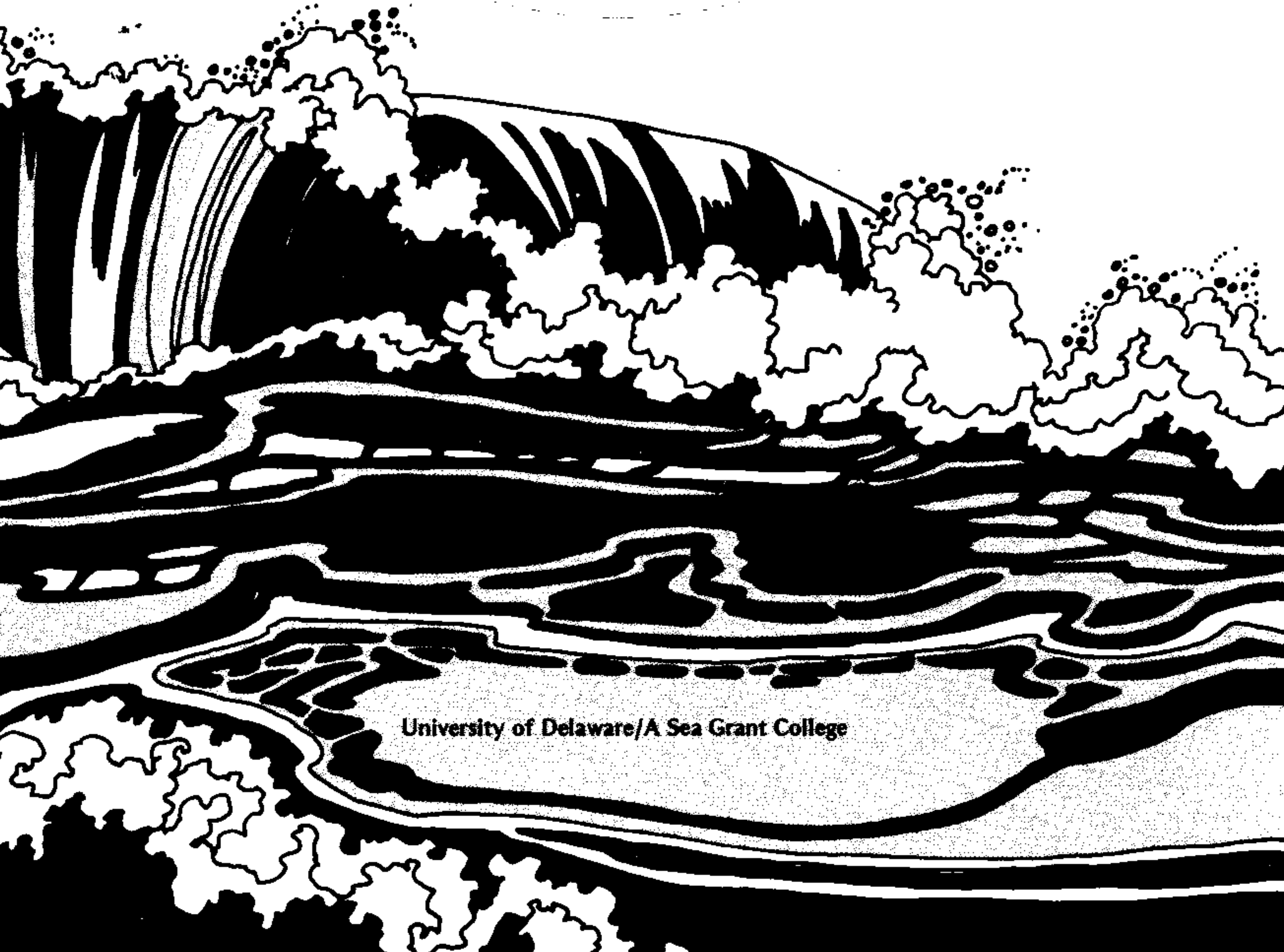
A Delaware Sea Grant Technical Report



University of Delaware/A Sea Grant College

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THE INFLUENCE OF GEOLOGICAL STRUCTURE AND HISTORICAL CHANGES IN MORPHOLOGY OF DELAWARE BAY COMMUNITIES ON ENVIRONMENTAL PLANNING

$3.00

By

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PREFACE

The research presented herein is a combination of a geological study of the immediate shore zone and a socio-economic analysis of the inhabitants of the small villages along the western shoreline of Delaware Bay, a major estuary. By means of analysis of the various types of geological structures and sedimentary environments in the shore zone related to the various villages, the investigator has been able to analyze the loci of the various villages in terms of their viability for long term survival in a transgressive coastal setting.

This research report does not solve the problem. Rather, it presents an analysis of the situation from both the view point of the inhabitants of the coastal zone and the geological structure of the coastal zone. This information should be of use to planners in terms of determining future plans for defense or abandonment of some of the coastal villages. The criteria stated herein clearly define the more viable villages as opposed to those which would require great expense to maintain in their present position. Recommendations are made for the possible use of planners and the inhabitants of the coastal zone. However, it is not the intent of this report in its own right to form a developmental or programmatic plan for the development or defense of man's structures in the Delaware Bay coastal villages. Rather, information is provided for planners so that they might more intelligently make these decisions.

This study was financed by the Coastal Zone Management Program of the State of Delaware, Office of Management, Budget and Planning, Dover, Delaware. The study was carried out in close cooperation with an ongoing study of transgressive coastal processes in the Atlantic Ocean and Delaware Bay shorelines under the support of the NOAA Sea Grant Program at the University of Delaware.

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Local, county, state, and federal government officials, including Bob Henry and Dave Hugg, offered their assistance regarding governmental regulations and beach preservation programs, and Mike Hardisky deserves thanks for his help and advice concerning the state wetlands maps. I would also like to thank Dr. Tom Meierding, Bill Hoyt, and Pam Palinski for some much-needed assistance with drafting and diagrams.

Finally, I would like to express my appreciation to several realtors, and the residents and visitors who took the time to speak with me and express their opinions about the coastal communities of Delaware--I hope this report will result in changes that will bene-

fit these people and others who are concerned about the future of the coastal zone of Delaware.

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ABSTRACT

As relative sea level rises, the beaches along the western shore of Delaware Bay are migrating landward and upward, threatening existing housing in many areas. Future development is greatly restricted as a result of the 1973 Delaware Wetlands Act, which prohibits development of wetlands, including those adjacent to the Delaware coastal communities. However, millions of dollars have been spent on beach preservation measures during the last 20 years, and future programs are likely as well. To determine the relative suitability for development and/or beach preservation of 11 communities and undeveloped areas along the western shore of Delaware Bay (from Port Mahon south to Broadkill Beach), the general environmental and geological characteristics of this shoreline, as well as the demographic and geological characteristics of the individual areas, were studied.

Characteristics of the Delaware Bay shoreline environment which are considered include winds, which vary seasonally, but are strongest in the winter months, when their prevailing direction is from the northwest; waves, which generally follow the same patterns as winds; longshore currents, which flow southward approximately 3/4 of the year, with local variations; winter ice, which may lead

to shoreline change as a result of entrained sediment, or may protect the shoreline from wave attack; and relative sea level, which has risen at the rate of about 0.3 m/century for the past 70 years.

The subsurface geology of this shoreline varies considerably along its length, due to a series of Pleistocene interfluves and valleys oriented perpendicularly to the coast. At interfluves, Pleistocene material is close to the surface, providing stability and sometimes serving as a sediment source to the beaches. At former valley locations thick layers of marsh and lagoonal muds between the ground surface and Holocene/Pleistocene interface can lead to settling of houses, subsidence of the ground itself, and greater erosion rates due to this subsidence and the erodability of the muds.

The 11 study areas vary demographically from having no development at all, to small summer communities with 10-20 year-round residents and 100-300 summer residents, to well-established communities with permanent and summer populations of up to 325 and 550 people, respectively. Their subsurface geologies also cover a wide range; one community (Bowers) is situated on barrier sands which directly overlie Pleistocene material, another area (Port Mahon) is located on coastal marsh, where muds extend six meters below the surface to Pleistocene-aged sediments, and the remaining areas are situated on barrier sands which overlie from 2-30 m of marsh and/or lagoonal muds, over Pleistocene material. Shoreline changes over the last 100 years range from 3.5 m/yr of accretion to 7.6 m/yr of ero-

sion, with almost all of the areas currently eroding at varying rates. Resident interviews at four study areas indicate a general concern with erosion rates and varying degrees of support for past beach preservation efforts.

Based on five demographic and six environmental/geological criteria, beach preservation value ratios on a scale of zero to one were determined for each community. For the 11 study areas, these ratios ranged from 0.2 to 0.8, with a higher value indicating a greater suitability for future beach preservation efforts.

The study areas could be grouped into three classes; those with very low preservation value ratios, which are demographically and geologically poorly-suited for future beach preservation, those with middle-range ratios, which are potentially suitable for preservation if certain characteristics are improved or compensated for, and those with high ratios, which are most deserving of such efforts, based on the criteria chosen.

INTRODUCTION

During the past several years the coastal zone has received increased attention, in the form of coastal development legislation and scientific research. Despite the recognition of the hazards of coastal development, shorefront property continues to be among the highest in demand, both for industries that need the proximity to the ocean, for transportation, communication, or the water itself; and private citizens, who are attracted by recreational and aesthetic features. As relative sea level rises throughout much of the world, coastal erosion continues. On cliffed coasts, huge quantities of material can be cut away during a single storm event, often leaving expensive houses perched perilously at the top of the cliff face. On barrier islands and low-lying coastal headlands like those along Delaware Bay, changes are not usually as dramatic, but coastal processes such as wave action, littoral transport, and overwash act in conjunction with sea level rise, leading to a gradual landward and upward migration of the barrier, or headland erosion.

It might be argued that because of the known hazards associated with coastal development, this practice should be discontinued completely. This is not possible, due to industrial requirements of coastal locations, and the desires of many influential people for shorefront property. Perhaps what is needed is a better understanding of the causes of these coastal hazards, to determine which areas are more suitable for development or beach preservation than others. One way of doing this is through geological studies of each coastal area, supplemented by environmental (i.e. hydrologic and climatologic) information.

Although for many coastal locations, few investigations of this type have been done, other areas have been studied fairly intensively regarding subsurface geological and/or environmental factors. The western shore of Delaware Bay is such an area. At present, much is known about this area in relation to its wind and wave climates, current patterns, tidal characteristics, past rates of sea level rise, storm damage, subsurface geology, coastal morphology, and sediment sources. However, this information has never been brought together in a comprehensive form, to enable coastal managers, planners, and residents to make the wisest decisions regarding coastal development or preservation, thereby preventing or minimizing coastal hazards. This study was designed to create this type of comprehensive document for part of this coast, supplemented by several cores to more accurately determine the subsurface geology of several areas (Appendix IV) and interviews of residents, beachgoers, and realtors to discover residents' perceptions of beach changes and demographic characteristics (Appendix III). Finally, a scheme by which coastal areas can be evaluated in terms of development or preservation potential is proposed and applied to the study areas.

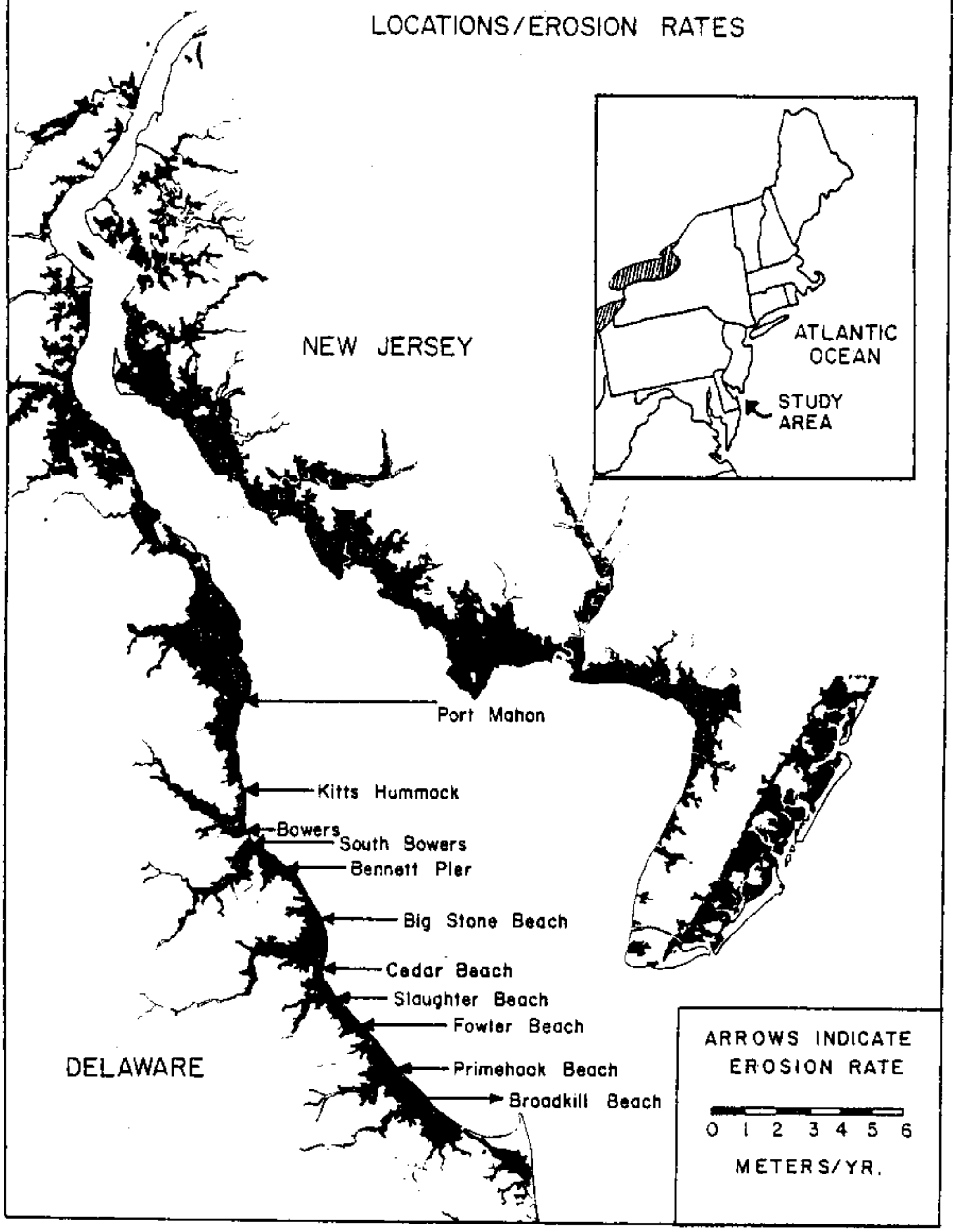
Along the western shore of Delaware Bay, from Port Mahon south to Broadkill Beach, there are eleven coastal areas that vary considerably in extent and type of development (Figure 1). Three of these have no housing development at all, the others can be described as small single-family residential communities which vary in population size and the ratio of summer to year-round residents. None of these areas support industry of any type. The geological and demographic characteristics of these areas were examined through the use of a literature search, subsurface coring (using vibracore, Eijelkump gouge auger, and jetwash techniques) (Appendix I), and/or resident interviewing (Appendix III). Due to time restrictions, it was not possible to do in-depth geological and demographic studies of all eleven areas; however, available data on their physical environments, geological characteristics (surficial and subsurficial), and erosion rates were gathered, along with information on their legal wetlands boundaries and development legislation. Four of these areas--Bowers, South Bowers, Slaughter Beach, and Broadkill Beach--were studied in greater detail. For each of these areas, the following is presented: 1) demographic characteristics of the area, including population, property values, beach use, and housing characteristics, 2) surficial geologic characteristics, 3) physical environmental data, 4) a three-dimensional geologic model, 5) erosion rates, 6) residents' perceptions of these coastal changes, and 7) a description of past beach preservation measures and their impact on residents. Please note that any time monetary information is presented in this report (e.g. property values,

Figure 1. Map of Delaware Bay showing study areas. Black area is coastal salt marsh. Rates of erosion are based on federal coastal surveys over the past 130 years (Maurmeyer, 1978).

Figure 1

WESTERN DELAWARE BAY

LOCATIONS/EROSION RATES



beach nourishment costs) the first figure shown is in actual dollars for that year. Following that figure, in parentheses, is the approximation of that value in 1980 dollars, based on published GNP deflation rates for each year (Economic Report of the President, 1980) and discrete compound interest factors.

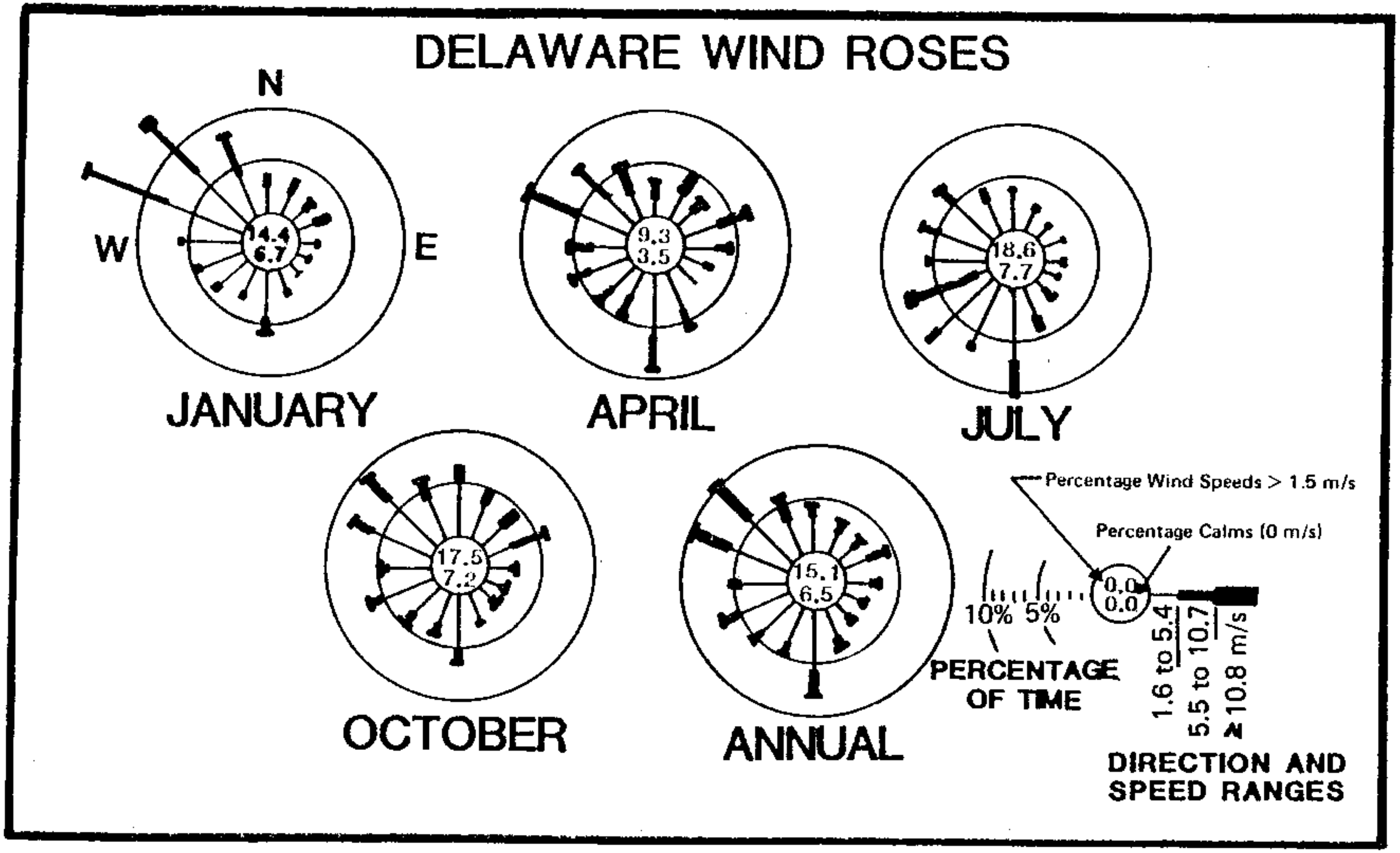
Based on this information, each community is then rated according to several geological and environmental criteria, regarding suitability for low-density residential development and advisability of future beach preservation measures. When discussing the possibility of further community development, legal restrictions at the local, state, and Federal level must be considered, and these are discussed for each site, as well.

THE DELAWARE BAY SHORELINE ENVIRONMENT

Environmental Conditions

The hydrologic and climatologic environment of the coastal areas along the western shore of Delaware Bay can be described in terms of 1) winds, 2) waves, 3) currents (including longshore), 4) ice effects, and 5) sea level rise. Wind roses showing annual and seasonal wind speed directions at Wilmington, Delaware, are shown in Figure 2. On a yearly basis, prevailing winds are from the northwest, while dominant winds are from the northeast (U. S. Army Corps of Engineers, 1977). Seasonally, prevailing winds during winter are from the northwest; during spring, northwest winds still prevail, but there is an increase in southwesterly, southeasterly, and northeasterly winds. In the summer, southwest winds occur most often, while in the fall winds are variable, with no prevailing direction. Wind speeds along Delaware Bay are greatest in the winter, and least in summer. Delaware Bay is not characterized by winds of very long duration--a specific wind comes from a certain direction for less than six hours about half the time, and only rarely does wind of a specific speed prevail for more than two days. Wind fetch varies greatly along the western shore of the bay. Fetch is limited in the upper reaches due to

Figure 2. Delaware wind roses, summarizing annual and seasonal wind speed and direction, Wilmington, Delaware, 1951-1960 (After Maurmeyer, 1978).



DELAWARE WIND ROSES

the shape of the estuary, increasing in the central portion, until in the southern areas, winds from the east and southeast are unrestricted by land (Maurmeyer, 1978).

Wave distribution correlates with wind speed and direction, implying that most of these waves are generated by local winds. Annually, most waves in the bay are from the northwest and southwest. On a seasonal basis, 60% of winter waves are from the northwest, while most spring and summer waves are from the southwest; in the fall, the majority are from the north and northeast (Maurmeyer, 1978). When considering the orientation of this coast, however, one should keep in mind that only waves ranging in direction from northeast to southeast will have marked effects on the Delaware Bay shore. Also, localized onshore and offshore winds created by the temperature difference between the land and water could influence nearshore wave directions. Waves in Delaware Bay are generally low, averaging less than 0.6 m almost 80% of the time, and greater than 1.8 m only 2% of the time. The largest waves occur in winter--during January, 31% are greater than 0.6 m--and the smallest are in summer, when only 9% are greater than 0.6 m. Directions of the majority of wave energies correspond fairly well with prevailing wind directions. Annually, most wave energy is associated with waves from the north and northwest. During January, the highest energy is from the northwest, in April most is from the north and south, July shows a change from southwesterly to northeasterly dominance, and during October, all wave energies were about equal. As would be expected from wind data, wave energies are greatest in winter and least in summer (Maurmeyer, 1978).

Currents in the bay are generated by tides, winds, and breaking waves. Due to the flow of the Delaware River, ebb tidal currents are greater than flood tidal currents at all locations, by 0.1 to 0.3 m/s. For example, at the outlet of the Smyrna River, north of Port Mahon, ebb currents average 0.8 m/s, while flood currents are 0.6 m/s. At Bowers Beach, ebb and flood currents average 0.4 and 0.3 m/s, respectively, and at Cape Henlopen they average 1.15 and 1.00 m/s (Maurmeyer, 1978). Apparently factors such as shoreline orientation, offshore contours, bay width, and the presence or absence of a river mouth affect these current velocities. Longshore currents, defined as wave-induced currents landward of the breaker zone, move southward 74% of the time, at an average velocity of 0.16 m/s, and northward 26% of the time, at an average of 0.10 m/s. These speeds and directions correlate well with incident wave direction, though they may also be influenced by tidal currents (Maurmeyer, 1978). Longshore currents do vary along this coast, from place to place and day to day. This can markedly affect erosion rates and determine the suitability of various beach protection measures.

Several residents have reported that nearshore areas of Delaware Bay sometimes freeze over in the winter, and ice can be piled on the shore to depths of a meter or more. Although the effects of ice have not been studied in this area, Evanson and Cohn (1979) have examined ice found near the shores of the Great Lakes. They found that sediment can be incorporated into the "ice foot" (their term that encompasses several zones of different types of ice) by four different mechanisms, and large quantities of material have been found in lake ice. Trenching of Lake Michigan ice cones showed layers of ice-cemented sand up to 2.5 cm thick, and two measurements on relatively "clean" ice showed as much as 3 cm^3 sand/liter melted ice (Marsh, Marsh, and Dozier, 1973). The fate of this entrained material after ice foot destruction occurs varies, depending on the sequence of events that occurs. If onshore winds prevail, sediments are redeposited in the surf zone or driven onto the beach by waves and wind (Evanson and Cohn, 1979). Marsh, et. al. (1973) describe an instance where an extensive ice foot complex was destroyed in two days--in this case, it can be assumed that the ice was not basally attached, so much of the ice could have floated away. The detachment and setting adrift of ice floes has also been noted by O'Hara and Ayers (1972).

Ice has traditionally been assumed to play a destructive role in mid-latitude beaches, due to the gouging of ice floes on shore and the formation of ice hummocks which damage protective structures. The protective role of shore ice in the arctic has been demonstrated by McCann (1973), but this function has not been investigated at mid-latitude locations. However, it is generally true that once the shoreline is mantled by successive ice formations, wave erosion of the beach is impossible. The active outer edge of the ice foot absorbs most of the wave impact, and onshore ice adds to this protection. According to a study of Lake Ontario beaches, which indirectly examined this protective role, from 1971-1973 beach retreat was as high as 3 m/yr, and all of this was caused by wave energy during the ice-free period (i.e. 40% of the total wave energy)--apparently, if the ice were never present, erosion rates would be much higher (Cohn, 1973).

Following a particularly severe cold period that lasted more than a week, two of the study areas (South Bowers and Slaughter Beach) were visited to observe ice effects (Figures 3 and 4). At both places, ice mantled the shoreline, to a depth of 0.5-1.0 m, in rough shards, several centimeters thick and up to two meters across. Some of this ice was fairly clean and some appeared almost black from incorporated sediment (mostly silt- and sand-sized). Despite the amounts of sediment in the ice, this ice mantle (qualitatively) appeared to serve more of a protective role in these areas. In addition, large chunks of ice (up to several meters across) were floating in the nearshore and offshore areas. Since the day these observations were taken was not very windy, it was difficult to tell if this floating ice had a wave-dampening effect, but the quantity of floating ice was great enough to suggest that this was the case. The sandbag jetty and groins at Bowers and South Bowers were also partially covered with ice shards; these probably either had little effect, or acted to reinforce the jetty's and groins' effects. It is not known how often this type of ice buildup occurs along the coast of western Delaware Bay, but several residents who were interviewed suggested that it occurs every few years. Quantitative studies of the amounts of sediment incorporated into the ice, the wave dampening effects of floating ice, and the frequency of this freezing are needed to understand the impacts of ice on erosion rates in these areas.

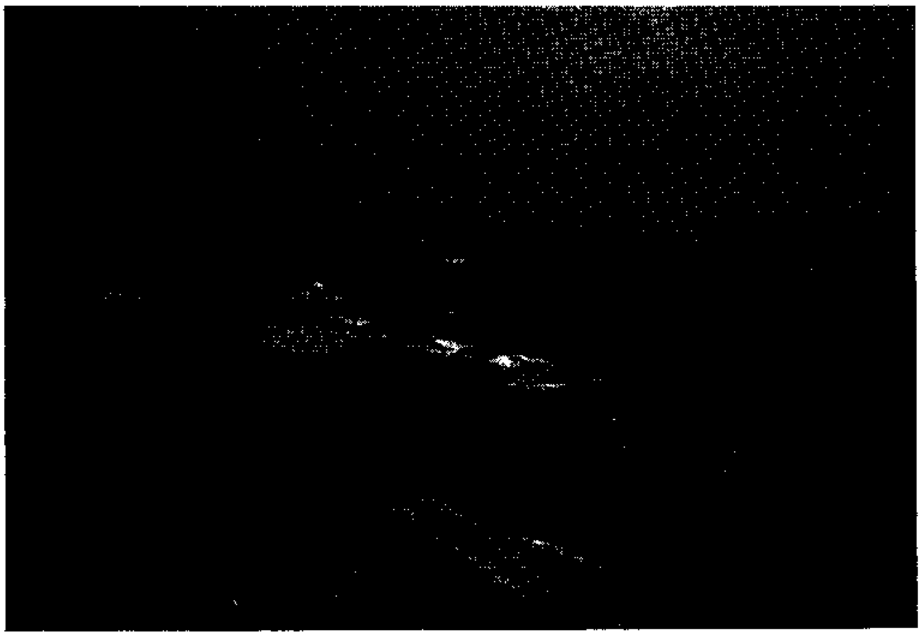


Figure 3. Ice on beach at South Bowers, Delaware (January, 1981). Note large quantities of entrained sediments. Ice blocks range in size from 0.3-1.0 m high.

Figure 4. Frozen sand and ice at Slaughter Beach, Delaware (January, 1981).

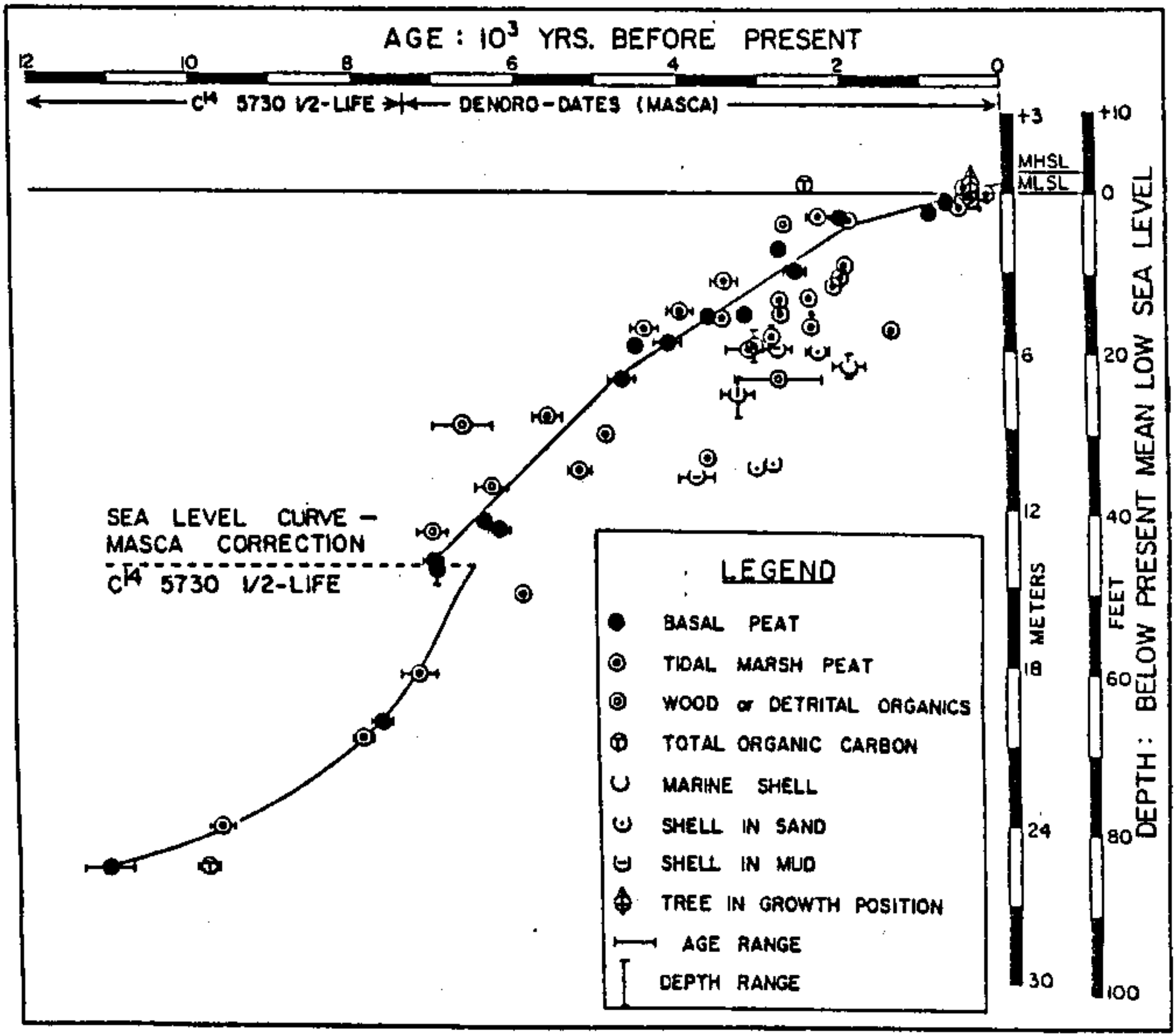
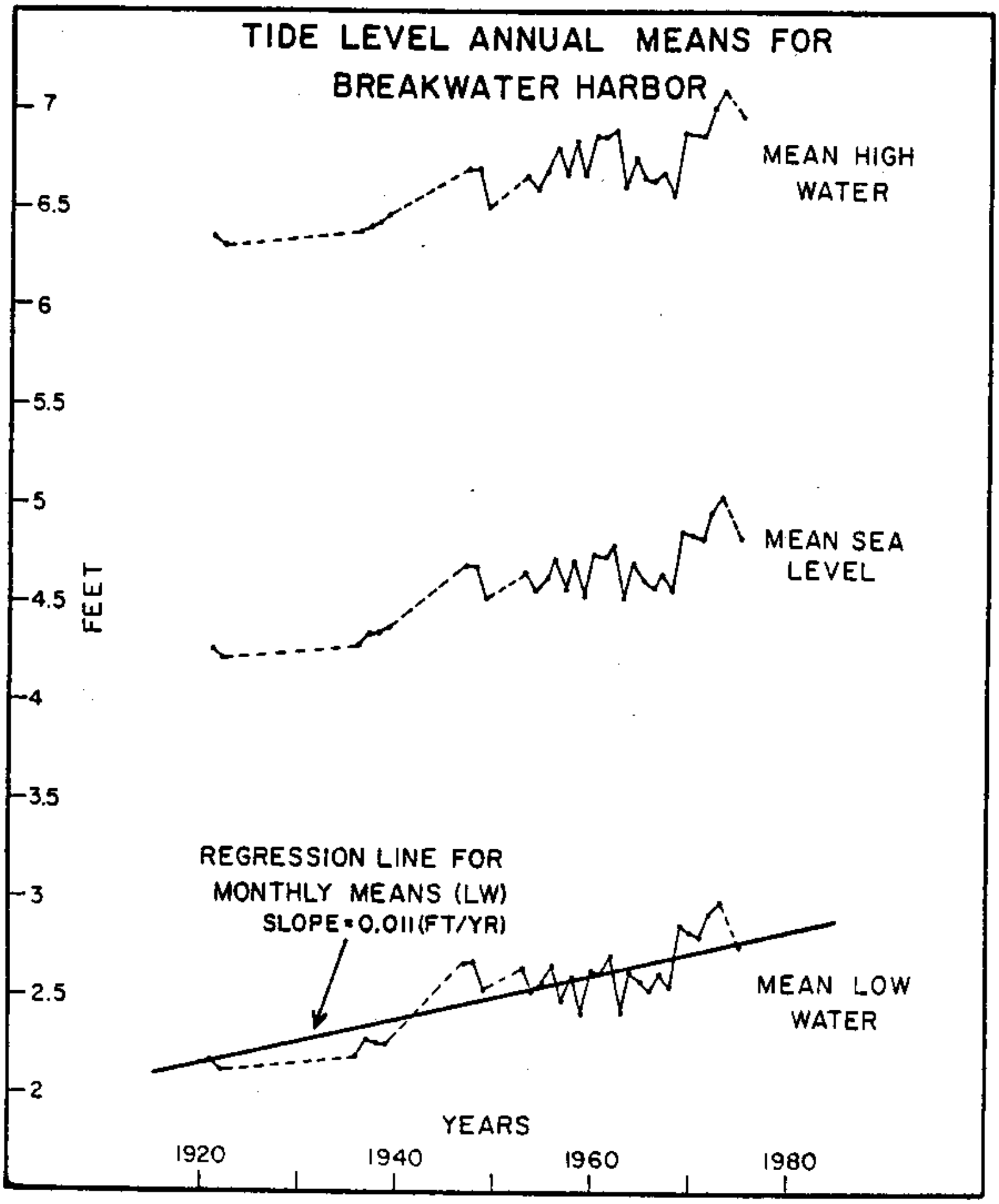


Figure 5. Relative sea level rise curve for the Delaware coast: 12,000 B.P. to present (after Kraft, 1976).

Figure 5 shows the trend of sea level rise along the Delaware coast since 12,000 years before present (B.P.). Although rates of relative sea level rise have generally decreased over this period, during the last 70 years there has been an acceleration of relative sea level rise in this area (Figure 6) (Demarest, 1978). In general, there are five possible causes of relative sea level rise: 1) freezing and thawing of glacial ice during the Pleistocene stadials (over the last three million years), 2) effects of the weight of ice on the land beneath it (isostatic adjustment)--as the ice over glaciated regions melts, the land rebounds upward--although Delaware is beyond the maximum extent of the most recent glaciers, perhaps the Delaware region bulged up at that time, and is now dropping, causing a relative sea level rise (Newman, Fairbridge, and March, 1971), 3) tectonic effects--Delaware is located on the flank of the Baltimore Canyon trough geosyncline, and the relative instability of the crust allows local sinking to occur. Also, there may be large-scale worldwide tectonic effects on sea level described by the plate tectonics theory (i.e. rise and fall of plates of the sea floor), 4) sedimentation--sediments flowing into the ocean fill it up, causing water levels to rise, or compaction of the land mass occurs as a result of previous sedimentation, causing the land to sink, and 5) subsidence caused by the weight of water on the continental shelf (Bloom, 1967). As a result of one or more of these factors, relative sea level has risen at the rate of ca. 0.3 m/century for the past 100 years along the Delaware

Figure 6. Relative sea level rise, Breakwater Harbor, Delaware: 1920-1980. Dashed lines indicate gaps in the record (after Demarest, 1978).


TIDE LEVEL ANNUAL MEANS FOR
BREAKWATER HARBOR
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
FEET
MEAN HIGH
WATER
MEAN SEA
LEVEL
REGRESSION LINE FOR
MONTHLY MEANS (LW)
SLOPE = 0.011 (FT/YR)
MEAN LOW
WATER
YEARS
1920
1940
1960
1980

Bay coast. The importance of relative sea level rise vs. storms, wave action, and other processes on erosion rates has been debated. Some scientists maintain that since sea level is rising at such a low rate its effects are negligible compared with those of storm surges, currents, and tides. Others say that when beach and offshore slopes are very gradual, as they are in Delaware (on the order of 1:100 or less, in many areas) a small vertical change in sea level would result in a major landward encroachment by the ocean; even though other processes may result in more dramatic erosional effects, these effects can be short-lived--for example, sand eroded during a storm is often deposited in a bar offshore, with subsequent wave action resulting in its redeposition on the beach. Most geologists, myself included, probably believe that wave action and sea level rise act together to produce the landward and upward barrier migration found in most areas.

Geological Characteristics

Subsurface Geology and Coastal Morphology

As indicated by the geological cross sections and three-dimensional models that follow, as each area is discussed individually, the nature and depth of sedimentary units along the Delaware Bay coast vary considerably. Although in some cases this is due to events that have occurred over the last several hundred years, for example the migration of a river mouth or closing off of an inlet, as in the case of Broadkill Beach, most of the variations found result from the fact that prior to 10-15,000 years B.P., the area that is now the Delaware Bay coast consisted of a series of Pleistocene interfluves and valleys, oriented perpendicularly to the present coast. This former topography is shown by the Pleistocene surface in Figure 7, a coast-parallel cross section of western Delaware Bay. These valleys have since become infilled with marsh and/or lagoonal muds which are very different in texture, erodability, and compaction potential from Pleistocene headlands.

