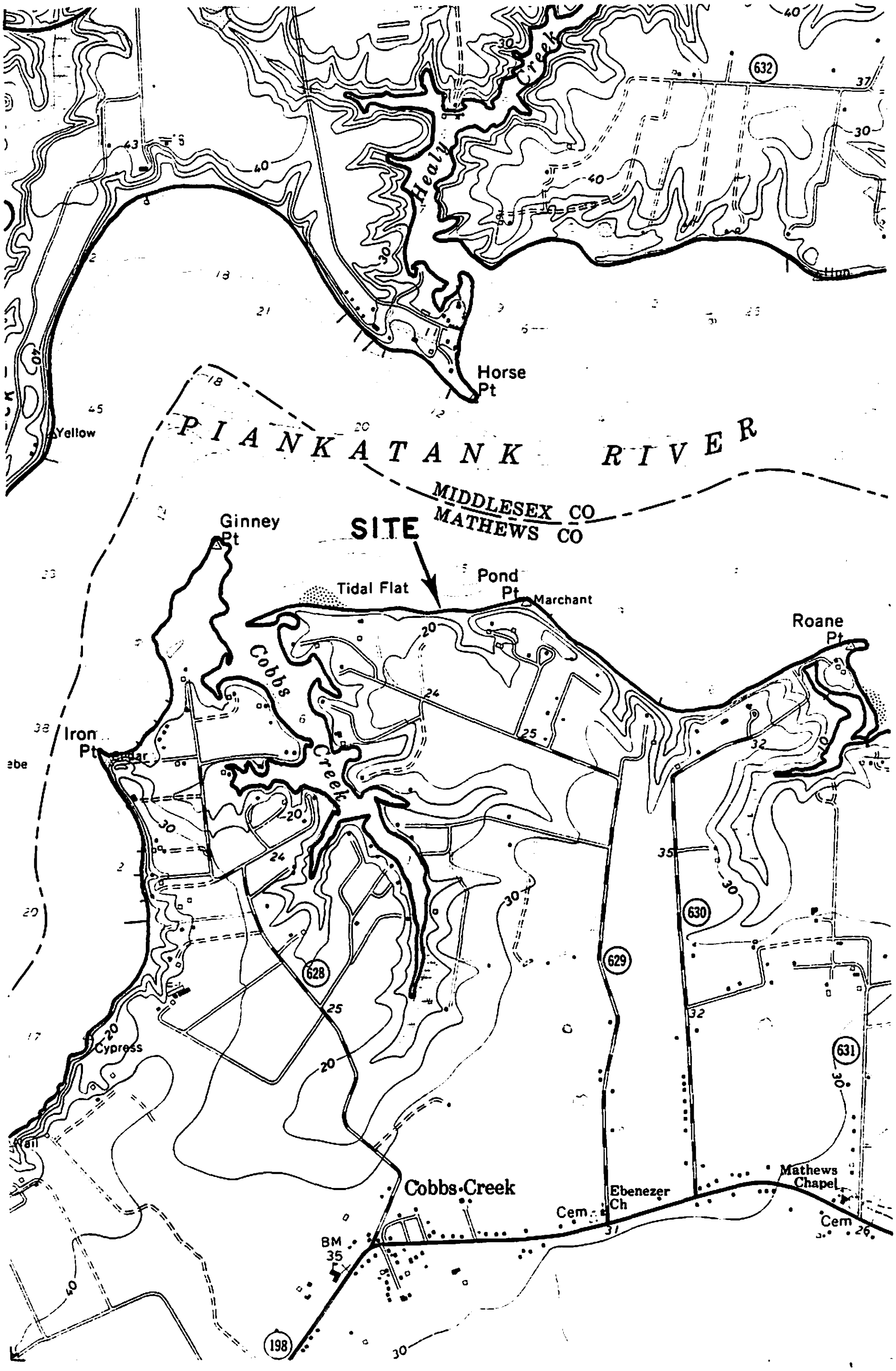


Figure 64. Murphy Site - from Wilton 7.5 minute quadrangle.
Scale: 1 inch = 2,000 feet.

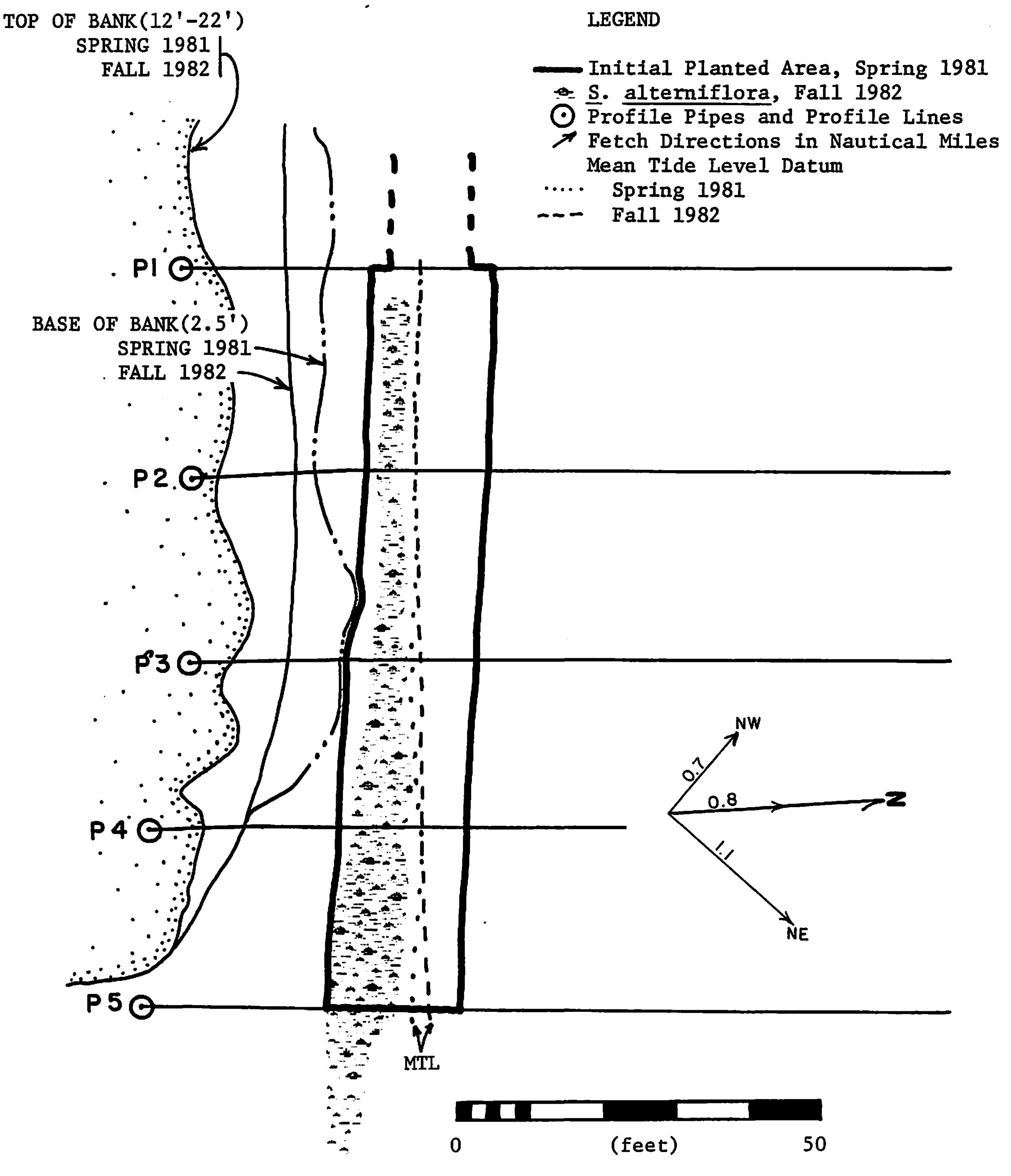


Figure 65. Murphy Site - Base Map.

FIGURE 66

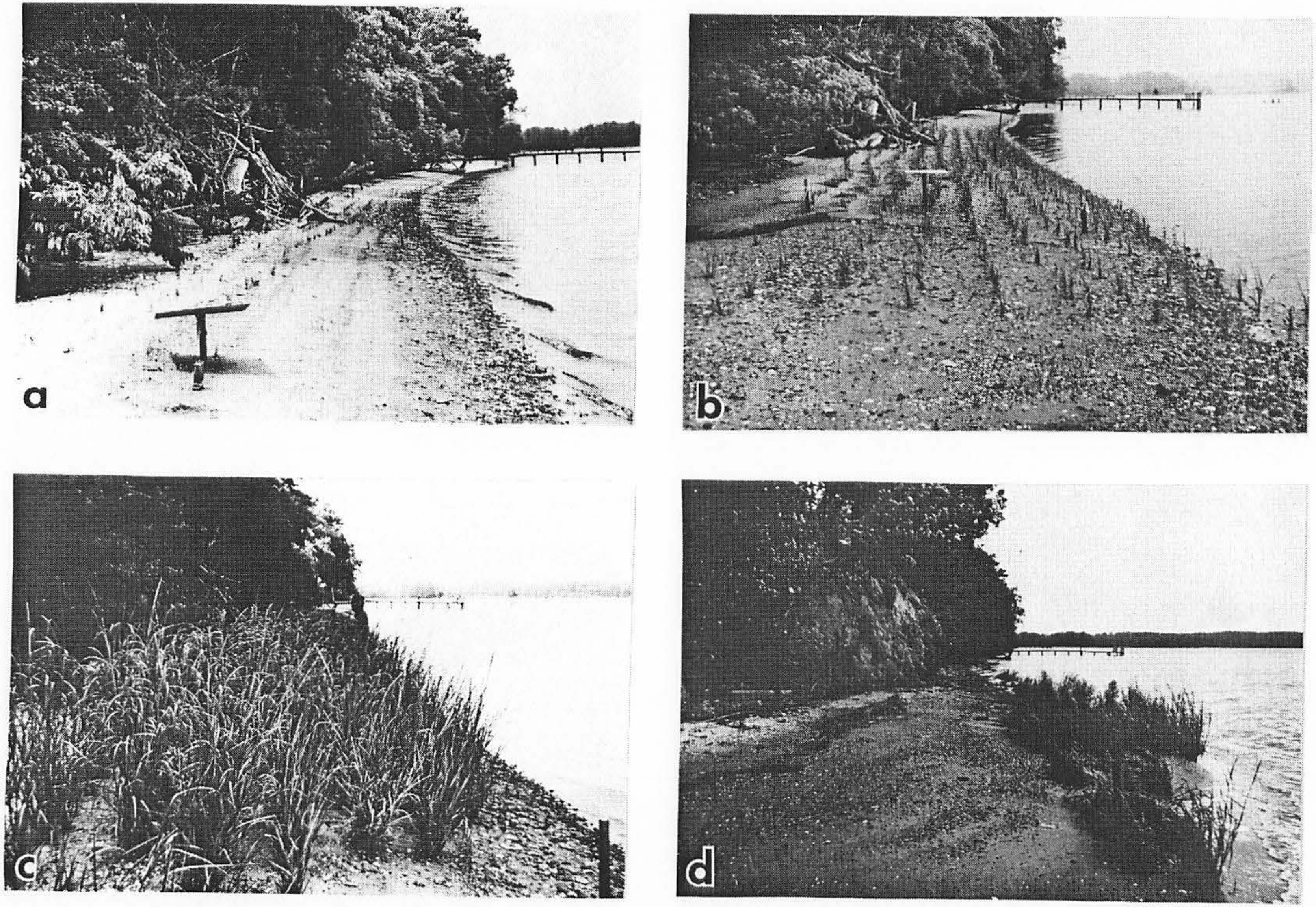
MURPHY

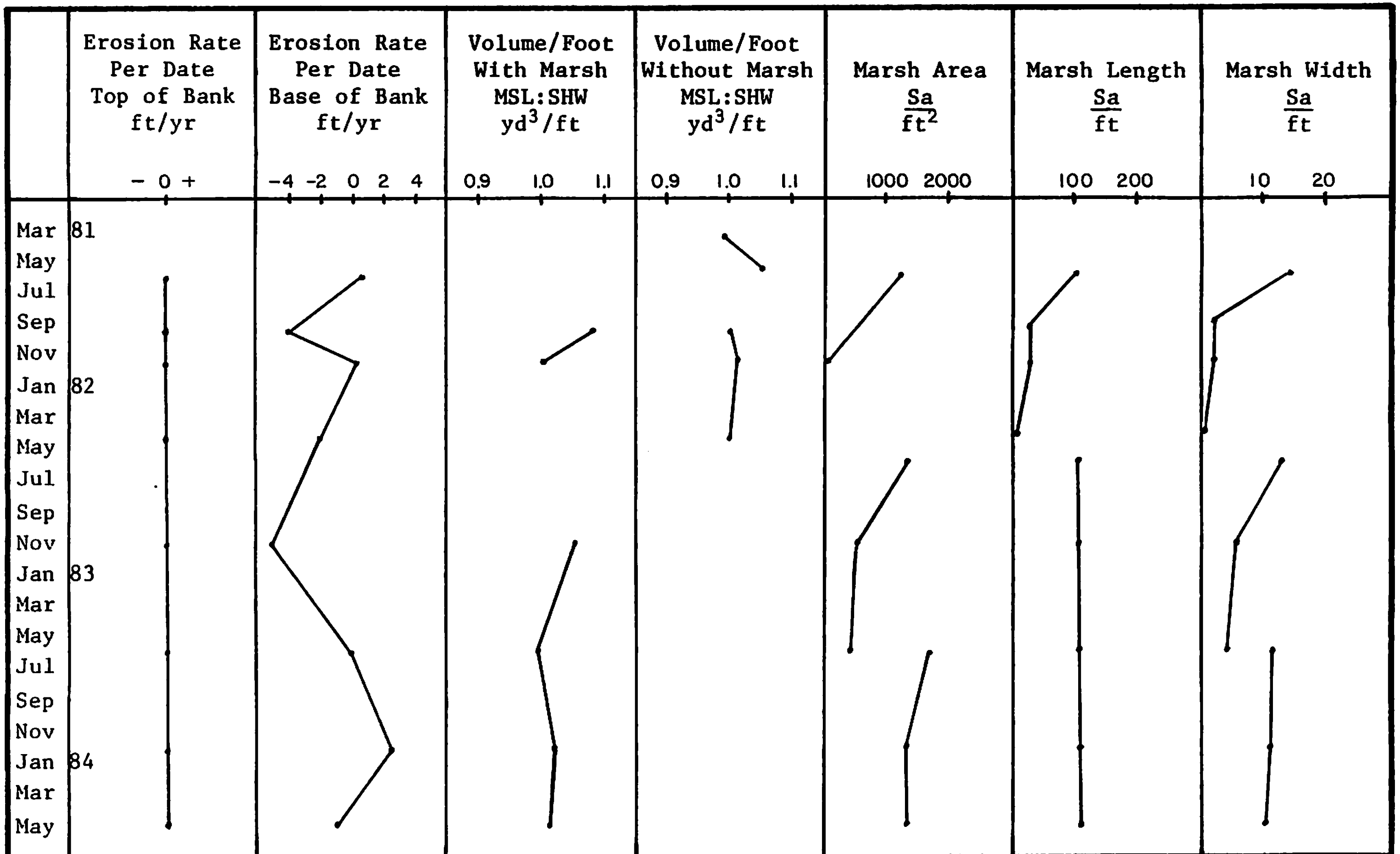
a. June 9, 1981
Looking west.

b. May 27, 1982
Looking west.

c. August 31, 1982
Looking west.
Before bulldozer.

d. September 30, 1982
Looking west.
After bulldozer.


a
b
c
d



Cumulative Erosion Rate (ft/yr) - Top of Bank = 0.0
Cumulative Erosion Rate (ft/yr) - Base of Bank = −1.5

Sa = *Spartina alterniflora*

Figure 67. Murphy Time Series.

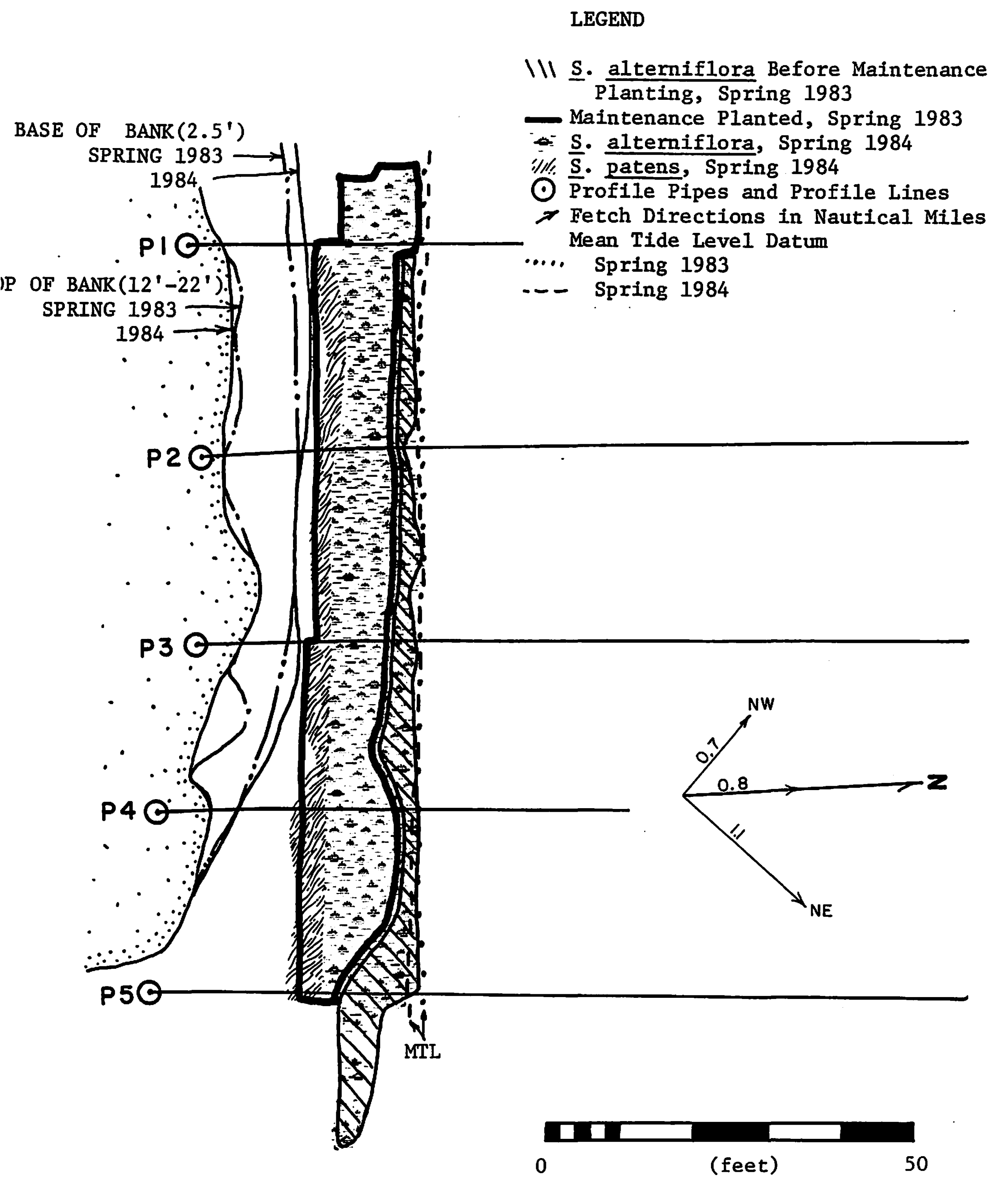


Figure 68. Murphy Site - Base Map.

FIGURE 69

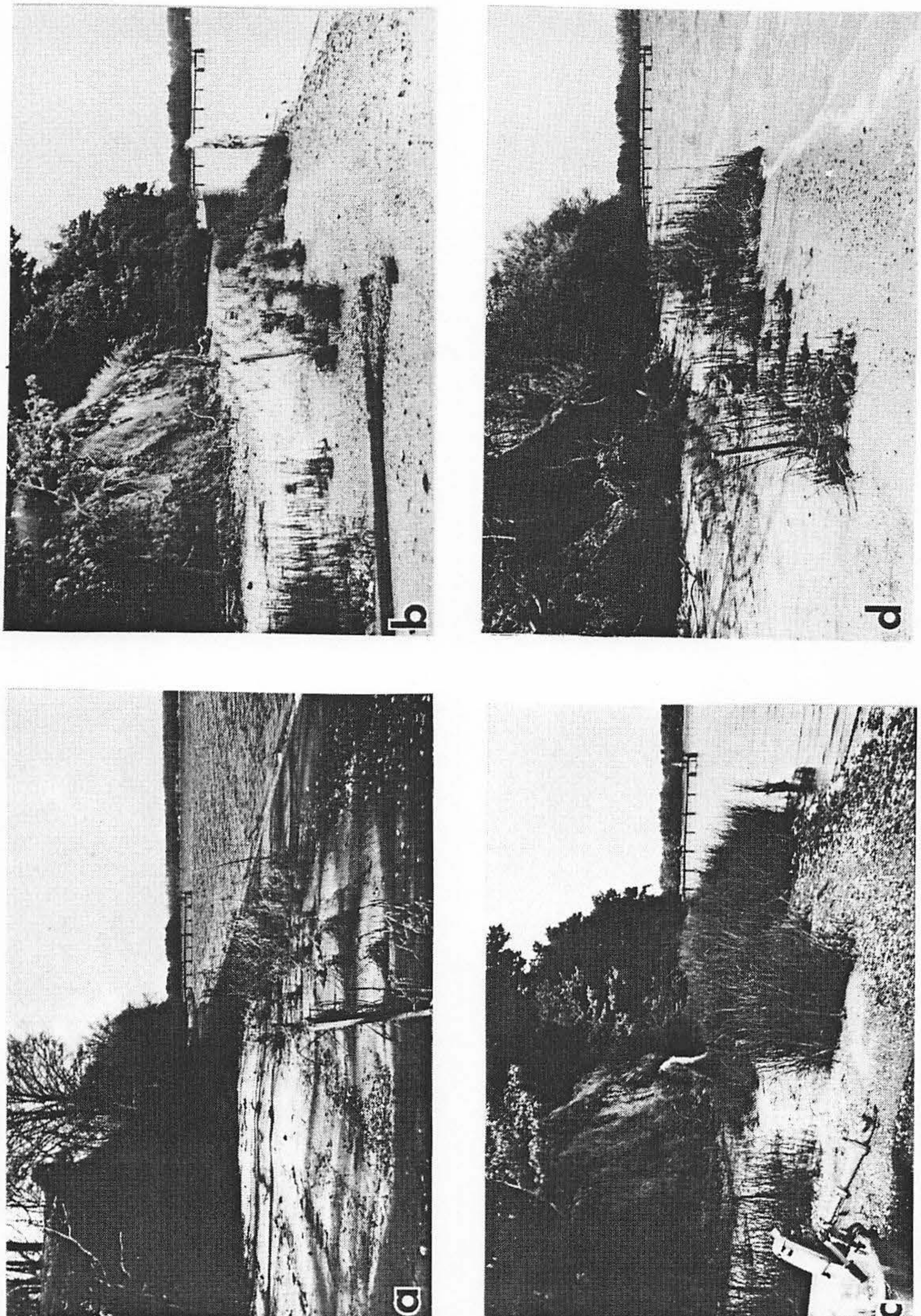
MURPHY

a. January 25, 1983
Looking west.

b. June 3, 1983
Looking west.

c. July 29, 1983
Looking west.

d. April 29, 1984
Looking west.



In the fall of 1983 there was slumping of the fastland bank which probably supplied material to the marsh fringe. There was a standing crop of smooth cordgrass in February 1984, but this was reduced along the upper fringe by April 1984 (Figure 69d). The base of the bank eroded some during last winter but the marsh remained intact.

The marsh fringe itself is starting to establish a peat substrate. Although the saltmeadow hay area is down, the backshore elevation is up slightly since fall 1983 (Figure 70). The long term success is hard to quantify due to the bulldozer episode. However, with time and a little maintenance planting the fringe should expand and begin to stabilize the adjacent bank. A foreseeable problem will be a major northeast storm event which may cause a great undercutting and consequent slumping. This would effectively bury much of the fringe.

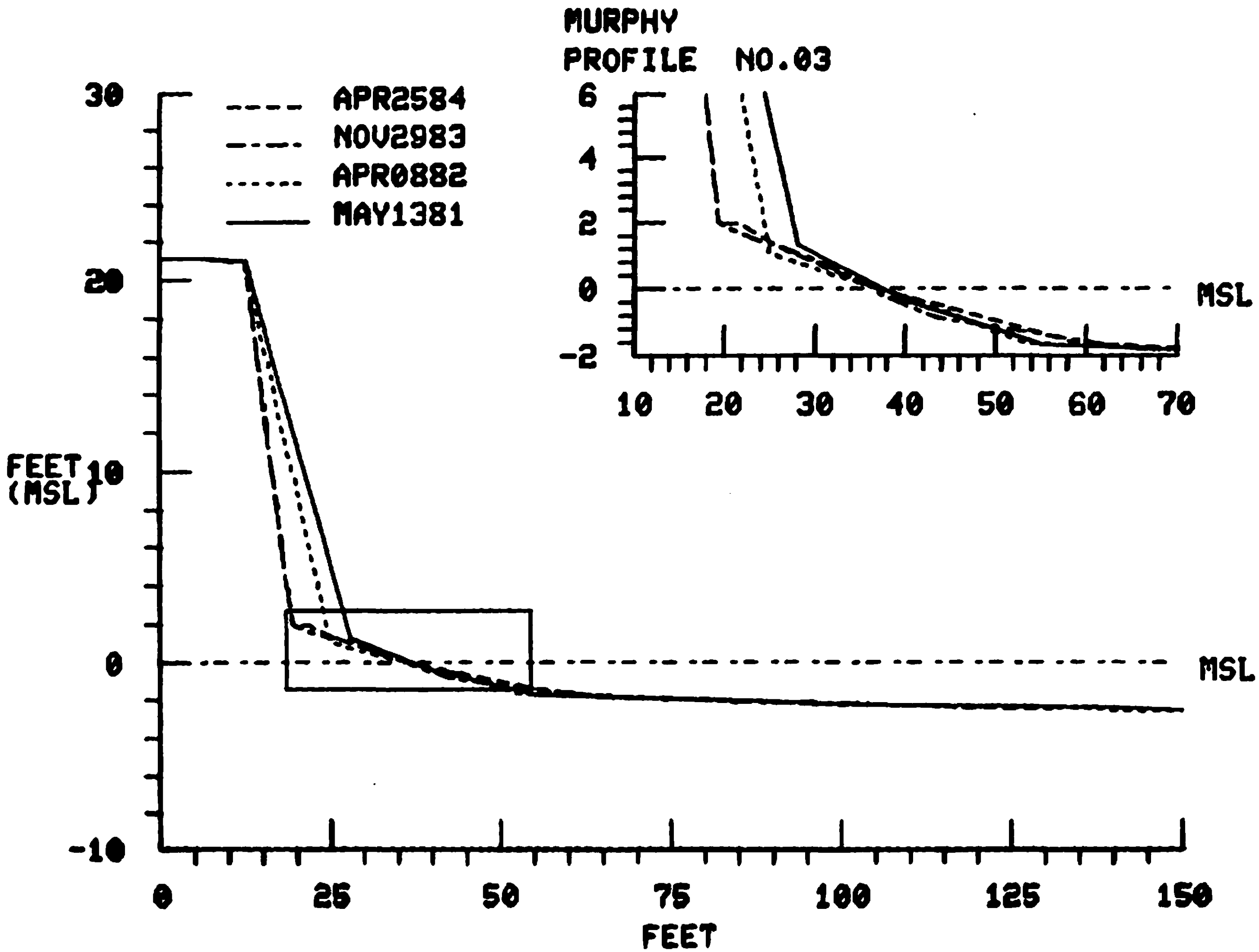


Figure 70. Murphy Site - Representative Profile.

13. POOLE - TABBS CREEK, LANCASTER COUNTY

Planted 1982

(Refer to Appendix B)

The Poole site is a low energy shore with a high graded fastland bank on the north shore of Tabbs Creek (Figure 71). The shore faces south southwest with an average fetch of only 0.04 nautical mile. The historical erosion rate is minimal. However, there was an exposed erosional cliff face to the bank before grading, indicating active erosion. After grading, hay bales were placed along the base of the bank. The slope of the graded bank was planted with tall fescue.

There is a narrow intertidal beach composed of fine silty sand. This extends from the hay bales riverward for 15 feet. Most sediments which supported the existing beach probably came from erosion of the previously exposed bank. Natural stands of smooth cordgrass occur adjacent to the site.

The Poole site was first planted with smooth cordgrass in the spring of 1982 (Figure 72). There was a significant reduction in marsh area and width by August of 1982. The losses were along the lower edge. Also, the lower edge existed at about MTL (Figure 73b). Over the winter of 1982-1983 there was a slight gain in marsh area. There was also some base of bank erosion which was really more due to deteriorating hay bales.

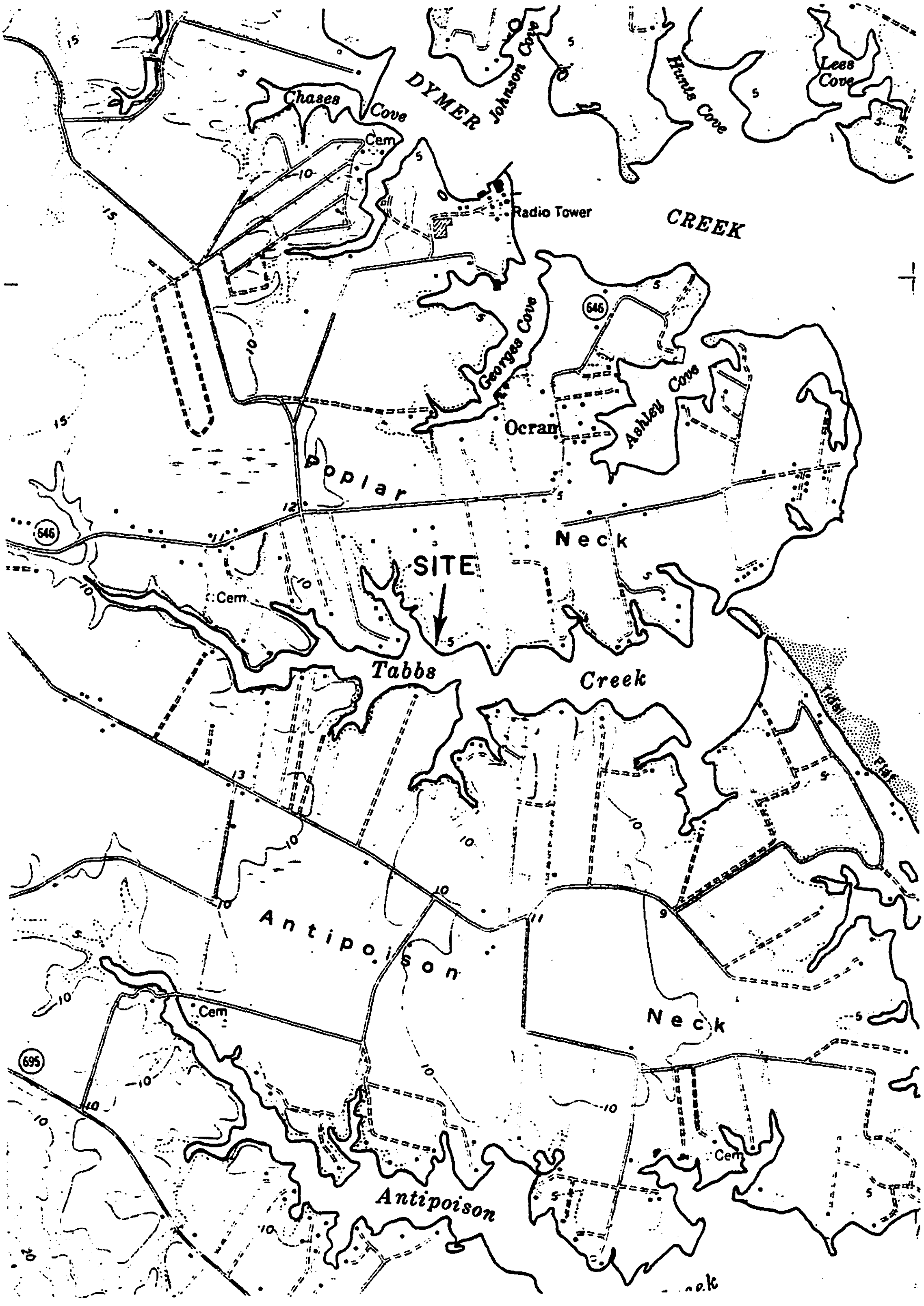


Figure 71. Poole Site - from Fleets Bay 7.5 minute quadrangle.
Scale: 1 inch = 2,000 feet.

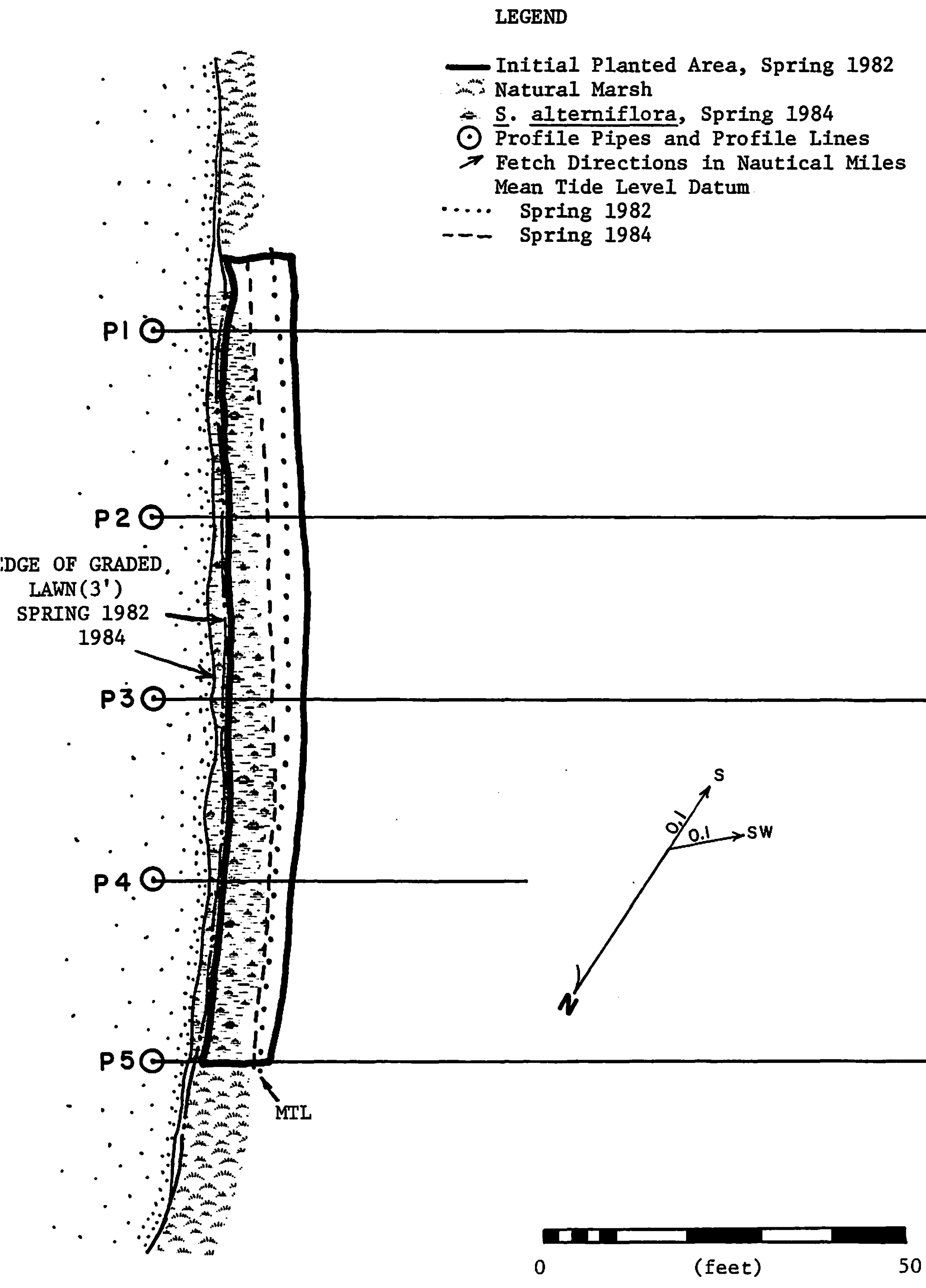


Figure 72. Poole Site - Base Map.

FIGURE 73

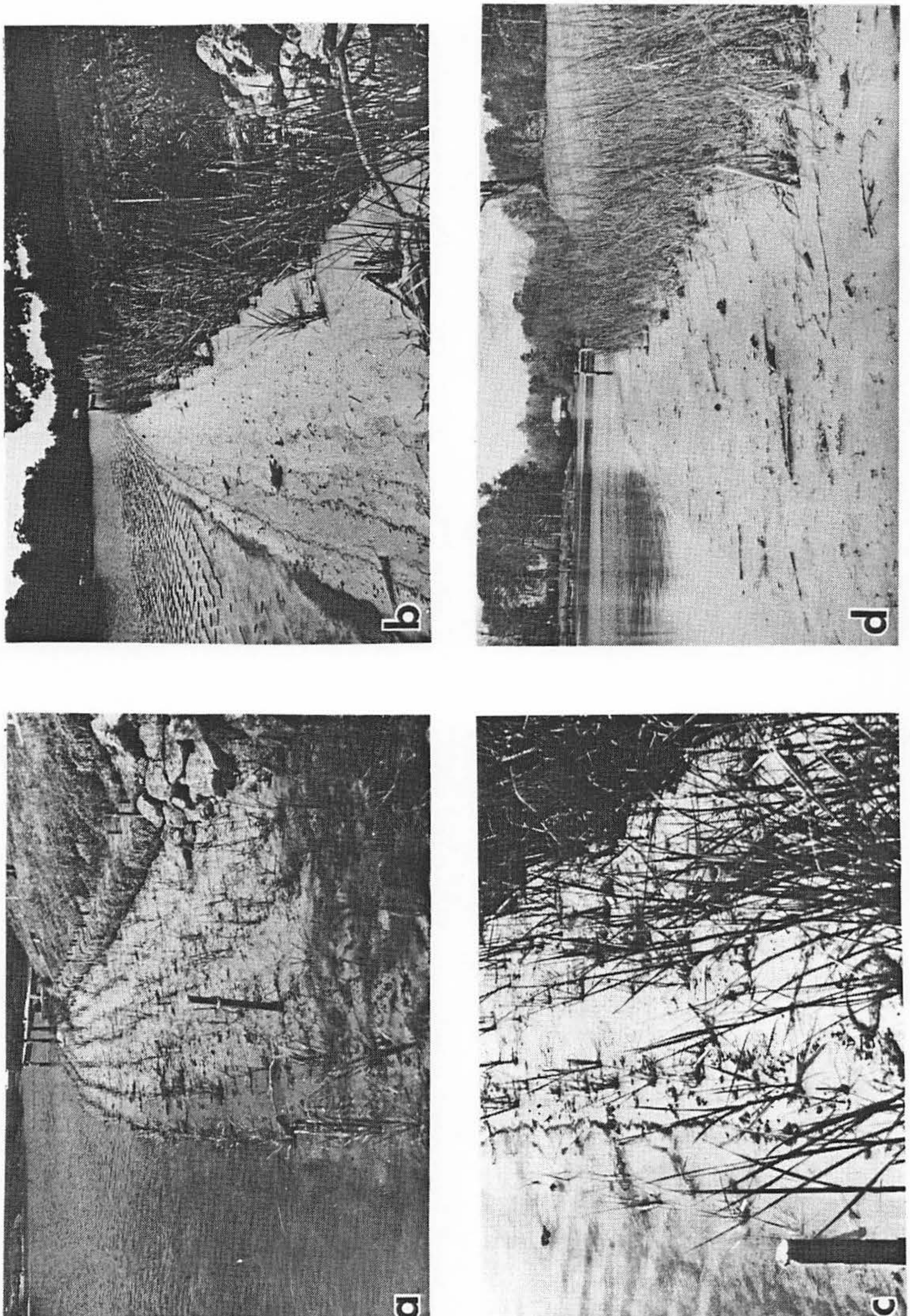
POOLE

a. May 18, 1982
Looking west.

b. August 31, 1982
Looking west.

c. June 5, 1983
Looking west.

d. March 12, 1984
Looking west.


a
b
c
d

Maintenance planting was done in the spring of 1983. The planting was extended to its original limits of the initial 1982 planting (Figure 73c). By late August the lower limit had retreated to its previous position before maintenance planting at MTL. Complete deterioration of the hay bales caused some loss along the base of the bank which is probably not attributable to wave action (Figure 74).

There was a slight loss of sediment within the intertidal fringe over the winter of 1983-1984. By the spring of 1984 there was a slight increase in marsh area and width (Figure 73d). Rhizome spread had begun as early as mid-March from the fringe where the lower limit corresponded almost exactly to MTL (Figure 72).

The Poole site has been able to maintain a stable upper tidal zone (Figure 75) and a thick continuous fringe through time. Although slight bank erosion has occurred, the site is definitely trending toward success.

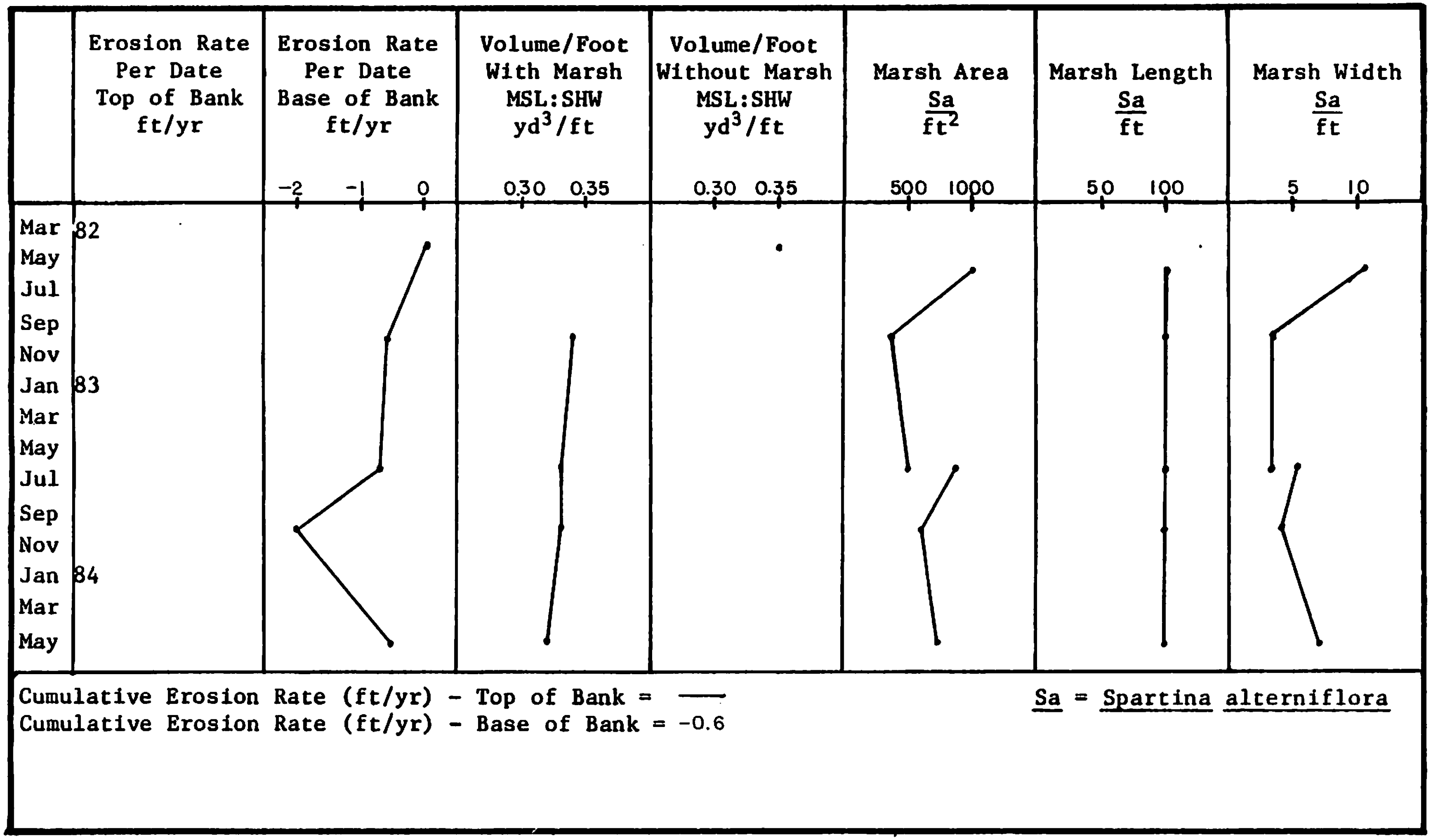


Figure 74. Poole Time Series.

