ABSTRACT

Title of Thesis: Island Land Loss in the Chesapeake Bay: A Quantitative and Process Analysis

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The rates and processes of land loss were studied for seven islands in the Chesapeake Bay: Barren, Bloodsworth, Hooper, James, Poplar, Smith and South Marsh Islands. Rates and patterns of land loss were quantified for the years 1848 to 1987 with the Metric Mapping technique which utilizes digitized data from historical maps and vertical aerial photographs. Processes of land loss were determined through field surveys and correlated with environmental factors.

Two distinct island types were identified which exhibited different, long-term patterns of land loss. Small, upland islands, termed the Northern Group, showed rapid land loss along the main stem of the Bay primarily due to wave action driven by the predominant westerly winds. Land loss appeared to accelerate during periods of high storm frequency. The long-term averaged land loss rate for Northern Group islands is 1.9 ha/yr. The averaged erosion rate on the western side of the islands is 4.9 m/yr, compared to 0.68 m/yr on the eastern side of the islands.

In contrast, the large, marshy islands of the Southern Group experienced uniform marsh edge erosion and interior marsh degradation. The Southern Group islands lost land at an averaged rate of 5.6 ha/yr, with an averaged rate of marsh edge erosion of 1.2 m/yr. Land loss appeared to be weakly correlated to storm frequency. Interior marsh loss was not quantified for this study, however, so this study provides an underestimation of total land loss of coastal wetlands.

ISLAND LAND LOSS IN THE CHESAPEAKE BAY:

A QUANTITATIVE AND PROCESS ANALYSIS

by

Rachel Donham Wray

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CHAPTER 1: INTRODUCTION

Introduction

During the last two million years, coastal areas worldwide have evolved dramatically with the oscillations of sea level due to Ice Ages, altering the physiography as well as the climate of coastal regions. Climate change during the last ten thousand years has caused the transformation of the Susquehanna River valley to form the Chesapeake Bay estuary that exists today (Coleman and Mixon, 1988). Widespread saltmarsh development throughout the northeast United States was associated with decreased rates of sea-level rise around 4,000 years ago (Redfield and Rubin, 1962; Rampino and Sanders, 1981; Orson, et al., 1987). Marshes in the Chesapeake Bay also began to develop around this time. The Bay has continued to evolve geomorphologically during the last few centuries, through shore erosion, marsh degradation and accretion, and gradual submergence of low-lying upland areas. Erosion and marsh loss are collectively called land loss.

Coastal erosion is the most obvious means of land loss. Erosion results in a loss of valuable shorefront land and wetland habitat, damage to buildings and other structures, diminished beach capacity at recreational areas, and adverse impacts to cultural and historic resources (Leatherman, 1984). In the past century, it is estimated that over 18,000 hectares of coastal areas of Chesapeake Bay have eroded, providing about 3.6 million cubic meters of sediment to the Bay each year (US Army Corps of Engineers, 1991). From historical records of the Bay, it is clear that land loss has been occurring since at least the mid-19th century (Singewald and Slaughter, 1949; Mowbray, 1981; Kearney and Stevenson, 1991). Due to the record of eustatic sea-level rise during the last 15,000 years, however, it is clear that land loss has been occurring since long before the 19th century.

Shore erosion has previously been shown to be an important process in the Bay (Singewald and Slaughter, 1949; Wang, et al., 1982). Coastal erosion, however, has only recently been recognized as the major input of sediment into the Bay (Marcus and Kearney, 1991), increasing toxins and nutrient loads in the water. Sediment loading from increased runoff due to land clearing is also responsible for many problems in the Bay, principally subsidence. Such a discovery may be a first step towards focusing on land loss as a problem in the Bay and treating it on a Bay-wide basis. For example, sediment input to the Bay will be reduced by curbing erosion.

The extent of land loss in the Chesapeake Bay has been significant, and its importance and impact is perhaps easiest to comprehend in terms of the response of the islands in the Bay. The Bay islands provide excellent case studies of land loss because they have been so reduced in size that most have become uninhabitable; others have even been reduced to shoals. In addition, most have essentially unprotected shorelines, whereas much of the mainland has been protected by bulkheads and revetments. Without such structures, the natural processes of land loss are unimpeded, and can be studied more easily. In addition, anecdotal and historical records exist for many of the islands, and provide examples of relatively large island communities which no longer exist. This is good indirect evidence of the extent of land loss in terms of both erosion and the conversion of uplands to marsh. Many islands, which once provided homes and ample farm land, are no longer habitable and some are barely large enough to stand on. Today, only a few of the islands are inhabited, including Hooper Island, Smith Island, and Tangier Island.

The human exodus from the islands can be attributed, in part, to three mechanisms: submergence, erosion, and the impact of large storms. However, the specific causes have never been thoroughly investigated. A combination of factors, including the harsh island environment, erosion, waterlogged soils, flooding from hurricanes, and a more desirable lifestyle on the mainland, presumably provided incentives to leave. For some islands, such as Bloodsworth Island, the frequency of flood events due to submergence increased to the point where living there became impractical (GEO-RECON, 1980). For other islands, such as Poplar Island, erosion continually encroached upon established communities until there was no longer room to continue living and farming (Meyer, 1986). There are many other examples of island land loss in the Chesapeake Bay, and some of these will be discussed in detail in this thesis.

Waterfowl in the Bay are also affected by island land loss. For example, most black ducks rely on remote areas, such as uninhabited islands for breeding and nesting presumably because of the species' aversion to human disturbance. The loss of isolated islands and the increasing development in other areas are thought to be primary causes of the black duck population decline in the Chesapeake Bay (Krementz, et al., 1991). The distribution of other waterfowl species such as bald eagles, ospreys, herons, egrets, various duck species, and swans is being impacted as available space for breeding and nesting is becoming increasingly limited due to land loss (Stotts, 1985). The mainland is becoming a less viable option for inhabitation for many wildlife species because of development and cultivation. As a result, species distribution and diversity is being affected by the reduction of available habitat.

Study objectives

The processes and rates of historic land loss in the Chesapeake Bay were studied for seven islands (Figure 1.1):

Barren Island
Bloodsworth Island
Hooper Island
James Island
Poplar Island
Smith Island
South Marsh Island

The most important goal of this study was to understand how and why this land loss is occurring. Therefore, the specific objectives were to:

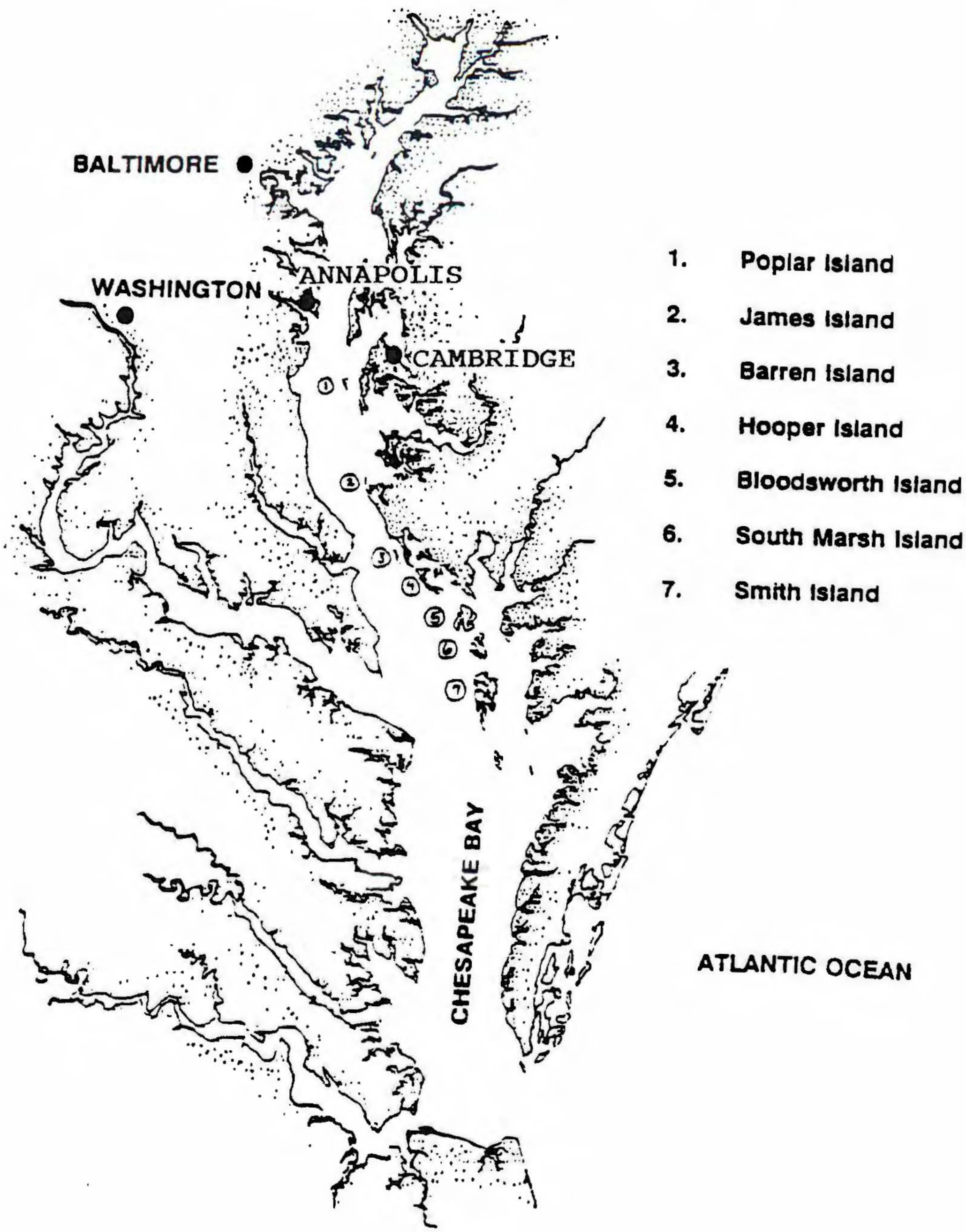
(i) quantify the rates and patterns of island land loss;

(ii) determine and quantify the causes of land loss;

(iii) project the future evolution of these islands with and without accelerated sea-level rise;

(iv) correlate these findings with field data.

Figure 1.1 Map of the Chesapeake Bay with the location of seven Islands



CHAPTER 2: STUDY AREA

Environmental Characteristics

Geomorphology

The Chesapeake Bay, located in the middle Atlantic Coastal Plain Province, is a classic coastal plain estuary formed by the post-Wisconsin rise in sea level which drowned the lower valley of the Susquehanna River (Ryan, 1953). The Bay is about 300 km long from the mouth of the Susquehanna River to the Cape Charles-Cape Henry entrance to the Bay (Figure 2.1). It ranges in width from 5 to 56 km, the widest point being in Tangier Sound in the southern Bay, with an average width of about 40 km. The shoreline of the Bay is extremely irregular, totalling 12,900 km in length. With an average depth of only 8 to 10 m, the Bay is very shallow compared to its width. The deepest part of the Bay is the incised main channel of the former Susquehanna River which runs the entire length of the Bay, with depths over 50 m (Kehrin, et al., 1988).

Much of the western shore consists of high relief, clay/sand cliffs and narrow sandy beaches, especially in Calvert County, Maryland. The eastern shore of the Chesapeake Bay is characterized by low elevation and a scarcity of sandy deposits with few exceptions. All the islands in the study area generally lie less than 2.5 m

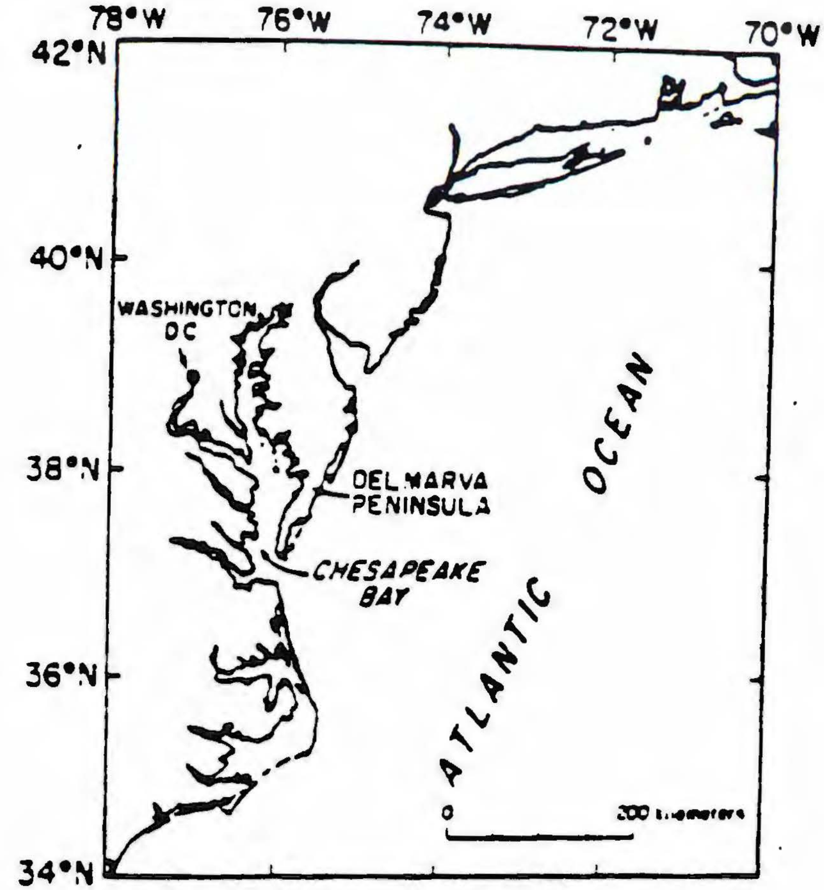


Figure 2.1 Vicinity map of the Chesapeake Bay

above mean sea-level according to recent topographic surveys. The majority of the island shorelines are eroding marsh edge (Plate 2.1) and eroding silt/clay bluff (Plate 2.2). The bluffs are generally between 1 and 2 m above mean sea level. In addition, several small, sandy, pocket beaches have developed between resistant marsh headlands in some places on the island shores (Plate 2.3). These beaches are thin veneers of sand which overlay marsh peat or clay. Rosen (1980) classifies these as "impermeable beaches", which overlie impermeable sediments such as silt/clay. They are highly erodible because they have low swash filtration and low beach elevation.

Climate

The Chesapeake Bay is in the northern Temperate Zone, with mild winters and hot, humid summers. Average annual rainfall for the region is 106 cm, with the most rainfall occurring between June and August. During the winter, the Appalachian Mountains and the waters of the Bay have a moderating effect on the cold air from the northwest (US Department of Agriculture, 1966). The predominant wind direction in the Bay on an annual basis is west-northwest at an average speed of 9.2 mph. The only exception is during September when the predominant

Plate 2.1 View of an eroding marsh edge on Bloodsworth Island

Plate 2.2 View of an eroding clay cliff on Poplar Island

Plate 2.3 View of a pocket beach on Coaches Island (Poplar Island), with a marsh "headland"

wind direction switches to south. Higher wind speeds are generally experienced during the winter months, with more gentle winds during the summer (Table 2.1) (US Department of Commerce, 1990). The highest wind speeds are experienced during periodic storms such as northeasters which usually occur during the winter months, and hurricanes and tropical storms which usually occur in late summer.

Storms

Seventy-nine major storms, both tropical and extratropical, have occurred in the Bay vicinity between 1871 and 1986 (Appendix A) (Neuman, et al., 1987). Hurricanes and tropical storms generally occur in late summer and early fall months, but can occur as early as June and into December. In the winter months, extratropical or "northeasterly" storms, which originate over land, bring the highest winds and worst weather to the Bay area. On an annual basis, northeasters occur more frequently than hurricanes or tropical storms. However, due to elevated water levels (storm surge) and high wind-driven waves, hurricanes and tropical storms can be highly destructive forces on coastal areas.

Wang et al. (1982) performed a wave hindcast for the Chesapeake Bay to simulate storm-wave conditions. The

Table 2.1 Fourty-year average wind data from Baltimore, Maryland (from U.S. Dept. of Commerce, NOAA, 1990)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean Speed (MPH)	9.7	10.3	10.9	10.6	9.2	8.5	8.0	7.8	8.0	8.7	9.3	9.3
Prevailing Direction	WNW	NW	WNW	WNW	W	WNW	W	W	S	NW	WNW	WNW

distribution of zones of "high" and "medium" wave energy which resulted from the model are presented in Figure 2.2. More "high" wave energy areas are found along the western shore of the Bay than the eastern shore.

Although most of the high wave energy zones are located in areas known to have high erosion rates, the reverse is not true. There are high wave energy zones in places with lower erosion rates, such as Calvert County, Maryland along the western shore and some of the island shorelines along the eastern shore (Wang, et al., 1982; Downs, in prep.). Clearly, there are several factors which determine the potential erosion rate of a particular area. One factor alone, such as wave energy, cannot explain the entire process.

Waves

Wave conditions near the shore and the directions of wave energy flux are probably the most important factors which are needed to assess erosion potential. Wang et al. (1982) used a wave-hindcast numerical model to calculate wave statistics for the Chesapeake Bay, accounting for bottom friction, irregular fetch areas, and wave breaking. The results indicate that "annual" average wave climate is composed principally of waves whose heights are 0.15 to 0.3 m. These wave heights are fairly small due to limited fetch and shallow water

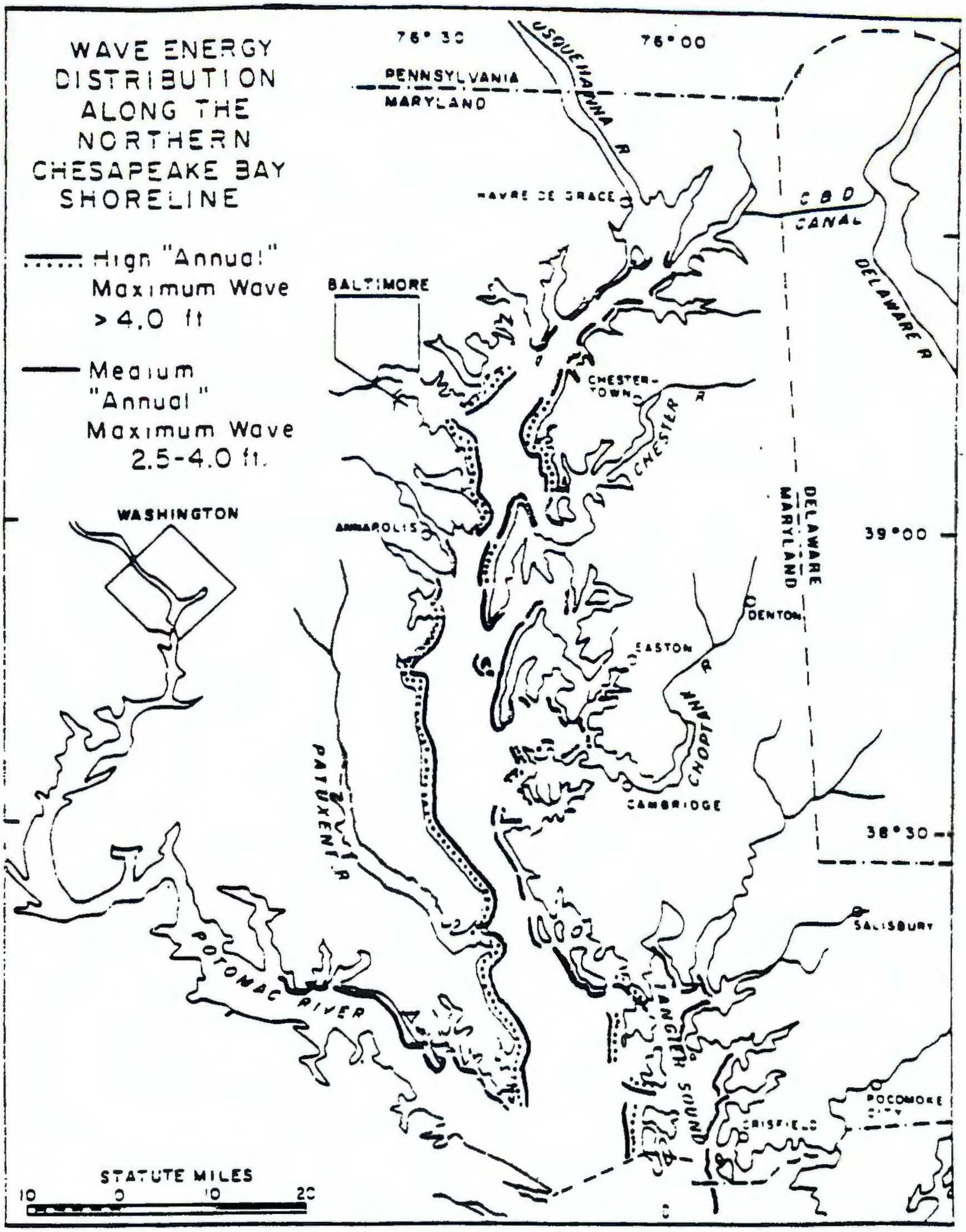


Figure 2.2 Wave energy distribution along the northern Chesapeake Bay shoreline (from Wang, et al., 1982)

depths in the Bay which preclude the formation of large wind-driven waves (US Army Corps of Engineers, 1984)). Because these average heights are fairly low, storm-wave conditions are almost certainly more important in assessing shore erosion.

Vegetation Communities

The two major ecosystems of all the islands in the study area consist of open coastal marshes and upland forested areas. The vegetation found on the islands is typical of the ecosystem in the Chesapeake Bay region. Table 2.2 identifies the major vegetation communities on the islands in the study area.

Geologic History of Chesapeake Bay

The Chesapeake Bay was formed as sea level rose during the past 15,000 years, and the Susquehanna River valley was flooded to form the present estuary (Coleman and Mixon, 1988). The modern Bay is the most recent of at least three generations of estuaries, which have formed in a similar fashion during interglacials. Three paleochannels of the former Susquehanna River valleys have been located and dated (Figure 2.3). They are known as the Cape Charles, Eastville and Exmore paleochannels,

TABLE 2.2
MAJOR VEGETATIVE COMMUNITIES

Environment	Latin Name	Common Name
Saltmarsh	Spartina alterniflora	Cordgrass
	Spartina patens	Saltmeadow Hay
	Distichlis spicata	Salt Grass
	Juncus roemerianus	Black Needlerush
	Atriplex patula	Orach/Spearscale
	Salicornia	Saltwort/Glasswort
	Borrichia frutescens	Sea Oxeye
Margin	Iva frutescens	Marsh Elder
	Baccharis halimifolia	Groundsel Tree
Beach	Panicum virgatum	Switch Grass
Upland	Pinus taeda	Loblolly Pine
	Myrica pennsylvanica	Bay Berry
	Myrica spp.	Wax Myrtle
	Sassafras albidum	Sassafras
	Prunus serotina	Wild Black Cherry
	Juniperus virginiana	Red Cedar/Juniper
	Ilex opaca	American Holly
	Lonicera japonica	Honeysuckle
	Phytolacea americana	Poke weed
	Rhus radicans	Poison Ivy
	Celtis occidentalis	Hackberry (spp.)

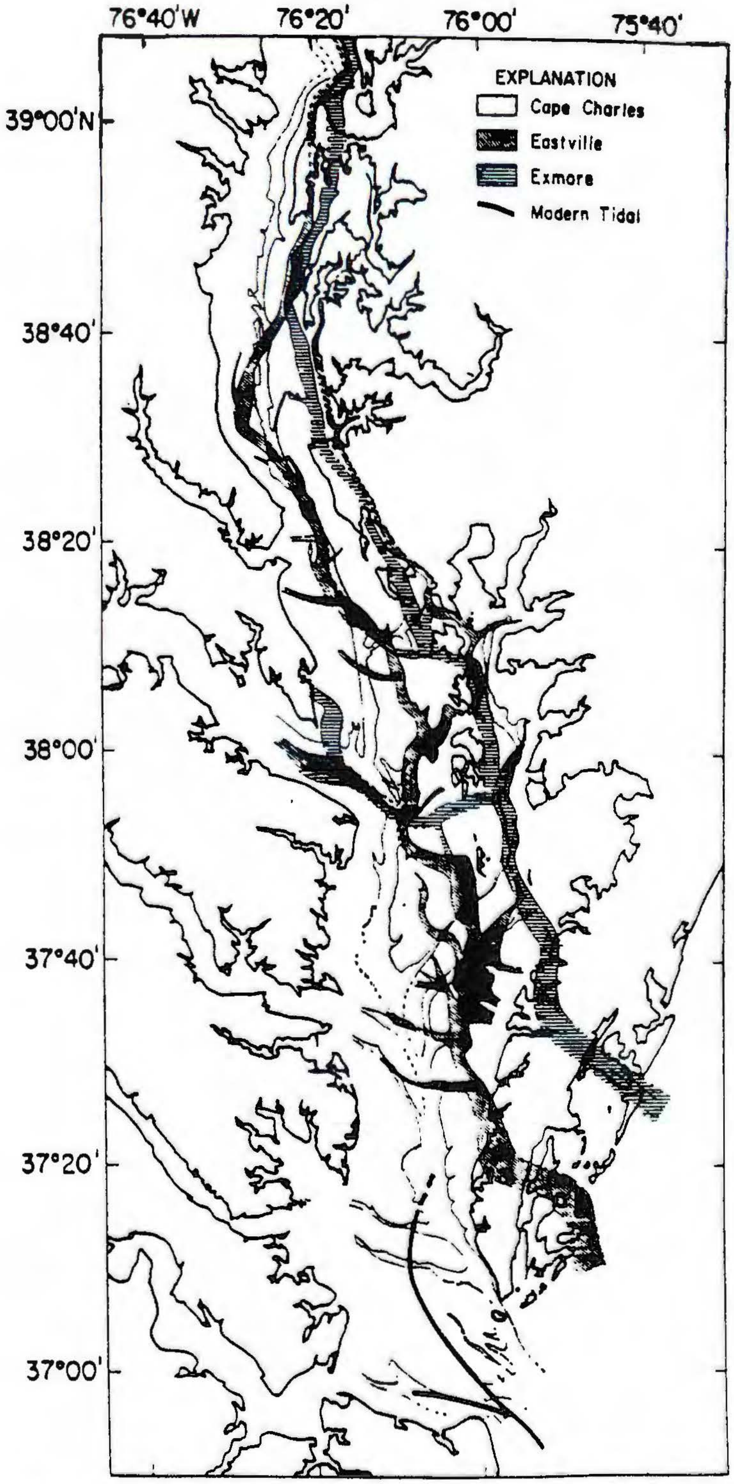


Figure 2.3 Location of the three major paleochannels in the Chesapeake Bay (from Coleman, et al., 1990)

in order of increasing age (Coleman, et al., 1990). These channels were formed during glacial low sea-level stands. Each paleochannel exhibits the same sedimentology, with lower fluvial channel-fill deposits consisting of sand and fine gravel. These fluvial deposits are covered by river-estuarine sediments, consisting of interbedded muddy sand, silt and peat (Coleman and Mixon, 1988).

The oldest channel, the Exmore channel, is not clearly dated, but appears to be 200 to 400 thousand years old. It extends from the mouth of Eastern Bay, through the Poplar Island area, into the Taylor Island area, and down into the southern Bay. This channel runs essentially parallel with the chain of islands in this study. The Eastville channel appears to be late Illinoian in age, or about 150 ka. The youngest paleochannel, the Cape Charles channel, is clearly of late Wisconsin age, about 18 ka (Coleman, et al., 1990). This channel was formed when sea level was about -85 m on the mid-Atlantic continental shelf during the most recent low sea-level stand. During this time the area occupied by the Chesapeake Bay was subaerially exposed and a narrow, steep-walled valley was incised into the coastal plain strata by the Susquehanna River and its major tributary the Potomac River (Coleman, et al., 1990). Sea level began to rise around 15 thousand years ago and the

Cape Charles channel was flooded, eventually forming the modern Chesapeake Bay.

All the islands in the study area appear to be composed of fine-grained clay deposits which are either exposed in areas of high elevation or buried under marsh peats in low-elevation marshy areas. This deposit is known as the Kent Island Formation, which is thought to be estuarine in origin and likely represents the "old Chesapeake Bay bottom which preceded the formation of the modern Chesapeake Bay" (Owens and Denney, 1979). Therefore, the sediments which comprise the islands were probably deposited during the most recent Pleistocene high sea-level stand. The Kent Island Formation has never been dated, however, so its precise age and origin remains a subject of research.

While the Cape Charles paleochannel was filling in at the beginning of the Holocene, the deposits which formed the Kent Island Formation were submerged and reworked by the rising water, and areas of high elevation were surrounded by water to become islands. Therefore, the deposits that form the islands and parts of the southern Delmarva Peninsula are all geologically young, younger than the Eastville or Exmore paleochannels (Coleman, et al., 1990).

Sea-Level Rise

An underlying cause of land loss in the Chesapeake Bay is rising sea level. Sea-level rise affects coastal areas in several ways, including erosion, inundation of low-lying areas, saltwater intrusion into aquifers, higher water tables, and increased flooding and storm damage (NRC, 1987). Erosion and inundation account for the loss of land which has been occurring in the Bay. Rising water tables and saltwater intrusion have altered the vegetation on large areas of some of the islands and along the margins of the eastern shore. Increased flooding and storm damage have reduced the amount of inhabitable land on the islands.

The rate of local sea-level rise in the Chesapeake Bay appears to be accelerating (Kearney and Stevenson, 1991) at the rate of about 3.0 mm per year for the last few centuries (Froomer, 1980), as compared to the slower rate of 1.2 to 1.5 mm per year for the last several millennium (Newman, et al., 1980). A recent rise in global sea level is consistent with the termination of the Little Ice Age around 1850 (Grove, 1988). It is assumed that the recently accelerated rate of sea-level rise in the Chesapeake Bay accounts for the increased rate of island erosion, interior marsh loss, and vertical marsh accretion, since the mid-19th century as demonstrated by area estimates of islands and marsh core samples (Kearney and Stevenson, 1991).

The rate of local sea-level rise in the Chesapeake Bay is also well above the eustatic (global) rate of sea-level rise during the last century for which best estimates are 1 to 2 mm/yr (IPCC, 1990). This has been attributed to downwarping of the earth's crust underneath the Chesapeake due to sediment loading of approximately 8 trillion kilograms of silt during the last century, as a result of human land-use practices (Donoghue, 1991). Davis (1987) has also suggested that high rates of relative sea-level rise in the Chesapeake Bay are caused by regional subsidence due to withdrawal of underground water sources. In the Chesapeake Bay, the rate of subsidence appears to increase towards the south and culminates in the lower Virginia portion of the Bay (Holdahl and Morrison, 1974)

In a detailed examination of tide gauge records, Douglas (1991) estimates that the rate of sea-level rise at the Baltimore, Maryland, tide gauge station during the period 1880 to 1980 is 2.1 mm/yr ± 0.1, when the effects of post-glacial rebound (PGR) are removed from the calculations. Douglas' finding is the only instance where the process of post-glacial rebound is ascribed to the Chesapeake Bay; most studies of the Bay suggest that the Bay is sinking rather than rebounding (e.g., Kearney and Stevenson, 1991).

We are presently in an interglacial sea-level period. It is unclear whether the observed eustatic trend of increased sea-level rise during the last century is simply the natural variability in the long-term climatic record, or whether it is an indication of anthropogenic global warming due to the greenhouse effect.

Marsh Response to Sea-Level Rise

Marsh stratigraphic records and pollen dating analysis show that marshes can develop and keep pace with sea-level rise. This is accomplished by building upward and outward with additions of dead biomass (detritus) and inorganic sediment settling on the marsh surface (Redfield, 1972; Stevenson et al. 1986). By reporting basal peat dates in the Chesapeake Bay as old as 4510 BP, Pardi et al. (1984) demonstrated that Chesapeake Bay marshes have generally been keeping up with rising sea-levels for at least this long. However, in the last few centuries the reduction of a sediment source and the increased pace of sea-level rise in the Chesapeake Bay has created a sediment deficit in relation to sea-level rise (Stevenson, et al., 1985). As a result, marshes such as Blackwater National Wildlife Refuge are deteriorating (Pendleton and Stevenson, 1983). The large marshy islands, such as Bloodsworth, South Marsh and Smith, are also experiencing interior marsh degradation, which is evident by examining sequential aerial photographs of the same location. It is likely that a combination of a sediment deficit, local subsidence, and rising sea levels are causing the marsh loss.

Marshes also respond to sea-level rise by migrating inland, encroaching on upland areas and subsequently converting them to marsh. This process of upland conversion is evident on many of the islands today, where trees are dying at the edge of upland forests (Plate 2.4), and where marsh peats are developing over the clay layer of the Kent Island Formation (Plate 2.5). The peat layer varies in thickness and therefore in age. GEO-RECON (1980) estimates that some of the marshes on Bloodsworth Island first began to develop around 400 years ago, based on depths of the peat layer.

Future Sea-Level Rise

Another question to consider is the effects of a continued and/or accelerated future sea-level rise. The possible impacts of an accelerated sea-level rise include: (1) coastal inundation, (2) increased erosion, (3) change in the circulation and salinity of estuaries and lagoons, (4) increased storm damage, (5) loss of

Plate 2.4 View of tress dying at the edge of an upland area on Lower Hooper Island, an example of the upland conversion process.