Marsh and lagoonal muds are generally soft, uncompacted sediments consisting of silt, clay, and sometimes sand-sized grains, and a high moisture content. Marsh muds are often characterized by the presence of peat or plant fragments as well, and lagoonal sediments often contain shell material--it should be noted, however, that these are not conclusive indicators of the environment of deposition. In many cases, neither marsh nor lagoonal sediments will have plants or shells, and sometimes shells are found in marsh muds and plants are

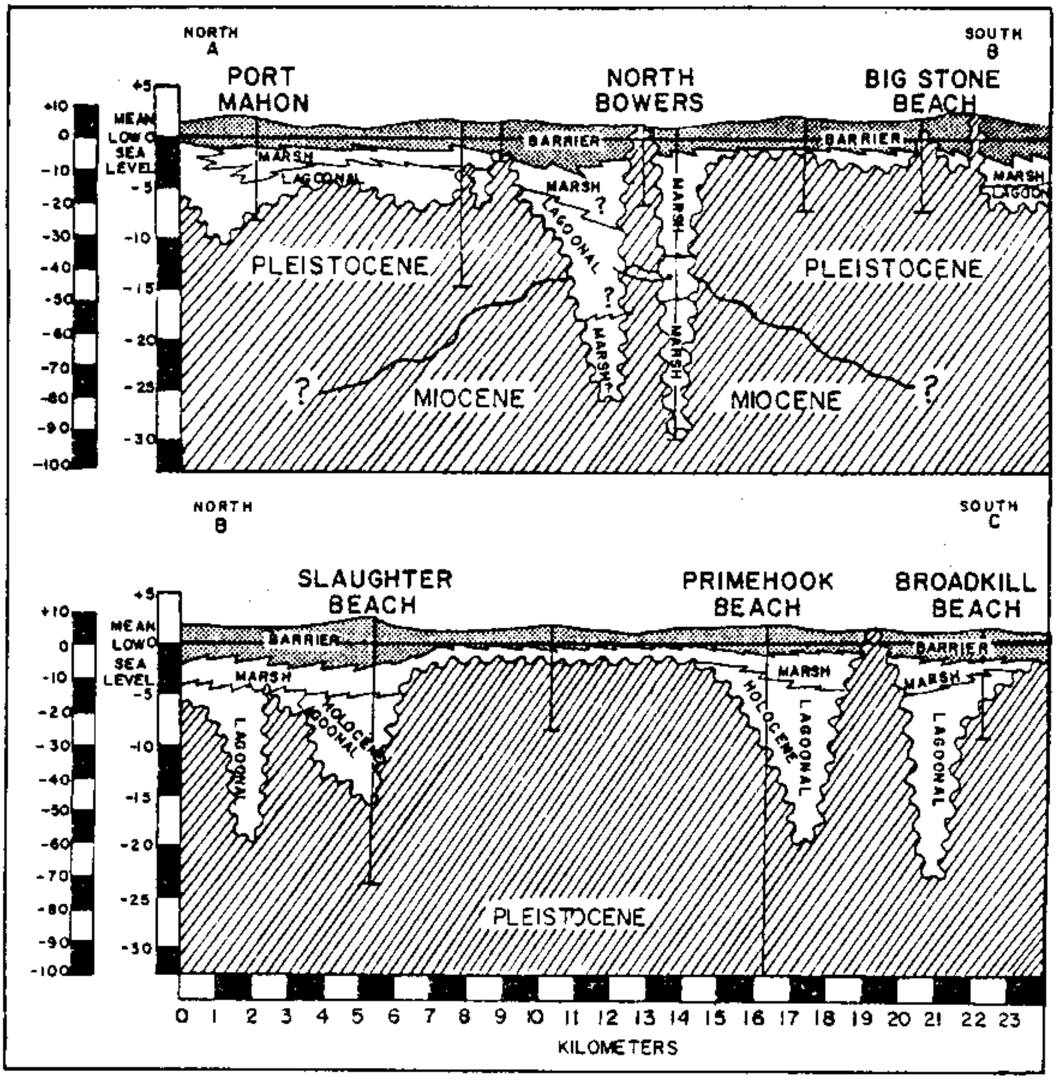


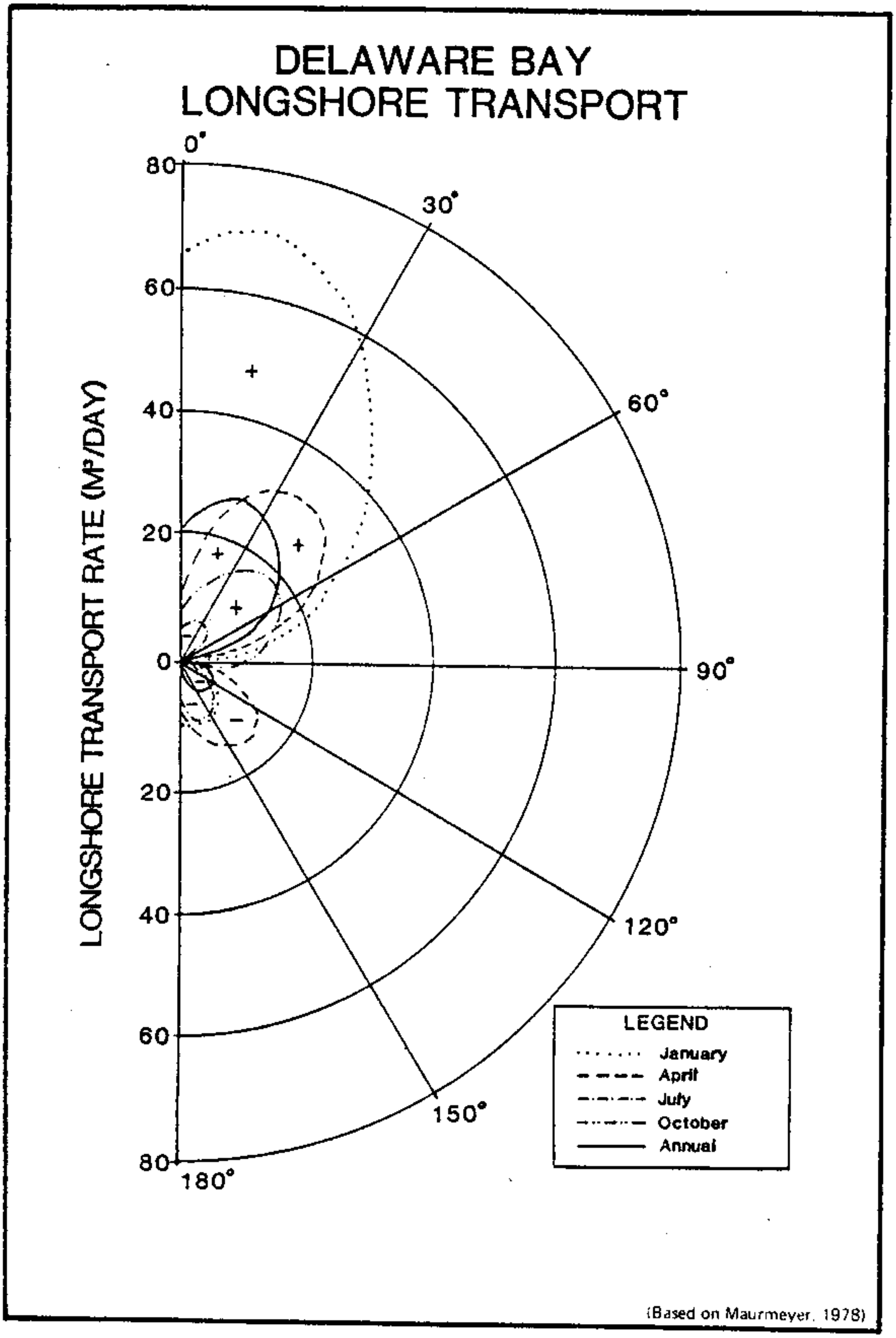
Figure 7. Coast-parallel geologic cross section of the western shore of Delaware Bay, Port Mahon to Broadkill Beach. Note the variation in Holocene mud thickness resulting from the series of Pleistocene headlands and sediment-infilled ancestral valleys (after Kraft and Marx, in press).

found in lagoonal facies. These muds will vary in erodability depending on moisture content, compaction, grain size, and the presence or absence of plant and shell material. Pleistocene-aged sediments in the study areas are usually sands and gravels of varying grain size and degree of compaction, but silts and clays are also found. These sediments generally have a lower moisture content than Holocene muds and are often bright yellow, orange, or green in color, sometimes having a "milky" appearance when encountered during jetwashing (Appendix I). They are moderately erodable, depending mainly on grain size and degree of compaction.

Surficially, the lower western Delaware Bay coast consists of fairly narrow beaches (3.0-15.2 m wide at high tide), backed by a belt of dunes, 15-100 m wide and 2.5-3.5 m high, which are often covered with grasses and woody plants (*Baccharis halimifolia* and *Iva frutescens*). Salt marshes, 0.8-3.2 km wide and populated by *Spartina alterniflora*, *Spartina patens*, *Distichlis spicata*, and/or *Phragmites communis*, separate these dunes from highlands in most areas (U. S. Army Corps of Engineers, 1972). However, proceeding northwest, up the coast, the beach and dunes become smaller, in width and thickness, until just south of Port Mahon, where coastal marshes extend all the way to the shoreline. According to Maurmeyer (1978), barrier dimensions range from 30-60 m wide and 1 m thick in the northern barriers to more than 100 m wide and 2-4 m thick in the southern sections. This trend is due mainly to increased wave energy to the south, with the potential for more onshore sand transport, and greater sediment supply from Pleistocene headlands. All along the coast, barriers may be narrow, thick, and compact or wide, thin, and elongate, depending on the dominance of beach or overwash processes and on provenance and supply of Pleistocene sediments from headlands. If beach processes prevail, most of the barrier sands are in the active beach zone and a small proportion are in the washover area. There is usually a foredune or nearshore ridge which protects the back barrier from flooding during storms and permits dune buildup through aeolian processes. Overwash-dominated barriers are wide and thin, and much of the sand is landward of the dune line. The low relief of these areas leads to frequent flooding, with the prevention of the establishment of a substantial dune ridge. Barriers can change from one form to another, depending on storm frequency and variations in sediment supply (Maurmeyer, 1978).

Although barrier profiles vary along the coast, they do have several elements in common. First, the seasonal cycle of accretion and erosion takes the following pattern: in spring, sand moves onshore as a ridge which migrates up the beach face and welds onto the berm. In the fall, sand is removed from the beach face, mainly during storms; this continues throughout the winter. Variations in beach width are generally less than 10 m., averaging between four and six meters. These seasonal changes were not noticed by most residents of Bowers, South Bowers, Slaughter Beach, and Broadkill Beach who were interviewed for this study--perhaps because the beach is used infrequently in the fall, winter, and spring. Second, erosion and scarping at steep beaches (e.g. Bowers) don't usually result in restoration--material is generally transported offshore and alongshore. Although there may be some recovery in the lower beach profile, the upper profile doesn't usually recover. Third, the surface of washover terraces is usually lowered in spring due to strong offshore (northwest) winds. Vegetation effectively traps sand so backshore and foredune elevations are increased (Maurmeyer, 1978).

Figure 8. Littoral drift rose for the western shore of Delaware Bay showing net longshore sediment transport rates. "+" indicates southward transport and "-" indicates northward transport.



(Based on Maurmeyer, 1978)

Sediment Sources

Six sediment sources have been identified for the Delaware Bay coast. The first of these is material eroded from pre-Holocene sediments along the shore. The exposure of these sediments along the coast generally follows the pattern explained previously, i.e. a series of headlands or necks which separate ancient stream drainage systems. Erosion of these headlands occurs not only where they occasionally outcrop at the beach face (e.g. Bowers) but also in the offshore erosion zone, since the subsurface projection of these headlands extends into this zone. Direct erosion of this material supplies coarse-grained sediment to the beach and fine-grained material (silt and clay) to offshore tidal flats, deeper parts of the Bay and, through resuspension, tidal flushing, and other processes, to marshes. Quantitatively, erosion of these sediments probably accounts for the largest proportion of coarse-grained material supplied to western Delaware Bay beaches (Maurmeyer, 1978).

Longshore transport from adjacent beaches is a second possible sediment source. Retention of sediment by groins, jetties, and other obstructions, and the migration and deflection of inlets and shoals indicate this is a significant process. Although the direction and extent of littoral drift varies along the coast according to sediment source, coastal morphology, fetch, and man's intervention, it is probably influenced to the greatest extent by wave orientation, which is, in turn, dependent on shoreline orientation. Figure 8 shows longshore transport rates along the Delaware Bay coast, including positive (southward) and negative (northward) littoral drift for all shoreline orientations, in m^3/day. In general, predicted southward transport is greater than predicted northward transport at all locations (despite the fact that transport was generally northward before the construction of the breakwaters in Breakwater Harbor). Southward transport varies considerably with shoreline orientation, from 13.0 m^3/day to 39.0 m^3/day, while northward transport stays relatively constant, at 8.0-11.0 m^3/day. Seasonal variations are also shown by Figure 8. Since wave energy is greatest in winter, with dominant wave energies from the northern quadrants, maximum transport at this time is as much as 80 m^3/day, southward. During spring and summer, southward transport decreases, and is as low as 3.0 m^3/day in some areas in July. Although northward transport stays fairly uniform from January to July, the decrease in southward transport causes a net northward movement along much of the coast during these months. In the fall, wave energy increases, and since a greater percentage of waves are from the northeast, there is a dominance of southward transport, averaging 20-40 m^3/day (Maurmeyer, 1978). In several areas (e.g. Slaughter Beach), observed sand accumulations at groins or jetties indicate dominant northward transport. This could be dependent on sand source, barrier morphology, or man's interventions.

Third, some material is probably transported from the ocean coast. Prior to the 20th century, sand was transported via longshore currents around Cape Henlopen and northward up the bay, supplying sand to beaches as far north as Primehook Beach. However, construction of the inner and outer breakwaters in Breakwater Harbor altered the current pattern and virtually cut off this sediment supply to Delaware Bay beaches (Kraft and Caulk, 1973) (see also the description of the geologic history of Broadkill beach under "Delaware Bay Communities and Undeveloped Areas: North to South").

A fourth possible sediment source may be offshore shoals within Delaware Bay. There are two types of shoals. Linear sand shoals, which are elongate, asymmetrical in cross section, and oriented parallel to tidal channels, are formed through the scouring of the channels by tidal currents, depositing ridges along the margins. Although they have migrated as much as five kilometers in the last century (Weil, 1977), a consistent pattern of onshore movement was not noticed, so these shoals probably do not represent a significant source of sand for these beaches. (However, this may now be a more significant source, due to recent beach nourishment efforts.) Ebb tidal deltas, on the other hand, form at inlet mouths from sand supplied to the area by littoral transport, are crescentic in form, consisting of moderately-well-sorted, fine- to coarse-grained sands, and may contain some gravel (Strom, 1972). If the inlet closes, much of this material is driven onshore by waves, eventually welding onto the beach. This results in localized, short-term accretion, and may have been an important sediment source to various western Delaware Bay beaches during the past century, including Slaughter Beach (Maurmeyer, 1978). A similar process has occurred recently in South Bowers, where spoils from the dredging of the Murderkill River were placed on either side of the channel, offshore, and may have been subsequently transported landward by wave action.

Fifth, sediment may be supplied by the continental shelf. However, although there is movement of these sands into Delaware Bay, there is no reasonable mechanism for moving this material from the shelf to the beaches (Maurmeyer, 1978). Sixth, some material may be eroded inland and transported to the coast by streams; however, this is thought to play a minor role (Maurmeyer, 1978).

TABLE 1

Sand Surface Area Analysis

Location	Length (m)	Sand Area, 1973 (m^2)	Sand Area, 1979 (m^2)	ΔArea (m^2) 1973-1979	% Change
Port Mahon	590.9	9.4×10^3	1.8×10^4	$+8.3 \times 10^3$	+46.8%
Kitts Hummock	991.2	8.2×10^4	1.2×10^5	$+3.4 \times 10^4$	+28.7%
Bowers Beach	514.7	8.8×10^4	9.1×10^4	$+3.2 \times 10^3$	+ 3.5%
South Bowers	381.2	3.8×10^4	4.2×10^4	$+3.0 \times 10^3$	+ 7.2%
Bennett's Pier	324.1	2.6×10^4	1.9×10^4	-6.8×10^3	-35.4%
Big Stone Beach	948.4	8.0×10^4	8.8×10^4	$+7.2 \times 10^3$	+ 8.3%
Slaughter Beach	1143.7	1.5×10^5	1.8×10^5	$+2.9 \times 10^4$	+16.4%
Fowler Beach	209.7	1.4×10^4	1.6×10^4	$+2.3 \times 10^3$	+14.6%
Primehook Beach	1391.6	2.2×10^5	2.4×10^5	$+1.3 \times 10^4$	+ 5.5%
Broadkill I	781.6	1.8×10^5	2.1×10^5	$+3.1 \times 10^4$	+14.3%
II	724.4	1.6×10^5	2.0×10^5	$+4.3 \times 10^4$	+21.1%
III	819.7	1.2×10^5	1.4×10^5	$+1.8 \times 10^4$	+12.8%

Table 1. Changes in sand surface areas based on 1973 and 1979 aerial photographs. Sand areas include apparent washover fans and were corrected for tide level. Beach nourishment, if any, for each area or adjacent areas, is not accounted for.

Shoreline Changes: Accretion, Erosion and Storm Damage

Accretion

Shoreline accretion does occur on a short-term basis, for example when offshore bars are transported landward following a storm or as sand or mud accumulates on the updrift side of a jetty or groin. Also, Broadkill Beach had a period of accretion during the late 19th century due to the elongation of a shore-parallel spit. However, when spit growth stopped, erosion began. Although many of the study areas appear to have accreted in recent years (Table 1), this is, in most cases, due to beach nourishment in that area, or the longshore transport of nourishment from adjacent beaches. In addition, the sand surface area analysis shown in Table 1 involves several approximations and sources of error in the methodology used (Appendix II), which may have made the results misleading.

Erosion

If nourishment were discontinued, most of the western shore of Delaware Bay would undergo continual erosion at varying rates (Figure 1) as they have in the past. Erosion can occur on a continual basis, due to wave action, currents, and rising sea level, or it can occur sporadically, as a result of the increased wave action and water levels often associated with storms.

Continual erosion can result from waves with a frequency of more than ten per minute. Observers of the Delaware coastal zone have reported repeated incidences of massive erosion over the past several centuries, and these seem to be more frequent in the 10-20 years prior to the publication of this report (Kraft and John, 1976). This could be a "real" phenomenon, due to sharp sea level rise in the latter part of the 1960's (sea level rose approximately 8.4 cm from 1968-1976) (Figure 6) or it could be due to increased populations in these areas generating more observations. A third possibility is that more people were building on the beach face itself, and thus had greater concern for erosion rates. In general, highest erosion rates occur along marsh shorelines, e.g. Bombay Hook, Kent, and Kelly Islands (all north of Port Mahon) where the shoreline retreated at an average rate of 4.4-5.8 m/yr during the past century. High erosion rates also occur in areas with high subsidence rates (due to compaction of underlying mud layers (e.g. South Bowers) and areas adjacent to inlets (e.g. Broadkill). Erosion is less of a problem where the shoreline is formed from pre-Holocene headlands, since these can serve as a sediment source to the beach, not only where they outcrop directly behind the beach (e.g. Bowers) but also in areas where they outcrop offshore and are continually eroded by wave action (Maurmeyer, 1978).

Storm Damage

In addition to the continual, long-term erosion that is occurring in these areas, storms can cause drastic shoreline changes within a short time. Although there has also been an increase in the frequency of storm damage in Delaware and along the east coast, especially from 1942-1964, this has been attributed to 1) increased coastal development, and 2) more accurate reporting and greater interest in these areas. There is actually no evidence of an increase in the number or severity of coastal storms in Delaware. Compared with other sections of the east coast of the United States, the Delmarva peninsula and New Jersey have a "low" storm hazard potential (Mather, Field, and Yashioka, 1967). Storms in this area are one of two types. Some are tropical storms and hurricanes, which originate over the warm waters of the Gulf of Mexico and Atlantic Ocean--these can have winds of more than 120.8 kph, along with heavy rains, and usually occur in the summer and fall. Extratropical storms, or "northeasters" develop as strong low-pressure areas, and move offshore to the Atlantic Ocean. Winds blow from the northeast or east for sustained periods of time--although these are not of hurricane force, the resulting flood height and duration, and extent of structural damage, have equaled or exceeded those resulting from hurricanes (Friedlander, et. al., 1977). According to residents, this is especially true when the storm lasts for more than one tidal cycle. Based on hydrographic (tidal) data, the average duration of all storms at Lewes is approximately 40 hours (1952-1973) (although as recently as 1962 there was a storm that persisted through five high tides). Meteorological records would show a shorter period of time, but often tides remain high after the storm has passed. During these years, 26 coastal storms have been identified--14 were northeasters, occuring between September and May, and 12 were hurricanes or tropical storms (Friedlander, et. al., 1977).

The potential of coastal storms to produce damage depends on winds (velocity, direction, fetch, and duration), storm track (direction of movement, position relative to the coastline, and speed of movement over the earth's surface), and precipitation (volume, duration, and rate). However, these are "primary" factors and not the major causes of damage. Most damage occurs as a result of 1) storm surge, 2) wave action, and 3) back flooding from marshes. Storm surge results from two effects: a wind-produced current, leading to a piling up of water, especially in shallow coastal estuaries, bays, canals, and nearshore areas along the leeward coast, and a rise in water level due to a drop in atmospheric pressure. This factor alone accounts for a rise in sea water level of 33 cm for each drop of 2.5 cm of mercury. Tropical storms and hurricanes can have barometric pressures well below 70 cm (or nearly 3 cm below normal), leading to a sea level rise of almost 66 cm due to this factor alone. The effects of storm surge on a coastline depend to a great extent on tidal height--effects are minimized during a low or falling tide. When a storm lasts through several lunar high tides, e.g. the March, 1962 storm, which lasted for five high tides, huge storm surges can be built up. Wave action is another major cause of storm damage. Storm waves traveling at 48.0-80.5 kph are not uncommon. Since one cubic meter of water weighs 967 kg, these can represent a significant erosional force (Friedlander, et. al., 1977). Back flooding from marshes is a third significant cause of storm damage and occurs frequently in barriers such as those along Delaware Bay which have extensive tidal marshes behind the barrier, often accompanied by streams, rivers, or drainage ditches which can fill with water and lead to flooding of the barrier as well. To summarize the frequency and characteristics of Delaware Bay storms in the recent past, Table 2 presents extreme winds and waves predicted for the Delaware Bay coast and offshore area at several recurrence intervals, and Table 3 gives the duration and maximum tidal heights for coastal storms at Breakwater Harbor, from 1952-1974 (Friedlander, et. al., 1977).

When considering the flood hazard of this section of coastline, it is also important to examine the incidence of overwash, since this occurs most often during storms, and is an important component of the natural landward and upward migration of barrier islands that occurs due to sea level rise. Overwash can occur in three different ways--there can be an isolated incident in which water flows through a single, constricted area (this occurs fairly frequently in south Broadkill Beach--see Figure 9), or flow can occur through a closely-spaced series of breaks, forming coalescent washover fans, or there can be sheet-like flow over a low dune ridge or backshore, causing deposition of a tabular or prismatic sand body (Schwartz, 1975). For a given area, at a given time, whether or not overwash occurs will depend on physical factors, including wave parameters and tide levels, and barrier morphology, including maximum elevation, beach face slope, and nearshore bathymetry. In terms of physical factors, for a given tide level, short period waves require greater heights than long period waves to overtop the barrier

TABLE 2

Extreme Winds

Delaware Bay Area

Mean Recurrence Interval	5 yrs	10 yrs	25 yrs	50 yrs
Maximum Sustained Wind	63 kts	70 kts	80 kts	92 kts

Offshore Delaware Bay Area

Mean Recurrence Interval	5 yrs	10 yrs	25 yrs	50 yrs
Maximum Sustained Wind	71 kts	80 kts	92 kts	100 kts

Extreme Waves

Delaware Bay Area

Mean Recurrence Interval	5 yrs	10 yrs	25 yrs	50 yrs
Max. Significant Wave Ht.	3.4 m	4.3 m	5.2 m	6.7 m
Extreme Wave Height	6.1 m	7.6 m	9.2 m	10.7 m

Offshore Delaware Bay Area

Mean Recurrence Interval	5 yrs	10 yrs	25 yrs	50 yrs
Max. Signif. Wave Ht.	11.3 m	12.5 m	14.3 m	16.2 m
Extreme Wave Height	18.3 m	21.4 m	25.9 m	29.0 m

Table 2. Predicted Extreme winds and waves for the Delaware Bay coast and offshore area (Friedlander, et. al., 1977).

TABLE 3

Duration and Maximum Tide Height For
Coastal Storms (1952-1974): Breakwater Harbor, Delaware

Date	Duration (hrs)	Max. Tide Ht. (Above MLW)	Date	Duration (hrs)	Max. Tide Ht. (Above MLW)
9/5/52	35	1.7 m	4/5/71	37	2.0 m
8/13/53	44	1.8 m	8/26/71	13	1.9 m
9/26/56	62	2.2 m	11/23/71	48	1.8 m
9/19/61	45	1.9 m	2/11/72	31	1.9 m
3/6, 3/8/62	96	2.9 m	2/17/72	19	2.2 m
8/27/62	46	1.6 m	6/20/72	32	1.8 m
11/2/62	33	2.3 m	9/1/72	32	1.9 m
1/12/64	43	2.3 m	9/19/72	54	2.2 m
9/15/67	49	2.1 m	12/21/72	20	2.5 m
5/26/68	52	1.9 m	3/20/73	42	2.2 m
11/10/68	34	2.2 m	10/24/73	42	2.2 m
8/19/69	31	1.8 m	12/7/73	42	2.4 m
11/1/69	45	1.8 m			

Mean Duration (defined as total time in which storm tide level exceeds a height of 0.3 m above predicted normal tide level): 40.4 ± 16 hrs.

Mean Height: 2.1 ± .3 m.

Table 3. Duration and maximum tidal heights for coastal storms (1952-1974), Breakwater Harbor, Lewes, Delaware (Friedland, et. al., 1977).

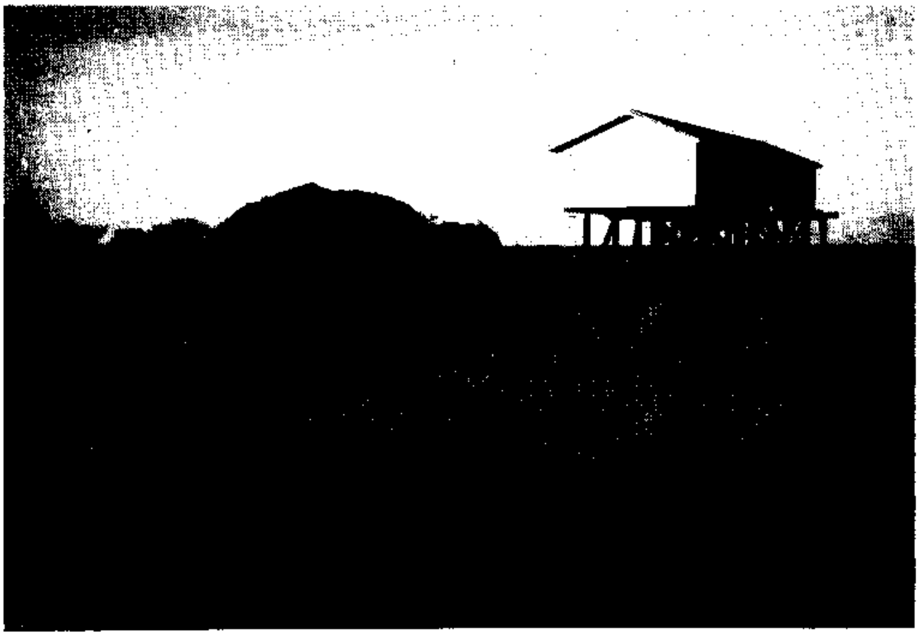


Figure 9. South Broadkill Beach, Delaware, following washover resulting from October, 1980 northeast storm. Overwash sand was present to depths of 0.3 m, west of the road.

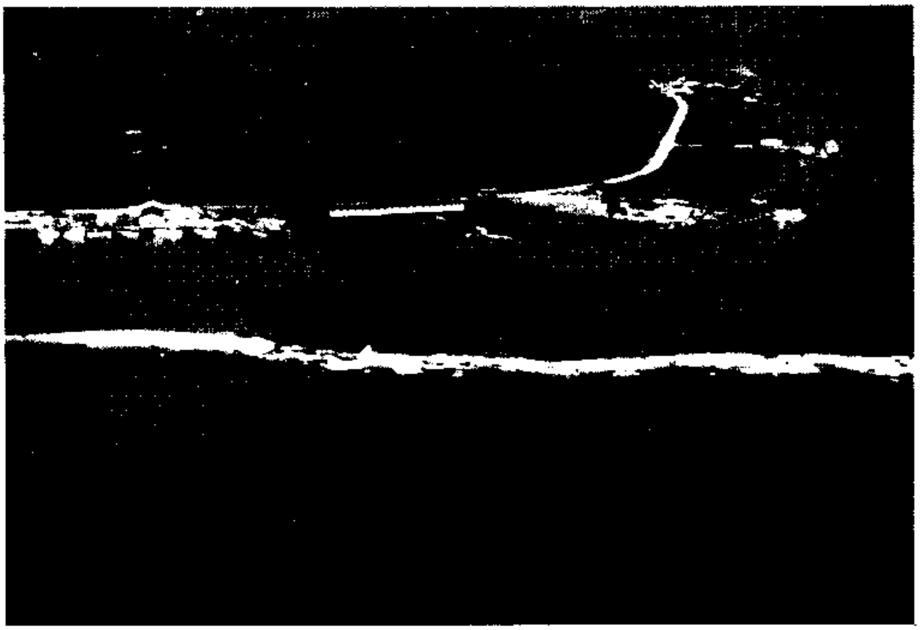


Figure 10. Northern section of Port Mahon, Delaware, showing piers, public boat ramp (July, 1974).

(see Table 4); while for a given wave height, short period waves require greater tide levels than long-period waves. In general, storm surge (i.e. tide height) is much more important than wave period or wave height. Regarding barrier morphology, the maximum profile elevation is the major factor in determining threshold conditions for overwash, but beach face slope is also closely related to the extent of wave runup. On beaches with fairly steep slopes, e.g. Woodland Beach (which is not one of the study areas, but has the same slope as several of these areas, i.e. 1:10), up to a certain point, an increase in wave height causes an increase in wave runup, but beyond this point runup decreases, since larger waves break further from shore. Also, as wave period increases, runup increases, since the backwash of the first wave interferes less with the uprush of the next wave. In areas with more gentle slopes, such as South Bowers, whose slope is 1:16, with a tidal flat extending several hundred meters offshore, there is generally less runup, since waves break farther offshore--for identical wave height and period, runup is only 1/6 that of Woodland Beach (Maurmeyer, 1978). Along the western Delaware Bay shoreline, northern and central barriers were found to require tide levels between 2.0 and 2.5 m above mean low water (MLW) for overwash. This generally occurs 15-100 times per century, or once every one to seven years. Southern barriers, which have higher maximum elevations, generally require tides of more than 3.0 m above MLW, which only occurs three to four times per century (Maurmeyer, 1978).

DETERMINATION OF POTENTIAL FOR DEVELOPMENT AND/OR BEACH PRESERVATION

Coastal Wetlands

Estimates have been made of the extent of Delaware's wetlands. In 1953, the Fish and Wildlife Service estimated that Delaware had 130,000 acres while in 1977, Reimold estimated the state had only 43,000 acres (however, this may have been referring to salt marshes alone). Almost all of the coastal areas along the western shore of Delaware Bay are bordered to the southwest by wetlands (Figure 1). These vary in width up to five kilometers. In 1973, the state of Delaware enacted the 1973 State Wetlands Act (7 Del Code 66) designed to protect these valuable areas from filling, dredging (except for mosquito-control ditches) and many other activities. From 1973 to 1976, the entire state was surveyed and wetlands boundaries were drawn onto aerial photographs taken in 1973. Areas that were designated as wetlands needed to meet three criteria: 1) they must support, or be capable of supporting, any one of a number of plant species generally associated with wetlands (which were listed), 2) they must be tidally influenced, and 3) they must be below an elevation of 0.6 m above MHW. Between 1973 and 1976, filling and other activities were permitted, as the wetlands maps were not yet completed, but after 1976, these activities were prohibited unless the proper permits were obtained (M. Hardisky, U. Delaware, personal communication).

In 1979·the state was again photographed by air, and revisions of the 1973 boundaries were made. These included areas that were filled between 1973 and 1976, areas of permitted fill since 1976, areas of violation fill since 1976, wetlands that were lost due to "natural" causes (in most cases, this is a result of overwash), wetlands that were gained due to natural causes (an example would be where a marsh built out into a lagoon), and upland areas that were reclassified as wetlands. One final classification is called "wetlands dropped (1979)"--this could result from many causes. In some cases, areas that were actually not wetlands were mistakenly designated as such in 1976, and this decision was reversed. In other cases, landowners or political bodies may have put pressure on the state to change the classification of an area. Alternatively, landowners may have caused the designation to be changed by erecting a flood gate or similar structure to prevent the area from being tidally influenced.

Altogether, preliminary estimates indicate that since 1973 approximately 20 acres were legally filled between 1973 and 1976, less than two acres have been filled by permit since 1976, about 100 acres were violation filled, 40 acres were lost due to natural causes, 10 acres were gained due to natural causes, 370 acres were previously considered upland and reclassified as wetland, and 375 acres were reclassified from wetlands to uplands (M. Hardisky, U.

Delaware, personal communication).

The maps that follow, for each study area, show the 1976 and 1979 legal wetlands boundaries, and the areas where a classification change occurred. In addition, "actual" wetlands are designated by marsh plant symbols--in most cases, these are the same as the "legal" wetlands, but areas that were previously filled (e.g. the northwest area of South Bowers) or simply overwashed, are not classified as wetlands by the state, but should still be considered as such in a geological context.

Please note that the "legal" boundaries referred to in the text and shown on the maps for each area were copied from maps drawn by the state of Delaware; these are not government documents.

Preservation Value Ratios

In the following discussions of each of the study areas, references are made to their "preservation value ratios." These ratios, designed to summarize certain demographic, environmental, and geological information for each community, enable the reader to analyze and evaluate each area individually and compare different areas, quickly and easily. The criteria used to determine these ratios, and their actual values for each study area, are presented in Table 4. Demographic information includes population (year-round, and summer--defined as the number of people who own or rent and either live in the area during the summer, or vacation there for more than several days), the number of houses in 1979 (counted from aerial photographs), the change in number of houses from 1973 to 1979 (also from aerial photographs), and the estimated property values in 1966 (presented in 1980 dollars). Maximum and minimum depth to Pleistocene material (estimated from a coast-parallel cross-section of Delaware Bay, Figure 7), average erosion rates from 1884-1954, beach nourishment efforts since 1962 (shown in m^3 sand placed, and minimum and maximum cost estimates in 1980 dollars), and overwash potential for waves of four- and six-second periods are the environmental and geological criteria presented.

These actual values were then used to create a rating system for each criterion, on a scale of 0-4, or, in one case, 0-2 (Table 5). A value of zero indicates the area is very unfavorable for

Table 4: Preservation Criteria Chart

Area	Yr-rd Pop. ('65)	Summer Pop. ('65)	Current Hses.	New Houses Since 1973	Property val. (1980 dollars)	Min. Depth to Pleistoc. (m)	Max. Depth to Pleistoc. (m)	Erosion (m/yr) (1884-1954)	Nourish. Qty. (m^3)	Nourish. (Min. cost)	Nourish. (Max. cost)	Overwash Pot. (Nec. wave ht.) T=4 sec.	Overwash Pot. (Nec. wave ht.) T=6 sec.
Port Mahon	0	0	0	0	0	5	8	7.6*	---	---	---	---	---
Kitts Hummock	15	280	130	0	$356,000	2	3	1.3	178,800	665,100	1,051,300	-2.1	.95
Bowers	325	550	130	0	$934,000	0	3	1.1	69,200	257,400	406,900	.05	.025
South Bowers	5	120	37	0	$245,000	6	30	2.3	44,500	165,500	261,700	-1.6	-1.3
Bennett's Pier	0	0	0	0	0	2	2	1.7	---	---	---	---	---
Big Stone Beach	20	160	52	1	$293,000	0	3	1.5	20,000	74,400	117,600	-0.4	-0.3
Cedar Beach	?	?	16	9	?	12	16	3.5	---	---	---	0.1	.07
Slaughter Beach	130	430	151	0	2,023,000	2	14	0.6	514,400	1913,600	3024,700	1.5	1.0
Fowler Beach	0	0	0	0	0	1	1	2.2	---	---	---	1.65	1.0
Primehook Beach	25	300	125	5	1,441,000	5	15	+1.3	15,500	57,700	91,140	none	none
Broadkill Beach	35	550	275	18	1,223,000	1	10	+3.5	648,200	2411,300	3811,400	none	0.7

*(1910-1956)

Table 4. Chart showing selected demographic and geological criteria used to evaluate the preservation value of the study areas. Population figures and 1966 property values are from the U.S. Army Corps of Engineers. Erosion rates and overwash potentials are based on Maurmeyer (1978). Past beach nourishment is from DNREC (1980).

Table 5: Evaluation of Criteria

			Rating Value		
Criterion	0	1	2	3	4
Yr.-rd. Pop.	0	1-10	11-50	51-150	>150
Summer Pop.	0	1-100	101-200	201-300	>300
Current Hses.	0	1-50	51-100	101-150	>150
New Houses	0	1-5	>5		
Prop. Values (1966)	0	0-$333,000	$333,000-833,000	$833,000-1,333,000	>$1,333,000
Min. Depth to Pleist.	>15	11-15	6-10	3-5	0-2
Max. Depth to Pleist.	>15	11-15	6-10	3-5	0-2
Erosion	>4	3-4	2-3	1-2	<1
Nourish. Qty.	>300,000	200,000-300,000	100,000-200,000	50,000-100,000	1-50,000
Overwash T=4 sec.	<-1.5	-1.5-0	0-1	>1	None
Overwash T=6 sec.	<-1.0	-1.0-0	0-.8	>.8	None

Table 5. Criteria chart explaining the establishment of values used to determine the preservation value ratio for each area. Specifications, units, and sources are given in Table 4.

Table 6: Preservation Value Ratio Chart

Criterion	Port Mahon	Bennett's Pier	Cedar Beach	South Bowers	Fowler Beach	Kitts Hummock	Big Stone Beach	Slaughter Beach	Bowers	Broadkill Beach	Primehook Beach
Yr.-rd. Populat.	0	0	---	1	0	2	2	3	4	2	2
Summer Populat.	0	0	1	2	0	3	2	4	4	4	3
Current Houses	0	0	1	1	0	3	2	4	3	4	3
New Houses	0	0	2	0	0	0	1	0	0	2	1
Prop. Values (1966)	0	0	---	1	0	2	1	4	3	3	4
Min. Depth to Pleistocene	3	4	1	2	4	4	4	4	4	4	3
Max. Depth to Pleistocene	2	4	0	0	4	3	3	1	3	2	1
Erosion	0	3	1	2	2	3	3	4	3	4	4
Nourishment	---	---	---	4	---	2	4	0	3	0	4
Overwash (T=4 sec)	---	0	2	1	3	0	1	3	2	4	4
Overwash (T=6 sec)	---	0	2	1	3	1	1	3	2	2	4
Total # Points	5	11	10	15	16	23	24	30	31	31	33
Total Possible	30	38	26	42	38	42	42	42	42	42	42
Preservation Value Ratio	.17 ≃.2	.29 ≃.3	.38 ≃.4	.36 ≃.4	.42 ≃.4	.55 ≃.6	.57 ≃.6	.71 ≃.7	.74 ≃.7	.74 ≃.7	.79 ≃.8

the continuation (or initiation) of beach preservation, in terms of that criterion, with increasing values denoting increasing worthiness for future preservation. No statistical methods were used to derive these scales, but I believe they are an accurate representation of the range of conditions found along Delaware Bay, and their effects on each community's preservation value. Based on this rating system, a chart summarizing these values for each area is presented as Table 6. In some cases, data were not available for certain criteria for individual areas--these spaces were left blank. For this reason, the sum of values for each area is divided by the total number of possible points, to determine the preservation value ratio.

Whenever a lot of information is summarized in a very short form, some accuracy and precision must be lost. This is true for the preservation value ratio as well. Although the demographic information can be considered fairly complete and accurate, some of the geological information involves many more variables than can be accounted for in a quick summary such as this one. Depth to Pleistocene can vary considerably over the length of a town (see Slaughter Beach, for example, Figure 44). In most cases, not enough information is available to precisely quantify this effect for each study area--however, it is hoped that minimum and maximum values of depth to Pleistocene will give a good approximation.