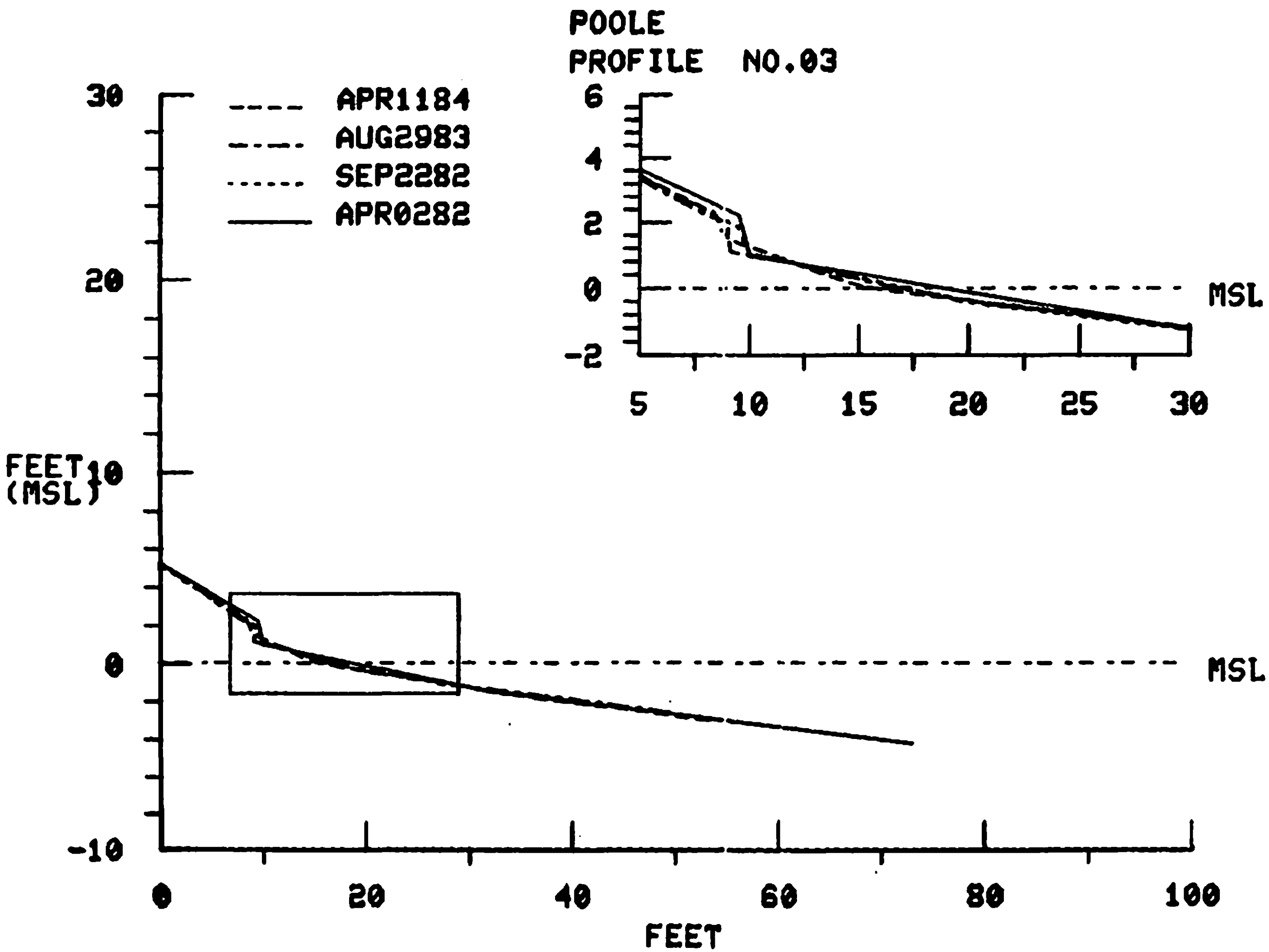


Figure 75. Poole Site - Representative Profile.

14. YORK RIVER STATE PARK - YORK RIVER, JAMES CITY COUNTY

Planted 1982

(Refer to Appendix B)

York River State Park represents the only continuous marsh shore site in the VEC project (Figure 76). It is a medium energy shore which faces northeast. The historical erosion rate is about two feet per year (3). The marsh bank is a wave cut peat scarp (about two feet above MTL) which is actively eroding. At high water the base of the peat bank is inundated. Indigenous smooth cordgrass occupies a narrow fringe along the top of the peat bank.

The narrow beach along the base of the peat bank varies in width from five to ten feet adjacent to the irregular marsh shore planform. The beach is composed of fine to coarse sand and extends down to about MTL. Sediment source for the beach comes mostly from erosion of a high fastland bank upriver. There are two separate planting areas at this site.

In June 1982 there was approximately 1,120 square feet of smooth cordgrass planted on two sites at York River State Park. Figure 77 shows the east site planting. By the fall of 1982 the west site was completely washed out and the east site was significantly reduced (Figure 78b). The storm of October 25, 1982 may have been partially responsible. Calculations for sediment volume in the intertidal fringe were not possible at this site and are not seen in the time series graph (Figure 79).

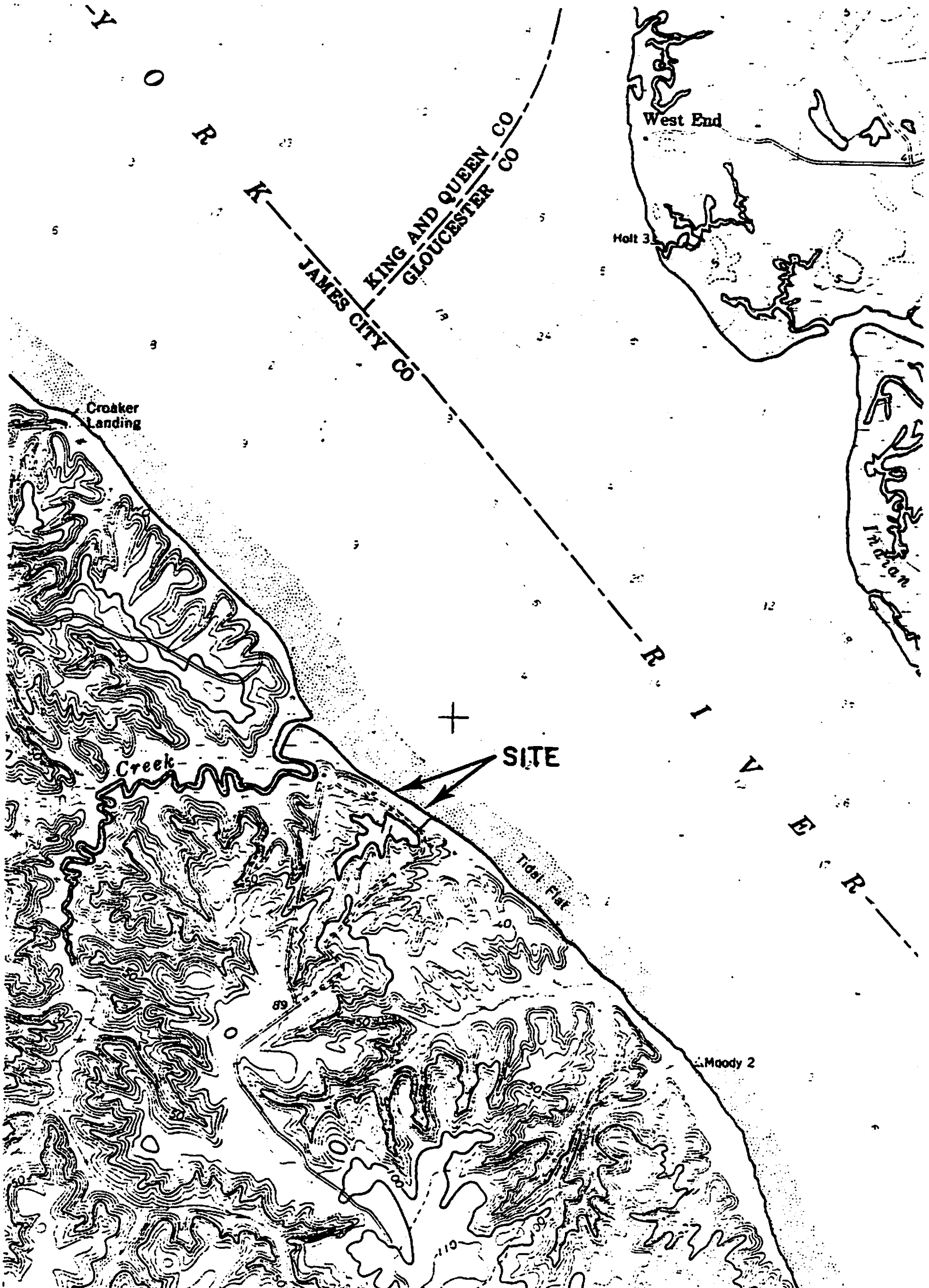


Figure 76. York River State Park Site - from Gressitt 7.5 minute quadrangle.
Scale: 1 inch = 2,000 feet.

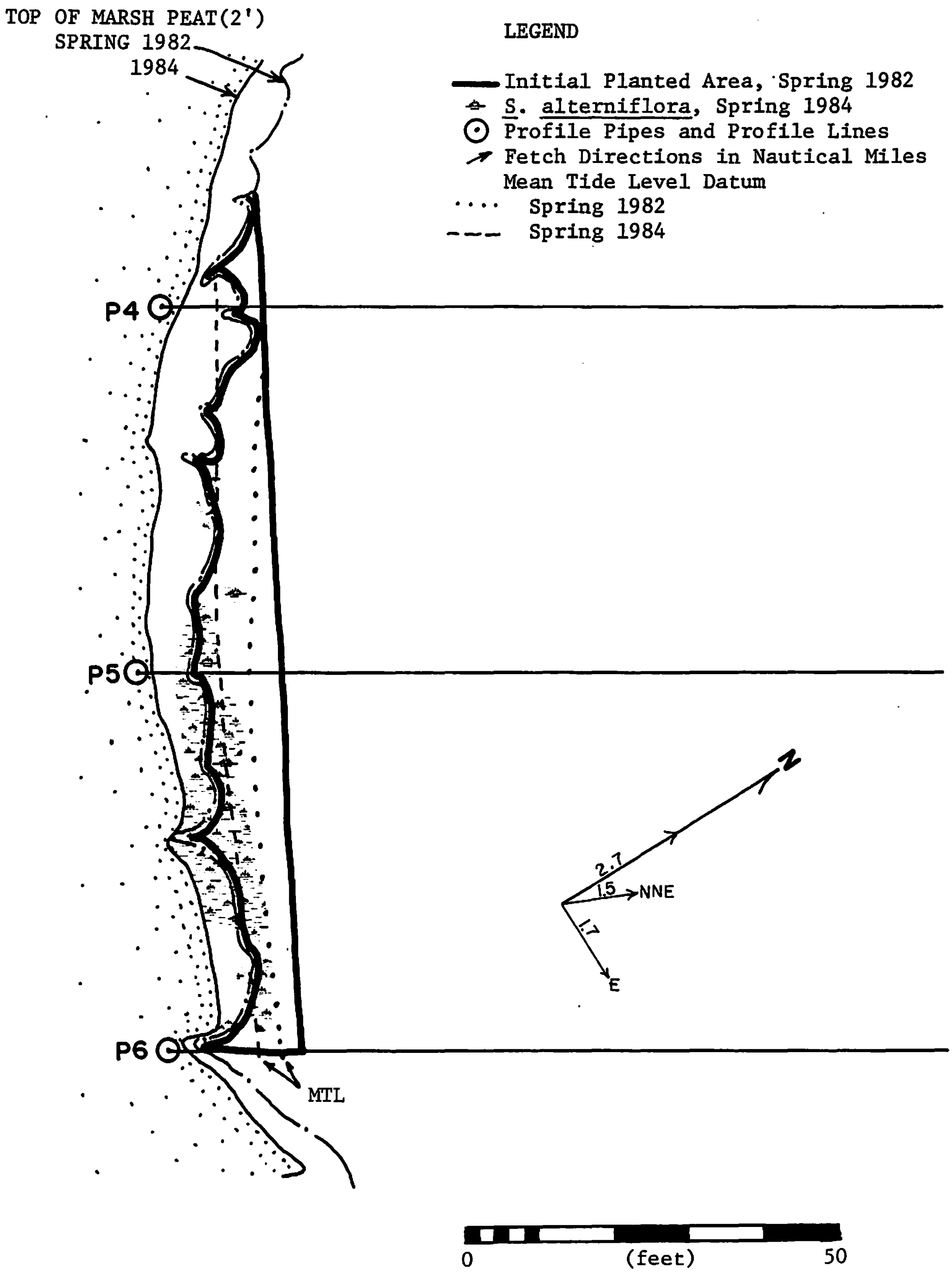


Figure 77. York River State Park Site - Base Map.

FIGURE 78

YORK RIVER STATE PARK

a. June 2, 1982
Looking east.

b. September 2, 1982
Looking west.

c. July 21, 1983
Looking west.

d. May 11, 1984
Looking west.


a

b

c

d

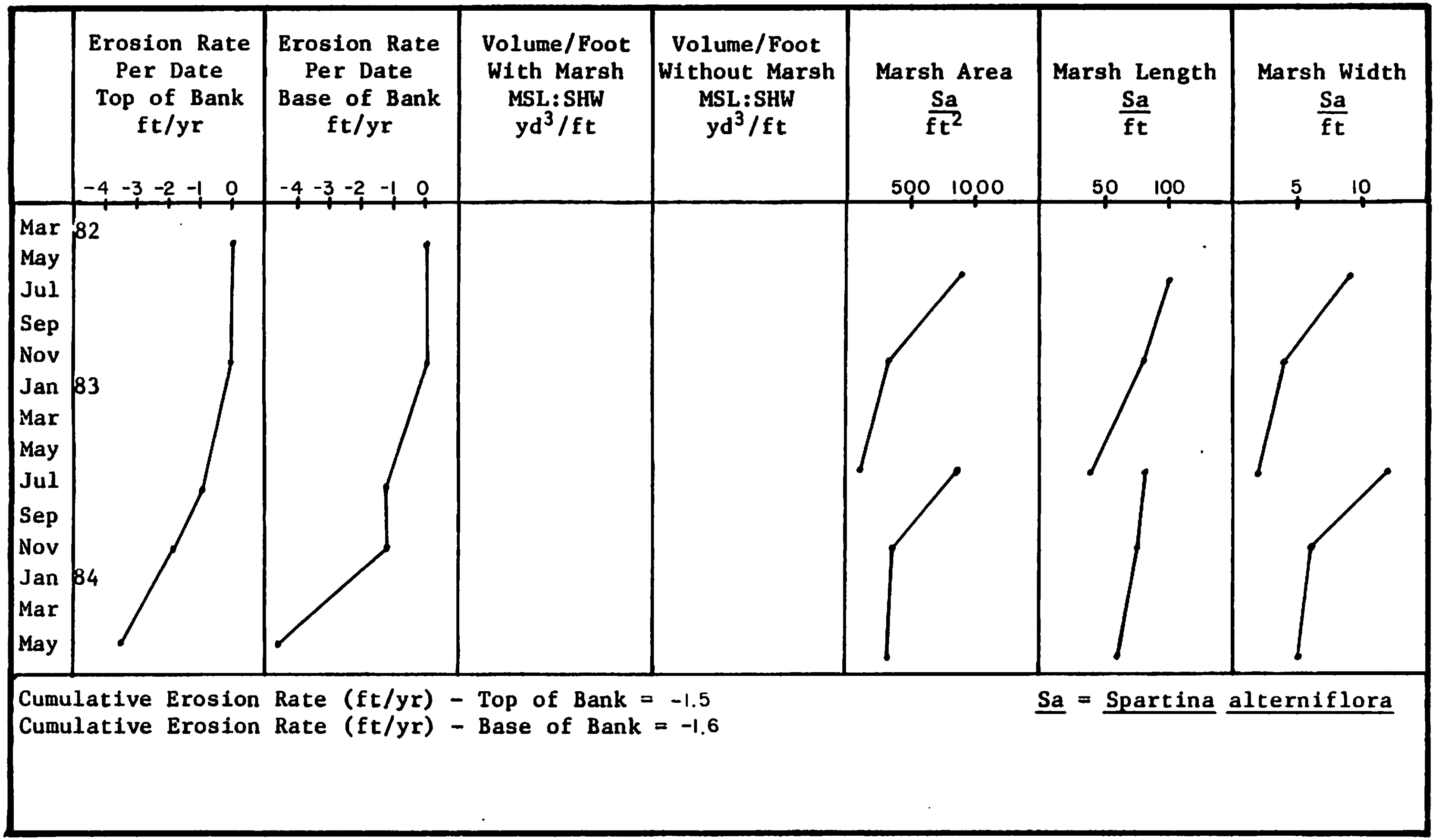


Figure 79. York River State Park Time Series.

During the winter of 1982-1983 the marsh area, length and width were reduced even further (Figure 79). Consequently, maintenance planting was done in the spring of 1983. Most of the plants were taking hold by mid-summer (Figure 78c) but significant reduction in marsh area was seen by the fall (Figure 79).

Wave action during the winter of 1983-1984 further reduced the planting and erosion of the marsh peat bank increased (Figure 80). The planting has been unable to hold the backshore and establish a substantial peat substrate. The trend here seems toward failure. The planting is situated below MHW and probably receives wave reflection off the peat bank which may make it difficult to maintain backshore elevation.

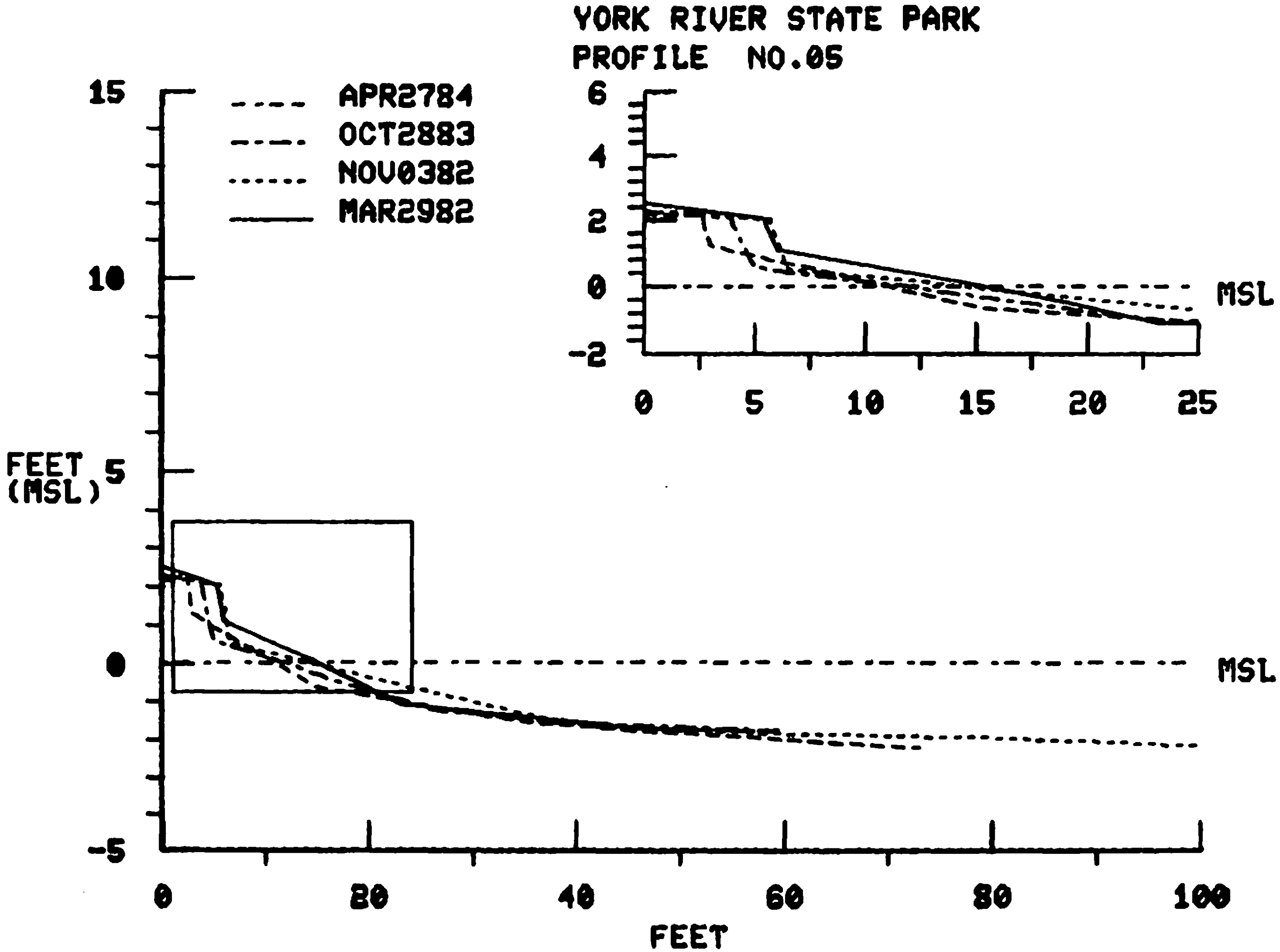


Figure 80. York River State Park Site - Representative Profile.

15. ELEY - JAMES RIVER, SURRY COUNTY

Planted 1982

(Refer to Appendix B)

The Eley site is located on a straight shoreline at Mount Pleasant Plantation on the James River and represents a medium energy shore (Figure 81). It has a bluff shore which ranges between 40 and 70 feet above MTL. The shore faces almost due north and has a historical erosion rate of about one foot per year (3). Most of the bank face is vertically exposed across the upper portion and is covered with slumped material across the base. Kudzu grows prolifically over much of the bank slope. There is usually a small wave cut scarp along the base of the slump material. The beach consists of medium to very coarse sand, gravel, and fossil shell material. The source of sediments is from erosion of the adjacent bank and banks further upriver. The beach extends from the base of the bank riverward for about 40 feet.

The planting of the marsh fringe at the Eley site was first done in June 1982 with a total of 2,581 square feet of smooth cordgrass (Figure 82). By August almost 40% of the planting had been washed out (Figure 83b). Losses were random throughout the fringe. The October 25, 1982 storm caused considerable erosion along the base of the slump material with subsequent deposition within the backshore and remaining intertidal fringe (Figure 84). The upper portion of the fringe was mostly buried.

During the winter of 1982-1983 further losses of marsh area, width and length were seen. Thus, the need for maintenance planting in June

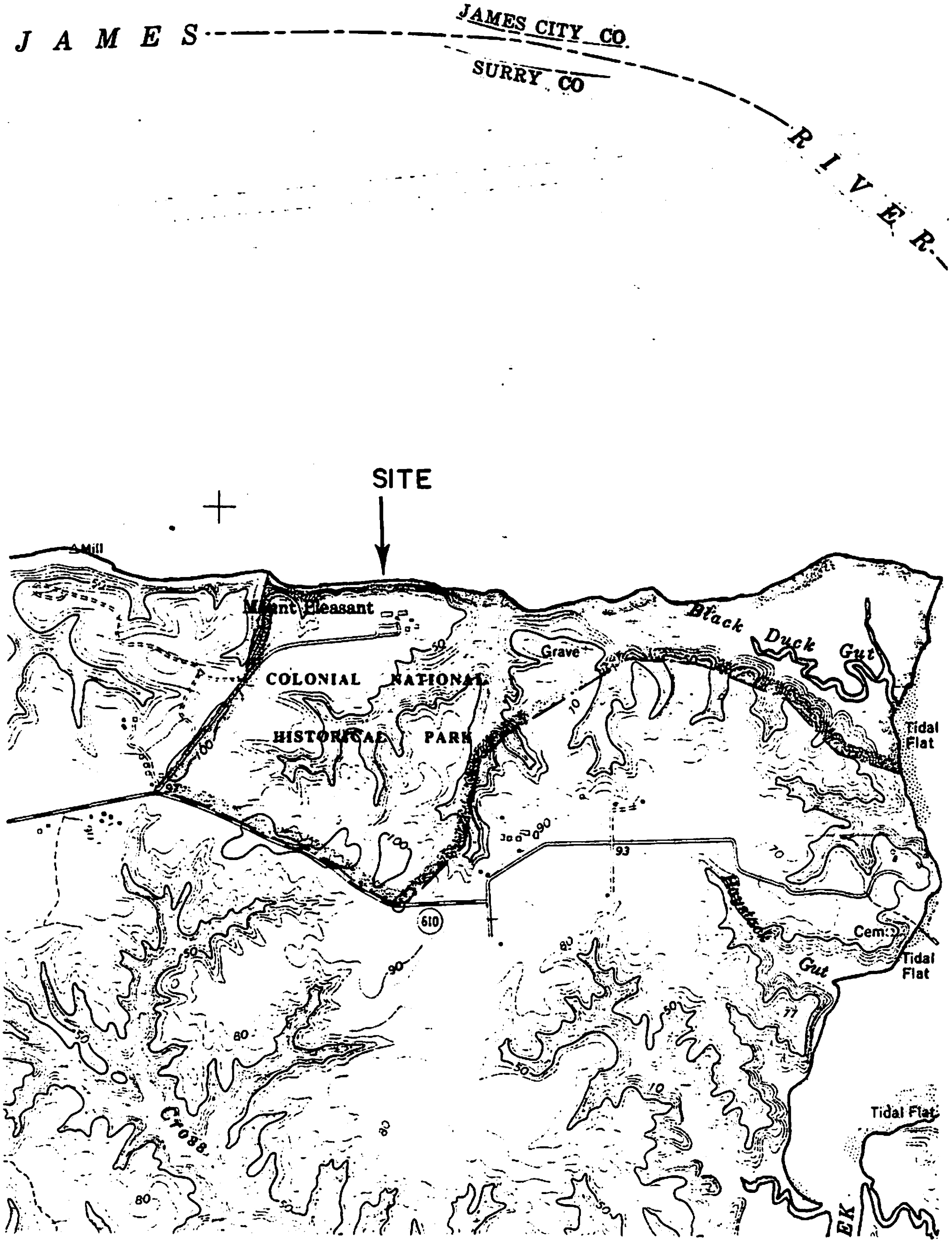


Figure 81. Eley Site - from Surry 7.5 minute quadrangle.
Scale: 1 inch = 2,000 feet.

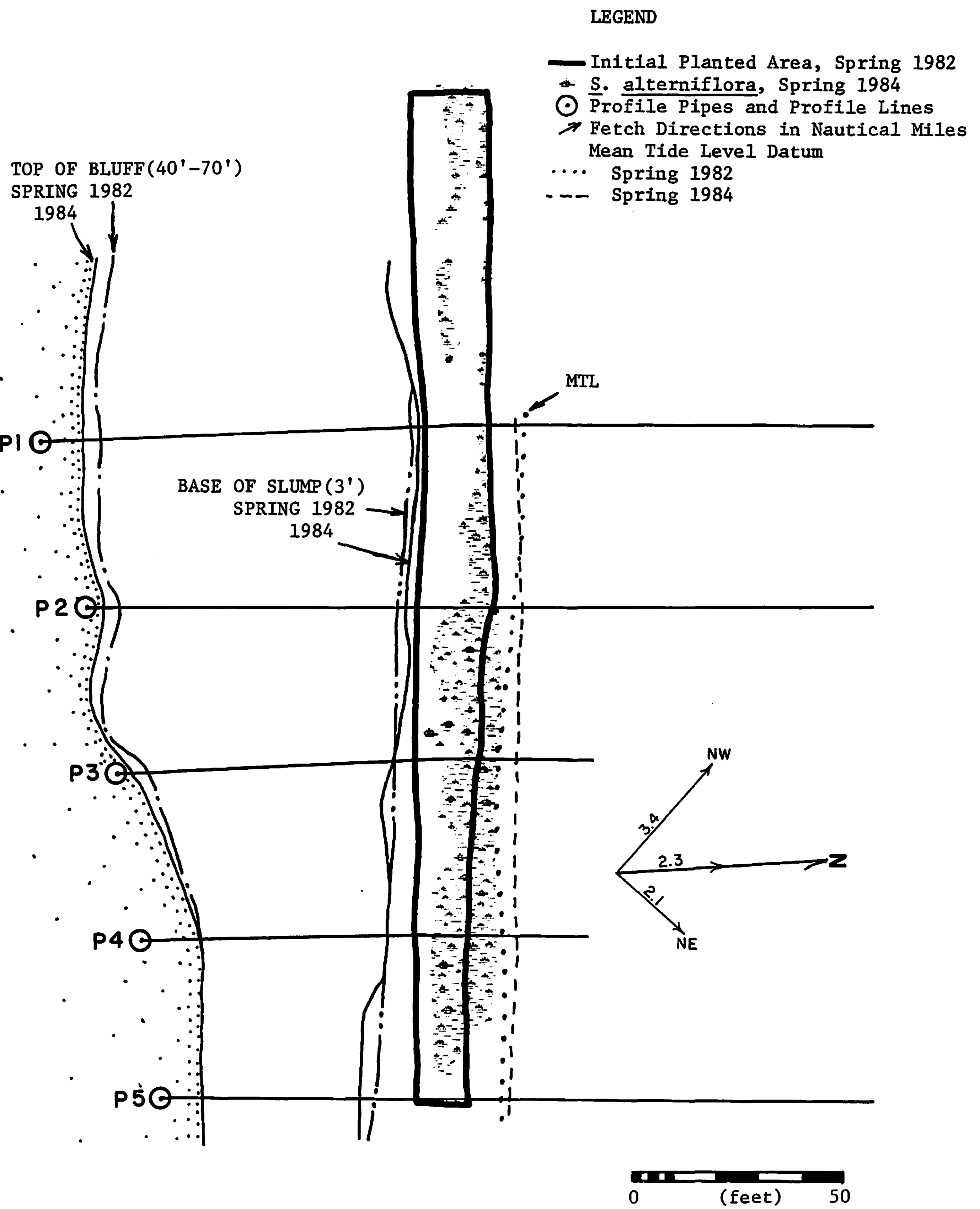


Figure 82. Eley Site - Base Map.

FIGURE 83

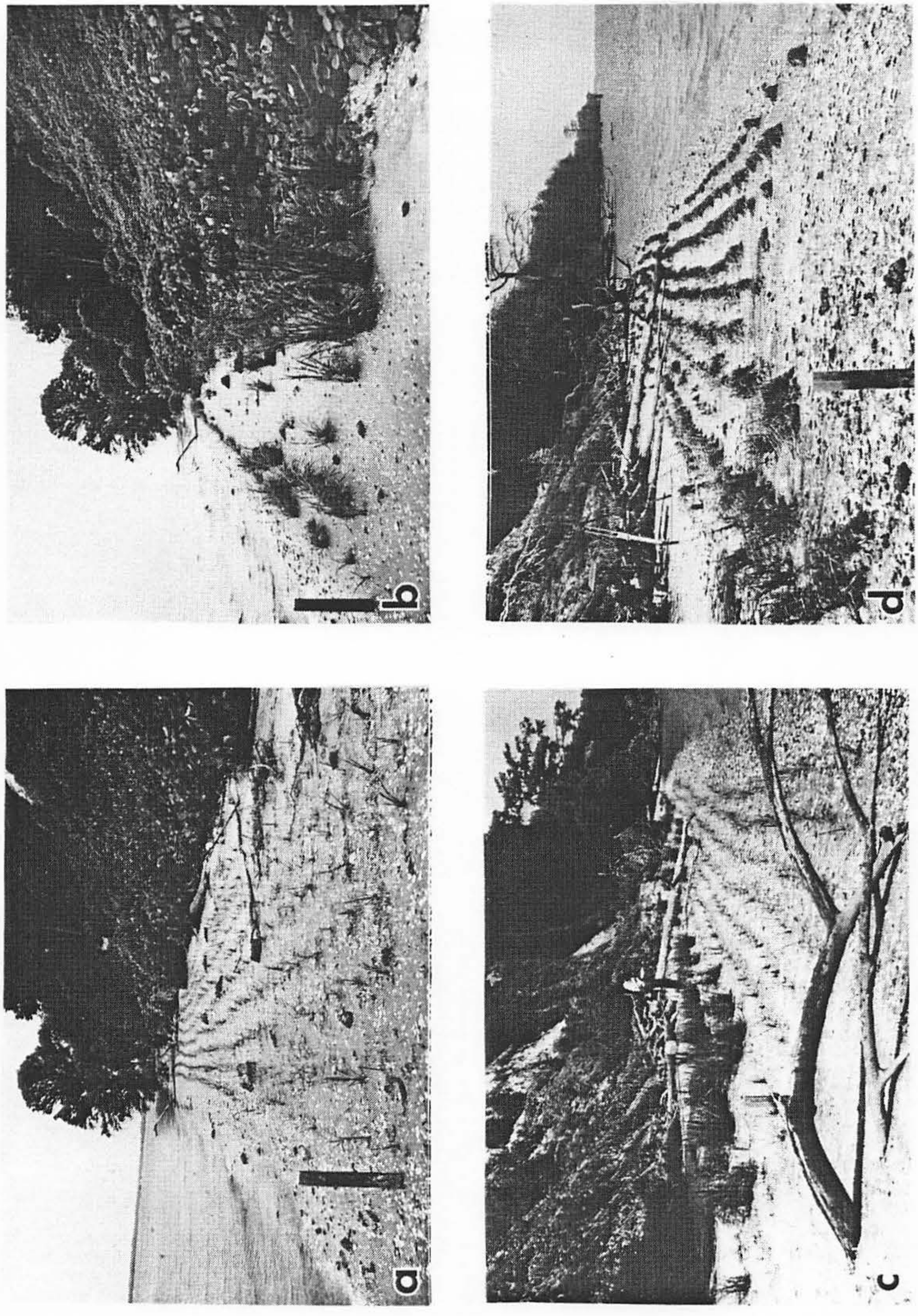
ELEY

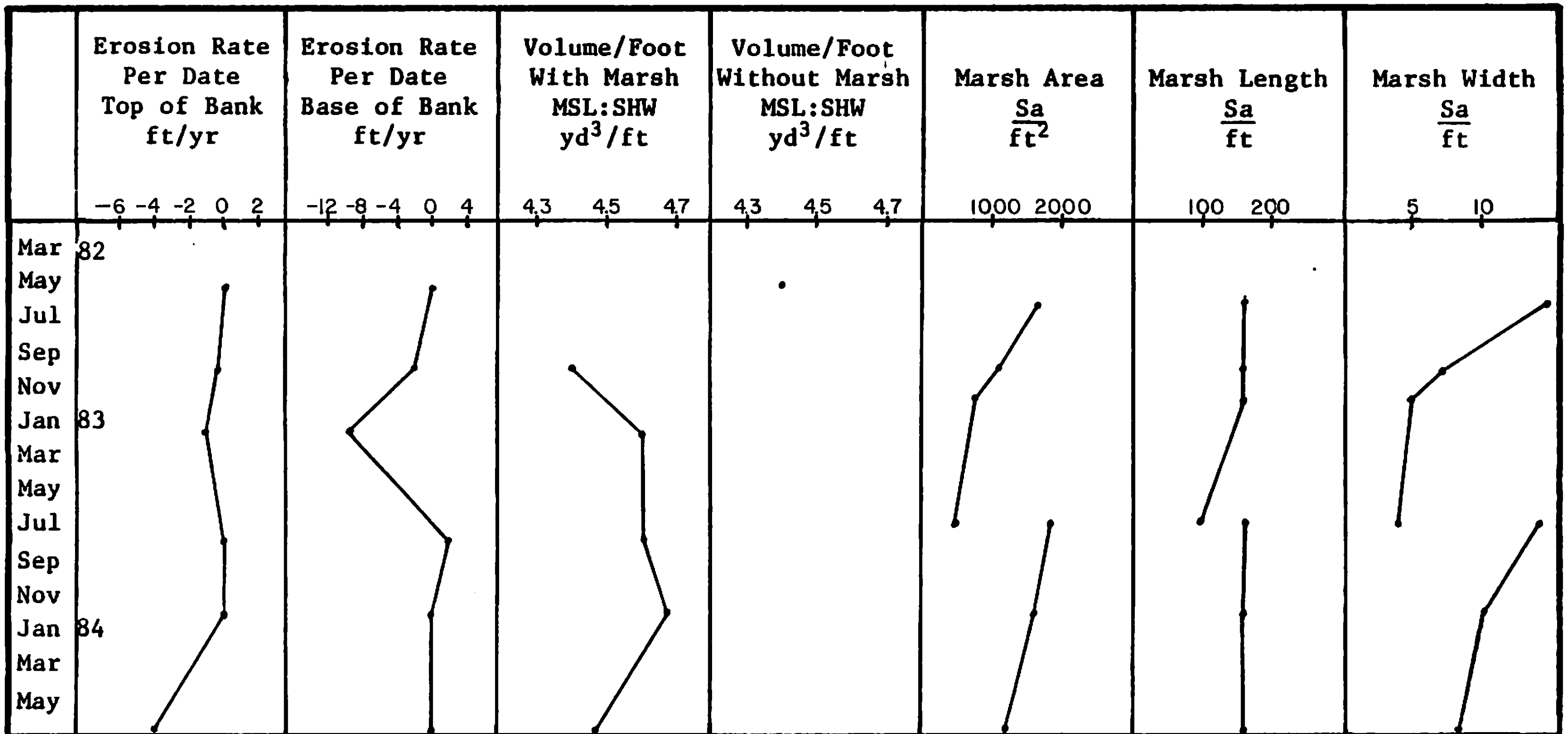
a. June 2, 1982
Looking east.

b. August 12, 1982
Looking east.

c. June 15, 1983
Looking west.

d. April 19, 1984
Looking west.





Cumulative Erosion Rate (ft/yr) - Top of Bank = -1.1
Cumulative Erosion Rate (ft/yr) - Base of Bank = -1.1

Sa = *Spartina alterniflora*

Figure 84. Eley Time Series.

1983. An advance in the position of base of bank was noted in July 1983 as a result of slumping since January 1983. Losses along the lower edge of the maintenance planted fringe were noted in the fall of 1983 with a reduction in width. However, the volume of sediment trapped in the intertidal fringe had increased (Figure 85). Also, the backshore elevation had increased slightly.

The winter of 1983-1984 saw a further loss of marsh area and width with a significant loss of sediment volume in the remaining intertidal fringe. Figure 83d shows exposed rhizomes within the marsh. This leaves the culms very vulnerable to washout until sediment returns to the fringe. There was noted erosion of the top of the bank by the spring of 1984 but the base remained stable as did the backshore elevation.

The marsh fringe to date is fairly continuous but the width varies.Since July 1983 the backshore elevation and the base of the bank have remained stable. As mentioned before, there were no severe storm events during the past winter. The site may regain sediment within the intertidal fringe over the summer of 1984 and the marsh will probablly spread and grow. Hopefully, this will increase the peat substrate.

The high bluff shore will undoubtedly continue to supply the fringe with sediment. The bank face slope has decreased over the past year. These factors would tend to support at least a partial success of the maintained planted fringe. Although the site seems trending toward success, it seems unlikely the fringe will endure without continued

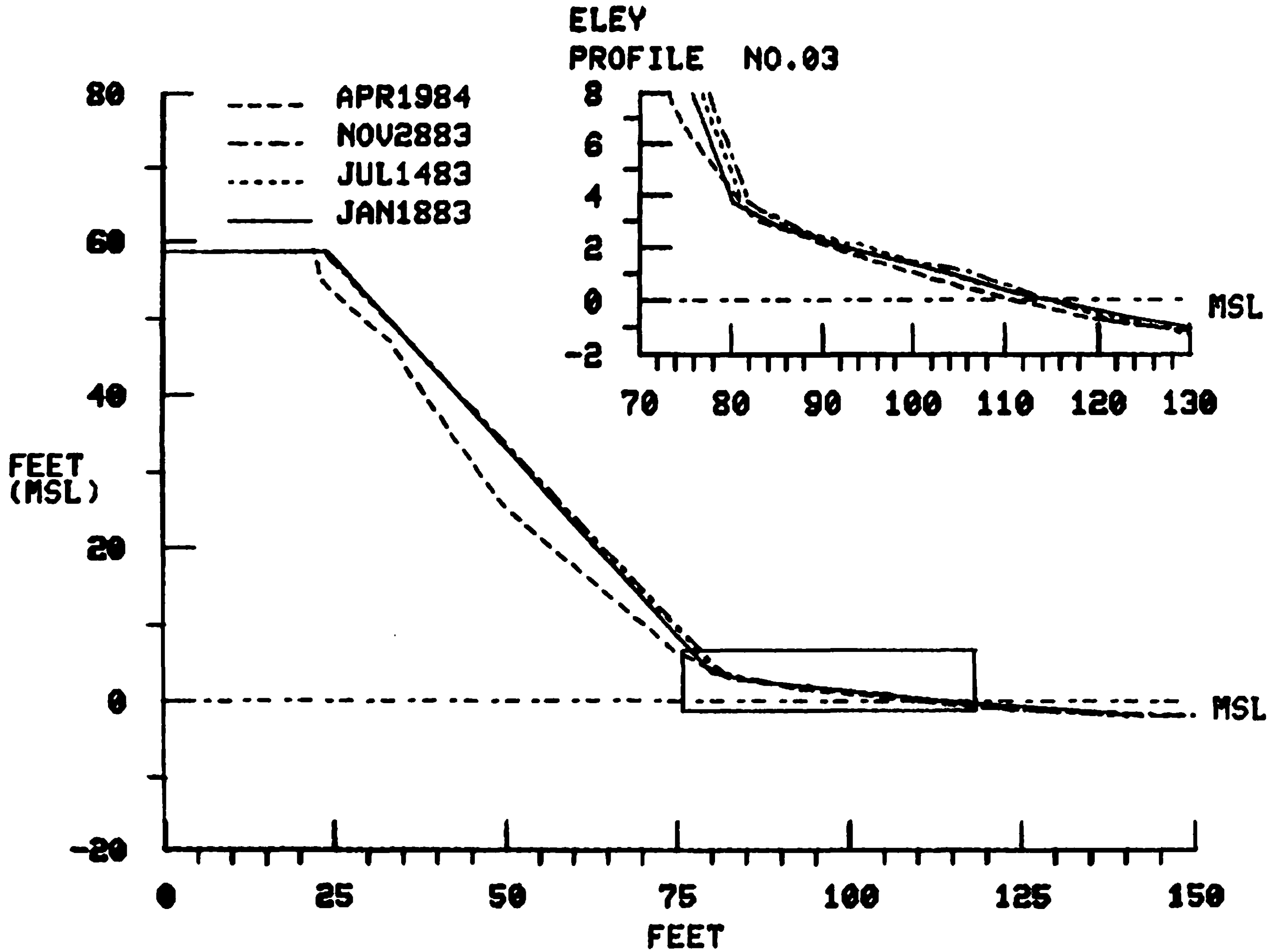


Figure 85. Eley Site - Representative Profile.

maintenance. The shore is exposed to all the northerly wind directions. The longer the time until the next northeaster the better the opportunity for substantial peat formation.