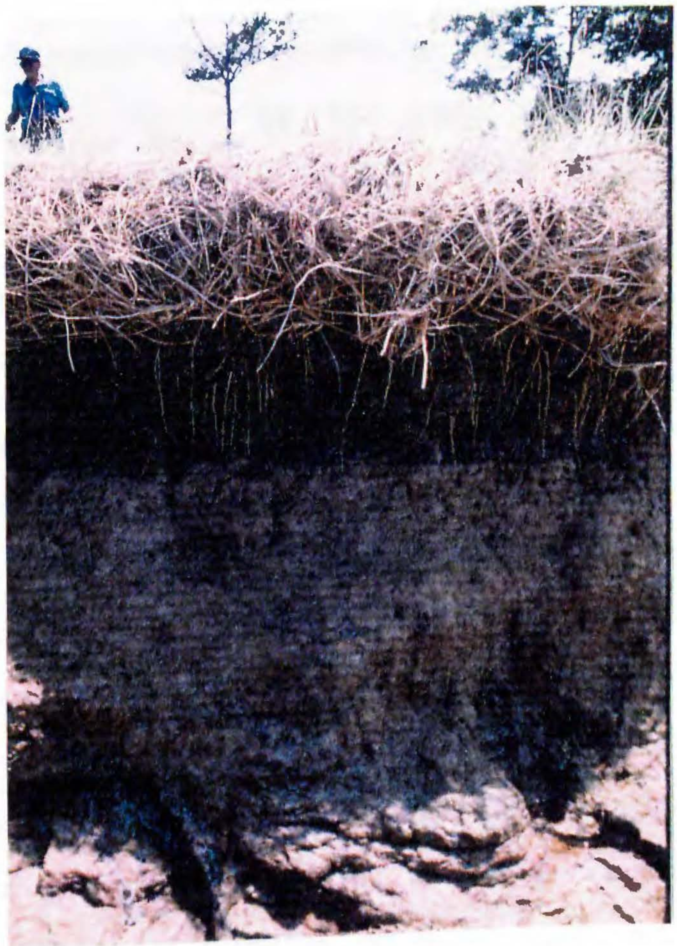


Plate 2.5 View of a marsh peat layer over the silt/clay layer on Lower Hooper Island

wetlands, (6) changes in the ecotomes and habitats, (7) loss of turtle and bird nesting areas, and (8) increased saltwater intrusion into groundwater (Emery and Aubrey, 1991). The Intergovernmental Panel on Climate Change (1990) estimates that eustatic sea level will rise between 8 and 29 cm by the year 2030, with a best estimate of 18 cm (Figure 2.4). This rate of sea-level change is from 3 to 6 times faster than the last 100 years. If sea-level is rising in the Bay at a rate two to three times faster than the global average and this trend continues, then the best estimate for the Bay would be a rise in sea level of about 24 cm by the year 2030, 56 cm by the year 2070, and 82 cm by 2100. The Chesapeake Bay figures are obtained by calculating the rate difference between the global sea-level trend (1.8 mm/yr) and the Baltimore trend (3.3 mm/yr). This difference (1.5 mm/yr) is multiplied by the number of years in a given time period, and then is added to the IPCC best estimate calculation.

The IPCC estimates are based on scientific theories and careful modeling of climate warming due to the increased presence of radiative gases in the atmosphere. Radiative or "greenhouse" gases, including CO_2, NO, water vapor, methane and chloroflourocarbons, have the ability to trap outgoing radiation or heat emanating from the Earth's surface, thereby trapping heat in the atmosphere.

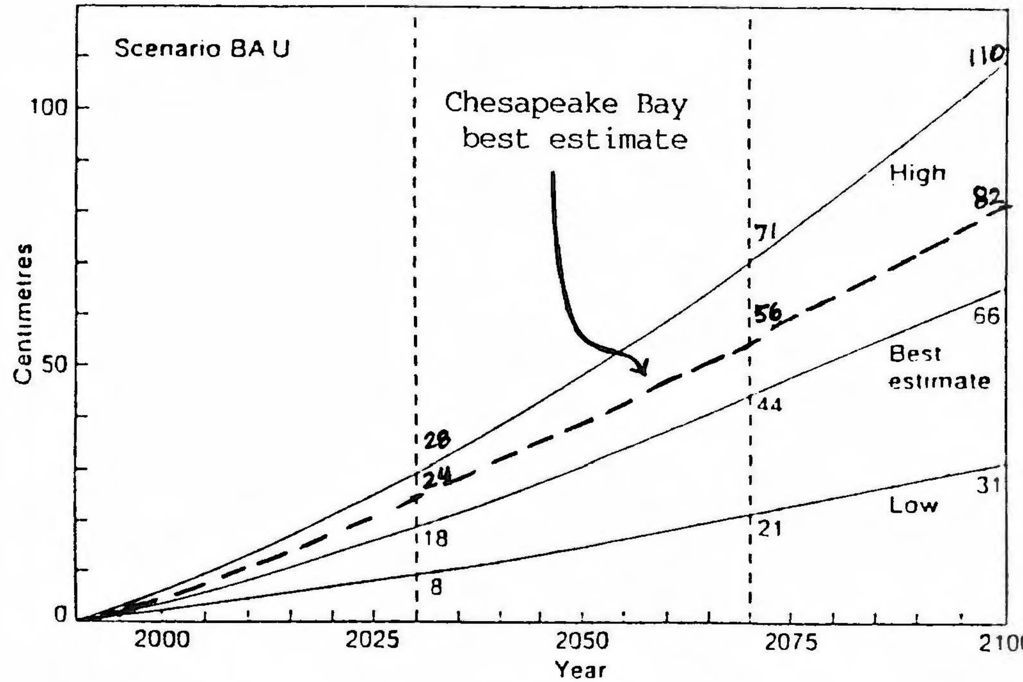


Figure 2.4 Global sea-level rise, 1990-2100, for Policy Scenario Business-as-Usual. (Adapted from IPCC, 1990).

The theory of global warming predicts that the higher surface temperatures on earth will cause substantial climate warming which will result in sea-level change due to thermal expansion of the surface layer of the ocean, continental ice melting and retreat, and changes in ocean circulation and wind patterns. Due to large uncertainties about the extent of future temperature change due to global warming, there are many questions about how important each of these effects might be. However, even with substantial reductions in the emissions of the major radiative gases, future increases in temperature and consequently sea level are unavoidable due to the lags in the climate system. In other words, there is a "commitment" to a rise in sea level which is estimated to be 18 cm by 2030 and 41 cm by 2100 (IPCC, 1990). Future rates of sea-level rise are an important consideration for coastal areas such as the Chesapeake Bay. An acceleration in the rate of sea-level rise can only exacerbate the rapid coastal land loss already occurring in the Bay.

Islands in the Study Area

Introduction

The study area consists of a sample of seven islands along the eastern shore of Chesapeake Bay (Figure 1.1):

Barren Island
Bloodsworth Island
Hooper Island
James Island
Poplar Island
Smith Island
South Marsh Island

The islands are very low-lying, with elevations less than about 2.5 meters above sea level, based on USGS topographic charts. The highest elevation measured during fieldwork was 2.4 m above mean sea level (MSL) on Poplar Island. Tidal range in the Bay is about 1 m at the mouth of the Bay and decreases to about 0.3 m at Baltimore. The tidal range at all the island sites is about 0.5 m (Wang, et al., 1982). Much of the eastern shore is used for agriculture and farming, and the towns are the homes and ports for watermen.

The islands can generally be divided into two morphologically distinct types: large marshy islands and small upland/marsh islands. Bloodsworth, Hooper, Smith and South Marsh Islands are large, marshy islands. Barren, James and Poplar are small, upland/marsh islands. The island shores mainly consist of eroding clay bluffs, eroding marsh, and a few small pocket beaches.

No detailed study of the origin of the islands has been undertaken. One possible mechanism is related to the antecedent topography of the Chesapeake Bay, as mentioned earlier (Kehrin, et al., 1988). As sea level rose and flooded the Susquehanna River valley, areas with elevations high enough to remain above the rising water eventually became cut off from other areas and became islands or peninsulas. Since sea level has continued to rise, these islands have been reduced in size by submergence and erosion. These processes are still occurring in the Bay today, as existing islands and the mainland shore are experiencing rapid land loss.

Human populations have historically used the islands for living, farming and fishing. Watermen and their families from nearby areas settled on the islands because they provided easy access to the Bay. In addition, in the 18th and 19th centuries, many of the islands offered ample space for settlement and farming which was an attractive proposition for many Bay-area pioneers (Meyer, 1986). The populations of most of the islands peaked around the end of the 19th century.

However, the processes of land loss since the mid-19th century have reduced the availability of arable, habitable land. As a result, most of the islands which were once inhabited have been abandoned. Hooper and Smith Islands still have permanent towns which exist barely above the water level. South Marsh Island is the only island which was never inhabited by European settlers. Poplar, James, Barren and Bloodsworth Islands each have a history of settlement and subsequent abandonment of human communities.

Barren Island

Barren Island, located in Dorchester County, Maryland, is about 1.6 km west of Hooper Island. It is currently about 75 ha which is dominated by upland forested areas, with some fringe marshes. Barren Island has seen the rise and disappearance of a prosperous community. Families settled on Barren Island because of its proximity to the Bay for fishing and oystering, and for available farm land. By 1877, the community of Barren Island reached a maximum of 13 farms and a schoolhouse (Cronin, 1988). Soon thereafter, families began moving their houses to the mainland where the living conditions were preferable. By 1916, the last family had left the island.

There is still a hunting lodge on Barren Island which was built in the 1920's by William Siskind who owned the island until recently. Originally, it was more than 300 m from the western shore of the island. Twenty-three years later, in 1952, the lodge had to be protected by a wooden bulkhead built about 30 m to the west of the building, a clear sign that erosion was rapidly encroaching on the lodge. In 1964 the breakwall was still intact, but was seriously undermined on either end. By 1987, the breakwall had failed, the house had partially fallen in the Bay and the site was abandoned.

A site visit in 1991 revealed that the property is completely abandoned, except for a family of peregrine falcons nesting on the roof of the dilapidated structure (Plate 2.6). The erosion continues to cut away at the western side of the island at a rapid rate with no likelihood of stopping. At one time, Siskind appealed to Dorchester County and the U.S. Army Corps of Engineers to help stabilize his property, but his proposal was denied (Cronin, 1988).

The U.S. Fish and Wildlife Service has recently acquired Barren Island due to its important habitat resources for ducks and other waterfowl. In addition, the island hosts a large heron and egret rookery and a bald eagle nest. Exact plans for the island are not yet known, and feasibility studies would be required for any type of habitat restoration project (Walter Quist, U.S. Fish and Wildlife Service, personal communication, October, 1991).

Bloodsworth Island

Bloodsworth Island, in Dorchester County, Maryland, is located about 5.6 km west of Deal Island. The island today is about 1,909 ha of marsh with one linear upland ridge of about 1.2 ha. The ridge, called Fin Creek Ridge, is sparsely covered with Virginia pine and black cherry trees. Surveys on the ridge revealed building

Plate 2.6 View of the hunting lodge on Barren Island

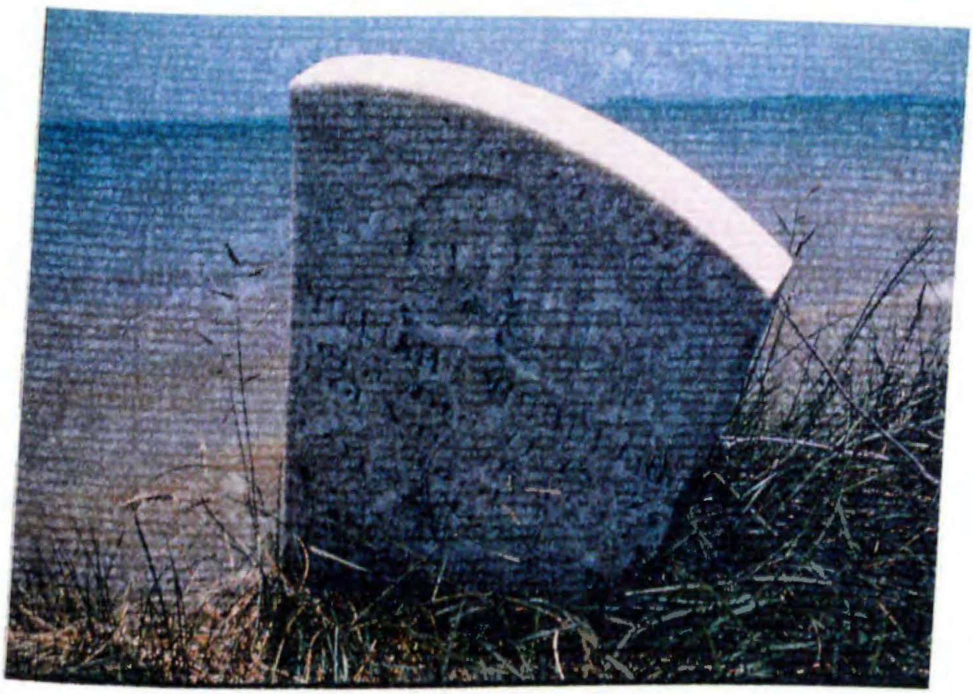


Plate 2.7 View of an eroding graveyard on Lower Hooper Island

foundations, brick rubble, and other artifacts beneath about 15 cm of loam, and overlaying a layer of sterile tan clay (GEO-RECON, 1980). A 1849 NOS chart shows seven buildings on several small upland areas, but the majority of the island is denoted as salt marsh. Some of the upland areas appear to be cleared and diked, and an orchard can be seen in one area (Figure 2.5). In 1877, land records indicate that 14 landowners or residents occupied the island (GEO-RECON, 1980). Now, Bloodsworth Island is completely uninhabited by humans.

In 1948 the U.S. Navy bought the island which has since been used as a bombing range and testing area. Despite the regular bombing of the island, it is an important overwintering and stop-over area for waterfowl, including geese, ducks, herons, egrets, songbirds, ospreys, and a Bald Eagle (U.S. Navy, 1981). The U.S. Fish and Wildlife Service and the U.S. Navy are formulating a cooperative waterfowl/wetland management program for Bloodsworth Island. Part of their study will determine the effects of bombing craters on waterfowl and the health of the marsh.

Hooper Island

Hooper Island, in Dorchester County, Maryland, has been occupied since at least the mid-19th century. It is a combination of upland and marsh areas. The island is

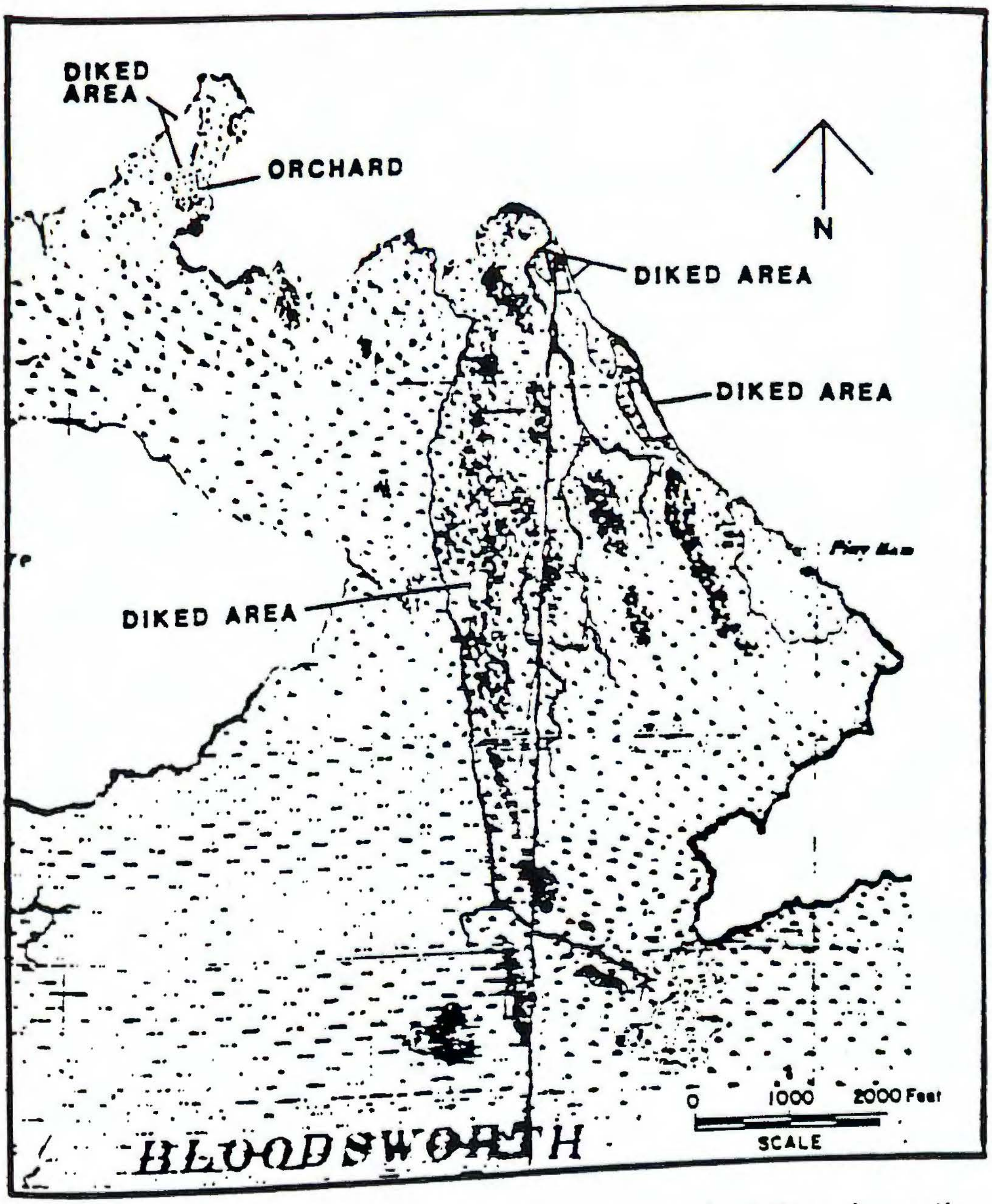


Figure 2.5 Enlargement of the 1848 T-sheet of Bloodsworth Island, showing the location of an orchard and several diked areas (from GEO-RECON, 1980)

attached to the southern part of Taylor's Island by a bridge, so access to Hooper Island is relatively easy. Running along the western side of the Honga River, the island is about 13 km long (North-South) and 1.6 km wide (East-West) at the widest point. Three towns on the island are Honga, Fishing Creek, and Hoopersville.

Erosion is an evident problem for the residents of Hooper Island. Wooden breakwalls and revetments have protected much of the island from the erosion on both the western and eastern sides since the mid 1900's. This has provided the island with physical stability which, together with vehicular access to the island, has allowed the inhabitants to remain. On the southern end of Hooper Island there is a small graveyard on the edge of a marsh which is being eroded to the point where gravestones are falling in the water and wooden coffins are protruding from beneath the surface layer of the marsh (Plate 2.7). This part of the island does not have any shore protection structures and appears to be rapidly eroding.

Flooding is also a problem for the residents as many of the houses and buildings are elevated above the ground by about 0.5 m or more. In addition, coffins must be encased in cement to prevent the wooden coffins from becoming afloat with the high water table (Plate 2.8), and many lawns are level with the watertable (Plate 2.9). The entire island is less than a meter above sea-level,

Plate 2.8 View of cement encased graves on Middle Hooper Island

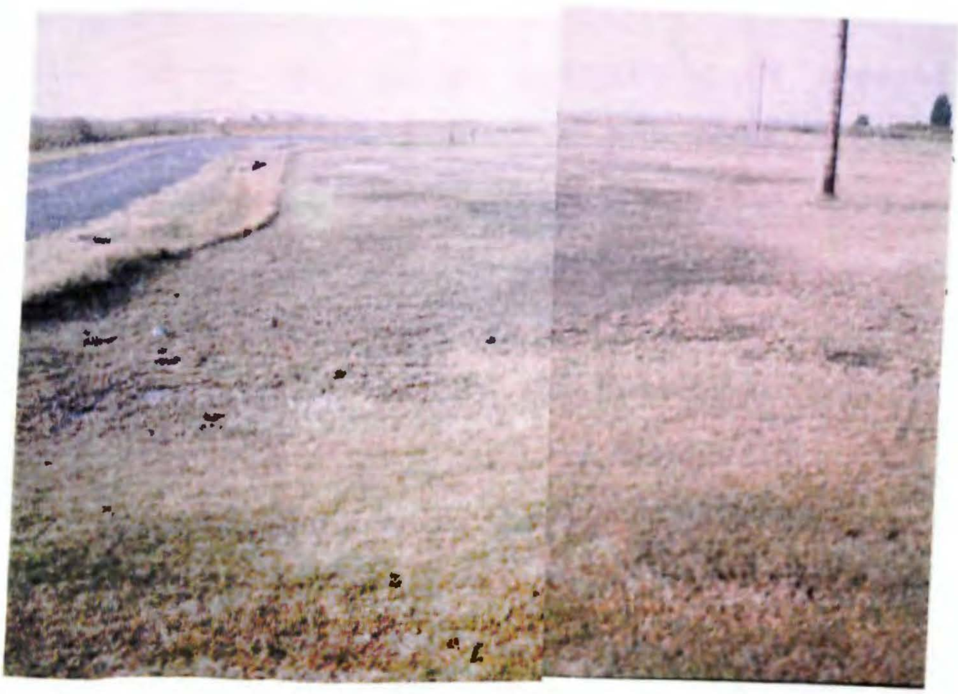


Plate 2.9 View of a flooded lawn on Middle Hooper Island

and in many places only about 100 m wide. A major Northeaster on October 31, 1991 flooded the entire island by about 0.3 m.

James Island

James Island, in Dorchester County, Maryland, is located about 1 mile north of the northernmost point of Taylor's Island. From observations of a 1848 NOS chart, it is clear that James Island was formerly a peninsula which was attached to the northern point of Taylors Island (Figure 2.6). A single road from Taylors Island extended north along the length of James Island with a few small side roads. There were eleven buildings and about 70% of the island appears to be cleared and cultivated. Because the Island was close to the Bay's fishery resources and readily accessible by Taylor's Island, it was probably an attractive place to settle.

By 1901 James Island had become a true island as the connecting neck of lowland was totally eroded (Figure 2.7). There was no road and only five buildings at this time. About half of the island was cultivated, including one tree farm. Clearly, around the time the island was separated from the mainland to become a true island, the inhabitants began to move to the mainland rather than remain on a rapidly eroding island.

Figure 2.6 Enlargement of 1848 T-Sheet of James Island showing the island attached to the mainland

Figure 2.7 Enlargement of 1901 T-sheet of James Island showing the island separated from the mainland

By 1941, there were no farms, and the island had separated into two pieces. No one inhabited the island after this point; it was eroding so rapidly from the west that living on the island had probably become very unattractive. Today the island is only about 45 ha in size.

Poplar Island

Poplar Island, in Talbot County, Maryland, is located 1.6 km west of Tilghman Island, about 8 km north of the mouth of the Choptank River. In the late 1600's Poplar Island was a single island. Less than 200 years later, in 1846, it had broken into three islands, known as Coaches, Jefferson, and Poplar Island. Together these three islands are known as the "Poplar Complex". The Poplar Complex now consists of two large islands, Jefferson and Coaches, and seven small islets. Today, the total size of the Poplar Complex is about 43 ha.

Poplar Island has received a great deal of attention in the press presumably because a large community persisted on the island for nearly 50 years, and the Jefferson Island Club which entertained Presidents Roosevelt and Truman was located on Jefferson Island. From the 1880's to 1920's, as many as 20 families lived on the island and the community included a general store, post office, one-room schoolhouse, church, lumberyard, and 6 farms which grew tomatoes, tobacco, watermelons, cantaloupes, corn, wheat and trees. Delores Reese, a former resident of Poplar Island, who now lives in St. Michaels, Maryland, described Poplar as a "beautiful island with oyster shell walks and little white picket fences" (Cronin, 1985). By 1918, the schoolhouse was closed, which indicates that the population had begun to decline and as soon as 1929 the island was uninhabited.

The island is currently owned by the Poplar Investment Group who use the island during the hunting season. There is one building on the southern point of Jefferson Island and a trailer on Coaches Island for visitors. The small islets range in size from about 1 m^2 to under 0.5 hectare, but they are completely uninhabitable (Plate 2.10).

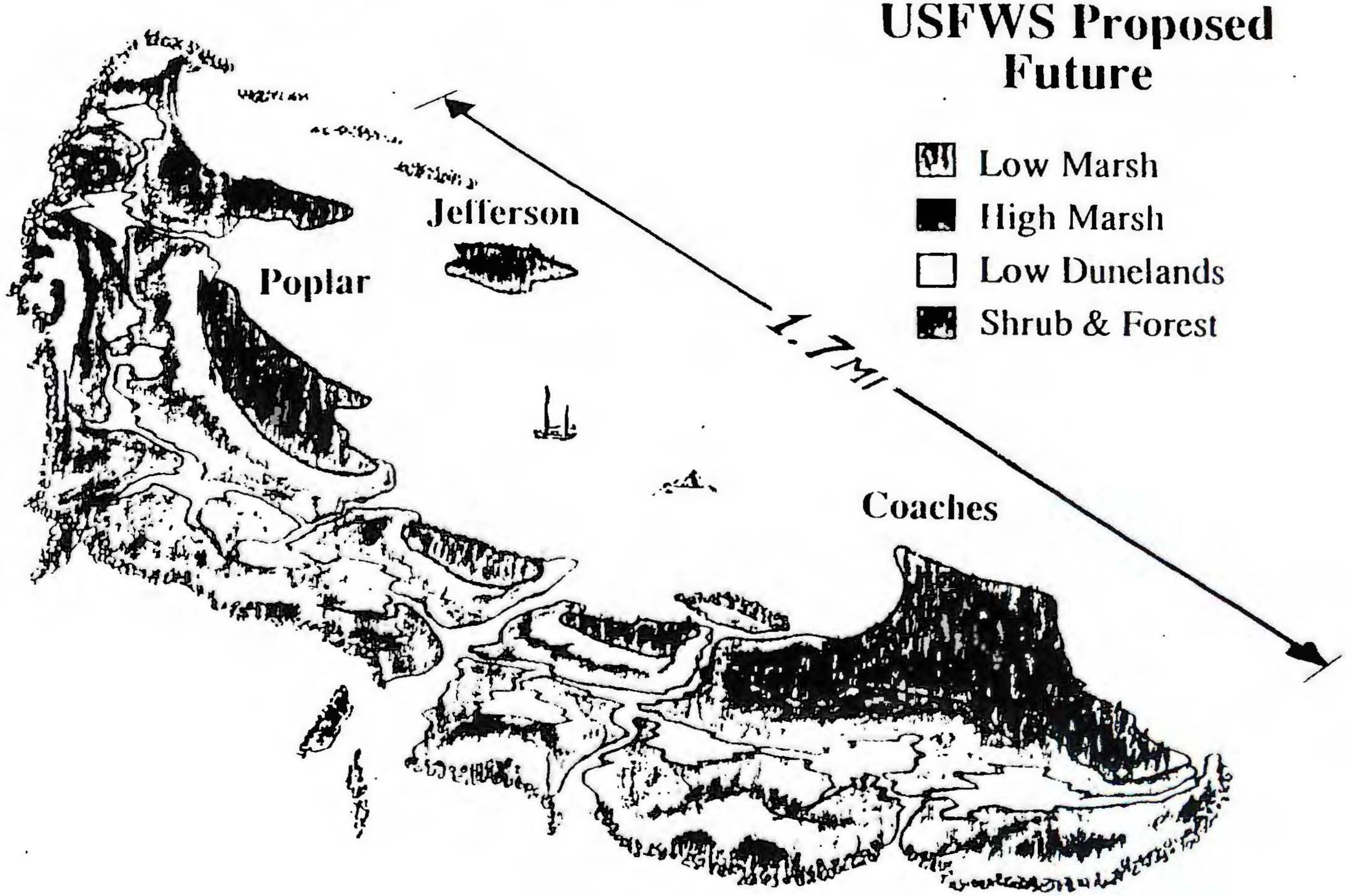
The State of Maryland and the U.S. Army Corps of Engineers are presently considering a proposal by the U.S. Fish and Wildlife Service to use Poplar Island as a waterfowl habitat restoration project. This project proposes to use dredge material to recreate valuable waterfowl habitat including tidal marsh and upland areas (Figure 2.8) (John Gill, US Fish and Wildlife Service, personal communication, June 16, 1991).

Smith Island

Smith Island, in Somerset County, Maryland, is

Plate 2.10 View of Poplar Island islets

Figure 2.8 Schematic drawing of Poplar Island habitat enhancement proposal (from U.S. Fish and Wildlife Service, undated draft)



located 13 km west of the town of Crisfield. It is about 2,800 ha, dominated by wetlands with a few linear upland ridges. Three of the largest ridges are occupied by the towns of Ewell, Tylerton, and Rhodes Point, which make up the entire population of the island of about 530 (Figure 2.9). The northern portion of the island comprises the Glenn L. Martin National Wildlife Refuge.

Smith Island was colonized in 1657 by the Tyler, Bradshaw and Evans families who settled on the island in search of available land for farming. Although farming is no longer an industry on the island because of frequent flooding, the towns have evolved into important fishing communities for the entire Chesapeake Bay. Most buildings are slightly elevated to help prevent damage from frequent flooding.

The effects of flooding and inundation are more important to the island's residents than is erosion because flooding affects them more directly. The majority of the island is very low-lying marsh, less than about 0.5 m above mean sea-level (msl). The ridges are a little higher, being only about 1 m above msl, according to recent USGS topographic surveys. Over 95% of Smith Island is mapped within the 100-year flood zone (FEMA, 1980; U.S. Army Corps of Engineers, 1984). As a result, flooding from storms causes frequent and recurring damage.

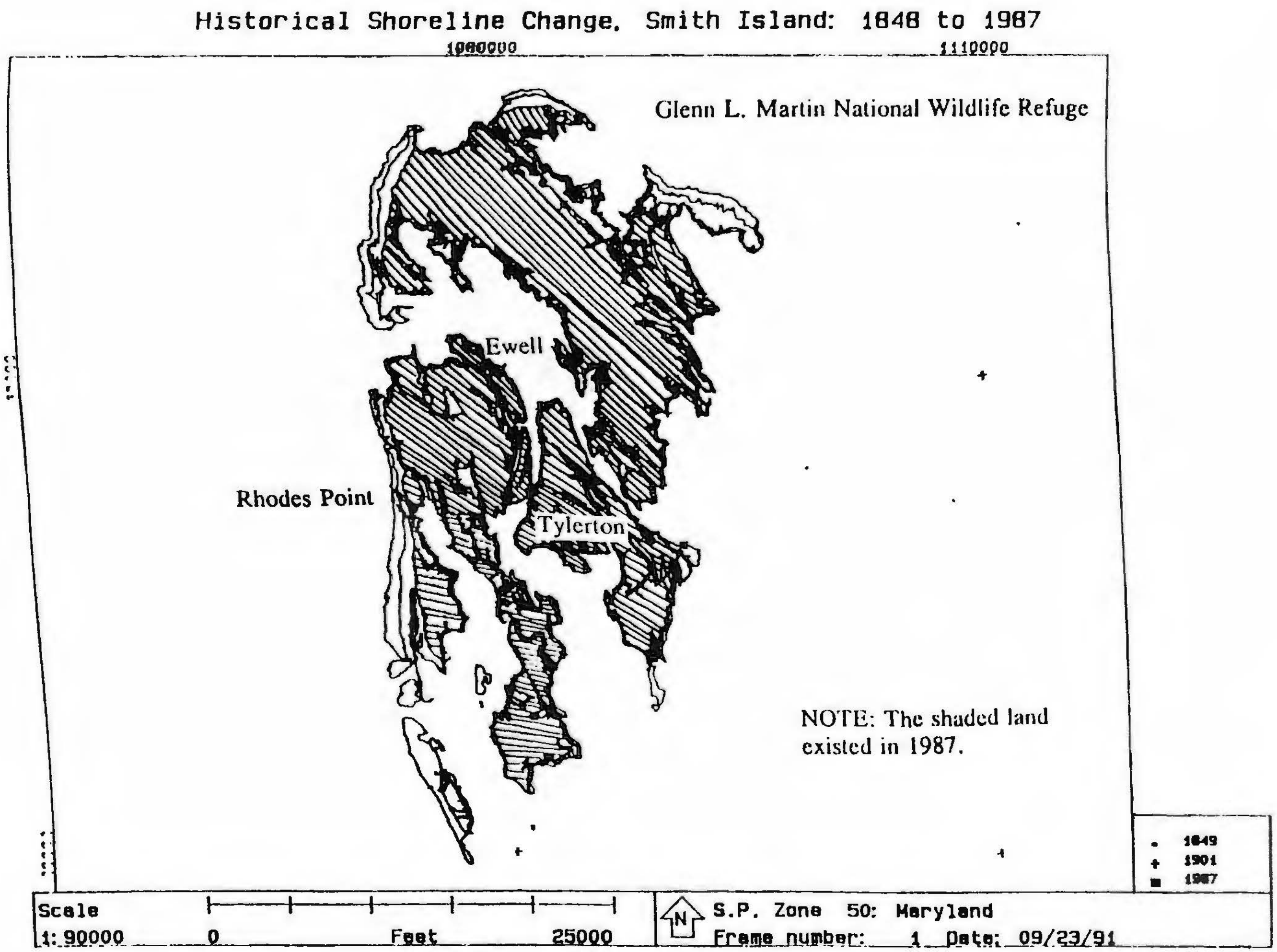


Figure 2.9 Map of Smith Island with town locations

The eroding edges of the island are not directly impacting the towns which are slightly inland. Rhodes Point is the most threatened town. Erosion cannot be overlooked as a component of land loss for this island, however, since over 1,200 hectares have been eroded from the perimeter of the island since the mid-1800's.

Because Smith Island has been so isolated from the mainland, it has managed to retain some of its traditional culture from when it was colonized in the 17th century. The main lifestyle of most Smith Islanders is still that of the watermen. Some residents of the island speak with a unique dialect which originates from colonial English. Many of the residents are descendants from the original families who settled on the island. However, the ferry service from Crisfield, Maryland and Reedville, Virginia carries tourists regularly to the island, bringing along modern-day ideas of development and tourism. Although the culture is changing with the introduction of modern conveniences, the island and its residents still retain some of their original charm and uniqueness.

South Marsh Island

South Marsh Island, in Somerset County, Maryland, is a Maryland State Wildlife Management Area. European settlers have never occupied South Marsh Island, which is a 1,200-hectare, marshy island and an important breeding and nesting area for waterfowl in the Bay. At the present time, the island is entirely salt marsh, with no upland ridges. Despite the lack of ridges, this island likely formed in a similar manner as Bloodsworth and Smith Islands (GEO-RECON, 1980). The lack of ridges can be explained if the island has a very flat or lower pre-Holocene clay layer. Hovever, no cores or detailed geologic survey have been undertaken to confirm this conclusion.

CHAPTER 3: METHODS

Introduction

The processes and rates of shoreline change were investigated for seven islands in the Chesapeake Bay. The study consisted of several phases, each of which contributed to the understanding of the processes of land loss for the study area and predictions of the islands' future. The phases were:

I: Historical Shoreline Mapping

II: Field Surveys

III: Data Analysis

IV: Forecast Modeling

Historical shoreline change maps were generated for each island using a computer mapping procedure, showing the land loss for each island between the period of about 1848 to 1987. Therefore, the historical data for each island covered nearly 140 years, enabling long-term trends of shoreline behavior to be identified. Modeling future shoreline response was based on the long-term historic erosion rates and the predictions of future sea-level rise (see Figure 2.4).