Since erosion rates can vary greatly over periods of several years, due to natural causes and man's intervention, the ideal way to compare study areas in this regard would be to include erosion rates for each area, for identical time spans, on the order of five to ten years. However, erosion rate data are not available for the same time periods for all areas, with the exception of 1884-1954 (or, in the case of Port Mahon, 1910-1956). This time span was therefore used to evaluate erosion rates for each area--admittedly, in some cases this could be misleading. The reader is referred to the individual discussions of erosion rates for each area, and/or the graphs summarizing erosion rates found on the map for each area, for more complete and accurate erosion information.

Past beach nourishment efforts can be presented in terms of quantities of material placed and cost. Since accurate information is available on the quantities used, these values were used for the preservation value ratio determination. Although in some cases, the cost of nourishment programs is known (see individual discussions for each area, and Tables 7-11), in many cases this information was not available. In order to estimate these costs, minimum and maximum cost estimates for nourishment ($\$3.72/m^3$ and $\$5.88/m^3$ respectively, in 1980 dollars) were multiplied by the quantities of sand used. (This information is presented in Table 4, but not in Table 6, since to do so would be redundant).

Information on overwash potential for each area is available in the form of graphs of tidal height vs. wave height required for overwash, for waves of four different periods (i.e. there are four curves for each study area). These graphs are based primarily on barrier morphology, and do not account for differences in tidal height, wave height, or wave period actually found during storms along the Delaware Bay coast (Maurmeyer, 1978). Although information on storm wave heights and periods could not be found for the individual areas, according to Dalrymple (U. Delaware, personal communication) these parameters should not vary greatly along the coast. Storm tide heights for the December, 1974 storm (a severe northeaster), at Woodland Beach (18 km north of Port Mahon), Bowers Beach, and Slaughter Beach are known, and were used to create a graph of storm tide height vs. distance along the Delaware Bay coast--from this graph, tide height values were derived for the other communities. Since storm wave periods are probably on the order of four to six seconds in most cases (at the mouth of Delaware Bay) (K. Bodge, U. Delaware, personal communication), the overwash potential for each area was evaluated on the basis of wave height required for overwash to occur, given the estimated tidal height of the December, 1974 storm, for four- and six-minute waves (note--even though "negative" wave heights are a physical impossibility, in this case they indicate that no wave height would be required for overwash, even at lower tidal levels. It is still true that the lower the wave height value, the less "favorable" the area.)

One final drawback of the preservation value ratio chart is that it does not account for aesthetic and recreational differences between study areas. There are two reasons for this. First, aesthetic qualities are by definition subjective, and therefore hard to quantify and justify. What may be an ugly tidal flat to one person may be a fascinating area for exploration during low tide to another. Although estimates of recreational value may be easier to obtain, these, too, would depend on the type of recreation desired by visitors and residents. In addition, both the aesthetic and recreational value of an area could be substantially altered by the preservation measures that may or may not result from the chart's evaluation of the area.

Although these drawbacks to the preservation value ratio table exist, they do not detract from the primary purpose of the chart, to facilitate a quick and simple evaluation and comparison of the study areas, based on quantifications of many demographic, geological, and environmental criteria. In each case more complete information can be found in the discussions of the individual areas that follow, or other referenced sources.

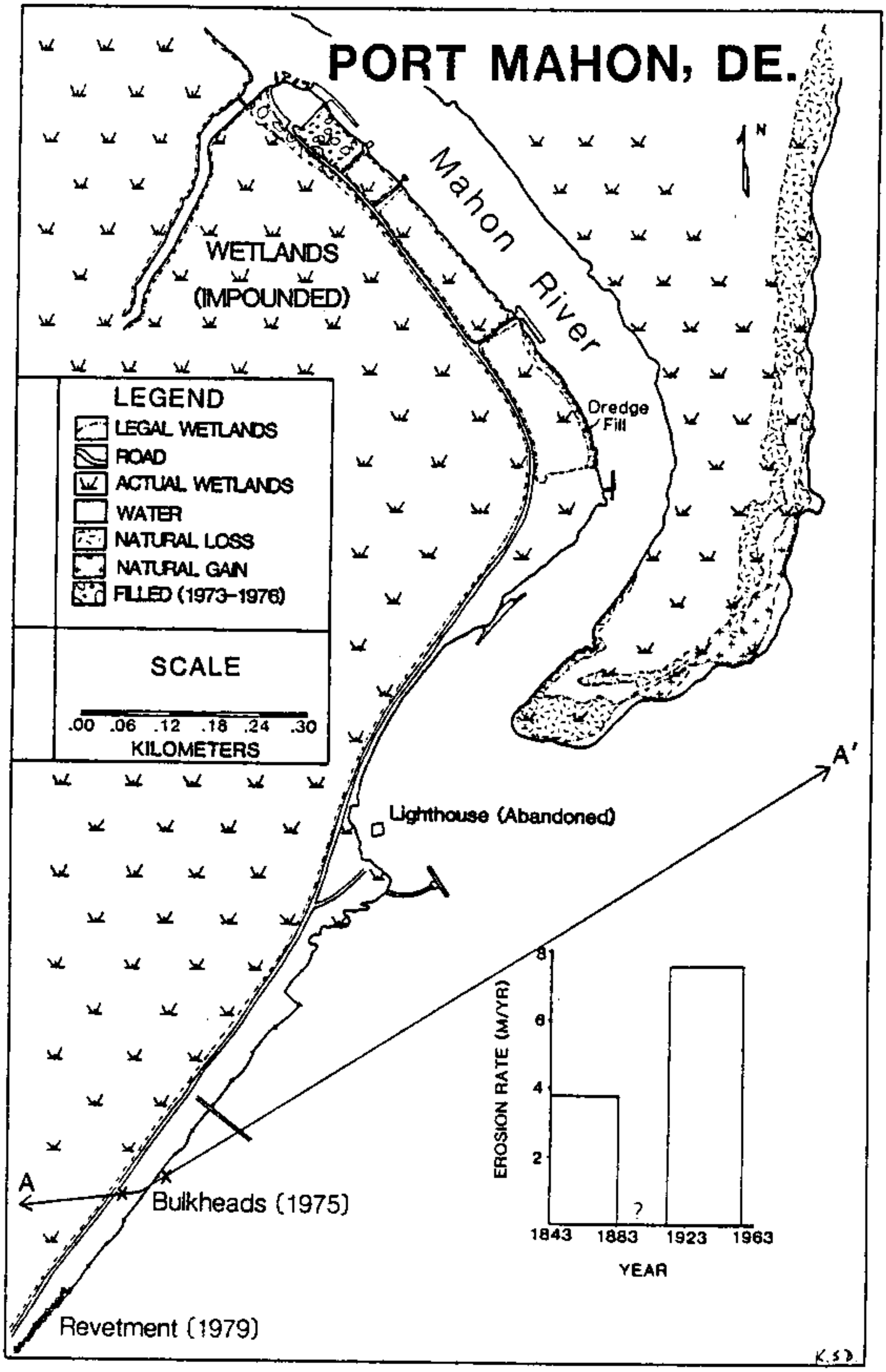
DELAWARE BAY COMMUNITIES AND UNDEVELOPED AREAS: NORTH TO SOUTH

Although many aspects of the Delaware Bay shoreline environment are fairly uniform along this coast, considerable variations in many factors exist between the eleven study areas. These differences are discussed in the following section, in which each area is examined more closely.

Port Mahon

Port Mahon, the northernmost study area, consists of a broad tidal marsh (approximately 2.4 km wide) covered predominantly with Spartina spp. bordered to the west by highlands (Figures 10 and 11). In the past, open water lagoonal conditions probably existed at one time, after which a marsh gradually developed as the lagoon became filled with fine sediment (Kraft, et. al., 1976). Based on radiocarbon dates, this probably occurred approximately 3170 to 3210 years before present (B.P.) (Kraft and John, 1976). A geologic cross-section through Port Mahon is shown in Figure 12. Along the coast, there is a six meter thick layer of muds, the bottom two meters of which may be lagoonal in origin, overlying Pleistocene material. Port Mahon is an area of major coastal erosion, and has been

Figure 11. Map of Port Mahon, showing developed area, past and present wetlands classifications, line of cross section, core locations (X's), and historical erosion rates.


PORT MAHON, DE.
N
Mahon River
WETLANDS
(IMPOUNDED)
Dredge Fill
LEGEND
LEGAL WETLANDS
ROAD
ACTUAL WETLANDS
WATER
NATURAL LOSS
NATURAL GAIN
FILLED (1973–1976)
SCALE
.00 .06 .12 .18 .24 .30
KILOMETERS
Lighthouse (Abandoned)
A
A'
Bulkheads (1975)
Revetment (1979)
EROSION RATE (M/YR)
8
6
4
2
?
1843
1883
1923
1963
YEAR
K.S.D.

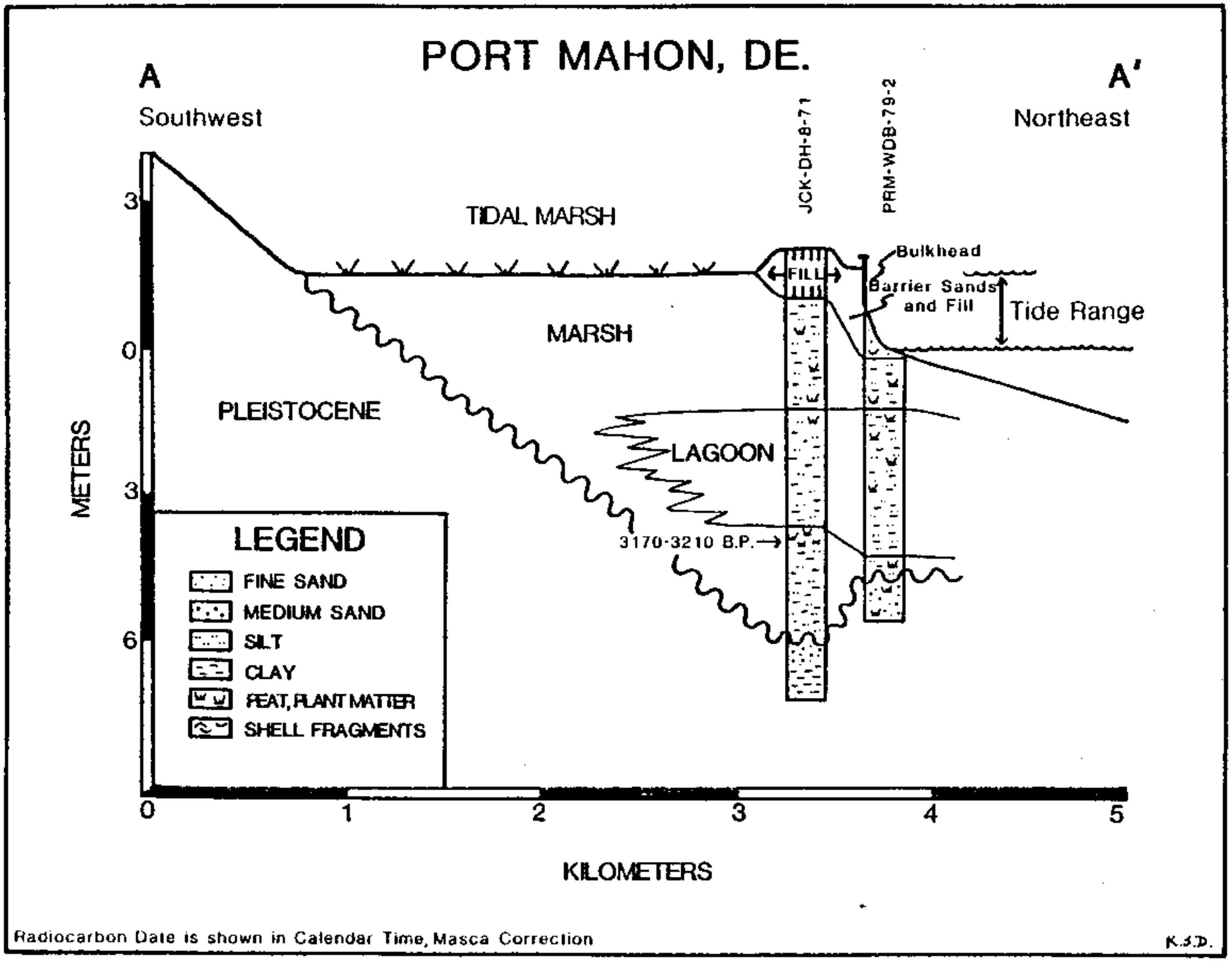
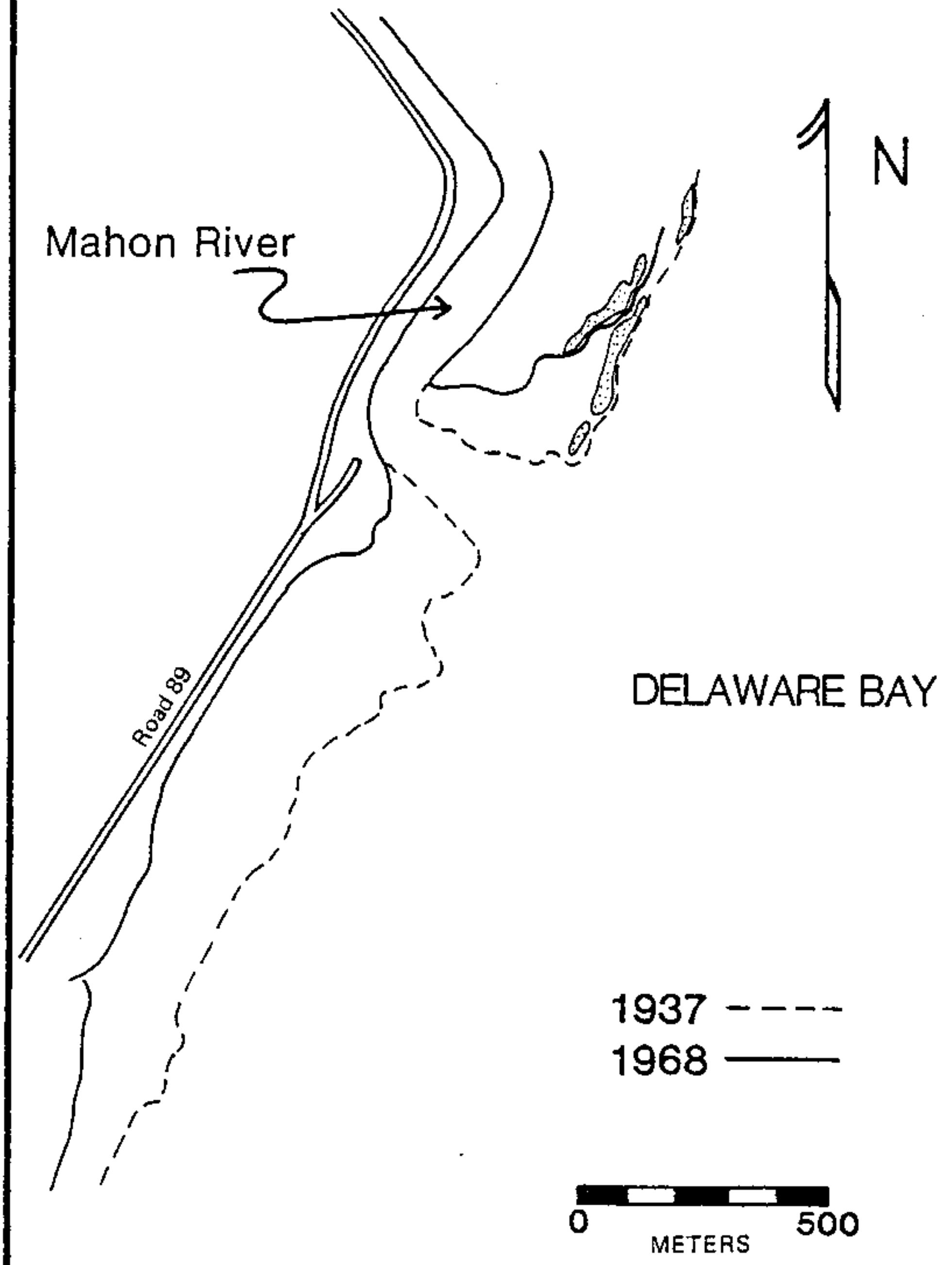


Figure 12. A geologic cross section at Port Mahon showing coastal environment sedimentary units based on core data.

for at least the past 125 years, probably due to the high erodability of the marsh muds, perhaps in conjunction with compaction of these sediments and the shoreline orientation such that southeast winds and waves from the Atlantic are virtually unobstructed. Estimates of past erosion rates vary. According to Kraft and John (1976), there has been more than 3.0 m/yr erosion over the past 125 years. Kraft, et. al. (1976) give a higher estimate, saying that about 0.8 km of shoreline have been eroded and transgressed since 1845 (i.e. an average rate of 6.1 m/yr). Perhaps these discrepancies are due to the differences in erosion rates at different points along the shore. According to Maurmeyer (1978) who studied erosion rates at six points along the coast, the area has been eroding at increasing rates, from 3.8 m/yr (1843-1883) to 7.6 m/yr (1910-1956). Since 1936, the area has eroded at an average rate of 4.6 m/yr, but some rates are as high as 12.3 m/yr. Figure 13 shows the shoreline changes from 1937-1968 that have resulted from this erosion (Maurmeyer, 1978).

There are no houses at Port Mahon, so the high erosion rates do not pose a problem in that regard. However, there is an access road, as shown in Figure 11, which is necessary for the maintenance of pipelines that supply oil tanks for Dover Air Force Base, located to the west of Port Mahon. In addition, there is a Coast Guard station in this area, as well as a public boat ramp that seems to be

Figure 13. Map of Port Mahon depicting shoreline erosion, 1937-1968, currently endangering the access road.



PORT MAHON
SHORELINE EROSION: 1937-1968

(Based on Maurmeyer, 1978)

used extensively (on Friday, June 13, 1980, at 2:00 P.M., there were approximately 40 cars there; large boats were being taken into and out of the water, and some people were fishing off a pier there as well). To protect this road, a bulkhead was constructed in 1975, at a total cost of more than $687,000 (981,000) (R. McDowell, personal communication) (Figure 14) and concrete revetment was placed along the road north of the bulkhead (Figure 16). However, since the bulkhead pilings were sunk to a depth of only 4.9 m (A. Terchunian, U. Delaware, personal communication) and the muds in this area are 6.0 m thick, the bulkheads soon proved to be totally ineffective in halting coastal erosion in this area. At this time, water comes up to the bulkhead at high tide, with ponding behind the wall, and other areas appear to pond regularly (Figure 15). It should be noted that at the time of construction, information on the subsurface geology was available to the state, and if the pilings had been several meters longer, extending into Pleistocene material, it would have meant the difference between structures that last two or three years and those that might last 20 or 30 years. The road is constructed on artificial fill; road elevation is 1.0-3.0 m above mean high water level, and about 20 m back from the bulkhead. However, south of the bulkhead there is a 5.0 m wide mound of concrete rubble, approximately 15-20 m long, that is all that separates the road from Delaware Bay (Figure 16).

It is evident that this area is undesireable in certain respects for any type of development due to: 1) the high erodability

Figure 14. Bulkheads constructed at Port Mahon to protect Road 89, soon after bulkhead construction (note the buckling that has already begun).

Figure 15. Present condition of the bulkheads at Port Mahon.

Figure 16. Rock revetment at Port Mahon, soon after placement.

Figure 17. Aerial photograph of Kitts Hummock, Delaware, showing breakwaters offshore (September, 1979).

of the marsh material, 2) compaction that would probably result if construction were attempted, 3) legal prohibitions of wetland construction (Figure 11), and 4) the high flood hazard of this area. This is in agreement with the very low preservation value ratio shown by Table 6, which can be attributed to a lack of housing and residents, and high erosion rates. The question Port Mahon must face now is whether or not to continue attempts to maintain the present road. Since the need for this road has been demonstrated and will probably continue, and erosion can also be expected to proceed at a high rate, perhaps the best solution would be to relocate the road. This has been considered by the state Dept. of Natural Resources and Environmental Control (DNREC), who explored two possible routes, one in which the road would be displaced westward, approximately parallel to its current position, and the other in which the road would be routed directly to the launching ramp. Both ideas were abandoned due to legal and cost considerations (Moore, personal communication).

The only other alternatives would be construction of a more massive bulkhead, or the addition of fill to the present road, to raise its elevation. At this time, the state is conducting a "shoreline erosion project" to protect the road, consisting of a 1.2 m deep, 10.7 m wide revetment, utilizing 45-2,300 kg rocks. The first phase of this project (initiated in November, 1980, and completion planned for one year later) will extend south from the bulkhead for 0.2 km and north from the bulkhead for 0.7 km at a cost of $774,000.

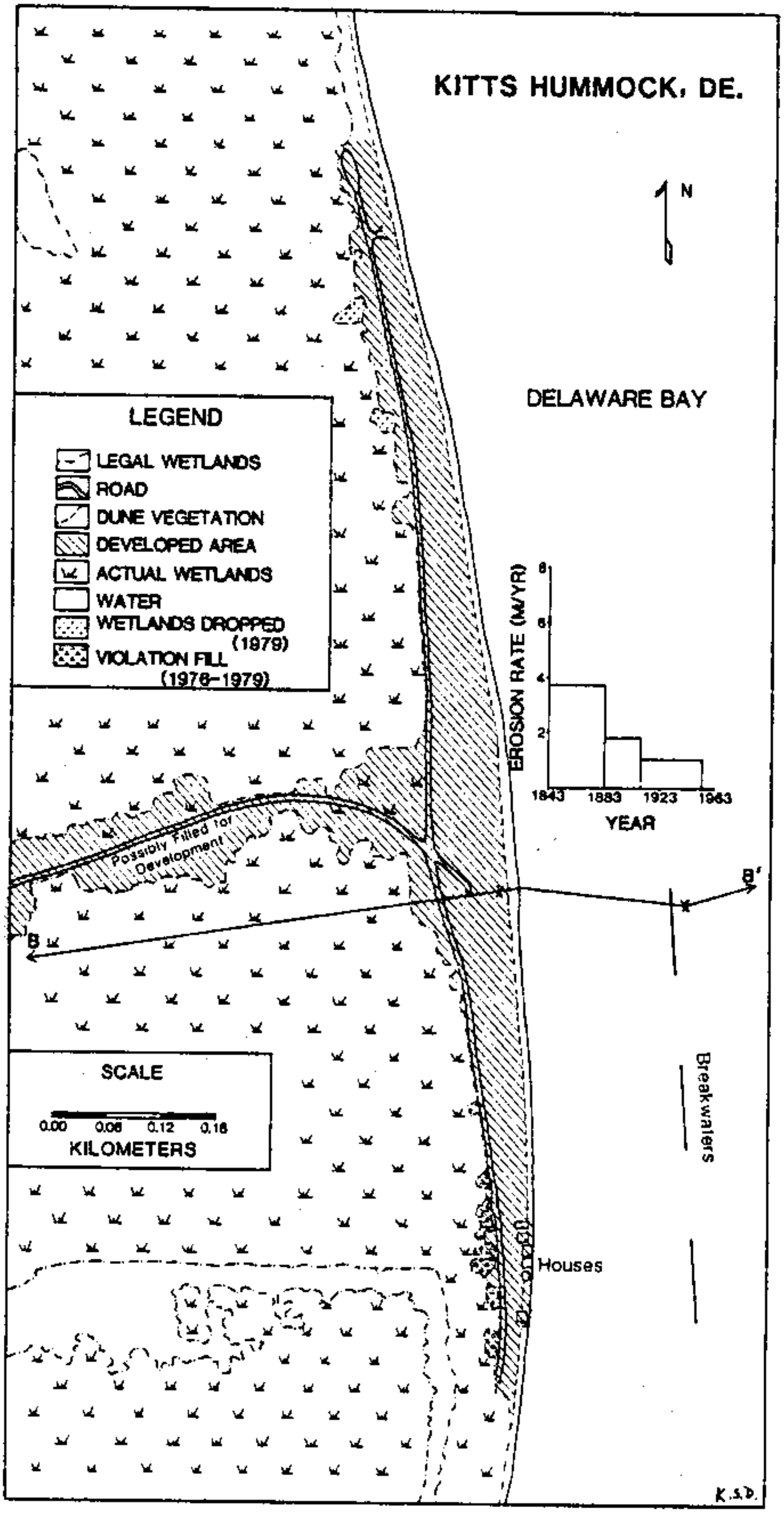
This project is financed entirely by state funds, through the capital improvement budget, and if more money is made available, rocks will be placed behind the existing bulkhead as well (Moore, personal communication). This "solution," as well as the alternate of raising the road, will probably be temporary at best, given the high erosion rates of the area. In addition, the revetment is likely to be overtopped by waves with subsequent erosion landward of the structure.

Kitts Hummock

Kitts Hummock is a small fishing resort community, extending approximately 0.8 km along shore (Figure 17). There are about 100 cottages, mostly summer residences, half of which are along the access road, the other half of which are along the bay, along the landward edge of the dune. In 1965, there were only 15 permanent residents and 280 summer residents (U.S. Army Corps of Engineers, 1966). In 1966, the total fair value of property at Kitts Hummock was only $160,000 ($356,000) (U.S. Army Corps of Engineers, 1966). However, it should be kept in mind that this was 15 years ago; the cost of real estate has probably increased at a greater rate than the GNP inflation rate, and the number of houses has probably increased as well.

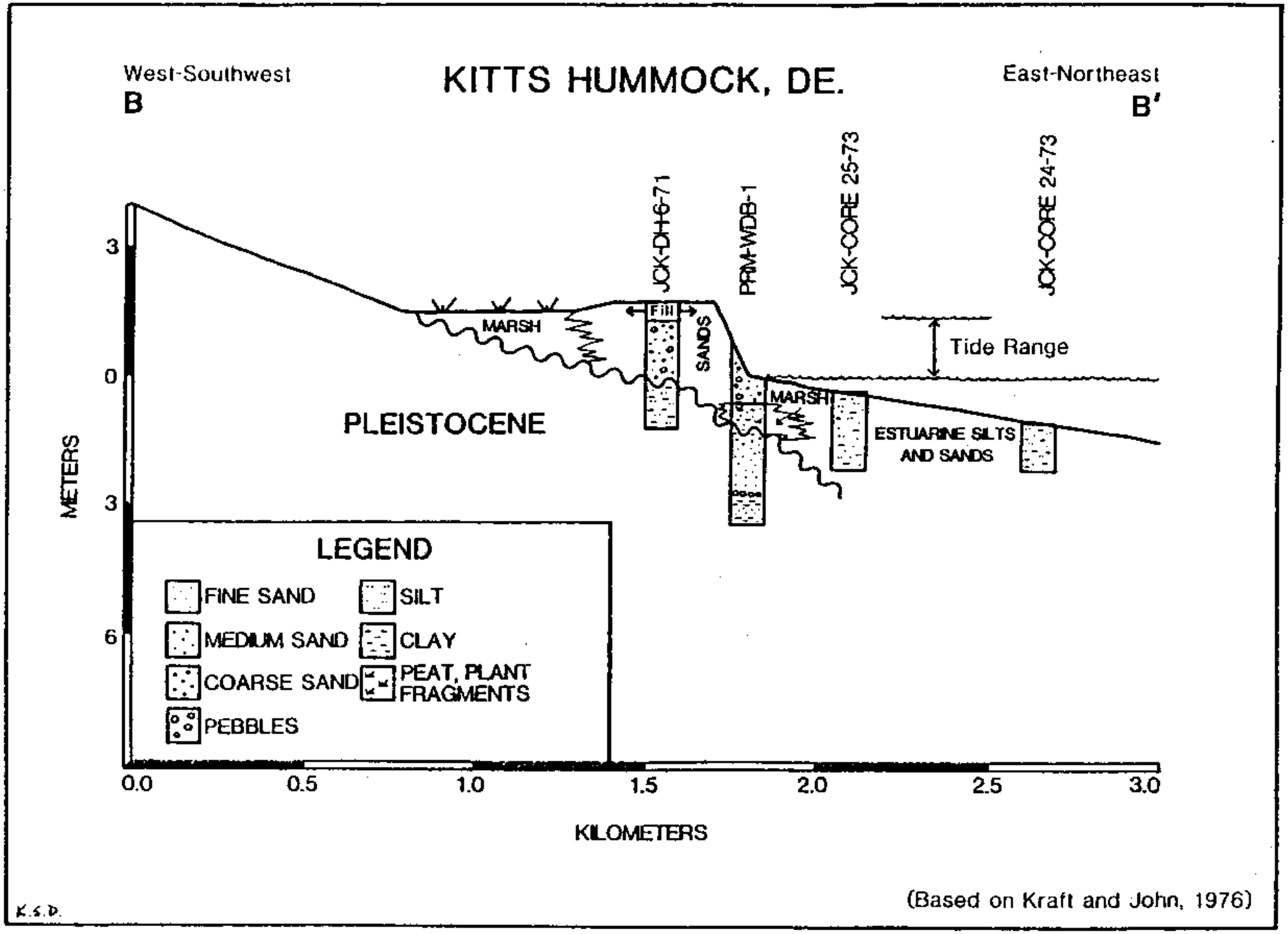
This community is constructed on a narrow sandy barrier, bordered to the west by only 0.5 km of tidal marsh, west of which is Pleistocene highlands (Figure 18). The total width of the barrier is 60 m, 40 m of which is washover terrace, which dips landward with a 1:50 slope. The beach face is 20 m wide (presumably at low tide), with a 1:9 slope (Maurmeyer, 1978); a low sand-covered dike (consisting of sand and gravel) extends along the length of Kitts Hummock--the dike is approximately 6.1 m wide at the base, with a top elevation about 3.7 m above MLW (U.S. Army Corps of Engineers, 1966). (Since the tide range is 1.5 m in this area, the maximum el-

Figure 18. Map of Kitts Hummock, Delaware, showing developed area, past and present wetlands classification, line of cross section, core locations (X's) and historical erosion rates.


KITTS HUMMOCK, DE.
N
DELAWARE BAY
LEGEND
LEGAL WETLANDS
ROAD
DUNE VEGETATION
DEVELOPED AREA
ACTUAL WETLANDS
WATER
WETLANDS DROPPED (1979)
VIOLATION FILL (1976-1979)
EROSION RATE (M/YR)
8
6
4
2
1843
1883
1923
1963
YEAR
Possibly Filled for Development
B
B'
SCALE
0.00
0.06
0.12
0.18
KILOMETERS
Breakwaters
Houses
K.S.D.

evation is only approximately 2.1 m above MHWL). A cross section through Kitts Hummock (Figure 19) indicates that a layer of artificial fill overlies a thin sandy barrier (less than 3 m thick) which, in turn, overlies silts and clays that appear to be Pleistocene material (Kraft and John, 1976). Cores have also indicated the presence of two layers of washover deposits, with a thin layer of marsh muds between them (Maurmeyer, 1978), indicating that there was a period of time when the barrier had a lower profile, or major storms were more common, followed by a more quiescent period during which the marsh was able to build itself up, followed by another stormy period or one in which other factors led to a lowering of barrier elevation (leading to overwash).

Coastal erosion occurs along the length of Kitts Hummock, but to a lesser extent than that found at Port Mahon. This can probably be attributed to the erosion of the lower tidal zone and below, which may supply some sand to the beach (Kraft and John, 1976). The beach profile does change seasonally, with beach accretion occurring in the spring--during one season, the berm widened one to two meters through the addition of 3.1 m^3/m shore of material (the average volume of the barrier itself is 33 m^3/m). At this time, new stands of _P_. _communis_ grew, trapping sand and raising the dune height by 0.1 m (Maurmeyer, 1978). However, on an annual basis, erosion has prevailed at a rate of 3.7 m/yr from 1843-1884, decreasing to 1.8 m/yr from 1884-1910, which decreased further to 1.04 m/yr from 1910-1954 (Kraft, et. al., 1976). The reasons for this are not



(Based on Kraft and John, 1976)

Figure 19. A geologic cross section at Kitts Hummock showing coastal environment sedimentary units based on core data.

clear, since this was before any beach preservation measures were instituted. Perhaps there was a change in the nature of the beach face material, with less easily eroded sediments gradually being exposed. Another possibility is that the decreased erosion rates are related to the development of the community--maybe as a result of the fill that was placed. A third explanation could be a change in the amount of material supplied to the beach by longshore transport. To my knowledge, this has not been measured during this time period. However, in 1978, the northern section, with an outward normal of 75°, had a total southward transport of 7,400 m^3/yr, total northward transport of 3,800 m^3/yr, and net transport of 3,600 m^3/yr to the south (Maurmeyer, 1978). These values are relatively low compared with those of other Delaware Bay communities, but this could have been a contributing factor.

Beach preservation measures that have been taken at Kitts Hummock include periodic beach nourishment (Table 7) (in the past 20 years, 155,400 m^3 of material have been placed on the beach, at a cost well in excess of $233,600 (300,100))(Dept. of Natural Resources and Environmental Control, 1980); construction of a dike in 1962 (along 1500 linear meters of dune line, using 23,400 m^3 fill, at a cost of $71,100 (169,400)); and building of three breakwaters approximately 183 m offshore, in summer of 1979 (R. Henry, DNREC, personal communication).

In general, although Kitts Hummock has no available land for further development (due to legal wetlands boundaries--Figure 18), it

TABLE 7

Beach Preservation Measures: Kitts Hummock, DE.

Year	Action Taken	Cost
1961	61,100 m^3 fill placed	?
1962	Dike constructed along 1500 linear m of beach, using 23,400 m^3 fill	$71,100 (169,400)
1973	2,300 m^3 fill placed	$11,500 (19,000)
1974	35,500 m^3 fill placed	$82,300 (128,700)
1979	56,500 m^3 fill placed	$139,800 (152,400)
	Breakwaters constructed	?
	Total:	$304,700+ ($612,400+)

TABLE 8

Beach Preservation Measures: Bowers, DE.

Year	Action Taken	Cost
1962	27,200 m^3 fill placed	$89,400 (213,000)
1968	13,800 m^3 fill placed	?
1972	16,200 m^3 fill placed	?
1973	12,000 m^3 fill placed	$15,800 (26,200)
1974	22,000 m^3 fill placed	$28,800 (45,000)
1975	Beach grass planted	$150 (214)
	Sandbag jetty constructed	$20,000* (28,600)
	Total:	$154,150+(313,014+)

*Estimated (R. Henry, DNREC, personal communication)

Tables 7 and 8. Kitts Hummock and Bowers beach preservation measures and costs, where known (numbers in parentheses are in 1980 dollars) (Dept. of Natural Resources and Environmental Control, 1980).

has some qualities that would make it desirable for future beach preservation: 1) the subsurface is stable for existing structures (i.e. building subsidence is not a problem), 2) erosion rates are moderate, 3) since littoral transport rates are low, any material that is placed here would not be quickly lost, given the proper grain size and slope of the fill, and 4) although there are few permanent residents, there are a moderate number of summer residents and houses. However, it could be argued that beach preservation is undesirable, since normal high tidal water levels almost reach the height of the washover barriers, so the community will always be subject to storm wave attack; as a result of this, according to Kraft and John (1976), there is no economically reasonable way to protect the village from an extreme storm event, since most bayfront houses are too close to the high tide line. All of these factors combined to give Kitts Hummock a preservation value ratio of 0.55 (Table 6). If there were more permanent residents here, and existing housing were modified to accomodate the overwash that is likely to occur, this value could be increased.

Figure 20. Aerial photograph of Bowers and South Bowers, Delaware (August, 1980).

Figure 21. Fishing docks at Bowers, Delaware.

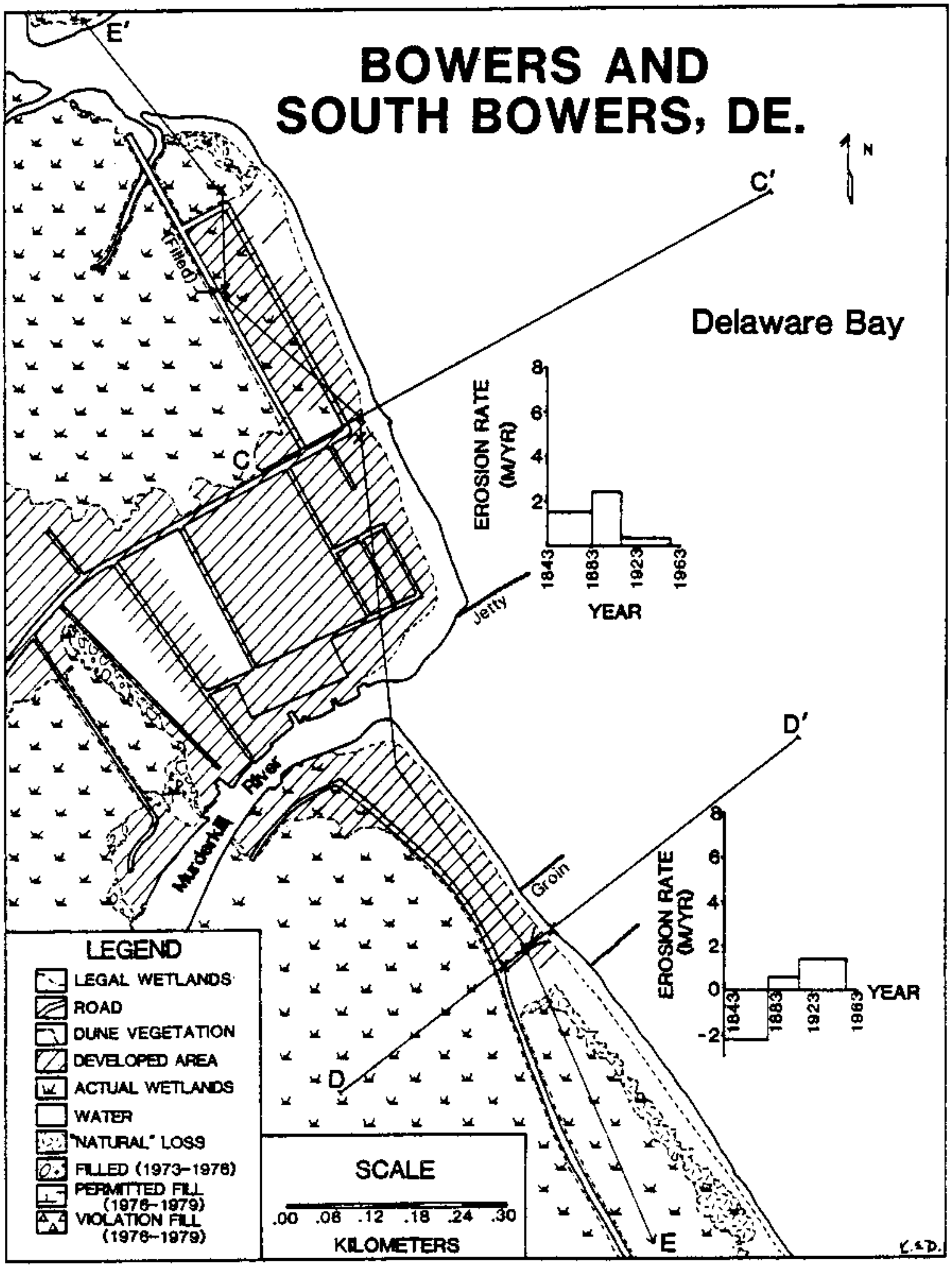


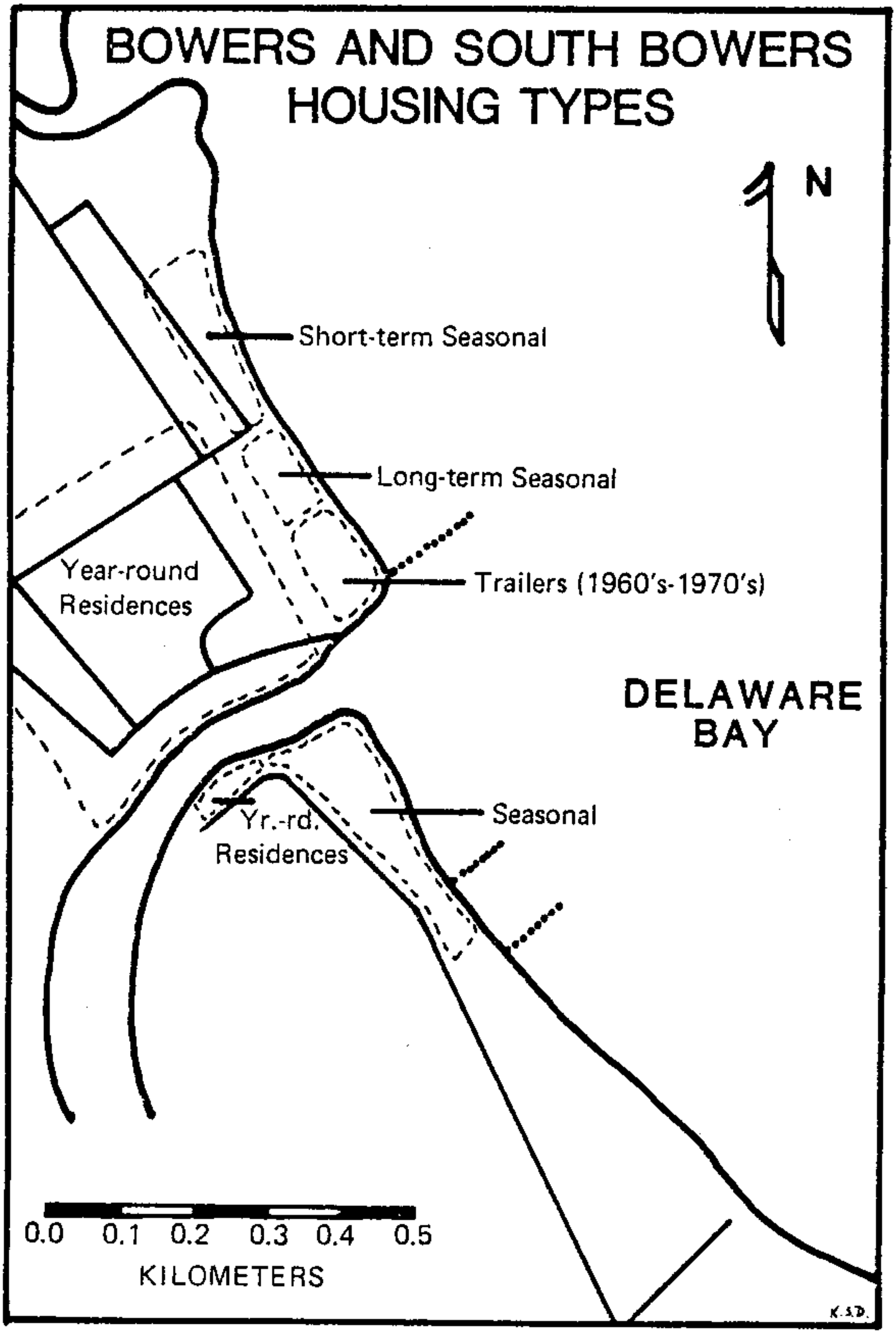
Figure 22. Map of Bowers and South Bowers, Delaware, showing developed area, past and present wetlands classification, lines of coast-perpendicular and coast-parallel cross sections, core locations (X's) and erosion rates.

