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AN AERIAL PHOTOGRAMMETRIC SURVEY OF LONG-TERM SHORELINE CHANGES, SOUTHERN RHODE ISLAND COAST

BY

DONALD ROBERT REGAN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
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1976

ABSTRACT

For shore protection analysis, the collection of data on coastal erosion by extensive field measurements is expensive and is complicated by the problem of extrapolating results obtained from short-term field observations into long-term erosional trends. On the other hand, surveys utilizing quantitative aerial photogrammetric techniques are less expensive than field surveys and accuracy on the order of three meters is possible. Aerial photographs show the location of the beach and features adjacent to the beach. These features can be used as stable locations to reference these shoreline and duneline photogrammetric measurements.

Photogrammetric measurements of the distance from a stable reference location to the dune and high tide lines were made at 300 m. (1000 ft.) intervals along the Rhode Island shoreline on four sets of aerial photographs taken between 1939 and 1972. These measurements were converted to ground distances by scale determination using ground control surveys and, subsequently, compared in order to determine shoreline changes over the study period. Shoreline changes were determined for the 11-year average time intervals among the four sets of aerial photographs and also, for the entire 33-year study period. Mean annual amounts of change were also computed for each time interval and for the entire study period. The long-term trend of shoreline change was generally erosional, averaging 0.2 m./yr. (0.7 ft./yr.), but within shorter term (11-year) time intervals, considerable variation from

this trend occurred. Locally, headlands or barrier beaches, on a shorter time basis, eroded or even accreted up to 2.0 m./yr., but in general, headlands and barriers both eroded an average of 20 cm./yr. or about 6-7 m. over the 33 year study period.

Contrary to a model of a submerging shoreline with headland erosion and barrier accretion, the entire Rhode Island shoreline appears to be eroding. Locally, sea level rise has averaged 0.3 cm./yr. over the past 40 years, or accountable for about 15 percent of the vertical component of average annual shoreline retreat for Rhode Island.

Shoreline readjustment on an offshore profile of equilibrium according to the Bruun model, is by deposition equal to the rate of sea level rise. On a submerging shoreline, beach erosion occurs if no other sediment source is available, as in the case of the Rhode Island shore. With the above rate of sea level rise, the potential sediment loss from the Rhode Island beaches to maintain equilibrium is 1500 times greater than the actual loss of material along this shoreline as determined in this study.

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Mr. Daniel Spangler of the U.S. Department of Agriculture, Soil Conservation Service in Warwick, R.I. supplied some of the aerial photographs used in this study.

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INTRODUCTION

A beach is a transient feature which is continually eroding or accreting as a result of the action of wind and waves. The U.S. Army Coastal Engineering Research Center (C.E.R.C.) (1964) has noted that planning of coastal development is critical because of the danger of occupying the low-lying land along the coast. Knowledge of the patterns of shoreline change is essential to the safe and orderly development of a coastal region. This is particularly true for coastal Rhode Island which is currently undergoing rapid development. Quantitative evaluation of those potential areas of beach erosion is of utmost importance if severe economic losses, both public and private, are to be avoided in present and future development. In the past, adequate data on coastal erosion have not been readily available.

Collection of data on coastal erosion is not a simple task. Extensive field measurements are expensive and the analysis of historical observations produces results of questionable accuracy. Field surveys are seriously complicated by the problem of extrapolating results obtained from short-term field observations into long-term erosional trends. Analysis of historical observations is difficult because the observations needed to accurately determine changes in the beach were not made in the past when the need for them was not recognized. Regardless of the method, coastal data collection requires considerable time and expense.

Aerial photographs are an ideal means of collecting coastal data. They show the location of the beach and natural and cultural features adjacent to the beach that can be used as stable locations to reference beach measurements. Aerial photographs also show great ground detail while maps show only selected detail. The primary objective of this investigation was to apply a proven procedure for surveying coastal changes of the southern Rhode Island coast in order to determine past, present and future areas of erosion and accretion of the beaches. The procedure consisted of measuring distances between stable reference images and points on the transient beach on photographs taken in different years. The measurements were converted to actual ground distance by multiplying by the photograph scale. Comparison of beach location obtained from the earlier photograph with that obtained from the later photograph determined the erosion or accretion that occurred during the time interval between the photographs. Movements of two lines along the beach, the dune line and the high tide line, were examined. The survey procedure involved: the selection of points to reference the beach location, the selection of survey points on the beach, field surveys of reference points for scale determination of each photograph, the actual photogrammetric measurements, and the subsequent data interpretation and analysis.

Primary sources of aerial photographs were the Agricultural Stabilization and Conservation Service and the Soil Conservation Service of the U.S. Department of Agriculture, the U.S. Geological Survey, the National Archives and Records Service of the General Services Administration, and private industry. Several flights of aerial photographs were available for the Rhode Island coast to determine changes in beach location for several increments of time, the earliest beginning in 1939. These photographs allowed measurement of coastal changes in increments of roughly 10 years until 1972. The data obtained from the several increments were combined for analysis to give a complete survey of shoreline changes between the dates of the earliest and latest usable aerial photographs.

The southern Washington County, Rhode Island shoreline was chosen for this study because of availability of suitable aerial photographs and accessibility along the coast for scale verification (Figure 1). This shoreline is composed of barrier "beaches" (spits) and unconsolidated glacial till and outwash headlands, and, is currently undergoing commercial and residential development. Four stabilized breachways (inlets) are the only breaks through the barrier beaches into the salt ponds and marshes behind. Photogrammetric measurements were made from stable reference points to the shoreline on aerial photographs taken on different dates. These photogrammetric measurements were converted to ground distances in order to analyze shoreline changes between Napatree Point on the west and Point Judith in the east.

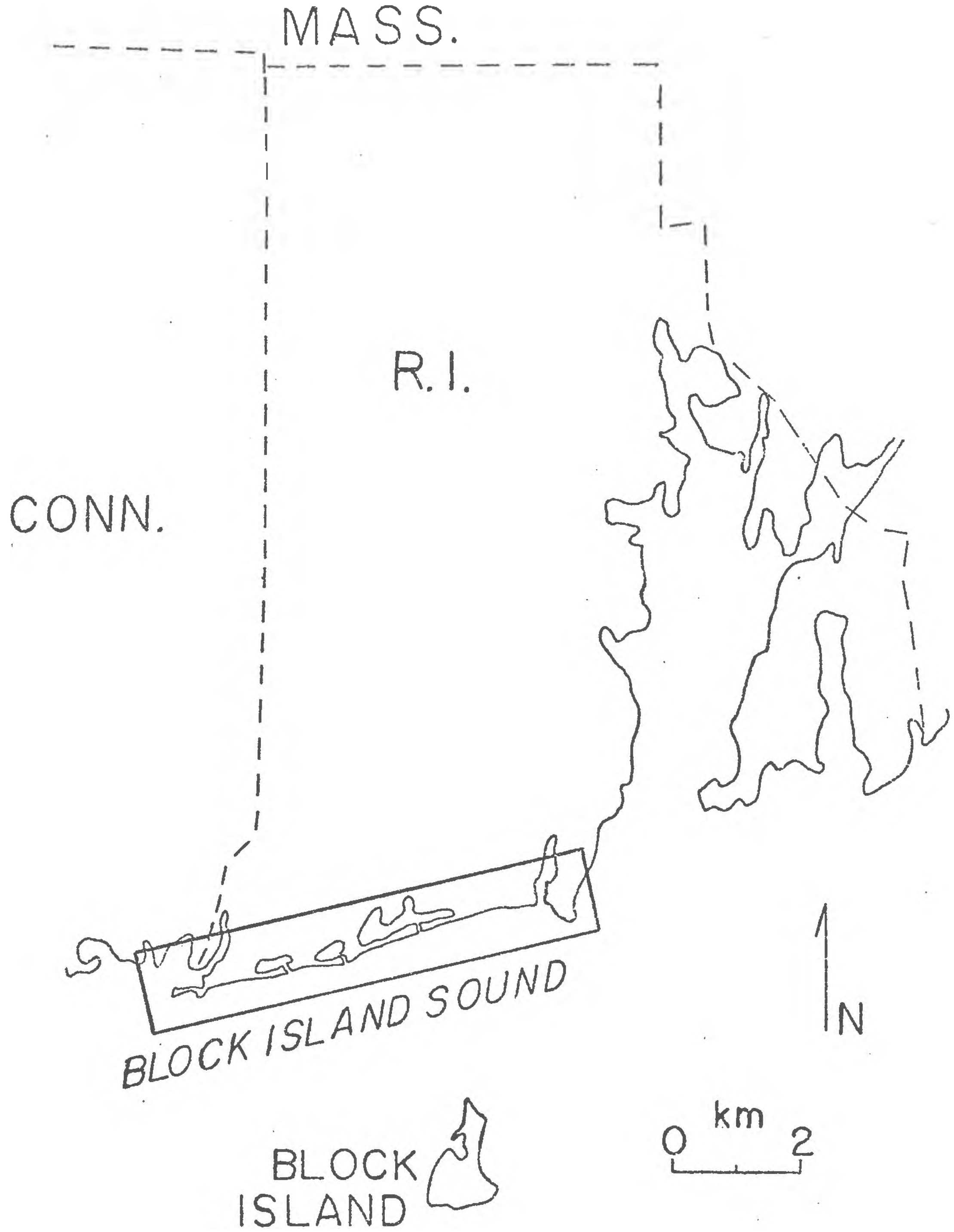


Figure 1. Location of Study Area, southern Rhode Island coast.

Previous Coastal Aerial Photographic Studies

Using aerial photographs to study coastal features is not a new concept. Many qualitative studies have used aerial photographs to illustrate specific beach features and conditions. However, few attempts have been made to derive quantitative information from the photographs. In the earliest coastal aerial photographic study in Rhode Island, Nichols and Marston (1939) used oblique photographs to illustrate changes in the Rhode Island coast caused by the 1938 hurricane. Quantitative data were obtained largely by ground surveys because of the difficulty of working with oblique aerial photographs of varying scales.

Dietz (1947) discussed the possibility of using aerial photographs in investigations of coastal changes and used a pair of oblique photographs to illustrate beach changes at Santa Monica, California over a 9 year period as a result of construction. However, no attempt was made to derive quantitative data from the oblique photographs. He specifically noted the lack of comparative aerial photography in 1947 but stated that aerial photographs being made then would have value in the future for comparison purposes.

Shepard (1950) discussed the use of both ground and aerial photographs to show changes in the shoreline caused by storms and cyclic seasonal changes. He noted that aerial photographs are better for studying changes in larger coastal features than ground photographs.

El Ashry (1966) made use of comparative aerial photographs to study the effects of hurricanes on selected areas of the east coast. Photographs of cape points, inlets and the barrier beach in North Carolina taken before and after a 1958 hurricane were compared to identify areas of change in these features.

El Ashry and Wanless (1965) reported the use of aerial photographs to monitor the growth of a tidal delta at the site of a new inlet formed in Hatteras Island, North Carolina by a March 1962 storm. The area of the delta was measured on photographs taken 2 months and 10 months after the opening of the inlet. They concluded that comparative aerial photographs were an excellent means for determining the rate of growth of depositional landforms.

El Ashry and Wanless (1968) also presented a comprehensive description of changes in coastal features such as capes, inlets and barrier beaches in North Carolina by comparing several sets of aerial photographs dated from 1939 to 1962.

El Ashry (1971, 1973) used comparative sets of aerial photographs in qualitative studies of coastal changes from hurricanes and severe storms on shorelines of the United States. He concluded that aerial photographs are an indispensable tool in studies of changes in shore processes and shoreline features.

In an early quantitative study, Athearn and Ronne (1963) used eight sets of comparative photographs dating from 1945 to 1962 in a study of shoreline changes at Cape Hatteras, North Carolina. The scale of each photograph was computed by comparison of measured photograph distances to the same distances on topographic maps. Measurements from common reference points to the high water line were made on comparative aerial photographs, revealing shoreline change.

Comparative aerial photography, topographic maps, and U.S. Coast and Geodetic Survey charts were utilized by Kaye (1973) in a study of shoreline changes of Martha's Vineyard, Massachusetts. Quantitative data were obtained and areas of erosion and accretion were identified.

In a survey of Pamlico Sound, North Carolina shoreline changes, Stirewalt and Ingram (1974) made photogrammetric measurements of marsh and lagoonal shoreline positions on comparative sets of aerial photographs. Photographs taken between 1938 and 1971 were compared and average annual rates of change were calculated.

Stafford (1968) developed a technique for a photogrammetric study of the Onslow and Carteret county shorelines of North Carolina. Stafford made precise measurements from reference points to the dune line and high tide line on scaled and rectified enlargements of aerial photographs taken between 1938 and 1968. Areas of erosion and accretion and average annual rates of change were computed. Subsequent studies by Wahls (1973), which updated the Stafford study, and Stephen, *et al* (1975) in South Carolina have utilized the same procedure. With modification, this technique was utilized in this study of Rhode Island shoreline changes.

METHODS OF STUDY

Advantages and Disadvantages of Using Aerial Photographs in a Shoreline Survey

Using aerial photographs to conduct a coastal erosion-accretion survey has advantages over other methods. Aerial photographs represent a permanent record of the position and shape of the shoreline at the time the photographs were taken. The Rhode Island photographs depict such features as the dune line, high tide line and vegetation while maps show only selected detail. When aerial photographs are taken over several decades, long-term studies of shoreline changes are possible. Government agencies have found that surveys utilizing aerial photographs are less expensive than field surveys and therefore, numerous photographs of the Rhode Island coast have been taken in the last 35 years. For the 6 flights taken during the past 35 years at roughly 7-year intervals, the cost of a 9 by 9 inch contact print from federal government sources is about 3 dollars. From private firms the price is generally double for contact prints.

There are some disadvantages and limitations to using aerial photographs in a shoreline survey. Computed changes are subject to error because photographs record shoreline position at a specific time that may not be typical of average conditions. Daily, monthly and seasonal cycles of change exist in Rhode Island beaches. Daily and monthly cyclic variations are believed small for Rhode Island shorelines and were ignored and seasonal cycles were compensated for by selecting aerial photographs taken in the spring and fall. Beach profile studies under the direction of McMaster (1975) indicate that spring and fall shoreline profiles approximate the average between the winter and summer cycles common to Rhode Island beaches. In addition, photographs studied were not taken immediately after storms when storm effects would be most evident. In short-term (seasonal) field surveys of shoreline erosion, seasonal cycles in beach profiles might lead to erroneous data on shoreline position. If these data are to be extrapolated to long-term (yearly or longer) erosion or accretion rates, the rates would be erroneous.

Possible errors inherent in aerial photographs such as tilt and scale variations are a disadvantage. These errors have been corrected or compensated for in this study by means of ground control surveys.

Aerial Photograph Acquisition

Determination of the coverage of aerial photographs from all sources was the initial phase in this study. An important factor affecting the validity of the study was the suitability of the date and scale of existing photographs. An interval of 10 to 12 years between flight coverages and a photographic scale of less than 1:20,000 was desired. The degree to which errors of scale variation, tilt, and relief displacement could be compensated was also important in locating suitable photographs for this study.

