1977

A Photogrammetric Survey of Backbarrier Accretion on the Rhode Island Barrier Beaches

Elizabeth Jean Simpson
University of Rhode Island

Recommended Citation

Simpson, Elizabeth Jean, "A Photogrammetric Survey of Backbarrier Accretion on the Rhode Island Barrier Beaches" (1977). *Open Access Master's Theses.* Paper 2031.
https://digitalcommons.uri.edu/theses/2031

A PHOTOGRAMMETRIC SURVEY OF BACKBARRIER ACCRETION ON THE RHODE ISLAND BARRIER BEACHES

BY

ELIZABETH JEAN SIMPSON

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
IN
GEOLOGY

UNIVERSITY OF RHODE ISLAND
1977

ABSTRACT

Washover fans and tidal deltas are known to be significant sediment storage sites on the barrier islands of the Outer Banks of North Carolina and the Texas Gulf Coast. No previous studies, however, have attempted to quantify the importance of these sediment sinks in the littoral sediment budget.

The relative importance of washover and tidal delta sedimentation on the erosional shoreline of Rhode Island has been determined from a photogrammetric analysis of the backbarrier shoreline changes on the south shore barrier beaches from Napatree Point to Point Judith over the period of 1939 to 1975 (the dates of the earliest and latest aerial photographic coverage). Amounts of areal changes were measured directly or were calculated from direct measurements. Determination of volumetric changes required additional information concerning annual rates of vertical washover sedimentation (0.03-0.04 m/yr, from Godfrey, 1976; and 0.05 m/yr, this study) and an estimate of volumetric change per areal change of eroded beach from the U. S. Army, Coastal Engineering Research Center (1973) in which a change of 0.09 m^2 along the shoreline is equivalent to a volumetric change of 0.76 m^3, or a change of 8.44 m^3/m^2.

Backbarrier areas were measured using a square grid point-counting technique. These direct areal measurements were converted to ground areas using the representative fractional scales determined for each individual photograph from ground truth measurements, and the amounts of areal changes

of supratidal and subtidal washover and tidal delta deposits and of eroded beach were calculated for the period of 1939 to 1975. Total areal change of supratidal plus subtidal washover deposits was +522,792 + 267,953 m^2 = +790,745 m^2; total areal change of supratidal plus subtidal tidal delta deposits was +188,238 + 862,322 m^2 = +1,050,560 m^2. Total area of eroded beach for the whole south shore was -608,558 m^2. Annual rate of areal changes of washover deposits for the whole south shore was calculated to be +21,965 m^2/yr; for annual tidal delta accretion, +29,182 m^2/yr; and for annual rate of beach erosion, -16,904 m^2/yr.

According to these values of areal changes, subtidal plus supratidal tidal delta sedimentation is 1 1/3 times more effective than subtidal plus supratidal washover sedimentation in the landward transportation, deposition, and storage of sediment. Supratidal washover accretion, however, is nearly three times more effective than supratidal tidal delta accretion.

Using the derived annual rate of vertical washover sedimentation of 0.05 m/yr to compute the approximate volumetric values of changes for both washover and tidal delta deposits (in the absence of any indication of vertical tidal delta accretion rates), and using the Coastal Engineering Research Center's value of 8.44 m^3 sediment loss (or gain) per 1 m^2 areal units of beach erosion (or accretion) to compute the volume of eroded beach, the following results were obtained. Washover accretion was determined to be +1,354,809 m^3 for the whole south shore over the entire study period, tidal delta accretion is +1,822,476 m^3, and the amount of eroded beach is -5,138,934 m^3. According to these values, overwash can account for 26% of the sediment eroded from the beaches and tidal delta sedimentation for 35%. Losses to alongshore and offshore transport of sediment therefore total 39% of the volume of sediment eroded from the beaches of the south shore of

Rhode Island.

The greatest factor controlling the occurrence and amount of washover accretion appears to be an erosional beach. At 27% of the transects at which washover accretion was significant (i.e., more than the mean value of +18,000 m^2), beach erosion was also significant (i.e., less than the mean value of -6,000 m^2). At 66% of the transects at which washover accretion was significant to moderate (i.e., greater than +18,000 m^2 or greater than 0 and less than +18,000 m^2), beach erosion was also significant to moderate (i.e., less than -6,000 m^2 or greater than -6,000 m^2 but still less than 0). Other related controlling factors are the height and continuity of the dunes, the development of transitory inlets, and the width of the barrier beach (which is a function of the development of tidal deltas and washover backbarrier deposits and of the amount of beach erosion).

ACKNOWLEDGMENTS

Funds for this project were provided by Sea Grant (Grant number 506-010; Principal Investigator, John J. Fisher). The 1939, 1951-52, and 1963 sets of aerial photographs were provided by the Department of Geology, University of Rhode Island, and the 1972 and 1975 sets of aerial photographs were purchased with funds from Sea Grant for continuing coastal geology studies.

I thank Drs. Robert L. McMaster and Jon C. Boothroyd for their invaluable advice and criticisms which greatly benefited the final draft of this paper as well as my understanding of coastal processes, geomorphology, and sedimentation. Special appreciation is extended to Dr. John J. Fisher for his guidance, patience, and advice through all phases of this study; many a lively discussion resulted in a clearer perception of Rhode Island coastal geology and photogrammetric techniques.

TABLE OF CONTENTS

LIST OF FIGURES

Figure Page

LIST OF TABLES

Table Page

Appendix I

Appendix II

INTRODUCTION

Washover fans and tidal deltas are considered to be potentially significant reservoirs of sediment in barrier island systems. However, no attempt has been made to quantify the importance of these backbarrier and lagoon deposits as sediment sinks in the littoral sediment budget. This study analyzes the significance of washover fans and tidal deltas as sediment sinks on the barrier beaches of southern Rhode Island between Napatree Point and Point Judith (figure 1).

The analysis of the long-term (in this study 36 years) sediment budget of a barrier island system includes recognition of those processes which transport sediment into, through, and out of the system, as well as the possible sources and sinks for the sediment. Sediment which can be transported by coastal processes alongshore, offshore, as well as landward must be accounted for. Most sediment budget studies have emphasized alongshore and offshore transport of sediment; this study concentrates on the landward transport of sediment. By analyzing the quantitative changes that have occurred on the coast, the relative importance of the sinks in the barrier island system can be assessed, and the probable causes operative along the coast that are responsible for the long-term changes can then be extrapolated.

In the analysis of the long-term sediment budget, as long a range of time as possible to measure the changes along the coast would be most valuable. For this study the most recent (1975) and the oldest (1939) sets of

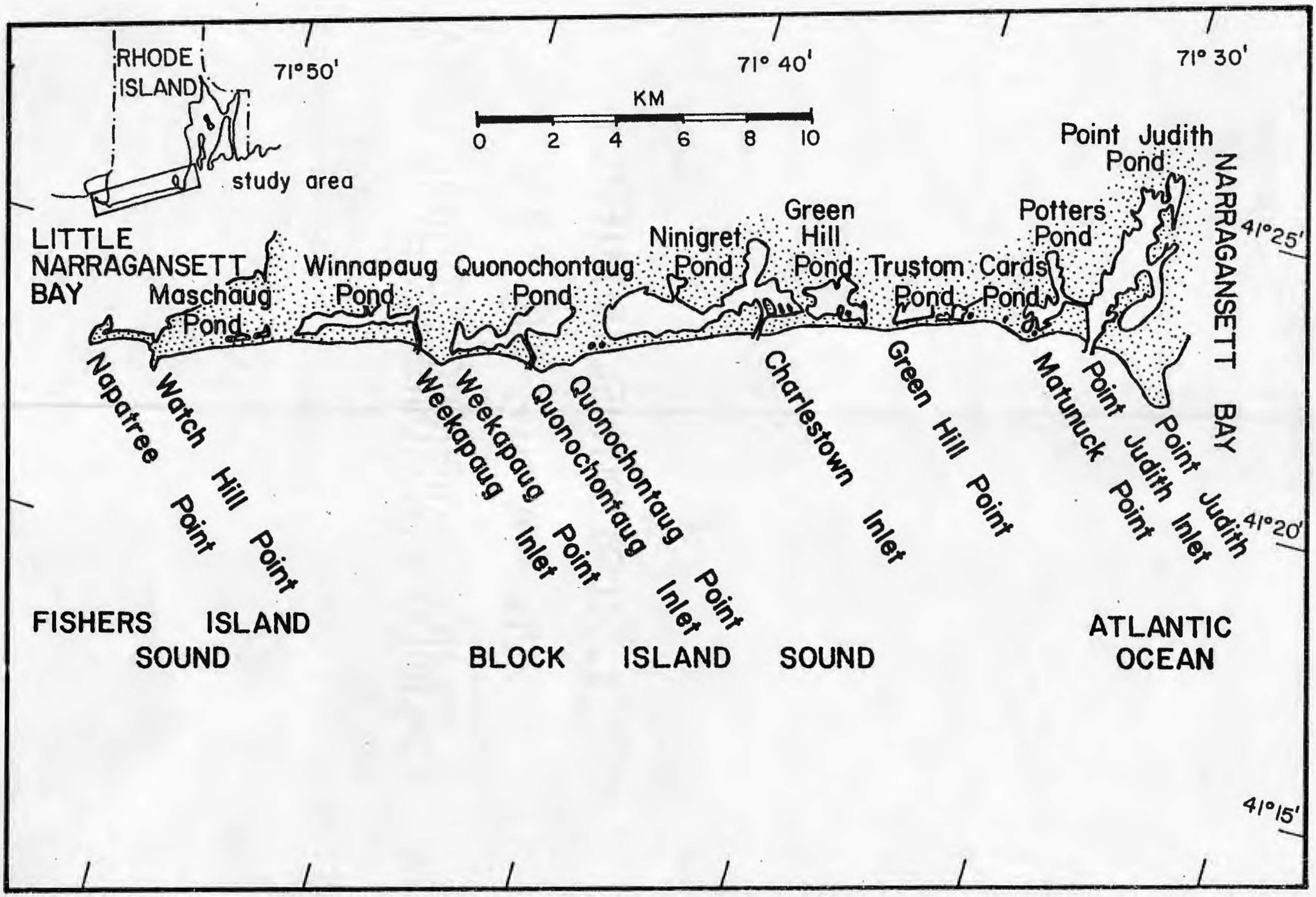

RHODE ISLAND
study area
71° 50'
71° 40'
71° 30'
KM
0 2 4 6 8 10
41°25'
41°20'
41°15'
LITTLE NARRAGANSETT BAY
Maschaug Pond
Winnapaug Pond
Quonochontaug Pond
Ninigret Pond
Green Hill Pond
Trustom Pond
Cards Pond
Potters Pond
Point Judith Pond
NARRAGANSETT BAY
Napatree Point
Watch Hill Point
Weekapaug Inlet
Weekapaug Point
Quonochontaug Inlet
Quonochontaug Point
Charlestown Inlet
Green Hill Point
Matunuck Point
Point Judith Inlet
Point Judith
FISHERS ISLAND SOUND
BLOCK ISLAND SOUND
ATLANTIC OCEAN

FIGURE 1

aerial photographs were chosen to determine photogrammetrically the changes in areas of the backbarrier and lagoon deposits, and to distinguish the changes as washover or tidal delta sedimentation. Changes along the beach as measured at the high water line indicate the possible amount of sediment that is available to be transported landward by overwash and tidal delta processes. Backbarrier sedimentation resulting from landward eolian transport of sediment could not be distinguished from overwash transport of sediment on the basis of this study, but eolian transport was believed to be less significant than overwash transport on the basis of other sediment budget analyses (Bartberger, 1976).

TERMINOLOGY

The terms "overwash" and "washover" have occasionally been used interchangeably in the literature, but a distinction drawn by Schwartz (1975) between the terms is adopted for use in this study. Schwartz defined "overwash" as the mass of water that overtops the barrier island as well as the process of overtopping and "washover" as the sediment deposit or geomorphic feature produced by the process of overwash.

"Backbarrier" as used in this study refers to the supratidal section of a barrier beach behind the foredune ridge that extends landward to the lagoon or bay shoreline. "Barrier beach" is a local term used in reference to the relatively small-scale barrier islands that extend between the headlands and across the relatively small lagoons or salt ponds along the south shore of Rhode Island. As defined by the American Geological Institute (1976), a barrier beach is "a single, elongate ridge rising above the high tide level and extending generally parallel with the coast, but separated from it by a lagoon." The barrier beaches of

Rhode Island have a single foredune ridge, vegetated zones, and marshy terraces extending to the lagoons.

"Supratidal" as used in this study refers to the portion of the coast that lies immediately above the high tide level, "subtidal" occurs below the low tide level, and "intertidal" occurs between the high and low tide levels.

PREVIOUS STUDIES

AERIAL PHOTOGRAMMETRIC STUDIES

Aerial photographs have been used commonly in the past by many workers to analyze coastal changes qualitatively (Dietz, 1947; Lueder and Belcher, 1954; Rib, 1957; Ray, 1960; El Ashry, 1963; El Ashry and Wanless, 1965, 1968; Nordquist, 1972; Godfrey and Godfrey, 1974; Langfelder, French, McDonald, and Ledbetter, 1974), and only recently have aerial photographs been used to determine quantitative coastal changes. A detailed photogrammetric technique for measuring beach erosion along extended stretches of a coast has been developed by Stafford (1968, 1971). His method has been used in subsequent studies of coastal changes (Stafford and Langfelder, 1970, 1971; Wahls, 1973; Stirewalt and Ingram, 1974; Zarillo, 1974; Stephen, Brown, FitzGerald, Hubbard, and Hayes, 1975; Regan, 1976). Other workers have also used aerial photographs in quantitative coastal erosion studies in conjunction with other sources of information, such as historical and recent charts, surveys, and maps, old newspaper reports and interviews with local residents, ground surveys, and other remote sensing imagery, such as Skylab and Landsat-1 imagery (Kaye, 1973; Ogden, 1974; Oertel and Chamberlain, 1975; Glaeser, Muehlberger, and Herron, 1976; Hardin, Sapp, Emplaincourt, and Richter, 1976). A working draft manuscript on the "Standards for Measuring Shoreline Changes" (Tanner, 1977) considers many of the quantitative aspects of using aerial photographs in the photogrammetric determination of shoreline changes described by Stafford.

No known studies have attempted to quantify widespread backbarrier shoreline changes in the manner of this study. Stirewalt and Ingram (1974) measured shoreline changes over a thirty year period along the mainland salt marsh environment in Pamlico Sound, North Carolina, but only at isolated localities.

STUDIES OF OVERWASH AND WASHOVER DEPOSITS

The dynamics of overwash, washover fan sedimentation and morphology, and the implications of overwash on the evolution of barrier beaches have been studied by several workers (Andrews, 1967; Pierce, 1969, 1970; Scott, Hoover, and McGowen, 1969; Nordquist, 1972; Fisher, Leatherman, and Perry, 1974; Schwartz, 1975; Leatherman, 1976, 1977).

Schwartz's recent definitions of "overwash" as the process as well as the mass of water overtopping the barrier and of "washover" as the geomorphic feature and the sedimentation product will be used in this study.

Overwash

The actual process of overwash has been described as a unidirectional, discontinuous flow or pulse of sediment-charged water which occurs in response to the storm wave runup and storm surge overtopping the barrier (Schwartz, 1975; Fisher, Leatherman, and Perry, 1974). Overwash is generally accepted as occurring as a result of the combined effects of a storm surge, storm waves, and normal or unusually high tides, although occasions of overwash occurring in response to monthly high tides or "supratides" alone have been reported by Mikesh, Howard, and Mayou (1968) at Sapelo Island, Georgia, and by Ray, Domeracki, and Waddell (1976) along the South Carolina coast.

over wash

The major factors affecting where along a stretch of beach that overwash is most likely to occur appear to be: the continuity and height of the foredune ridge, and the width, slope, and composition of the beach, since overwash tends to occur where the barrier beach is lowest and presents the least resistance to the storm surges and waves. The erosive capability of the overwash surges on the barrier beach is a function of the parameters listed above, as well as such parameters as the width, height, composition, and vegetation of the backbarrier (which is defined here as the supratidal portion of the barrier beach lagoonward of the foredune ridge), as well as the height of the storm surge, the tidal range along the coast, and the tidal stage (high or low) and tidal phase (spring or neap) during which the storm or hurricane makes landfall (Hayes and Boothroyd, 1969; McGowen and Scott, 1975; Morton, 1976). If the combined height of the surge, waves, and tide is greater than the height of the barrier beach, the barrier will experience overwash. If the combined parameters produce considerable frictional resistance, the overwash flow velocity will be minimized, and depositional processes will predominate over erosional processes on the backbarrier. If the frictional resistance is low, overwash flow velocity will be maximized, and erosion will predominate over deposition. Under such conditions, overtopping waves and storm surge can erode the dunes and barrier beach nucleus down to a level so that a current flows across the barrier beach into the lagoon. Such a storm breach can be opened by overwash from either the lagoon or ocean side of the barrier (Pierce, 1970; Fisher, Leatherman, and Perry, 1974; Godfrey and Godfrey, 1974; Schwartz, 1975).

Washover Deposits

The geometry of a washover deposit is controlled by the degree of foredune development and the backbarrier topography. Overwash localized at an isolated low point in the foredune (such as a blowout, former overwash channel, or beach buggy access road) generally produces an isolated washover fan. If a fairly continuous section of the foredune is lower than the combined level of the storm surge, wave heights, and tide level, then overwash will occur over all of the section, producing a coalescing or sheetlike deposit of sediment on the backbarrier (which has been termed a washover apron or washover ramp). Backbarrier topography can affect the washover geometry by serving to disperse or contain overwash surge and sediment deposition (Andrews, 1967; Schwartz, 1975).

Individual, generally isolated washover fans are subrectangular to semicircular or elongate in plan view, with the landward margin commonly being lobate (Andrews, 1967; Nordquist, 1972; Schwartz, 1975). In cross-section the fans are generally wedge-shaped (Andrews, 1967; Scott, Hoover, and McGowen, 1969) or tabular to prismatic (Schwartz, 1975) and range in thickness from a feather edge at the bayward margin to a meter or so in the central portion (Nordquist, 1972). Distributary channels can form a set of radiating furrows across the fan, originating from a single broad washover channel (Price, 1947; Andrews, 1967) or from a single braided channel system (Scott, Hoover, and McGowen, 1969). Low ridges and broad, wedge-shaped elevations (Price, 1947), eolian mounds ("elongate mounds of eolian sand stabilized by dense growths of grasses and thorny shrubs") (Andrews, 1967), or dunes (Nordquist, 1972; Godfrey, 1976) may occur in the interdistributary areas.

The sources of the sediment that is transported by overwash onto the backbarrier are the dunes, the adjacent and updrift beach, the shoreface, and the shelf, according to analyses of the texture, composition, and content of organic remains in the washover detritus (Andrews, 1967; Hayes, 1967; McGowen and Scott, 1969; Schwartz, 1975).

Washover fan sediments can be modified after deposition on the backbarrier by storm return flow over the barrier beach, which can redistribute the previously deposited washover sediment oceanward (Hayes, 1967; Scott, Hoover, and McGowen, 1969). Succeeding storm surges overtopping the barrier beach as overwash can also erode previously deposited washover sediment, truncating strata and producing a scour surface (Andrews, 1967; Nordquist, 1972; Hosier and Cleary, 1975; Schwartz, 1975). Eolian processes can also cause winnowing of the washover sediments by transporting the finer grades to the dunes, marsh, tidal flats, or beach, depending on the wind direction and magnitude (Pierce, 1969; Scott, Hoover, and McGowen, 1969; Dolan and Godfrey, 1973; Fisher, Leatherman, and Perry, 1974; Godfrey, 1976).

Internally the individual washover fans consist of an imbricate, rhythmic series of graded sheet sands, with generally parallel to subparallel, horizontal to low angle (less than 4-5°) landward-dipping strata, overlying coarse or heavy mineral-rich lag deposits (which can be eolian-winnowed deposits), which are in turn underlain by an undulating scour surface. A thin, dark, organic-rich sandy or silty layer at the base of the washover deposits may mark the top of the pre-storm surface. The heavy mineral-rich layers may mark discrete surges within one washover event. Important but less widespread is the occurrence of buried grasses, inclined at an angle to the roots in the direction of flow. Medium-scale, high-angle, planar cross-bedding (delta foreset strata) commonly occur in the distal deposits of the washover fan where the sediment has been transported into the lagoon or pond (Andrews, 1967; Scott, Hoover, and McGowen, 1969; Schwartz, 1975; Leatherman, 1977).

The internal features of the washover fan may be interpreted as the result of the discontinuous, high-velocity (transitional to upper flow regime) flow of sediment-laden water across the generally low slope of the backbarrier. Segregation of the traction load and suspended load occurs rapidly because of the low depositional slope, percolation of the overwash surge into the relatively permeable backbarrier deposits, and rapid decrease in the flow velocity, with concurrent decreases in the capacity and competence to transport sediment in the surges. Repeated overwash surges across the dunes and onto the backbarrier would produce a rhythmic sequence of bedload-suspended load sedimentation units (Schwartz, 1975; Leatherman, 1977). The parallel strata represent transitional flow regime flat beds, and the subparallel to wavy strata probably represent upper flow regime standing waves (antidunes).

Washover deposition appears to have an important long-term effect on barrier beach evolution in maintaining the existence of the barrier beach. Many workers recognize overwash as a process that rejuvenates the backbarrier marsh by creating new marsh fringe (Godfrey, 1976; Godfrey and Godfrey, 1974, 1975; Scott, Hoover, and McGowen, 1969), although continuous, excessive washover deposition can result in the destruction of the marshes by exceeding their capacity to recover and benefit from the input of new substrate (Godfrey, 1976). Washover deposition on the backbarrier also results in the vertical accretion of sediment in addition to the lateral accretion which occurs at the marsh or lagoon fringe (Nordquist, 1972; Godfrey and Godfrey, 1973; Godfrey, 1976; Leatherman, 1976).

STUDIES OF INLETS AND TIDAL DELTAS

Tidal inlets and tidal deltas on sandy shores are intimately interdependent in the manner that sedimentation processes and products are interrelated. Studies of the forms of sediment accumulation in ebb and flood tidal deltas and their relation to the types and intensities of tidal and hydraulic currents in the inlet and tidal delta channels have been made by the University of Massachusetts Coastal Research Group (1969), Hayes and Kana (1976), and Cronin (1975). Inlet dynamics have been studied in detail by O'Brien (1976) and Price (1947, 1963). The geomorphic and sedimentologic aspects of tidal deltas have been studied by Lucke (1934a, 1934b), Fisher (1962), Hoover (1969), Caldwell (1972), and Oertel (1972, 1975). The interrelationship of marshes, washover, and tidal delta sedimentation in the evolution and development of the barrier beach system has been studied by Pierce (1970), Godfrey and Godfrey (1973, 1974, 1975), and Godfrey (1976). The evolutionary development of tidal deltas has been considered by Morton and Donaldson (1973), who develop and interpret Lucke's (1934a, 1934b) three stages of tidal delta development, and by DeAlteris (1976), who considers lagoon infilling as a factor of inlet and lagoon hydraulics.

Inlets

Three principal modes of inlet formation on sandy shores have been recognized by Caldwell (1972). An inlet can form contemporaneously in two ways as the barrier beach develops: 1) by submergence of pre-existing dune and beach ridges as a result of sea level rise, as suggested by Hoyt (1967), or 2) by prolongation of spits across an embayment, as suggested by Gilbert (1885). An inlet can also develop 3) as a result of overwash processes eroding a channel through a barrier beach between the ocean and a lagoon.

The viability and form of an inlet are controlled by the relationship between the scouring capability of the currents flowing through the inlet and the "advection" of sand by littoral drift to the inlet (Byrne, DeAlteris, and Bullock, 1974). The scouring capability of the currents at the inlet and the capacity and competence of the inlet currents to transport sediment as suspended and bedload are primarily a function of the tidal prism, or the total amount of water that flows through the inlet in a tidal cycle, which tends to create and maintain the most energy-efficient cross-section of the inlet (O'Brien, 1976). The tidal currents are transformed into hydraulic currents in the inlet because damping of the ocean tide results in differences in tidal levels in the ocean and lagoon, which produce a hydraulic head and slope through the inlet (O'Brien, 1976; Price, 1947, 1963).

Tidal Deltas

Accumulations of sediment develop at both the oceanward and lagoonward ends of an inlet in response to the tidal flow through the inlet, the wave climate, and the supply of sediment from longshore drift, fluvial discharge, and from the offshore. Hayes and Kana (1976) identify three principal sand units associated with inlets: flood tidal deltas, ebb tidal deltas, and recurved spit-inlet fill sediments associated with inlet migration. The degree of development of flood and ebb tidal deltas appears to be a function of the amount of sediment supplied to the inlet area, and of the interaction of waves, longshore drift, tidal currents, and fluvial discharge.

Noting that tidal range appears to have the broadest effect in determining large-scale differences in estuary or lagoon sand accumulations of all the process variables (tidal range, tidal currents, wave conditions, and storm action), Hayes and Kana (1976) consider three coastal models: microtidal (tidal range less than 1 m), mesotidal (tidal range 1-4 m), and macrotidal (tidal range greater than 4 m). On microtidal coasts the effects of waves generally dominate over those of the tide. For this reason ebb tidal deltas are generally absent or poorly developed. Tidal currents generated through the inlet are generally capable of transporting only fine sediment or relatively insignificant amounts of sediment, which tends to be redistributed by the waves faster than it can accumulate. Flood tidal deltas on a microtidal coast are also generally poorly developed, although they tend to be better developed than their associated ebb deltas. On mesotidal coasts both the ebb and flood tidal deltas tend to be well-developed and have characteristic morphologies (described and illustrated in Hayes and Kana (1976) and in the University of Massachusetts Coastal Research Group (1969) field guidebook). On macrotidal coasts the effects of the tide are so dominating that the sediment bodies tend to be oriented parallel to the flow of the tides rather than normal to the flow of the tides and to approaching waves as in the micro- and mesotidal models (Hayes and Kana, 1976).

RHODE ISLAND COASTAL STUDIES

Processes

Data concerning process factors in shoreline development (winds, waves, tides, littoral drift, storms, and hurricanes) have not been comprehensively studied since the compilation of such data by the U. S. Army Beach Erosion Board (1949).

Prevailing winds on the Rhode Island coast are from the southwest, west, and northwest, with storm winds approaching from every direction except the southwest, with the northwest favored for duration and velocity. Winds from the southeast are rare, but their infrequency is more than compensated for by their severity, with the southeast winds causing a maximum damaging effect for each occurrence. Swells are predominantly from the east for low swells (0.3 - 2.0 m), with swells from the northeast, southeast, south, and southwest also being common, and medium (2.0 - 4.0 m) and high (greater than 4.0 m) swells being predominantly from the east (U. S. Army Beach Erosion Board, 1949).

Littoral drift is generally west to east along the greatest part of the south shore from Watch Hill to the Charlestown Breachway and from Matunuck Point to the Point Judith Breachway (McMaster, 1960; U. S. Army Beach Erosion Board, 1949). The Beach Erosion Board believes the direction of drift between Napatree and Watch Hill Points to be east to west, based on the accretion of sediment on the eastern side of a jetty at the eastern end of Napatree Beach. McMaster believes there to be a nodal point at the Charlestown Breachway according to heavy mineral analysis, with the drift being east to west between the Breachway and the area to the west of Matunuck Point. The existence of a nodal point in the region to the west of Matunuck Point was corroborated by Beale's (1975) study of the currents, waves, and sediment dispersal in that area. Before the construction in the area between Matunuck Point and Point Judith, the drift direction was east to west, which reversed to west to east following the construction (McMaster, 1960; U. S. Army Beach Erosion Board, 1949).

The Rhode Island coast is a micro- to mesotidal coast, according to the tidal ranges taken from the N.O.A.A. Tide Tables. The mean tidal ranges above mean low water vary from 0.76 m at Watch Hill to 1.07 m at Narragansett, with the extreme spring tidal ranges being 0.94 m at Watch Hill and 1.34 m at Narragansett.

The U. S. Army Beach Erosion Board (1949) estimates that tropical storms pass within an effective radius of Rhode Island on the average of one every three years, although the majority have dissipated much of their strength. Hurricanes that have affected the study period include severe hurricanes in 1938, 1944, and 1954, and less severe hurricanes in 1955, 1960, 1963, and 1968.

Sea level rise trends recorded at Newport, Rhode Island, since 1931 indicate that the rate over the period of 1931 to 1972 has been a rise of 3.04 mm per year (Hicks and Crosby, 1974).

Coastal Geomorphology

The headlands along the south shore are comprised mostly of glacial till, in the form of low hills of ground moraine (McMaster, 1960), with granitic bedrock occurring at Weekapaug and Quonochontaug Points. Gravel and sand till overlies stratified sand and silt at Matunuck Point (McMaster, 1960), and cobble and boulder beaches and low tide terraces left from former erosion occur at Matunuck Point, Green Hill Point, Quonochontaug Point, Weekapaug Point, Napatree Point, and Point Judith (U. S. Army Beach Erosion Board, 1949). At Matunuck Point the "broad bouldery pavement at and a bit below high tide" is purported to "mark former low hills of the ablation moraine complex that have been planed off by recent wave erosion" (Kaye, 1960).

The five major lagoons along the south shore, Winnapaug (formerly Babcock's and Pawawget), Quonochontaug, Ninigret (also called Charlestown), Green Hill, and Point Judith Ponds, are all rather shallow and overlie the till and outwash deposits south of the recessional Charlestown Moraine, a continuation of the Harbor Hill Moraine of Long Island, New York. Sediment in Ninigret and Green Hill Ponds includes marine and estuary deposits of beach and tidal delta sands, estuary deposits of fine lagoonal, organic-rich sand-silt-clay, and glacially-derived sediments produced by reworking and removal of fines from the glacial outwash and till composed of coarse sand, gravel, and cobbles (Conover, 1961; Dillon, 1970).

The four inlets, Weekapaug, Quonochontaug, Charlestown, and Point Judith, have all been stabilized with jetties and dredged, and are referred to as breachways, to distinguish then from unstabilized inlets. The jetties at Weekapaug and Quonochontaug Inlets were constructed in the period between 1951 and 1963, with the east jetty at Weekapaug Inlet being present prior to 1939. The Charlestown jetties were originally constructed in 1904 and were lengthened from 60 to 100 feet in 1951-1952. Dredging of the Charlestown Breachway and in the narrows between Ninigret and Green Hill Ponds was carried out in 1956-1957, and in 1962 the channel from the Charlestown Breachway to the east end of Ninigret Pond near the "narrows" was dredged parallel to the barrier through the marsh and islands. The breakwaters and jetties at the Point Judith Breachway were constructed in 1886-1909 (U. S. Army Beach Erosion Board, 1949; U. S. Army Corps of Engineers, 1965a; Conover, 1961; Short, Nixon, and Oviatt, 1974). A fifth, presently unstabilized inlet between Napatree Point and Sandy Point formed during the September, 1938 hurricane and has widened and shoaled considerably as Sandy Point has continued to migrate northward at a rate of about

9 m/year (Nichols and Marston, 1939).

Dune heights along the south shore have been surveyed by Olsen and Grant (1973), who have also described the vegetational cover of the south shore barrier beaches, which consists predominantly of American beachgrass (Ammophila breviligulata), with other dispersed perennial plants on the dunes, most notably seaside goldenrod (Solidago sempervirens), beach pea (Lathyrus maritimus), and dusty miller (Artemisia stelleriana). In relatively well-stabilized area thickets of wild rose (Rosa rugosa) are common, and in protected places growths of shrubs and small trees may be very dense. The most common plant in the salt marshes on the backbarrier is the tall cord grass (Spartina alterniflora) in the intertidal zone. Above the Spartina alterniflora grow meadows of salt grass (Spartina patens). Above the Spartina and reach of the normal tides grows a band of black rush (Juncus gerardi) and spike grass (Distichlis spicata). Beyond this grow salt-tolerant shrubs and then whatever terrestrial species are adapted to the soil of the surrounding land. In many places where natural ground cover has been disturbed by fill or dredging, the normal succession of plants in the marsh has been interrupted by an invasion of plume grass (Phragmites communis), which flourishes in salt or fresh water and on dry, gravelly wastelands. After Spartina one of the most common plants in the salt ponds is eelgrass (Zostera marina), which forms dense meadows in the shallow protected waters (Olsen and Grant, 1973; Sterling, 1967).