Historical Shoreline Mapping

The historic rate of land loss for each island was quantified using a computer mapping technique termed Metric Mapping (Leatherman and Clow, 1983), which:

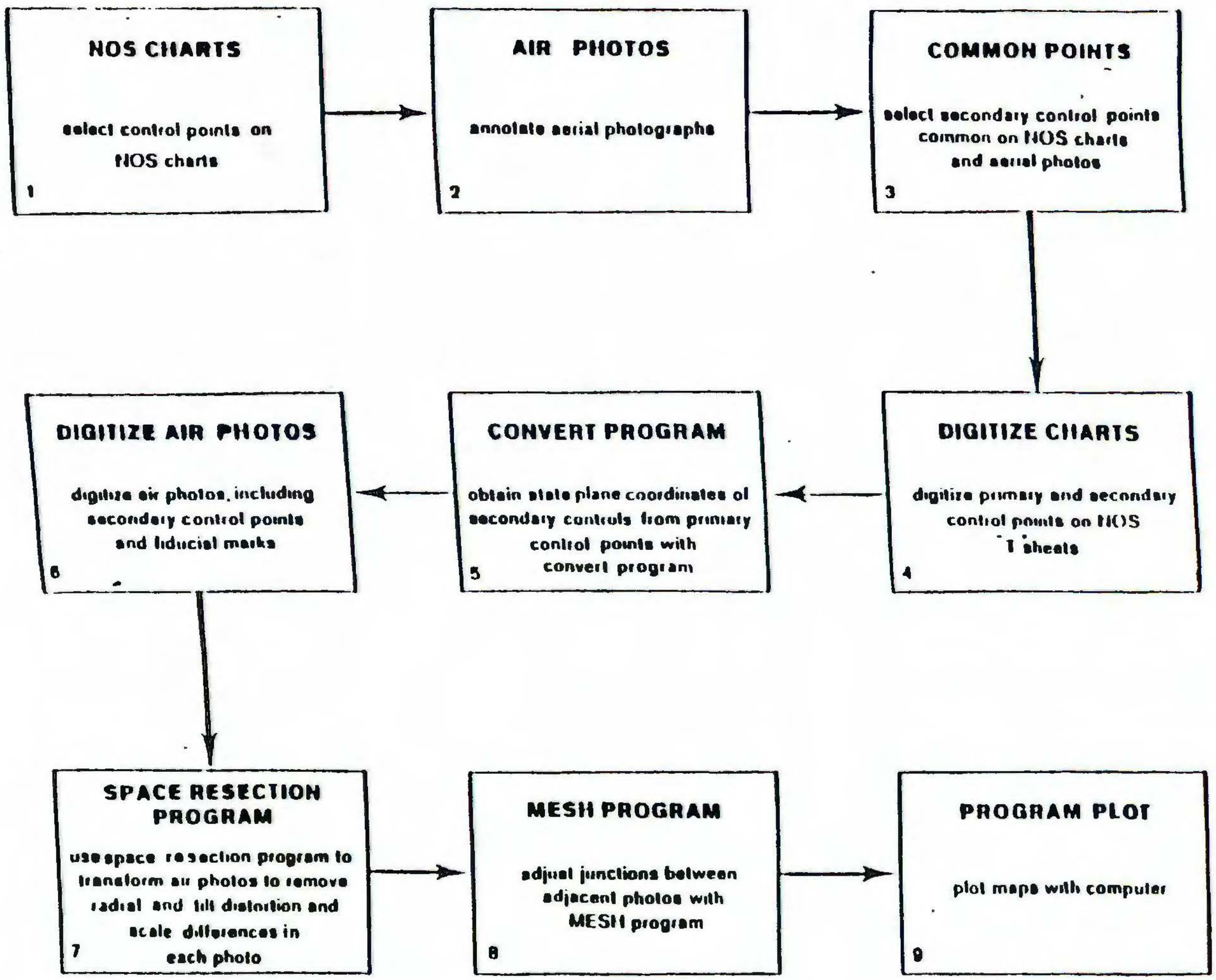
1. utilizes different historical shoreline data from NOS Topographic Surveys ("T-sheets") and vertical aerial photographs;
2. corrects errors inherent in these sources; and
3. displays each shoreline on a common grid system to allow for quantitative comparisons.

Shoreline change maps generated by this system meet and generally exceed National Map Accuracy Standards (Crowell et al., 1991). Metric Mapping proceeds in three general steps: 1) data selection and preparation; 2) shoreline digitization; and 3) data processing and analysis (Figure 3.1). The Metric Mapping Users Guide (Laboratory for Coastal Research, 1990) provides a detailed explanation of the entire procedure.

Data selection

The data for each island includes a combination of NOS T-sheets and vertical aerial photographs. Twenty-two NOS T-sheets and 48 aerial photographs were used for this study (Appendix B).

Figure 3.1 Flow chart of Metric Mapping procedure



NOS T-Sheets

NOS T-sheets were produced about every 40 years, beginning in the mid-1800's. These maps are an excellent source of shoreline data for several reasons: (1) they are the most accurate historic shoreline data commonly available (Leatherman and Clow, 1983); (2) they have large scales of 1:10,000 or 1:20,000, and therefore provide a high level of detail; (3) the surveying program covered the entire coastline in the Chesapeake Bay, including each of the islands in the study area; and (4) the surveying program extends back to the mid-1800's, providing about 140 years of data.

However, there are three major problems with using these maps as a data source: (1) there are no recent T-sheets available in the study area due to a reduction in the surveying program beginning in the mid-1900's; (2) some of the older NOS T-sheets are distorted because less accurate surveying techniques were used in the past; and (3) in some cases the triangulation stations are not updated to the 1927 datum (Shalowitz, 1964). These respective problems are overcome by: (a) using recent aerial photographs to update the map shoreline information; (b) quality control which identifies and hence, eliminates distorted or inaccurate maps; and (c) updating triangulation stations to North American Datum of 1927 (NAD 27) using coordinate data from the National

Geodetic Survey in Rockville, Maryland.

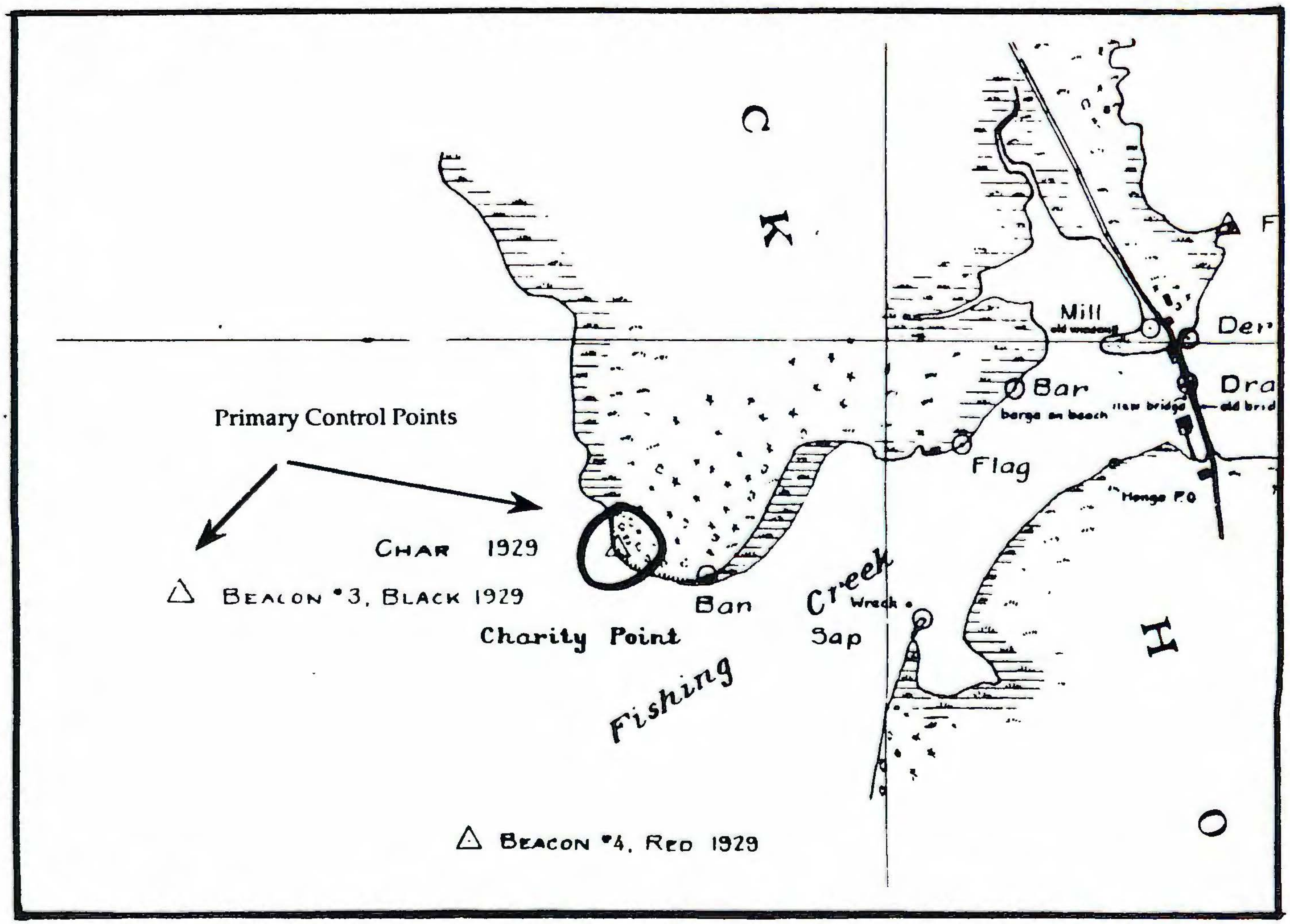
Vertical Aerial Photographs

The photographs used in this study were obtained from the U.S. Department of Agriculture. These black and white vertical aerial photographs, dated from 1952, 1964 and 1987, are at a scale of either 1:7,920 or 1:12,000. For the smaller islands - Barren, James and Poplar - one photograph provided total coverage for each island. For the larger islands, such as Bloodsworth, Hooper, Smith and South Marsh, a mosaic of overlapping photographs was used for complete coverage of each island.

Data Preparation

Several steps are required to prepare the maps and the photographs for digitizing by the Metric Mapping procedure. First, primary control points were carefully chosen on the maps, digitized, and then checked for accuracy. Primary control points are points with known latitude-longitude coordinates which have been updated to NAD 27. These are either latitude-longitude tick marks or specific triangulation stations, for which the exact location were obtained from the National Geodetic Survey (Figure 3.2). To check for accuracy, the computer compared the digitized coordinates of the primary control points with the known coordinate system. In all cases,

Figure 3.2 Example of Primary Control Points



the accuracy of the primary control points was within 0.2 mm of the exact location, meaning that it is within 4 m of the exact location for a 1:20,000 map and within 2 m for a 1:10,000 map (Crowell et al., 1991). Since 0.2 mm is within the accuracy acceptance limits, no T-sheets were discarded. Shoreline segments were then identified on the maps at intervals around the island and numbered for digitizing.

For the aerial photographs, secondary control points, which are locationally stable points common to both the maps and the photographs, were identified on the photographs and the base map. The base map is used to transform the photographs to the latitude-longitude coordinate system of the maps. Some of the most commonly used secondary control points are structures such as corners at the base of buildings, road intersections, piers and jetties (Figure 3.3). In some cases, where roads or buildings were not in the photograph, geomorphic features such as stream intersections, stream openings and small, erosion-resistant promontories served as secondary control points.

The paucity of both geomorphic and structural secondary control points was the major constraint on data accuracy in this study. For Smith Island and South Marsh Island, there was an insufficient number of viable geomorphic control points. This is due to the dramatic

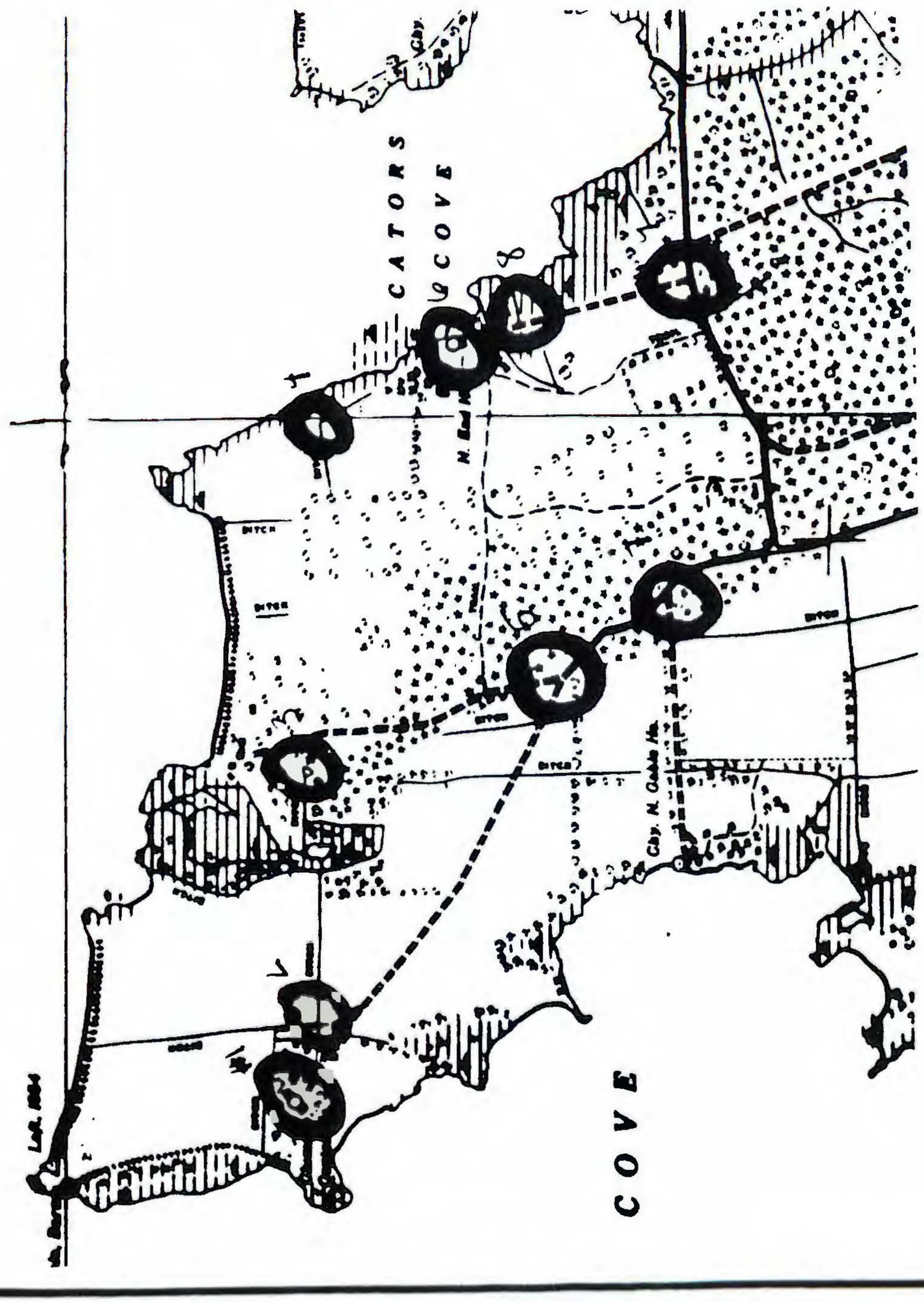


Figure 3.3 Example of Secondary Control Points (circled)

physical changes which had occurred between the date of the most recent map (the "base map") and the photographs. For this study, the base maps were dated around 1942 or 1943. The lack of stable infrastructure also caused difficulties in locating accurate structural control points. The 1952-series photographs for these two islands could not be tied accurately to the latitude-longitude coordinate system of the maps in the same manner as the other islands. Thus, it was necessary to discard them.

In addition, an alternative method was developed to tie the 1987 photographs for Hooper, South Marsh and Smith Islands to the map coordinate system. This method used recent 7.5 minute topographic maps ("USGS quads"), from 1972 and 1985, to identify secondary control points for the 1987 photographs. The USGS quads were used merely to identify secondary control points; their shorelines were not digitized. Significantly less shoreline change had occurred between the time the USGS quads were surveyed and the photographs were taken. As a result, finding viable geomorphic secondary control points was much easier. In general, using the USGS quads to identify secondary control points proved to be an accurate methodology.

The approximate shoreline location was identified on the photographs and marked with a fine red pencil. Most of the shoreline was composed of a 1 to 2 m cliff face or an eroding marsh scarp. In these areas, the shoreline was identified as the marsh/water or cliff/water interface. Where a small pocket beach was present, the mean high water line was identified as the line of dark sand. Shoreline segments were then numbered for digitizing.

Digitizing

Digitizing was accomplished with the Atlas Draw digitizing program, an integral component of Metric Mapping. Shoreline segments were identified on both the maps and photographs at lengths appropriate for accurate digitizing. For the smaller islands, Barren, James, and Poplar, each map and photograph covered an entire island. The larger islands required a mosaic of photographs and maps for complete coverage of the island. As a result, line segments had to be connected on adjoining photographs and maps, which made digitizing more complicated and added a potentially significant error factor due to photograph distortion and overlap. The 1987 photographs of Hooper Island and South Marsh Island exclude a small fraction of the island. However, this omission is insignificant and the overall pattern of shoreline change is still discernable.

Data Analysis

The digitized data were then run through the Space Resection program, another integral component of Metric Mapping (Leatherman and Clow, 1983). This program corrects for scaling differences among the maps and photographs, and determines if the data are distorted. Space Resection is also used to overlay the various data sources onto a common grid system, which allows for comparison between data sources and years, and for the calculation of erosion rates.

For the maps, Space Resection computes the scale differences between maps and adjusts the digitized information accordingly. For the photographs, Space Resection is much more complicated as it must adjust for several potential sources of error, such as 1) scale differences in the photographs and the maps, and 2) distortion due to photograph angle, relief displacement and flying height of the camera. The Space Resection Program uses the secondary control points to "tie" the photograph to the map, thereby pulling the photograph into place on the latitude-longitude grid system of the maps.

After the data were digitized and Space Resected, the maps were merged together to make a complete file for each island which included all historical shoreline data. The ends of the digitized line segments were joined by another program called the Tie Program. This program also joined line segments on adjacent photographs and maps, thereby melding each map or photo-mosaic.

The complete file for each island was then plotted using the Plot Map Program. The resulting maps had several shorelines, each representing a particular time period. The final maps graphically demonstrated the spatial and temporal shoreline change for each island from about 1848 to 1987.

All the data for each island were compiled, annotated, digitized, Space Resected, merged, tied together, and plotted. The erosion rates and net amounts of erosion were then calculated for each island using the Transect Program of Metric Mapping. The Transect Program is designed to calculate the rate of change and total amount of change between two historical shorelines at any desired location along the study shoreline. This is done by projecting transects across the shorelines (Figure 3.4), from which the computer calculates the distance/time (i.e., erosion rate), as well as the net distance between any two shorelines. The program is designed for straight or gently curving shorelines, and problems arose in this study because the shorelines and island shapes are quite irregular. Additional problems arose where an island had broken into sections. Ordinarily, one spine is used which parallels the entire

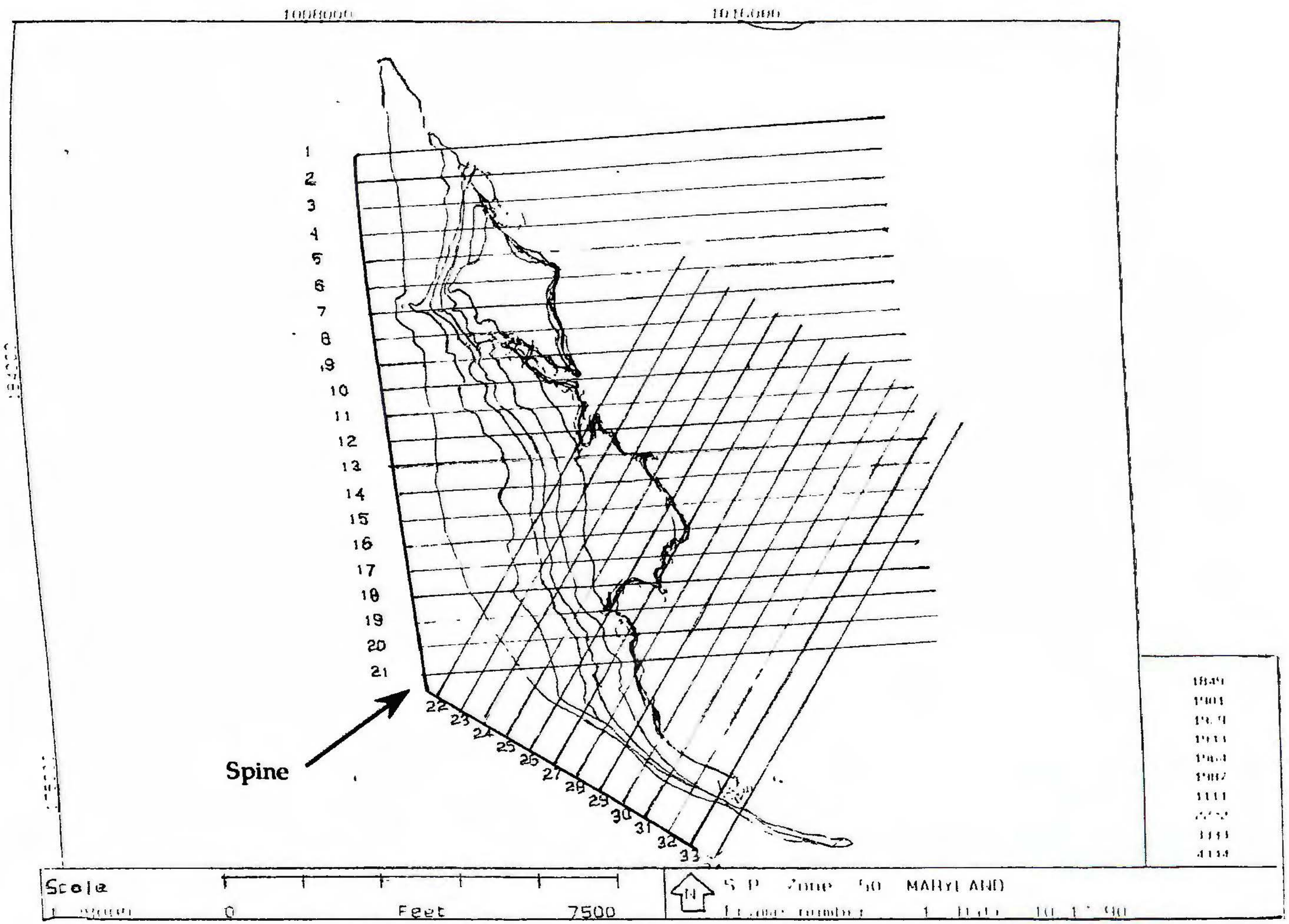


Figure 3.4 Example of transects along western side of Barren Island

shoreline, from which perpendicular transects are projected across the historical shorelines. For the islands, it was necessary to run several small spines along relatively straight areas which were representative of the rest of the island in terms of shoreline change. This was necessary to prevent the transect lines from crossing one another and producing spurious results.

The transect data were subjected to careful quality control before erosion rates were calculated. Some of the transects had to be omitted from the final analysis because they appeared to measure both the near and far shorelines and produced spurious results. Other transects were omitted because they were oriented at an angle to the parallel shorelines, and therefore overestimated the erosion rates and net amount of erosion (for example, see transect number 22 on Figure 3.4).

Accuracy Assessment

Because of the several data sources and the many steps involved in the Metric Mapping program, there are a number of potential sources of error which can be quantified to give confidence limits to the erosion rates and shoreline change maps developed from the program. Past shoreline mapping studies have successfully used the Metric Mapping program in Massachusetts, New York, New Jersey, Delaware, and Calvert County, Maryland (Crowell, et al., 1991). These studies have shown that if care is taken to screen and correct the various data sources for error and distortion, and if raw data are computer corrected, then an accurate and reliable map product and erosion rate analysis can be obtained. In addition, in areas where the shoreline change is large, such as these islands, the associated measurement error will be small in comparison with this change, and erosion rates will be highly reliable. The actual magnitude of error is much less than the worst-case error estimates calculated by Crowell et al. (1991).

In general there are two sources of error: error associated with the raw data and error associated with digitizing the raw data. The original raw data is prone to error due to distortion, and surveying or cartographic error. Digitizing errors are due to such things as digitizing the inner or outer margin of the mean high water line on the maps, digitizer error, and digitizer-operator error. Crowell et al. (1991), quantified the worst-case error estimates for all types of data which can be applied to most historic mapping studies which use similar data sources. These estimates represent the root mean square of all possible sources of error. The worst-case error estimate for a shoreline digitized from an NOS T-sheet dated prior to 1880 was calculated as $\pm$ 8.9 meters plus sketching error (cartographer's error in creating the map). For a T-sheet dated between 1880 and 1930, the worst-case error estimate is estimated at ± 8.4 meters plus sketching error. A recent T-sheet, dated after 1930, has a calculated error estimate of ± 6.1 meters plus inaccurate interpretation of the high water line. For aerial photographs, the worst-case error estimate using structural control is calculated to be ± 7.5 meters and ± 7.7 meters if using geomorphic control, plus misinterpretation of the high water line.

Using the same methodology and error estimates calculated by Crowell et al (1991), worst-case error estimates of the annual average erosion rate for each island in this study were calculated. The error estimate for each island was calculated as the sum of the error estimate for the oldest map and the most recent aerial photograph, divided by the number of years between the data. Because each island had a unique set of data, this calculation was done separately for each island. However, the maximum possible error was calculated to be ± 0.12 m for all long term erosion rates from the 1848 data and 1987 data, for all islands. Other error estimates resulted from calculations derived from varying time spans. It is important to note that the error estimates for this study are considered to be conservative.

Field Surveys

Field surveys were conducted to determine the composition and geomorphic characteristics of the islands. All islands were visited except for South Marsh Island. Near surface sediment samples were taken in appropriate locations on each island. Samples were taken to a depth of about 0.15 m using a shovel to obtain the sample after having removed the surface layer. Samples were taken of eroding cliff, eroding marsh, healthy marsh, sandy pocket beaches, and sand spits.

Subsurface samples were taken in marshes, marsh-upland margins, and ridges on Hooper Island to the depth of the clay layer using a shovel (Plate 3.1). A transect at 7.62 m intervals and about 45.7 m in total length was conducted from the crest of an upland ridge to the center of an adjacent marsh to determine the stratigraphic relationships at the marsh-upland border and the slope of the surface of the clay layer underlying the area.

At Poplar Island, offshore samples were taken with a Van Veen grab sampler in a transect at about 100 m intervals offshore. The transect was extended to a point just outside the offshore limit of the island as it was mapped in 1848. This position was determined by locating the latitude-longitude coordinates of an offshore point from a map and then relocating the exact position using

Plate 3.1 View of a pit dug on Hooper Island with silt/clay layer showing beneath a <u>Phragmites</u> marsh

a hand-held Global Positioning System (GPS).

Sediment samples were analyzed in the laboratory to determine the percent sand by weight. The samples were dried in the oven at 140 degrees celsius, and then weighed to obtain the total dry weight. The dried sample was then deflocculated with Calgon to break up the silt and clay particles and rinsed through a 4 phi sieve to retain the entire sand fraction. The sediment retained in the sieve was then dried and weighed to determine the percentage sand in the sample.

A transit and rod were used to take beach profiles and to determine the present day elevational characteristics of the islands relative to the water level. The time of day was recorded and used later to determine the approximate tidal elevation at the time the measurements were taken. The measurements were then reduced to the common datum, National Geodetic Vertical Datum (NGVD), by extrapolating from the Baltimore tide tables. Subsequent elevations were then recorded where it was determined to be useful: marsh edge, upland margin, upland, top and base of an eroding edge, storm wrack lines on the marsh.

The geomorphological character of the island was noted on each field visit, including the presence and location of eroding scarps, eroding marsh, stable marsh, pocket beaches, sediment composition, and the condition and composition of vegetative and wildlife communities.

Data Analysis

Sea-Level Change Analysis

The Baltimore, Maryland tidal record was used as a measure of the change in sea level because it has the longest record of sea-level change for the Chesapeake Bay, dating back to 1903. A 5-year running mean was used to smooth the Baltimore record and to reduce the large interannual variation which is typical of mean sea-level records. This variation can be caused by storms and other climatic and astronomical factors (Figure 3.5).

Comparisons of the rate of sea-level change at Baltimore were made with other tide stations around the Bay including Annapolis, Solomons, Washington, D.C., and Kiptopeke (Figure 3.6). The rate of sea-level rise has been slightly higher at the four other stations, but the Baltimore record is much longer than the other stations so it was used as a more conservative estimate of sea-level change in the Bay during most of the 20th Century.

The Hampton Roads, Virginia station also has a fairly long record dating to 1927, but the area has been experiencing a relatively large amount of subsidence (Holdahl and Morrison, 1974; Davis, 1987). Therefore,

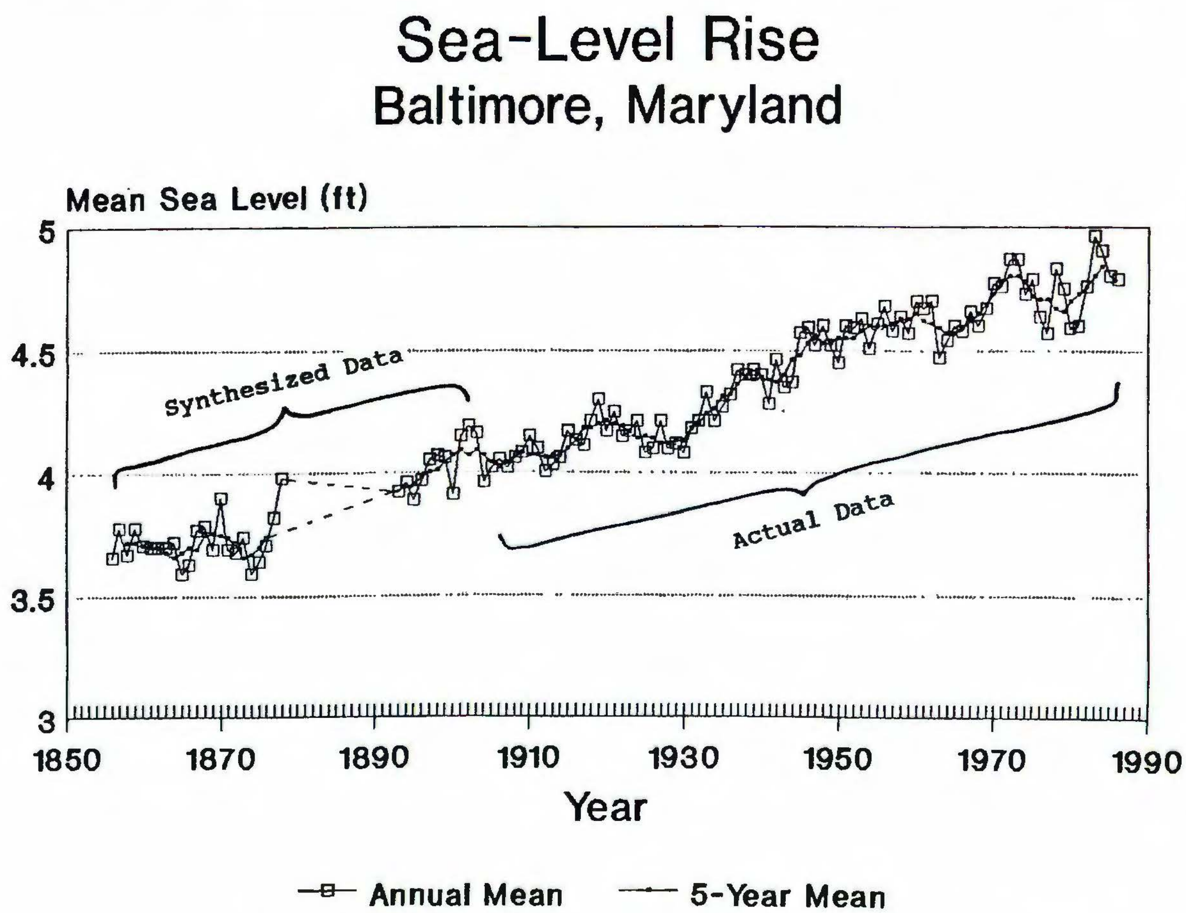


Figure 3.5 Baltimore, Maryland tide gauge record, with five-year running mean

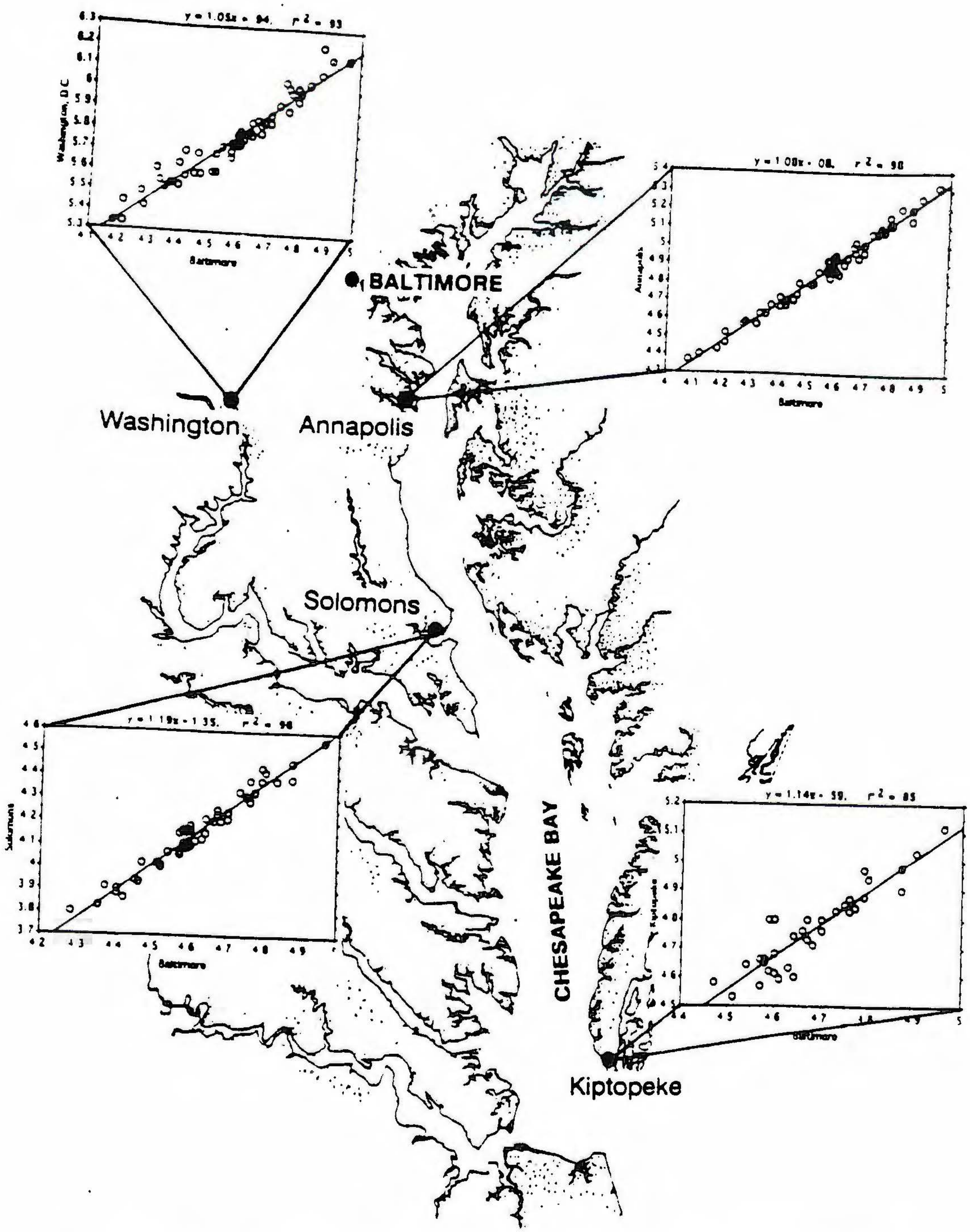


Figure 3.6 A comparison between Baltimore tide record and four other tide gauge stations in the Chesapeake Bay, showing station locations

the Hampton Roads tidal record is unrepresentative of the Bay.