Agencies of the federal government that maintain records of existing aerial photographs were contacted. The two most important agencies in this respect are the Agricultural Conservation and Stabilization Service of the U.S. Department of Agriculture and the National Archives and Records Service. These agencies maintain records of aerial photographs held by the federal government and commercial aerial survey firms. Information on photographs of Rhode Island since 1940 was obtained from these agencies and the National Archives and Records Service provided information on photographs taken earlier than 1940. Three coverages of Washington County taken at 10-year intervals were available from the Agricultural Conservation and Stabilization Service. In addition, the U.S. Geological Survey, National Oceanic and Atmospheric Administration (N.O.A.A.), and the U.S. Army Corps of Engineers were contacted for information on holdings of Rhode Island coastal aerial photographs.

At the state level, the Rhode Island Department of Natural Resources and the Transportation Department were also contacted. A more than adequate number of coverages of photographs from all sources were determined to be available for the Washington County coast. Several coverages were judged unsuitable because of too long or short a time interval, too small a scale, or excessive cost, as in certain commercially-flown photography. Some photographs were judged unsuitable because the scale was too large; at least three or four times larger than the average 1:12,000 scale desired.

Index sheets are necessary to determine which individual photographs would be needed to provide coverage of the shoreline. Index sheets were acquired for all federal or commercial aerial photography of the desired date and scale for the study area. The index sheets were used to order sufficient contact prints from the selected flight coverages to cover the Washington County shoreline for 4 separate time periods. Contact prints that would permit stereoscopic examination of the beach and measurements of shoreline erosion or accretion were selected.

Photographs selected were dated 1939, 1951, 1963 and 1972. The 1939 photographs were obtained from the National Archives (RISWHPS CONT. 3903, May 1939, 1:14,000 scale). The 1951 and 1963 photographs were obtained from the Agricultural Stabilization and Conservation Service (DPK series, Nov. 1951, 1:20,000 scale, and Sept. 1963, 1:20,000). The 1972 photographs were obtained from Aerial Data Reduction Associates, Inc., Peacedale, R.I. (073 72 series, April 1972, 1:12,000 scale).

Monthly field measurements of barrier beach profile changes have been made at four locations along the Washington County shoreline over the past 14 years under the direction of R.L. McMaster (1975). Evidence was found that generally, during winter months (November to February), when high storm waves are more common along the coast, an erosional profile commonly exists and the shoreline recedes landward. During summer months (May to August), when high storm waves are less common and fair weather prevails, an accretional profile generally is formed and the shoreline builds up and out (seaward). Spring and fall profiles are usually intermediate between erosional and accretional. Photographs used in this photogrammetric study were taken in the spring and fall and trends observed on them probably approximate an average of the year-round shoreline position. Since none of the photographs were taken immediately after a severe storm or hurricane (even the 1939 photographs followed the 1938 hurricane by seven months), they were deemed desirable for this study. Local newspapers and weather service records were checked for 2 weeks prior to the dates of each set of photographs to verify that no severe weather had occurred.

Photogrammetric Scale Determination

Several sources of error should be considered in using aerial photographs to conduct a coastal erosion-accretion survey or any study which requires that accurate photogrammetric measurements be made on aerial photographs. These are errors due to scale variations, tilt, and relief displacements.

The most important is the possible error due to scale variations between adjacent photographs. The scale of a single vertical photograph (expressed as a representative fraction) is governed by the ratio of the focal length of the lens to the altitude of the camera above the terrain being photographed. The camera focal length is a known constant while the altitude may vary between each successive exposure. The pilot usually flies at a specific altitude to produce the desired nominal scale. However, variations in scale of as much as five percent are not uncommon. Specifications for aerial photographs frequently specify that if variations in scale exceed five percent, the photographs may be rejected (A.S.C.S., 1965). The scale given with a flight of aerial photographs (nominal scale) is the average scale for the entire flight and individual photographs may vary.

Aerial photographs that vary significantly from the nominal scale cannot be assumed to have the nominal scale if accurate photogrammetric measurements are to be made on the photographs. This error in nominal scale is critical when differences in measurements on different photographs are to be used as the primary data. The use of erroneous nominal scales can produce a difference in ground distances computed from measurements on two different photographs where no difference actually exists. Therefore, the scale of each photograph must be determined by using control data from a source other than the photograph. There are several methods for accomplishing this.

One method for computing scale uses distances measured on the aerial photograph and distances measured on a topographic or planimetric map (Avery, 1962). The distance between any two well-defined points on a map which also can be located precisely on the aerial photograph is measured and the result multiplied by the known map scale. The product is divided by the distance between the same two points as measured on the aerial photograph to give the photograph scale. Computing several scales for each photograph and then using the average reduces measurement error. This method was judged not sufficiently accurate for a photogrammetric survey of Rhode Island shoreline changes since available topographic (1:24,000) maps do not depict the location of any prominent features with an error of less than 10 ft. (J. Fisher, personal commun.).

Another procedure to minimize error due to scale variations is to utilize photographic scaled or rectified enlargements that have a known average scale. The use of photographic enlargements that have been projection printed to a common scale reduces errors in measurement caused by scale variations between photographs. Stafford (1968) used this procedure in his North Carolina shoreline study. Another advantage of photographic enlargements is that the enlarging process produces aerial photographs having a larger scale for measurement purposes than that of the original contact print. For this survey in Rhode Island, the expense of procuring such enlargements of each contact print was prohibitive. In addition, the contact prints obtained were of sufficient quality that an accurate survey of shoreline changes appeared feasible without requiring enlargements.

The technique to determine the scale of each photograph in this Rhode Island survey was to survey ground control points in the field that could be determined and measured on the photographs. This technique for scale determination also allows correction for scale errors due to camera tilt and ground relief.

Another possible scale error that must be considered when making aerial photogrammetric measurements is that due to tilt. Although aerial photographs in which the optical axis of the camera is not intentionally tilted from true vertical are generally called vertical photographs, few photographs are truly vertical. In most cases, the optical axis of the camera is tilted from vertical by a small unknown angle. The angle of tilt is usually visualized as having two components--one about an axis perpendicular to the line of flight and the other about an axis which coincides with the line of flight.

The effect of the resultant tilt is to cause the scale to vary over the photograph while only the center of the photograph is close to the true scale. Therefore, measurements made throughout the photograph and multiplied by a single average photograph scale might yield erroneous ground distances. In this Rhode Island study, photographs used were divided into nine sections. The least possible error due to tilt would occur in the center (Avery, 1962) while the eight sections around the center would vary from the true scale due to tilt more than the center section. An average scale was needed for each section in which photogrammetric measurements were to be made. In this survey, to reduce possible error due to tilt, scale was determined in the field for each photograph section.

Errors or distortions are also introduced into each aerial photograph by elevation or relief differences within the terrain on the ground. The errors caused by relief appear as radial displacements of images from their true or map positions. Objects above the average elevation of the terrain are displaced outward from the center and objects below the average level are displaced inward (Avery, 1962).

The magnitude of the relief displacement of an image is directly proportional to the difference between the average ground elevation and the elevation of the object. Relief displacements have a minimum value of zero at the center of the photograph and increase linearly with the distance of the image from the center of the aerial photograph.

The maximum local differences in elevation that occur along the southern Washington County coast are small, generally 9 m. or less. This fact serves to limit relief displacements considerably. Errors due to relief displacements also can be minimized by choosing survey points that are at or near the average elevation of the terrain. Measurement errors due to relief displacements can be further decreased by making measurements as near the center of the photograph as possible. By proper choice of photographs and by utilizing the 30 to 40 percent overlap in photographs in adjacent flight lines, most measurements can be made within a small distance of the photograph center. Use of all the factors that can reduce errors caused by relief displacements insures that measurement errors due to displacement of relief will be small and not have a significant effect. Other errors considered in normal photogrammetry such as camera lens distortions and film and paper shrinkage are eliminated by use of ground control surveys.

Ground Control

To minimize error due to scale variations, tilt, and relief displacements in this Rhode Island shoreline survey, a confirmation of each photograph scale from known ground control data was made. Field surveys were made between objects with distinct photographic images by survey taping to an accuracy of the nearest 0.3 m. Corners of single-level buildings were generally selected as points for the field measurements provided these buildings were 30 to 60 m. apart and clearly visible on all aerial photographs. The use of ground control measurements to determine photograph scales eliminates the error involved in selecting images and making measurements on a map. Earlier map comparisons made by the

U.S. Army Corps of Engineers (1957) indicated Washington County shoreline changes were small, so a fairly high level of accuracy was needed for this photogrammetric survey. Another possible error eliminated by ground control data is that of a mistake in comparing the photograph images of the points being used to determine scale to the same images depicted on a map. Buildings and other cultural and non-cultural features can be located on aerial photographs but may not appear on maps.

With suitable ground control data, the scaling procedure consists of measuring the distance on the aerial photograph between the photograph images of the control points and dividing the distance by the known ground distance. Control points from near the center and from each quadrant of the photograph were selected and scale determinations made to minimize scale variations <u>within</u> each photograph as well as <u>between</u> adjacent photographs. When more than two suitable control points appeared in a section of the photograph, duplicate scale determinations were made and an average scale value computed. Other errors such as those due to tilt and relief displacements were reduced by employing the average of the computed scales for each section of the photograph in the later measurement procedure.

In addition, the author also visited and observed the beaches of the entire Rhode Island shoreline from Point Judith to Napatree Point during the period of field surveys for the necessary ground control.

Reference Point Selection

After suitable sets of aerial photographs were procured and average scales of each photograph calculated, stable points to reference shoreline location were selected. From two photographs of the same area of shoreline from different flights, identical reference points were located so that differences in ground distance between reference points and points on the high tide or dune lines would reflect changes in beach location over time. Generally corners of single level buildings were selected again as reference points because of their sharp, clearly defined boundaries that could be readily identified on photographs of different flights.

Selection of improper points could adversely affect the accuracy of subsequent shoreline measurements. Objects selected for reference points had to have stable locations that did not move with time from natural or man-made causes. Images of objects on hills or sand dunes were not selected whenever possible in an effort to eliminate errors due to relief displacement. In some cases where no man-made objects existed or could not be clearly identified on identical photographs from each flight, natural objects such as clumps of vegetation that showed no apparent outline change over the study period were selected.

Stable reference points were selected as near to the beach as possible. Shoreline changes calculated from the measurements would be less affected by errors due to scale variations or tilt if reference points near the beach were used. Reference points located such that a shorter distance were measured would produce a smaller error in distance due to possible scale variations. Generally, photogrammetric reference points were located less than 3 cm. from the shoreline whenever possible.

Survey Point Selection

After the reference points had been selected, marked, and numbered, the locations on the beach (survey points) to which measurements would be made were selected and marked. (See Figure 2A and 2B.) These beach survey points were located on the aerial photographs on lines drawn perpendicular to the beach trend from each reference point. In some instances, where the orientation of the beach changed appreciably during the time interval between the dates of two aerial photographs, survey points were always located along identical lines on both aerial photographs, of which only one would be perpendicular to the beach. For example, if the shoreline trend changed by 10 degrees, the difference in perpendicular distance would be 10 percent. In no area of this study was the change in shoreline trend observed to be greater than 1 degree and, therefore, the difference in perpendicular distance was less than 1 percent.