Washovers along the Rhode Island south shore have been noted by Nichols and Marston (1939), Kaye (1960), and Dillon (1970). Severe erosion of the foredunes on many sections of the south shore during the 1938 hurricane allowed overwash to erode channels across the barrier and deposit "great scallops of sand, which extended out over the marsh as much as

750 feet from the eroded foredune" in the lagoons or on the backbarrier (Nichols and Marston, 1939). Kaye (1960) notes that "high storm waves may breach, or top, dunes and carry large quantities of beach and dune sand shoreward. This sand comes to rest in a salt pond behind the barrier beach or on the landside of the foredunes, where it forms a sand apron. This apron, which is simply a flat or very gently sloping expanse of sand, grows landward with each major storm." Dillon (1970) believes that most of the backbarrier sand on the Charlestown-Green Hill barrier beaches has been dumped over the barrier from the ocean side during storms, forming lobate fans behind "blowouts." An increase in the sand size behind the barrier after a hurricane was cited by Dillon as documenting the overwash input.

Dillon's (1970) studies of the tidal delta at the Charlestown Breachway indicates that the pond is a "dead end" for entering sediment because the inlet current velocities are very high compared with currents in the pond. Sedimentation rates on the tidal delta are apparently rather low, since the thickness of lagoonal marine sediment measured by Dillon in the pond is only about 1.0 - 1.5 m. The tidal delta is composed of finer sand than the beaches on the ocean side of the barrier (the delta has a median diameter of about 0.15 mm, whereas the beach has a median diameter of 0.2 - 0.3 mm) and shows no apparent consistent changes in size or sorting away from the inlet (Dillon, 1970).

A photogrammetric survey of coastal erosion trends along the south shore of Rhode Island over the period 1939-1972 was conducted by Regan (1976), with 113 transects spaced about 250-500 m apart along the 40 km of the south shore. Regan's results indicate that most of the south shore beaches are erosional over the long term, although some sections of the beaches have experienced accretion, particularly in the post-1938 hurricane recovery period between 1939 and 1951. Dillon (1970), from his stratigraphic study of the Charlestown and Green Hill barrier and lagoon sediment, also believes that general long-term erosional trends are the situation along the Rhode Island south shore, causing the barrier beaches to be submerged by the rising sea level.

PROCEDURE

INTRODUCTION

Five sets of aerial photographs were available for use in this study: 1939 (RISWHPS CONT 3903, taken in May, with a nominal scale of 1:14,000, obtained from the National Archives), 1951-1952 and 1963 (DPK series, taken in October and November of 1951, May of 1952, and September and October of 1963, with nominal scales of 1:20,000, obtained from the Agricultural Stabilization and Conservation Service), 1972 (073-72 series, taken in April, with a nominal scale of 1:12,000, obtained from Aerial Data Reduction Associates in Peace Dale, Rhode Island), and 1975 (058-75 series, taken in April, with a nominal scale of 1:12,000, also obtained from Aerial Data Reduction Associates). The 1939 and 1975 photographs were primarily used in this study for making the measurements of the backbarrier changes, and all five sets of photographs were used for identification of geomorphic and sedimentologic features and for documenting the qualitative changes along the coast.

In this study the changes in positions of the backbarrier and beach shorelines have been determined by comparing the shoreline positions on the earliest (1939) and latest (1975) sets of aerial photographs available of the Rhode Island south shore. By transferring the 1939 shorelines to overlays of the 1975 photographs with the use of the Zoom Transfer Scope, direct measurements of the observable changes were made and then converted to actual ground distances and areas with the scales determined for each photograph. Changes in the widths of the barrier beaches were also calculated from widths measured on the 1939 and 1975 photographs. From these calculations, the proportionate amounts of sediment being deposited in the tidal deltas and washover fans and being eroded from the beaches can be determined, in order to estimate the relative importance of overwash and tidal delta sedimentation on the littoral sediment budget and on the evolution of the barrier beach system of the south shore of Rhode Island.

BACKBARRIER CHANGE DETERMINATION: PHOTOINTERPRETATION AND MAPPING OF THE BACKBARRIER UNITS

Backbarrier features were examined on the 1939 and 1975 photographs using stereographic pairs and mirror and pocket stereoscopes. Features were distinguished as supratidal, intertidal, or subtidal from this examination by determination of the tide levels in the ponds from approximated times of each photograph exposure, known dates of the photographs, tidal data from the N.O.A.A. Tide Tables, and the tidal ranges in the larger ponds. The beach high water line, the backbarrier shoreline, and the outline of the subtidal and intertidal shoals in the lagoons from each individual 1939 and 1975 photograph were then traced on dimensionally stable nine-inch by nine-inch sheets of graphed acetate (one-tenth inch by one-tenth inch ruled to the square inch). Very little of the shoals could be classified as intertidal because of the low tidal ranges in all of the ponds except for Point Judith Pond, so all intertidal shoals were categorized with the subtidal shoals.

Because the scales of the 1939 and 1975 photographs are different and variable, the overlays from the different years could not simply be superimposed over each other. The 1939 photographs with their overlays were optically enlarged through the Zoom Transfer Scope. Viewing the 1939 and 1975 photographs and their overlays simultaneously, the beach and backbarrier shorelines from the 1939 overlays were transferred graphically to the 1975 overlays. The 1975 overlays then showed both the 1939 and 1975 beach and backbarrier shorelines and the outlines of the 1975 subtidal shoals. The 1939 subtidal shoal boundaries were not transferred to the 1975 overlays because an attempt to transfer the outlines of the shoals resulted in too much confusion on the 1975 overlays because the shoals often shifted positions and they do not have continuous extents in all situations.

From examination of all sets of photographs, the subtidal and supratidal deposits on the backbarrier and in the lagoons were differentiated as either washover or tidal delta deposits. This was done by identifying geomorphic features, such as overwash channels or former inlets, and by noting the qualitative changes that had occurred between the successive sets of photographs.

QUANTITATIVE DETERMINATION OF AREAS

Scale

Because small amounts of changes were to be measured on the photographs, the scales of the photographs had to be determined as accurately as possible. Because the scales vary between photographs as well as within photographs and because the nominal scales of the photographs are not exact enough for such a detailed photogrammetric study, the scale of each individual photograph had to be determined. The most accurate method of scale determination is to measure the ground truth of distances between objects that are stable, easily identifiable points on all sets of photographs used. Field survey data between ground control points were taken from Regan's (1976) field notes, and an Altender microrule was used to measure the same distances on the photographs as were measured in the field. The relationship for determining the scale of each photograph from this data as a representative fraction (RF) is as follows:

$$\text{RF} = \frac{\text{distance between two points on photograph}}{\text{distance between same two points on ground}} \quad \text{(in the same units of measurement)}$$

These scales values for each photograph were then used to convert the measured distances and areas on the photographs into actual ground distances and areas.

Transects

Transects were established to delineate areas along the coastline for which areal measurements of changes could be made. 113 transect stations established by Regan (1976) for his beach erosion study were used in this study for two reasons. By using Regan's transects, data from this study could be correlated with the data from his study. Smaller divisions of the backbarrier and lagoon deposits also allows for a greater possibility of determining any patterns of sedimentation on the backbarrier, which might not be apparent with larger, less frequent units of measurement.

Measurement of Areas on the Backbarrier

Principal devices used for area measurement include: a) polar planimeters (or areameters), b) transects, and c) dot grids (Avery, 1977). The preferred method of measuring areas on contact prints is the use of dot grids, which are transparent overlays with dots systematically arranged in a grid pattern. A variation of this point-count method is the use of ruled squares or grids instead of dots for tallying each area classification. The recommended dot or square grid density (i.e., the number of dots or squares per square inch) depends on the photograph scale, size of the area to be measured, and the desired precision. For tracts less than one square mile in size, it is desirable to use a dot density that will result in a conversion factor of ¼ acre to 1 acre per dot or square (Avery, 1969, 1977). The grid density used for this study was 100 squares per square inch, which results in a conversion factor of 0.23 acres per square for a scale of 1:12,000 and a conversion factor of 0.31 acres per square for a scale of 1:14,000, which are well within the recommended limits of Avery.

From the 1939 and 1975 overlays the following distinct areas were measured:

On the 1975 overlays:

a) A, the area of supratidal barrier beach (includes the beach, dunes, and washover and tidal delta supratidal deposits up to the edges of the lagoons and ponds);

b) B, the area of the subtidal washover shoals;

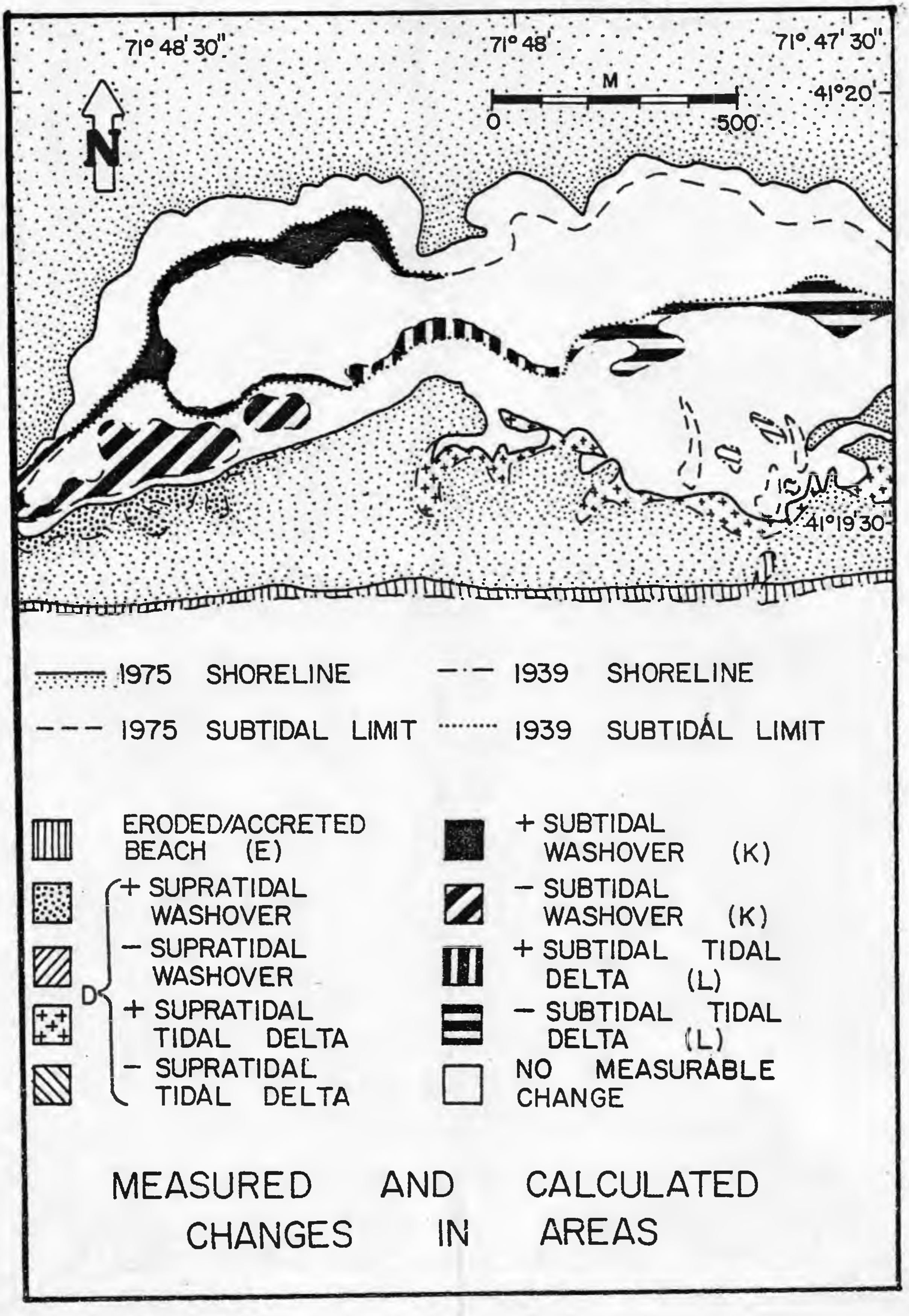
c) C, the area of the subtidal tidal delta shoals;

d) D, the area converted from subtidal washover and tidal delta shoals in 1939 to supratidal washover or tidal delta deposits in 1975 (schematically shown in figure 2);

e) E, the area of beach eroded (or accreted) between 1939 and 1975 (schematically shown in figure 2).

On the 1939 overlays:

a) F, the area of supratidal barrier beach;



MEASURED AND CALCULATED CHANGES IN AREAS

FIGURE 2

On the 1975 overlays:

a) A, the area of supratidal barrier (includes the beach, dunes, and washover and tidal delta supratidal deposits up to the edges of the lagoons and ponds);

b) B, the area of the subtidal washover shoals;

c) C, the area of the subtidal tidal delta shoals;

d) D, the area converted from subtidal washover and tidal delta shoals in 1939 to supratidal washover or tidal delta deposits in 1975 (schematically shown in figure 2);

e) E, the area of beach eroded (or accreted) between 1939 and 1975 (schematically shown in figure 2).

On the 1939 overlays:

a) F, the area of supratidal barrier;

b) G, the area of the subtidal washover shoals;

c) H, the area of the subtidal tidal delta shoals.

The areas (as number of squares) measured on the 1939 and 1975 overlays were then converted to actual ground area (in square meters) by using the individual photograph scales, according to the following relationships:

a) number of squares (1/100 in^2) to m^2 conversion:

$1 \text{ square} = 1/10 \text{ in} \times 1/10 \text{ in} = 1/100 \text{ in}^2$

$1/100 \text{ in}^2 = 0.06452 \text{ cm}^2 = 0.000006452 \text{ m}^2$

b) scale conversion:

$$RF^2 = \frac{\text{photo area (no. of squares)}}{\text{same ground area } (\text{m}^2)} \times 0.000006452 \text{ m}^2/\text{square}$$

or

$$\text{ground area } (\text{m}^2) = \frac{\text{photo area (no. of squares)}}{RF^2} \frac{(0.000006452 \text{ m}^2)}{\text{square}}$$

b) G, the area of the subtidal washover shoals;

c) H, the area of the subtidal tidal delta shoals.

The areas (as numbers of squares) measured on the 1939 and 1975 overlays were then converted to actual ground areas (in square meters) by using the individual photograph scales, according to the following relationships:

a) number of squares (1/100 in^2) to m^2 conversion:

$$1 \text{ square} = 1/10 \text{ in} \times 1/10 \text{ in} = 1/100 \text{ in}^2$$

$$1/100 \text{ in}^2 = 0.06452 \text{ cm}^2 = 0.000006452 \text{ m}^2$$

b) scale conversion:

$$RF^2 = \frac{\text{photo area (no. of squares)}}{\text{same ground area } (m^2)} \times 0.000006452 \text{ m}^2/\text{square}$$

$$\text{or ground area } (m^2) = \frac{\text{photo area (no. of squares)}}{RF^2} \left(\frac{0.000006452 \text{ m}^2}{\text{square}}\right)$$

Calculated Changes of Area on the Backbarrier

In order to determine the relative significance of washover and tidal delta accretion to the measured areas of beach erosion (or accretion), several values to be used in the sediment budget were calculated from the direct measurements of areas on the 1939 and 1975 overlays. The values that are an indication of the rates of sedimentation on the backbarrier and in the lagoon include those showing changes in areas of the subtidal shoals, as well as areas changed from subtidal shoals in 1939 to supratidal deposits in 1975 (which could be measured directly on the 1975 overlays). If the 1939 and 1975 subtidal shoals could be superimposed on the same overlays, it could be readily observed whether the subtidal shoals had increased in their lateral extent into the lagoons between 1939 and 1975; the areas of the subtidal shoals need not be increased for this to happen, because the entire barrier beach system could migrate landward a greater distance than the subtidal shoals could compensate for by lateral growth. However, because the 1939 and 1975 subtidal shoals could not be superimposed without a great deal of confusion, a method was devised to determine only the area of new subtidal shoals in the lagoon. By comparing the 1939 area of subtidal shoals (either washover, G, or tidal delta, H) and the 1975 area of subtidal shoals (washover, B, or tidal delta, C) and compensating for the change in the position of the backbarrier shoreline between 1939 and 1975 by adding in the amount of area converted from 1939 subtidal shoals to 1975 supratidal deposits (D), the area of the new subtidal deposits were calculated. This change in the areal extent of the subtidal deposits into the lagoons reflects the effects of washover and tidal delta sedimentation in causing the lagoon to infill with sediment as the barrier beach system migrates landward.

With all measured areas converted to actual ground areas, comparisons between the 1939 and 1975 measurements could then be made. The following amounts of areal change in addition to the previously determined changes along the backbarrier shoreline (area converted from subtidal in 1939 to supratidal in 1975, D) and along the ocean shoreline (area of eroded or accreted beach, E) can be calculated:

a) I, the change in area of subtidal washover deposits between 1939 and 1975 (B - G);

b) J, the change in area of subtidal tidal delta deposits between 1939 and 1975 (C - H);

c) K, the change in areal extent of subtidal washover deposits into the lagoons between 1939 and 1975 (B + D - G) (schematically shown in figure 2);

d) L, the change in areal extent of subtidal tidal delta deposits into the lagoons between 1939 and 1975 (C + D - H) (schematically shown in figure 2).

Rates of change were then determined from the calculated total areas of change for the entire study period by dividing by the number of years in the study period (36 years). The results of these calculations are listed in tables A, B, C, and D in Appendix I, and are illustrated in figures 3 through 12.

Change in the Width of the Barrier Beaches

Linear measurements of barrier beach widths on the 1939 and 1975 photographs were made along the transects to determine the changes in barrier beach width over the study period. Barrier beach width and change in barrier beach width reflect areas where overwash has occurred significantly in the past, as well as indicating where the combined effects of beach erosion (or accretion) and backbarrier accretion (or lack of accretion) tend to maintain an equilibrium barrier beach width (which may be correlative to that indicated by Leatherman, 1976). The results of this comparison are listed in Table 1. Positive values of change in barrier beach width indicate an increase in width, negative values a decrease in width.

Beach Profile Survey

Over the period of the week of October 4-11, 1976, a beach profile survey was conducted from which beach widths from mean low water to the dune crests and dune heights above mean low water have been determined. This survey was made following a period of beach erosion after Hurricane Belle's attack on the coast to the west of the study area in August, 1976.

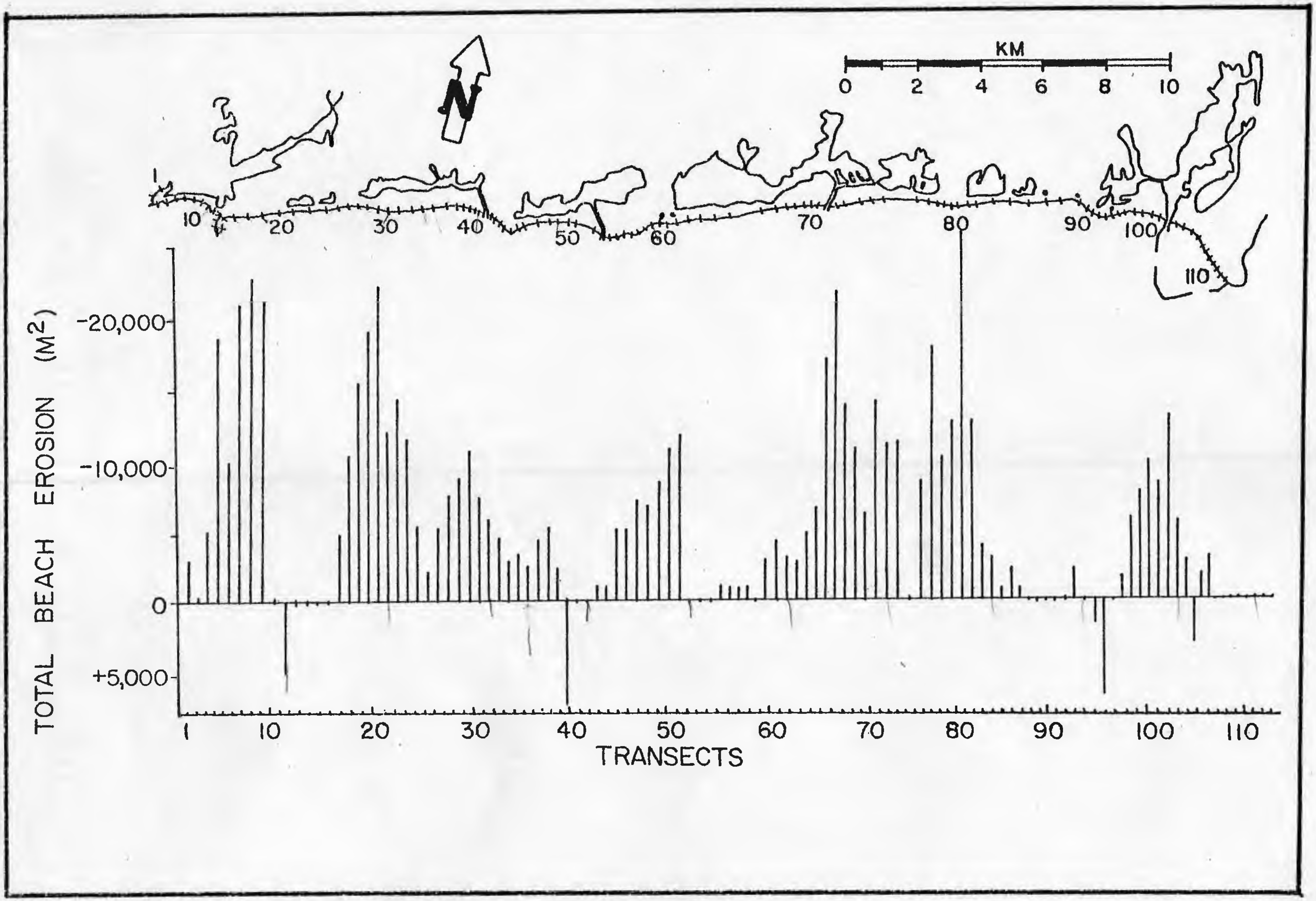

N
KM
0
2
4
6
8
10
1
10
20
30
40
50
60
70
80
90
100
110
TOTAL BEACH EROSION (M^2)
-20,000
-10,000
0
+5,000
1
10
20
30
40
50
60
70
80
90
100
110
TRANSECTS

FIGURE 3

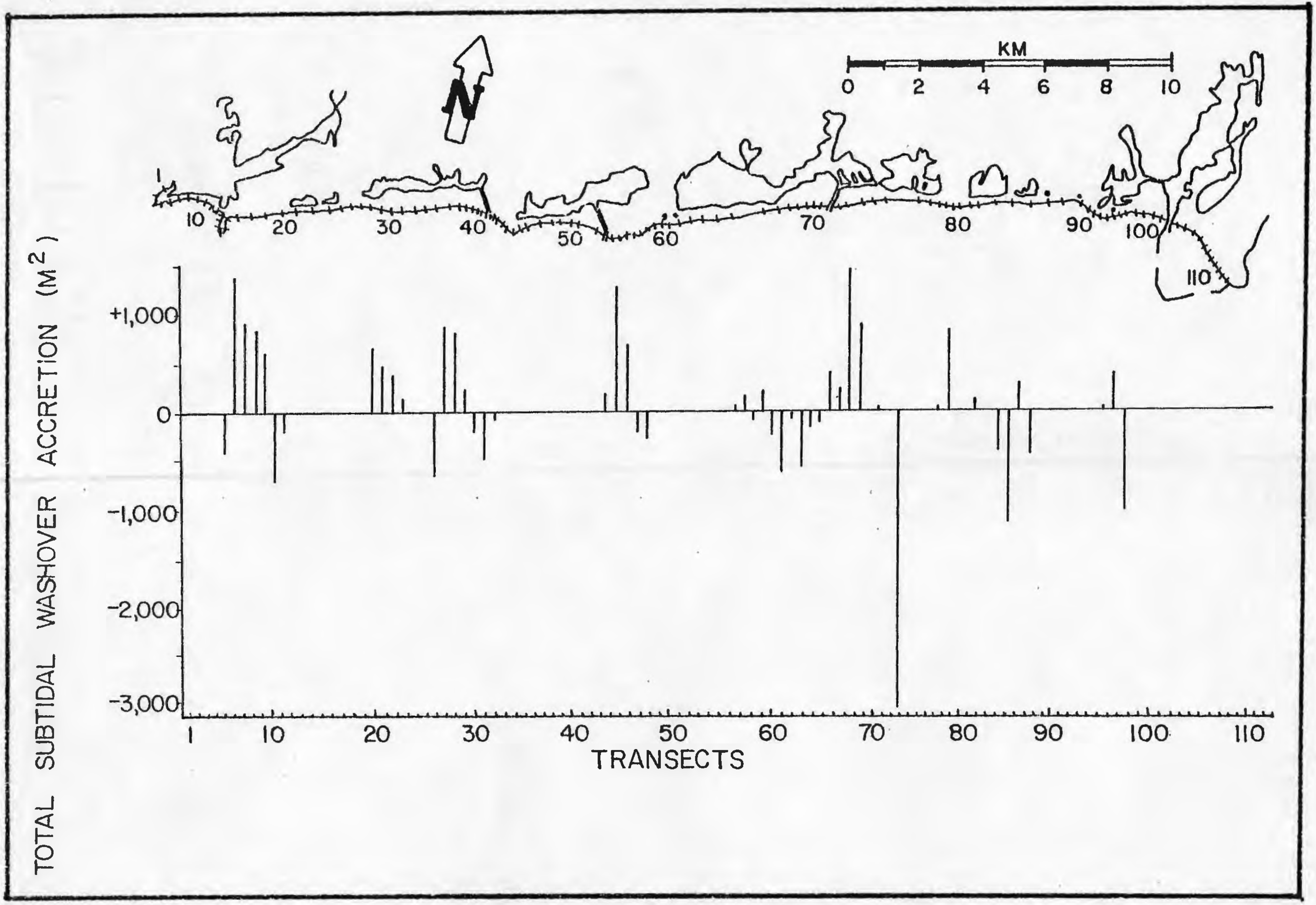

KM
0
2
4
6
8
10
N
1
10
20
30
40
50
60
70
80
90
100
110
TOTAL SUBTIDAL WASHOVER ACCRETION (M^2)
+1,000
0
-1,000
-2,000
-3,000
1
10
20
30
40
50
60
70
80
90
100
110
TRANSECTS

FIGURE 4

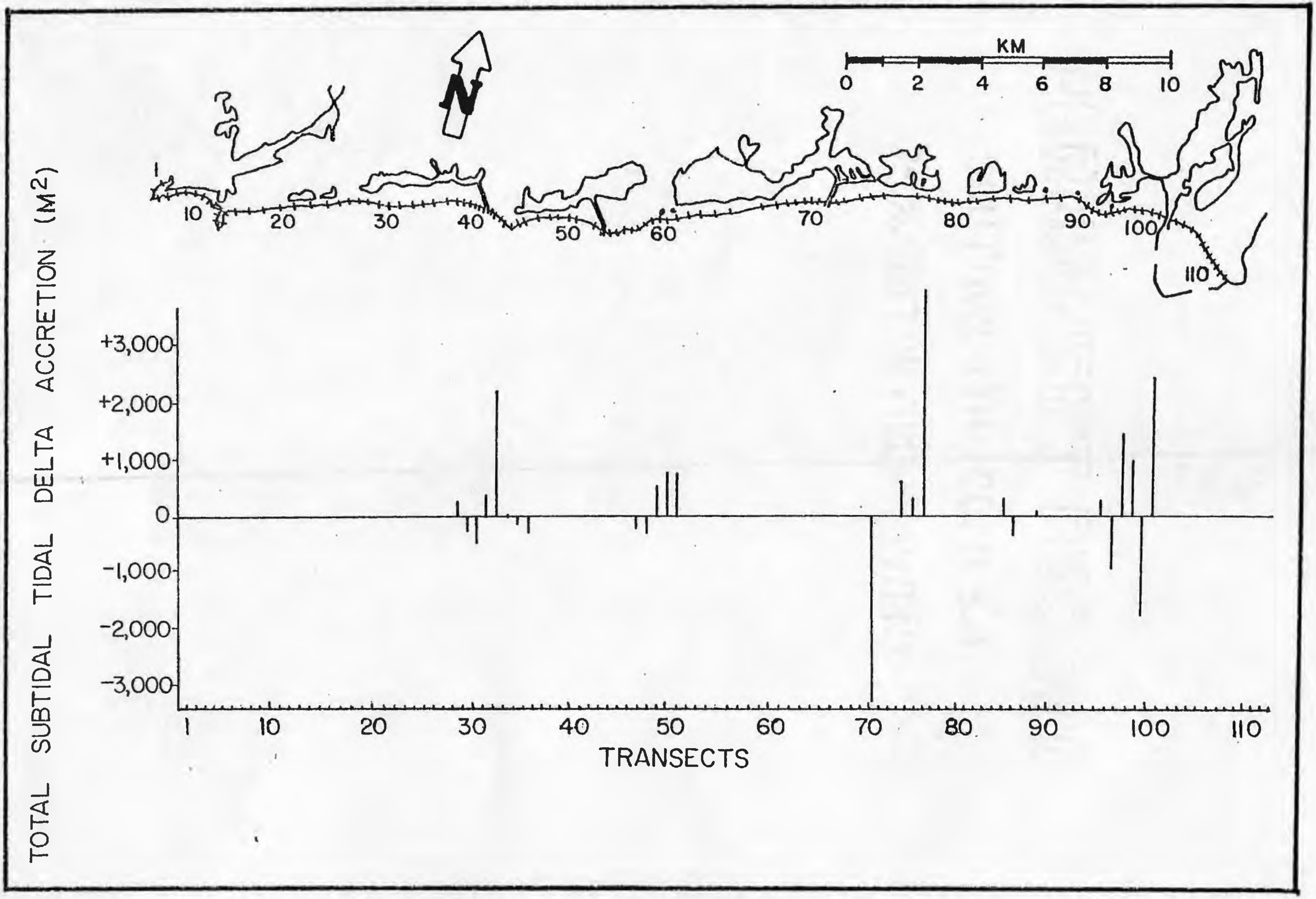

KM
0
2
4
6
8
10
N
1
10
20
30
40
50
60
70
80
90
100
110
TOTAL SUBTIDAL TIDAL DELTA ACCRETION (M²)
+3,000
+2,000
+1,000
0
-1,000
-2,000
-3,000
1
10
20
30
40
50
60
70
80
90
100
110
TRANSECTS