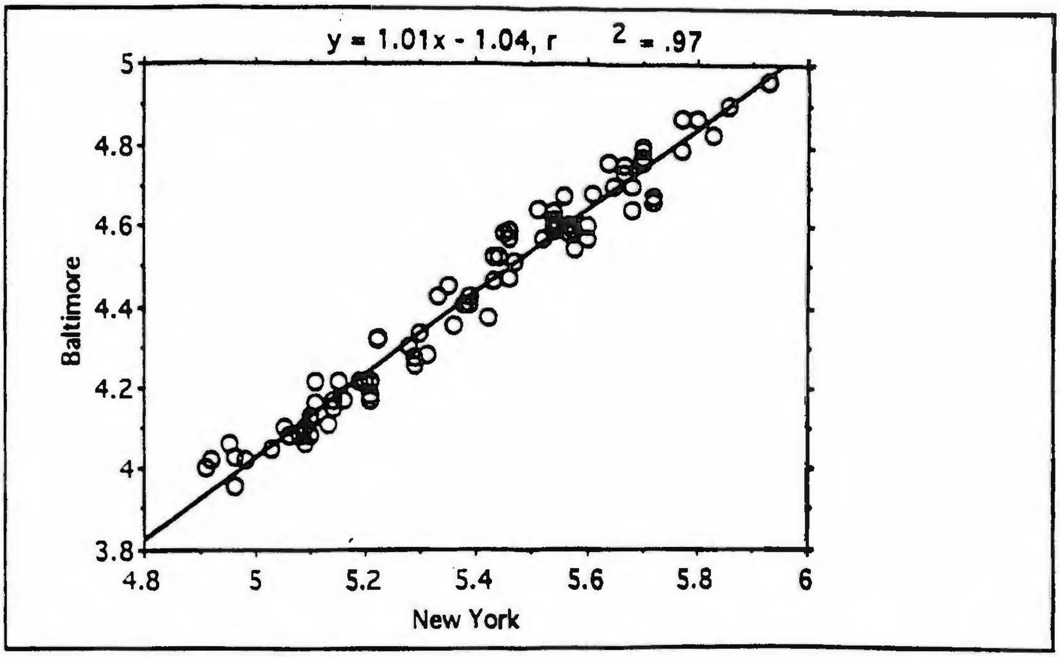
It was also observed that a strong correlation exists between the rates of sea-level change at Baltimore and New York (r=+.98) from 1903 to 1986 (Figure 3.7). This is useful as the New York record extends back to 1856. As a result, the regression equation from the New York-Baltimore analysis was used to predict sea level at Baltimore between 1856 and 1902.

It is important to note that different processes are affecting sea level at the New York and Baltimore stations. The Baltimore station, near the head of a large estuary, is affected by various processes such as subsidence. The New York station, in a more open ocean environment, is being affected by neotectonic activity (Emery and Aubrey, 1991). However, there is a strong agreement between the rates of change between the two stations which gives confidence to hindcasting the record at Baltimore from the New York data.

Areal Analysis

A planimeter was used to determine the size of the islands in hectares for every shoreline year for all islands. Each year-interval was measured three times and the average of the measurements taken. The planimeter

Figure 3.7 Regression analysis between the Baltimore, Maryland and New York, New York tide gauge stations



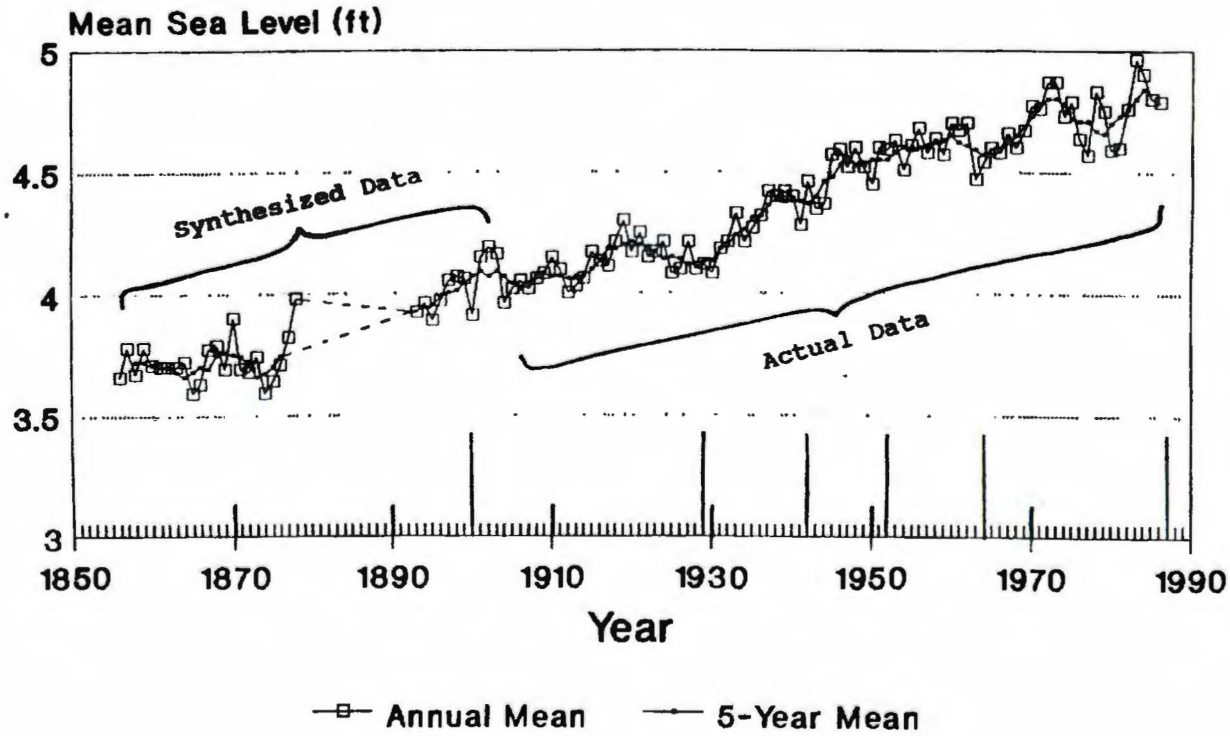
O Annual mean sea level

error was calculated to be between ± 3.29 ha and ± 19.74 ha, based on the averages of three measurements. Because the island shorelines are so irregular and the historic shoreline change on these islands exhibited such spatial variability, the rate of land loss in ha/yr is a more meaningful assessment of historical land loss than is an erosion rate in m/yr. The sizes of the islands were then plotted against time to assess the trend of land loss for each island. These data were also used to determine land loss rates and percentages, and to correlate sea-level rise with land loss.

Land Loss vs. Sea-Level Rise Analysis

The rates of island land loss in the Bay were correlated with the rates of sea-level change at Baltimore during concurrent time periods to determine if any relationship existed between the rate of sea-level rise and the rate of perimeter land loss. The time spans which were used for comparisons were determined by the map and photograph data used for digitizing (Figure 3.8). The New York tide gauge data was used to hindcast the Baltimore record to 1856, so that the earlier land loss data could be used. There is a gap between the earliest land data of 1848 and the earliest sea-level data of 1858 synthesized from the New York data. This synthesized

Figure 3.8 Sea-Level Rise
Baltimore, Maryland



record is the best data available and it is assumed that the general trend did not change during the 10 years of missing data.

Forecast Modeling

Introduction

In order to predict how these islands will respond in the future with or without an acceleration in the rate of sea-level rise, three models were examined which predict shoreline response to sea-level rise. The three models include the Bruun Rule, Inundation Model, and Historic Trends Analysis.

The Bruun Rule

The Bruun Rule was omitted from consideration for several reasons. The Bruun Rule which applies to sandy beaches and nearshore areas (Bruun, 1962), does not fit the eastern shore Chesapeake Bay environment. Indeed, the island shorelines generally fall into two categories, neither of which are appropriate for Bruun Rule calculations: marsh edge and eroding clay cliff. In addition, the Bruun Rule is invalid because the island shorelines have been erosional features since the Holocene and have not been in an equilibrium state for thousands of years, if ever. The Bruun Rule loses physical meaning along marsh shores because the flora controls both vertical and horizontal shoreline movement of the marsh (Rosen, 1978). According to Hands (1983), the Bruun Rule predicts rapid and permanent erosion for shorelines comprised of fine sediment such as silt and clay because the sediment is suspended in the water column rather than placed offshore, and is therefore lost from the equilibrium profile.

The Inundation Model

The inundation model, also called the "drowned valley concept", uses the existing topography and bathymetry of a coastal area to model shoreline response to future sea-level rise. For this model, shore slope is the most important variable, because it will determine the amount of horizontal displacement that an area will experience (Figure 3.9) (Leatherman, 1991). Shore profiles and slopes were determined by field surveys. Topographic charts were not used because the resolution of these maps is too low to be useful.

Historic Trends Analysis

The historic trends analysis was used to calibrate historic erosion trends with respect to sea-level rise. This model accounts for the natural variability of

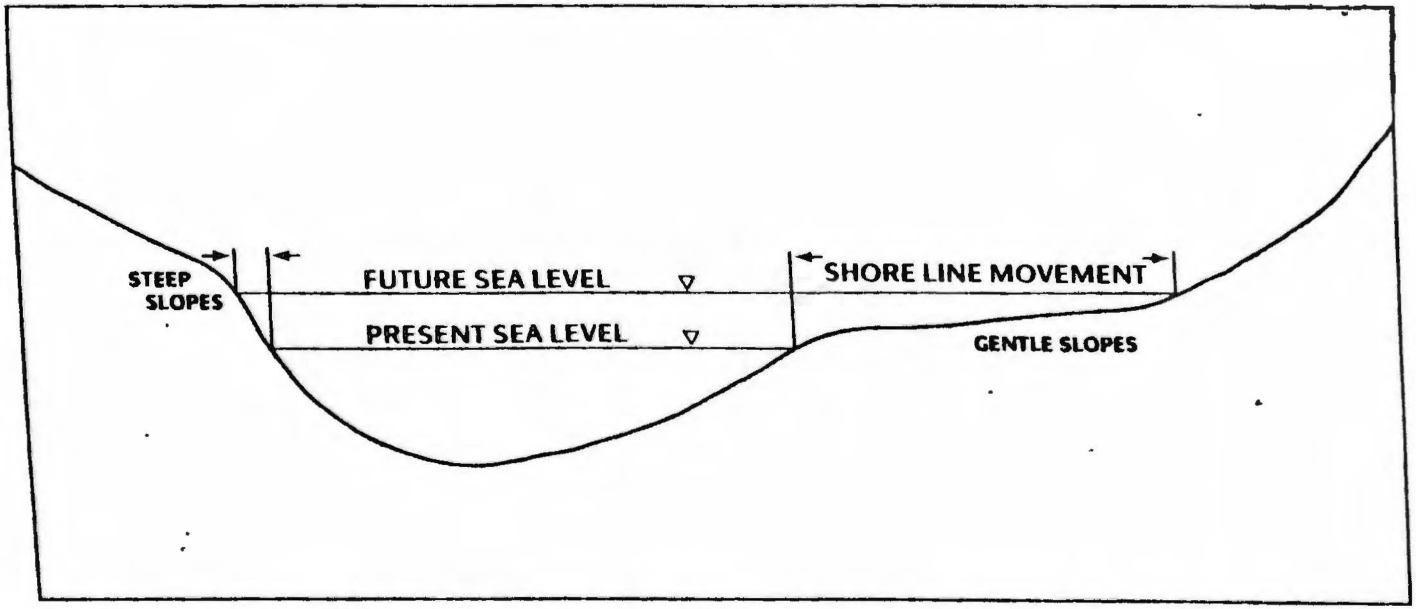


Figure 3.9 Conceptual diagram of the inundation model (from Leatherman, 1990a)

shorelines to respond to sea-level changes due to coastal processes, sediment types, and energy conditions. The underlying assumption behind the historic trends analysis is that shorelines will respond in similar ways in the future as they have in the past, since sea-level rise is the main variable and all other parameters remain essentially the same (Leatherman, 1984). The historic rate of shoreline change was determined using the Metric Mapping procedure. The Baltimore tide record was used to establish a rate of historic sea-level change for the study area, as previously described. Future rates of shoreline change were based on these two variables. Future rates of sea-level rise were taken from the Intergovernmental Panel on Climate Change (1990) scenarios, which were calibrated to the higher rate of sea-level rise which has been occurring in the Chesapeake Bay (Figure 2.4).

CHAPTER 4: RESULTS

Historical Shoreline Mapping

Introduction

The results of the historical shoreline mapping are presented in Figures 4.1 through 4.7. Two very distinct patterns of land loss are immediately apparent from the analysis. The islands were thus divided into the "Northern Group" and the "Southern Group", according to geographic location, geomorphic conditions and patterns of shoreline change. The Northern Group consisted of Barren Island, James Island and Poplar Island; the Southern Group consisted of Bloodsworth Island, Smith Island and South Marsh Island.

Although the geomorphology and general pattern of land loss on Hooper Island fits that of the Southern Group, it is excluded from either Group because much of the shoreline has been protected with engineering structures so the natural processes of land loss are obscured. Despite shore protection along most of the island, Hooper Island has been reduced in size by 25% since 1848, at an average rate of 2.9 ha/yr (Figure 4.7). Much of this loss occurred between 1848 and 1952. The rate of land loss has slowed since 1952, presumably because shoreline protection structures were built around this time. Hooper and South Marsh Islands had similar