The horizontal spacing of the survey points along the

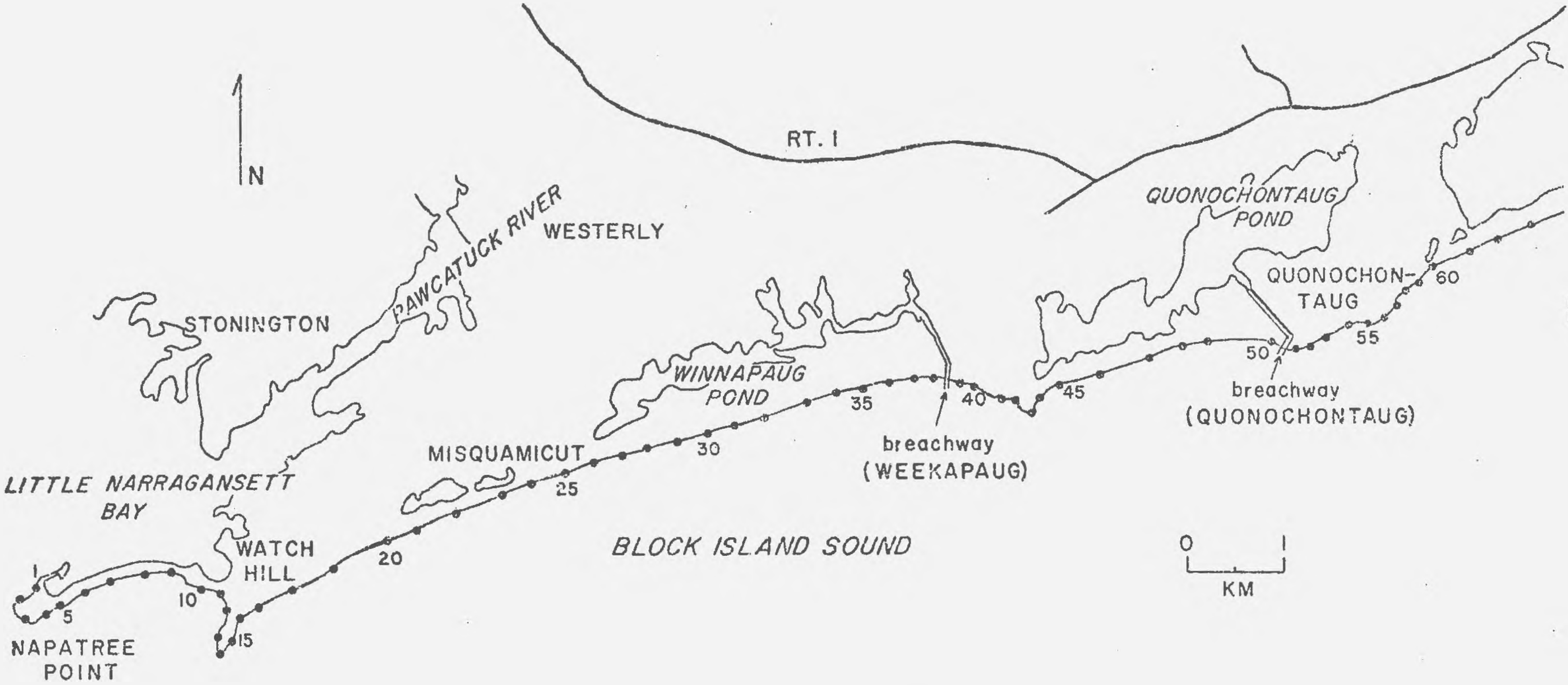


Figure 2A. Survey Point Locations, western section

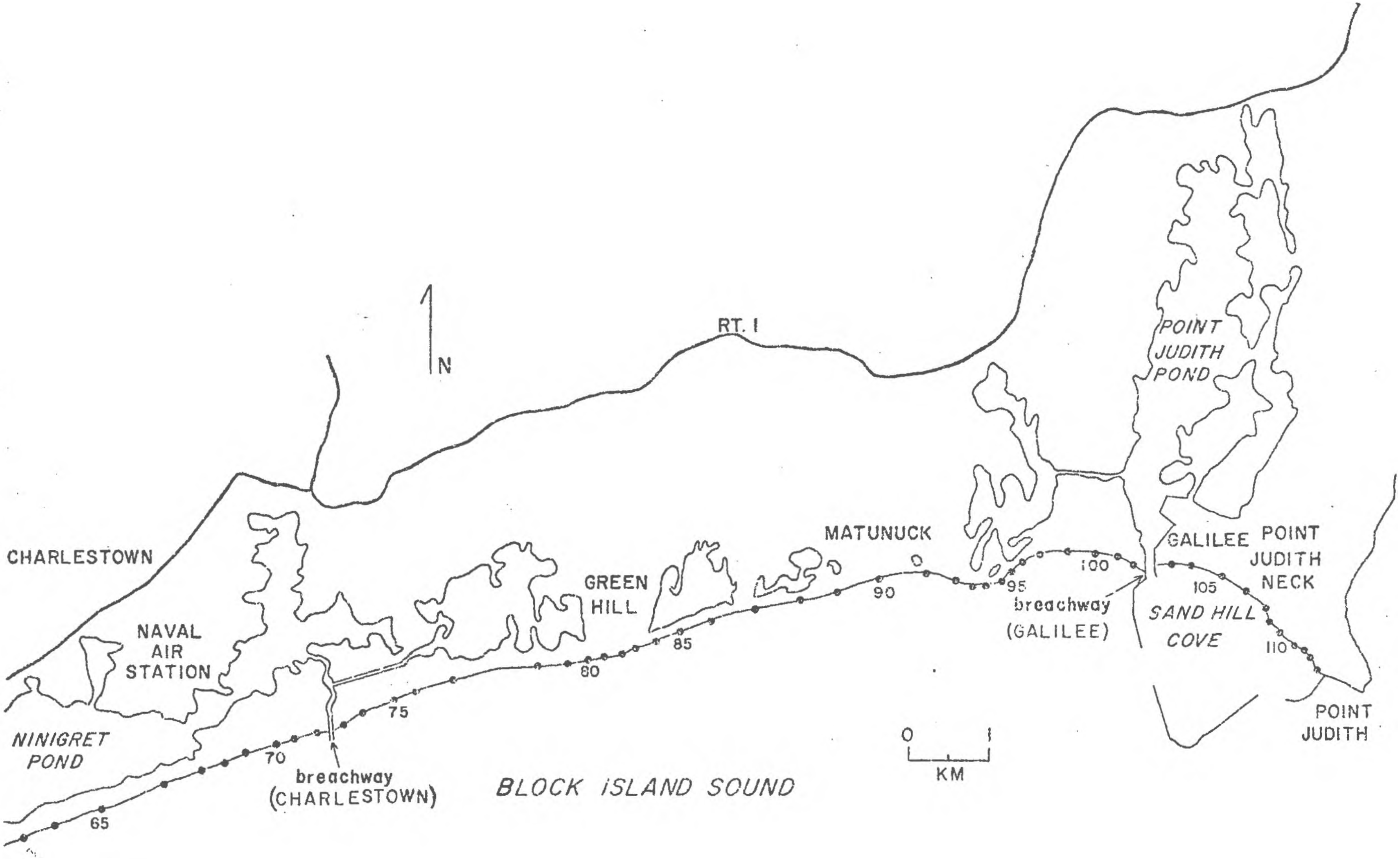


Figure 2B. Survey Point Locations, eastern section shoreline was chosen so that the frequency of measurement was sufficiently large as to give ample sampling of the beach changes, but not so large that the measurements would require much time and labor. Stafford (1968) concluded after several trials that a spacing of approximately 1000 ft. (305 m.) provided suitable survey accuracy. A spacing of 1000 ft. was found to be appropriate for this Rhode Island survey and was used along the entire shoreline whenever suitable survey points were located. In areas of anticipated greater change, such as around inlets, spits, or headlands, a spacing of 500 ft. (150 m.) was employed for greater accuracy where possible.

a. high tide line

The last high tide line was chosen for measurement of shoreline change. Stafford (1968) utilized the high tide line to locate survey points in his photogrammetric study of North Carolina. This line is usually depicted by a change in gray tone on the aerial photograph caused by differences in water content of the sand on each side of the high tide line. The tone registered by sand on an aerial photograph is, in this case, a function of the water content of the sand (Avery, 1962). The sand seaward of the high tide line becomes saturated or nearly so at each high tide and the water content remains high in this area throughout the tidal cycle. Therefore, the area seaward of the high tide line appears darker than the area immediately landward.

The line of saturated sand is actually formed at the inland limit of wave run-up on the sloping beach and varies with the height of waves that have been breaking on the beach. However, the variation of the high tide line from this location is not significant except during periods of abnormal wave conditions. Stafford (1968) believed that this variation was not large because aerial photographs are usually not taken during storms or high winds when abnormally high waves would predominate. McBeth (1954) maintained that the difference between the high water line represented by the last high tide and the mean high tide line was insignificant for most purposes.

Another factor affecting the location of the high tide line is the wind tide or variations in the water level due to wind. Wind tides have the effect of causing the high tide level to be slightly higher or lower than the mean high tide level depending on whether the wind is onshore or offshore. This water level variation is believed to be small because, again, aerial photographs are usually taken during fair weather. During storms, however, tides could be quite significant.

The high tide line is sometimes accented by a line of debris that accumulates at the limit of wave run-up. The debris line either coincides with, or is located inland from the high tide line, depending on the height of the waves striking the coast in the immediate past. After high storm waves, the debris line appears inland of the present high tide line and is called the storm high tide line. Where the sotrm high tide line was inland of the high tide line, the debris line was ignored and survey points were selected on the high tide line. If normal fair weather waves have been common, the debris line coincides closely with the high tide line and aided in the location of the high tide line on the aerial photographs. Occasionally, there was difficulty in distinguishing a debris line from the last high tide line. In such a case, the most seaward of the two lines was always chosen as the high tide line. In addition, from Weather Service, Coast Guard, and newspaper records, the stage of the tide and time of day when each photograph was taken was computed.

Seasonal fluctuations in the beach profile may occur which could affect the location of the high tide line. For example, the high tide line might be displaced seaward from its "normal" position by the occurrence of a large foreshore berm. In this study, whenever possible, measurements were not made through an area where it appeared the high tide line might be so displaced.

b. dune line

The seaward base of the vegetated sand dune paralleling the beach is called the dune line. This line is the boundary between wind- and/or wave-deposited dunes and the beach, and is represented sometimes by a wave-cut scarp or break in topography. In most areas, the scarp is easily identified on aerial photographs, especially when the terrain is viewed in three dimensions through a stereoscope. A difference in gray tone between the vegetated dune and the bare beach often exists and can aid in the location of the dune line.

The dune line is a significant indicator of erosional trends because of the protection against wave damage and flooding afforded by the dunes. Thus, recession or landward movement of the dune line usually means a loss of protection to manmade facilities or loss of land for future development. As an indicator of shoreline change, the dune line is probably a better measure of long- or short-term erosion than of accretion. This is because erosion of sand dunes by wave action occurs easily and rapidly and is evident immediately after if occurs. The opposite process, accretion, or a seaward extension of the dune line, lags behind the conditions that build the dune line because of the slow rate of the dune-building process. Whereas a high tide line may recover from serious erosion in a season, the dune line may take years to be rebuilt and recover. In addition, in evaluating the use of the dune line as a shoreline change indicator, it should be noted that erosion of the dune line probably occurs exclusively during periods of storms. Where dunes are extremely low or do not exist, the dune line cannot be located on the aerial photographs and the erosion information is derived from the high tide line measurements.

Photogrammetric Technique

In this Rhode Island Survey, 113 reference points were selected between Napatree Point and Point Judith. Measurements to the high tide and dune lines were made from each of these reference points on all 4 sets of aerial photographs. These measurements are in addition to the 300 to 400 measurements made earlier for photogrammetric scale determination as well as the ground control surveys.

All photogrammetric measurements from reference points to survey points were made with a patented Microrule (Theo. Altender and Sons, Philadelphia, Pa.). The Microrule is a micrometer-style measuring device with a vernier dial scale that allows measurements to be read to the nearest 0.001 inch (.3 mm.),and is available in various sizes. For 9 by 9 inch contact prints, a 12 inch rule was adequate. To locate points to be used for the measurements, a 5x magnifying glass or binocular stereoscope was needed to aid the eye.

After photogrammetric measurements were completed on all 4 sets of aerial photographs, tabular and graphical summaries of shoreline changes were constructed. Data on reference point-to-survey point distances were converted to sequential shoreline changes. The mean and individual values of the amounts (rates) of change were calculated for each time period for the high tide and dune line survey points.

The accuracy of the photogrammetric measurement technique relative to field measurements was ± 3 m. This accuracy was determined by making three or more photogrammetric measurements of the distance between ground control points in the same photograph quadrant. From these photographic measurements and similar measurements in the field, the exact scale of the photograph in that quadrant was determined. A subsequent photogrammetric measurement was made of the distance between two more control points in the same quadrant and the previously determined photograph scale was applied to convert the measurement to real ground distance. A field survey check by tape of this distance was made. Comparison of the computed distance and the field tape distance revealed the photogrammetric procedure accuracy. An accuracy check was made several times for each of the four flights of aerial photographs and found to be within ± 3 m. of ground distance throughout.

The photogrammetric determination of shoreline changes for one period of time of this study (1963 to 1972) can be compared to possible dune and high tide line positions as determined by four continuing transit surveys along the Rhode Island shoreline (McMaster, 1975). Monthly beach profile measurements have been made under the direction of R.L. McMaster since 1961 at Moonstone Beach (in vicinity of survey points 86-87, Figure 2B), Green Hill Beach (points 78-79), East Beach (points 62-63), and Weekapaug Beach (point 46). Since the base stations of the transit surveys are not locatable to any reference point visible on aerial photographs, it is not possible to compare directly the transit surveys with the photogrammetric surveys. However, we can determine relative differences between the two sets of data; i.e. the amount of change in position of the dune line and high tide line during the 1963 to 1972 period. Differences in position of the dune and high tide line survey points are determined with the photogrammetric technique and from the beach profiles, with certain limitations.

The limitations that were considered in order to utilize these field profiles in a comparison with the photogrammetric measurements were: that the dates of the field profiles were within several weeks of the dates of photography; that the profiles were made from a common stake in the back dune at each site; that the general transit profile locations could be identified on the aerial photographs by recent survey personnel (N. Donovan, 1975, U.R.I. School of Oceanography, personal commun.); and that the present author accompany a transit survey party in the field to all stations. It was also necessary to estimate the high tide line location on McMaster's field profile data (only the low tide line is indicated), and to refer to the field notes of the transit surveys in order to determine the location of the dune line on the field profiles.

In general, the difference between the location of the dune line as indicated on the transit surveys and the dune line determined photogrammetrically, is less than the differences between the location of the high tide line estimated from transit surveys and the high tide line determined photogrammetrically. The relative differences in the amount of change in dune line position is less than 3 m. at 3 out of 4 transit profile locations, and slightly over 3 m. when the high tide lines are compared. For one transit survey profile location, Weekapaug Beach, the difference in dune line location from the two measurement techniques was 1 m. and for the high tide line, 3 m. However, for Green Hill Beach, the difference was 9 m. between dune lines and 13 m. for the high tide line. This is 3 times the amount of difference of the other profile locations and may be due to: (a) a difference between the indicated and actual transit profile locations; (b) a difference between transit survey profile compass bearings on the photographs and in the field; (c) a variation between the low tide datum as indicated on the profiles and the actual low tide line, since all 4 profiles could not be surveyed at the same tide stage on the same day; (d) the indistinct appearance of the high tide line on some of the 1963 photographs, or; (e) less likely, the fact that the 1963 photographs are at only a scale of 1:20,000, while the 1972 photographs are 1:12,000.

SHORELINE CHANGES

Data Presentation Method

Stafford, in 1968, grouped the data from his measurements into geographic sections for interpretation, whereas in this Rhode Island study they were analyzed individually. Stafford found that averaging the amount of change calculated for a section of beach had the effect of removing much of the variation in individual erosion or accretion values. He also found that presenting an average value of change for a group of reference points also required considerably less labor. In this Rhode Island survey, data on the amount of shoreline change at each reference point has been presented to avoid introducing possible error into an average value when one defines a section of beach. If different geomorphic shoreline units were inadvertently combined into one section in an averaging process, bias might be introduced when an average erosion/accretion value is computed for that group of reference points.

Graphical presentation of shoreline change data for each reference point enables a visual inspection of all changes and identification of lateral trends on the beach. Tabular and graphical summaries of average (mean) annual rates of change in high tide and dune line position were computed and are also presented in the appendix, as well as a table of latitude and longitude locations of the intersection of all perpendicular survey lines with the mean low water line.

Types of Data Presented

Three types of shoreline erosion and accretion changes were computed in this survey: 1) the total amount of change as measured directly at each survey point in each time increment, 2) the mean annual rates of change for each survey point in each time increment, and 3) a composite mean annual rate of change for each survey point for the 33 year study period. Total changes in dune and high tide line position for each survey point are presented graphically (Figures 3-8) and in tabular form in the appendix, Table 1. Changes in dune and high tide line position computed from measurements on the 1963 and 1972 aerial photographs cover a 9 year period while comparisons of the 1939 to 1951 and 1951 to 1963 photographs cover 12 year periods respectively. Therefore, total changes in survey point positions computed between the 1963 and 1972 photographs have occurred during only 75 percent (9 years) as much time as the other two aerial photographic intervals (12 years). Mean annual rates of change for each survey point were computed to facilitate direct comparison of change data from these different time increments.

Mean annual rates of change in survey point positions for each time increment were computed by dividing the total change in that time interval by the number of years spanned by the two photographs from different flights being compared (9 or 12 years). In this way, the average (mean) annual rate of change for each point in that time interval was computed. Mean annual rates of change for each survey point in each time interval are presented in the appendix, Table 2. Mean annual rates of change for the entire 33 year study period are referred to as composite mean annual rates of change and are presented graphically (Figure 9) and summarized in the appendix, Table 3.

Stafford, in 1968, defined segments of coast of approximately equal length (about 4 miles) in order to present data on total changes and mean annual rates of change. Position changes of survey points within the segment of coast were combined and an average change for that segment was computed. Variability in individual values of change at each survey point was represented by computing the standard deviation of the total change within each segment. In this more detailed Rhode Island survey, position change data are presented for each survey point, not an average value of a segment of coast.

Mean annual rates of change for each survey point can be more significant than total change data in indicating shorter term variations in dune or high tide position. Computation of mean annual rates allows direct comparison of survey point changes between different sets of aerial photographs or, within the same flight, between adjacent photographs. Total change data is significant in indicating the long-term trends in the position of a point or group of points on the dune or high tide line. In addition, a single high tide line and a single dune line average of all mean annual rates of change has been computed for the entire coast. These values are discussed in more detail in the analysis section.

Discussion by Study Periods

The total amount of shoreline change at survey points on the dune and high tide lines will be discussed for the 1939 to 1951, 1951 to 1963, and 1963 to 1972 time increments. In addition, mean annual rates of change in survey point position within each time increment were computed and will be discussed. Composite mean annual rates of change over the 33 year study period are also discussed. Finally, mean annual rates of change for the entire shoreline are presented and discussed.