FIGURE 5

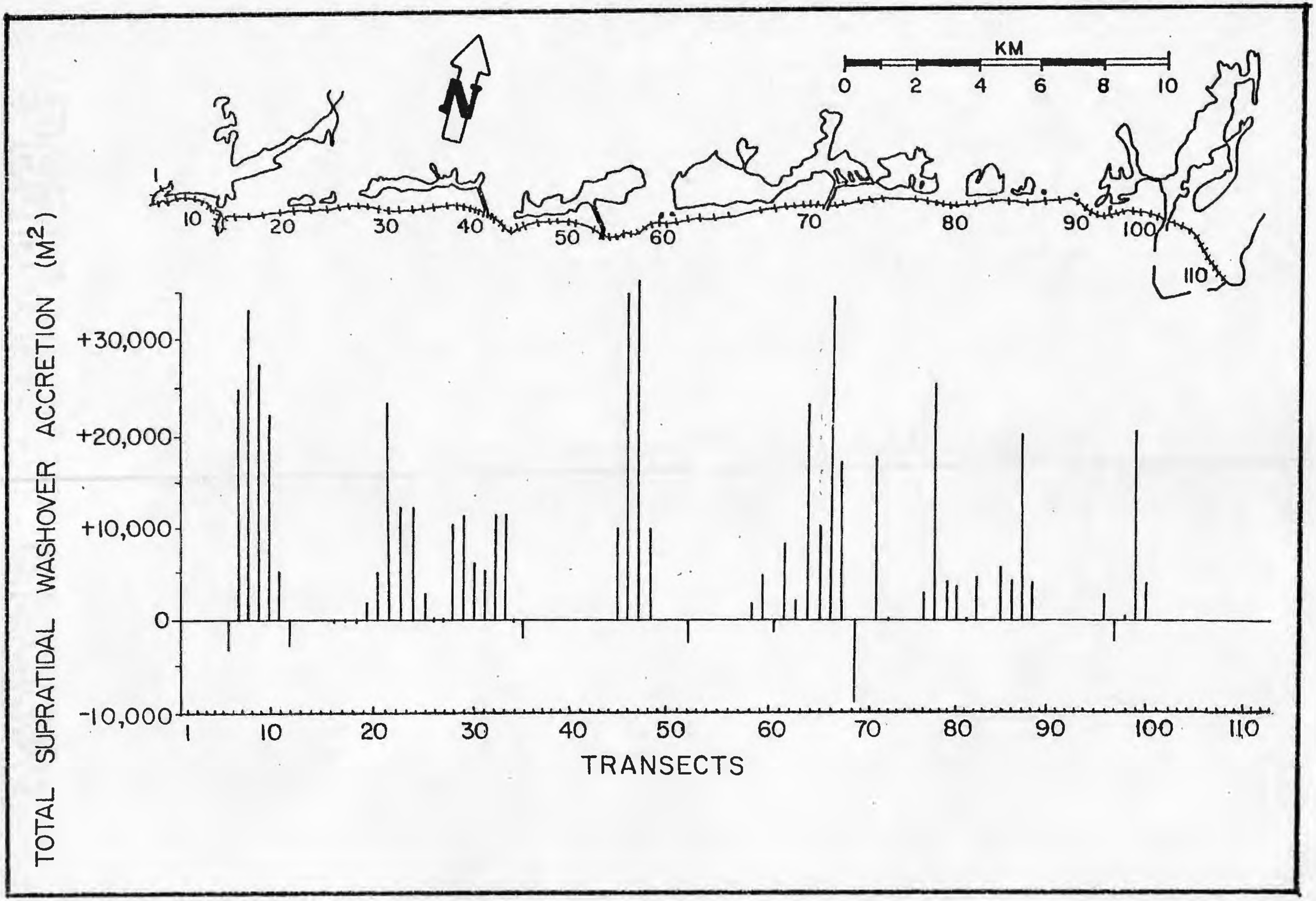

KM
0
2
4
6
8
10
N
1
10
20
30
40
50
60
70
80
90
100
110
TOTAL SUPRATIDAL WASHOVER ACCRETION (M²)
+30,000
+20,000
+10,000
0
-10,000
1
10
20
30
40
50
60
70
80
90
100
110
TRANSECTS

FIGURE 6

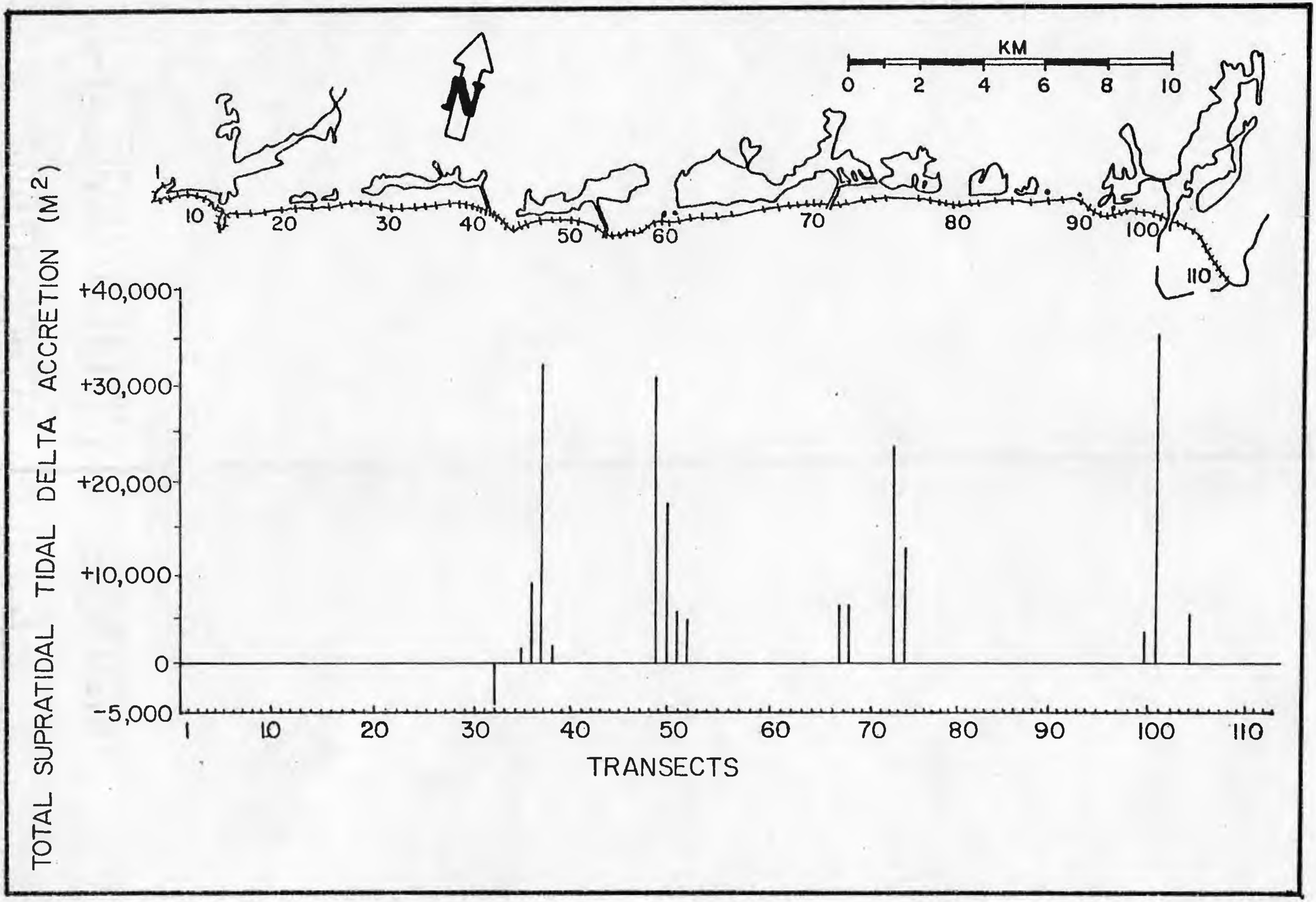

KM
0
2
4
6
8
10
N
1
10
20
30
40
50
60
70
80
90
100
110
TOTAL SUPRATIDAL TIDAL DELTA ACCRETION (M^2)
+40,000
+30,000
+20,000
+10,000
0
-5,000
1
10
20
30
40
50
60
70
80
90
100
110
TRANSECTS

FIGURE 7

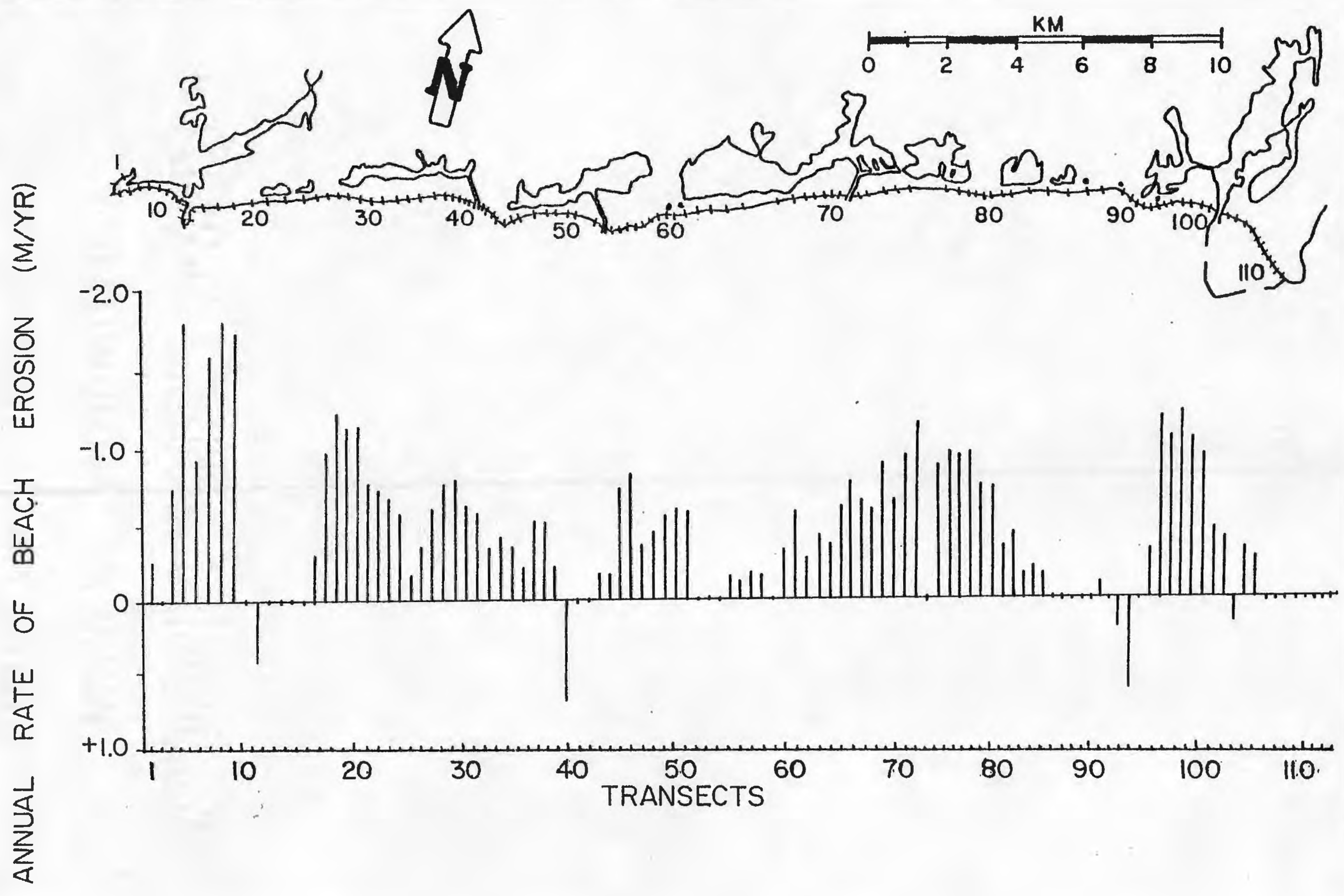

KM
0
2
4
6
8
10
N
1
10
20
30
40
50
60
70
80
90
100
110
ANNUAL RATE OF BEACH EROSION (M/YR)
-2.0
-1.0
0
+1.0
1
10
20
30
40
50
60
70
80
90
100
110
TRANSECTS

FIGURE 8

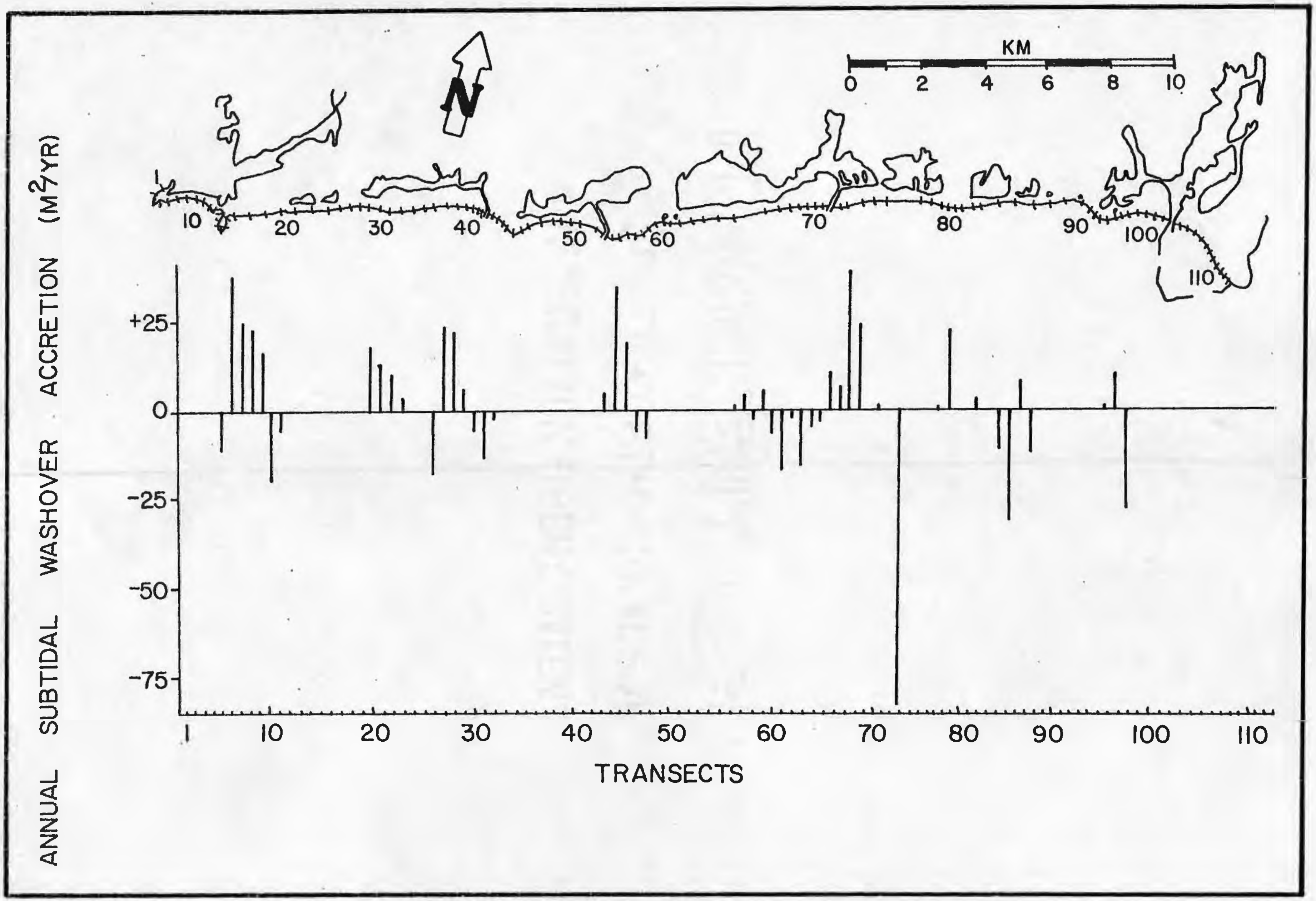

ANNUAL SUBTIDAL WASHOVER ACCRETION (M^2/YR)
KM
0
2
4
6
8
10
N
1
10
20
30
40
50
60
70
80
90
100
110
+25
0
-25
-50
-75
1
10
20
30
40
50
60
70
80
90
100
110
TRANSECTS

FIGURE 9

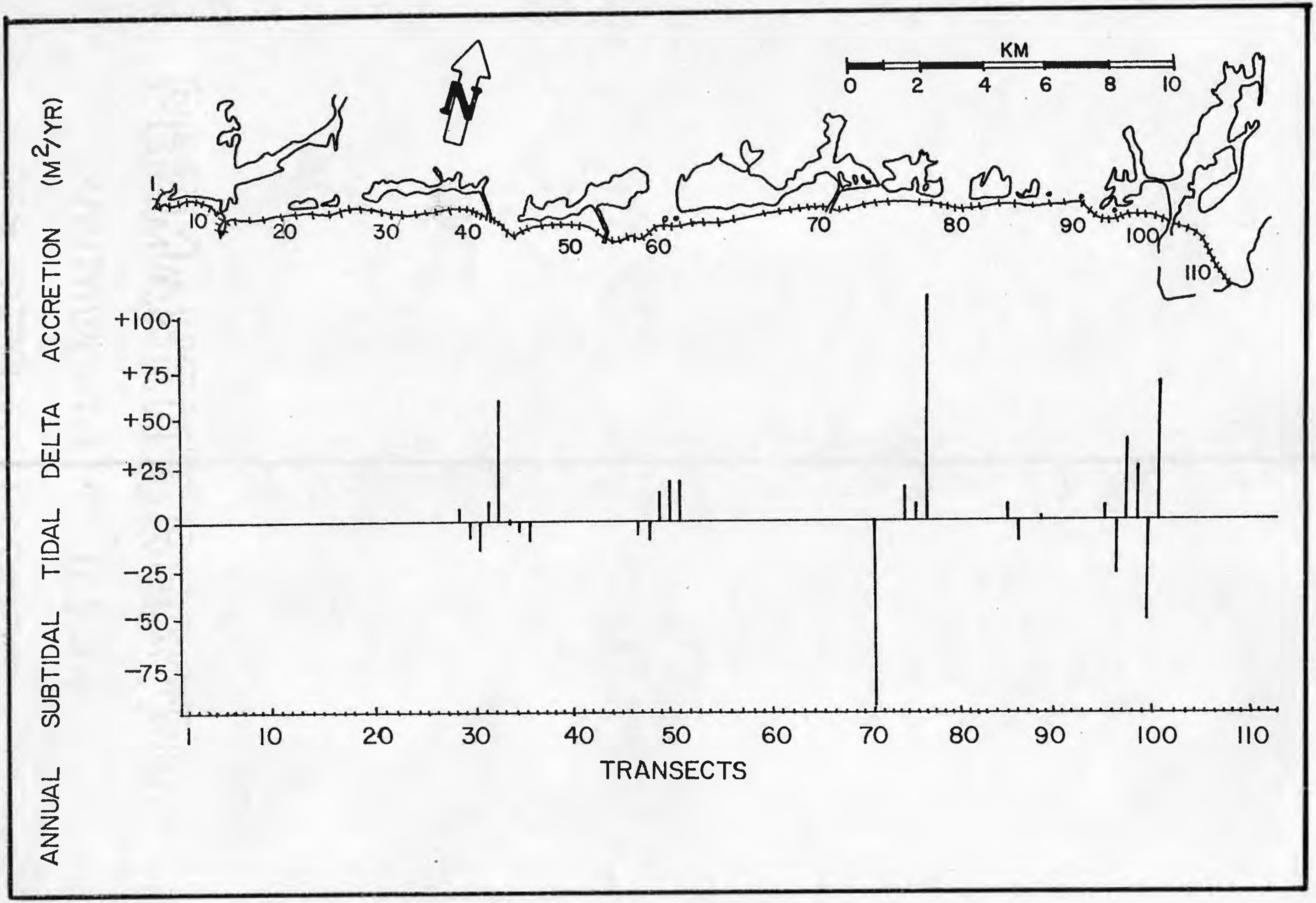

KM
0
2
4
6
8
10
N
1
10
20
30
40
50
60
70
80
90
100
110
ANNUAL SUBTIDAL TIDAL DELTA ACCRETION (M^2/YR)
+100
+75
+50
+25
0
-25
-50
-75
1
10
20
30
40
50
60
70
80
90
100
110
TRANSECTS

FIGURE 10

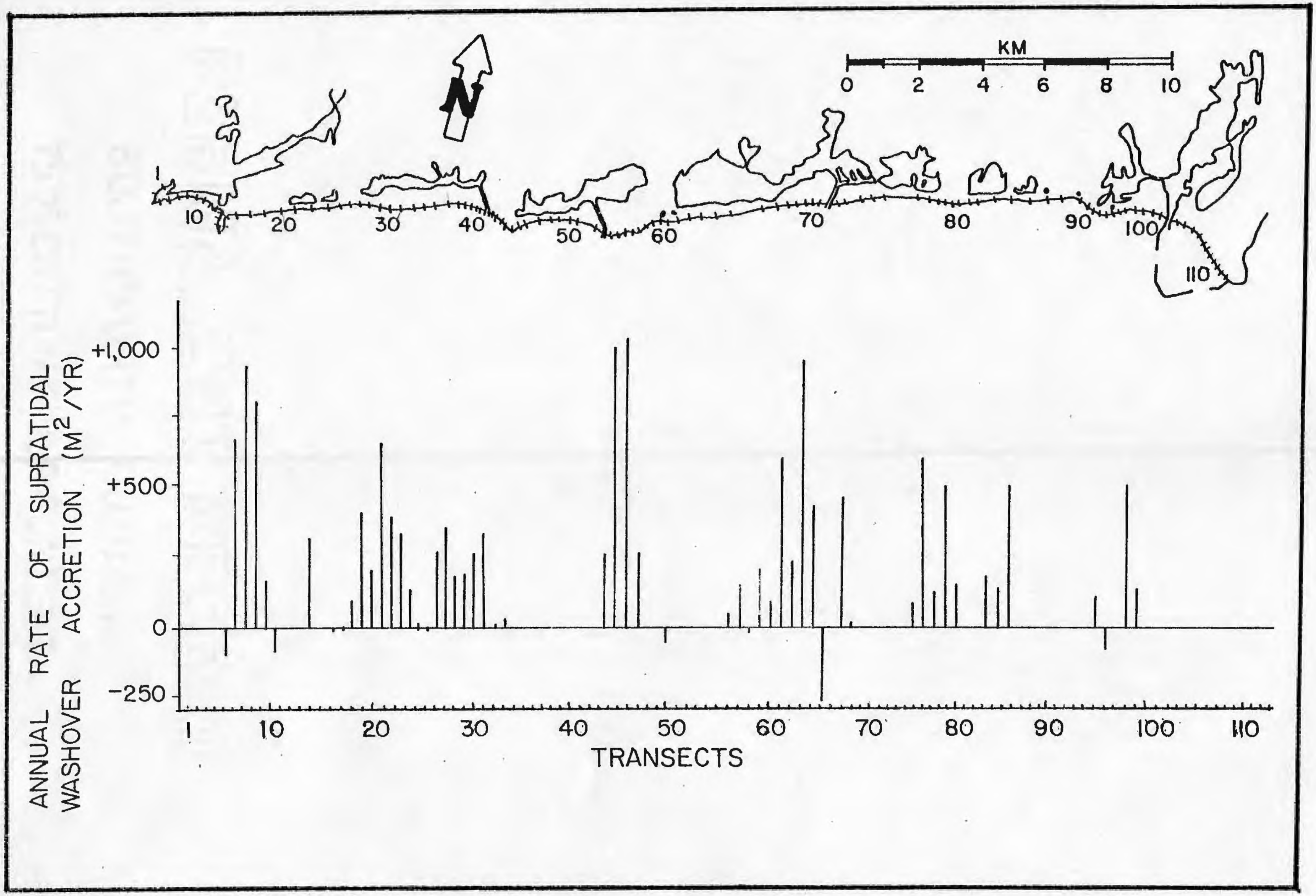

KM
0
2
4
6
8
10
N
1
10
20
30
40
50
60
70
80
90
100
110
ANNUAL RATE OF SUPRATIDAL WASHOVER ACCRETION (M² /YR)
+1,000
+500
0
-250
1
10
20
30
40
50
60
70
80
90
100
110
TRANSECTS

FIGURE 11

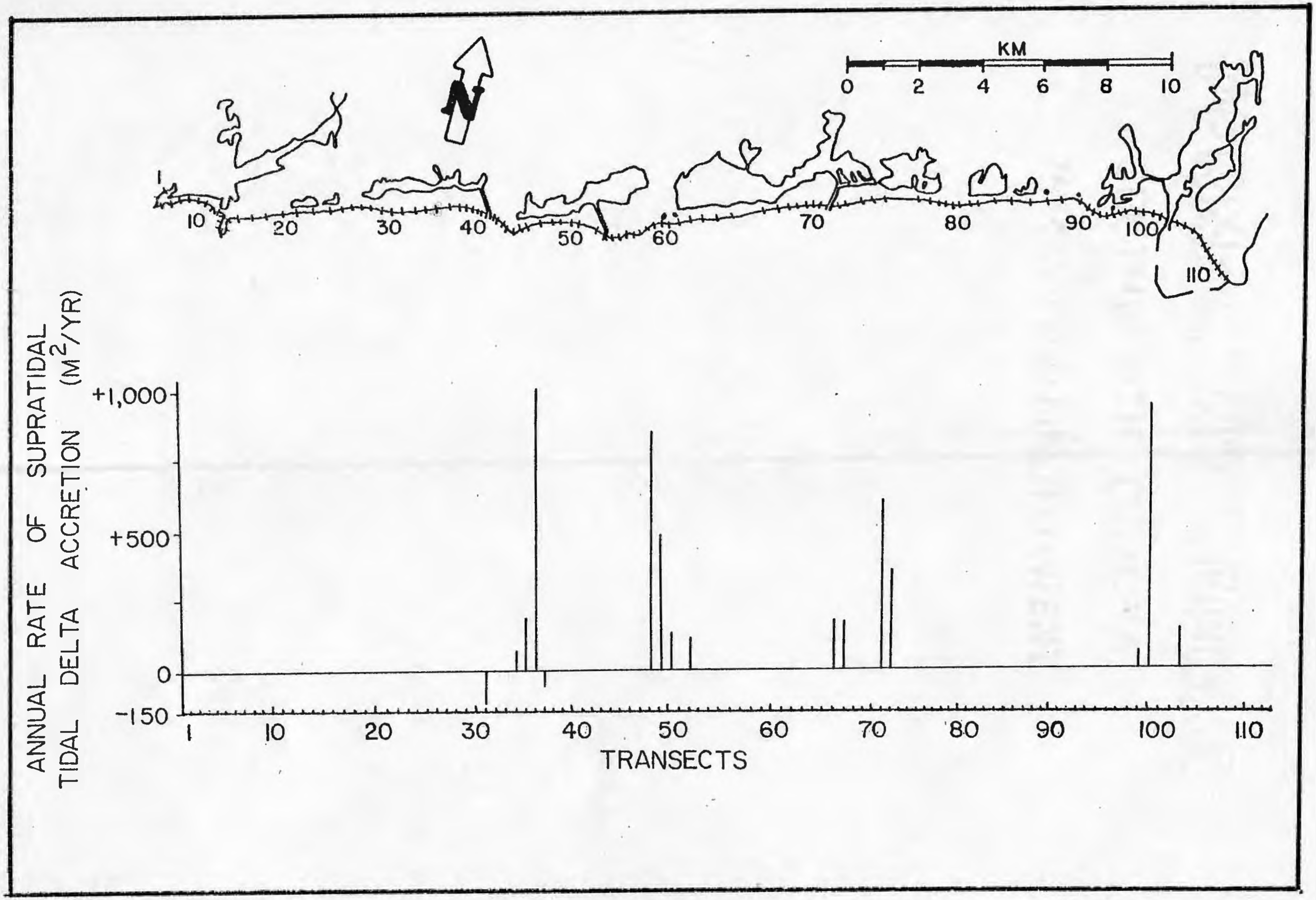

N
KM
0
2
4
6
8
10
1
10
20
30
40
50
60
70
80
90
100
110
ANNUAL RATE OF SUPRATIDAL TIDAL DELTA ACCRETION (M²/YR)
+1,000
+500
0
-150
1
10
20
30
40
50
60
70
80
90
100
110
TRANSECTS

FIGURE 12

TABLE 1

WIDTHS OF BARRIER BEACHES (IN METERS)

transects	1939 width	1975 width	change in width
5	108	105	-3
6	86	120	+34
7	103	109	+7
8	79	98	+20
9	121	91	-30
10	59	71	+12
21	89	111	+21
22	68	97	+29
23	56	59	+3
27	152	218	+67
28	283	279	-4
29	437	428	-9
30	323	260	-63
31	126	197	+71
32	358	354	-4
33	374	361	-13
34	431	430	-1
35	411	421	+10
36	301	268	-32
37	572	547	-25
45	140	180	+40
46	141	222	+81
47	128	216	+88
48	274	253	-21
60	131	92	-39
62	206	191	-15
63	189	178	-11
64	213	257	+44
65	192	213	+21
66	243	236	-7
67	202	205	+3
68	247	231	-15
69	406	383	-23
70	348	299	-48
76	406	358	-48
77	376	334	-42
78	200	193	-7
79	437	421	-16
84	76	117	+41
85	97	103	+6
86	94	111	+17
87	112	139	+27
88	141	145	+4
93	169	160	-9
95	83	88	+5
97	92	66	-26
MEAN			+4

Profiles conducted during the pre- and post-hurricane months indicate that the beaches did not recover to the accretion levels prior to the hurricane (McMaster, personal communication). Comparison of the October, 1976, profiles with other pre-hurricane profiles indicated, however, that the heights of the dunes varied only slightly over the periods preceding and following Hurricane Belle (Gautie, personal communication). The dune heights measured during this survey do not necessarily represent either maximum or mean dune heights along a particular stretch of barrier beach, since the transects along which the beach profiles were made were randomly located with reference to dune heights, and are used only to summarize recent representative dune heights along the south shore beaches.

A field survey of dune heights along the south shore made by Olsen and Grant (1973), completed in October, 1972, however, did attempt to measure representative average and extreme dune heights above mean sea level. To compare the results of the two surveys and compensate for the differences in mean low water and mean sea level datums, Olsen and Grant's (1973) were adjusted to the mean low water datum by subtracting from their values half of the average tidal range along the south (averaged from tidal range data for Watch Hill and Point Judith to be 0.44 m).

Beach width and dune height values are significant because they indicate those areas along the coast where overwash or inlet formation could occur or has occurred in the past. Dune height and beach width values are listed in table 2 and are illustrated in figures 13 and 14, respectively.

Volume Calculations

A significant disadvantage of photogrammetric surveys of coastal changes is that the changes in the elevations of the beach and backbarrier

TABLE 2

BEACH WIDTHS AND DUNE HEIGHTS

	Oct., 1976 survey		Olsen & Grant (1973)		Oct., 1976 survey		Olsen & Grant (1973)
Trans	beach width to MLW (M)	dune ht. above MLW (M)	dune ht. corrected to MLW (M)	Trans	beach width to MLW (M)	dune ht. above MLW (M)	dune ht. corrected to MLW (M)
1	50.9	2.81	-	49	64.7	7.52	-
3	33.0	4.44	-	50	73.0	5.71	7.01
4	39.2	3.67	-	51	35.4	3.21	-
5	44.9	3.57	2.75	53	36.0	3.33	-
6	50.2	3.34	-	54	18.3	1.72	-
7	49.1	3.95	2.75	55	40.3	3.14	-
8	48.6	3.95	-	56	20.8	1.83	-
9	42.4	4.76	-	57	36.9	3.37	-
10	39.4	3.48	3.51	58	28.0	2.03	-
12	17.0	1.82	-	59	49.9	3.60	3.51
17	44.0	4.18	-	60	35.9	4.77	3.20
18	49.0	4.48	-	61	41.6	3.99	-
19	44.0	3.40	-	62	50.4	3.89	3.20
20	57.6	4.68	-	63	48.2	4.65	3.20
21	63.0	4.18	-	64	48.1	4.08	3.51
22	53.6	2.57	2.90	65	52.9	4.59	-
23	44.4	3.07	-	66	48.4	4.31	4.57
24	51.4	4.01	-	67	50.8	4.22	-
25	46.0	3.85	-	68	44.6	4.06	-
27	55.1	4.58	-	69	44.6	4.88	4.12
28	45.4	4.74	3.66	70	56.6	4.57	-
29	46.7	4.36	-	71	70.4	5.24	3.97
30	40.4	3.50	-	72	79.8	4.56	-
31	42.4	3.92	-	73	33.7	4.22	-
32	42.4	3.94	4.42	74	39.2	5.24	-
34	43.6	4.76	-	75	42.4	4.51	3.05
35	36.0	3.42	-	76	48.6	5.64	-
36	33.8	2.71	-	77	41.2	4.85	3.36, 5.03
37	42.0	2.27	-	78	42.2	4.35	3.20
38	86.0	6.22	9.60	79	51.3	3.46	-
41	44.0	3.68	-	80	53.0	4.55	3.81. 2.75
42	18.8	2.43	-	81	40.0	3.93	-
44	35.7	4.28	4.42	82	32.4	4.06	-
45	28.8	4.69	-	83	30.6	3.15	-
46	54.8	4.83	-	84	-	-	2.14
47	55.0	5.29	-	85	-	-	2.29
48	60.2	5.62	6.10	86	38.4	4.43	3.05

TABLE 2

Trans	Oct., 1976 survey beach width to MLW (M)	dune ht. above MLW (M)	Olsen & Grant (1973) dune ht. corrected to MLW (M)
87	-	-	2.90
88	36.4	4.40	3.97
90	46.3	5.81	-
91	40.0	3.46	1.68
92	52.6	4.61	-
93	36.0	2.98	-
94	24.4	3.08	-
95	13.2	2.20	-
96	14.6	1.67	-
97	35.0	2.41	-
99	63.0	3.22	-
100	80.0	3.49	-
101	62.2	3.33	-
102	68.0	5.07	4.70
103	48.2	4.70	-
104	47.0	4.37	6.86
105	48.7	3.84	-
106	61.6	2.33	-
107	30.0	2.88	-
108	33.4	2.73	5.03
109	45.0	2.91	-
110	36.0	3.44	-
111	16.4	2.48	-
112	28.2	3.25	-
113	29.2	2.91	-
MEAN	44.2	3.87	

Olsens and Grant's (1973) dune height values (above mean sea level) were corrected to mean low water datum by adding half the value of the average, mean tidal range along the south shore (0.44 M) to their dune heights.