Bowers Beach

Bowers is a relatively large, well-established fishing community, founded in colonial times, whose population has fluctuated little since 1940 (Figures 20 and 21). In 1977, there were 286 permanent residents (Bureau of the Census, 1979) and probably about 1.5 times as many summer residents. Per capita income increased from $2400/yr (4800/yr) in 1969 to $3805/yr (5400/yr) in 1975. The town itself is approximately 4.83 km square, 3/4 of which is occupied land (Friedlander, et. al., 1977) (Figure 22). Housing at Bowers includes small trailers located along the bay, on the south end (which was damaged extensively in the 1962 storm), some houses built in the 1930's and 1940's, and many homes built in the 1920's (D. Ames, U. Delaware, personal communication). Although Bowers seems to be subdivided into several housing areas (Figure 23), it also appears to be occupied by a majority of long-term residents. Not only permanent residents, who have lived there most of their lives, but summer residents as well. In fact, many homes have been in the same family for two or more generations.

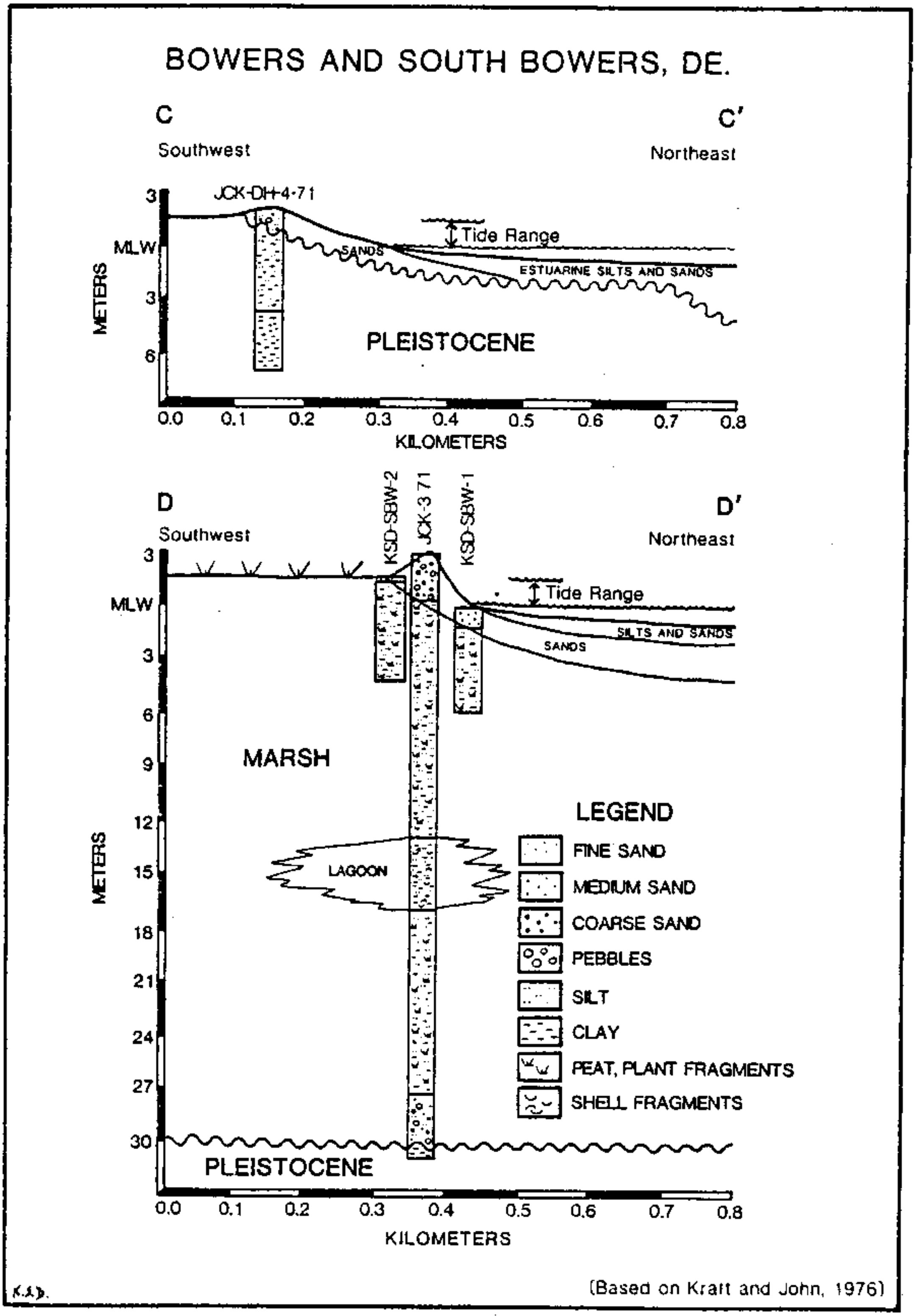
Bowers differs from most other communities in the southern part of Delaware Bay in that it is not located on a barrier system. (Kitts Hummock may also not be considered a barrier, since only a very narrow strip of wetlands separates the beach from highlands.) Although there are wetlands to the north and west of the town, the

Figure 23. Bowers and South Bowers housing patterns.


BOWERS AND SOUTH BOWERS
HOUSING TYPES
N
Short-term Seasonal
Long-term Seasonal
Year-round Residences
Trailers (1960's-1970's)
DELAWARE BAY
Seasonal
Yr.-rd. Residences
0.0 0.1 0.2 0.3 0.4 0.5
KILOMETERS
K.S.D.

sand body along the coast directly overlies Pleistocene material, and this material itself crops out in several areas. Bowers is located on the southern side of a 0.5 km long body of land between the mouths of the St. Jones and Murderkill Rivers. The beach is approximately 12.2 m wide with a relatively steep beach face (according to one source, this slope is 1:8 (Friedlander, et. al., 1977), according to another it is 1:10 (Maurmeyer, 1978)). Seaward of this is a gently-sloping low tide tidal flat (Maurmeyer, 1978), and landward of the beach is a dune or dike comprised of mixed gravel and sand, approximately 9.1 m wide at the base, with a 2.7-3.3 m elevation above MLW (U.S. Army Corps of Engineers, 1966), or 1.3-1.9 m above MHWL. In addition, sand spits extend seaward from the north and south ends of Bowers (Maurmeyer, 1978). These are called "channel margin linear bars" by Fitzgerald (1976) and are formed as ebb tidal currents erode sand from the beach and deposit it perpendicular to the shoreline (Maurmeyer, 1978). Their presence has been described by residents as well, and is apparently unrelated to the sandbag jetty located at the south end of Bowers, since the spits were there before jetty construction. A cross section through Bowers (Figure 24a) shows a thin (less than three meter) sand body directly overlying Pleistocene material, with estuarine silts and sands offshore. The Pleistocene sediments below the surface consist of estuarine or marine sandy and silty muds, relatively strongly compacted and oxidized, which were probably deposited during the Sangamon interglacial age, approximate-

Figure 24a,b. Coast-perpendicular geologic cross sections at Bowers (Figure 24a) (C-C') and South Bowers (Figure 24b) (D-D') showing coastal environment sedimentary units based on core data.



BOWERS AND SOUTH BOWERS, DE.

(Based on Kraft and John, 1976)

ly 80,000-100,000 years B.P. (Kraft and John, 1976). These sediments indicate that this area was once a shallow sea at a time of higher sea level. Since then, erosion has occurred, leaving a narrow section of highland between the Murderkill and St. Jones Rivers. The three-dimensional geological structure of Bowers Beach is shown by Figure 25. The locations of Murderkill Neck (a Pleistocene highland), the dune or dike line, and the wetlands north of town are indicated, and the proximity of the Pleistocene surface to the ground surface is again illustrated. (The legend for this and other three-dimensional diagrams is shown as Figure 26).

Although the underlying Pleistocene material is relatively resistant to erosion and erosion is occurring at a lesser rate than at most of the other study areas, the highlands are eroding and supplying sediment to the shores of Delaware Bay, via the littoral drift system. From 1843-1884, erosion rates averaged 1.5 m/yr. These increased to 2.4 m/yr from 1884-1910, then decreased to 0.33 m/yr from 1910 to 1954 (Maurmeyer, 1978). These changes in erosion rates were probably due to variations in the number or intensity of storms, changes in the erodability of exposed Pleistocene material, fluctuations in the position of the river mouths, or dredging of the Murderkill River (and associated spoils dumping). Although there are no data available on recent erosion rates, residents are in general agreement that either erosion has slowed in the past several years, or the beach has actually accreted, probably due to the sandbag jetty construction, beach nourishment, and/or the prac-

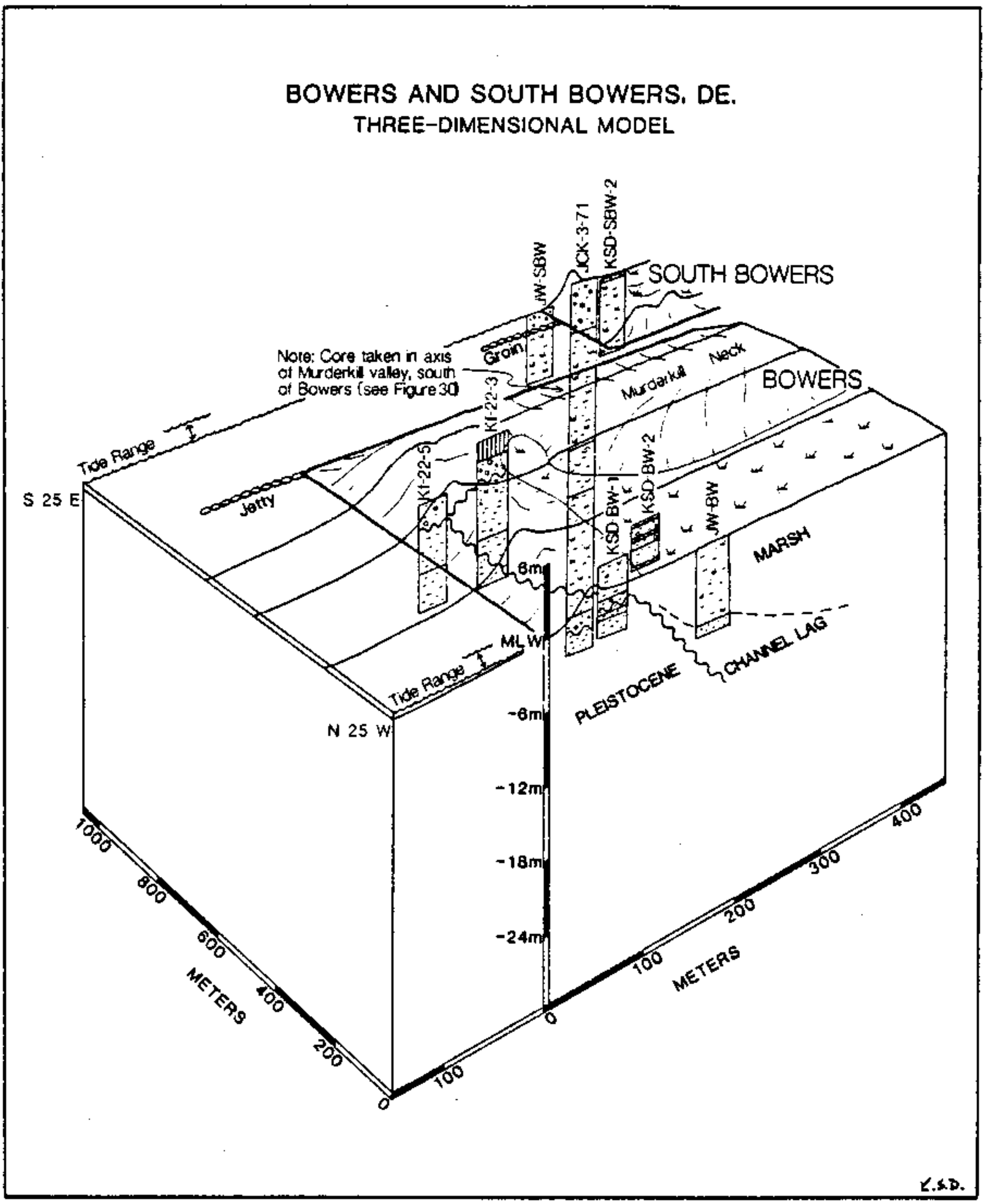


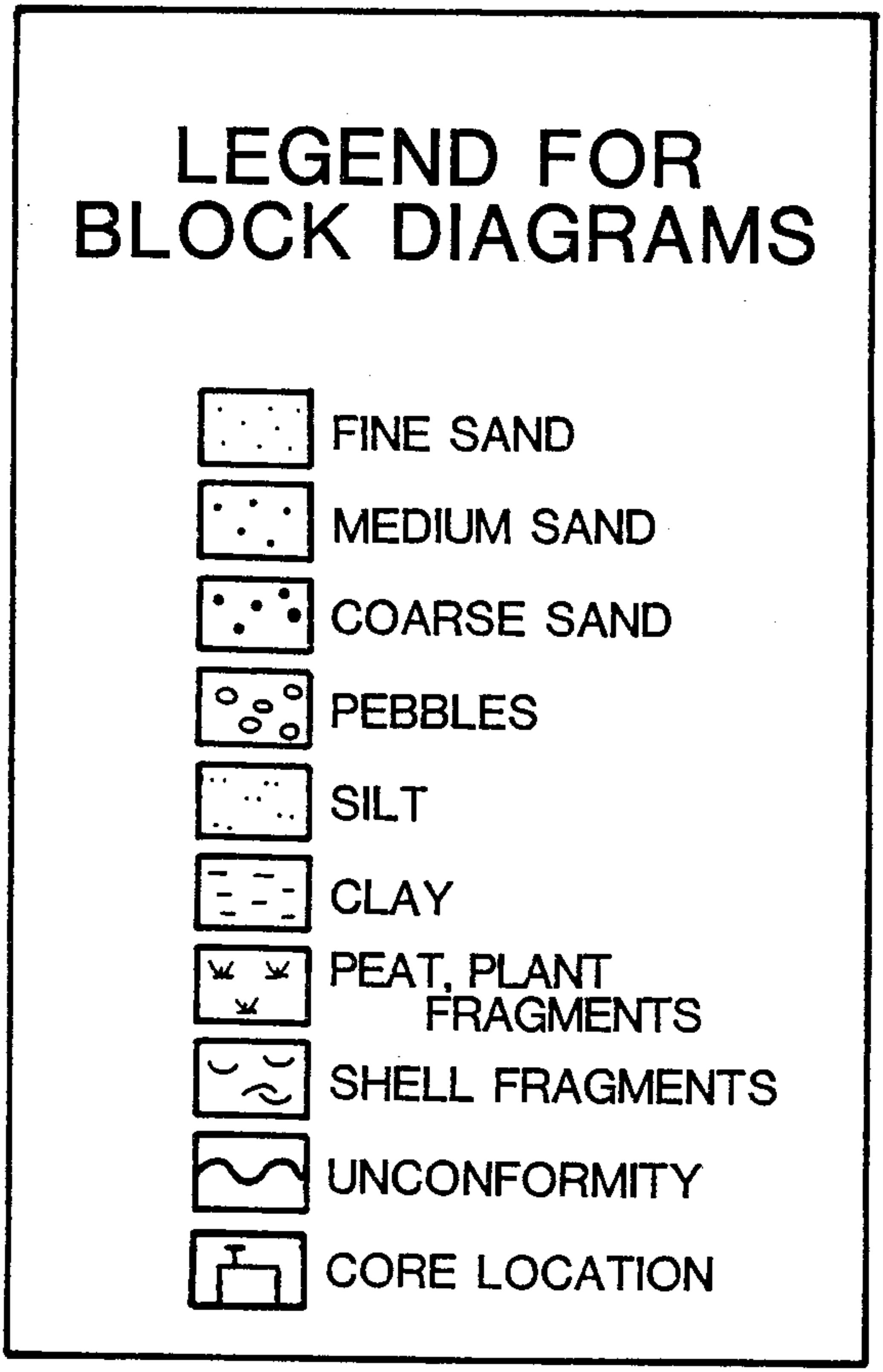
Figure 25. A three-dimensional diagram of the Bowers/South Bowers area depicting subsurface sediments based on core and jetwash logs, and surficial morphology based on U.S. Coast and Geodetic Survey maps and DNREC (1979) maps. See Figure 26 for legend.

tice of dumping dredge spoils from the Murderkill River on either side of the channel, beyond the jetty. In this area, the orientation of a line normal to the shoreline (i.e. θ_n) is 65°, total southward transport is 9100 m^3/yr, total northward transport is 3700 m^3/yr, resulting in a net transport of 5400 m^3/yr southward (Maurmeyer, 1978).

Flooding, as a result of both river and bay overflow, is common in Bowers, due to several factors: 1) the proximity of the St. Jones and Murderkill Rivers, 2) a mosquito ditch system that extends throughout the marsh area and provides inland access to flood waters that might otherwise be contained in a smaller area, 3) beach erosion, and 4) strong winds which tend to "pile up" the water inland and keep it there until the wind direction changes (Friedlander, et. al., 1977). Residents have agreed that flooding occurs frequently, sometimes from the marsh (due to storm and spring high tides) and other times from the bay. Although almost all interviewees agreed that most storms result in severe erosion, the relative damage caused by northeast vs. southeast storms is a subject of disagreement.

Several types of beach protection programs have been attempted by the state since 1962 (Table 5). Between 1962 and 1974, 91,000 m^3 of fill was taken from 1.6-3.2 km offshore and dumped directly on the beach (Dept. of Natural Resources and Environmental Control, 1980).

Figure 26. Legend for three-dimensional (block) diagrams (Figures 25, 42, and 58).



LEGEND FOR BLOCK DIAGRAMS

Following the 1962 storm, the state began a flood control project--at this time, the beach was widened and a sand/gravel dike was built to protect homes. The artificial dune was constructed at Bowers and South Bowers, extending 3000 linear meters, utilizing 37,000 m^3 of material at a total cost of $112,100 (267,100) (Schmidt, personal communication). Unfortunately, volume and cost data are not available for Bowers and South Bowers individually. These proved to be inadequate, since they did not protect residences during the 1974 storm. In 1975, beach grass was planted along the dune line, mainly for the control of wind erosion, and in December of 1975 a sandbag jetty was constructed at the south end of the beach (Figure 27). Residents have generally favorable impressions of all of these protection measures. Most agree that the beach fill was compatible with natural material, seemed to last a fairly long time, and did help protect against erosion. Most interviewees also mentioned the dike and either felt that it was effective, except when it washed through in 1974, or had no feelings one way or the other. All interviewees felt that beach grass planting was a beneficial measure; many said that it has been very useful in holding wind-blown sand and that they could see the difference before and after it was planted. They also agreed on the effectiveness of the sand bag jetty, saying that since it was built, sand has accreted north of the jetty (however, it may not be keeping the channel clear, since dredge spoils are presently dumped at either side of the channal and are subsequently washed back in). However, since the jetty was built in 1975, it has been damaged extensively

Figure 27. Sandbag jetty at Bowers, when first constructed (1977).

Figure 28. Sandbag jetty at Bowers (1980). Extensive damage resulted from boat propellers and fishermen's knives.

by boat propellers (since no warning signs were placed near it) and fishermen's knives, used to cut bait on the sandbags. As a result, the jetty, originally five bags thick, is now only one bag thick (Figure 28) and its effectiveness has probably declined significantly.

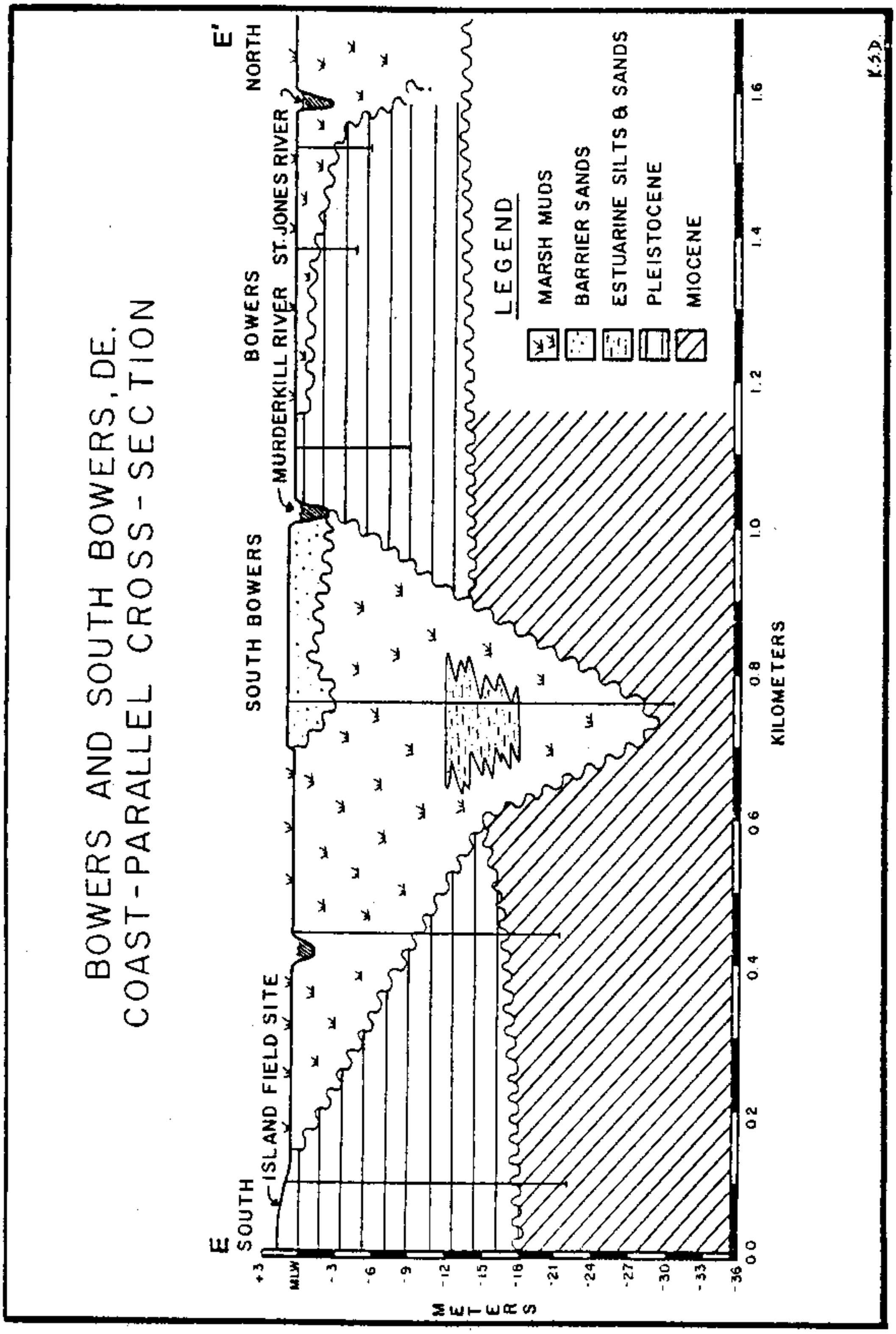
The beach itself seems to be fairly important to residents and visitors of Bowers, despite the community's main orientation towards fishing. Although two of the eight residents interviewed do not presently use the beach, the remainder use it regularly for swimming, sunbathing, and walking; sometimes fishing and waterskiing as well. In addition, two beach surveys were done (Appendix III-B). The first, taken on Saturday, August 16, 1980, at 2:00 P.M. (a sunny, windy, 80°F day, at approximately high tide) showed 26 people using the beach--five were fishing, the rest sunbathing. There were equal numbers of homeowners (or their families) and visitors for the day. A second survey was done on Sunday, August 31, 1980, at 3:00-3:15 P.M. (the weather was sunny, with a temperature of approximately 90°, and the tide level was again close to high). At this time, there were 52 people on the beach, 31 were summer residents, 12 were visitors, five were year-round residents, and four were renters.

It is clear that if coastal development had to occur along the Delaware Bay shoreline, Bowers was a good place for it. Overall, the preservation value ratio for this town is very high (0.74), its only serious drawback being its susceptibility to overwash, from the bay, marsh, and Murderkill and St. Jones Rivers. This flooding will probably continue, unless the causes outlined previously are remedied, but this does not seem to pose a real danger to residents, and in problem cases, houses could be raised onto pilings. Unfortunately, despite the favorable aspects for the development of Bowers, future development of any type is unlikely, since most of the undeveloped land consists of wetlands. In the north part of town there is an area that has been subdivided into residential lots, and these are for sale (Figure 30). The owner was contacted, and she admitted that during very high tides, flooding does occur, and only two lots are suitable for sewer line construction, due to the height of the water table, but if the proper permits are obtained (to allow the filling of wetlands) construction in this area is possible. Despite the favorable aspects of Bowers described above, this would probably not be advisable, due to the height of the water table, the problem with flooding, and the damage to the wetlands that would result from the development. Fortunately, at this time, such permits are very difficult to obtain from the state and federal government (Hardin, personal communication).

South Bowers

Although Bowers and South Bowers are separated only by a river mouth (Figure 20), they are very different demographically and geologically. South Bowers is a small summer community, with no stores, restaurants, businesses, or churches. In 1965 there were only five permanent residents, and 120 summer residents (U.S. Army Corps of Engineers, 1966) occupying the 45 houses located in South Bowers. According to interviewees, these numbers (and the people themselves) have not changed much since then--there are at present only two or three year-round households. On the surface, South Bowers looks very much like Bowers (Figure 22), except there are no Pleistocene outcrops. The barrier is approximately 70 m wide, overall, with a maximum thickness of only 1.5 m, and a volume of approximately $50m^3/m$ shoreline. Offshore, there is a wide expanse of relict marsh deposits which have a very gentle slope (about 1:1000) so that at spring low tide as much as 500 m of tidal flat may be exposed (Maurmeyer, 1978). The beach itself is about 13 m wide (Friedlander, et. al., 1977), with a slope of 1:16 (Maurmeyer, 1978). Landward of the berm crest there is a wide, flat washover terrace which is approximately 50 m wide. The wide, thin nature of this barrier is characteristic of a washover-dominated system (Maurmeyer, 1978). West of the barrier is one to two kilometers of wetlands which are bordered to the west by Pleistocene highlands. A coast-perpendicular cross section through South Bowers illustrates the difference between this area and Bowers in the subsurface (Figure 24b). In South Bowers, barrier sands directly overly 30 m of soft Holocene marsh muds which, in turn, overly Pleistocene material. The marsh muds infilled the late Pleistocene valley of the Murderkill River shown in a coast-parallel cross-section through Bowers and South Bowers, extending to the Island Field Site located south of South Bowers (Figure 29) (Kraft, 1976a). The steepness of the northern wall of this ancient river valley accounts for the fact that Pleistocene material crops out in Bowers while it is found about 30 m below the surface at South Bowers, located less than 50 horizontal meters away. Historically, at least 9700 years B.P., tidal marshes existed in the area, about 26 m below present sea level; subsequently, about 5,000 years ago, the area was covered by a lagoon, perhaps due to land subsidence, a rapid rise in sea level, or a change in the course of the Murderkill River. This was then gradually infilled by tidal salt marsh, which has existed for at least the last 3630 years. 1.6 km offshore, there are remnant marsh peats at 3.7 m below present sea level dated at 2700 years B.P., indicating that at this time the shoreline was seaward of this, at an unknown position (Kraft and John, 1976).

Erosion and washover are dominant processes here, as indicated by the barrier profile characteristics and internal sedimentary structures of sand, gravel, and shells in landward-dipping, foreset cross-laminations, truncated at the seaward side (Note also the low ratings for overwash potential in the preservation value chart (Table 6)). Erosion/accretion rates have varied considerably in the


BOWERS AND SOUTH BOWERS, DE.
COAST-PARALLEL CROSS-SECTION
E
SOUTH
ISLAND FIELD SITE
SOUTH BOWERS
MURDERKILL RIVER
BOWERS
ST. JONES RIVER
NORTH
E'
LEGEND
MARSH MUDS
BARRIER SANDS
ESTUARINE SILTS & SANDS
PLEISTOCENE
MIOCENE
+3
MLW
-3
-6
-9
-12
-15
-18
-21
-24
-27
-30
-33
-36
METERS
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
KILOMETERS
K.S.D.

past. From 1843-1884, the beach accreted at an average rate of 2.2 m/yr. However, from 1884-1910, erosion occurred at a rate of 0.6 m/yr, which increased to 1.4 m/yr from 1910-1954 (Kraft, et. al., 1976). However, these values could be misleading, since the north and south ends of South Bowers have differed in their erosion rates. The north end has had variable accretion and erosion due to 1) the change in position of the mouth of the Murderkill River, 2) the emplacement and reworking of dredged material from the river (Maurmeyer, 1978), 3) the construction of a coast-parallel dike along the dune line in 1962, and 4) the construction of two sandbag groins in 1977. The south end, on the other hand, has eroded continuously during the past 100 years at an average rate of 2.3 m/yr due to 1) the low elevation of the barrier, permitting frequent overwash and landward transport of beach sands, 2) land subsidence at the rate of about 0.15 m/century, leading to a greater relative rate of sea level rise, and 3) the high erodability of the underlying marsh muds (Maurmeyer, 1978).

Rates of longshore transport also vary between the north and south ends of town. The northern section, with an outward normal of 53^{o}, has a total southward transport of 10,400 m^{3}/yr, a total northward transport of 3200 m^{3}/yr, and a net transport of 7200 m^{3}/yr southward. The south end is characterized by slightly higher rates. θ_{n} is 40^{o}, total southward transport is 12,200 m^{3}/yr, and total

Figure 29 (previous page). Coast-parallel geologic cross section extending from the St. Jones River marsh north of Bowers, southward across the Bowers highland and the deeply-incised, Holocene sediment-infilled ancestral Murderkill River valley at South Bowers, to the Island Field Site highland.

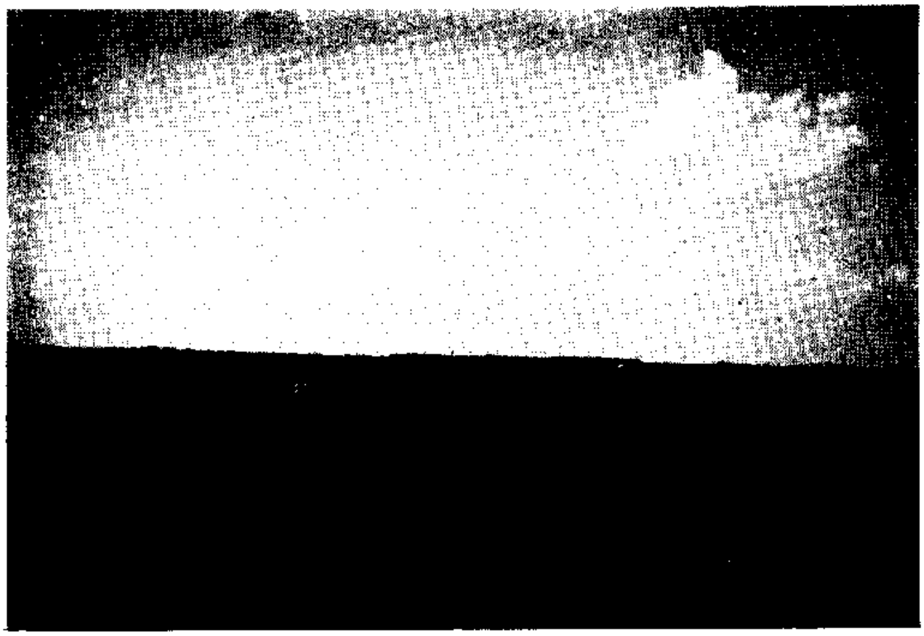


Figure 30. Sign advertising "Beachfront Lots for Sale" in wetlands of northern Bowers.

Figure 31. Ground photograph of South Bowers, Delaware, looking northward towards Bowers.

northward transport is 3200 m^3/yr, giving a predicted net transport of 9000 m^3/yr southward. Although these calculated values indicate southward transport, groin accumulations indicate dominant transport to the north. Pre-Holocene headlands and the linear channel-margin shoals (that existed prior to the jetty construction) may prevent waves from the north from reaching the South Bowers shore, or flood tidal waters into the inlet could transport sand to the north (Maurmeyer, 1978).

Most interviewees felt that erosion was not a very serious problem at present, especially at the north end of town, except some erosion does occur continually, and storms also result in erosion. Most of those that felt there was a difference in the erosion potential of northeast vs. southeast storms said that southeast storms created more damage--this indicates that the headlands or channel-margin shoals of Bowers may, in fact, serve a protective function for South Bowers, and in recent years, the sandbag jetty may have as well. Two residents mentioned flooding that occurs from the marsh to the west of town. Apparently, although the access road to South Bowers was raised and rebuilt ten years ago, it now floods periodically, during very high tides, and the state is currently raising the road in this area again, at least providing a temporary solution to this problem.

Several types of beach preservation measures have been undertaken in South Bowers (Table 9). Although South Bowers has received fewer cubic meters of nourishment sand than many other areas, and thus has a high preservation value rating for this criterion (Table 6) this value is misleading, since South Bowers has a very short length of beach to nourish, and thus requires less sand when nourishment is done. In addition, the landward transport of dredged material from the Murderkill River could have reduced nourishment needs. The beach has been nourished four times between 1961 and 1976, for a total of 36,900 m^3 in 15 years, or an average of 2500 m^3/yr (Dept. of Natural Resources and Environmental Control, 1980). After the 1962 storm, a dike was built using material trucked in from another source. Two sandbag groins of similar construction to the jetty at Bowers were built in 1977, and are also currently in a state of disrepair. However, they do seem to be holding sediment near shore, as evidenced by the patterns of shoaling found. In addition, dune grass was planted in 1975, at an approximate cost of $100.

Dredging of the Murderkill River (1912-1930) and the Murderkill River entrance channel (1931-1979) has been done by the U.S. Army Corps of Engineers approximately every 2-3 years (U.S. Army Corps of Engineers, 1981) and has also probably affected erosion rates in South Bowers. Although no data are available on this, it is conceivable that erosion along the north shore of South Bowers would be accelerated by the greater tidal currents that could result from the dredging. Alternatively, this dredging could serve to add sand to the beach, either directly, as in 1976, when 7200 m^3 of dredge spoils were dumped on the South Bowers beach, or

TABLE 9

Beach Preservation Measures: South Bowers, DE.

Year	Action Taken	Cost
1961	15,300 m^3 fill placed	?
1962	Dike built (7,600 m^3 fill)	$25,200 (60,000)
1974	3,000 m^3 fill placed	$14,200 (22,200)
	Dike repaired	?
1975	11,400 m^3 fill placed	$15,000 (21,400)
	Beach grass planted	$100 (143)
1976	7,200 m^3 fill placed	?
1977	Sandbag groins built	$16,000 (22,800)
	Total:	$70,500(126 543+)

TABLE 10

Beach Preservation Measures: Slaughter Beach, DE.

Year	Action Taken	Cost
1920	South Mispillion jetty built: 1784 m	?
1939	North Mispillion jetty built: 1979 m	?
1940	4 Timber groins at south end	?
1943	2 timber groins north of others	$43,200 (207,500)
		?
1947	7 timber groins north of others	?
1950	3 timber groins north of others	$15,630 (49,000)
		??
1954	Repair and exten. of north groin	?
	2 timber groins north of others	$11,540 (32,200)
		?
1957	2 timber groins north of others	$46,250 (121,000)
		$8,280 (21,900)
1958	37,400 m^3 fill along 457.5 m shore	?
1961	126,000 m^3 fill along 457.5 m shore	?
1962	43,200 m^3 fill along 1,525.0 m shore	$117,700 (280,500)
1964-1966	Private bulkheads built	?
1966	Jetties inspected: N--good; S--fair	?
1975	Private bulkheads repaired	?
	206,200 m^3 fill on S. Slaughter B.	$270,100 (385,700)
	Beach grass planted	$300 (428)
	265,000 m^3 fill on N. Slaughter B.	$347,100 (495,700)
	Total:	$860,100+(1,594,000+)

Tables 9 and 10. South Bowers and Slaughter Beach preservation measures and costs, where known (numbers in parentheses are in 1980 dollars) (DNREC, 1980) indirectly, when spoils that were deposited offshore were transported onshore through wave and current processes.

Like those of Bowers, intervewees of South Bowers were generally in agreement that the beach protection measures have been effective (Figure 31). Most liked the beach nourishment that was done (except one person, who said it made the beach coarser, with more shells and pebbles) and that it generally lasts a long time (although one resident said that it gets washed away during the next southeast storm). The groins are perceived to help control erosion as well, though their effectiveness may be diminished due to their state of disrepair. Somewhat surprisingly, about half of the people talked to did not realize that beach grass had been planted (probably since it was done in October, when few people were there) but the other half said that it has been effective in controlling aeolian erosion.

In addition to the erosion problem faced by South Bowers residents, the high subsidence rates of the underlying marsh muds create problems for many residents as well. Although the natural subsidence rate is only 0.15 m/century (Belknap and Kraft, 1977), this is greatly accelerated when anything is built on top of these muds. One permanent resident said that when pilings were driven in along the south side of the Murderkill River to construct a dock, their weight was sufficient to practically drive themselves in (G. Washington, personal communication). Other residents have spoken of the need to jack up their houses periodically, as they settle. One man said that he used to think sand was piling up around the house, but since the dike was constructed, there has not been much sand movement,yet the house continued to sink. The house was jacked up 16 years ago. Since then, it has sunk 76 cm and needs to be raised again. Apparently, this is a common problem--when the house raiser came several years ago, he worked on about eight houses in the area. The extent of structural damage that has resulted from this sinking is not known. Most of the houses in South Bowers are constructed on pilings, but these are generally only 3.05 m long, with 1.8 m underground (J. Reynolds, resident, personal communication). According to Kraft, et. al. (1976), stable building foundations would require pilings to extend at least 30.5 m underground, at considerable cost to the homeowner.

South Bowers, like most of the other communities studied, has no land available for further development, since it is bordered by wetlands (Figure 22). The continuation of beach preservation measures is economically unjustifyable at this time, based on the parameters studied for this report. There are only about five year-round residents here, and very few summer residents. Since there are only about 37 houses altogether, the total property values are quite low as well. Geologically, this is a very unfavorable area for a community--the town is underlain by up to 30 meters of soft, unconsolidated marsh muds, leading to sinking problems for many homeowners; in addition, although erosion rates are only moderate, they would be likely to increase if beach nourishment (here, or on adjacent beaches), and dredging of the Murderkill River (with associated spoils dumping) were discontinued. Finally, the barrier itself is highly prone to washover (Table 6).