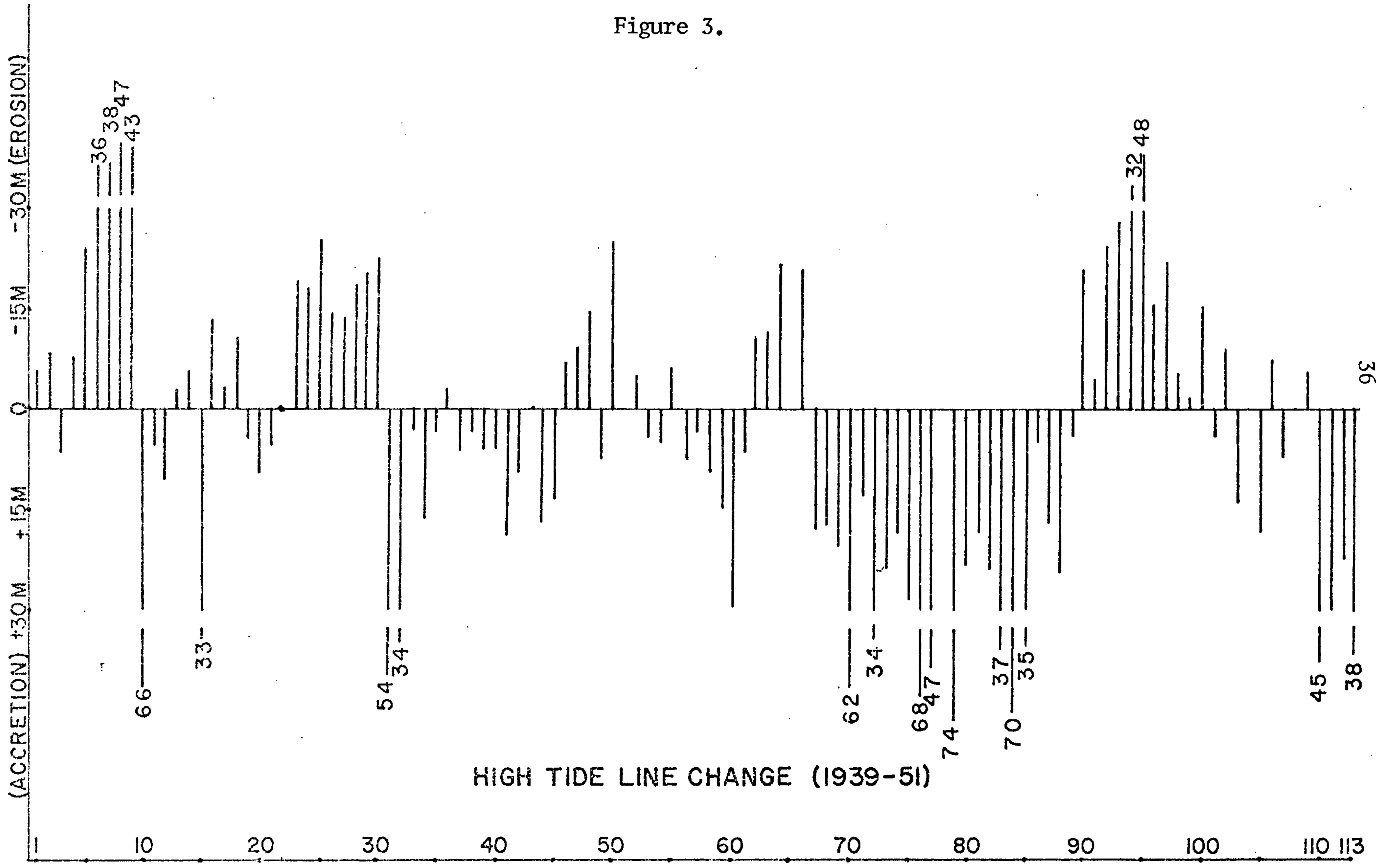
a. Shoreline Changes - high tide line

1. 1939 to 1951

The westernmost extension of the Rhode Island south shore, a tombolo known as Napatree Beach, shows an erosional or retreating trend (Figure 3). Survey points 5 to 9 located along the central portion of the tombolo show Block Island Sound high tide line retreat of 20 to 45 m. during the period. The Little Narragansett Bay high tide line also moved northward (advanced) between 15 and 60 m., widening the tombolo slightly. Accretion is evident at survey point 10 which is located in the shadow of a groin that was constructed in 1949 to stabilize sand on the eastern end of Napatree Beach. Most of the high tide line measurements from Watch Hill (point 18) eastward to East Beach (point 69) indicate changes of less than 15 m. in the 12 year period

Figure 3. Shoreline Changes - high tide line, 1939-1951

Figure 3.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-15M
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34
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45
38
36
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47
43
-32
48
36
HIGH TIDE LINE CHANGE (1939-51)
1
10
20
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40
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70
80
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100
110
113

from 1939 to 1951 (Figure 3). Survey points 22 to 29 were erosional, points 33 to 43 were accretional, and 44 to 67 were variable, but all had 15 m. or less of change. Exception is in the area of points 31 and 32 where an old inlet visible in 1939 was closed off by 1951. Shoreline advance of 30 to 50 m. occurred at these points. The high tide shoreline from Charlestown Breachway (inlet) to Moonstone Beach (points 70 to 85) accreted as much as 30 to 70 m. from 1939 to 1951 (Figure 3). This trend reverses gradually to one with erosion in the Matunuck Point area (points 94 to 97) of 15 to 45 m., and then back to relative stability in the Galilee area (points 100 to 109), an area of two jetties and several groins. Accretion of 20 to 40 m. is evident at points east of the Sand Hill Cove groins (points 110 to 113) for the period 1939 to 1951.

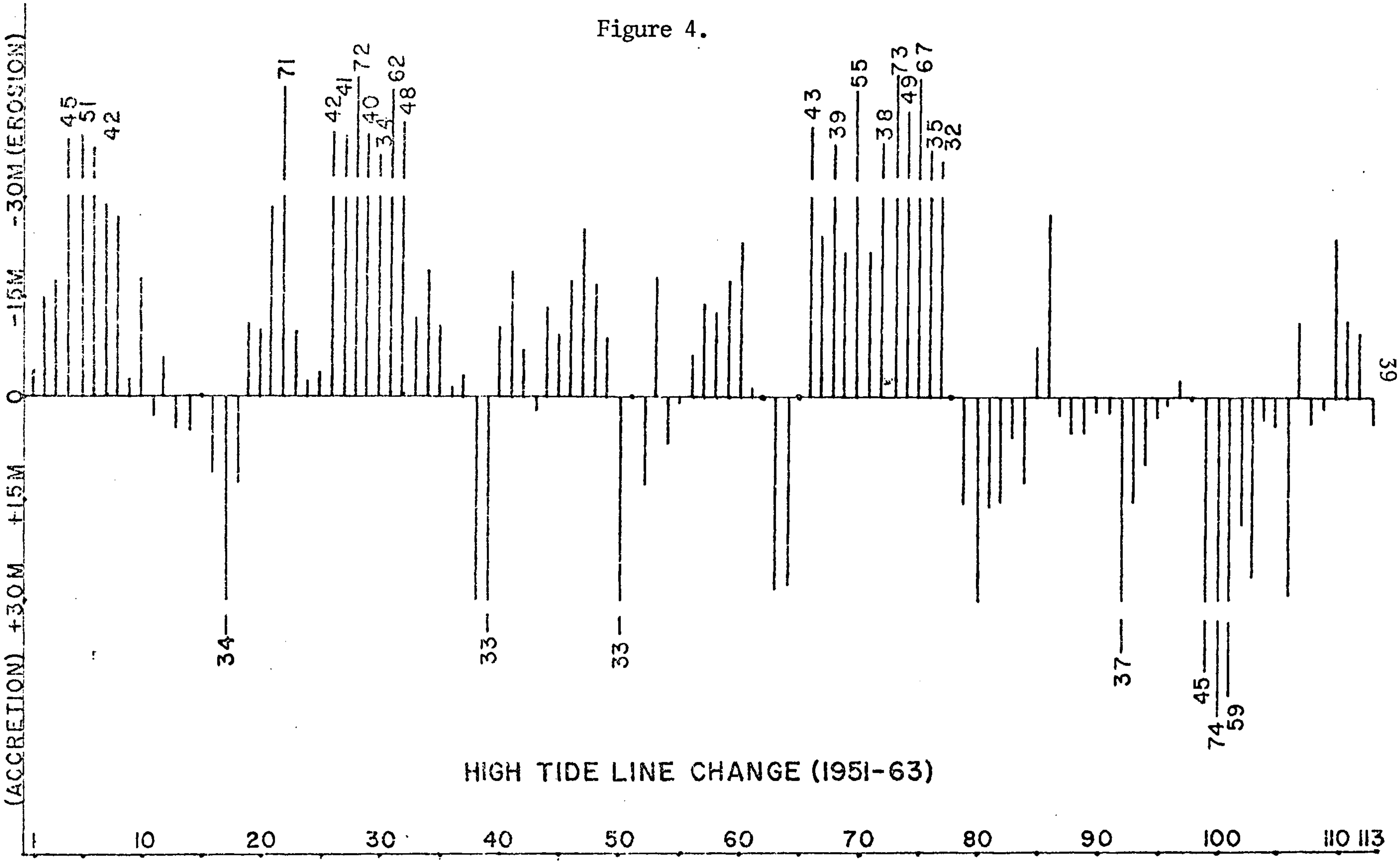
The extreme accretion mentioned above in the vicinity of Charlestown Breachway (points 70 to 72, 76 to 79) and Moonstone Beach (points 82 to 85) may be related to the construction of breachway stabilization structures between 1950 and 1952. Sand appears to have accreted in the lee of the breachway jetties that were constructed. The Matunuck Point area (points 94, 95) appears to be an eroding headland, and Moonstone Beach further to the west (points 85 to 89) advanced during this time interval, perhaps by addition of material eroded from Matunuck Point and transported westward by littoral drift. With the exception of those areas, as well as Napatree Beach which seems to be moving landward, the remaining shoreline varied from 5 to 15 m. of erosion or accretion over the 12 year period, or about 1 m. of change per year.

2. 1951 to 1963

Napatree Beach continued retreating northward (40 to 50 m.) between 1951 and 1963 on both ocean and bay shorelines (Figure 4, points 4 to 9). With the exception of a small area just east of Weekapaug Breachway and another immediately west of Quonochontaug Breachway where both advanced 33 m., the high tide line trend has been erosional between Watch Hill and Quonochontaug (points 17 to 60). In particular, in the Misquamicut area (points 22 to 31), this erosion of 30 to 70 m. is especially evident and may be related to the construction of the Misquamicut State Beach facilities between 1960 and 1962 and beach modification by the State of Rhode Island. Continuing erosion in this State Beach area is suggested by the fact that sand placed on the beach by the State in 1962 was completely eroded away in only one season (T. Bruha, 1975, personal commun.). Further east, the high tide line survey points between Charlestown Breachway and Green Hill (points 70 to 78) eroded 30 to 70 m. in contrast to the previous time interval, 1939 to 1951, when this section was significantly accreted (30 to 70 m.). The completion of the Charlestown Breachway stabilization in 1952, including jetties, may have interrupted established littoral transport and allowed significant erosion of the

Figure 4. Shoreline Changes - high tide line, 1951-1963

Figure 4.


(ACCRETION) +30M +15M 0 -15M -30M (EROSION)
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HIGH TIDE LINE CHANGE (1951-63)
1 10 20 30 40 50 60 70 80 90 100 110 113

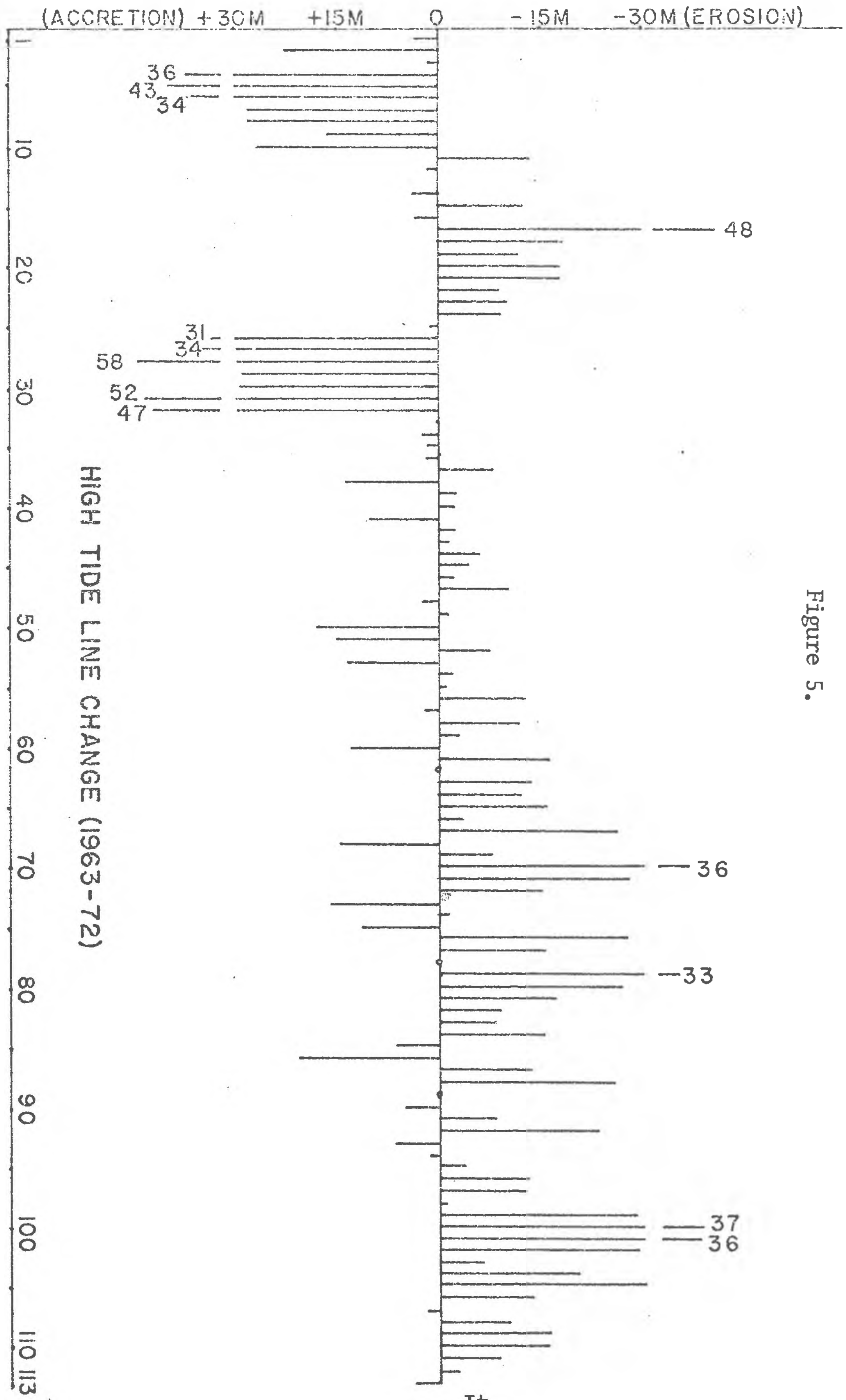
beach immediately to the east of this breachway. Further east, Matunuck Point and East Matunuck Beach (points 92 to 102) accreted 40 to 70 m. during this interval, opposite the trend of erosion between 1939 and 1951.

3. 1963 to 1972

Comparison of measurements made on the 1963 and 1972 aerial photographs indicates that both the ocean and bay high tide lines of Napatree Beach advanced southward (Figure 5), opposite the trends observed for the 1939 to 1951 and 1951 to 1963 periods. The section of the Napatree tombolo between survey points 5 to 9 widened 20 to 40 m. between 1963 and 1972 since the ocean high tide line advanced from 30 to 40 m. during the 9 year interval, while the bay high tide line moved southward less than 10 m. In the Misquamicut area (points 25 to 34), the high tide line also advanced considerably seaward (30 to 50 m.), a trend opposite the erosion measured for the 1951 to 1963 period. In contrast, eastward, along the Charlestown-Green Hill section of barrier beach (points 60 to 85), erosion of generally less than 20 m. occurred, a decrease from the previous period. Further east, the high tide line in the Matunuck area (points 85 to 100) also eroded an average of less than 30 m., an erosional trend similar to that of the 1939 to 1951 period, but of lesser magnitude.