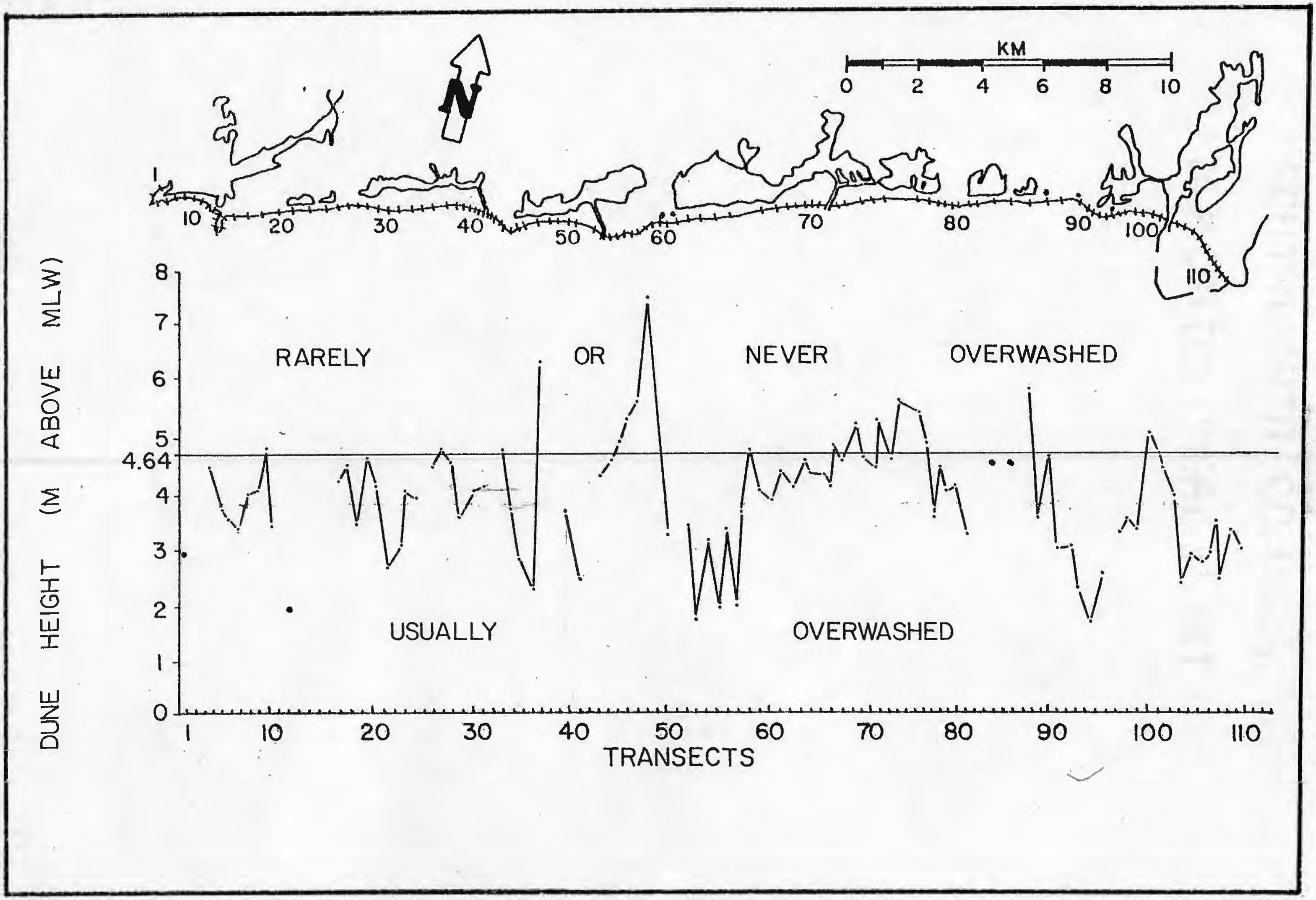

KM
0
2
4
6
8
10
N
1
10
20
30
40
50
60
70
80
90
100
110
DUNE HEIGHT (M ABOVE MLW)
8
7
6
5
4.64
4
3
2
1
0
RARELY OR NEVER OVERWASHED
USUALLY OVERWASHED
1
10
20
30
40
50
60
70
80
90
100
110
TRANSECTS

FIGURE 13

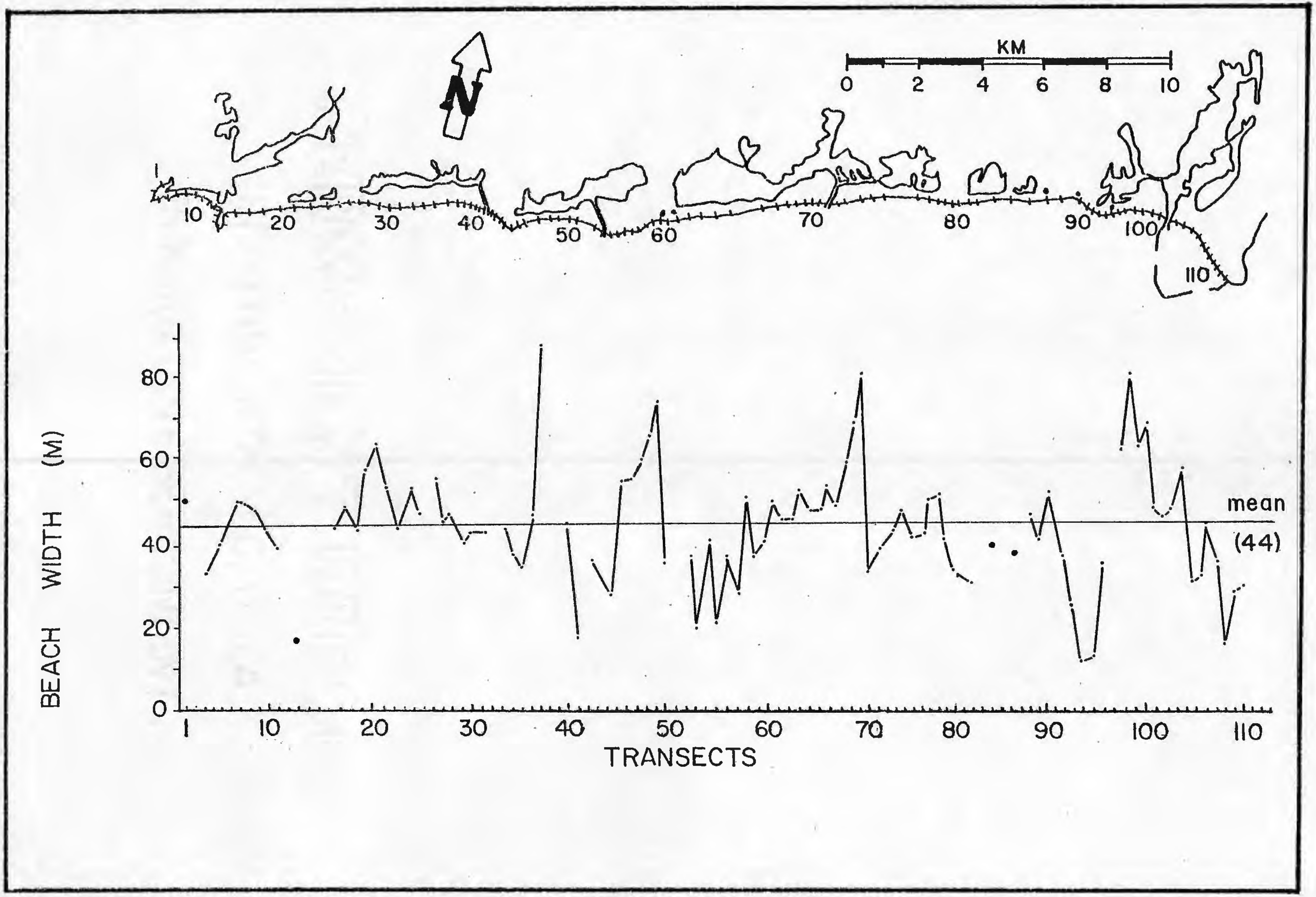

KM
0
2
4
6
8
10
N
1
10
20
30
40
50
60
70
80
90
100
110
BEACH WIDTH (M)
0
20
40
60
80
mean
(44)
1
10
20
30
40
50
60
70
80
90
100
110
TRANSECTS

FIGURE 14

features from which the volumetric changes could be calculated cannot be measured photogrammetrically. In order to determine the volumes of change, additional information must be incorporated into the survey in order to derive volumes from areas of change. Volumetric changes can be calculated if the changes in the elevations of the beach and backbarrier features can be measured over the study period, or if annual vertical sedimentation rates are known or can be derived.

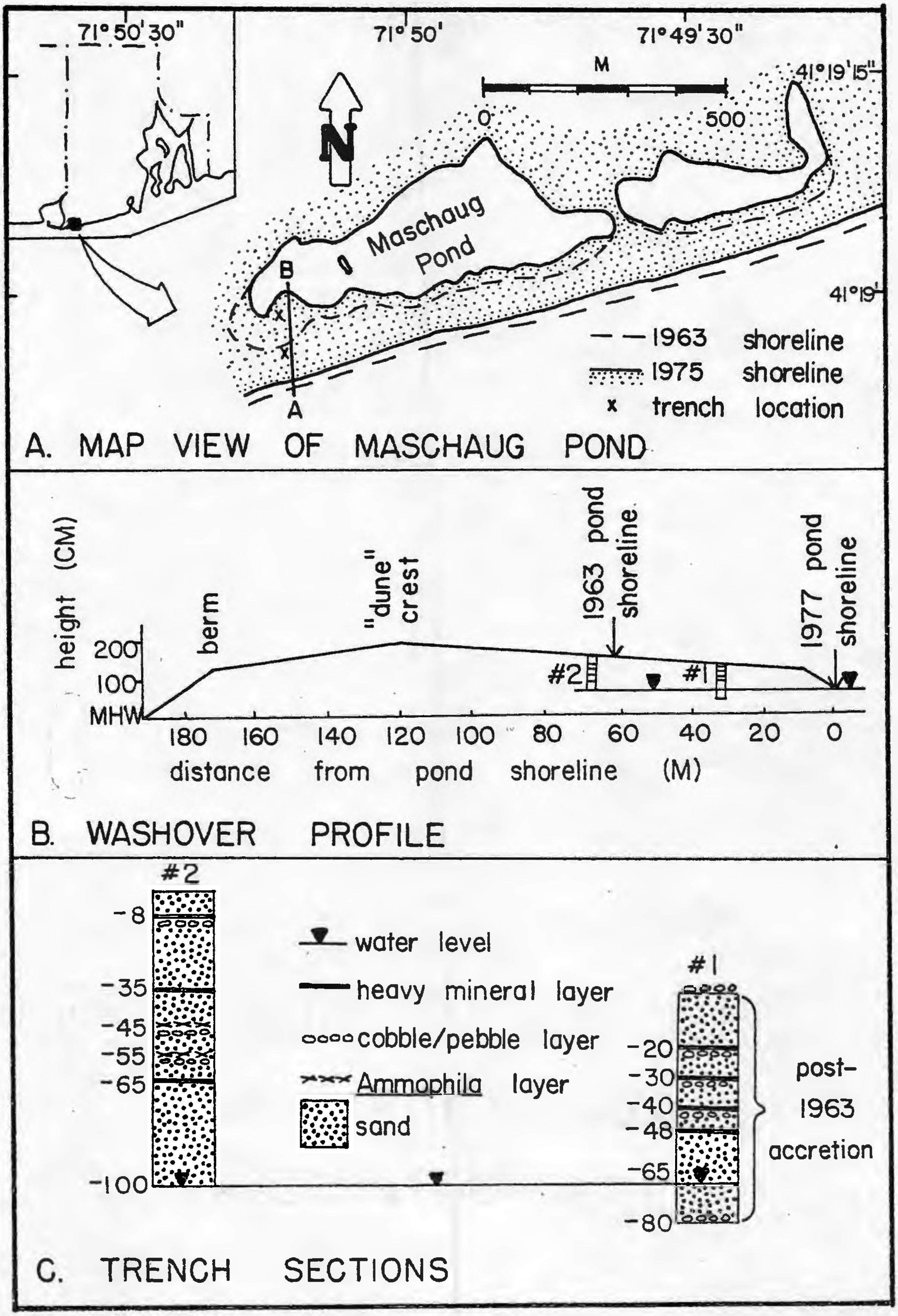
Determination of the volumes of backbarrier shoreline changes from the areas of change would be relatively straightforward using annual rates of sedimentation. The total or annual rates of change on the backbarrier shoreline (measured as areas) would be multiplied by the value of the vertical rate of sedimentation to derive the total or annual volumetric changes.

Determination of the volumes of eroded (or accreted) beach from areas of eroded (or accreted) beach measured at the high water line is more complicated because of the equilibrium of the beach and nearshore profile and the dynamic processes responsible for that equilibrium. According to the Bruun theory of beach erosion, "if the beach and nearshore profile is at equilibrium, as sea level rises, foreshore erosion will take place in order to provide sediments to the nearshore so that the nearshore profile can be elevated in direct proportion to the rising sea level" (DuBois, 1975). The lateral extent of the zone of deposition and the depth to which deposition must occur in order to maintain the profile of equilibrium are debatable: it may be only one meter or so wide, extending to the surf zone, or it may extend about one kilometer to mean wave base (Fisher and Regan, 1977).

An empirical relationship determined by the U. S. Army, Coastal Engineering Research Center (1973) estimates that an areal change of 0.09 m^2 along the shoreline is equivalent to a volumetric change of 0.76 m^3 of sediment. In his determination of the sediment budget for the section of coast between Hatteras Inlet and Cape Lookout, North Carolina, Pierce (1969) used this estimate to derive the volume of eroded beach from areas of change measured from smooth sheets of the U. S. Coast and Geodetic Survey bottom surveys. For lack of a better estimate of vertical changes on a beach that correlates to areal change, this empirical relationship is adopted for use in this study.

Annual Rates of Washover Sedimentation: Annual rates of washover accretion can be determined from data given in Godfrey's (1976, fig. 15; also Godfrey and Godfrey's, 1973, fig. 6) cross-section through a washover fan on Core Banks, Cape Lookout National Seashore, North Carolina. The amount of vertical accretion on the backbarrier due to washover deposition can be measured between three sets of datums: between October, 1971, and the 1940's (a period of about thirty years) 1.25 m of washover sediment accumulated; between October, 1971, and 1958 (thirteen years) 0.4 m of washover sediment accumulated; and between the 1940's and the 1960's (about twenty years) 0.65-0.70 m of washover sediment accumulated. The annual rates of vertical accretion derived from these data are, respectively, 0.04 m/yr, 0.03 m/yr, and 0.03-0.04 m/yr.

Annual rates of washover accretion can also be determined from observations made in February, 1977, along the south shore of Rhode Island at the Maschaug Pond barrier beach (see figure 15). From aerial photographs a region where significant supratidal washover accretion had occurred along the pond margin between 1963 and 1975 was identified. In the field two trenches were dug in the washover fan, one at a location within the supratidal region accreted since 1963 and the other at a location within the pre-1963 supratidal portion of the barrier beach. The depths



A. MAP VIEW OF MASCHAUG POND

B. WASHOVER PROFILE

C. TRENCH SECTIONS

FIGURE 15

of both trenches were restricted by the level of water in the trenches. In the trench closest to the pond (#1), water ponded at a depth of 65 cm below the surface of the fan, and in the trench nearer the dunes (#2), water ponded at a depth of 100 cm below the fan surface. From a survey of the surface of the washover fan, it is known that the depths of water in the two trenches occurs approximately at the elevation of the present pond level (figure 15B).

Abover the water levels in the two trenches, discrete sedimentation units of about 10 cm thickness could be identified. These units consist of coarse (boulder-cobble-pebble size) or heavy mineral-rich layers of generally poor sorting, grading upward in texture and sorting to finer, generally well-sorted, light mineral-rich layers of sand. In trench #2, layers of American beach grass (Ammophila breviligulata) in a horizontal position were identified at depths of 45 and 55 cm (figure 15C).

A minimum value of the vertical amounts of washover accretion at the Maschaug Pond barrier beach can be determined by noting that the 1963 surface of the subtidal washover deposits was lower than the present pond level (which has remained essentially constant over the study period, as determined by comparing the position of the northern shoreline of the pond on the 1939, 1963, and 1975 photographs, using the Zoom Transfer Scope). It is possible that the 1963 subtidal washover surface could have been at any level from just below the present pond level to the present depth of the pond adjacent to the washover fan (a depth of about two meters). The minimum rate of vertical washover sedimentation can then be calculated by dividing the vertical amount of sediment that has accumulated above the present pond level since 1963 (65 cm) by the number of years that elapsed between 1963 and 1977, the date of the field observations (thirteen years). The annual rate of vertical washover accretion thus determined would be 0.05 m/yr. The actual rate of accretion is probably even greater at this location, because the actual amount of sediment extending down to the subtidal level of the 1963 washover fan surface is undoubtedly greater than the depth to the present pond level, and because the 65 cm of vertical accretion observed in trench #1 could have actually occurred over a time period of less than the thirteen years which elapsed between 1963 and 1975.

Although this value is a minimum rate of washover sediment accretion at the Maschaug Pond barrier beach, it probably represents a very high rate of washover accretion along the majority of the Rhode Island south shore barrier beaches. The washover fan at Maschaug Pond was chosen for field observation because the supratidal portion of the fan had accreted significantly in the past thirteen or so years, more so than other washover fans along the south shore backbarrier.

This rate of washover accretion on the Rhode Island backbarrier compares relatively well with the rates of washover accretion determined from Godfrey's (1976) cross-section of the Core Banks washover fan. This sedimentation rate for the Rhode Island washover fans was used in this study to derive the volumes of accreted washover fans from areas of changes.

No similar calculations of annual rates of vertical tidal delta accretion exist (Boothroyd, personal communication) for which volumes of tidal delta changes can be derived from areas of tidal delta changes measured in this study. For lack of a better indication of tidal delta sedimentation rates, the washover accretion rate was also applied to the determination of volumetric tidal delta changes in this study.

ACCURACY OF PHOTOGRAMMETRIC MEASUREMENTS

In order to determine the amounts of error or variability resulting from the measurement process, scale determination and scale variation, microrule precision, cartographic variability, and operator variability, a ground truth survey of linear distances and areas was made. Linear distances were measured in the field at several localities at the same elevation. These linear ground measurements were used to calculate the ground areas of rectangular playing fields and buildings, to be used as ground truth values for both linear distances and areas that were then measured on a 1972 photograph (073-72 series, with a nominal scale of 1:12,000).

The quantitative amounts of error or variance resulting from the linear and areal measurements of the objects of known areas (determined from the field measurements) average 2.1% and range from 0.3 to 4.8%. Further details of the technique used in determining these results, the tabulated data, and the details of the factors affecting this variance in the determination of ground areas on photographs, are presented in Appendix II.

BEACH SHORELINE CHANGES

Areal changes on the beach at the high water line were measured between successive transects after using the Zoom Transfer Scope to transfer the 1939 beach high water line onto overlays of the 1975 photographs. Quantitative areal changes (erosion or accretion) along the beachface were computed by converting measured photograph areas to actual ground areas by using the exact scale determined for each photograph.

From this analysis, it can be seen that the majority of the transects along the south shore indicate that the beaches are erosional (the mean annual rate of shoreline change for the whole south shore is -0.46 m/yr; figures 3 and 8, and Table C in Appendix I).

RHODE ISLAND SHORELINE CHANGES:
INLET AND WASHOVER INVENTORY

The southern Rhode Island coast from Napatree Point to Point Judith can be segmented into barrier beaches (and spits) and headlands. The barrier beaches separate coastal ponds and lagoons from the open ocean (Block Island Sound, Fishers Island Sound, and the Atlantic Ocean). Two important depositional processes active along the barrier beaches of the south shore of Rhode Island are washover and tidal delta sedimentation on the backbarrier and in the lagoons and ponds.

The observed general trend of washover and tidal delta sedimentation on these barrier beaches is to deposit sediment on the backbarrier or in the adjacent lagoons. On a generally erosional shoreline such as the Rhode Island south shore, the result of beach erosion and washover deposition is the landward migration of the barrier beach system (Dillon's, 1970, "rollover" effect). If sufficient sediment is supplied to the barrier beach system by washover, tidal delta, and dune sedimentation to balance offshore and downdrift beach losses, then the barrier form will maintain itself.

The general relationships of washover and tidal delta sedimentation to beach erosion on the south shore of Rhode Island are considered in the light of the results of the aerial photogrammetric analysis of backbarrier and lagoon shoreline changes.

PRESENT INLET CHANGES

There are five permanent inlets on the southern shore connecting the large lagoons with the ocean: Weekapaug Inlet at Winnapaug Pond, Quonochontaug Inlet at Quonochontaug Pond, Charlestown Inlet at Ninigret (or Charlestown) Pond, and Point Judith Breachway at Point Judith Pond. A fifth, permanent, unnamed inlet, north of Napatree Point, connecting Little Narragansett Bay with Fishers Island Sound, was formed during the hurricane of 1938, and has widened considerably since then to a width of about 975 m in 1975.

Several temporary inlets into coastal ponds and lagoons have opened periodically, either naturally or artificially, to drain high water levels, occasionally in response to hurricane effects. Some inlets have been dredged open, such as the temporary inlet at Trustom Pond, which has been opened in the past to drain the pond in order to plant rye grass around the perimeter for migratory waterfowl. Other temporary inlets include an inlet at Cards Pond and an inlet, or drainage feature, from a very small coastal pond and marshy area at Green Hill Point (figure 16).

PAST INLET CHANGES

Other short-lived inlets have resulted from hurricane attack along the coast. Inlets opened by the erosive hurricane of 1938 include a breach cut near the center of Sandy Point, a deep cut near the eastern end of Napatree Beach, another deep cut at Misquamicut Beach (which widened to a width of 122 m on the ocean side and 21 m on the lagoon side shortly after opening), and a wide, shallow breach cut in Quonochontaug Beach just to the east of Weekapaug Point (Nichols and Marston, 1939; U. S. Army, Beach Erosion Board, 1949) (figure 16).

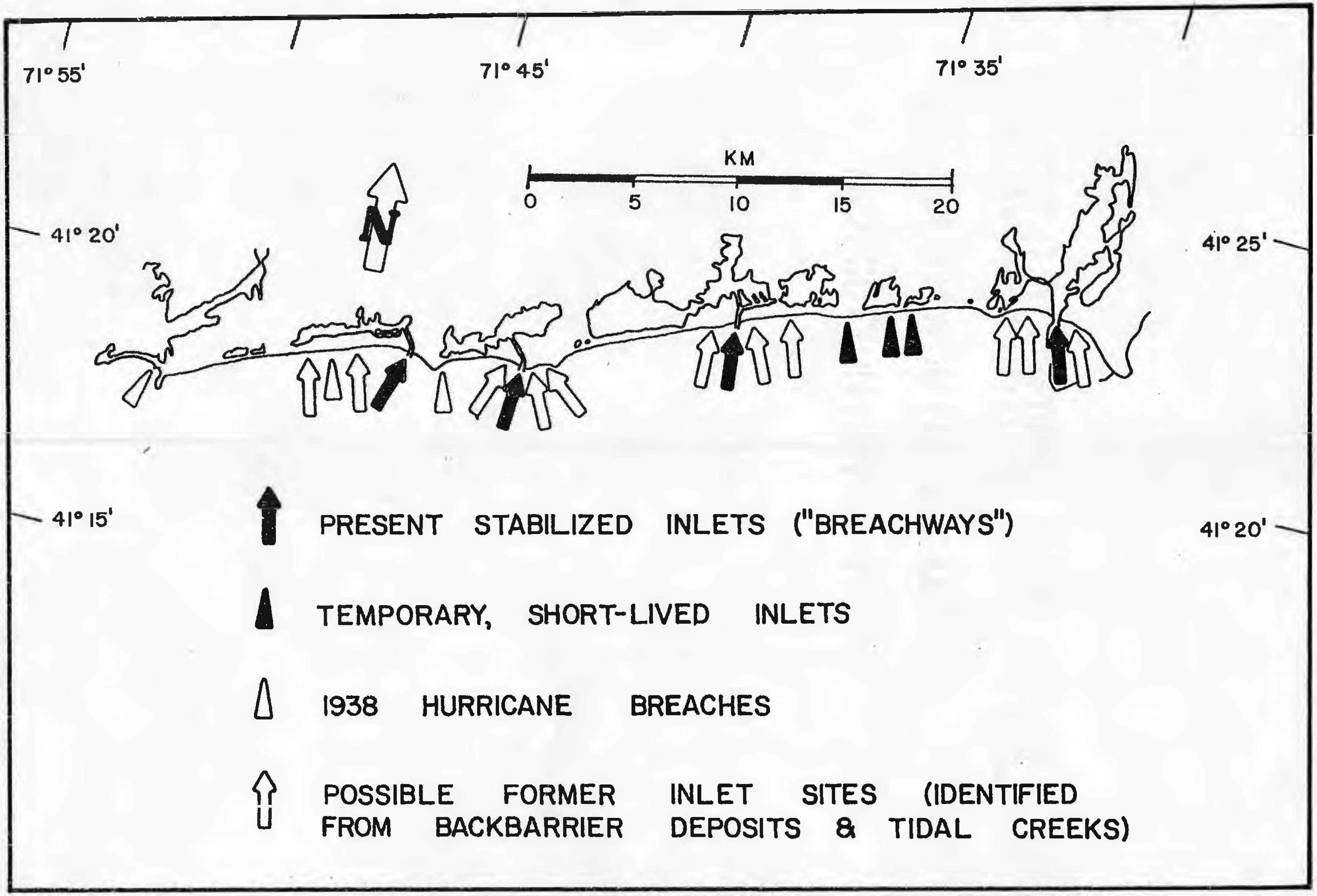
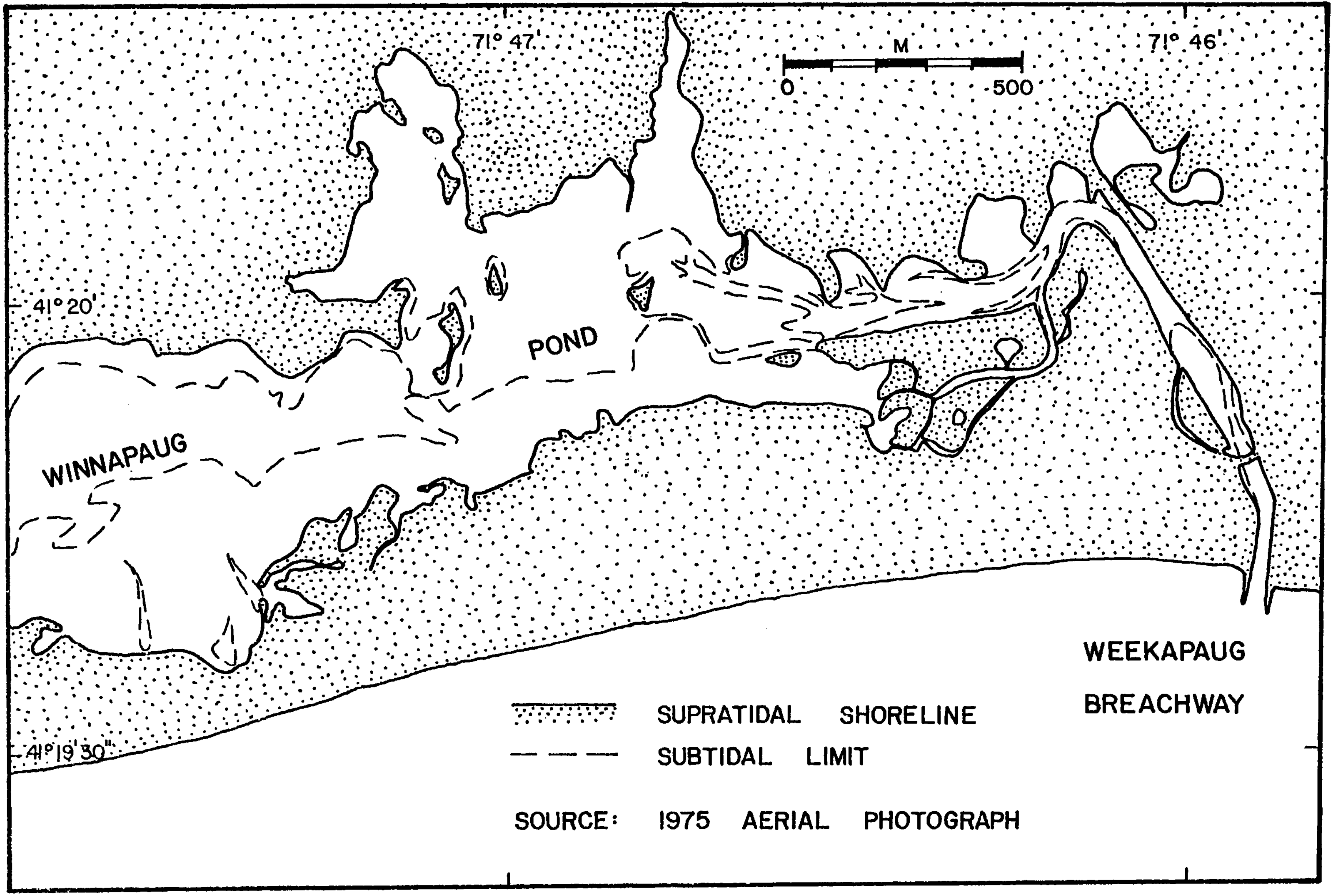

71° 55'
71° 45'
71° 35'
41° 20'
41° 25'
41° 15'
41° 20'
N
KM
0
5
10
15
20
PRESENT STABILIZED INLETS ("BREACHWAYS")
TEMPORARY, SHORT-LIVED INLETS
1938 HURRICANE BREACHES
POSSIBLE FORMER INLET SITES (IDENTIFIED FROM BACKBARRIER DEPOSITS & TIDAL CREEKS)

FIGURE 16

Photogeologic analysis of the geomorphology of the backbarrier of the barrier beaches indicates locations where other past inlets previous to the study period may have developed (figure 16). At the west end of Winnapaug Pond (figure 17) to the west of the inlet cut through Misquamicut Beach by the 1938 hurricane are fairly extensive backbarrier deposits cut by tidal creeks. Overwash has been active in that area, as seen by the unvegetated washover deposits, particularly visible on the 1939 photographs; it is unlikely, however, that overwash alone has accounted for the extent of the backbarrier deposits. Nor do the deposits appear to be material of glacial origin because of their lack of relief. Some material has been dredged from the lagoon and deposited on a section of the backbarrier to help in the construction of the Misquamicut State Beach parking lot, but the fill material represents a small amount of the backbarrier deposits that accreted between 1939 and 1975. The only other process capable of producing such broad, channel-cut backbarrier deposits is tidal delta sedimentation, which requires that an inlet have been present contiguous with the backbarrier deposits and tidal creeks.