16. BROAD BAY MANOR - BROAD BAY, VIRGINIA BEACH

Planted 1982

(Refer to Appendix B)

Broad Bay Manor is located on the southern shore of Broad Bay in Virginia Beach (Figure 86). It is a low energy shore facing northeast. The historical rate of erosion is less than 0.5 foot per year (3). It is a straight high bank shore about 25 feet above MTL. The base of the bank is covered with slump material eroded from the vertically exposed upper bank. Much of the slump was vegetated and fairly stable until the October 25, 1982 storm which created a high (10-foot) wave cut scarp across the slump and bank face in many places.

The beach consists of fine to coarse sand and gravel. Most of the beach sediment comes from erosion of the adjacent fastland bank. The beach is about 30 feet wide and extends from the base of the bank slump to about MTL.

In June 1982 four different strains of saltmeadow hay were planted at Broad Bay Manor in separate plots. There was one strain of smooth cordgrass planted which was grown in different fertilizers and planted on four separate plots (Figure 87).

The following is a listing of the different plots at the Broad Bay site in 1982.

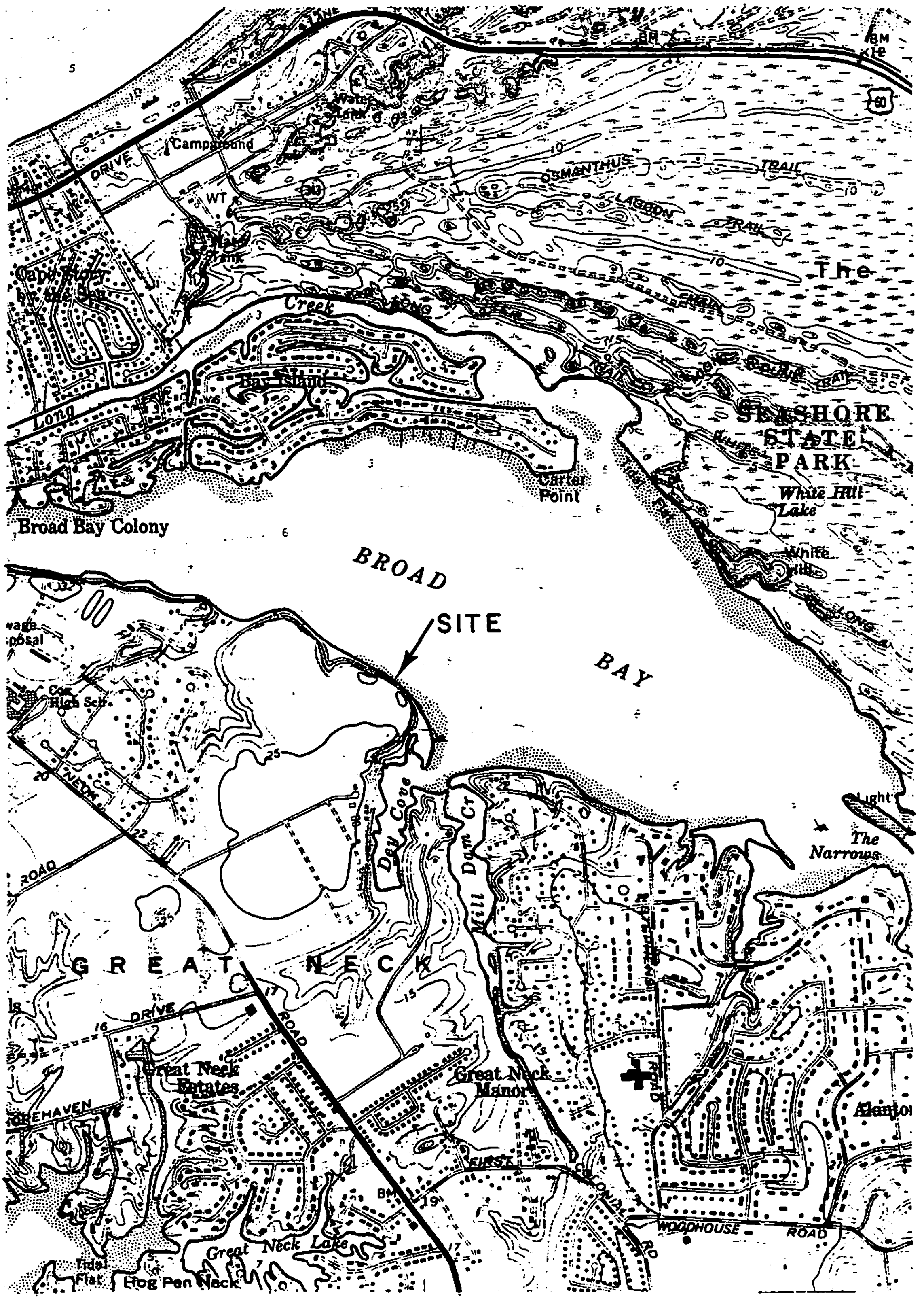


Figure 86. Broad Bay Manor Site - from Cape Henry 7.5 minute quadrangle.
Scale: 1 inch = 2,000 feet.

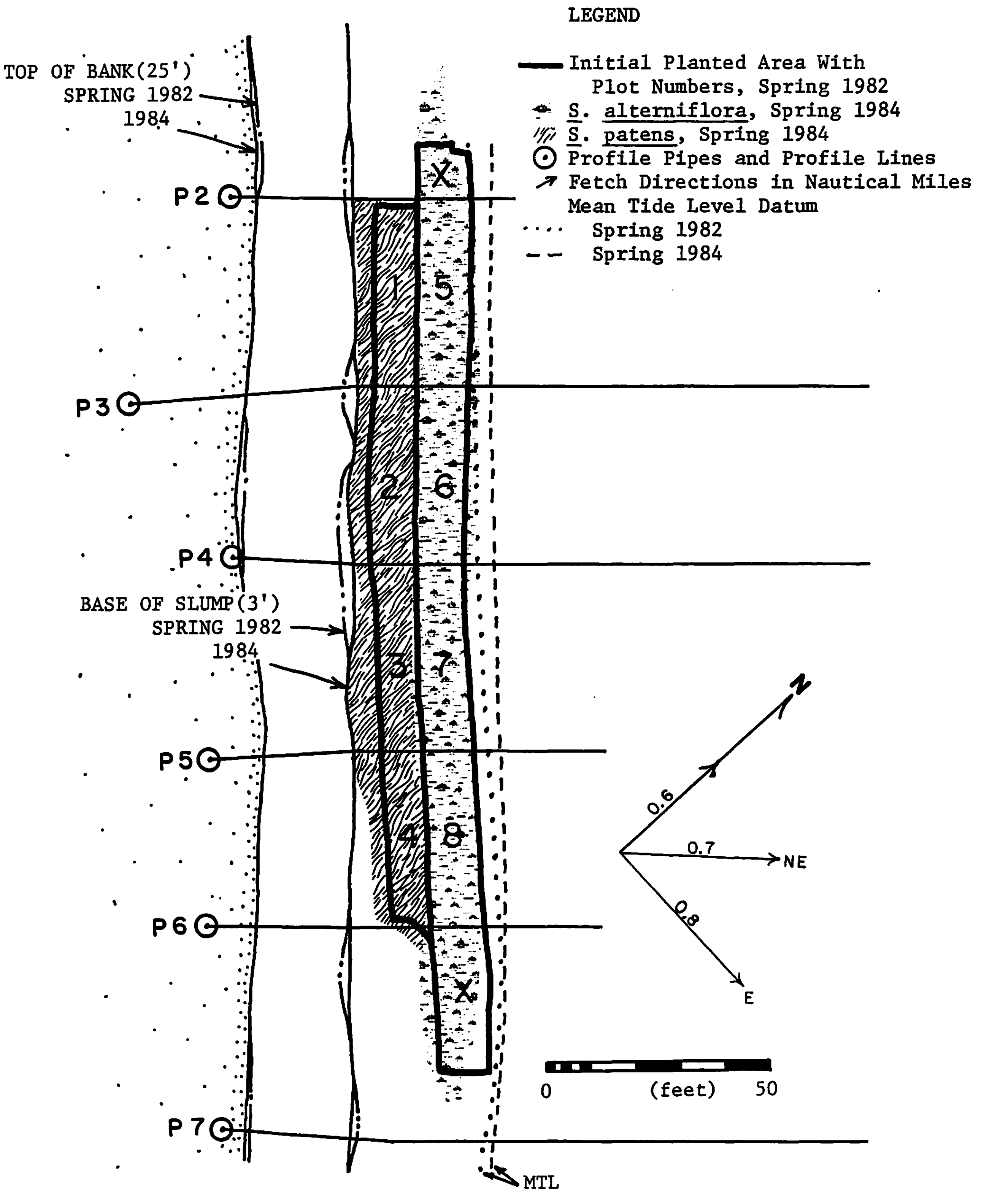


Figure 87. Broad Bay Manor Site - Base Map.

Plot Number

1 Saltmeadow hay - strain numbers 262-421

2 Saltmeadow hay - strain number 390

3 Saltmeadow hay - strain number 238

4 Saltmeadow hay - strain number 237

5 Smooth cordgrass - raised with tomato fertilizer

6 Smooth cordgrass - raised with 5 month 10-10-10 fertilizer

7 Smooth cordgrass - raised with 3 month 10-10-10 fertilizer

8 Smooth cordgrass - raised with no fertilizer

X Smooth cordgrass - mixed plants

There was a lot of recreational boat wake activity observed during the occasional visits to the site. Almost 40% of the smooth cordgrass was lost during the first summer and the width was reduced mostly along the lower edge. The October 25, 1982 storm only accounted for an additional 5% washout even though the base of the bank eroded from 3 to 8 feet behind the fringe.

During the winter of 1982-1983 the base of the bank advanced by slumping from the position it held just after October 25, 1982. Figure 88b shows the sand accumulation in the saltmeadow hay after the storm and a subsequent wave cut scarp. By spring 1983 there was also a significant gain in sediment volume within the intertidal fringe (Figure 89). The saltmeadow hay remained very well intact through that winter and an increase in elevation across the backshore was measured. Both species showed marked area gain since the fall of 1982. However the smooth cordgrass was still 20% less than the original planting area.

FIGURE 88

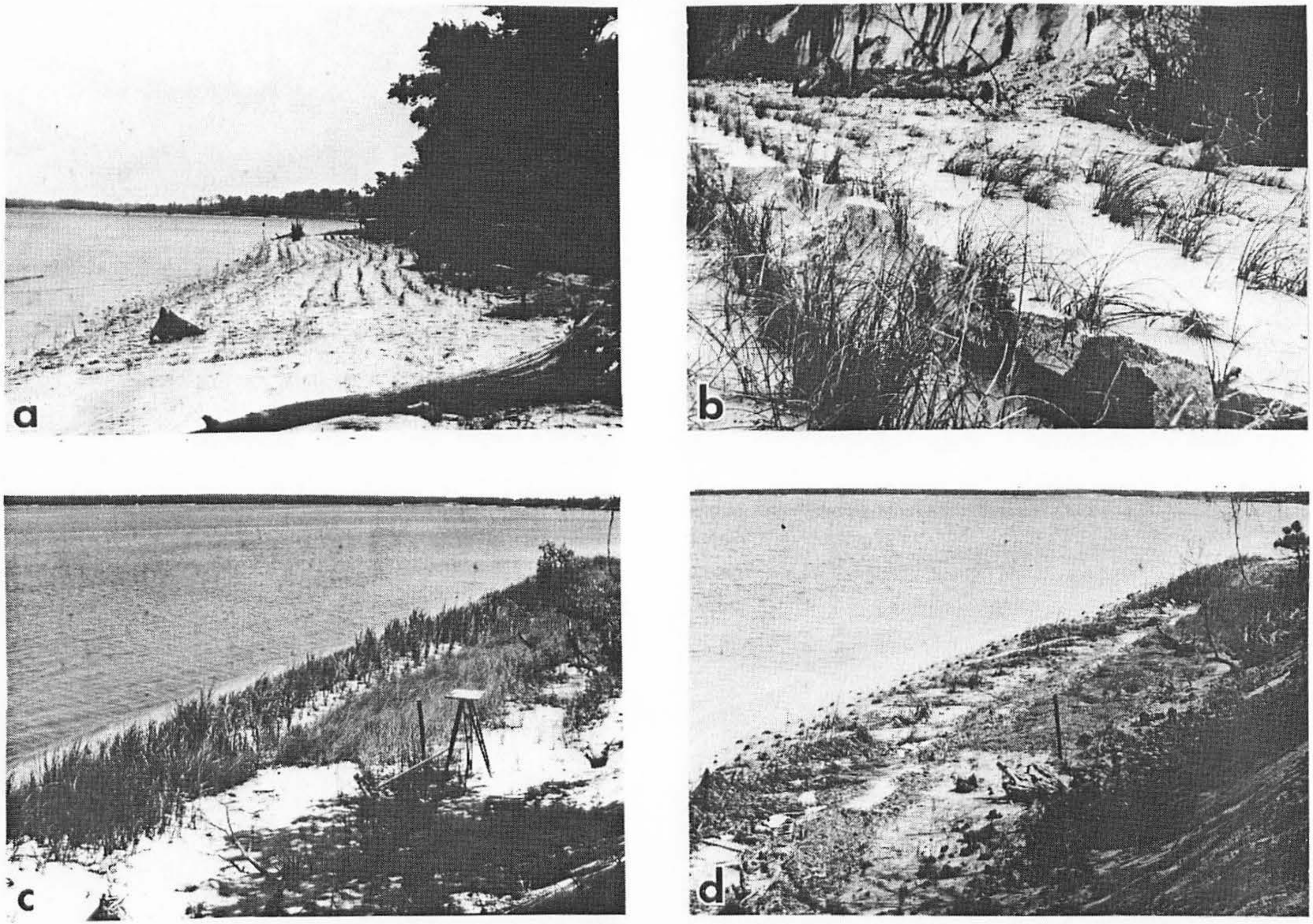
BROAD BAY MANOR

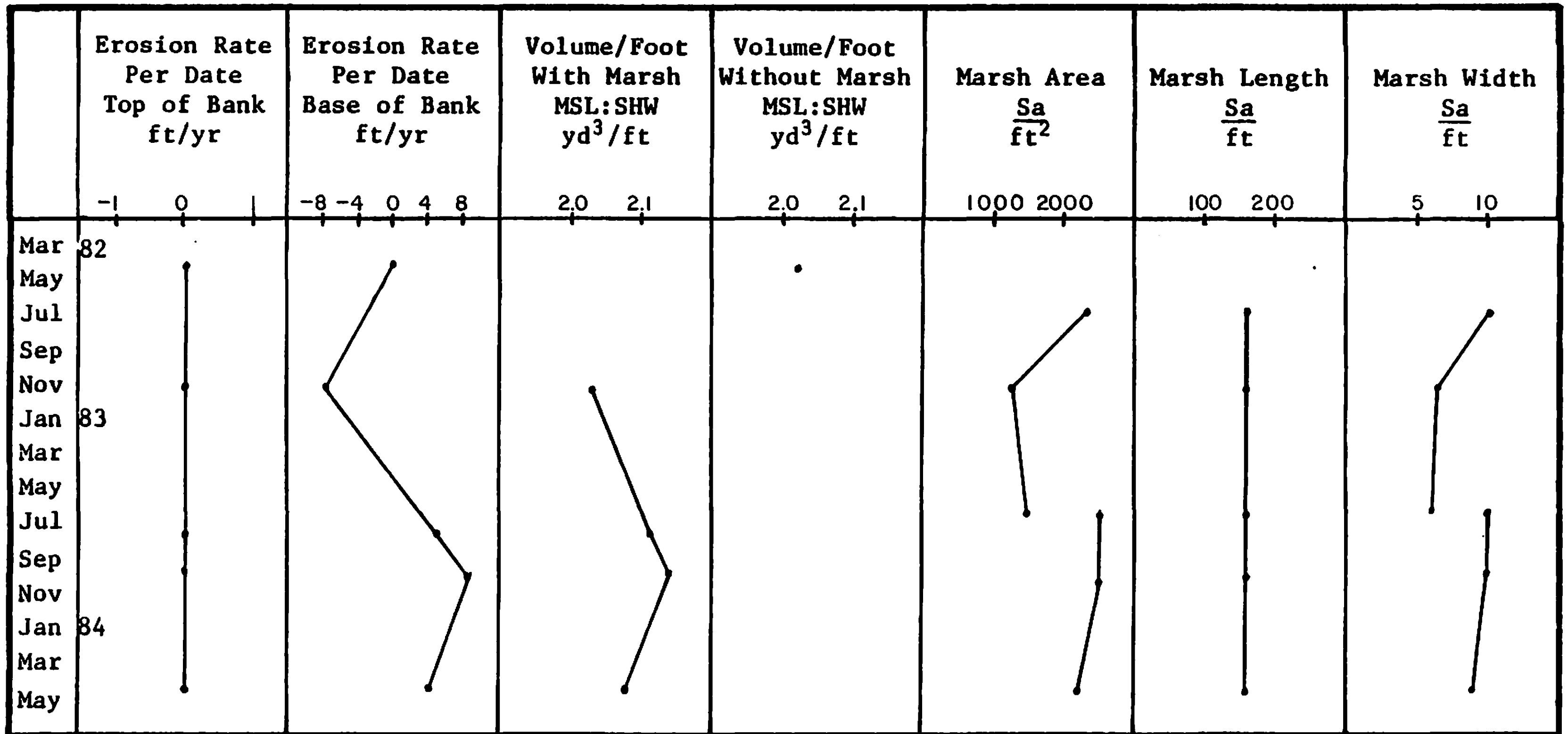
a. June 15, 1982
Looking southeast.

b. November 1, 1982
Looking southeast.
Post October 25, 1982
storm. Note new slump
material in saltmeadow
hay with ½-foot wave
cut scarp.

c. July 22, 1983
Looking southeast.

d. March 27, 1984
Looking southeast.


a
b
c
d



Cumulative Erosion Rate (ft/yr) - Top of Bank = 0.0
Cumulative Erosion Rate (ft/yr) - Base of Bank = +1.5

Sa = Spartina alterniflora

Figure 89. Broad Bay Manor Time Series.

Thus, maintenance planting of smooth cordgrass was done in the spring of 1983.

There was little or no change in area, length or width of the intertidal fringe by September 1983. There was continued accretionary advance of the base of the bank by slumping and subsequent sediment entrapment in the intertidal fringe as well as increased backshore elevation.

Bank slumping continued through the winter of 1983-1984 (Figure 90). There was a small loss of intertidal marsh fringe and sediment volume. With all the bank slumping that has occurred at this site, the very top of the bank has not moved. This perhaps will only be a matter of time.

Statistically, the Broad Bay Manor site would seem a success. The entire marsh fringe is very healthy and continuous. The backshore has increased considerably since planting and the base of the bank has accreted at 1.5 feet per year. The site is classed upper low energy and is exposed to 0.8 nautical mile of fetch to the northeast. This, plus the occurrence of boat wake activity, will require continued maintenance planting to ensure long term stabilization of the entire bank.

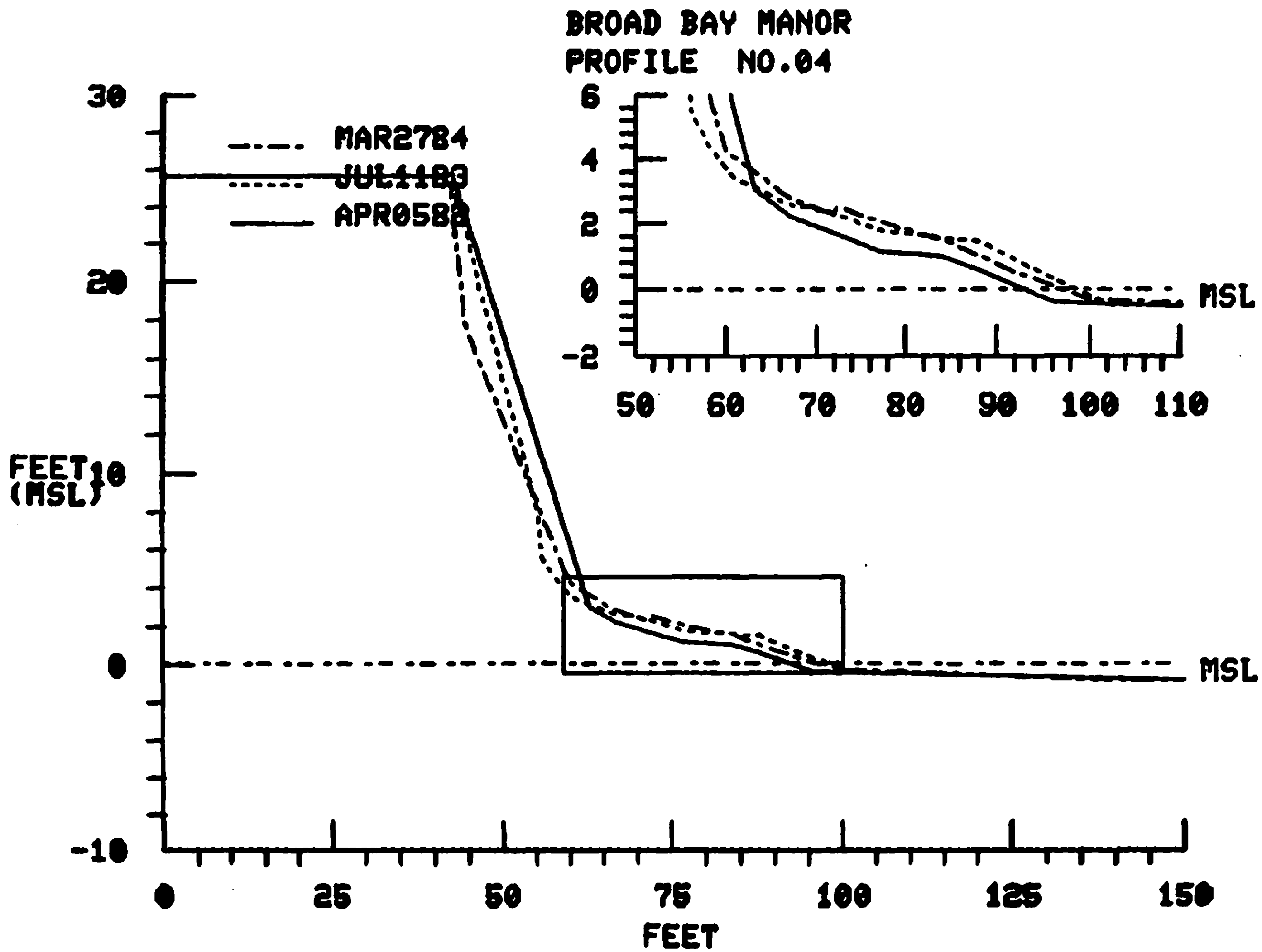


Figure 90. Broad Bay Manor Site - Representative Profile.

17. MARINERS MUSEUM - JAMES RIVER, NEWPORT NEWS

Planted 1982

(Refer to Appendix B)

The Mariners Museum site is located adjacent to Lake Maury on the James River (Figure 91). The shore occurs as a low sand bank with a wave cut scarp. The low sand bank is part of a low sandy strand in front of a stable high fastland bank. The shore faces southwest with a 5.7 nautical mile average fetch. The low bank is about 5.5 feet above MTL. The bank face slopes into the backshore and is sparsely covered with upland vines, grasses and a few salt bushes. After a storm or high water event a wave cut scarp is created on the lows and bank but quickly slumps down to the angle of repose due to its sandy nature. The beach consists of clean, medium to coarse sand eroded from the adjacent low bank. The beach extends from the base of the low bank to about 10 feet beyond MTL.

The first planting at the Mariners Museum site was in June 1982 (Figure 92). Both smooth cordgrass and saltmeadow hay were planted. Strong southerly winds during late June caused considerable washout of smooth cordgrass along the upper half of that planting. Several of the lower rows of smooth cordgrass were completely buried with sand. By September 1982 over 90% of the smooth cordgrass and 85% of the saltmeadow hay had been eliminated (Figure 93b). There was also significant erosion of the low sandy bank by the fall (Figure 94).

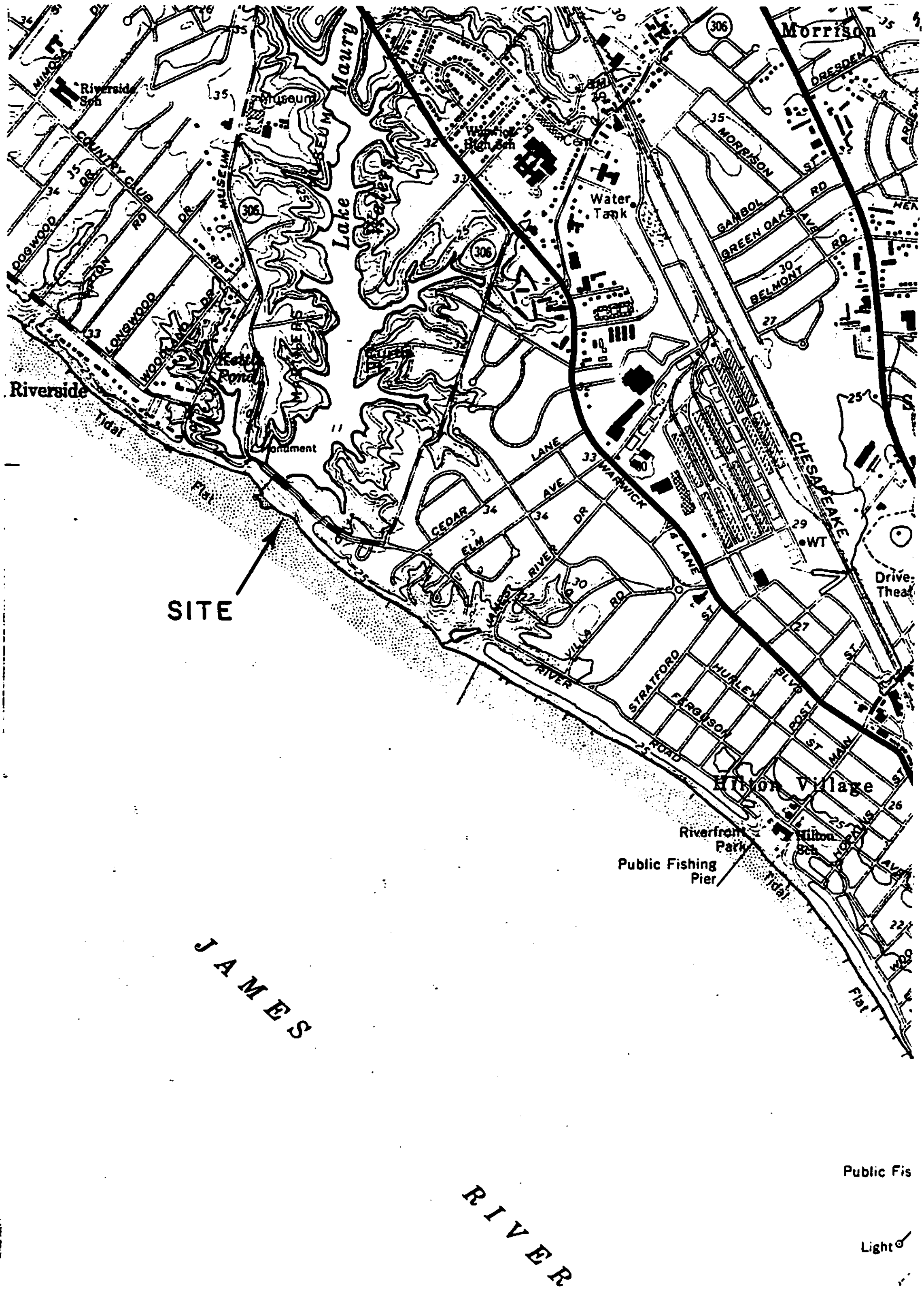


Figure 91. Mariners Museum Site - from Newport News North 7.5 minute quadrangle.
Scale: 1 inch = 2,000 feet.

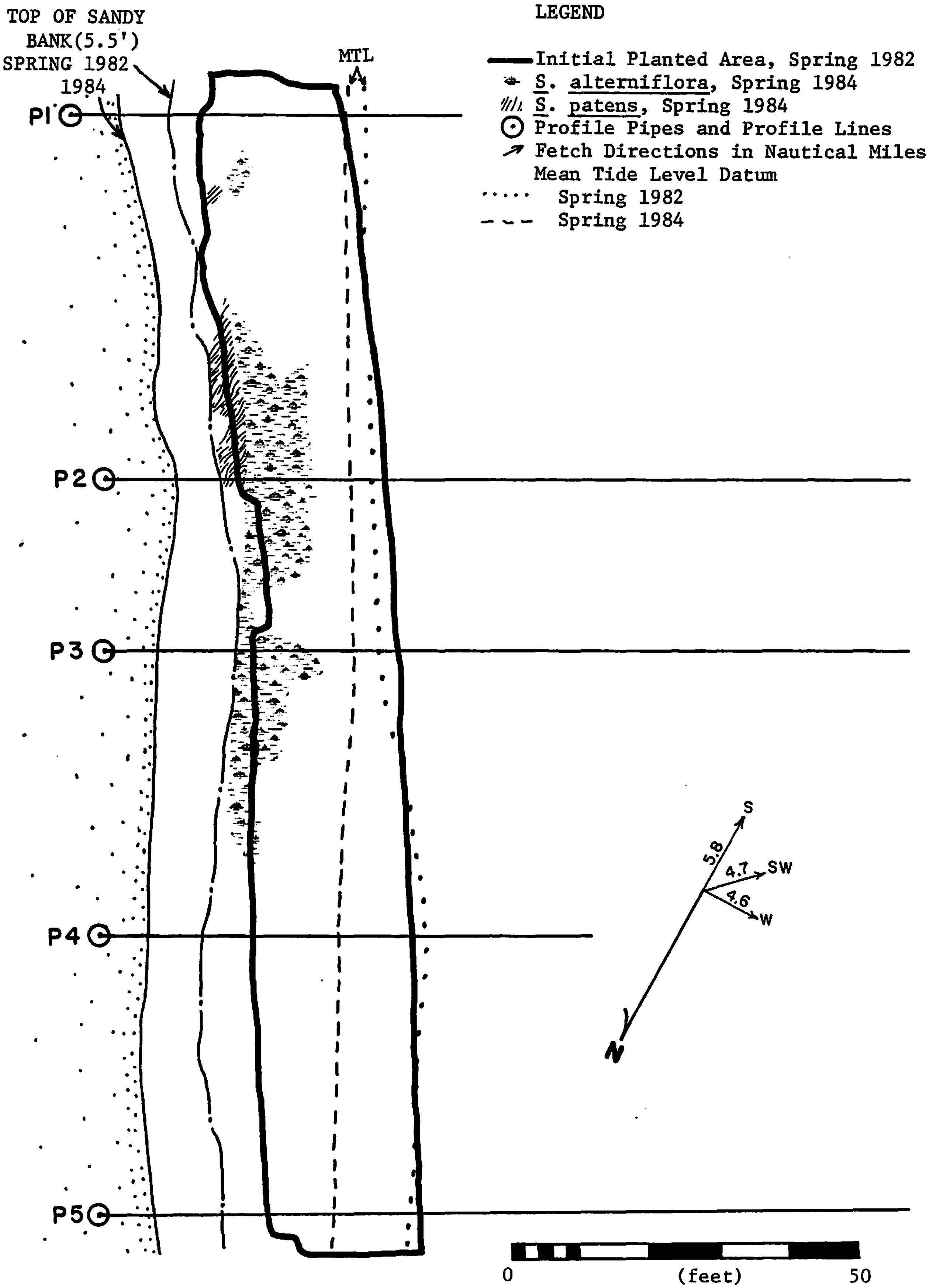


Figure 92. Mariners Museum Site - Base Map.

FIGURE 93

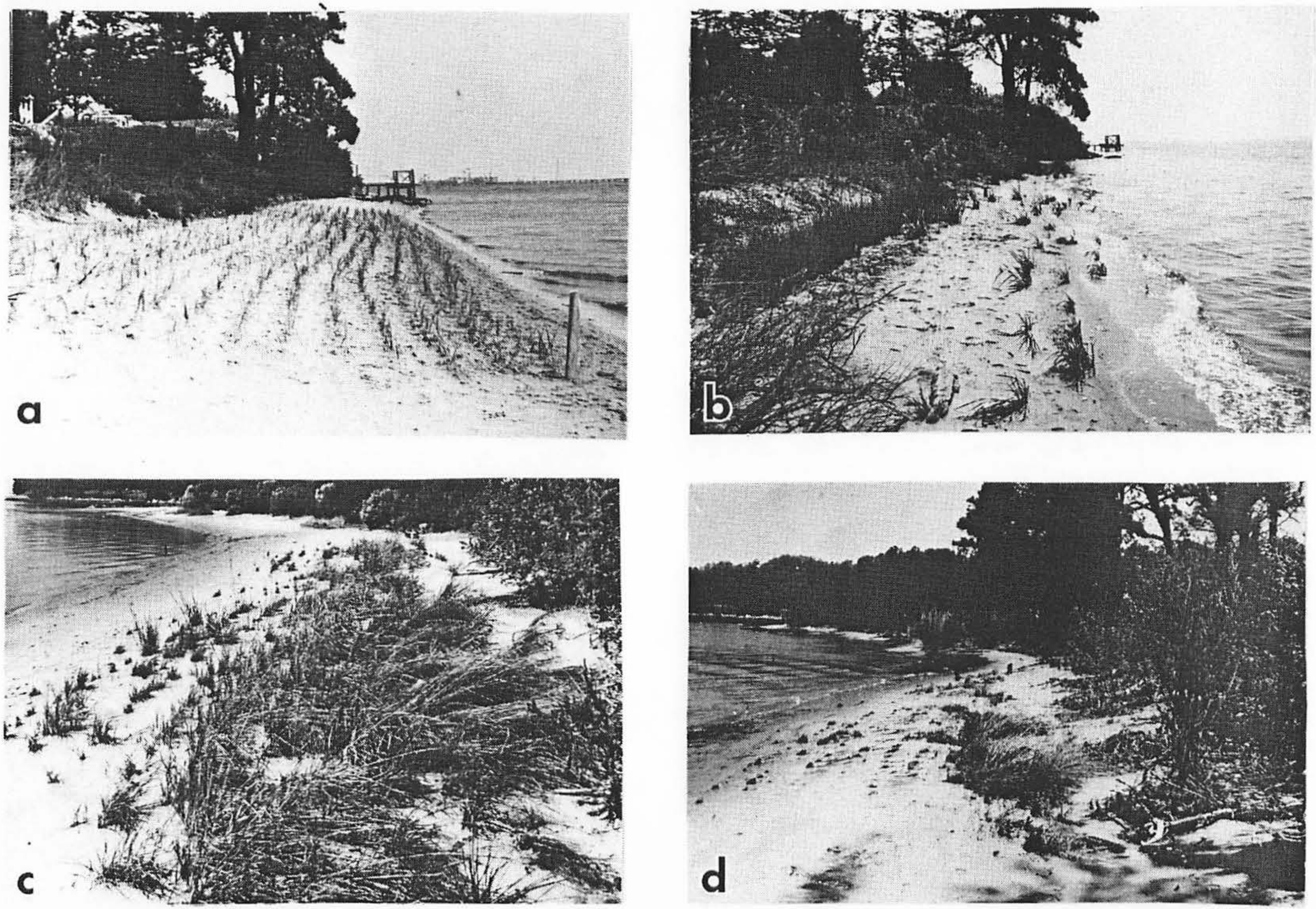
MARINERS MUSEUM

a. June 3, 1982
Looking southeast.

b. September 7, 1982
Looking southeast.

c. October 3, 1983
Looking northwest.

d. April 26, 1984
Looking northwest.


a
b
c
d

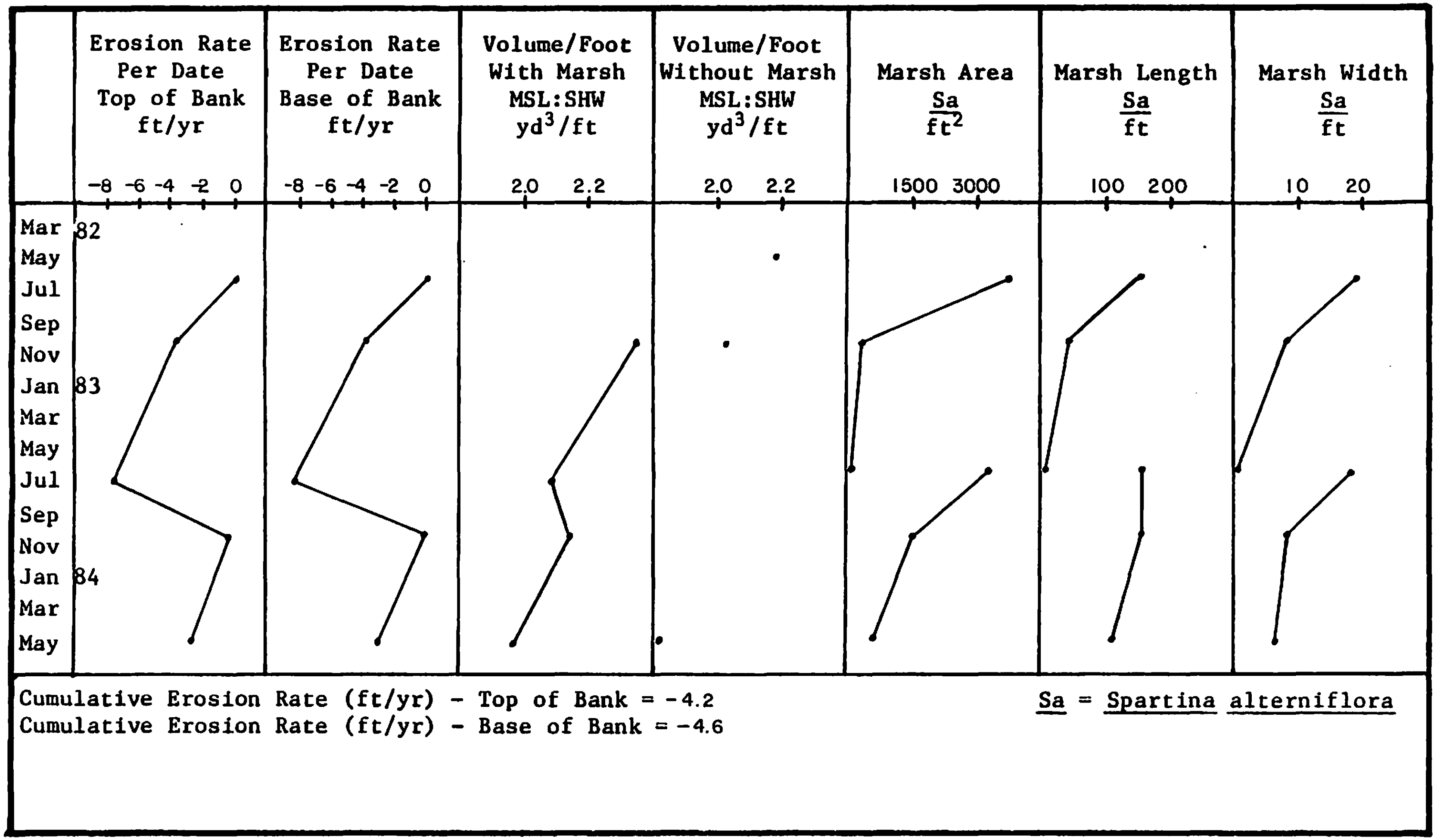


Figure 94. Mariners Museum Time Series.

Bank erosion increased over the winter of 1982-1983. There was loss of sediment along the upper intertidal zone and further reduction of the marsh fringe to almost zero. Maintenance planting was done in the spring of 1983. Only smooth cordgrass was planted. The maintenance planted fringe was reduced 50% by the fall of 1983. Bank erosion had stopped and the remaining fringe was able to trap some sand (Figure 93c).

Over the winter of 1983-1984 the fringe was further reduced. Sediment was lost from the intertidal fringe and bank erosion was renewed. The saltmeadow hay that remained in the spring of 1983 was essentially still intact in the spring of 1984 (Figure 93d). The remaining fringe was very discontinuous and narrow and unable to stabilize the backshore (Figure 95). With the history of marsh losses and shifting sands, the Mariners Museum site is trending toward failure.

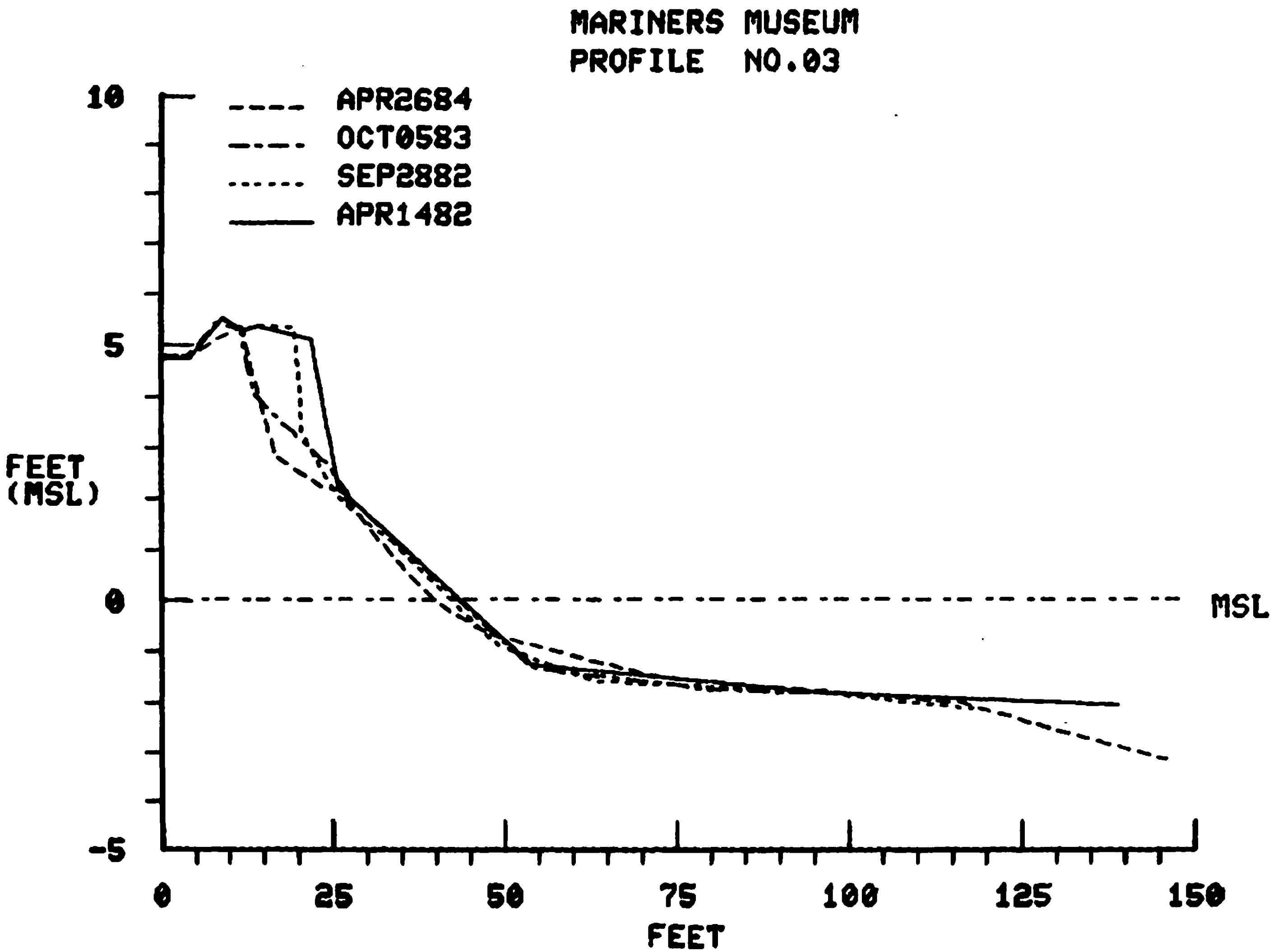


Figure 95. Mariners Museum Site - Representative Profile.