The change from the northward retreat of Napatree Beach during the 1939 to 1951 and 1951 to 1963 time intervals, to the southward advance and widening from 1963 to 1972, has

Figure 5. Shoreline Changes - high tide line, 1963-1972


(ACCRETION) +30M
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HIGH TIDE LINE CHANGE (1963-72)
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Figure 5.

been confirmed by comparison of direct photographic overlays. The reason for this reversal in trend of the Napatree high tide line during the 1963 to 1972 period is not known. However, during the 1939 to 1951 and 1951 to 1963 periods, there were several hurricanes and severe storms, but none in the 1963 to 1972 period. The seaward advance of the high tide shoreline in the Misquamicut area after erosion in the 1951 to 1963 period and since the State Beach facilities were completed in 1962, is typical of a barrier beach model in which the barrier accretes while the flanking headlands erode (Davis, 1954). Some artificial sand fill was placed at Misquamicut by the State of Rhode Island when the State Beach was completed, but the balance of the observed accretion is likely due to littoral transport of sand from headland or offshore sources into the slightly embayed Misquamicut beach area. Further east, in the Matunuck area, the re-occurrence of an erosional trend during this 1963 to 1972 interval suggests that the 1951 to 1963 accretion in the area was a shorter term effect and not the long-term trend. Matunuck Point is a till and outwash sand headland (Kaye, 1954) and would, in respect to the barrier beach/headland model, be expected to erode with time, as in the 1963 to 1972 and 1939 to 1951 trends. In general, the entire high tide shoreline east of Misquamicut shows erosion of less than 30 m., the prevailing trend in the high tide line for the period 1963 to 1972. Again, an absence of severe storms or hurricanes during this period may be the reason for the slight erosion and minimal variability in this trend. This continuity suggests a slightly erosional profile of equilibrium may have been established.

b. Shoreline Changes - dune line

1. 1939 to 1951

The retreat of Napatree Beach is as clearly evident in the dune line changes as in the previously mentioned high tide line extreme retreat (Figure 6). Between 1939 and 1951 in this area (points 5 to 9), the dune line eroded from 40 to 55 m., an amount as great as anywhere else on the Rhode Island shore. Erosion of from 10 to 45 m. was also the prevailing process reflected in the dune line from Watch Hill to Charlestown (points 15 to 67). In some areas, indicated by an open circle on the figures (o), data is lacking due to man-made development obscuring or eliminating the dune line. From Charlestown Breachway to Green Hill, the dune line advanced with a magnitude and extent similar to that of the adjacent high tide line (Figure 3). Post-1938 hurricane recovery is the likely cause of this dune accretion. Further east, the data suggest accretional and erosional trends similar to those measured for the high tide line between 1939 and 1951, however, much rebuilding of summer cottages after the 1938 hurricane widely obscured the newer dune line in 1951.

Figure 6. Shoreline Changes - dune line, 1939-1951

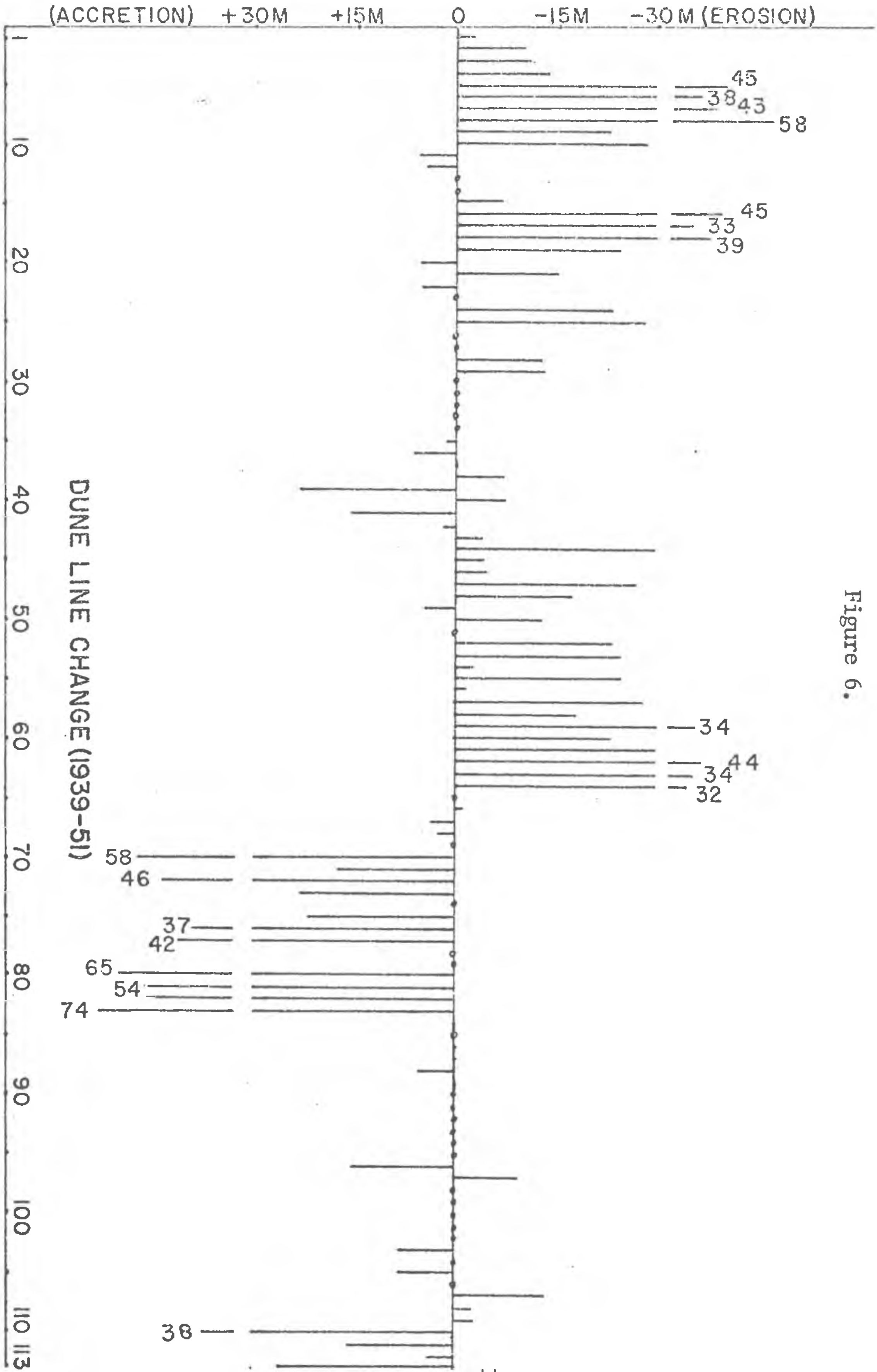
(ACCRETION) +30M +15M 0 -15M -30M (EROSION)
DUNE LINE CHANGE (1939-51)
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Figure 6.

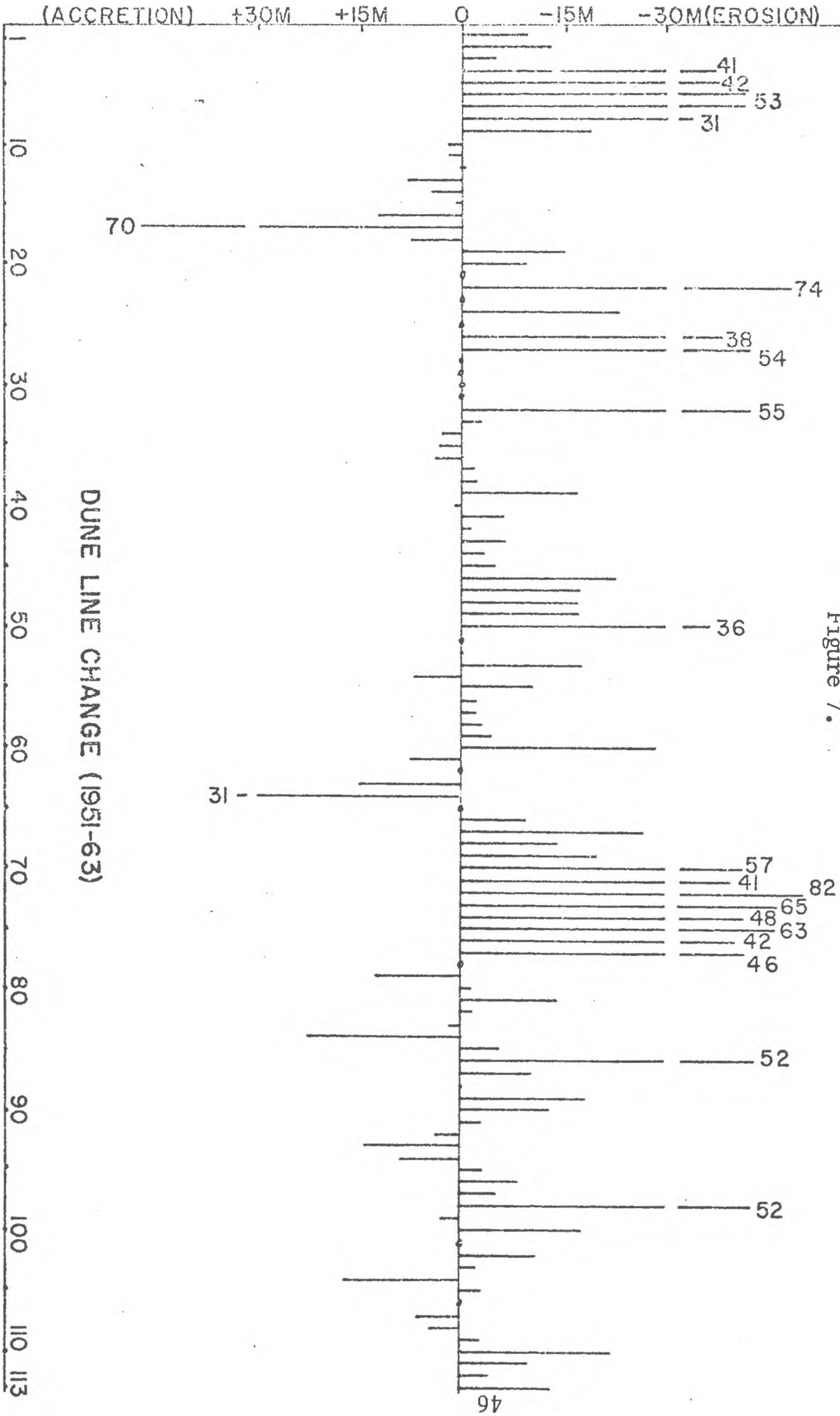
2. 1951 to 1963

Erosion on the order of 30 to 50 m. occurred over most of the dune line between Napatree Point and Quonochontaug (points 3 to 60) during the period 1951 to 1963 (see Figure 7). This trend in erosion is in the same direction but of greater magnitude than that measured for the high tide line erosion in the same time interval. In addition, this dune line erosion might still reflect damage inflicted by the 1954 and 1960 hurricanes when numerous washovers occurred and dunes and vegetation were devastated. East of Quonochontaug, dune line retreat was also common, especially in the Charlestown Breachway vicinity (points 69 to 76), where from 40 to 80 m. of erosion was measured. This dune line retreat is similar and almost of the same magnitude as the adjacent high tide line retreat. The additional 10 m. of dune line retreat may be due to man-made activity during breachway stabilization in 1952.

3. 1963 to 1972

For this time period, from Napatree Point to Point Judith, the dune line generally advanced seaward from 15 to 30 m. (Figure 8). Exception to this general advance is a single case of extensive dune line retreat of 60 m. at Watch Hill (point 17). This is in an area of intensive commercial development and more than likely reflects modification of the dunes by man. The overall accretional nature of the dune line during this period (1963 to 1972) is probably due to continued recovery of dune vegetation and dune accretion fol-

Figure 7. Shoreline Changes - dune line, 1951-1963

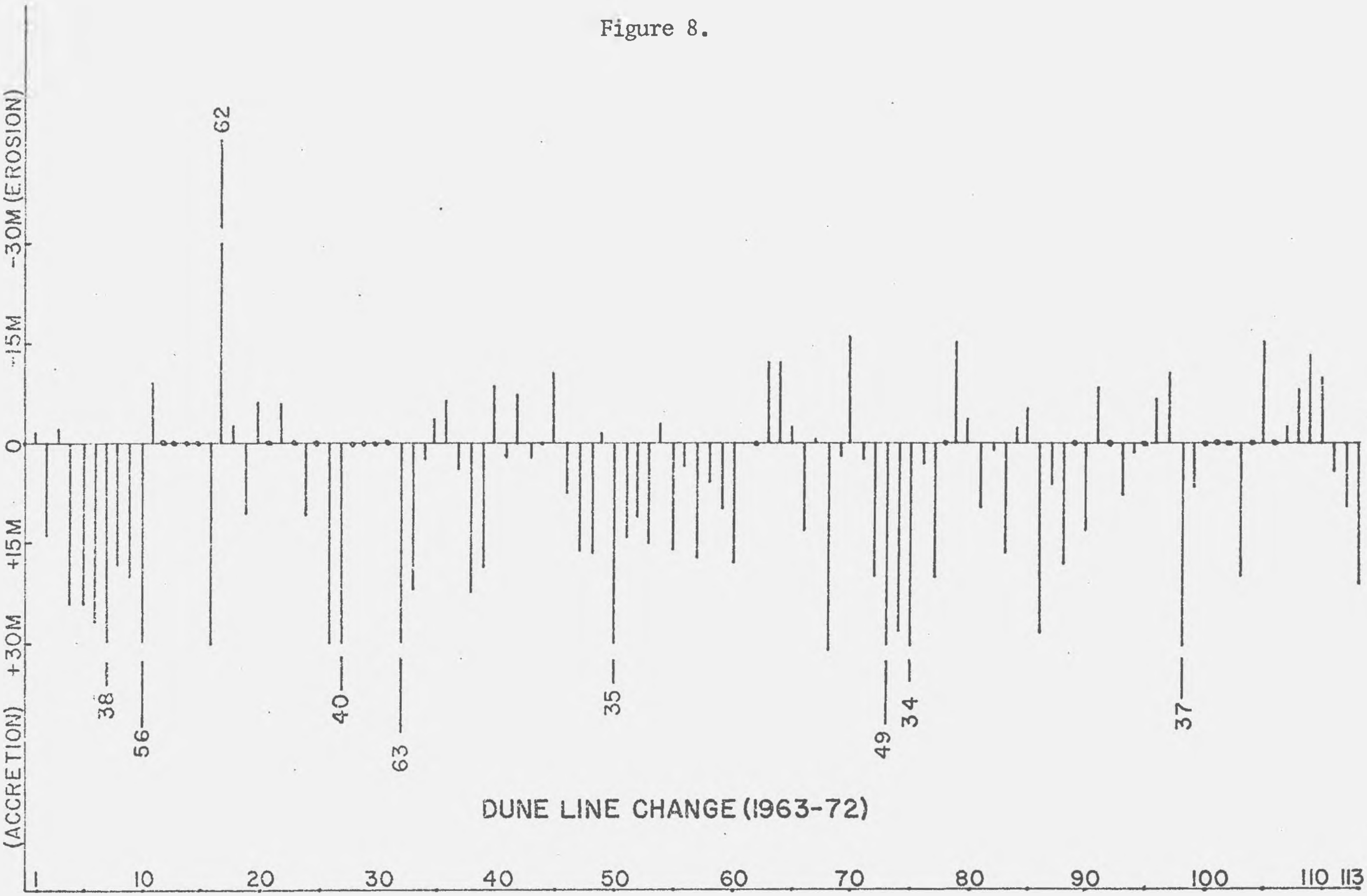


DUNE LINE CHANGE (1951-63)

Figure 7.