However, despite the unfavorable characteristics of South Bowers described above, one could also argue that South Bowers is a viable community, that should be left alone. First, although this is a very small summer community, with very few year-round residents, it cannot be described as transient. Like Bowers residents, those of South Bowers have generally been associated with the area for many years (interviewees had been coming here for 12 to 68 years, with the average being almost 33 years). This low turnover rate was also mentioned by a realtor for the area, who said that his company had to do a land appraisal in the community several years ago, but had nothing to base it on, since there have been few or no housing sales in the last ten years or so (W. Bryan, personal communication). Also, based on resident interviews and beach surveys, beach characteristics do not appear to be very important to residents, since only 1/3 of those interviewed used the beach for sunbathing, and only 1/6 ever went swimming there--the rest either did not use the beach at all, or only for walking or fishing. The Saturday, August 16, 1980 beach survey, done at 2:30 P.M., showed that only six people were on the beach at the time (all of whom owned their own homes, and were seasonal residents), and five were sunbathing, one was walking. The Labor Day weekend survey (Sunday, August 31, 1980, at 2:15-2:30 P.M.) showed only five people using the beach, all of whom were seasonal residents. Perhaps, for these reasons, beach nourishment programs at South Bowers could be reduced or eliminated, without serious consequences to the current residents for the next 10-15 years at least, allowing them time to either relocate or make their homes more adaptable to washover. Before such a program is begun, however, it would be advisable to conduct more interviews and surveys to more accurately determine the extent of beach use.

Bennett's Pier

This section of coast, located approximately 3.2 km south of South Bowers, has no houses or other buildings, but an access road does exist (Figure 32). It is similar to South Bowers in overall morphology (i.e. barrier sands backed by marsh), but the beach face is slightly steeper, and the barrier contains more sand: its maximum width and thickness are about 80 m and 1.8 m respectively. The barrier volume is relatively large: about 70 m^3/m. This may be due to the proximity of a pre-Holocene hill which crops out at the shoreline north of Bennett's Pier, supplying sand by longshore transport (Maurmeyer, 1978). The beach itself is only about five meters wide (to MLW), and the low dune is covered with _P. communis_ and extends to the high tide line. Tidal marshes extend about one kilometer southwest of the barrier, to pre-Holocene highlands (Figure 34), and marsh also outcrops under the barrier sands on the beach face. The subsurface of Bennett's Pier is shown by the cross-section in Figure 35. Barrier sands characterized by very coarse material overlie only about two meters of Holocene marsh muds, with an interlayering of muds and washover sands landward of the barrier. Pleistocene material underlies these muds (Kraft and John, 1976).

Erosion is moderate in this area. From 1843-1884, the beach accreted at an average rate of 1.5 m/yr, but from 1884-1910, erosion occurred at the rate of 2.3 m/yr. From 1910-1954, this decreased to 1.4 m/yr (Kraft, et. al., 1976). Reasons for the earlier accretion

Figure 32. Aerial photograph of Bennett's Pier, Delaware, showing recent washover deposits (September, 1979).

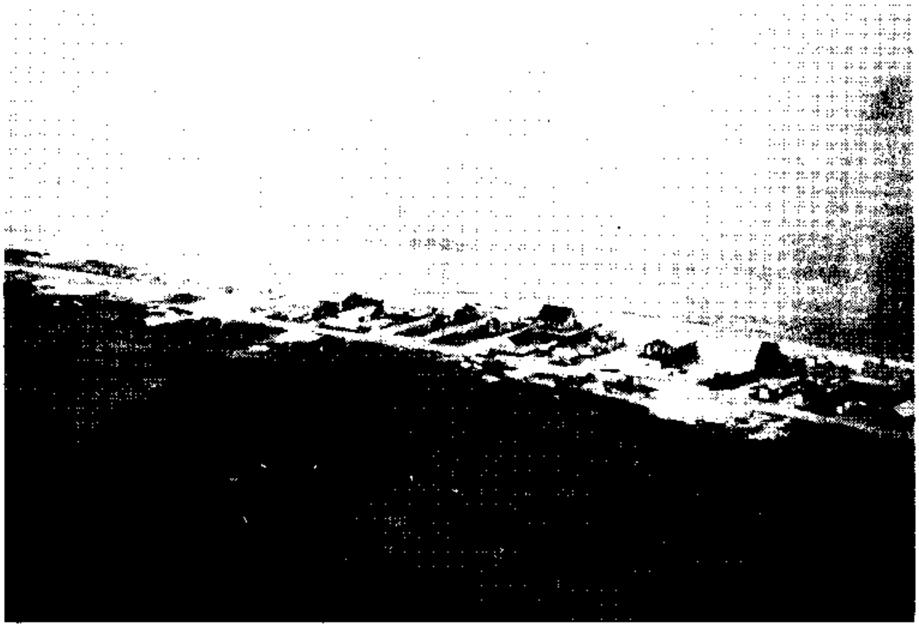


Figure 33. Aerial photograph of Big Stone Beach, Delaware (May, 1976).

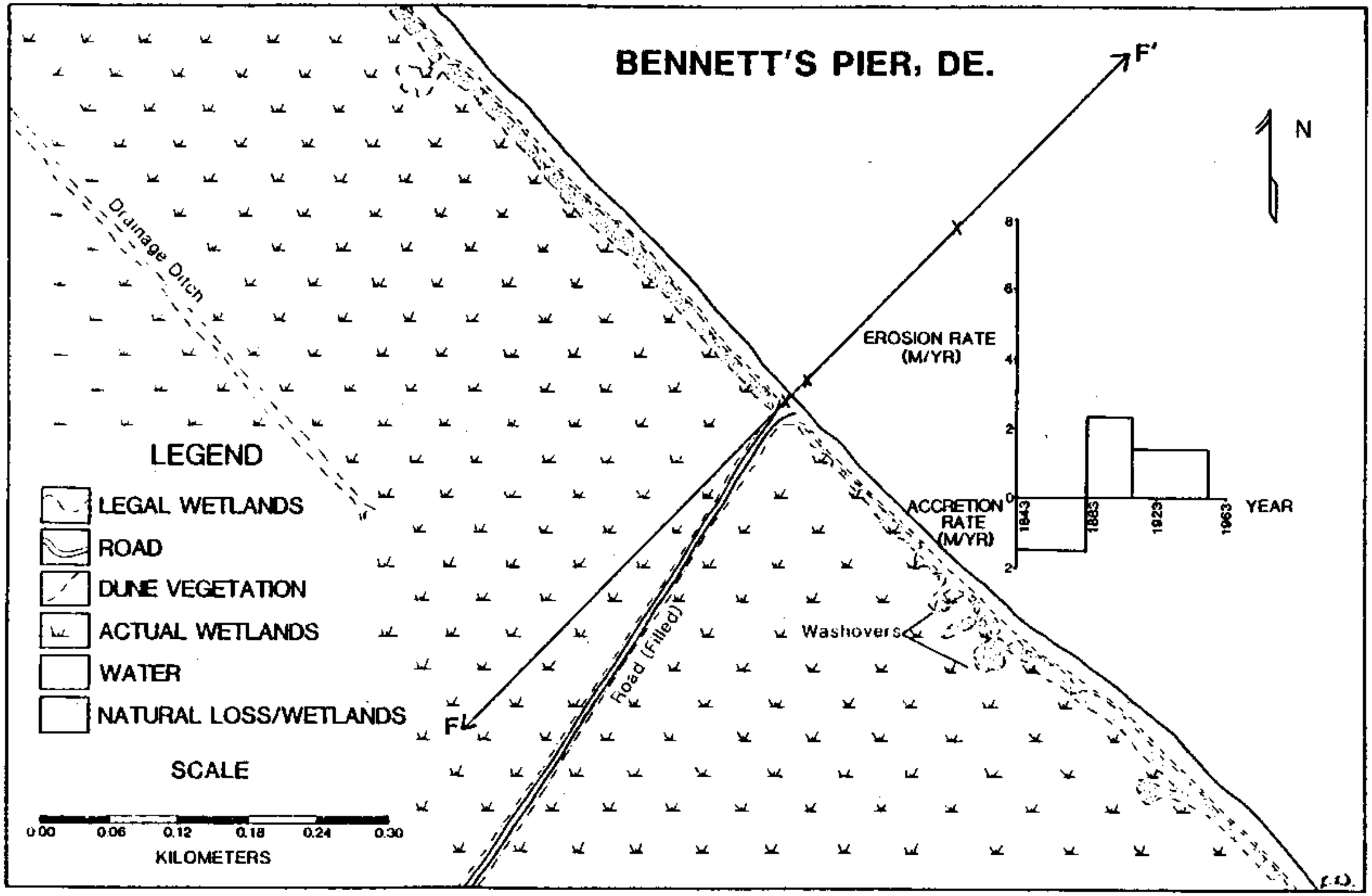
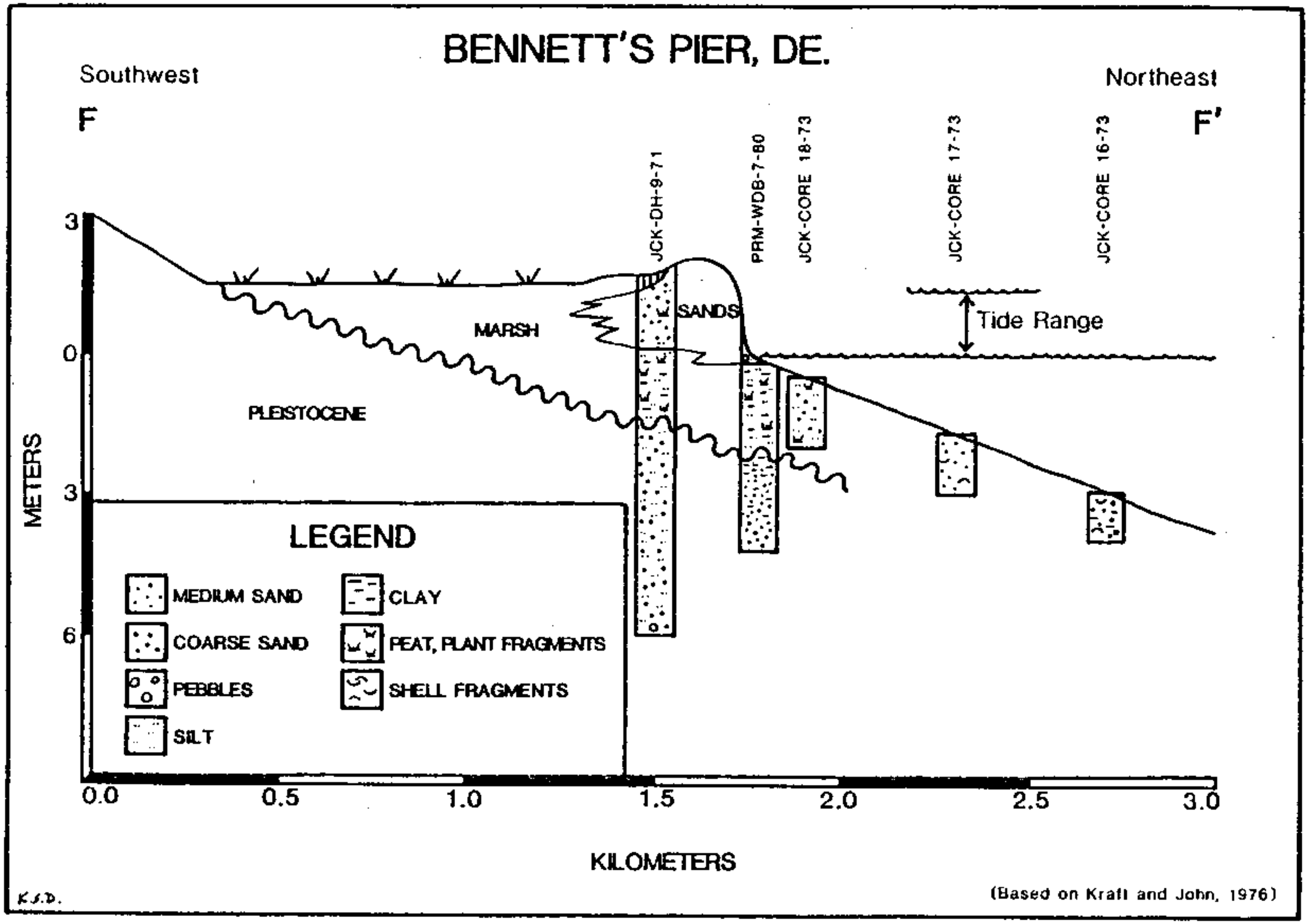


Figure 34. Map of Bennett's Pier, Delaware, showing past and present wetlands classification, line of cross section, core locations (X's) and historical erosion rates.



(Based on Kraft and John, 1976)

Figure 35. A geologic cross section at Bennett's Pier, showing coastal environment sedimentary units based on core data.

and subsequent erosion are not known, but may be related to the relatively high longshore transport rates found: θ_n is 42° here, with a total southward transport of 11,900 m^3/yr, total northward transport of 3,200 m^3/yr, and net transport of 8,700 m^3/yr (predicted) to the south (Maurmeyer, 1978). Perhaps erosion of the pre-Holocene headland north of Bennett's Pier was accelerated for some reason during this time, and the material was transported to this section of coast, or maybe the wave climate was such that there was an onshore migration of sand from the offshore (in fact, coarse sand was found offshore in recent years (Figure 35) (Kraft and John, 1976)).

The beach profile of this area was monitored for several months, and illustrates the events that can occur after a washover. During a storm, 0.15 m of sand was deposited on a washover fan. A profile was taken in December, and by this time, 0.8 m^3/m sand was removed from the fan by aeolian processes and the surface was lowered by 0.05 m (i.e. 33%). In addition, the beach face slope steepened slightly since material was removed from the lower beach face and deposited near the berm crest. In March of the following year, a sand ridge began migrating onto the beach face and by May it had welded onto the berm. This resulted in four meters of seaward accretion of the beach, a 0.5 m increase in berm height, and the addition of 2.6 m^3/m of sand to the profile (Maurmeyer, 1978).

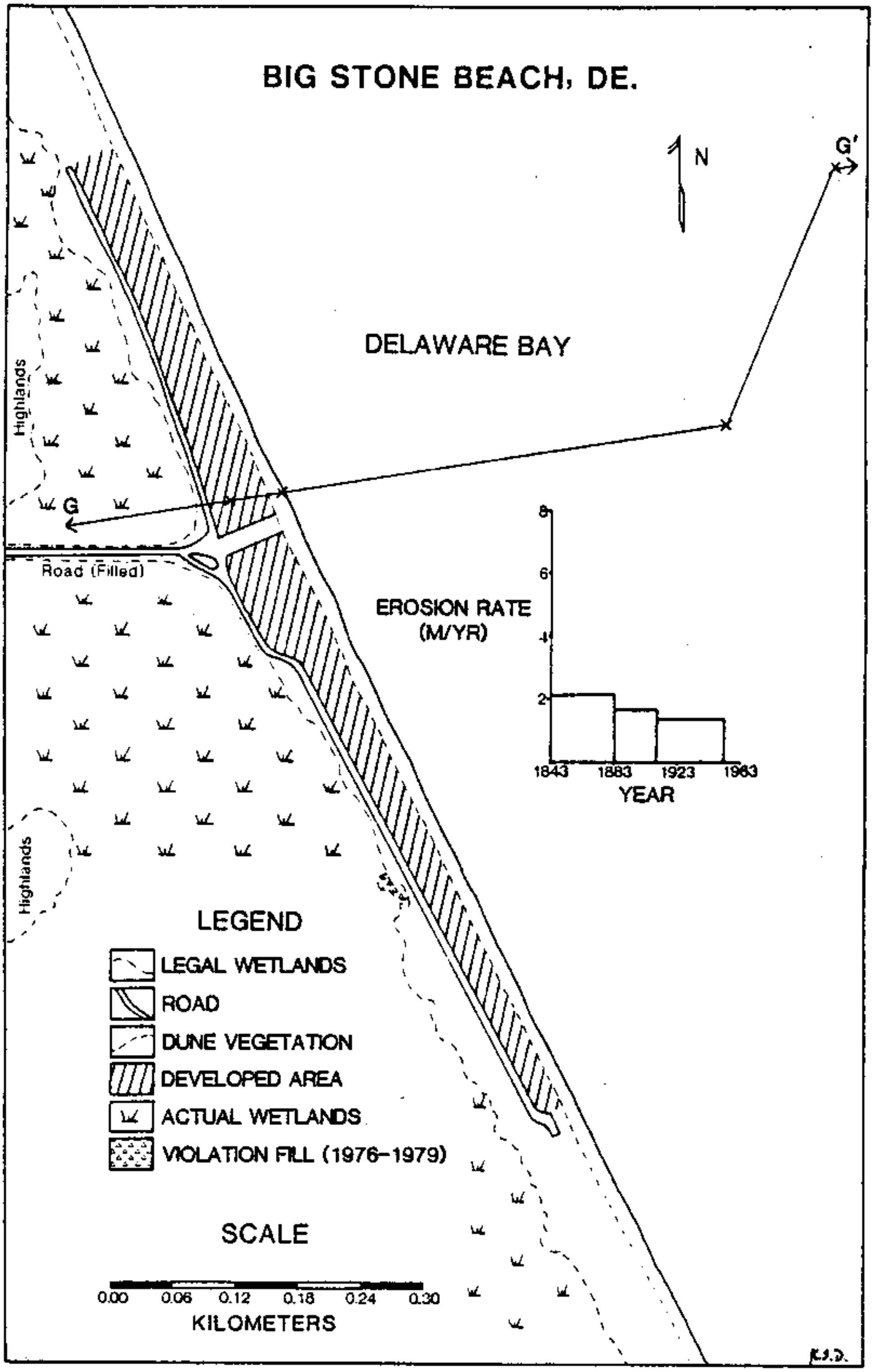
Overall, Bennett's Pier has a very low preservation value ratio (0.29) (Table 6). This is due mainly to the lack of development and residents, and the susceptibility of the area to washover. Although washover fans have developed since 1973 (Figure 34), resulting in a strip of land up to 30 m wide, west of the dune line, this area should probably not be developed, since it actually consists of just a thin (probably less than 0.3 m) veneer of sand over marsh deposits.

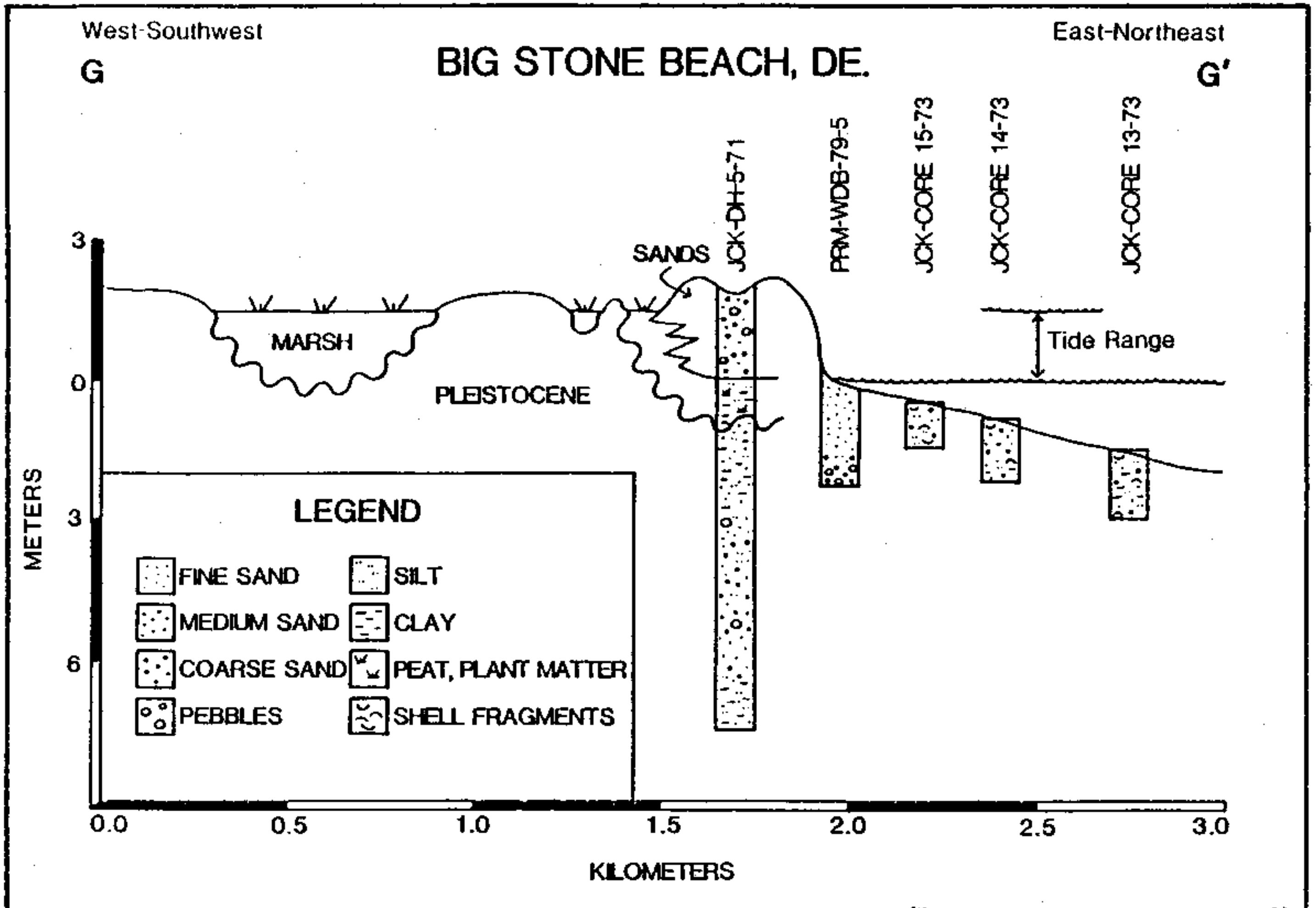
Big Stone Beach

Big Stone Beach, located approximately 4.0 km southeast of Bennett's Pier, has a developed section about 0.8 km long (Figures 33 and 36) with about 60 houses, most of which are only occupied in the summer. All of these are located along the landward edge of the dune line. The permanent population in 1965 was 20, and the summer population was 160. The beach in this area is approximately 21.3 m wide to the high water line, with a slope of 1:7, and is backed by a mixed sand and gravel dune, about 6.1 m wide at the base, with a maximum elevation of about 3.0 m above MLW (or 1.6 m above MHW) (U.S. Army Corps of Engineers, 1966). Several hundred meters west of the barrier, pre-Holocene highlands crop out at the surface, and, as indicated by a cross section through Big Stone Beach (Figure 37), although the barrier is situated over a thin (approximately one meter) layer of marsh muds, Pleistocene material is quite close to the surface (Kraft and John, 1976).

This section of coast has been eroding at a fairly constant rate since 1843. In the north part of Big Stone Beach, for the first 41 years, the beach eroded at an average rate of 2.2 m/yr. Between 1884 and 1910, this decreased slightly to 1.7 m/yr, and from 1910 to 1954 there was a further decrease to 1.4 m/yr. In the

Figure 36. Map of Big Stone Beach, Delaware, showing past and present wetlands classification, line of cross section, core locations (X's), and historical erosion rates.


BIG STONE BEACH, DE.
N
G'
DELAWARE BAY
Highlands
G
Road (Filled)
EROSION RATE
(M/YR)
8
6
4
2
1843
1883
1923
1963
YEAR
Highlands
LEGEND
LEGAL WETLANDS
ROAD
DUNE VEGETATION
DEVELOPED AREA
ACTUAL WETLANDS
VIOLATION FILL (1976–1979)
SCALE
0.00
0.06
0.12
0.18
0.24
0.30
KILOMETERS
K.J.D.



(Based on Kraft and John, 1976)

Figure 37. A geologic cross section at Big Stone Beach, Delaware, showing coastal environment sedimentary units based on core data.

southern section, the average erosion rate for this time period (1843-1954) was 1.4 m/yr (Kraft, et. al., 1976). Apparently, erosion has occurred fairly continually, due to a combination of rise in sea level, storm damage, wave action, and longshore transport of sand. θ_n of Big Stone Beach is 60°, total southward transport is 9,900 m^3/yr, total northward transport is 3,400 m^3/yr, resulting in a predicted net transport of 6,500 m^3/yr southward (Maurmeyer, 1978). The fact that Big Stone Beach did not accrete overall from 1843-1884, as did Bennetts Pier, tends to invalidate the possibility that during this time there was increased erosion of the headlands north of Bennett's Pier, increasing the sand supply to that area--however, it is still unclear why marked accretion would occur at Bennett's Pier at that time, while erosion occurred farther down the coast, when longshore transport would tend to carry sand southward. Perhaps longshore transport characteristics were different at that time, in terms of quantities of material carried, or dominant direction. The distance between Big Stone Beach and the source material may be another important consideration. Beach profile monitoring at Big Stone Beach showed a general pattern of a wide beach in June, recession from October to December, onshore sand migration in the spring, and a welding of this ridge to the berm in May. There was a three meter variation in beach width throughout the year, and a net accretion of 1.0 m/yr from 1976-1977. However, this was probably just a short-term effect (Maurmeyer, 1978) perhaps caused by fewer storms during this time period.

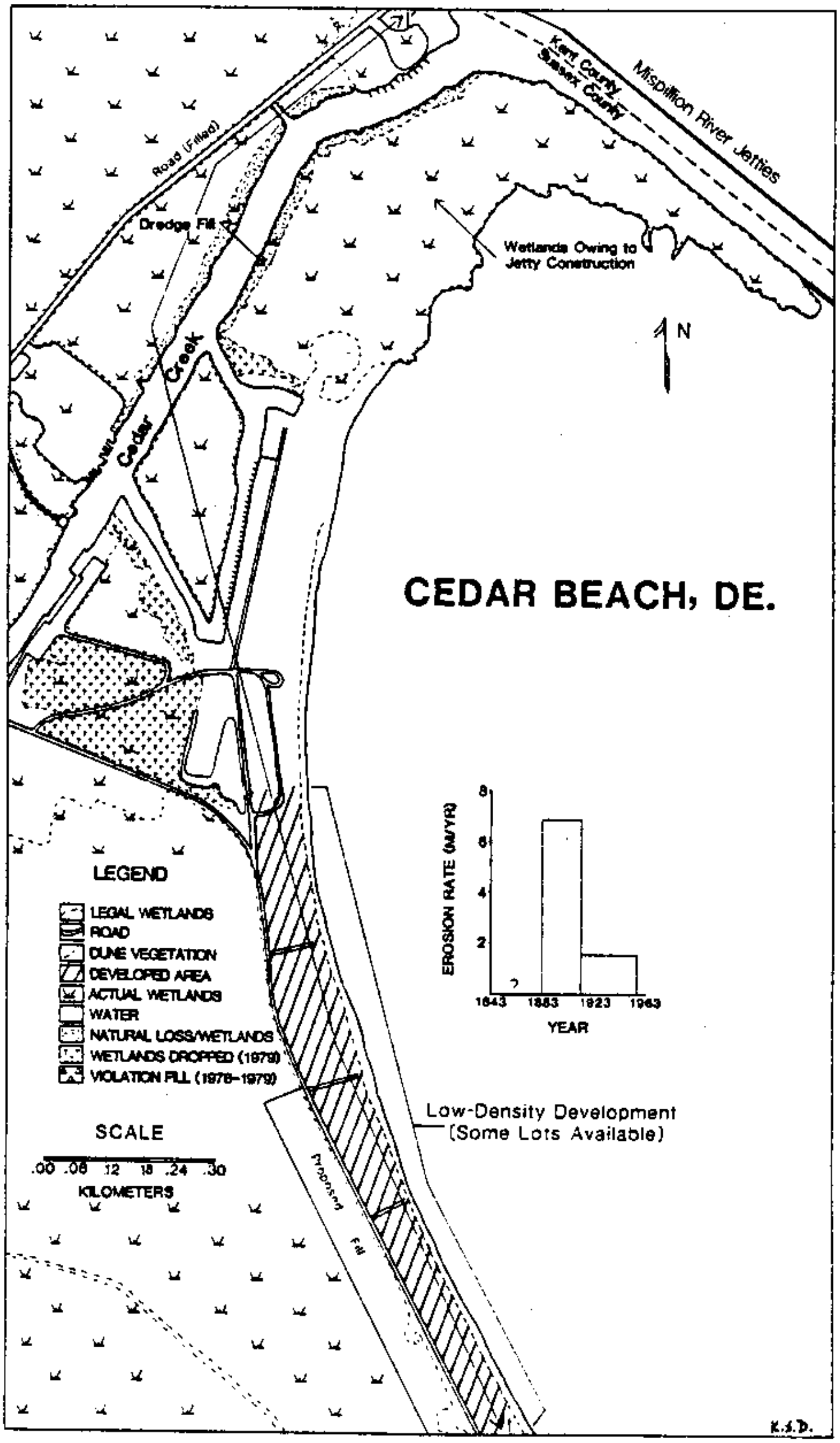
Beach nourishment was done in 1962, after the March storm, at which time 19,800 m^3 sediment were placed on the beach, at a cost of $57,100 (136,100) (Dept. of Natural Resources and Environmental Control, 1980). To my knowledge, this is the only beach preservation measure that has been taken.

The preservation value ratio for Big Stone Beach is moderate (0.57) (Table 6) mainly due to its small population, low property values, and high overwash potential. However, based on the other geological factors, Big Stone Beach is one of the more favorable areas for low-density residential development and/or beach preservation along the western shore of Delaware Bay, and, in fact, there are some lots available for housing, within the town and to the north and south. Like Bennett's Pier, it has a fairly stable subsurface, so subsidence should not create a problem. Although erosion probably occurs continually, recent figures are not available on this, and even if erosion continues at a rate of 1.37 m/yr, this could be controlled through beach nourishment, and probably groin construction (since longshore transport rates are moderate here). In any case, it might be worthwhile to interview the summer and year-round residents to find out how long they have lived there or been spending summers there, and their perceptions of beach changes and storm damage that have occurred in the time they have been associated with the area.

Cedar Beach/Slaughter Beach

These coastal communities are located directly south of Mispillion Inlet, where the Mispillion River and Cedar Creek empty into Delaware Bay (Figures 38, 39, and 40). The inlet is currently stabilized with two jetties, and is used by recreational fishing boats; it is also the location of a public launch ramp, a launch service, private marinas, and a restaurant. Cedar Beach is a small community consisting of 25 houses, which is really a northern extension of Slaughter Beach. Slaughter Beach, an incorporated town, has a developed area that extends 2.4 km along the coast, and, in 1979, included about 150 houses. The population has grown in the past 40 years: in 1940 there were 46 permanent residents, in 1950 this increased to 85, in 1960 there were 107, and in 1965 there were 130 permanent residents and 430 summer residents (U.S. Army Corps of Engineers, 1966) (this influx was due mainly to private homeowners, and a few renters, since there are no commercial hotels or motels (Friedlander, et. al., 1977)). Between 1960 and 1970, the number of permanent residents declined to 85, and has remained relatively constant through 1977 (Bureau of the Census, 1979). In 1980, the town secretary estimated the permanent population to be 85 and the summer population to be about 400 (Jaywork, personal communication).

Figure 38. Map of Cedar Beach, Delaware, showing developed area, past and present wetlands classification, lines of coast-parallel and coast-perpendicular cross-section, core locations (X's) and historical erosion rates. Note extensive areas of "Wetlands Dropped (1979)."


Kent County
Sussex County
Mispillion River Jetties
Road (Filled)
Dredge Fill
Wetlands Owing to Jetty Construction
N
Cedar Creek
CEDAR BEACH, DE.
EROSION RATE (M/YR)
8
6
4
2
?
1843
1883
1923
1963
YEAR
LEGEND
LEGAL WETLANDS
ROAD
DUNE VEGETATION
DEVELOPED AREA
ACTUAL WETLANDS
WATER
NATURAL LOSS/WETLANDS
WETLANDS DROPPED (1979)
VIOLATION FILL (1976–1979)
SCALE
.00 .06 .12 .18 .24 .30
KILOMETERS
Proposed Fill
Low-Density Development (Some Lots Available)
K.S.D.

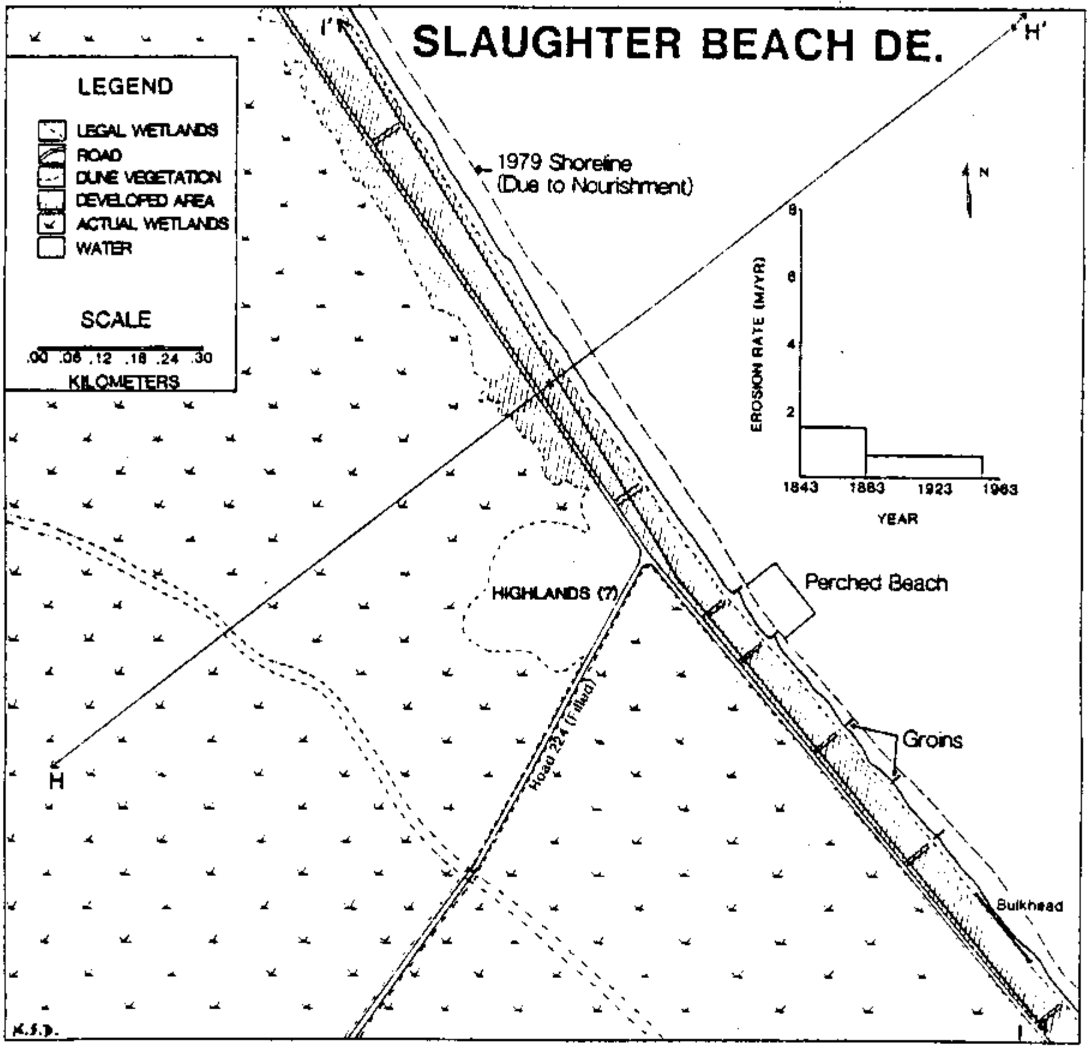


Figure 39. Map of Slaughter Beach, Delaware, showing developed area, past and present wetlands classification, lines of coast-parallel and coast-perpendicular cross section, core locations (X's) and historical erosion rates.

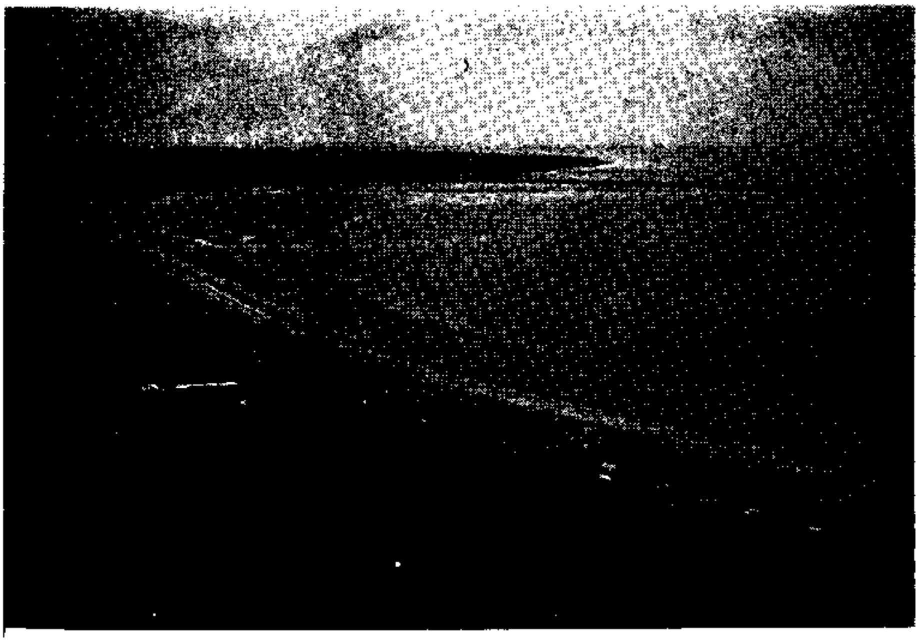


Figure 40. Aerial photograph of Cedar Beach to the north (top of picture) and Slaughter Beach (August, 1980).

Figure 41. Photograph of tidal flat at Cedar Beach, Delaware, exposed at normal low tide. Beaches along western Delaware Bay are typically covered with horseshoe crabs for one month during the summer.

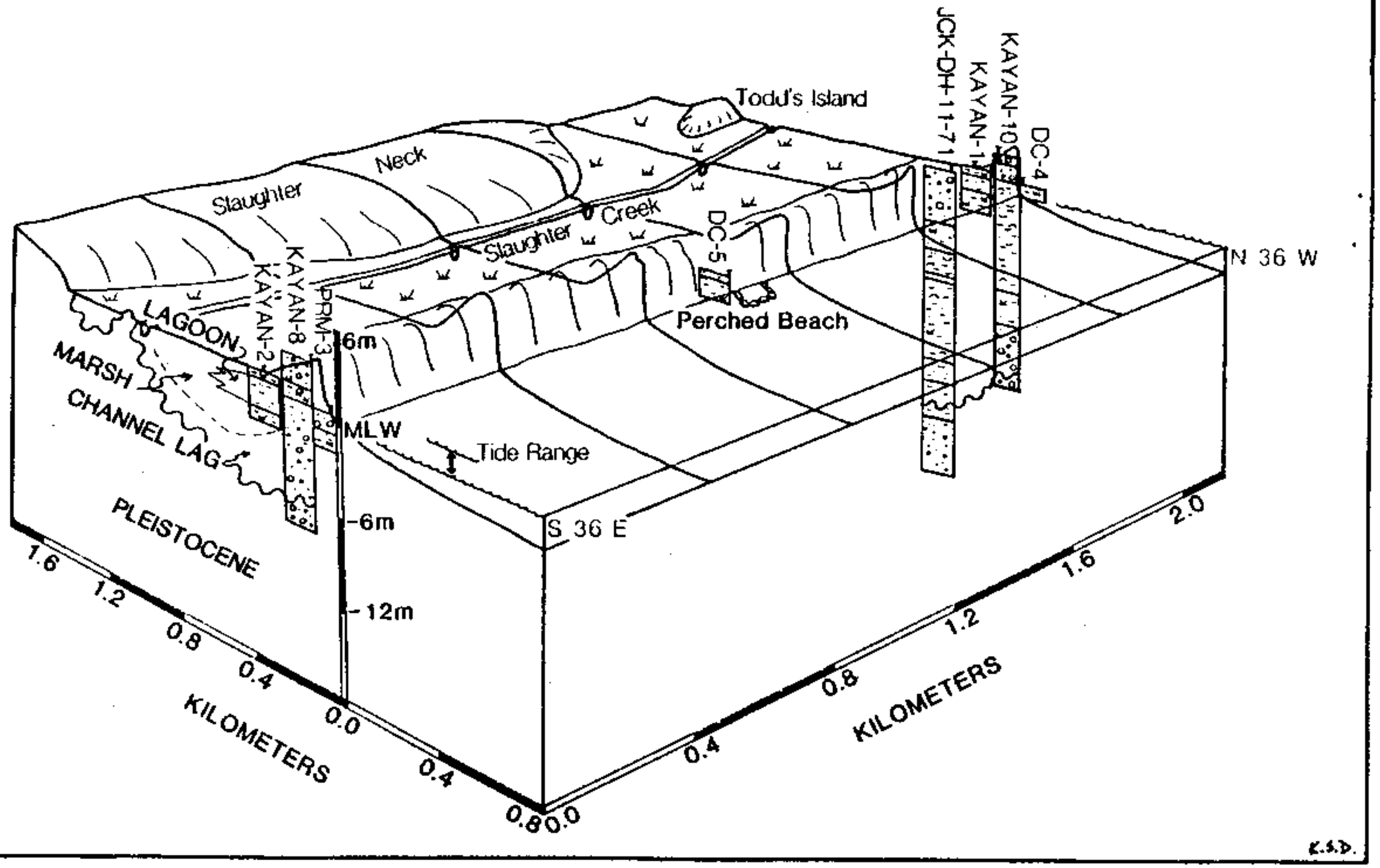
Map views of Slaughter Beach (Figure 39) and Cedar Beach (Figure 38) show that the barrier ranges from 110 to 150 m in width. The beach is about 30.5 m wide, including a 9.2 m berm; the beach slope is 1:10 (Friedlander, et. al., 1977). Landward of this, wetlands extend 0.7-2.0 km to Pleistocene headlands. Offshore characteristics vary from a slope of 1:450 off the shore of southeast Slaughter Beach to a tidal flat that extends from Cedar Beach and northern Slaughter Beach to the south jetty of Mispillion Inlet (Figure 41).