Figure 4.1 HISTORICAL SHORELINE CHANGE, BARREN ISLAND

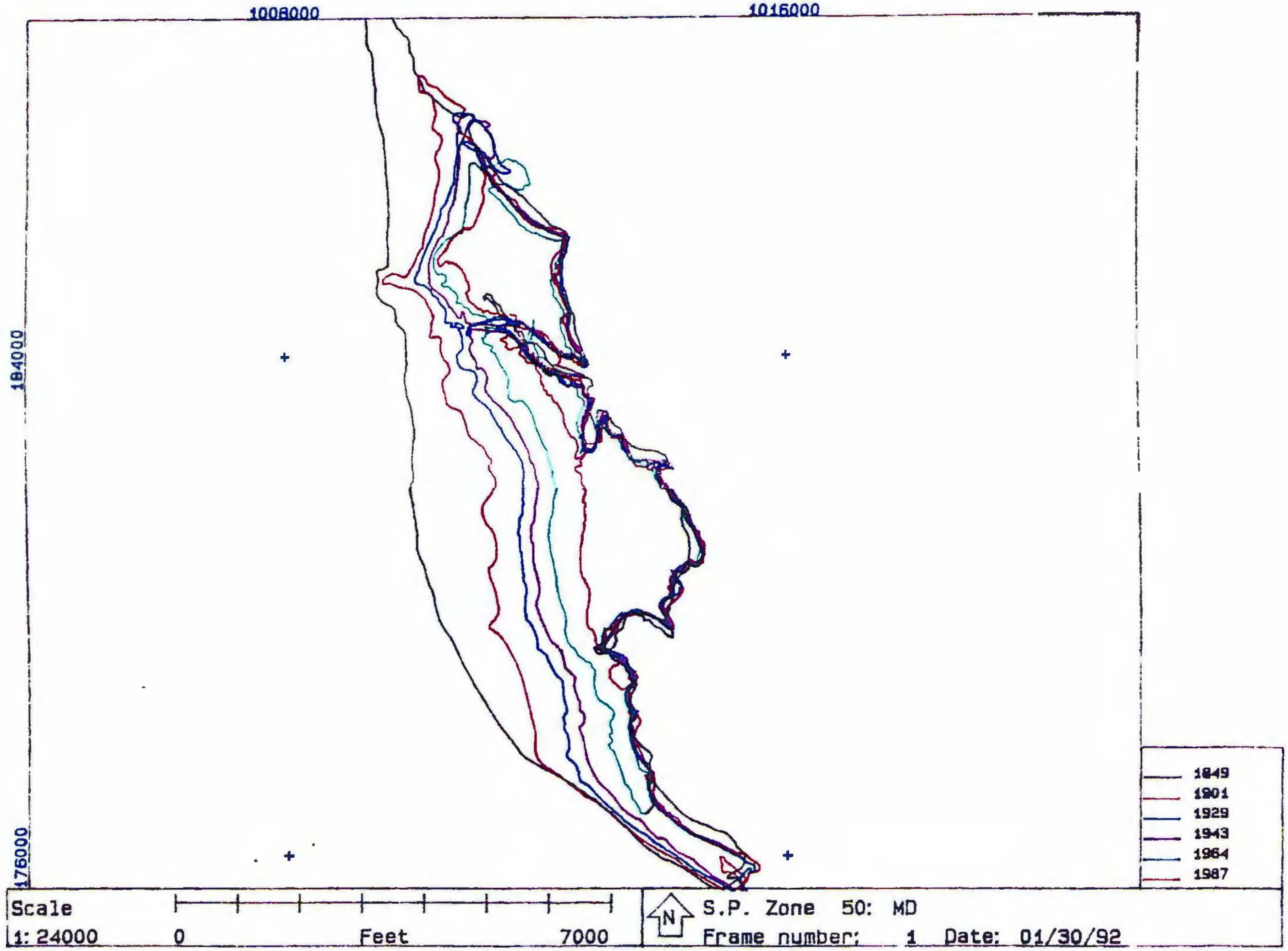


Figure 4.2 HISTORICAL SHORELINE CHANGE, JAMES ISLAND

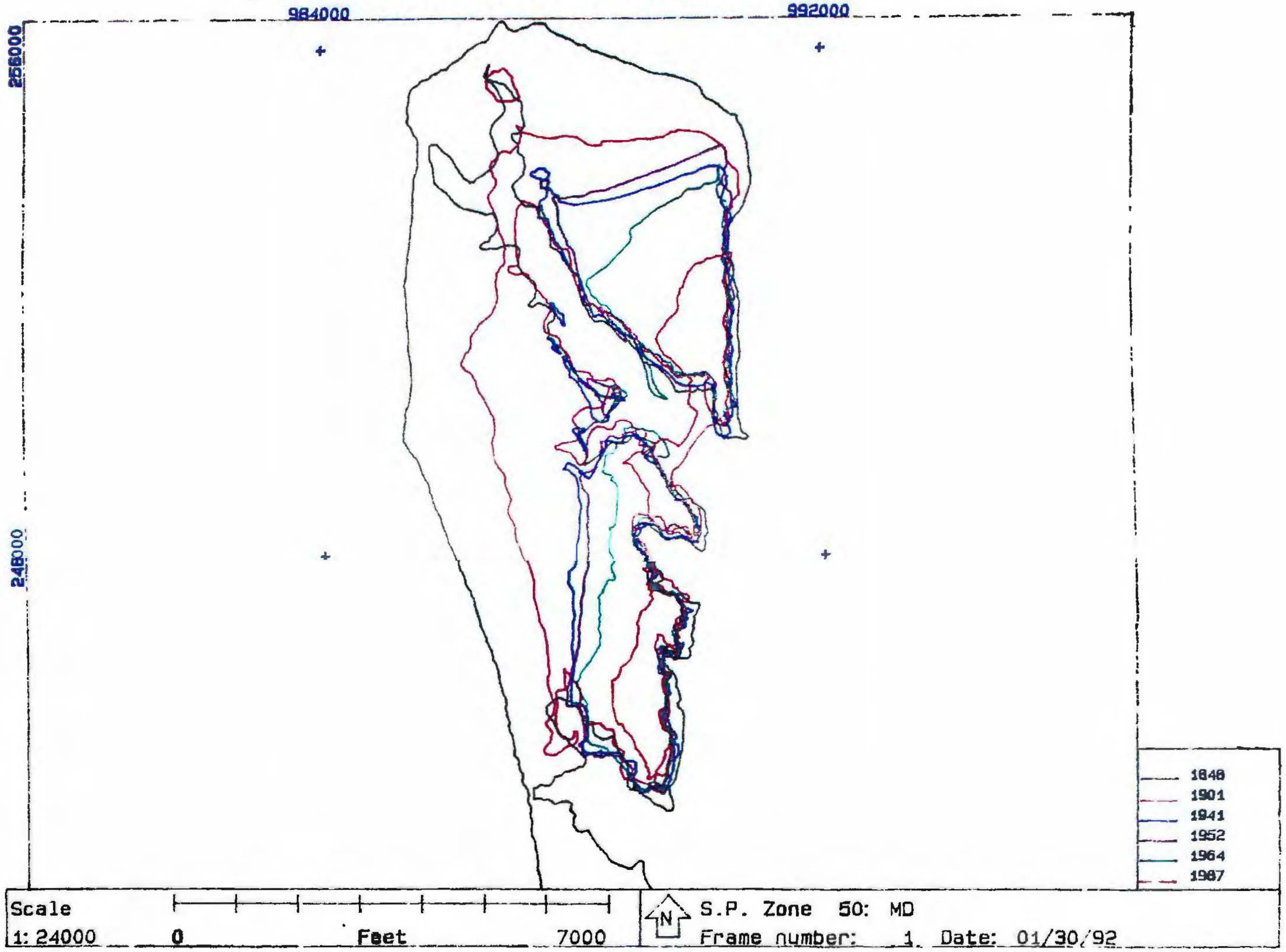


Figure 4.3 Historical Shoreline Change, Poplar Island

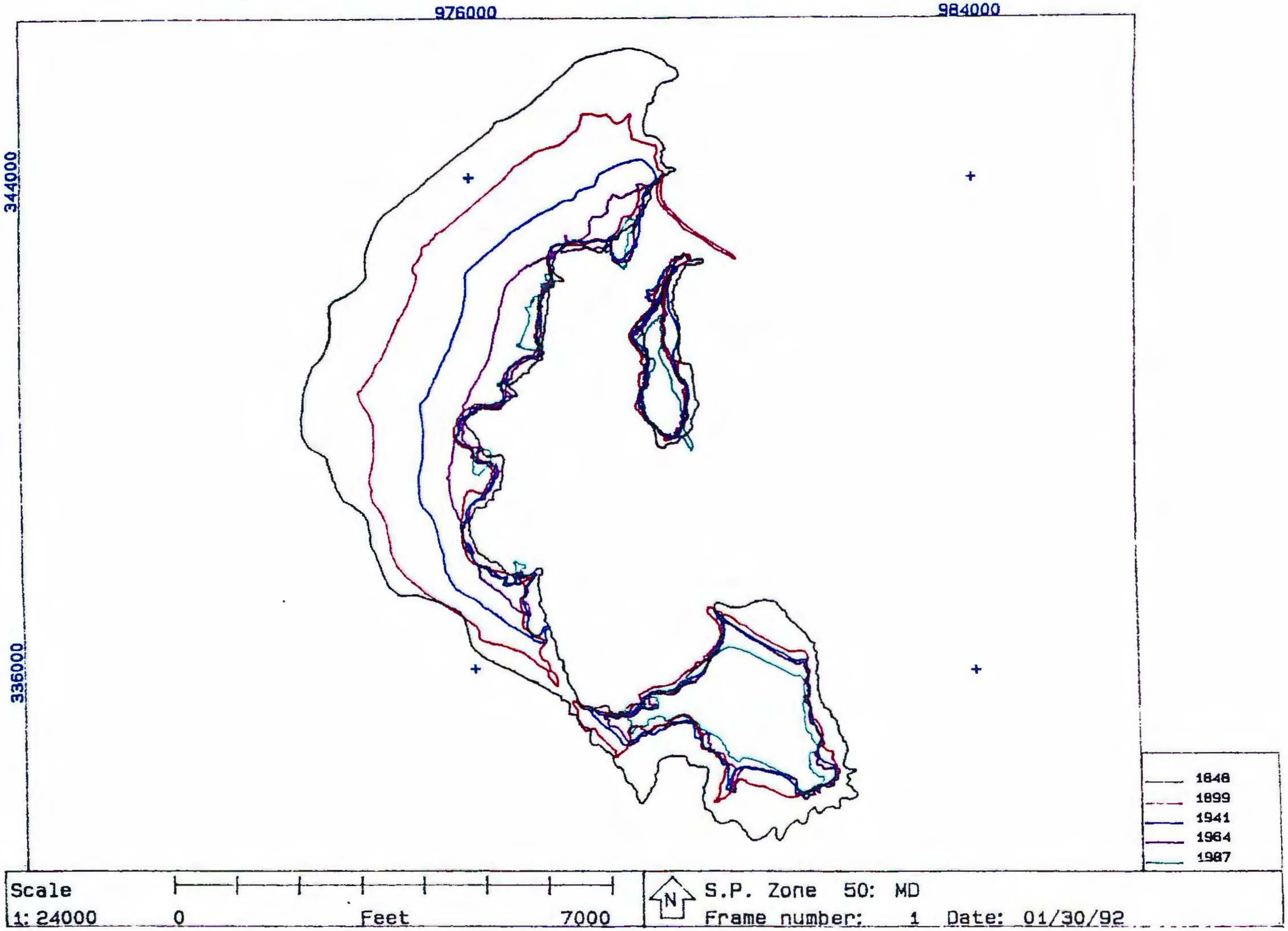


Figure 4.4 HISTORICAL SHORELINE CHANGE. BLOODSWORTH ISLAND

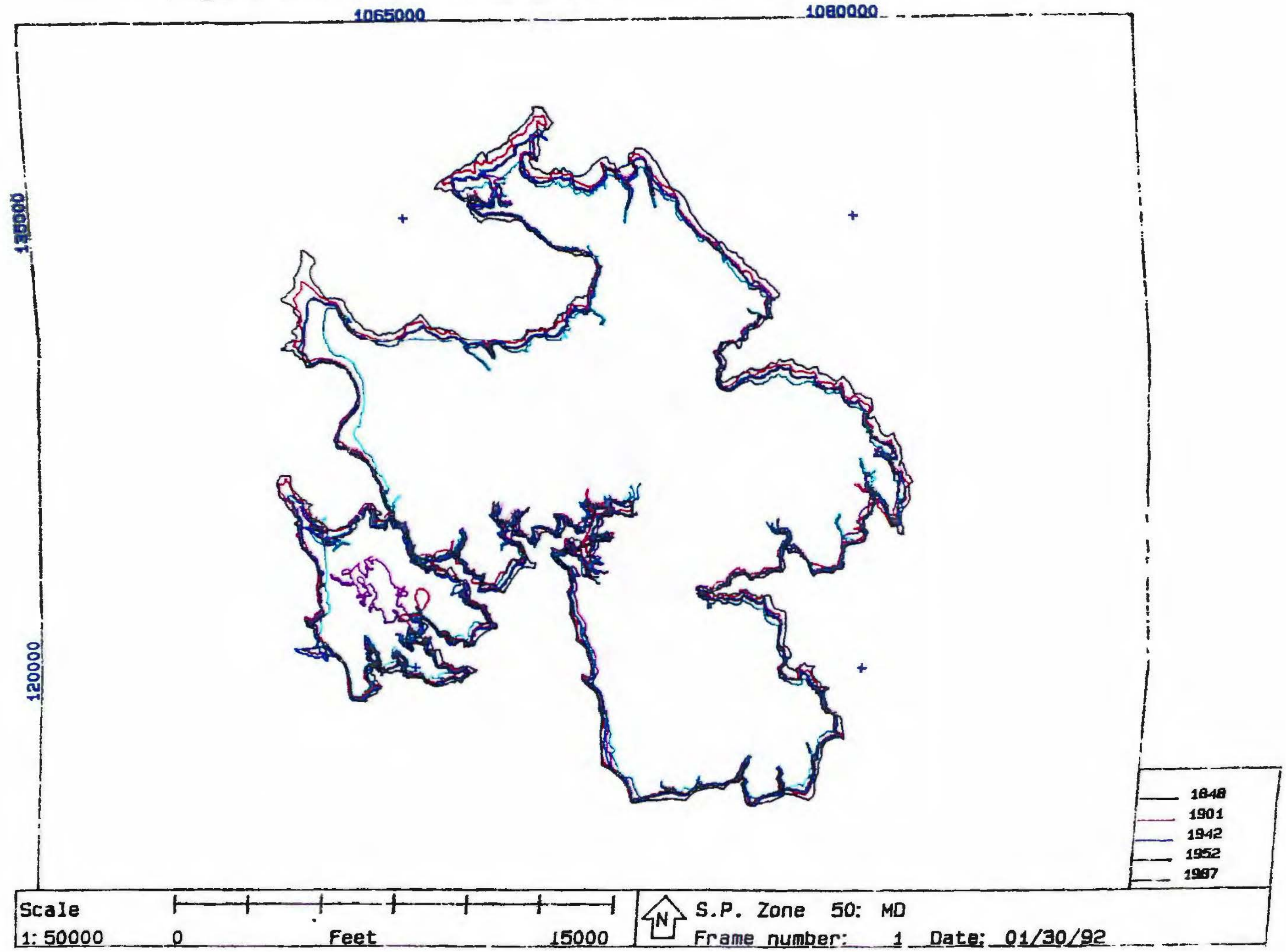


Figure 4.5 HISTORICAL SHORELINE CHANGE, SMITH ISLAND

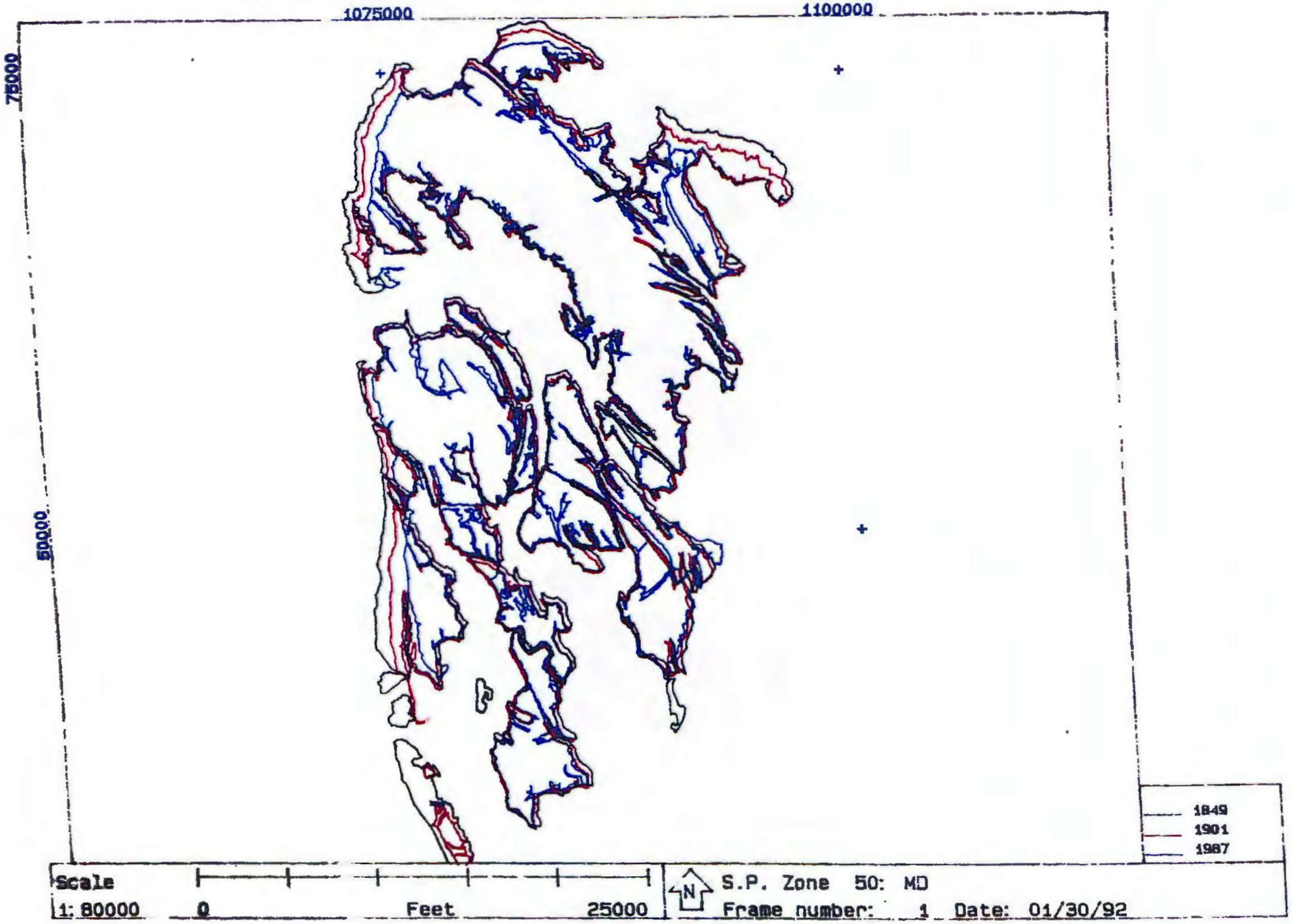


Figure 4.6 HISTORICAL SHORELINE CHANGE, SOUTH MARSH ISLAND

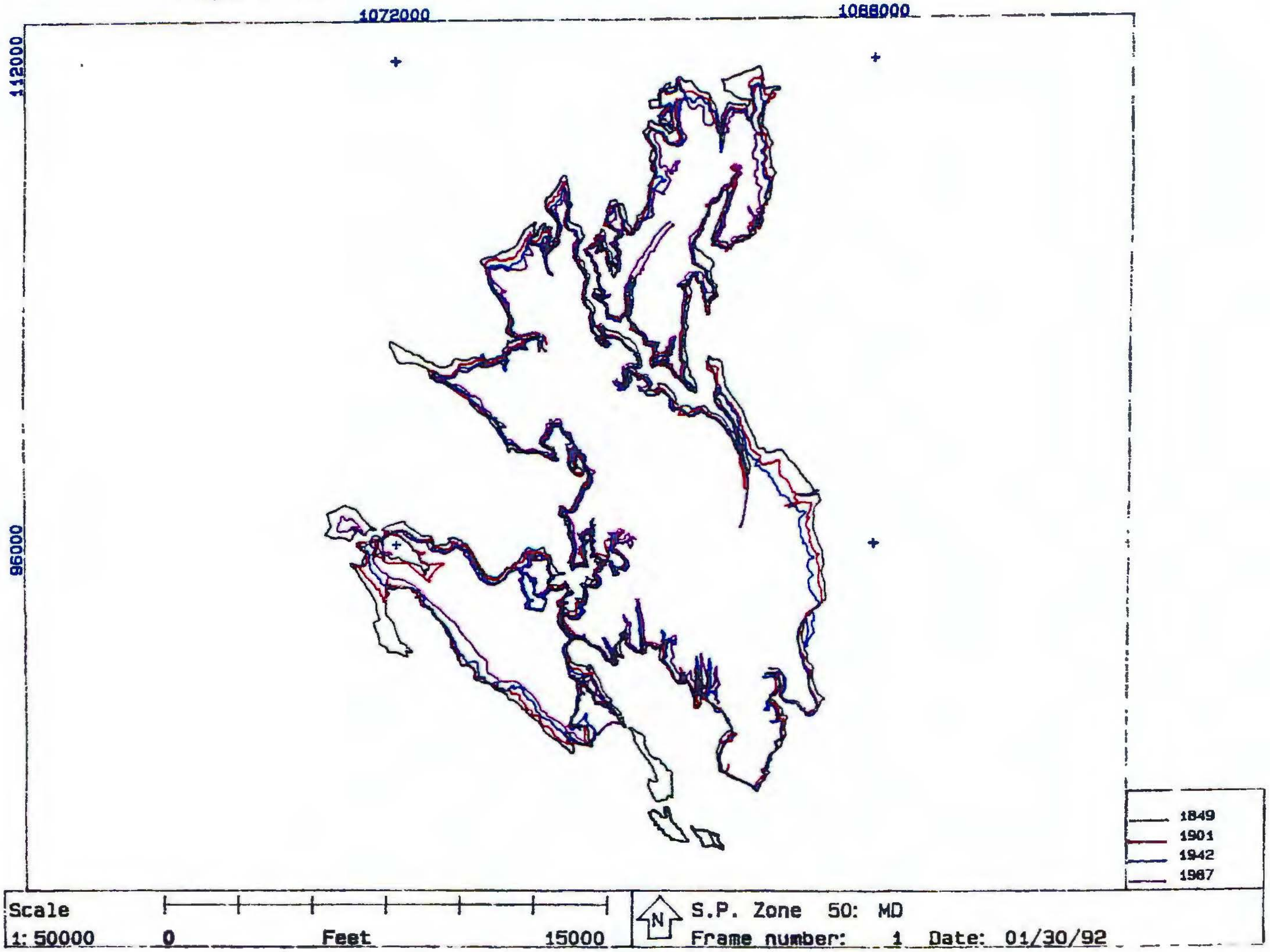
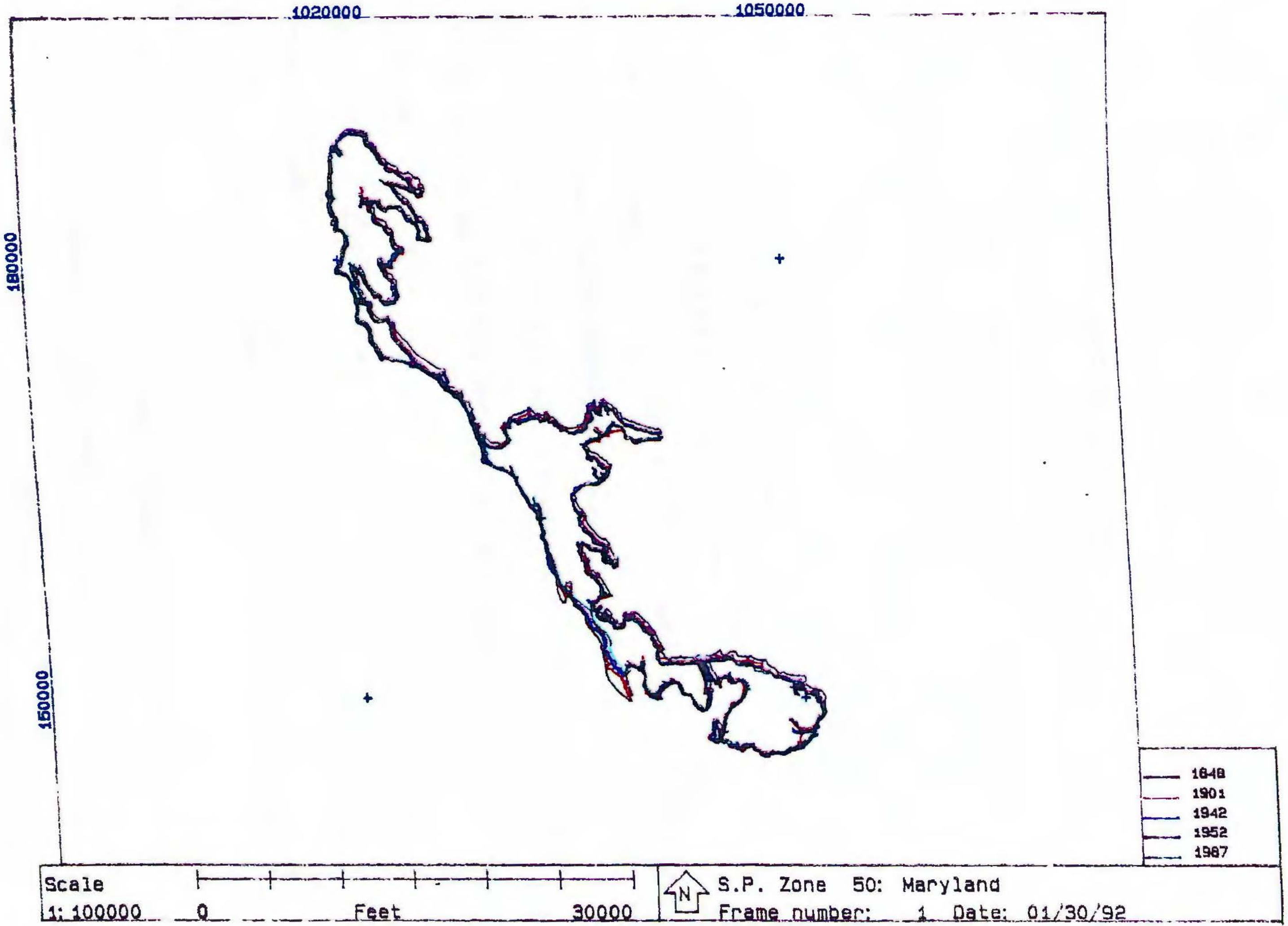


Figure 4.7 HISTORICAL SHORELINE CHANGE, HOOPER ISLAND



rates of land loss until 1952, when the rate of land loss on Hooper Island slowed slightly (Figure 4.9).

All the islands in the study area are losing land rapidly. Tables 4.1 and 4.2 present the historic land loss for the Northern Group and Southern Group and the rates of land loss. Figures 4.8 and 4.9 show the rates of land loss during the study period.

Northern Group

Patterns of Land Loss

The Northern Group of islands are all similar geologically and geomorphologically. They are dominated by thick, upland Loblolly and Virginia Pine forests with fringing Spartina patens and S. alterniflora marshes in some areas (Plate 4.1). The islands are fairly low lying; the highest elevation measured during field surveys was about 2 m above mean sea level. The marsh areas are less than about 0.5 m above mean sea level (Table 4.3).

The Northern Group showed dramatic loss of land from the north and west, with very little change on the protected, eastern side of each island (Figures 4.1, 4.2, and 4.3). Each island has a steep (45 to 90 degree), eroding clay bank which varies in height from 1 to 2 m on

Table 4.1.
HISTORIC ISLAND LAND LOSS IN THE CHESAPEAKE BAY: NORTHERN GROUP

BARREN ISLAND

Year	Hectares	% Reduction	Average Rate (ha/yr)
1848	306		
1901	217	30	1.7
1929	176	20	1.5
1943	153	13	1.6
1964	107	30	2.1
1987	75	30	1.4
Total Lost:	231	76%	1.7

JAMES ISLAND

Year	Hectares	% Reduction	Average Rate (ha/yr)
1848	398		
1901	230	43	3.2
1941	137	40	2.3
1952	133	3	0.4
1964	95	29	2.4
1987	45	53	2.2
Total lost:	353	89%	2.1

POPLAR ISLAND

Year	Hectares	% Reduction	Average Rate (ha/yr)
1848	343		
1899	209	39	2.6
1941	127	39	1.9
1952	103	19	2.2
1964	79	24	2.0
1987	43	46	1.6
Total Lost:	300	88%	2.0

Table 4.2
HISTORIC ISLAND LAND LOSS IN THE CHESAPEAKE BAY: SOUTHERN GROUP

BLOODSWORTH

Year	Hectares	% Reduction	Average Rate (ha/yr)
1848	2,280		
1901	2,111	8	3.2
1942	2,066	2	1.1
1952	2,003	4	6.3
1987	1,909	5	2.7
Total Lost:	371	16%	3.3

SMITH

Year	Hectares	% Reduction	Average Rate (ha/yr)
1849	4,467		
1901	3,737	16	13.8
1987	3,168	15	6.6
Total Lost:	1,299	29%	**10.2**

SOUTH MARSH

Year	Hectares	% Reduction	Average Rate (ha/yr)
1849	1,538		
1901	1,336	13	3.9
1942	1,285	4	1.2
1952	1,238	4	4.7
1987	1,113	10	3.6
Total Lost:	425	28%	3.3

Figure 4.8 **Island Land Loss**
in the Chesapeake Bay
(Northern Group)

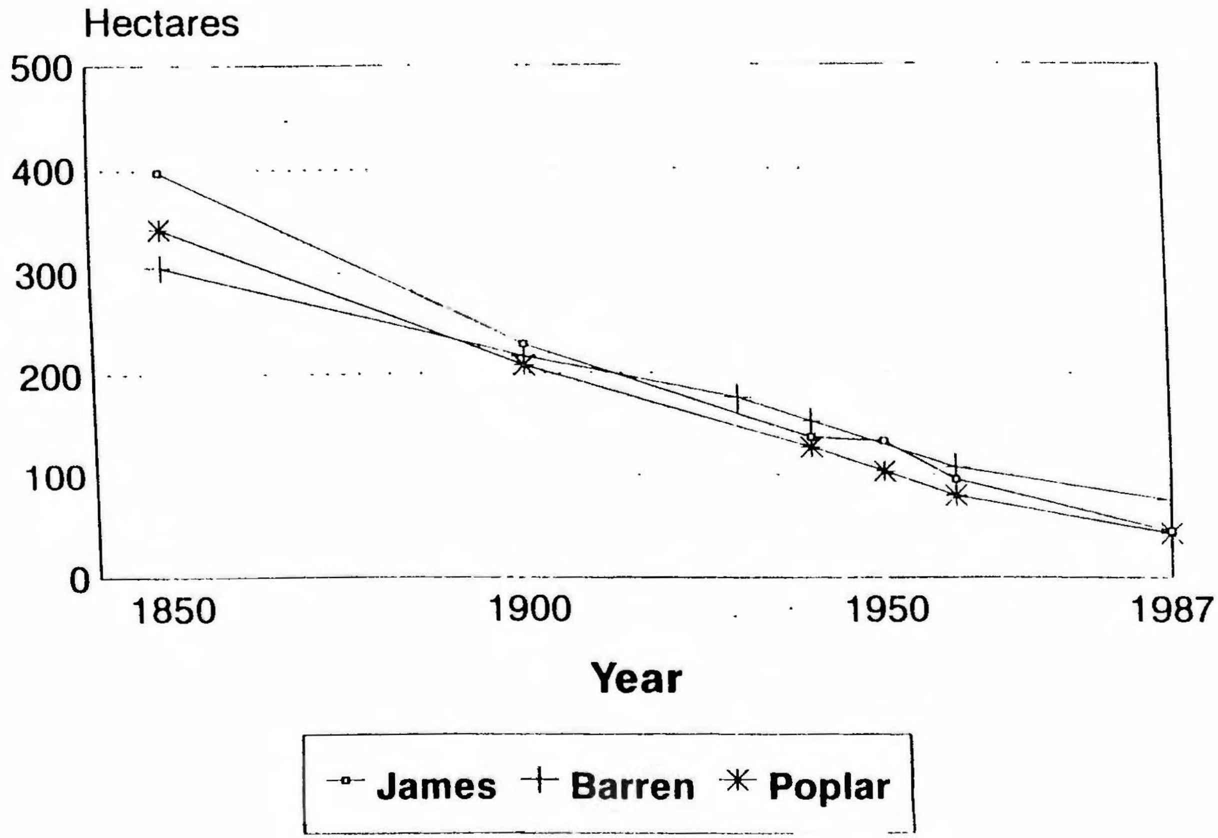


Figure 4.9 Island Land Loss

in the Chesapeake Bay
(Southern Group)

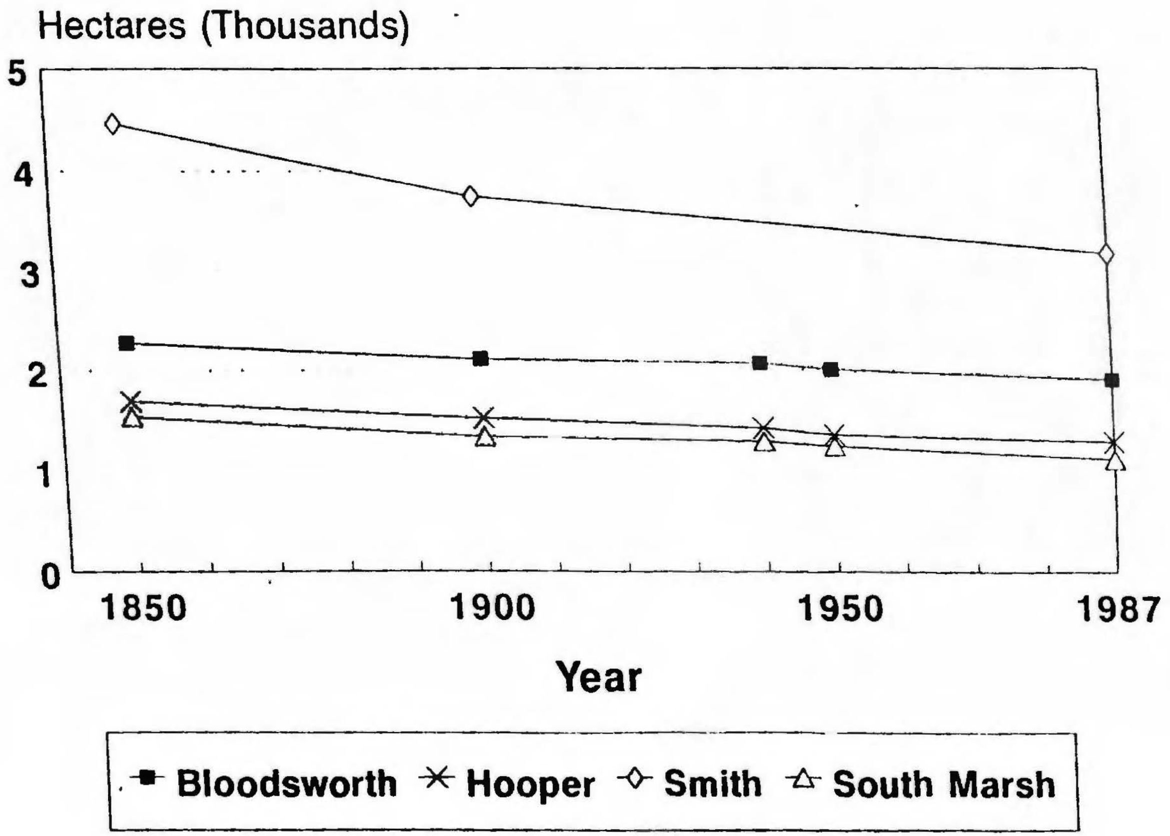


Plate 4.1 Mixed upland and wetland habitat on Coaches Island (Poplar Island)

Plate 4.2 Clay bluff and dead trees on Poplar Island which is typical of the Northern Group islands.

Table 4.3. Elevational Characteristics of the Northern Group Islands*			
	ELEVATION (m)**		
Island	Marsh	Margin	Upland
Barren	.25, .39, .15	.52, .30, .39	.53, .37, 1.0
James	.11	.58	.75, 1.3, .86, .57
Poplar	.48, .50	***	2.3, 1.3

* Elevation above present day mean water level.
** Each elevation represents a measurement taken in the field and is referenced to present day mean sea level, as extrapolated from the Baltimore tide tables.
*** No measurements taken in upland/marsh margin areas.

the western shore of the island (Plate 4.2). The rate of shoreline recession on the eastern side of the islands is considerably lower with only a small amount of shoreline recession. A fetch analysis for each island (Table 4.4), presents the variations in fetch length which can alter wind and wave patterns along a shoreline resulting in variable shoreline response.

Rates of Land Loss

All the islands in the Northern Group have been reduced in size by more than 76% since 1848 (Table

4.1), all currently being less than 100 ha. Barren, James and Poplar Islands have lost 76%, 89% and 88%, respectively. The mean rates of loss between 1848 and 1987 have been 1.7 ha/yr, 2.1 ha/yr, and 1.9 ha/yr, respectively. The rates of land loss tend to vary during different periods, but the long-term rate has remained relatively constant (Figure 4.8). The rate of land loss for the Northern Islands does not appear to be directly correlated to the rate of sea-level rise during the same periods (r= +.04) (Figure 4.10). This result is not unexpected as sea-level rise per se does not cause erosion. Sea-level rise exacerbates the effects of waves and storms by allowing larger, higher energy waves to reach the shore. Thus, sea-level rise is the underlying driver of shoreline change caused by wave action.

Rates of Erosion

The overall averaged annual rates of erosion of the island shorelines for each time span are presented in Table 4.5. Annual average rates of erosion for the western side of Barren, James and Poplar Islands are 4.38 ± 0.12 m/yr, 6.52 ± 0.12 m/yr, and 3.99 ± 0.12 m/yr, respectively. These figures are in sharp contrast to the annual erosion rates on the islands'

Table 4.4: Fetch Analysis
for 7 Islands in the Chesapeake Bay

	Approximate Distance (km) and Direction							
Island	N	NE	E	SE	S	SW	W	NW
Barren	2.7	1.8	1.8	1.8	143.2	15.7	12.9	20.3
Bloodsworth	1.8-7.4	8.3	6.4	6.4	2.7	24.0	22.2	6.0-36.1
Hooper	2.7-7.4	2.7-5.5	1.8 - 6.0	1.8 - 7.4	131.9	36.1	13.8 - 18.5	1.8 - 7.4
James	17.5	3.7 - 12.0	6.4	3.7	1.8	12	14.8	20.3
Poplar	7.4	4.0	2.7	2.7 - 3.7	41.6 - 60.1	18.5	15.7	16.6
Smith	4.0	12.0	9.2	9.2	12.9	20.3	30.0	33.3
South Marsh	2.7	6.0	6.0 - 12.0	13.8	4.0	30.0	25.0	5.0

Table 4.5
Erosion rates for the Northern Group
(in m/yr)

BARREN	1849 - 1901	1901 - 1929	1929 - 1943	1943 - 1964	1964 - 1987	TOTAL AVERAGE
East	*	*	*	*	*	*
West	3.86	4.21	3.76	4.91	4.97	4.38
Error range	± 0.33	± 0.60	± 0.87	± 0.64	± 0.60	± 0.12

JAMES	1848 - 1901	1901 - 1941	1941 - 1952	1952 - 1964	1964- 1987	TOTAL AVERAGE
East	0.75	0.42	0.36	1.43	0.13	0.56
West	6.50	6.15	4.03	8.13	7.87	6.52
North	5.82	6.04	*	*	19.75	9.59
Error range	± 0.32	± 0.36	± 1.25	± 1.25	± 0.66	± 0.12

POPLAR	1848 - 1899	1899 - 1941	1941 - 1964	1964 - 1987		TOTAL AVERAGE
East	0.99	0.41	1.03	*		0.81
West	3.80	4.73	6.51	2.36		3.99
Error range	± 0.33	± 0.34	± 0.59	± 0.66		± 0.12

* Insufficient data to calculate erosion rates

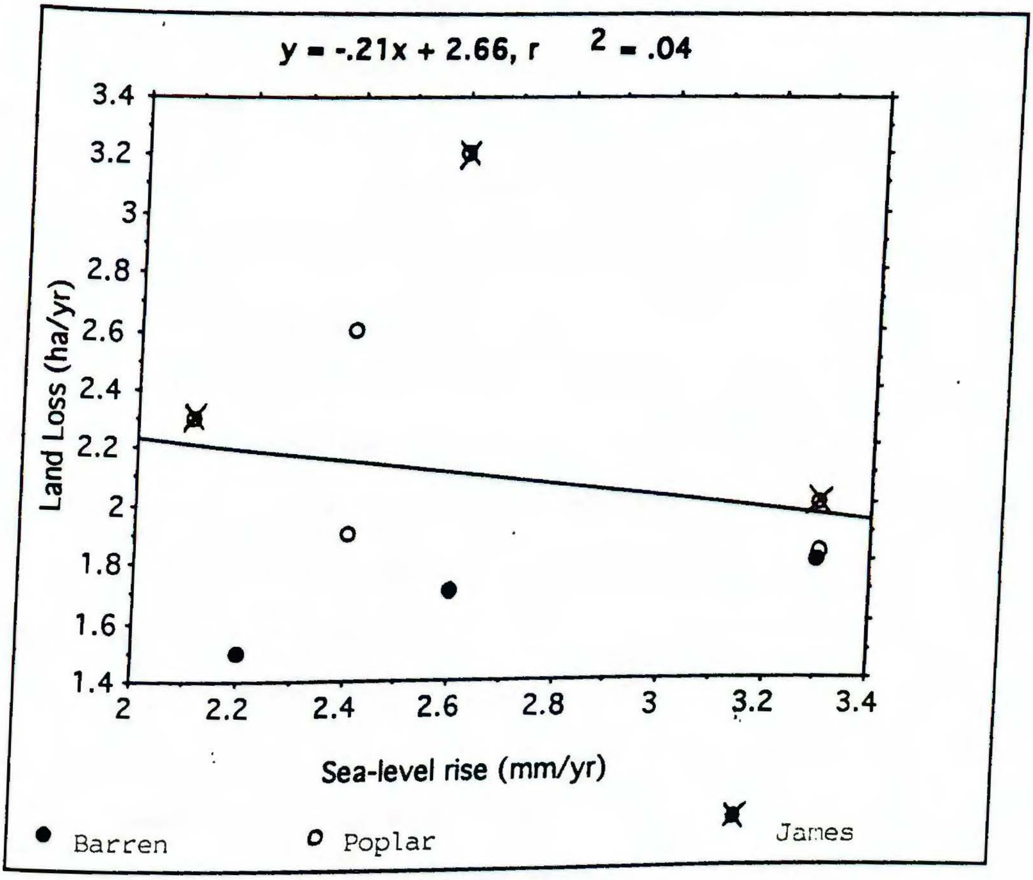


Figure 4.10 A comparison between the rate of sea-level rise and the rate of land loss for the Northern Group

eastern shores, which are 0.56 ± 0.12 m/yr for James Island and 0.81 ± 0.12 m/yr for Poplar Island. These numbers are the average of all the transects included in the analysis. The highest rates of erosion are on the north shore of James Island.

Sediment Analysis

The location of sediment samples and surveys performed during fieldwork are presented in Figures 4.11, 4.12, and 4.13. Sediment analysis revealed that the islands are composed of silt and clay and contain very little sand. Grain size analysis of a sediment sample from Poplar Island demonstrated that all the sand in the samples was greater than 2 phi, meaning that it is fine to very fine according to the Wentworth Classification of grain sizes. In fact, 95% of the sand was greater than 3 phi, meaning it is very fine.

Poplar Island had 13.6% and 17.6% sand by weight in two samples analyzed. Barren Island had 7.9% and 3.7% sand in two samples. James Island had 3.3% and 2.3% sand in two samples analyzed. Clearly, there is some variability in the percent sand found among islands, although there is a relatively strong agreement within each island. Other samples collected during fieldwork were examined visually and texturally and were determined to be similar to the 6 analyzed samples.

Figure 4.11 Sample locations for Barren Island - 5/17/91

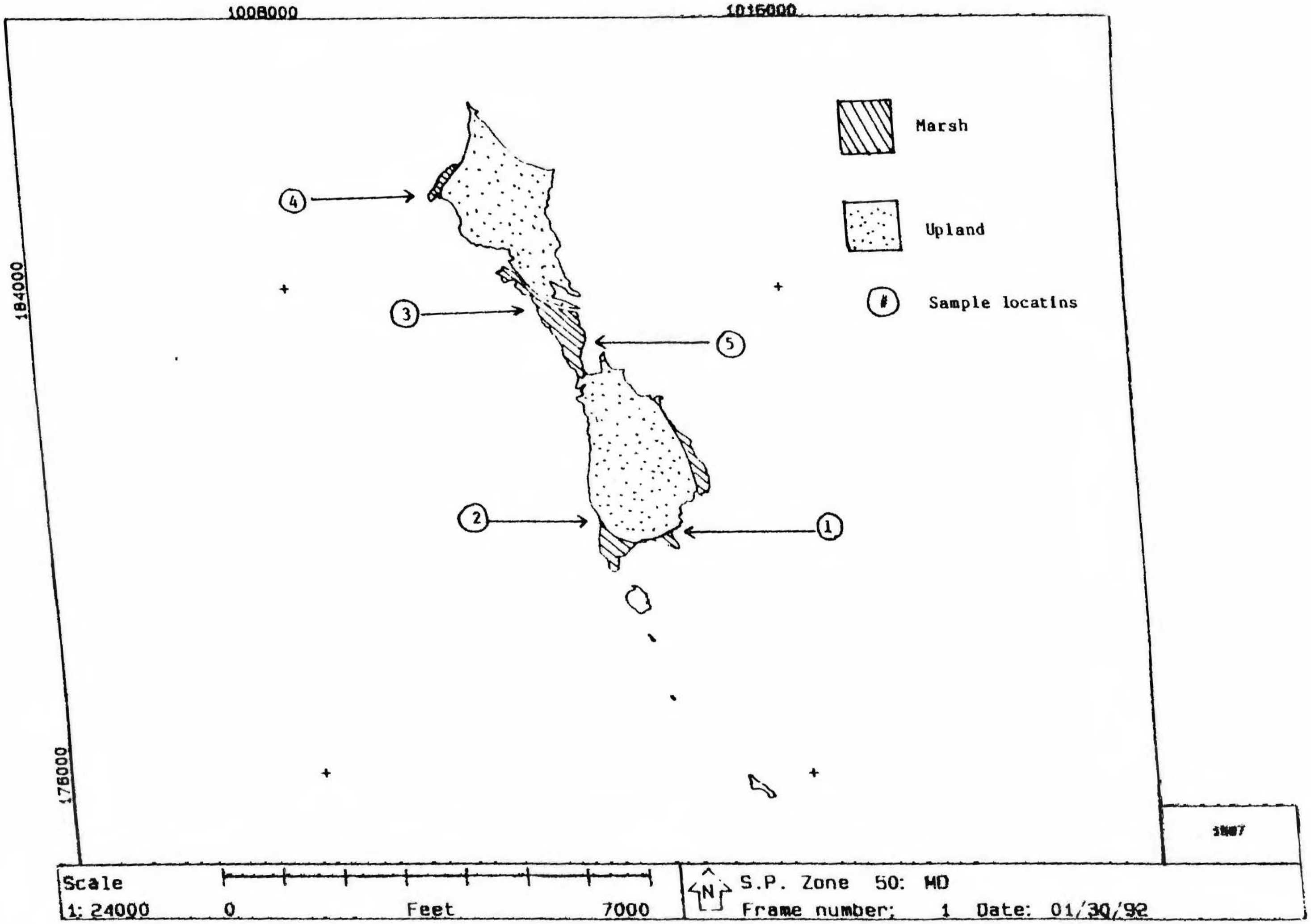


Figure 4.12 Sample locations for James Island - 5/15/91

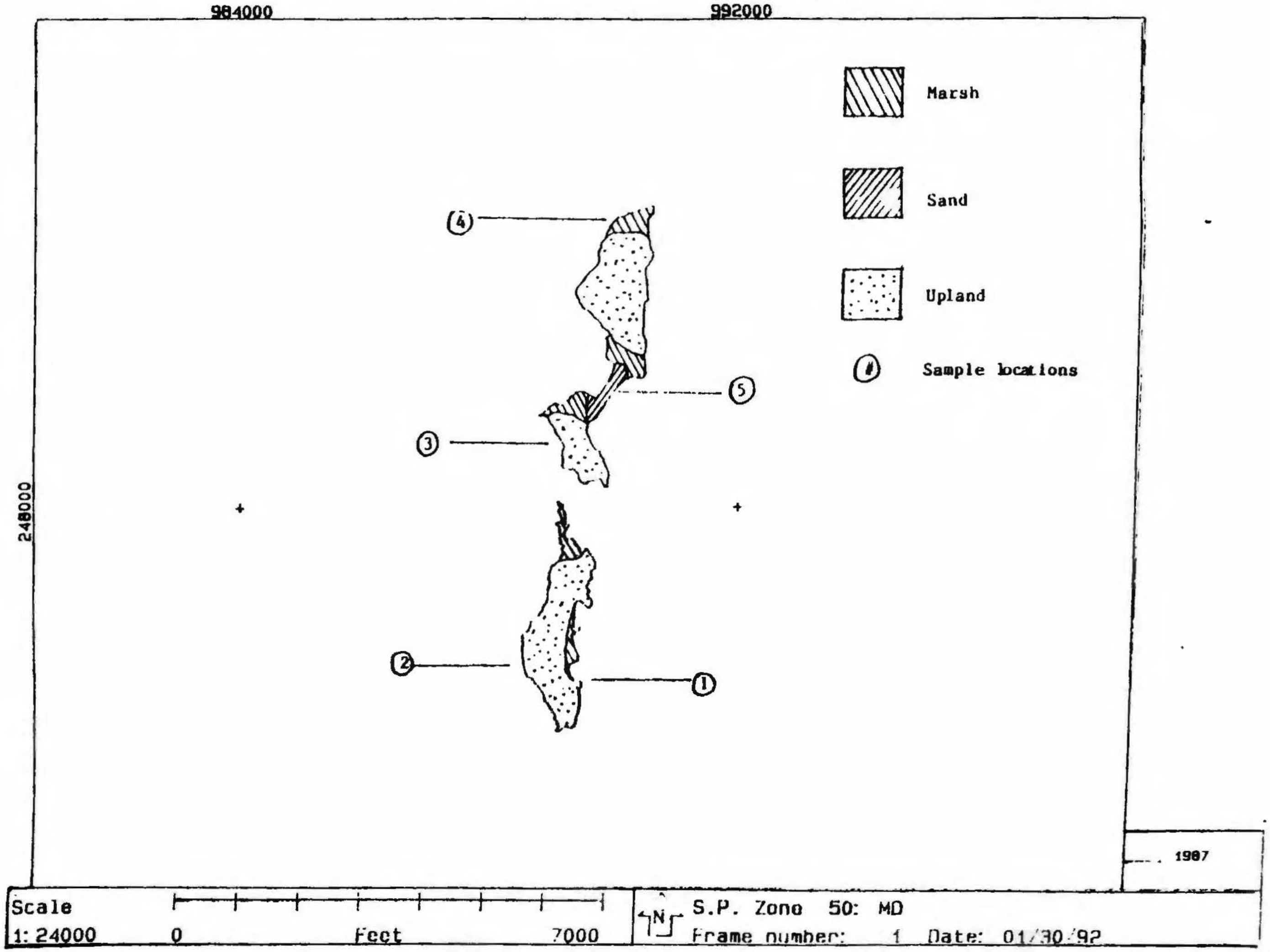
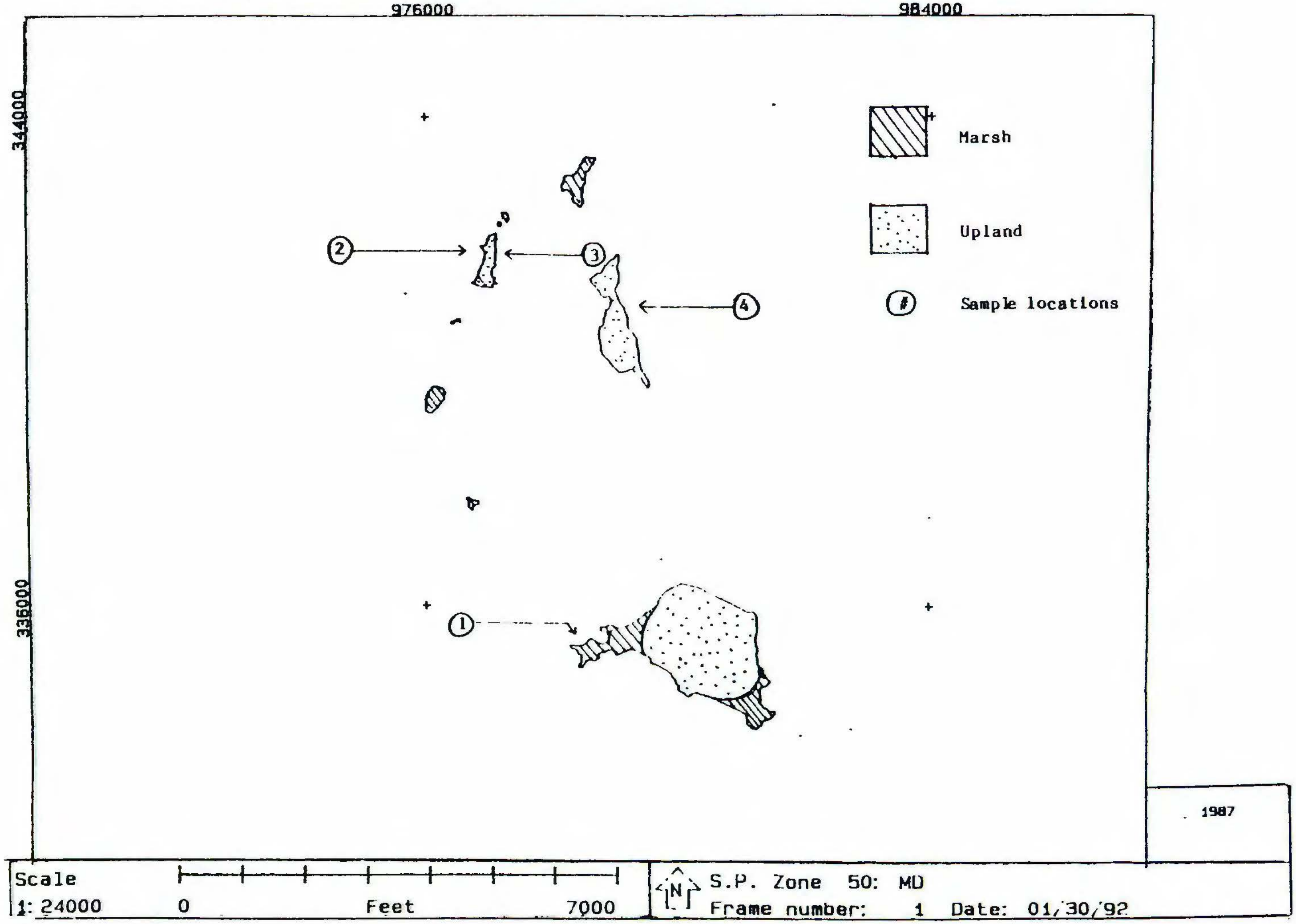


Figure 4.13 Sample locations for Poplar Island - 5/1/91



Sometime between 1964 and 1987 a sand bridge developed between the northern and southern sections of James Island (Plate 4.3). A very small spit is visible on the northern section of the island in the 1964 photograph, but a complete bridge between the two island halves is clearly visible in the 1987 photograph. The spit is currently about 35 m wide and 2,100 m long. Sediment analysis revealed that the composition of the spit is more than 96% sand. The middle section is dominated by a Spartina marsh with no peat development beneath the marsh plants. This spit possibly developed over the years as a lag deposit of sand which remained in the nearshore area as the island eroded and the fine-grained silt/clay was carried into suspension by waves and currents, away from the island. The sand deposit has been subsequently shaped by longshore currents to form the spit which exists today.