Figure 8. Shoreline Changes - dune line, 1963-1972

Figure 8.


(ACCRETION) +30M +15M 0 -15M -30M (EROSION)
DUNE LINE CHANGE (1963-72)
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lowing the erosional effects of the 1960 and 1954 hurricanes and the March 1962 northeast storm. This general dune rebuilding along the shoreline is thus, apparently not greatly affected by the slight erosional trend of the high tide line during this same period.

c. Mean Annual Changes (incremental study periods)

1. high tide line

Mean (average) annual rates of change in high tide and dune line position are important to this survey because they enable direct comparison of data on survey point position changes from the different time increments. This information is especially useful when comparing shoreline changes from time increments of unequal length (12 or 9 years in this study). Mean annual rates of change for each survey point for each of these time increments (1939 to 1951, 1951 to 1963, and 1963 to 1972) are presented in the appendix, Table 2. The mean annual rates are derived from the previously discussed total rates of erosion and accretion during each time interval. The total rates are divided by 12 or 9 years, respectively, to arrive at a mean value for that period.

In the Napatree Beach area (points 5 to 9), both the high tide and dune line eroded between 2.0 and 4.0 m./yr. during the 1939 to 1951 and 1951 to 1963 time increments. The Little Narragansett Bay high tide line also retreated northward 2.0 to 4.0 m./yr. During the 1963 to 1972 interval of time, the mean annual change trend reversed as the dune line and ocean high tide line accreted or advanced southward less than 1.0 m./yr. though, as Napatree Beach was apparently widened during the 1963 to 1972 period. A lack of severe storms during the period may have allowed Napatree Beach to accrete.

From Watch Hill east to Charlestown (points 15 to 68), the high tide line generally varied between erosion and accretion of 1.0 m./yr. in the 1939 to 1951 interval, erosion of 1.0 to 3.0 m./yr. during the 1951 to 1963 interval, and again, the high tide line varied between erosion and accretion during the 1963 to 1972 period. Between 1939 and 1951, the Charlestown Breachway vicinity (points 69 to 80) accreted significantly as, generally, 2.0 to 5.0 m./yr. was added to the high tide line. Stabilization of the breachway by man was previously mentioned as the likely cause, interrupting established littoral transport patterns. In the same breachway vicinity, the high tide line eroded significantly (2.0 to 5.0 m./yr.) between 1951 and 1963, and during the 1963 to 1972 period erosion also prevailed, but was much less significant (generally only 0.5 to 2.0 m./yr.). Continued inlet modification by man until completion in 1952, and the 1954 and 1960 hurricanes were probably responsible for the severe retreat measured for the period 1951 to 1963, while more moderate weather and waves between 1963 and 1972 probably explains the less severe erosional trends.

In the Matunuck Point vicinity (points 90 to 100), considerable high tide line erosion (2.0 to 4.0 m./yr.) occurred between 1939 and 1951, considerable accretion (1.0 to 5.0 m./yr.) between 1951 and 1963, and during the 1963 to 1972 period, moderate erosion of 1.0 to 2.0 m./yr. Matunuck Point is a source of material for the beaches, as indicated in a beach sand mineralogy study by McMaster (1960). The true long-term erosional trend is probably best represented by the 1963 to 1972 period average change when moderate weather prevailed. The 1951 to 1963 accretion is probably a shorter term accretional cycle within the long-term erosional trend.

Groins were constructed along Sand Hill Cove State Beach in 1940 (points 104 to 109). Generally, accretion of less than 1.0 m./yr. prevailed during the 1939 to 1951 interval. From 1951 to 1972, erosion of 0.1 to 1.0 m./yr. prevailed on the high tide shoreline. Similar values were measured for the Point Judith high tide line (points 110 to 113) further east with erosion of 0.1 to 1.0 m./yr. during both the 1951 to 1963 and 1963 to 1972 time periods. Where data is available, dune line measurements confirm these trends in both the Sand Hill Cove and Point Judith shorelines.

2. dune line (mean annual changes-incremental study periods)

At Napatree Beach (points 5 to 9), the dune line eroded from 3.0 to 5.0 m./yr. between 1939 and 1951, an amount as great as anywhere else on the Rhode Island shoreline (see appendix, Table 2). For the period 1951 to 1963, erosion of 2.0 to 4.0 m./yr. was measured, but between 1963 and 1972, the trend was reversed as 1.0 to 2.5 m./yr. of accretion was measured for Napatree Beach. As previously mentioned, milder weather may have allowed dune growth and recovery between 1963 and 1972.

From Watch Hill to Charlestown (points 15 to 65), dune line erosion of 1.0 to 4.0 m./yr. was measured for the period 1939 to 1951, and even greater erosion of about 2.0 to 4.0 m./yr. was measured for these points for the period 1951 to 1963. Measurements of the dune line position between 1963 and 1972 from Watch Hill to Charlestown showed that accretion of 1.0 to 3.0 m./yr. had generally occurred. In fact, 1.0 to 3.0 m./yr. of dune line accretion was measured along almost the entire coast from Napatree Point to Point Judith for the period 1963 to 1972.

From Charlestown Breachway to Green Hill (points 70 to 84), the dune line accreted with a magnitude similar to the adjacent high tide line (2.0 to 6.0 m./yr.) between 1939 and 1951. Local continued recovery from the 1938 hurricane erosion may be the reason for this accretion. For the 1951 to 1963 time interval, the dune line in the Charlestown Breachway area (points 68 to 76) was eroded about 0.5 to 7.0 m./yr., but in the Green Hill area (points 77 to 85) changes varied between erosion and accretion of 0.5 to 1.0 m./yr. As mentioned above, for the period 1963 to 1972, the dune line from

Charlestown through Green Hill accreted 1.0 to 3.0 m./yr.

From Green Hill to Sand Hill Cove (points 86 to 109), where 1939 to 1951 data was available, the dune line varied between erosion and accretion of 1.0 m./yr. The Point Judith area (points 110 to 113) showed 0.2 to 3.0 m./yr. of accretion. Between 1951 and 1963, the dune line from Green Hill through Point Judith generally eroded from 0.2 to 4.0 m./yr. Except for the Sand Hill Cove area (points 104 to 110) where erosion of about 1.0 m./yr. occurred, generally the reverse, 0.2 to 3.0 m./yr. of accretion occurred between 1963 and 1972 from Green Hill to Point Judith. Again, probably the moderate weather between 1963 and 1972 allowed the dunes to accrete without a major cut-back.

In summary, mean annual rates of change for the entire shoreline show that between 1939 and 1951, the high tide line accreted less than 1.0 m./yr. while the dune line eroded about 1.0 m./yr. Dune line erosion is probably due to several severe storms that occurred during the period. For the 1951 to 1963 time increment, both the dune and high tide lines retreated about 1.0 m./yr. The 1954 hurricane (Carol) and other severe storms during the period might be responsible for the continued dune line retreat along the coast. For the 1963 to 1972 time increment, the dune line accreted 1.0 to 1.5 m./yr. while the high tide line eroded slightly (less than 1.0 m./yr.). The absence of severe storms has probably allowed the dune line to build and advance over the length of the shoreline.

For each time increment, mean annual rates of change indicate the average annual change in position of each survey point. When the trend has varied in direction (shoreline advance or retreat), then the incremental mean annual rates indicate that variability over the 33 year study period. These short-term variations in trend direction and magnitude are apparent when mean annual rates are examined for each time increment. The varying direction of high tide line change in the Matunuck area (points 85 to 100) is a good example. Mean annual rates of change indicated the high tide line eroded about 2.0 m./yr. between 1939 and 1951, and 1963 to 1972, but accreted 1.0 to 2.0 m./yr. during the 1951 to 1963 interval. The composite mean annual rates for 33 years show only the longer term, net erosional trend of approximately 1.0 m./yr. Similarly, short-term variations in the mean annual rates of change, even when direction is constant, are significant when the short term variation is of greater magnitude than the net long-term trend.

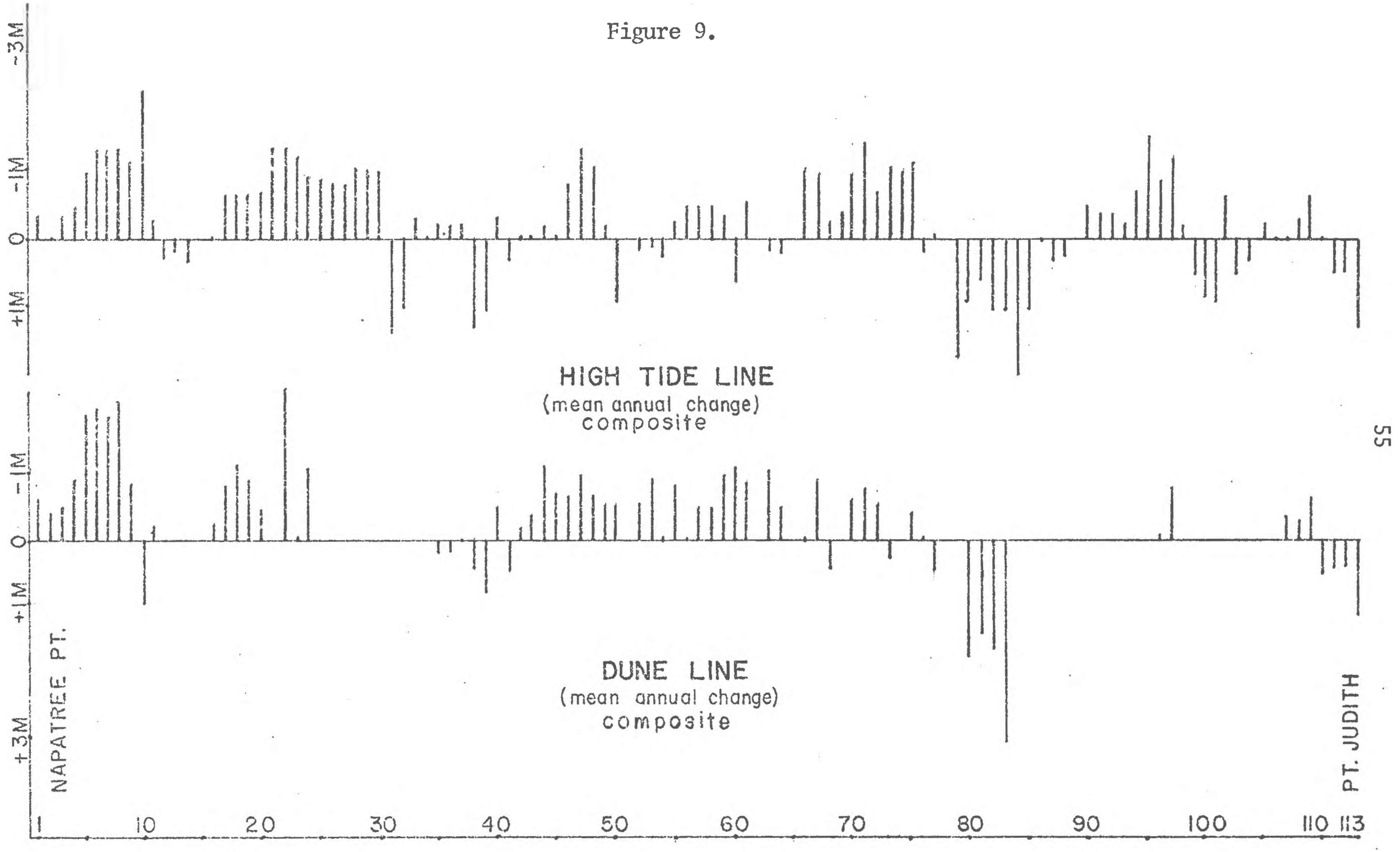
d. Composite Mean Annual Changes (total study period)

A composite mean annual change, in contrast to the previously discussed mean annual change per time increment, is the average position change of a survey point computed over the entire period of study (in this case, 33 years). If the direction of change (either erosional of accretional) has varied among the shorter 12 or 9 year time increments, then the composite rate for the entire study may be misleading since it is an average and can have only one direction. One might think from the composite rate that a survey point has always eroded, when in reality, during a shorter increment of time, it may have accreted slightly. Even when the direction of change is constant, shorter term variations in magnitude of erosion or deposition might be greater than the average. In the case of coastal engineering shoreline protection, these shorter term annual rates would be more useful than the composite rate. Whether this direction of change has varied or not, these composite mean annual rates average the shorter term variations and reveal the longer term trend. In this Rhode Island survey, composite mean annual rates of change are presented graphically (Figure 9), and in tabular form (appendix, Table 3).

In the previous discussion of mean annual changes by time increment, it was noted that between 1963 and 1972, Napatree Beach showed a marked seaward accretion of 1.0 to 4.0 m./yr. of both the high tide and dune lines, while prior to 1963 the reverse was the trend. The composite mean annual changes for 33 years, however, average this shorter term variation in direction and indicate that the long-term trend for Napatree Beach is about 1.0 to 2.0 m./yr. of erosion over the 33 year period. Between Watch Hill and Charlestown (points 15 to 65), the mean annual rates indicate that generally, the area eroded slightly over the entire study period. This agrees with the composite mean annual rates which also

Figure 9. Composite mean annual changes (1939-1972)

Figure 9.


-3M
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HIGH TIDE LINE
(mean annual change)
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NAPATREE PT.
DUNE LINE
(mean annual change)
composite
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100
110
113

show 0.1 to 0.5 m./yr. of erosion on the average. An exception is in the area of the Misquamicut State Beach (points 26 to 32), which showed shoreline accretion between 1963 and 1972.

The composite mean annual rates in the Charlestown Breachway vicinity (points 65 to 78) indicate erosion of about 1.0 m./yr. In contrast, the mean annual rates for the 1939 to 1951 time interval showed 1.0 to 3.0 m./yr. of accretion. Even with this significant shorter term reversal, the long-term trend in the Charlestown Breachway area is one of erosion. In the Green Hill area (points 80 to 85), the long-term composite mean annual rates indicate about 1.0 m./yr. of accretion. In the shorter term, the 1939 to 1951 and 1951 to 1963 mean annual rates showed accretion, but for the period 1963 to 1972, erosion of 1.0 to 2.0 m./yr. was measured. Further to the east, the composite mean annual rates for the Matunuck Point area (points 90 to 97) indicate long-term shoreline erosion of about 1.0 m./yr. even though the shorter term 1951 to 1963 interval mean annual rates indicated Matunuck Point had accreted 1.0 to 2.0 m./yr. at one time. Conversely, composite mean annual rates for the Point Judith area (points 110 to 113) indicate long-term accretion of less than 1.0 m./yr. while erosional rates, since Sand Hill Cove groin construction, measured for the 1951 to 1963 and 1963 to 1972 time increments, indicate erosion of 0.1 to 1.0 m./yr. In this case, the long-term composite rate is biased by significant accretion that occurred prior to groin completion in 1940. The shorter term, erosional rates probably better approximate present day conditions since the area has been modified extensively by man.