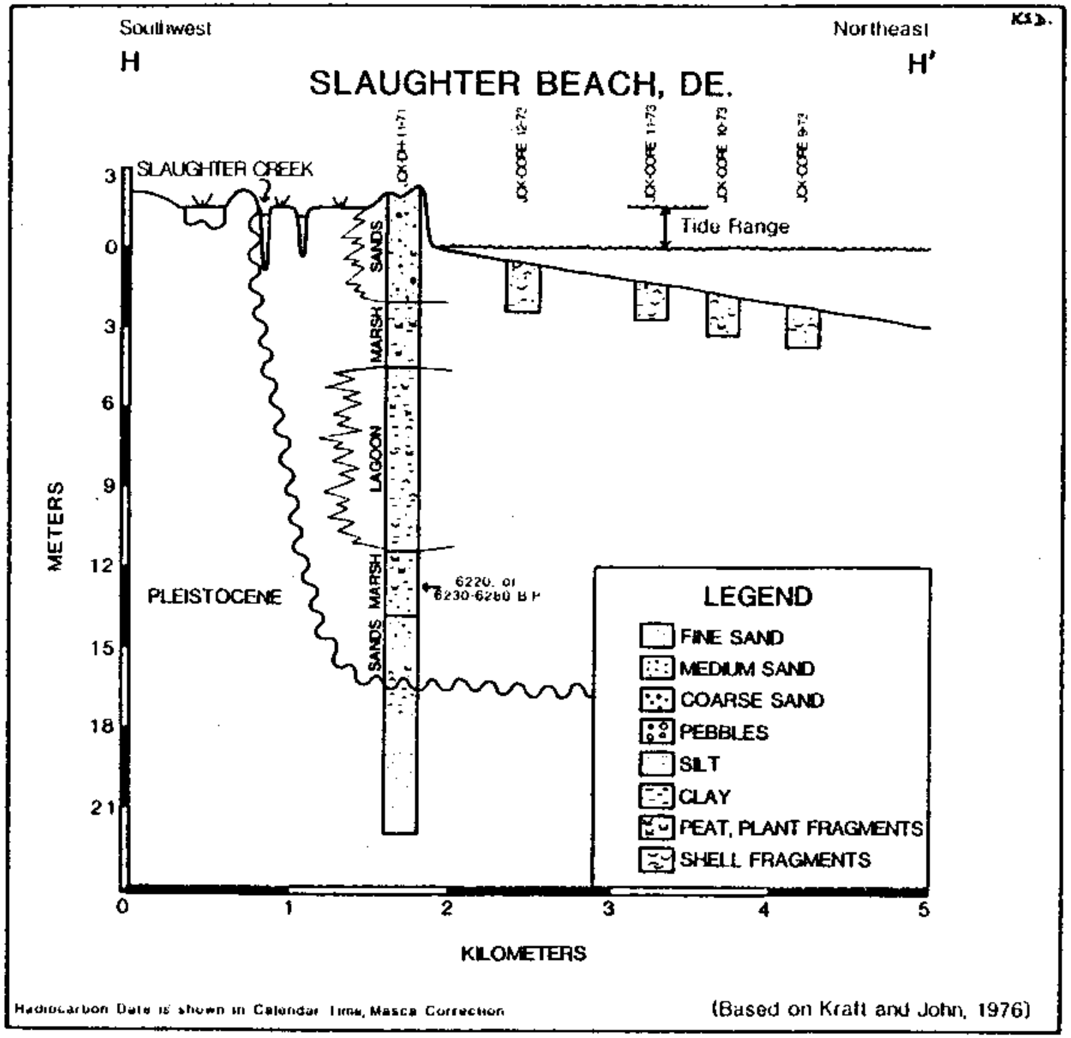
This area has a fairly unique geologic history, as shown by the sequence of sediments of a three-dimensional model (Figure 42) and coast-perpendicular cross-section (Figure 43). Prior to about 10,000 years B.P., basal sands directly overlaid Pleistocene material (Kayan and Kraft, 1979). As the transgression continued, marsh muds were deposited over the sands, until about 6,000 B.P. when a lagoon formed, due to land subsidence or a sudden rise in sea level. At about 3600 B.P. the lagoon was gradually infilled by marsh muds and grasses and since this time the marsh was, and is being, transgressed by barrier sands. When viewed from Delaware Bay, looking landward, a coast-parallel cross section (Figure 44) further illustrates the subsurface complexity. A situation similar to that found in Bowers and South Bowers exists: two Pleistocene headlands

Figure 42. A three-dimensional diagram of Slaughter Beach, Delaware, depicting subsurface sediments based on core and jetwash logs, and surficial morphology based on U.S. Coast and Geodetic Survey maps and DNREC (1979) maps. See Figure 26 for legend.

SLAUGHTER BEACH, DE.

THREE-DIMENSIONAL MODEL

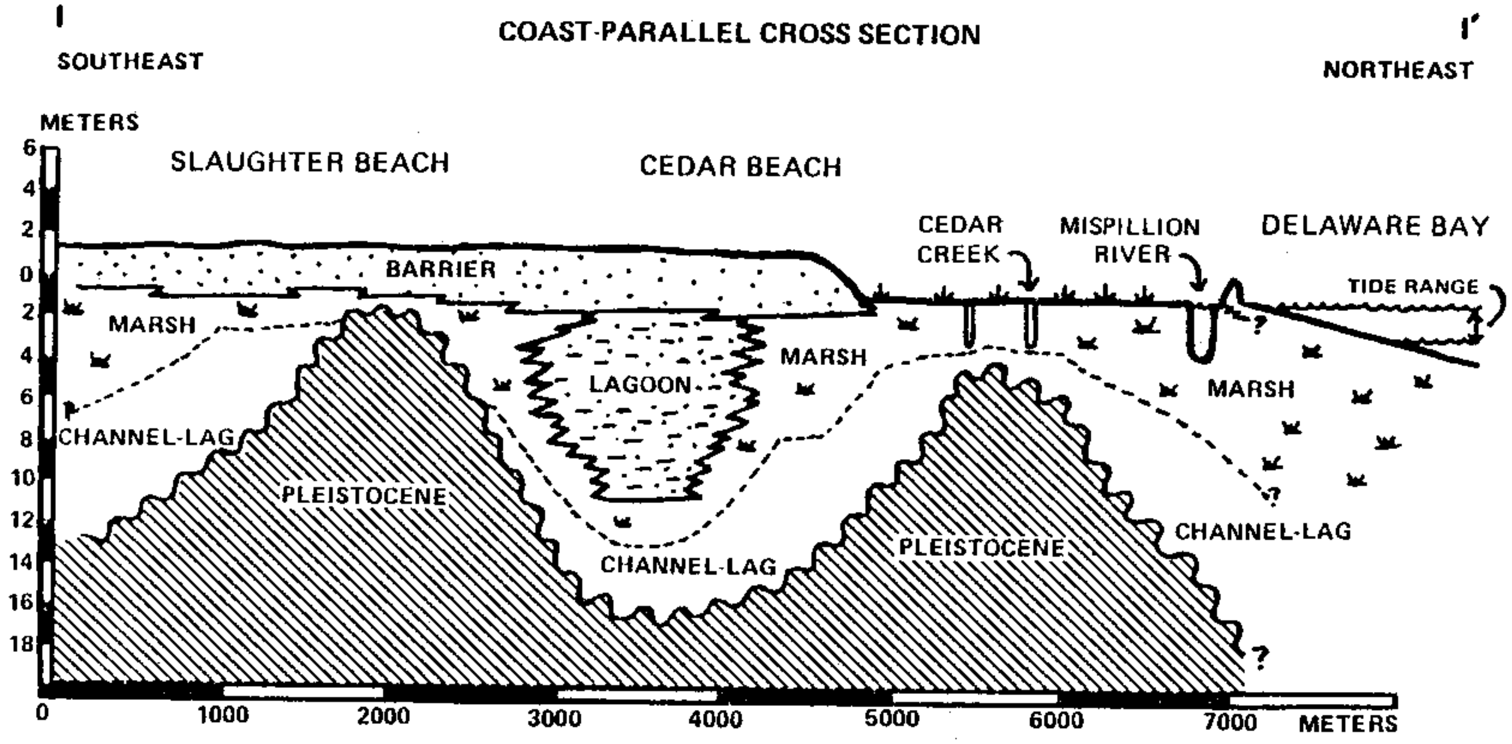




Radiocarbon Date is shown in Calendar Time, Masca Correction

(Based on Kraft and John, 1976)

Figure 43. Coast-perpendicular geologic cross section at Slaughter Beach, showing coastal environment sedimentary units based on core data.



(After Kayan, I. and Kraft, J. C., 1979)

K.S.D.

Figure 44. Coast-parallel geologic cross section of the Slaughter Beach/Cedar Beach area.

extend towards the bay, with an ancient valley between them, resulting in considerable variation in the subsurface geology of Cedar Beach, north Slaughter Beach, and south Slaughter Beach. Beneath Cedar Beach, barrier sands overly up to 13 meters of marsh and lagoonal muds which in turn overlie channel lag and Pleistocene deposits; in north Slaughter Beach the same thickness of barrier sands is found almost directly on top of Pleistocene material, and in south Slaughter Beach up to seven meters of marsh muds lie between barrier sands and channel lag/Pleistocene deposits.

In 1978, longshore transport rates at Cedar Beach were quite low, as might be expected (due to the sheltering effects of the Mispillion jetties and the offshore tidal flat). θ_n for this area was 85°, total predicted southward transport was 5800 m^3/yr, total predicted northward transport was 3800 m^3/yr, causing a net transport of 2000 m^3/yr southward. In north Slaughter Beach θ_n was 60°, total predicted southward transport was 9900 m^3/yr, northward transport was 3400 m^3/yr, so net transport should have been 6500 m^3/yr to the south. In south Slaughter Beach, predicted transport rates were even higher--since the outward normal was 48°, 11,100 m^3/yr of sediment should have been carried southward, 3,100 m^3/yr northward, resulting in a net transport of 8,000 m^3/yr southward. However, although calculated values predict transport to the south, groin accumulations indicate that dominant transport is northward. This is probably due to 1) protection by the Mispillion Inlet jetties from waves from the north, 2) the induction of northward transport by flood tidal currents into the inlet (Maurmeyer, 1978), and 3) refraction of northeast waves around the jetties.

Erosion rates along this section of coast have been influenced by two major factors in the past: subsurface sediments and beach preservation efforts. Prior to man's intervention, erosion rates decreased significantly in Cedar Beach, from 6.9 m/yr from 1884-1910 to 1.5 m/yr from 1910-1956. In Slaughter Beach, erosion rates were fairly uniform along the length of what is now the developed area, varying somewhat throughout history: from 1843-1884, they averaged 1.5 m/yr., decreasing to 0.64 m/yr from 1884-1954, partly due to the natural closing-off of the outlets of Cedar Creek and Slaughter Creek and the subsequent shoreward transport of their ebb-tidal shoals (Kraft, et. al., 1976). During the latter part of this period, and since then, erosion rates of both areas have been considerably affected by several types of coastal construction (Table 10). In 1920 and 1939 the south and north jetties at Mispillion Inlet (1.8 and 2.0 km long) were built. Since then, the area between the south jetty and Cedar Beach has shoaled extensively, due to 1) protection of the coast from the action of northeast storm waves, and 2) the creation of a settling basin at high slack tide when mud-laden waters are trapped and held in this area, allowing much of the fine material to settle out of suspension. A mud flat now exists in this sheltered area, which is almost entirely exposed at low tide (Figure 41). In south Slaughter Beach, these jetties may have had an opposite effect, tending to focus northeast storm waves onto the shore, thereby increasing erosion.

Jetty construction and the variation in three-dimensional geology along the Cedar Beach/Slaughter Beach shoreline have resulted in erosion rates that range from about 0.0 m/yr in the north up to 2.2 m/yr in the south. Great amounts of money and effort have been spent to combat this erosion (Table 10). Between 1940 and 1957, a series of 20 groins were built, several at a time. After each series was completed, accretion occurred to the south of the system and erosion occurred to the north, necessitating the construction of additional groins to the north. In 1958 groin construction was discontinued and a beach nourishment program was begun, with hydraulic dredging of material from 2.0-4.0 km offshore. After the 1962 northeaster, which breached the dune line in several places and resulted in destruction or damage to many homes, several homeowners in the south end of town constructed bulkheads on an individual basis, and large quantities of sand were pumped onto the beach. However, another storm in 1974 removed much of this sand and destroyed many of the bulkheads. Subsequently, these bulkheads were repaired and even greater quantities of sand (470,000 m^3) were used to nourish the beach. The groin field was actually covered at the time, and remains covered today (Figure 45a,b) (Dept. of Natural Resources and Environmental Control, 1980). Since then, rates of shoreline retreat at both Cedar Beach and Slaughter Beach have been minimal, but in Slaughter Beach this is due mainly to the presence of the bulkheads and periodic beach nourishment. In addition, in 1979

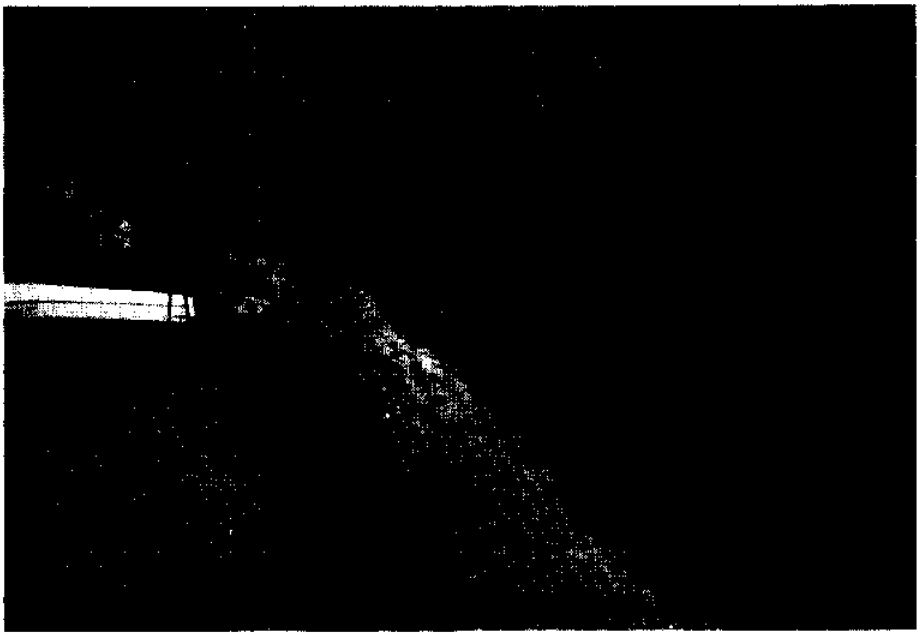


Figure 45a. Bulkheads at south Slaughter Beach, before 1975 beach nourishment.

Figure 45b. Bulkheads at south Slaughter Beach, after 1975 beach nourishment (a total of 470,000 m^3 of sand were placed on the beach at this time).

the government installed a "perched beach" to protect a more highly erodable section. This consisted of a wall located offshore, extending 91.5 m into the bay, with a length of 370 m, enclosing a rectangular area on three sides, and back-filled with sand. The wall was built from different materials in different areas, to determine relative strengths. These included concrete blocks, driven pilings and sheet steel, and nylon sand bags (Jaywork, personal communication) (Figure 46).

Although flooding cannot be considered a major problem at Slaughter Beach, it does occur occasionally, during severe storms. In these cases, it can come from three sources: 1) onshore flooding from Delaware Bay, 2) back flooding from the marsh southwest of town, and 3) back flooding from Slaughter Creek, which runs parallel to town, through the marsh. Flooding generally first occurs from the bay side, then as waters continue to rise, back flooding from the marsh and creek becomes the major problem. During the 1974 northeaster, wave action caused less damage than did overflow from the creek into the marsh. Whereas in 1962, dunes were breached in the north and south ends of town, in 1974 this only occurred to the south, probably due to 1) the abrupt end of bulkheads and groins in the south end, allowing water to wash onto these properties (Friedlander, et. al., 1977), 2) refraction of storm waves around the Mispillion jetties, or 3) the greater distance from sand sources found in the southern end.

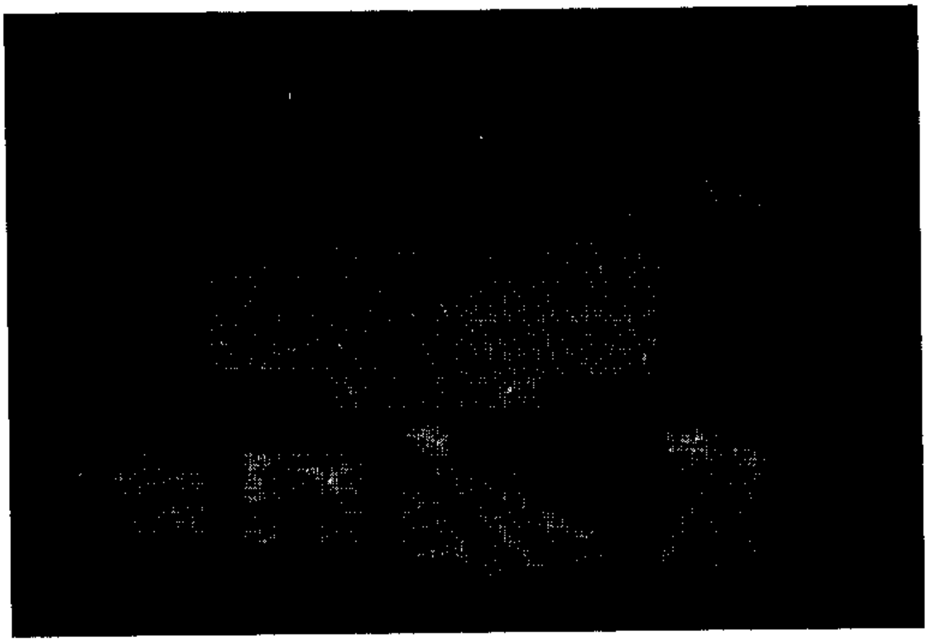


Figure 46. Perched beach explanation sign at Slaughter Beach, Delaware.

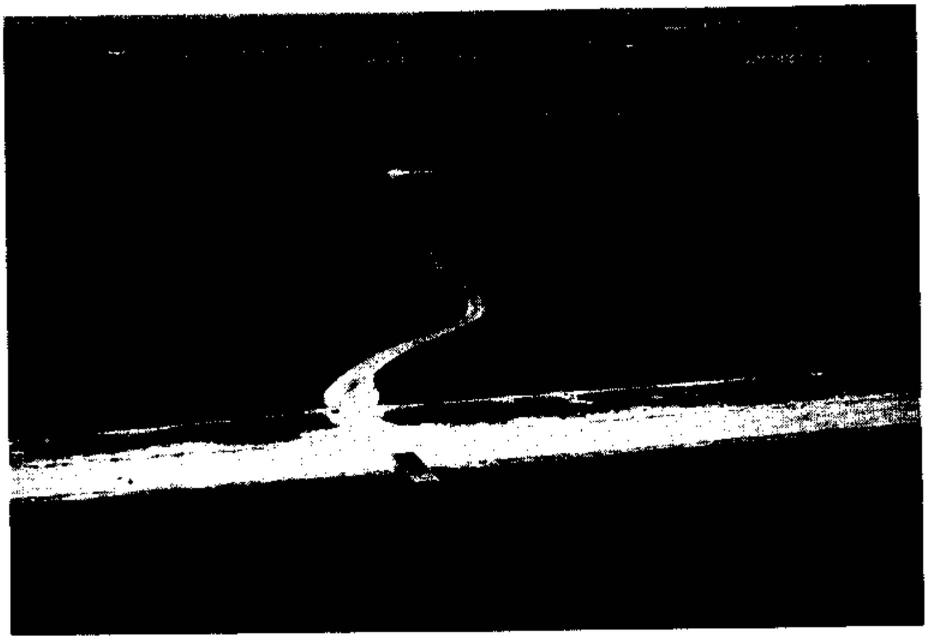


Figure 47. Aerial photograph of Fowler Beach, Delaware, showing pier that was abandoned due to coastal erosion (July, 1974).

Figure 48. Aerial photograph of Primehook Beach, Delaware (September, 1979).

Regarding natural causes of erosion, most interviewees felt that some erosion occurs continually at the south end, while the north end erodes very little if at all. Some mentioned that accretion can occasionally occur, in the absence of storm events. Most respondents also said that northeast storms can cause considerable erosion, sometimes accompanied by coarsening or steepening of the beach, whereas southeast storms either have little effect, or actually help build up the beach. Several people mentioned that sand that is eroded from the south end (either continually or during storms) is deposited in bars offshore which later migrate onto the beach at the north end, or is simply transported northward along the shore.

Like the residents of other Delaware Bay communities, most of the interviewees here agreed that beach protection measures have been helpful, except for the groins and perched beach. Either respondents were indifferent to the groins, or felt that either they were useless, tended to increase erosion, or were constructed to stop people from seine fishing (!) Most of those who mentioned the perched beach felt that it was pointless--although it may help control erosion, its construction makes swimming in that area impossible. One person said that beach nourishment was useless, since the additional sand gets washed away after one or two years, but most felt that it was worthwhile, and should be continued periodically, especially in the south end. Beach grass planting was also viewed favorably; many people mentioned that they could see a difference in wind erosion rate before and after it was planted, and two said that where other homeowners had removed the grass, more erosion subsequently occurred.

The future of Cedar Beach and Slaughter Beach can be considered in respect to two factors: 1) the future of beach preservation programs, and 2) the potential for further development. General housing trends were discussed with two local realtors, who reported that waterfront lots generally sell for $10,000-$12,000 and back lots cost about half as much. Houses range in price from $25,000-$70,000 and about $45,000-$50,000 is average. When asked if there has been a recent increase or decrease in the amount of development, one said that it fluctuates seasonally, with more sales in the summer, but the number of sales was about the same as last year; the other reported an increase in development over the past 10-20 years, in terms of population and number of new homes. The amount of time that a house stays on the market depends on its cost, the season, and the availability of mortgage money, but is generally on the order of several months. People come to the area from Delaware and Philadelphia, predominantly, but others come from New Jersey and the Washington, D.C. area. Most buyers are looking for a summer home (one realtor estimated the ratio of summer:permanent to be on the order of 2:1). When asked if beach erosion has affected property values, one realtor said no, since the beach is not very important to people here. The other said that people ask about it, but since beach nourishment has been done in south Slaughter Beach, there has not been an erosion problem, and although the siltation problem has existed to the north ever since the jetties were constructed (Haight and Marvel, realtors, personal communication), apparently this does not deter potential buyers.

Regarding the future of beach preservation programs, the south end of Slaughter Beach is eroding at an approximate rate of 2.2 m/yr, and this can be expected to continue, unless there is a change in the rate of sea level rise, sand source material, or some other factor. If protection of the beach and houses of this area is desired, some preservation measures are needed, either periodic nourishment, or perhaps nourishment in conjunction with rebuilding and connecting the bulkheads to make them stronger and to form a continuous line. Cedar Beach and north Slaughter Beach face another problem--the shoaling that has occurred between the south jetty and the shoreline, making swimming and fishing almost impossible, and (as evidenced by interview results) reducing the desirability of this area proportionately. Since the need for the jetties will probably continue, one solution might be dredging of this area--probably at considerable cost. This has not, to my knowledge, been proposed. In fact, it seems unlikely, since during the winter of 1979-1980 the state of Delaware dredged parts of Cedar Creek and deposited the spoils to the south of the south jetty, possibly aggravating the shoaling problem further. Since then the Army Corps of Engineers proposed dredging of parts of Mispillion Inlet, again dumping spoils in this vicinity--this time, residents found out and were able to prevent this action (R. Henry, DNREC, pers. commun.).

Beach survey results indicate that the beach at Slaughter Beach is used relatively intensively. On Saturday, August 16, 1980, at 3:00 P.M., there were 17 people on the beach--of these, six were sunbathing, five were walking, four were fishing, and two were swimming. Five people were visiting for the day, and most of the remainder owned their own houses (six of these were year-round residents, and the rest were seasonal). On Sunday of Labor Day weekend, 1980, at 12:30 P.M., there were 60 people on the beach, including 26 summer residents, 18 visitors, 8 year-round residents, 2 summer residents, and 6 whose status could not be determined.

In terms of development potential, property in the south end of town is owned by one person who, to my knowledge, has no plans to sell or develop this area in the near future. The central portion of town has already been developed to capacity, unless wetlands are filled. Similar limits to growth are faced by Cedar Beach, although some lots are still available. One developer has been trying to obtain the necessary permits for four years, to subdivide approximately 4.0 ha of wetlands in south Cedar Beach, west of the road (Figure 38). An 80 m wide strip of land would be involved, with a 30 m wide strip remaining as wetlands and the remainder filled to a depth of 0.3-1.3 m. In addition, on September 9, 1980, one person who owned land in north Slaughter Beach auctioned off 14 waterfront lots (15.2 m x 61 m each) at $10,000-11,000 each, and 24 back lots (selling all of the property that was put up for sale). However, construction in both areas could be undesirable, since they are underlain by up to 12 m of marsh and lagoonal muds, which could lead to settling unless pilings longer than 12 m are used. In addition, the characteristics of the offshore area preclude swimming, fishing, and other forms of recreation, and may be aesthetically unappealing to many people (Figure 41). At this time, the town of Slaughter Beach has no plans for development other than to install its own water system and build a new Town Hall (Jaywork, personal communication).

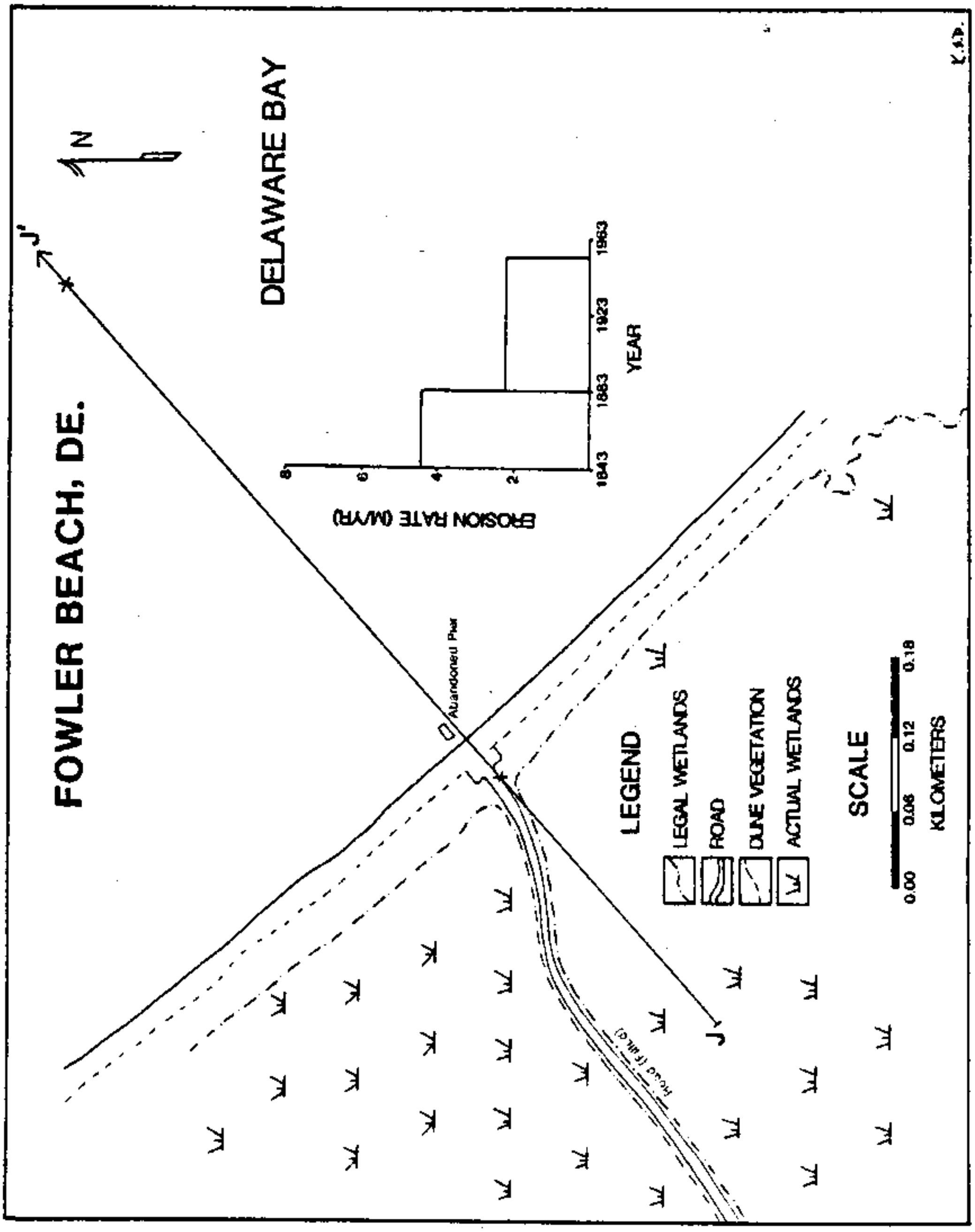
On the other hand, beach preservation is probably economically justifiable in Slaughter Beach. There are large year-round and seasonal populations, high property values, relatively low erosion rates and overwash potential, and small minimum depth to Pleistocene, giving Slaughter Beach a preservation value ratio of 0.71 (Table 6). Although the maximum depth to Pleistocene (14 m) is fairly high, interviewees did not mention any settling problems, and if settling of homes occurs, this can be remedied by raising (as is done in South Bowers) or by using pilings greater than 14 m long when building new homes. A lot of beach nourishment has been done in Slaughter Beach since 1962 (and before), as evidenced by the very low (0) rating for this parameter (Table 6). Given the characteristics of the community, the fairly high use of the beach, by both residents and visitors, and the generally favorable geological conditions of this area, this is a relatively good area for the continuation of beach nourishment programs.

Fowler Beach

Fowler Beach, like Bennett's Pier, contains no houses or development of any kind (Figures 47 and 49). At present, there is an access road to the area, and parking that can accommodate five to ten cars. The barrier here is quite narrow, with a total width of about 105 m, maximum thickness of only 2.4 m, and volume of 135 m^3/m (Maurmeyer, 1978). The beach itself is comprised of clean sand, with some grass debris, a slope that varies from 1:8 in the winter to 1:10 in the summer (Maurmeyer, 1978) and a width of about 6 m. Since there is little or no dune development (dunes are less than one meter high, with grasses, _P_. _communis_, _B_. _halimifolia_, _I_. _frutescens_) the backshore has little protection from overwash, and between the barrier and the back barrier marsh (which extends 1.5 km to Pleistocene highlands) there is a well-developed washover area. It should also be noted that relict marsh crops out one meter seaward of the low tide line, and this broad subtidal flat extends almost 1.6 km offshore (Kraft, et. al., 1976). Material that was found about 0.48 km offshore, 2.44 m below present sea level, was dated at 2700 years B.P. (Kraft and John, 1976) indicating that at this time the barrier was seaward of this position.

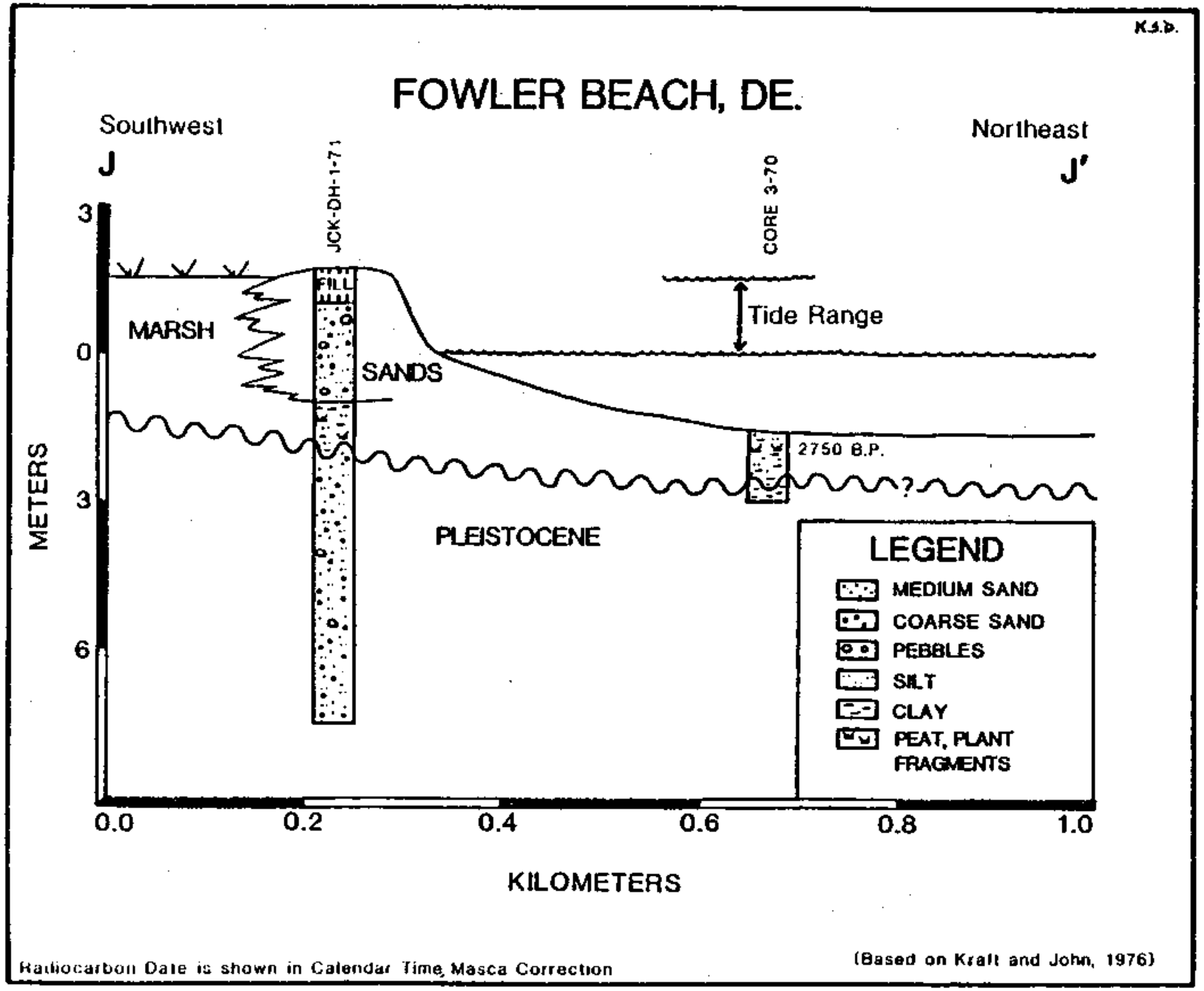
The extensive marsh outcrop is shown by a cross section

Figure 49. Map of Fowler Beach, Delaware, showing past and present wetlands classification, line of cross section, core locations (X's), and historical erosion rates.


FOWLER BEACH, DE.
DELAWARE BAY
N
J'
J
Abandoned Pier
Road (Paved)
EROSION RATE (M/YR)
8
6
4
2
1843
1883
1923
1963
YEAR
LEGEND
LEGAL WETLANDS
ROAD
DUNE VEGETATION
ACTUAL WETLANDS
SCALE
0.00
0.06
0.12
0.18
KILOMETERS

through Fowler Beach (Figure 50). However, this marsh mud layer, which underlies the barrier as well, is probably less than 2 m thick in most areas, and is underlain by Pleistocene sands and gravels (Kraft and John, 1976). A closer examination of the washover fan shows two washover deposits, with a thin layer of marsh mud (that extends about 45 m seaward) between them. Another, much older washover deposit underlies the beach face, showing the position of the landward edge of the barrier at some previous time. These sands crop out at the beach face and are being reworked by beach processes.

The thinness of the subsurface marsh mud layer might lead to the expectation that erosion rates in this area would be low; however, this is not the case, perhaps due to the low barrier profile, increasing its susceptibility to washover, or the high longshore transport rates which would carry material southward. θ_n for Fowler Beach is about 45^o, and 11,500 m^3/yr is transported southward. Since only 3,100 m^3/yr is transported northward, the net transport rate is predicted to be 8400 m^3/yr southward (Maurmeyer, 1978). Between 1843 and 1884, Fowler Beach experienced extreme erosion, on the order of 4.4 m/yr. From 1884-1954 this decreased somewhat, but was still considerable: 2.2 m/yr (Kraft, et. al., 1976). Although sand is probably supplied to the area from the erosion of headlands to the north, e.g. the subsurface of Big Stone Beach or Slaughter Beach, the quantities may be insufficient to compensate for material lost from Fowler Beach. Alter-



Radiocarbon Date is shown in Calendar Time, Masca Correction

(Based on Kraft and John, 1976)

Figure 50. A geologic cross section at Fowler Beach, Delaware, showing coastal environment sedimentary units based on core data.