Southern Group

Patterns of Land Loss

The Southern Group, consisting of Bloodsworth, Smith and South Marsh Islands, were grouped together based on their similar geomorphology, shoreline response pattern and relative geographic location in the southern section of the study area. Geomorphologically distinct from the

Plate 4.3 Sand bridge on James Island, looking south

Plate 4.4 View of an upland ridge on Smith Island.

Northern Group, these are large, marshy islands with general elevations less than about 0.5 m above msl. All of these islands are over 1,000 ha (Table 4.2).

Smith Island has several linear ridges running approximately North-South with upland vegetation. Bloodsworth has one ridge, known as Fin Creek Ridge. Maps and photographs of South Marsh Island do not show any upland ridges. According to measurements for this study and topographic surveys, the ridges lie between 0.5 and 1.5 m above MSL. The subtle elevational differences between marsh and ridges define the landscape on these low-lying islands. Even small increases in elevation are enough to support upland vegetation (Plate 4.4). On Smith Island, the largest ridges host the island's three towns: Ewell, Rhodes Point and Tylerton (Plate 4.5). The Ewell, Maryland-Virginia USGS topographic quadrangle, dated 1968, indicates that small areas of these ridges reach 1.6 m above MSL. This survey uses NAD 27 data, however, which would overestimate the present elevation of the islands since sea level in the Chesapeake has risen about 0.2 m since 1927. However, the majority of these ridges are below the 5 foot (1.6 m) contour and lie almost imperceptibly above the surrounding marsh. The distinct vegetation on the ridges causes them to stand out above the flat marsh surface.

The Southern Group demonstrated a very different

Plate 4.5 View of Rhodes Point on a ridge in the distance, one of the towns on Smith Island

Plate 4.6 Interior marsh ponding on Smith Island

pattern of land loss than the Northern Group. Since 1848, these islands have had a more uniform pattern of land loss around their perimeters (Figures 4.4, 4.5, and 4.6). The Southern Group also experienced land loss in terms of interior ponding of open marsh areas and apical erosion of tidal creeks (Plate 4.6). This process was clearly visible from observations of the maps and aerial photographs, although it was not quantified in this study. Because the methodology in the present study does not account for internal ponding and marsh loss, the land losses reported for the Southern Group are under-estimated. A detailed examination of internal marsh loss shows a dramatic increase in open water area since the turn of the century on Smith Island (Davison, 1990) (Figure 4.14). Similar analyses are unavailable for the other islands.

Rates of Land Loss

The Southern Group has been losing land at higher rates than the Northern Group (Table 4.2). However, they have lost smaller percentages of land since they are all larger than the Northern Group. Bloodsworth, Smith, and South Marsh Islands have lost 16%, 29%, and 28% of their land area since 1848, at rates of 3.3 ha/yr, 10.2 ha/yr, and 3.3 ha/yr, respectively. As with the Northern Group, the trend in the rate of loss is fairly constant over

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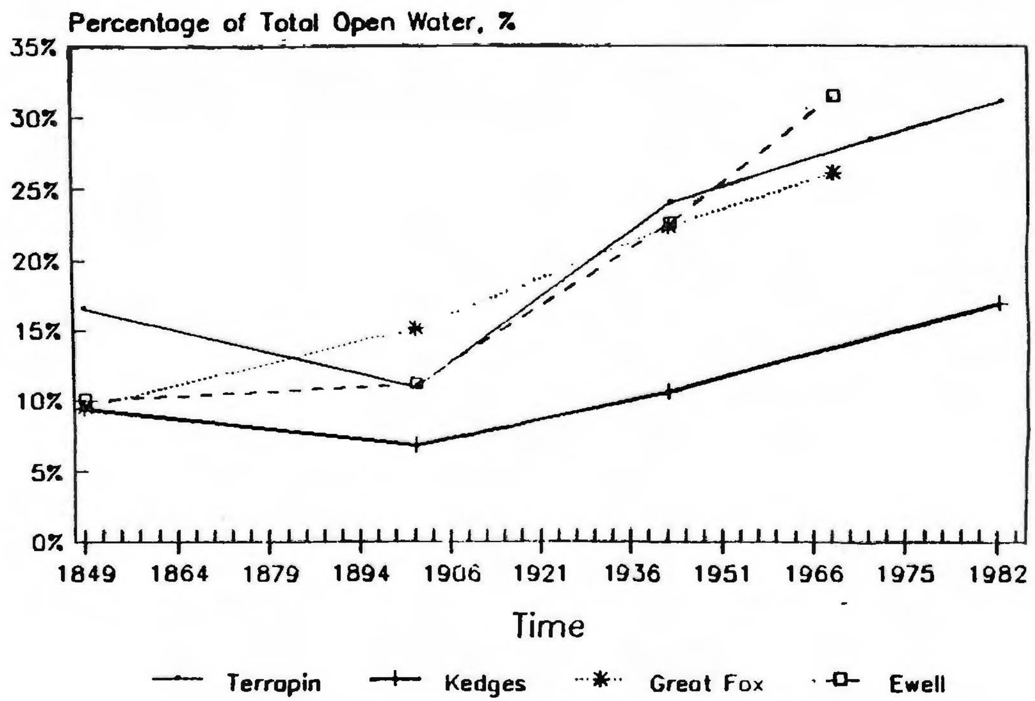
Figure 4.14 Historical change in the percent of total open water in four quadrants of Smith Island: Terrapin Sand Point, Kedges Straits, great Fox Island, and Ewell (from Davison, 1990)

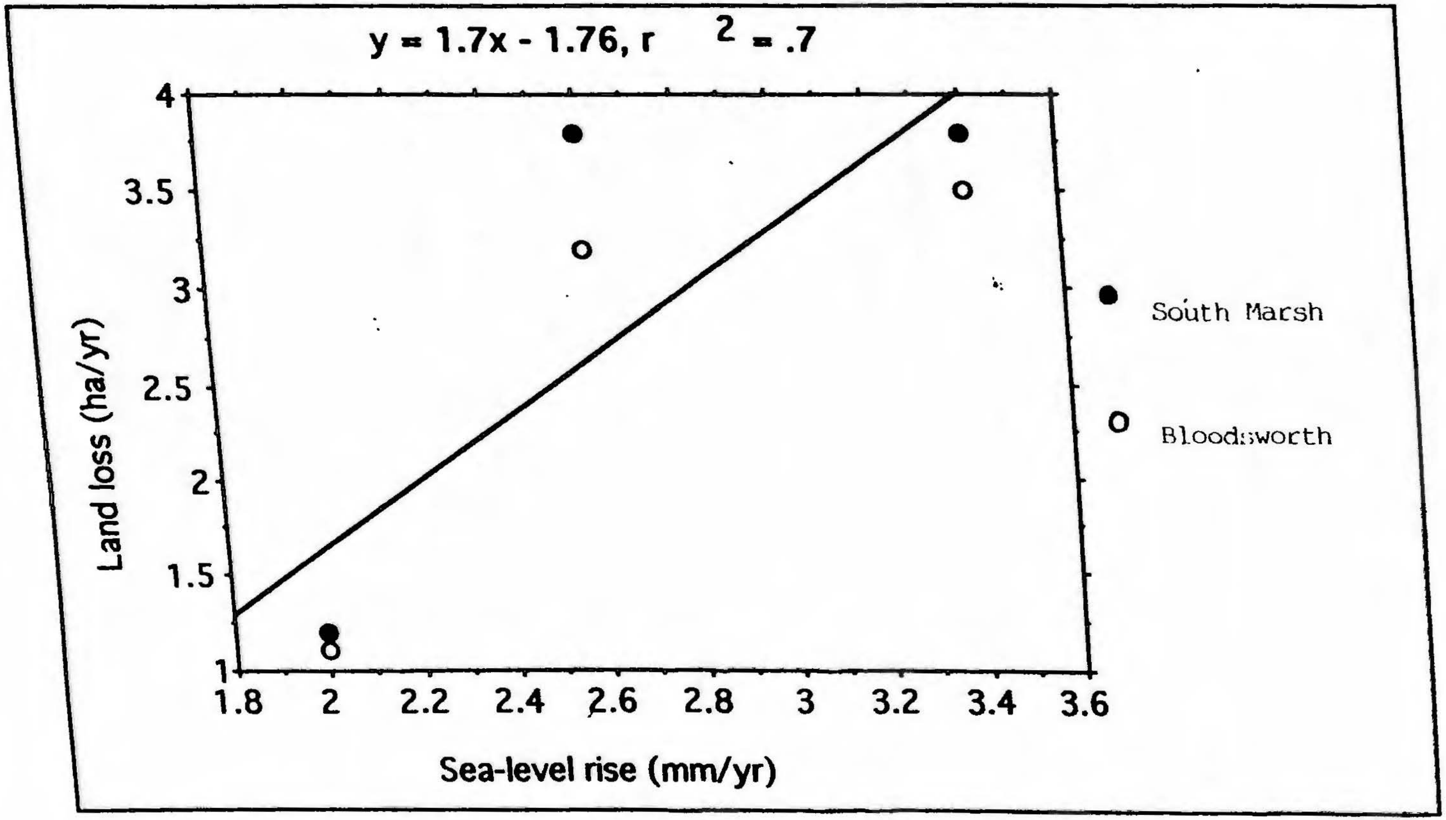


time (Figure 4.9).

The rate of land loss on Smith Island is much higher than the other islands. Since 1849, there has been a significant amount of perimeter erosion along the western shore and from Terrapin Sand Point in the northeast corner of the island (Figure 4.5). Thus, the pattern of erosion resembles that of the Northern Group. However, due to the geomorphic similarities between Smith and the two other southern islands, Smith remains in the Southern Group. Smith has also been experiencing interior marsh loss, which is characteristic of the Southern Group.

The rate of land loss for Bloodsworth and South Marsh Islands appears to be weakly correlated to the rate of sea-level rise during the same time periods ($r= +.84$) (Figure 4.15). The rate of sea-level rise was calculated as the difference in sea level divided by the number of years between measurements, using the actual and synthesized tide gauge data at Baltimore. The trend for Smith Island does not fit into either the Northern or Southern Group, due to the anomalous rates of land loss. Although this correlation is not very strong due to a small data set ($p = .04$), there does appear to be a relationship between the rate of sea-level rise and land loss for the Southern Group but not for the Northern Group. Clearly, more land loss data from other Southern Group type of islands is needed to strengthen this

Figure 4.15 A comparison between the rate of sea-level rise and the rate of land loss for the Southern Group



relationship.

Rates of Erosion

Erosion rates for the Southern Group were more difficult to obtain due to the irregularity of the shorelines. Therefore, erosion rates were not calculated for the entire shoreline of these islands. Instead, erosion rates were determined for relatively straight segments of the shorelines in order to get a representative idea of the rate of erosion for each island. For example, three transects were run for Bloodsworth Island from which erosion rates were calculated (Figure 4.16). Average annual erosion rates from these transects were 1.19 ± 0.12 m/yr, 1.67 ± 0.12 m/yr and 1.24 ± 0.44 m/yr (Table 4.6). For Smith Island, two transects produced erosion rates of 2.64 ± 0.12 m/yr, and 0.47 ± 0.12 m/yr (Figure 4.17). Two transects were run on segments of the South Marsh Island shoreline, producing erosion rates of 1.18 ± 0.12 m/yr and 0.55 ± 0.12 m/yr (Figure 4.18).

Sediment Analysis

Because the Southern Group islands are geomorphologically similar, it is likely that the clay layer which was identified under Bloodsworth Island extends

Figure 4.16 Location of transects for determining erosion rates on Bloodsworth Island

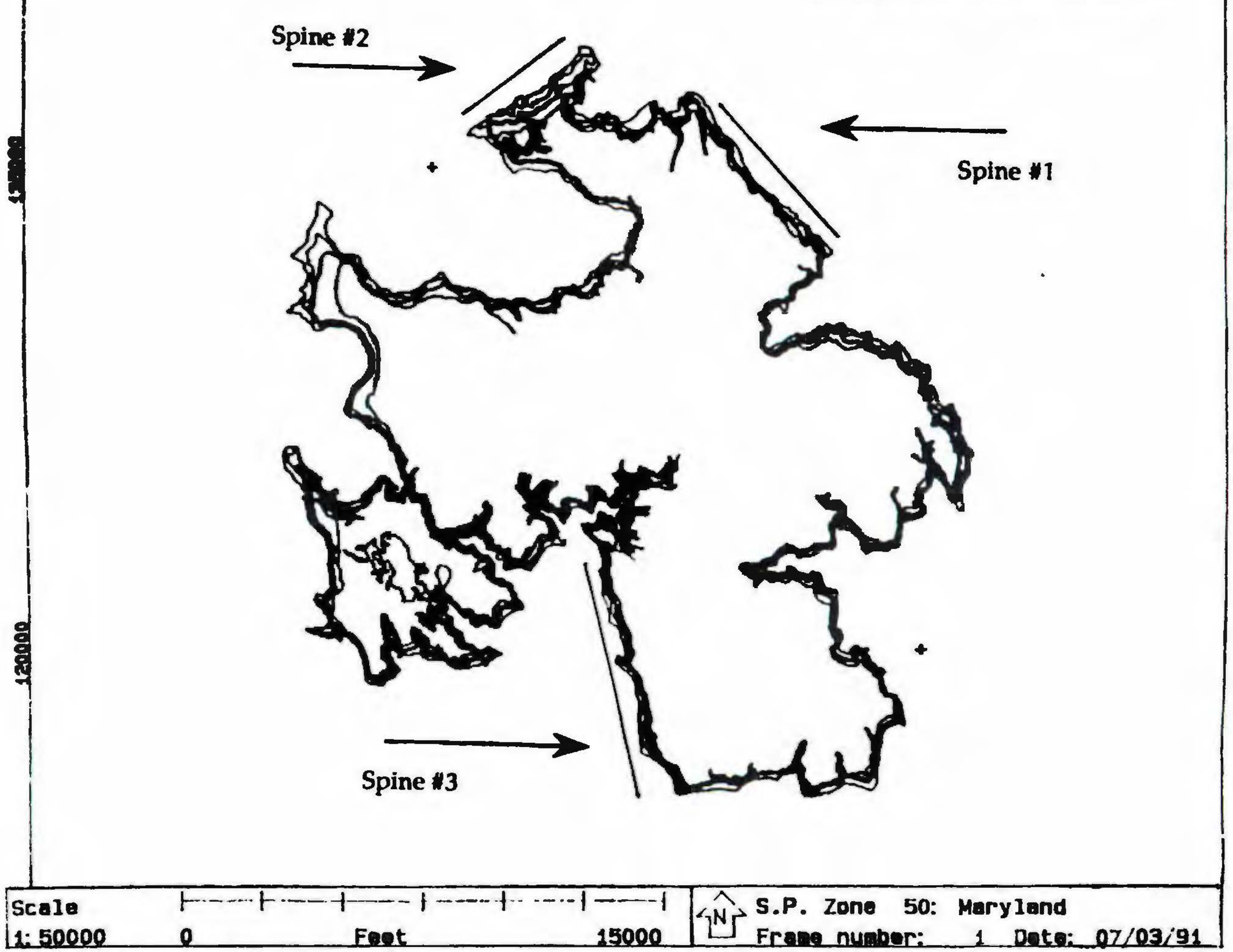


Table 4.6
Erosion rates for the Southern Group
(in m/yr)

BLOODSWORTH	1848 - 1901	1901 - 1942	1942 - 1952	1952 - 1987	TOTAL AVERAGE
Transect 1	*	*	*	1.19	1.19
Transect 2	0.88	1.58	1.61	2.62	1.67
Transect 3	0.63	0.38	3.65	0.83	1.24
Error rates	± 0.32	± 0.35	± 1.38	± 0.44	± 0.12
SMITH	1849 - 1901	1901 - 1987			TOTAL AVERAGE
Transect 1	2.83	2.45			2.64
Transect 2	0.31	.64			.47
Error rates	± 0.33	± 0.18			± 0.12
SOUTH MARSH	1849 - 1901	1901 - 1942	1942 - 1987		TOTAL AVERAGE
Transect 1	1.00	0.72	1.83		1.18
Transect 2	0.65	0.21	0.79		0.55
Error rates	± 0.33	± 0.35	± 0.30		± 0.12

* Insufficient data to calculate erosion rates

Figure 4.17 Location of transects for determining erosion rates on Smith Island

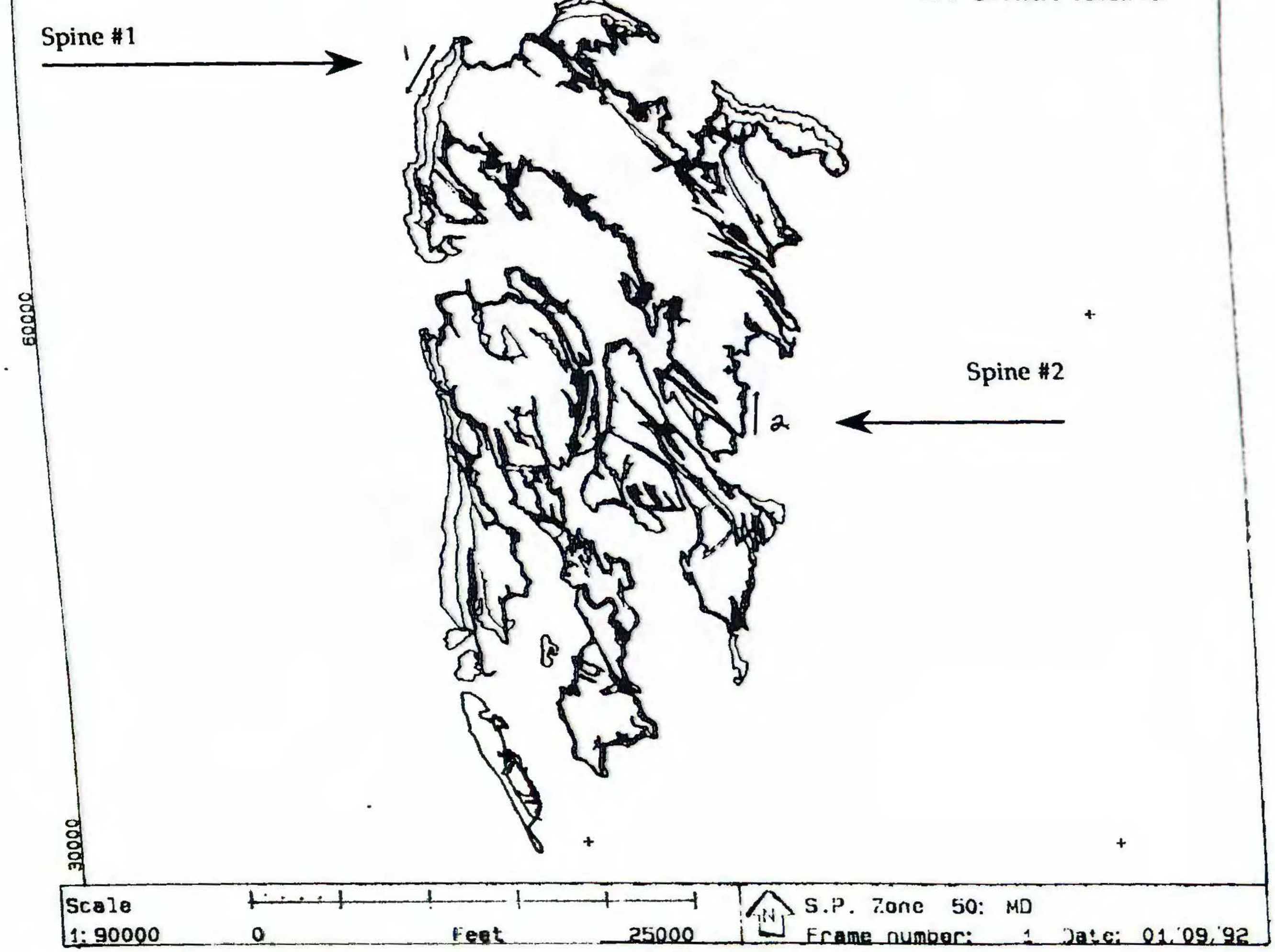
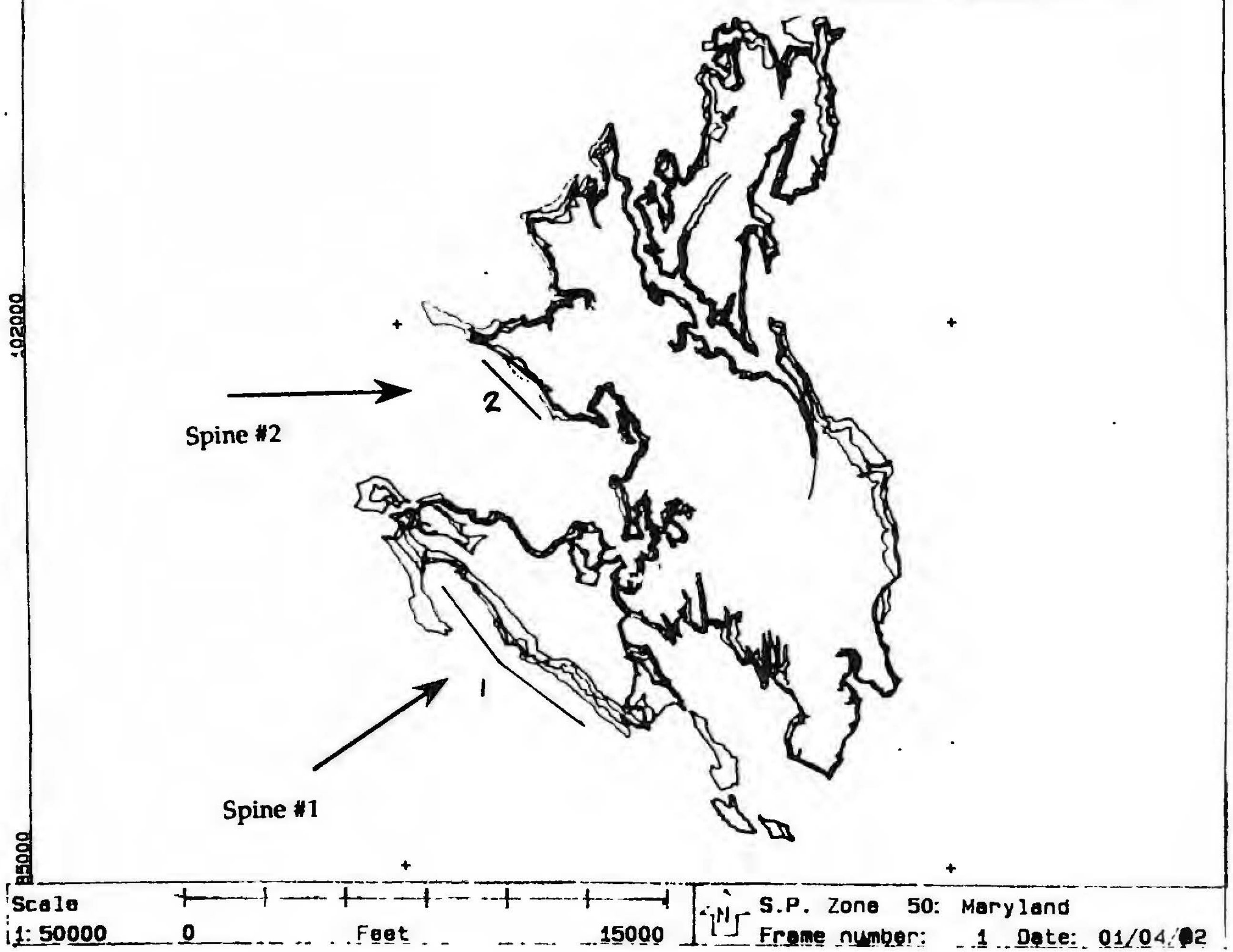


Figure 4.18 Location of transects for determining erosion rates on South Marsh Island



south and underlies both South Marsh and Smith Islands (Figure 4.19) (GEO-RECON, 1980). Although cores have not been taken through the marsh on Smith Island, the soil type beneath the ridges has been classified generally as silt and silt-clay loam (USDA, 1966).

No sediment samples were taken on Smith or South Marsh Islands. Two sediment samples were collected from Bloodsworth Island along the channel edge of Fin Creek Ridge. These samples were not analyzed in the laboratory, however they were examined visually and texturally and determined to be high silt/clay content with little to no sand. The samples appeared similar to the samples analyzed for the Northern Group, suggesting that the basement composition of the Southern Group islands is possibly the same as the Northern Group.

Shoreline Response Modeling

The Inundation Model

Northern Group

Slopes and heights were determined from field surveys since the resolution of topographic maps is too coarse, with contour intervals of 1.6 m (5 feet). Most of the shorelines of the Northern Group islands are steep scarps, either clay or marsh. Therefore, the most

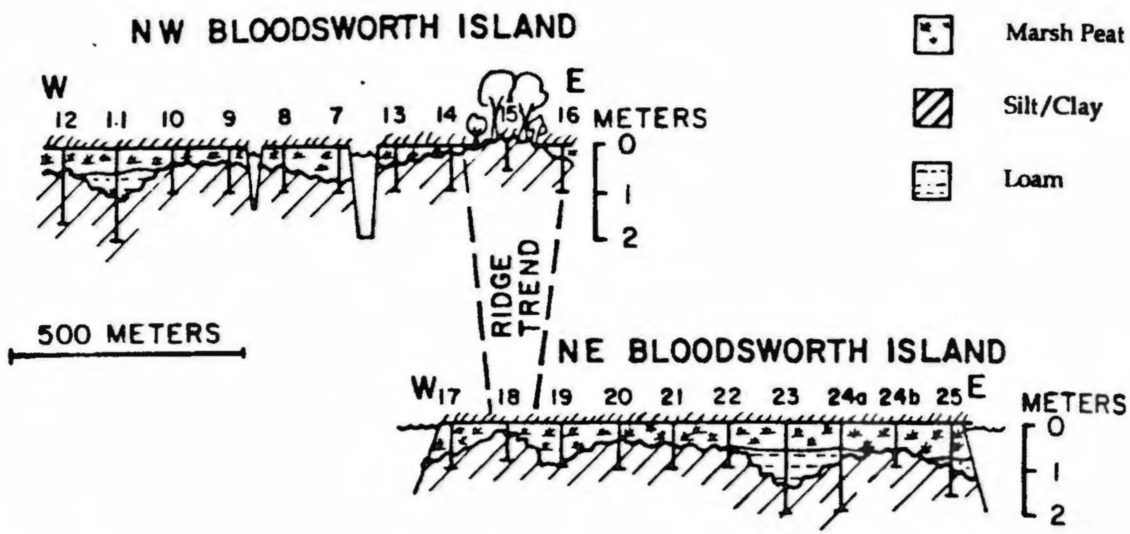


Figure 4.19 Geologic section through northern Bloodsworth Island showing development of marsh over the clay layer (from GEO-RECON, 1980)

important variable is the height of the scarp, or the island. The heights measured for the three islands are presented in Table 4.3.

It is clear from Table 4.3 that there are height variations throughout the islands. The upland areas lie between 0.37 and 2.3 m above MSL; the marsh areas range from 0.11 m to 0.5 m above MSL; and the marsh/upland marginal areas are between 0.3 and 0.58 m above MSL. The upland area which measured 0.37 m was probably an upland/wetland margin area rather than an upland area. If sea level rises according to the IPCC scenarios for the Bay, by 2030 the water level will rise 21 cm (Figure 2.4). This will have large impacts on the marsh areas which will be inundated unless they can keep pace by increased sedimentation rates. In addition, as the marsh/upland marginal areas are inundated they will be converted to marsh; and upland areas will become margin areas, and eventually marsh. Thus, vegetation zones will migrate landward, where possible. By the year 2100, virtually everything except the highest upland areas will be below the water level, which is predicted to be 82 cm higher than it is today (Figure 2.4). Greater than seventy percent of the areas surveyed during this study will be completely inundated.

Southern Group

If the islands in the Southern Group were static systems, then the inundation model would predict that a 0.5 m rise in sea-level would completely inundate the islands except for the few remaining upland ridges. However, these marshy systems are not static over time. The depth of the peat layer on these islands suggests that they have been vertically accreting in response to sea-level rise for at least the last few centuries. Without such accretion the islands would have been mostly inundated one or more centuries ago.

In order to understand how successfully these islands are responding to sea-level rise, it is essential to know both the vertical accretion rates of the islands and the rate of sea-level rise in the Bay. Island vertical accretion rates are not available, so such an analysis was impossible. However, the apparent degradation of the interior marshes indicates that the rate of sea-level rise is currently exceeding the rate of vertical accretion.

Hooper Island

Hooper Island is a good area for examining the process of upland conversion to marsh in response to sea-level rise. There are many examples of upland ridges which are being submerged and are becoming marsh (Plate 2.4). Figure 4.20 presents the results of a transect from the center of a ridge to the middle of the adjacent marsh, showing the depth of the clay layer beneath the marsh surface and the upland ridge. Figure 4.20 also shows the intruding wedge of marsh.

The slope of the surface of the basement clay layer is only 0.2 degrees, which translates to 2.86 m of horizontal displacement of the wetland/upland border for every 1 cm rise in sea level. This model suggests that the entire transect in Figure 4.20 was upland during the last century since sea level has risen approximately 30 cm in the last 100 years to cause nearly 86 m of horizontal displacement at a 0.2 degree slope. A rise in sea level of about 65 cm would inundate this ridge, which may occur by 2090.

The topography of Hooper Island will ultimately determine the extent of inundation due to sea-level rise. All the marsh areas lie less than about 0.5 m above MSL, but the ridges vary in height throughout the island. A small ridge measured only about 7.6 cm above the adjacent marsh; a larger ridge measured 1.4 m above the adjacent marsh (Figure 4.21). Even if some of the ridges are high enough to remain above the rising water level, they are small in area and could not support the island population. More importantly, the lack of fresh water

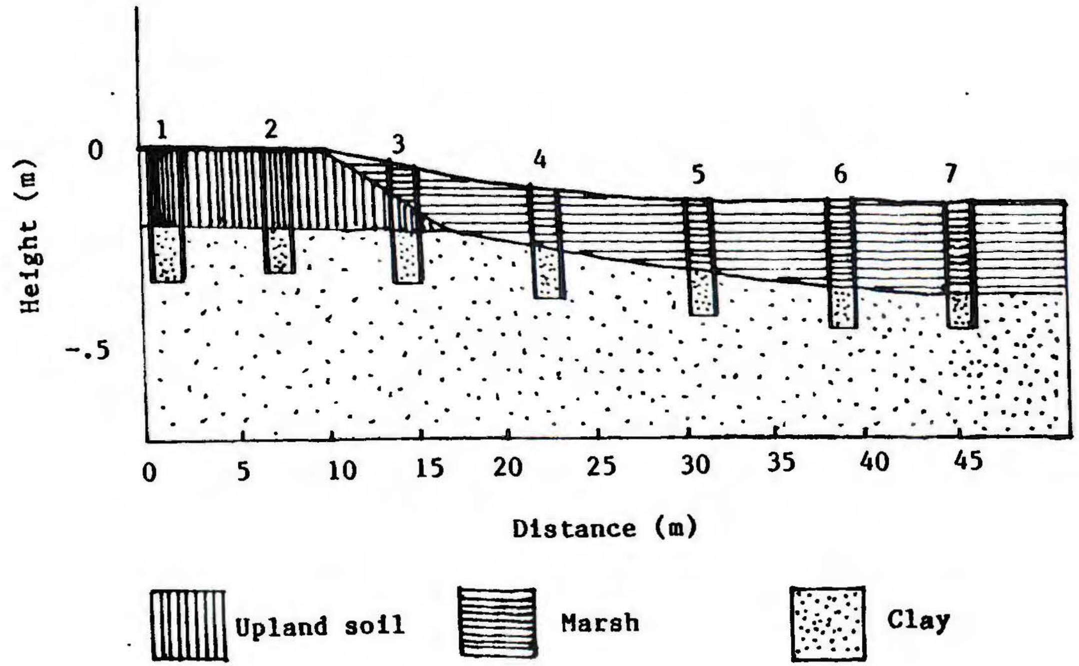


Figure 4.20 Geologic section of Lower Hooper Island.