18. KING - JAMES RIVER, ISLE OF WIGHT COUNTY

Planted 1982

(Refer to Appendix B)

The King site is located near Rescue on the south shore of the James River (Figure 96). It is a high energy shore with a high fastland bank. The historical erosion rate is about 1.2 feet per year (3). The shore faces northeast and the bank is about 20 to 25 feet above MTL. In the spring of 1982 the bank face was vertically exposed along the upper one-third and covered with eroded slump material along the lower two-thirds. The bank is composed of a basal stiff blue-grey sandy clay overlain by a slightly clayey fine to coarse sand and gravel. The top of the clay is 5 to 10 feet above MTL and acts as an aquaclude to downward percolating ground water. This increases the tendency to slump during heavy rains and storm events. There was little or no vegetation across the bank slope before planting. Winter storms, especially the October 25, 1982 storm, caused considerable erosion of the slump and inplace bank. The beach is composed of medium to coarse sand and gravel eroded from the adjacent bank and those banks updrift to the northwest.

Smooth cordgrass and saltmeadow hay were planted on the King Site on June 3, 1982 (Figure 97). Losses during the summer of 1982 were mostly from washout of both species. There was some bank erosion during that summer which apparently supplied material to the backshore and intertidal fringe (Figure 98).

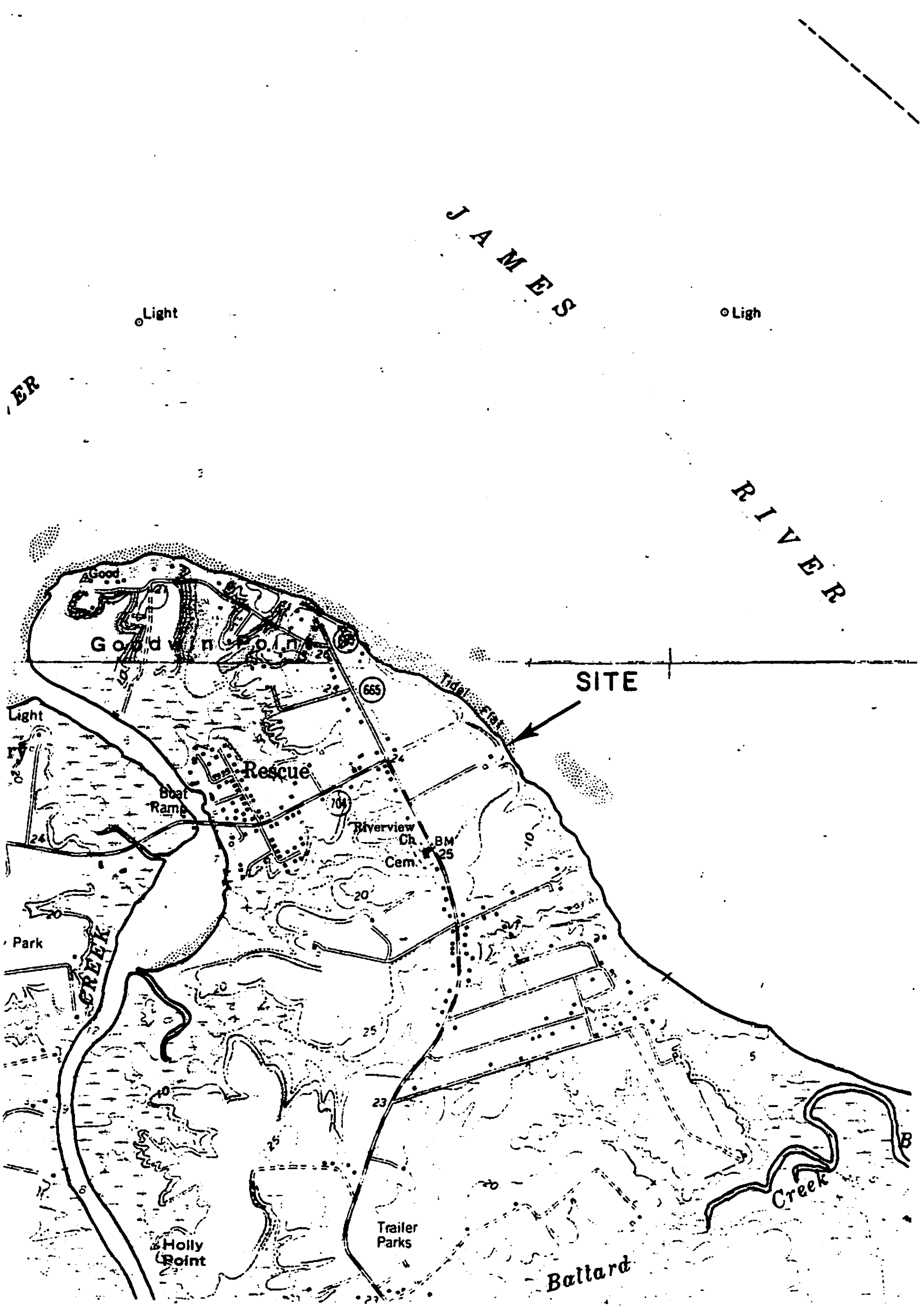


Figure 96. King Site - from Benns Church and Mulberry Island 7.5 minute quadrangles.
Scale: 1 inch = 2,000 feet.

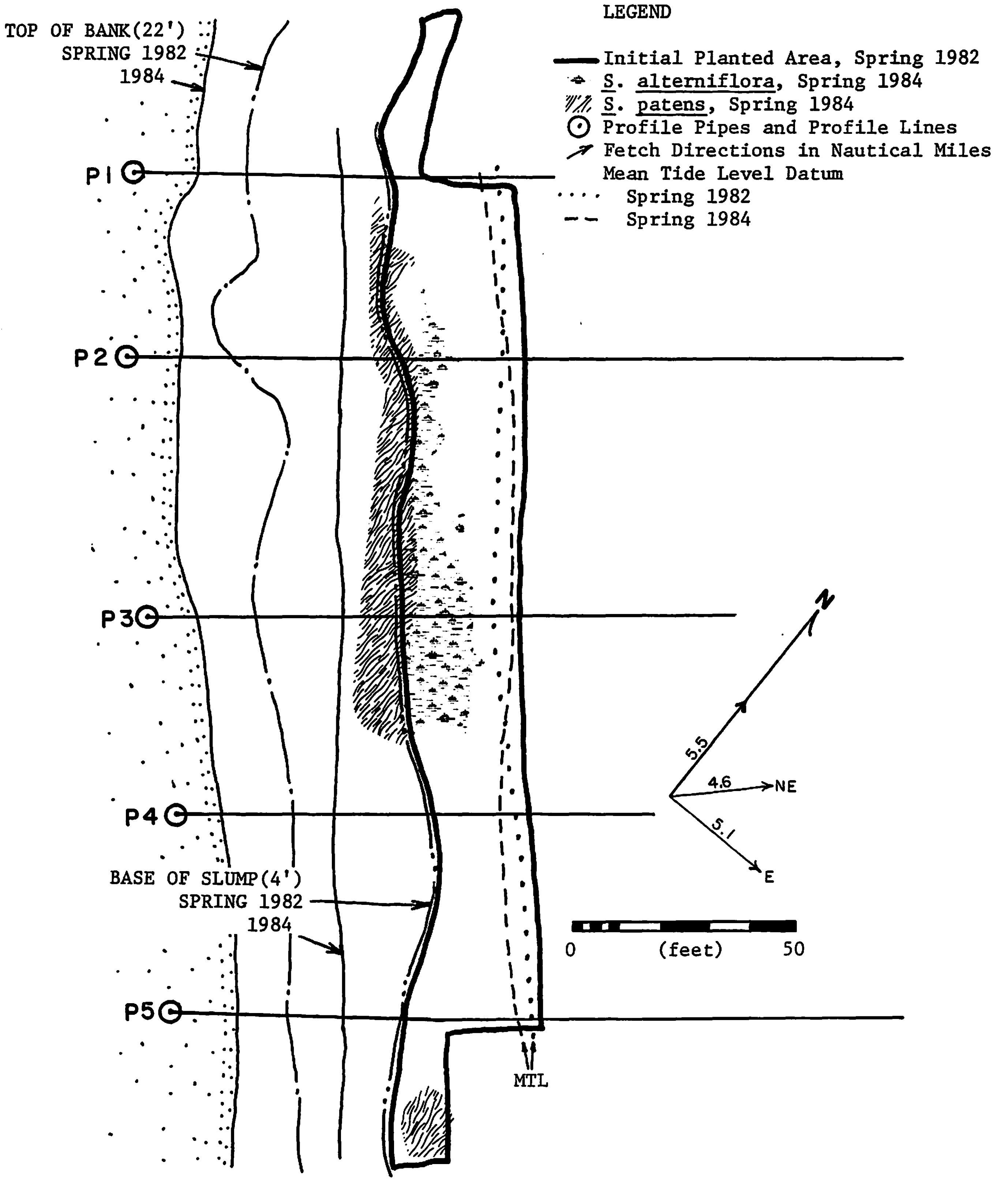


Figure 97. King Site - Base Map.

FIGURE 98

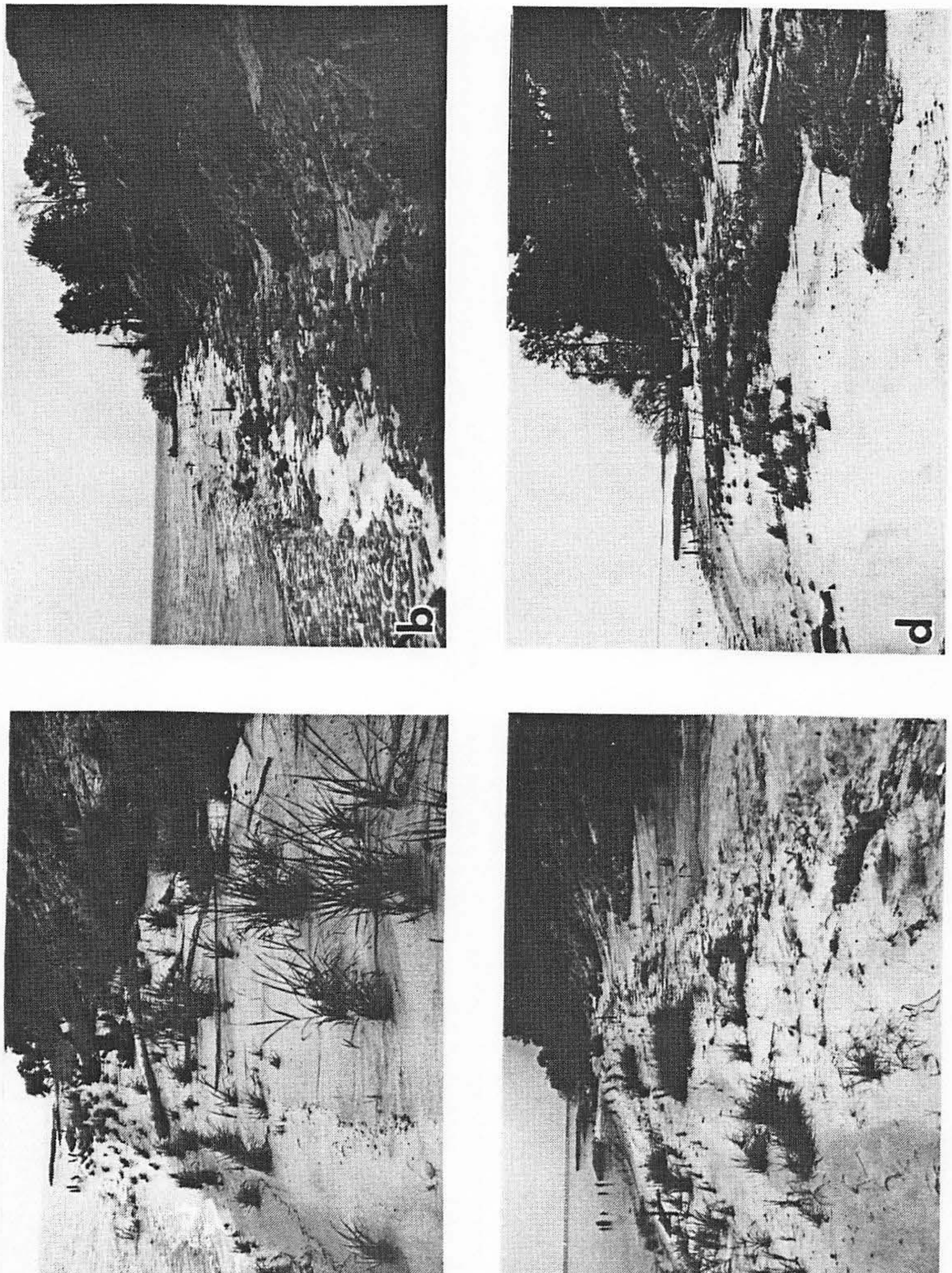
KING

a. August 12, 1982
Looking southeast.

b. January 28, 1983
Looking southeast.

c. June 15, 1983
Looking southeast.

d. April 26, 1984
Looking southeast.



As previously mentioned the single most significant event to affect this and several other sites was the October 25, 1982 northeast storm. Water level at the King Site was at least 2.5 feet above MHW. Observed waves approaching from the north shortly after passage of the storm were 2.1 feet high with a period of 3.2 seconds. Four to six feet of the top of the bank were lost and 11 to 14 feet were eroded along the base. At one point, between P4 and P5, a large slump block buried all the saltmeadow hay and parts of the smooth cordgrass in front of it. Burial was common across much of back parts of the fringe. Material deposited into the nearshore region forced the tidal datum riverward. The high loss of bank is reflected in a base of bank erosion rate of over 30 feet per year and top of bank of 18 feet per year for 1.5 months between September and November 1982 (Figure 99). A consequent gain in the intertidal fringe is noted.

Bank erosion continued at a lesser pace through the winter of 1982-1983. The intertidal marsh fringe was further reduced in area and width and the ability to trap sediment. Much of the slump material along the backshore had been removed and by spring 1983 the marsh was reduced in area, length and width. Maintenance planting was done in July with both species of grasses. No new grass was planted between P4 and P5.

Erosion during the summer of 1983 was mostly between P4 and P5 along the base of the bank. Subsequent deposition is noted in the upper intertidal zone by September 1983 (Figure 99). The marsh fringe was reduced in area and length by September. Further reduction by washout occurred over the winter of 1983-1984. Bank erosion continued and the

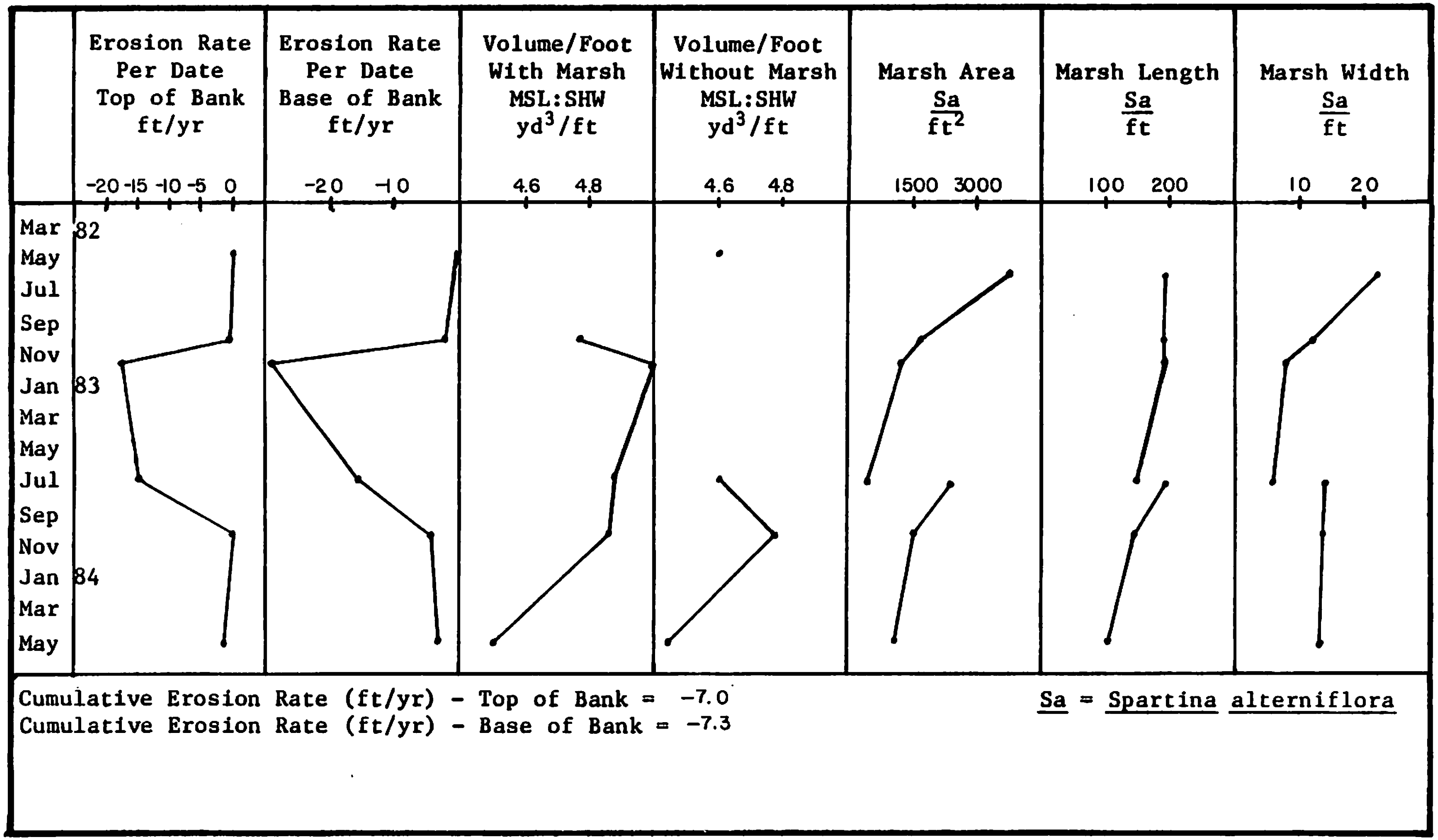


Figure 99. King Time Series.

volume of material in the intertidal fringe and adjacent unvegetated intertidal zone was greatly reduced. The backshore elevation has remained stable where the saltmeadow hay remains (Figure 100) but reduced where it is absent.

Although at present the remaining fringe is doing well and holding the backshore, it will be difficult for the planting to withstand the northeast storm events. Maintenance planting would have to be done annually and with no real hope of abating the bank erosion in the long run. This site would be a good candidate for a permanent offshore wave stilling structure behind which a marsh fringe could hopefully be established.

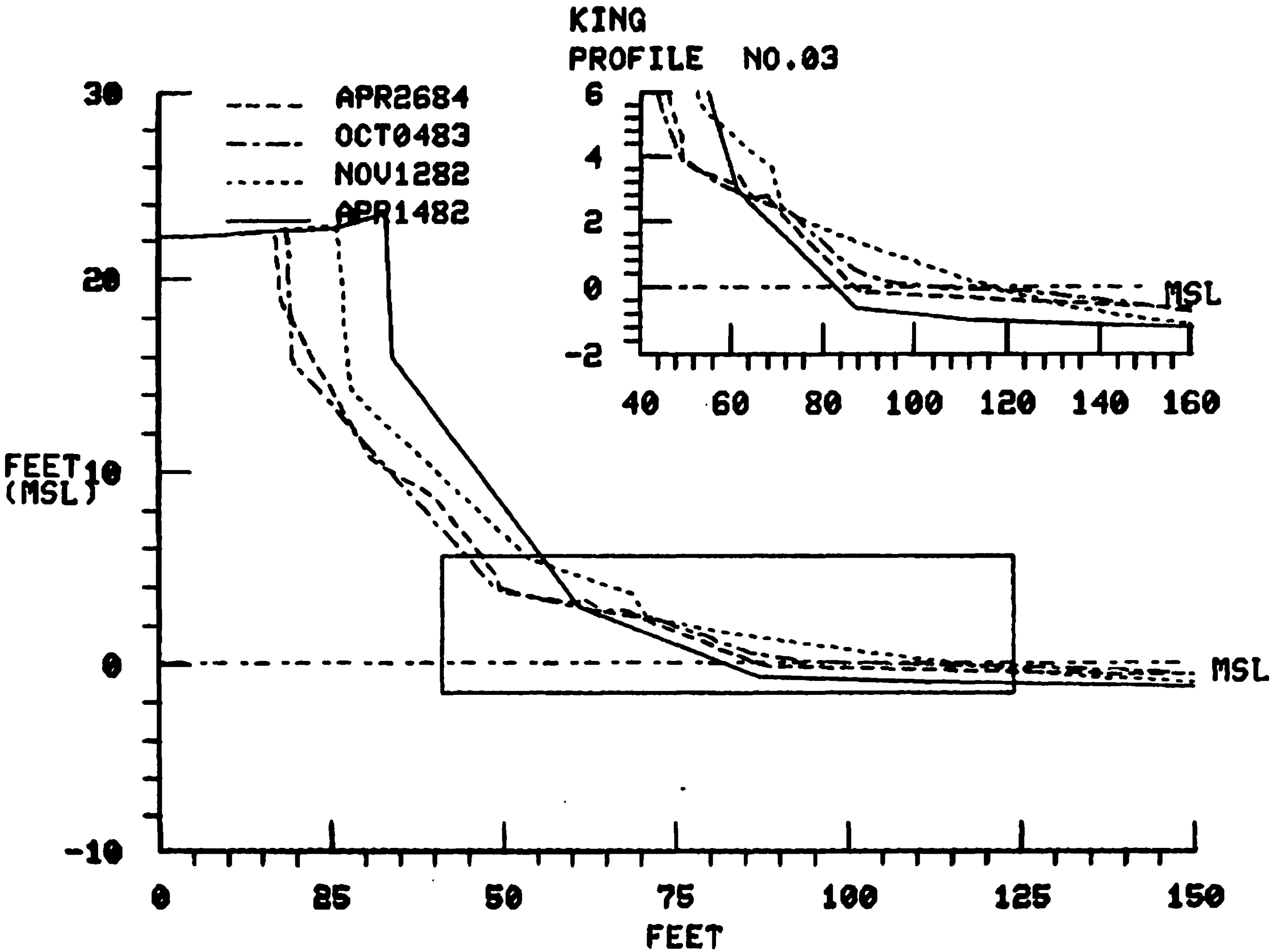


Figure 100. King Site - Representative Profile.

19. MARSHALL - OCCOHANNOCK CREEK, NORTHAMPTON COUNTY

Planted 1982

(Refer to Appendix B)

Marshall is a low energy shore facing almost due north on Occohannock Creek (Figure 101). The historic erosion rate of the high fastland bank is less than 0.5 foot per year (3). Much of the shore at the site occupies a shallow cove. The bank is about 13 feet above MTL. The upper portion is vertically exposed showing continual erosion by rain runoff. The lower part of the bank is partly covered with slump material which is vegetated with upland grasses. Before planting there was an intermittent and irregular fringe of saltmeadow hay along the backshore. In some places it extends out 20 feet from the base of the bank. The bank is undercut by wave action and exposed where this fringe is absent.

The beach extends from the base of the bank or lower limit of the saltmeadow hay fringe out to about MTL. The beach consists of a fine to medium-coarse sand and gravel. The source of sand comes from bank erosion within the reach and possibly from nearshore shoals. Sand movement fluctuates but the net drift appears to be upstream toward the east.

The Marshall site was planted with both species in June 1982. The smooth cordgrass planting varied in width (Figure 102). The saltmeadow hay was planted in embayments between the existing saltmeadow hay headlands (Figure 103a). Some initial losses were noted along the lower

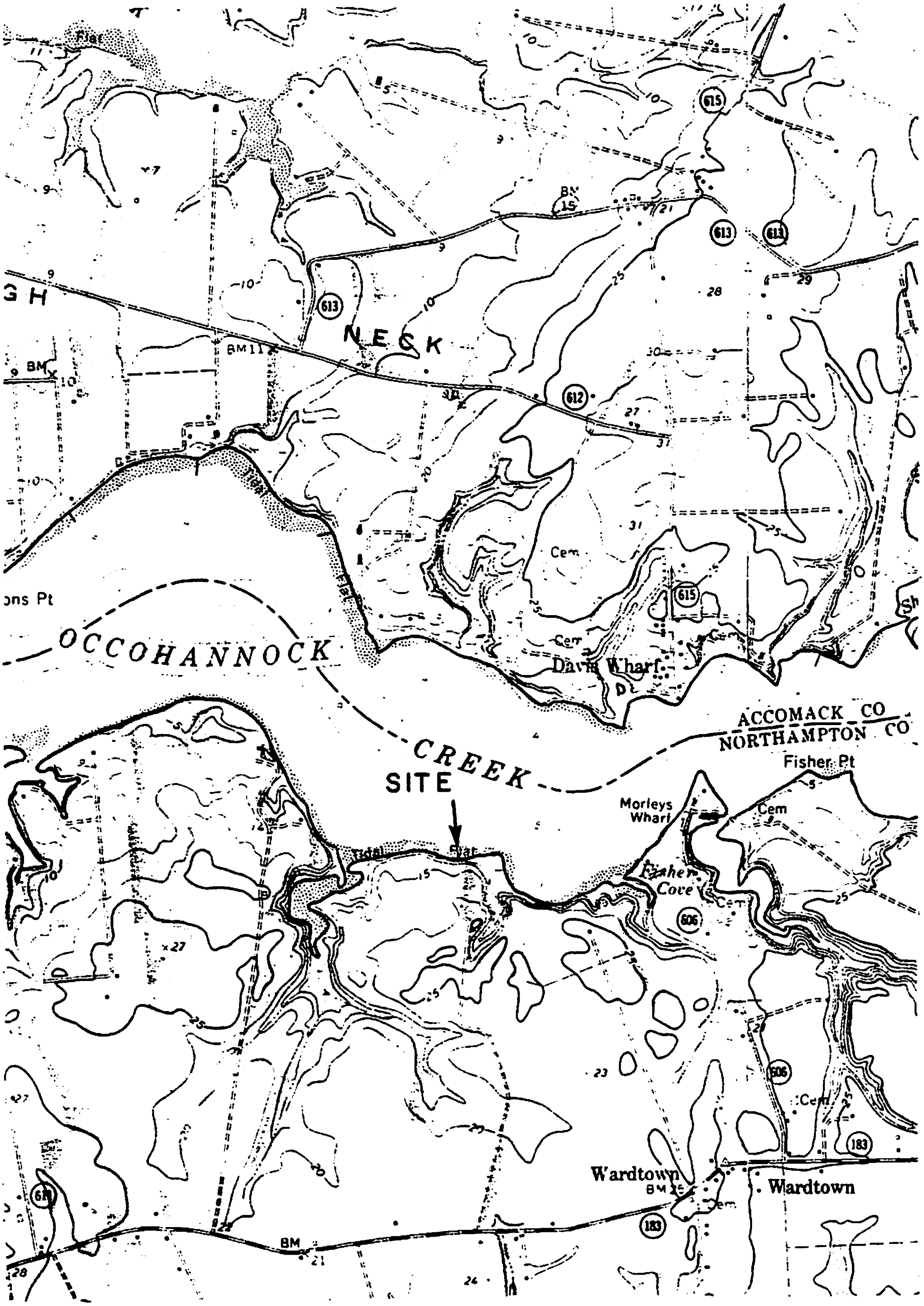


Figure 101. Marshall Site - from Jamesville and Exmore 7.5 minute quadrangles.
Scale: 1 inch = 2,000 feet.

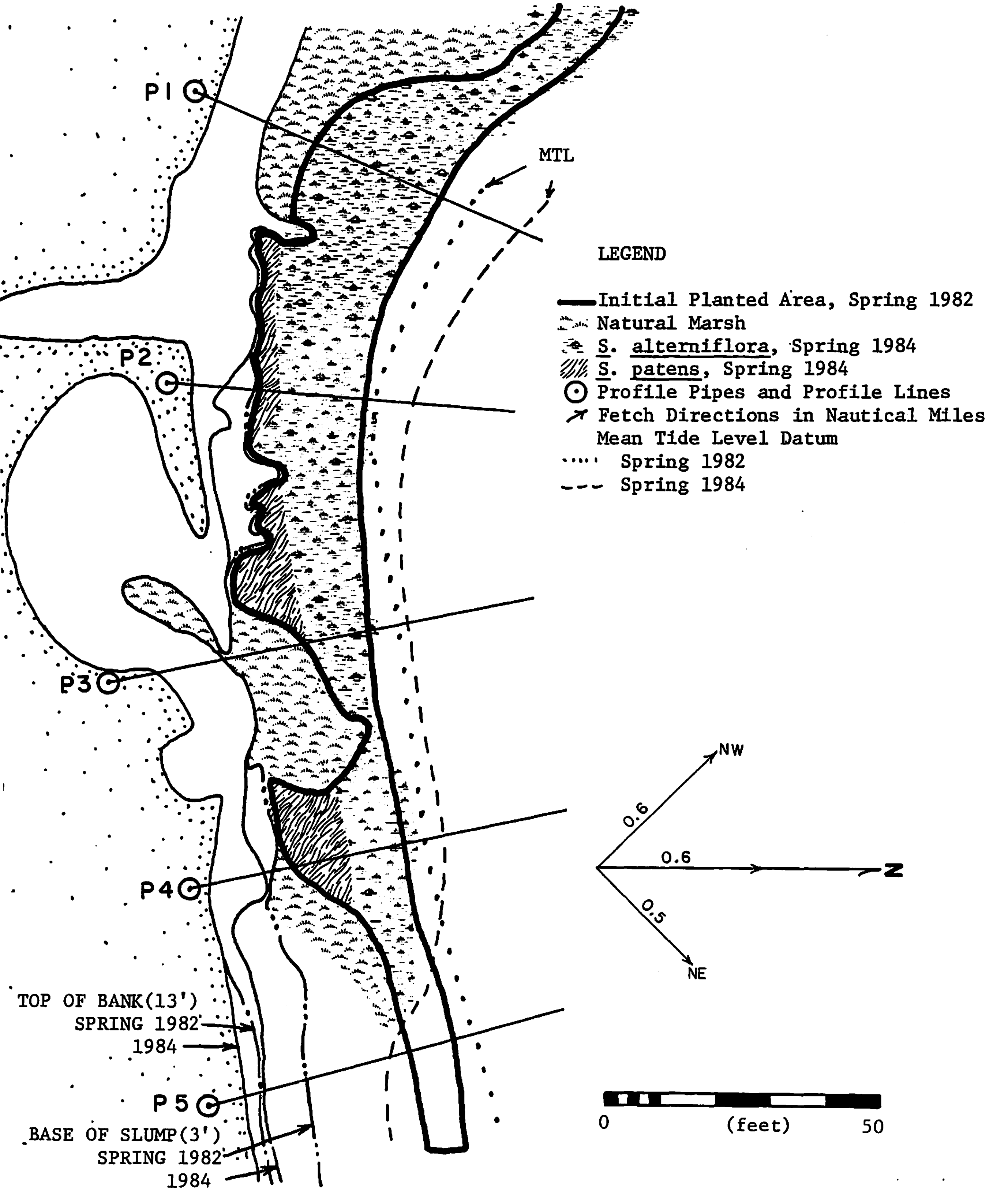


Figure 102. Marshall Site - Base Map.

FIGURE 103

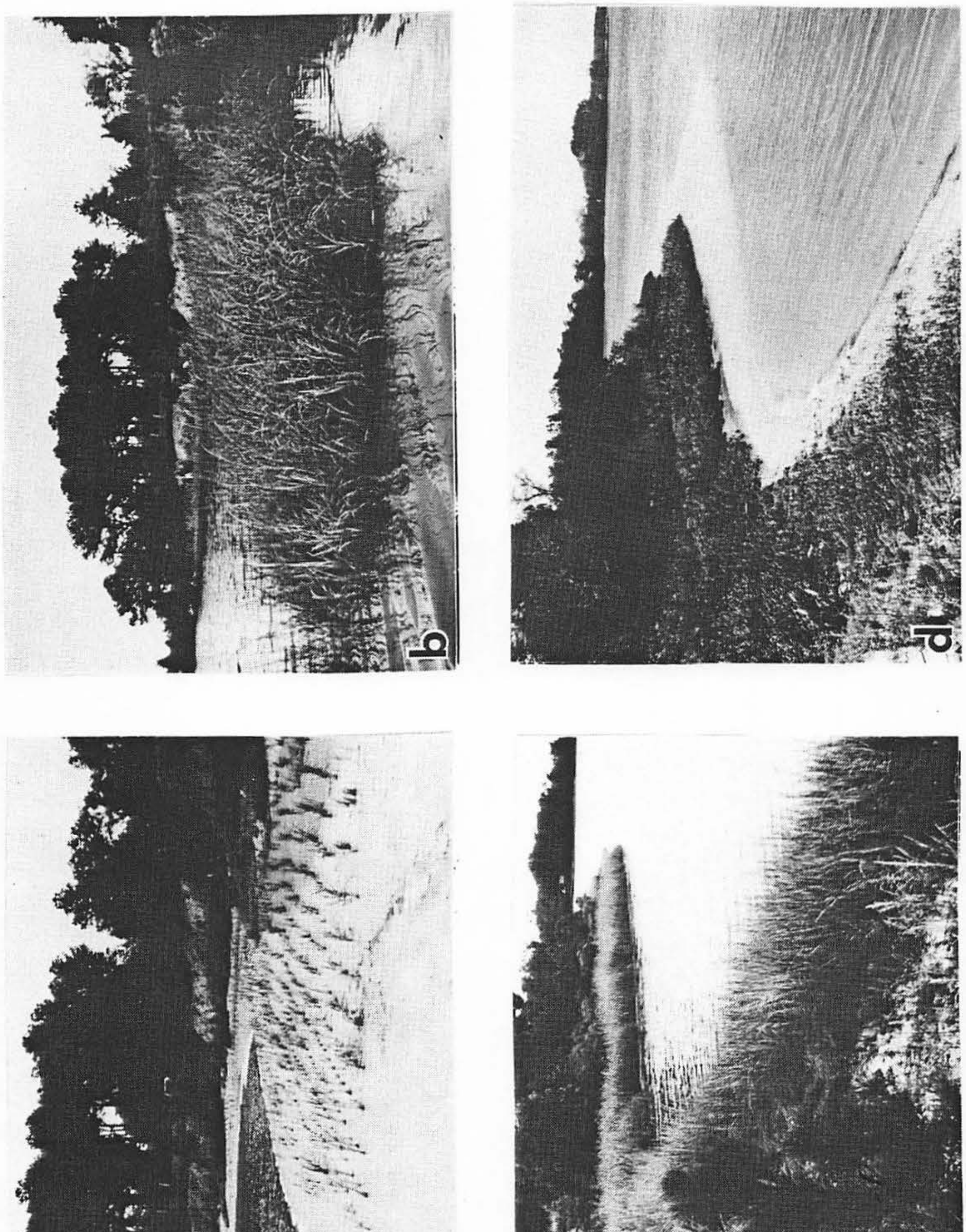
MARSHALL

a. July 1, 1982
Looking east.

b. October 11, 1982
Looking east.

c. September 16, 1983
Looking west.

d. April 12, 1984
Looking west.



edge and east end of the site. This might be attributed to the October 25, 1982 storm. Loss of base of bank and top of bank were also noted by November 1982 (Figure 104).

Erosion of top of bank continued during the winter of 1982-1983 along with slumping along the base of bank which increased its position by the spring of 1983. There was a slight loss of sediment in the intertidal fringe (Figure 104).

By the fall there was a measurable increase in marsh area and width. The position of base of the bank slump had receeded by erosion and there was an increase in sediment volume in the intertidal fringe. Sediment source to the backshore comes mostly from bank erosion. However, there is an abundant supply of sediment moving within the littoral system, much of which has been effectively trapped by the fringe, especially the western half (see Appendix D).

Much of the bank erosion during the winter of 1983-1984 was near P5 where the smooth cordgrass had been partially washed out. By spring 1984 bank erosion was continuing at P5. Sediment volume in the intertidal fringe was stable. The backshore elevation had mostly increased along the bank where the fringe remained (Figure 105). There was a negligible loss of smooth cordgrass and saltmeadow hay since September 1983 but an actual net gain of smooth cordgrass since the first planting in 1982.

Bank erosion at the Marshall Site has been on previously exposed banks especially between P4 and P5. However, increased backshore elevation across most of the site plus a healthy continuous intertidal

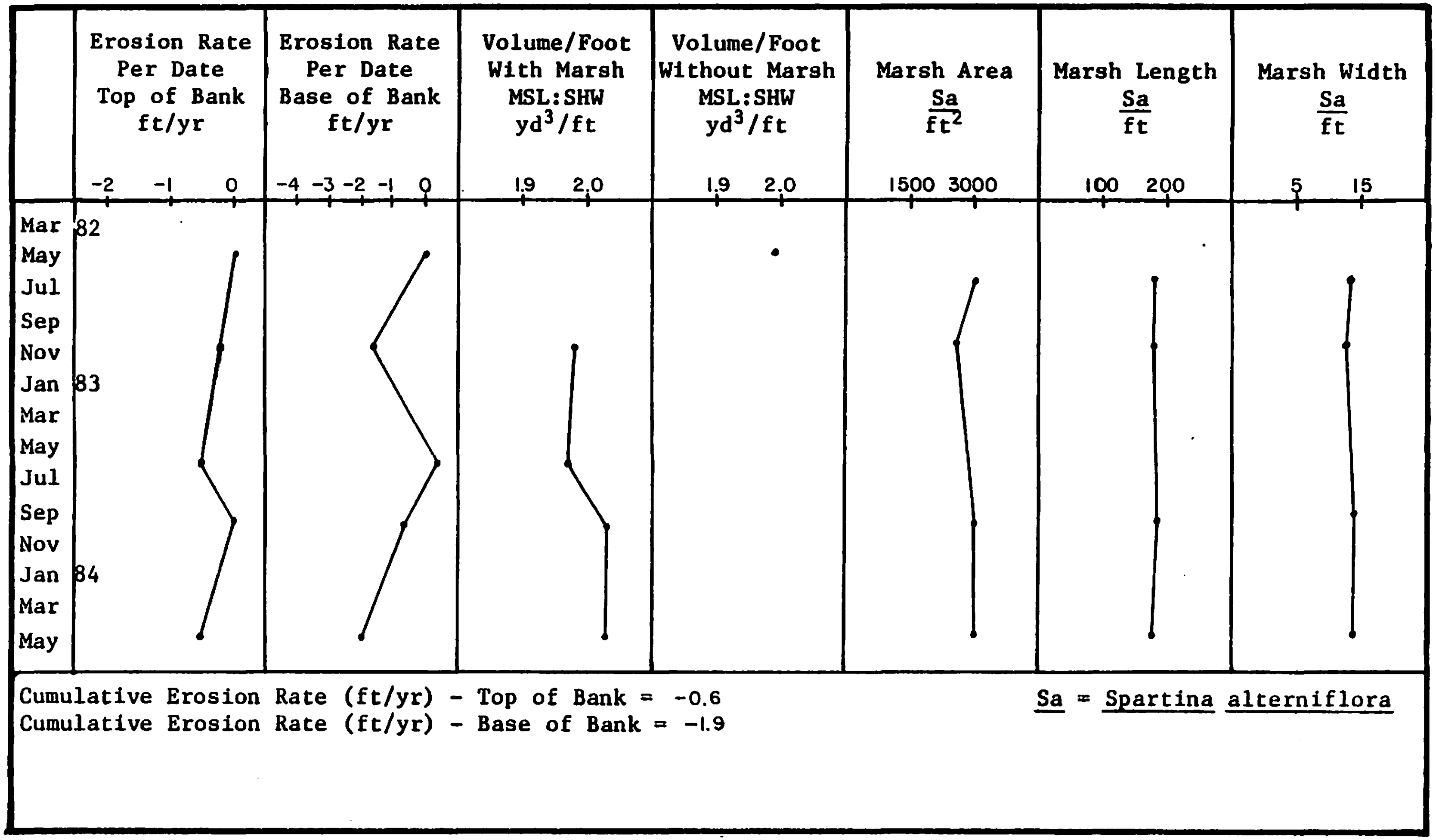


Figure 104. Marshall Time Series.

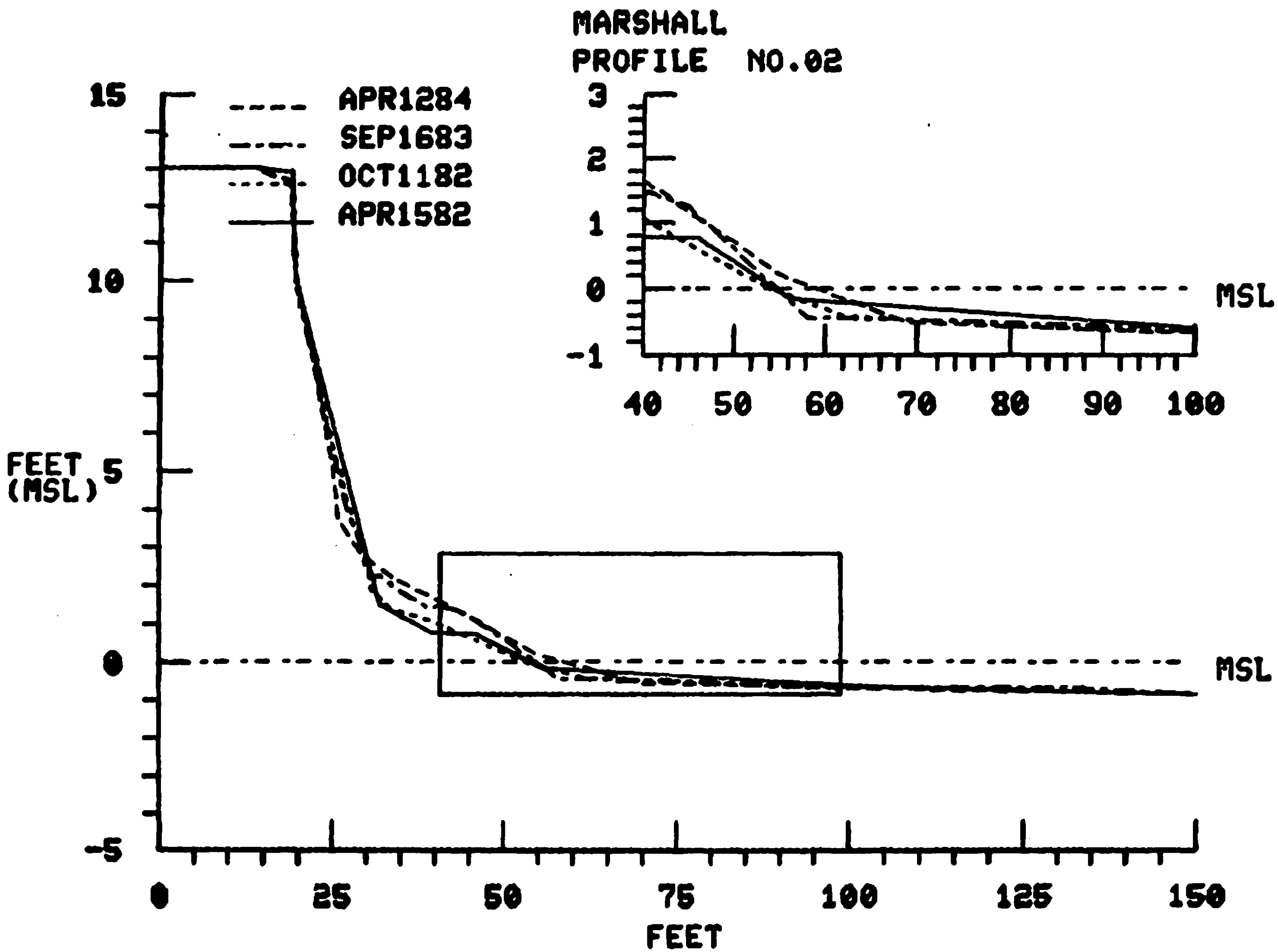


Figure 105. Marshall Site - Representative Profile.

fringe should lead to future base of bank stabilization (Figures 103c and 103d). In this regard the marsh fringe is termed a success. The bank erosion that has occurred behind the fringe is feeding the backshore fringe area. With time and perhaps some maintenance planting, the Marshall site should halt the erosion of the adjacent bank.