An average value of mean annual change was also computed for the entire coastline by averaging the composite rates of change for each survey point along the coast. Separate average values for the entire high tide line length and dune line length were calculated. For the 33 year study period, both the high tide line and dune line of the entire shoreline eroded at an average rate of 0.2 m./yr. (0.7 ft./yr.) between Napatree Point and Point Judith.

SHORELINE CHANGES - GEOMORPHIC ANALYSIS

The southern Washington County, Rhode Island coast is, geomorphically, a submergent coast consisting of drowned glacial outwash channels, several headlands composed of till and outwash sands, and interconnecting baymouth barriers, locally called barrier beaches. In addition, Napatree Point on the west, is composed of till and, in association with Napatree Beach, is probably a tombolo. Initially, it was anticipated that the headlands might exhibit erosional trends and the barriers accretional trends in a manner similar to the model of a shoreline submergence of Davis (1954). In this model, under normal wave conditions, headland areas are a focus of refracted wave energy and erode while adjacent accretion takes place in the form of baymouth barriers ("bridging bars") or bayhead "pocket" beaches. May and Tanner (1973) have developed a quantitative model of this latter case of headland erosion and bayhead deposition utilizing wave energy data.

Generally, the trends in high tide and dune line observed in this study of Rhode Island agree with the implications of both models, but with the added difference that the entire coast is also undergoing erosion. At Napatree Point (points 3, 4), which has probably acted as a "headland" to supply new material for Napatree Beach, a composite mean annual rate of erosion of 0.3 to 0.5 m./yr. has been measured for the high tide line. The dune line eroded about 0.4 m./

yr. Quonochontaug Neck (points 55-59), a less prominent headland, has eroded about 0.3 to 0.5 m./yr. and Matunuck Point (points 92-97) has eroded 0.5 to 1.5 m./yr. on both high tide and dune lines. These headland erosion rates are about two times or more greater than the average for the entire coast which is about 0.2 m./yr. Weekapaug Point (points 42-44) was found to erode about 0.2 m./yr., the same as the average for the coast. Green Hill (points 80-85) does not fit the model because the composite mean annual rates indicate accretion of 0.5 to 2.0 m./yr. of both the high tide and dune lines. Watch Hill Point (points 11-15) is a headland composed of end moraine till over bedrock which has been modified by the building of shore protection seawalls; high tide line composite rates showed accretion of about 0.2 m./yr. Dune line data were unavailable due to dune absence or removal by man.

The mean annual rates by time interval (1939-51, 1951-62, 1963-72) for Napatree Point, Quonochontaug Neck and Matunuck Point headlands generally confirm the Davis model. Between 1939 and 1951, all headlands except Matunuck Point accreted about 0.5 m./yr., but between 1951 and 1963, and 1963 and 1972, these headlands generally were eroded about 0.5 m./yr. The accretion may well have been related to the jetties built at the inlets during the 1939 to 1951 period immediately adjacent to these headlands. The Green Hill headland accretion is further indicated by the mean annual rates during the 1939 to 1951 and 1951 to 1963 periods, but between 1963 and 1972 the Green Hill high tide shoreline was eroded.

From the composite mean annual rates of change (Figure 9), it appears that the interconnecting baymouth barriers erode almost as much as the adjacent headlands (about 0.2 to 0.6 m./yr.). Dillon (1970), in a stratigraphic subsurface study, found evidence that the Charlestown-Green Hill barrier beach was probably formed at a lower sea level and has moved landward as the sea transgressed. Dillon further noted that "the small size of this barrier places its base at a shallow depth (less than 13 m.), resulting in erosion of the entire seaward side by storm waves and also permitting considerable transport of sand across the barrier to the lagoon side." He observed that lack of sand supply seems to be the dominant factor allowing landward migration (erosion of the seaward beach face) of the barrier, and that no significant amounts of sand are contributed from the land because the only rivers entering the ocean in the Charlestown-Green Hill vicinity flow into effective sediment traps (Narragansett Bay and Long Island Sound). He also suggested that little sand is supplied from offshore because offshore sampling indicated that these sediments ranged from coarse sand to gravel in size.

The landward movement of this barrier as the sea transgresses as described by Dillon, is a process occurring over thousands of years. On the other hand, this Rhode Island photogrammetric study covers a time period of only 33 years, a very short time with respect to sea level fluctuations. Still, photogrammetric measurements indicate that barrier erosion, has occurred. The composite mean annual changes for the Charlestown-Green Hill barrier indicate a general erosion of the high tide shoreline of 0.5 to 1.0 m./yr. In a similar manner, the Misquamicut barrier beach (points 20-30) has also eroded 0.5 to 1.5 m./yr., as much erosion as any headland along this shoreline. This sand, eroded from the high tide line along the coast, probably has not gone into the building of the dune line since the dunes have also eroded (about 0.2 to 0.3 m./yr. The eroded sand in part might be presently in tidal deltas at the various inlets, washover fans, in the increased width of the Napatree tombolo, or, alternatively, deposited nearshore.

The computed average coastal erosion of 20 cm./yr. (0.2 m./yr.) horizontally on this submerging coast may simply be due to submergence due to sea level rise and not actual erosion. The sea level rise curve of Hicks and Crosby (1973) shows an average rise of 0.3 cm./yr. at Newport, Rhode Island over the past 40 years. The vertical component of the measured horizontal retreat of 0.2 m./yr. on an assumed beach slope of 5 degrees would be 2.0 cm./yr. A submergence of 0.3 cm./yr. due to sea level rise, therefore accounts for only 15 percent of the vertical component of the measured yearly retreat. Thus, 85 percent of the shoreline retreat must be due to erosion.

A possible mechanism for this erosive loss along the entire Rhode Island shoreline may be the readjustment to a profile of equilibrium of a submerging shoreline, as suggested by Bruun (1962). Bruun pointed out that a sea level rise relative to an adjacent shoreline would require an offshore profile adjustment (deposition) in order to continuously maintain the same depth of water as sea level rises. This deposition in the nearshore zone would be a vertical equivalent to the amount of sea level rise. Bruun further pointed out that in areas of little or no sediment supply, this needed depositional material would be eroded from the shoreline. Again, using the sea level rise of 0.3 cm./yr. for the Rhode Island coast, and deposition by wave action to an effective wave base of about 9 m. (1 km. from shore), then the potential sediment deposition per unit length of shoreline, as required by the Bruun model, can be calculated.

The cross-sectional area of sediment that could be deposited offshore to maintain a constant water depth as sea level rises, is about 3.0 m.^{2}/yr. per unit length of shoreline. For the Rhode Island shoreline with an average beach slope of five degrees and 0.2 m./yr. of horizontal erosion, the cross-sectional area of beach loss per unit length of shoreline is only 0.002 m.^{2}/yr. Therefore, the potential sediment "sink" is about 1500 times (3.0 m.^{2} vs. 0.002 m.^{2}) greater than the actual loss of material along the Washington

County shoreline due to submergence and erosion. Non-shoreline deposition such as washover fans (although not extensive) and tidal delta deposition may account for a portion of the material actually eroded from the shoreline. As previously mentioned, there has been no net dune growth or advance during this study period. Apparently, many more times erosion than the 0.2 m./yr. average retreat measured in this photogrammetric study could occur annually and still be absorbed by the potential sediment sink offshore as sea level rises at the current rate.

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APPENDIX

Table 1

Total Change (meters)

	1939-1951		1951-1963		1963-1972	
	dune line	high tide line	dune line	high tide line	dune line	high tide line
1.	-3.3	-5.7	-9.0	-4.5	-1.8	4.5
2.	-9.3	-7.5	12.6	-15.0	13.5	22.2
3.	-10.0	6.0	3.2	-17.4	-1.2	1.8
4.	-13.0	-6.9	-40.5	-44.1	24.0	35.1
5.	-43.8	-24.0	-41.1	-50.1	24.3	42.6
*5A.	-	-33.0	-	-36.9	-	11.7
6.	-37.5	-35.7	-52.2	-41.1	26.7	33.9
*6A.	-	-57.0	-	-39.9	-	2.4
7.	-42.6	-37.2	-52.5	-28.5	37.2	27.0
*7A.	-	-58.5	-	-29.4	-	2.4
8.	-57.0	-46.2	-30.9	-23.7	18.3	27.3
*8A.	-	-75.3	-	-11.1	-	8.7
9.	-23.1	-42.0	-19.5	-2.4	20.1	16.2
*9A.	-	-12.3	-	-12.6	-	10.8
10.	-28.2	65.1	2.1	-19.5	54.9	25.5
11.	4.2	5.1	1.8	2.7	-11.1	-12.0
12.	3.0	10.5	-0.3	-5.7	-	1.5
13.	-	-2.1	6.9	4.5	-	0
14.	-	-4.5	3.6	5.1	-	4.8
15.	-6.0	-	0.6	-	-	-10.8
16.	-43.8	-12.9	12.0	9.0	30.9	4.2
17.	-32.4	-3.3	69.0	33.9	-60.6	-47.7
18.	-38.7	-10.2	8.1	11.4	-2.4	-19.5
19.	-23.1	3.9	15.3	-10.5	11.1	-10.5
20.	4.5	9.3	-9.0	-9.6	-5.7	-17.7
21.	-12.9	4.8	-	-27.6	-	-19.8
22.	4.8	32.1	-73.2	-69.9	-5.1	-8.1
23.	-	-18.9	-	-8.7	-	-9.6
24.	-21.6	-17.4	-22.8	-2.7	10.2	-8.7
25.	-28.8	-24.9	-	-4.2	-	0.9
26.	-	-13.8	-37.8	-41.4	27.6	30.9
27.	-	-12.9	-52.8	-40.5	39.0	33.0
28.	-12.0	-18.6	-	-70.8	-	57.3
29.	-13.2	-19.8	-	-39.6	-	28.8
30.	-	-22.2	-	-33.6	-	29.4
31.	-	53.4	-	-60.9	-	50.7
32.	-	33.0	-53.7	-46.8	62.1	46.2
33.	-	2.7	-3.3	-10.1	21.3	0
34.	-	16.2	3.0	-20.4	1.8	3.0
35.	0.6	2.7	3.6	-9.6	-2.4	2.1
36.	5.1	-3.0	4.2	-1.2	-6.0	1.5
37.	0	5.7	-2.1	-3.0	3.0	-7.5

*("A" is corresponding point on bay high tide line)

Total Change (meters)

	1939-1951		1951-1963		1963-1972	
	dune line	high tide line	dune line	high tide line	dune line	high tide line
38.	-6.3	3.3	-2.7	29.4	22.5	12.0
39.	23.4	5.4	-16.4	32.1	17.4	-3.6
40.	-6.9	5.4	0.6	-9.6	-8.7	-3.3
41.	16.5	19.5	-5.4	-18.9	1.8	10.5
42.	1.5	8.7	-1.5	-6.0	-6.6	-3.6
43.	-3.9	-0.6	-5.7	1.5	2.1	-1.8
44.	-30.0	16.8	-3.0	-12.0	0	-6.6
45.	-3.6	14.1	-4.2	-8.4	-11.1	-4.8
46.	-4.5	-6.6	-21.6	-17.1	0.6	-2.4
47.	-25.2	-9.0	-18.0	-24.0	16.2	-9.9
48.	-18.0	-13.7	-16.7	-18.0	16.8	2.4
49.	4.5	6.9	-18.0	-8.1	-1.2	-1.5
50.	-12.0	-24.6	-35.4	32.4	34.2	18.6
51.	-	-	-	-	14.1	14.7
52.	-22.2	-5.1	0	14.1	9.9	-6.6
53.	-24.9	3.9	-16.7	-19.2	15.0	12.9
54.	-2.7	4.8	6.9	6.9	-3.9	-3.0
55.	-25.2	-5.4	-11.4	-0.6	15.6	-0.6
56.	-1.5	7.2	-2.4	-6.6	2.4	-12.0
57.	-27.6	2.1	-2.4	-14.4	17.1	2.1
58.	-18.9	9.3	-3.3	-12.3	5.7	-10.5
59.	-33.0	15.0	-4.1	-18.6	10.5	-3.9
60.	-21.3	29.1	-29.1	-23.1	17.7	12.6
61.	-29.7	6.0	7.5	-1.8	0	-16.5
62.	-43.5	-10.8	-	-	-	-
63.	-33.0	-12.0	15.3	27.9	-8.7	-14.1
64.	-31.5	-21.6	30.6	27.3	-12.0	-10.8
65.	-	-	-	-	-1.8	-16.5
66.	-2.1	-20.7	-9.6	-42.0	12.9	-5.1
67.	3.6	18.0	-27.6	-23.4	-0.3	-25.2
68.	2.4	17.4	-14.4	-38.1	31.2	14.7
69.	-	20.4	-20.1	-21.3	1.2	-7.5
70.	56.7	60.9	-56.4	-54.0	-15.9	-35.1
71.	18.0	12.6	-40.2	-21.3	1.8	-27.9
72.	45.0	33.0	-81.0	-37.8	20.1	-15.0
73.	22.8	24.0	-63.9	-71.7	48.6	15.9
74.	-	18.9	-46.8	-48.0	27.6	-1.8
75.	20.1	25.8	-62.1	-66.3	33.0	9.3
76.	36.9	66.9	-41.1	-34.8	1.8	-27.0
77.	41.1	45.9	-45.0	-31.5	19.5	-16.2
78.	-	-	-	-	3.9	-25.5
79.	-	73.2	12.3	18.6	-15.6	-32.4
80.	64.2	23.4	-0.6	30.0	-3.6	-25.5
81.	53.1	18.6	-14.4	19.5	8.7	-18.0
82.	53.1	23.7	-1.5	16.8	0.6	-9.9
83.	72.9	36.9	0.9	6.9	17.1	-8.1

Total Change (meters)

	1939-1951		1951-1963		1963-1972	
	dune line	high tide line	dune line	high tide line	dune line	high tide line
84.	-	69.0	22.2	13.8	-2.1	-16.5
85.	-	34.2	-5.4	-7.5	-4.5	6.6
86.	-	4.2	-51.6	-27.0	28.2	21.0
87.	-	16.5	-10.8	2.4	5.7	-13.2
88.	5.4	24.0	0	6.0	18.3	-24.6
89.	-	3.0	-18.3	5.7	-	-
90.	-	-20.7	-13.2	1.8	13.2	5.4
91.	-	-24.6	3.6	36.3	-8.1	-7.5
92.	-	-5.1	-2.7	1.5	-	-23.1
93.	-	-28.5	14.4	17.1	7.5	6.0
94.	-	-31.5	9.3	9.3	0.6	0.6
95.	-	-47.4	-3.3	2.7	-	-4.2
96.	15.3	-15.6	-8.7	0.6	-6.0	-12.9
97.	-9.0	-22.5	-5.7	-2.4	-9.9	-12.6
98.	-	-3.6	-51.0	0	36.9	-0.6
99.	-	-1.2	3.0	44.4	6.3	-28.5
100.	-	-15.9	-17.4	73.2	-	-36.0
101.	-	3.6	-	58.5	-	-35.1
102.	-	-9.0	-11.4	19.2	-	-29.4
103.	8.4	-5.1	-1.8	26.4	19.8	-6.6
104.	-	-	17.7	4.5	-	-17.7
105.	8.4	18.6	-2.7	5.7	-15.3	-30.0
106.	-	-7.5	-	28.5	-	-13.8
107.	-13.8	7.2	5.4	-11.4	-2.7	2.4
108.	-2.1	0	3.6	4.5	-8.1	-11.4
109.	-3.0	-5.4	-3.0	1.2	-12.9	-17.1
110.	37.5	44.4	-20.4	-23.1	-9.0	-15.9
111.	15.6	30.0	-10.5	-11.7	4.5	-7.2
112.	4.2	22.2	-4.5	-9.6	9.3	-3.3
113.	24.3	37.8	-13.2	4.5	20.7	3.9