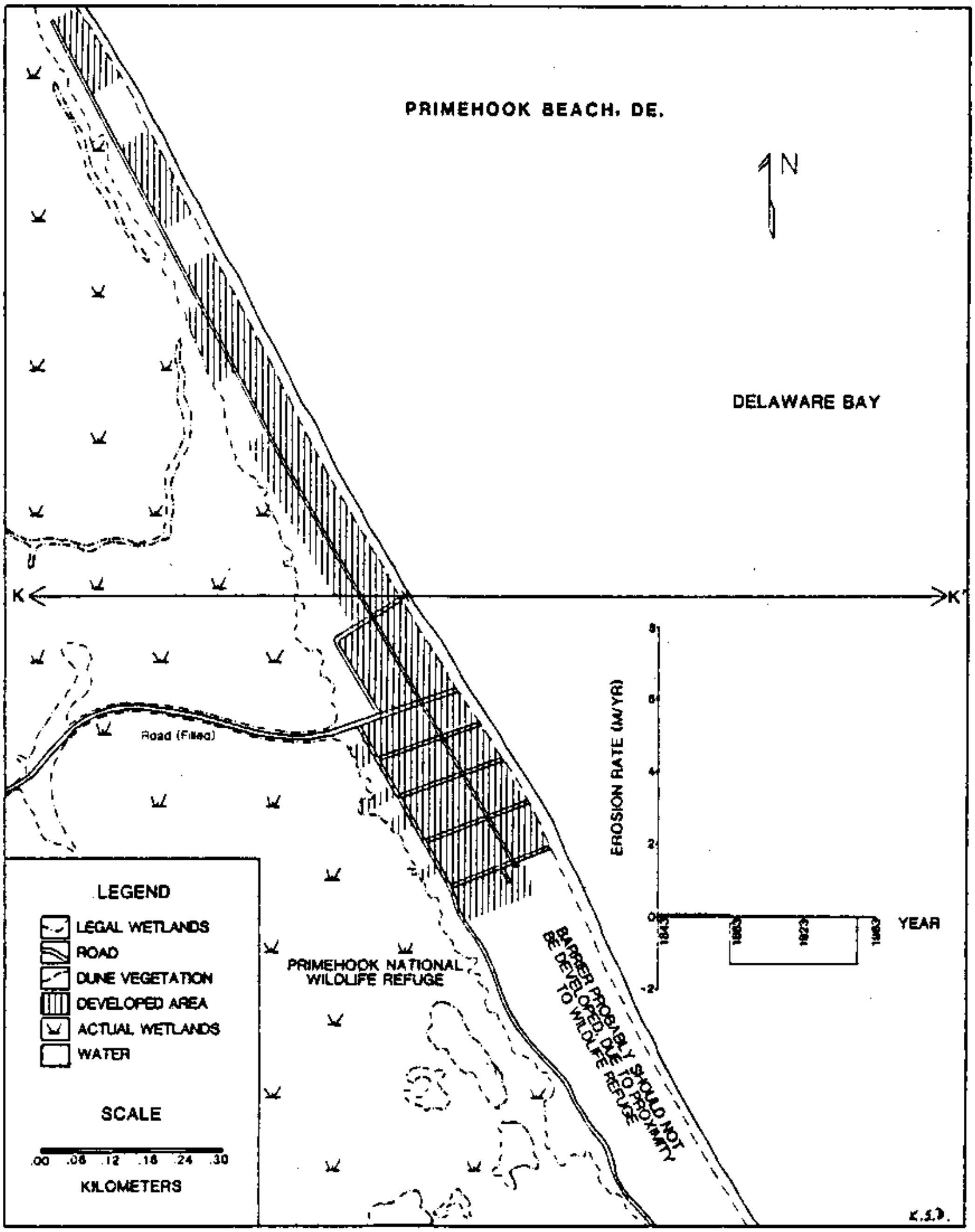
natively, Fowler Beach may be denied these sand sources by induced northward longshore currents like those found at Slaughter Beach. The only protective measure that has been taken at Fowler Beach was the construction of a timber groin in 1932. Perhaps this helped decrease erosion rates at that time, but at present this structure has deteriorated to the point that its permeability prevents even the determination of longshore transport direction (Maurmeyer, 1978).

Fowler Beach has a preservation value ratio of only .42 (Table 6), mainly as a result of the lack of residents and houses. Geological criteria range from moderate (erosion rates) to favorable (depth to Pleistocene and overwash potential). The barrier here may have sufficient room for development, since there is a 30 m wide strip of land between the dune vegetation line and the back barrier marsh. However, any type of development of Fowler Beach would probably be inadvisable, unless a serious need for such development occurs. First, there is a high risk of flooding here, due to the low dune elevation, and the proximity of Slaughter Creek which flows behind Fowler Beach, parallel to shore. Second, erosion would have to be contended with, probably through beach nourishment or groin construction, and third, the mud flat that extends 1.6 km offshore would make this section of coast less desirable for swimming and other water-related recreation.

Primehook Beach

Directly south of Fowler Beach is the small community of Primehook Beach, which could be characterized as a summer resort community (Figures 48 and 51). It consists of about 100 homes along 1.2 km of shoreline, 45 of which are on the beachfront and 55 of which are on the west side of the road that runs parallel to the beach (U.S. Army Corps of Engineers, 1966). Most of these houses are not on pilings, and are only two to three meters above MHWL. In 1965 there were 25 permanent residents and 300 summer residents (U.S. Army Corps of Engineers, 1966) but current populations are not known. The beach along this section of coast is about 24 m wide to MHWL, with a 1:9 slope (U.S. Army Corps of Engineers, 1966) consisting of fairly clean sand with some grass and debris. The dunes, like those of Fowler Beach, are broad (about 6.1 m wide at the base) and low (maximum elevation is about 4.3 m above MLW, or 2.9 m above MHW) (U.S. Army Corps of Engineers, 1966), and are generally grass-covered, sloping gradually on the landward and seaward sides. Primehook Beach is bordered to the west by two to three kilometers of marsh, and a broad subtidal flat (probably

Figure 51. Map of Primehook Beach, Delaware, showing developed area, past and present wetlands classification, line of cross section, core location (X), and historical erosion rates. The Primehook National Wildlife Refuge extends the length of town and to the north and south as well.

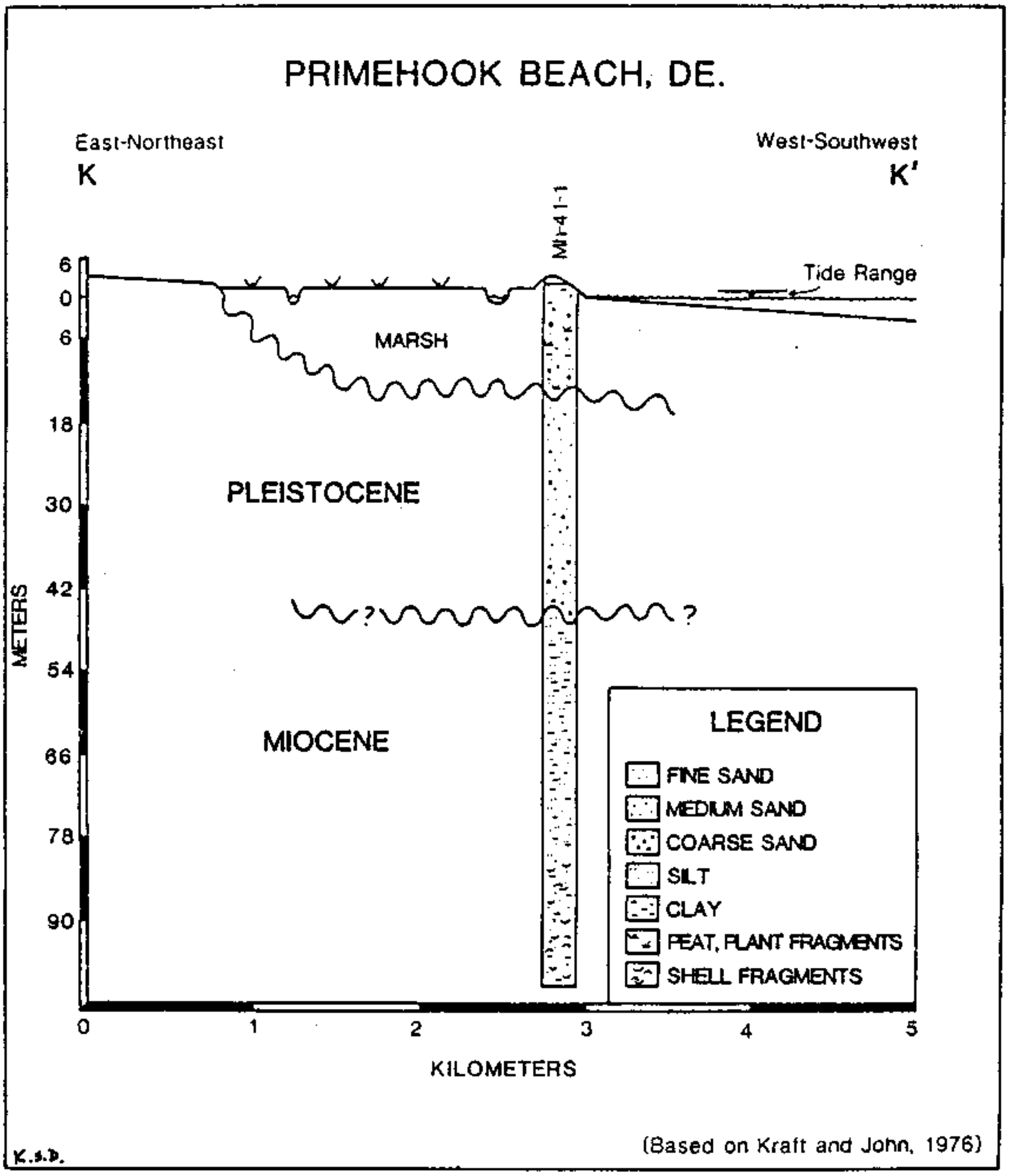

PRIMEHOOK BEACH, DE.
N
DELAWARE BAY
K
K'
Road (Filled)
PRIMEHOOK NATIONAL WILDLIFE REFUGE
BARRIER PROBABLY SHOULD NOT BE DEVELOPED, DUE TO PROXIMITY TO WILDLIFE REFUGE
EROSION RATE (M/YR)
8
6
4
2
0
-2
YEAR
1843
1883
1923
1962
LEGEND
LEGAL WETLANDS
ROAD
DUNE VEGETATION
DEVELOPED AREA
ACTUAL WETLANDS
WATER
SCALE
.00
.06
.12
.18
.24
.30
KILOMETERS
K.S.D.

a relict marsh) extends almost 1.6 km offshore. A coast-perpendicular cross section through this area (Figure 52) shows that the barrier itself is very thin (less than 3 m), and overlies about 12 m of Holocene muds and sands. Below this, approximately 30 m of Pleistocene sands and gravels overlie Miocene material.

Despite the thinness of the barrier, its low profile, and its location towards the south part of Delaware Bay (where wave fetch distances are longer), Primehook Beach had no shoreline change at all from 1843-1884, and from 1884-1954 it actually accreted by 1.3 m, perhaps as a result of material transported from the Atlantic coastline, around Cape Henlopen, prior to the construction of two breakwaters in Breakwater Harbor which changed the longshore transport direction.

Primehook Beach is oriented with an outward normal of 55°; in 1978 total predicted southward longshore transport was 10,400 m^3/yr and total northward transport was 3,200 m^3/yr, giving a net transport rate of only 7,200 m^3/yr southward (Maurmeyer, 1978). Although no recent figures on erosion rates are available, apparently erosion was a problem in 1962, or large quantities of sand were lost as a result of the 1962 northeaster because at this time 15,400 m^3 of material were placed by the state, at a cost of \$40,300 (\$96,000) (Dept. of Natural Resources and Environmental Control, 1980).

According to most of the criteria analyzed, with the excep-



(Based on Kraft and John, 1976)

Figure 52. A geologic cross section at Primehook Beach, Delaware, showing coastal environment sedimentary units based on core data.

tion of the maximum depth to Pleistocene, Primehook Beach seems to be a relatively favorable area for future beach preservation or low-density residential development. In fact, the preservation value ratio (0.79) is the highest of all eleven study areas. There are some lots available in town which could still be built on, but the proximity of these lots, and all available land south of town, to the Primehook National Wildlife Refuge should be considered before these areas are developed. The increased population and possible associated effects on water quality could create a hazard to the flora and fauna of the adjacent refuge. However, the high preservation value ratio does indicate that future beach preservation may be economically justifiable in this area.

Broadkill Beach

Broadkill Beach is one of the largest communities along this section of coast, occupying a 4.5 km long strip of land (Figures 53 and 55). The beach here is about 21.4 m wide to MHWL, with a slope of 1:11, and the generally grass-covered dunes are about 9.1 m wide at the base, with a top elevation of 3.0-3.7 m above MLW. Although it is similar to most of the other Delaware Bay communities in that it has a substantial influx of people during the summer months (in 1965 the permanent population was 35 and the summer population was 550) (U.S. Army Corps of Engineers, 1966) it is quite different from the rest since it is an area of active development, with many new lots for sale, especially at the north end of town. Between 1954 and 1973 the total number of houses increased from 74 to 291 (Friedlander, et. al., 1977). There is a fairly low turnover rate of residents (excluding those buying property there for the first time), as indicated by the results of one survey, which showed that 36% of the respondents had been living at or coming to the area for more than ten years (Friedlander, et. al., 1977). Residences cover a broad range of types and sizes, ranging from small trailers to fairly large, new houses ($75,000-$100,000). In the central and northern sections, all of the houses are at least 7.6 m behind the dune line, but to the south, particularly along a 100 m long section of coast which seems to be undergoing severe erosion, several houses are stranded on pilings on the beach face, to such an extent that they are uninhabitable (Figure 54). Most

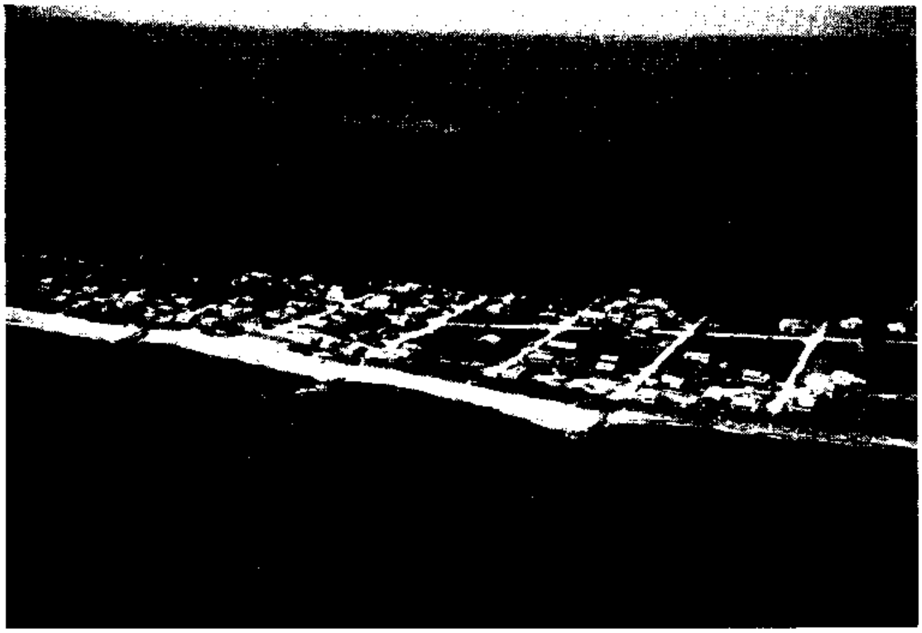


Figure 53. Aerial photograph of northern Broadkill Beach, Delaware, showing new development and groins (September, 1979).

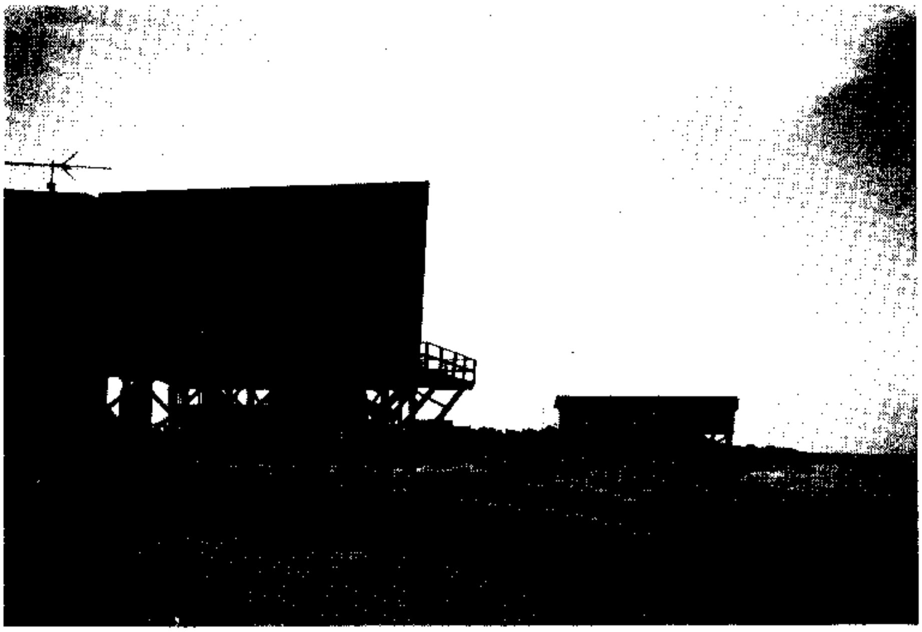


Figure 54. Houses stranded on pilings in south Broadkill Beach. This particular section of coast has experienced erosion at a rate of 15 m/yr for the past several years.

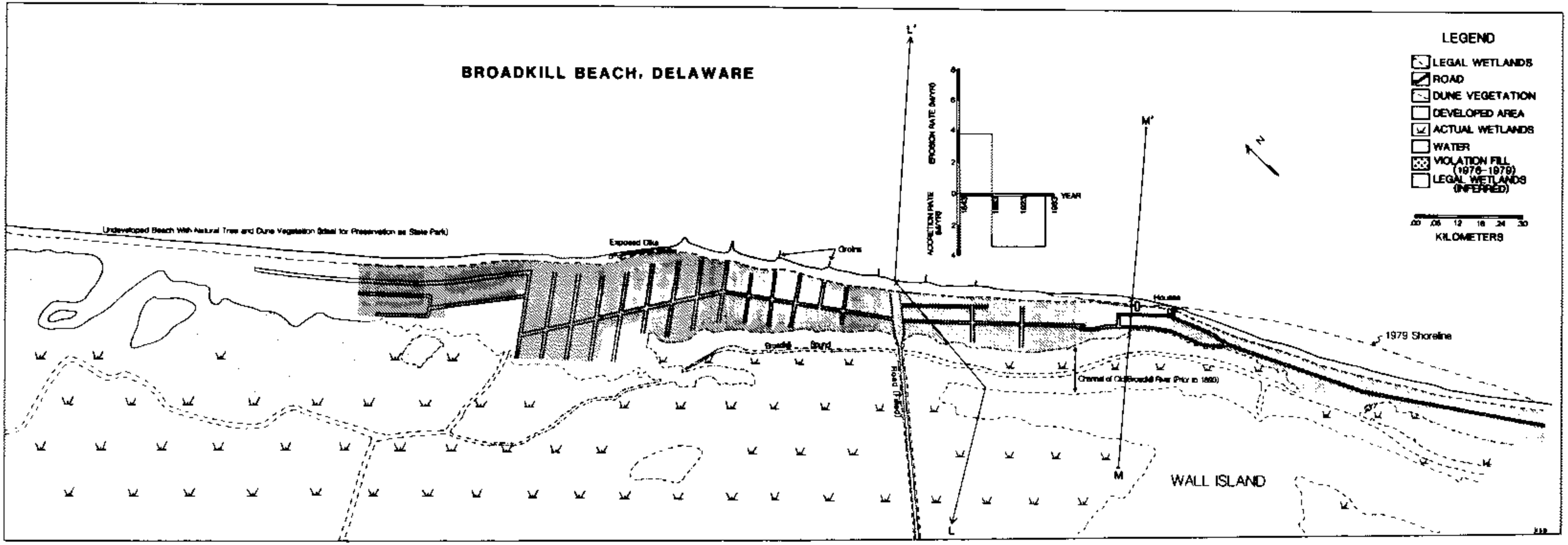


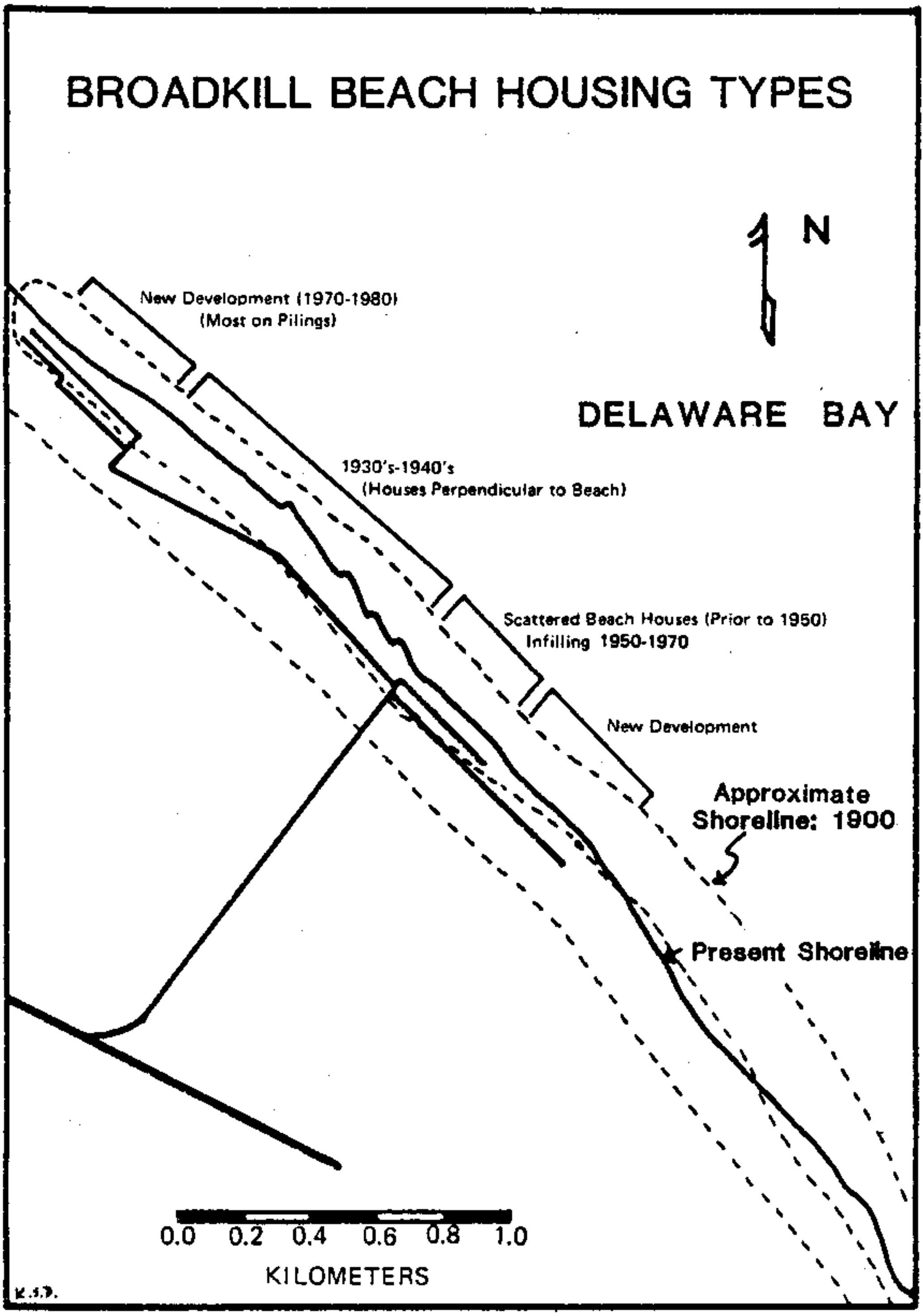
Figure 55. Map of Broadkill Beach, Delaware, showing developed areas, past and present wetlands classification, lines of cross section, core locations (X's) and historical erosion rates.

of the houses in the northern section of town are on pilings, to comply with zoning regulations, but the older homes are generally not.

Like Bowers Beach, Broadkill can be subdivided into several different sections according to housing characteristics (Figure 56). The northwesternmost end consists of new development which has occurred mainly since the 1970's. Between this area and the access road is a fairly densely-populated section of older homes (ca 1930's-1940's)--this is indicated, in part, by their perpendicular orientation to the beach. Southeast of the access road is densely populated with beach houses built before 1950, along with some that infilled the area in the 1950's and 1960's. Farther down the coast is an area of relatively new development of fairly large, expensive homes, behind a narrow dune line (D. Ames, U. Delaware, personal communication).

The subsurface of Broadkill Beach is highly variable, due to the presence of several small Pleistocene highlands that crop out approximately two kilometers to the west and extend under the town at various depths, and the unique and complex geologic history of the area (Maurmeyer, 1974; Kraft and Caulk, 1973; Kraft, Allen, and Maurmeyer, 1978). Until the late 19th century, the Broadkill River, which now flows parallel to shore, and empties at Roosevelt Inlet, emptied into Delaware Bay at a point north of Broadkill Beach. At

Figure 56. Broadkill Beach housing patterns.



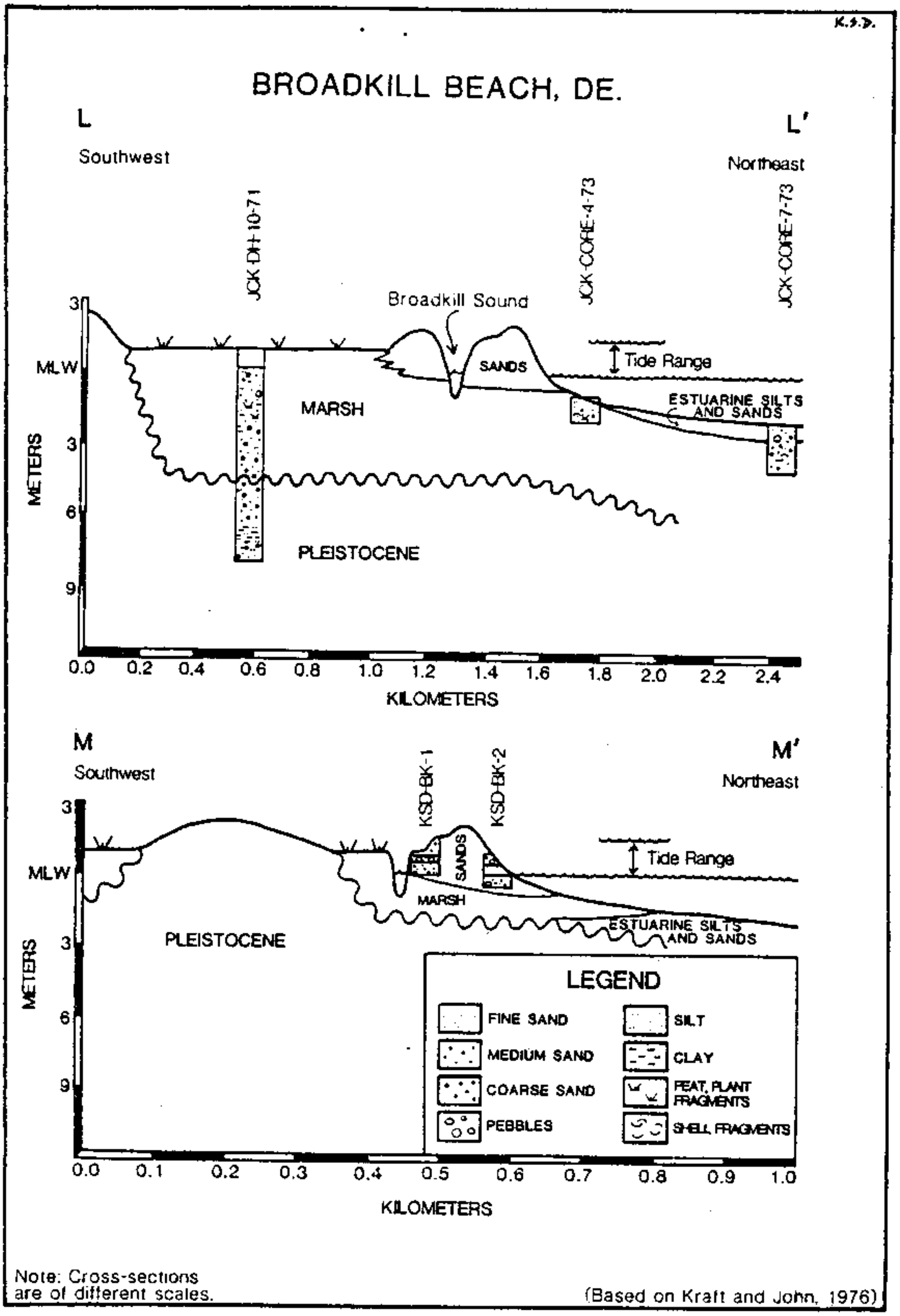
BROADKILL BEACH HOUSING TYPES

Since the Broadkill River was thus diverted southward to empty at this point, the northern end of the spit at Broadkill and "old inlet" shoaled and joined the mainland (Kraft and Caulk, 1973). Therefore, at present, the southern end of town is located in the area of "old inlet," and probably occupies a sandy barrier that has migrated landward of the original spit position. This area is very narrow (only wide enough for one house lot), but at the southernmost end, developers have filled some marsh behind the barrier to create additional homesites. The central and northern sections of town are on the westwardly-eroding remnants of what was formerly the coast-parallel spit.

Figures 57a,b show cross sections through the north and south ends of town, respectively, and Figure 58 depicts a three-dimensional model of the Broadkill area. These illustrate the variability found in the subsurface. The northern section is characterized by a wider barrier, overlying about four meters of marsh muds, while the barrier is much thinner to the south, and is underlain almost directly by Pleistocene sediments.

Erosion rates for Broadkill Beach have changed markedly in the past, as the path of the Broadkill River and the supply of sediment from the Atlantic shoreline were altered, due to natural causes and man's actions. On the average, between 1843 and 1884 the coast

Figure 57a,b. Geologic cross sections at Broadkill Beach, Delaware, showing coastal environment sedimentary units based on core data.



Note: Cross-sections are of different scales.

(Based on Kraft and John, 1976)

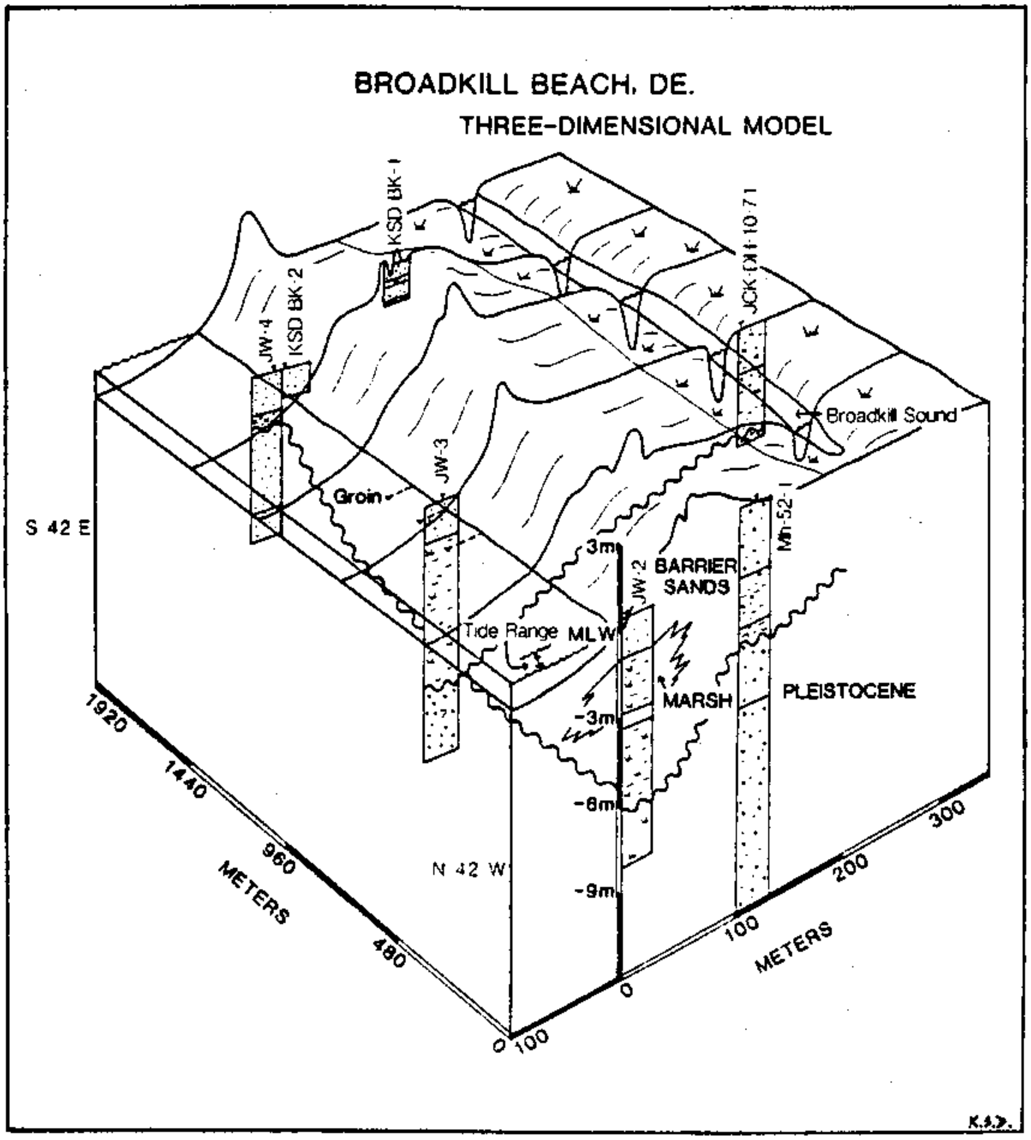


Figure 58. A three-dimensional diagram of Broadkill Beach, Delaware, depicting subsurface sediments based on core and jetwash logs, and surficial morphology, based on U.S. Coast and Geodetic Survey maps and DNREC (1979) maps. See Figure 26 for legend.

eroded at a rate of 3.8 m/yr, apparently due to natural processes such as currents, wave attack, and sea level rise. Between 1884 and 1954 this trend was reversed, and there was an average accretion of 3.5 m/yr (Kraft, et. al., 1976) probably due to the spit accretion discussed previously, and the construction of five timber groins, from 1950-1954 (beach nourishment was not begun until three years later). These groins were the first part of a rather extensive beach protection program which was begun to combat the erosion that began when the sediment supply from Cape Henlopen was greatly reduced (Table 11). After three 58 m timber groins were constructed in 1950, near the center of town, erosion occurred north of the groins and two more were constructed to the north in 1954 (U.S. Army Corps of Engineers, 1972). In addition, the beach was nourished six times between 1957 and 1976, for a total of 648,000 m^3 (or an average of 34,000 m^3/yr) (Dept. of Natural Resources and Environmental Control, 1980). Also, in 1969 the state built a dike by dumping broken concrete parallel to the coast, along the dune line, and covering it with sand and gravel. Storm fence which was erected in 1975 washed away shortly thereafter. Beach grass was also planted at this time, and seems to have helped stabilize the dune (Department of Natural Resources and Environmental Control, 1980). As a result of these protective measures, the beach is fairly stable in most sections (with periodic beach nourishment) and the concrete dike is covered with sand, forming a natural-looking dune line. However, erosion has continued to occur north of the groin field,

TABLE 11

Beach Preservation Measures: Broadkill Beach, DE.

Year	Action Taken	Cost
1950	3 groins constructed	?
1954	2 groins constructed, north of others	?
1957	58,600 m^3 fill placed	?
1961	91,600 m^3 fill placed	?
1962	137,000 m^3 fill placed	?
1969	Dike constructed	?
1973	90,200 m^3 fill placed	\$165,500 (274,300)
1975	225,200 m^3 fill placed	\$558,000 (796,900)
	Storm fence erected	?
	Beach grass planted	\$300 (428)
1976	45,600 m^3 fill placed	\$122,000 (159,100)
	Total:	\$845,500+(1,230,300+)

Table 11. Broadkill Beach preservation measures and costs, where known (numbers in parentheses are in 1980 dollars) (Dept. of Natural Resources and Environmental Control, 1980).

and the concrete rubble is exposed in this area. Also, the necessity of continued nourishment is shown by a section of beach in south Broadkill, where several houses are stranded on pilings on the beach face, that is not receiving nourishment and had eroded at about 15 m/yr for the past several years (Figure 54). During a relatively small storm event in October, 1980, this was the only area of Broadkill Beach where a washover occurred, resulting in a shoreline regression of several meters, some structural damage to houses in the area, and covering of the road with sand (Figure 9).

Longshore transport here is northward in the summer and southward in fall, winter, and spring, resulting in net transport southward. In north Broadkill, θ_n is 47°, total southward transport is 11,300 m^3/yr, total northward transport is 3,100 m^3/yr, giving a predicted net transport rate of 8,200 m^3/yr to the south. South Broadkill Beach is oriented with an outward normal of 50°. Total southward transport is 11,000 m^3/yr, and total northward transport is 3,000 m^3/yr, resulting in a net transport rate of 8,000 m^3/yr southward (Maurmeyer, 1978).

There are three sources of flooding in the Broadkill Beach area--Delaware Bay, the marsh to the south and west of town, and Broadkill Sound. Flooding from the bay is most common, since the town is located near the mouth of Delaware Bay, resulting in greater fetch distances over which winds can act--this is especially true for northeasterly winds, which are often associated with storms. Flooding from the marsh and Broadkill Sound occurs when exceptionally high tides and waves cause waters in Broadkill Sound to rise and flood the marsh, or bay waters to break through the barrier and flood the marsh. In the 1962 northeaster, flooding occurred from both the bay and marsh, since at that time there was a natural inlet south of Broadkill Beach, enabling water to rise behind the barrier. During the 1974 northeaster, when the configuration of the barrier was as it is now, flooding came from the bay alone (Friedlander, et. al., 1977).

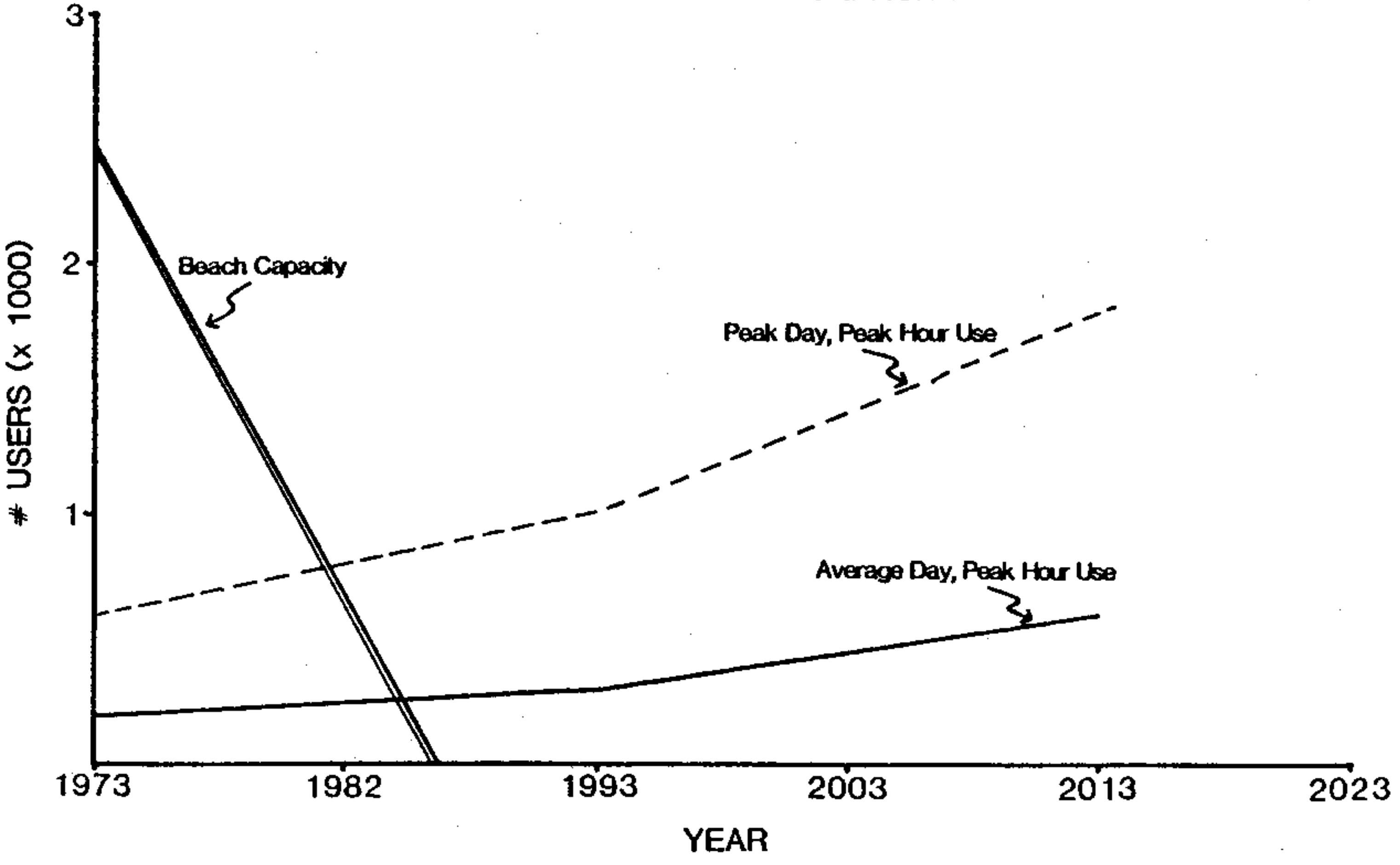
Interviewee's perceptions of the erosion problem, and their opinions about various beach protection measures, were fairly consistent. They report that erosion occurs continually, especially at the south end of town, and is accelerated by storms, especially those with winds from the northeast. Several mentioned the dependency of storm damage on the temporal correlation between high tide and the storm's location. According to two residents, the beach does not rebuild itself after storms; another interviewee said that while northeast storms result in erosion, southeast storms, or the correct combination of southeast winds and high tidal levels, can lead to accretion. Respondents agreed that beach nourishment has been effective, and the sand added in 1975 widened the beach by about 33 m. One said that if there were no major storms, nourishment would probably have to be repeated every four years or so. The concrete slab dike was generally viewed as an effective measure, as was the beach grass, although one resident said that even though the grass effectively reduces wind erosion, it tends to break off in chunks when hit by waves. This person also stated that the groins were basically a good idea, but have not been maintained as they should be, since they are overtopped during storms. When asked for suggestions regarding future beach preservation, interviewees said that nourishment should be continued. Also, two residents favored breakwater construction, and suggested that reopening the inlet that was south of town would help reduce erosion and return the area to its natural state.