20. JOHNSEN - CRYSTAL LAKE, CITY OF VIRGINIA BEACH

Planted 1982

(Refer to Appendix B)

The Johnsen site is located in a cove on Crystal Lake (Figure 106). It is a low energy site in terms of wind driven waves but receives considerable wave action from pleasure boat wakes (oral communication, Mrs. Johnsen). There are two planting areas at the Johnsen site (Figure 107). The northern most shore (area no. 1) was a vertically exposed low bank before it was graded and hay bales placed along its base. This shore received the brunt of wave action from boat wakes. More recently a riprap revetment was emplaced along this segment of shore. Area no. 2 is south of area no. 1 and occupies a very small well protected cove. The bank is very low with a small wave cut scarp. This bank was partially graded. There is a small patch of smooth cordgrass near the south end of area no. 2. Between area no. 1 and area no. 2 is a small sandy headland which is vegetated with black needlerush (Juncus roemerianus) and saltmeadow hay.

At area no. 1, before planting, there was a narrow intertidal beach extending out from the hay bales about 10 feet to MLW. Beach sediments consisted of slightly clayey organic fine to medium sand. These had come mostly from the previously eroding adjacent bank. Area no. 2 has no distinct beach but rather a muddy, fine sandy highly organic soft substrate extending from the base of the bank to below MLW.

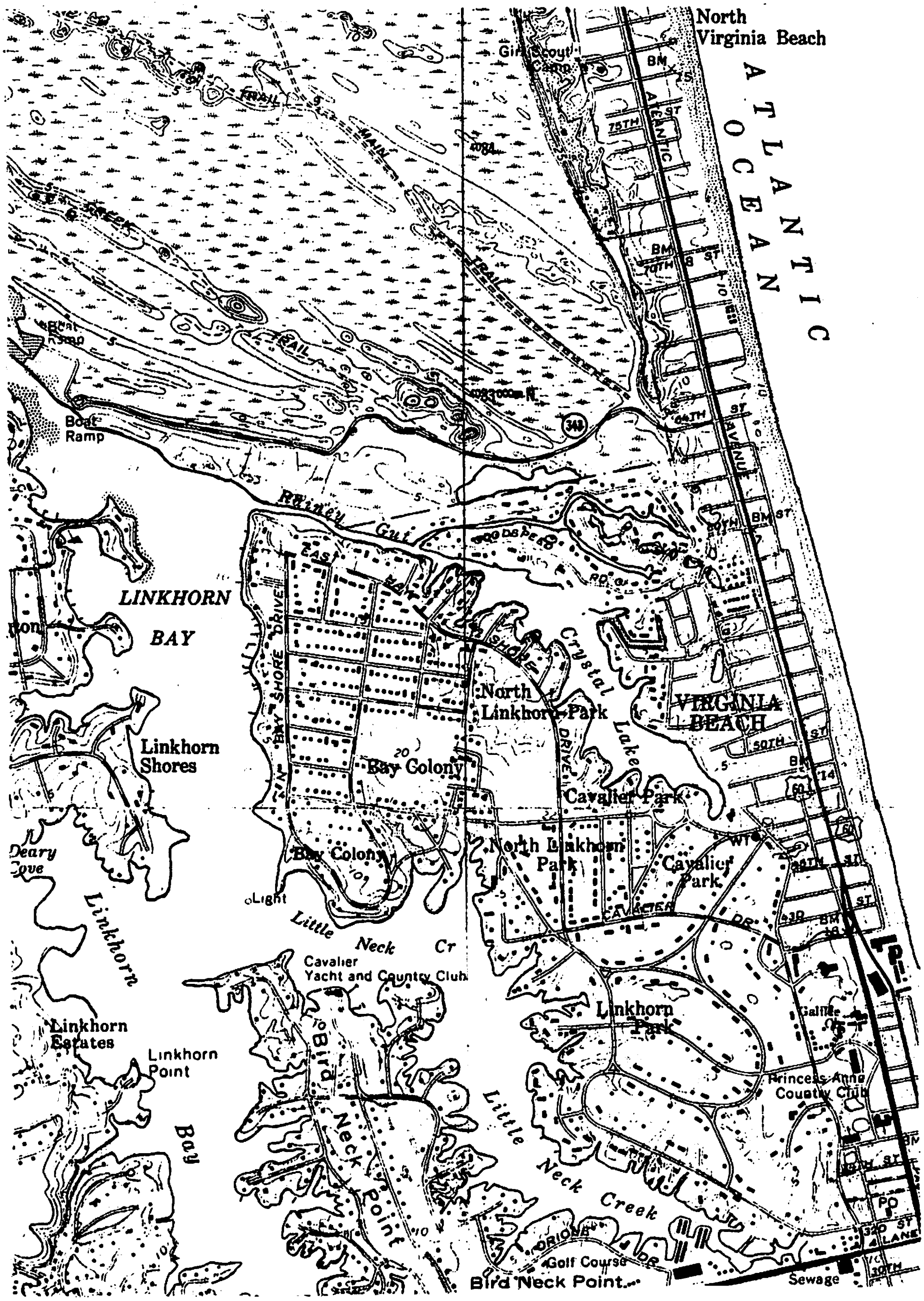


Figure 106. Johnsen Site - from Cape Henry, Virginia Beach, and Princess Ann 7.5 minute quadrangles.
Scale: 1 inch = 2,000 feet.

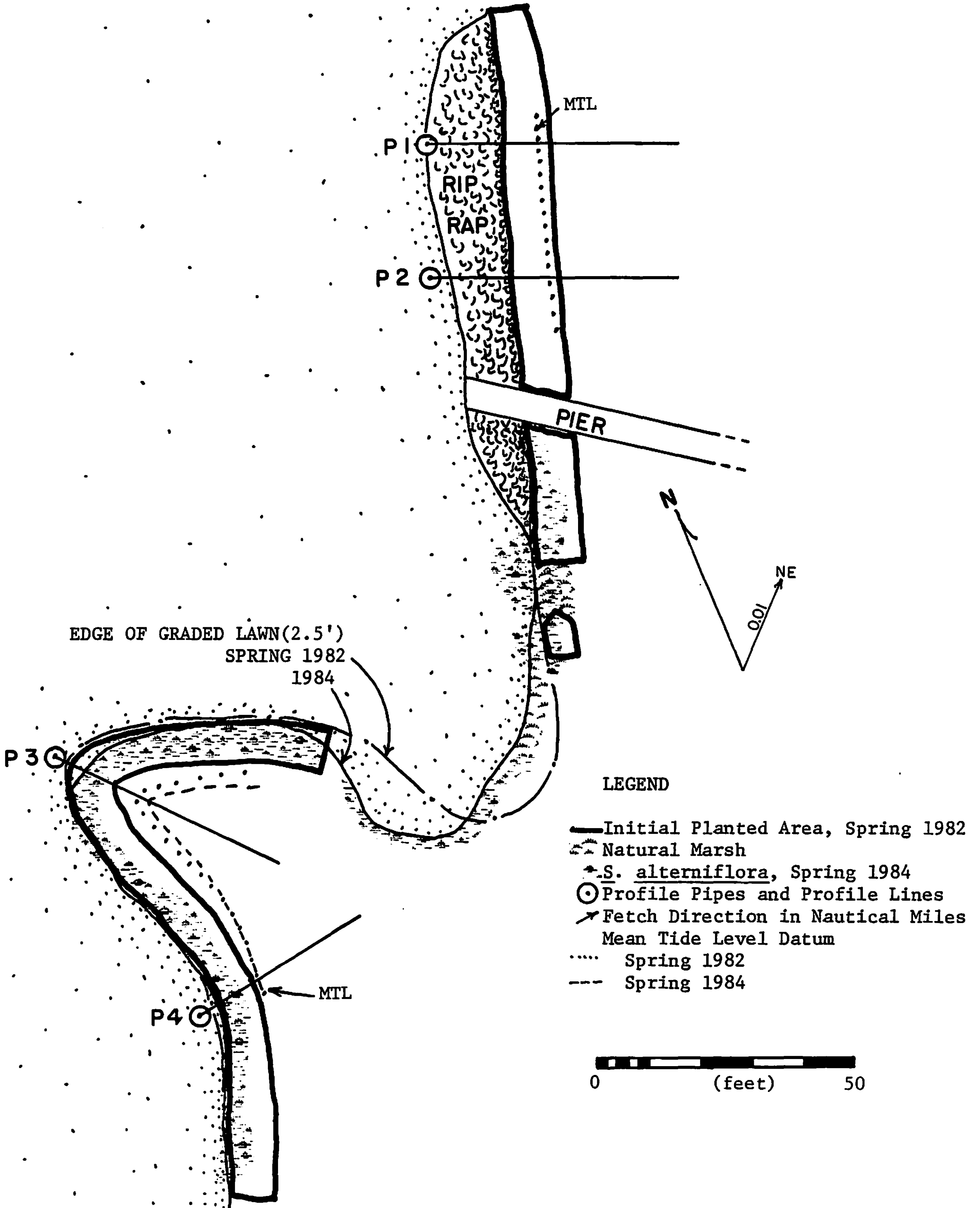


Figure 107. Johnsen Site - Base Map.

On June 15, 1982, 960 smooth cordgrass peat pots were planted. About half the smooth cordgrass were planted at area no. 1, the other half at area no. 2. The hay bales had deteriorated and the remaining hay was spread about the upper tidal zone at area no. 1 (Figure 108a).

During the summer of 1982 area no. 1 apparently came under severe wave attack from recreational boat activity on Crystal Lake. By mid-August only parts of the upper row of plants remained and undercutting of the graded bank was proceeding. The Johnsens felt this was an unsatisfactory situation and emplaced a riprap revetment.

Figure 109 depicts changes in marsh area, length and width for site no. 2 only. During the summer and early fall of 1982 the site was significantly reduced in area and width. All losses were along the lower rows. By the spring of 1983 the marsh had expanded a little.

Maintenance planting was done in the spring of 1983, mostly along the lower edge. Additional plants were placed on the point between site no. 2 and old site no. 1. This area expanded over the summer of 1983 and continued to expand during the spring of 1984. In fact some of the rhizomes are growing up into the lawn.

The fringe appears to be stabilized and holding the upper intertidal zone (Figure 110). Bank erosion has been essentially zero since 1982. The site is termed successful.

FIGURE 108

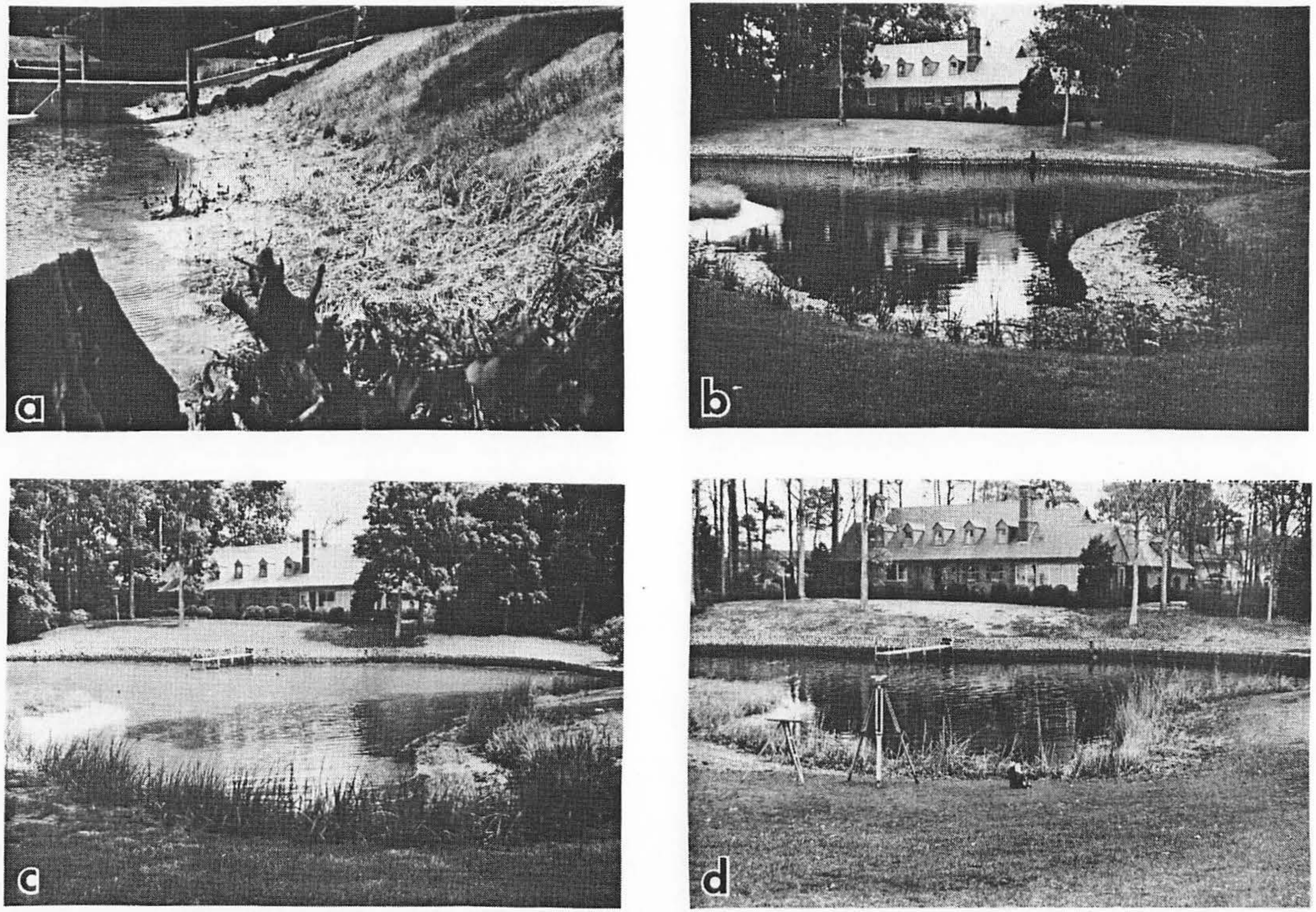
JOHNSEN

a. June 15, 1982
Area No. 1 - looking south.

b. August 12, 1982
Area No. 2 - looking east.

c. June 8, 1983
Area No. 2 - looking east.

d. March 27, 1984
Area No. 2 - looking east.


a
b
c
d

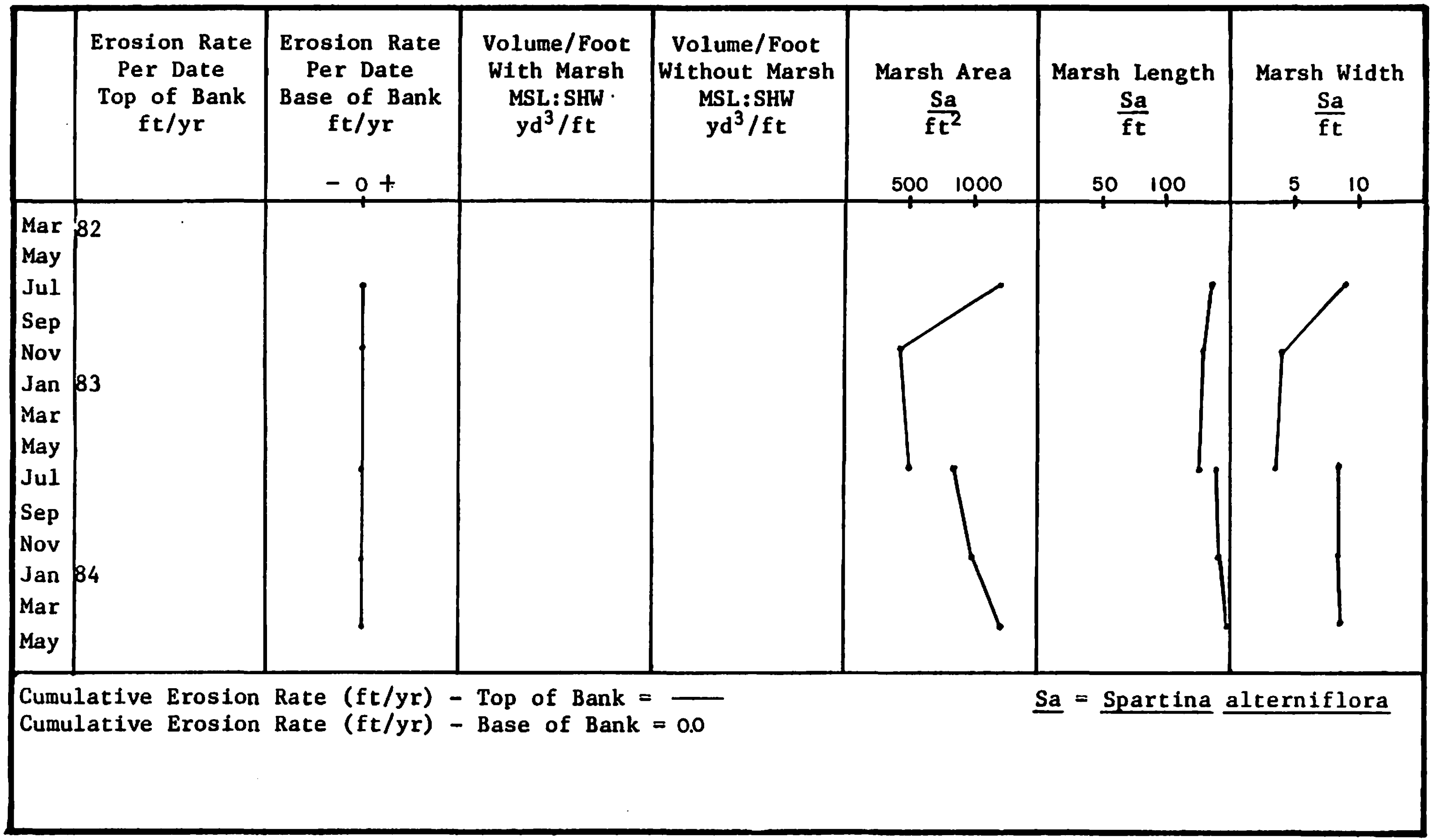


Figure 109. Johnsen Time Series.

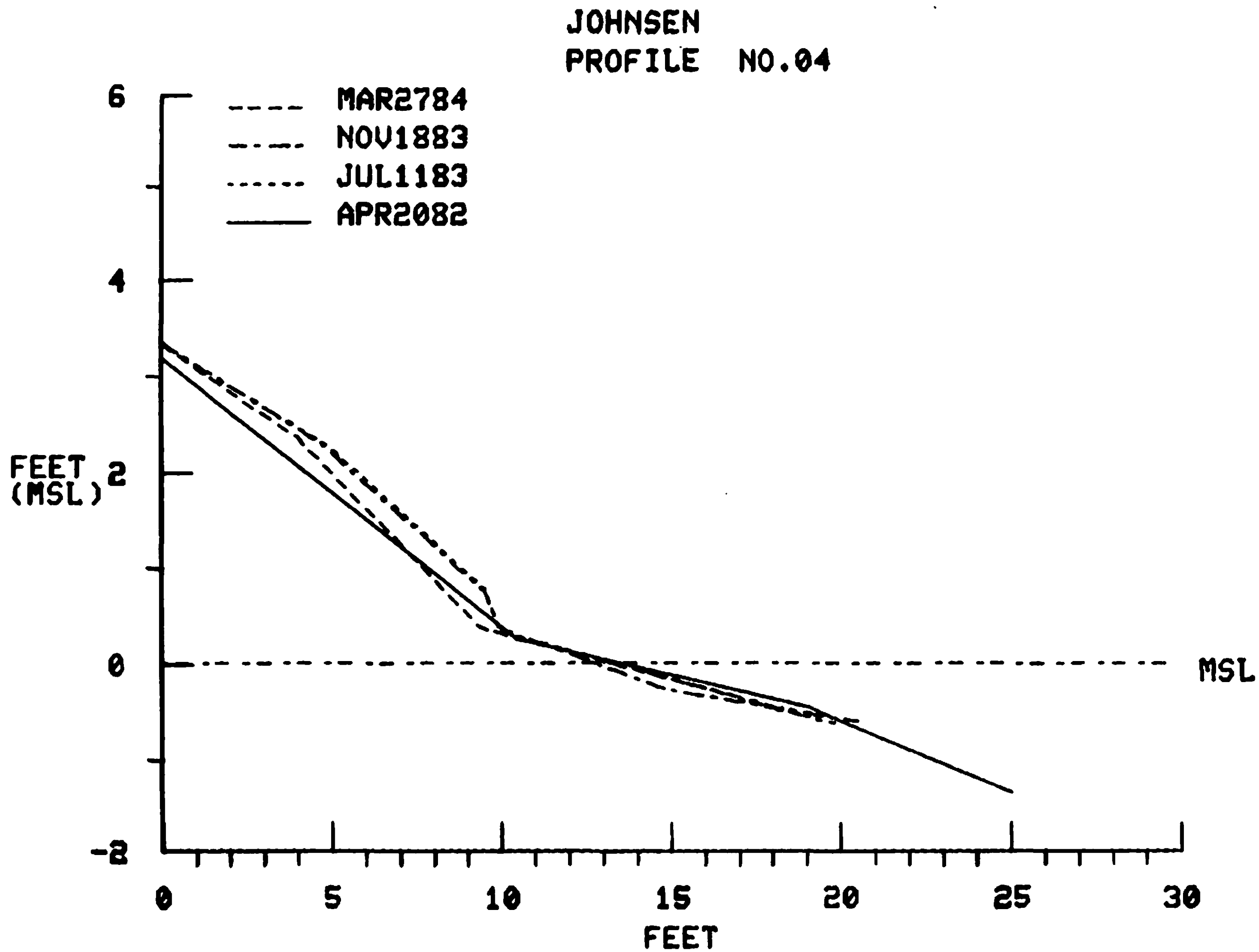


Figure 110. Johnsen Site - Representative Profile.

21. VANDERSLICE - MILFORD HAVEN, MATHEWS COUNTY

Planted 1982

(Refer to Appendix B)

The Vanderslice sites are located at Point Breeze on Milford Haven (Figure 111). There were originally two planting areas designated North Site and South Site. The historic erosion rate is about 2.3 feet per year (3). The shore faces almost due east. It has been assigned a medium energy wave climate. A long exposure to the southeast through "The Hole in the Wall" Inlet will allow considerable wave action during storms.

The north site is a very low sandy bank which retreats by washover. The south site is a low slightly clayey sand fastland bank. The beach extended from the base of the bank out some 35 feet. The beach consists of fine to coarse grained sand mostly from bank erosion within the reach.

The north site and south site were first planted in May 1982 with one species, smooth cordgrass (Figures 112 and 113). By the fall of 1982 most of the north site was washed out and the south site was greatly reduced (Figures 114b and 114c), especially along the lower edge. This was mostly due to the October 25, 1982 storm. Measurements in Figure 115 are for the south site. Also, The October 25, 1982 storm caused considerable erosion of the low fastland bank at the south site (Figure 114d). This apparently supplied material to the backshore and the remaining intertidal fringe (Figure 115). Also, ponies which were

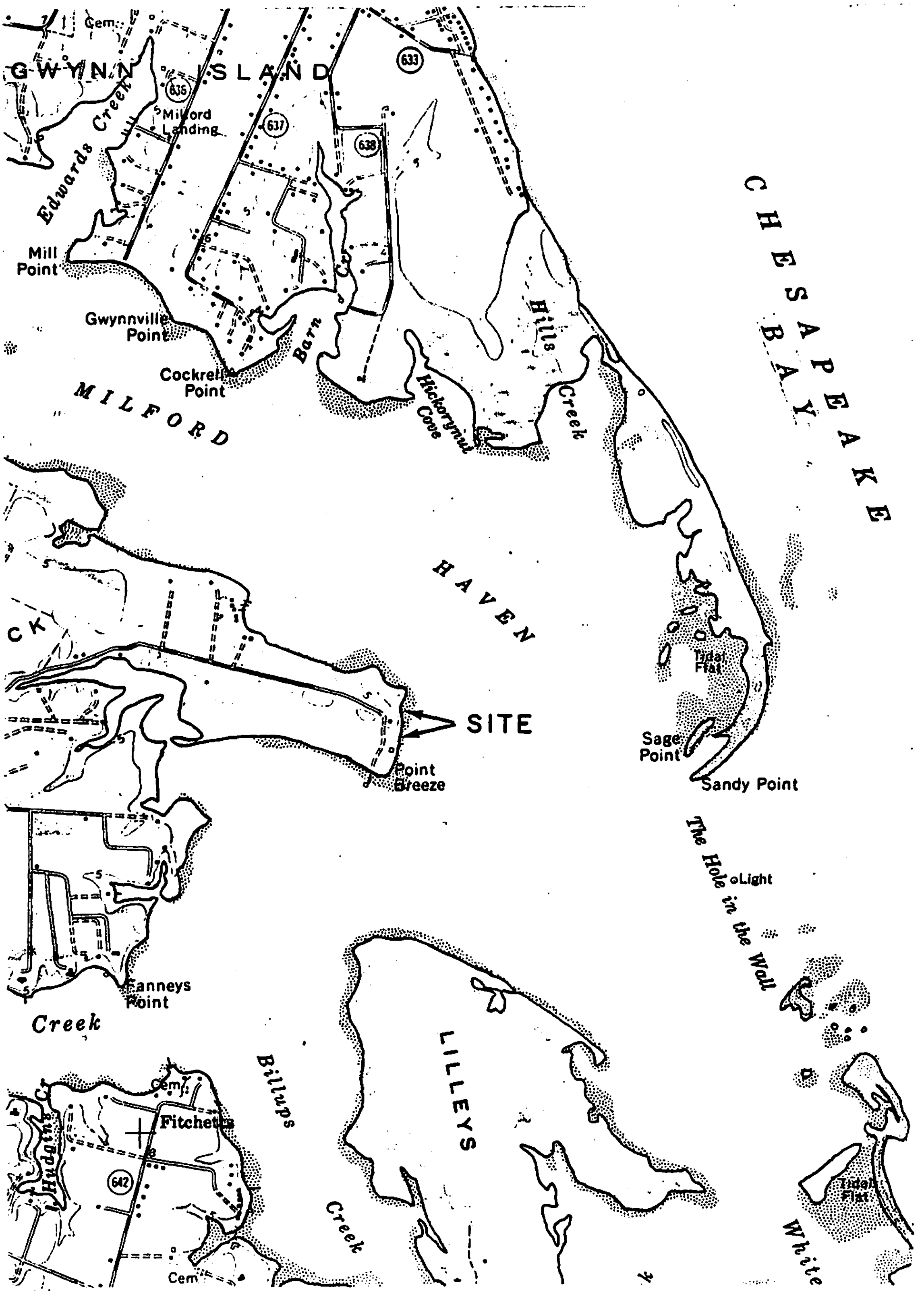


Figure 111. Vanderslice Site - from Mathews 7.5 minute quadrangle.
Scale: 1 inch = 2,000 feet.

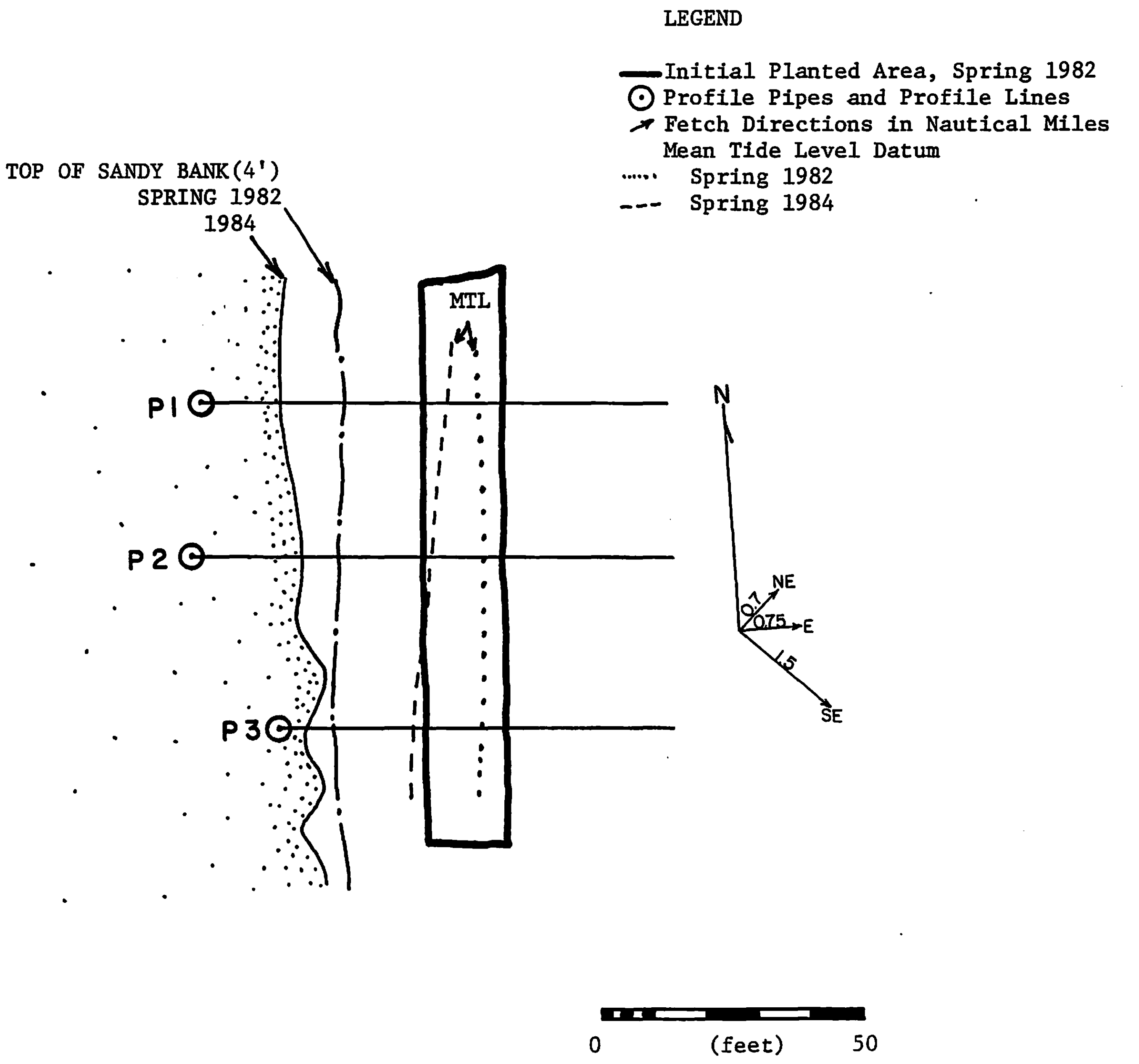


Figure 112. Vanderslice, North Site - Base Map.

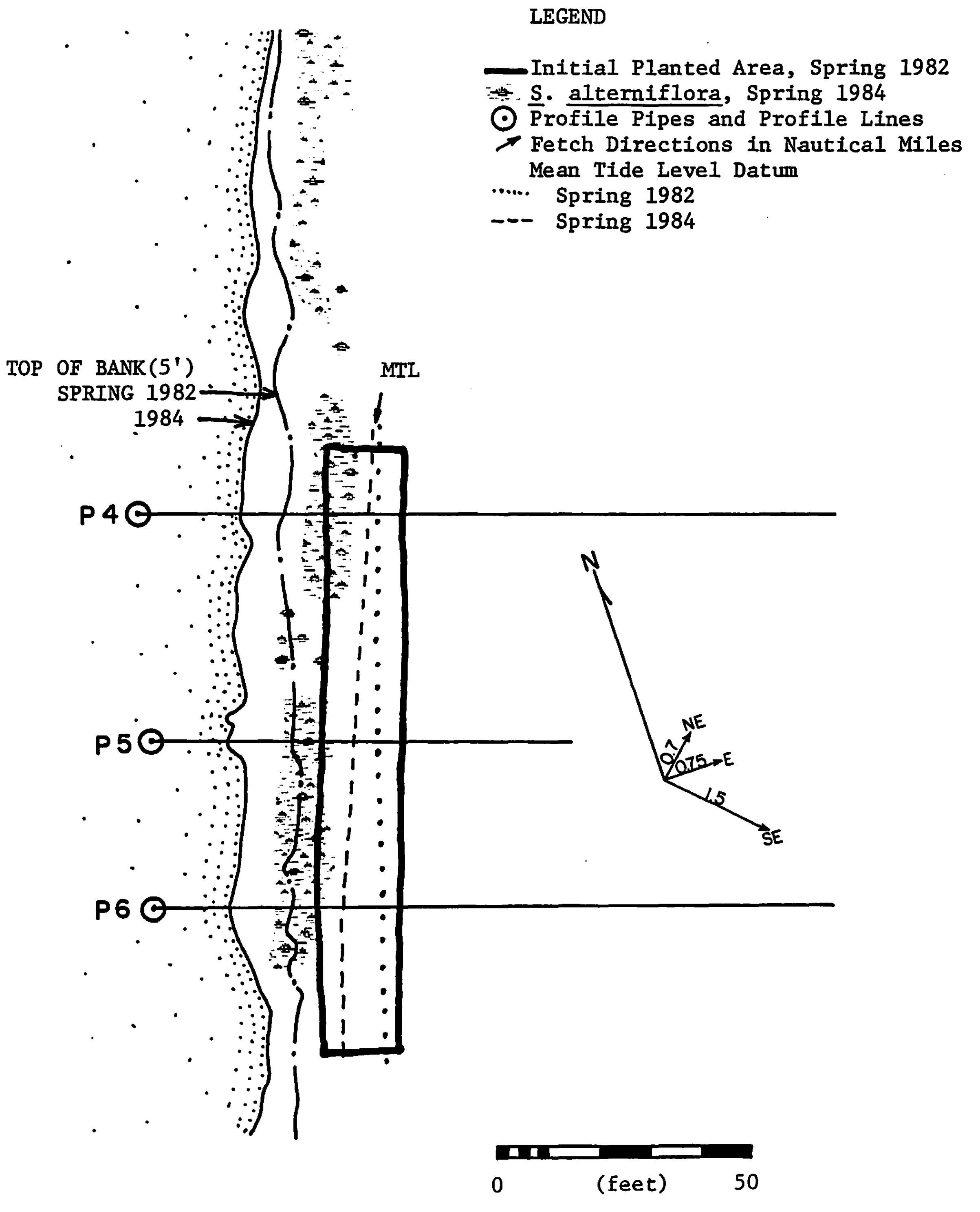


Figure 113. Vanderslice, South Site - Base Map.

FIGURE 114

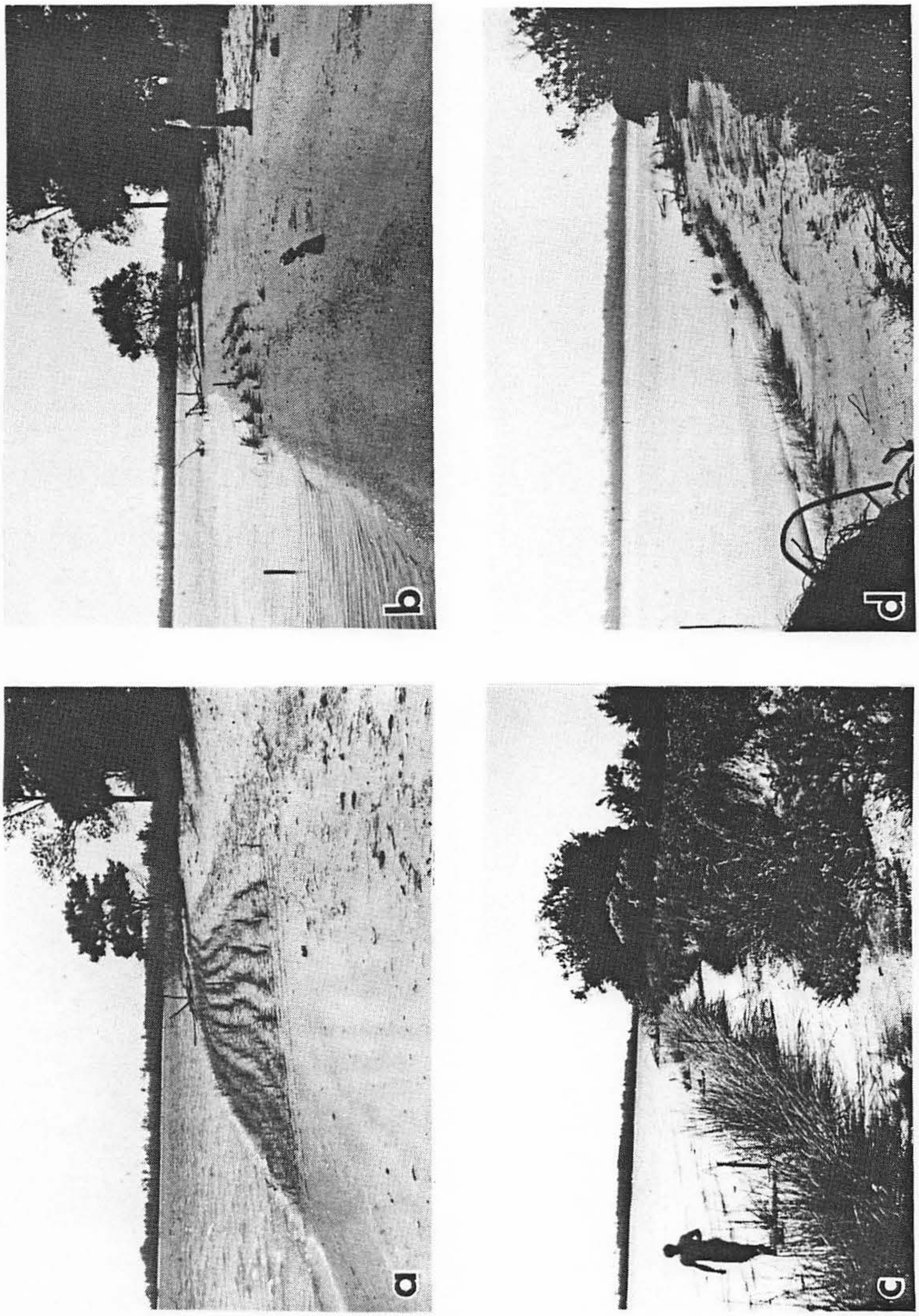
VANDERSLICE

a. May 19, 1982
North Site - looking south.

b. October 29, 1982
North Site - looking south.

c. September 24, 1982
South Site - looking south.

d. October 29, 1982
South Site - looking south.
Post October 25, 1982 storm.



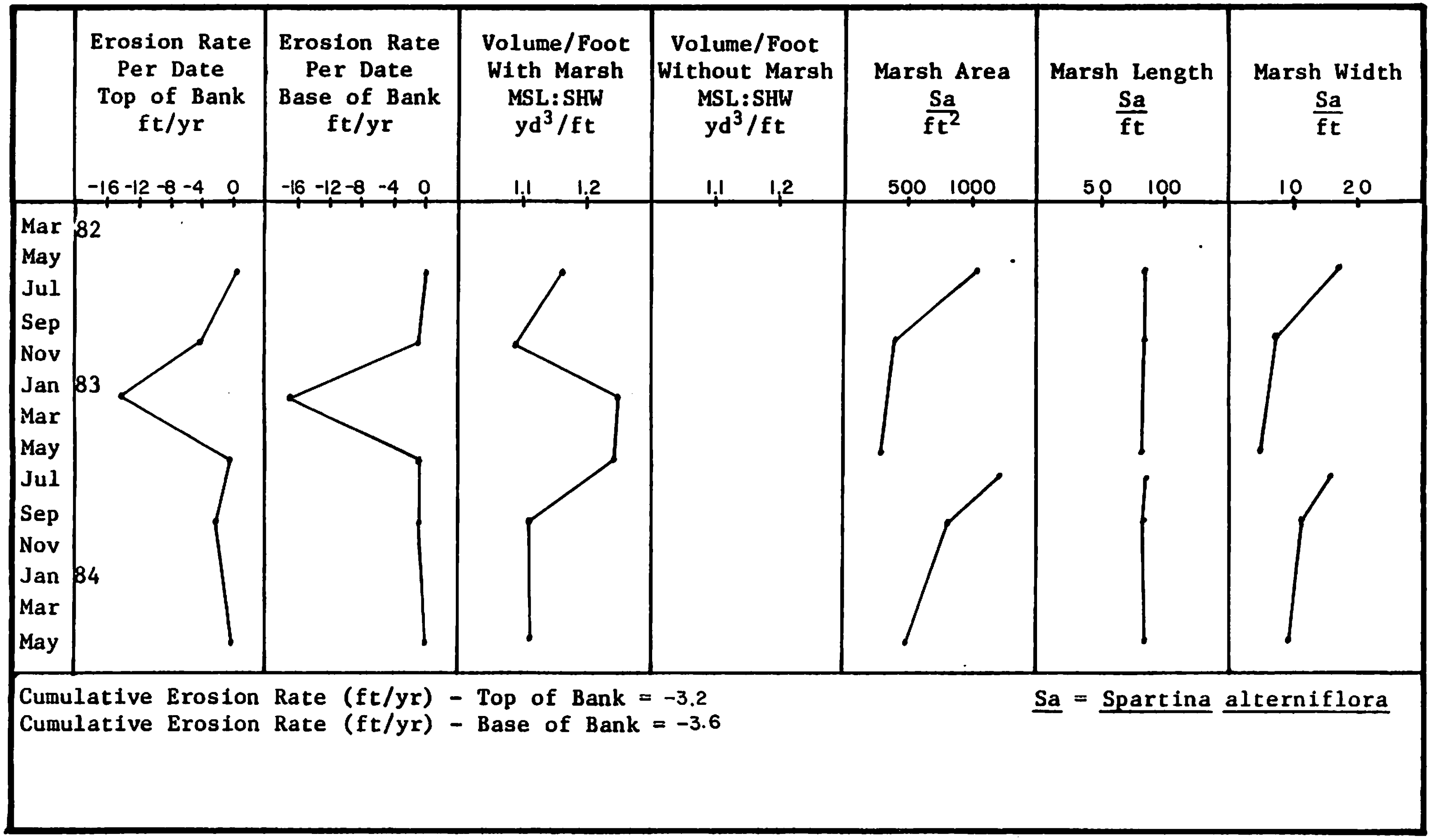


Figure 115. Vanderslice Time Series.

kept on the property were able to get to the fringe, graze and reduce above ground growth on plants remaining at each site.