There are other, very extensive backbarrier deposits in Winnapaug Pond (figure 17) to the east of the 1938 hurricane-formed Misquamicut Beach breach. These deposits are also generally low in relief and channeled, indicating that they are also relict tidal delta deposits formed by a preexistent inlet. Concerning the mode of development of these extensive backbarrier tidal delta deposits, there are two likely possibilities. Lucke's (1934a, 1934b) studies of tidal delta deposits at Barnegat Inlets and other inlets on the New Jersey coast introduced the hypothesis that stationary inlets opening either successively or simultaneously and migrating inlets opening either successively or simultaneously produce generally indistinguishable

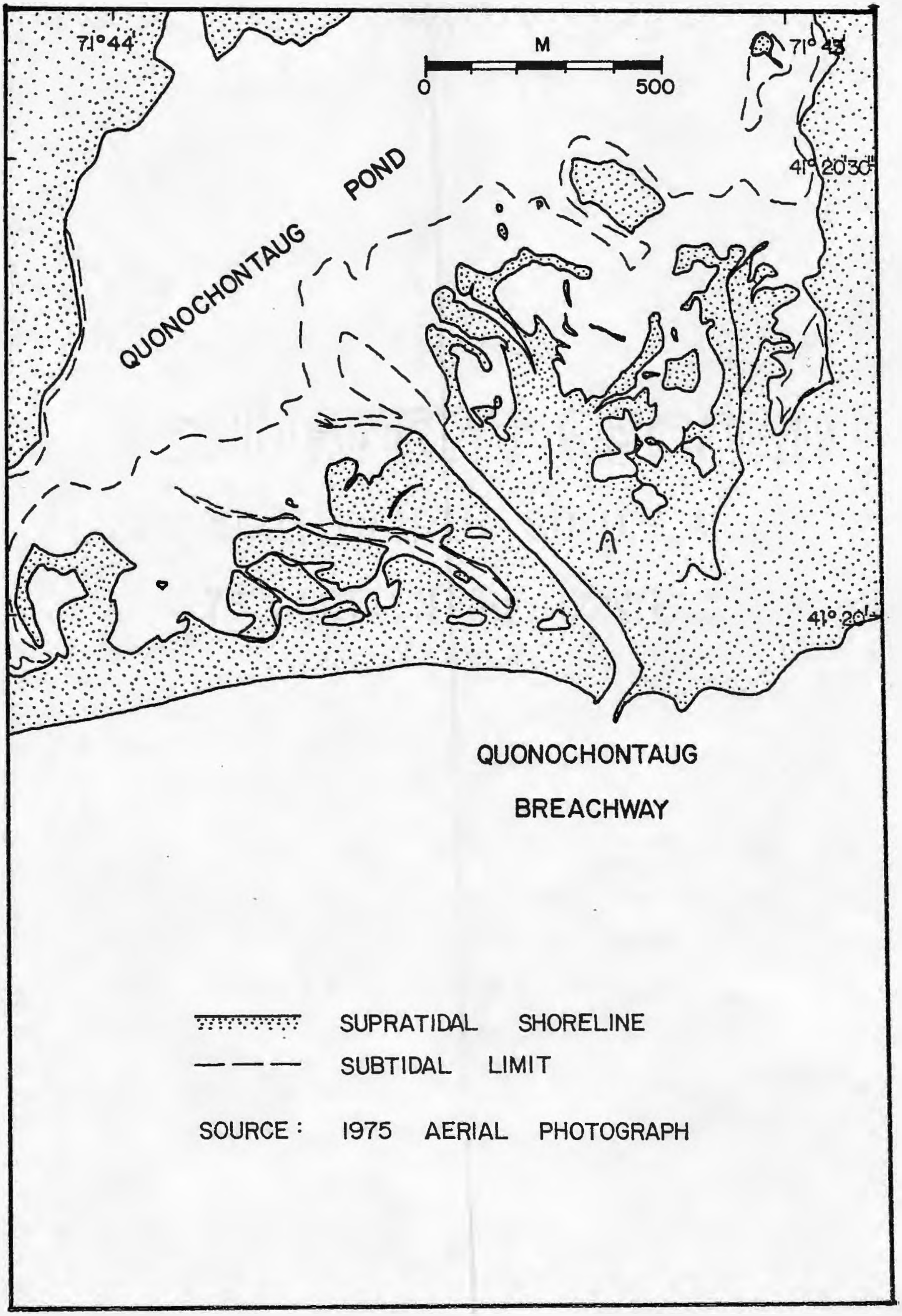


SOURCE: 1975 AERIAL PHOTOGRAPH

FIGURE 17

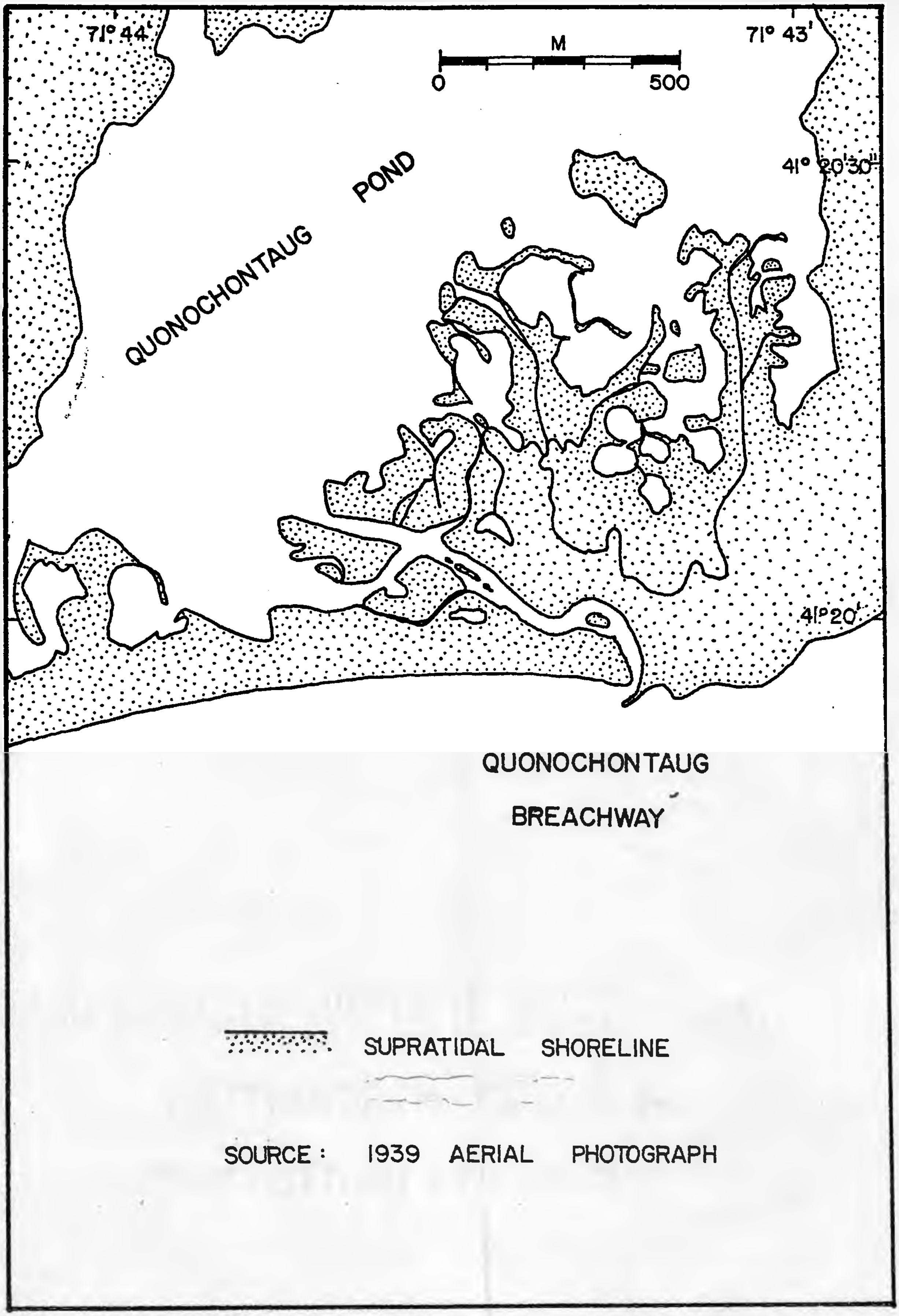
lagoon deposits at similar stages of maturity. Because of the relatively small sizes of the Rhode Island lagoons and consequently small tidal prisms and the trend of the present single inlets toward decreasing flushing efficiency and an inability to maintain themselves, there is little likelihood that multiple inlets could be maintained into the lagoons for a long enough period to produce the observed backbarrier and lagoon deposits. Evidence supporting the existence of a former migrating inlet into Winnapaug Pond is the location of the present Weekapaug Inlet at the farthest downdrift edge of Winnapaug Pond. The abundance of storm-opened inlets and the tendency of the present inlets to close as a result of the combined effects of insufficient tidal prism and an abundant volume of sediment being deposited at the inlet mouth by longshore drift support the concept that relatively stabilized, single, consecutive inlets were the situation along the Rhode Island barrier beaches. The evidence is inconclusive at this time to decide whether the former inlets into Winnapaug Pond were clearly either migratory or stable.

The present inlet at Quonochontaug Pond (figure 18) also shows evidence of having either been migratory or stable and opening and closing several times. The delta deposits are quite extensive, generally lack relief (and so are not dominantly glacial deposits), and except in the immediate area of the stabilized breachway, there is no clear evidence of dredging and filling. Some of the backbarrier and delta deposits have been cut by shallow drainage ditches, presumably for mosquito control. At this location, the possibility of the former inlets having been migratory appears to be more likely than the possibility that the former inlet or inlets were stable, opening as a result of storm attack and closing as a result of longshore drift depositing sediment at the inlet mouths. The form of the



SOURCE: 1975 AERIAL PHOTOGRAPH

FIGURE 18



SOURCE: 1939 AERIAL PHOTOGRAPH

FIGURE 19

tidal delta deposits is such that the inlet and tidal delta channels appear to have migrated across the backbarrier as the sediment was deposited; there are three lobes of the delta visible on the 1939 photographs (figure 19), with the westernmost lobe being occupied by the 1939 Quonochontaug Inlet. The two lobes to the east appear to be older, now abandoned lobes, as the tidal creeks bissecting them appear to be shallower and are only partially filled with water. The present inlet, as seen on the 1975 photographs (figure 18), was dredged through portions of the two westernmost lobes of the relict tidal delta deposits.

The Charlestown Inlet area (figure 20) also exhibits evidence that other inlets may have formerly existed to the west as well as to the east of the present stabilized breachway. The most prominent evidence lies just to the west of the present breachway. A wide, although presently shallow channel of fairly linear configuration apparently served as a washover channel during the 1938 hurricane, as evidenced on the 1939 photographs by the fresh, unvegetated washover deposits lying seaward of the channel. There are also prominent, although not extensive, delta deposits adjacent to and lagoonward of this channel, which adjoin extensive glacial deposits (recognizable by their somewhat greater relief and secondary vegetation). Deposits and channels to the east of the present breachway also suggest that an inlet may have formerly existed there. The lack of evidence indicating a migrational trend of the inlet channels and tidal delta deposits as well as the relatively central location of the Charlestown Inlet along the Ninigret Pond barrier beach may indicate that these former inlets were generally stable and opened by hurricane or storm attack.

On the far western edge of Green Hill Pond (figure 20) near the narrows into Ninigret Pond there are channels and generally insignificant, low-lying backbarrier deposits which exhibit roughly the form of previous tidal delta deposits. These deposits and channels may indicate the former existence of a small, or short-lived, inlet, which was unable to maintain an access to the ocean from the lagoon against the volume of longshore drift.

In the regions of Potters and Point Judith Ponds (figure 21) there are very extensive, channeled, backbarrier deposits, with occasional glacial deposits interspersed among them. Early maps previous to 1846 (which include 1846, 1842, 1838, 1824, 1816, 1804, 1796, and 1794 editions; see Appendix III, table I) show an inlet located to the east of the present breachway, abutting the glacial deposits at Point Judith, whereas maps dated later than 1860 (which include 1860, 1877, 1908, and 1935 editions; table I) show an inlet located to the west of the present breachway in the region behind the present East Matunuck State Beach. The importance of the inlet located to the west of the present breachway is emphasized by the division of the Towns of South Kingstown and Narragansett at the site of this former inlet.

INLET - FLOOD TIDAL DELTA CHANGES

Weekapaug, Quonochontaug, Charlestown, and Point Judith Inlets all have moderately well developed flood tidal deltas associated with them that have increased in area with time. The inlet between Napatree Point and Sandy Point is a special case and has developed a wide-spread, subtidal flood tidal delta, and a poorly formed but extensive ebb tidal delta. It is doubtful that the degree of development of this flood tidal delta will increase very much because of the nature of the inlet; as it continues to widen, flow through it will become increasingly less channelized, resulting in a broad, shallow inlet rather than a narrow deep inlet like the others on the south shore.

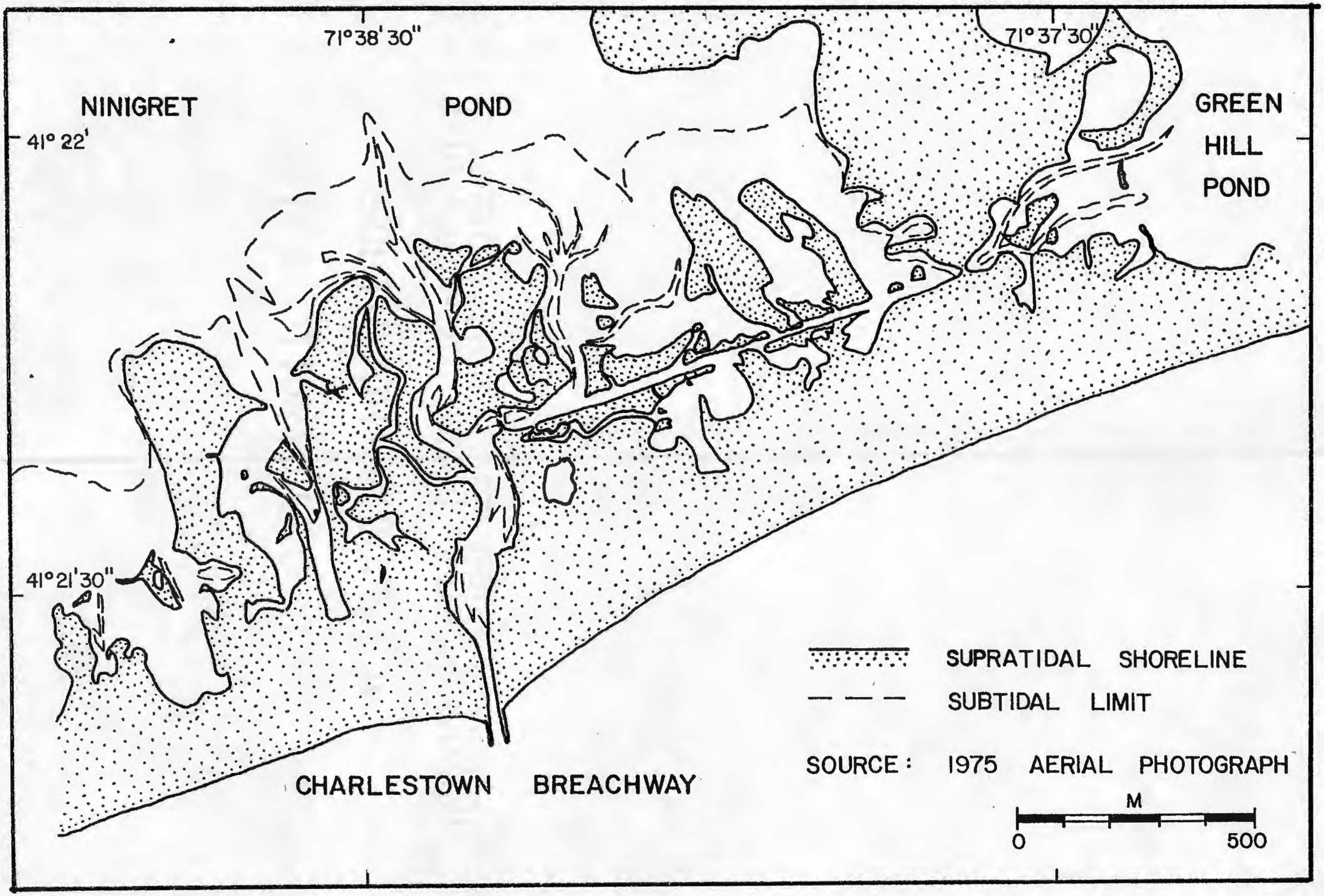

71°38'30"
71°37'30"
NINIGRET
POND
GREEN
HILL
POND
41° 22'
41°21'30"
CHARLESTOWN BREACHWAY
SUPRATIDAL SHORELINE
SUBTIDAL LIMIT
SOURCE: 1975 AERIAL PHOTOGRAPH
M
0
500

FIGURE 20

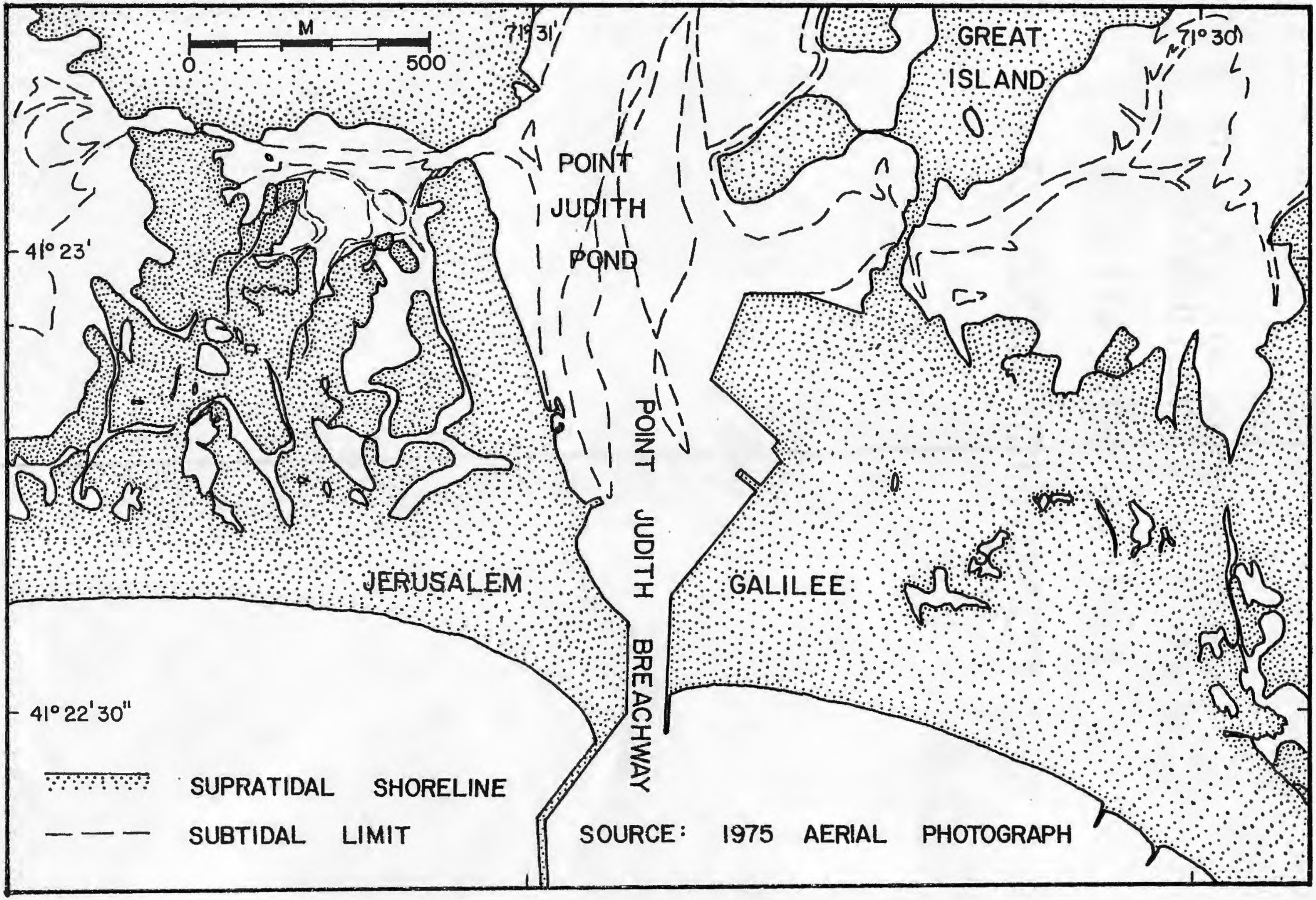

M
0
500
71° 31'
71° 30'
41° 23'
41° 22' 30"
GREAT ISLAND
POINT JUDITH POND
POINT JUDITH BREACHWAY
JERUSALEM
GALILEE
SUPRATIDAL SHORELINE
SUBTIDAL LIMIT
SOURCE: 1975 AERIAL PHOTOGRAPH

FIGURE 21

The tidal delta at Weekapaug Inlet consists of large subtidal lobes dissected by a bifurcating, sinuous channel and widespread, fairly continuous supratidal, vegetated deposits. Over 45,000 m^2 of tidal delta deposits have developed from subtidal shoals in 1939 to supratidal deposits in 1975 in the near vicinity of the inlet channel. The subtidal delta shoals also extended further into the lagoon in 1975 than they did in 1939, by the addition of over 73,000 m^2 of sediment. Probably a major factor in effecting these changes was the stabilization of the inlet with jetties and revetments and straightening and deepening the inlet with dredging in the period between 1951 and 1963. Straightening and dredging of the inlet increased the tidal prism of the lagoon, resulting in higher flow velocities with consequently greater amounts of sediment being transported into and eventually deposited in the lagoon.

At Quonochontaug Inlet the subtidal portion of the tidal delta has accreted more than 46,000 m^2 and the supratidal portion has accreted more than 57,000 m^2. Some of this change has resulted from the dredge and fill operation associated with the inlet stabilization, but the greater amount of change has probably resulted from the rejuvenation of the tidal prism by the stabilization, as well as the normal trend towards sediment accumulation in the lagoon.

The Charlestown Inlet channel, although straightened somewhat during its stabilization in 1951-1952, remains sinuous and bifurcating towards the distributaries. The overall form of the delta is more like that of the classic delta: essentially triangular or arcuate in plan view, with lobes of subtidal or supratidal deposits dissected by stable to somewhat migratory channels. There are subtidal shoals similar in location within the tidal channels to fluvial point bars, with the thalweg of the channel occurring at the outer, or undercut, bank. Most of these subtidal shoals are nearly intertidal, being almost emergent at spring low tides. Photogrammetric measurements indicate that more than 432,000 m^2 of subtidal delta shoals have accreted and over 46,000 m^2 of delta deposits were converted from subtidal shoals in 1939 to supratidal deposits in 1975 in Ninigret Pond. Incorporated in the value denoting change in the subtidal shoals is a loss of subtidal shoals in the region north of the Green Hill Pond narrows, in Ninigret Pond. This loss of subtidal shoals was apparently a result of the channel dredging that diverted the tidal flow that exits from Green Hill Pond through the narrows from a northward route around the glacial islands in the eastern portion of Ninigret Pond, to a more direct westward route. Before the channel was dredged sediment would have been deposited by the Green Hill Pond ebb flow in the area to the north of the narrows. in Ninigret Pond. After the channel was dredged and the sediment supply was cut off to this area, minor currents and waves in Ninigret Pond were apparently able to disperse the sediment formerly deposited by the Green Hill Pond ebb flow. The dispersal of the sediment was manifested on the aerial photographs as a decrease in the extent of the subtidal shoals.

The tidal delta at the Point Judith Breachway has undoubtedly been changed greatly in form as a result of the inlet stabilization. The channel has also been dredged, notably between 1951 and 1963, with the dredge spoils being used as land fill to build docks on the eastern bank of the breachway at Galilee and to produce habitable property on the western, Jerusalem bank of the breachway. The tidal delta presently appears as a maze of tidal creeks and subtidal shoals and intertidal marsh and tidal flat deposits in the regions away from the breachway. Subtidal shoals extend parallel to the main, bifurcating channels as fingers and arcuate lobes, with some intertidal shoals, mostly mussel and clam flats, developed on the subtidal shoals. The amount of measured change in the area of the tidal delta south of Great Island indicates an increase in the supratidal deposits of nearly 43,000 m^2 and an increase in subtidal delta deposits of over 198,000 m^2. Much of this change may be marginally attributable to the effects of dredging and land filling, although an attempt was made to discern changes of an artificial nature from those of a natural character.

Ebb tidal deltas, if present on the south shore, are not visible on the aerial photographs or in the field (although McMaster, personal communication, indicates that offshore profiling has indicated the presence of features near the inlets which may be ebb tidal deltas). Their absence could be attributed to a dominance of wave over tidal energy as well as a dominance of flood over ebb flow, which would result in the deposition by flood tidal currents of sediment in the lagoons coarser and more abundant than that which the ebb tidal currents are able to transport out of the lagoon. The jettied nature of all of the four major inlets on the south shore also probably prevents the development of marginal flood channels adjacent to the main ebb channels.

OVERWASH CHANGES

To determine the potential for overwash to occur on the south shore of Rhode Island, the representative dune heights from table 6 were compared with the representative hurricane stillwater levels and the tidal ranges along the coast (table 3). The maximum hurricane stillwater level during the 1938 hurricane was measured as 4.96 m above mean sea level, and the maximum hurricane stillwater level measured during the 1954 hurricane was 3.90 m above mean sea level (U. S. Army, Corps of Engineers, 1965a, 1965 b). Mean tidal ranges range from 0.76 to 1.07 m and average 0.87 m .

TABLE 3

A. TIDAL RANGES (M)

	Mean Ocean	Mean Inlet	Mean Pond	Spring Ocean
Narragansett	1.07	-	-	1.34
Point Judith	0.94	0.91	0.91	1.19
Charlestown	0.85	0.43	0.06	1.07
Quonochontaug	0.82	0.55	0.06	-
Winnapaug	0.79	0.46	0.15	-
Watch Hill	0.76	-	-	0.94

(From U. S. Army, Beach Erosion Board, 1949; N.O.A.A. Tide Tables)

B. HURRICANE STILLWATER LEVELS (M ABOVE MSL)

	1938	1944	1954
Point Judith	4.18-4.96	-	3.90
Charlestown	3.85	-	-
Watch Hill	3.28	2.49	-
Narragansett	3.74-4.21	2.52	3.90
Westerly	1.70-3.60	1.39	3.47

(from U. S. Army, Corps of Engineers, 1965a and 1965b) along the south shore. To determine the maximum effect of the hurricane surge levels in combination with a high tide, a maximum height was calculated by adding half the value of the average tidal range (0.44 m) to the maximum measured hurricane stillwater level above mean sea level (4.96 m) to derive the height of the maximum measured hurricane stillwater level at mean high water (5.40 m). The representative dune heights were then compared with this value to determine which areas along the south shore would be expected to experience overtopping of the barrier beaches on the basis of their representative dune heights by hurricane stillwater levels equivalent to the maximum measured hurricane high water during the 1938 hurricane (figure 13). The maximum hurricane levels would be further increased by hurricane wave heights, which have been observed to be highly variable along the Rhode Island coast.

According to this maximum hurricane flood level of 5.40 m above mean sea level, the following areas would be overwashed: all of Napatree Beach, the Maschaug Pond barrier beach, most of the Winnapaug and Quonchontaug Pond barrier beaches, all of the Ninigret Pond barrier beach, and most of the coast east to Point Judith. Visual inspection of all sets of aerial photographs for evidence of fresh (unvegetated) washover deposits on the backbarrier confirms the above predicted occurrences of overwash. Compilation of the quantitative values of changes in subtidal and supratidal washover deposits for the following sections of barrier beaches further confirms the expectations.

Napatree Point to Weekapaug Point: Over 107,000 m^2 of supratidal and over 102,000 m^2 of subtidal washover deposits have accreted on the backbarrier of Napatree Beach. On the Maschaug Pond barrier more than 78,000 m^2 of supratidal and nearly 58,000 m^2 of subtidal washover deposits have accreted, most in the western portion of Maschaug Pond; the rest has accumulated in Little Maschaug Pond and in smaller coastal ponds to the west. Along the Winnapaug Pond barrier over 54,000 m^2 of supratidal washover deposits have accumulated, and 104,000 m^2 of subtidal deposits have accumulated, most in the western part of the pond where the width of the backbarrier is at a minimum. Changes in the subtidal shoals in the region of the 1938 hurricane breach at Misquamicut Beach have been attributed to tidal delta rather than overwash processes, although overwash has undoubtedly been operative along this narrow section of the barrier beach. The dredging of a portion of the subtidal washover shoals at the western edge of the pond has also effected some change on the backbarrier, as the dredge spoils were apparently used as land fill in constructing the State Beach parking lot.

Weekapaug Point to Quonochontaug Point: On the Quonochontaug Pond barrier over 90,000 m^2 of supratidal and more than 83,000 m^2 of subtidal washover deposits have accreted, most of this at the western edge of the pond. To the east, the effects of overwash are masked by the effects of tidal delta deposition, if overwash is at all operative along that section of the beach where the dunes are relatively high and the backbarrier is very wide. Along a low section (2.30 - 3.37 m high dunes) of Quonochontaug Point at Michel, Garden, and East Ponds, more than 22,000 m^2 of subtidal and supratidal washover deposits have accumulated in the ponds.

Quonochontaug Point to Green Hill Point: On the backbarrier of the Ninigret Pond barrier more than 86,000 m^2 of supratidal and more than 50,000 m^2 of subtidal washover deposits have accumulated. A loss of over 54,000 m^2 of subtidal washover deposits in the western portion of the pond is concealed by the value of total pond-wide change. This loss of subtidal washover shoals resulted from supratidal washover accretion occurring more rapidly than adjacent subtidal washover deposition and does not represent erosion of the shoals, but rather the lack of additional deposition. This explanation is substantiated by the fact that where the greatest amounts of loss of subtidal washover shoals occurred, the greatest amount of accretion of supratidal washover deposits also occurred. Supratidal washover accretion in Green Hill Pond amounted to more than 31,000 m^2, while subtidal washover accretion of nearly 3,100 m^2 occurred, most in the eastern portion of the pond at an isolated washover sluice. Minor overwash at the site of a very small coastal pond on Green Hill Point resulted in the accretion of 4,000 m^2 of supratidal deposits.

Green Hill Point to Matunuck Point: At Trustom Pond more than 28,000 m^2 of supratidal washover deposits accreted on the backbarrier, with a gain of over 11,000 m^2 of subtidal washover shoals. Incorporated in this value is a loss of subtidal deposits which, again, may be attributed partly to the more rapid accumulation of supratidal deposits and to a less rapid accumulation of adjacent subtidal material. Major changes in the form and location of the minor and transitory inlet into Trustom Pond may also account for the measured loss of subtidal washover shoals. Similarly, a loss in subtidal washover shoals (more than 10,000 m^2) and a minor amount of supratidal accretion (more than 4,000 m^2) occurred in Cards Pond. This loss of subtidal deposits is essentially identical to that in Trustom Pond, as the form and location of the transitory inlet into Cards Pond have also changed with time.