According to two realtors, waterfront lots (23 m x 30.6 m) in Broadkill Beach sell for prices in the low $20,000's, and back lots cost $10,000-12,000. Although lots make up the majority of sales, some houses are for sale also. House prices vary, one (on a 15 x 30 m lot) sold recently for $28,000, and was on the market for less than two months. Another was just listed for $75,000, and includes two lots, and a new home just behind it was recently listed at the same price, also including two lots. According to one source, the personal market (i.e. through telephone conversations, personal interviews) is good, while the average market (newspaper and magazine advertisements) is bad; the other said that houses here do not move as fast as in Lewes or Rehoboth (in these locations there isn't enough supply to meet the demand) but Broadkill Beach is becoming more popular; this is especially true in the north part of town, because it has had less of an erosion problem. Another study reported that beach use should continue to increase in the next several decades as well (Figure 59) (U.S. Army Corps of Engineers, 1972).

Based on the two beach surveys performed, the beach here is used fairly intensively. On August 16, 1980, I did not survey Broadkill Beach until 4:00 P.M., yet at this time, there were still 13 people present--five were walking down the beach, six were swimming and sunbathing, and two were playing horseshoes. Unlike the other towns surveyed, the majority of these people (10 out of 13) were

Figure 59. Graph showing current and predicted beach use and capacity for Broadkill Beach, Delaware (U.S. Army Corps of Engineers, 1972).

BROADKILL BEACH:
BEACH USE AND CAPACITY



visiting, the remainder owned homes there. In August 31, 1980, between 10:30 and 11:30 A.M., there were 95 people using the beach. A large majority of these were summer residents (60), and there were 17 visitors, 7 year-round residents, 5 summer renters, and 6 of unknown status. Of the people interviewed on an individual basis, two out of five just used the beach for walking, and the other three went swimming, sunbathing, and fishing there as well.

Since future expansion of Broadkill Beach, to the north and possibly to the south as well, is likely, it is important to examine the desirability of this development and/or future beach nourishment. Broadkill Beach has a very high preservation value ratio (0.74) (Table 6) indicating that according to the criteria used to establish this ratio, this town is a relatively favorable area for development or the continuation of beach preservation measures. Overall, the only exceptions are the criteria of year-round population size, maximum depth to Pleistocene, past amounts of beach nourishment required, and overwash potential for six-second waves. The problem with using a single preservation value ratio for the entire town is that considerable variation exists along its length, as evidenced by 1) the higher overwash potential in the south end where the barrier was overtopped during the October, 1980 storm (Figure 9), and 2) the severe (approximately 15 m/yr) erosion in the south end of town, while the north end seems to be eroding to a much lesser extent.

The difficulties involved in predicting future erosion rates based on past patterns are illustrated by a study done in 1972 which concluded that the best protective plan would involve the placement of 81,400 m^3 of fill on central Broadkill Beach (this was done in 1973), maintaining this with 5,400 m^3/yr, along 800 m of coast, and erecting 1,400 m of sand fence for berm preservation. This estimation proved woefully inadequate, since 270,800 m^3 of sand have been added to the beach in the three years following the 1973 nourishment (at an average of 90,000 m^3/yr, as opposed to expected requirements of 5,400 m^3/yr) (U.S. Army Corps of Engineers, 1972).

In conclusion, Broadkill Beach is a fairly large, well-established community, the beach plays a major role in attracting residents and visitors to the area, and erosion appears to be controllable (although this is currently at a rather large expense, and does not seem to be effective in south Broadkill Beach during moderate storms). According to these and other criteria, this area is better suited for low-density residential development and beach preservation, particularly in the north end, than are other Delaware Bay communities, provided the appropriate building restrictions, in terms of distance from the shore and elevation on pilings, are followed.

CURRENT LEGISLATION INVOLVING COASTAL DEVELOPMENT

Coastal areas can be studied in the most minute detail in regards to meteorological and wave forces, subsurface geological structure, erosion rates, and other factors that would affect their suitability for development, but if this information is not applied to ensure the proper future for these areas, it is useless.

County and Local Zoning Regulations

Most zoning regulations are drawn up by county or local governments. Of the eleven study areas, only one (Slaughter Beach) is incorporated, having its own zoning regulations. The others fall under the jurisdiction of the Kent or Sussex County Planning and Zoning Commissions.

In Kent County, three types of zoning districts are represented by the study areas--these are A-C (agricultural-conservational), A-R (agricultural-residential), and R-S (single-family residential). Zoning ordinances for the A-C district (which includes Port Mahon and Bennett's Pier) outline permitted uses, which include detached single-family dwellings, mobile homes, agriculture, animal hospitals, and others. No businesses are allowed except greenhouses. Permitted accessory uses are also described including farm buildings, garages, and docks, along with permitted signs. Conditional uses (those that require a public hearing, approval by the Kent County Levy court, and a site plan) are exemplified by airports, marinas, and public buildings, and special exceptions (which require a public hearing and approval by the Kent County Board of Adjustment) include convalescent homes, transmission stations, and many other uses. In addition, yard size requirements, maximum building height (2 1/2 stories, or 10.7 m) and off-street parking and loading requirements are outlined. House lots must be 0.4 ha or more, with a minimum width of 45.7 m and a minimum length of 53.4 m (Kent County Zoning Ordinance, Article 4, Section 1).

The guidelines for A-R zones (including Kitts Hummock and Big Stone Beach) are similar to those for A-C areas, with the following exceptions--there are several additional conditional uses for A-R districts, and lot size requirements are only 0.2 ha for single-family dwellings or mobile homes (i.e. 30.5 m minimum width, 38 m minimum depth) (Kent County Zoning Ordinance, Article 4, Section 2).

R-S regulations, involving Bowers and South Bowers, are for generally more "urban" areas, with smaller lots, public water and sewer facilities, and less emphasis on agricultural land. These ordinances are also similar to those for A-C districts, except that mobile homes are not permitted, except as special exceptions. If there is neither a public sewer system nor a public water supply, the minimum lot size is 2000 m^2. If there is one or the other, minimum lot size is 1670 m^2, and if both are present, lots must be at least 1120 m^2 (Kent County Zoning Ordinance, Article 4, Section 3).

In addition to these general regulations, Kent County also has Flood Plain District regulations, encompassing all lands within the 100-year flood plain (Kent County Zoning Ordinance, Article 4, Section 9). All of the study areas in Kent County are included in this district. Generally speaking, no mobile homes are permitted in these areas, except in existing parks or subdivisions, and several criteria for the construction or placement are outlined: 1) buildings must be anchored, and built with flood-resistant materials, utilizing correct construction methods, 2) the lowest floor must be at least 0.3 m above Base Flood Elevation (i.e. the 100-year flood level), 3) if fill is used to achieve this, it must conform to specifications regarding type and contouring, 4) if pilings are used with mobile homes, they must be placed in "stable soil" no more than 3 m apart (there is no mention of piling length, or what is considered stable soil), 5) buildings must be placed to minimize obstruction to water flow, and 6) water systems and sanitary disposal systems must be waterproofed to .3 m above base flood elevation.

The Delaware Bay communities in Sussex County are either A-R1 (Agricultural-Residential Single Family Residential), G-R (General Single Family Residential), or M-R. In general, the regulations for these districts are very similar to those for Kent County. In A-R districts, including Fowler Beach, and G-R areas, including

Broadkill Beach, south of the access road, there is an emphasis on the preservation of agriculture, with some low-density housing. M-R districts, including Primehook and the north end of Broadkill Beach, generally have moderate-density residential development, where public water and sewers may or may not be available (Sussex County Zoning Ordinance, Sections 1 and 2).

Sussex County also has special regulations for coastal protection, including the following: 1) there can be no removal or displacement of berm or beach material before construction is completed, and then only to build up the seaward slope of the dune (in fact, this regulation could be counter-productive, since building up the foredune in this way could lead to increased erosion due to the creation of a steeper beach face), 3) the first floor of buildings extending seaward of the dune line must be between 4.9 m and 5.5 m above MLW, 4) if land below the 100-year flood level is developed, new construction must be landward of MHT (this is not very restrictive) and elevated on "adequately anchored" piles or columns (this is too vague) to a lowest floor level at or above the 100-year flood level, and the space below the lowest floor must be free of obstructions, and 5) buildings must be aligned to minimize resistance. In addition, there are specifications regarding anchoring (though these are not very specific), basement floors, foundation walls, interior floors, walls, ceilings, electrical systems, plumbing, and storage areas (Sussex County Zoning Ordinance, Section 13).

The zoning regulations for Slaughter Beach are administered by the Town Council, which is a body of five elected members, with terms of two years. In general, this group enacts ordinances which will benefit the town, plans for long-range improvements, grants franchises such as utilities, sets the tax rate, and spends and borrows town monies (Jaywork, personal communication). The town zoning ordinances specify the same sorts of building restrictions as the county ordinances discussed previously, including permitted use, accessory uses, lot sizes, yard sizes, and building heights. Only two of these restrictions are directly applicable to the prevention of flood damage. First, all new buildings must be 2.6 m above mean sea level (which was determined in three places by the National Geodetic Survey), and on the west side of route 204 the first floor must be at least 2.6 m above MSL. Second, if pilings are enclosed with materials such as sheathing, the enclosures must give way under wave pressure, and there can be no living space within the enclosed area. Also, ordinances prohibit the use of motor vehicles on the beach, the erection of mobile homes or trailers, and the destruction of beach grass (Jaywork, personal communication).

State Regulations

At the state level, the Department of Natural Resources and Environmental Control (DNREC), Wetlands Section, is involved with the implementation of the 1973 State Wetlands Act, which concerns dredging, filling, and construction on wetlands (7 Del Code 66) (See also discussion under "Coastal Wetlands"). To alter wetlands in any of these ways, one must apply for either a Type 1 (if the area is less than 0.4 ha) or Type 2 (if the area is greater than 0.4 ha) permit (Type 2 permits involve a more involved evaluation process) from this department. The application is available for public inspection for 20 days, and at the same time, adjacent landowners, state and city agencies, and private concerns are also notified. If any objections are raised, the applicant can request a public hearing. If there are no objections, the permit is sent to the secretary of the DNREC, who decides whether or not to oppose it. If the permit is denied, the applicant can appeal to the Wetlands Appeal Board for review, and if the DNREC objects to the decision of the Appeal Board, the case goes to Delaware Superior Court (one case has lasted for three to four years as a result of this process). Finally, if the permit is not granted, and the property owner feels that a "taking" without just compensation has occurred (since he is unable to use the wetlands as he would like), the superior court can decide whether or not a taking has occurred, and if it has, the DNREC must offer to purchase the land at "fair market value" within two years (Dept. of Natural Resources and Environmental Control, 1976).

Federal Regulations

In addition to the local, county, and state regulations described above, the Federal Emergency Management Agency (a division of the Army Corps of Engineers) has established "Requirements for Flood Plain Management Regulations" (Chapter 1, Part 60, Subpart A). In general, the local and county regulations must be as strict as, or stricter than, these regulations, but for purposes of completeness, a brief description of these regulations is included here. All of the study areas are either "D level" or "E level" communities. D level areas (including Port Mahon, Kitts Hummock, Bowers, South Bowers, Bennett's Pier, Big Stone Beach, and one or more of the Sussex County study areas) are those in which a 100-year flood elevation and a floodway (i.e. non-tidal section of a watercourse, probably not applicable in these areas) have been established. In D level communities, the floodplain must be kept unobstructed--within the floodplain, any building or other development must exert no effects on flood tidal heights. E level communities (including Slaughter Beach, and some other Sussex County areas) also have a 100-year flood level and floodways established, and include V-zones, i.e. areas of "high velocity water or tidal flooding." In these zones, the lowest structural member must be at or above the 100-year flood line, buildings cannot be located seaward of the mean high tide line (note--this is not a very strict restriction), and anchoring requirements must be met. In addition, pilings must be used (not fill), and the space between the lowest structural member and the ground surface must not be enclosed, except by walls designed to break away during a flood. Finally, mobile homes cannot be located in V-zones or floodways (Gavin, personal communication).

Federal agencies involved with the implementation of Section 404 of the Clean Water Act also regulate coastal development, by requiring permits for any dredging or filling of wetlands. Before a 404 permit is approved, it is evaluated by three federal agencies: the Environmental Protection Agency (EPA), which is concerned mainly with the water quality impacts of the proposed project, the Fish and Wildlife Service, which reviews the permit based on the project's impact on the aquatic habitat and wildlife of the area, and the National Marine Fishery Service, whose concern is the fish and shellfish populations of the area. These three agencies then submit the permit application to the Army Corps of Engineers, along with their recommendations. After giving notice to the public, the Corps issues or denies the permit; however, the EPA has ultimate veto power. If the permit is denied, the applicant can appeal to the district engineer, and finally to the Federal District Court (W. Muir, personal communication).

CONCLUSIONS AND RECOMMENDATIONS

Development

Although very little developable area remains in the coastal locations due to legal restrictions on the development of wetlands, the lots that are available for residential development and the possibility of future construction by a homeowner, or following property transferral, warrant a discussion of the implications for development of these areas. Recommendations include 1) general modifications of existing coastal legislation, and 2) the implementation of a coastal research and monitoring program, the results of which could be made available to anyone considering construction in the coastal zone.

With the few exceptions noted, the county and city zoning ordinances and state and federal regulations seem reasonable and useful--however, I believe they are far from adequate. In some cases, the criteria utilized by the regulations should be changed. For example, establishing a minimum height for the lowest floor is necessary, but this should be done in relation to certain flood levels (as it is in Kent County) and not mean sea level (as it is in Sussex County) (unless a certain flood level was, in fact, used to determine the minimum height above mean sea level). In other cases, regulations are not specific or strong enough. An example of this is the requirement that houses be built on pilings to a certain minimum level (which is true for Sussex County)--terms like "adequate anchorage" and "stable soil" need to be defined, and strict criteria met when defining them.

Based on the results of the research and literature search done for this report, I believe that before the sale or development of coastal property, the following procedures should be followed:

1) A geological core or cores taken, or a rough geological cross section drawn up;
2) Erosion rates or shoreline position monitored at least every five years;
3) Tests done to determine the potential for settling if construction is attempted;
4) Flooding monitored, and residents interviewed regarding past flooding (utilizing a clear definition of the term).

The results should then be automatically shown to potential property buyers or those who would like to build on land they already own. When coastal development is proposed by the government or industry, laws should require the incorporation of this data into any development plans. It is apparent from the Port Mahon bulkhead fiasco that, if left to their own discretion, engineers or designers sometimes ignore such information, even when it is made available.

Beach Preservation

Over the past 20 years, millions of government dollars have been spent on beach nourishment and other preservation methods for the communities along the Delaware Bay coast. Since the erosion problems faced by these areas will probably recur, or be amplified in the future, in conjunction with reduced government money available for beach preservation, there is a need for studies which quantify and compare certain variables for coastal locations, to determine which are more deserving of beach preservation dollars than others. The beach preservation value ratios presented in this report help in this determination. Based on the five demographic and six environmental criteria presented, the preservation value ratios for the 11 study areas range from 0.2 to 0.8, with a mean of 0.52. These communities and undeveloped areas seem to fall into three groups. The first, including Port Mahon, Bennett's Pier, Cedar Beach, and South Bowers, have ratios of less than 0.4, and are poorly-suited for beach preservation according to almost all of the criteria, both demographically and geologically. A second group includes those with ratios between 0.4 and 0.6, and includes Fowler Beach, Kitts Hummock, and Big Stone Beach. These areas are favorable for preservation in some respects and unfavorable in others. In some cases, if certain criteria were improved, for example the population characteristics of Big Stone Beach, the community could achieve a much higher ratio (also, in this case, provided the current and future development allows for the high incidence of overwash). The third class of towns includes Slaughter Beach, Bowers, Broadkill Beach, and Primehook Beach, with ratios greater than 0.7. These areas are characterized by fairly large permanent and summer populations, high property values, stable subsurface geological characteristics, low erosion rates, varying amounts of past beach nourishment, and medium-to-low susceptibility to overwash. Based on the criteria presented, these areas are most suitable for future beach preservation efforts.

However, no one person can say that the state should provide beach nourishment to some of these towns and leave the houses of another to fall into the sea (or purchase all property from the owners). Such decisions require an evaluation of political, economic, social, and biological factors, along with the environmental and geological criteria discussed in this report. This study shows that the task of evaluating and comparing coastal communities on the basis of certain criteria is not monumental. If used in conjunction with studies from other disciplines, decisions on the future of these and other coastal areas can be based on factual analysis, resulting in economic benefits for all levels of government, reduced hazards to coastal dwellers, and a greater public appreciation of the natural hazards of the coastal environment and its natural beauty as well.

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APPENDIX

I. Coring Procedures

Vibracore

This method involves the use of a gasoline-powered motor to vibrate an aluminum pipe down through the sediment, resulting in a core that can be taken back to the laboratory for analysis. When a vibracore is taken, first the head of a long cable attached to the motor is clamped to one end of a 6-8 cm diameter aluminum pipe. The pipe is held vertically and the engine started; the vibration of the sediments near the end of the pipe allows the pipe to be driven downwards. When the core is completed, the distance between the upper end of the pipe and the inside sediment, and the distance between this end and the ground surface are measured, to account for "rodding" (which occurs when the pipe is driven down into the ground but sediment does not enter the pipe at the bottom). In addition, the orientation of the core is marked on the pipe. The top of the pipe is then filled with water, and plugged with an adjustable wing-nut plug. The core is removed from the ground through the use of ropes (used as Prussic knots), come-alongs, and a 5-6 m high tripod which is situated over the core. After the core is removed, the lower end is capped, the excess pipe on the upper end is cut off, and that end is capped as well.

Analysis of the core involves cutting the core lengthwise (along the desired orientation, if sedimentary structures are important) and logging the different facies found. One half of the core is then cut into meter-long sections and photographed. Cores can then be placed in plastic bags to preserve most of the moisture of the sediments, for future analysis.

The vibracore technique is advantageous in that a core can be brought back to the laboratory and analyzed and photographed in detail, and preserved for future study. The gasoline engine is fairly inexpensive, as is the core pipe and other equipment involved. Generally, at least three people are required for vibracoring, and several cores can be taken in one day.

Jetwash

During jetwashing, water is pumped down through a narrow (several centimeter diameter) steel pipe, which is pushed down into the sediment, flushing up the material around the outside of the pipe. A gasoline-powered pump, with large intake hose and narrow (garden hose-sized) output hose is used. The narrow hose is attached to one end of a three meter long steel pipe, which is then held vertically, with the free end at ground level. The input hose is filled with water to prime the pump, and the engine is started, causing water to be forced down the steel pipe. The pipe is pushed gently downward and the sediment near the bottom of the pipe is carried to the surface by the water. In this way, the nature of this sediment can be determined and noted, along with its depth (since the pipe is marked in meter-length sections). When the entire three meter long section of pipe has been driven into the ground, the water flow can be shut off and another three meter section attacked to the first; the hose is then reattached and water flow resumed, to continue the jetwash.

Jetwashing has the advantages of being very fast and inexpensive, and is a good method to use for surveying an area, to get a general idea of the subsurface sediments, to determine the location of a certain layer or surface (for example, the Pleistocene surface) or to decide on the best location for another coring technique, such as vibracoring. Although jetwashing is fairly reliable and accurate, the sediments cannot be analyzed for grain size, organic content, moisture content, etc., since the slurry that comes up around the pipe can contain not only sediments from the bottom of the pipe, but overlying material as well. Other disadvantages with this method are that sedimentary structures cannot be analyzed, and a water supply is needed.

Eijelkump Gouge Auger

This type of coring is a technique in which a two centimeter diameter steel pipe is driven down into the sediments by hand (using handles oriented perpendicularly to the pipe) and withdrawn. Since one side of the pipe is cut away, the material in the pipe can be analyzed visually and sampled (if desired) for further analysis. Although each pipe section is only one meter long, sections can be joined to go to greater depths. The advantages of this method include its ease of operation, portability, speed, and inexpense, but cores cannot be preserved for future use, and the length of the core is limited by the nature of the sediments and the strength of the experimenter.

II. Air Photo Analysis: Sand Surface Areas

In order to determine recent changes in the sand surface areas of the communities and undeveloped areas, the following procedure was followed:

1) Northeast and southwest boundaries were decided on for each area, generally at the edges of housing development. Two areas (Broadkill Beach and Port Mahon) were then subdivided, due to differences in orientation, presence or absence of groins, and other differences between the sections.

2) The sand surface area (usually bounded by wetlands or roads to the southwest, and the Delaware Bay water line to the northeast) was then traced onto clear plastic from 1973 and 1979 photos, of 1:12,000 scale.

3) Since a planimeter was unable to accurately record sand surface areas from this plastic (due to the slipperiness of the surface), the areas were then traced onto tracing paper.

4) the length of each area was measured, converted to true distance, and recorded.

5) The area itself was determined with a planimeter, and corrected for planimeter error (which was determined through the use of a tool that delineates a known (ten square inch) area).

6) Areas were then corrected for tidal height through the use of photography times, actual tidal information (given times and heights of high and low tides for that date), average tide range for that location, and approximate beach face slopes (all surface areas were converted to what they would be at high tide).

7) Aerial changes and percent changes from 1973 to 1979 were then determined and recorded for each community.

III. Interviews

A. Resident Interviews

I chose subjects for interviews on the basis of the length of time they have lived in the area, or have been associated with it in some way, and their degree of familiarity with the beach--prospective interviewees were often recommended by other people I spoke with or interviewed. In this regard, the people who were interviewed probably do not represent a cross section of that town's residents. In addition, sample sizes were very small. There were five interviewees at Broadkill Beach, six at South Bowers, eight at Bowers, and eleven at Slaughter Beach. This was due mainly to time restrictions, given the depth of the interviews. Although no real statistical analysis can be performed on the responses, the purpose of these interviews was not to get a large volume of survey information; instead, this section of the study was designed to see how some fairly long-term residents view the beach changes that have occurred in the past, due to natural and artificial events, and to discover their impressions of beach preservation measures that have been implemented in the past, or might be considered for the future. In each case, I contacted the interviewee approximately one week before the interview and told him or her the general nature of the questions that would be asked, to give the interviewee time to think about the topic. I usually conducted interviews in the person's home; although two interviews involved more than two interviewees, the remainder were with one or two people. The interviews lasted from 40-90 minutes and generally lasted about one hour. The questions asked appear on the following pages.

Resident Interview Questionnaire

I. Background

- A. What is your name, address, telephone number?
- B. Do you own or rent here?
- C. Who else lives here with you?
- D. How much time do you usually spend here, over a one-year period?
- E. During what months?
- F. How long have you been a resident, or coming to this area?
- G. If the house is owned, was it previously owned by a relative? If so, how long has it been in your family?
- H. Why did you decide to move here? (What attracted you to the area?
- I. What do you use the beach for? (Swimming, sunbathing, walking, fishing, other?)

II. Beach Changes

- A. Natural
  1. How has the beach changed since you've lived here, or been associated with the area, due to storms or other natural forces?
  2. Are there differences in the amount of erosion that occur due to northeast vs. southeast storms?
  3. Does the beach ever rebuild naturally, either following storms or at other times?
  4. Have you noticed any changes in the beach on a seasonal basis?
- B. Artificial
  1. How has the beach changed, in your experience, due to man's activities?
  2. What have been the effects of:
     - a. Groin and/or jetty construction?
     - b. Beach nourishment (How long does it last?

Does it change the nature of the beach?)

c. Dune grass planting?

d. Other preservation measures?

C. General--In general, do you feel erosion is a problem at present?

III. Population and Beach Use Characteristics

A. Do you feel the permanent (year-round) population is increasing, decreasing, or staying the same? Why? Do you think this will continue?

B. Do you feel the summer population is increasing, decreasing, or staying the same? Why? Do you think this will continue?

C. Do you think beach use, by residents or visitors, is increasing, decreasing, or staying the same? Why? Do you think this will continue? Do you think the beach is mainly used by residents, visitors, or both?

IV. Recommendations for the Future

A. For the following beach preservation measures, please tell me your opinions of them, if any, and whether or not you think they might be useful in this area, to help the erosion problem: (for each of these, I would explain the meaning of the term, if necessary).

1. Dune stabilization (grass or snow fence)
2. Beach nourishment
3. Groin or jetty construction
4. Bulkhead or seawall construction
5. Breakwater construction
6. Zoning regulations or setback lines

B. Where should the money to pay for these measures come from? Why?

C. If the government or other sources were only able to pay for part of the proposed measures, would you be willing to help finance such projects yourself, if you felt they would be worthwhile? Do you think others of this community would?

B. Beach Surveys

I conducted beach surveys twice during the summer of 1980 at Broadkill Beach, Slaughter Beach, Bowers, and South Bowers, on Saturday, August 16, and Sunday, August 31 (Labor Day weekend), in order to determine how many people were using the beach, their association with that area, and their activities on the beach. In each case, I walked down the beach and spoke to every person or group of people (or just recorded their presence, if I was unable to speak with them). I recorded the weather and time, and reversed the order in which the towns were covered between the two surveys. During the August 16 survey, I asked the following questions:

1) Are you a visitor or are you staying here?
2) If you are staying here, do you or a friend or relative own the house, or are you renting?
3) How long are you staying here this year?
4) For how many years have you (or your friend or relative) owned or rented here? (if applicable)

In addition, I recorded the number of people and their activities.

During the August 31 survey I asked fewer questions, so that all the towns could be covered during the time of day that the beach should have been most crowded. In this case, I recorded only the number of people and their resident status (year-round resident, summer resident, summer renter, or visitor).

C. Realtor interviews

In interviewed several realtors associated with Bowers, South Bowers, Slaughter Beach, and Broadkill Beach, by phone or in person, to obtain a general idea of housing and property trends for the areas. In these interviews, I asked the following questions:

1) Has there been a recent increase or decrease in the amount of development?
2) How much do houses and/or lots currently sell for?
3) How long do houses and/or lots usually stay on the market?
4) Where are the buyers from?
5) Are buyers looking for a seasonal or permanent residence?
6) Why are people selling lots or houses?
7) What is the length of time between the purchase of a lot and construction?
8) Has beach erosion seemed to affect property values?

IV. Core Logs and Photographs

Core Logs

KSD-BW-1

Location: North end of North Bowers, in wetlands currently for sale. For position, see map (Figure 22, northernmost core), three-dimensional model (Figure 25), and coast-parallel cross section (Figure 29).

Depth (m)	Description
0-2.98	Dark brown marsh muds; highly organic; grasses, peat (no large chunks); fairly uniform color, texture.
2.98-3.56	Fine-med. grained, poorly sorted muddy sands (non-cohesive); grades medium brown to grey; few large pebbles (1-2 cm) (less than 5%) but no intermediate-sized pebbles; gradual gradation of color; some organics (peat strands).
3.56-3.72	Grey clayey sand (fairly cohesive, with large pebbles (50%) (up to 3 cm)).
3.72-4.66	Mottled grey/dk. grey sandy clay grading to clay; no organics; "milky" appearance; uniform gradation in texture; uniform mottling.
4.66-5.70	Grades from mottled grey clay, with very little, fine-grained sand, to very sandy clay with medium grained sand; color grades from grey with few yellowish-tan streaks to mottled yellowish tan/olive green to mottled olive green, with some yellow tan; olive green material is medium-grained very sandy clay; yellow-tan material is finer-grained, slightly sandy clay.

KSD-BW-2

Location: Approx. 100 m southwest of KSD-BW-1. For position, see map (Figure 22, second northernmost core), three-dimensional model (Figure 25), and coast-parallel cross section (Figure 29).

Depth (m)	Description
0-0.26	Marsh muds; dark brown; highly organic (plant stems, peaty material); increasing sand content in lower 10 cm.
0.26-0.96	Orangish-grey muddy sand; medium-grained, poorly-sorted; few pebbles (less than 5%) (.5-1.0 cm).
0.96-1.12	Grey muddy sands with some organics and many (70-80%) large pebbles (1-3 cm); some greenish-grey shale chunks, also, approx. 0.5-1.0 cm.
1.12-2.20	Orangish-brown muddy sand; grades from medium-grained, poorly-sorted wet material to very coarse, poorly-sorted drier sand; pebbles (0.5-2.0 cm) increase in number and size going down; some thin coarse layers (less than 1.0 cm thick) within finer area, but no fine layers in coarser area; no organics.
2.20-3.00	Greyish-tan clayey sand; moderately cohesive; mottled with small amount of tan clay; sand is fairly fine, fairly well-sorted; no organics or pebbles.
3.00-3.78	Mixture of clay and sandy clay; grades from mottled grey/brown sandy clay to mottled grey/bright orange sandy clay to pure bright orange sandy clay.
3.78-3.90	Almost pure grey clay with some fine sand and some orange mottling.

KSD-SBW-1

Location: Approx. 3 m seaward of landward edge of tidal flat, off end of short, coast-perpendicular access road, just south of developed area. See map (Figure 22) and coast-perpendicular cross section (Figure 24b).

Depth (m)	Description
0-0.15	Medium-grained, moderately well-sorted sand; tan; few shell fragments; few pebbles (0.5-1.0 cm).
0.15-0.26	Medium-grained, moderately well-sorted grey sand with many large pebbles (1-2 cm) (about 70%) and large shells; few grey clay chunks, may be out of place.
0.26-0.78	Fairly poorly-sorted, medium-grained grey sand; few small (0.5-1.0 cm) pebbles; sand is uniform throughout length; few grey clay chunks, may be out of place.

KSD-SBW-2

Location: Approx. 100-150 m southwest of KSD-SBW-1, 7.0 m east of main road into town, in washover area (presently covered by grasses). See map (Figure 22) and coast-perpendicular cross section (Figure 24b).

Depth (m)	Description
0-0.04	Orangish-brown clayey sand; fine sand, some roots (approx. 5%).
0.04-0.10	Orange, medium-grained, moderately well-sorted sand, some roots (approx. 1%).
0.10-0.26	Medium-grained, moderately well-sorted sand, grading from orange to dark grey. Some stem material (less than 1%); few pebbles (less than 1.0 cm, less than 1%).
0.26-3.37	Dk. grey marsh muds, highly organic, with peat and plant material (approx. 20% organic); fairly uniform color and organic content throughout section.
3.37-4.38	Dk. grey marsh muds with fewer organics (10-20%), some small (1 cm) patches of orange organic matter, and some peaty patches (1-3 cm).
4.38-5.20	Dk. grey marsh muds, highly organic (30-40%), with dark peaty chunks and orange organic chunks (orange material is pure organics); some variability in organic content throughout section, with layering 2-8 cm thick.
5.20-5.74	Dk. grey marsh muds, fewer organics (10-20%); organics are mainly dark grey peaty areas.

KSD-BK-1

Location: South Broadkill Beach, southwest side of main road, near houses stranded on pilings, in washover lobe (20 m northeast of edge of washover lobe). See three-dimensional model (Figure 58) and coast-perpendicular cross section (Figure 57b).

Depth (m)	Description
0-0.76	Well-sorted, medium-grained sand; grades dk. brown to tan; no rocks, pebbles or organics; clean.
0.76-1.02	Coarse, poorly-sorted light grey sand; few pebbles (0.5 cm); clean.
1.02-1.06	Small pebbles, with some fine-medium grained sand; mostly quartz; clean.
1.06-1.48	Clean sand, grades from fine, well-sorted tan to coarse, well-sorted grey; few pebbles at 1.1801.20 cm depth (max. diameter of 2 cm.).
1.48-1.56	Grey to green muddy sands (gradation of color); some clay mixed in (not chunks); medium-grained sand.

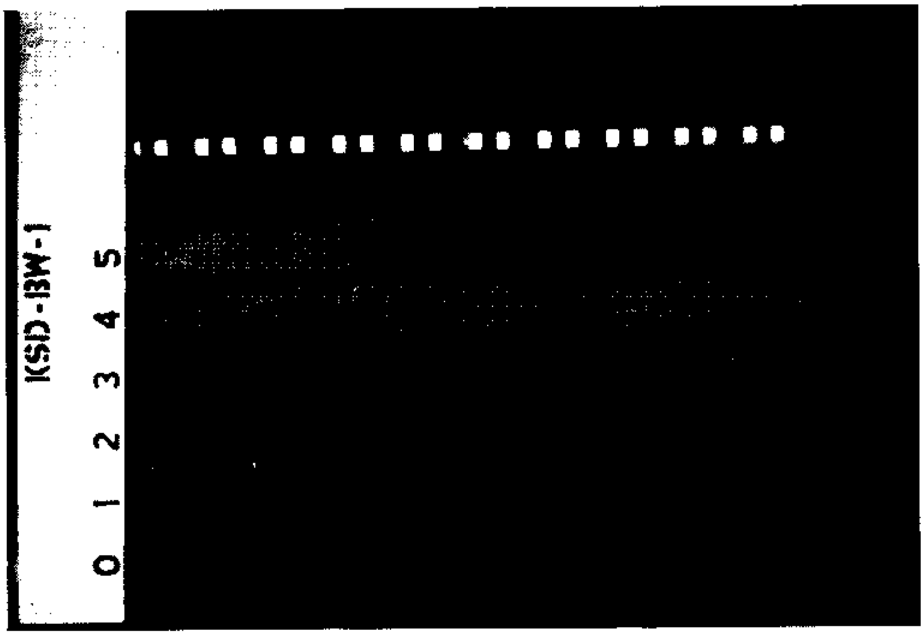
KSD-BK-2

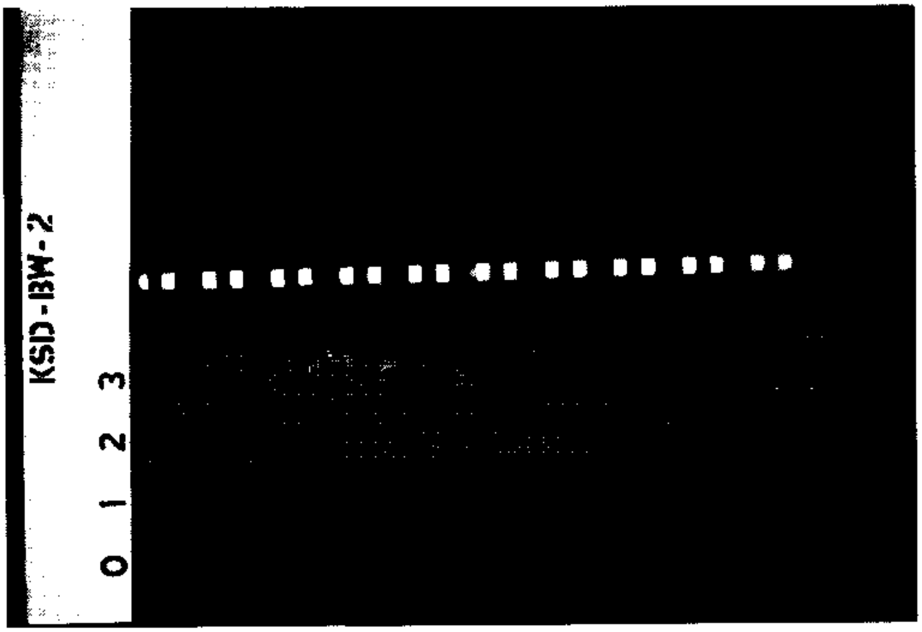
Location: Northeast of KSD-BK-2, at base of beach face, near long house on pilings. See three-dimensional model (Figure 58) and coast-perpendicular cross section (Figure 57b).

Depth	Description
0-0.44	Clean, moderately well-sorted tan sand with some pebbles (about 5%, 0.5-2.0 cm).
0.44-0.86	Clean, fine, well-sorted tannish grey sand; uniform.
0.86-1.16	Clean, greyish-tan moderately well-sorted sand, with some (approx. 15%) small pebbles (less than 0.5 cm).
1.16-1.23	Clean, poorly-sorted grey sand, grading coarse to fine.

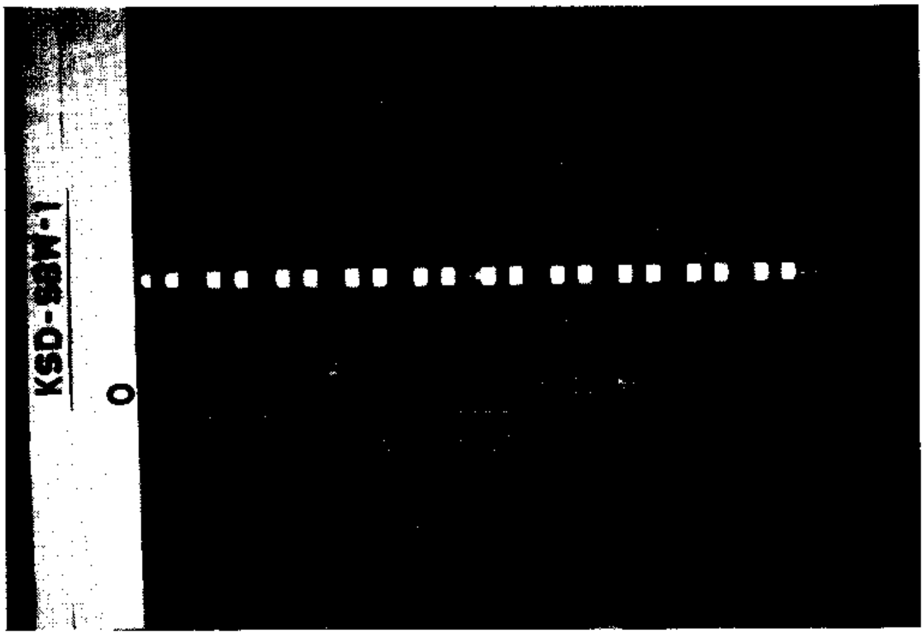
Note: No size analysis of these sediments was done, so all references to cleanliness, grain size, etc. are subjective determinations. Similarly, pebble sizes are approximations, as are descriptions of cohesiveness. All references of grading refer to gradations from the upper part of that section to the lower part.

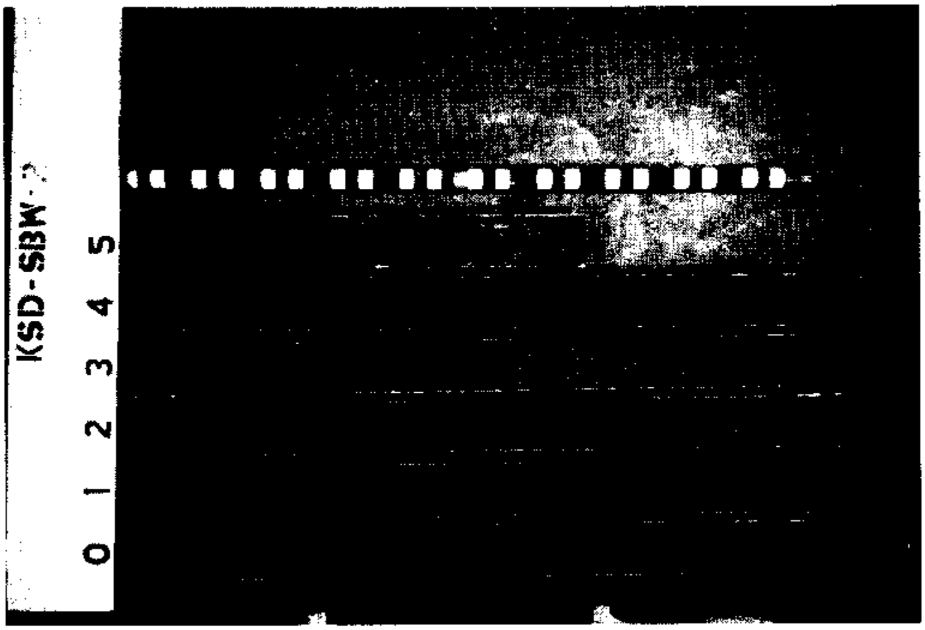
Core Photographs: KSD-BW-1 and KSD-BW-2
(Bowers, Delaware)





Core Photographs: KSD-SBW-1 and KSD-SBW-2
(South Bowers, Delaware)





Core Photographs: KSD-BK-1 and KSD-BK-2
(Broadkill Beach, Delaware)