The bank erosion rate slowed over the winter of 1982-1983 and there was continued loss of marsh area due to washout. Maintenance planting was done in the Spring of 1983 at the south site only (Figure 116a). No plants remained on the north site and it was not planted. The maintenance plants were planted landward of the original planting limits due to the increase in backshore width and landward movement of the tidal datums.

By fall of 1983 marsh area and width were reduced. Sediment was lost in the intertidal fringe and backshore region. Minor bank erosion was also noted but at a greatly reduced rate owing to calmer summer conditions (Figure 115). There was continued loss of plants over the winter of 1983-1984. However there was a decrease in backshore elevation since fall 1983. Bank erosion had almost ceased (Figure 117).

By spring 1984 the remaining plants appear to have held the backshore to some degree though they are patchy. Even though the site is moderately exposed, during storm conditions varied water levels and Bay swells act to severely erode the bank regardless of any existing fringe. Eroded material if maintained by the fringe elevates the backshore and may reduce wave impingement during the next event. Peat development is noted but without continued and extensive maintenance planting the site will trend toward failure.

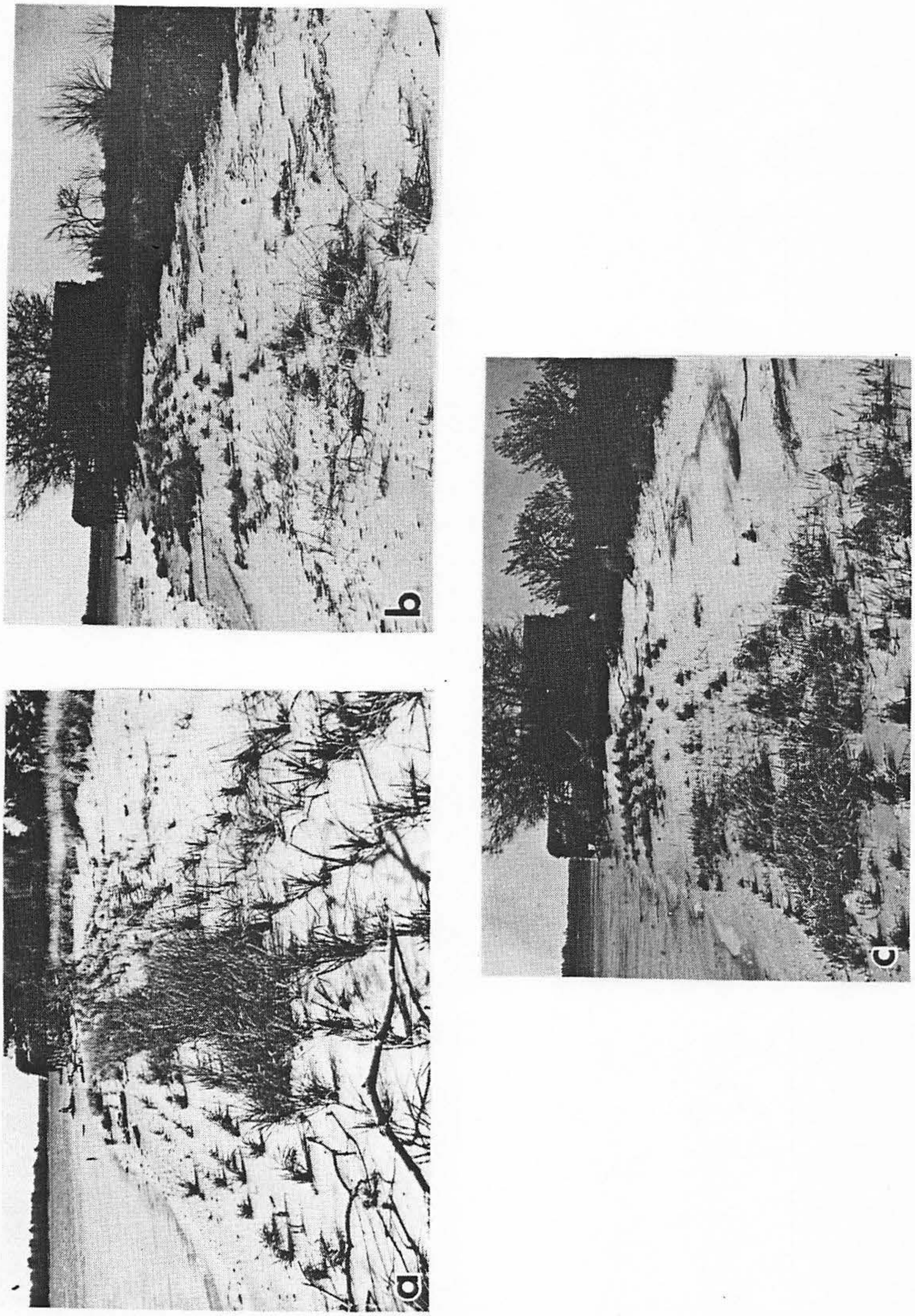
FIGURE 116

VANDERSLICE

a. July 29, 1983
South Site - looking south.

b. February 8, 1984
South Site - looking south.

c. April 25, 1984
South Site - looking south.


b
a
c

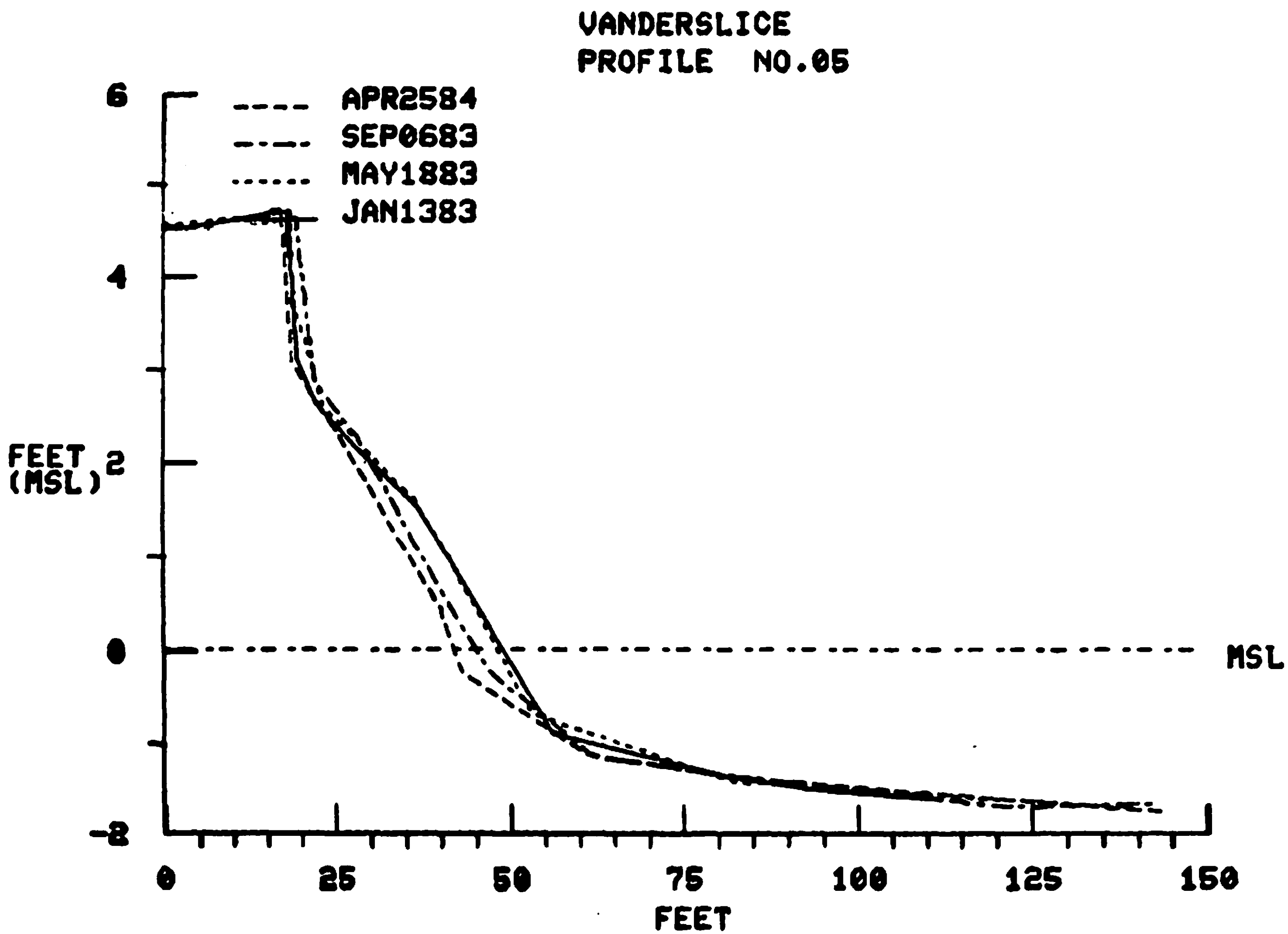


Figure 117. Vanderslice Site - Representative Profile.

22. COLLIER - YORK RIVER, GLOUCESTER COUNTY

Planted 1982

(Refer to Appendix B)

The Collier site is located on Jenkins Neck just north of Sandy Point at the mouth of the York River (Figure 118). The very low fastland bank shore faces south. The historic erosion rate is 1.9 feet per year (3). The bank is very sandy and is about 3 feet above MTL. Initially there was a wave cut scarp along the face of the bank. This is a fetch compromising site similar to Vanderslice. It has been assigned a medium energy site that is well protected by Sandy Point shoals but high water levels from storm surge will readily flood the fastland.

The beach is composed of medium to coarse sand derived from bank erosion and offshore shoals within the reach. This extends from the base of the fastland bank out about 25 feet just beyond MTL.

The Collier site was first planted in June 1982 (Figure 119). The planting suffered essentially no initial washout or die-off. However, by late July dead eel grass detritus began accumulating along the upper tidal zone. This acted as a natural mulch and began smothering out plants in that area. By mid-August even more eel grass detritus had accumulated. It had killed much of the smooth cordgrass across the center of the planted area. A vain attempt was made to remove the debris. In a few short weeks more debris had accumulated along the same area of the planting. By the first of September 53% of the planting

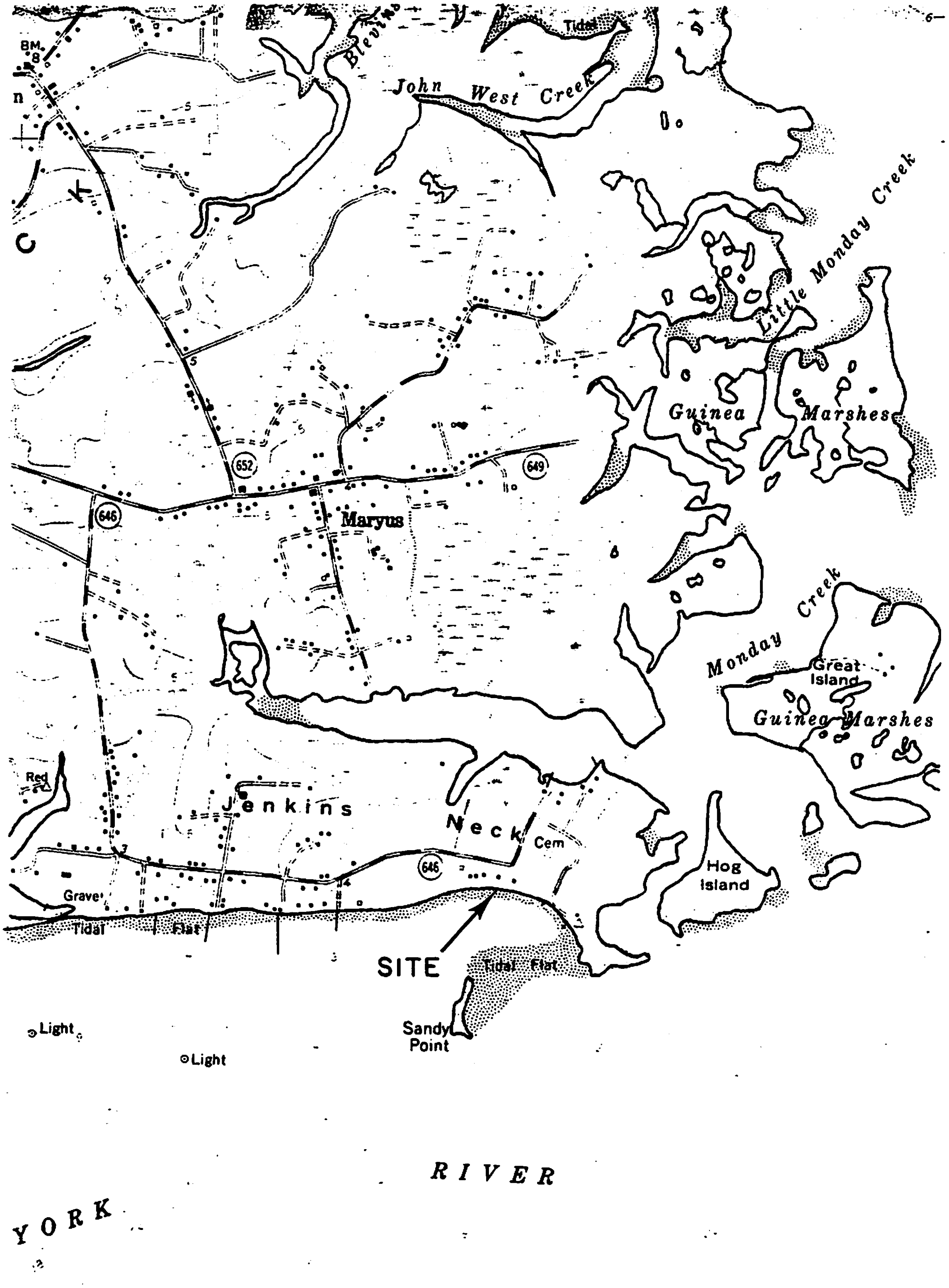


Figure 118. Collier Site - from Achilles 7.5 minute quadrangle.
Scale: 1 inch = 2,000 feet.

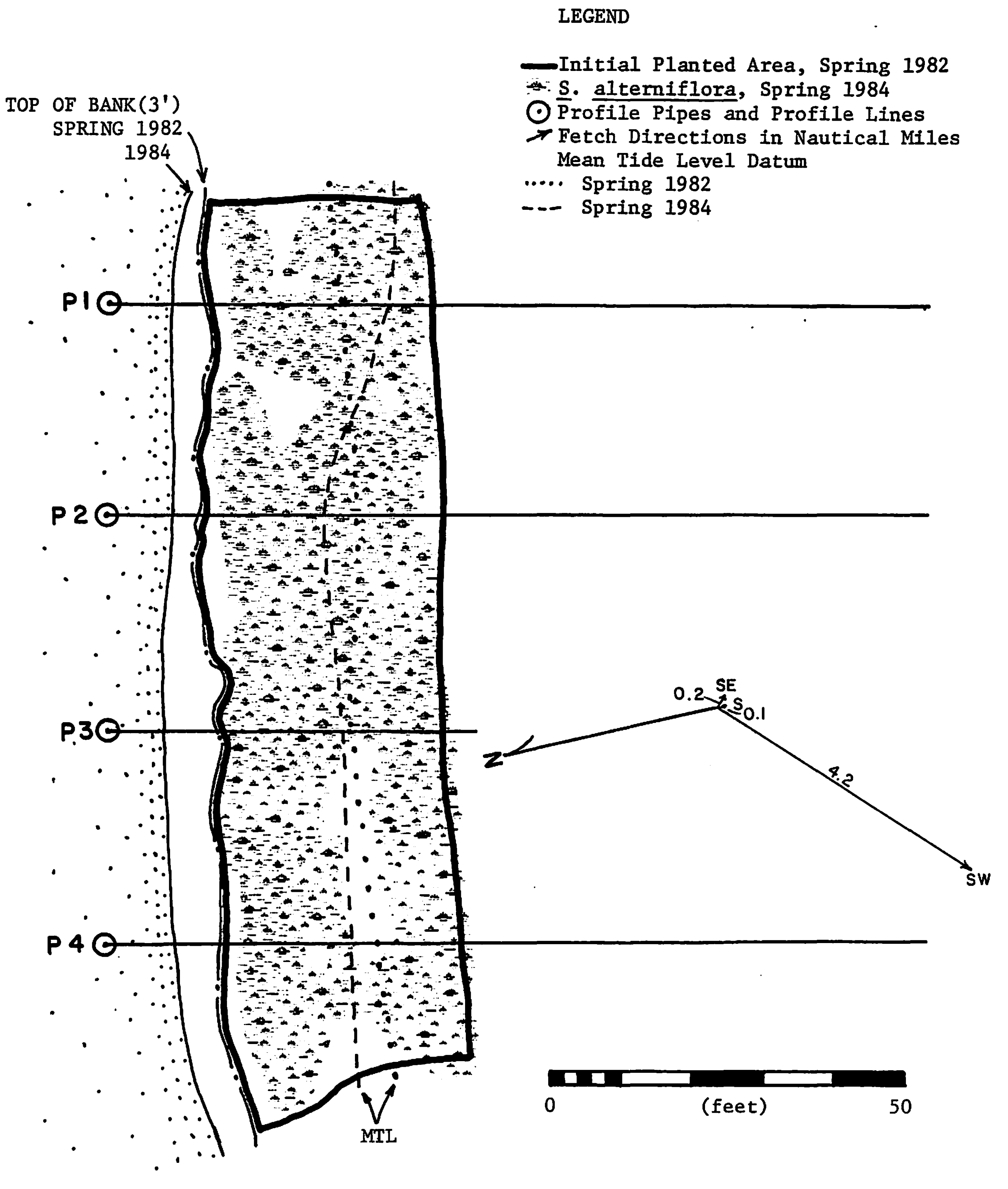


Figure 119. Collier Site - Base Map.

had been lost due to the eel grass accumulation. By early February the lower five to six rows of the planting still survived (Figure 120). During the winter of 1982-1983 the Collier site suffered severe bank erosion and sediment loss from the intertidal fringe (Figure 121).

The Collier site was maintenance planted in the spring of 1983 (Figure 120c). Once again the dead eel grass debris accumulated along the mid and upper portions of the planting but not as much as the previous summer. Marsh area and width decreased slightly by the fall of 1983 almost solely due to smothering by the eel grass. The rate of bank erosion decreased and there was continued loss of sediment in the upper intertidal fringe. This zone occupies the upper part of the planting where grasses had died.

By the spring of 1984 the marsh area had expanded and trapped sediment in the upper intertidal fringe. The erosion rate had further decreased also. The backshore has been stabilized (Figure 122) and the marsh is starting to expand. It seems to be trending toward success. If it were not well protected by Sandy Point the successful situation may have been more difficult to achieve.

FIGURE 120

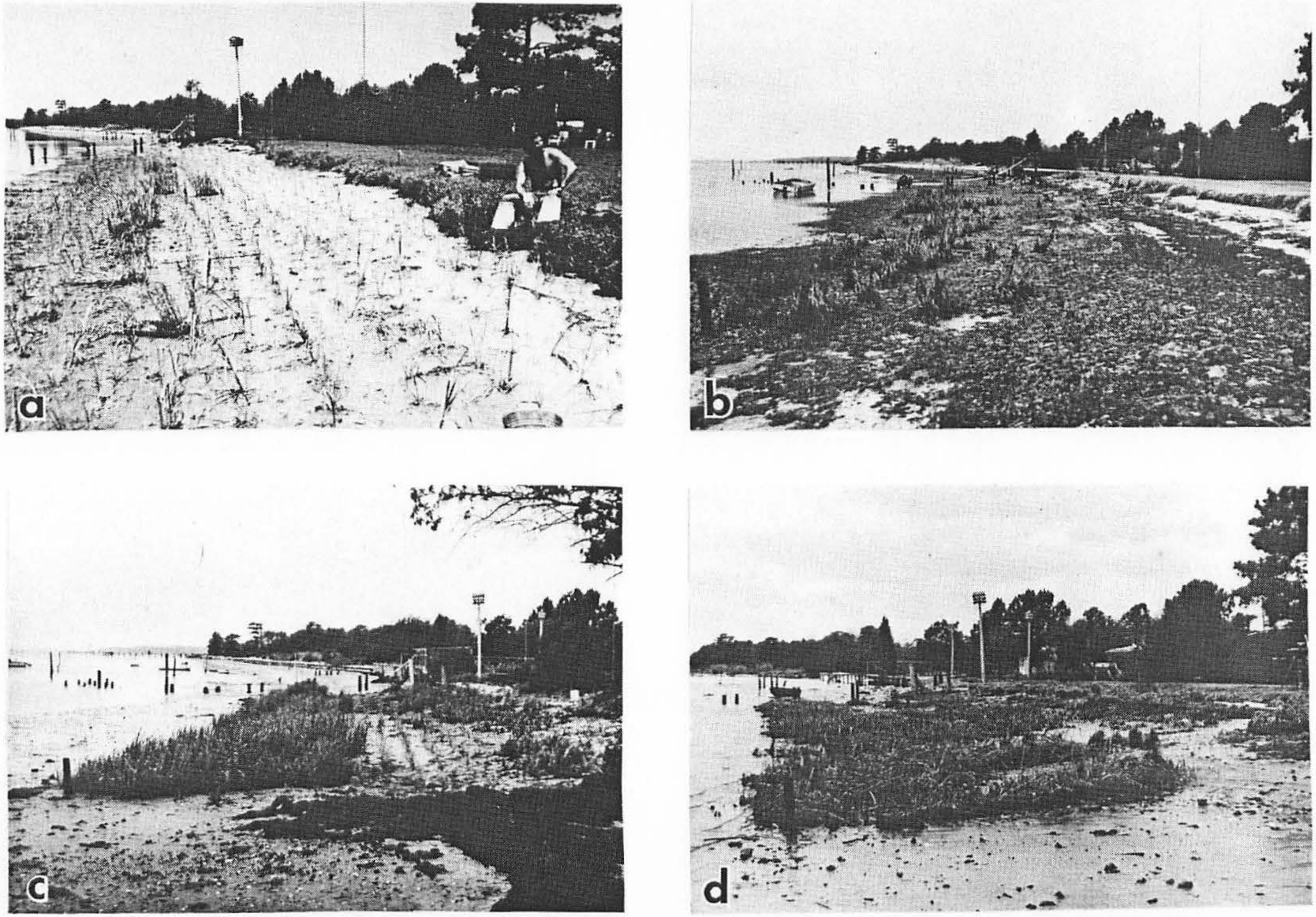
COLLIER

a. June 2, 1982
Looking west.

b. February 7, 1983
Looking west.

c. June 7, 1983
Looking west.

d. March 30, 1984
Looking west.


a
b
c
d

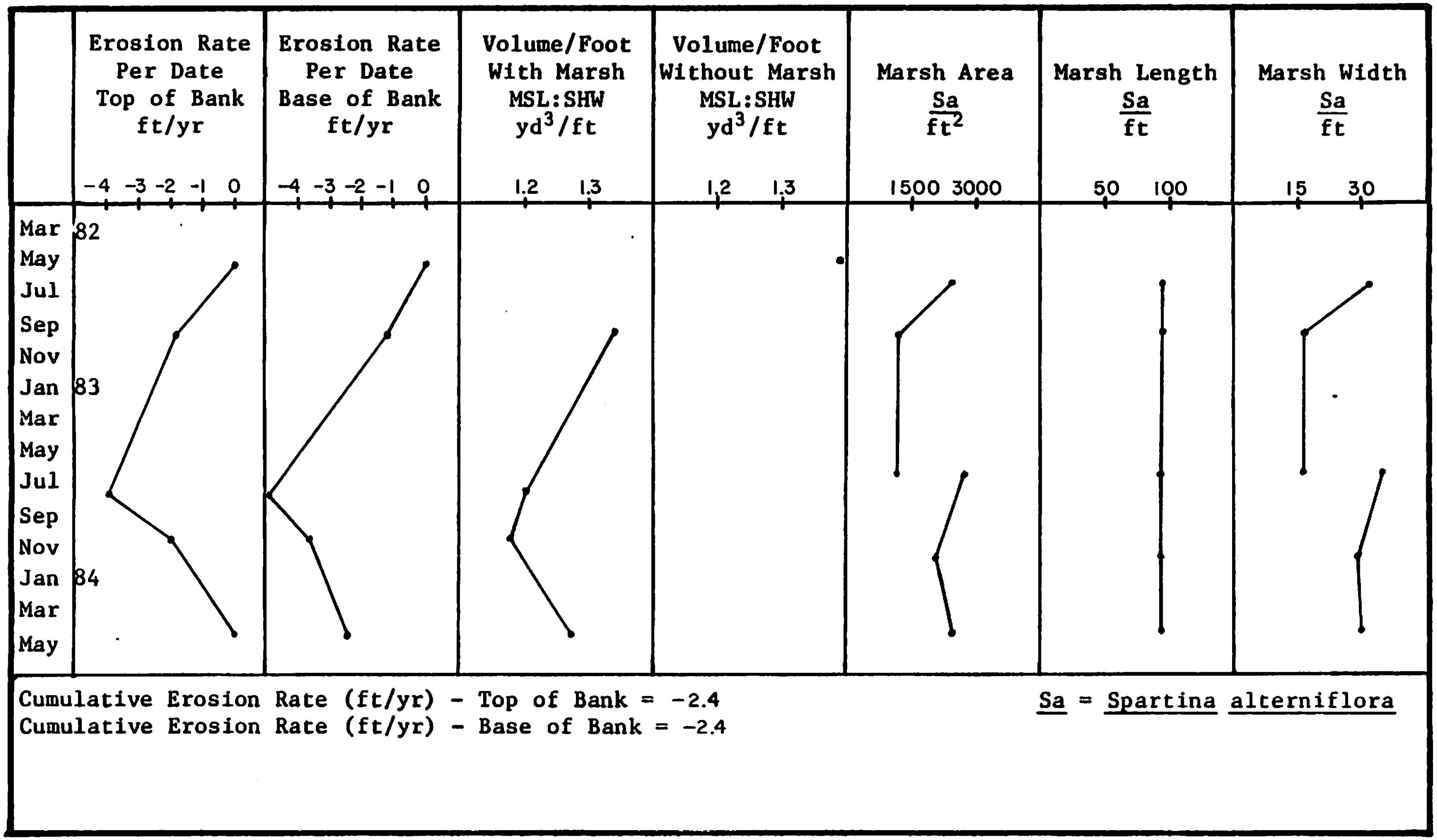


Figure 121. Collier Time Series.

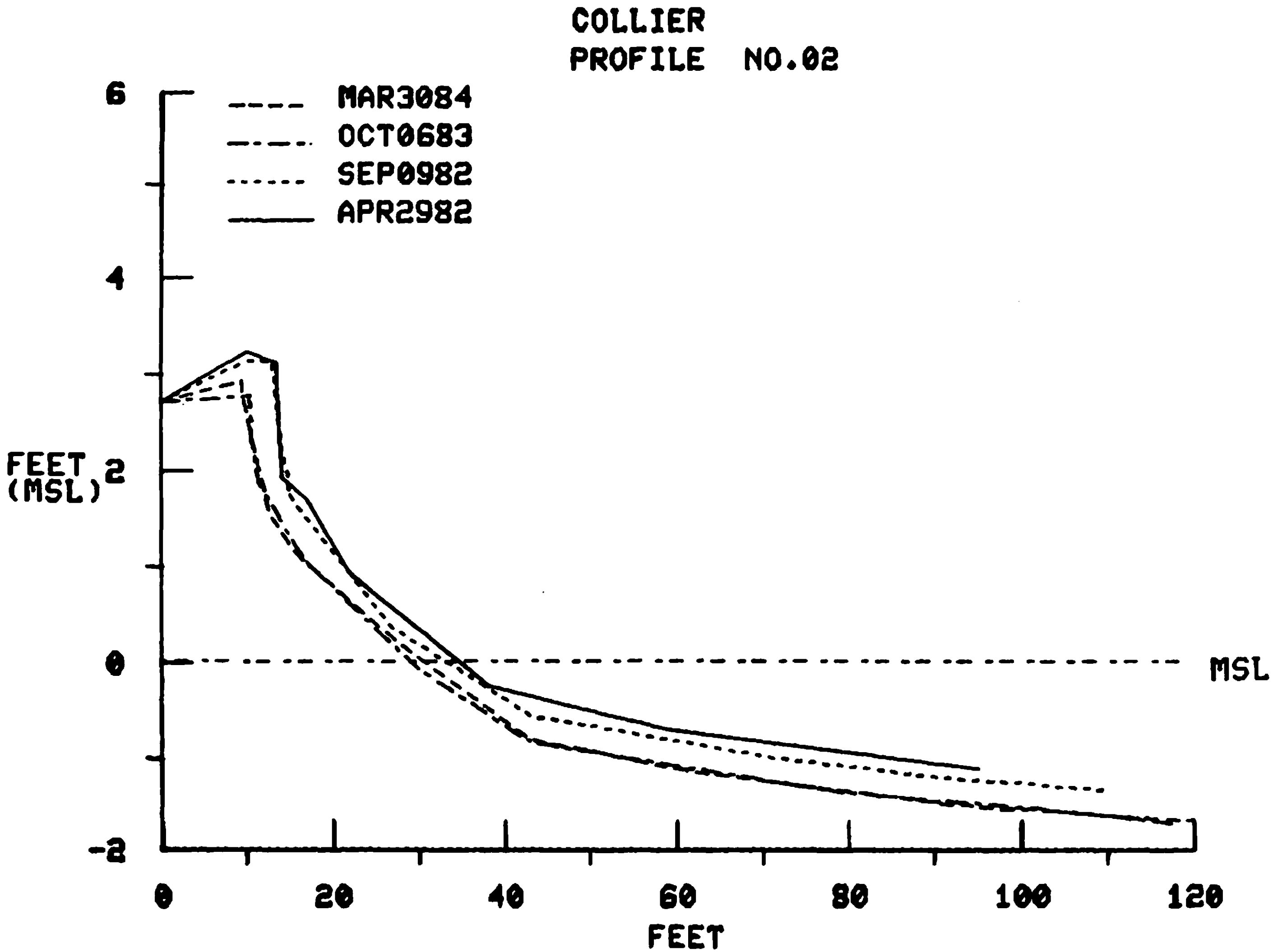


Figure 122. Collier Site - Representative Profile.

23. DAVIS - PAMUNKEY RIVER, NEW KENT COUNTY

Planted 1982

(Refer to Appendix B)

The Davis site is located across from Sweet Hall Marsh on the Pamunkey River (Figure 123). It is a low energy shore facing north northwest with an annual erosion rate of less than 0.5 foot per year (3). The fastland bank rises approximately 7 feet above MTL. The bank slope is mostly stabilized with upland vegetation. There is however a small scarp along the base of the bank in places. This scarp is produced by high water events and a combination of slight wind and boat generated waves as well as tidal currents.

There is a vegetated backshore extending from the base of the bank to just shoreward of MHW. A narrow beach extends about 12 feet from MHW to MTL. The beach is composed of silty fine to coarse sand and gravel. The substrate is rather soft. The beach sediments come from local erosion of the adjacent fastland banks and riverborne material.

There are marsh headlands on either side of VEC planting. These headlands are dominantly smooth cordgrass. Some arrow arum (*Peltandra virginica*) and three square (*Scirpus spp.*) occur along the upper limit of the headlands. Their lower limit occurs approximately 10 feet beyond the planted marsh. The upper limit of the adjacent marsh headlands is about 7 feet beyond the upper limit of the planted marsh.

The VEC site was planted in June 1982 (Figure 124). By the fall of 1982 the fringe had expanded slightly (Figure 125b) and erosion of the

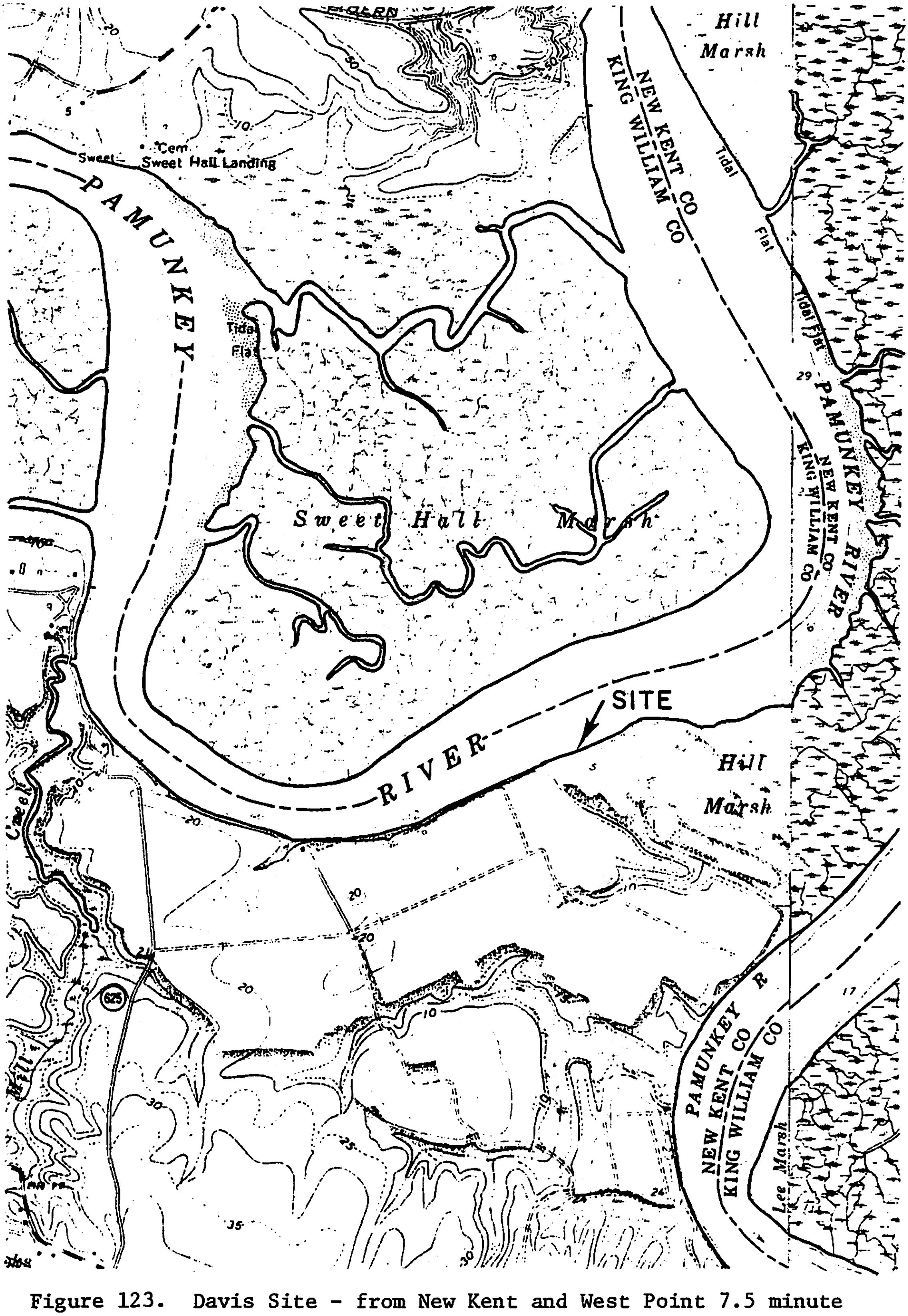


Figure 123. Davis Site - from New Kent and West Point 7.5 minute quadrangles.
Scale: 1 inch = 2,000 feet.

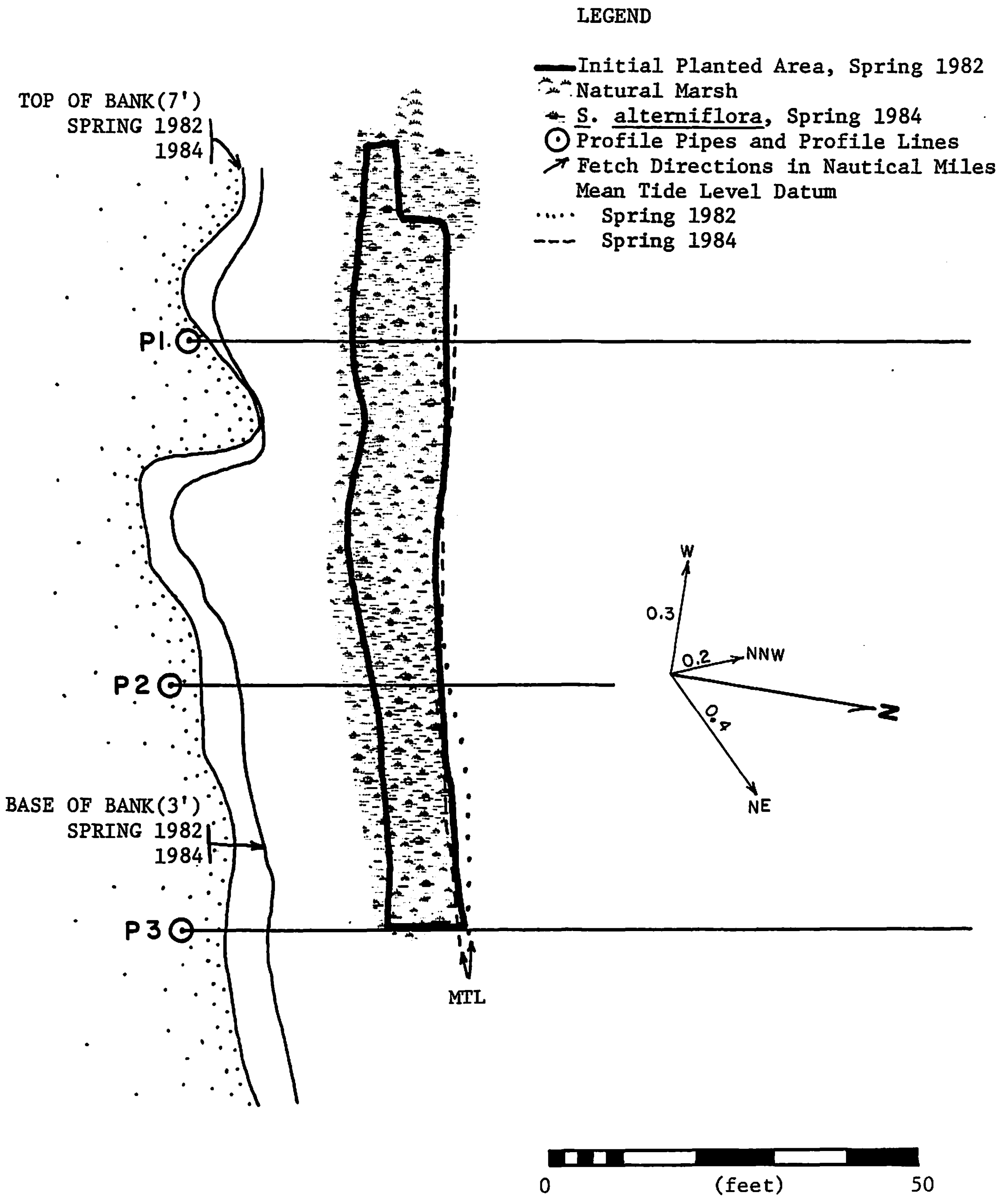


Figure 124. Davis Site - Base Map.

FIGURE 125

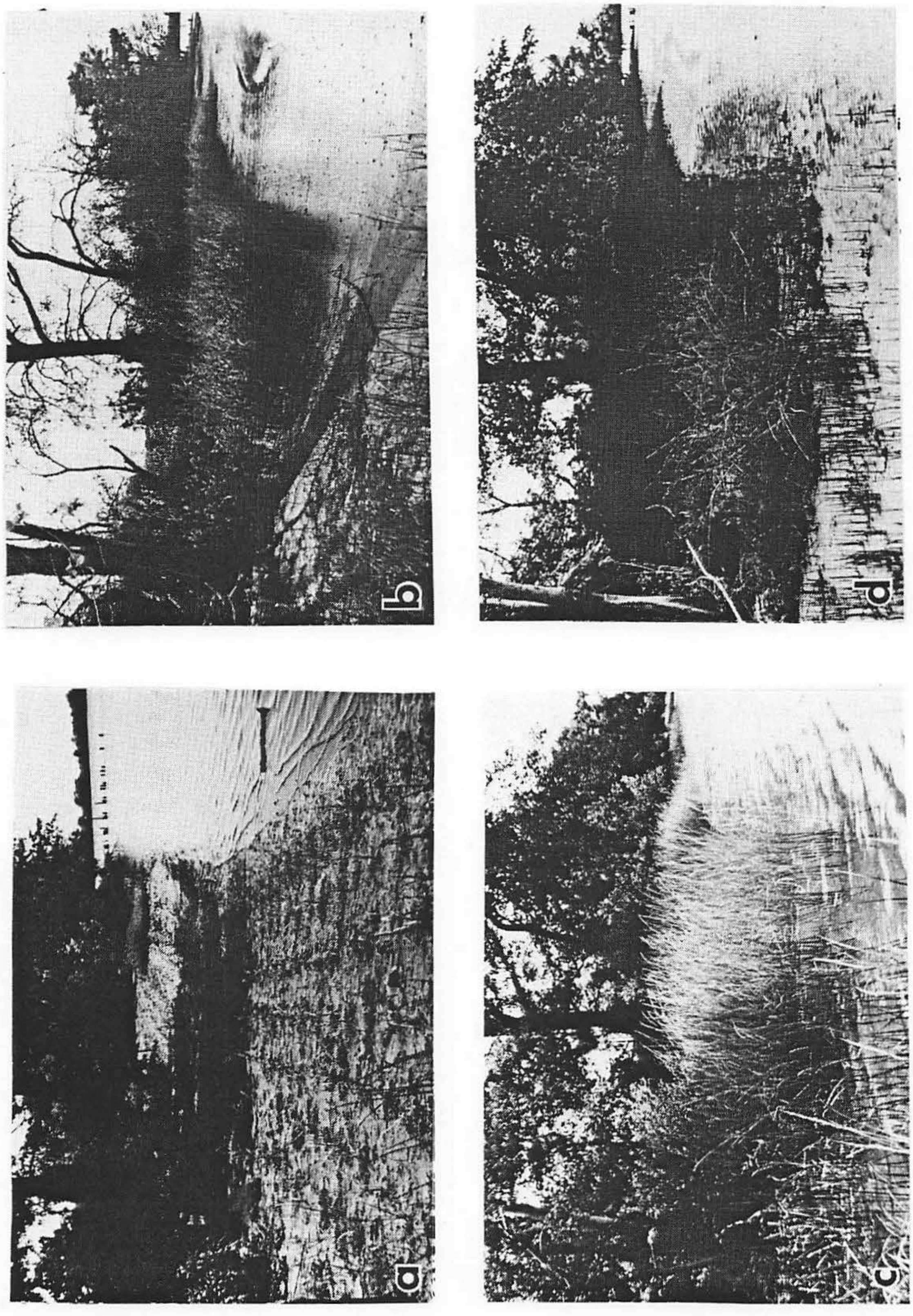
DAVIS

a. June 2, 1982
Looking west.

b. November 10, 1982
Looking west.

c. September 26, 1983
Looking west.

d. May 11, 1984
Looking west.



base of bank was noted (Figure 126). This was probably due to high water and ebb tidal current velocities after the October 25, 1982 storm. A standing crop of grasses remained through the winter of 1982-1983.