Matunuck Point to Point Judith: A significant amount of washover accretion (nearly 8,000 m^2) occurred in the small coastal pond at Matunuck Point. Just east of this pond more than 20,000 m^2 of supratidal washover accretion has occurred on Potters Pond backbarrier, most of it along the southeastern edge of the pond. Most of this change occurred as infilling of former tidal channels across the backbarrier by overwashed sediment. Subtidal washover accretion was relatively insignificant because of the predominance of tidal delta accretion and changes caused by dredging and land filling in Potters Pond. Changes in Point Judith Pond are similarly difficult to distinguish as artificial or natural because of the changes imposed by the breachway construction that were not documented by the aerial photographs (Point Judith Breachway was stabilized between 1886 and 1909, before the earliest photographic coverage, U. S. Army, Beach Erosion Board, 1949).

IMPLICATIONS OF WASHOVER AND TIDAL DELTA CHANGES ON RHODE ISLAND SHORELINE DEVELOPMENT

WASHOVERS AND SHORELINE EROSION

From previous studies of washover sedimentation and geomorphology, there appears to be a correlation between the frequency and amount of washover accretion on an erosional shoreline. Leatherman (1976), in his study of overwash on Wachapreague Island, Virginia, was able to recognize a correlation between overwash occurrence and barrier island width, which he related directly to shoreline erosion: "if the barrier island is too narrow (because of excessive beach erosion), overwash will be effective in transporting enough material over the island to compensate for bayside shoreline losses. If the barrier island is too wide (because of little or no beach erosion), then bayside overwash deposition will not be able to keep pace with the concurrent shoreline erosion, because much of the material transported by the overwash surges would be deposited short of this critical distance with little sand actually reaching the backbarrier." It is likely that Leatherman's hypothesis also relates to overwash occurrence along the Rhode Island south shore, in that overwash deposition would be expected to be most noticeable where beach erosion is most effective in decreasing the barrier beach width from the ocean side, although at these same sections of shoreline where overwash effectively deposits sediment on the backbarrier and in the adjacent lagoon the barrier beaches will tend to widen to a critical equilibrium width.

A photogrammetric shoreline erosion survey made by comparing the position of the high water lines in 1939 and in 1975 using the Zoom Transfer Scope (figures 3 and 8, table G in Appendix II) and analysis of the orientations of sections of the barrier beaches and headlands (table 4) indicate the following relationships: beaches facing southeast (oriented roughly northeast-southwest) appear generally to experience greater erosion than beaches facing south or southwest. The probable explanation for this observed phenomenon is that winds and waves of the most severe storms and hurricanes approach most commonly from the southeast. The U. S. Army, Beach Erosion Board (1949) found that the relative infrequency of storm winds from the south and southeast is more than compensated for by their severity. It would be expected that storm and hurricane winds and waves approaching from the south and southeast would also be responsible for overwash occurrence. Examination of the orientations of the sections of barrier beaches experiencing the greatest supratidal and subtidal washover accretion indicates that there is a distinct relationship between storm attacks causing beach erosion and overwash, since beaches oriented northeast-southwest (facing the direction from which the greatest number of and most severe storms and hurricanes come) have experienced the greatest washover accretion as well as the greatest beach erosion.

From a comparison of figures 4 and 6 showing changes in area of subtidal and supratidal washover deposits, figure 3 depicting high water line beach changes, and figure 22 showing the ratio between these two parameters (tables 5, 6, and 7), it can be seen that it is generally true that where overwash occurred, the beach was significantly (greater than mean) erosional. Similarly, where overwash did not occur significantly (i.e., was less than the mean value of accretion of washover deposits), the beach was

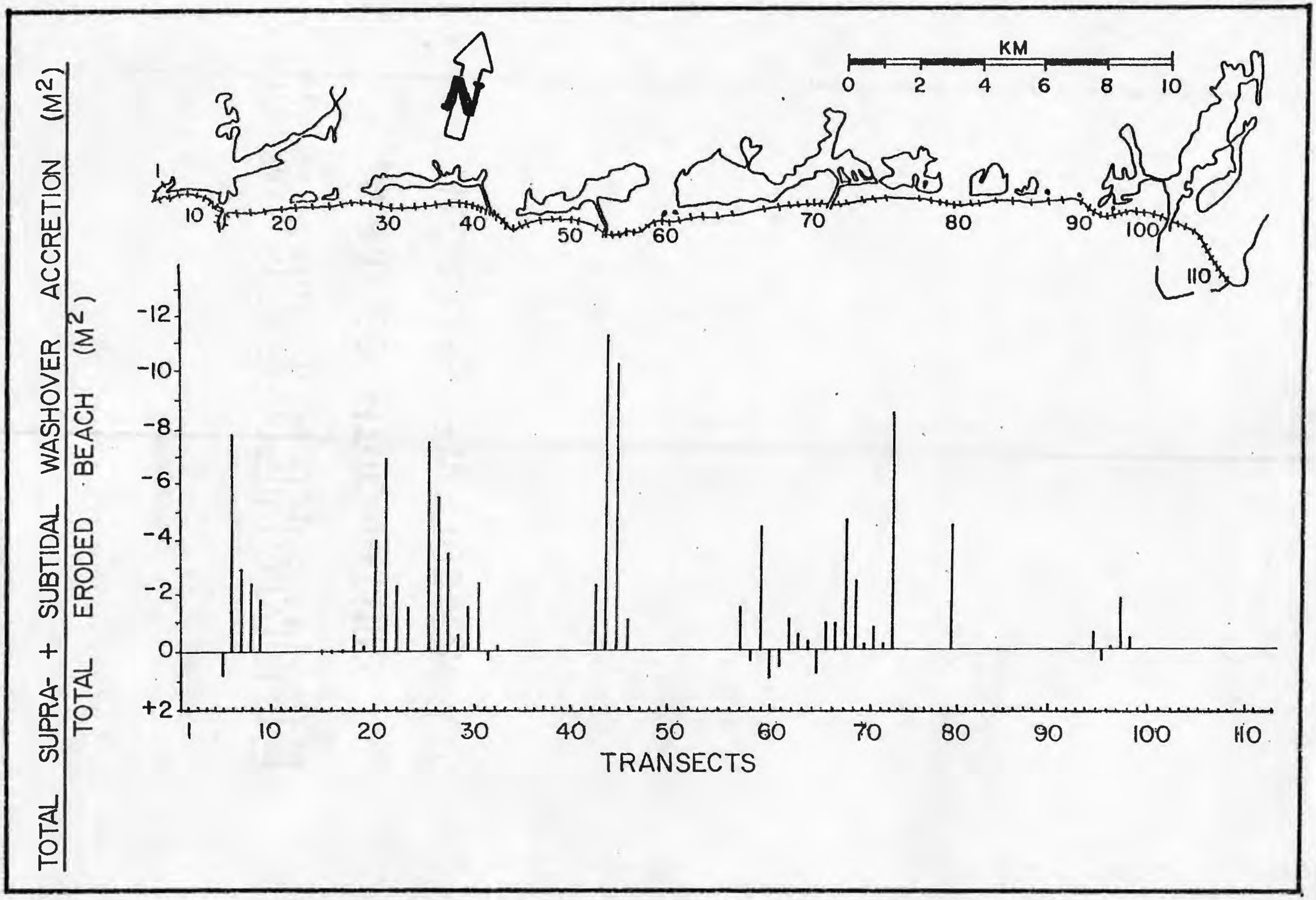

TOTAL SUPRA- + SUBTIDAL WASHOVER ACCRETION (M²)
TOTAL ERODED BEACH (M²)
-12
-10
-8
-6
-4
-2
0
+2
1
10
20
30
40
50
60
70
80
90
100
110
TRANSECTS
KM
0
2
4
6
8
10
N

FIGURE 22

TABLE 4

BARRIER BEACH ORIENTATIONS

transect	location	orientation
1-2	Napatree Point spit	N 60° E
3-9	Central Napatree Beach	N 75° E
9-10	Eastern Napatree Beach	N 75° W
10-12	Western Watch Hill Point	N 15° W
17-38	Eastern Watch Hill Point to Weekapaug Inlet	N 70° E
38-43	Weekapaug Inlet to Weekapaug Point	N 70° W
44-51	Weekapaug Point to Quonochontaug Inlet	N 75° E
52-72	Quonochontaug Inlet to Charlestown Inlet	N 65° E
73-81	Charlestown Inlet to Green Hill Point	N 75° E
81-91	Green Hill Point to Matunuck Point	N 75° E
95-98	Western Jerusalem (East Matunuck) Beach	N 65° E
98-101	Central Jerusalem (East Matunuck) Beach	E - W
101-102	Eastern Jerusalem (East Matunuck) Beach	N 75° W
103-113	Point Judith Breachway to Point Judith	N 50° W

TABLE 5

TOTAL SUPRA- AND SUBTIDAL WASHOVER ACCRETION (M^2) (Tables A & D)
TOTAL BEACH EROSION (M^2) (Table C)

transects	ratio	transects	ratio	transects	ratio
4-5	+0.96	31-32	-2.67	70-71	-2.87
5-6	-7.85	32-33	±0.26	76-77	-0.25
6-7	-3.17	33-34	-0.33	77-78	-0.82
7-8	-2.62	44-45	-2.74	78-79	-0.37
9-10	-2.33	45-46	-11.31	79-80	-8.20
15-16	0	46-47	-10.37	81-82	-4.00
16-17	0	47-48	-1.13	95-96	-0.67
17-18	-0.20	58-59	-1.67	96-97	+0.37
18-19	-0.79	59-60	+-.25	97-98	-0.10
19-20	-0.26	60-61	-4.67	98-99	-2.00
20-21	-4.01	61-62	+1.21	99-100	-0.38
21-22	-7.44	62-63	+0.66	MEAN	-2.25
22-23	-2.45	63-64	-1.10		
23-24	-1.57	64-65	-0.72		
26-27	-7.61	65-66	-0.48		
27-28	-5.64	66-67	+0.98		
28-29	-3.59	67-68	-1.31		
29-30	-0.86	68-69	-1.10		
30-31	-1.50	69-70	-4.87		

TABLE 6

$\frac{\text{TOTAL SUPRA- AND SUBTIDAL TIDAL DELTA ACCRETION } (M^2) \text{ (Tables A \& D)}}{\text{TOTAL BEACH EROSION } (M^2) \text{ (Table C)}}$

transects	ratio	transects	ratio
31-32	+1.01	75-76	-2.39
33-34	-4.19	76-77	-1.06
34-35	-36.58	77-78	-5.54
35-36	-1.66	89-90	-0.18
36-37	-6.05	96-97	-1.70
37-38	+3.60	97-98	+3.94
47-48	+0.97	98-99	-6.23
48-49	-1.86	99-100	-3.06
49-50	-3.04	100-101	-27.74
67-68	-0.60	101-102	-30.08
68-69	-1.00	104-105	-1.25
71-74	-8.90		
74-75	-7.50	MEAN	-5.88

TABLE 7
(From Tables A and D)

A. TOTAL SUPRATIDAL + SUBTIDAL WASHOVER ACCRETION (M^2)

transects	
4-5	-17,839
5-6	+75,564
6-7	+68,351
7-8	+59,263
8-9	+45,605
9-10	-11,970
10-11	- 9,633
15-16	0
16-17	0
17-18	+ 2,982
18-19	+14,912
19-20	+ 5,965
20-21	+47,783
21-22	+29,230
22-23	+27,753
23-24	+ 8,213
24-25	0
25-26	0
26-27	+50,935
27-28	+45,214
28-29	+36,034
29-30	+ 6,016
30-31	+ 9,024
31-32	+10,747
32-33	+ 1,043
44-45	+14,409
45-46	+83,377
46-47	+ 8,637
50-52	- 2,031
57-58	+ 2,103
58-59	+ 5,079
59-60	- 1,016
60-61	+14,220
61-62	- 3,415
62-63	- 3,093
63-64	+ 7,258
64-65	+12,141
65-66	+10,923
66-67	-13,394
67-68	+13,850
68-69	+ 6,992
69-70	+67,090
70-71	+32,694
76-77	+ 3,053
77-78	+21,374
78-79	+ 4,541
79-80	+33,333
81-82	+ 4,067
84-85	- 8,608
85-86	-38,343
86-87	+17,886
87-88	+ 4,472
95-96	+ 3,922
96-97	- 2,941
97-98	+ 977
98-99	+17,582
99-100	+ 4,884

B. TOTAL SUPRATIDAL + SUBTIDAL TIDAL DELTA ACCRETION (M^2)

transects	
31-32	- 4,091
33-34	+13,107
34-35	+76,279
35-36	+ 6,924
36-37	+31,514
37-38	- 9,432
47-48	- 7,482
48-49	+19,670
49-50	+35,060
50-52	+28,297
52-53	+28,491
67-68	+ 6,337
68-69	+ 6,337
71-74	+175,074
74-75	+125,327
75-76	+24,718
76-77	+12,994
77-78	+145,117
89-90	+ 2,236
96-97	+13,303
97-98	-38,518
98-99	+54,747
99-100	+38,890
100-101	+135,477
101-102	+88,132
104-105	+ 4,889

or was not severely erosional. It was not always true, however, that overwash occurred everywhere that the beach was severely erosional (see table 8 and figure 23). At 27% of the transects where washover accretion was significant (i.e., greater than the mean value of +18,000 m^2), the beach was significantly erosional (i.e., less than the mean value of -6,000 m^2). At 66% of the transects significant to moderate washover accretion (i.e., less than +18,000 m^2, but greater than 0) occurred where the beaches were significantly to moderately erosional (i.e., less than -6,000 m^2, but not greater than 0). The 29% anomalous occurrences of losses of washover deposits result from a combination of moderately erosional to stable beaches, dredging or actual erosion of washover deposits, or situations where possible washover deposits were classified as predominantly tidal delta deposits in this study.

WASHOVERS AND SHORELINE MORPHOLOGY

There are several shoreline morphology factors other than beach erosion which appear to affect the occurrence and amount of washover accretion on the backbarrier. These factors include: less than mean dune height (figure 24), narrower than average barrier beach width, and the existence of transitory inlets. For example, in the area just to the east of the site of the Misquamicut Beach 1938 hurricane breach (at transects 32-33), the beach is stable to slightly erosional, and a minor amount (about 1,000 m^2) of washover accretion occurred over the study period. The dunes are relatively high here (3.94 m at transect 32), and the barrier beach is relatively wide (354 to 361 m wide in 1975). The minor amount of supratidal washover accretion probably occurred as the result of the spillover of sediment from overwash slightly to the west at the site of the hurricane breach, where the dune is about the same height (3.92 m), but the barrier

TABLE 8

RELATIONSHIPS BETWEEN WASHOVER CHANGES AND BEACH CHANGES

	(M^2) washover changes	(M^2) beach changes	transects	total number of transects
a	> +18,000	< -6,000	5-6,6-7,7-8,8-9,18-19, 20-21,21-22,22-23,27-28, 28-29,45-46,46-47,69-70, 70-71,77-78,98-99,	16
b	> +18,000	-6,000 - 0	31-32,44-45,47-48,60-61, 79-80	5
c	> +18,000	0	86-87	1
d	+18,000 - 0	< -6,000	17-18,19-20,29-30,30-31, 63-64,64-65,65-66,67-68, 68-69,76-77,78-79,97-98, 99-100	13
e	+18,000 - 0	-6,000 - 0	23-24,33-34,58-59,81-82, 95-96	5
f	+18,000 - 0	0	57-58,87-88	2
g	< -10,000	< -6,000	26-27,66-67	2
h	< -10,000	-6,000 - 0	9-10,85-86	2
i	-10,000 - 0	< -6,000	4-5,96-97	2
j	-10,000 - 0	-6,000 - 0	32-33,59-60,61-62,62-63	4
k	-10,000 - 0	0	50-52,84-85	2
l	-10,000 - 0	> 0	10-11	1
m	0	-6,000 - 0	15-16,16-17,24-25,25-26	4
			TOTAL	59

TABLE 8

EXPLANATION:

$> +18{,}000\ m^2$ = significant washover accretion

$+18{,}000\ m^2$ = mean washover accretion

$0 - +18{,}000\ m^2$ = moderate washover accretion

$-10{,}000\ m^2$ = mean lack of washover accretion

0 = no washover change

$< -6{,}000\ m^2$ = significant beach erosion

$-6{,}000\ m^2$ = mean beach erosion

$0 - -6{,}000\ m^2$ = moderate beach erosion

0 = stable beach

RESULTS:

Significant washover accretion and significant beach erosion occurred 27% of the time: 16a/59 X 100 = 27%.

Significant to moderate washover accretion and significant to moderate beach erosion occurred 66% of the time: 16a + 5b +13d + 5e = 39/59 X 100 = 66%.

Significant to moderate washover accretion and a stable beach occur 5% of the time: 1c + 2f = 3/59 X 100 = 5%.

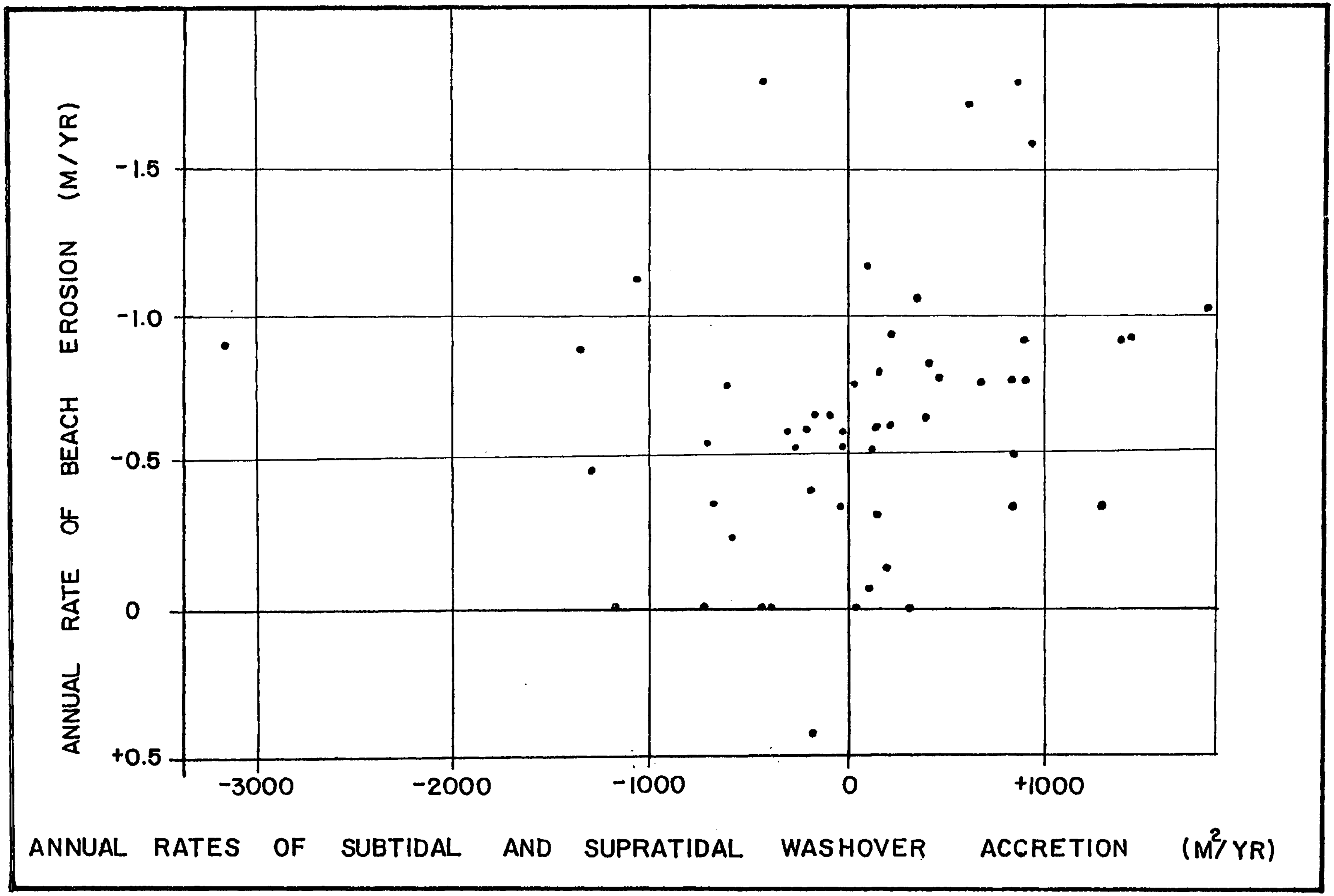

ANNUAL RATE OF BEACH EROSION (M/YR)
-1.5
-1.0
-0.5
0
+0.5
-3000
-2000
-1000
0
+1000
ANNUAL RATES OF SUBTIDAL AND SUPRATIDAL WASHOVER ACCRETION (M^2/YR)

FIGURE 23

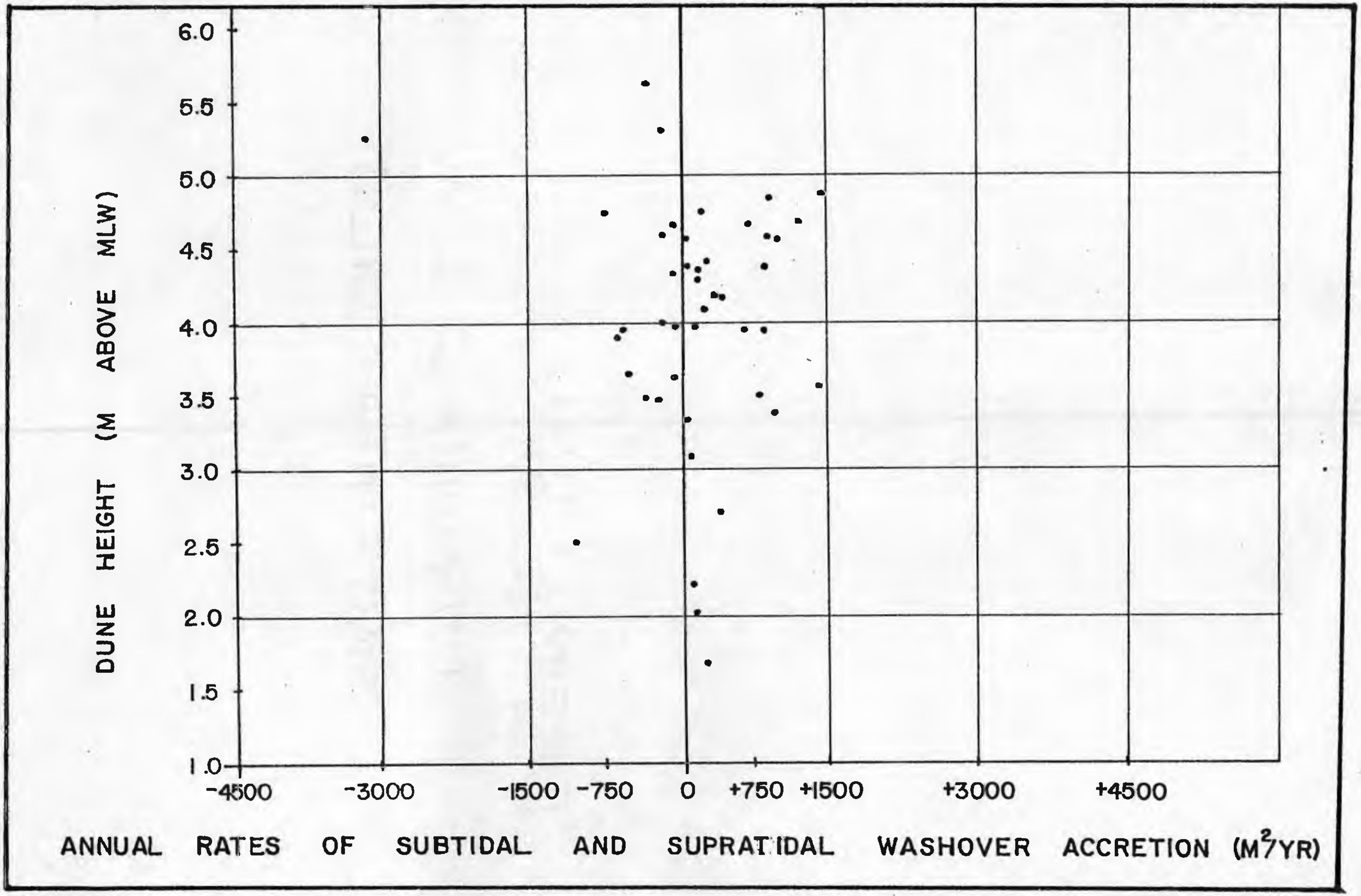

DUNE HEIGHT (M ABOVE MLW)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
-4500
-3000
-1500
-750
0
+750
+1500
+3000
+4500
ANNUAL RATES OF SUBTIDAL AND SUPRATIDAL WASHOVER ACCRETION (M²/YR)

FIGURE 24

beach is much narrower (196 m wide in 1975). At the site of a very small coastal pond on Green Hill Point (at transects 81-82) the shoreline is stable to accretional, and a minor amount (about 4,000 m^2) of washover accretion occurred in the pond. The dunes are relatively well-developed in this area (3.93 - 4.06 m high), but they are not continuous on the beach adjacent to the pond; in fact, the pond and the marshy area surrounding it drain almost continuously across the beach through a low spot in the dunes, which may be a former overwash sluice, blowout, or inlet-like feature. The proximity of the pond to the high water line (about 80 m in 1975) also explains the washover accretion in the pond.

Along the western edge of Trustom Pond (at transects 84-85) the shoreline is stable. A minor amount (6,000 m^2) of washover accretion occurred in an area where the dunes are relatively low (1.68 - 1.83 m, according to Olsen and Grant, 1973), and the barrier beach is relatively narrow (117 - 103 m wide in 1975). It is probably for the very reason that the beach is not distinctly erosional that such a minor amount of overwash occurred. Along the eastern edge of Trustom Pond (at transects 86-87) much more significant amounts of washover accretion occurred (nearly 18,000 m^2). This area is the site of a transitory inlet which has changed its location and form over the study period, the dunes are low (2.59 - 2.44 m high, according to Olsen and Grant, 1973), and the barrier beach is narrow (111 m wide in 1975). Although the beach is stable, the presence of the transitory inlet and the low and discontinuous dunes and narrow barrier beach could combine to allow significant overwash deposition at this site. The situation is similar in front of Cards Pond (at transects 87-88). The shoreline is stable, a transitory inlet has changed its form and location over the study period, the dunes are fairly low (2.44 m, according to Olsen and

Grant, 1973) and are discontinuous in the vicinity of the inlet, and the barrier beach is narrow (145 m wide in 1975 at a somewhat wider portion of the beach to the east of the inlet).

On the eastern side of Matunuck Point (at transects 95-96), a minor amount of overwash (nearly 4,000 m^2) occurred at a small coastal pond, located about 40 m from the high water line in 1975. The dunes are low in this region (2.20 - 1.67 m high), although most of the Matunuck Point area is protected from overwash by relief provided by glacial deposits. In this situation, the shoreline immediately adjacent to the coastal pond has receded noticeably over the study period.

Negative values of change in the subtidal deposits result from: a) migration of the barrier system landward into the lagoons with conversion of subtidal shoals into supratidal deposits; b) erosion or redistribution of the deposits by currents or waves in the lagoons; or c) dredging of the subtidal shoals to deepen channels for navigation or to provide land fill. At the Trustom and Cards Ponds barrier beaches subtidal washover deposits were decreased probably as a result of erosion or redistribution of the sediment in the shoals, which resulted from currents that developed when temporary inlets were opened into the ponds, either articially or as a result of the overtopping of the barrier beach by storm surge and waves. The subtidal deposits may have been redistributed within the ponds, or they may have been eroded and transported out of the ponds into the ocean as the higher water levels in the ponds drained into the ocean. The most common cause of a decrease in the subtidal deposits appears to be the conversion of subtidal washover shoals to supratidal deposits, although, locally, dredging, particularly of tidal delta deposits, is also a significant cause.

Negative values of areas converted from 1939 subtidal deposits to

1975 supratidal deposits result from: a) dredging along the backbarrier shoreline or b) erosion along the backbarrier shoreline. Generally, where the greatest amounts of loss of subtidal washover deposits occurred, the greatest amounts of accretion of supratidal deposits also occurred.

SEDIMENT BUDGET ANALYSIS

The relationships between the areal changes in washover and tidal delta deposits and the amount of eroded beach over the whole study period for the entire south shore are as follows:

(1) Total area of eroded beach:	-608,558 m^2
(2) A, total area of subtidal washover accretion:	+267,953 m^2
B, total area of subtidal tidal delta accretion:	+862,322 m^2
C, total area of subtidal washover and tidal delta loss:	-76,147 m^2
Total (2) subtidal washover and tidal delta accretion:	+786,442 m^2
(3) A, total area of supratidal washover accretion:	+522,792 m^2
B, total area of supratidal tidal delta accretion:	+188,238 m^2
Total (3) supratidal washover and tidal delta accretion:	+711,030 m^2
Total (2) + (3): subtidal and supratidal washover and tidal delta accretion:	+1,497,472 m^2

Subtidal washover accretion (+267,953 m^2) is only about one third (0.31) as effective as subtidal tidal delta accretion (+862,322 m^2) in the lagoons, whereas supratidal tidal delta accretion (+188,238 m^2) is only about one third (0.36) as effective as supratidal washover accretion (+522,792 m^2). Subtidal and supratidal washover accretion (+790,745 m^2) is three-quarters (0.75) as effective in transporting sediment landward as subtidal and supratidal tidal delta accretion (+1,050,560 m^2). It is to be expected that tidal delta sedimentation is more effective in transporting sediment into the lagoon and onto the backbarrier than are overwash processes, because tidal delta sedimentation processes are steady and relatively continuous, whereas overwash is catastrophic (i.e., discontinuous and erratic).

Using the calculated value for the annual rate of washover accretion along the Rhode Island south shore to approximate the rates of accretion for washover fans as well as for tidal deltas (in the absence of any rates of tidal delta sedimentation) and using the Coastal Engineering Research Center's estimate of the volume of beach lost (0.76 m^3) per areal loss of beach (0.09 m^2) to derive a value of 8.44 m^3 sediment loss per 1 m^2 areal units of beach erosion, the following values for the whole south shore over the entire study period can be computed:

Washover accretion: $0.05\ \text{m/yr} \times 36\ \text{yr} \times \left(267{,}953 + 522{,}792 - \frac{76{,}147}{2}\right) = 1{,}354{,}809\ \text{m}^3$

Tidal delta accretion: $0.05\ \text{m/yr} \times 36\ \text{yr} \times \left(862{,}322 + 188{,}238 - \frac{76{,}147}{2}\right) = 1{,}822{,}476\ \text{m}^3$

Beach erosion: $8.44\ \text{m}^3/\text{m}^2 \times -608{,}558 = -5{,}138{,}934\ \text{m}^3$

Washover: $(1{,}354{,}809 \div -5{,}138{,}934) \times 100 = 26\%$

Tidal delta: $(1{,}822{,}476 \div -5{,}138{,}934) \times 100 = 35\%$

Washover and tidal delta: $(3{,}177{,}285 \div -5{,}138{,}934) \times 100 = 62\%$

According to these calculations, washover accretion accounts for 26% of the volume of beach eroded, and tidal delta accretion accounts for 35% of the volume of beach eroded. These calculations from the photogrammetric analysis of the areal backbarrier shoreline changes indicate that washover and tidal delta sedimentation may be responsible for 62% of the sediment that is eroded from the beaches, and 38% of the sediment being eroded from the beaches is available to be transported offshore and/or alongshore.