Table 2

Mean Annual Rates of Change (meters)

	1939-1951		1951-1963		1963-1972	
	dune line	high tide line	dune line	high tide line	dune line	high tide line
1.	-0.3	-0.6	-1.0	-0.6	-0.3	-0.6
2.	-1.0	-0.6	-1.2	-1.2	1.2	-2.4
3.	-1.0	-0.6	-0.3	-1.5	-0.3	0.3
4.	-1.2	-0.6	-3.3	-3.6	2.6	3.9
5.	-3.6	-2.1	-3.3	-4.2	2.7	4.8
*5A.	-	-2.7	-	-3.0	-	0.3
6.	-3.0	-3.0	-4.5	-3.3	3.0	3.9
*6A.	-	-4.8	-	-3.3	-	0.3
7.	-3.6	-3.0	-4.5	-2.4	4.2	3.0
*7A.	-	-4.8	-	-1.0	-	0.3
8.	-4.8	-3.9	-2.7	-2.1	2.1	3.0
*8A.	-	-6.3	-	-1.0	-	1.0
9.	-1.8	-3.6	-1.5	-0.3	2.4	1.8
*9A.	-	-1.0	-	-1.2	-	1.2
10.	-2.4	5.4	0.3	-1.5	6.0	2.7
11.	0.3	0.3	0.3	0.3	-1.2	-1.2
12.	0.3	1.0	0	-0.6	-	0.3
13.	-	-0.3	0.6	0.3	-	0
14.	-	-0.3	0.3	0.3	-	0.6
15.	-0.6	-	0	-	-	-1.2
16.	-3.6	-1.2	1.0	1.0	3.3	0.6
17.	-2.7	-0.3	5.7	2.7	-6.6	-5.4
18.	-3.3	-1.0	-0.6	1.0	-0.3	-2.1
19.	-1.8	0.3	-1.2	-1.0	1.2	-1.2
20.	0.3	1.0	-1.0	-1.0	-0.6	-2.1
21.	-1.2	0.3	-	-2.4	-	-2.1
22.	0.3	2.7	-6.0	-5.7	-0.6	-0.9
23.	-	-1.5	-	-0.6	-	-1.2
24.	-1.8	-1.5	-1.8	-0.3	1.2	-0.9
25.	-2.4	-2.1	-	-0.3	-	0
26.	-	-1.2	-3.3	-3.6	3.0	3.3
27.	-	-1.2	-4.5	-3.3	4.2	3.6
28.	-0.9	-1.5	-	-0.6	-	6.3
29.	-1.2	-2.1	-	-3.3	-	3.3
30.	-	-1.8	-	-2.7	-	3.3
31.	-	4.5	-	-5.1	-	5.7
32.	-	2.7	-4.5	-3.9	6.9	5.1
33.	-	0.3	-0.3	-0.9	2.4	0
34.	-	1.2	0.3	-1.8	0.3	0.3
35.	0	0.3	0.3	-0.9	-0.3	0.3
36.	0.3	-0.3	0.3	0	-0.6	0.3
37.	0	0.6	-0.3	-0.3	0.3	-0.9

*("A" is corresponding point on bay high tide line)

Mean Annual Rates of Change (meters)

	1939-1951		1951-1963		1963-1972	
	dune line	high tide line	dune line	high tide line	dune line	high tide line
38.	-0.6	0.3	-0.3	2.4	2.4	1.2
39.	2.1	0.6	-1.5	2.7	1.8	-0.3
40.	-0.6	0.6	0	-0.9	-0.9	-0.3
41.	1.5	1.5	-0.6	-1.5	0.3	1.2
42.	0.1	0.6	-0.1	-0.6	-0.6	-0.3
43.	-0.3	0	-0.6	0.1	0.3	-0.3
44.	-2.4	1.5	-0.3	-0.9	0	-0.6
45.	-0.3	1.2	-0.3	-0.6	-1.2	-0.6
46.	-0.3	-0.6	-1.8	-1.5	0.1	-0.3
47.	-2.1	-0.6	-1.5	-2.1	1.8	-0.9
48.	-1.5	-1.2	-1.5	-1.5	1.8	0.3
49.	0.3	0.6	-1.5	-0.6	0	-0.1
50.	-0.9	-2.1	-3.0	2.7	3.9	1.5
51.	-	-	-	-	1.5	1.2
52.	-1.8	-0.3	0	1.2	1.2	-0.6
53.	-2.1	0.3	-1.5	-1.5	1.8	1.2
54.	-0.3	0.3	0.6	0.6	-0.3	-0.3
55.	-2.1	-0.6	-0.9	0	1.8	0
56.	-0.1	0.6	-0.3	-0.6	0.3	-0.9
57.	-2.4	-1.2	-0.3	-1.2	1.8	0.3
58.	-1.5	0.9	-0.3	-0.6	0.6	-0.9
59.	-2.7	1.2	-0.6	-1.5	1.2	-0.3
60.	-1.8	2.4	-2.4	-1.8	2.1	1.2
61.	-2.4	0.6	0.6	-0.3	0	-1.5
62.	-3.6	-0.9	-	-	-	-
63.	-2.7	-0.9	1.2	2.4	-1.0	-1.2
64.	-2.7	-1.8	2.7	2.4	-1.2	-0.9
65.	-	-	-	-	-0.3	-1.5
66.	-0.3	-1.8	-0.9	-3.6	1.2	-0.6
67.	0.3	1.5	-2.4	-2.1	0	-2.1
68.	0.3	1.5	-1.2	-6.3	3.6	1.2
69.	-	1.8	-1.8	-1.8	0	-0.6
70.	4.8	5.1	-4.8	-4.5	-1.8	-3.9
71.	1.5	1.2	-3.3	-1.8	0.3	-3.0
72.	3.9	2.7	-6.9	-3.3	2.1	-0.2
73.	1.8	2.1	-5.4	-6.0	5.4	0.2
74.	-	1.5	-3.9	-3.9	3.0	-0.3
75.	1.8	2.1	-5.1	-5.7	3.6	0.9
76.	3.0	5.7	-3.3	-3.0	0.3	-3.0
77.	3.3	3.9	-3.9	-2.7	2.1	-1.2
78.	-	-	-	-	-	-
79.	5.4	6.0	0.9	1.5	-1.8	-3.6
80.	-	1.8	0	2.4	-0.3	-2.7
81.	4.5	1.5	-1.2	1.5	0.9	-2.1
82.	4.5	2.1	0.1	1.5	0	-1.2
83.	6.0	3.0	0	0.6	1.8	-0.9

Mean Annual Rates of Change (meters)

	1939-1951		1951-1963		1963-1972	
	dune line	high tide line	dune line	high tide line	dune line	high tide line
84.	-	5.7	1.8	1.2	-0.3	-1.8
85.	-	3.0	-0.6	-0.6	-0.6	0.6
86.	-	0.3	-4.2	-2.4	3.0	2.4
87.	-	1.5	-0.9	0.3	0.6	-1.5
88.	0.6	2.1	0	0.6	2.1	-2.7
89.	-	0.3	-1.5	0.6	-	-
90.	-	-1.8	-1.2	0.3	1.5	0.6
91.	-	-0.6	-0.3	3.0	-	-2.7
92.	-	-2.1	0.3	0.1	-0.9	-0.9
93.	-	-2.4	1.2	1.5	0.9	0.6
94.	-	-2.7	0.9	0.9	0	0
95.	-	-3.9	-0.3	0.3	-	-0.6
96.	1.2	-1.2	-0.6	0	-0.6	-1.5
97.	-0.9	-1.8	-0.6	-0.3	-1.2	-1.5
98.	-	-0.3	-3.2	0	4.2	0
99.	-	0	0.3	3.6	6.0	-3.0
100.	-	-1.2	-1.5	6.0	-	-3.9
101.	-	0.3	-	3.8	-	-3.9
102.	-	-0.6	-0.9	1.5	-	-3.3
103.	0.6	-0.3	-0.3	2.1	2.1	-0.6
104.	-	-	1.5	0.3	-	-2.1
105.	0.6	1.5	-0.3	0.6	-1.2	-3.3
106.	-	-0.6	-	2.4	-	-1.5
107.	-1.2	0.6	0.3	-0.9	-0.3	0.3
108.	-0.3	0	0.3	-	-0.9	-1.2
109.	-0.3	-0.3	-0.3	0	-1.5	-1.8
110.	3.6	3.6	-1.8	-1.8	-0.9	-1.8
111.	1.2	2.4	-0.9	-0.9	0.6	-0.9
112.	0.3	1.2	-0.3	-0.9	0.9	-0.3
113.	2.1	3.0	-1.2	0.3	2.4	0.3

Table 3

Composite Mean Annual Rates (meters)

	dune line	high tide line		dune line	high tide line		dune line	high tide line
1.	-.42	-.18	39.	0.6	1.2	82.	1.5	0.9
2.	-0.1	0	40.	-0.6	-0.3	83.	2.7	1.2
3.	-4.5	-0.3	41.	0.3	0.3	84.	-	2.1
4.	-0.9	-4.8	42.	-0.3	0	85.	-	1.2
5.	-1.8	-0.9	43.	-0.3	0	86.	-	-0.1
*5A.	-	-1.8	44.	-0.9	-0.1	87.	-	0.2
6.	-1.9	-1.2	45.	-0.6	0	88.	0.6	0.2
*6A.	-	-3.0	46.	-0.7	-0.9	89.	-	-
7.	-1.8	-1.2	47.	-0.9	-1.2	90.	-	-0.3
*7A.	-	-2.7	48.	-0.6	-0.9	91.	-	-0.3
8.	-2.1	-1.2	49.	-0.6	-0.1	92.	-	-0.3
*8A.	-	-2.4	50.	-0.3	0.9	93.	-	-0.2
9.	-0.6	-0.9	51.	-	-	94.	-	-0.6
*9A.	-	-0.6	52.	-0.3	0.1	95.	-	-1.5
10.	0.9	2.1	53.	-0.9	-0.1	96.	0	-0.9
11.	-1.5	-0.1	54.	0	0.3	97.	-0.9	-1.2
12.	-	0.2	55.	-0.6	-0.1	98.	-	-0.1
13.	-	0.1	56.	-0.1	-0.3	99.	-	0.5
14.	-	0.2	57.	-0.3	-0.6	100.	-	0.6
15.	-	-	58.	-0.6	-0.3	101.	-	0.9
16.	-0.2	0	59.	-0.9	-0.3	102.	-	-0.6
17.	-0.6	-0.6	60.	-0.9	0.6	103.	0.9	0.6
18.	-0.9	-0.6	61.	-0.6	-0.3	104.	-	0.2
19.	-0.9	-0.6	62.	-	-	105.	-0.3	-0.2
20.	-0.3	-0.6	63.	-0.8	0.1	106.	-	0
21.	-	-1.2	64.	-0.3	0.2	107.	-0.3	0
22.	-2.1	-1.5	65.	-	-	108.	-0.2	-0.2
23.	-	-1.2	66.	0	-2.1	109.	-0.6	-0.6
24.	-1.2	-0.9	67.	-0.9	-0.9	110.	0.3	0
25.	-	-0.9	68.	0.6	-0.2	111.	0.3	0.3
26.	-	-0.9	69.	-	-0.3	112.	0.3	0.3
27.	-	-0.6	70.	-0.6	-0.9	113.	0.9	1.5
28.	-	-0.9	71.	-0.6	-1.2			
29.	-	-0.9	72.	-0.6	-0.6			
30.	-	-0.9	73.	0.3	-0.9			
31.	-	1.2	74.	-	-0.9			
32.	-	0.9	75.	-0.3	-0.9			
33.	-	-0.3	76.	-0.1	0.2			
34.	-	0	77.	0.6	-0.1			
35.	0.1	-0.2	78.	-	-			
36.	0.1	-0.1	79.	-	1.8			
37.	0	-0.3	80.	1.8	0.9			
38.	0.3	1.5	81.	1.5	0.6			

*("A" is corresponding point on bay high tide line)

Table 4

Latitude and Longitude of Survey Points

1.	41°18'02"N,	71°53'03"W
2.	57"	11"
3.	17'50"	08"
4.	54"	52'58"
5.	57"	50"
*5A.	18'00"	50"
6.	03"	35"
*6A.	07"	35"
7.	07"	09"
*7A.	10"	09"
8.	08"	51'58"
*8A.	11"	58"
9.	08"	46"
*9A.	11"	46"
10.	05"	34"
11.	17'57"	25"
12.	55"	24"
13.	45"	26"
14.	43"	26"
15.	45"	25"
16.	54"	17"
17.	18'00"	07"
18.	35"	50'56"
19.	42"	38"
20.	50"	15"
21.	55"	00"
22.	19'00"	38"
23.	06"	16"
24.	09"	05"
25.	12"	48'49"
26.	15"	33"
27.	19"	19"
28.	21"	09"
29.	24"	47'53"
30.	25"	41"
31.	27"	30"
32.	32"	12"
33.	35"	46'59"
34.	36"	50"
35.	40"	36"
36.	41"	26"
37.	42"	13"
38.	43"	45'59"
39.	42"	45"
40.	40"	40"
41.	41°19'36"N,	71°45'25"W
42.	34"	16"
43.	31"	10"
44.	35"	04"
45.	37"	44'49"
46.	45"	24"
47.	49"	07"
48.	53"	43'50"
49.	55"	37"
50.	52"	14"
51.	50"	06"
52.	50"	43'00"
53.	54"	42'51"
54.	56"	41"
55.	20'00"	30"
56.	02"	07"
57.	05"	02"
58.	12"	41'56"
59.	18"	45"
60.	21"	40"
61.	27"	26"
62.	31"	18"
63.	35"	03"
64.	39"	40'52"
65.	48"	20"
66.	58"	39'55"
67.	21'03"	35"
68.	06"	19"
69.	09"	08"
70.	12"	38'53"
71.	16"	40"
72.	19"	30"
73.	20"	15"
74.	25"	05"
75.	34"	37'43"
76.	37"	32"
77.	41"	13"
78.	48"	12"
79.	49"	36'10"
80.	50"	36'00"
81.	51"	35'51"
82.	54"	44"
83.	56"	34"
84.	59"	27"
85.	22'05"	06"

*("A" is corresponding point on bay high tide line)

Table 4

Latitude and Longitude

86.	41°22'09"N,	71°34'54"W
87.	13"	23"
88.	18"	33'56"
89.	21"	42"
90.	24"	17"
91.	25"	32'55"
92.	24"	43"
93.	21"	30"
94.	21"	22"
95.	23"	14"
96.	27"	10"
97.	30"	02"
98.	33"	31'52"
99.	34"	42"
100.	34"	27"
101.	33"	16"
102.	31"	05"
103.	30"	30'42"
104.	30"	32"
105.	25"	17"
106.	20"	02"
107.	16"	29'50"
108.	11"	46"
109.	05"	41"
110.	21'57"	31"
111.	54"	27"
112.	51"	24"
113.	46"	21"