By spring of 1983 the volume of sediment in the intertidal fringe had increased, as had the marsh area and width. Continued growth over the summer of 1983 continued to expand the marsh landward as well as trap more sediment. There was slight accretion along the base of the bank also (Figure 127).

The winter of 1983-1984 showed a slight loss of marsh area along the lower edge. There was also some loss in sediment volume. Bank erosion has abated. The Davis site is a success with a thick continuous marsh fringe, stable or elevated backshore, and reduced bank erosion.

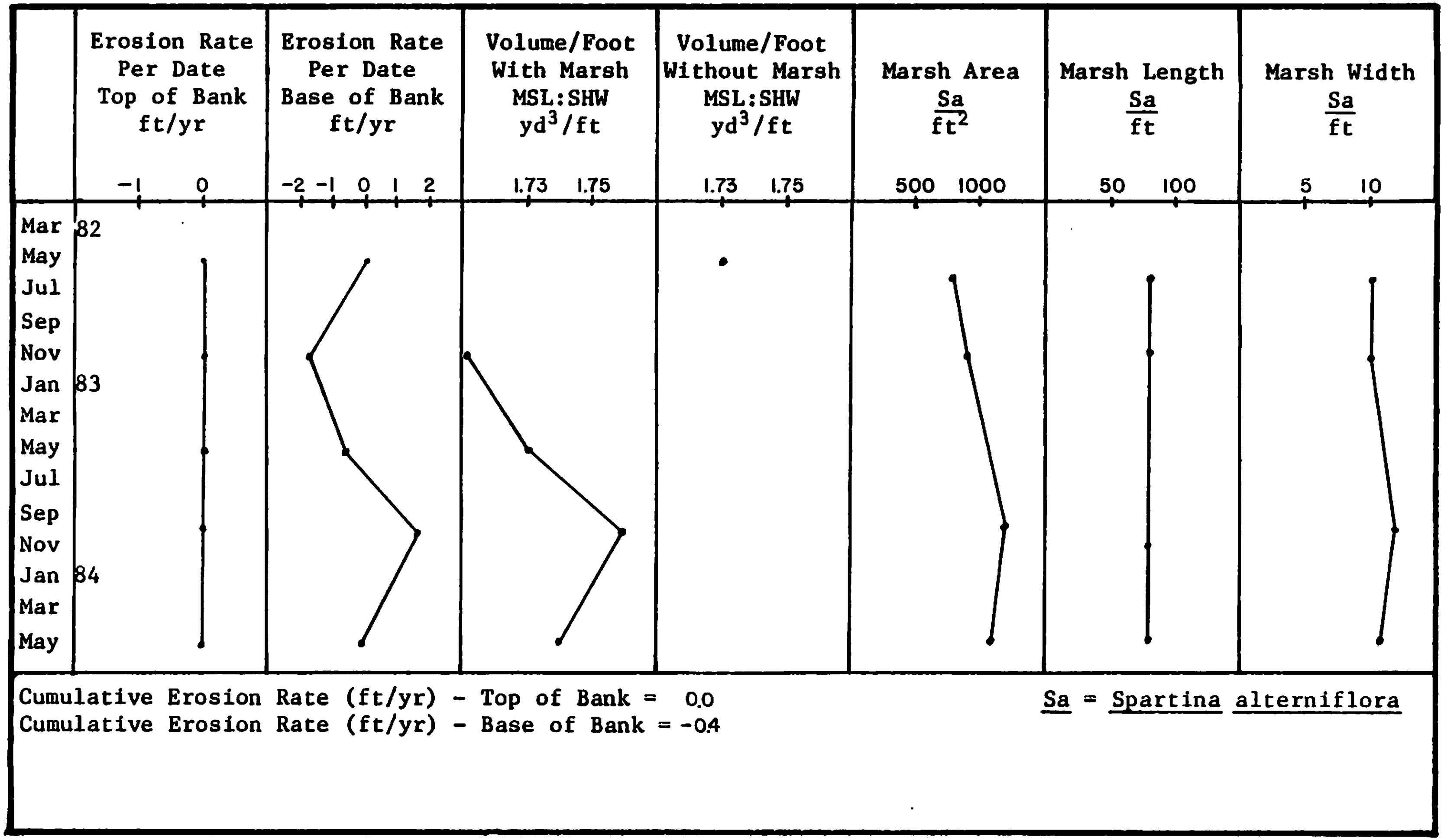


Figure 126. Davis Time Series.

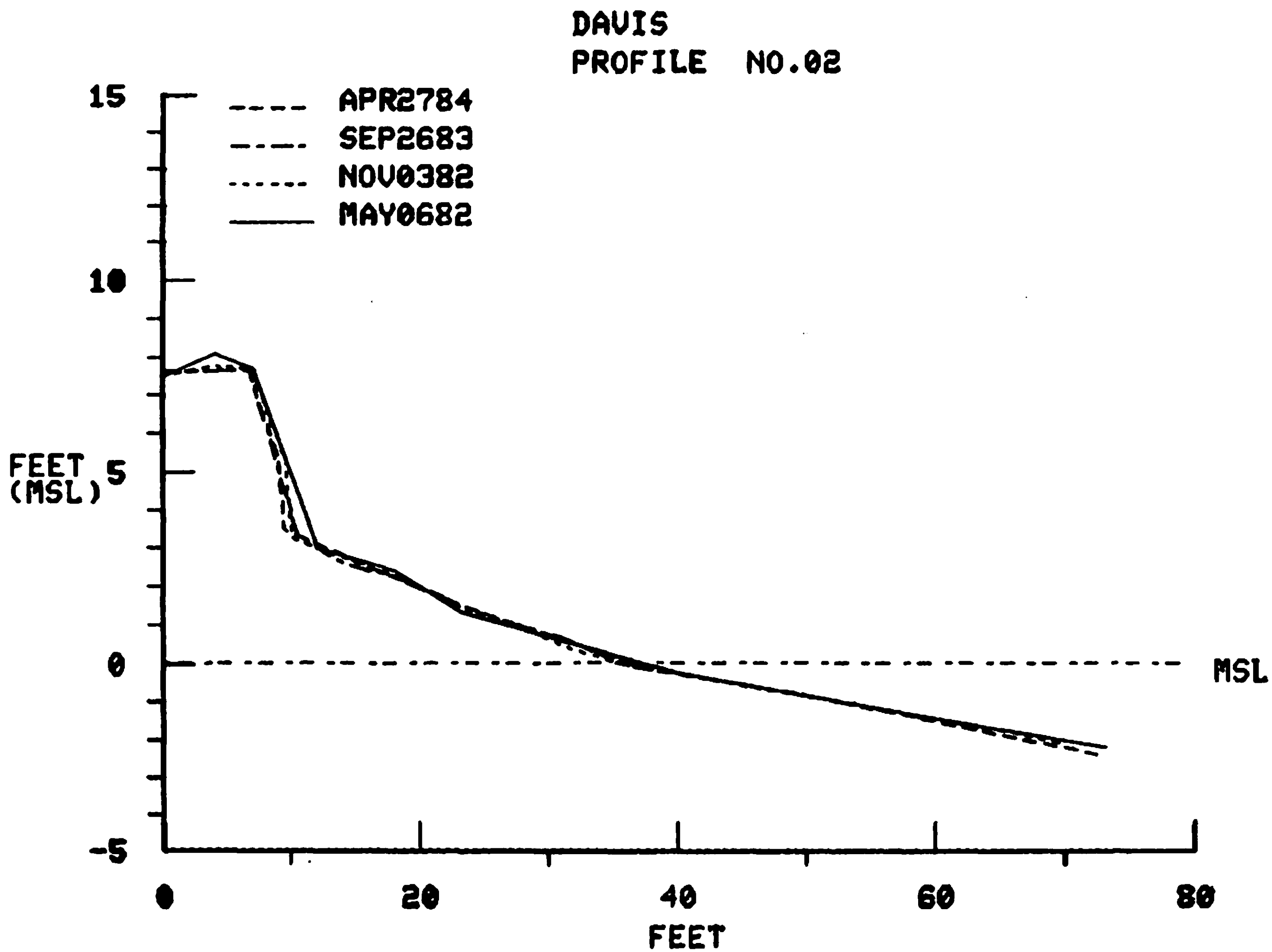


Figure 127. Davis Site - Representative Profile.

24. HOG ISLAND - JAMES RIVER, SURRY COUNTY

Planted 1983

(Refer to Appendix B)

The site is on the west facing shore of Hog Island just north of the Surry Nuclear Power Plant (Figure 128). It is a medium energy shore with 3.2 nautical miles fetch. There is a high dredge spoil bank between profiles 4 and 5. The rest of the site south is a low silty peat bank. The beach is composed of coarse sand and gravel derived from erosion of high fastland banks to the south. Thus, the net drift would be to the north along a fairly straight reach.

The initial planting was in the spring of 1983 (Figure 129). This was the youngest site in terms of monitoring and the only new one planted in 1983. There was a slight loss in marsh area over the summer of 1983 which was mostly along the lower edge. Bank erosion of the dredge spoil bank was observed.

During the winter of 1983-1984 the marsh was reduced in area and width. Bank erosion was severe (Figure 130c) and little or no sediment was retained by the intertidal fringe (Figure 131). The backshore elevation decreased (Figure 132).

Although the Hog Island site was unable to maintain the backshore elevation and reduce erosion, the marsh fringe remains very much intact. With time and maintenance the site may show a trend toward success.

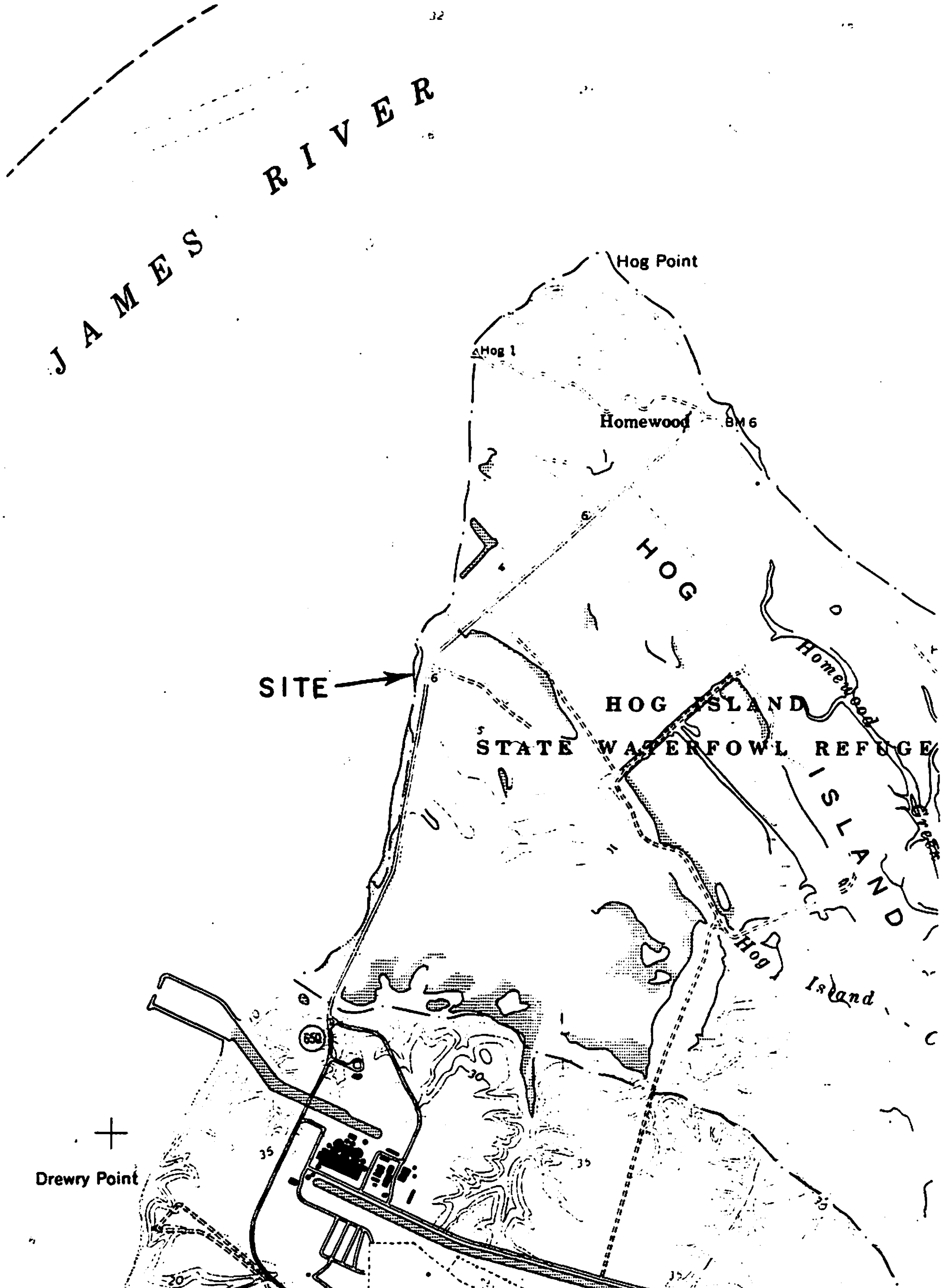


Figure 128. Hog Island Site - From Hog Island 7.5 minute quadrangle
Scale: 1 inch = 2,000 feet.

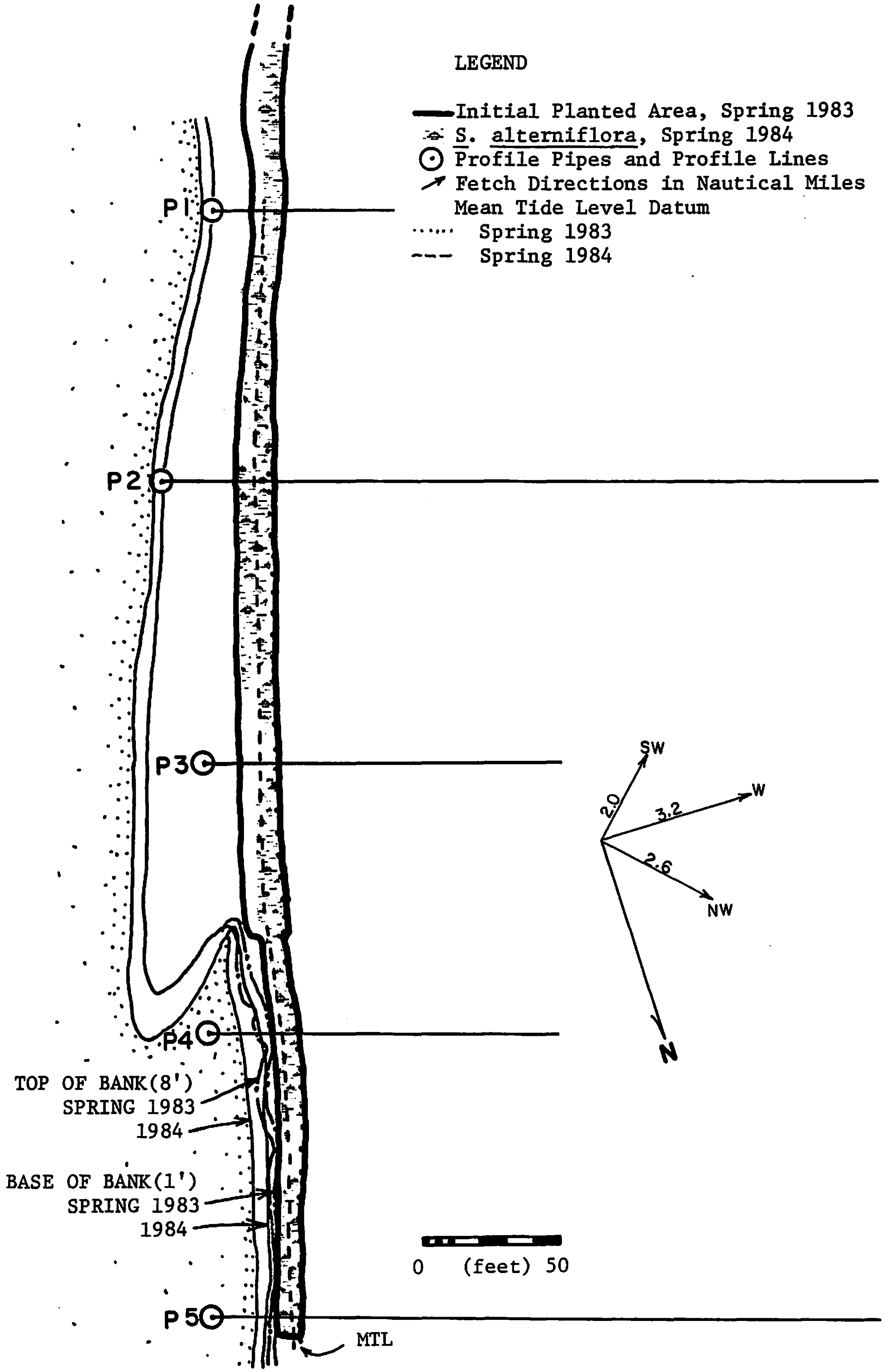


Figure 129. Hog Island Site - Base Map.

FIGURE 130

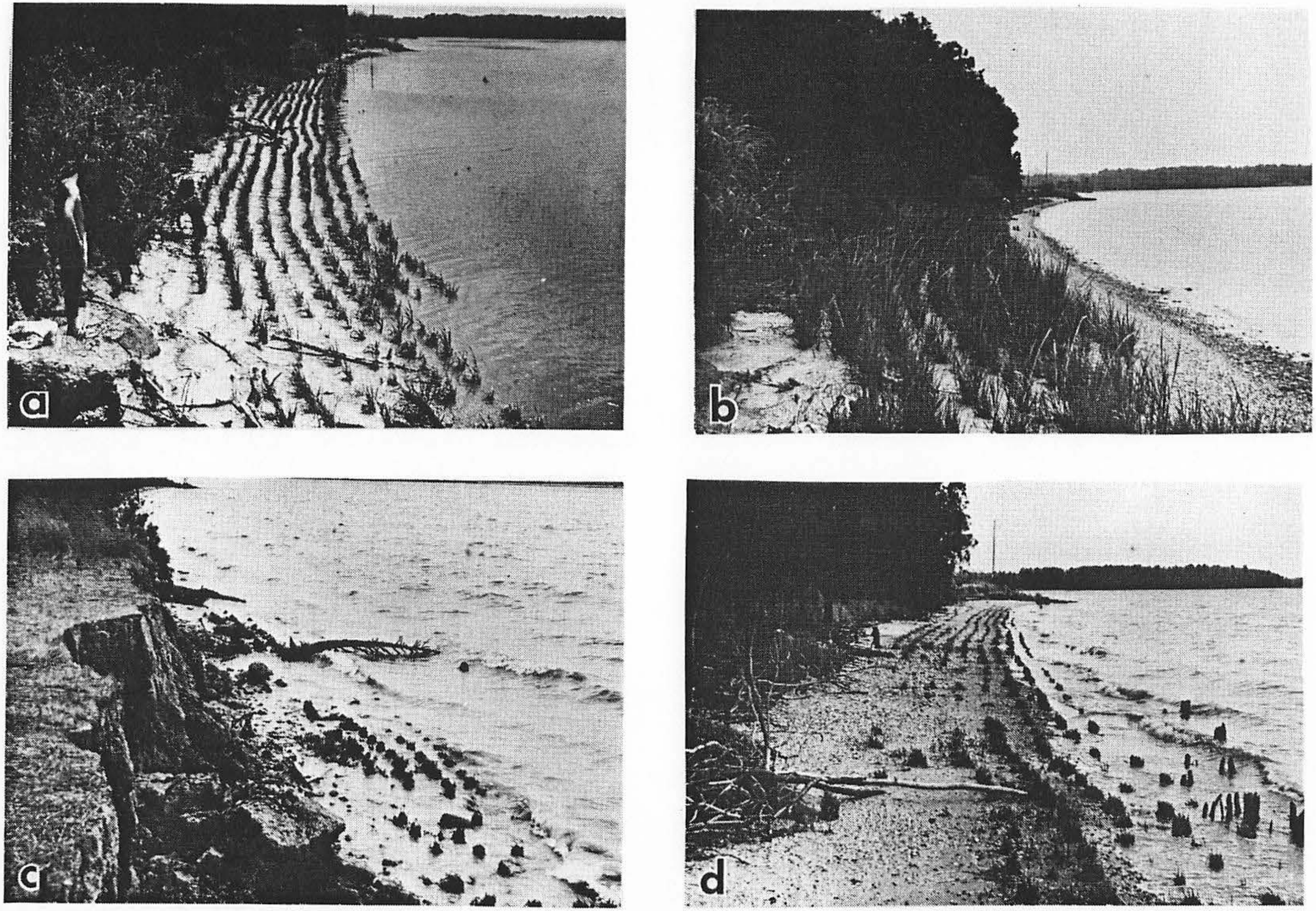
HOG ISLAND

a. July 29, 1983
Looking south.

b. September 1, 1983
Looking south.

c. April 6, 1984
Looking south.

d. April 6, 1984
Looking south.


a
b
c
d

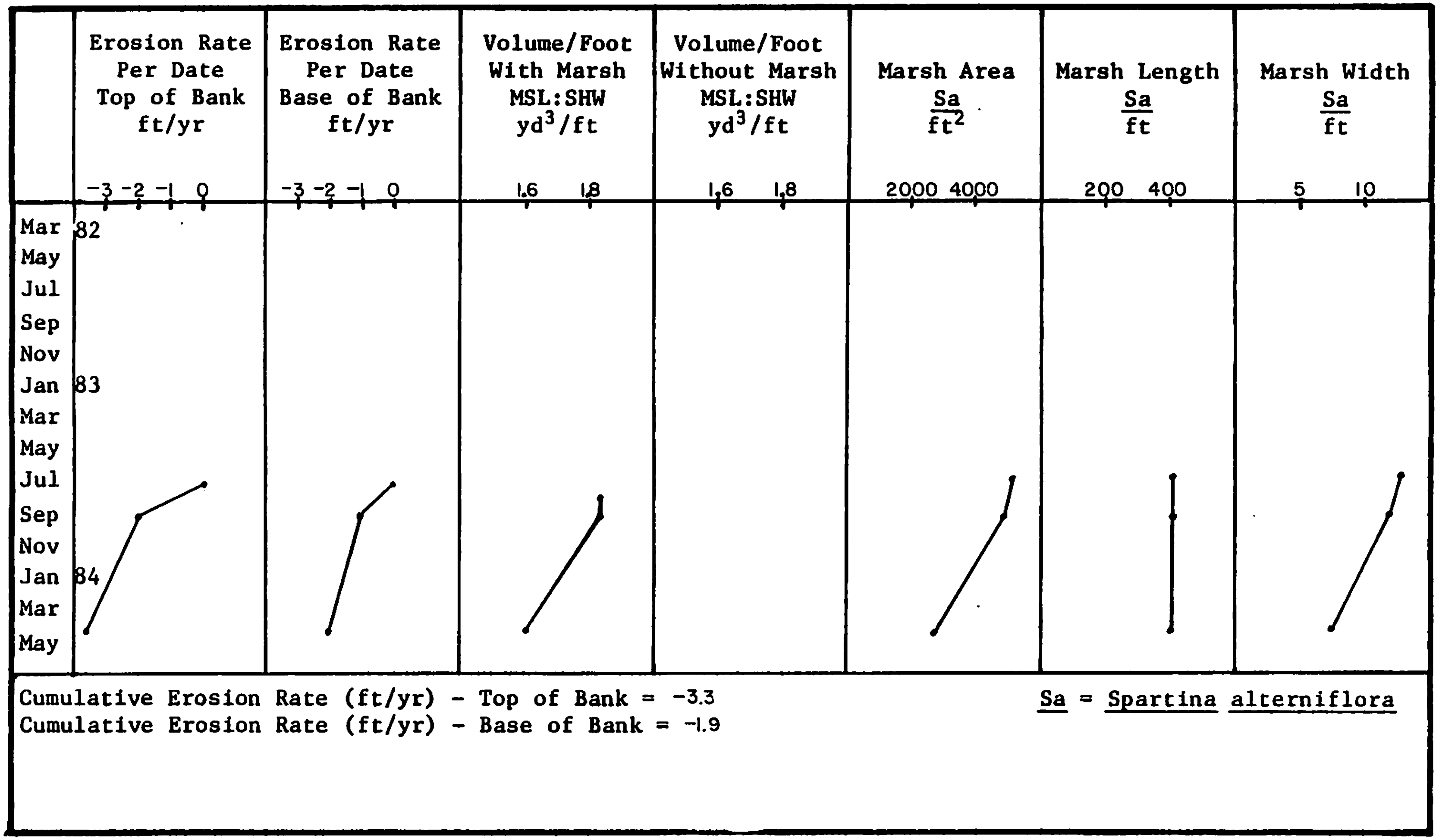


Figure 131. Hog Island Time Series.

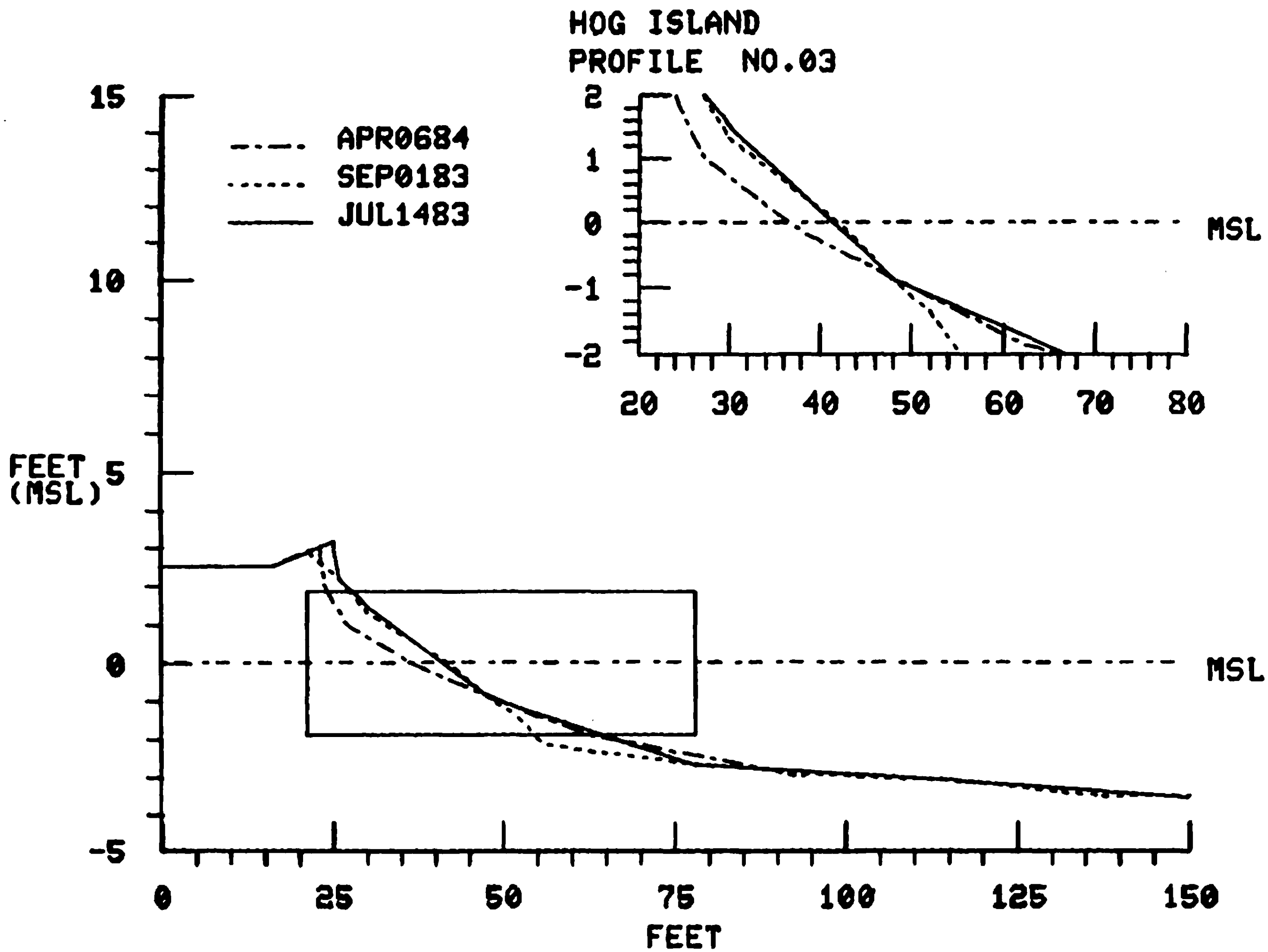


Figure 132. Hog Island Site - Representative Profile.

RESULTS

Site Analysis

There are two factors required for a planted marsh fringe to be considered successful:

1) The marsh fringe will be continuous in length and width in order to offer some degree of stabilization along the shore.
2) The elevation of the backshore will have remained stable or will have been increased due to the trapping of sediment (i.e. the adjacent eroding fastland bank or littoral drift). With the elevated backshore and stabilized upper tidal zone by the fringe, the frequency of direct wave attack on the fastland bank will be reduced and reduced bank erosion should follow.

The most critical parameter in establishing a successful marsh fringe is the wave climate at the site. This is best expressed by the average fetch. Table 6 lists the VEC sites in order of increasing average fetch (Column no. 1). The shoreline geometry (Column no. 2) and orientation (Column no. 3) are listed for each site as is the cumulative yearly erosion rate (Column no. 4) for the top and base of the bank over the monitoring period. The cumulative yearly erosion rate is the rate per year of bank erosion measured since the beginning of the project at each site.

A numerical indexing system was devised in order to provide a basis for comparison of planting success among sites. The condition of the marsh fringe at each site as of spring 1984 is given a number value.

TABLE 6

RESULTS OF THE VEGETATIVE EROSION CONTROL PROJECT AS OF JUNE 1984

			1	2	3	4		5		6	7	8
			Average Fetch (Nautical Miles)	Geometry[1]	Orientation	Cumulative Erosion Rate (Ft/Yr) Top of Bank	Base of Bank	Fringe Condition[2] Sa	Sp	Backshore Elevation[3]	Columns 5 + 6	Score* (% of Total Possible)
Low Energy	20.	Johnsen	0.01	●	NE	0.0	0.0	2	-	1	3	75
Low Energy	13.	Poole	0.04	●	SSW	0.0	-0.1	2	-	1	3	75
Low Energy	23.	Davis	0.30	■	NNW	-0.1	-0.4	2	-	1	3	75
Low Energy	4.	Lee	0.60	●	NNE	-0.1	-0.4	2	2	2	6	100
Low Energy	19.	Marshall	0.70	●	N	-0.6	-1.9	2	2	2	6	100
Low Energy	16.	Broad Bay Manor	0.80	■	NE	0.0	+1.5	2	2	2	6	100
Low Energy	12.	Murphy	0.84	■	N	0.0	-1.5	2	1	2	5	83
Medium Energy	21.	Vanderslice**	1.00	▲	E	-3.2	-3.6	1	-	1	2	50
Medium Energy	9.	Durham South	1.46	●	SSW	+0.3	-	2	2	2	6	100
Medium Energy	22.	Collier	1.50	●	S	-2.4	-2.4	2	-	1	3	75
Medium Energy	10.	Durham West	1.60	■	W	-1.7	-2.4	2	-	0	2	50

[1] ● - Semi-Protected Shore
■ - Straight or Meandering Shore
▲ - Headland

[2] 0 - Little or No
1 - Discontinuous
2 - Continuous

[3] 0 - Loss
1 - Stable
2 - Gain

* Sites with Sa will have a score total of 4 possible.
Sites with Sp will have a score total of 6 possible.
** On a headland but semi-protected from the Bay by barrier islands.

Sa = *Spartina alterniflora*

Sp = *Spartina patens*

TABLE 6
Cont'd.

		1 Average Fetch (Nautical Miles)	2 Geometry[1]	3 Orientation	4 Cumulative Erosion Rate (Ft/Yr) Top of Bank	 Base of Bank	5 Fringe Condition[2] Sa	 Sp	6 Backshore Elevation[3]	7 Columns 5 + 6	8 Score* (% of Total Possible)
Medium Energy	14. York River State Park	2.00	■	NNE	-1.5	-1.6	1	-	0	1	25
	8. Wellford	2.30	■	SW	-0.2	-0.3	1	-	1	2	50
	15. Eley	3.00	■	N	-1.1	-1.4	2	-	1	3	75
	2. Camp Chanco	3.10	●	ENE	-0.4	-1.4	1	1	1	3	50
	24. Hog Island	3.20	■	W	-3.3	-1.9	2	-	0	2	50
	11. Garrett	3.50	●	ENE	-0.1	-0.8	2	1	1	4	66
High Energy	18. King	5.10	■	ENE	-7.0	-7.3	1	1	2	4	66
	17. Mariners Museum	5.70	■	SW	-4.2	-4.6	0	1	0	1	17
	6. Hickman	11.00	●	NW	-5.7	-	2	-	0	2	50
	3. Windmill Point	13.40	▲	SSW	-4.5	-	0	0	0	0	0
	5. Gill	15.00	■	NNE	-3.6	-4.6	0	0	0	0	0
	1. Mountjoy	15.60	■	S	-3.9	-3.9	0	-	0	0	0
	7. Tankard	22.0	■	WNW	-16.5	-17.7	0	0	0	0	0

[1] ● - Semi-Protected Shore
■ - Straight or Meandering Shore
▲ - Headland

[2] 0 - Little or No
1 - Discontinuous
2 - Continuous

[3] 0 - Loss
1 - Stable
2 - Gain

* Sites with <u>Sa</u> will have a score total of 4 possible.
Sites with <u>Sp</u> will have a score total of 6 possible.

** On a headland but semi-protected from the Bay by barrier islands.

<u>Sa</u> = <u>*Spartina alterniflora*</u>

<u>Sp</u> = <u>*Spartina patens*</u>

Each grass species is treated separately where appropriate. A continuous fringe, defined as having about 75% of the original planted length remaining, is assigned a value of 2. A patchy, discontinuous fringe with 25% to 75% of its original planted length remaining is assigned a value of 1. A fringe with less than 25% of the original planting length is given a value of 0. These values are listed in column No. 5.

The backshore elevation in terms of gain, loss or no change is also given a numerical value. These are listed in column No. 6. A value of 2 was given a site if the backshore elevation (that area between the marsh fringe and base of bank) had measurably increased since the initial planting. If there was a stabilized backshore even with slight gains and losses over time, the site was given a value of 1. Cases with a significant loss in backshore elevation were given a value of 0.

The numerical values given to the condition of the fringe marsh and backshore elevation at each site were added to see the trend toward a successful or failing result (column No. 7 in Table 6). Since experience has shown that it may take several years for complete marsh establishment, it may still be too early to see a dramatic effect on erosion rates for all sites. Therefore erosion rate was not used in the numerical ranking system.

Sites with only smooth cordgrass remaining will have a total possible score of 4. A site with smooth cordgrass and saltmeadow hay has a total possible score of 6. Column 8 displays each site's score in terms of percent.

For a site to be trending toward success it must have a continuous marsh fringe in order to adequately protect an eroding bank. Thus, a fringe condition score of 2 is necessary. The sites most trending toward success will have a continuous fringe and a stable or elevated backshore (if there is an adequate supply of sediment). Thus, a score of 75% and a fringe condition of 2 is needed to achieve these criteria. A site with a score of 25% or less and a fringe condition of 1 or less will be a failure. Partially successful sites will have a score between 25% and 75% with a fringe condition of 2. A score between 25% and 75% and a fringe condition of 1 or 0 indicates a trend toward failure.

It is apparent in Table 6 that all the low energy sites are trending toward success. The lower low energy sites (less than 0.5 nautical mile average fetch), Johnsen (No. 20), Poole (No. 13) and Davis (No. 23), have an insufficient source of sediments to the backshore due to negligible bank erosion. Thus, there is no significant increase in backshore elevation. The upper low energy (0.5 to 1.0 nautical mile average fetch) sites, Lee (No. 4), Marshall (No. 19), Broad Bay Manor (No. 16) and Murphy (No. 12) all had a wide enough backshore region (*i.e.* above MHW) to plant saltmeadow hay. Bank erosion supplied much of the material to elevate the backshore.

The relatively high cumulative erosion rate at Marshall is due to severe bank erosion at profile 5 (page 192). Here the fringe is scant to non-existent. In fact the fringe to the west is almost acting as a groin to trap and hold sand, and prevent its movement to the east. Thus, the beach at profile 5 decreased. With no fringe and a narrow beach wave attack on the sandy high bank is frequent. The cumulative erosion rate at Murphy is anomalously high due to a bulldozer modifying the base of the bank. At Broad Bay Manor an accretion rate is noted along the base of the bank. This is due to bank erosion with subsequent slumping which carried bank material down and beyond the position of the initial mapping in the spring of 1982.

It should be noted that none of the low wave energy sites needed extensive maintenance planting except Murphy. (A bulldozer destroyed much of the planting at the Murphy site in the fall of 1982.) Maintenance planting will be an important consideration for a property owner who is deciding whether marsh implantation is the erosion control method he wants.

In the medium energy regime shoreline geometry and orientation become more important factors. The most successful medium energy site to date is Durham South (No. 9). It is a south facing semi-protected shore with an accretion rate of the base of bank and the only 100% score in its wave energy class.

The Durham South site is one of three sites in the medium wave energy realm with a saltmeadow hay fringe. Also that fringe is in the best condition. As mentioned, Durham South is semi-protected and has an abundant supply of sand. It has also experienced an advance in the position of the bank.

Two other sites in the medium wave energy class strongly trending toward success (percent scores of 75% or better with a fringe condition of 2) are Collier (No. 22) and Eley (No. 15). The Collier site, very wave attack on the sandy high bank is frequent. The cumulative erosion rate at Murphy is anomalously high due to a bulldozer modifying the base of the bank. At Broad Bay Manor an accretion rate is noted along the base of the bank. This is due to bank erosion with subsequent slumping which carried bank material down and beyond the position of the initial mapping in the spring of 1982.

It should be noted that none of the low wave energy sites needed extensive maintenance planting except Murphy. (A bulldozer destroyed much of the planting at the Murphy site in the fall of 1982.) Maintenance planting will be an important consideration for a property owner who is deciding whether marsh implantation is the erosion control method he wants.

In the medium energy regime shoreline geometry and orientation become more important factors. The most successful medium energy site to date is Durham South (No. 9). It is a south facing semi-protected shore with an accretion rate of the base of bank and the only 100% score in its wave energy class.

The Durham South site is one of three sites in the medium wave energy realm with a saltmeadow hay fringe. Also that fringe is in the best condition. As mentioned, Durham South is semi-protected and has an abundant supply of sand. It has also experienced an advance in the position of the bank.

Two other sites in the medium wave energy class strongly trending toward success (percent scores of 75% or better with a fringe condition of 2) are Collier (No. 22) and Eley (No. 15). The Collier site, very well protected by Sandy Point spit, (a very shallow nearshore, broad intertidal zone) has the widest fringe of all sites. The Eley site has, after maintenance planting, a substantial fringe but has been unable to elevate the backshore even with sufficient sediment input via bank erosion. At this point there is enough backshore width to plant saltmeadow hay. This action might help trap sand and increase the backshore elevation thereby reducing wave activity against the base of the bank. However, the Eley site is rather exposed (straight shore) with an average fetch of 3.0 nautical miles. From our experience maintenance planting will be required.

The Garrett site (No. 11) has a score of 66% with a tendency toward success due to a healthy continuous fringe. It is semi-protected by a marsh headland and fallen trees on the shore to the west and a rock revetment headland to the east. Thus, the cumulative erosion rate is relatively low given the average fetch exposure.

In contrast to the protected Garrett site, the Vanderslice site (No. 21) is situated on a headland. The discontinuous marsh fringe has partially stabilized the backshore which has become wider due to bank erosion. An application of saltmeadow hay would be appropriate. However, severe wave conditions exist due to the close proximity to the Chesapeake Bay. The site is trending toward failure. Marsh establishment will require ongoing maintenance planting.

The Durham West (No. 10) and Hog Island (No. 24) sites both face west and are exposed to relatively high wave conditions. They both have continuous smooth cordgrass fringes but are unable to stabilize the backshore due to their exposure. With time and maintenance planting they may begin to have a positive effect on the backshore. Proposed maintenance planting of Hog Island in the spring of 1984 will be a help.

Camp Chanco (No. 2) is protected from northwest winds but is very exposed to the north and northeast. Three years of growth without maintenance planting has left a discontinuous smooth cordgrass and saltmeadow hay fringe. Even though the backshore appears stabilized the site is trending toward failure. There is a proposed maintenance planting in the spring of 1984.

The Wellford site (No. 8) had a continuous successfully trending smooth cordgrass fringe in 1981 and 1982 with an elevated backshore. The fringe has deteriorated since the fall of 1982 even with maintenance planting in spring of 1983. Much of the once elevated backshore has been reduced and with a very discontinuous fringe the site is trending toward failure.

York River State Park (No. 14) has little of the original smooth cordgrass fringe remaining. The peat bank has been continuously eroding and the backshore decreasing in elevation. The site is strongly trending toward failure.

Three high wave energy sites have fringes remaining. The King site (No. 18) has a discontinuous smooth cordgrass and saltmeadow hay fringe left that are maintaining an elevated backshore region and helping to stabilize the adjacent slump material. However, without continued maintenance planting the site seems to be trending toward failure due to potential and recorded wave attack at the site. Mariners Museum (No.

17) with little or no smooth cordgrass fringe remaining and a discontinuous saltmeadow hay fringe which has not stabilized the backshore is trending toward failure. The Hickman site (No. 6) has a healthy continuous fringe but no backshore due to minimal sand supply. Erosion of the adjacent banks supplies only fine sand and silt which are quickly carried off. The Hickman site is partially protected by a sand spit and an offshore tire breakwater which the landowner is installing. The marsh fringe may last longer than its long fetch exposure would allow under unprotected conditions.

The last four sites are Windmill Point (No. 3), Gill (No. 5), Mountjoy (No. 1) and Tankards (No. 7). They failed in the first growing season of each planting. No grasses remain.

Biomass Results

In 1983-1984, the final year of the project, greater focus was placed on below ground production than in the past for several reasons. First, it is this component of production which survives through the winter and initiates new growth in the spring. Since the roots and rhizomes are the more stable portions of the plants, we would expect additions in biomass each year if the marshes are doing well. In previous years, below ground samples of a particular site, species, or plot were combined before processing because all that was desired was an average biomass value. In 1983-1984, however, each sample was analyzed separately in order to assess differences in below ground production at higher elevations to production at lower elevations of a marsh, and below ground production differences in one year old versus two year old plants. We found that vegetative production was generally superior in the upper elevations of the marshes than in the lower elevations. Also, by separating the below ground samples of the original marsh from those of the portions which had been replanted, we had much more information available regarding early marsh growth. Production generally improved from one year to the next in low and medium energy environments.

The method in which the age(s) of the vegetation on each site was determined is as follows. In 1981, 12 sites had been planted, of which only 2 (Camp Chanco and Hickman) did not receive any maintenance planting. As of fall 1983 these two sites were the only ones which were completely the product of three years growth. There was, however, one other site which was treated as having three years of growth. The Lee site was planted in 1981 but was maintenance planted with very few new sprigs in June 1983. Because none of the fall 1983 samples were taken in the new growth, the biomass data reflects only the production of the three-year old vegetation. The remaining nine sites were partially or totally replanted once or twice in the following two years.

Eleven new sites were added in 1982, and of these only 2 were not replanted the following year. However, the new plants which were added to 2 other sites did not survive, apparently because they were planted too low in the intertidal zone. Consequently at the end of 1983, 4 of these 11 sites had only 2 year old plants.