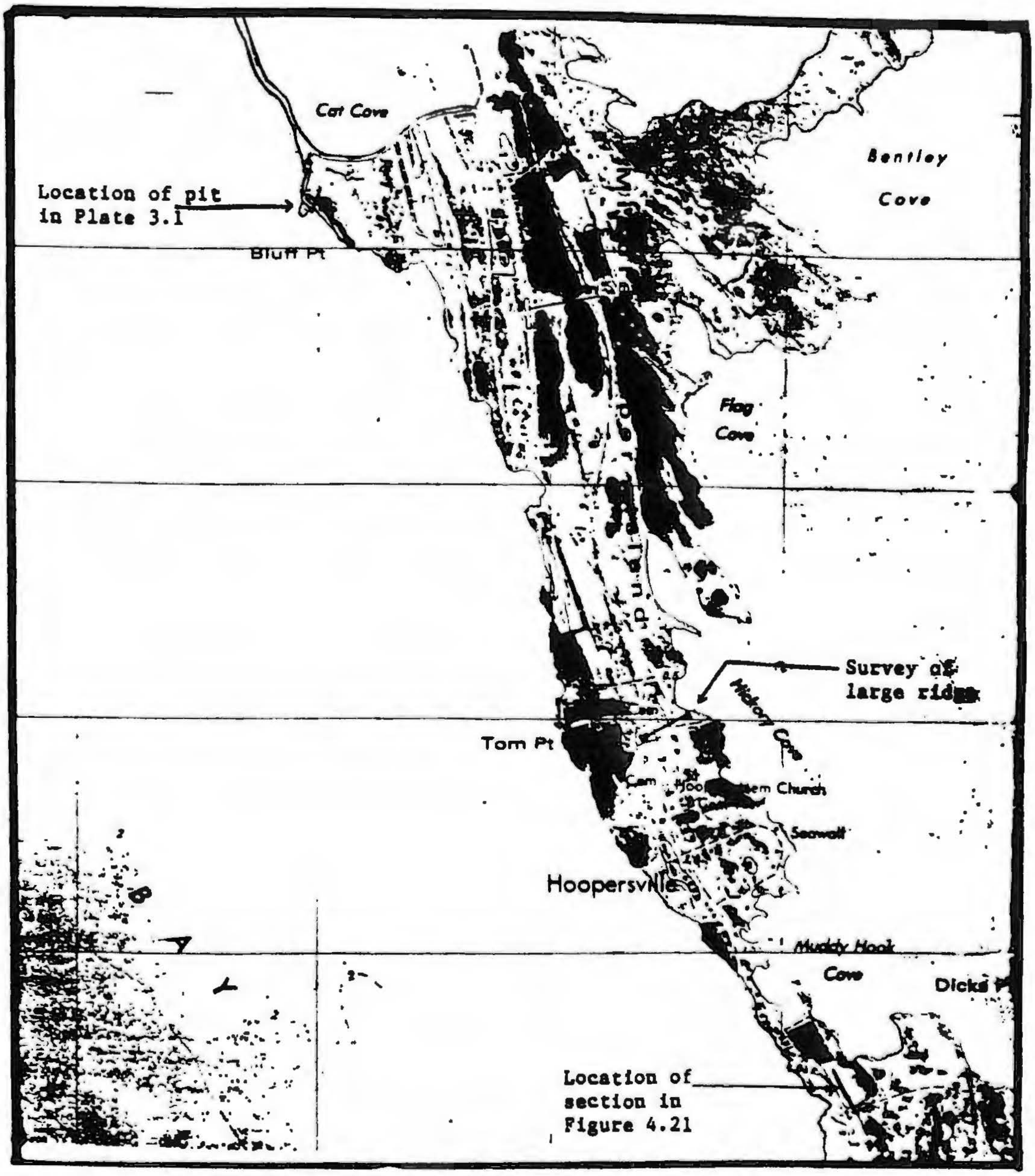


Figure 4.21 Location of survey sites for Hooper Island- 11/23/91.

due to saltwater intrusion into the groundwater would render the small ridges uninhabitable long before they are submerged.

Historic Trends Analysis

Northern Group

The trend of land loss was extended into the future to predict when the islands will disappear, given the current rate of erosion and sea-level rise. The trends in Figure 4.22 suggest that James and Poplar Islands may disappear around the year 2000, and that Barren Island will disappear by the year 2040. This prediction is based on the existing conditions and does not account for an accelerated rise in sea level. The historic trend of rapid erosion of the Northern Group islands will likely continue regardless of any change in the rate of sea-level rise.

Future rates of sea-level rise were calculated for the Northern Group, based on the IPCC scenarios as calibrated to the higher rate of sea-level rise in the Chesapeake Bay. Table 4.7 suggests that by 2030 the current rates of land loss will double; by 2070 they will nearly triple; and by 2100 they will more than triple. At these rates, Barren Island will be gone in 20 years; James and Poplar Islands will be gone in less than 10 years.

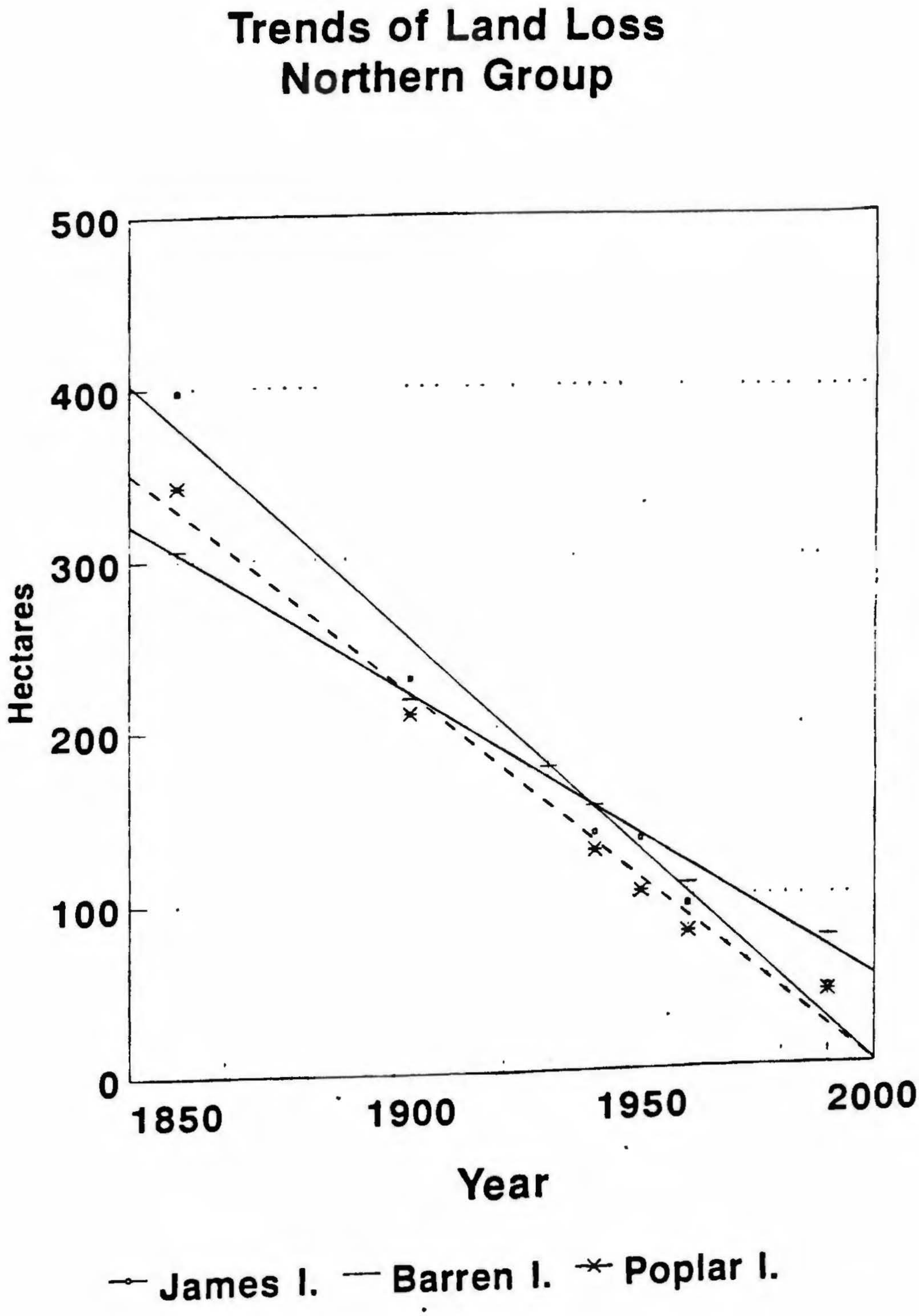
Table 4.7 Historic and Future Rates of Land loss for the Northern Group

Island	Historic Land Loss		Future Land Loss Rate (ha/yr)**		
	Erosion (ha/yr)	SLR Rate (mm/yr)*	1990 to 2030	2030 to 2070	2070 to 2100
Barren	1.7	2.7	3.7	5.0	5.4
James	2.1	2.7	4.6	6.2	6.6
Poplar	2.0	2.7	4.4	5.9	6.3

* Based on the Baltimore tide gauge station, 1903 to 1986.

** Based on scenarios of sea-level rise for the Chesapeake Bay as calibrated from the Best Estimate IPCC (1990) scenarios: 6 mm/yr by 2030, 8 mm/yr by 2070, and 8.6 mm/yr by 2100 (see Figure 2.4).

Figure 4.22

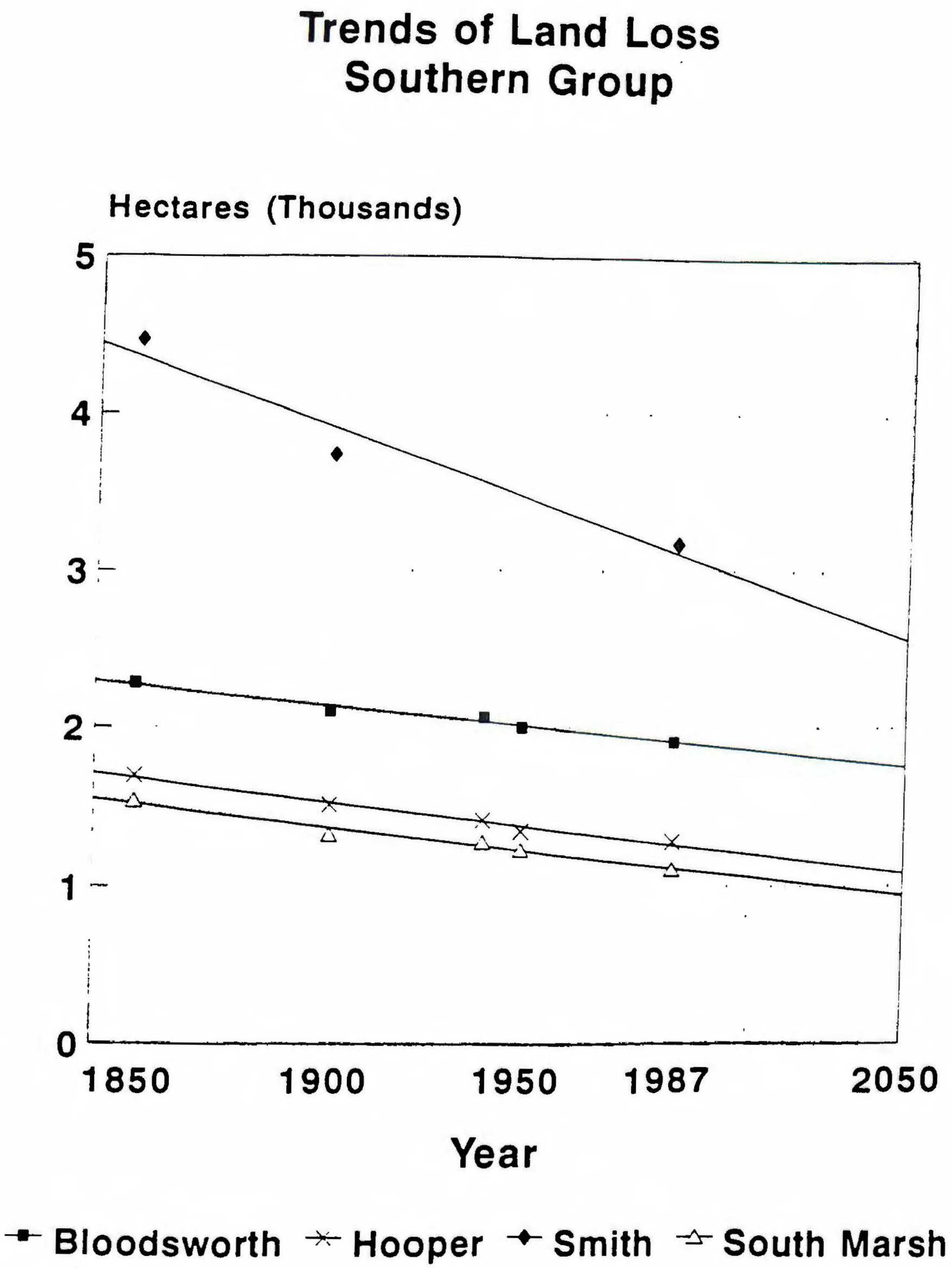

Trends of Land Loss
Northern Group
500
400
300
200
100
0
Hectares
1850
1900
1950
2000
Year
James I.
Barren I.
Poplar I.

Southern Group

The historic trends analysis for the Southern Group is conservative because it only accounts for perimeter erosion and does not include the effects of interior ponding, stream widening, and marsh loss which are important land loss processes for the Southern Group (DeLaune, et al., 1983). When the trend line for the Southern Group is extrapolated beyond the end of the graph, it suggests the disappearance of the islands sometime in the 23rd Century (Figure 4.23). However, when the effects of interior marsh degradation were considered for Smith Island, the actual loss of the island is more likely to be sometime in the middle part of the 21st Century (Davison, 1990).

Tables 4.8 and 4.9, and Figure 4.24 present the results of the historic trends analysis for the Southern Group. Future calculations were based on the IPCC scenarios of sea-level rise to the years 2030, 2070 and 2100, which were then calibrated to the higher rate of sea-level rise in Chesapeake Bay. Table 4.8 suggests that by 2030, the current rates of land loss will more than double; by 2070, they will nearly triple, and by 2100 they will more than triple. Table 4.9 predicts that Smith Island and South Marsh Island will disappear sometime between the years 2070 and 2100. Bloodsworth

Figure 4.23



Trends of Land Loss
Southern Group
Hectares (Thousands)
5
4
3
2
1
0
1850
1900
1950
1987
2050
Year
Bloodsworth
Hooper
Smith
South Marsh

Island will be reduced to less than half of its 1987 size; Hooper island will be reduced to less than one-fourth of its 1987 size. However, it is important to note that if calculations of interior marsh loss are considered, the life of these islands will surely be much shorter.

Table 4.8 Historic and Future Rates of Land Loss for the Southern Group and Hooper Island

Island	Historic Land Loss		Future Land Loss Rate (ha/yr)**		
	Erosion (ha/yr)	SLR Rate (MM/yr)*	1990 to 2030	2030 to 2070	2070 to 2100
Bloodsworth	3.3	2.7	7.3	9.8	10.5
Hooper	2.9	2.7	6.4	8.5	9.2
Smith	10.2	2.7	22.7	30.2	32.5
South Marsh	3.3	2.7	7.3	9.8	10.5

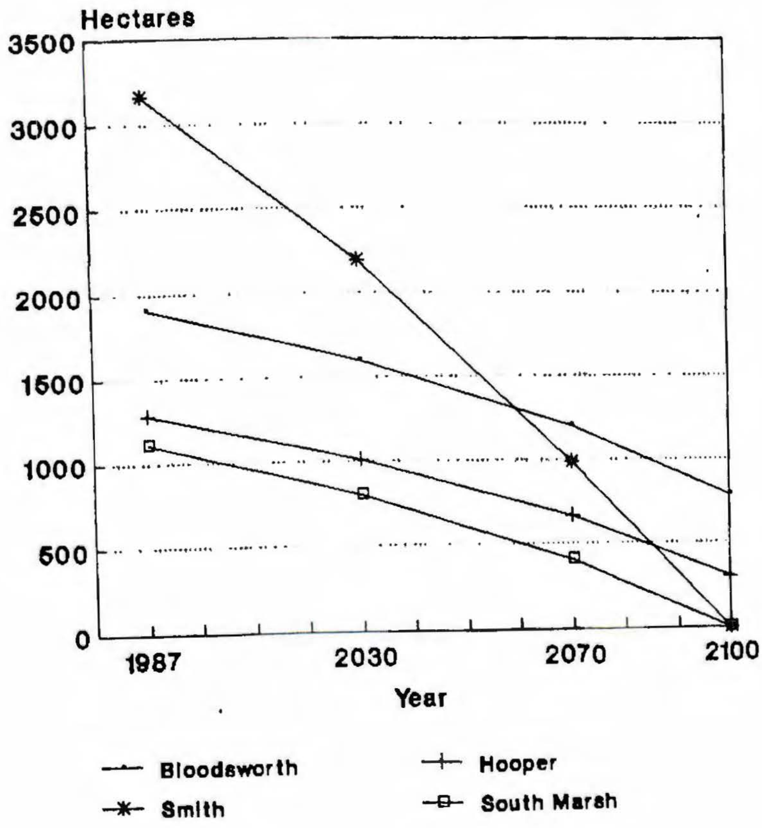
* Based on the Baltimore tide gauge station, 1903 to 1986.

** Based on scenarios of sea-level rise for the Chesapeake Bay as calibrated from the Best Estimate IPCC scenarios (1990): 6 mm/yr by 2030, 8 mm/yr by 2070, and 8.6 mm/yr by 2100 (See Figure 2.4).

Table 4.9 Future Projections of Island Size for the Southern Group and Hooper Island				
	Island Size (ha)*			
Island	1987	2030	2070	2100
Bloodsworth	1909	1595	1203	783
Hooper	1285	1010	670	302
Smith	3168	2192	984	- 0 -
South Marsh	1113	799	407	- 0 -

* Based on scenarios of sea-level rise for the Chesapeake Bay as calibrated from the Best Estimate IPCC scenarios (1990): 6 mm/yr by 2030, 8 mm/yr by 2070, and 8.6 mm/yr by 2100 (See Figure 2.4). Also based on rates of land loss presented in Table 4.7.

Figure 4.24 Future Projections of Southern Group Islands



CHAPTER 5: DISCUSSION

Introduction

The patterns of land loss of the Northern and Southern Groups suggest that very different processes are causing the land loss for each group. The Northern Group is eroding from the west with more limited change on the protected, eastern shore of the islands. The Southern Group has a different pattern, consisting of (a) more uniform erosion around the perimeter of the island, and (b) interior marsh degradation by means of ponding and apical erosion of tidal marsh creeks. The differences in the processes of land loss can be attributed to the geomorphological characteristics of the two groups.

The Northern Group

The pattern of land loss for the Northern Group is related to several factors, including (1) wave characteristics, (2) storm frequency, (3) sediment type, and (4) tidal range. These interrelated factors are driving the erosion which has reduced the aerial extent of the islands by more than 76% in 138 years.

Wave Characteristics

Waves are the primary agent of coastal erosion (Komar, 1983). The pattern of erosion of the Northern

Group suggests that wind-driven waves from the west and northwest are the driving force. Indeed, the predominant wind direction in the Bay is from the west and northwest (Table 2.1) and the longest fetch distances are from the western quadrants (Table 4.4). As a result, larger waves with more energy reach the western shore of the islands. The eastern shore has a shorter fetch and is protected from the predominant winds. Significantly less shore erosion is occurring on the eastern shores of the islands (Table 4.5). During all field visits, the eastern shores were noticeably calmer than the western shores (Plate 5.1).

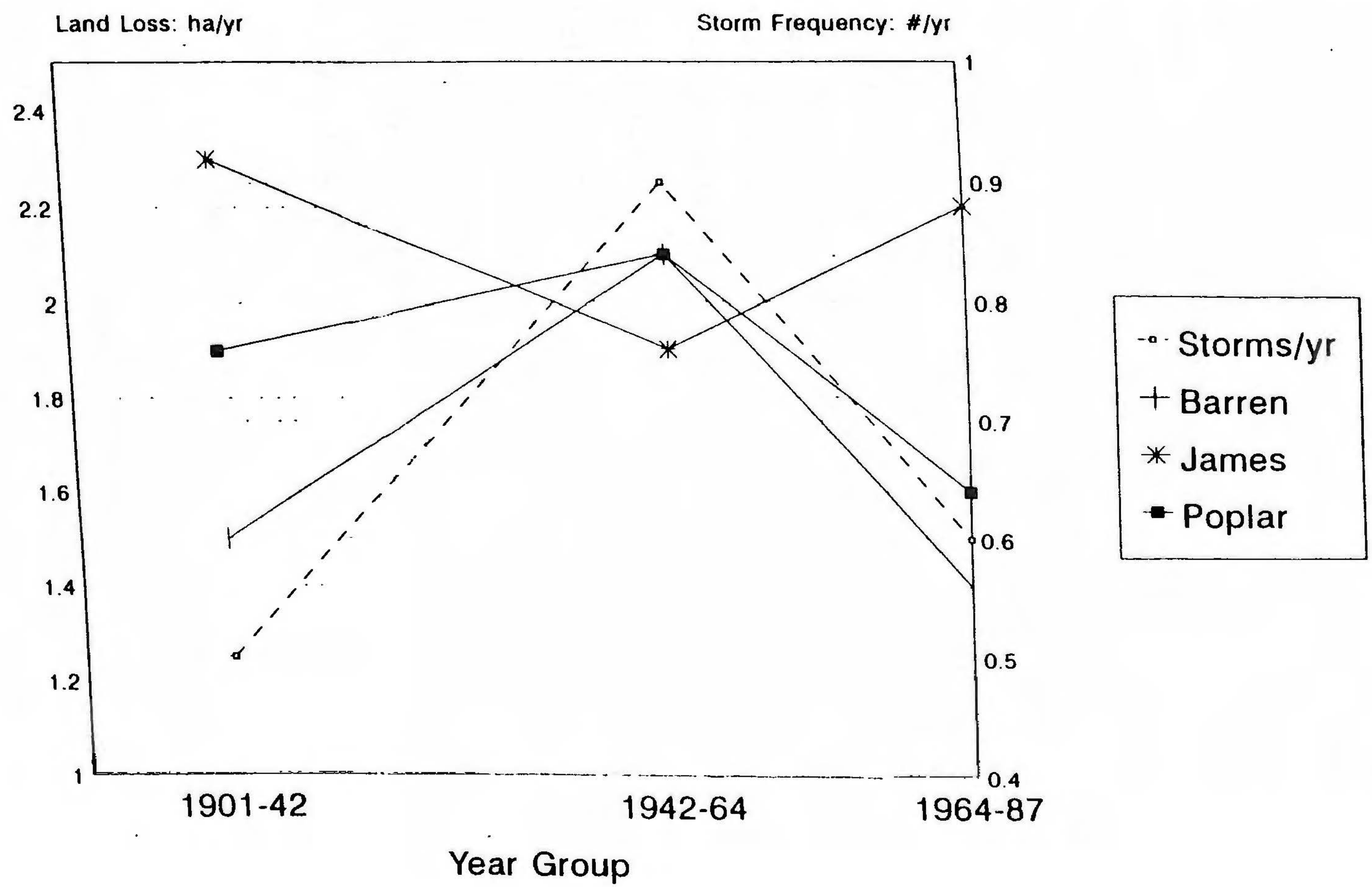
The rates of erosion for the Northern Group islands are very high, much higher than the Atlantic coast average of 0.8 m/yr (NRC, 1987) or the Chesapeake Bay average of 0.6 to 0.9 m/yr (Wang, et al., 1982). The erosion of the western facing clay bluffs is a continuous process which is occurring at all tide levels and wave conditions, and is exacerbated during storm conditions, thereby increasing the rates of erosion.

Storm Frequency

Erosion rates appeared to increase during periods of high storm frequency (Figure 5.1), suggesting that the erosion is linked to storm frequency. James Island did not clearly respond to the high storm period between 1942

Plate 5.1 Eastern side of Barren Island

Figure 5.1 Land loss v. Storm frequency
The Northern Group



and 1964 (see Appendix A). However, the land loss rate in Figure 5.1 represents an average of two periods, 1942-1952 and 1952-1964, which experienced very different rates of loss. Between 1942 and 1952, James Island changed very little, at a rate of 0.4 ha/yr. However, between 1952 and 1964 James Island lost an average of 2.4 ha/yr. Both were periods of high storm frequency, but the period 1952-64 affected the island more severely. The orientation and strength of the storms, relative to James Island, could possibly account for the different erosion rates during these two periods. The 1962 northeaster which affected the Bay area could have had a major impact on the Bay islands. James Island, unlike all the other islands, has a very short fetch from the south and is thus relatively well protected from storms approaching from this direction. However, the orientation of James Island is such that it is prone to wave attack from the northeast.

Sediment Type

The sediments and the environmental characteristics for the Northern Group islands are very similar to those of Lake Erie and the processes of bluff toe erosion in the two areas also appear to be much the same. The cliffs along the western shores of the islands are composed of cohesive silt/clay, which are eroding rapidly. In studies along a Lake Erie coast, Carter and Guy (1988) documented that erosion of clay cliffs which are comprised of cohesive sediments occurs by two main processes: (1) abrasion, the gradual wearing away of a deposit by sediment transported by the waves and wave uprush, and (2) quarrying, the tearing away or dislodging of discrete pieces of the deposit by hydraulic and/or pneumatic forces. Quarrying was determined to be the principle erosion process. An important difference is that during the winter, the Lake Erie bluffs are protected from erosion by ice packs along the shore (Carter and Guy, 1988). The Chesapeake Bay rarely has ice and certainly not for prolonged periods, so erosion occurs throughout the year.

Examples of bluff toe weathering and erosion can be seen along the western edge of Barren, James and Poplar Islands (Plate 5.2). Blocks of silt/clay which have broken off the bluff are more easily eroded by wave action. Wave erosion is the crucial erosion process; removal of material from the toe prevents the development of a stable slope, thereby allowing the process of erosion to continue indefinitely (Carter and Guy, 1988).

Because the eroded sediment is nearly all fine silt/clay, it remains in suspension or is carried offshore, rather than depositing in the nearshore (Komar, 1976). As a result, it is not available for beach

Plate 5.2 Bluff toe weathering on Poplar Island

recovery following a storm, as in a sandy, coastal environment. Therefore, once the fine material has been quarried and weathered, it is easily and permanently eroded.

This mode of sediment behavior is very different than on a sandy coastline, where periods of accretion usually follow erosional events. The shore position along a sandy coast is essentially an average of the location of the shoreline over time. For areas where the eroded sediment goes directly into suspension, there is no accretionary period and the shoreline only retreats. As a result, the erosion rates are high because they reflect only retreat and no accretion.

Tidal Range

During all observations in the field, waves impacted against the bluff toe, thus expending their energy directly against the toe during most, if not all, of the tidal cycle. The tidal range in the area of the Northern Group is low, only about 0.5 m. In areas with a large tidal range the energy is spread over a wide area and a beach face can form (Marcel Stive, pers. comm.). In microtidal environments such as the Chesapeake Bay and where there is no beach face, the energy is focused more locally at the bluff toe through all tidal cycles. Without the protection of sandy beaches, the energy is not dissipated so even small waves provide an erosive force. Under these circumstances, the pattern of erosion can be expected to continue indefinitely as long as erodible sediments are exposed to wave attack (Phillips, 1986).

For these low-lying islands, virtually all wave conditions are causing erosion and erodible sediments are continually available, so this pattern will persist until the islands have disappeared or shore protection structures are built. Marcel Stive, (personal discussions, 1991) described a similar situation in Holland, where there is a small tidal range and wave action is producing a wave-cut scarp with a level platform offshore.

Summary

The process of bluff toe erosion for the Northern Group is illustrated in Figure 5.2. Non-storm waves quarry and undercut the vertical bluff surface on a daily basis, eventually creating an unstable bluff (Plate 5.2). Storm waves provide enough energy to break off unstable blocks of bluff substrate. Significant and rapid horizontal retreat of the shore can therefore result from storm wave energy. Erosion of the Northern Islands has occurred in pulses of erosion during high storm spells, followed by slower erosion rates during more quiescent

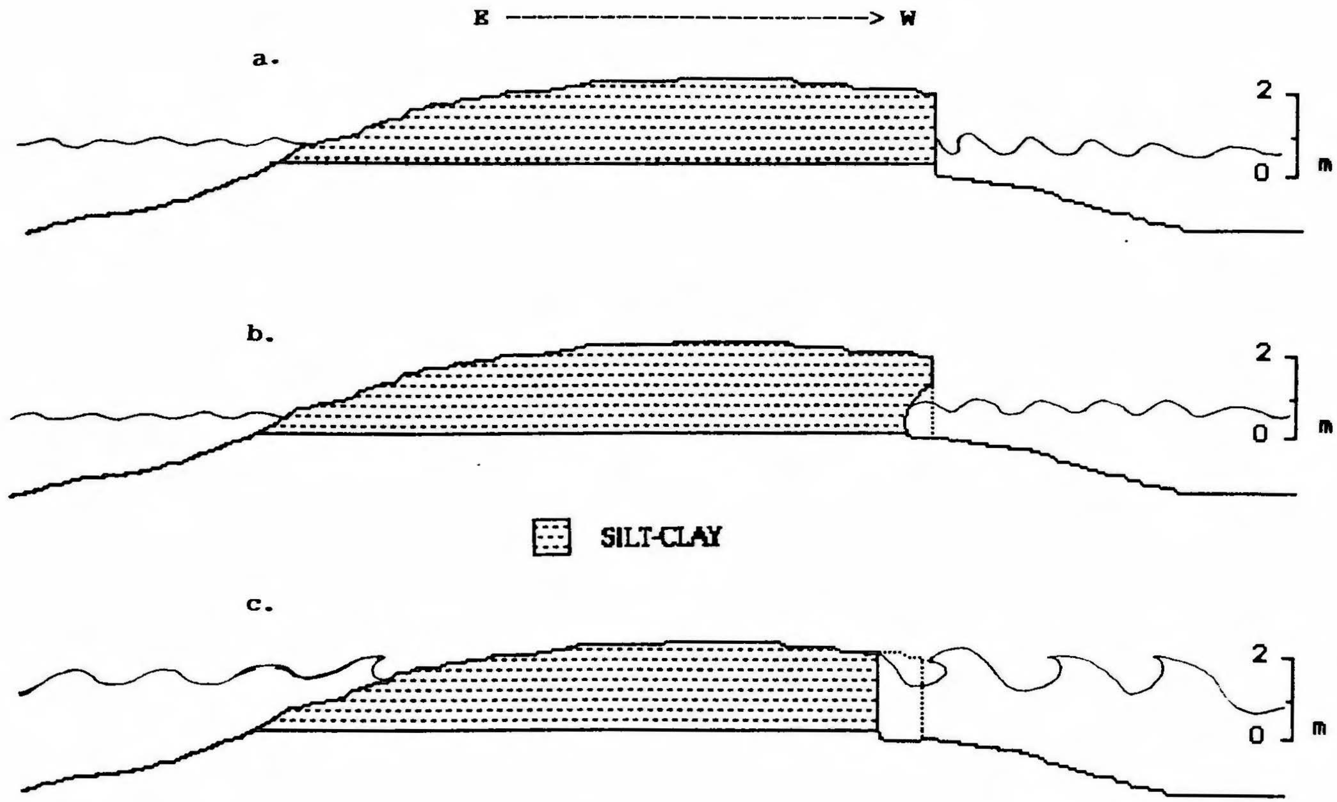


Figure 5.2 Schematic diagram of erosional processes of a Northern Group Island; (a. and b.) Unstable bluff created by erosion of bluff toe by non-storm wave activity; (c.) Energy of storm waves quarry bluff and cause shore recession.

periods.

This pattern of erosion will continue in the future regardless of a rise in sea level. However, due to rising sea-level, erosion rates during storms may increase. Therefore, rising sea level will likely exacerbate the existing effects of storms on the Northern Group islands by allowing higher storm surge and storm waves to reach the shore.

Southern Group

Land loss for the Southern Group is occurring through marsh edge erosion and interior marsh degradation. Both of these processes have been attributed to sea-level rise (Orson, et al., 1985). Interior marsh loss was not quantified for this study, so land loss estimates refer only to marsh edge erosion, except where indicated otherwise. The land loss estimates in Table 4.2, therefore, are much lower than true rates of land loss since interior marsh loss represents an important process of marsh response to sea-level rise (DeLaune, et al., 1983). Interior marsh loss estimates at Blackwater Wildlife Refuge in the Chesapeake Bay approximates 56 ha/yr (Pendleton and Stevenson, 1983), and 49.6 ha/yr in the Nanticoke estuary (Kearney et al., 1988). These rates are an order of magnitude higher than marsh edge erosion rates estimated in this study (from 3.3 to 10.3 ha/yr). Therefore, estimates of total land loss for the Southern Group would probably be much higher if interior marsh loss is factored in. This is not to compare interior marsh loss and marsh edge erosion; those processes are quite different. However, it is important to note that both processes are occurring and therefore both should be considered when estimating true rates of land loss.

The results of this study indicate that the observed marsh edge erosion, at least for Bloodsworth and South Marsh Islands, is weakly correlated to increasing sea level in the Chesapeake Bay (Figure 4.15). As long as sea level continues to rise, these processes will continue; if sea level rise accelerates, the rate of land loss will increase accordingly.

Marsh Fringe Erosion

Marsh fringe erosion is causing high erosion rates around the United States, from over 4 m/yr in the St. Lawrence River estuarine marshes (Dionne, 1986), 3.2 m/yr in Delaware Bay marshes (Phillips, 1986; French, 1990), and 5 m/yr in Louisiana marshes (Penland, et al., 1985). Estimates of island marsh fringe erosion from this study are lower than these trends, between about 0.5 m to 1.6 m/yr. (Table 4.6).

Table 5.1
A Sample of Marsh Fringe Erosion
Rates from Several Geographic Regions

Regions	Erosion Rate (m/yr)	Study
St. Lawrence River estuary	4.0	Dionne 1986
Delaware Bay	3.2	Philliips 1986; French 1990
Louisiana	5.0	Penland, et al, 1985

Certain areas of all the islands, notably promontories, are eroding at rates comparable to the areas noted in Table 5.1. However, due to difficulties calculating erosion rates for irregular shorelines as previously described, erosion rates were not computed for these areas from the Metric Mapping program. It is possible to visually estimate the erosion rates of some rapidly eroding areas such as promontories. Some of the island promontories and most of the western edge of Smith Island were estimated to be eroding at rates exceeding 3 m/yr. The truncation of marshy peninsular points due to erosion was also described for Delaware Bay (Phillips, 1986). In addition, dramatic shoreline change was often associated with the opening of streams, both in Delaware Bay (Phillips, 1986) and in this study.