The value of 0.05 m/yr represents the annual rate of vertical accretion on the supratidal washover fan surface in an area receiving perhaps abnormally high volumes of sediment from the overwash process; values indicating rates of vertical accretion on subtidal washover shoals have not been determined, but are probably less than the value for vertical supratidal washover accretion. Refinement of this and the other values used in the volumetric calculations may alter the relationships somewhat, but the calculations still strongly indicate that washover and tidal delta sedimentation are clearly significant processes transporting sediment landward on the Rhode Island south shore. Of the four possible sinks for sediment along the coast (which include the beaches and dunes, the tidal deltas, the washover fans, and the offshore zone), it is clear from this photogrammetric study of backbarrier and lagoon shoreline and sediment deposit changes that washover fans play nearly as significant a role in backbarrier and lagoon storage of sediment as tidal deltas do.

IMPLICATIONS OF BACKBARRIER ACCRETION ON SHORELINE DEVELOPMENT

Washover and flood tidal delta sedimentation over the short term represent a loss of sediment to the littoral sediment budget. Over the long term, however, this sediment becomes incorporated into the barrier beach system as the barriers erode and migrate landward. Both washover and tidal delta accretion on the backbarrier shoreline provide new substrate for marsh growth as the elevation of the subtidal shoals is raised to the low tide level in the lagoons through continuing deposition. Above the low tide level *Spartina alterniflora* begins to colonize the shoals from lateral growth of the rhizomes of plants higher on the marshes or grow from fragments and seeds deposited on the shoals by the currents. Marshes that develop on the delta shoals in particular help entrap fine sediment by baffling the tidal currents and allowing the fine sediment to be deposited, as well as add to the productivity of the marsh by providing organic debris to the waters and sediment of the lagoon. Sedimentation rates in the tidal marsh generally decrease with increasing elevation (Richard, 1976). Although *Spartina alterniflora* aids in the trapping and binding of the sediment, the effects of elevation are more important than vegetation density in governing sedimentation rates in a tidal marsh (Richard, 1976). The effects of vegetation on sedimentation would be expected to increase as the tidal delta shoals become elevated above the low tide level.

Sedimentation on flood tidal deltas also tends to increase the width of the barrier island in addition to increasing its elevation, if only in the immediate vicinity of the inlet, and to decrease the depths in the lagoons. The tidal delta may become connected to the barrier through the action of washover deposition on the flanks of an active tidal delta system, on the updrift edge when an inlet is migrational, or more commonly when an inlet closes. The effects of overwash in the vicinity of flood tidal deltas are primarily inhibited by the greater width of the barrier due to the tidal delta deposition.

The significance of overwash in maintaining the form of the Rhode Island barrier beaches is indicated by the fact that the barrier beach width over the study period has maintained itself (table 1). Washover and tidal delta sedimentation have been able to compensate for the losses of sediment to beach erosion by allowing the barrier beaches to accrete on the lagoonal shoreline, the "rollover" effect recognized by Dillon (1970), Pierce (1969, 1970), Schwartz (1975), Godfrey (1976), Godfrey and Godfrey (1973, 1974), and Leatherman (1976).

Overwash in particular plays a critical role in the evolution and maintenance of the barrier beach system. The effects of rising sea level, lack of sediment being supplied to the beaches, and frequent damaging storms and hurricanes along the Rhode Island coast result in an erosional trend on the beaches. Natural, unstabilized beaches, such as most of the Rhode Island south shore beaches, have proved themselves better able to adapt to steady state processes and catastrophic events than overly stabilized, impenetrable barrier beach systems. Natural barrier beaches present relatively little resistance to storm surge and wave attack and allow this energy to be dissipated across the beach, among the low dunes, and onto the backbarrier behind, allowing the barrier beach system to gain material from the eroding beach. These backbarrier deposits can then later serve as sources of sediment for new dune growth, as well as for new marsh growth (Dolan, 1973; Dolan and Godfrey, 1973; Godfrey and Godfrey, 1973; Bartberger, 1976).

Washover and tidal delta sedimentation affect the lagoons and ponds along the Rhode Island south shore by causing the backbarrier to encroach into the lagoons and by causing sediment deposits to shoal the regions adjacent to the backbarrier and in the vicinity of tidal inlets. The long term effect of washover and tidal delta sedimentation is indicated in Bloom's (1963) postglacial stratigraphic study of coastal Connecticut. Until about 3,000 years ago, rapid submergence of the coast by sea level rise exceeded the rate of sedimentation in the coastal bays and lagoons. During the last 3,000 years, however, submergence has been slow enough to be nearly equalled by the sedimentation rate, and salt marshes have filled former bays and lagoons. It is likely that the small size of the Rhode Island coastal lagoons and the moderate energy of the waves and tidal currents along the coast are gradually causing the infilling and destruction of these lagoons. At the present time, however, creation of the salt marsh on the backbarrier is just keeping pace with shorefront beach erosion (according to the measured changes in the barrier beach widths, table 1).

This importance of overwash on the evolution of the barrier beach system of Rhode Island has significance in the long-range planning and management of the coastal zone. Stabilized, continuous and high dunes obstruct the dissipation of storm surge and wave energy and prevent the deposition of washover sediment on the backbarrier, which would eventually lead to the destruction of these barrier beaches.

APPENDIX I

TABLE A

MEASURED AREAS OF SUBTIDAL AND SUPRATIDAL DEPOSITS, ERODED BEACH, AND 1939 SUBTIDAL DEPOSITS CONVERTED TO 1975 SUPRATIDAL DEPOSITS (M^2)

	1975			1939 subtidal to 1975 supratidal					1939		
	supra-	1975 subtidal				dredge/	inlet	eroded	supra-	1939 subtidal	
transects	tidal	washover	delta	washover	delta	fill	changes	beach	tidal	washover	delta
	A	B	C		D			E	F	G	H
1-2		-	-	-	-	-	-	- 2,916		-	-
2-3		-	-	-	-	-	-	0		-	-
3-4	122,452	-	-	-	-	-	-	- 4,859	164,924	-	-
4-5		33,524	-	- 8,648	-	-	-	-18,587		44,979	-
		-	-	+ 5,456	-	-	-	-		-	-
5-6	36,952	30,984	-	+24,584	-	-	-	- 9,642	29,986	4,498	-
6-7	44,165	7,190	-	+33,579	-	-	-	-21,558	34,484	5,997	-
7-8	35,948	11,298	-	+27,731	-	-	-	-22,596	32,985	7,497	-
8-9	35,948	15,406	-	+22,596	-	-	-	-21,569	32,985	14,993	-
9-10	47,246	9,244	-	- 4,108	-	-	-	- 5,135	46,479	31,486	-
	-	-	-	+ 9,244	-	-	-	+ 5,135	-	-	-
10-11	-	1,027	-	- 3,081	-	-	-	+ 5,135	-	4,498	-
11-12	-	-	-	-	-	-	-	0	-	-	-
12-13	-	-	-	-	-	-	-	0	-	-	-
13-14	-	-	-	-	-	-	-	0	-	-	-
14-15	-	-	-	-	-	-	-	0	-	-	-
15-16	-	-	-	0	-	-	-	- 3,545	-	-	-
16-17	-	-	-	0	-	-	-	- 9,941	-	-	-
17-18	-	-	-	+ 2,982	-	-	-	-14,912	-	-	-
18-19	-	-	-	+14,912	-	-	-	-18,889	-	-	-

TABLE A

transects	1975 supra-tidal	1975 subtidal		1939 subtidal to 1975 supratidal				eroded beach	1939 supra-tidal	1939 subtidal	
		washover	delta	washover	delta	dredge/ fill	inlet changes			washover	delta
	A	B	C	D				E	F	G	H
19-20	-	-	-	+ 5,965	-	-	-	-22,865	-	-	-
20-21	-	2,982	-	+23,859	-	-	-	-11,930	-	2,917	-
21-22	50,861	6,713	-	+13,744	-	-	-	-13,929	50,948	4,971	-
22-23	39,203	4,356	-	+13,068	-	-	-	-11,325	39,720	2,739	-
23-24	1,370	871	-	+ 4,356	-	-	-	- 5,227	10,957	1,370	-
24-25	-	-	-	0	-	-	-	- 1,742	-	-	-
25-26	-	-	-	0	-	-	-	- 5,013	-	-	-
26-27	63,167	74,196	-	- 3,485	-	-	-	- 6,690	53,674	39,911	-
	-	-	-	+11,810	-	-	-	-	-	-	-
27-28	69,183	74,196	-	+13,034	-	-	-	- 8,021	60,555	55,050	-
28-29	130,344	61,162	-	+ 6,016	-	-	-	-10,026	126,615	37,159	-
29-30	106,281	59,156		+ 6,106	-	-	-	- 7,019	100,466	57,803	
30-31	69,183	91,241		+ 9,024	-	-	-	- 6,016	64,684	110,100	
31-32	117,310	144,381		+10,747	- 4,091	-	-	- 6,597	105,971	183,041	
	-	-	-	-	-	-	-	+ 2,566	-	-	-
32-33	105,287	53,165	-	- 3,127	-	-	-	- 3,127	126,693	53,973	
	-	-	-	+ 3,127	-	-	-	-	-	-	-
33-34	114,669	-	34,443	- 1,042	-	-	-	- 3,127	82,934	-	22,379
	-	-	-	+ 2,085	-	-	-	-	-	-	-
34-35	218,914	-	131,348	-	+ 2,085	-	-	- 2,085	176,400	-	59,239
35-36	91,735	-	27,104	-	+ 8,340	-	-	- 4,170	71,087	-	36,860
36-37	160,537	-	43,783	-	- 2,085	-	-	- 5,212	107,946	-	78,985
	-	-	-	-	+35,443	-	-	-	-	-	-
37-38	230,381	-	32,316	-	- 3,155	-	-	- 4,193	224,381	-	44,876
	-	-	-	-	+ 4,719	-	-	+ 1,570	-	-	-
38-39	50,037	-	-	-	-	-	-	+ 7,863	43,474	-	22,438
39-40	-	-	-	-	-	-	-	0	-	-	-

TABLE A

transects	1975 supratidal	1975 subtidal		1939 subtidal to 1975 supratidal				eroded beach	1939 supratidal	1939 subtidal	
		washover	delta	washover	delta	dredge/ fill	inlet changes			washover	delta
	A	B	C		D			E	F	G	H
40-41	-	-	-	-	-	-	-	0	-	-	-
41-42	-	-	-	-	-	-	-	- 1,054	-	-	-
42-43	-	-	-	-	-	-	-	- 1,054	-	-	-
43-44	-	-	-	-	-	-	-	- 5,268	-	-	-
44-45	28,448	3,161	-	+ 8,429	-	-	-	- 5,268	25,243	5,610	-
45-46	136,972	89,559	-	+36,877	-	-	-	- 7,375	100,971	79,936	-
46-47	86,372	22,073	-	+38,387	-	-	-	- 6,718	54,043	29,212	-
47-48	74,858	70,057		+ 8,637	-	-	-	- 7,677	78,873	86,176	
48-49	123,800	155,469		-	+30,710	-	-	-10,557	103,704	197,183	
49-50	266,795	-	208,252	-	+17,274	-	-10,557	-11,516	303,808	-	197,183
50-52	250,883	-	111,729	- 3,047	- 2,031	-	- 6,094	0	279,750	-	86,495
	-	-	-	+ 1,016	+ 7,117	-	+ 1,016	-	-	-	-
52-53	117,824	-	44,692	-	+ 4,063	-	-	0	122,985	-	24,327
53-54	-	-	-	-	-	-	-	- 1,016	-	-	-
54-55	-	-	-	-	-	-	-	- 1,016	-	-	-
55-56	-	-	-	-	-	-	-	- 1,016	-	-	-
56-57	-	-	-	-	-	-	-	- 1,016	-	-	-
57-58	-	-	-	+ 2,103	-	-	-	0	-	-	-
58-59	-	-	-	+ 5,079	-	-	-	- 3,047	-	-	-
59-60	-	-	-	- 1.016	-	-	-	- 4,063	-	-	-
60-61	-	-	-	- 3,047	-	-	-	- 3,047	-	-	-
	-	-	-	+10,157	-	-	-	[illegible]	-	-	-
61-62	42,158	74,011	-	+ 2,810	-	-	-	- 2,810	47,649	83,046	-
62-63	76,821	106,801	-	+20,611	-	-	-	- 4,684	68,070	151,116	-
63-64	75,885	99,306	-	+ 8,432	-	-	-	- 6,558	73,516	108,912	-
64-65	187,369	176,127	-	+33,726	-	-	-	-16,863	163,368	231,438	-
65-66	215,051	317,270	-	+15,347	-	-	-	-21,446	256,860	337,741	-
66-67	157,360	139,406	-	-10,561	-	-	-	-13,729	152,747	131,678	-
											-

TABLE A

transects	1975 supra-tidal	1975 subtidal		1939 subtidal to 1975 supratidal				eroded beach	1939 supra-tidal	1939 subtidal	
		washover	delta	washover	delta	dredge/ fill	inlet changes			washover	delta
	A	B	C	D				E	F	G	H
67-68	123,564	54,917	-	-	+ 6,337	-	-	-10,561	106,660	47,404	-
68-69	119,340	50,693	-	-	+ 6,337	-	-	- 6,337	118,511	50,038	-
69-70	166,865	149,967	-	+15,842	-	-	-	-13,729	123,778	114,561	-
70-71	168,851	122,236	-	0	-	-	-	-11,395	147,480	89,542	-
71-72		-		-		-				-	
72-73	573,886	-	243,436	-	+21,754	-	-29,005	-19,682	595,673	-	111,870
73-74		-		-		-				-	
74-75	291,087	-	217,538	-	+12,439	+16,574	-	-16,574	284,761	-	133,663
75-76	164,707	-	106,697	-	-	- 2,072	+20,718	-10,359	140,928	-	79,907
76-77	131,300	-	26,463	+ 3,053	-	- 5,179	-	-12,214	155,962	-	11,343
77-78	291,097	-	311,458	+21,374	-	- 3,108	-	-26,214	273,612	-	167,304
78-79	137,407	9,160	-	+ 4,071	-	-	-	-12,214	134,694	12,761	-
79-80	97,618	38,640	-	+ 3,051	-	-	-	- 4,067	92,695	11,409	-
80-81	-	-	-	-	-	-	-	- 3,051	-	-	-
81-82	-	-	-	+ 4,067	-	-	-	- 1,017	-	-	-
82-83	-	-	-	-	-	-	-	- 2,034	-	-	-
83-84	-	-	-	-	-	-	-	- 1,017	-	-	-
84-85	51,860	51,860	-	+ 6,101	-	-	-	0	45,634	72,730	-
85-86	29,489	16,270	-	+ 4,067	-	-	-	0	25,669	62,747	-
86-87	111,790	108,437		+17,886	-	-	-	0	92,656	114,717	
87-88	97,258	4,472		+ 4,472	-	-	- 3,354	0	89,715	16,178	
88-89	45,834	-	-	-	-	-	-	0	54,417	-	-
89-90	-	-	-	-	-	-	+ 2,236	- 2,236	-	-	-
90-91	-	-	-	-	-	-	-	0	-	-	-
91-92	-	-	-	-	-	-	-	+ 1,961	-	-	-
92-93	-	-	-	-	-	-	-	+ 6,863	-	0	-
93-94	-	-	-	-	-	-	-	0	-	-	-

TABLE A

transects	1975 supra-tidal	1975 subtidal washover	1975 subtidal delta	1939 subtidal to 1975 supratidal washover	1939 subtidal to 1975 supratidal delta	1939 subtidal to 1975 supratidal dredge/ fill	1939 subtidal to 1975 supratidal inlet changes	eroded beach	1939 supra-tidal	1939 subtidal washover	1939 subtidal delta
	A	B	C		D			E	F	G	H
94-95	-	-	-	-	-	-	-	- 1,961	-	-	-
95-96	-	-	-	+ 3,922	-	-	-	- 5,882	-	0	-
96-97	14,706	76,472		- 2,941	-	-	-	- 7,843	20,076	60,228	
97-98	56,652	121,118		+ 977	-	-	-	- 9,763	80,304	160,607	
98-99	87,908	-	121,118	+17,582	-	-	-	- 8,791	90,313	-	83,953
99-100	358,470	-	75,210	+ 4,884	+ 2,930	-	-	-12,698	348,537	-	47,064
100-101	223,678	-	175,816	-	+35,163	-	-	- 4,884	249,314	-	110,665
101-102	190,468	-	100,601	-	-	-24,419	-	- 2,930	222,682	-	36.888
102-103	238,329	-	-	-	-	+10,744	-	+ 2,930	181,897	-	-
103-104	190,685	-	-	-	-	-11,734	-	- 1,956	211,154	-	-
104-105	500,669	-	-	-	+ 4,889	-	-	- 3,911	431,211	-	-
MEAN		59,618	118,353	8,169	9,907	- 3,839	- 3,577	- 5,741			
TOTAL		1,907,771	2,012,004	522,792	188,238	-19,194	-25,040	-608,558			

TABLE B

ANNUAL CHANGES IN AREAS OF SUBTIDAL DEPOSITS, ERODED BEACH, AND 1939 SUBTIDAL DEPOSITS CONVERTED TO 1975 SUPRATIDAL DEPOSITS (M^2/ YR)

	1939 subtidal to 1975 supratidal							change in extent of subtidal	
transects	washover	delta	dredge/ fill	inlet changes	eroded beach	change in subtidal washover	delta	washover	delta
	D				E	I	J	K	L
1-2	-	-	-	-	- 81	-	-	-	-
2-3	-	-	-	-	0	-	-	-	-
3-4	-	-	-	-	-135	-	-	-	-
4-5	- 89	-	-	-	-516	-318	-	-407	-
5-6	+683	-	-	-	-268	+730	-	+1,419	-
6-7	+933	-	-	-	-599	+ 33	-	+966	-
7-8	+770	-	-	-	-628	+106	-	+876	-
8-9	+628	-	-	-	-599	+ 11	-	+639	-
9-10	+143	-	-	-	0	- 618	-	-732	-
10-11	- 86	-	-	-	+143	- 69	-	-182	-
11-12	-	-	-	-	0	-	-	-	-
12-13	-	-	-	-	0	-	-	-	-
13-14	-	-	-	-	0	-	-	-	-
14-15	-	-	-	-	0	-	-	-	-
15-16	0	-	-	-	- 98	-	-	-	-
16-17	0	-	-	-	-276	-	-	-	-
17-18	+ 83	-	-	-	-414	-	-	-	-
18-19	+414	-	-	-	-525	-	-	-	-
19-20	+166	-	-	-	-635	-	-	-	-
20-21	+663	-	-	-	-331	+ 2	-	+665	-
21-22	+382	-	-	-	-387	- 48	-	+430	-
22-23	+363	-	-	-	-315	+ 45	-	+408	-
23-24	+121	-	-	-	-145	- 14	-	+107	-
24-25	0	-	-	-	- 48	-	-	-	-

TABLE B

	1939 subtidal to 1975 supratidal							change in	
transects	washover	delta	dredge/ fill	inlet changes	eroded beach	change in washover	subtidal delta	extent of washover	subtidal delta
			D		E	I	J	K	L
25-26	0	-	-	-	-139	-	-	-	-
26-27	+231	-	-	-	-186	-930	-	-699	-
27-28	+362	-	-	-	-223	+532	-	+894	-
28-29	+167	-	-	-	-279	+667	-	+834	-
29-30	+167	-	-	-	-195	+ 38		+205	
30-31	+251	-	-	-	-167	-524		-273	
31-32	+299	-114	-	-	-116	-1,074		-589	
32-33	0	-	-	-	- 87	- 22		- 22	-
33-34	+ 29	-	-	-	- 87	-	-	-	+364
34-35	-	+ 58	-	-	- 58	-	+335	-	+2,061
35-36	-	+232	-	-	-116	-	+2,003	-	- 39
36-37	-	+927	-	-	-145	-	-271	-	- 51
37-38	-	+ 43	-	-	- 73	-	-978	-	-305
38-39	-	-	-	-	+218	-623	-349	-	-
39-40	-	-	-	-	0	-	-	-	-
40-41	-	-	-	-	0	-	-	-	-
41-42	-	-	-	-	- 29	-	-	-	-
42-43	-	-	-	-	- 29	-	-	-	-
43-44	-	-	-	-	-146	-	-	-	-
44-45	+234	-	-	-	-146	- 68	-	+160	-
45-46	+1,024	-	-	-	-205	-267	-	+1,292	-
46-47	+1,066	-	-	-	-187	-198	-	+868	-
47-48	+240	-	-	-	-213	-448	-	-208	
48-49	-	+853	-	-	-293	-1,159		-307	
49-50	-	+480	-	-293	-320	-	+307	-	+494
50-52	- 56	+141	-	-141	0	-	+701	-	+645
52-53	-	+113	-	-	0	-	+566	-	+679
53-54	-	-	-	-	- 28	-	-	-	-

TABLE B

	1939 subtidal to 1975 supratidal							change in extent of subtidal	
transects	washover	delta	dredge/ fill	inlet changes	eroded beach	change in subtidal washover	change in subtidal delta	washover	delta
	D				E	I	J	K	L
54-55	-	-	-	-	- 28	-	-	-	-
55-56	-	-	-	-	- 28	-	-	-	-
56-57	-	-	-	-	- 28	-	-	-	-
57-58	+ 58	-	-	-	0	-	-	+ 58	-
58-59	+141	-	-	-	- 85	-	-	+141	-
59-60	- 28	-	-	-	-113	-	-	- 28	-
60-61	+198	-	-	-	- 85	-	-	+198	-
61-62	+ 78	-	-	-	- 78	-251	-	-173	-
62-63	+573	-	-	-	-130	-1,231	-	-658	-
63-64	+234	-	-	-	-182	-267	-	- 33	-
64-65	+937	-	-	-	-468	-1,536	-	-600	-
65-66	+426	-	-	-	-596	-569	-	-142	-
66-67	-293	-	-	-	-381	+215	-	- 79	-
67-68	-	+176	-	-	-293	+209	-	+385	-
68-69	-	+176	-	-	-176	+ 18	-	+194	-
69-70	+440	-	-	-	-381	+984	-	+1,424	-
70-71	0	-	-	-	-317	+908	-	+908	-
71-72	-	-	-	-		-			
72-73	-	+604	-	-	-547	-	+3,655	+ 29	+4,259
73-74	-		-	-		-			
74-75	-	+346	-	-406	-	+2,330	-	-	+2,675
75-76	-	-	-	-	-288	-	+744	-	+687
76-77	+ 85	-	-	-	-339	-	+420	-	+361
77-78	+594	-	-	-	-726	-	+4,004	-	+4,031
78-79	+113	-	-	-	-339	-100	-	+ 13	-
79-80	+ 85	-	-	-	-113	+756	-	+841	-
80-81	-	-	-	-	- 85	-	-	-	-
81-82	+113	-	-	-	- 28	-	-	+113	-
82-83	-	-	-	-	- 57	-	-	-	-

TABLE B

transects	1939 subtidal to 1975 supratidal washover	delta D	dredge/ fill	inlet changes	eroded beach E	change in subtidal washover I	delta J	change in extent of subtidal washover K	delta L
83-84	-	-	-	-	- 29	-	-	-	-
84-85	+169	-	-	-	0	-580	-	-410	-
85-86	+113	-	-	-	0	-1,291	-	-1,178	-
86-87	+497	-	-	-	0	-174		+322	
87-88	-	-	-	- 93	0	-325		-418	
88-89	-	-	-	-	0	-	-	-	-
89-90	-	-	-	+ 62	- 62	-	-	-	+ 62
90-91	-	-	-	-	0	-	-	-	-
91-92	-	-	-	-	- 54	-	-	-	-
92-93	-	-	-	-	+191	-	-	-	-
93-94	-	-	-	-	0	-	-	-	-
94-95	-	-	-	-	- 54	-	-	-	-
95-96	+109	-	-	-	-163	+109	-	+109	-
96-97	- 82	-	-	-	-218	+451		+370	
97-98	+ 27	-	-	-	-271	-1,097		-1,070	
98-99	+489	-	-	-	-244	-	+1,032	-	+1,521
99-100	+136	+ 81	-	-	-353	-	+782	-	+999
100-101	-	+977	-	-	-136	-	-2,776	-	+3,064
101-102	-	-	-678	-	- 81	-	+1,770	-	+2,448
102-103	-	-	+298	-	+ 81	-	-	-	-
103-104	-	-	-326	-	- 54	-	-	-	-
104-105	-	+136	-	-	-109	-	-	-	-

TABLE C

BEACH EROSION DATA

transects	total area (m^2) eroded beach	distance (m) between transects	1939-1975 distance (m) eroded back	1939-1975 annual rate of erosion (m/yr)
1-2	- 2,916	290.8	-10.03	-0.28
2-3	0	212.8	0	0
3-4	- 4,859	187.2	-25.96	-0.72
4-5	-18,587	289.0	-64.31	-1.79
5-6	- 9,642	292.0	-33.02	-0.92
6-7	-21,558	379.8	-56.76	-1.58
7-8	-22,594	352.7	-64.06	-1.78
8-9	-21,557	350.8	-61.45	-1.71
9-10	0	342.9	0	0
10-11	+ 5,135	331.9	+15.47	+0.43
11-12	0	173.4	0	0
12-13	0	281.3	0	0
13-14	0	89.0	0	0
14-15	0	96.0	0	0
15-16	- 3,545	352.7	-10.05	-0.28
16-17	- 9,941	298.7	-33.28	-0.92
17-18	-14,911	336.8	-44.27	-1.23
18-19	-18,888	467.3	-41.42	-1.12
19-20	-22,864	570.3	-40.09	-1.11
20-21	-11,929	428.9	-27.81	-0.77
21-22	-13,927	493.8	-28.20	-0.78
22-23	-11,324	493.8	-22.93	-0.64
23-24	- 5,227	271.3	-19.26	-0.54
24-25	- 2,742	365.5	- 4.77	-0.13
25-26	- 5,013	401.7	-12.48	-0.35
26-27	- 6,690	327.1	-20.45	-0.57
27-28	- 8,020	291.4	-27.52	-0.76
28-29	-10,025	363.9	-27.55	-0.77
29-30	- 7,018	319.1	-21.99	-0.62
30-31	- 6,015	301.2	-19.97	-0.55
31-32	- 4,031	476.1	- 8.47	-0.24
32-33	- 3,128	243.8	-12.83	-0.36
33-34	- 3,128	199.0	-10.46	-0.29
34-35	- 2,085	350.2	- 5.95	-0.17
35-36	- 4,170	239.3	-17.39	-0.48
36-37	- 5,212	293.8	-17.74	-0.49
37-38	- 2,623	349.3	- 7.51	-0.21

TABLE C

transects	total area (m^2) eroded beach	distance (m) between transects	1939-1975 distance (m) eroded back	1939-1975 annual rate of erosion (m/yr)
38-39	+ 7,863	314.6	+24.99	+0.69
39-40	0	124.4	0	0
40-41	0	329.5	0	0
41-42	- 1,054	198.4	- 5.31	-0.15
42-43	- 1,054	198.1	- 5.32	-0.15
43-44	- 5,268	216.4	-24.34	-0.68
44-45	- 5,268	183.5	-28.71	-0.80
45-46	- 7,375	570.3	-12.93	-0.36
46-47	- 6,717	402.7	-16.68	-0.46
47-48	- 7,677	411.7	-18.66	-0.52
48-49	-10,556	498.7	-21.17	-0.59
49-50	-11,515	538.9	-21.37	-0.59
50-52	0	394.4	0	0
52-53	0	157.3	0	0
53-54	- 1,016	226.5	- 4.49	-0.12
54-55	- 1,016	257.0	- 3.95	-0.11
55-56	- 1,016	206.7	- 4.92	-0.14
56-57	- 1,016	214.3	- 4.74	-0.13
57-58	0	173.7	0	0
58-59	- 3,047	269.8	-11.29	-0.31
59-60	- 4,063	207.6	-19.57	-0.54
60-61	- 3,047	371.3	- 8.21	-0.23
61-62	- 2,811	200.6	-14.01	-0.39
62-63	- 4,684	367.9	-12.73	-0.35
63-64	- 6,588	315.2	-20.81	-0.58
64-65	-16,863	614.5	-27.44	-0.76
65-66	-21,446	939.4	-22.83	-0.63
66-67	-13,730	565.4	-24.28	-0.67
67-68	-10,562	350.8	-30.11	-0.84
68-69	- 6,337	289.3	-21.90	-0.61
69-70	-13,730	413.0	-33.24	-0.92
70-71	-11,394	339.3	-33.58	-0.93
71-72	-11,394	289.0	-39.42	-1.10
72-73	-	337.4	-	-
73-74	- 8,286	278.9	-29.71	-0.83
74-75	-16,573	507.8	-32.65	-0.91
75-76	-10,358	315.2	-32.86	-0.91
76-77	-12,215	361.5	-33.79	-0.94
77-78	-26,214	962.6	-27.23	-0.76
78-79	-12,215	455.1	-26.84	-0.75
79-80	- 4,067	32-.4	-12.69	-0.35
80-81	- 3.051	198.7	-15.35	-0.43
81-82	- 1,017	174.0	- 5.84	-0.16
82-83	- 2,034	267.9	- 7.59	-0.21
83-84	- 1,017	162.8	- 6.25	-0.17

TABLE C

transects	total area (m^2) eroded beach	distance (m) between transects	1939-1975 distance (m) eroded back	1939-1975 annual rate of erosion (m/yr)
84-85	0	522.4	0	0
85-86	0	251.8	0	0
86-87	0	476.8	0	0
87-88	0	680.9	0	0
88-89	0	319.7	0	0
89-90	- 2,236	657.8	- 3.40	-0.09
90-91	0	509.9	0	0
91-92	+ 1,961	316.4	+ 6.20	+0.17
92-93	+ 6,863	303.9	+22.61	+0.63
93-94	0	196.9	0	0
94-95	- 1,961	161.2	-12.16	-0.34
95-96	- 5,883	139.3	-42.23	-1.17
96-97	- 7,843	209.1	-37.51	-1.04
97-98	- 9,766	243.2	-40.16	-1.12
98-99	- 8,790	232.9	-37.74	-1.05
99-100	-12,696	374.9	-33.87	-0.94
100-101	- 4,883	285.9	-17.08	-0.47
101-102	- 2,930	215.5	-13.60	-0.38
102-103	+ 2,930	592.5	+ 4.95	+0.14
103-104	- 1,956	174.7	-11.19	-0.31
104-105	- 3,911	384.4	-10.18	-0.30
105-106	-	352.4	-	-
106-107	-	377.0	-	-
107-108	-	202.4	-	-
108-109	-	175.6	-	-
109-110	-	309.7	-	-
110-111	-	155.2	-	-
111-112	-	109.4	-	-
112-113	-	183.2	-	-
MEAN	- 5,908	317.7	-16.56	-0.46
TOTAL	-631.205			

TABLE D

SUBTIDAL WASHOVER AND TIDAL DELTA ACCRETION (M^2)