Only one additional site was planted in 1983. Although not all of the marshes had survived, there were a total of 24 sites which had been planted and monitored during the project. Since several of these sites were substantially replanted during the course of this project, there was much information available on the biomass production during a planted marsh's first year. For example, since Garrett's was totally replanted 3 times in the 3 years we monitored that site, we collected biomass measurements of only 1 year's growth each time. Furthermore, the below ground sampling procedures were more detailed in 1983 than in the previous two years. As a result, we have much more data, and therefore confidence, regarding early marsh growth than we do for older marsh production.

Table 7 displays the average above and below ground biomasses for *Spartina alterniflora* and *Spartina patens* at the end of 1, 2, and 3 years. The numbers in parentheses beside the averages represent the number of data sets that were available to obtain the averages. If there were few data sets available for a particular average, then we cannot be very confident that the average represents the normal trend for a marsh. For example, the values for above ground *Spartina alterniflora* at the end of 3 years' growth are lower than we would expect for the Low and Medium Energy sites. Likewise, the values for above ground *Spartina patens* at the end of 2 and 3 years of growth are higher than expected for the Medium Energy sites. As previously mentioned, since some sites were totally replanted, there were more data sets available for the 1 and 2 year columns than we would have if the sites were not replanted.

TABLE 7

BIOMASS RESULTS FOR VEC PROJECT

	Above Ground Sa Lb/Ft^2			Below Ground Sa Lb/Ft^2			Above Ground Sp Lb/Ft^2			Below Ground Sp Lb/Ft^2		
	1	2	3	1	2	3	1	2	3	1	2	3
Low Energy	.11(9)	.23(6)	.09(1)	.04(10)	.09(6)	.15(1)	.04(5)	.05(4)	.16(1)	.03(5)	.07(4)	.02(1)
Medium Energy	.07(19)	.12(6)	.04(2)	.04(19)	.04(6)	.04(2)	.02(8)	.19(2)	.23(1)	.03(8)	.10(2)	.02(1)
High Energy	.02(10)	-	-	.01(10)	-	-	.02(7)	.01(1)	-	.02(7)	.01(1)	-
Total	.07(38)	.18(12)	.06(3)	.03(39)	.07(12)	.08(3)	.03(20)	.09(7)	.20(2)	.02(20)	.07(7)	.02(2)

Sa = *Spartina alterniflora*

Sp = *Spartina patens*

It was also observed that, although the Spartina stems were dying and being washed away during late fall, the roots were increasing greatly in biomass. This increase was due to translocation of nutrients from the stems to the roots before the stems die. This mechanism enhances the potential for a good start the following spring.

The analysis of below ground biomass further indicated that Spartina alterniflora grows best between mean sea level (MSL) and mean high water (MHW). It is suspected that once the marsh becomes established in this zone, it will then be able to gradually spread to lower water levels via rhizome production.

On low energy sites there was a tendency for culm diameters of Spartina alterniflora to be slightly greater than those in medium and high energy sites. This may affect growth under less stressful conditions of wave climate. Also, there was a tendency for greater stem densities among the Spartina alterniflora fringes on southern facing sites. This may be attributed to longer exposure to direct sunlight. Culm diameter and stem density are considered important factors in wave attenuation by marsh grass fringes.

Wave Climate

We have stressed that wave climate is the single most important factor in establishing a planted marsh fringe. Stress by wave action will determine how soon a marsh can become established. The frequency, elevation and direction the waves approach from are determined by the accompanying wind field. The fetch exposure, shore orientation and offshore bathymetry will determine how a given wind will impinge on a particular site.

For example, let us say a site along a straight shore is receiving a steady 20 mph wind directly across about 2.0 nautical miles of open water. The water level is 3 feet above MLW. The depth of river over which the wind is blowing can be divided into segments of equal depth; in this example case, the farshore shelf (5 feet), mid-river (30 feet) and the nearshore shelf (5 feet). A steady 20 mph wind starts building the waves on the water surface across the shallow farshore shelf. As the waves approach the deeper mid-river they become greater in height. When the waves reach the shallow nearshore shelf bottom friction due to shoaling at reduced water depths causes a reduction in wave height but there will be a slight increase in height at the shore just before they break. Generally, the higher the water level (storm surge) the greater the potential wave height and of course the longer the fetch the greater the potential wave height. Also, the stronger the wind the greater the wave height. Wave refraction and defraction around headlands and coves will alter the wave approach. So one can see that a complex set of variables will determine the wave climate at a given site.

An empirical analysis was done at each site by determining the fetch exposure for several wind directions that affect each site. Bathymetric changes were measured across the creek, river, or bay where the site is located. This data was run through a computer program developed by Kevin Kiley at VIMS (7). Different water levels and wind velocities could then be applied to the physical situation of each site.

Table 8 shows impinging wave height, period, and length for each site under conditions of a water level 3 feet above MLW, a 20 mph wind and wind direction normal to the site. Wave heights vary across medium and high energy sites; nearshore bathymetry being the apparent controlling factor. Low energy sites show low wave heights as expected (i.e. fetch-limited). Limited wave observation at Wellfords, Camp Chanco and Durham West support these results.

Wave Attenuation

As the VEC marshes continue to grow and expand, their ability to trap sediment and reduce wave action against the adjacent bank should increase. Knutson et al. performed a field study in 1982 to quantify wave damping in smooth cordgrass marshes (10). The objective of this field test was to test an empirical model developed by R.G. Dean for wave damping in vegetation and to calibrate this model for use in coastal marshes.

Waves generated by a passing boat were measured as they passed through the field study marsh with a series of surface wave gages. Also, biomass samples were taken at each gage to measure 1) plant height, 2) stem length, 3) stem density and 4) stem diameter.

It was assumed that waves transmitted through a marsh actually encounter the vertical stems of plants. And so, for a given marsh this assumption becomes less valid as water depth is increased (10). Under the field test conditions the taller plants exceeded the depth of water.

In analyzing the wave data there are four principle variables affecting wave damping according to Dean's model. They are: 1) the

TABLE 8

POTENTIAL WAVE GENERATION ON VEC SITES

WITH 20 MPH WIND AND A 3-FOOT SURGE

	Wind Direction	Effective Fetch (ft)	Wave Height (ft)	Wave Period (sec)	Wave Length (ft)
Johnsen	NE	67	0.14	0.66	2.21
Poole	SSW	657	0.36	1.13	6.58
Davis	NNW	1439	0.50	1.36	9.51
Lee	NNE	3150	0.68	1.63	13.40
Marshall	N	3435	0.66	1.62	13.19
Broad Bay Manor	NE	4018	0.71	1.69	14.22
Murphy	N	4700	0.79	1.81	16.09
Vanderslice	E	27250	0.51	1.39	9.86
Durham South	SW	11250	1.04	2.26	23.10
Collier	S	37000	0.95	2.37	23.02
Durham West	W	10200	1.08	2.36	24.50
York River State Park	NNE	9173	0.96	2.08	20.29
Wellford	SW	10300	0.99	2.15	21.25
Eley	N	13780	1.12	2.56	27.50
Camp Chanco	NE	15540	1.12	2.57	27.50
Hog Island	W	19300	1.28	2.74	31.90
Garrett	NE	15700	1.12	2.56	27.50
King	ENE	27700	0.95	2.36	22.88
Mariners Museum	SW	28650	0.95	2.37	22.99
Hickman	WNW	75000	1.12	2.57	27.60
Windmill Point	SW	28150	1.28	2.74	31.90
Gill	NNE	67000	1.28	2.74	31.90
Mountjoy	S	45000	0.95	2.37	22.97
Tankard	W	103220	1.12	2.56	27.50

height of the wave approaching the marsh, 2) the distance through the marsh the wave has traveled, 3) the depth of the water as the wave passes through the marsh and 4) the diameter and spacing of the plants. The height of the transmitted wave can be estimated by the following equation:

$$H_2 = \frac{H_1}{1 + AH_1 \Delta \ell}$$

where H_2 = the wave height at the end of each $\Delta \ell$ increment,

H_1 = the wave height at the beginning of each $\Delta \ell$ increment,

$\Delta \ell$ = the incremental spacing through the marsh (= 0.1 feet in our analysis),

$$A = \frac{C_p D}{3 \pi S^2 d}$$

In the above equation,

C_p = plant drag coefficient (determined to be appoximately 5 from best fit comparisons with experimental data),

D = average grass stalk diameter,

S^2 = stem spacing term (= 1/stem density),

d = water depth at each $\Delta \ell$ increment through marsh.

A drag coefficient of 1.0 was used for a series of rigid vertical cylinders in laboratory tests by Dean. These were compared to stems in a marsh. According to Knutson stems in a living marsh differ in that they deflect in response to wave force. More of its length is submerged and the circular cross-section of the round stem appears as an ellipse to the velocity of flow. This compresses the distance between stems (decreasing their effective spacing) and increases the effective diameter of the stems. Also, the leaves which were not quantified diverge from the stem and most likely contribute to the surface area and effective diameter of the stem (10). To account for the different fraction between cylinders and live stems, a higher drag coefficient was used. As a result of the field tests, a drag coefficient of 5 seemed to give the best agreement between observed and predicted wave heights.

A computer program developed byBrochu utilizes equation 1 for the variables involved and analyzing the attenuation of a given incident wave (2). In the program the wave height is calculated every 0.1 foot as it progresses through the marsh using equation 1. Table 9 shows the results of Knutson's field tests. On the average more than 50% of the energy (wave height) associated with the boat generated transmitted waves was dissipated within the first 2.5 meters (8.2 feet) of the marsh. Virtually no wave energy persists at 30 meters (98.0 feet).

Knutson's wave tests were performed on two wide (greater than 100 feet) well-established marsh plantings; one of which is over 50 years old. Conversely, the young planted marsh fringes in the VEC project have an overall average width of only about 10 feet. The widest one being 31.5 feet (Collier) and the narrowest is 4.0 feet (Johnsen).

TABLE 9

WAVE HEIGHT AND WAVE ENERGY LOSS

Distance Between Seaward and Landward Stations (meters)	Average Wave Height Seaward Station (H)	Landward Station (H)	Wave Height Loss (Percent)	Wave Energy Loss (Percent)
2.5	0.15	0.09	40	64
5.0	0.15	0.08	57	72
10.0	0.17	0.06	65	88
20.0	0.16	0.02	87	98
30.0	0.18	0.01	94	100

Empirical tests were done on the VEC sites using Brochu′s computer program. Only the smooth cordgrass fringes were analyzed. Two types of tests were done. First (Test 1) a 1 foot wave was transmitted through each fringe where the water depth at the upper limit of the smooth cordgrass fringe was 1 foot. This was done in order to compare each site′s ability to attenuate waves under similar conditions of water depth. Secondly (Test 2), a 1 foot wave was allowed to pass through each marsh fringe with a water depth of 2 feet above MHW. This gives a more realistic setting of how the marshes are affected under similar storm surge conditions. The marsh fringes occupy different positions across above and below the normal tidal zone. Results are shown in Table 10 for Test 1 and Test 2.

It is apparent that under similar conditions of water depths (Test 1), the widest marshes, the Marshall and Collier sites, have the best

TABLE 10

VEC MARSH SITES RESULTS OF WAVE ALTERNATION ANALYSIS FOR SMOOTH CORDGRASS. DATA FROM FALL OF 1983.

	Marsh Width	Stem Density	Stem Diameter	Marsh Limits Relative to MTL		TEST 1 Transmitted Wave	TEST 1 Percent Reduction	TEST 2 Transmitted Wave	TEST 2 Percent Reduction
	ft	stem/ft^2	inches	ft		ft	%	ft	%
				Lower Limit	Upper Limit				
Camp Chanco	4.5	30.63	0.11	0.82	1.53	0.96	4.0	0.97	3.0
Lee	9.9	24.15	0.17	-0.14	1.27	0.91	9.0	0.93	7.0
Hickman	14.7	24.90	0.14	0.08	0.87	0.88	12.0	0.93	7.0
Wellford	11.5	33.82	0.15	-0.09	1.50	0.88	12.0	0.90	10.0
Durham South	8.6	57.60	0.13	0.46	1.65	0.86	14.0	0.88	12.0
Durham West	12.8	36.79	0.18	-0.97	0.74	0.84	16.0	0.90	10.0
Garrett	14.8	31.59	0.15	-0.11	1.51	0.87	13.0	0.89	11.0
Murphy	11.3	20.00	0.20	0.07	1.36	0.90	10.0	0.92	8.0
Poole	6.0	43.48	0.20	0.22	1.71	0.89	11.0	0.88	12.0
York River State Park	-	-	-	-	-	-	-	-	-
Eley	12.1	35.50	0.13	1.08	2.09	0.87	13.0	0.84	16.0
Broad Bay Manor	12.2	16.97	0.23	0.74	1.86	0.89	11.0	0.84	16.0
Mariners Museum	13.3	40.00	0.13	1.08	2.96	0.87	13.0	0.79	21.0
King	14.2	36.42	0.13	1.22	2.65	0.87	13.0	0.83	17.0
Marshall	17.5	31.22	0.20	0.27	1.63	0.80	20.0	0.82	18.0
Johnsen	4.0	37.33	0.17	0.87	2.35	0.95	5.0	0.90	10.0
Vanderslice	14.9	7.99	0.17	0.16	2.27	0.96	4.0	0.91	9.0
Collier	31.5	55.70	0.18	-0.86	1.59	0.63	37.0	0.43	57.0
Davis	11.9	23.78	0.21	-0.01	1.24	0.87	13.0	0.92	8.0
Hog Island	9.5	31.34	0.16	0.03	1.21	0.89	11.0	0.92	8.0

wave attenuation potential. Both of these sites are in semi-protected shoreline situations with broad shallow nearshore flats.

The VEC marsh fringes not only vary in width but the upper and lower limits also occupy different positions relative to MTL. Results of Test 2 show eight sites with a greater percentage of wave reduction than in Test 1. They are Poole, Eley, Broad Bay Manor, Mariners Museum, King, Johnsen, Vanderslice and Collier. All of these sites except Collier have upper limits of smooth cordgrass greater than one foot above MHW. The remaining sites show less wave attenuation in Test 2 than in Test 1 and have upper limits of smooth cordgrass less than one foot above MHW. Although Collier has an upper limit of smooth cordgrass less than one foot above MHW, the fringe is almost twice as wide as the next widest fringe which is Marshall. This expanded width provides the greatest wave attenuation potential of all the VEC sites.

Calculations for saltmeadow hay wave propagation potential have not been done to date because empirical methods do not exist. The addition of this zone of grasses above MHW where possible adds greatly in wave reduction. Saltmeadow hay has shown its worth in the ability to trap sand and thereby increase backshore elevation. It is a necessary part of a planted marsh fringe where possible. Successful fringes in the upper low and medium energy sites have continuous saltmeadow hay above the smooth cordgrass.

DISCUSSION

In general, there is a stepwise progradation or sequence a marsh goes through from the initial planting through time, the time continuum mentioned previously. Knutson and Woodhouse recognize a "functional life" of a planted marsh in which planted marshes proceed through a cycle. The "functional life" is the period over which the marsh has functioned to reduce erosion. The cycle begins with marsh establishment, then stability and finally erosion of the marsh. The life of a planting is influenced by the severity of wave conditions which impinge upon the shore. Areas subject to more severe wave conditions require longer time to establish and have a shorter functional life (11).

Knutson et al. performed a national survey of planted salt marshes in the contiguous United States (9). Twelve coastal states were involved with a total of 86 sites. For shore erosion control the sites were evaluated subjectively as follows:

1) Failure (Type One) - Evidence of erosion; absence of intertidal vegetation.
2) Failure (Type Two) - Evidence of erosion landward of the planting, presence of intertidal vegetation.
3) Partially Successful - No evidence of erosion landward of planting but evidence of erosion on seaward edge of planting, presence of intertidal vegetation.

4) Successful - No evidence of erosion, presence of intertidal vegetation.

Knutson among others recognized wave stress as the principal factor in salt marsh establishment. Indicators of wave stress were determined to be fetch, longest fetch, shore geometry and sediment grain size. Figure 133 is an evaluation form developed from analysis of the 86 sites.

Of the 86 sites Knutson and Woodhouse used in their evaluation of planted marshes, 67 were over 3 years old. In contrast only four of the 24 VEC marshes have fringes remaining that are 3 years old. These are Camp Chanco, Lee, Hickman and Wellford. There has also been a great deal of annual maintenance planting done to establish a fringe on the VEC sites. So most of the sites are 2 years old with maintenance. Knutson's success criteria is more appropriate for older well established fringes.

The progress of the VEC project planted marsh fringes have been evaluated in terms of their continuity and ability to hold and/or elevate the backshore. Our results show that the low energy sites are trending toward success. The high energy sites failed. Some of the intermediate sites have marsh fringes trending toward success. The "functional life" of VEC sites trending toward success has yet to be realized. The two and three year old marsh fringes which are successful are just becoming established and partially stabilized. Without maintenance planting the marshes in the low energy regime would most likely have the longest "functional life". Of course the frequency of

1. SHORE CHARACTERISTICS	2. DESCRIPTIVE CATEGORIES (SCORE WEIGHTED BY PERCENT SUCCESSFUL)				3. WEIGHTED SCORE
a. FETCH-AVERAGE AVERAGE DISTANCE IN KILOMETERS (MILES) OF OPEN WATER MEASURED PERPENDICULAR TO THE SHORE AND 45° EITHER SIDE OF PERPENDICULAR 	LESS THAN 1.0 (0.6)	1.1 (0.7) to 3.0 (1.9)	3.1 (1.9) to 9.0 (5.6)	GREATER THAN 9.0 (5.6)	
	(87)	(66)	(44)	(37)	
b. FETCH-LONGEST LONGEST DISTANCE IN KILOMETERS (MILES) OF OPEN WATER MEASURED PERPENDICULAR TO THE SHORE OR 45° EITHER SIDE OF PERPENDICULAR 	LESS THAN 2.0 (1.2)	2.1 (1.3) to 6.0 (3.7)	6.1 (3.8) to 18.0 (11.2)	GREATER THAN 18.0 (11.2)	
	(89)	(67)	(41)	(17)	
c. SHORELINE GEOMETRY GENERAL SHAPE OF THE SHORELINE AT THE POINT OF INTEREST PLUS 200 METERS (660 FT) ON EITHER SIDE	COVE 	MEANDER OR STRAIGHT 	HEADLAND 		
	(85)	(62)	(50)		
d. SEDIMENT[1] GRAIN SIZE OF SEDIMENTS IN SWASH ZONE (mm)	less than 0.4	0.4 – 0.8	greater than 0.8		
	(84)	(41)	(18)		
4. CUMULATIVE SCORE					

5. SCORE INTERPRETATION			
a. CUMULATIVE SCORE	122 – 200	201 – 300	300 – 345
b. POTENTIAL SUCCESS RATE	0 to 30%	30 to 80%	80 to 100%

(from Knutson, et al., 1983)

[1]Grain-size scale for the Unified Soils Classification

Clay, silt, and find sand - 0.0024 to 0.42 millimeter
Medium sand - 0.42 to 2.0 millimeters
Coarse sand - 2.0 to 4.76 millimeters.

Figure 133. Vegetative Stabilization Site Evaluation Form.

strong wind and storm events will greatly affect how quickly a marsh can be established. The first season is the critical period.

Figure 134 shows how the VEC sites scored in the CERC Vegetative Stabilization Evaluation Form. The scores are for conditions before planting and the VEC sites are plotted by their score against their average fetch exposure. As expected the greater the average fetch the less chance for success. There is a very good fit between the Potential Success Rate and how the sites scored in column No. 8 of Table 6. The VEC scores in Table 6 do not really address the rates of bank erosion. Figure 135 compares the potential success rate of the VEC sites with the percent score for each site from Table 6. The trend toward success, partial success and failure fall closely in line with the predicted potential success rate.

The parameters on the CERC Vegetative Stabilization Site Evaluation form are meant to indicate the severity of wave climate at a site. Average fetch, longest fetch, and shoreline geometry are true indicators. Sediment type must be evaluated with care. Sediments supplied to the beach and nearshore are most often products of local bank erosion. Coarse sand and gravel can be found in relatively low wave climates.

Sediment analysis was done the first year on site numbers 1 through 12. Results show variable mean grain sizes for the toe of the beach where the coarsest sediments are usualy found. This presumably corresponds to the swash zone region of the CREC Evaluation form and analysis. Table 11 shows the 12 sites in order of increasing fetch and

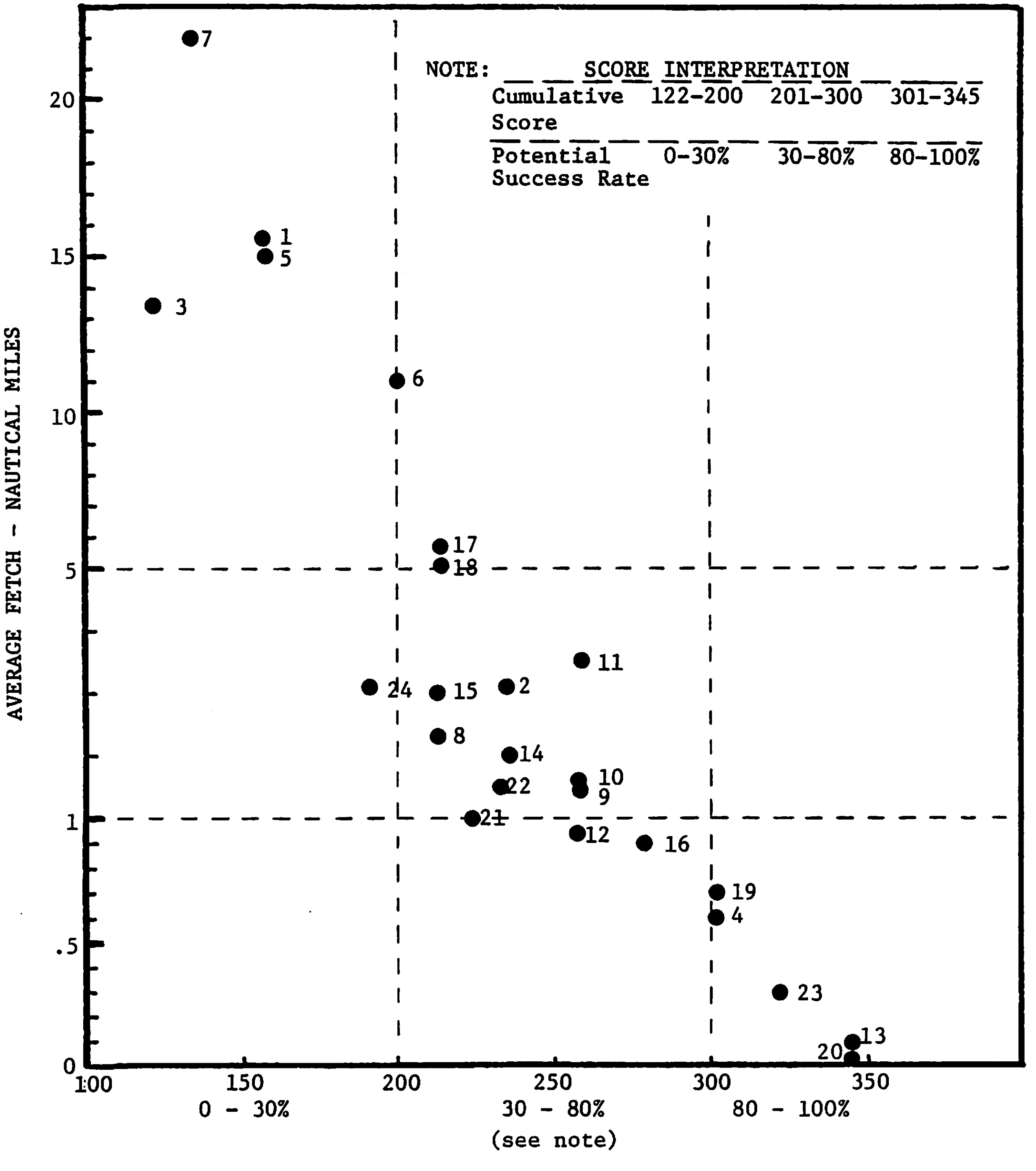


Figure 134. CERC vegetative evaluation score vs. average fetch at the VEC sites.

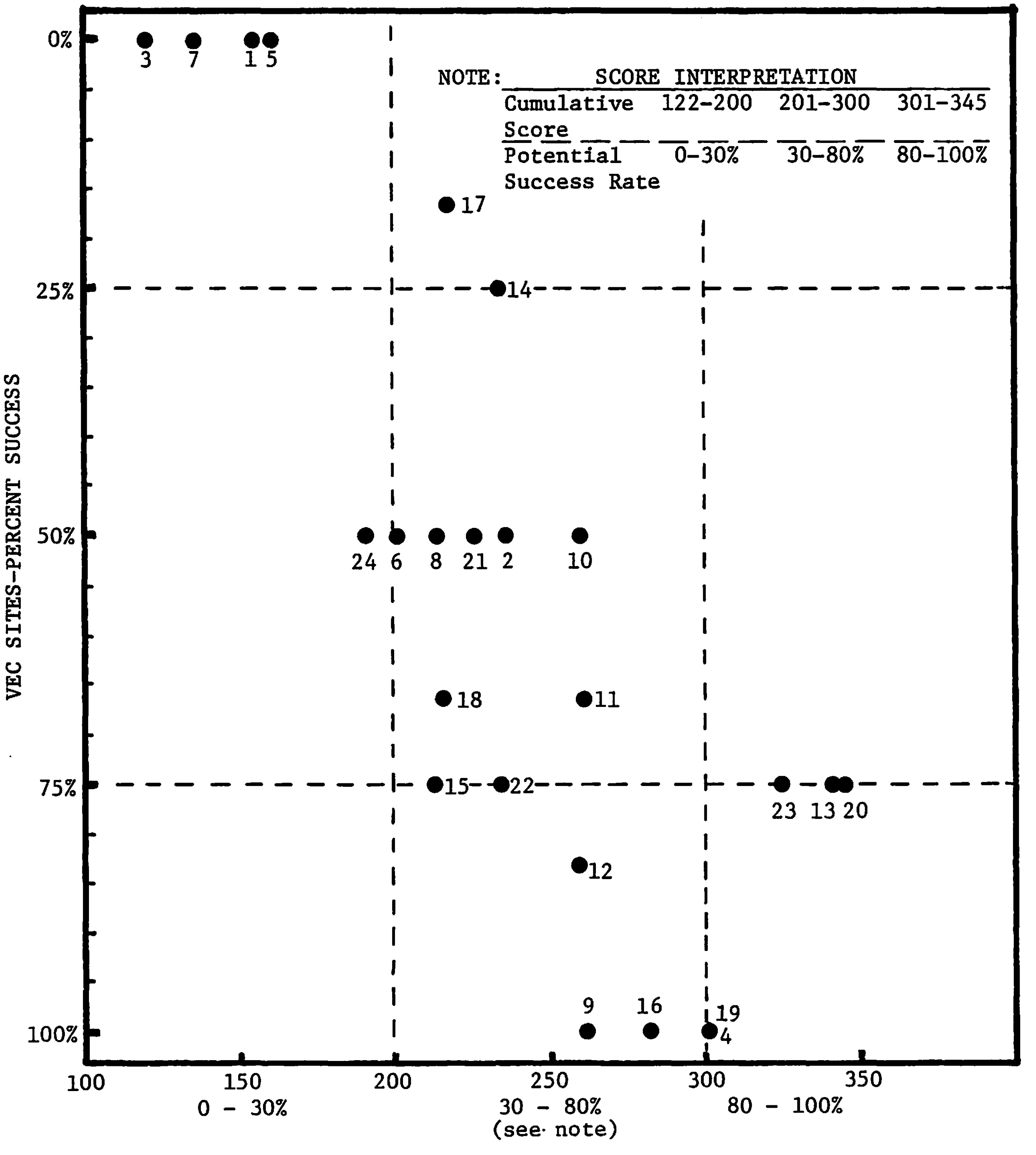


Figure 135. CERC vegetative evaluation score vs. percent success of VEC sites.

the corresponding mean grain size at the toe of the beach before planting. It can be readily seen that some of the higher energy sites have fine mean grain sizes and some of the low energy sites have coarse grain sizes. This is mostly due to the nature of the composition of adjacent eroding fastland banks. A more comprehensive analysis of sediment distribution across a planted marsh through time would show how the marsh fringe affects sedimentation at a given site.

TABLE 11

SEDIMENT ANALYSIS FOR FIRST YEAR VEC SITES

	Mean Grain Size (Toe of Beach) (mm)	Average Fetch (Nautical Miles)
Lee	0.50	0.60
Murphy	0.80	0.84
Durham South	0.70	1.46
Durham West	0.75	1.60
Wellford	0.90	2.30
Camp Chanco	0.90	3.10
Hickman	0.09	11.00
Windmill Point	1.05	13.40
Gill	1.10	15.00
Mountjoy	0.50	15.60

Seasonal Trends

The over wintering of the marsh fringes is somewhat different between low and medium energy sites. Generally the low energy sites will maintain a standing crop of dead stalks through most of the winter even if they were infected by the rust fungus. Parts of the fringe may be reduced, usually the lower edge, but at least some portion will remain standing. On the other hand the medium energy sites have little or no standing crop in the winter due to more severe wave exposure. The same is true with King, Mariners Museum and Hickman, the high energy sites with remaining fringes. Thus, the ability to trap and maintain sediment in the intertidal fringe and backshore elevation is greatly reduced. Noted losses of both are seen over the winter. Consequently, bank erosion is most severe during this time when there is no standing crop wave buffer. However, sites with a good saltmeadow hay fringe offer a better chance to maintain and hold the backshore (e.g. Durham South).

The development of a substantial peat substrate is quite important. Return of the remaining fringe in the spring depends on how the peat faired through the winter. The leading edge is usually ragged along the medium energy sites due to wave attack. Losses along this edge are common in the winter. This effect can be seen to a lesser degree on the low energy sites.

The marshes begin shoot growth early in the spring. Rhizome spread also begins early, especially for smooth cordgrass. Marshes at both low and medium sites show similar patterns of early growth and rhizome spread. After losses along the leading and side edges during the winter the rhizomes begin to spread downward to reestablish this lower leading edge. If there is no sediment covering the base of the culms, spreading will be reduced. Generally, however, there is sufficient sediment for rhizome spread by late spring.

Summer brings vibrant growth to the marshes. Their sand trapping abilities generally increase and bank erosion slows. Of course there are much fewer storm events which attack the backshore region during this time.

Low energy sites show the strongest trending toward success. With time and minor maintenance they should be able to reduce or halt bank erosion rates. Maintenance quantity and frequency will probably increase with increasing fetch exposure. Smooth cordgrass has needed maintenance more than the saltmeadow hay on low energy sites. The obvious reason being that the smooth cordgrass is exposed to more frequent wave impingement being in the intertidal zone.

There are 4 of 8 sites with marsh fringes trending toward success (with substantial continuous fringes with stable or elevated backshore regions) in the medium wave energy regions. They are Durham South, Collier, Eley and Garrett. Three of four of these sites are semi-protected by headlands or offshore spits. Eley is not and will probably not continue the trend toward success without considerable maintenance planting. Of these four sites two have saltmeadow hay fringes and only Durham South has a substantial one.

Two other medium energy sites with an existing substantial fringe but without a stable or elevated backshore are Durham West and Hog Island. These fringes are sitting below MHW and the adjacent banks continue to erode, especially in the winter. Maintenance planting between the bank and fringe could be done to substantially increase the smooth cordgrass width. Durham West was originally planted with saltmeadow hay but it washed out and was never replanted. Annual maintenance planting may prove its worth on these two sites.

Vanderslice, although exposed to a relatively small fetch can be subjected to bay-like conditions during easterly storm events. Its future is toward failure even with annual plantings. York River State Park has too little intertidal bank and too much fetch exposure to withstand time and tide.

Camp Chanco was doing pretty well and is semi-protected from westerlies by the upriver headland. Its long exposure to the east and northeast has caused its slow obliteration. Annual plantings could possibly give long term relief to the high bank erosion.

The Wellford site was doing so well the first two years it seemed trending toward success. However, heavy losses over the winter of 1982-1983 initiated maintenance planting in the spring of 1983. This seemed to do little help because most of the new plants were washed out in the winter of 1983-1984. One noticeable trend at Wellfords was a tendency for a strong net littoral drift of beach sediments to the east. This site was the only one which showed a groin like effect of sediment trapping updrift and sediment loss downdrift with a corresponding decrease in beach width. Any shore which receives a net strong, frequent oblique component of wave approach will most likely have a strong net littoral sediment drift. This tendency at Wellfords was to gradually reduce the marsh width downdrift and work its way updrift leaving a remnant fringe on the updrift end. Wave climate, shore orientation and offshore bathymetry are generally responsible for the nature of littoral drift processes.

Durham South and Marshall also showed this groin like effect. Sediment trapping was observed updrift of these fringes with a consequent increase in beach width. Also, sediment loss was seen downdrift with a corresponding decrease in beach width.

Shore Classification

One of the main objectives of the VEC project was to better determine the physical limits in which a planted marsh could be established. As we have stressed the physical limit is the severity of the impinging wave climate which is a function of fetch and shore geometry. In the lower low energy regime (fetch less than 0.5 nautical mile) these factors are negligible. Exposure to sunlight and boat wakes appear to be more critical. Fetch and shore geometry become more important in the upper low energy regime and the medium energy regime.

Referring to Figure 136, approximately 60% of the stippled shoreline is low energy. Most of this has natural marsh fringes at present. The need to establish a marsh fringe will occur where the natural fringe has been eroded away or seriously reduced, so as to be an ineffective wave buffer.

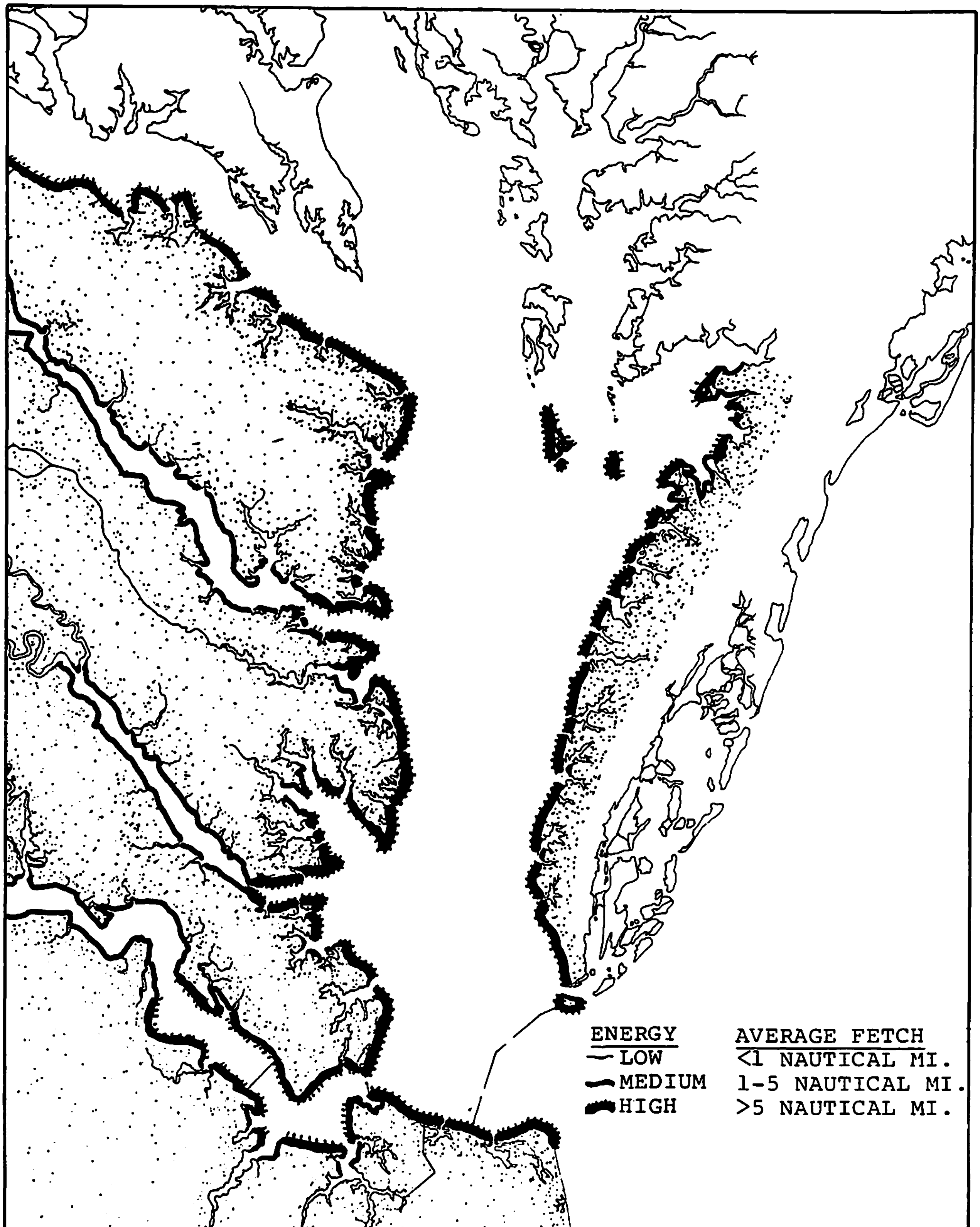


Figure 136. Relative wave energy by average fetch on low, medium, and high energy shores in Virginia's Chesapeake Bay. Shore length measured on stippled portion.

Approximately 30% of the stippled shore in Figure 136 is high energy shore. Plant establishment on these shores is almost impossible by itself. However, there may be areas where shoreline geometry will provide a protective situation (e.g., Hickman).

The remaining 10% of shoreline is within the medium energy regime. These shores mostly occur along the trunks of the rivers. It is conjectured that southward facing shores will have a better likelihood of establishment (i.e. less maintenance planting) than the north facing shores due to less exposure to northerly winds. Also, semi-protected shores and those in the lower medium energy regime (fetch-limited) will have a better survival rate. Annual maintenance planting will be the rule even after the marsh is firmly establishment.

On this note it would seem that research on the use of offshore wave damping devices should be implemented. Temporary breakwaters could be installed cheaply to allow a planting to become firmly established. The structure could then be removed. Permanent but more expensive structures might be appropriate for long stretches of eroding bank (e.g. farm land and timber land).

A guaranteed one time planting can be expected to suffice on a lower low energy shore with no boat wakes and good sunlight exposure. The degree of maintenance planting will increase as fetch increases. Annual planting may be necessary when the fetch is on the order of 1.0 nautical mile; it will be imperative when the fetch exceeds 3.0 to 3.5 nautical miles.

CONCLUSIONS

The following conclusions are drawn from three years of research on the Vegetative Erosion Control Project:

1) Establishing a marsh grass fringe can be accomplished with little or no maintenance planting on the low wave energy regime shores (average fetch less than 1.0 nautical mile). Frequent boat wake activity and insufficient sunlight are the most limiting factors. The majority of this type of shoreline will be along the creeks of the Commonwealth. A combination marsh fringe of saltmeadow hay and smooth cordgrass should be implanted where possible for best results.

2) Along medium wave energy shorelines exposed to 1.0 to 3.5 nautical miles average fetch, the establishment of a combination marsh fringe of saltmeadow hay and smooth cordgrass is necessary. Much of this shore exposure is along the major tributaries of the Chesapeake Bay. The saltmeadow hay will trap sand, dissipate wave action, and help elevate the backshore. The smooth cordgrass will also trap sand, dissipate wave action, and help protect the saltmeadow hay fringe. Semi-protected shorelines, especially coves and embayments, will have a better chance for marsh establishment than will straight or headland shores. Maintenance planting will be needed at varying intervals.

3) On straight shorelines with average fetch exposures of 3.0 to 5.5 nautical miles (mostly found along the lower portions of the major tributaries of the Chesapeake Bay), it will be impractical to attempt to establish a marsh fringe without some type of permanent offshore wave-stilling device (_i.e._ a breakwater). Semi-protected shores will have a better chance of establishmnt but continual maintenance planting will be necessary. Design and research on offshore breakwater systems for marsh implantation seems to be an appropriate next step in this line of research.

4) Shorelines with an average fetch of greater than 5.5 nautical miles (mostly along and near the Chesapeake Bay) should not be considered for marsh grass implantation unless well protected by a headland, island or spit. The use of offshore breakwaters in combination with marsh implantation is a consideration but further research will be needed.

5) The CERC Vegetative Site Evaluation Form appears to be a good assessment of site conditions for the purpose of determining the potential success of a planted marsh. To date, the success, partial success, or failure of the VEC marsh fringes was closely predicted by the CERC Vegetative Site Evaluation Form.

CITED REFERENCES

1) Bellis, V., M.P. O'Connor, and S.R. Riggs. 1975. "Estuarine Shoreline Erosion in the Albemarle-Pamlico Region of North Carolina". University of North Carolina Sea Grant Program Publication UNC SG 75-29, 67 p.

2) Brochu, R. 1982. BASIC Computer program "FINITE".

3) Byrne, R.J. and G.L. Anderson. 1977. Shoreline Erosion in Tidewater Virginia. Special Report in Applied Marine Science and Ocean Engineering No. 111 of the Virginia Institute of Marine Science, Gloucester Point, Virginia, 102 p.

4) Byrne, R.J, C.H. Hobbs, III, N.B. Theberge, W.R. Kerns, M. Rangeland, J. Scheid, N.J. Barber, and R.J. Olthof. 1979. "Shoreline Erosion in the Commonwealth of Virginia: Problems, Practices and Possibilities". SRAMSOE No. 220, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, 265 p.

5) Hardaway, C.S. 1980. "Shoreline Erosion and its Relationship to the Geology of the Pamlico River Estuary, North Carolina". Unpublished Masters Thesis, East Carolina University, Greenville, North Carolina, 116 p.

6) Hardaway, S. and G. Anderson. 1980. "Shoreline Erosion in Virginia". Sea Grant Program, Marine Advisory Service,Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, 25 p.

7) Kiley, K. 1982. "A Shallow Water Wind Wave Prediction Program". Based on U.S. Army Corps of Engineers Program Developed by CERC, Fort Belvoir, VA.

8) Knutson, P.L. 1977. "Planting Guidelines for Marsh Development and Bank Stabilization". CETA No. 77-3, U.S. Army Corps of Engineers, C.E.R.C., Fort Belvoir, Virginia.

9) Knutson, P.L., Julie C. Ford, Margaret R. Inskeep and John Oyler. 1981. National Survey of Planted Salt Marshes. Wetlands, The Journal of Wetlands Scientists, Vol. Sept., p. 129-157.

10) Knutson, P.L., R.A. Brochu, W.N. Seilig, and M. Inskeep. 1982.Wave Damping in Spartina alterniflora Marshes. Wetlands, The Journal of the Society of Wetlands, Scientist, Vol. 2, 1981, pp. 87-104.

11) Knutson, P.L. and W.N. Woodhouse, Jr. 1983. "Shore Stabilization with Salt Marsh Vegetation". U.S. Army Corps of Engineers, CERC, Fort Belvoir, VA, Special Report No. 9, January, 95 p.

12) Komar, P.D. 1976. Beach Processes and Sedimentation. Prentice-Hall Inc., Englewood Cliffs, New Jersey, 429 p.

13) U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service, National Climatic Center, Federal Building, Asheville, North Carolina.

14) Virginia Marine Resources Commission. 1974. "Wetlands Guidelines". Virginia Marine Resources Commission, 2401 West Avenue, Newport News, Virginia.

15) Woodhouse, W.W., Jr. 1979. "Building Salt Marshes Along the Coasts of the Continental United States". Special Report No. 4, U.S. Army Corps of Engineers, C.E.R.C., Fort Belvoir, Virginia.