French (1990) found that marsh edge erosion in

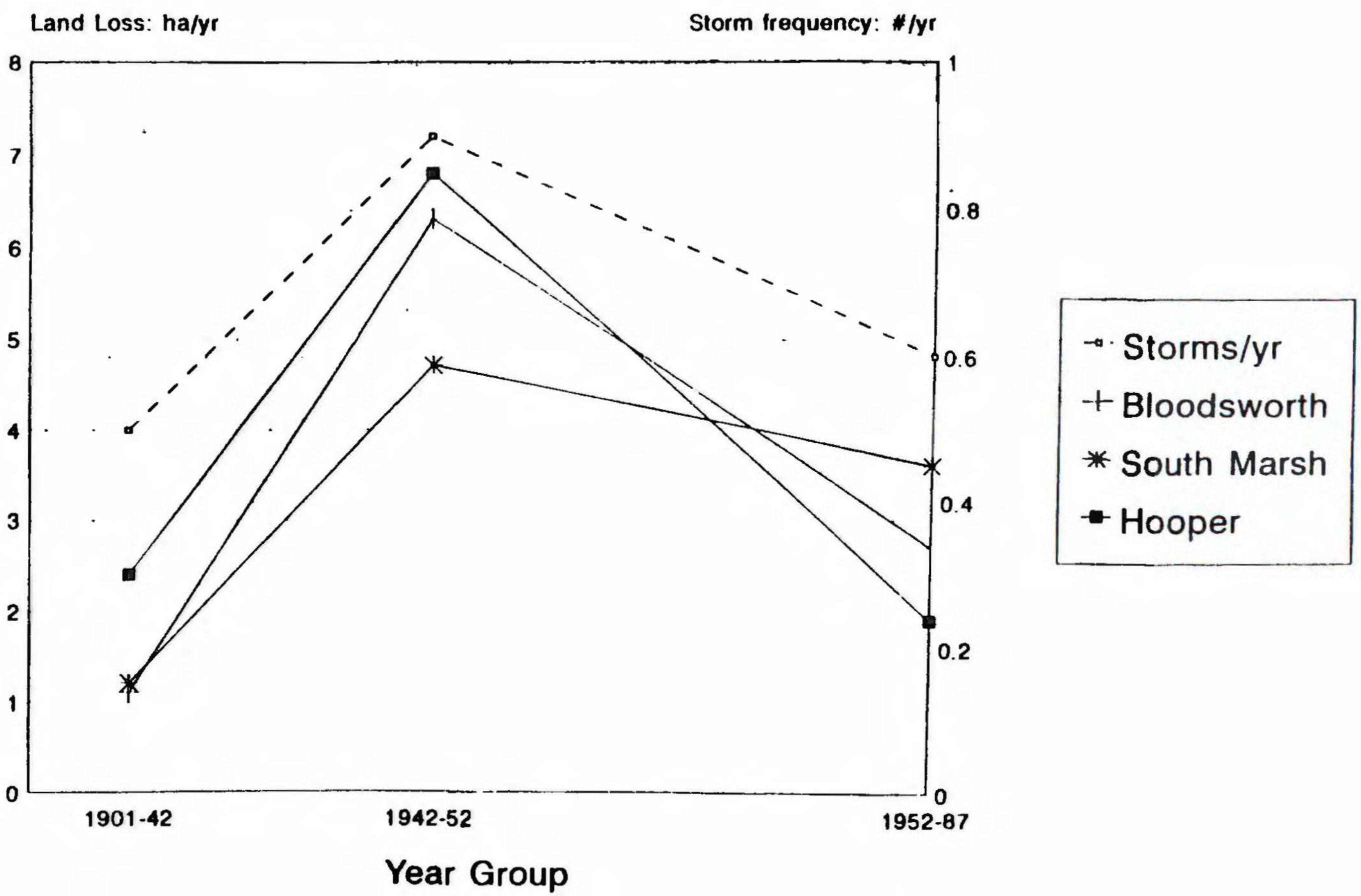
Delaware Bay is constant through time and does not increase during high storm periods. In contrast, Finkelstein and Hardaway (1988) found that marsh edge erosion was particularly impacted by storm wave activity. The results of this study show an increase in erosion during a particularly stormy period (Figure 5.3), thereby suggesting that marsh edge erosion is influenced by wave activity. Exposure to high wave energy has been found to contribute to seaward edge erosion of marshes in Chesapeake Bay (Froomer, 1980). Marshes in Delaware Bay are somewhat protected from high storm energy approaching from the Bay mouth, which may explain their lack of response to storms (French, 1990).

Smith Island is not included in Figure 5.3 because there were too few year groups for comparison. Hooper Island was included because of the rapid erosion of the southern end of the island, which is almost entirely marsh.

Figure 5.4 depicts the process of marsh edge erosion for the Southern Islands. This process occurs when chunks of marsh peat are undermined by normal, daily wave energy and loosened by biogenic activity of crabs and worms (Plate 2.1). During smaller storms, waves which impact the marsh edge break off any loosened blocks of peat, causing horizontal recession of the marsh edge. Under this scenario, erosion rates may increase.

Figure 5.3 Land loss v. Storm frequency

The Southern Group



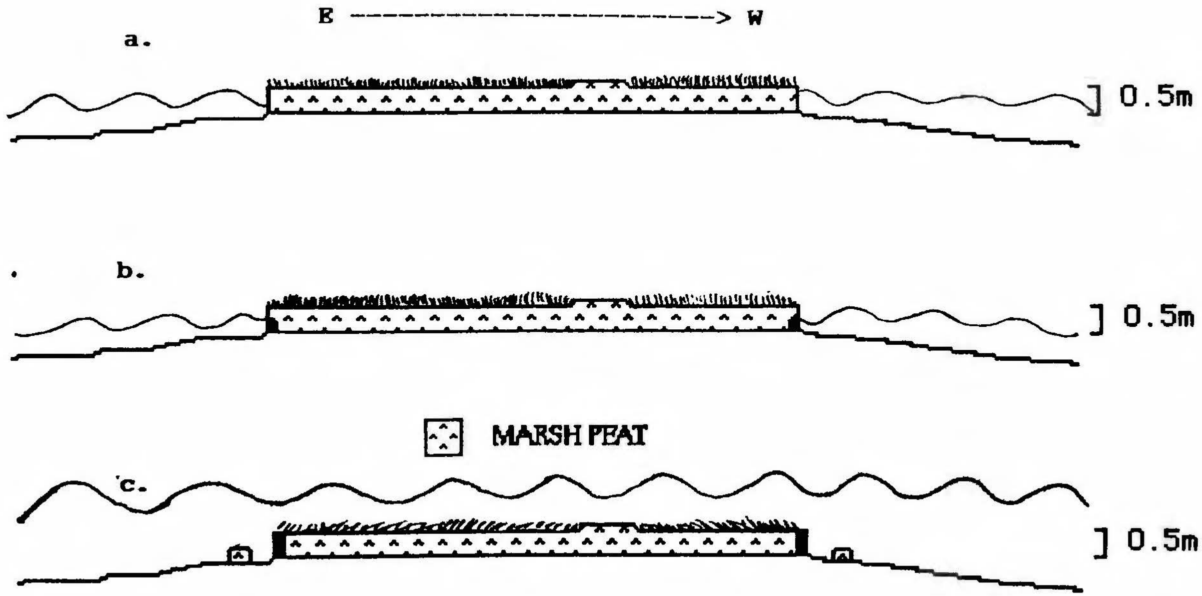


Figure 5.4 Schematic diagram of erosional processes of a Southern Group island; (a. and b.) Unstable marsh edge created by non-storm wave activity and loosened by biogenic activity; (c.) During major storm surges, marsh is submerged and waves overtop the marsh.

However, during larger storms the surge is high enough to overtop the low-lying islands, thereby largely dissipating wave energy on the marsh surface rather than at the marsh edge (Figure 5.4). When this occurs, a storm may have little effect on the marsh edge in proportion to the storm's size. In this regard, the response of the Southern Group to storms differs from that of the Northern Group. The Northern Group bluffs are higher and are therefore affected at all times by wave activity, both during major storm surges and on a daily basis. The marsh edge of the Southern Group islands is low enough that large waves accompanied by storm surge may have a smaller effect on the marsh edge.

Interior Marsh Loss

Several factors appear to contribute to the degradation of the interior island marshes, including lack of a sediment source, land subsidence, small tidal range, and the vulnerability of submerged upland type of marsh. Although not quantified for this study, it is clear from other studies that this process is significantly affecting marshes around the Chesapeake Bay.

Where submergence is occurring at a rate that is higher than the marsh's ability to keep up with relative sea-level rise, marsh loss occurs through interior pond formation, coalescence and enlargement. This process has been documented previously in marshes in the Chesapeake Bay at Blackwater Wildlife Refuge (Pendleton and Stevenson, 1983), the Nanticoke Estuary (Kearney, et al., 1988), and Smith Island (Davison, 1990). This has also been shown to be important in Louisiana marshes (DeLaune, et al., 1983) Although the process of marsh loss was not quantified for this study, it was observed in sequential aerial photographs of the three Southern Group islands that ponds are enlarging, channels are widening, and the incidence of interior open water is increasing.

Sediment source

Marsh loss occurs by submergence resulting from subsidence of the land and an inadequate sediment supply in the face of rising sea level. These islands are prone to submergence because there is no upland inorganic sediment supply; the most important source of inorganic sediment is probably erosion of the marsh edge (cf. Reed, 1988) and storm flooding (Baumann, 1980). Organic production through plant death and culm debris accounts for a small percent of vertical accretion, but cannot amount to much without sufficient inorganic input (personal communication, Pendleton, E.C., 1992). The percent of organic vs. inorganic material in the island marshes has not yet been studied.

The material being deposited on the marsh surface by overwash probably does not reach the interior of the marsh and is more likely placed near the edge of the marsh, creating a streambank effect. However, because of rapid marsh edge erosion this material may never benefit the island marsh system. It is ironic that storms, which are so detrimental to the marsh edge, are critical to the survival of the marsh by sediment input.

Tidal range

Stevenson et al (1986) suggest that tidal range is important to a marsh's ability to respond to sea-level rise, and that a marsh with a low tidal range is more vulnerable to sea-level changes. This would imply that marshes around the Chesapeake, including the islands, are particularly vulnerable to the rapid rate of sea-level rise in the Bay. A marsh in an area with low tidal amplitude has a small vertical range, thus is more sensitive to elevational changes in water level. The interior of the expansive island marshes do not flood regularly and therefore have limited inorganic sediment input. Accretion of the interior marsh surface is therefore limited to organic input from culm debris and organic material from root production although this source is poorly (or not) quantified. Once this material is compressed and degraded, it probably adds little to the surface elevation (personal communication, Pendleton, E.C., 1992). Inorganic sediment input is critical for marsh accretion and, therefore, survival of the islands.

Marsh Type

The Southern Group islands appear to be submerged upland marshes. Kearney et al. (1988) reported that this type of marsh experienced the most rapid rate of loss of the principal marsh systems in the Chesapeake Bay. As a first response to rising sea level, interior ponds form in apparently random locations due to anoxia and plant death (Mendelssohn et al., 1981). The ponds enlarge and coalesce after they form, eventually becoming large areas of open water. Davison (1990) established that interior pond formation is occurring very rapidly on Smith Island. It is likely that all the large marshy islands are experiencing similar modes of interior pond formation and enlargement.

The processes of interior pond enlargement have not been identified for this study area. However, a discernible west-northwest to east-southeast axis of many ponds suggests that wave erosion, driven by the predominant winds, may be an important factor for pond growth (Stevenson, et al., 1985b; Davison, 1990). After ponds reach a critical size, wind-generated waves begin to erode the marsh edge, which in turn expands the pond. Figure 5.3 explains the various methods of open water formation in an island marsh system.

The process of land loss becomes nonlinear as it progresses and begins to accelerate. With more ponds, larger tidal channels, and an eroding marsh edge, the incidence of coalescence is higher and the percent of open water increases. Thus, the rates of marsh deterioration in advanced stages are higher than in early stages.

Summary

Land loss for the Southern Group is occurring by two processes: shore erosion and interior marsh loss. Both processes are significantly affecting the integrity of the large marshy Southern Islands. Interior marsh loss is probably accounting for a higher percentage of land loss than perimeter erosion. It is likely that if rates of interior marsh loss were quantified for the islands, they would be an order of magnitude higher than the perimeter erosion rates. Thus, the land loss estimates for the Southern Group are very low and the ultimate demise of the islands is more imminent that predicted in Figure 4.25.

Hooper Island

Hooper Island is being affected by the processes of erosion and submergence. Erosion has been slowed where engineering structures have been built (Plate 5.3), but some unprotected shores have been eroding at an average annual rate of about 0.7 m/yr since 1848. Submergence is increasingly becoming a problem as the island surface becomes closer to mean water level. Hooper Island is slowly submerging by land subsidence and sea-level rise. There is ubiquitous physical evidence for this process, including the conversion of upland to marsh, elevated groundwater, recurrent flooding, and erosion.

These effects are important because they indicate that the real problem is not being solved, despite attempts to prevent erosion. The most serious problem for the residents of Hooper Island is the encroaching sea which is turning upland to marsh, causing frequent flooding, saturating lawns and basements, and generally decreasing the quality of life on the island. These problems cannot be solved with seawalls, revetments or bulkheads; the only options are retreating from the area, raising the height of the land, or possibly using dike and water control systems as in Holland.

The timing of these processes is an important variable. According to Figure 4.21, the marsh has most recently extended from location #3 to #2, a distance of

Plate 5.3 Example of erosion control measures along the wetsern shore of Hooper Island

Plate 5.4 View of an upland ridge on Hooper Island, surrounded by the encroaching marsh

approximately 7.62 m. If the slope of the clay layer beneath the marsh is .22 degrees, then mean sea level must have risen 3 cm for a horizontal displacement of 7.81 m. Therefore, using the Baltimore tide gauge record with an average rise of 2.7 mm/yr, the process of inundation from location #3 to #2 has occurred in about the last 11 years.

Hooper Island has transformed since 1901 from an island with a high proportion of upland to an island dominated by wetlands. The shrinking upland ridges are the only upland areas remaining (Plate 5.4). As the island is submerging and the process of upland conversion continues, the island will progressively become less habitable. Table 4.8 predicts that Hooper will be reduced to less than one-fourth of its current size by the year 2100. However, this does not include marsh loss processes which will become more important as the island submerges and sea-level rises in the Chesapeake Bay.

CHAPTER 6: CONCLUSIONS

This study is the first instance where an accurate historical mapping procedure has been used to quantify the spatial and temporal processes of land loss for islands in the Chesapeake Bay. Previous studies have used visual comparisons of historic maps and photographs to identify island shoreline changes, which have been enhanced by anecdotal descriptions of the islands (Singewald and Slaughter, 1949; Kearney and Stevenson, 1991). Field surveys were performed to identify the geomorphological processes at the shoreline. The processes of land loss were then analyzed from this data. This is also the first example where Metric Mapping has been used for irregular, island shorelines.

This study identifies two geomorphologically distinct island types, termed the Northern Group and the Southern Group, which have exhibited very different patterns of shoreline behavior. A comparison of the two island groups has resulted in a detailed examination of the mechanisms of land loss. Erosion is the dominant land loss mechanism for the Northern Group; erosion and submergence are the dominant processes of land loss in the Southern Group. For the Northern Group, the trend will continue with or without an accelerated rise in sea level. The processes of erosion are being controlled by wind and storm-driven waves which will continue regardless of further sea-level change, but will increase with accelerated sea-level rise predicted for the coming decades. The processes of land loss for the Southern Group and Hooper Island can be attributed to sea-level rise and wave-induced erosion of the marsh edge. Submergence of these islands, which is causing marsh deterioration and conversion of uplands to marsh, will be accelerated with an increased rate of sea-level rise.

The prognosis for either group of islands is not good. The Northern Group is eroding rapidly and the islands are small; the Southern Group islands are larger, but submergence is reducing any available upland and both salt water intrusion and inundation is rendering these islands uninhabitable.

Land loss for the Southern Group has been grossly underestimated in this study because it did not account for interior marsh loss. Further analysis should include quantifying internal marsh loss, and identifying the processes and causes of ponding and pond enlargement on the islands. The islands' future response to sea-level rise can be more accurately predicted with knowledge of the timing, magnitude and mechanisms of marsh loss.

To fully understand the process of island submergence, a study of island marsh accretion rates is essential. Rates of accretion could be compared to subsidence rates in the Bay to determine how the islands are responding to sea-level rise. In addition, island accretion rates could be compared to other marsh accretion rates from previous studies. In addition, it would be critical to know the organic/inorganic composition of the island marsh peat, as a means to determine whether the islands are sediment starved and are therefore vulnerable to interior marsh loss.

Additional field research should include transects to determine the depth of the clay layer beneath Bloodsworth, Smith and South Marsh Islands. This information would be helpful for the definitive identification of the Kent Island Formation beneath the Southern Group islands. In addition, identification of the clay layer beneath the small marshes on the Northern Group islands would support the theory that the Kent Island Formation extends from Kent Island to Tangier Island. This research could also clarify the present understanding of the evolution of these islands during the Holocene.

The U.S. Fish and Wildlife Service has a vested interest in Barren Island, Smith Island, and Bloodsworth Island. Other islands are also important to the Service because they provide isolated sanctuaries for breeding and nesting waterfowl. The reduction of these islands is already reducing potential nesting habitat. However, with the exception of black ducks (Krementz, et al., 1991), a connection between reduced habitat and the number of waterfowl in the Bay has not yet been made. Management implications of reduced nesting area on waterfowl is dependent on delineating the islands evolution and what is likely to happen in the future.

Because of their importance as waterfowl habitat along the Atlantic flyway, there is a growing interest in developing management alternatives for the islands. There are several options for island protection and restoration, including (1) hard stabilization such as bulkheads and revetments, (2) soft stabilization using dredge material, or (3) a combination of hard and soft stabilization alternatives.

Hard stabilization includes structures such as stone revetments, and metal or wooden bulkheads. Bulkheads and revetments are common around the mainland shores of the Bay. However, except for Hooper Island, they are generally absent from the island shores. A small revetment was built in the last few years on Coaches Island (Poplar Island). The Federal government has on occasion shown interest in protecting valuable habitat by using hard stabilization if necessary. A segmented offshore breakwater and beach fill project is currently being constructed to protect Eastern Neck National

Wildlife Refuge, in the northern part of Chesapeake Bay.

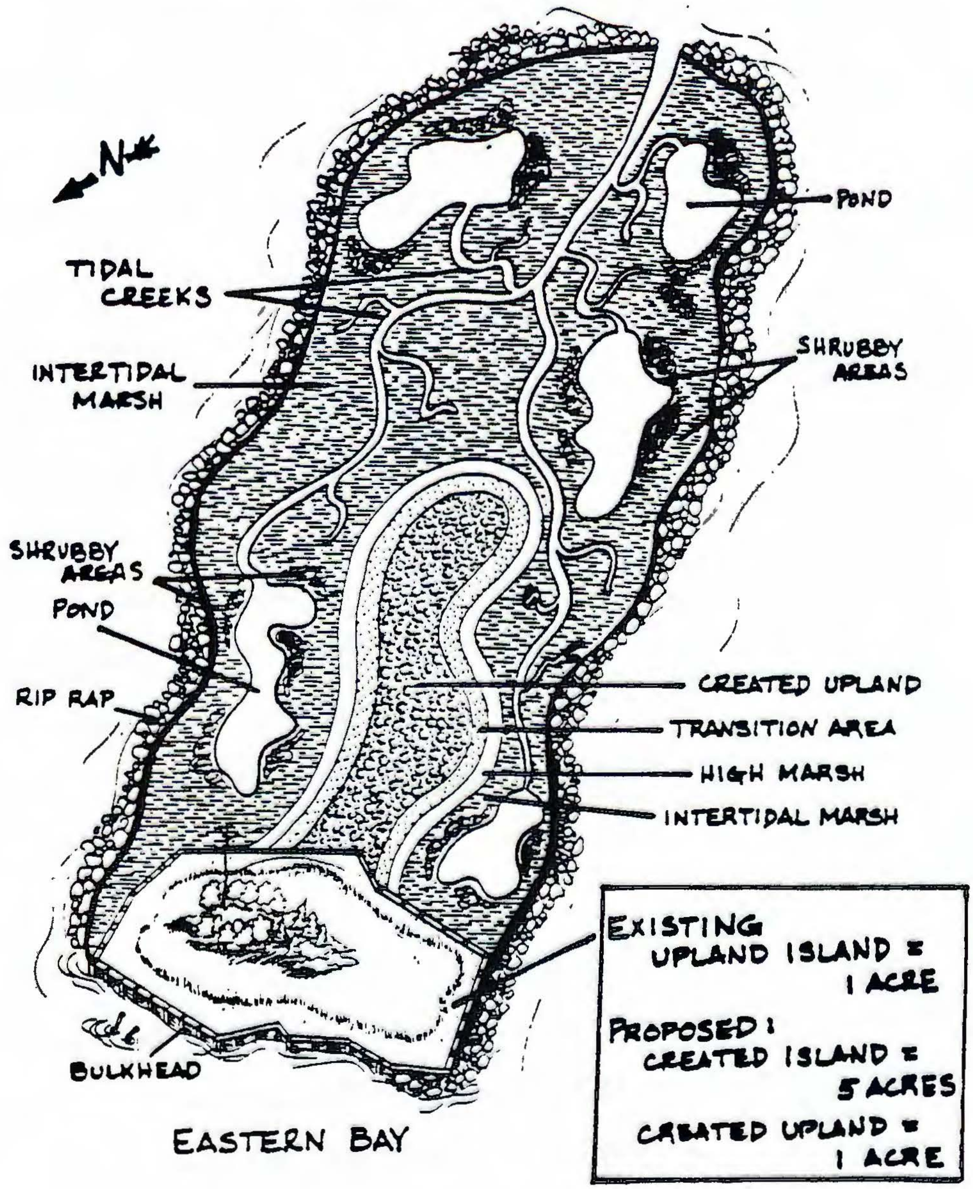
For the marshy islands, coastal erosion is not an immediate threat to the upland areas which are surrounded by marsh, so alternative hard stabilization suggestions have been developed. The U.S. Army Corps of Engineers (1984) has proposed building a floodwall around the ridges on Tangier Island, which is geomorphologically similar to Smith Island. The floodwall would be designed to the 100-year flood level plus 1 m of freeboard. An alternative is to build a 100-year floodwall around a community center or school to provide a sanctuary against severe floods.

Hard stabilization will not be the best recourse in all situations. As Hooper Island demonstrates, erosion control structures will not ensure the integrity of a marshy island, since submergence is the most important problem for these islands. It will be necessary to raise the island's surface in response to sea-level rise. One option which has been tested in Louisiana marshes and has great potential, is to apply a thin layer of dredge material onto a marsh surface using a high pressure spray. This technique was developed to avoid creating a spoil bank as a result of channel dredging for oil operations (Cahoon and Cowan, 1988). Spoil banks restrict overbank flooding which contributes to marsh submergence and deterioration. Cahoon and Cowan (1988) found that in two sites monitored, marsh vegetation recolonizes after two growing seasons or after one growing season in areas where the sprayed layer is very thin. This method appears to have great potential for maintaining subsiding marshes, and could be very effective in the Chesapeake Bay. A critical parameter is the height or thickness of the spoil layer on the marsh which allows marsh species to establish. The grain size and suitability of the spoil material must also be considered.

Another potential option for habitat protection or restoration is the use of clean dredge material to expand the island size in combination with hard stabilization to impound the dredge material. Such a proposal is being considered by the State of Maryland, the U.S. Fish and Wildlife Service, and the U.S. Army Corps of Engineers, for Bodkin Island, a small one-acre island in the northern part of the Bay (Figure 6.1). Preliminary designs have also been made for Poplar Island (Figure 2.9). Parameters such as dredge spoil transportation costs, dredge spoil suitability, and the cost of additional protection must be considered for these projects and may not prove to be cost effective.

Islands made of dredge material have proven to be good nesting sites for waterfowl, so recreating islands with dredge material may be very effective. Sundown

Figure 6.1 Schematic drawing of Bodkin Island habitat enhancement proposal (from U.S. Fish and Wildlife Service, undated draft)



Island in Port O'Conner, Texas is a dredge spoil island that has been a breeding site for brown pelicans and other species since 1987. This island is eroding rapidly. Concerned for the nesting birds, the National Audubon Society is hoping to enlarge the island with dredge material (Associated Press, 1991).

Queen Bess Island in Barataria Bay, Louisiana is another small, eroding island which is an important breeding ground for brown pelicans. This island is eroding at a rate of about 0.25 ha/yr, a much lower rate than the islands in this study. The state of Louisiana and the Army Corps of Engineers are now working to rebuild Queen Bess Island. A dike is being built and dredge material is being placed behind the dike. Preliminary surveys show that pelicans are already taking advantage of the newly created areas (Marcus, F.F., 1990).

The last alternative is to encourage retreat from the inhabited islands. Many residents of flood-prone communities view flooding as a temporary inconvenience which is balanced by the aesthetic and cultural attractions of living on an island (U.S. Army Corps of Engineers, 1984), so retreat may not be the preferred alternative for island residents. A time will come, however, when flooding on Smith and Hooper Islands will be more than an inconvenience; it will not be feasible to inhabit the islands once submergence has completely altered the physiography of the area. This may not come for another generation, but it is inevitable as long as sea-level continues to rise.

Summary

1. Two distinct types of islands were identified in the Chesapeake Bay, small upland islands (the Northern Group) and large marshy islands (the Southern Group).

2. The two island groups are losing land in different manners: bluff erosion by wave action is the mechanism of land loss for the Northern Group; and marsh edge erosion by wave action as well as marsh deterioration caused by submergence are causing land loss for the Southern Group.

3. The Northern Group is losing land at an averaged long-term rate of 1.9 ha/yr. The western side of the islands are eroding at an averaged rate of 4.9 m/yr; the eastern side is eroding at an averaged rate of 0.6 m/yr.

4. The Sothern Group is losing land at an averaged, long-term rate of 5.6 ha/yr, with an averaged erosion rate of 1.2 m/yr. Interior marsh loss was not quantified for this study, however, so these land loss rates are

considered to be low.

5. Land loss appears to be weakly correlated to sea-level rise for the Southern Group. Land loss appears to be related, in part, to storm frequency for both island types.

6. The prognosis for the islands is poor. At the current rates of land loss, the Northern Group will be gone between the years 2000 and 2040. It is difficult to predict the demise of the Southern Group islands without a quantitative understanding of the rate and processes of interior marsh loss. Marsh edge erosion rates for Bloodsworth, Hooper, Smith and South Marsh Islands grossly underestimate the life expectancy of these islands. With an accelerated sea-level rise, marsh edge erosion calculations alone predict that Smith and South Marsh Islands will be gone by the year 2100. With the progression of interior marsh loss, however, these islands would become uninhabitable long before 2100.

7. Management alternatives for the islands include shoreline control structures, beneficial use of dredge spoil, a combination of hard and soft techniques of shore stabilization, and retreat. All of these options have important benefits and costs which must be weighed

carefully on a site-specific basis. Management decisions should consider the beneficial use of dredge material as a feasible and positive solution to island deterioration.

APPENDIX A

HISTORICAL STORM DATA

Major Storm Tracks in the Chesapeake Bay Region, 1871 - 1986*

YEAR	DATES	STAGE IN CHESAPEAKE	IN OR NEAR BAY	NAME
1872	October 25-26	Hurricane	Near	
1874	September 29-30	Hurricane	In	
1876	September 17-18	Hurricane	Near	
1877	October 4-5	Hurricane	In	
1878	October 23	Hurricane	Near	
1879	August 25	Hurricane	In	
1881	September 10	Hurricane	In	
1882	September 23	Hurricane	In	
	September 11-12	Hurricane	In	
1883	September 12-13	Hurricane	Near	
1885	October 13	Hurricane	Near	
1886	June 22-23	Hurricane	In	
	July 2	Hurricane	In	
1888	September 10-11	Tropical Storm	In	
1889	September 24-25	Hurricane	In	
1893	October 23	Tropical Storm	In	
	June 16-17	Hurricane	Near	
1894	October 9-10	Hurricane	In	
	September 29	Hurricane	Near	
1897	September 23-24	Tropical Storm	In	
	October 25	Tropical Storm	Near	
1899	August 18-19	Hurricane	Near	

	October 31 - November 1	Extratropical	In	
1900	October 13-14	Extratropical	Near	
1901	July 11	Hurricane	Near	
1902	June 16	Extratropical	In	
	October 10-11	Extratropical	In	
1904	September 14-15	Extratropical	In	
1907	September 23	Extratropical	In	
	June 29	Extratropical	Near	
1912	June 15	Tropical Storm	Near	
1915	August 3-4	Extratropical	In	
1918	August 15	Tropical Storm	Near	
1923	October 23-24	Extratropical	In	
1924	September 30	Extratropical	In	
	August 25-26	Hurricane	Near	
1925	December 2-3	Tropical Storm	Near	
1927	October 3	Extratropical	Near	
1928	August 11-12	Extratropical	In	
	September 19	Tropical Storm	Near	
1929	October 2	Extratropical	Near	
1933	August 23	Tropical Storm	Near	
1934	June 18-19	Extratropical	Near	
1935	August 6	Tropical Storm	Near	
1936	September 18	Hurricane	Near	
1938	October 25	Tropical Storm	Near	
1943	September 30	Tropical Storm	Near	
1944	August 2-3	Tropical Storm	In	
	September 14	Hurricane	Near	
	October 20-21	Tropical Storm	In	
1945	September 18	Extratropical	Near	
1947	September 25	Extratropical	Near	
1949	August 28-29	Tropical Storm	Near	
1952	September 1	Tropical Storm	Near	Able
1953	August 14	Hurricane	Near	Barbara

1952	September 1	Tropical Storm	Near	Able
1953	August 14	Hurricane	Near	Barbara
1954	August 30-31	Hurricane	Near	Carol
1955	August 12-13	Tropical Storm	In	Connie
	September 19-20	Tropical Storm	Near	Ione
1956	June 27	Extratropical	Near	
1958	August 28-29	Hurricane	Near	Daisy
1959	July 10-11	Tropical Storm	Near	Cindy
1960	July 29-30	Tropical Storm	In	Brenda
	September 12	Hurricane	Near	Donna
1961	September 14-15	Tropical Storm	In	
1962	August 28	Hurricane	Near	Alma
1965	June 16	Extratropical	Near	
1966	September 16-17	Tropical Storm	Near	Doria
1969	August 20	Tropical Storm	Near	Camille
1970	May 27	Extratropical	Near	
1971	August 27-28	Tropical Storm	Near	Doria
1972	June 21-22	Tropical Storm	In	Agnes
1976	August 9-10	Hurricane	Near	Belle
1979	September 5-6	Tropical Storm	Near	David
1981	July 1	Tropical Storm	Near	Bret
1983	September 30	Tropical Storm	In	Dean
1984	September 14	Tropical Storm	Near	Diana
1985	August 19	Extratropical	In	Danny
	September 26-27	Tropical Storm	Near	Gloria
1986	August 17-18	Tropical Storm	Near	Charley

* (Neuman et al., 1987)

APPENDIX B

HISTORICAL SHORELINE DATA SOURCES

1. National Ocean Survey Topographic Charts

ISLAND	YEAR	MAP NUMBER	MAP SCALE
Barren	1848	T 255	1:20,000
	1901-2	T 2564	1:20,000
	1929	T 4445	1:10,000
	1943	T 8117	1:20,000
Bloodsworth	1848	T 269	1:20,000
	1901	T 2558	1:20,000
	1942	T 8135	1:20,000
Hooper	1848	T 265	1:20,000
	1848	T 255	1:20,000
	1901	T 2564	1:20,000
	1942	T 8136	1:20,000
	1942	T 8118	1:20,000
James	1848	T 250	1:20,000
	1901	T 2561	1:20,000
	1941	T 5718	1:10,000
Poplar	1846	T 215	1:20,000
	1899	T 2293	1:20,000
	1941	T 5723	1:10,000
Smith	1849	T 271	1:20,000
	1901	T 2556	1:20,000
South Marsh	1849	T 269	1:20,000
	1901	T 2558	1:20,000
	1942	T 8135	1:20,000
	1942	T 8149	1:20,000

2. Aerial Photographs

ISLAND	DATE	SCALE	NUMBER
Barren	1952	1:7920	ANJ-6K-20
	1964	1:7920	ANJ-4EE-135
	1987	1:7920	NAPP-B-142B
Bloodsworth	1952	1:12000	ANJ-1K-63, ANJ-1K-74, ANJ-1K-134, ANJ-1K-136, ANJ-1K-72, ANJ-1K-65
	1987	1:12000	NAPP-10-135D, NAPP-10-135C, NAPP-13-75B, NAPP-13-75A
Hooper	1952	1:12000	ANJ-5K-186, ANJ-5K-188, ANJ-5K-133, ANJ-5K,125, ANJ-5K-127, ANJ-5K-43
	1987	1:12000	NAPP-13-135-TC, NAPP-13-135-BC, NAPP-13-81L, NAPP-13-80-ECIW
James	1952	1:7920	ANJ-1K-03
	1964	1:7920	ANJ-4EE-177
	1987	1:12000	NAPP-14-3JC
Poplar	1952	1:7920	AHY-5K-101
	1964	1:7920	AHY-4DD-277
	1987	1:7920	NAPP-14-64B
Smith	1952	1:12000	ANL-5K-10, ANL-5K-28, ANL-5K-56, ANL-5K-58, ANL-5K-26, ANL-5K-12
	1987	1:12000	NAPP-10-129A, NAPP-10-128R, NAPP-10-129D, NAPP-10-128L, NAPP-10-130D, NAPP-10-130A
South Marsh	1952	1:12000	ANL-5K-35, ANL-5K-04, ANL-5K-

		33, ANL-5K-31, ANL-5K-06
1987	1:12000	NAPP-10-134-EC, NAPP-10-133-EC

3. USGS 7.5 Minute Quads

ISLAND	DATE	QUAD NAME
Hooper	1972	Richland Point
	1985	Honga
Smith	1972	Ewell
	1972	Great Fox Island
	1972	Kedges Straits
	1972	Terrapin Sand Point
South Marsh	1972	Kedges Straits

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