<table>
<tr><th>transects</th><th>subtidal washover accretion</th><th>subtidal tidal delta accretion</th></tr>
<tr><td></td><td>K=B+D-G</td><td>L=C+D-H</td></tr>
<tr><td>4-5</td><td>-14,847</td><td>-</td></tr>
<tr><td>5-6</td><td>+51,070</td><td>-</td></tr>
<tr><td>6-7</td><td>+34,772</td><td>-</td></tr>
<tr><td>7-8</td><td>+31,532</td><td>-</td></tr>
<tr><td>8-9</td><td>+23,009</td><td>-</td></tr>
<tr><td>9-10</td><td>-17,106</td><td>-</td></tr>
<tr><td>10-11</td><td>- 6,552</td><td>-</td></tr>
<tr><td>20-21</td><td>+23,924</td><td>-</td></tr>
<tr><td>21-22</td><td>+15,486</td><td>-</td></tr>
<tr><td>22-23</td><td>+14,685</td><td>-</td></tr>
<tr><td>23-24</td><td>+ 3,857</td><td>-</td></tr>
<tr><td>26-27</td><td>+42,610</td><td>-</td></tr>
<tr><td>27-28</td><td>+32,180</td><td>-</td></tr>
<tr><td>28-29</td><td>+30,019</td><td>-</td></tr>
<tr><td>29-30</td><td colspan="2">+ 7,369</td></tr>
<tr><td>30-31</td><td colspan="2">- 9,835</td></tr>
<tr><td>31-32</td><td colspan="2">-32,004</td></tr>
<tr><td>32-33</td><td>- 808</td><td>-</td></tr>
<tr><td>33-34</td><td>-</td><td>+13,107</td></tr>
<tr><td>34-35</td><td>-</td><td>+74,194</td></tr>
<tr><td>35-36</td><td>-</td><td>- 1,416</td></tr>
<tr><td>36-37</td><td>-</td><td>- 1,844</td></tr>
<tr><td>37-38</td><td>-</td><td>-10,996</td></tr>
<tr><td>44-45</td><td>+ 5,980</td><td>-</td></tr>
<tr><td>45-46</td><td>+46,500</td><td>-</td></tr>
<tr><td>46-47</td><td>+31,248</td><td>-</td></tr>
<tr><td>47-48</td><td colspan="2">- 7,482</td></tr>
<tr><td>48-49</td><td colspan="2">-11,040</td></tr>
<tr><td>49-50</td><td>-</td><td>+17,786</td></tr>
<tr><td>50-52</td><td>-</td><td>+23,211</td></tr>
<tr><td>52-53</td><td>-</td><td>+24,428</td></tr>
<tr><td>57-58</td><td>+ 2,103</td><td>-</td></tr>
<tr><td>58-59</td><td>+ 5,079</td><td>-</td></tr>
<tr><td>59-60</td><td>- 1,016</td><td>-</td></tr>
<tr><td>60-61</td><td>+ 7,110</td><td>-</td></tr>
<tr><td>61-62</td><td>- 6,225</td><td>-</td></tr>
<tr><td>62-63</td><td>-23,704</td><td>-</td></tr>
<tr><td>63-64</td><td>- 1,174</td><td>-</td></tr>
<tr><td>64-65</td><td>-21,585</td><td>-</td></tr>
<tr><td>65-66</td><td>- 5,124</td><td>-</td></tr>
<tr><td>66-67</td><td>- 2,833</td><td>-</td></tr>
<tr><td>67-68</td><td>+13,850</td><td>-</td></tr>
<tr><td>68-69</td><td>+ 6,992</td><td>-</td></tr>
<tr><td>69-70</td><td>+51,248</td><td>-</td></tr>
<tr><td>70-71</td><td>+32,694</td><td>-</td></tr>
<tr><td>71-74</td><td>-</td><td>+153,320</td></tr>
<tr><td>74-75</td><td>-</td><td>+96,314</td></tr>
<tr><td>75-76</td><td>-</td><td>+24,718</td></tr>
<tr><td>76-77</td><td>-</td><td>+12,994</td></tr>
<tr><td>77-78</td><td>-</td><td>+145,117</td></tr>
<tr><td>78-79</td><td>+ 470</td><td>-</td></tr>
<tr><td>79-80</td><td>+30,282</td><td>-</td></tr>
<tr><td>81-82</td><td>+ 4,067</td><td>-</td></tr>
<tr><td>84-85</td><td>-14,769</td><td>-</td></tr>
<tr><td>85-86</td><td>-42,410</td><td>-</td></tr>
<tr><td>86-87</td><td colspan="2">+11,606</td></tr>
<tr><td>87-88</td><td colspan="2">-10,588</td></tr>
<tr><td>89-90</td><td>-</td><td>+ 2,236</td></tr>
<tr><td>95-96</td><td>+ 3,922</td><td>-</td></tr>
<tr><td>96-97</td><td colspan="2">+13,303</td></tr>
<tr><td>97-98</td><td colspan="2">-38,512</td></tr>
<tr><td>98-99</td><td>-</td><td>+54,747</td></tr>
<tr><td>99-100</td><td>-</td><td>+35,960</td></tr>
<tr><td>100-101</td><td>-</td><td>+110,314</td></tr>
<tr><td>101-102</td><td>-</td><td>+88,132</td></tr>
<tr><td>MEAN</td><td>+10,177</td><td>+43,116</td></tr>
<tr><td></td><td colspan="2">- 8,576</td></tr>
<tr><td>TOTAL</td><td>+386,736</td><td>+862,322</td></tr>
<tr><td></td><td colspan="2">-77,183</td></tr>
</table>

APPENDIX II

DETERMINATION OF THE ACCURACY AND PRECISION OF THE PHOTOGRAMMETRIC TECHNIQUES

Advantages

Coastal zone studies can be classified into three categories, dependent upon the scale and detail of the study: 1) reconnaissance of a large section of the coast, 2) studies at the intermediate level, which involve some systematic process measurements, and 3) detailed time-series studies of a small area (Hayes, Owens, Hubbard, and Abele, 1973).

Detailed studies of a small segment of the shoreline involve closely spaced (temporally and spatially) observations of changes in beach morphology and of the dynamic processes responsible for the changes. Conclusions derived from investigations at this level provide necessary base information needed to integrate studies at the intermediate and reconnaissance level investigations.

Intermediate level, localized, problem-oriented studies provide insight into local process factors responsible for systematic changes in distinct morphologic features, such as the sand bodies formed at an inlet and patterns of wave refraction and inlet circulation. The study of larger scale, distinct physiographic units along the coast helps to integrate information from more detailed, perhaps fragmented studies.

Reconnaissance studies resolve the detailed observations from the lower level studies concerning the process-product relationship along the coast and use them to interpret regional patterns of coastal morphology and sedimentation. Also, from reconnaissance studies, problem areas necessitating more detailed investigation at the lower level studies may be determined (Hayes, Owens, Hubbard, and Abele, 1973).

Aerial photographs have proved to be particularly invaluable in reconnaissance and intermediate level coastal studies, for both short and long term studies, when used in conjunction with the observations and data of detailed field studies. A set of aerial photographs can be used in the identification of surface features of a distinct physiographic unit, or a series of aerial photographs can be used to document changes in coastal features in either a qualitative or a quantitative manner. When certain conditions are understood and strict photogrammetric techniques are followed, photogrammetrically determined values of coastal changes can be considered to be reliable measures of long term, mean shoreline changes.

A hierarchy of natural cyclic phenomena including tides, seasonal changes in wave climate, storms, sediment supply, and relative sea level changes (Morton, 1977) produce variable effects in shoreline changes. The short term variability can be minimized by increasing the time interval of the study and thereby averaging the shorter term changes. Averaged, long term rates of change probably more closely approximate the historical shoreline changes that can be recorded in the geological record, while short term rates indicate the actual, fluctuating changes operative along the coast. Measurements of long term coastal changes are most accurately accomplished using a combination of aerial photographic and field surveys (Goldsmith and Oertel, 1977).

Studies of long term changes utilizing aerial photographs tend to be more accurate than those utilizing maps or charts. Aerial photographs are better records than maps or charts of the locations of objects because photographs contain more detail and allow for better identification and recognition of features. Maps and charts present limited details of physical features (both natural and artificial). U. S. Geological Survey standards for the horizontal accuracy of maps require only that "at least 90% of the well-defined points shall be plotted correctly within 1/50 inch (approximately 0.51 mm) on the published maps" (Anonymous, 1969). Maps thus introduce an additional limitation on the accuracy of coastal change measurements past that introduced in scale determinations and actual measurements on the photographs. The major advantage of utilizing maps and charts in addition to aerial photographs in the determination of coastal changes is that the maps and charts provide information for the time prior to the date of the first photographic coverage. Maps and charts do not appear to be particularly useful for making straight-forward measurements of shoreline changes (Tanner, 1977). The great amount of detail shown on aerial photographs also allows the photo interpreter to distinguish between shoreline changes produced by overwash and changes produced by tidal delta deposition as well as to distinguish subtidal and intertidal shoals in the lagoons.

Precision of Instrumentation

The major limit of a photogrammetric study is the degree of precision and accuracy possible in determining the scale of the features on the individual photographs and in making precise measurements on the photographs, which is a factor of the quality of the photographs and the ability of the photointerpreter. The value of a photogrammetric survey is largely a function of the availability and quality of the photographs. Photographs with unfavorable or overly variable scales, poor textural and tonal contrasts, as well as other inherent deficiencies, such as unacceptable amounts of tilt or relief distortion, are not useful for the accurate determination of amounts of changes along the shoreline, particularly where small changes are involved. The extent and dates of the coverage are also factors affecting the worth of such a study.

Small scale photographs is inconvenient to use because of difficulties encountered in locating exact, easily reproducible points on the photographs for scale determination or other measurements due to the reduced sizes of the objects. Greater variations in measurements are also produced on smaller scale photographs because of limits on the measurements which the human eye can consistently make (Tanner, 1977). The Altender microrule used for making linear measurements on the aerial photographs is calibrated to 0.001 inch, and is precise to about 0.005 to 0.01 inch. For various scales determined for the 1939 and 1975 photographs used in this study, the "smallest field distance measurable" (Tanner, 1977) can be listed as follows:

TABLE E

MICRORULE PRECISION

	"strict" 0.005 inch		"generous" 0.01 inch	
	(smallest field distance in meters)			
1975				
1:13,163	1.71	(0.05 m/yr)	3.29	(0.09 m/yr)
1:11,620	1.51	(0.04 m/yr)	2.91	(0.08 m/yr)
1939				
1:15,471	2.01	(0.055 m/yr)	3.87	(0.11 m/yr)
1:14,041	1.83	(0.05 m/yr)	3.51	(0.10 m/yr)

These distances must be divided by the number of years of the study, to yield the "smallest measurable change per year" (which are listed in the parentheses above). Any measurements smaller than these limits must be accepted to mean "no detectable change." Because two photographs are necessary in any determination of rate or change, there are two distinct sources of error, and two limits, which should be added (Tanner, 1977).

The smallest measured area on the ruled acetate in this study was one square, which is 1/100 square inch, or 0.0000064516 m^2. For the same scales listed above, the smallest measurable ground areas would be as follows:

TABLE F RULED ACETATE PRECISION (smallest measurable ground area = one square on acetate)

1975	
1:13,163	1,118 m^2
1:11,620	871 m^2
1939	
1:15,471	1,544 m^2
1:14,041	1,272 m^2

As with linear distances, these amounts must be added for the two photographs used in a determination of rate or change, and any measurements smaller than these values must be accepted to mean "no detectable change."

Factors Affecting the Accuracy of the Photogrammetric Measurements

Possible errors in the photogrammetric measurements made to determine beach trends and changes in the areal extent of backbarrier and lagoon deposits can result from many different causes. Photographs can vary in scale within as well as between prints, a variability which can affect the calculations of ground distances or ground areas. Scale variability can result from: relief distortion, caused by variability in the altitude of the aircraft as well as in the elevation of the terrain; tilt, which is the variation of the optic axis of the camera lens from true vertical at the time of the photograph exposure; lens distortion, which can cause features on the photographs to be radially distorted outward from the optical center of the photograph; and shrinkage of the film or photographic paper. Scale can also be incorrectly determined through operator or instrument variability.

Relief distortion is minimal along the Rhode Island coast because of small differences in the elevation that occur along the south shore. Tilt on the photographs used is also small, being limited by government standards to less than 2 or 3°. The amounts of lens distortion and shrinkage of the film or paper would be difficult to determine. It is believed that the effects of these inherent photographic distortions have been minimized by making measurements as near as possible to the center of the photograph, where the distortions are minimal, by utilizing the 60% overlap and 30% sidelap. Using ground control points in determining scale values also minimizes these inherent photographic distortions, particularly because the control points lie near sea level, where the measurements of changes (both linear and areal) were made.

Instrument variability is a function of the precision of the instrument used to make measurements on the photographs and is itself a function of the scale and quality of the photographs. The limitation on the smallest unit of distance that can be measured consistently and accurately on a photograph, as discussed above, is also a function of the calibration of the instrument.

Another source of error in making measurements of beach changes can result from difficulty in locating the dune line and high water line on the photographs because of unfavorable scales and poor tonal contrasts, especially in distinguishing the high water line from the swash limit of the waves or from storm debris lines. A limitation on the accuracy of relocating the 113 transects on the photographs also exists, which may result in small variations in the linear and areal measurements of the shoreline changes.

Field Determination of the Photogrammetric Accuracy

Cartographic distortion in producing the overlays of the 1939 and 1975 photographs and in optically transferring the 1939 shoreline position to the 1975 overlays using the Zoom Transfer Scope also affect the accuracy of this study. To check the photogrammetric techniques used in this study for determination of the photograph scales and for making the linear and areal measurements as well as the cartographic techniques of transferring the data between photographs, a survey of linear distances and areas of objects in the field and on the photographs was made.

Linear distances were measured in the field at several localities at the same elevation on the University of Rhode Island campus in Kingston along the perimeters of rectangular playing fields and buildings, which are easily identifiable on a 1972 photograph of the campus (073-72 series from Aerial Data Reduction Associates, nominal scale 1:12,000). These linear ground measurements were used to determine the ground areas of the rectangular objects, to be used as ground truth values. Linear measurements of these objects were then made on the photograph, using the Altender microrule. Measurements of the areas of the objects were also made on the photograph, using the same square counting method used in the determination of backbarrier areas (by transferring the outline of the objects onto a sheet of ruled acetate and counting the squares). The linear measurements made on the photograph were used to derive the average scale of the photograph as well as the areas of the rectangular objects. Three values of the ground areas were thus calculated: ground area determined from multiplication of linear ground measurements (used as the standard); ground area determined from multiplication of linear photograph measurements and scale conversion; and ground area determined from areal photograph measurements and scale and square grid conversions.

The linear measurements on the photograph incorporates scale variation, microrule precision, and operator variability. The areal measurements on the photograph derived by the square counting method incorporates scale variation, microrule precision, cartographic variability, precision of the square grid intensity, and operator variability. Using the area measurements calculated from the linear measurements made in the field as standards of actual ground areas, the amount of variance resulting from the derivation of ground areas from linear photograph measurements and scale conversion and from the derivation of ground areas from areal photograph measurements, scale conversion, and square grid conversion have been calculated (tables G and H).

TABLE G

CALCULATED ACCURACY OF AREAL PHOTO MEASUREMENTS

objects	dimensions	Linear Ground Measurements	Calculated Ground Area	Linear Photo Measurements	Calculated Photo Area	Scale (RF)	Calculated Ground Area $\frac{(\text{Photo Area})}{RF^2} \times 144$	Measured Photo Area	Calculated Ground Area $\frac{(\# \text{SQ'S})(1/100)}{RF^2} \times 144$
		FT	FT^2	IN	IN^2		FT^2	# SQ'S	FT^2
A	a	559,25	375,816	.526	.3387	1:12,759	371,936	32.50	356,892
	b	672.00		.644		1:12,522			
B	b	30,00		.028		1:12,857			
	d	225.00		.217		1:12,442			
	e	300.00	48,225	.288	.0438	1:12,500	48,098	4.50	49,416
	f	160.75		.152		1:12,691			
C	g	114.00	31,042	.107	.0274	1:12,785	30,089	2.75	30,199
	h	272.30		.256		1:12,764			
D	i	220.30		.210		1:12,589			
E	j	241.00	69,589	.239	.0664	1:12,100	72,916	6.00	65,880
	k	288.75		.278		1:12,464			
F	l	123.00	18,450	.118	.0170	1:12,508	18,668	1.75	19,217
	m	150.00		.144		1:12,500			

Average scale: 1:12,575

TABLE H

Calculated Ground Areas (FT^2)

	A From Linear Ground Measurements	B From Linear Photo Measurements	C From Areal Photo Measurements	$\frac{A - B}{A} \times 100$ Linear Variation (%)	$\frac{A - C}{A} \times 100$ Areal Variation (%)
A	375,816	371,936	356,892	1.0%	5.0%
B	48,225	48,098	49,416	0.3%	2.5%
C	31,042	30,089	30,199	3.0%	2.7%
F	69,589	72,916	65,888	4.8%	5.3%
G	18,450	18,668	19,217	1.2%	4.2%

APPENDIX III

HISTORICAL MAPS
(Source: Special Maps Room,
John D. Rockefeller Library, Brown University)

date	publisher/engraver
1780	Published by J. Bew, London.
1794	Published by L. Stockdale, Piccadilly; L. Mutlaw Sculp & James.
1796	H. Harris, engraved by Sc. Hill, Boston; Thomas & Andrews.
1804	Arrowsmith & Lewis, 7th American map of Rhode Island; engraved by A. Lawson, drawn by S. Lewis.
1816	Lucas, engraved by H. S. Tanner, Baltimore.
1824	Engraved by Young & Delleker, A. Finley, Philadelphia.
1838	Bradford, engraved by G. W. Boynton, Boston.
1842	Bradford & Goodrich, engraved by G. W. Boynton, Boston.
1860	U. S. Coast Survey coast chart No. 14.
1877	Copyright by Cowperthwait & Co., Philadelphia.
1908	A. von Haake, topographer, Post Office Dept. (post route map).
1935	Prepared by Educational Exhibition Co.

REFERENCES CITED

American Geological Institute, 1976, Dictionary of geological terms: Garden City, New York, Anchor Books, 472 p.

Andrews, P. B., 1967, Facies and genesis of a hurricane washover fan, St. Joseph Island, central Texas coast: unpublished Ph. D. dissertation, Univ. Texas at Austin, 290 p.

Avery, T. E., 1969, Forester's guide to aerial photo interpretation: U. S. Dept. of Agriculture, Forest Service, Agriculture Handbook No. 308, 40 p.

____1977, Interpretation of aerial photographs (third edition): Minneapolis, Burgess Publishing Co.

Bartberger, C. E., 1976, Sediment sources and sedimentation rates, Chincoteague Bay, Maryland and Virginia: Jour. Sed. Petrology, v. 46, p. 326-336.

Beale, R. A., 1975, Beach-nearshore sediment dispersal, Matunuck Point, Rhode Island: unpublished M. S. thesis, Univ. Rhode Island, 131 p.

Bloom, A. L., 1968, Postglacial stratigraphy and morphology of coastal Connecticut, Trip A-1: New England Intercollegiate Geological Conference Field Trip Guidebook.

Byrne, R. J., DeAlteris, J. T., and Bullock, P. A., 1974, Channel stability in tidal inlets: a case study: 14th Conference on Coastal Engineering, v. II, p. 1585-1604.

Byrnes, J. B., Colquhoun, D. J., and Pierce, J. W., 1970, Importance of tidal-inlet sedimentation in barrier island systems (abs.): American Assoc. Petroleum Geologists Bull., v. 54, p. 839.

Caldwell, D. M., 1972, A sedimentological study of an active part of a modern tidal delta, Moriches Inlet, Long Island, New York: unpublished M. S. thesis, Columbia Univ., New York, 70 p.

Conover, R. S., 1961, A study of Charlestown and Green Hill Ponds, Rhode Island: Ecology, v. 42, n. 1, p. 119-140.

Cronin, L. E. (ed.), 1975, Estuarine research, geology and engineering: Academic Press, New York, v. 2, 587 p.

DeAlteris, J. T., 1976, A speculative model for the evolution of a barrier island, tidal inlet-lagoon system: I., regional analysis: Geological Society America Abs. with Programs, v. 8, p. 159.

Dillon, W. P., 1970, Submergence effects on a Rhode Island barrier and lagoon and inferences on migration of barriers: Jour. Geology, v. 78, p. 94-106.

Dolan, R., 1973, Barrier islands: natural and controlled: in Coates, D. R. (ed.), Coastal Geomorphology, S. U. N. Y. Binghamton, Publications in Geomorphology, p. 263-278.

Dolan, R., and Godfrey, P. J., 1973, Effects of Hurricane Ginger on the barrier islands of North Carolina: Geological Society America Bull., v. 84, p. 1329-1333.

DuBois, R. N., 1975, Support and refinement of the Bruun rule on beach erosion: Jour. Geology, v. 83, p. 651-657.

El-Ashry, M.T., 1963, Effects of hurricanes on parts of the U. S. coastline as illustrated by aerial photographs: unpublished M. S. thesis, Dept. of Geology, Univ. Illinois, Urbana.

El-Ashry, M. T., and Wanless, H. R., 1965, Birth and early growth of a tidal delta: Jour. Geology, v. 73, p. 404-406.

____1968, Photo interpretation of shoreline changes between Capes Hatteras and Fear (North Carolina): Marine Geology, v. 6, p. 347-379.

Fisher, J. J., 1962, Geomorphic expression of former inlets along the Outer Banks of North Carolina: unpublished M. S. thesis, Univ. North Carolina, Chapel Hill, 120 p.

Fisher, J. J., and Regan, D. R., 1977, Relationship of shoreline erosion rates to eustatic sea level rise, Rhode Island coast: Geological Society America Abs. with Programs, v. 9, p. 265.

Fisher, J. S., Leatherman, S. P., and Perry, F. C., 1974, Overwash processes on Assateague Island: 14th Conference on Coastal Engineering, v. II, p. 1194-1212.

Gilbert, G. K., 1885, The topographic feature of lake shores: U. S. Geological Survey 5th Annual Rept., p. 69-123.

Glaeser, J. D., Muehlberger, F. D., and Heron, S. D., Jr., 1976, Controls on barrier island sand budget of Shackleford Banks, North Carolina: Geological Society America Abs. with Programs, v. 8, p. 180.

Godfrey, P. J., 1976, Special supplement to the New England Intercollegiate Geological Conference Guidebook - 1976: field trips to Cape Cod, Massachusetts: Dept. of Botany and National Park Service Cooperative Research Unit, Institute for Man and Environment, Univ. Massachusetts, Amherst, 29 p.

Godfrey, P. J., and Godfrey, M. M., 1973, Comparison of ecological and geomorphic interactions between altered and unaltered barrier island systems in North Carolina: in Coates, D. R. (ed.), Coastal Geomorphology, S. U. N. Y. Binghamton, Publications in Geomorphology, p. 239-258.

____1974, The role of overwash and inlet dynamics in the formation of salt marshes on North Carolina barrier islands: Ecology of Halophytes, Academic Press Inc., New York, p. 407-427.

____1975, Some estuarine consequences of barrier island stabilization: in Cronin, L. E. (ed.), Estuarine Research, geology and engineering, Academic Press, New York, v. 2, p. 485-516.

Hardin, J. D., Sapp, C. D., Emplaincourt, J. F., and Richter, K. E., 1976, Shoreline and bathymetric changes in the coastal area of Alabama: a remote-sensing approach: Geological Survey of Alabama, Info. Series 50, 125 p.

Hayes, M. O., 1967, Hurricanes as geologic agents, south Texas coast: American Assoc. Petroleum Geologists Bull., v. 51, p. 937-942.

Hayes, M. O., and Boothroyd, J. C., 1970, Storms as modifying agents in the coastal environment (abs.): Geological Society America Abs., v. 2, p. 24.

Hayes, M. O., and Kana, T. W. (eds.), 1976, Terrigenous clastic depositional environments: some modern examples: a field course sponsored by the American Assoc. Petroleum Geologists; Coastal Research Division Tech. Rep. No. 11-CRD, Dept. of Geology, Univ. South Carolina, 302 p.

Hicks, S. D., and Crosby, J. E., 1974, Trends and variability of yearly mean sea level, 1893-1972: N. O. A. A. Tech. Memo NOS 13, Rockville, Maryland, 14 p.

Hoover, R. A., 1969, Physiography and surface sediment facies of a recent tidal delta, Harbor Island, central Texas coast (abs.): Dissertation Abs., v. 29, p. 3790B.

Hosier, P. E., and Cleary, W. J., 1975, Cyclic geomorphic patterns on an overwash-dominated barrier island in southeastern North Carolina (abs.): Geological Society America Abs. with Programs, v. 7, p. 501.

Hoyt, J. H., 1967, Barrier island formation: Geological Society America Bull., v. 78, p. 1125-1136.

Kaye, C. A., 1960, Surficial geology of the Kingston quadrangle, Rhode Island: U. S. Geological Survey Bull. 1071-I, p. 341-396.

____1973, Map showing changes in shoreline of Martha's Vineyard, Massachusetts, during the past 200 years: U. S. Geological Survey Misc. Field Studies, Map. MF-534.

Langfelder, J., French, T., McDonald, R., and Ledbetter, R., 1974, A historical review of some of North Carolina's coastal inlets: The Center for Marine and Coastal Studies, North Carolina State Univ., Rpt. No. 74-1, 40 p.

Langfelder, L. J., Stafford, D. B., and Amein, M., 1968, A reconnaissance of coastal erosion in North Carolina: Coastal Research Program, Project ERD-238, Civil Eng. Dept., North Carolina State Univ., 127 p.

Leatherman, S. P., 1976, Barrier island migration: an assessment of the overwash process: Geological Society America Abs. with Programs, v. 8, p. 215.

____1977, Interpretation of overwash sedimentary sequences: Geological Society America Abs. with Programs, v. 9, p. 292.

Lucke, J. B., 1934a, A study of Barnegat Inlet: Shore and Beach, v. 2, n. 2, p. 45-94.

____1934b, Tidal inlets: a theory of evolution of lagoon deposits on shorelines of emergence: Jour. Geology, v. 42, p. 561-584.

Lueder, D. R., and Belcher, D. J., 1954, Determination of beach conditions by means of aerial photographic interpretation: photographic gray tones as an indication of the size of beach materials: Tech. Rpt. n. 6, v. 4, School of Civil Eng., Cornell Univ.

McGowen, J. H., and Scott, A. J., 1975, Hurricanes as geologic agents on the Texas coast: in Cronin, L. E. (ed.), Estuarine research, geology and engineering: Academic Press, New York, v. 2, p. 23-46.

McMaster, R. L., 1960, Mineralogy as an indicator of beach sand movement along the Rhode Island shore: Jour. Sed. Petrology, v. 30, p. 404-413.

Mikesh, D. L., Howard, J. D., and Mayou, T. V., 1968, Depositional characteristics of a washover fan, Sapelo Island, Georgia: Geological Society America Annual Meeting, Mexico City, p. 201.

Morelock, J., 1977, Puerto Rico: in Tanner, W. F. (ed.), Standards for measuring shoreline changes: a study of the precision obtainable and needed in making measurements of changes (erosion and accretion): Coastal Plains Center for Marine Development Services, Wilmington, Delaware, p. 31-32.

Morton, R. A., 1976, Effects of Hurricane Eloise on beach and coastal structures, Florida Panhandle: Geology, v. 4, p. 277-280.

____1977, Analysis of sequential shoreline changes: in Tanner, W. F. (ed.), Standards for measuring shoreline changes: a study of the precision obtainable and needed in making measurements of changes (erosion and accretion): Coastal Plains Center for Marine Development Services, Wilmington, Delaware, p. 20-22.

Morton, R. A., and Donaldson, A. C., 1972, Evolution of tidal deltas along a tide dominated shoreline: Geological Society America Abs. with Programs, v. 4, p. 604.

____1973, Sediment distribution and evolution of tidal deltas along a tide dominated shoreline, Wachapreague, Virginia: Sedimentary Geology, v. 10, p. 285-299.

Nichols, R. L., and Marston, A. F., 1939, Shoreline changes in Rhode Island produced by the hurricane of September 21, 1938: Geological Society America Bull., v. 50, p. 1357-1370.

Nordquist, R. W., 1972, Origin, development, and facies of a young hurricane washover fan on southern St. Joseph Island, central Texas coast: unpublished M. S. thesis, Univ. Texas at Austin.

O'Brien, M. P., 1976, Notes on tidal inlets on sandy shores: U. S. Army Corps of Engineers, Coastal Engineering Research Center General Investigation of Tidal Inlets (GITI) Rep. 5, 26 p.

Oertel, G. F., 1972, Sediment transport on estuary entrance shoals and the formation of swash platforms: Jour. Sed. Petrology, v. 42, p. 858-863.

____1975, Ebb-tidal deltas of Georgia estuaries: in Cronin, L. E. (ed.), Estuarine research, geology and engineering: Academic Press, New York, v. 2, p. 267-276.

Oertel, G. F., and Chamberlain, C. F., 1975, Differential rates of shoreline advance and retreat at the coastal barriers of Chatham and Liberty Counties, Georgia: Transactions Gulf Coast A.G.S., v. 25, p. 383-390.

Ogden, J. G., III, 1974, Shoreline changes along the southeastern coast of Martha's Vineyard, Massachusetts, for the past 200 years: Quaternary Research, v. 4, p. 496-508.

Olsen, S. B., and Grant, M. J., 1973, Rhode Island's barrier beaches: Coastal Resources Center, Univ. Rhode Island, 2 volumes, 234 p.

Pierce, J. W., 1969, Sediment budget along a barrier island chain: Sedimentary Geology, v. 3, p. 5-16.

____1970, Tidal inlets and washover fans: Jour. Geology, v. 78, p. 230-234.

Price, W. A., 1947, Equilibrium of form and forces in tidal basins of coast of Texas and Louisiana: American Assoc. Petroleum Geologists Bull., v. 31, p. 1619-1-63.

____1963, Patterns of flow and channeling in tidal inlets: Jour. Sed. Petrology, v. 33, p. 279-290.

Ray, P. K., Domeracki, D. D., and Waddell, M. G., 1976, Transgressive barrier island sedimentation in the tide dominated coastline of South Carolina: Geological Society America Abs. with Programs, v. 8, p. 253.

Ray, R. G., 1960, Aerial photographs in geologic interpretation and mapping: U. S. Geological Survey Prof. Paper 373.

Regan, D. R., 1976, An aerial photogrammetric survey of long-term shoreline changes, southern Rhode Island coast: unpublished M. S. thesis, Univ. Rhode Island, 76 p.

Rib, H. T., 1957, The application of aerial photography to beach erosion studies: unpublished M. S. thesis, Cornell Univ.

Richard, G. A., 1976, Seasonal and environmental patterns of short-term sediment accretion in a salt marsh: Geological Society America Abs. with Programs, v. 8, p. 255.

Schwartz, R. K., 1975, Nature and genesis of some storm washover deposits: U. S. Army, Corps of Engineers, Coastal Engineering Research Center Tech. Memo. No. 61, 69 p.

Scott, A. J., Hoover, R. A., and McGowen, J. H., 1969, Effects of hurricane "Beulah," 1967 on Texas coastal lagoons and barriers: in Ayala-Castanares, A., and Phleger, F. B. (eds.), Coastal lagoons, a symposium, p. 221-236.

Short, F. T., Nixon, S. W., and Oviatt, C. A., 1974, Field studies and simulations with a fine grid hydrodynamic model: seagrass and circulation in Charlestown Pond: Coastal Resources Center Mar. Tech. Rpt. No. 33, Univ. Rhode Island, 27 p.

Stafford, D. B., 1968, Development and evaluation of a procedure for using aerial photos to conduct a survey of coastal erosion: unpublished Ph. D. dissertation, North Carolina State Univ., Raleigh.

____1971, An aerial photographic technique for beach erosion surveys in North Carolina: U. S. Army, Corps of Engineers, Coastal Engineering Research Center, Tech. Memo. No. 36, 115 p.

Stafford, D. B., and Langfelder, L. J., 1970, An aerial photographic survey of coastal erosion: Proc. 36th Annual Meeting of American Society Photogrammetry, p. 533-558.

____1971, Air photo survey of coastal erosion: Photogram. Engr., v. 37, p. 565-575.

Stephen, M. F., Brown, P. J., FitzGerald, D. M., Hubbard, D. K., and Hayes, M. O., 1975, Beach erosion inventory of Charleston County, South Carolina: a preliminary report: Coastal Research Division, Tech. Rep. No. 4, Dept. Geology, Univ. South Carolina, 74 p.

Sterling, D., 1967, The outer lands: a natural history guide to Cape Cod, Martha's Vineyard, Nantucket, Block Island, and Long Island: Garden City, New York, the American Museum of Natural History, 192 p.